SANDIA REPORT

SAND88—3284 • UC—92
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Printed March 1989

Multiwell Experiment Final Report: III. The Coastal Interval of the Mesaverde Formation

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Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
under Contract DE-AC04-76DP00789

SF2900Q(8-81)

510 p. + 7 mf

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Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes
Printed copy: A22
Microfiche copy: A01

SAND88-3284
Unlimited Release
UC Category 92

MULTIWELL EXPERIMENT FINAL REPORT:
III. THE COASTAL INTERVAL OF THE MESAVERDE FORMATION

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Printed January, 1989

ABSTRACT

The Department of Energy's Multiwell Experiment (MWX) is a field laboratory in the Piceance Basin of Colorado which has two overall objectives: to characterize the low permeability gas reservoirs in the Mesaverde Formation and to develop technology for their production. Different depositional environments have created distinctly different reservoirs in the Mesaverde, and MWX has addressed each of these in turn. This report presents a comprehensive summary of results from the coastal interval which lies between 6000 ft and 6600 ft at the MWX site. The interval is a complex, upper delta plain, depositional environment consisting of interbedded sandstone channels, and carbonaceous siltstones and mudstones. Separate sections of this report are background and summary; site descriptions and operations; geology; well testing, stimulation, analysis, and reservoir evaluation of a pair of distinct sandstones; supporting laboratory studies; hydraulic fracture diagnostics; and a bibliography. Additional detailed data, results, analyses, and data file references are given on microfiche in several appendices. Overall, the results show that the coastal contains very low permeability reservoirs of limited extent and productivity. Nevertheless, the results provide additional insight into the geology and gas production from Mesaverde reservoirs.

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1.0 BACKGROUND AND SUMMARY

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1.1 INTRODUCTION

New and improved technology is required to enhance natural gas production from the low permeability reservoirs of the United States. This is a large potential resource with an estimated maximum recoverable resource of over 600 TCF.[1] The U.S. Government's efforts to stimulate production from these reservoirs began in the mid-1960s. The early work evaluated the use of nuclear explosives for fracturing, but this technique was abandoned in 1973.[2] Efforts then focused upon massive hydraulic fracturing and several government-industry projects were conducted.[3,4] The results were disappointing and did not result in either an improved technology or confident, commercial production. The basic shortcoming was that these past field tests provided insufficient data to define the critical factors affecting gas production from this resource.

The U. S. Department of Energy's Multiwell Experiment (MWX) was conceived as a field laboratory to obtain sufficient information on the geologic and technical aspects to understand this resource. A key feature of MWX is three wells between 110 and 215 ft apart. Detailed core, log and well test data from such close spacings provide a detailed characterization of the reservoir. Interference and tracer tests as well as the use of fracture diagnostics in offset wells, give additional, out-of-the-ordinary information on stimulation and production. A second key is the synergism resulting from a broad spectrum of activities: geophysical surveys, sedimentological studies, core and log analyses, well testing, in situ stress determinations, stimulation, fracture diagnostics, and reservoir analyses. All these activities are further enhanced by the closely spaced wells. Thus, the Multiwell Experiment provides a unique opportunity for understanding the factors affecting production from tight gas reservoirs. The long-term research program under way at this facility is managed by DOE's Morgantown Technology Center.

Further discussion of the rationale, plans, objectives, and activities of MWX can be found in References 5-8. The intent of this report is to compile results from activities associated with one interval--the coastal--at the MWX site. Final reports for the marine[9] and paludal[10] intervals have been completed. A similar final report will be compiled for the fluvial interval as well.

1.2 GEOLOGIC SETTING

The Multiwell Experiment's focus is the Mesaverde Formation in the Piceance basin of northwest Colorado. This thick sequence was deposited during the late Cretaceous age over a broad region of the western United States and contemporaneous formations are found in the Green River, Wind River, Uinta and San Juan basins. The great extent and thickness of these gas-containing deposits represent a significant natural gas resource.[1]

At the MWX site, the Mesaverde Formation lies at a depth of 4000 to 8250 ft, between the overlying Wasatch Formation and the underlying Mancos Shale (Figure 1.1). The Mesaverde is exposed in outcrop along the Grand Hogback and elsewhere in the Piceance Basin. These outcrops, especially those at Rifle Gap approximately 11 miles northeast of the MWX site, have given excellent insight into the subsurface geology at the site. The sandstones stand out clearly in outcrop and sedimentological studies have been performed on them. These studies show that the Mesaverde can be divided into five distinct intervals based upon different depositional environments and resulting sandstone morphologies.[11-13]

(1) The lowest interval, the marine, (7450-8250 ft) was formed immediately on either side of an oscillating coastline and is composed of widespread shoreline-to-marine blanket sandstones, marine shales, and paralic coals and mudstones. This interval contains the Corcoran, Cozzette, and Rollins Sandstones which are interspersed with Mancos Shale.

(2) The paludal interval (6600-7450 ft) lies above the Rollins Sandstone and contains thick, abundant coal deposits. These are interspersed with lenticular, distributary channel and splay sandstones formed in a lower delta plain environment. The sandstone percentage in this zone is markedly lower (26%) than other intervals (40%), and channel widths are probably 250-500 ft.

(3) The coastal interval (6000-6600 ft) is characterized by distributary channel sandstones deposited in an upper delta plain environment. Most of these sandstones are probably 250-500 ft in width and are interbedded with carbonaceous mudstones and siltstones. This interval is the focus of this report.

(4) The fluvial interval (4400-6000 ft) consists of irregularly shaped, multistory, composite sandstones which were deposited by broad meandering stream systems. These sandstones have widths on the order of 1000-2500 ft and contain abundant internal discontinuities.

(5) The uppermost interval, the paralic, (4000-4400 ft) is a zone of returned marine influence with more widespread, uniform sandstones. The interval is believed to be water-saturated at the MWX site.

Specific sandstones in the shoreline/marine, paludal, coastal and fluvial intervals have been the focus of separate MWX investigations.

1.3 MWX DESCRIPTION

The Multiwell Experiment field laboratory is located in the Rulison Field in the east central portion of the Piceance basin in northwestern Colorado. The site is located in the SW 1/4, NW 1/4, Sec. 34, T6S, R94W, Garfield County, and it is seven miles southwest of Rifle and just south of the Colorado River. Agreements on the lease and with landowners were obtained in mid-1981 and work at the site began in August of that year. A chronology of MWX activities is given in Figure 1.2.

Three wells were drilled: MWX-1 to a depth of 8350 ft in September-December 1981,[14] MWX-2 to a depth of 8300 ft in January-March 1982,[15] and MWX-3 to a depth of 7565 ft in June-August 1983.[16] Over 4100 ft of 4-in core, approximately 1135 ft of it oriented, were cut with a recovery of >99%. Numerous logging programs containing both standard and experimental logs were conducted. An overview of the coring and logging activities in all three wells in relation to the Mesaverde section at the site is given in Figure 1.3. The three wells are exceptionally straight as seen in Figure 1.4; relative separations are between 110 and 215 ft within the Mesaverde. Significant gas shows were encountered throughout the section in all three wells and mud weights as high as 15 lbs/gal were required to maintain well control. Wells were drilled as near to balanced conditions as possible to minimize invasion.

The entire Mesaverde at the MWX site, as seen by gamma ray logs in the three wells, is shown in Figure 1.5.

1.4 THE COASTAL INTERVAL

The coastal interval lies between 6000 and 6600 ft and is shown in detail in Figure 1.6. During the coring and logging of MWX-1, immediate interest was drawn to the two relatively thick sandstone units at the bottom of the coastal interval. These two, the Red and Yellow sandstones, were to become the focus of activities in the coastal interval and were believed to be typical of the nonmarine Mesaverde--the primary target of the Multiwell Experiment. Separate well tests in the two sandstones in the Fall of 1984 confirmed that these were complex, very tight reservoirs.

After discussions during the winter site shut-in, a deliberate experimental approach to the coastal interval was adopted. The new approach consisted of a series of stimulations and testing in the Red and Yellow sands over a long period of time and it was felt to be necessary to fully understand these complex lenticular tight reservoirs and their stimulation. Such a series of experiments allowed investigation of a range of different objectives that would not have been possible with a single test.

The test plan called for the following series of stimulations, all to be initiated in the Yellow sandstone in MWX-1:

- Nitrogen Gas Injection and Frac. An unpropped frac using nitrogen gas (the least damaging fluid) with the objectives of assessing the presence and effects of the possible fault near MWX-2,[7] investigating pressure transients at the two offset wells, and evaluating production from a nondamaging frac.

- Nitrogen Foam Frac--Small. A short, propped frac of 200-250 ft wing length designed to be contained within the Yellow sandstone, and having the objectives of assessing frac damage under mild frac conditions, measuring fracture geometry and containment, and predicting production.

- Nitrogen Foam Frac--Medium. A medium, propped frac of 500 ft wing length, a step-wise increase in size above the previous frac with the objectives of assessing frac growth and interaction with the underlying Red sandstone, determining frac damage at intermediate conditions, and measuring gas production.

- Nitrogen Foam Frac--Large. A longer, propped fracture of 1000-1500 ft wing length with the objectives of assessing frac growth at a lens boundary and interaction with the Red sandstone and other possible sandstones, measuring overall frac geometry with a full suite of diagnostic techniques, and maximizing the intersection of potential pay and resulting production.

The first two steps in this series were conducted successfully and are described in Section 7.2. However, several factors (the limited production potential of these sands, problems of isolation/communication between the Red and Yellow sandstones, and programmatic needs) led to the decision during the 1985-1986 winter shut-in to terminate operations in the coastal interval and to move uphole to the fluvial interval.

1.5 ACTIVITY SUMMARIES

The results of MWX activities conducted in the coastal interval of the Mesaverde are presented in separate sections of this report; each are authored by the principal investigator. Summaries of these sections are presented here.

1.5.1 Geology (Section 3.0)

The rocks of the coastal interval are lenticular, distributary-channel and splay sandstone reservoirs, interbedded with mudstones and carbonaceous shales. These strata were deposited on an upper delta plain environment that was similar to that of the underlying paludal interval. However, coals were not deposited in the coastal zone, and their absence marks the principal difference between the upper (coastal) and lower (paludal) delta plain environments.

Seven sandstone zones were identified as shown in Figure 1.6. Core (where available) and log data, along with outcrop studies, were analyzed from a sedimentological standpoint and have resulted in the following interpretations of the lithology and morphology for each of the seven zones. Sandstone widths were estimated by correlation percentages between the three wells and by empirical relationships between channel thickness and width for this depositional environment as measured in outcrop. Reservoir orientations were made from the spatial relationships in the three wells and from crossbedding data from a high resolution dipmeter log in MWX-3. (Field test activities were only conducted in the Red and Yellow zones.)

- Purple zone is a thin channel or possible splay deposit with limited correlation between the three wells. If it is a channel sandstone, it has an estimated width of 110 ft and trends NW-SE.

- Orange zone is a distributary channel which gives evidence of main channel deposits in all three wells. The channel has an estimated width of 270-340 ft and it trends SW-NE.

- Brown zone is a distributary channel. Its presence only in MWX-2 implies a NW-SE trend and its height in that well gives an estimated minimum width of 120 ft.

- Blue zone is a distributary channel with good sandstone correlation between the three wells. It is estimated that the main channel is situated in the vicinity of MWX-3 and trends NW-SE and with an estimated width of 230 ft.

- Green zone consists of five separate sandstones which do not correlate between the three wells. The thicknesses yield estimates of widths of 80-270 ft and various trends are inferred.

- Yellow zone consists of three apparently unrelated and independent sandstones separated by 3-5 ft of mudstones, except in MWX-2 where Yellow A contacts Yellow B. Yellow A is a distributary channel with clean, crossbedded sandstone in all three wells, an estimated minimum width of 200 ft and trends NW-SE. Yellow B is a distributary channel with an estimated minimum width of 300 ft, and an estimated trend of ESE-WNW. Yellow C is a splay or channel margin deposit with a source southwest of MWX-2 and with a northeasterly paleoflow.

- Red zone consists of two apparently unrelated and independent sandstones which are superimposed upon one another. Red A is a distributary channel with main channel deposits in MWX-1 and MWX-2 and channel margin deposits in MWX-3, an estimated minimum width of 500 ft, and a SW-NE orientation. Red B is a distributary channel which thickens towards MWX-3, has a minimum estimated width of 250 ft, and also trends SW-NE. Red B is scoured into by Red A in MWX-2.

Sandstone petrology (grain size, composition, and paragenetic history) is the primary control on reservoir porosity and matrix permeability. The reservoir sandstones are fine-grained, moderately sorted, and consist predominantly of quartz and lithic fragments, and can be classified as feldspathic litharenites. These sandstones have undergone a complex paragenetic sequence that includes early and late calcite cementation, quartz cementation, feldspar alteration, stages of authigenic clay formation, and dolomitization of calcite. The principal clay components are authigenic illite and mixed-layer illite-smectite.

The coastal sandstones contain many internal discontinuities, such as mudstone partings (shale breaks), carbonaceous zones, and sideritic or mudstone clast zones. Thirty-nine discrete barriers were identified in 600 ft of coastal core from the Red and Yellow sandstones. These internal reservoir features generally do not extend completely through a sandstone lens and thus segment the reservoir with a network of restrictions and tortuous flow paths. Natural fractures often terminate at these internal discontinuities, and thus fracture spacing is controlled by the smaller unit rather than gross reservoir thickness.

Sixty natural fractures were logged in coastal core; one was in oriented core and its 110° strike parallels the trend of regional fractures in the area. Most of these fractures are vertical extension fractures which contain calcite mineralization and terminate at mudstone boundaries. Other types of fractures include shear fractures, multiple fractures containing dickite mineralization (whose significance is not understood), and subhorizontal extension fractures. Natural fractures play a significant role in coastal reservoir performance (Section 7.1).

1.5.2 Log Analysis (Section 4.0)

Extensive logging programs were conducted during the drilling of the MWX wells. The well logs were analyzed with TITEGAS, a tight gas sandstone log interpretation model developed in conjunction with the MWX log data base.[17] This extensive data allowed analyses, cross-plotting, and verification of the results for porosity, matrix calculations, clay volume, water saturation, and permeability.

Fourteen distinct sandtones in the seven coastal zones in each of the three wells were analyzed with TITEGAS and the results are summarized in Table 1.1. The following general statements can be made about the relative quality of the coastal zones.

- The best reservoir appears to be the Orange sandstone. Matrix permeability is relatively high, but the sand is thin in MWX-1 and MWX-2.

- The Red and Yellow sandstones are relatively fair to poor reservoirs, but they are thick and continuous.

- The Blue and Purple sandstones are similar to the Red and Yellow sands with fair to poor reservoir quality and are considerably thinner, but these may be naturally fractured.

- The Brown and Green sandstones are the worst quality reservoirs as they are laterally discontinuous and very tight, but they may be naturally fractured.

The log analyses included the opportunity to compare several natural fracture identification logs in MWX-3 and to indicate which zones appeared naturally fractured. Assessments of cement bond quality, interpretation of stresses for hydraulic fracture containment, and determining the petrophysical relationships in the coastal interval were also part of the extensive coastal log analysis effort.

1.5.3 Core Analysis (Section 5.0)

A total of 870 ft of 4-in.-diameter core was taken in the coastal interval: 600 ft of continuous core in MWX-1 (through the entire interval), and 179 ft in MWX-2 and 97 ft in MWX-3 in the Red and Yellow sandstones. Two hundred seventy-six feet of this core; mostly below 6430 ft, were oriented. Core samples were distributed to participants in a comprehensive core analysis program.[18] Both routine and special core analyses for reservoir properties were made at frequent intervals in the sandstones. Many analyses also extended above and below the sandstones so that properties are also available for the bounding lithologies. The core analyses focused upon the Red and Yellow sands.

Core-derived (matrix) reservoir properties for the coastal interval are typified by the data shown in Figure 1.7 for the Red sandstones in MWX-1. Sandstone porosities are on the order of 5%-9%, water saturations are at 30%-40%, and dry Klinkenberg permeabilities are 2-8 μd measured at 3000 psi confining stress. The permeabilities are a strong function of water saturation: the dry permeabilities would be reduced by about a factor of 10 at these water saturations. This results in a realistic estimate for the true in situ matrix permeability of 0.5-0.6μd. Permeabilities are quite variable within a sandstone and were often measured to be enhanced along carbonaceous stringers and mineralized natural fractures. In addition, capillary pressures greater than 1000 psi were found at the prevailing water saturations.

The mechanical properties reflect the complex lithology of the coastal interval. At confining pressures around 2700 psi, Young's moduli range from 1.4 to 8.0 x 10^6 psi, Poisson's ratios from 0.15 to 0.33, and fracture toughnesses from 150 to 2300 psi$\sqrt{}$in. The sandstones have a relatively narrow range of moduli of 3.4 to 5.1 x 10^6 psi. However, the confining lithologies have moduli which range from 1.4 to 8.0 x 10^6 psi, often with large changes observed over a few feet.

Other core analyses included directional permeabilities, capillary pressure, caprock analyses, compressibility, permeabilities to brine in preserved and oven-dried core, triaxial tests for compressive strength, tensile strength, cation exchange coefficient, formation factor, resistivity index, vitrinite reflectance, and rock evaluation pyrolysis. Core samples were also used in other MWX activities such as sedimentology, mineralogy/petrology, natural fractures, in situ stress, and laboratory work supporting stimulation; these activities are reported in their respective sections of this report. Finally, correlations were also made between stress-related core measurements and televiewer and oriented caliper logs to determine in situ stress orientations.

1.5.4 In Situ Stress Measurements and Analyses (Section 6.0)

Fourteen cased-hole stress tests were attempted between 6374 and 6706 ft, eleven of which yielded stress results. These tests consisted of repeated small volume hydraulic fractures (<100 gal) conducted through a two-foot perforated interval under conditions where the instantaneous shut-in pressure is nearly equal to the minimum in situ stress.[19] The breakdown of the Red sandtones in MWX-2 provided an additional data point. The measured minimum in situ stresses and frac gradients are summarized in Table 1.2. Generally there is good correlation between rock type and in situ stresses: stress gradients in the sandstones and mudstones are typically 0.88 psi/ft and 1.01-1.08 psi/ft respectively. Thus, the stresses in the sandstones are 700-1300 psi less than the confining rocks and these contrasts bode well for hydraulic fracture containment. Even the thin shale stringer at 6527-29 ft between the Red A and Red B sandstones shows a stress 800-1000 psi greater than the massive sandstones on each side of it. These stress results, while clearer than the paludal results, are still not as reproducible and precise as the marine data. The complex layering in nonmarine rocks makes interpretation much more difficult.

Anelastic strain recovery (ASR) measurements were made on oriented core from all three wells, but analyses are presented only for MWX-3, for which a much improved strain measurement system was available.[20] The primary ASR result is the direction of the maximum horizontal in situ stress, which is the azimuth of a hydraulic fracture. Six samples in the Yellow sandstones yielded azimuths of N58°W to N88°W; the average of about N73°W is consistent with other stress measurements. Stress magnitudes were also calculated from ASR data via two different procedures. These data indicate the difference in horizontal stresses in the sandstones is around 600-800 psi, whereas the shales are isotropic. Differential strain curve and differential wave velocity analyses (DSCA and DWVA) were made on selected core samples and showed differences in horizontal stress of about 600 psi and an azimuth of N70°W.

1.5.5 Stimulation Experiments in Red and Yellow Sandstones (Section 7.0)

The major focus of coastal activities was stimulation experiments conducted in the Red and Yellow sandstones. Usually, MWX-1 was the production and main test well. MWX-2 and MWX-3 were also perforated in each sandstone and served as interference/observation wells. The sequence of activities included: prefrac production/interference testing in first the Red sandstones and then the Yellow sandstones, winter production from both zones, nitrogen gas injection test in both zones, a nitrogen gas step rate and frac in the Yellow sandstones, propped nitrogen foam stimulation of the Yellow sandstones, postfrac production/interference testing, segregated production tests between the Red and Yellow sandstones, and a brief reentry test of the coastal interval after five months of shut-in.

Individual prefrac tests in the Red and Yellow sandstones consisted of drawdown and buildup tests in MWX-1 while monitoring bottomhole pressures in MWX-2 and MWX-3 for possible interference (Figures 1.8 and 1.9). Gas production, conventional Horner analyses, and log-log/derivative type curve matching gave similar results for the two reservoirs: production rates of 45 and 55 MCFD, permeability-heights (kh) of 0.40 and 0.38 md-ft and reservoir pressures of >4365 and >4290 psi for the Red and Yellow sandstones, respectively. The average reservoir permeability is thus around 12 μd, considerably higher than the matrix permeability measured at restored reservoir conditions, which shows the effect of an extensive and interconnected natural fracture system. Thus, computer simulations were performed with a 3-D, single-phase, naturally fractured reservoir model.[21] The test data were successfully matched with a model having fracture permeabilities of 65 and 0.65 darcies for the primary and secondary fractures, an anisotropy of 100 to 1. For widths of 0.0005 in, these yield flow capacities for each fracture set of 2.7 md-ft and 0.027 md-ft, respectively. Additional calculations of stimulating such a reservoir with a hydraulic fracture, which paralleled the maximum permeability direction, showed that the best that could be expected for a 500-ft fracture would be a threefold increase in production, and even this would be less if any degradation of the natural fractures by frac fluids occurred.

Following commingled production of the two sands over the winter at rates of 25-40 MCFD, a nitrogen injection test was conducted in the combined Red and Yellow sandstones to quantify the flow capacity of the natural fractures and to obtain additional insight into the transient flow mechanisms involved. Nitrogen gas was injected into MWX-2 while MWX-1 and MWX-3 were continuously produced and monitored for nitrogen by gas chromatography. The average reservoir flow capacity of 0.78 md-ft (as measured in the prefrac tests) increased to 50-75 md-ft during injection and returned to 1.38 md-ft after injection. Bilinear fracture flow analysis provided a lumped equivalent primary fracture flow capacity of 1037 md-ft, an increase presumably caused by small increases in fracture width with pressure, a sensitivity invariably seen during MWX testing. Nitrogen gas was detected at the observation wells. The transit time from MWX-2 to MWX-1 was 1-5 hours, and corresponds to a minimum fracture permeability in the range between 32 and 160 md.

A nitrogen gas step rate test and frac was conducted in the Yellow sandstones in MWX-1 on June 11, 1985 (Figure 1.10). The frac's objective was to create a fracture of about 200 ft in length using a nondamaging fluid at the lowest possible pressures. A total of about 800,000 SCF of nitrogen were injected during the continuous step rate and constant frac rate procedure. Fracturing appeared to initiate at the 5000 SCFM rate with a fracture extension pressure of around 5600 psi. A frac pressure history match yielded a frac length of 250-300 ft with a nitrogen leakoff coefficient of 0.005 ft/$\sqrt{}$min. The maximum pressure of 6150 psi indicates that any conventional treatment will result in very high treatment pressures. Distinct pressure interference was measured in MWX-2 and MWX-3 beginning at the 5000 SCFM rate; the immediate response implies that the interference is poromechanical--the direct result of strain due to the fracture in MWX-1. Well tests after the frac showed that the early time flow regime in the reservoir had been noticeably altered and now resembled a linear system representative of a created fracture. Sustainable production in the Yellow sandstone was increased from 55-60 MSCFD to about 90 MSCFD.

A nitrogen foam frac was conducted in the Yellow sandstones in MWX-1 on August 1, 1985 (Figure 1.11). The frac was designed to be a small, minimal damage treatment using 14,000 gal of 75 quality nitrogen foam with a 20 lb/1000 gal linear gel in the liquid phase, 12,000 lbs of 20/40 mesh intermediate strength proppant, with a small pad and propped fracture length of 200-300 ft. The treatment was conducted as designed although the pressure record indicates a tip screen out just at the end of the job. Diagnostic data were limited and a treatment pressure history match provided the best estimate of the resulting frac: total and propped lengths of 295 and 275 ft respectively, total height of 96 ft (33 ft of growth upwards), fluid leakoff coefficient of 0.0019 ft/$\sqrt{}$min, and efficiency of 30%. Well tests after this frac (Figure 1.12) showed relatively little change from the linear system observed after the nitrogen frac. The average sustainable flow rate during an eight-day period was 100 MSCFD. This 1.7 times increase over pre-frac production suggested that the effective frac length is probably less than 150 ft and/or there is possible damage to the natural fracture system due to the fracture fluids.

Two additional tests were performed in this interval. Special well test configurations were used to study the communication that was detected in MWX-1 during the fracs between the Red and Yellow sandstones. The results showed that while pressure changes were readily detectable, the path was probably a microannulus as there was very little measurable flow between the two zones. The Red and Yellow sandstones were also produced after a 6-month shut-in. The combined production of 110 MSCFD suggested there was no significant increase in Yellow sandstone production due to alleviation of damage as was observed in the paludal interval after an 18-month shut-in.[10,22]

1.5.6 Laboratory Studies (Section 8.0)

Pre- and post-frac laboratory studies were performed as an integral part of the coastal zone operations.[23] These studies included: permeability degradation in matrix rock and artificially fractured core due to foam frac fluids, proppant embedment and crushing and creep effects upon frac closure, and frac and returned fluid analyses to estimate the state and amount of gel remaining in the formation and returned water compositions.

These studies eliminated several possible causes of low production: matrix permeability degradation and leakoff, polymer block in the proppant pack, proppant related effects such as embedment and crushing, imbibition of water. However, the studies clearly suggest that damage to the narrow natural fractures can be significant. The biopolymer in the foam fluid is extremely stable, and while only small amounts were used, these could enter and block the natural fractures, especially under the high treatment pressures. Exposure of artificially fractured core to brine and foam under simulated conditions significantly reduced fracture permeability.

1.5.7 Borehole Seismic Analysis (Section 9.0)

A redesigned borehole seismic system was fielded to provide fracture diagnostics for the nitrogen foam frac of August 1, 1985. The upgraded system performed well, but the complexity (of unresolved origin) of the perforation and fracture seismic data collected during coastal operations prevented immediate analysis on site. Thus, an extensive system evaluation was performed to insure that each element of the surface hardware was functioning as expected and not distorting the received waveforms. After several months of effort, several redigitizations of the data and attempts at analysis, and many hardware and software modifications, there was reasonable confidence that the existing instrumentation system and analysis techniques were performing correctly. However, location of seismic sources recorded during the frac could not be determined. The data set received by the tool in MWX-2 contained characteristics such as reduced amplitude, different spectral content, phase disparity, and multiple arrivals with distinct, overlapping p and s waveforms. Unfortunately, a gas leak in MWX-3 prevented any usable frac-related data in that well. The ability to unambiguously identify p and s arrivals and identical phase and amplitude response on the three geophone axes are prerequisite for this diagnostic technique.

Nonetheless, improvements were made in the areas of increased signal strength (the signals recorded in MWX-2 were too weak to have been recorded with the old system), increased digitization rate (to 4.76 kHz per channel), a null system and a synthetic event generator to balance and calibrate the entire electronic system, and a maximum likelihood event location algorithm. These improvements and the understanding gained during this effort spurred further diagnostic advances which were successful during the subsequent fluvial stimulations.[24]

1.5.9 Other Activities

Three geophysics-related experiments were conducted over the Mesaverde Formation at the MWX site: a three-dimensional surface seismic survey,[25,26] vertical seismic profiles (VSP),[25-27] and cross-well acoustic surveys.[25,28-31] (These studies are not presented in this report, but can be found in the referenced documents.) The focus of these studies was the lenticular sandstones of the paludal, coastal, and fluvial intervals. The lithologies in the coastal show essentially no relative impedance contrasts. Additionally, the uniform sine wave character of synthetic seismograms based on log data is indicative of an unresolved fine structure: the seismic wavelengths of the 3D and VSP surveys are significantly greater than the coastal's lithologic features.[26]

Los Alamos National Laboratories' cross-well acoustic surveys were focused upon the coastal interval.[28-31] The cross-well travel time at different stations and angle were processed and analyzed via tomographic algorithms resulting in the velocity reconstruction between MWX-1 and MWX-2 between 6070 ft and 6725 ft depth shown in Figure 1.13. Other analysis of the data led to estimates of in situ porosities, moduli, and seismic attenuation (Q).

1.6 COMPARISON WITH OTHER MESAVERDE INTERVALS

Results from the coastal interval investigations indicate that this interval has the lowest production potential of the four major intervals studied during the Multiwell Experiment. Gas production from the various individual Mesaverde reservoirs measured during MWX testing and stimulation is given in Table 1.3; there are definite correlations with depositional environment. The individual marine reservoirs have the highest production potential. The coastal and paludal intervals have the same basic limited, distributary channel reservoir morphologies. However, the coastal has lower potential than the paludal due to the latter's improved reservoir rock properties, higher pore pressures, and adjacent coal seams and organic-rich sediments. The coastal and fluvial reservoirs have similar unstimulated production, but fluvial reservoirs offer the potential of better stimulation ratios (postfrac rate/prefrac rate) due to their greater average width resulting from the broad meandering-stream depositional systems. The unstimulated production for the different intervals per foot of net perforated pay are approximately 2, <2, 5, and >10 MSCFD/ft for the fluvial, coastal, paludal and marine intervals, respectively.

1.7 SIGNIFICANT ACCOMPLISHMENTS

Three wells have been drilled which penetrate the Mesaverde Formation in the Piceance basin at a site near Rifle Colorado. These establish the Multiwell Experiment as a field laboratory for the study of the tight gas resource in this formation. The Mesaverde has been subdivided into distinct intervals based upon their depositional environments, which, in turn, strongly influence their reservoir characteristics. This report is the culmination of work in the third of the intervals--the coastal. (The marine and paludal final reports have been completed,[9,10] a similar report on the fluvial interval is in preparation.)

The coastal interval has been thoroughly characterized. It is a lithologically complex assortment of sandstones, siltstones and mudstones deposited in an upper delta plain environment. A comprehensive body of core, log, stress, and geologic data has been compiled for this interval of the Mesaverde Formation and is available publicly as a result of the Multiwell Experiment.

The importance of natural fractures in gas production from these tight sandstone reservoirs continues to be demonstrated (Figure 1.14). While the Red and Yellow sandstones have matrix permeabilities that are less than one microdarcy under in situ conditions of stress and water saturation, the overall reservoir permeability was found to be 12 μd, some two orders of magnitude higher.

In situ stress measurements and analyses indicate that stresses in the coastal sandstones are 700-1300 psi less than the confining lithologies; these differences indicate that a hydraulic fracture will be confined within these relatively narrow distributary channel sandstones which typify the coastal interval. In addition, anelastic strain recovery measurements on oriented core give an average direction of N73°W for the maximum horizontal in situ stress--a direction which parallels the primary natural fracture trend and minimizes the effectiveness of a hydraulic fracture.

Comprehensive series of pre- and post-frac well tests were performed to characterize coastal reservoir performance. Gas production from individual unstimulated coastal sands is around 45-55 MCFD, although commingled production over the winter was less at 25-40 MCFD. Pressure interference during production and shut-in periods was not observed at the nearby observation wells. However, during a nitrogen injection test, the reservoir's flow capacity increased by two orders of magnitude and nitrogen gas was measured in the other wells. These results further emphasize the pressure sensitivity of the reservoir and the importance of the natural fractures system.

Two fracturing experiments were conducted in the Yellow sandstones. A step rate test and frac with nitrogen gas gave information on fracturing pressures with a nondamaging fluid. Then a small nitrogen foam frac (14,000 gal of 75 quality foam and 12,000 lbs of proppant), designed as a minimal damaging frac confined within the sandstone, was conducted. Sustained postfrac production was about 100 MCFD, about a factor of two improvement. Subsequent larger stimulations in the same zone which were planned were not conducted due to various technical and programmatic reasons.

An advanced, naturally fractured, fully transient, reservoir simulator was developed and used to successfully match pressure data from the well tests conducted before and after the stimulations. A pseudo-3D, stimulation model was developed and used to history match the fracturing pressure data to yield hydraulic fracture parameters.

The preservation of the permeability of the natural fracture system intersected by a hydraulic fracture is critical to production enhancement. The fractures are susceptible to damage by liquids, fracturing fluid polymers, and high fracturing pressures. Laboratory studies have provided insight into the possible damage mechanisms, in particular the damage to the narrow natural fractures.

Overall, the coastal interval is characterized by relatively narrow (<500 ft), very low permeability sandstones (<1 μd) which contain an anisotropic natural fracture system that creates a low overall reservoir permeability (~12 μd). The coastal has the lowest production potential of the four major intervals studied during the Multiwell Experiment.

1.8 ACNOWLEDGMENTS

A project of this magnitude is clearly the result of the efforts of a large number of people. The principal investigators express their appreciation for the assistance received from the MWX project personnel at Sandia National Laboratories and CER Corporation. Special thanks are extended to the CER field crew for their hard work and dedication in maintaining the site and conducting the various tests, often under difficult conditions. We also acknowledge the contributions from many contractors and other participants in MWX who have helped us compile a unique, comprehensive set of data for this potential resource.

The Multiwell Experiment is the major production technology project in the U.S. Department of Energy's Western Gas Sands Subprogram. DOE personnel responsible for MWX in the past have been C. H. Atkinson, A. B. Crawley, and J. K. Westhusing. For the past five years, the Western Gas Sands Subprogram has been managed by K-H. Frohne, at DOE's Morgantown Energy Technology Center.

1.9 REFERENCES

1. National Petroleum Council, "Unconventional Gas Sources--Volume V: Tight Gas Reservoirs, Part I," Library of Congress Card Number 80-82488, December 1980.

2. Luetkehans, G. R. and J. Toman, "Status Report on Three Nuclear Experiments for Stimulation of Tight Gas Sands," Proceedings of the Symposium on Stimulation of Low Permeability Reservoirs, Golden, CO, February 16-17, 1976.

3. Fitch, J. L., W. L. Medlin, and M. K. Strubhar, "Demonstration of Massive Hydraulic Fracturing, Piceance Basin, Rio Blanco County, Colorado," Proceedings of the 5th Annual DOE Symposium on Enhanced Oil and Gas Recovery, Tulsa, OK, August 22-24, 1979.

4. Merrill, R. G., "Progress Report and Review of Natural Buttes Unit - Massive Hydraulic Fracturing Project," Proceedings of the 4th Annual DOE Symposium on Enhanced Oil and Gas Recovery, Tulsa, OK, August 29-31, 1978.

5. Atkinson, C. H., A. B. Crawley, D. A. Northrop, A. R. Sattler, R. L. Mann, and J. C. Schillo, "The Department of Energy's Western Gas Sands Project Multi-Well Experiment," SPE/DOE 9891, Proceedings of the 1981 SPE/DOE Symposium on Low Permeability Gas Reservoirs, Denver, CO, May 27-29, 1981, pp 577-582.

6. Crawley, A. B., D. A. Northrop, and A. R. Sattler, "The Department of Energy's Western Gas Sands Project Multi-Well Experiment Update," SPE 11183, the 57th Annual Society of Petroleum Engineer's Technical Conference and Exhibition, New Orleans, LA, September 26-29, 1982.

7. Northrop, D. A., A. R. Sattler, and J. K. Westhusing, "Multi-Well Experiment: A Field Laboratory for Tight Gas Sands," SPE/DOE 11646, Proceedings of the 1983 SPE/DOE Joint Symposium on Low Permeability Gas Reservoirs, Denver, CO, March 13-16, 1983, pp 393-398.

8. Northrop, D. A., A. R. Sattler, R. L. Mann, and K-H. Frohne, "Current Status of the Multiwell Experiment," SPE/DOE/GRI 12868, Proceedings of the 1984 SPE/DOE/GRI Unconventional Gas Recovery Symposium, Pittsburgh, PA, May 13-15, 1984, pp 351-358.

9. Multiwell Experiment Project Groups at Sandia National Laboratories and CER Corporation, "Multiwell Experiment Final Report: I. The Marine Interval of the Mesaverde Formation," Sandia National Laboratories Report, SAND87-0327, April 1987.

10. Multiwell Experiment Project Groups at Sandia National Laboratories and CER Corporation, "Multiwell Experiment Final Report: II. The Paludal Interval of the Mesaverde Formation," Sandia National Laboratories Report, SAND88-1008, May 1988.

11. Lorenz, J. C., "Sedimentology of the Mesaverde Formation at Rifle Gap, Colorado and Implications for Gas-Bearing Intervals in the Subsurface," Sandia National Laboratories Report, SAND82-0604, March 1982.

12. Lorenz, J. C., "Reservoir Sedimentology in Mesaverde Rocks at the Multiwell Experiment Site," Sandia National Laboratories Report SAND83-1078, June 1983.

13. Lorenz, J. C., "Reservoir Sedimentology of Mesaverde Rocks at the Multiwell Experiment Site and East Central Piceance Creek Basin," Sandia National Laboratories Report, SAND87-0040, January 1987.

14. CER Corporation, "Multi-Well Experiment: MWX-1 As-Built Report," Sandia National Laboratories Contractor Report, SAND82-7201, July 1982.

15. CER Corporation, "Multi-Well Experiment: MWX-2 As-Built Report," Sandia National Laboratories Contractor Report, SAND82-7100, August 1982.

16. CER Corporation, "Multi-Well Experiment: MWX-3 As-Built Report," Sandia National Laboratories Contractor Report, SAND84-7132, February 1984.

17. Kukal, G. C., "A Systematic Approach for the Effective Log Analysis of Tight Gas Sands," SPE/DOE/GRI 12851, Proceedings of the 1984 SPE/DOE/GRI Unconventional Gas Recovery Symposium, Pittsburgh, PA, May 1984, pp 209-220.

18. Sattler, A. R., "The Multi-Well Experiment Core Program," SPE/DOE 11763, Proceedings of the 1983 SPE/DOE Joint Symposium on Low Permeability Gas Reservoirs, Denver, CO, March 13-16, 183, pp 437-444.

19. Warpinski, N. R., P. Branagan, and R. Wilmer, "In Situ Stress Measurements at U.S. DOE's Multiwell Experiment Site, Mesaverde Group, Rifle, Colorado," Journal of Petroleum Technology, 37 (3), 527-536, March 1985.

20. Warpinski, N. R. and L. W. Teufel, "In Situ Stresses in Low-Permeability, Nonmarine Rocks," SPE/DOE 16402, Proceedings of the 1987 SPE/DOE Joint Symposium on Low Permeability Reservoirs, Denver CO, May 1987, pp 125-138.

21. Branagan, P. T., C. Cipolla, S. J. Lee, and J. Chen, "Designing and Evaluating Hydraulic Fracture Treatments in Naturally Fractured Reservoirs," SPE/DOE 16434, SPE/DOE Symposium on Low Permeability Reservoirs, Denver, Colorado, May 1987.

22. Branagan, P. T., C. L. Cipolla, S. J. Lee, and L. Yan, "Case History of Hydraulic Fracture Performance in the Naturally Fractured Paludal Zone: The Transitory Effects of Damage," SPE/DOE 16397, Proceedings of the 1987 SPE/DOE Joint Symposium on Low Permeability Reservoirs, Denver, CO, May 18-19, 1987.

23. Sattler, A. R., P. J. Hudson, C.J. Raible, B. L. Gall, and D. R. Maloney, "Laboratory Studies for the Design and Analysis of Hydraulic Fracture Stimulations in Lenticular, Tight, Gas Reservoirs," SPE/DOE GRI 15425, Proceedings of the Unconventional Gas Technology Symposium, Louisville, KY, May 1986.

24. Thorne, B. J. and H. E. Morris, "Passive Seismic Monitoring of Hydraulic Fracture Experiments at the Multiwell Experiment Site," Sandia National Laboratories Report, SAND88-1284, June 1988.

25. Searls, C. A., M. W. Lee, J. J. Miller, J. N. Albright, J. Fried, and J. K. Applegate, "A Coordinated Seismic Study of the Multiwell Experiment Site," SPE/DOE 11613 Proceedings of the 1983 SPE/DOE Joint Symposium on Low Permeability Gas Reservoirs, Denver, CO, March 13-16, 1983, pp 115-120.

26. Searls, C. A., "The Multiwell Experiment Geophysics Program; Final Report," Sandia National Laboratories Report, SAND85-1013, September 1985.

27. Lee, M. W., "Detection and Delineation of Lenticular-Type Sand Bodies by the Vertical Seismic Profiling Method," United States Geological Survey Open File Report, 84-757, November 1984, pp 121-134.

28. Albright, J. N., D. A. Terry, and C. R. Bradley, "Pattern Recognition and Tomography Using Crosswell Acoustic Data," SPE/DOE 13854, Proceedings of the 1985 SPE/DOE Joint Symposium on Low Permeability Reservoirs, Denver, CO, May 19-22, 1985, pp 55-63.

29. Johnson, P. A. and J. M. Albright, "In Situ Physical Properties Using Crosswell Acoustic Data," SPE/DOE 13881, Proceedings of the 1985 SPE/DOE Joint Symposium on Low Permeability Reservoirs, Denver, CO May 19-22, 1985, pp 311-319.

30. Albright, J. N. and P. A. Johnson, "Crosswell Acoustic Surveying of Gas Sands: Travel Time Pattern Recognition, Seismic Q, and Channel Waves," presented at Society of Professional Well Log Analysts 26th Annual Logging Symposium, Dallas, TX, June 17-20, 1985.

31. Albright, J. N., P. A. Johnson, W. S. Phillips, C. R. Bradley, and J. T. Rutledge, "The Crosswell Acoustic Surveying Project," Los Alamos National Laboratory Report, LA-11157-MS, March 1988.

Table 1.1 Log-Derived Reservoir Properties

Unit	Well	Depth (ft)	Pay* (ft)	ϕ (fraction)	S_w (fraction)	V_{Cl} (fraction)	kh (md-ft)
Purple	1	6025.0-6031.0	6.0	0.066	0.653	0.112	0.026
	2	6025.0-6036.0	5.5	0.071	0.631	0.128	0.030
	3	6029.0-6036.0	7.0	0.062	0.620	0.142	0.036
Orange	1	6061.0-6081.0	11.5	0.088	0.526	0.070	0.240
	2	6065.5-6080.5	15.0	0.082	0.614	0.086	0.158
	3	6067.5-6096.0	28.5	0.068	0.620	0.104	0.134
Brown	1	6179.0-6197.0	6.0	0.057	0.973	0.161	0.005
	2	6177.5-6188.5	11.0	0.076	0.737	0.137	0.046
Blue	1	6242.5-6253.0	10.5	0.076	0.651	0.090	0.084
	2	6239.0-6252.5	13.5	0.077	0.705	0.067	0.073
	3	6240.5-6263.0	22.5	0.074	0.642	0.093	0.135
Green A	3	6294.5-6309.0	14.5	0.081	0.635	0.127	0.089
Green B	1	6324.0-6343.5	4.5	0.048	0.885	0.189	0.003
	2	6342.5-6336.0	11.5	0.089	0.608	0.095	0.139
Green C	1	6350.5-6359.5	9.0	0.067	0.770	0.144	0.038
	3	6342.5-6370.5	28.0	0.079	0.582	0.134	0.207
Green D	1	6375.5-6380.5	5.0	0.070	0.722	0.149	0.019
	2	6375.5-6380.5	5.0	0.067	0.772	0.175	0.012
Green E	3	6386.0-6395.0	7.0	0.073	0.687	0.126	0.034
Yellow A	1	6425.0-6440.0	13.0	0.067	0.636	0.101	0.056
	2**	6422.5-6457.5	35.0	0.071	0.641	0.074	0.195
	3	6436.0-6450.5	11.0	0.056	0.733	0.134	0.021
Yellow B	1	6442.5-6461.5	19.0	0.074	0.628	0.091	0.100
	3	6454.0-6471.0	17.0	-	0.540	0.119	0.120
Yellow C	1	6466.0-647.0	0.0	-	-	-	-
	2	6466.0-6474.0	8.0	0.066	0.697	0.146	0.024
	3	6474.5-6479.0	4.5	0.051	0.653	0.198	0.006
Red A	1	6498.5-6521.0	23.0	0.067	0.548	0.144	0.108
	2	6496.0-6534.5	38.5	0.071	0.555	0.123	0.225
	3	6504.0-6520.0	10.5	0.053	0.535	0.208	0.021
Red B	1	6524.0-6550.5	16.0	0.069	0.626	0.091	0.073
	2	6536.0-6552.0	16.0	0.070	0.603	0.102	0.074
	3	6533.0-6561.5	19.5	0.061	0.558	0.149	0.072

*Includes sand with <25% clay and >3% porosity.
**Includes Yellow B in this well.

Table 1.2 Coastal Stress Data

Well	Depth (ft)	Lithology	σ_{min} (psi)	Estimated Error (psi)	Gradient (psi/ft)	νLaboratory	E (10^6 psi)
MWX-3	6765-67+	Mudstone	7100	50	1.05	--	--
	6706-08+						
	6606-08	Mudstone	7130		1.08	--	--
	6586-88	Mudstone	*				
	6565-67	Mudstone	6980	100	1.06	--	--
	6548-50	Sandstone	5640	20	0.86	--	--
	6527-29	Mudstone	6665	30	1.02	0.31	2.0
	6512-14	Sandstone	5845	30	0.9	0.19	4.2
	6483-85	Mudstone	**				
	6460-62	Sandstone	5670	30	0.88		
	6442-44	Sandstone	5720	30	0.89	0.21	3.9
	6420-22	Mudstone	6805	30	1.06	0.27	2.6
	6398-6400	Mudstone	6445	120	1.01	--	--
	6374-76	Mudstone	6540	150	1.03	--	--
MWX-2	6488-90	Mudstone	**			--	--
	6496-6553++	Sandstone	5740	50	0.88	0.19	4.2

*Inconclusive
**Communication
+Paludal Zone
++Breakdown test

Table 1.3 Comparison of Measurable Reservoirs

Interval	Reservoir	Approx. Depth (ft)	Reservoir Pressure (ft)	Perf. Net Pay (ft)	Production* Prefac (MSCFD)	Production* Postfrac (MSCFD)	Test Activity	Prefrac Production (MSCFD/ft)
Fluvial	E sandstone	5550	3100	30	70	240	Stimulation Experiment	2.3
	C sandstone	5725	3300	22	50	--	Unpropped Minifracs	2.3
	B sandstone	5825	3400	17	25	35	Stimulation Experiment	1.5
Coastal	Yellow sandstone	6450	4400	32	60	100	Stimulation Experiment	1.9
	Red sandstone	6525	4400	39	50	--	Interference Test	1.3
Paludal	Zones 3 and 4	7100	5300	48	250	170**	Stimulation Experiment	5.2
	Zone 2	7250	5400	28	160	--	Single Well Test	5.7
Marine	Upper Cozzette	7850	6300	37	550	--	Interference Test	15.0
	Lower Cozzette	7975	6400	14	>150	--	Single Well Test	>10.7
	Corcoren	8150	6600	65	>450	--	Single Well Test	>6.9

*Generally after 10 days production. Actual time may vary, but data reflect relative production.
**Became 400 MSCFD upon reentry after extended shut-in.

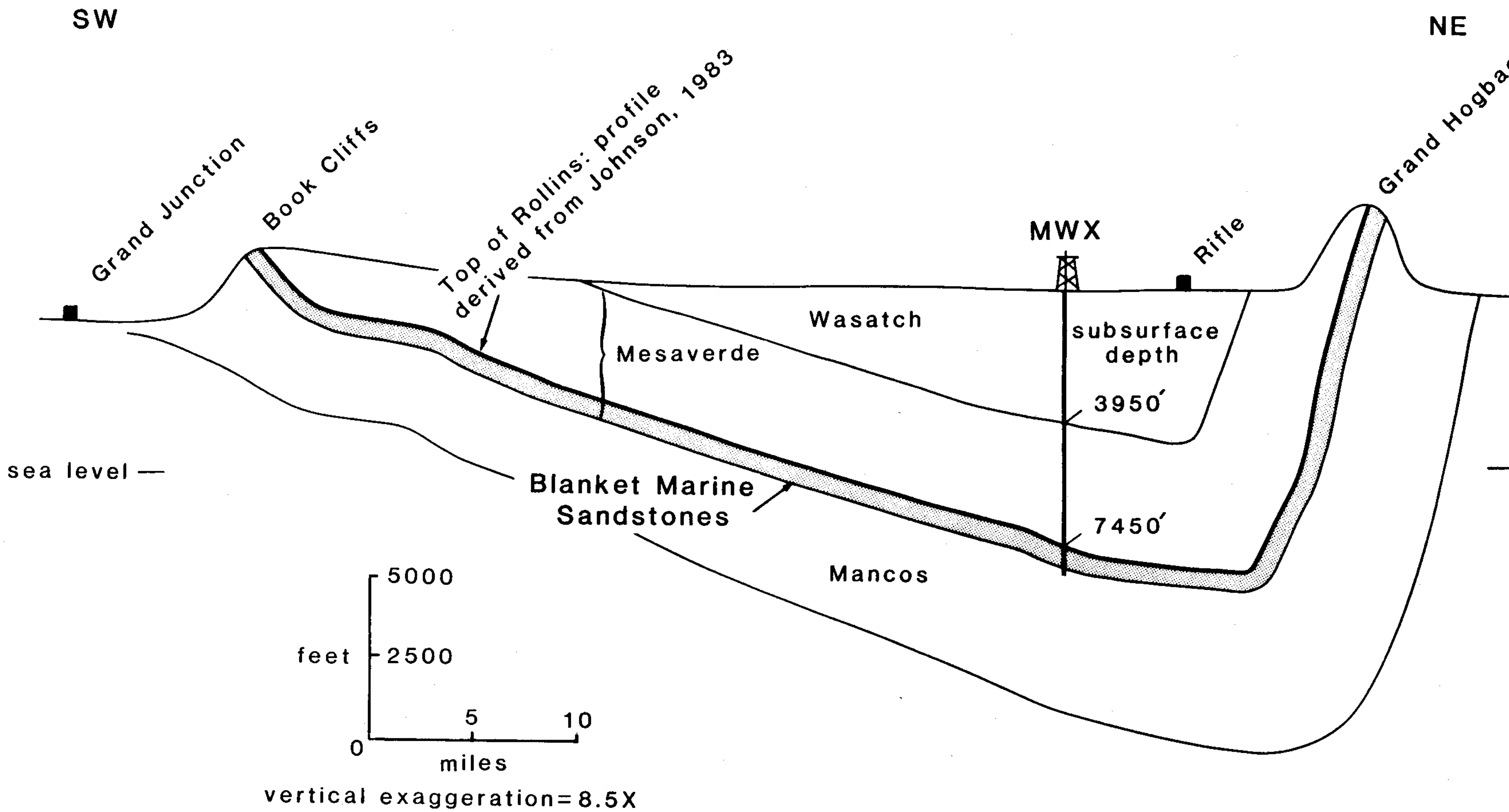

Figure 1.1 General Structure of the Mesaverde Formation in the Piceance Creek Basin, Northwest Colorado

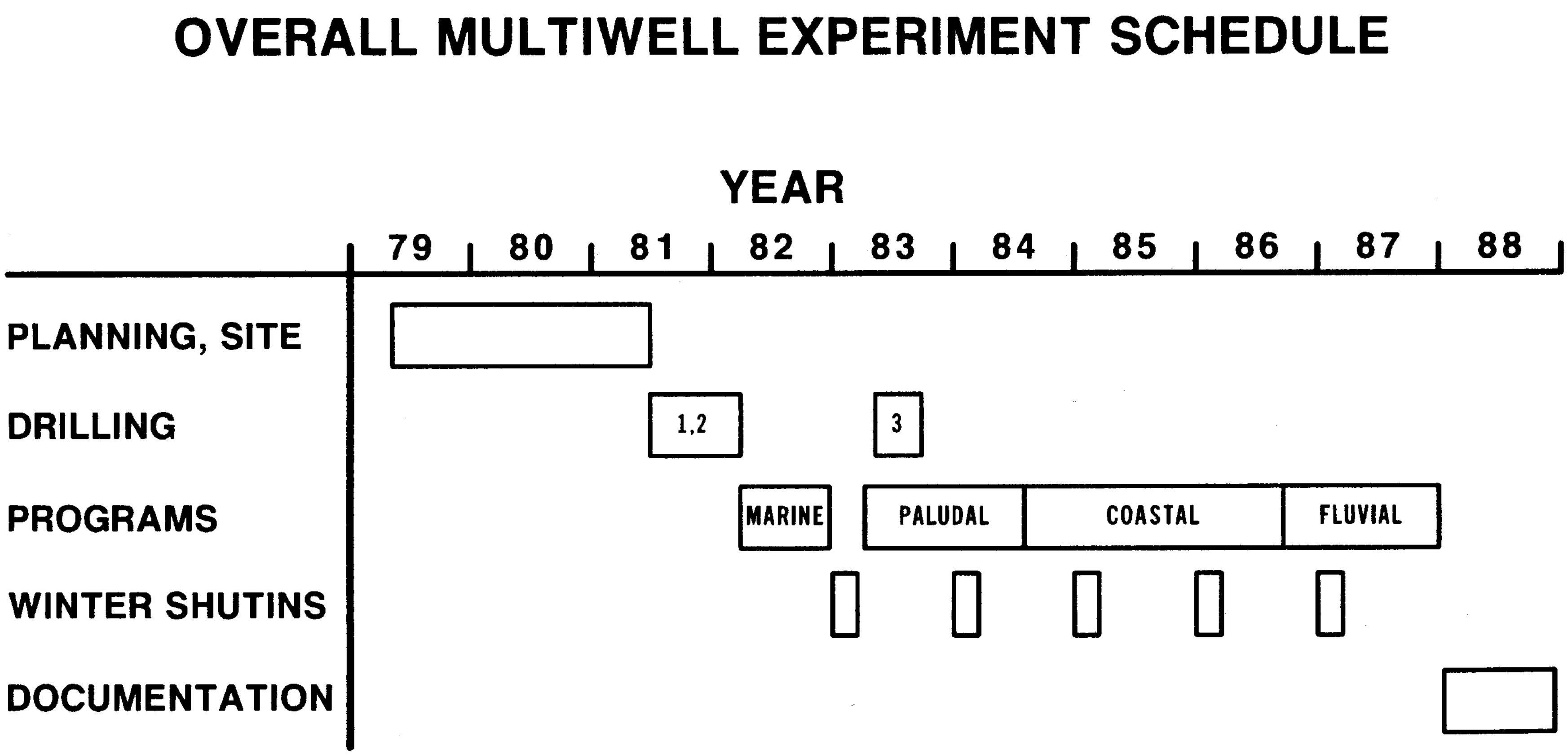

Figure 1.2 Overall Multiwell Experiment Schedule

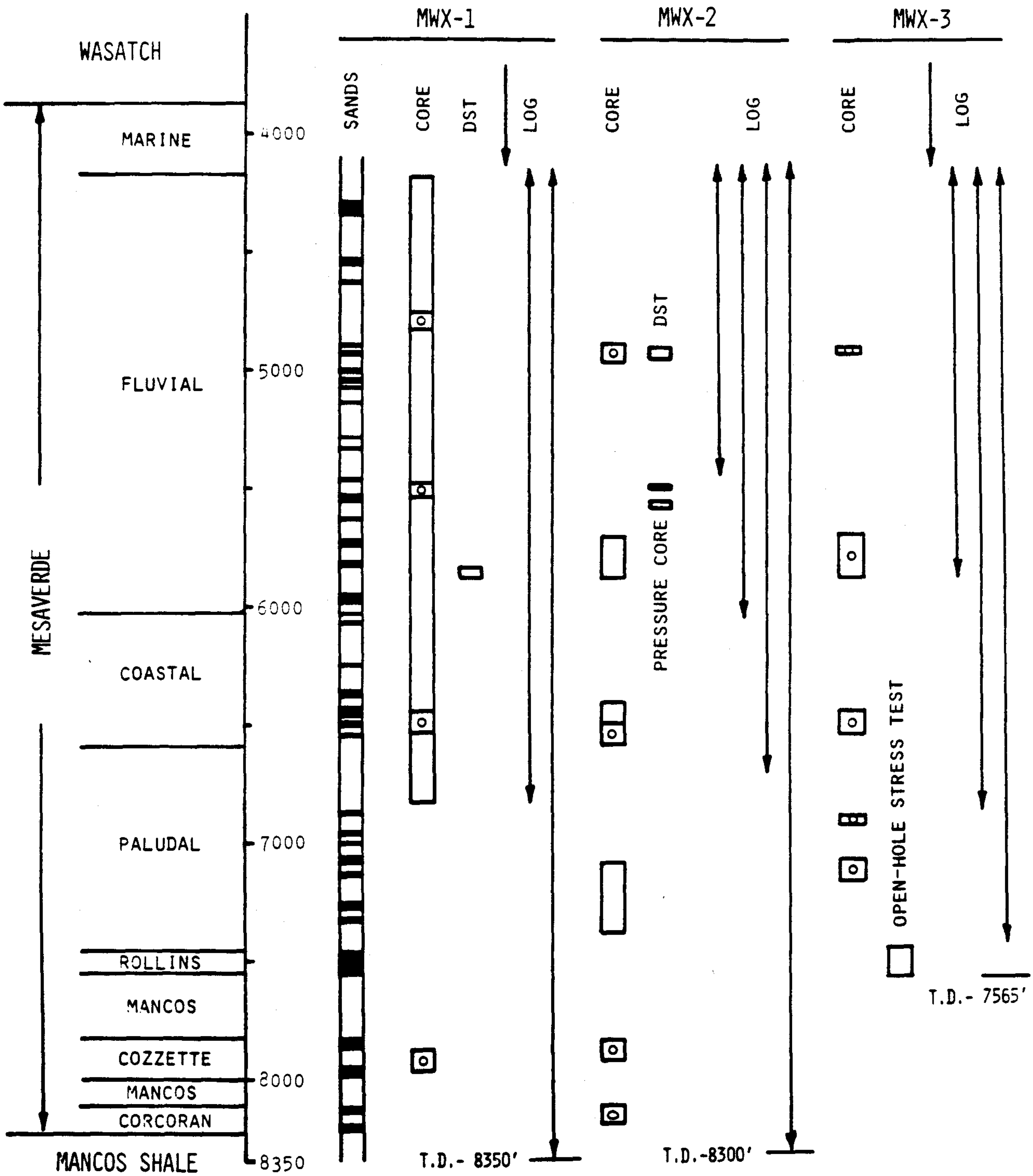

Figure 1.3 Summary of Coring and Logging Operations on the Three Multiwell Experiment Wells

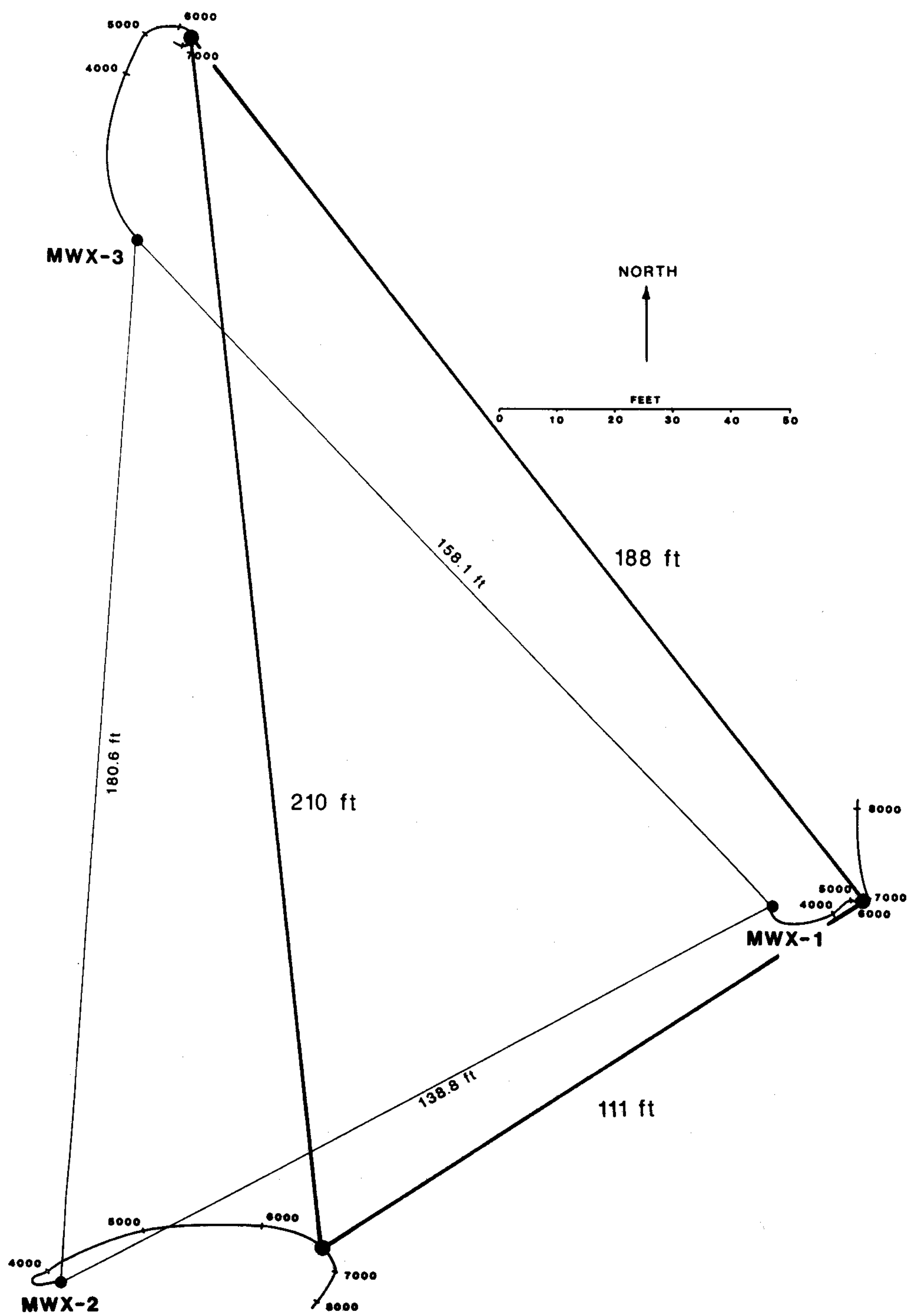

Figure 1.4 Relative Well Spacings at Surface and at 6500 ft in the Coastal Interval

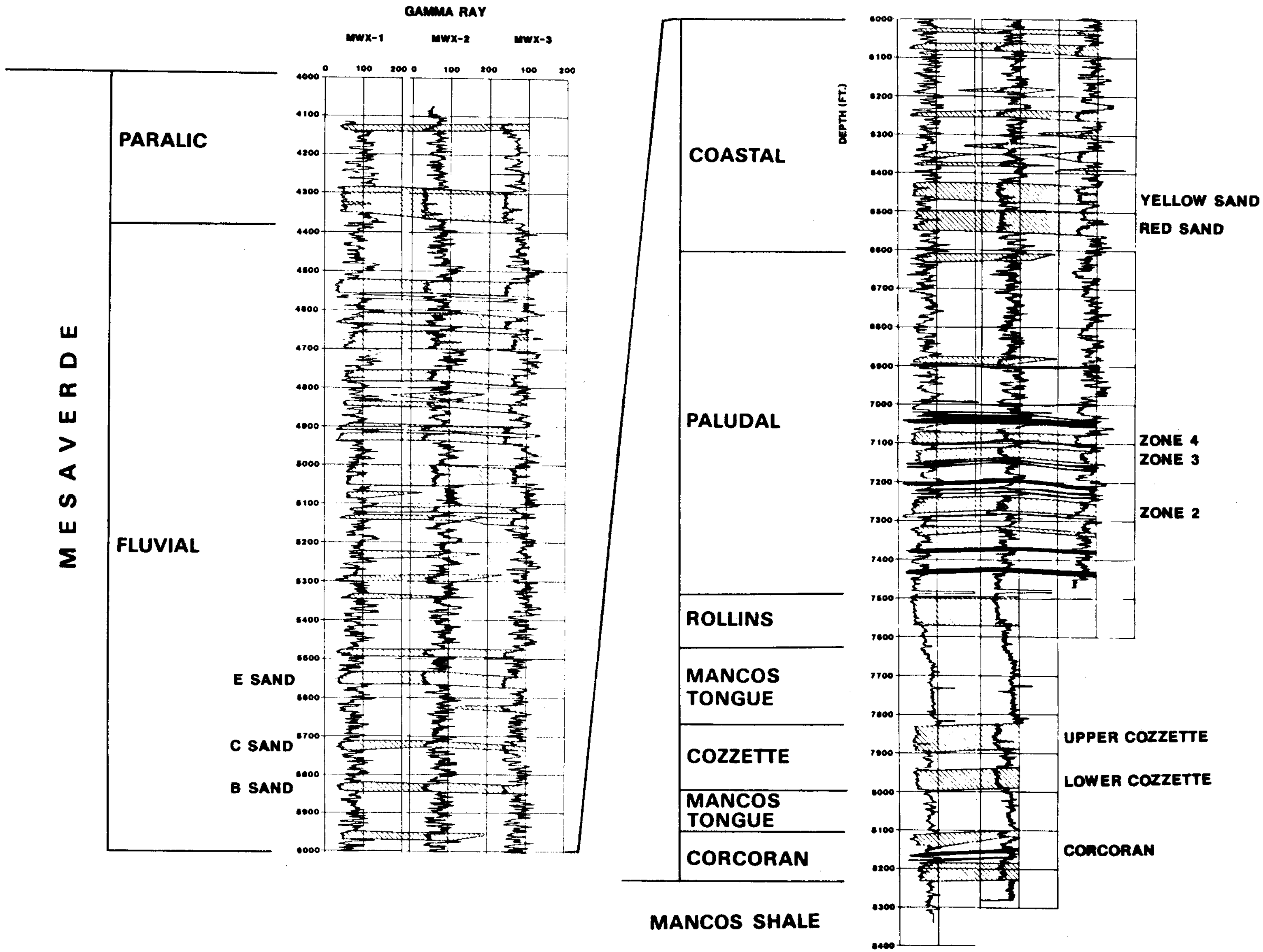

Figure 1.5 Gamma Ray Logs of the Three Multiwell Experiment Wells with Test Intervals Identified

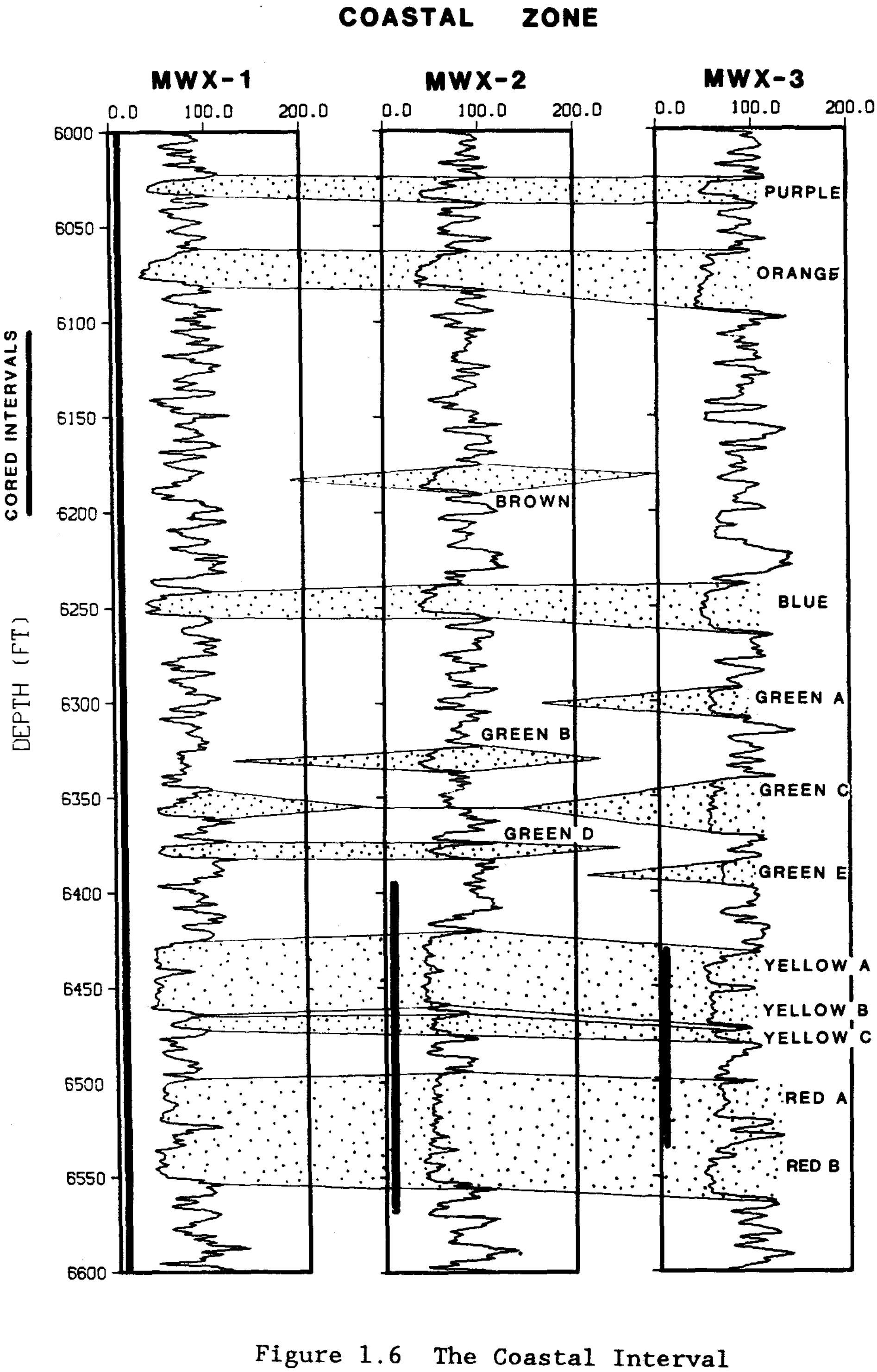

Figure 1.6 The Coastal Interval

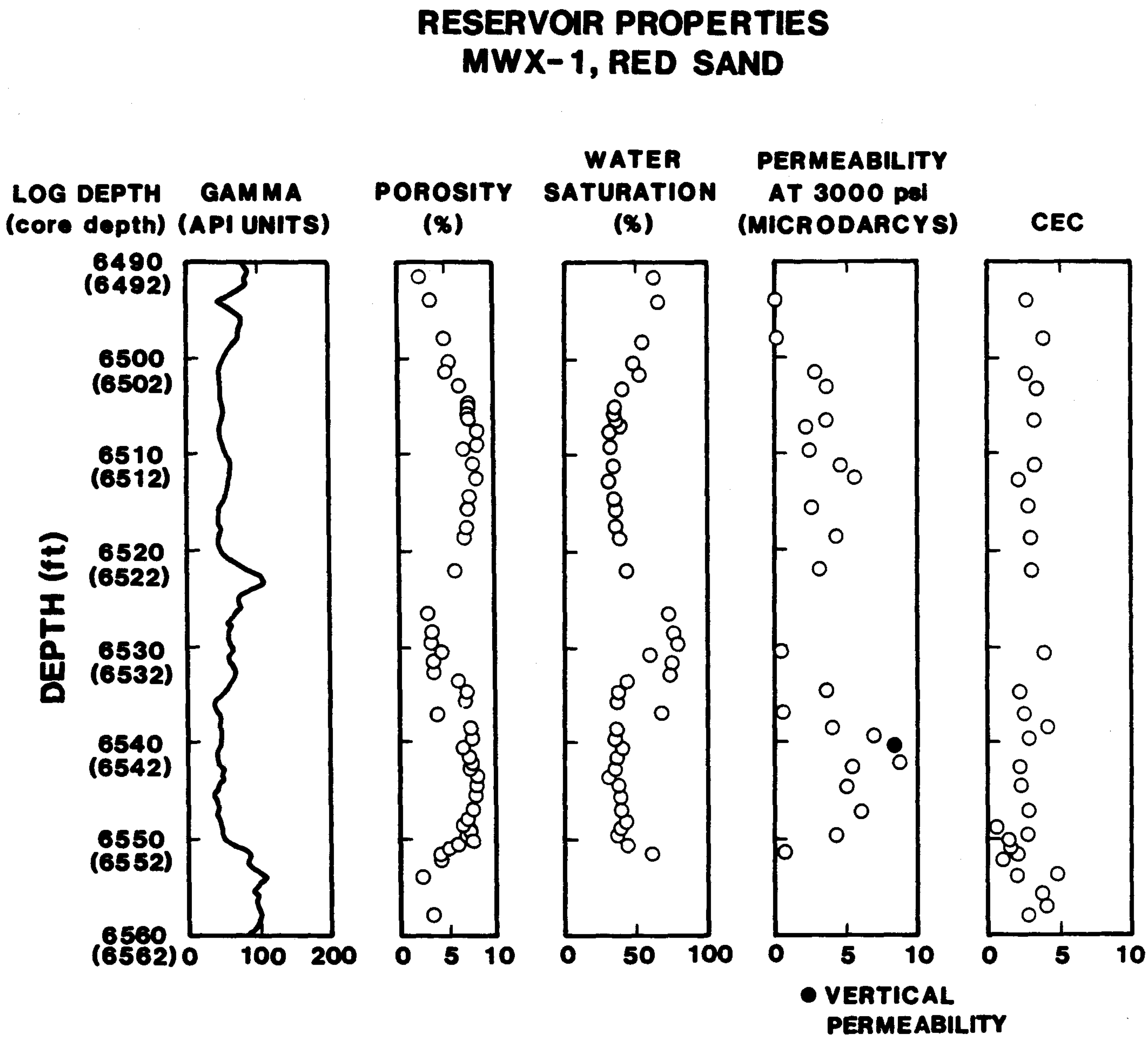

Figure 1.7 Typical Core-Derived (matrix) Coastal Reservoir Properties

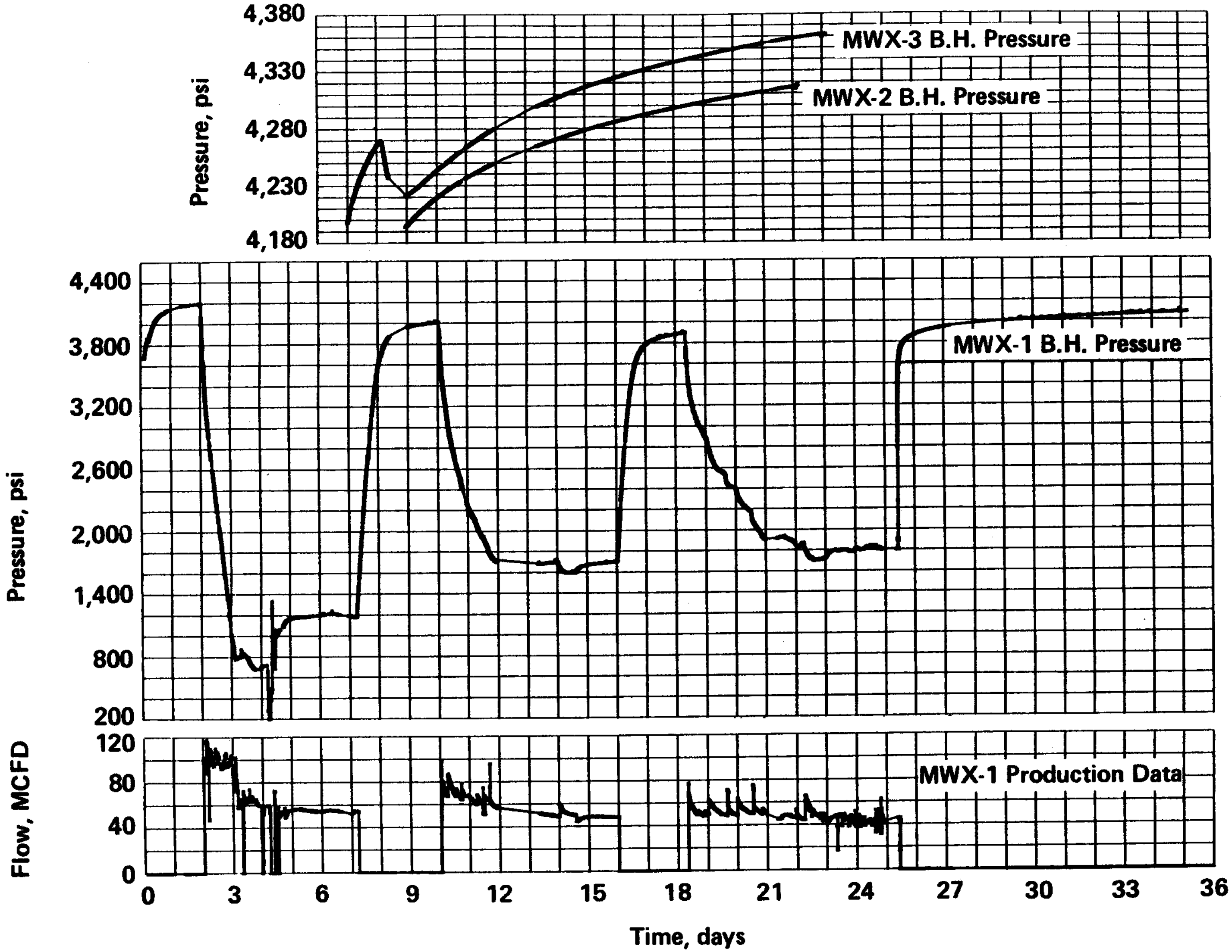

Figure 1.8 Pre-Frac Well Test and Interference Data from the Red Sandstones

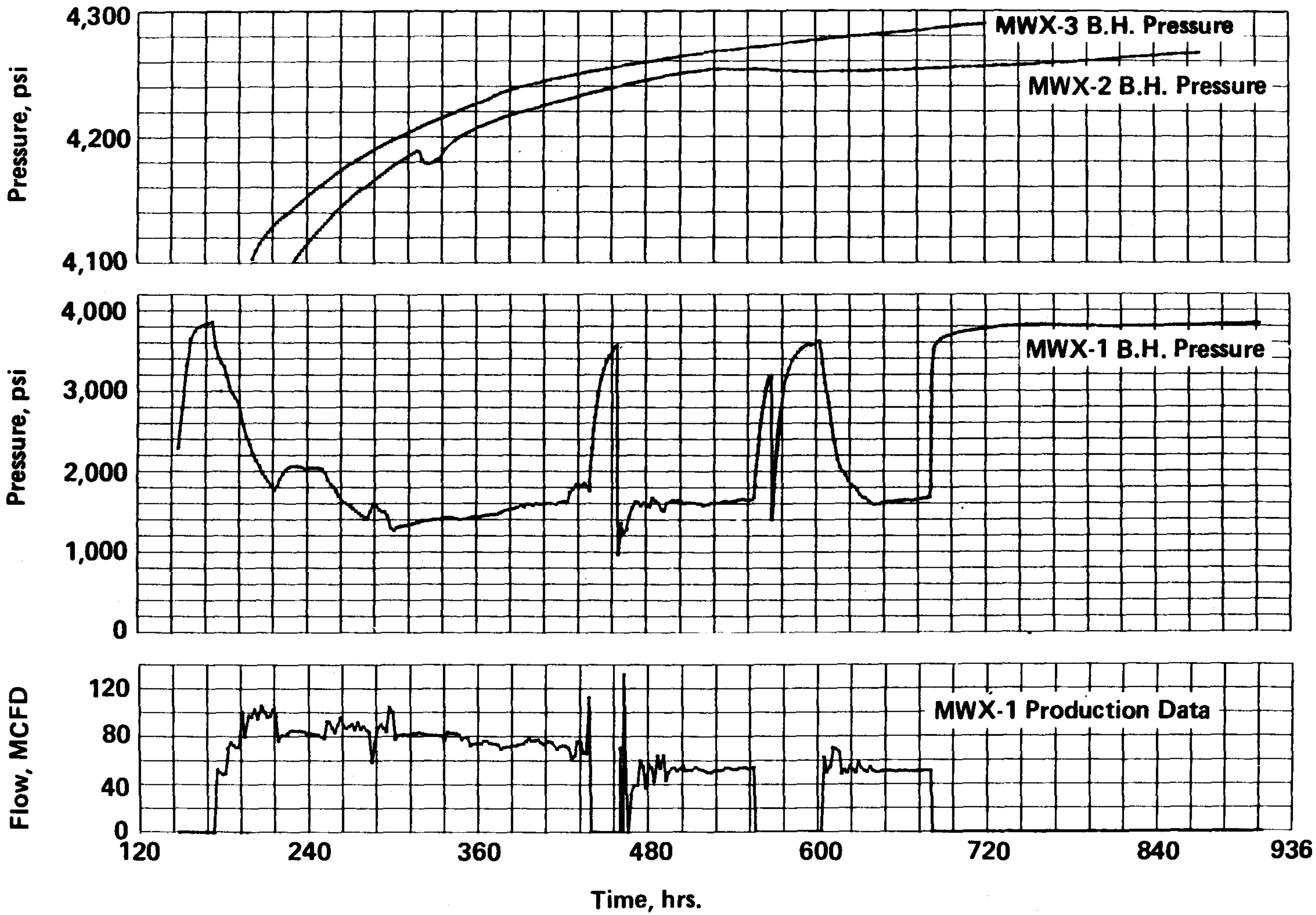

Figure 1.9 Pre-Frac Well Test and Interference Data from the Yellow Sandstones

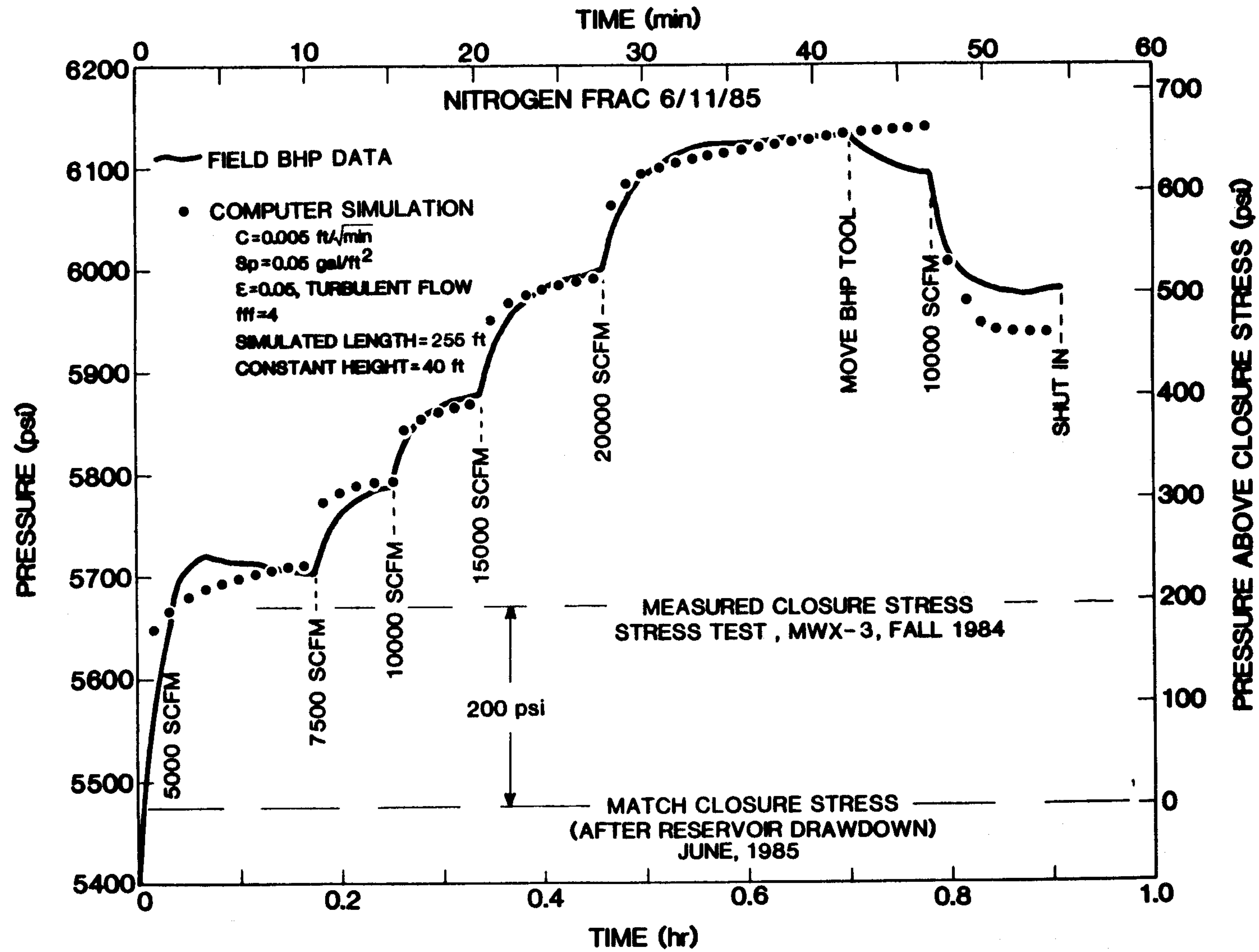

Figure 1.10 Treatment Pressure and Pressure History Match for Coastal Nitrogen Step Rate Test and Frac

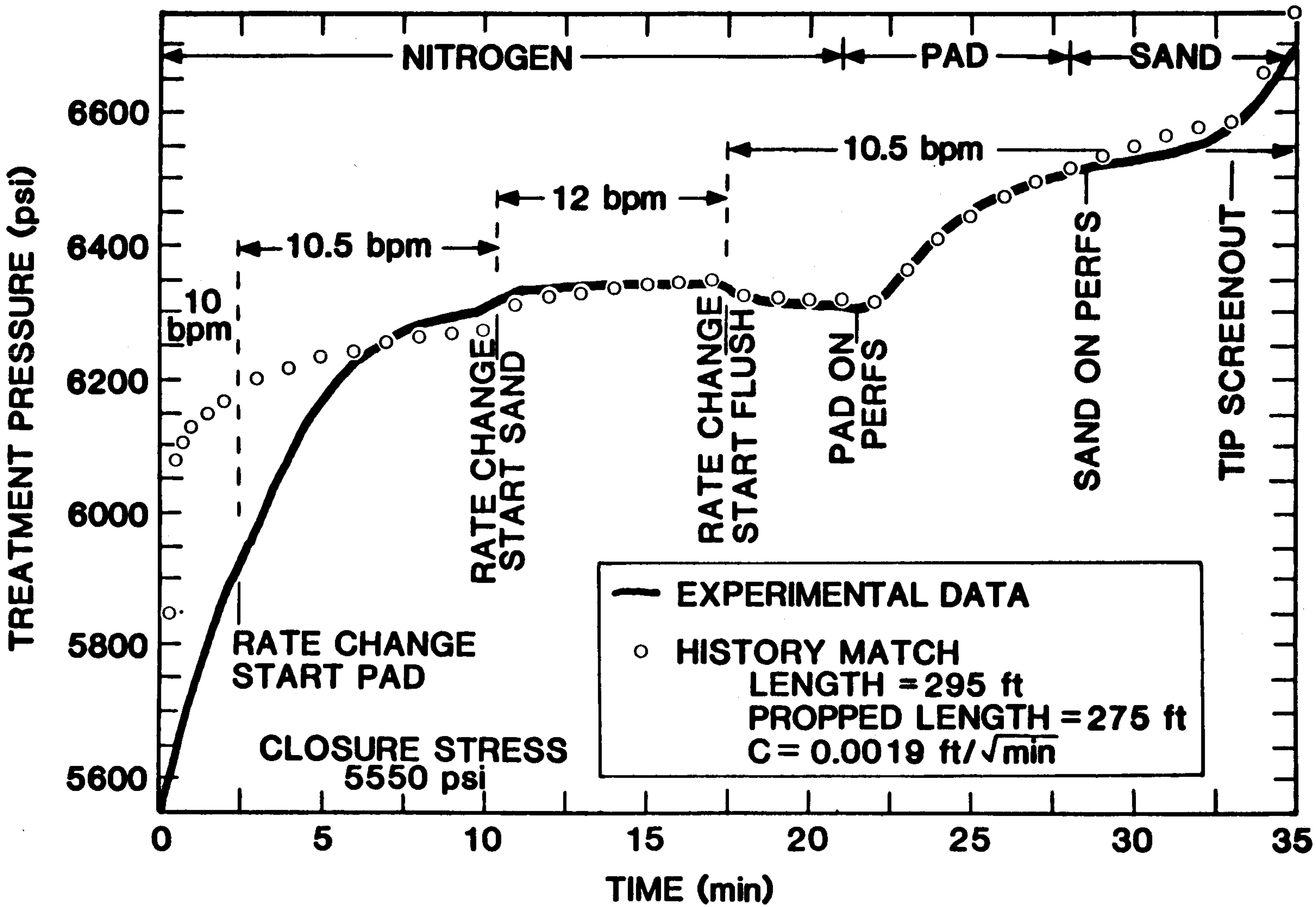

Figure 1.11 Treatment Pressure and Pressure History Match for Coastal Nitrogen Foam Frac

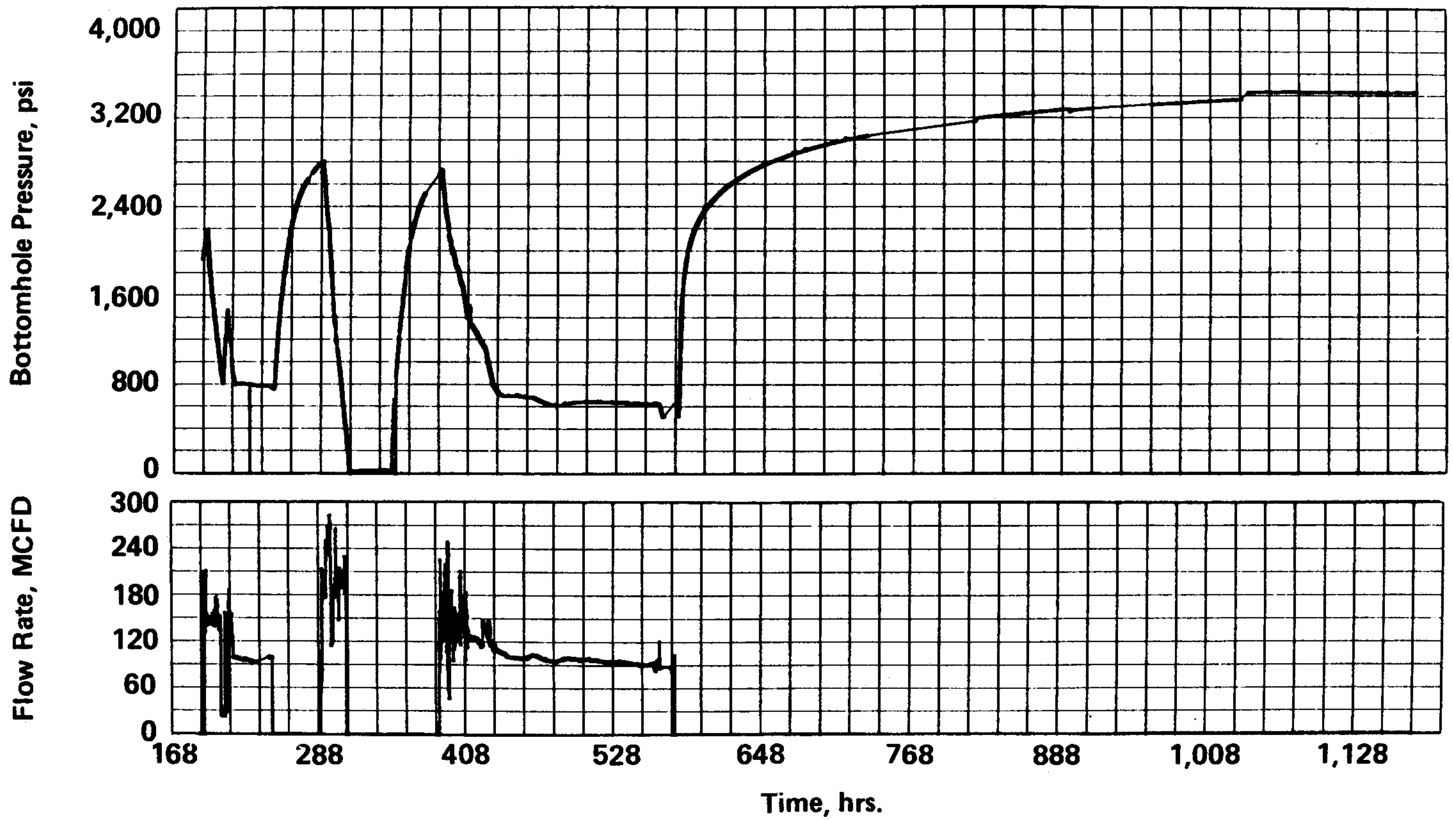

Figure 1.12 Post-Frac MWX-1 Bottomhole Pressure and Flow Data
(0 hrs = July 31, 1985)

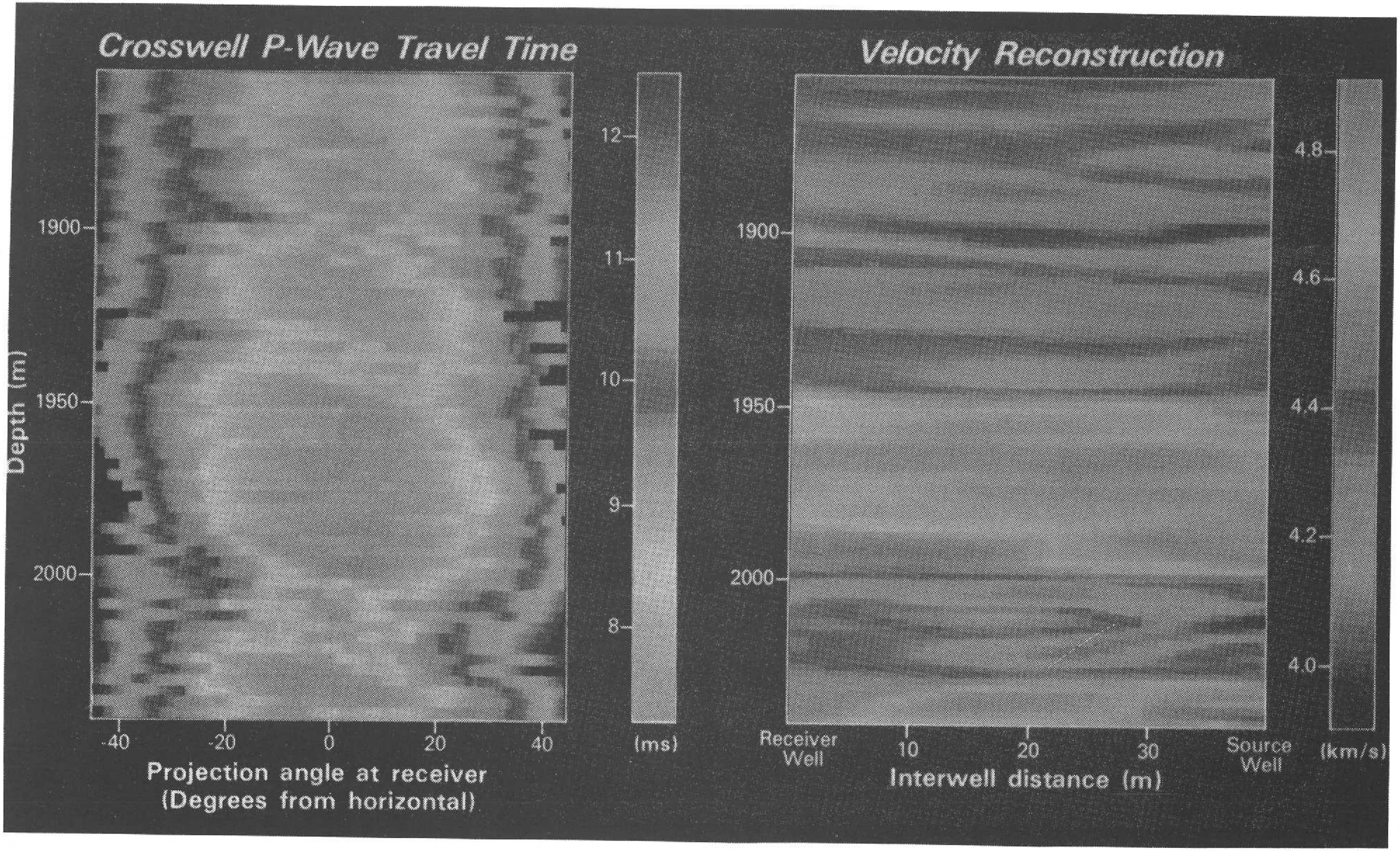

Figure 1.13 P-Wave Travel Time and Velocity Reconstruction from Crosswell Seismic Survey in the Coastal Interval (original in color)

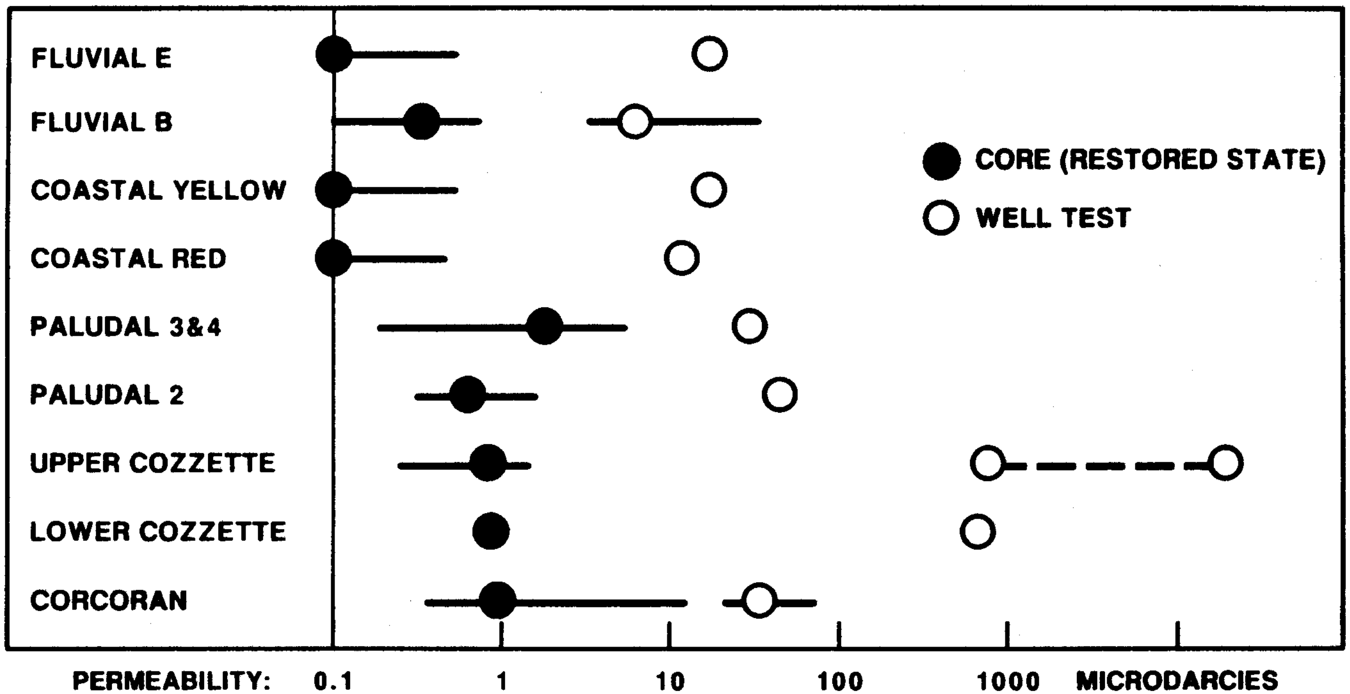

Figure 1.14 Comparison of Restored State (matrix) and Well Test (Reservoir) Permeabilities Showing the Influence of Natural Fractures on Reservoir Permeability

2.0 SITE DESCRIPTION AND OPERATIONS

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CER Corporation

2.1 WELL DRILLING AND WELL DESCRIPTIONS

As shown in Figure 2.1, the Multiwell Experiment (MWX) is located in the Rulison Field in the southeastern portion of the Piceance Basin in Colorado. The site is located in the SW1/4 NWI/4 Sec. 34, T6S, R94W, Garfield County, and is about 7 miles southwest of Rifle.

An agreement was reached with Superior Oil Company in mid-1981 and all necessary drilling and operating permits were acquired. Drilling of MWX-1 began in mid-September 1981, achieving total depth at 8350 ft. The well was drilled through the blanket marine Mesaverde sections and 7 in., 29 lb/ft N80 casing was run and cemented. As shown in Figure 2.2, a total of 2747 ft of the Mesaverde group was cored and recovered, including 470 ft of oriented core.

The rig was moved to the adjoining location and the second well was spudded on December 31, 1981. MWX-2 was also drilled through the blanket marine Mesaverde to a depth of 8300 ft with 915 ft of formation cored and recovered, as shown in Figure 2.3. The MWX-2 casing program was similar to the first well. The casing was run and cemented and the rig released on March 30, 1982.

The third well, MWX-3, was spudded on June 7, 1983, and was drilled to a depth of 7564 ft. As shown in Figure 2.4, it penetrated the Rollins Formation but not the Corcoran/Cozzette. "As-built" reports have been published on all three wells.[1,2,3] An approximate geologic section and the formation tops in MWX-1 are shown in Figure 2.5.

During the drilling of the three MWX wells, it was noted that a gradual increase of formation pressure was encountered starting at approximately

5600 ft. Mud weight had to be continually increased with depth from 9.0 lb/gal at 5600 ft to over 15.0 lb/gal at 8350 ft, as shown in Figure 2.6. The Cozzette required a pressure gradient of 0.71 psi/ft and the Corcoran 0.75 psi/ft to control the formation pressure during drilling. From these data and subsequent test data, it is apparent that the lower Mesaverde Formation is substantially overpressured.

Detailed directional surveys were also run in the wells to determine the relative well spacing at various depths, as well as at the surface. The wells were drilled with very little directional deviation so the relative spacing with depth does not change significantly. Figure 2.7 shows the relative locations of the three wells at the surface and at 6500 ft.

Complete logging suites were run on all three wells and the logs and analyses for the coastal interval are given in Section 4.0. A temperature log for MWX-1 is shown in Figure 2.8.

2.2 CHRONOLOGY OF COASTAL OPERATIONS

The chronology of events presented herein is a topical account of all coastal activities undertaken at the Multiwell Experiment. A summary of this information is presented in Figure 2.9.

2.2.1 Perforate, Breakdown Red Sands, MWX-1 (September 11-18, 1984)

September 11, the Red sands in MWX-1 were perforated by Dynajet with two 14-gm jet shots per foot (JSPF), (0.38-in. hole diameter) between 6535 ft and 6552 ft (17 ft) and between 6500 ft and 6524 ft (24 ft). The 2-7/8-in. tubing with a downhole shut-in (DHSI) tool, an Arrow "HD" packer, and two joints of tailpipe were run in the well and landed with the tubing tail at 6531 ft. The packer was set at 6480 ft in 20,000 lb compression. September 14, the casing-tubing annulus was successfully pressure tested to 3000 psi.

September 17, Smith Energy Services broke down the perforations with approximately 115 bbl of 3% KCl water and 164, 5/8-in. diameter, 1.3-SG, RCN ball sealers. The average injection rate was 4 BPM at an average treating pressure of 4200 psi. The instantaneous shut-in pressure (ISIP) was 3200 psi and the 15 minute shut-in pressure was 2986 psi. Good ball action was observed during the job, but no ballout occurred due to the maximum design treating pressure of 4300 psi being reached very early in the treatment and the injection rate falling off due to a large number of perforations being plugged.

2.2.2 Perforate, Breakdown Red Sands, MWX-2 (September 14-October 1, 1984)

September 14, the Red sands in MWX-2 were perforated by Dynajet with two 14-gm JSPF (0.38-in. hole diameter) between 6498 ft and 6553 ft (55 ft). A pinned coupling, 5 ft perforated sub, one joint of 2-7/8-in. tubing tailpipe, DHSI tool, and an Arrow "HD" packer were run in the well on 2-7/8-in. tubing with the tubing tail landed at 6466 ft. The packer was set at 6424 ft in 20,000 lb compression. The next day, the casing-tubing annulus was successfully pressure tested to 3000 psi.

September 24, the Red perforations were broken down with approximately 7 bbl of 3% KCl water at 1 BPM, using the rig pump. The maximum surface pressure during the perforation breakdown was 3250 psi.

October 1, Smith Energy Services broke down the perforations with 110 bbl of 3% KCl water containing 1 gal/1000 gal surfactant and 190, 5/8-in. diameter, 1.3-SG, RCN ball sealers. The average injection rate was 4 BPM at an average treating pressure of 3800 psi. The ISIP was 3100 psi. The well was immediately flowed back through the separator to recover breakdown fluid and measure gas production.

2.2.3 Stress Tests In And Below Red Sands, MWX-3 (September 24-30, 1984)

September 24, Dynajet perforated two intervals with four 12-gm JSPF (0.38-in. hole diameter) in preparation for stress testing operations:

6765-6767 ft and 6706-6708 ft. Following an unsuccessful attempt to run the stress test assembly past the perforations at 6706 ft, a bit, casing scraper and three 4-3/4-in. drill collars were run on the 2-7/8-in. tubing to roll out a suspected "burr" in the casing. Following a successful scraper run, a second unsuccessful attempt was made to run the stress test straddle packer assembly. It was then surmised that the casing was deformed opposite the uppermost set of stress test perforation. Stress testing was then undertaken on the combined interval, with four successful stress tests of the combined interval being completed September 25.

September 26, Dynajet perforated three additional intervals with four 12-gm JSPF (0.38-in. hole diameter) in preparation for stress testing operations: 6606-6608 ft, 6586-6588 ft, and 6565-6567 ft. Three separate stress tests were successfully run on the 6606-6608 ft and 6586-6588 ft intervals. The 6565-6567 ft interval would not break down at 6000 psi surface pressure. September 27, the interval was reperforated and successfully stress tested.

September 27, Dynajet perforated three new intervals with four 12-gm JSPF in preparation for stress test operations: 6548-6550 ft, 6527-6529 ft, and 6512-6514 ft. Each of these three intervals was successfully stress tested September 29.

2.2.4 Perforate, Breakdown Red Sands, MWX-3 (October 1, 1984)

October 1, Dynajet perforated the Red sands in MWX-3 with two 19-gm JSPF (0.46-in. hole diameter) between 6536 ft and 6561 ft (25 ft) and between 6506 ft and 6521 ft (15 ft). A pinned coupling, 10-ft perforated sub, one joint of 2-7/8-in. tubing, DHSI tool, and an Arrow "HD" packer were run in the well on 2-7/8-in. tubing with the tubing tail landed at 6480 ft. The packer was set at 6433 ft in 20,000 psi compression.

October 1, Smith Energy Services broke down the perforations with 57 bbl of 3% KCl water containing 1 gal/1000 gal surfactant and 180, 7/8-in. diameter, 1.3-SG, RCN ball sealers. The average injection rate was 5.5 BPM at an average treating pressure of 4600 psi. The ISIP was 3300 psi. The well was immediately flowed back through the separator to recover breakdown fluid and measure gas production.

2.2.5 Production/Interference Test, Red Sand, MWX-1 Producer (October 3-November 5, 1984)

October 3, MWX-1 was returned to production through the test separator at 100 MCFD and 1177 psi flowing bottomhole pressure (FBHP). MWX-2 and MWX-3 were intermittently flowed and shut in to maximize recovery of breakdown fluid prior to initiating interference testing. Interference testing was initiated October 6, with successful seating of the HP tools in the DHSI tool in MWX-2 (10:30 a.m.) and MWX-3 (11:00 a.m.). The interference testing in MWX-2 and MWX-3 was concluded on October 24. The flow test in MWX-1 was concluded at 6:15 p.m. October 25 when the well was shut in downhole for a pressure buildup. The pressure buildup was concluded November 5.

2.2.6 Stress Tests In And Below Yellow Sands, MWX-3 (October 25-28, 1984)

October 25, Dynajet set an Arrow wireline-set, tubing-retrievable, bridge plug at 6500 ft to isolate the perforations in the Red sands. Dynajet then perforated the following three intervals with four 19-gm JSPF (0.46-in. hole diameter) in preparation for stress testing operations: 6483-6485 ft, 6460-6462 ft, and 6442-6444 ft.

Initially, stress testing was attempted on the 6483-6485 ft interval. Pressure communicated to the annulus and the stress test assembly was pulled. October 26 the upper packer was redressed and the stress test assembly was rerun. The 6460-6462 ft interval was then successfully stress tested. A second unsuccessful attempt was then made to stress test the 6483-6485 ft interval. The stress test assembly was then positioned to straddle the perfs in the 6442-6444 ft interval which was successfully stress tested. The next day, a third unsuccessful attempt was made to stress test the 6483-6485 ft interval.

2.2.7 Perforate, Breakdown Yellow Sands, MWX-3 (October 29-November 6, 1984)

October 29, Dynajet perforated the Yellow sands in MWX-3 with two 19-gm JSPF (0.46-in. hole diameter) between 6438 ft and 6480 ft (42 ft). A pinned collar, one joint of 2-7/8-in. tubing, DHSI tool, and an Arrow "HD" packer were run in the well on 2-7/8-in. tubing with the tubing tail landed at 6405 ft. The packer was set at 6365 ft in 20,000 lb compression. October 30 the casing-tubing annulus was successfully pressure tested to 3000 psi.

November 6, Halliburton Company broke down the perforations with 92 bbl of 3% KCl water and 77, 7/8-in. diameter, 1.1-SG, RCN ball sealers. The average injection rate was 4 BPM at a maximum treating pressure of 4200 psi. The ISIP was 3150 psi. No ball action was observed during the breakdown. The well was immediately flowed back to the test tank to measure recovered fluid. Very little gas was observed following perforation breakdown.

2.2.8 Perforate, Breakdown Yellow Sands, MWX-2 (October 31-November 6, 1984)

October 30, Dynajet ran in MWX-2 and set an Arrow wireline-set, tubing-retrievable, bridge plug at 6490 ft and dumped two sacks of sand on top to isolate the perforations in the Red sands. Dynajet then perforated the Yellow sands in MWX-2 with two 19-gm JSPF (0.46-in. hole diameter) between 6424 ft and 6474 ft (50 ft). A pinned collar, one joint of 2-7/8-in. tubing, DHSI tool, and an Arrow "HD" packer were run in the well on 2-7/8-in. tubing with the tubing tail landed at 6400 ft. The packer was set at 6363 ft in 22,000 lb compression. November 6, the casing-tubing annulus was successfully pressure tested to 2000 psi.

November 6, Halliburton Company broke down the perforations with 56 bbl of 3% KCl water and 126, 7/8-in. diameter, 1.1-SG, RCN ball sealers. The injection rate varied from 3.3 BPM to 4.8 BPM. The formation broke down at 4000 psi, maximum treating pressure was 4200 psi, and the minimum pressure was 3900 psi. The ISIP was 3150 psi. Good ball action was observed during the breakdown but no ballout occurred. The well was immediately flowed back to the test tank to measure recovered fluid. Very little gas was observed following perforation breakdown.

2.2.9 Perforate, Breakdown Yellow Sands, MWX-1 (November 5-6, 1984)

November 5, Dynajet ran in the hole and set an Arrow wireline-set, tubing-retrievable, bridge plug at 6484 ft and dumped three sacks of sand on top to isolate the perforations in the Red sands. November 6, Dynajet perforated the Yellow sands in MWX-1 with two 19-gm JSPF (0.46-in. hole diameter) between 6428 ft and 6460 ft (32 ft). A pinned collar, one joint of 2-7/8-in. tubing, DHSI tool, and an Arrow "HD" packer were run on 2-7/8-in. tubing with the tubing tail landed at 6301 ft. The packer was set at 6350 ft in compression. The casing-tubing annulus was successfully pressure tested to 3000 psi.

November 6, Halliburton Company broke down the perforations with 32 bbl of 3% KCl water and 96, 7/8-in. diameter, 1.1-SG, RCN ball sealers. The injection rate varied from 4.0 BPM to 4.8 BPM. The formation broke down at 4200 psi, the maximum treating pressure was 4200 psi, and the minimum pressure was 3000 psi. The ISIP was 3200 psi. Very little ball action was observed during the breakdown and no ballout occurred. The well was immediately flowed back to the test tank to measure recovered fluid.

2.2.10 Production/Interference Test, Yellow Sands, MWX-1 Producer (November 8-December 15, 1984)

Following one week of intermittent flow from the three wells to maximize recovery of breakdown liquids, HP gauges were run in each of the wells in preparation for interference testing with MWX-1 as the producer, and MWX-2 and MWX-3 as the interference wells. The HP gauges were seated below DHSI tools in MWX-2 and MWX-3. Flow was initiated at 70 MCFD from MWX-1 at 10:00 p.m., November 14. This pressure drawdown was concluded at 5:00 p.m., December 5 with the seating of the HP gauge in MWX-1. The pressure buildup portion of this interference was concluded December 15.

2.2.11 Prepare MWX-1 For Red and Yellow Commingled Production (December 16-19, 1984)

December 16, the HP gauge and 6300 ft of wireline were lost in MWX-1 during retrieval operations. The next day, a well service unit was moved in, BOP's installed, the Arrow "HD" packer was released and the 2-7/8-in. tubing was pulled from the well. The HP gauge and wireline were recovered and the packer was laid down. The 2-7/8-in. tubing with a retrieving tool was run in the well, and sand and ball sealers were reverse circulated off the retrievable bridge plug at 6484 ft (above the Red sands). The retrievable bridge plug was pulled from the well and laid down. A pinned collar, ten joints of 2-7/8-in. tubing, DHSI tool, and an Arrow "HD" packer were run in the well on 2-7/8-in. tubing with the tubing tail landed at 6544 ft. The packer was set at 6221 ft in 20,000 lb compression. The BOP's were removed, the wellhead installed, and the well service unit was moved off the well.

2.2.12 Winter Shutdown And Production Test, MWX-1 (December 20, 1984-April 5, 1985)

December 20, all power to the test trailer had been disconnected and winterization operations had been completed.

At 12:00 noon on December 26, commingled gas production was begun from the Red and Yellow sands in MWX-1 into the Western Slope Gas Company line at 75 MCFD against 420 psi line pressure. Gas production was essentially continuous until 11:00 a.m., April 5, when the well was shut in for workover in preparation for 1985 MWX field activities.

2.2.13 Prepare MWX-2 For Red And Yellow Commingled Production (April 2-5, 1985)

April 2, a well service unit was moved onto the well, the BOP's were installed, the Arrow "HD" packer was released, and the 2-7/8-in. tubing was pulled from the well and the packer laid down. A retrieving tool was then run on the 2-7/8-in. tubing to the top of the sand fill and the sand and ball sealers were reverse circulated off the retrievable bridge plug at

6490 ft (above the Red sands) with 3% KCl water. The bridge plug was released, retrieved from the well, and laid down. A pinned collar, one joint of 2-7/8-in. tubing, DHSI tool, and Arrow "HD" packer were run in the well on 2-7/8-in. tubing with the tubing tail landed at 6400 ft. The packer was set at 6363 ft in compression. The BOP's were removed, wellhead installed, and the casing-tubing annulus was successfully pressure tested to 3000 psi.

2.2.14 Prepare MWX-3 For Red and Yellow Commingled Production (April 5-9, 1985)

April 5, a well service unit was moved on the well, the BOP's were installed, the Arrow "HD" packer was released, and the 2-7/8-in. tubing was pulled from the well and the packer laid down. A retrieving tool was then run on the 2-7/8-in. tubing to the top of the sand fill and the sand and ball sealers were reverse circulated off the retrievable bridge plug at 6500 ft (above the Red sands) with 3% KCl water. The bridge plug was released, retrieved from the well, and laid down. A pinned collar, one joint of 2-7/8-in. tubing, DHSI tool, and an Arrow "HD" packer were run in the well on 2-7/8-in. tubing. The packer was set at 6365 ft in 21,000 lb compression. The BOP's were removed, wellhead installed, the casing-tubing annulus was successfully pressure tested to 3000 psi.

2.2.15 Nitrogen Injection Into Red and Yellow Sands, MWX-2 (April 16-May 16, 1985)

Intermittent nitrogen injection was undertaken in MWX-2 between 1:00 p.m. April 16 and 2:00 p.m. April 18 at rates ranging from 800 SCFM to 5000 SCFM to provide insight into, and to help quantify, the flow mechanisms in naturally fractured reservoirs. A total of 361,292 SCF nitrogen was injected into MWX-2 during this test. The produced effluent gases from MWX-1 and MWX-3 were continuously monitored with gas chromatography throughout the nitrogen injection phase and up through April 22. MWX-2 was shut in at 2:00 p.m. April 18 for pressure buildup until the initiation of production testing at 7:00 a.m. May 8. MWX-1 and MWX-3 remained shut in, serving as interference monitoring wells through the conclusion of testing on May 16.

2.2.16 Stress Tests Above Yellow Sands, MWX-3 (May 29-June 3, 1985)

May 29, Dynajet perforated the following three intervals in MWX-3 with four 19-gm JSPF (0.46-in. hole diameter) in preparation for stress testing operations above the Yellow sands: 6420-6422 ft, 6398-6400 ft, and 6374-6376 ft.

A Squire-Whitehouse bottomhole pressure sonde (self-contained and battery-powered) was hung beneath a retrievable bridge plug that was to be used to isolate the Yellow sands below 6438 ft before stress testing. Then both were run below the Halliburton PPI stress test packer assembly. Following several unsuccessful attempts to set the retrievable bridge plug, it was decided to conduct the stress tests with the bridge plug and Squire Whitehouse sonde hanging unset below the stress test assembly. The three intervals listed above were successfully stress tested May 30 and 31. The stress test assembly was pulled from the well following completion of stress testing operations, but the retrievable bridge plug and Squire-Whitehouse sonde were not recovered. Fishing operations conducted June 1 and 2 resulted in successful recovery of both the retrievable bridge plug and the Squire-Whitehouse sonde.

2.2.17 Prepare MWX-2 and MWX-3 For Yellow Sand Pressure Observation (June 3-4, 1985)

Following successful fishing operations, MWX-3 was equipped for separate pressure observation in the Red and Yellow sands. A Squire-Whitehouse sonde to record pressures in the Red interval was run below a Halliburton retrievable bridge plug set at 6498 ft. The downhole assembly used to isolate the Yellow sand included a 2-7/8-in. pinned collar, 2-ft perforated 2-7/8-in. sub, Halliburton RTTS packer, one joint of 2-7/8-in. tubing and a DHSI tool run on 2-7/8-in. tubing, with the packer set at 6425 ft. The casing-tubing annulus was successfully pressure tested to 1000 psi with 3% KCl water. The pressure measurement in the Yellow sands was done through tubing using the HP gauge shut-in downhole to minimize wellbore effects.

The next day, MWX-2 was similarly equipped for separate pressure observation in the Red and Yellow sands. A Squire-Whitehouse pressure sonde was run below a Halliburton retrievable bridge plug set at 6485 ft. The downhole assembly used to isolate the Yellow sand included a 2-7/8-in. pinned collar, 2-ft perforated 2-7/8-in. sub, Halliburton RTTS packer, one joint of 2-7/8-in. tubing and a DHSI tool run on 2-7/8-in. tubing with the packer set at 6395 ft. The pressure measurement in the Yellow sands was done through tubing using the HP gauge shut-in downhole to minimize wellbore effects. The casing-tubing annulus was successfully pressure tested to 1000 psi.

2.2.18 Equip MWX-1 For Coastal Yellow Nitrogen Step Rate Test (June 8, 1985)

MWX-1 was equipped for pressure observation in the Red sands and for nitrogen step rate testing in the Yellow sands. A Kuster, self-contained pressure sonde was run below a Halliburton retrievable bridge plug, set at 6480 ft. The downhole assembly used to isolate the Yellow sands included a pinned collar, Halliburton RTTS packer, one joint of 2-7/8-in. tubing, DHSI tool, 2-7/8-in. x 4-1/2-in. crossover, two joints of 4-1/2-in. 11.6 lb/ft, N80 casing, and a 4-1/2-in. x 2-7/8-in. crossover run on 2-7/8-in. tubing. The packer was set at 6401 ft in 20,000 lb compression. The casing-tubing annulus was successfully pressure tested to 3000 psi.

2.2.19 Nitrogen Step Rate Test and Flow Test In MWX-1 (June 11-July 8, 1985)

The first of two fracturing experiments in MWX-1 began with a step rate test performed in the Yellow sands on June 11. The fracturing fluid was nitrogen gas and the fracture was executed using a series of stepped injection rates that ranged from 2000 SCFM to 20,000 SCFM. Bottomhole pressure and temperature were measured in the fracture well, MWX-1, and the two observation wells, MWX-2 and MWX-3. A total of about 820,000 SCF of nitrogen were pumped into MWX-1 during this portion of the test.

On June 13, the initial fracture was reopened by injecting nitrogen through MWX-1 at a surface rate of 10,000 SCFM for a period of 30 minutes. The total nitrogen pumped in this second fracturing experiment was 300,000 SCF. The objective of this portion of the test was to promote the transport of nitrogen through the induced and natural fractures and measure traces of nitrogen at the observation wells, MWX-2 and 3.

Squire-Whitehouse pressure sondes had been placed below retrievable bridge plugs in MWX-2 and MWX-3 to measure pressure in the isolated Red sands during testing and fracturing operations in the Yellow sands. The pressure sondes in MWX-2 and MWX-3, along with the Kuster gauge observing the Red sands in MWX-1, would be recovered later for pressure data analysis.

The production of MWX-2 and MWX-3 began June 13, about 18 hours after the initial frac. A semiautomatic gas chromatograph system was used to monitor the separate effluent gas streams for nitrogen content through June 23.

A modified isochronal flow test was initiated in MWX-1 at 12:00 noon June 17 and was terminated 10:00 a.m. June 26 when the HP gauge was seated downhole with nitrogen for a pressure buildup. The pressure buildup in MWX-1 was terminated, due to suspected casing leaks, at 8:00 a.m. July 8.

2.2.20 Cement Squeeze Stress Test Perforations, MWX-3 (June 25-July 4, 1985)

June 25, the Halliburton retrievable bridge plug with the Squire-Whitehouse pressure sonde was recovered from MWX-3 without incident. A retrievable bridge plug, retrieving head, 2-ft 2-7/8-in. tubing sub, and a Halliburton RTTS packer were then run in the well on 2-7/8-in. tubing. The bridge plug was set at 6428 ft with two sacks of sand on top in preparation for squeeze cementing perforations in three stress test intervals: 6420-6422 ft, 6398-6400 ft, and 6374-6376 ft.

Injection was established into the perfs at 1 BPM and 4700 psi, cement was spotted in the tubing, the Halliburton RTTS packer was set at 6240 ft, the casing-tubing annulus was pressured to 2000 psi, and squeeze operations were initiated. The perforated interval was squeezed with 75 sacks Class G cement containing 0.4% Halad 9. At the time the cement was across the perfs and the squeeze pressure was 5400 psi, communication developed to the annulus due to a circulating valve failure on the Halliburton RTTS packer. The cement in the tubing was reverse circulated from the well, and the tubing and packer were pulled from the well. The next day, a 5-7/8-in. insert bit, bit sub, casing scraper, four 4-3/4-in. drill collars, and a 4-3/4-in. x 2-7/8-in. crossover were run in the well on 2-7/8-in. tubing to drill out the cement across the squeezed interval. After drilling 140 ft of hard cement, the drill string twisted off just above the pin on the bottom joint of tubing at the 2-7/8-in. x 4-3/4-in. crossover sub. June 28, a 4-3/4-in. DOTCO overshot and a 4-ft extension were run on the 2-7/8-in. tubing, the fish was engaged and recovered, and cement drillout operations were completed.

June 29 the 2-7/8-in. tubing was run open-ended to 6422 ft and 74 sacks of Class G cement containing 0.4% Halad 9 was spotted over the perforated interval and displaced with fresh water. Excess cement was circulated from the well, the tubing was raised 16 joints, and the well was pressured to 2000 psi, and shut in overnight. Drillout operations were successfully undertaken but the squeeze was not successful.

July 1, a third cement squeeze with 75 sacks of Class G cement containing 0.4% Halad 9 was undertaken. A squeeze pressure of 5000 psi was achieved and held for 20 minutes without cement movement. Drillout operations were completed July 4 and the squeezed interval was successfully pressure tested to 3500 psi. A Mountain States wireline set, tubing retrievable, bridge plug was set July 8 at 6408 ft with 1.5 sacks of sand placed on top. The 2-7/8-in. tubing was run open-ended into the well and the retrievable bridge plug was successfully pressure tested to 3500 psi.

2.2.21 Stress Tests Between Red and Yellow Sands, MWX-2 (July 5-12, 1985)

July 5 the Halliburton RTTS packer was released, the retrievable bridge plug with Squire-Whitehouse pressure sonde was released, and the entire downhole assembly was pulled from MWX-2 on the 2-7/8-in. tubing and was laid down.

July 8, Dynajet perforated between 6488 ft and 6490 ft with four 19-gm JSPF in preparation for stress testing. The stress test assembly including a Squire-Whitehouse pressure sonde (enclosed in a 2-7/8-in. tubing sub) below a Halliburton PPI packer assembly (with a 6-ft 2-7/8-in. spacer between the upper and lower packoff), a Halliburton RC valve, and a DHSI tool was run on 2-7/8-in. tubing to straddle the perforations. The top packer element was set at 6485 ft and the lower packer element at 6493 ft. July 11, following three days of packer seating problems, further stress test efforts in this interval were terminated.

2.2.22 Borehole Seismic Calibration Tests, MWX-2 and MWX-3 (July 12-24, 1985)

July 12, the stress test assembly was pulled from MWX-2 and laid down. The flange for the 7-in. lubricator was installed on the BOP's and the well was ready for use in a Sandia borehole seismic experiment. July 16, the 2-7/8-in. tubing was pulled from MWX-3 and a 6-in. full open, 3000 psi gate valve was installed.

July 23, a borehole seismic tool was positioned about 6350 ft in MWX-3. Then Dynajet select-fired ten 6-gm charges between 6444 ft and 6453 ft in MWX-2. An additional five 6-gm charges were select-fired between 6437 ft and 6449 ft. The next day Dynajet fired five 1.8-gm charges between 6440 ft and 6444 ft in MWX-2, the first two simultaneously and the last three select fire.

2.2.23 Fracture Diagnostics Tests and Frac Preparations (July 16-31, 1985)

MWX-1

July 16 the Halliburton RTTS packer, DHSI tool, 4-1/2-in. downhole assembly, Halliburton retrievable bridge plug, and the Kuster gauges were recovered from MWX-1 without incident. A Mountain States wireline-set, tubing-retrievable, bridge plug was set at 6490 ft with two sacks of sand placed on top. July 17, the 2-7/8-in. tubing with a swaged collar on bottom was run in the well and landed at 6384 ft. The wellhead was installed and successfully pressure tested to 5000 psi, and the well was shut in for pressure buildup. MWX-1 was periodically flow tested between July 19 and 26 to the pit or into Western Slope's gathering system.

July 29 the sand was circulated off the Mountain States retrievable bridge plug at 6490 ft with nitrogen, and the plug was released and pulled from the well. A Mountain States retrievable bridge plug, with both a Squire-Whitehouse pressure sonde and a Kuster gauge (encased in a 2-7/8-in. perforated nipple), was run in the well by Dynajet and set above the Red sands at 6482 ft.

July 30, Dynajet fired twenty 6-gm shots between 6438 ft and 6447 ft to directionally orient the Sandia borehole seismic tools in MWX-2 and MWX-3.

July 31, a belled coupling, 1-ft 2-7/8-in. nipple, the 2-7/8-in. tubing, and a 3-ft long 2-7/8-in. blast joint were run in MWX-1 with the belled nipple landed at 6349 ft. The BOP's were removed, the wellhead and lubricator were installed, and an HP gauge was run in preparation for the Yellow sand foam frac.

MWX-3

July 25, the 2-7/8-in. tubing with a retrieving head was run in MWX-3, and the sand was reverse-circulated off the Mountain States retrievable bridge plug at 6408 ft. The retrievable bridge plug was released, and the 2-7/8-in. tubing and bridge plug were pulled from the well and laid down. July 27, Dynajet set a Mountain States retrievable bridge plug with a Squire-Whitehouse pressure sonde (encased in a 2-7/8-in. perforated nipple) above the Yellow sand at 6368 ft, with two sacks of sand on top. The hole was filled with 3% KCl water and casing was successfully pressure tested to 3500 psi.

July 27, Dynajet ran a Mountain States retrievable bridge plug with a Squire-Whitehouse pressure sonde (encased in 2-7/8-in. perforated nipple) and set it above the Red sands at 6480 ft. Dynajet then ran a second Mountain States retrievable bridge plug with a Squire-Whitehouse pressure sonde (encased in a 2-7/8-in. perforated nipple) and set it above the Yellow sand at 6416 ft. July 28, the hole was loaded with 3% KCl water, two sacks of sand were placed on the bridge plug, and the casing was successfully pressure tested to 3000 psi.

2.2.24 Nitrogen Foam Frac in MWX-1 (July 31-August 1, 1985)

July 31 the wellbore was pressured to 3500 psi with nitrogen and shut in for several hours. A nitrogen breakdown was then conducted with approximately 150,000 SCF of nitrogen to test both the fracturing equipment and the diagnostics.

A sand-propped, nitrogen-foam fracturing treatment was performed on the Yellow sands in MWX-1 on August 1, by Dowell Schlumberger using 13,880 gal of 75% quality foam to convey and place 12,000 lbs of 20/40 Proflow intermediate strength proppant. The proppant was tagged with 10 millicuries of Iodine 131 having an 8-day half-life.

At 5:30 a.m. August 1, the frac treatment was initiated. A 3000 gal, 75 quality foam pad was followed by 3000 gal of 75 quality foam containing 12,000 lb 20/40 Proflow intermediate strength prop, which in turn was flushed to the perforations by 7880 gal of 75 quality foam. The maximum treating pressure was 5400 psi and the minimum treating pressure was 4900 psi. The average treating rate was 10 BPM down the annulus between the 7-in., 29 lb/ft, N80 casing and the 2-7/8-in., 6.5 lb/ft, N80 tubing. The ISIP was 5315 psi, while the 15 minute shut-in pressure was 4895 psi. The pumping time was 41 minutes. The total liquid load to recover was approximately 90 bbl.

2.2.25 Flowback, Washing, Flow Test In MWX-1 (August 1-14, 1985)

August 1, while attempting to run a post treatment temperature survey, sand fill was encountered at approximately 6370 ft. The next day, a well service unit was moved on the well, the wellhead was removed, BOP's installed and the 2-7/8-in. tubing was pulled from the well. A retrieving tool was run on 2-7/8-in. tubing and the top of the sand fill was encountered at 6442 ft. Dowell reverse circulated the sand fill out of the well with nitrogen down to the Mountain States retrievable bridge plug at 6482 ft. The bridge plug was unseated and the 2-7/8-in. tubing, retrievable bridge plug, Squire-Whitehouse pressure sonde, and Kuster pressure gauge were retrieved from the well.

August 3, a belled 2-7/8-in. collar was run on the 2-7/8-in. tubing and landed at 6304 ft. A post frac gamma ray log was run through tubing, a Squire-Whitehouse pressure sonde and an HP pressure gauge were run, and the well was shut in for pressure buildup. August 6, the tubing was lowered 22 joints to 7002 ft and Dowell reverse circulated 20 bbls of fluid from the well with nitrogen. August 7, the 2-7/8-in. tubing was pulled from the well and a post frac gamma ray log was run from 6250 ft to 7000 ft. Then, Dynajet ran a Mountain States retrievable bridge plug with a Squire-Whitehouse pressure sonde and two Kuster gauges in tandem, and set the retrievable bridge plug at 6470 ft. A retrieving head, pinned collar, Mountain States "HD" packer, and a DHSI tool were run in the well on 2-7/8-in. tubing. The packer was set at 6304 ft in 16,000 lb compression. The BOP's were removed, the wellhead and lubricator were installed, and the service unit was moved off the well. The HP gauge was then run into the well for a short flow test and pressure buildup. The flow test was initiated at 7:00 a.m. August 8 at 150 MCFD and was shut in at 2:30 p.m. August 10. The pressure buildup was terminated at 9:30 a.m. August 12.

August 13, a well service unit was moved on MWX-1, the wellhead was removed, the BOP's were installed and the Mountain States retrievable packer was released. The tubing was lowered and the retrievable bridge plug was released. The 2-7/8-in. tubing, retrievable packer, retrievable bridge plug, Squire-Whitehouse pressure sonde, HP sonde, and two Kuster gauges were retrieved from the well. The next day, a Mountain States "HD" packer, one joint of 2-7/8-in. tubing, and the DHSI tool were run in the well on 2-7/8-in. tubing. The retrievable bridge plug was set at 6471 ft and the retrievable packer was set at 6316 ft. The BOP's were removed, and the wellhead, mast, and lubricator were installed, and the service unit was moved off the well. The HP gauge was run in the well at 5:30 p.m. August 14 in preparation for post frac interference testing.

2.2.26 Prepare MWX-2 For Interference Test (August 2-8, 1985)

August 2, well service unit was moved on MWX-2 (BOP's were already installed on the well) and a retrieving tool was run on 2-7/8-in. tubing to the sand fill at 6410 ft. The sand was then reverse circulated off the Mountain States retrievable bridge plug at 6416 ft, and the plug was released. The 2-7/8-in. tubing, retrievable bridge plug, and Squire-Whitehouse pressure sonde were pulled from the well. August 3, the retrieving head and 2-7/8-in. tubing were run in the well to 6480 ft to the second Mountain States retrievable bridge plug. The retrievable bridge plug was released, and the Squire-Whitehouse sonde, bridge plug, and 2-7/8-in. tubing were pulled from the well.

August 8, a Mountain States retrievable bridge plug, retrieving head, pinned collar, Mountain States "HD" packer, one joint of 2-7/8-in. tubing, and a DHSI tool were run in the well on 2-7/8-in. tubing. The retrievable bridge plug was set at 6492 ft, and the retrievable packer was set at 6398 ft in compression. The BOP's were removed, the wellhead was installed, the casing-tubing annulus was successfully pressure tested with 3% KCl water to 3000 psi, and the service unit was moved off the well. MWX-2 was now ready for post-frac interference testing in the Yellow sands.

2.2.27 Prepare MWX-3 For Interference Test (August 5-9, 1985)

August 5, well service unit was moved on MWX-3, the BOP's were installed, and a retrieving head was run in the well on 2-7/8-in. tubing to the Mountain States retrievable bridge plug at 6350 ft. The retrievable bridge plug was released, pulled from the well on 2-7/8-in. tubing, and laid down. The 2-7/8-in. tubing, with a retrieving head, was run in the well to the top of the sand fill at 6360 ft. The sand was reverse circulated off the Mountain States retrievable bridge plug at 6368 ft and the plug was released. The 2-7/8-in. tubing, retrievable bridge plug, and the Squire-Whitehouse pressure sonde were pulled from the well.

August 8, a McCullough casing inspection log run from 6370 ft to 4000 ft indicated no damage to the 7-in., 29 lb/ft N80 casing.

August 9, a Mountain States retrievable bridge plug, retrieving head, pinned collar, Mountain States "HD" packer, one joint of 2-7/8-in. tubing, and a DHSI tool were run in the well on 2-7/8-in. tubing. The retrievable bridge plug was set at 6494 ft, and the retrievable packer was set at 6335 ft in compression. The BOP's were removed, the wellhead was installed, and the casing-tubing annulus was successfully pressure tested to 3000 psi with 3% KCl water. MWX-3 was now ready for post-frac interference testing in the Yellow sands.

2.2.28 Production/Interference Test, Yellow Sand, MWX-1 Producer (August 16-September 7, 1985)

Post-frac pressure drawdown and buildup testing was initiated in the Yellow sands August 16. HP gauges were installed bottomhole in MWX-2 and MWX-3 for interference measurement, and also in MWX-1 for monitoring the flowing bottomhole pressure. Bottomhole shut-in tools were utilized in all three wells to minimize the effect of wellbore storage during testing. At 7:00 a.m. August 17, production was initiated at 140 MCFD from MWX-1 for the constant-rate pressure drawdown. The HP gauges were seated in the DHSI tools August 17 in MWX-2 and August 18 in MWX-3. The constant-rate pressure drawdown in MWX-1 was terminated at 9:30 a.m. August 24, when the HP gauge was seated with nitrogen pressure in the DHSI tool. The ensuing pressure buildup test in MWX-1 was concluded at 10:00 a.m. September 7.

2.2.29 Tests Between Red and Yellow Sands, MWX-1 (September 26-October 23, 1985)

September 26, a well service unit was moved on MWX-1, the wellhead was removed, BOP's were installed, and the Mountain States "HD" packer was released, pulled from the well and laid down. A retrieving head was run on the 2-7/8-in. tubing but was unable to latch onto the retrievable bridge plug at 6573 ft.

The retrieving head was pulled from the well and laid down. An Acme short catch overshot, a bumper sub, and hydraulic jars were run on the 2-7/8-in. tubing to 6573 ft. The fishing assembly latched onto and released the retrievable bridge plug. The bridge plug and fishing assembly were pulled from the well and laid down.

September 30, a downhole assembly consisting of a plugged perforated sub, lower Lynes packer, two joints of 2-7/8-in. tubing, Lynes CWL, upper Lynes packer, Lynes shut-in valve and twenty 2-7/8-in. tubing subs were run in the well on the 2-7/8-in. tubing. The inflating lines and signal cable were also installed at this time. The lower and upper Lynes packers were positioned at 6483 ft and 6404 ft, respectively. Both packers were inflated and the downhole shut-in was closed to allow the Red and Yellow sands to be isolated and build pressure overnight. At 7:00 a.m. October 1, the Red sands were flowed while the Yellow sands remained shut in. The Yellow pressure tracked that in the Red, indicating communication. The upper packer was pressured to 1950 psi, slowing the annulus leak considerably. The Red sand was flowed with the Yellow sand shut in until 4:30 p.m. October 3, when the lower packer was deflated and both the Red and Yellow sands were commingled overnight. October 4, the lower packer was inflated and the top packer was deflated. A total of 86,000 SCF nitrogen was pumped down the annulus into the Yellow sands at rates to 4000 SCFM at 2700 psi. The Lynes pressure probes failed just before nitrogen pumping, and at 10:00 p.m. the lower packer failed. October 8, the Lynes downhole assembly was pulled from the well on the 2-7/8-in. tubing and laid down. The electrical cable had been pulled loose at a splice going into the upper packer. Both packer elements were gas impregnated and torn. The upper packer had a slow leak in the steel portion of the packer. The lower packer had a completely ruptured internal bladder, and the downhole shut-in valve had a washed out seal.

October 14 a second Lynes downhole assembly consisting of a lower Lynes packer, two joints of 2-7/8-in. tubing, Lynes CWL, upper Lynes packer, two Lynes shut-in valves, and twenty 2-7/8-in. tubing subs were run on the 2-7/8-in. tubing and landed straddling the Yellow sands. (In addition, there was a Kuster gauge below the bottom packer and a second Kuster gauge banded to the 2-7/8-in. tubing above the upper packer.) October 15, the checkout of the Lynes equipment once the packers were set indicated no signal. October 16, the packers were released and the 2-7/8-in. tubing was pulled from the well. A break in the wireline was located 600 ft above the packers and repaired. October 17, the Lynes downhole assembly, with the two Kuster gauges, was run in the well on 2-7/8-in. tubing and landed straddling the Yellow sands. October 18, the upper packer was set with argon and nitrogen to 3200 psi and the bottom packer was set with argon and nitrogen to 3500 psi. October 18, both the Red and Yellow sands were shut in downhole. October 19, the Red was returned to production while the Yellow remained shut in. The pressure on both packers kept dropping, indicating leaks in the packoff system. October 20, the Lynes pressure probe signal was lost following blowdown of the casing annulus and deflation of the upper packer prior to nitrogen injection into the Yellow sands. A total of 242,000 SCF nitrogen was pumped into the Yellow sands at rates to 4800 SCFM with a maximum pressure of 3500 psi. The gas production from the Red sands was continuously monitored using gas chromatography to measure the nitrogen content of the effluent gas.

October 21, the Lynes downhole assembly was released, pulled from the well on the 2-7/8-in. tubing, and laid down. Both packers were pressure tested and held. The inflating line for the upper packer contained two holes, and the electrical leads inside the Lynes CWL were shorted.

October 22, a pinned collar, Mountain States "HD" retrievable packer, one joint of 2-7/8-in. tubing and a DHSI tool were run in the well on 2-7/8-in. tubing. The packer was set at 6340 ft in 20,000-lb compression. The BOP's were removed, the wellhead was installed, and the service unit was moved off the well. MWX-1 was then connected to flow through the test separator.

2.2.30 Assessment of Casing And Bridge Plug Below Coastal Sands, MWX-1 (October 31-November 5, 1985)

October 31, a service unit was moved on MWX-1, the wellhead was removed, BOP's installed, the Mountain States "HD" packer was released and the packer and 2-7/8-in. tubing were pulled from the well. A Mountain States "HD" packer with a Kuster gauge suspended below it, one joint of 2-7/8-in. tubing with a Kuster gauge strapped to the outside, and a DHSI tool were run in the well. The retrievable packer was set at 6573 ft (below the Red sands) in 22,000 lbs compression. The HP gauge was seated at 12:00 noon October 31 to begin monitoring the integrity of the bridge plug at 7040 ft.

November 1, the Mountain States "HD" packer was unseated and the downhole assembly was pulled from the well on the 2-7/8-in. tubing. A Mountain States retrievable bridge plug was set at 6650 ft. November 2, a retrieving head for the bridge plug, a 2-7/8-in. perforated tubing sub (with Kuster gauges inside), Mountain States "HD" packer, one joint of 2-7/8-in. tubing, a DHSI tool, one joint of 2-7/8-in. tubing, and a 10-ft 2-7/8-in. tubing sub (with Kuster gauge outside) were run in the well on 2-7/8-in. tubing with the tubing tail landed at 6617 ft.

The packer was set at 6586 ft in 22,000 lb compression. The HP gauge was seated in the DHSI tool at 6550 ft at 4:00 p.m. November 2 and gas from the Red and Yellow sands was flowed out the annulus at 200 MCFD until 8:00 p.m. that day when the annulus was shut in for pressure buildup. At 5:00 a.m. November 3, the annulus was blown down to the flare pit in preparation for pulling the downhole assembly. The 2-7/8-in. tubing, Mountain States "HD" packer, retrievable bridge plug, and Kuster gauges were pulled from the well.

November 4, a Kuster gauge (encased in a 2-7/8-in. perforated sub), the lower half of a Halliburton PPI straddle packer, two joints of 2-7/8-in. tubing, the upper half of the Halliburton PPI straddle packer, one joint of 2-7/8-in. tubing, DHSI tool, one joint of 2-7/8-in, tubing, and a 10-ft 2-7/8-in. tubing sub (with a Kuster gauge outside) were run in the well on 2-7/8-in. tubing with the top of the lower packer at 6557 ft. The Halliburton PPI packers were set in 20,000 lb compression. The BOP's were removed, the wellhead was installed, and the service unit was moved off the well. The lubricator and wireline unit were installed and the HP gauge was run in the well to 6452 ft, 10 ft above the DHSI tool. The well was equipped to produce the Red sands through the tubing and the Yellow sands through the casing-tubing annulus.

2.2.31 Red and Yellow Sand Production Test, MWX-1 (November 5-December 5, 1985)

MWX-1 was equipped to separate liquids and measure both liquid and gas production individually from the Red and Yellow sands, while testing into the Western Slope gas gathering system. Both remained shut in at the wellhead until 7:00 a.m. November 10 when the well was turned to the pipeline at a commingled 65 MCFD, with the Red sands contributing 15 MCFD and the Yellow sands 50 MCFD, respectively. At 8:00 p.m. November 18 both intervals were shut in at the surface for pressure buildup. At 7:00 a.m. November 21 the Red sands were returned to production at approximately 35 MCFD, while the Yellow remained shut in at the surface. At 5:00 p.m. November 22 the Red sands were shut in at the surface for pressure buildup, and remained shut in through the end of the test, 3:00 a.m. December 3. The Yellow sands remained shut in until 9:00 a.m. December 3 when the well was returned to the pipeline at 170 MCFD to reduce bottomhole pressure prior to initiating well work for reentry into the paludal stimulation interval, scheduled to begin December 5, 1985.

2.2.32 Prepare MWX-2 For Winter Shut-In (November 20-21, 1985)

November 20 a well service unit was moved onto MWX-2, the wellhead was removed, the BOP's were installed, the Mountain States "HD" packer was released, and the 2-7/8-in. tubing was lowered to retrieve the bridge plug at 6494 ft. The hole was loaded with 230 bbl 3% KCl water containing 15 gal of corrosion inhibitor. The 2-7/8-in. tubing, DHSI tool, Mountain States "HD" packer, pinned collar, retrieving head, and the retrievable bridge plug were pulled from the well and laid down. The next day, the BOP's were removed, one joint of 2-7/8-in. tubing was run in the well, the wellhead was installed, and the well service unit was moved off the well. MWX-2 was now equipped for winter site shutdown.

2.2.33 Abandon Coastal Sands, Test, Repair Casing Leaks, MWX-3 (October 18-November 14, 1985)

October 18, a well service unit was moved onto MWX-3, the wellhead was removed, the BOP's were installed and the 2-7/8-in. tubing was pulled from the well. A retrieving head was run on the 2-7/8-in. tubing to the Mountain States retrievable bridge plug at 6338 ft. The bridge plug was released and pulled from the well. October 29, Dynajet set a Mountain States cast-iron bridge plug at 6350 ft, abandoning the Red and Yellow sands.

October 20, a Mountain States retrievable bridge plug and retrievable packer were run in the well on 2-7/8-in. tubing in preparation for pressure testing the 7-in., 29 lb/ft, N80 casing for leaks. The retrievable bridge plug was set at 6336 ft and the retrievable packer was set at 5682 ft. Pressure testing conducted on October 21 with various settings of the retrievable packer indicated the existence of more than one casing leak below 5682 ft but above the retrievable bridge plug at 6336 ft. Above 5682 ft the 7-in 29 lb/ft, casing was successfully pressure tested to 5000 psi. October 23, a new Mountain States "HD" packer was run on the 2-7/8-in. tubing and hung, unset at 6327 ft. The BOP's were removed, the wellhead was installed, and the service unit was moved off the well.

November 6, a service unit was moved back onto the well, the wellhead was removed, the BOP's were installed, and the Mountain States "HD" packer was moved to 6310 ft and set. Pressure testing of the tubing and casing indicated a packer leak. The packer was released, the bridge plug at 6336 ft was released, and the entire downhole assembly was pulled from the well. Additional pressure testing for casing leaks was undertaken from November 8 through November 12. It was then decided to squeeze cement through perforations at 6342 ft to eliminate any possibility of gas migrating outside the casing, uphole from the coastal interval into the fluvial interval.

November 12, Dynajet perforated with two 19-gm JS at 6342 ft for squeeze cementing purposes. The next day, three joints of 2-7/8-in. tubing, and a Halliburton RTTS packer were run in the well on 2-7/8-in. tubing with the tubing tail landed at 6334 ft. Halliburton spotted 250 gal of 15% HCl across the perfs, the packer was set at 6224 ft, and following a 20-minute soak, an injection rate of 2.5 BPM at 3600 psi was established into the perforations. The acid was overflushed with 5 bbl of fresh water. The circulating ports on the RTTS packer were opened, cement slurry was spotted across the perforations, and 50 sacks of Class G cement containing 0.4% Halad 9 was squeezed away at 4000 psi. The RTTS packer was unseated, the tubing tail was raised to 6134 ft, excess slurry was reverse circulated from the well, and the RTTS packer was reset at 6024 ft with 2000 psi on the tubing.

November 14, the Halliburton RTTS packer was unseated and the cement top was tagged at 6134 ft. The RTTS packer and 2-7/8-in. tubing were pulled from the well and laid down. The BOP's were removed, the wellhead was installed, and the service unit was moved off the well. The coastal interval in MWX-3 was now permanently abandoned. No perforations were open in the well above the cement top at 6134 ft.

2.2.34 Reentry Test, Abandon Coastal Zone, MWX-1 (May 30-June 8, 1986)

May 30, the HP gauge was pulled from the paludal interval, and a tubing plug was set at 6950 ft to end the paludal reentry test.[4] The 2-7/8-in. tubing was then perforated with three 2-gm JSPF (0.42-in. hole diameter) from 6555 ft to 6557 ft to open the commingled Red and Yellow sands for production through the tubing, following a 6-month shut-in. The lubricator was installed and the HP gauge was run in the well to 6000 ft for bottomhole pressure measurement during the pressure drawdown portion of the coastal reentry testing. Production into Western Slope's gas gathering system began at 4:30 p.m. May 30 at 300 MCFD against prevailing line pressure. The gas producing rate was curtailed in steps to 50 MCFD within the first 24 hours of the drawdown and remained at that rate until 3:00 p.m. June 2, when the well was shut in for pressure buildup. The HP gauge and wireline were pulled from the well at this time and the lubricator was laid down. MWX-1 remained shut in on pressure buildup (surface measurements only) until 4:00 a.m. June 8, when coastal reentry testing was terminated.

June 12, Dynajet set a cast iron bridge plug at 6000 ft in MWX-1, permanently abandoning the coastal interval.

2.3 REFERENCES

1. CER Corporation, "Multi-Well Experiment: MWX-1 As-Built Report," Sandia National Laboratories Contractor Report, SAND82-7201, July 1982.

2. CER Corporation, "Multi-Well Experiment: MWX-2 As-Built Report," Sandia National Laboratories Contractor Report, SAND82-7100, August 1982.

3. CER Corporation, "Multiwell Experiment: MWX-3 As-Built Report," Sandia National Laboratories Contractor Report, SAND84-7132, February 1984.

4. Multiwell Experiment Project Groups at Sandia National Laboratories and CER Corporation, "Multiwell Experiment Final Report: II. The Paludal Interval of the Mesaverde Formation," Sandia National Laboratories Report, SAND88-1008, May 1988, Section 8.7.

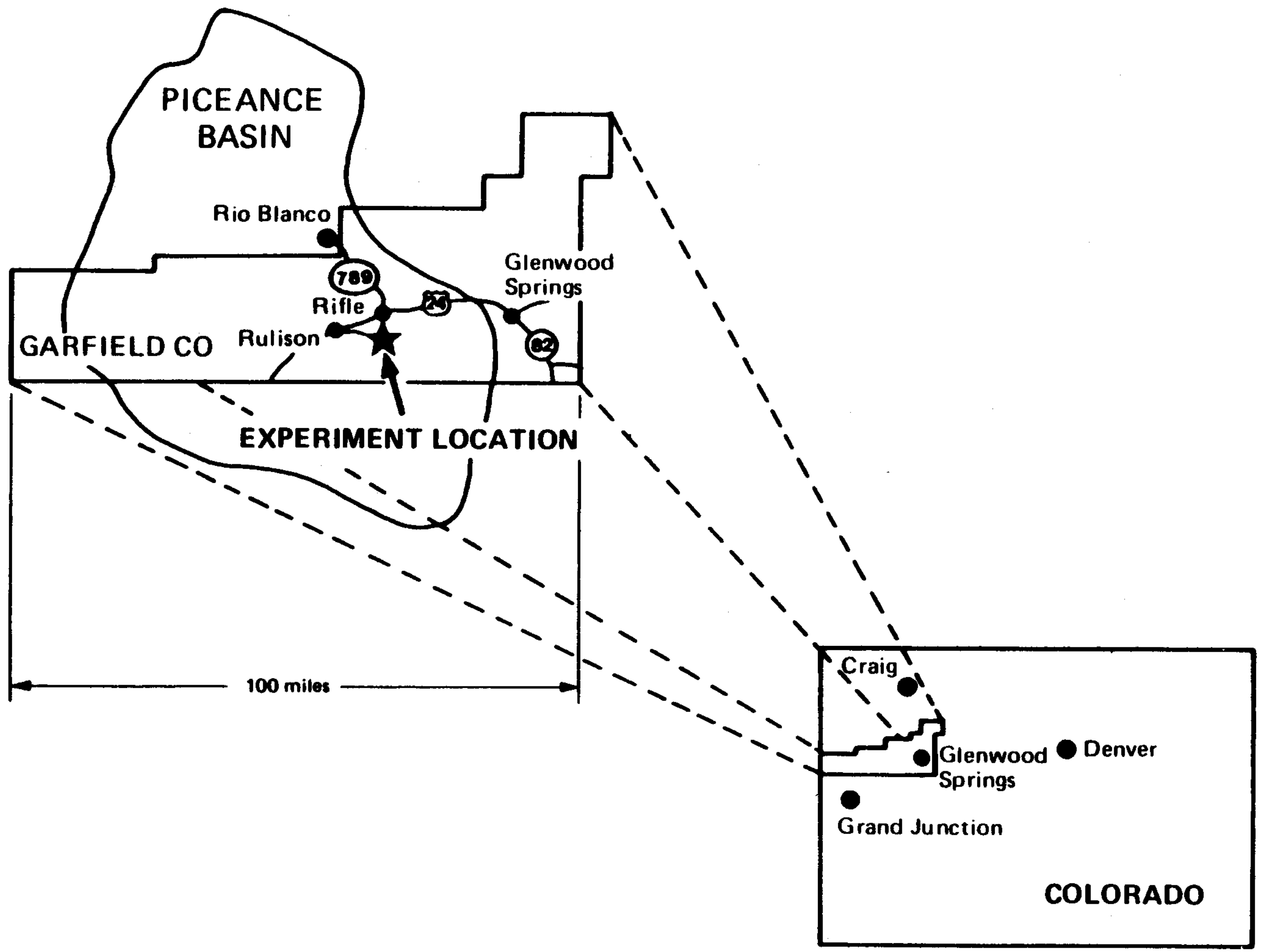


Figure 2.1 Multiwell Experiment Location

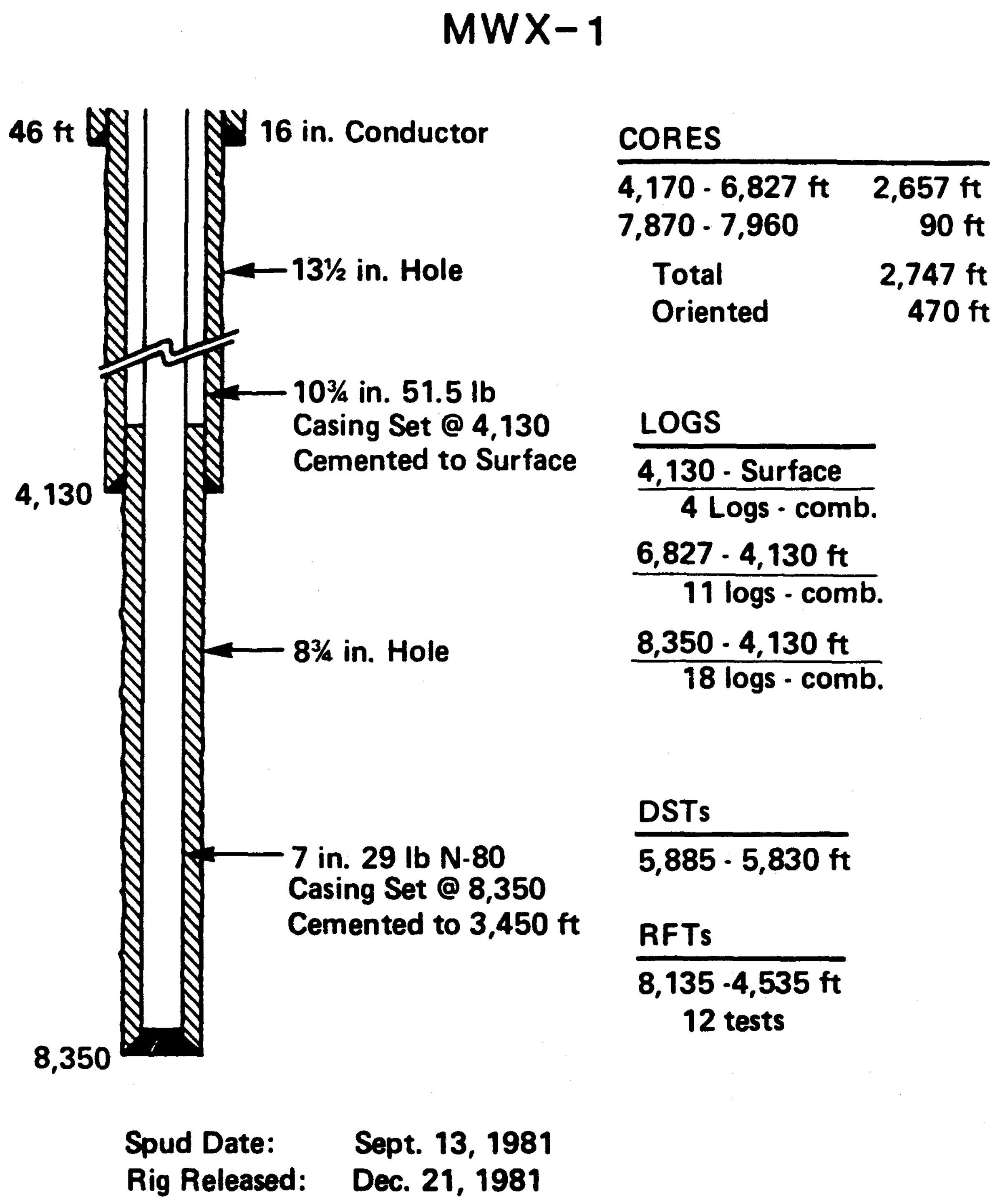
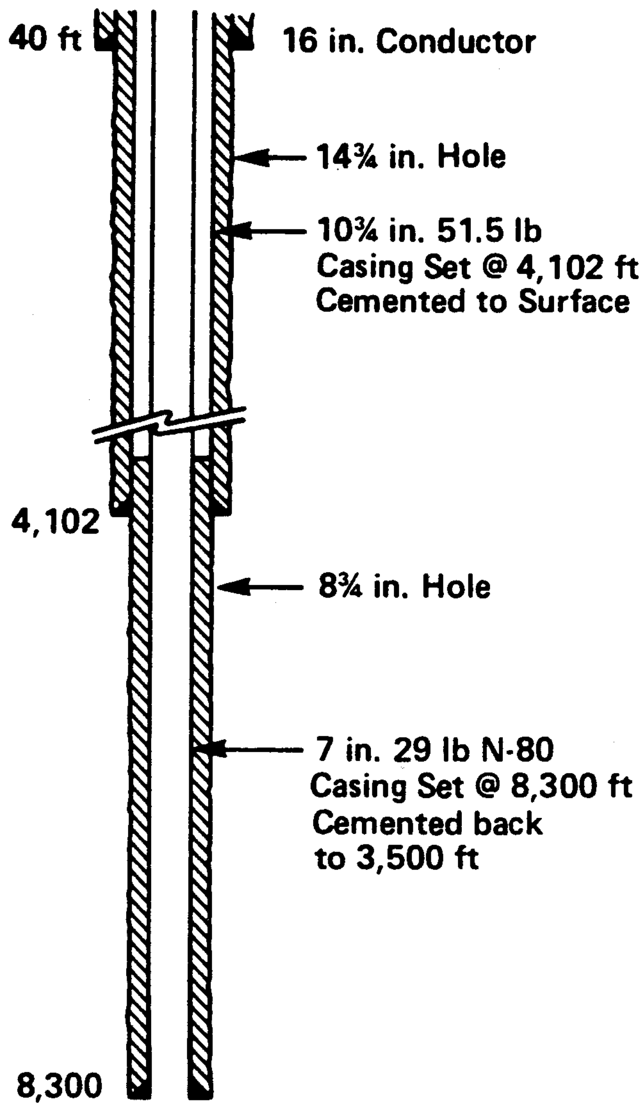


Figure 2.2 MWX-1 Well Information

MWX-2



CORES

4,870 - 4,956 ft
5,485 - 5,581 Pressure Core
5,700 - 5,880
6,390 - 6,568
7,030 - 7,385
7, 817 - 7,907
8,100 - 8,141

915 ft of Core
395 ft Oriented

LOGS

5,438 - 4,094 ft
3 logs - comb.

6,050 - 4,094 ft
3 logs

6,688 - 4,094 ft
9 logs - comb.

8,300 - 4,094 ft
15 logs - comb.

DST

4,895 - 4,955 ft

Spud Date: Dec. 31, 1981
Rig Released: Mar. 30, 1982
91 days

Figure 2.3 MWX-2 Well Information

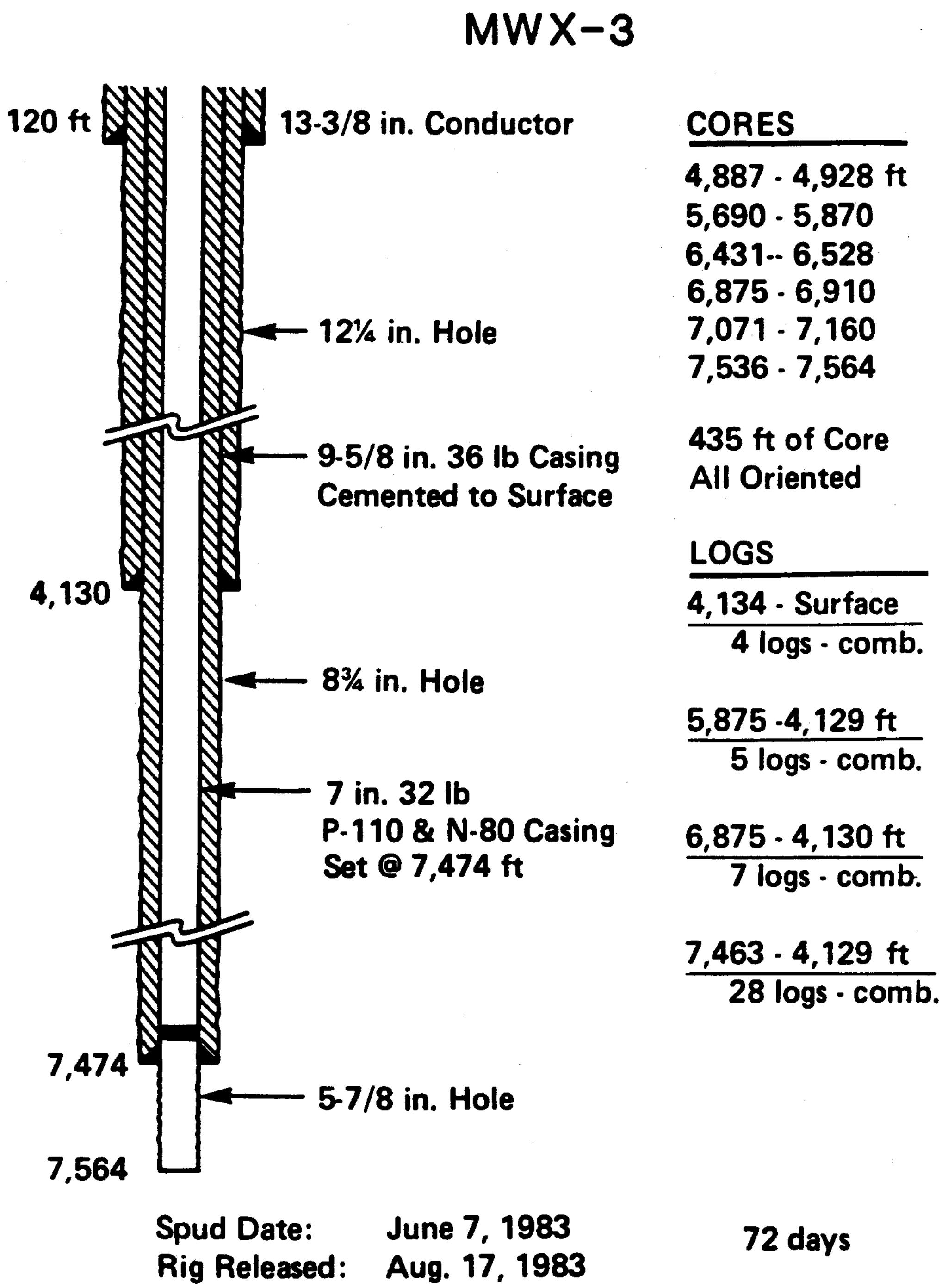


Figure 2.4 MWX-3 Well Information

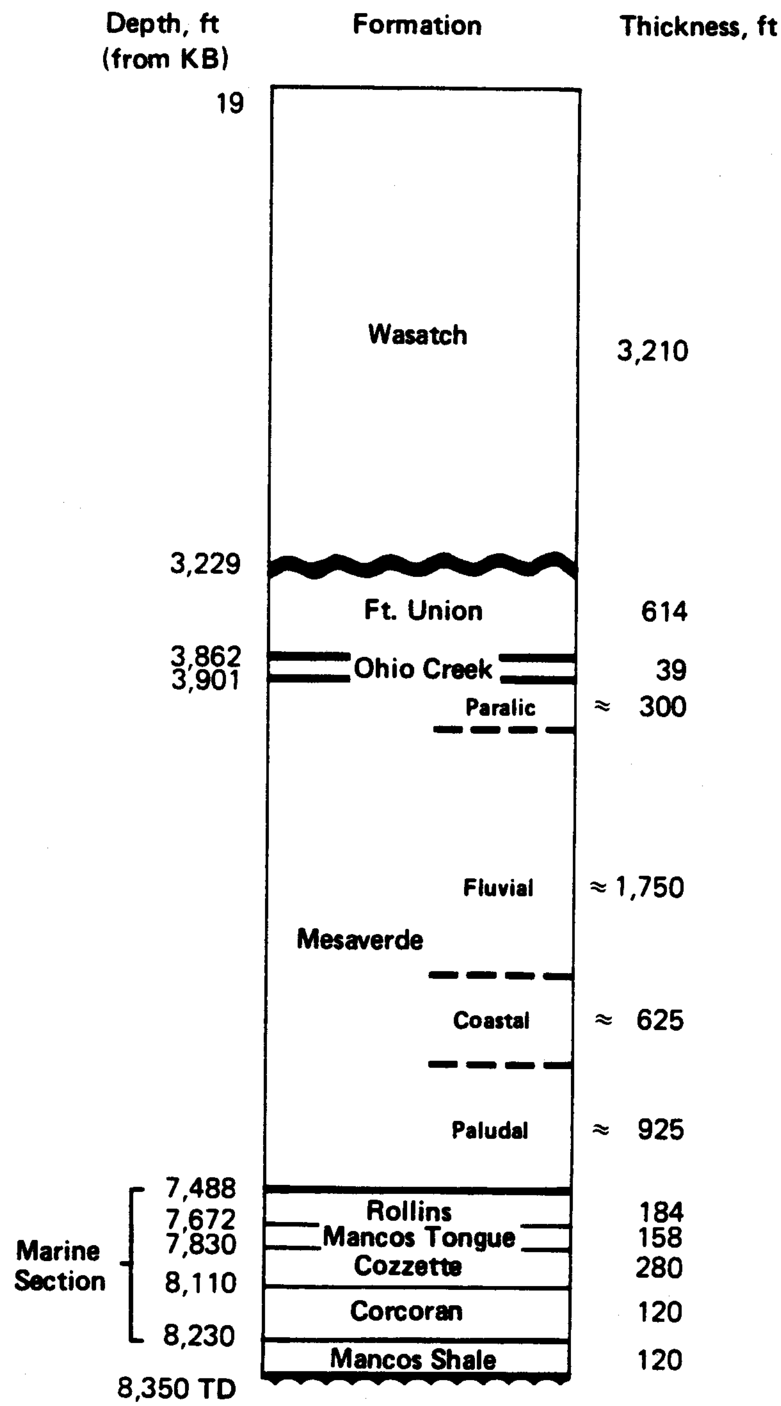


Figure 2.5 Geologic Cross section of MWX-1

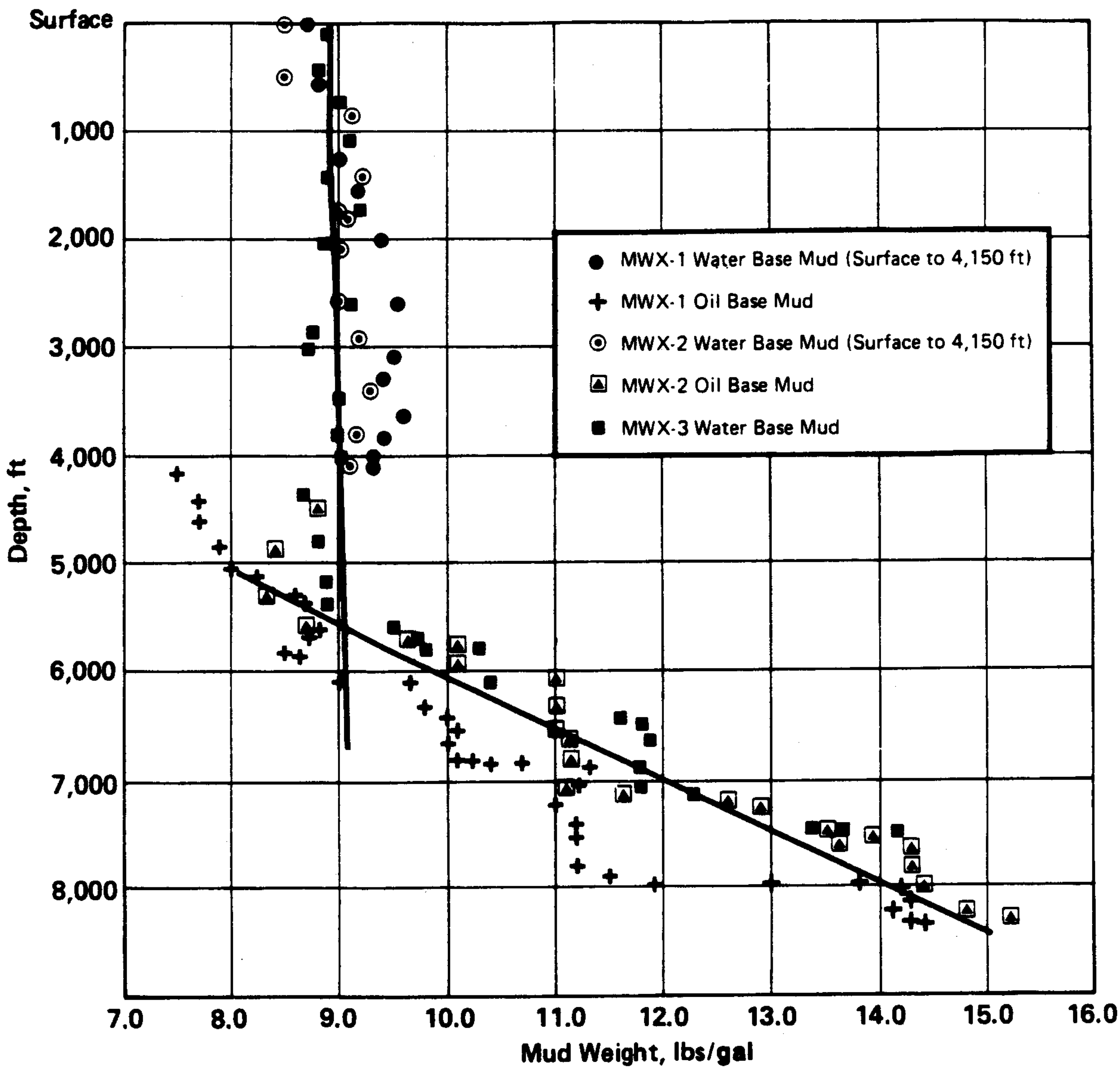


Figure 2.6 Mud Weight Versus Depth

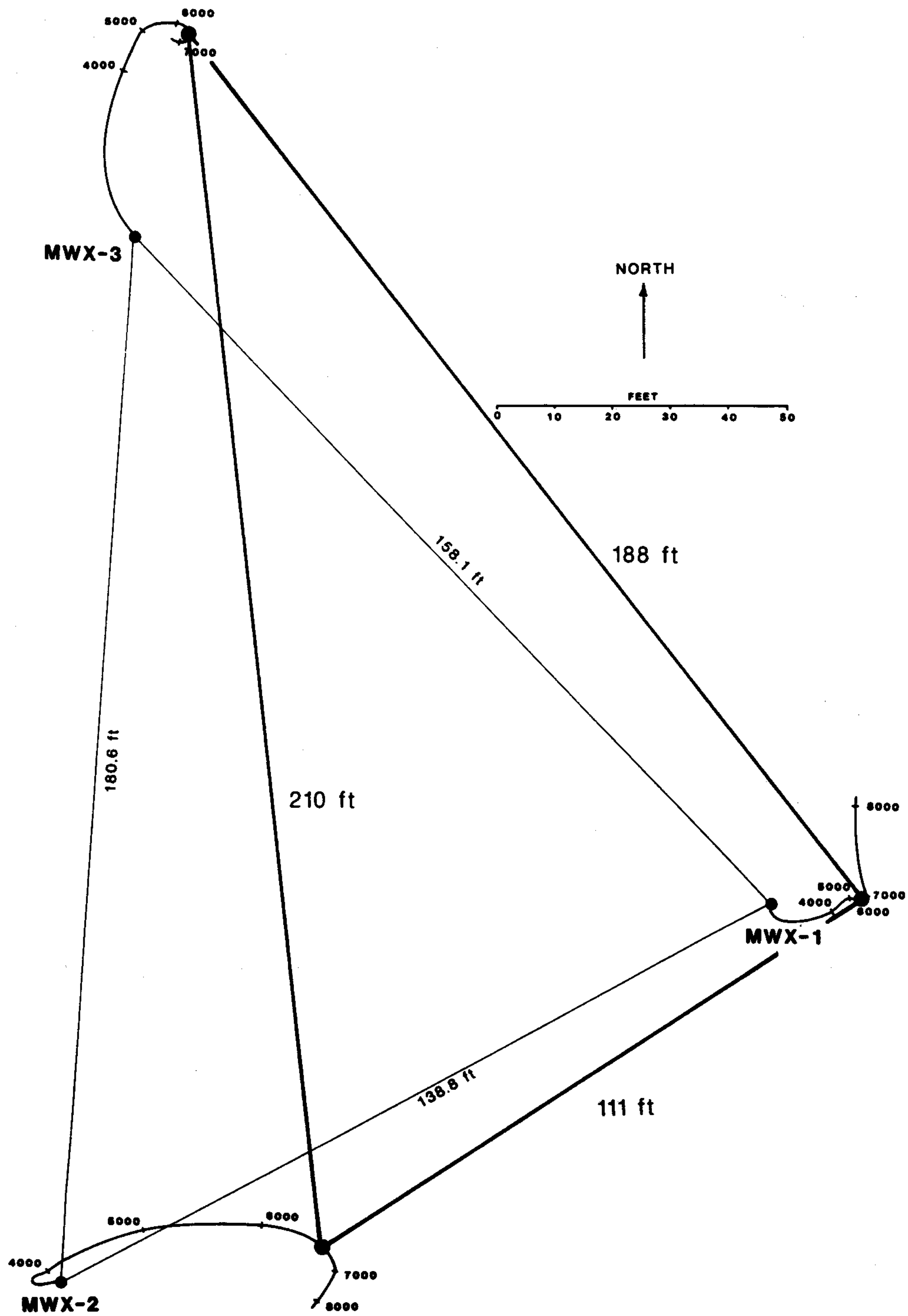


Figure 2.7 Relative Well Spacings at Surface and at 6500 ft (the deepest survey in all three wells)

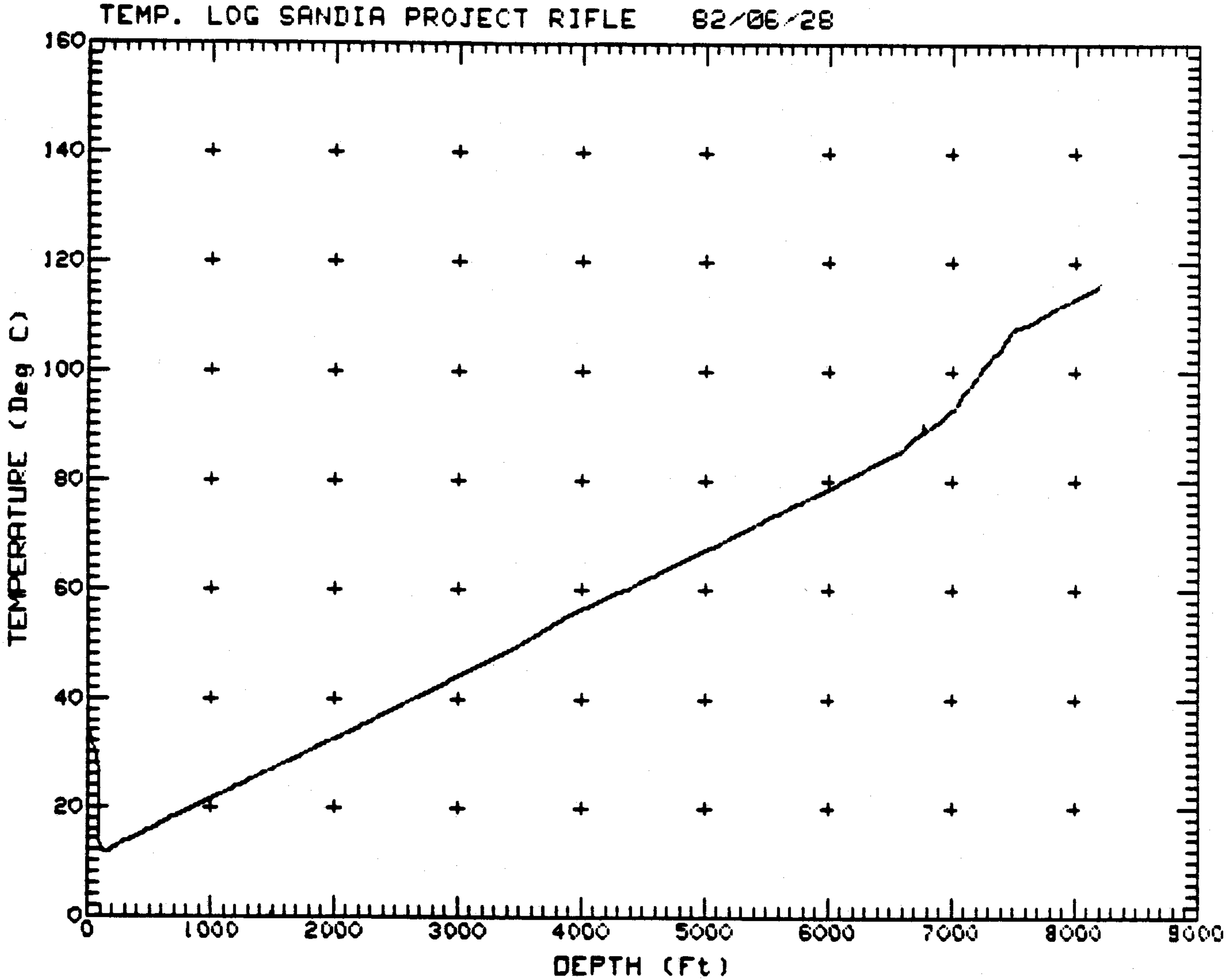


Figure 2.8 Temperature Log of MWX-1

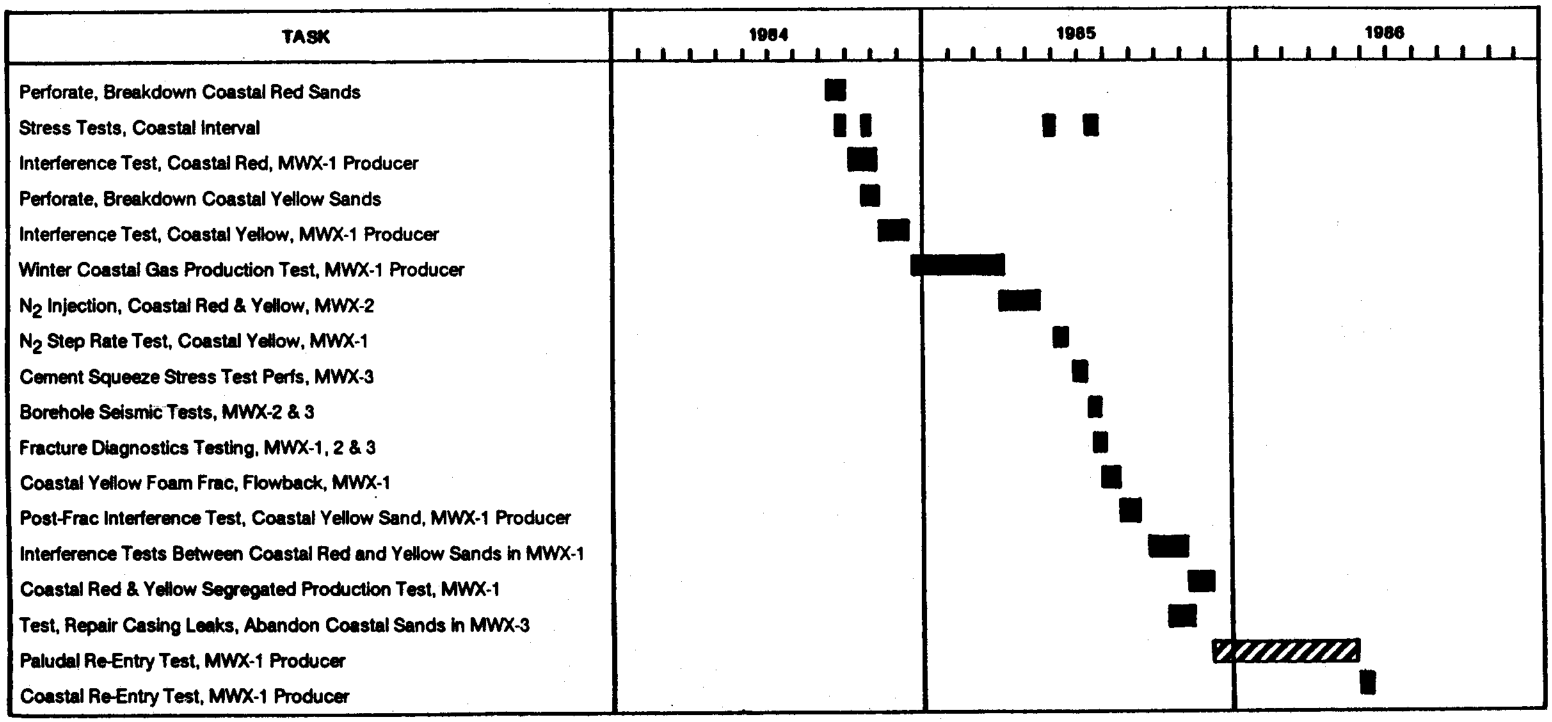


Figure 2.9 Chronology of Coastal Operations

3.0 GEOLOGY

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3.1 INTRODUCTION

The coastal zone occurs between the depths of 6000 and 6600 ft. at the MWX site. It is an interval of lenticular, distributary-channel and splay sandstone reservoirs, with interbedded mudstones and carbonaceous shales. These strata were deposited in an upper delta plain environment[1] that was similar to that of the underlying paludal zone. However, coals were not deposited in the coastal environment, and this marks the principal difference between the paludal and coastal zones. Otherwise, the sandstone reservoirs have similar morphologies. The presence or absence of coals also controlled differences in the diagenetic processes and resulting porosities and permeabilities in the two zones.

The coastal zone occurs near the middle of the Williams Fork Formation of the Mesaverde Group, of Late Cretaceous (Campanian) age. The Mesaverde Group is a package of marine and nonmarine strata that prograded southeast and east into the Western Interior Seaway in response to late Sevier and early Laramide orogenic activity.[2] These strata are well exposed along the Grand Hogback, particularly at Rifle Gap, 12 miles northeast of the MWX site. Other exposures occur at outcrops around the edges of the basin, with especially good exposures of the coastal zone being located in Coal Canyon, north and northwest of Cameo, Colorado.

Although a horst block exists in the deep subsurface in the vicinity of the MWX site,[3] the structural configuration of the shallower Mesaverde strata is unaffected. The Mesaverde strata dip gently to the northeast,[4] toward the Grand Hogback, at an angle of less than two degrees (Figs. 3.1, 3.2).

3.2 LITHOLOGY

3.2.1 Core

The coastal zone was penetrated by all three of the MWX wells. The entire zone was cored in MWX-1, but only two of the reservoir sandstones were cored in MWX-2 and MWX-3 (Fig. 3.3). The sandstones of interest were assigned color designations: thus from the top down, they are named the Purple, Orange, Brown, Blue, Green, Yellow, and Red (Fig. 3.3). The Red and Yellow reservoirs were studied and tested in detail.

Most of the coastal sandstones are distributary-channel deposits. Only two are possible splays, although numerous thin splays of lower quality exist in the interval. The splays are of indeterminate dimensions, whereas the channels are on the order of 200 to 500 ft. wide. There is no known preferred orientation of channel lenses. Estimates of individual lens trends can be made, however, based on crossbedding (paleoflow) vectors in oriented core and the spatial distribution of channel subfacies.[5]

3.2.2 Outcrop

Coastal zone outcrops contain both the lenticular, crossbedded, channel sandstones and the more amorphous, ripple-bedded splay deposits. The channel sandstones are commonly segmented by internal diagonal bedding planes produced by lateral accretion (point-bar) deposition. Although these indicate some degree of sinuosity, they are not as well developed as those of the overlying fluvial zone, and the lenses themselves are laterally restricted, suggesting low sinuosity. The diagonal bedding planes are commonly accented by thin mudstone partings, or by zones of mudstone or muddy carbonate ripup clasts, and sometimes by thin beds with a high content of carbonaceous/organic debris.

Other lenticular sandstones exposed in outcrop are more homogeneous in character, their principal features being large-scale, soft-sediment deformation structures. Both types of sandstones are narrow, usually less than 500 ft. wide, and they have sharp basal contacts with the underlying mudstones, but more gradual, sometimes interfingering contacts with the overlying and adjacent mudstones.

Splay sandstones thin gradually along the outcrops and lose their identity in the adjacent mudstones. These mudstones are commonly carbonaceous, but coals were not developed. They locally contain calcareous concretions suggestive of incipient soil formation, but never a well developed soil profile.

3.2.3 Sandstone Petrology

According to Pitman and Spencer,[6] the reservoir sandstones of the coastal zone are typically "fine-grained and moderately sorted, and consist dominantly of quartz, lithic fragments, and minor amounts of sodium feldspar," and are classified as feldspathic litharenites (Fig. 3.4). These compositionally heterogeneous sandstones (Table 3.1 and Appendix 11.1) have undergone a complex paragenetic sequence that includes early and late stages of calcite cementation, quartz cementation, alteration of feldspars, several stages of authigenic clay formation, and moderate dolomitization of calcite fragments.[7]

The principal clay components of the sandstones in the coastal zone are authigenic illite and mixed-layer illite-smectite.[6,7] The clay minerals occur as permeability obstructions in pore throats and grain coatings. Porosity measured in the laboratory is on the order of 6 to 7 percent, and permeabilities are on the order of 0.5 microdarcys.[8] Porosity is mostly secondary.

An independent report by Dowell Schlumberger[9] made on selected samples from the Red and Yellow sandstones suggests that compaction and cementation played roles equally important to that of clay formation in the reduction of permeability, although the early stage of calcite cementation noted by Bendix[7] was not observed. Otherwise, the reconstructed paragenetic sequences of the two reports are similar. The petrographically measured compositions are also similar, although Dowell-Schlumberger suggested that the sandstones contained somewhat less feldspar than noted by Bendix.

3.3 MORPHOLOGY

The following interpretations are based on slabbed core where core is available and supplemented by the geophysical logs in uncored intervals. Correlations are hung on the top of the sandstone in question, or the Kelly Bushing in the case of multiple zones of interest.

Sandstone body widths in the coastal are estimated using the outcrop height-to-width relationships observed in Coal Canyon north of Cameo:[5]

$$\text{width} = 8.6\ \text{height}^{1.1}$$

(correlation coefficient 0.62)

This quality of data is not available at Rifle Gap (nearer the MWX site) due to inaccessible and poor outcrops of this interval. Well-to-well correlation/probability calculations[10] for the coastal zone in the MWX wells suggest an average lens widths on the the order of 120 to 175 feet, but the data base is small, and sandstones are expected to be of widths similar to those in the paludal zone (200 to 500 feet wide).

Reservoir orientations are interpreted from the spatial relationships of the three wells at depth, and the specific subenvironments (main channel vs. channel margin or overbank) penetrated by each well. Crossbedding information from the SHDT* dipmeter in MWX-3 and from oriented core in the lower two zones supplement the conclusions.

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*Schlumberger's Super High-Resolution Dipmeter Tool

3.3.1 Purple Zone (Fig. 3.5)

MWX-1 core in this sandstone displays two 3 to 4-foot-thick sands separated by a thin, rippled siltstone bed, and over- and underlain by muddy and silty overbank deposits. The MWX-1 sandstones are crossbedded and could be main channel deposits, though the silty parting that separates them may indicate the more erratic discharge of a splay deposit. This latter interpretation is supported by the irregular gamma ray profile of this zone in MWX-2, which suggest temporal and spatial differences in deposition as on different lobes of a splay. The validity of correlating these beds from MWX-1 and MWX-3 to MWX-2, despite the different MWX-2 gamma ray profile, is supported by the density log crossover which occurs at the base of this sandstone in all three wells.

If this thin sandstone (less than 10 feet) is a splay, it is probably not extensive, as there is no definitive thickening trend toward any of the three wells. If it is a channel, it probably originated in the vicinity of MWX-2 trending southeasterly, and migrated northeastward (and upsection as deposition occurred) maintaining the same trend to intersect MWX-3 and MWX-1. However, a ten-foot-thick channel would have an expected width of only 110 feet which would not be expected to intersect all three wells.

3.3.2 Orange Zone (Fig. 3.6)

Core from the Orange reservoir in MWX-1 indicates a good main channel assemblage of lithologies: thick crossbedded sandstone with an abrupt base and an upper zone of rooted, finer sandstone and siltstone. The gamma ray logs of MWX-2 and MWX-3 suggest similar deposits, but are significantly thicker in MWX-3. This implies a northeasterly trending channel which is thinner in MWX-1 and MWX-2. If the 28-foot thickness in MWX-3 represents the thickest point of the channel, its width would be on the order of 340 feet. However, the upper 3 to 5 feet of the unit are probably silty overbank deposits as found in MWX-1 core, which suggests a minimum width more on the order of 270 feet.

3.3.3 Brown Zone (Fig. 3.7)

The presence of a good sandstone only in MWX-2 in the brown zone suggests a southeasterly channel trend. That this is indeed a channel is suggested by the fining upward trend portrayed in the gamma ray log. MWX-1 core at this level is entirely overbank material, although common thin rippled sandy and silty beds imply proximity to a channel. The MWX-3 gamma ray log is similar to that of MWX-1, and probably contains similar deposits. While it is possible that MWX-2 does not penetrate the maximum development of the channel, the 11-foot thickness there indicates a minimum width of 120 feet.

3.3.4 Blue Zone (Fig. 3.8)

Core from the Blue zone in MWX-1 shows probable channel deposits of crossbedded sandstone with an abrupt base, grading upward into rippled sandstone with interbedded mudstone. The gamma ray log of MWX-2 indicates similar sequences, with perhaps more mudstone beds near the top, whereas the MWX-3 log suggests a more homogeneous sandy interval. The MWX-3 unit, 20 feet thick, indicates a minimum channel width of 230 feet. The channel trend is ambiguous: the SHDT log from MWX-3 shows crossbedding (reflecting paleoflow, and roughly, channel orientation) toward the east and northwest at the top of the interval, toward the northwest and southwest in mid-interval, and probably most reliably, toward the northwest near the base. It is estimated that the main channel is situated in the vicinity of MWX-3 and trends about northwest, as this orientation allows a 230-foot-wide channel to be penetrated by all three wells, with MWX-3 near the center of the channel.

3.3.5 Green Zone (Fig. 3.9)

The Green zone consists of five sandstone bodies (A through E, top to bottom, respectively) which do not correlate well between the three MWX wells, implying that they are of restricted width.

Green A is about 14 feet thick in MWX-3 where the geophysical logs indicate a relatively clean, high porosity sandstone throughout. The SHDT log (MWX-3) displays one trend of symbols which is a textbook pattern for a trough crossbed and suggests northeasterly paleoflow. This is consistent with the absence of channel sandstones in MWX-1 and MWX-2. The 14-foot thickness suggests a minimum width of 160 feet.

Green B is sandy in MWX-2 but consists of only overbank siltstones and mudstones in MWX-1 core, and in the gamma ray log of MWX-3. Green B may be either a channel (at least 130 feet wide and trending either southeast or northeast between MWX-1 and MWX-3) or a splay deposit derived from a channel southwest of MWX-2. The latter interpretation is preferred in light of the silty nature of the core from MWX-1.

Green C is a homogeneous sandstone, about 23 feet thick in MWX-3, where several questionable SHDT readings suggest northeasterly through southeasterly paleoflow. The interval is mostly siltstone and mudstone in MWX-2, but is probably correlative at its base with a crossbedded sandstone in MWX-1 core, indicating a more southeasterly trend. The upper, thin-bedded, rippled sandstones in MWX-1 core of this interval resemble channel margin/overbank deposits correlative with the top of this unit in MWX-3. A minimum width of 270 feet is predicted.

Green D is a sandy interval with density log crossovers in both MWX-1 and MWX-2, but is nonexistant in MWX-3. A minimum width of 80 feet and a northeasterly trend are predicted, although a wider width is possible as it is unlikely that MWX-1 and MWX-2 both penetrated the channel center.

Green E, present as a sandstone in MWX-3 only, may parallel Green D since it is not present in MWX-1 or MWX-2, and a relatively consistent paleoflow to the northeast is depicted by the SHDT log.

3.3.6 Yellow Zone (Fig. 3.10)

The Yellow zone is a composite sandstone; two of the sandstone bodies (A and B) are separated 3 to 4 feet of mudstone in two wells, but interconnect in MWX-2 where A scoured down into B. In a horizontal plane, these two lenses are probably slightly divergent after intersecting. The third lens (C) has no obvious connection, but is separated from B by only 3 to 5 feet of mudstone.

Yellow A is a clean, crossbedded sandstone in all three wells, becoming rippled near the top. Its thickness in MWX-2 suggests a minimum width of 200 feet. Because it thins in MWX-1 and MWX-3, it is possible that the channel center runs between these two wells, trending northeast. However, crossbeds in oriented core and SHDT data (available for MWX-3 only) both suggest westerly paleoflow. The data is somewhat diffuse, and the SHDT data is only for low-angle (dubious significance) crossbedding, but its consistency is compelling. Most of the measurements indicate paleoflow between southwest and northwest (Fig. 3.11), but a slight angling towards the northwest is necessary in order to encompass all three wells within the projected 200 foot width, and is consistent with the majority of crossbeds. This lens seems to be a channel which was superimposed locally on Yellow B. The two lenses are probably unrelated and in plan view become separated beyond the MWX site.

Yellow B is another channel sandstone, the central parts of which were penetrated by MWX-2 and MWX-3. The oriented crossbedding and SHDT data indicate easterly to southeasterly paleoflow, diametrically opposed to that of Yellow A. (Again, the SHDT data is weak as most measured bedding have less than 10 degrees inclination, but it is consistent with itself and with the core crossbeds.) The crossbed pattern may be resolved into a dominantly east-northeast trend of trough crossbeds in MWX-3 core, and a dominantly southeast trend of planar crossbeds in MWX-1 core. Except that the crossbeds are of two distinct types, each with its dominant orientation, and that the lens is thickest in MWX-2, this might be taken to indicate a curved channel. It is more likely, however, that the planar crossbeds in MWX-1 represent a mid-channel bar with an avalanche slip face at some angle to overall flow, and that the trough crossbeds were formed in the channel thalweg, which may also vary in orientation with respect to overall channel trend (possibly diverted around the mid-channel bar). Overall channel trend is best estimated as an average of the two paleoflow directions, about east-southeast.

A reconstructed thickness, estimating the amount of the top of Yellow B that was removed by scour during the superposition of Yellow A in MWX-2, is about 25 feet. This yields a minimum width of 300 feet.

Yellow C is probably a splay or channel margin deposit, and consists primarily of rippled sandstone and siltstone in all three wells. Weak SHDT data from MWX-3 suggest northeasterly paleoflow from a source southwest of MWX-2. This may be corroborated by the slightly thicker deposits of this interval in MWX-2.

3.3.7 Red Zone (Fig. 3.12)

The Red zone is also a composite sandstone, consisting of two superimposed but apparently unrelated sandstone lenses.

Red A consists of 40 feet of main channel deposits in MWX-2 (suggesting a minimum width of 500 feet), thinner main channel deposits in MWX-1, and channel/channel margin deposits in MWX-3. Six good crossbed measurements from oriented core in MWX-1 and MWX-2 suggest northeasterly paleoflow, which is corroborated by two reliable SHDT patterns in MWX-3. The Red A lens therefore probably trends northeast, encompassing all three wells (Fig. 3.13). It begins to feather out to the northwest in the region of MWX-3. Since it also thins in the direction of MWX-1, reservoir rock probably does not extend much farther than the predicted width (500 feet) and the lens can be relatively well defined.

Red B is probably not directly related to Red A. Weak core crossbed and SHDT data suggest generally westerly paleoflow and possible lens trend, although data consistency is lacking. Red B thickens toward MWX-3, to 22 feet, suggesting 260 feet as a minimum width. Red B is scoured into by Red A in MWX-2, providing at least local interconnection. Based on sandstone thinning trends, the Red B channel sandstone is interpreted to be oriented at about N45°E, subparallel to the Red A channel and with its southeastern edge some 50 feet southeast of MWX-1.[11]

3.3.8 Permeability Breaks

Inhomogeneities are inherent in nonmarine deposits. Within a lens there are many discontinuities, such as shaley or carbonaceous layers, that segment the lens. As described in Section 3.2.2, these internal reservoir breaks are commonly inclined, but they may not extend entirely through the lenses. In addition, some natural fractures break through these barriers so individual segments of the reservoir are not completely isolated. The overall result is a network of restrictions and tortuous flow paths through the segments of the reservoir.

Within the approximately 600 feet of MWX core taken through the Red and Yellow zones, different types of permeability barriers were observed (Table 3.2). Nine of the occurrences in Table 3.2 are doubled points, wherein two factors are found together (i.e., a silty, carbonaceous zone). There are actually only 39 discrete barriers within the reservoirs, although there may have been others within the pieces of core that were removed for testing prior to this study.

Figure 3.14 portrays the distribution of the different types of lithology breaks within the Red and Yellow sandstones. The mudstone partings are generally concentrated in the top half of the reservoirs, as are the zones of very fine-grained sandstones, but the other types of discontinuities are more evenly distributed throughout the sandstone units.

3.4 NATURAL FRACTURES

Sixty natural fractures were logged in the coastal core from the MWX wells.* Only one was in oriented core: its strike is 110°, parallel to the trend of regional fractures at depth in the Mesaverde.[8]

The largest category of fractures (25) consists of vertical extension fractures (type 1) (Table 3.3). Eighty-four percent of these fractures occur in sandstones or siltstones, and 72 percent contain calcite mineralization. Of the known vertical terminations of these fractures, 68 percent occur at a mudstone boundary, 18 percent at a mudstone parting in sandstones, and 13 percent terminate within the same lithology. Twelve fracture terminations are unknown. Significantly, no fractures are seen to extend from a sandstone into a mudstone.

Thirteen shear fractures (type 2) were noted in the coastal core. Most follow subparallel bedding planes, usually along a thin mudstone parting within a sandstone. The sandstone-mudstone contact is commonly slickensided, but only half of these fractures are mineralized.

The other major fracture type (type 8) consists of zones of multiple fractures. The irregularity of individual fractures and of the fractures zones, their indiscriminate distribution in all lithologies, and their mineralization with dickite (often but not always in combination with calcite) mark these as a type not encountered in the marine, paludal or fluvial zones. Dickite is a high-temperature (~ 200°C) polymorph of kaolinite, and occurs at MWX as a later phase overlying calcite in those fractures where they occur together. The rock fabric in these fracture zones appears to be expanded, as if the fracturing and mineralization took

*Fracture data presented here are preliminary, and may differ slightly from data presented in the final fracture report.[12]

place under conditions of pore pressures that exceeded the hydrostatic, and possibly the lithostatic, gradients. These fractures are concentrated within a narrow interval of the wells from 6124 to 6242 feet, with smaller and less common dickite-filled fractures occurring from 5998 to 6312 feet. The origin and significance of this zone is unknown at present.

Five subhorizontal fractures without apparent shear were logged: three were mineralized with calcite, two were mineralized with an unidentified mineral, probably barite. Two additional planar, inclined fractures (type 6) were found in mudstones; one mineralized with calcite, one with dickite.

Finally, several hundred dewatering features (not listed in table) were noted in the mudstones. The "fractures" are irregular, commonly dipping 30° to 60°, curviplanar, often intersecting, and are inferred to have formed early during dewatering and compaction of the sediments. Similar features are seen in outcrop, in some cases below soft-sediment dewatering pipes in overlying sandstones. Three instances of such dewatering pipes, in sandstones overlying mudstones with dewatering fractures, were seen in the MWX core from the coastal zone. These fractures and planes of weakness in the rock probably formed by the alignment of clays, but they occur exclusively in the more plastic lithologies, and there is no indication (such as mineralization) that they are open or permeable at depth. They become apparent only during stress relief and breakage of the rock.

The effect of the permeability breaks described in Section 3.3.8 on natural fractures is an important consideration. Fracture systems will be different within each segment of the reservoir, as delineated by the reservoir breaks. The entire lens does not act as a single sandstone unit (or bed) with respect to the natural fractures.

Natural fractures commonly terminate at the thin lithologic discontinuities which provide local zones of stress difference (Fig. 3.15) and therefore (1) fracture spacing is probably proportional to the thinner sandstone units rather than to the gross reservoir thickness, and (2) fractures as permeability conduits probably form a much less completely interconnected network within the reservoir than they would if they extended top to bottom.

3.5 REFERENCES

1. Lorenz, J. C., "Reservoir Sedimentology of Mesaverde Rocks at the MWX Site, U.S. Geological Survey Open File Report 84-757," 1984, pp. 21-32. Also, Lorenz, J. C., "Reservoir Sedimentology of Mesaverde Rocks at the Multiwell Experiment Site and East Central Piceance Creek Basin," Sandia National Laboratories Report, SAND87-0040, 1987, 42 pp.

2. Lorenz, J. C., and A. K. Rutledge, Late Cretaceous Mesaverde Group Outcrops at Rifle Gap, Piceance Creek Basin, Northwestern Colorado, in Beus, S.S. (ed.), Rocky Mountain Section of the Geol. Soc. Am., Centennial Field Guide, Vol. 2, 1987, pp. 307-310.

3. Waetcher, N. B., and W. E., Johnson, Pennsylvanian-Permian Paleostructure and Stratigraphy as Interpreted From Seismic Data in the Piceance Basin, Northwest Colorado, in Stone, D.S. (ed.), New Interpretations of Northwest Colorado Geology, Rocky Mountain Assoc. Geol., 1986, pp. 51-64.

4. Johnson, R. C., Structure-Contour Map on the Top of the Rollins Sandstone Member of the Mesaverde Formation and Trout Creek Sandstone Member of the Iles Formation, Piceance Creek Basin, Colorado, U.S. Geological Survey Map MF-1667, 1983.

5. Lorenz, J. C., "Predictions of Size and Orientations of Lenticular Reservoirs in the Mesaverde Group, Northwestern Colorado," SPE/DOE 13851, Proceedings of the 1985 SPE/DOE Low Permeability Gas Reservoirs Symposium, Denver, CO, 1985, pp. 23-31.

6. Pitman, J.K., and Spencer, C.W., "Petrology of Selected Sandstones in the MWX Wells (Northwest Colorado) and Its Relationship to Borehole Geophysical-Log Analysis and Reservoir Quality," U.S. Geological Survey Open File Report 84-757, 1984, pp. 33-66.

7. Bendix Field Engineering Corp., Series of Contractor's Reports on the Petrologic Characteristics of Sandstones in the MWX Cores, 1982-1984, (unpublished). (Given in Appendix 11.1 for coastal-related reports.)

8. Lorenz, J. C., and S. J. Finley, "Differences in Fracture Characteristics and Related Production of Natural Gas in Different Zones of the Mesaverde Formation, Northwestern Colorado," SPE 16809, Proceedings of the 62nd Annual Technical Conference of the Soc. Petrol. Engineers, Dallas, TX, 1987, pp. 589-596.

9. Hudson, J., "Multiwell Core and Fluid Analysis of the MWX-1, 2, and 3 Wells," interim report, Dowell Schlumberger, Feb., 1986, (unpublished).

10. Lorenz, J. C., D. M. Heinze, J. A. Clark, and C. A. Searls, "Determination of Widths of Meander-belt Sandstones From Vertical Downhole Data," Mesaverde Group, Piceance Creek Basin, Colorado, Bull. Am. Assoc. Petrol. Geol., v. 69, pp. 710-721, 1985.

11. Lorenz, J. C., "Refined Geological Interpretations for the Coastal Zone," memorandum to distribution, Feb. 25, 1985.

12. Finley, S.J., and J. C. Lorenz, "Characterization of Natural Fractures in Mesaverde Core From the Multiwell Experiment," Sandia National Laboratories Report, SAND88-1800, September 1988.

Table 3.1

Summary of Petrologic Characteristics of Sandstones in the Coastal Zone
(from Bendix Reports[7])

	GREEN C	GREEN D	YELLOW (A&B)	RED (A&B)
Ave. mean grain size (mm)				
MWX-1	.13(.06-.18)	.09(.07-.10)	.11(.07-.13)	.11(.08-.15)
MWX-2			.14(.08-.18)	.12(.09-.18)
Ave. % pore space				
MWX-1	10.6 (8-15)	10.7 (4-15)	6.6 (4-8)	~6.1 (tr-14)
MWX-2			8.9 (2-14)	~9.2 (tr-21)
Ave. % calcite				
MWX-1	5.7 (2-13)	6.3 (4-10)	7.8 (4-20)	7.9 (4-16)
MWX-2			8.1 (3-25)	6.1 (2-16)
Ave. % dolomite				
MWX-1	7.0 (2-14)	12.3 (9-16)	5.7 (3-10)	8.3 (6-11)
MWX-2	-	-	3.5 (1-7)	5.7 (3-10)
Ave. % quartz				
MWX-1	52.3 (47-58)	51.7 (49-55)	67.5 (54-77)	68.8 (56-78)
MWX-2	-	-	65.9 (35-81)	62.4 (52-75)
Ave % K-feldspar				
MWX-1	~1.0 (tr-2)	~0.7 (tr-1)	~1.3 (tr-4)	~2.4 (1-4)
MWX-2	-	-	tr(tr-2)	tr(tr-2)
Ave % plagioclase				
MWX-1	7.1 (5-9)	4.7 (4-6)	11.3 (7-15)	7.9 (5-12)
MWX-2	-	-	7.9 (4-13)	7.4 (4-13)
Ave. % lithics				
MWX-1	8.1 (5-10)	6.3 (6-7)	6.0 (4-8)	11.8 (6-23)
MWX-2	-	-	19.5 (8-29)	25.8 (18-34)
Ave. % chert				
MWX-1	3.3 (1-6)	2.0 (1-3)	13.8 (7-21)	9.5 (5-12)
MWX-2	-	-	5.2 (2-12)	5.3 (1-11)
Ave. % silica overgrowths				
MWX-1	2.6 (2-3)	3.7 (3-4)	7.8 (5-12)	4.7 (2-9)
MWX-2	-	-	~2.4 (tr-5)	2.0 (1-5)
Ave. % clays in voids				
MWX-1	9.1 (7-10)	9.7 (3-14)	~1.6 (tr-7)	~3.0 (tr-12)
MWX-2	-	-	8.4 (2-13)	98.4 (tr-21)
Ave. % clays				
MWX-1	~1.2 (tr-2)	tr	13.2 (4-21)	10.3 (1-14)
MWX-2	-	-	5.2 (2-21)	4.9 (1-10)

Trace minerals (inconsistent)--siderite, muscovite, biotite, pyrite, other opaques, zircon, tourmaline, apatite, epidote, hornblende

Table 3.2

Summary of Frequency of Lithologic Discontinuities in the Red and Yellow Sandstones

	No. of Occurrences
Mudstone partings (1/2"-3")	7
Sideritic clast zones	8
Mudstone ripup clast zones	13
Carbonaceous (organic) zones	13
Very fine grained zones	7
	48

Table 3.3

Fracture Data from Core in the Coastal Zone

Depth (ft) (Top of Fracture)	Fracture Type*	Number of Fractures**	Fracture Height (ft) in Core	Max Width (mm) Including Mineralization	Dip	Fill Mineral***	Fill Amount+	Top Termination++	Bottom Termination++	Rock Type+++	Comments
6002.1	1	1	0.7	1.0	80	C	C	2	1	3	2 close strands
6007.7	1	1	2.8	3.0	85	C	PS	1	1	3	
6033.0	1	1	1.1	3.0	80	QD	PS	7	1	3	
6035.7	1	1	1.0	8.0	90	QCD	PS	1	5	3	curved planes
6047.2	1	1	0.4	0.8	90	D	P	1	1	3	
6048.4	1	1	0.9	1.0	80	DC	P	1	1	4	
6050.7	1	1	0.3	2.0	90	DC	P	1	1	3	
6060.0	6	1	0.1	-	30	C	PS	2	2	7	
6075.7	1	1	1.4	11.0	80	C	PS	2	2	2	
6081.5	1	1	1.1	0.6	90	D	C	1	1	5	
6084.4	1	1	0.1	0.1	90	C	C	1	1	5	
6088.7	1	1	0.4	0.2	90	C	C	1	3	3	
6100.2	1	1	0.9	2.0	90	C	P	1	1	6	
6106.9	1	1	1.1	0.4	90	C	C	1	1	6	
6117.9	1	1	0.6	0.4	90	C	C	1	1	5	
6119.1	2	1	0.1	-	05	C	PS	2	2	6	
6124.3	1	1	0.4	0.8	90	D	P	1	1	3	
6124.4	1	1	0.1	-	-	C	-	2	2	3	fracture just skims core
6129.0	8	6	1.5	6.0	90	DC	P	1	1	5	multiple irregular fractures

Table 3.3

Fracture Data from Core in the Coastal Zone (Continued)

Depth (ft) (Top of Fracture)	Fracture Type*	Number of Fractures**	Fracture Height (ft) in Core	Max Width (mm) Including Mineralization	Dip	Fill Mineral***	Fill Amount+	Top Termination++	Bottom Termination++	Rock Type+++	Comments
6131.8	8	6	0.7	3.0	0-90	DC	P	1	2	0	multiple irregular fractures
6134.9	8	6	0.9	5.0	40-90	DC	C	1	1	6	multiple irregular fractures
6143.6	8	1	-	-	10	DC	P	2	2	3	follows bedding
6146.8	8	6	2.0	0.5	0-80	DC	C	1	3	6	multiple irregular fractures
6149.3	8	6	2.0	2.0	0-90	DC	C	3	1	6	multiple irregular fractures
6151.1	6	1	0.2	-	35	D	P	2	2	7	
6151.8	8	4	1.1	0.2	0-90	D	C	1	1	0	multiple irregular fractures
6153.5	8	1	0.1	0.2	40	D	C	3	3	0	
6154.2	8	1	-	1.0	10	D	C	2	2	6	
6178.9	2	1	-	-	30	-	-	2	2	4	
6188.3	8	6	1.6	2.0	0-50	D	P	3	3	4	multiple irregular fractures
6189.9	2	1	-	-	20	CD	PS	2	2	4	
6190.2	8	1	0.3	-	60	DC	P	2	2	3	
6190.5	8	1	0.3	-	60	DC	P	2	2	3	
6190.8	2	1	-	-	0	D	P	2	2	4	
6190.9	2	1	-	-	0	-	-	2	2	4	
6192.6	1	1	0.9	0.6	80	D	C	3	5	3	

Table 3.3

Fracture Data from Core in the Coastal Zone (Continued)

Depth (ft) (Top of Fracture)	Fracture Type*	Number of Fractures**	Fracture Height (ft) In Core	Max Width (mm) Including Mineralization	Dip	Fill Mineral***	Fill Amount+	Top Termination++	Bottom Termination++	Rock Type+++	Comments
6193.0	2	1	-	-	0	D	P	2	2	4	
6193.9	1	1	0.8	0.2	90	C	C	5	3	4	
6195.2	1	1	0.8	0.4	60-80	D	C	2	2	0	
6195.4	2	1	-	-	0	-	-	2	2	0	
6195.4	1	1	1.5	0.3	80	C	C	5	5	3	
6197.1	2	1	-	-	05	-	-	2	2	4	
6197.7	2	1	-	-	10	-	-	2	2	4	
6197.7	8	6	0.9	2.0	50-75	DC	C	5	3	6	multiple irregular fractures
6203.0	2	1	0.1	-	20	C	P	2	2	4	
6242.9	8	2	0.2	0.3	30	D	C	3	3	6	
6248.0	2	1	-	-	-	-	-	-	-	4	
6249.2	1	1	1.3	1.0	90	QC	PS	5	2	3	
6312.4	8	6	0.3	4.0	70-90	DC	C	3	3	7	multiple irregular fractures
6328.5	7	1	-	5.0	10	C	C	2	2	7	
6358.7	1	1	0.3	0.8	85	C	C	5	2	3	
6396.5	7	1	-	-	10	B	P	2	2	3	
6396.5	1	1	0.2	1.0	90	D	C	3	3	3	
6396.8	7	1	-	-	10	B	P	2	2	3	
6399.0	1	1	2.9	0.2	90	C	C	1	1	2	
6430.4	2	1	-	-	15	C	P	2	2	6	
6501.3	2	1	-	-	10	-	-	-	-	4	

Table 3.3

Fracture Data from Core in the Coastal Zone (Concluded)

Depth (ft) (Top of Fracture)	Fracture Type*	Number of Fractures**	Fracture Height (ft) (in Core)	Max Width (mm) Including Mineralization	Dip	Fill Mineral***	Fill Amount+	Top Termination++	Bottom Termination++	Rock Type+++	Comments
6525.1	1	1	0.7	0.2	90	C	C	2	2	3	Strikes 110#
6584.3	7	1	-	-	0	C	P	2	2	4	
6584.7	7	1	0.2	1.4	30	C	P	2	3	4	

*Fracture Type:
1. Vertical extension
2. Shear along mudstone parting in sandstone
3. Dewatering (not listed here)
4. Shear showing motion, cuts across bedding
5. Miscellaneous shear
6. Planar fracture (shear?) in mudstone
7. Subhorizontal, no shear apparent
8. Zone of multiple irregular fracture

**Number of fractures: multi-stranded fractures were listed as a single fracture if the strands were spaced less than one inch apart.

***Fill mineral: C, calcite
Q, quartz
D, dickite
B, barite

+Fill amount: C, complete
P, partial
S, subhedral mineral crystals apparent

++Top and bottom terminations:
1. at mudstone contact
2. out of core (unknown)
3. within same lithology
4. at gradational change to mudstone
5. at mudstone parting
6. at grainsize change (other than at mudstone)
7. sampled (unknown)

+++Rock type:
0. thinly laminated mudstone and siltstone
1. coarse sandstone
2. medium sandstone
3. fine sandstone
4. fine sandstone with some mudstone laminations
5. mixed siltstone and mudstone
6. siltstone
7. mudstone
8. coal

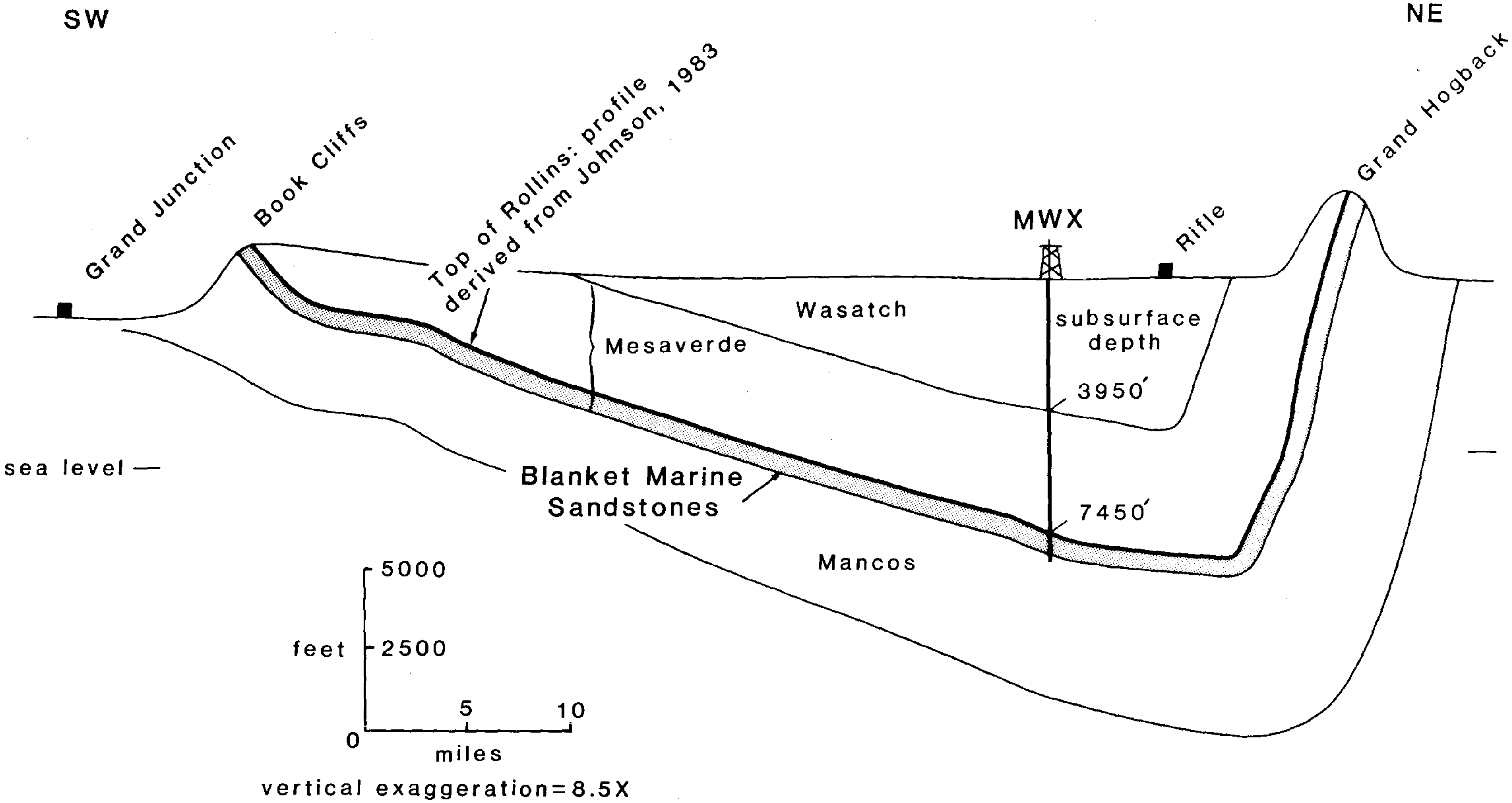

Figure 3.1. General Structure of the Mesaverde Formation in the Piceance Creek Basin

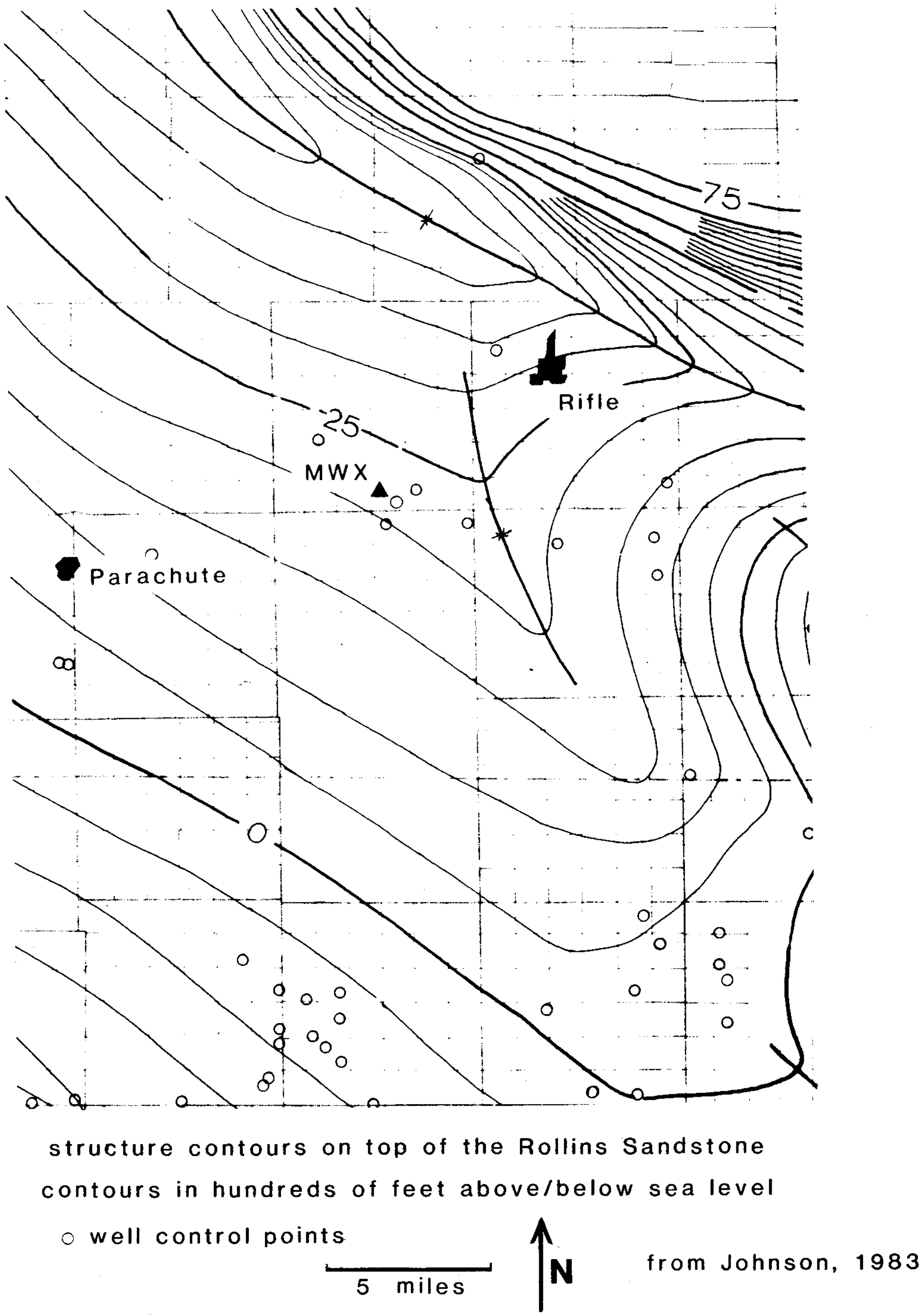

Figure 3.2. Structure Contours on Top of the Rollins Sandstone: Contours in Hundreds of Feet Above/Below Sea Level (from Johnson[4])

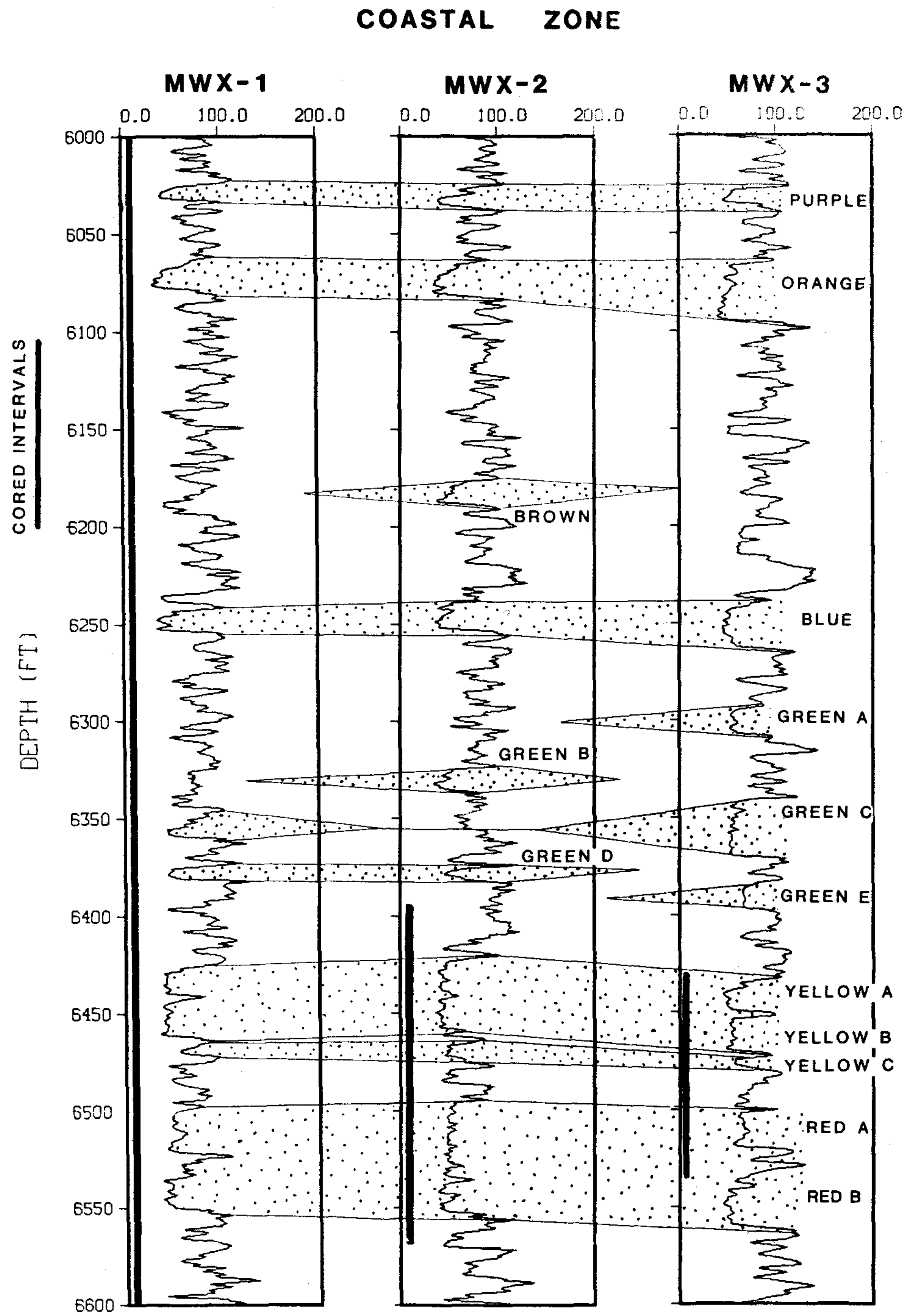

Figure 3.3. Gamma Ray Logs and Correlation of Reservoir Sandstones in the Coastal Zone

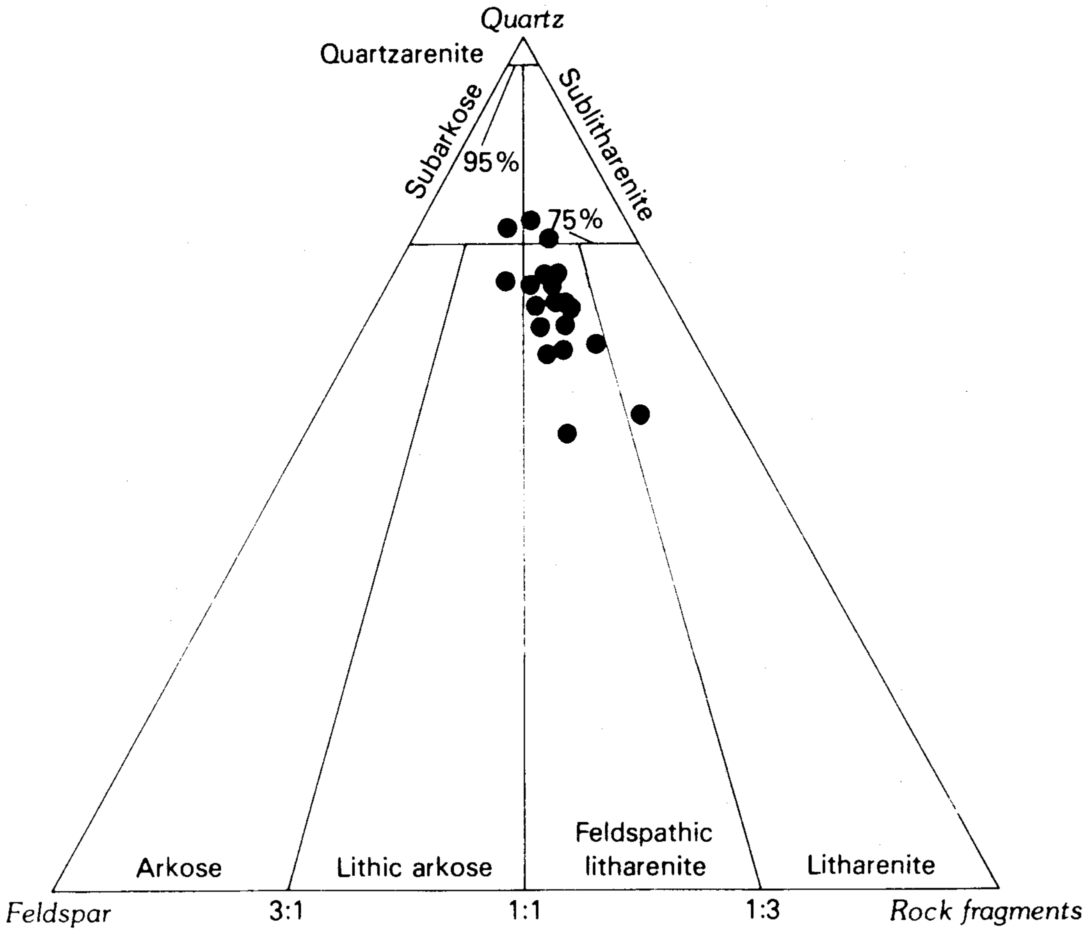

Figure 3.4. Ternary Plot Showing Mineralogic Composition of Sandstones in the Coastal Zone (From Pitman and Spencer[6])

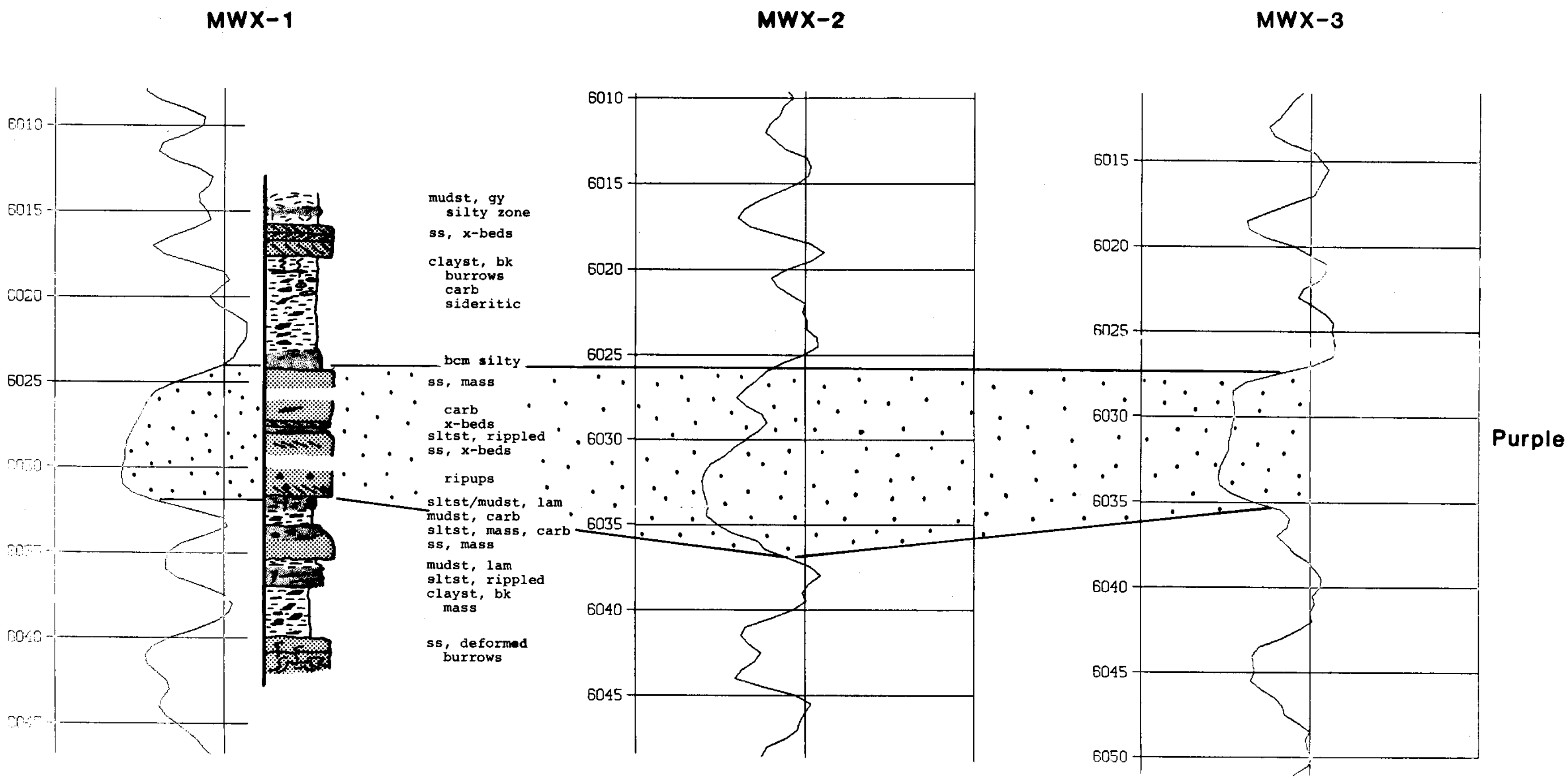

Figure 3.5. Core Lithology, Gamma Ray Logs, and Correlation of the Purple Zone in the Three MWX Wells

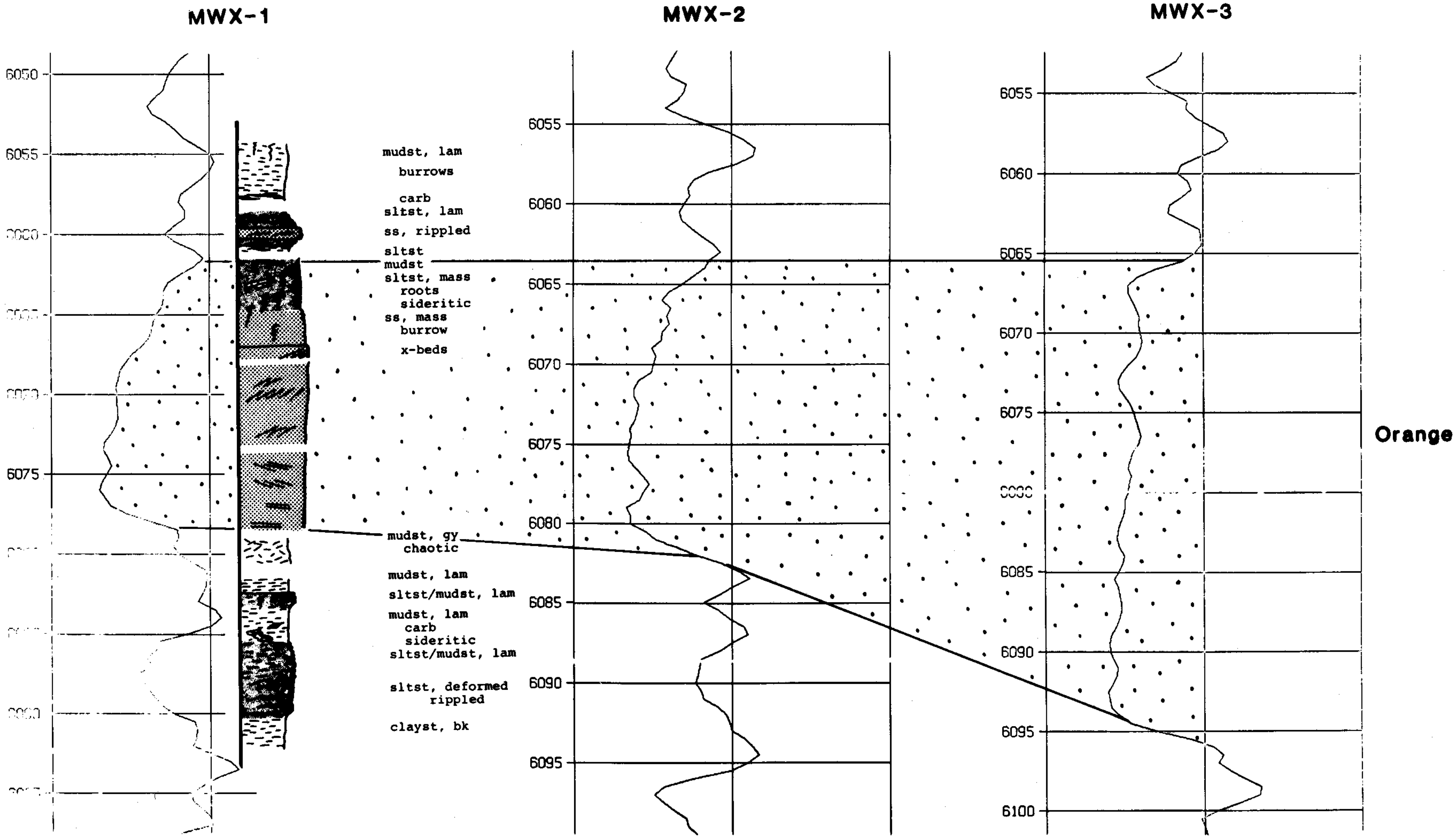

Figure 3.6. Core Lithology, Gamma Ray Logs, and Correlation of the Orange Zone in the Three MWX Wells

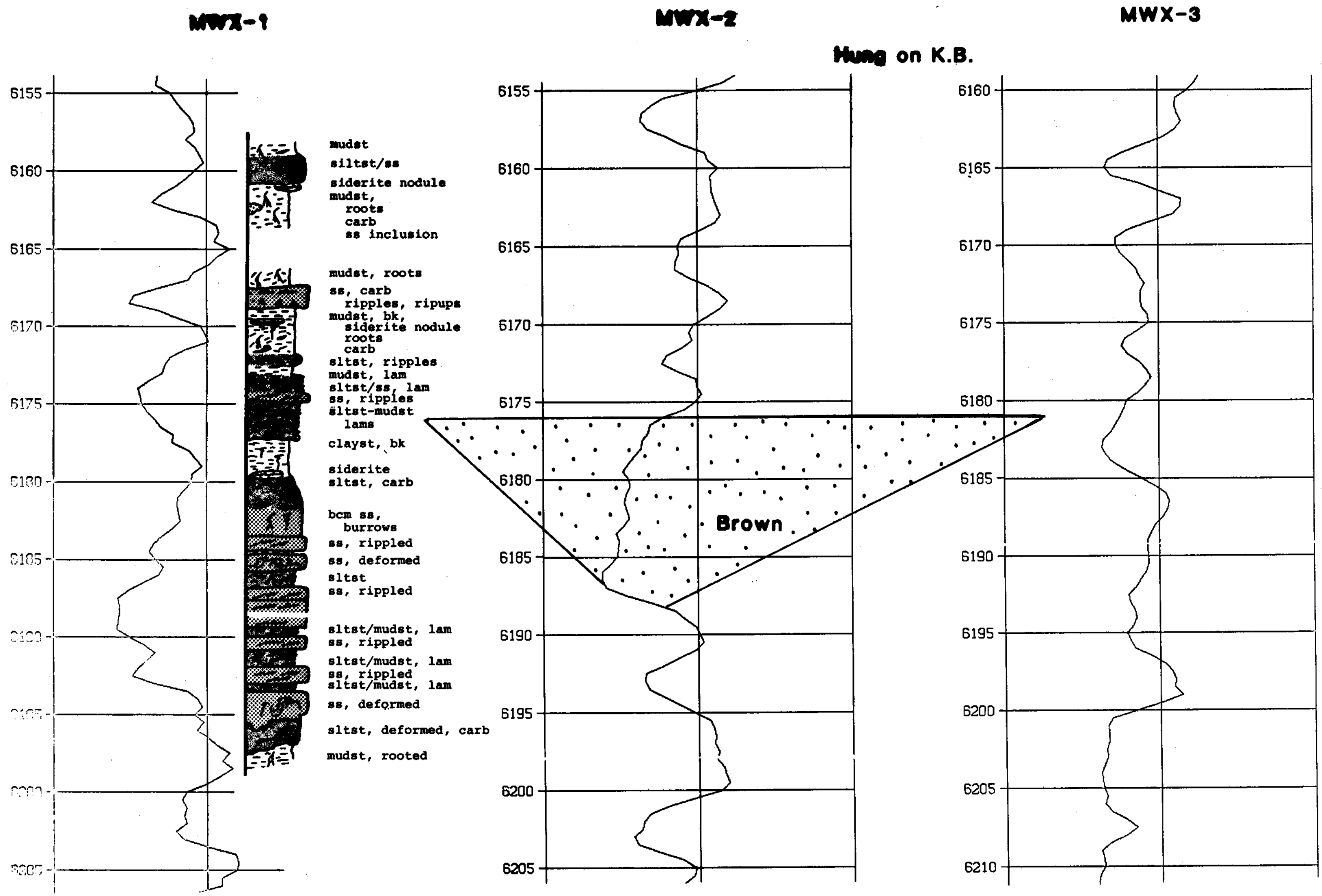

Figure 3.7. Core Lithology, Gamma Ray Logs, and Correlation of the Brown Zone in the Three MWX Wells

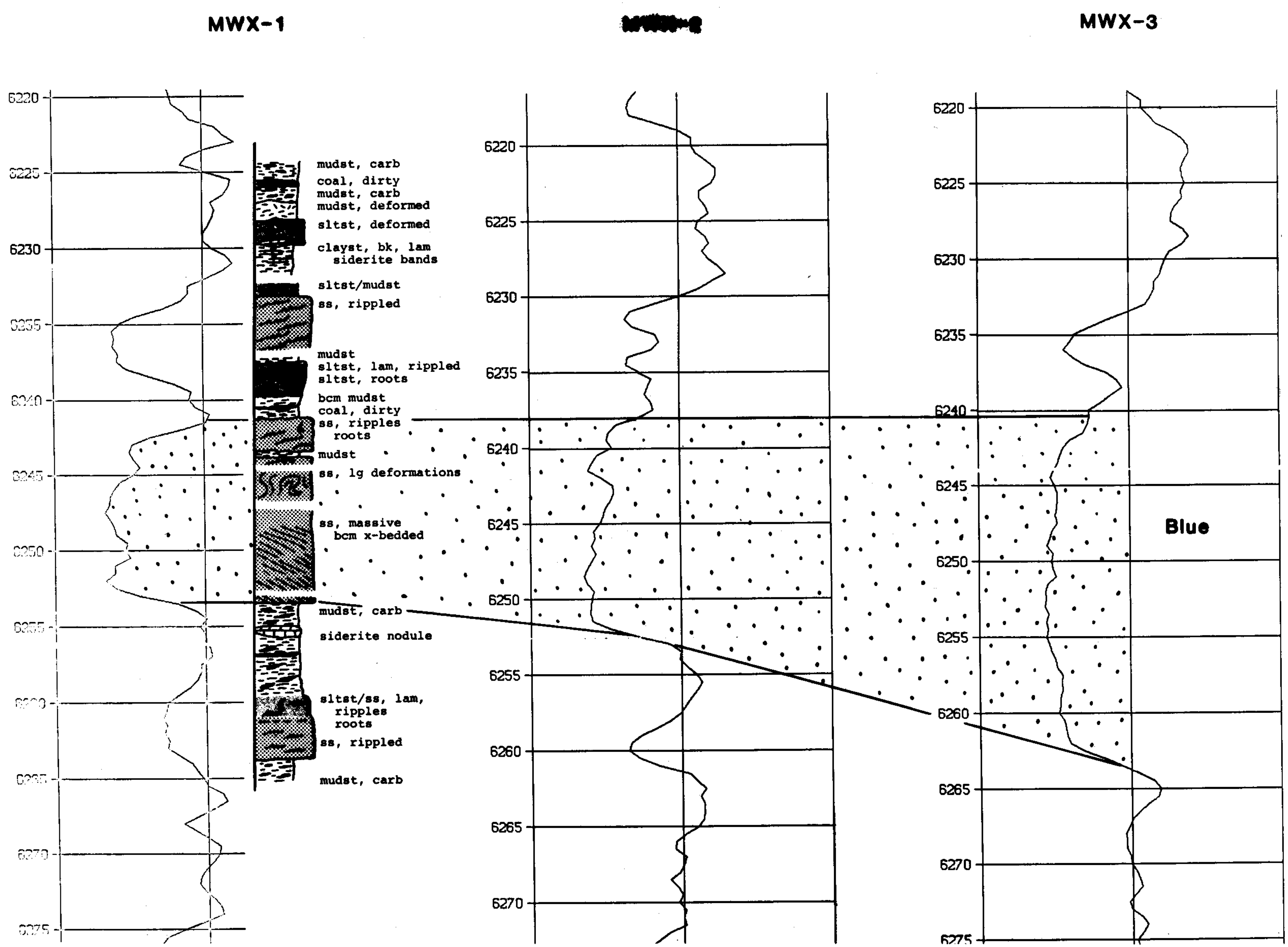

Figure 3.8. Core Lithology, Gamma Ray Logs, and Correlation of the Blue Zone in the Three MWX Wells

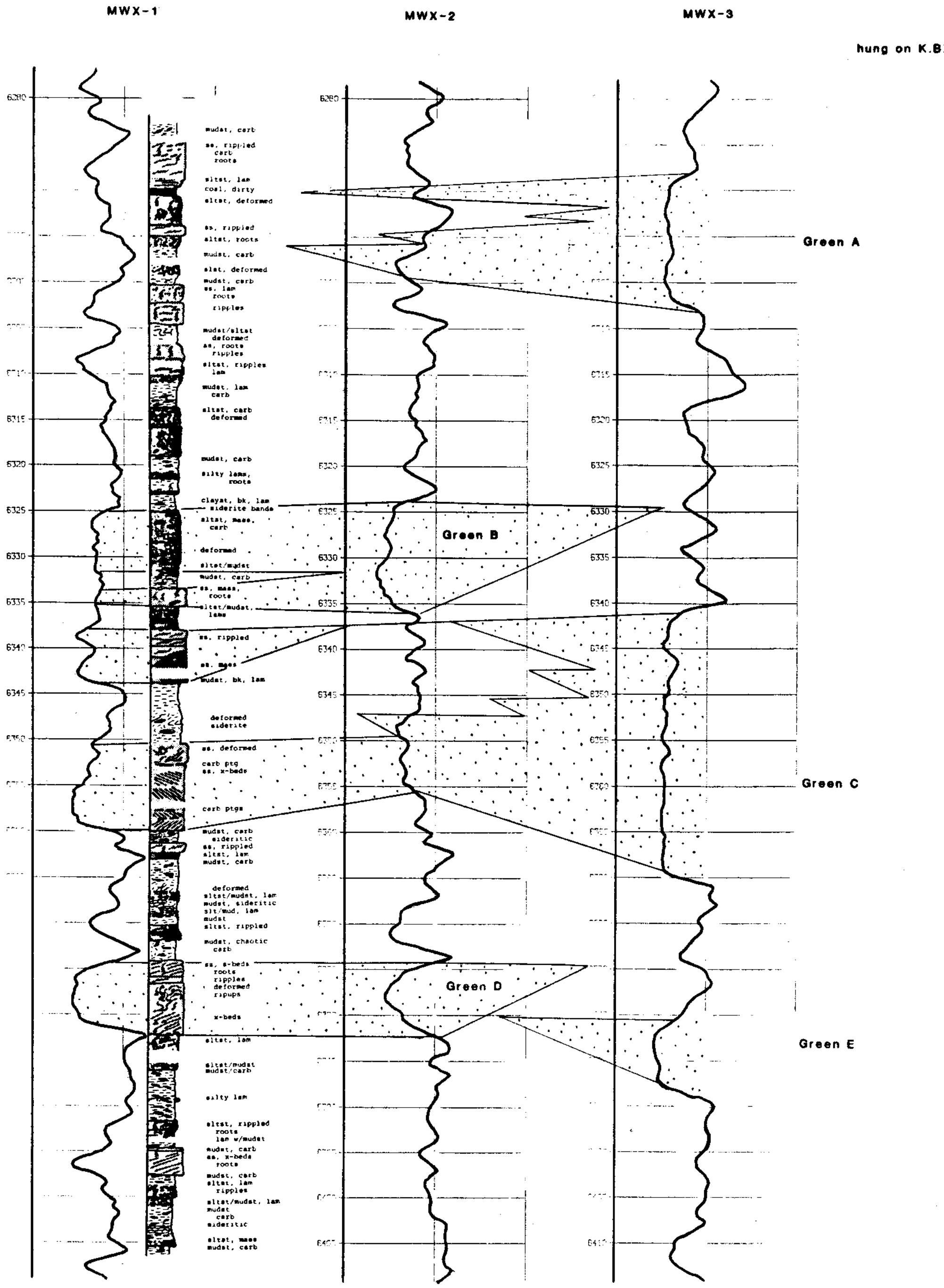

Figure 3.9. Core Lithology, Gamma Ray Logs, and Correlation of the Green Zone in the Three MWX Wells

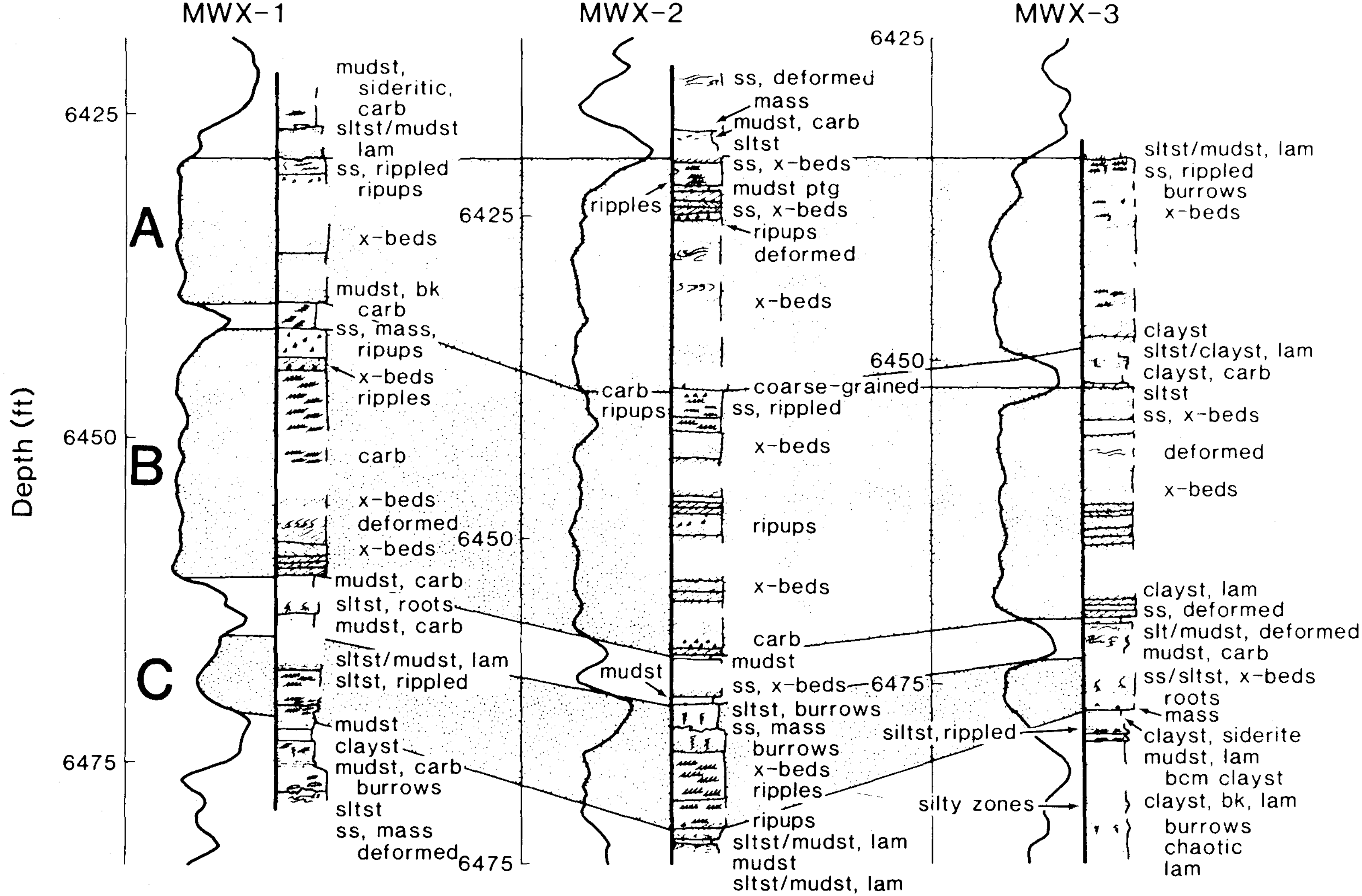

Figure 3.10. Core Lithology, Gamma Ray Logs, and Correlation of the Yellow Zone in the Three MWX Wells

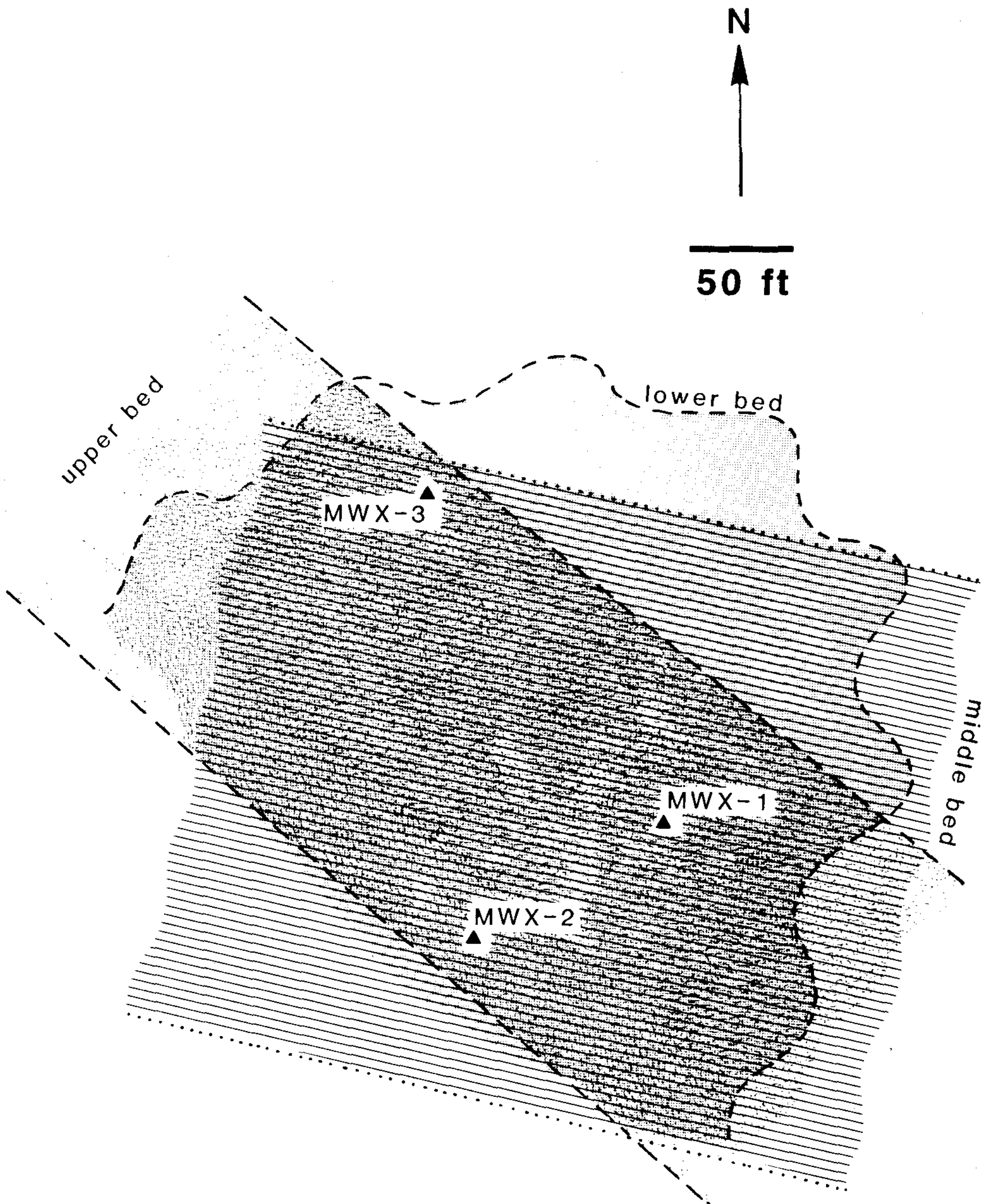

Figure 3.11. Plan View: Inferred Lens Trends in the Yellow Zone

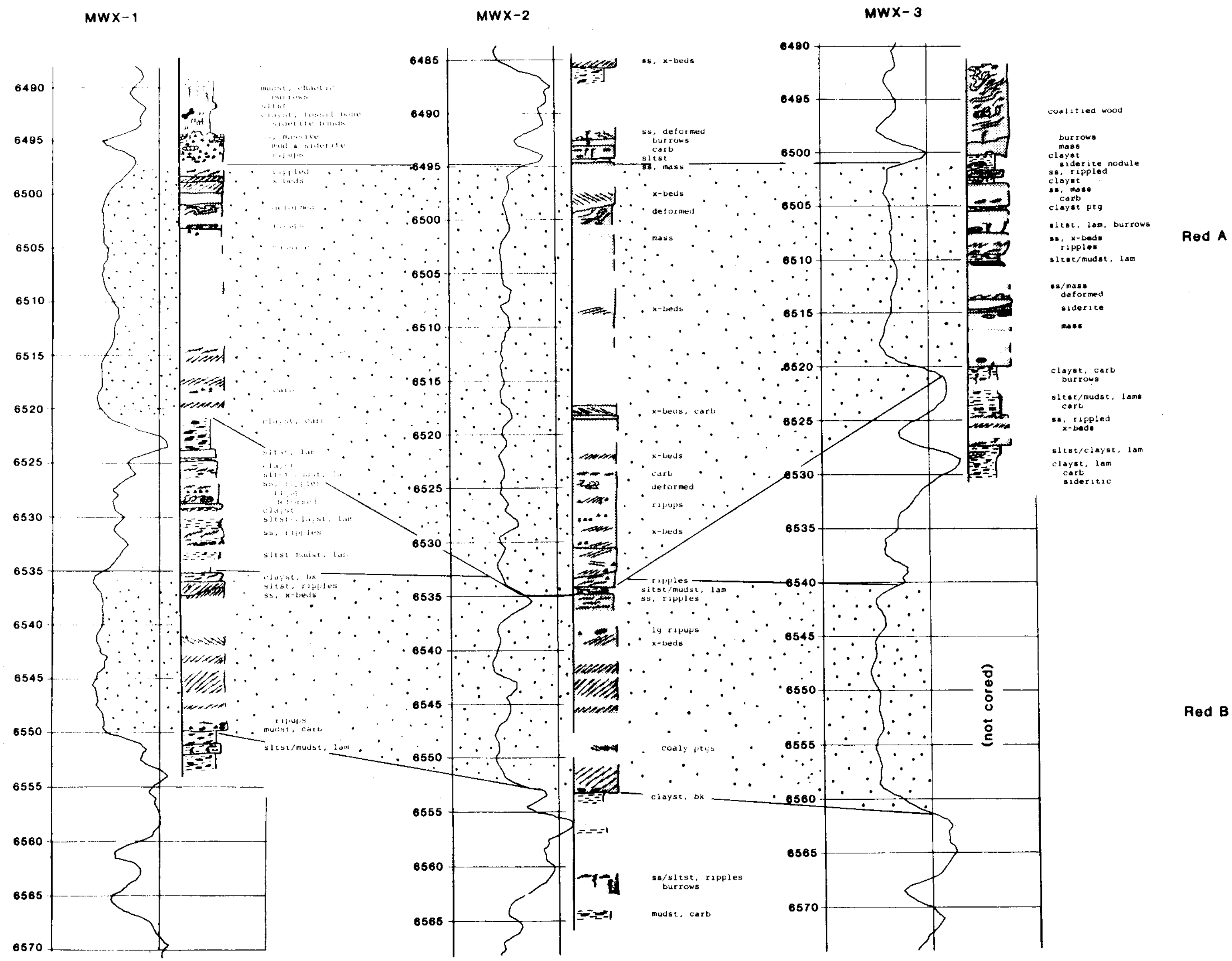

Figure 3.12. Core Lithology, Gamma Ray Logs, and Correlation of the Red Zone in the Three MWX Wells.

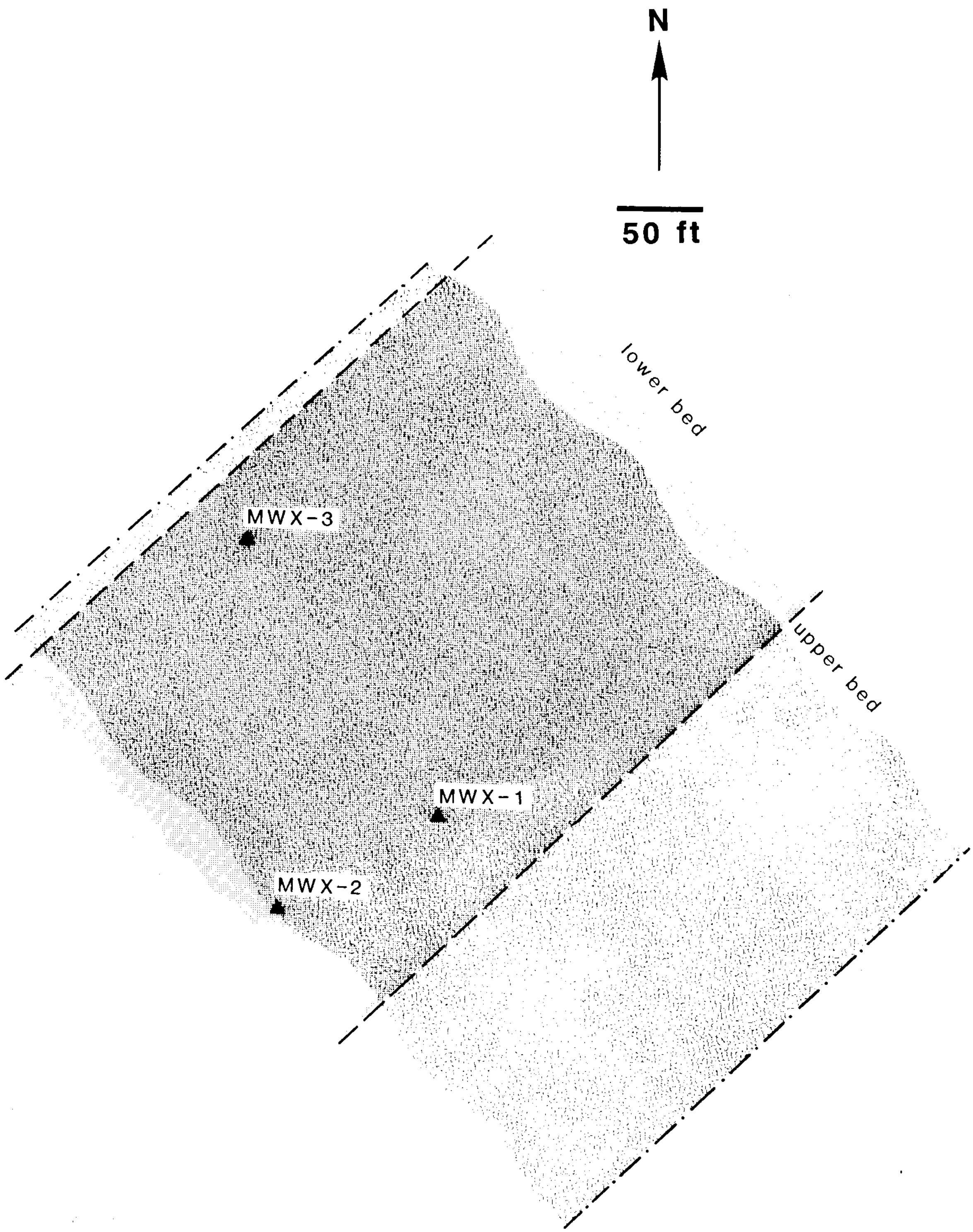

Figure 3.13. Plan View: Inferred Lens Trends in the Red Zone

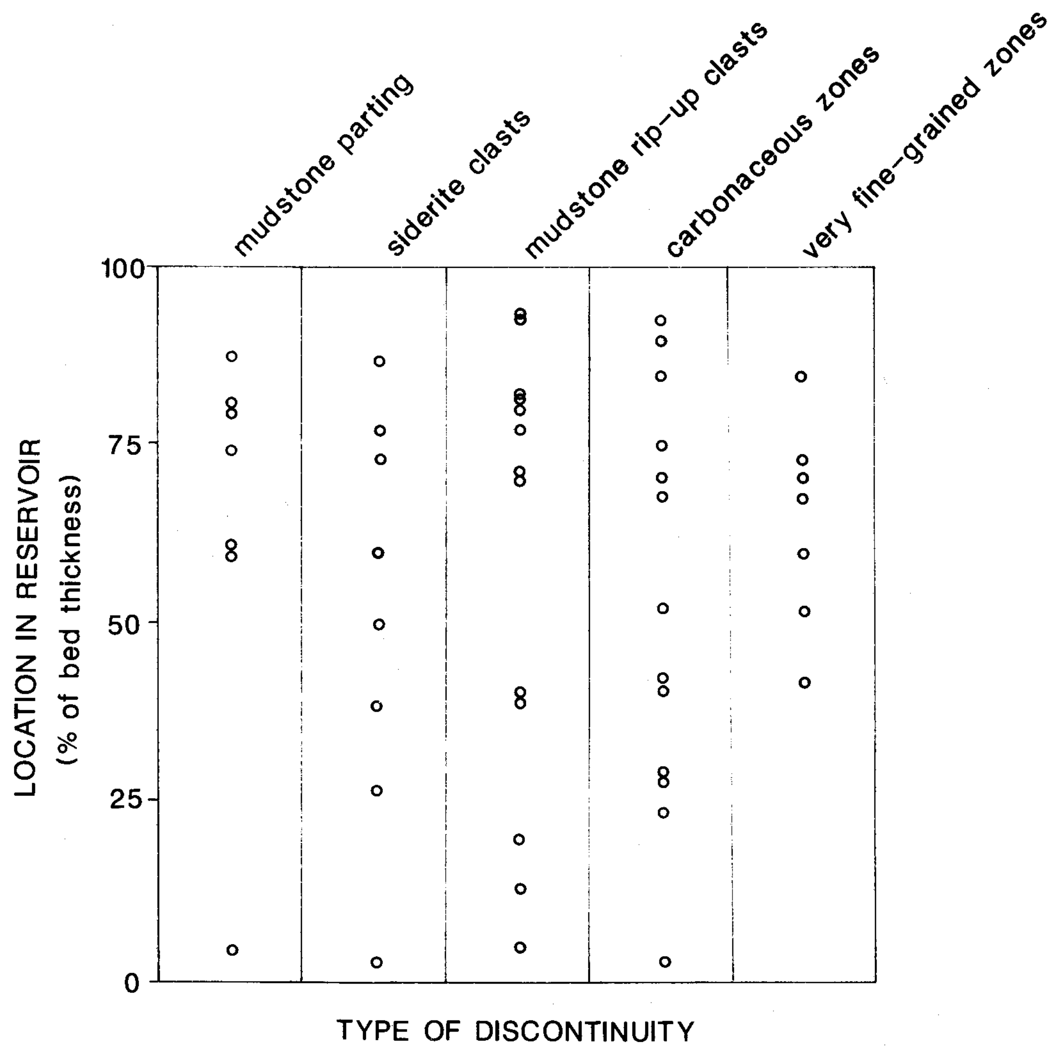

Figure 3.14. Distribution of Different Types of Lithologic Discontinuities (Permeability Breaks) in the Red and Yellow Sandstones

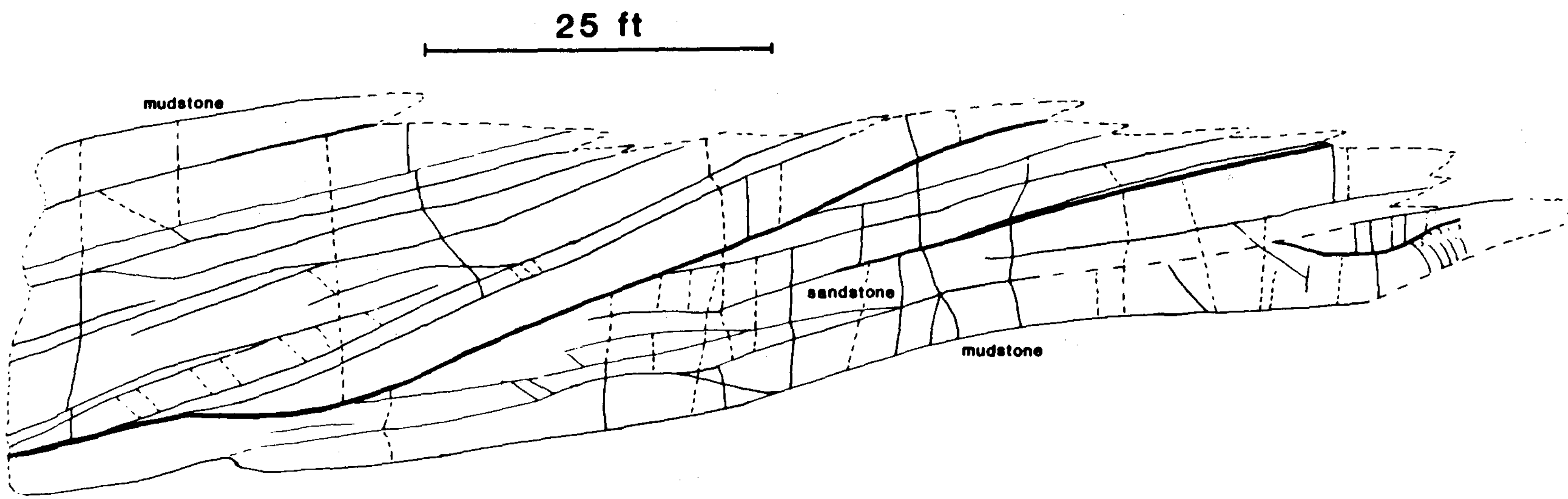

Figure 3.15 Vertical Outcrop Section through a Coastal Sandstone, Showing Diagonal Lithologic Discontinuities and Their Effects on Fracture Distribution.

4.0 LOG ANALYSIS

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4.1 INTRODUCTION

Extensive log analysis of the Mesaverde Group has been undertaken as part of the Department of Energy's Western Gas Sands Project Multiwell Experiment (MWX), a research effort aimed at developing new and improved technology to enhance natural gas production from low-permeability reservoirs. The Mesaverde Group of Western Colorado's Piceance Basin typifies low-permeability lenticular sandstone reservoirs which contain a large resource of natural gas but are difficult to characterize and produce. A log interpretation system developed specifically to deal with such tight, shaly reservoirs has been applied to the three wells drilled for the Multiwell Experiment. This report is a synopsis of a more comprehensive report presented previously.[1] It presents the results of the analysis of the coastal interval between 6000 and 6570 ft.

The coastal interval of the Mesaverde Group consists of a 600 ft-thick section of predominantly silt and mudstone enveloping isolated sand lenses 2 to 35 ft thick. Fourteen sand units with reservoir potential were targeted for analysis. Due to the restricted width of the lenses, some sands are not observable in all three wells, or are notably thinner. Table 4.1 lists the sand units' depths in the three wells. Figure 4.1 shows the correlation of the units.

4.2 GENERAL CHARACTERISTICS OF THE RESERVOIR ROCK

The sandstone lenses in the coastal interval are fairly consistent lithologically. They are feldspar and lithic rich quartz sandstones, well sorted and usually fine to very fine grained. Carbonate minerals average 10 to 15 percent of the rock, with an approximately equal amount of calcite and dolomite. Many sandstones contain mudstone lenses, and a few have carbonaceous stringers. The average sandstone has 5 to 15 percent clay, which is dominantly illite and illite/smectite mixed layer clay. Figure 4.2 shows the range of grain density for the coastal interval in MWX-1. Mean grain density is 2.673 gm/cc and is increased by both clay and carbonate.

The coastal reservoirs are very tight. Permeability is on the order of microdarcies; as a consequence, water saturation is high. The phenomena responsible for the extremely tight nature of these rocks appear to be small grain size, reduction of primary porosity through silica cementation and the presence of clay minerals. The clays line grain boundaries and bridge pore throats.

Porosity is generally less than 9 percent. Figure 4.3 shows the range of core porosity for the coastal interval in MWX-1. The distribution is distinctly bimodal. Coring through the MWX-1 coastal interval was continuous and sampling was somewhat random through the interval 6230 to 6560 ft. This resulted in sandstones, siltstones and mudstones each being well represented. The population of analyses peaking at 3 percent porosity consists of mudstones and siltstones, whereas the peak at 7.2 percent is sandstone. This conclusion is substantiated by Figure 4.4 which plots only samples in which the core was described as being a sandstone. The average porosity of sandstone within the coastal interval is 6.1 percent.

Natural fracture intensity within the upper coastal cored interval (6000 to 6250 ft) is high whereas it is less in the lower interval. Since matrix permeability for the interval is unusually low, it is probable that the individual reservoirs would require natural fractures for significant gas production.

4.3 COASTAL INTERVAL DATABASE

The basis of the extensive MWX log and core database is listed in Tables 4.2 and 4.3, respectively. The database is completely digitized.

All log curves are depth shifted to the primary resistivity log for each well. Core analyses have been depth-shifted and are stored at log depth. Additional data utilized in the coastal log analysis include core descriptions (digitized using a lithology code), the core gamma ray log, thin-section point count, x-ray diffraction analyses, and mud logs. Several visual fracture detection type logs which do not lend themselves to digitizing were analyzed manually.

The entire coastal interval was cored in MWX-1. In MWX-2, only the interval from 6390 to 6568 ft was cored. In MWX-3, the coastal interval was cored from 6431 to 6530 ft.

Intermediate-run log data was used in the coastal interval analysis to achieve the best analysis possible. The intermediate logs were run under better hole conditions and are less perturbed by invasion. Prior to analysis, density and neutron data histograms were compared between multiple runs in each well and between wells for differences of data distribution. Several diagnostic peaks and limits observed were useful to discern inconsistencies in the data sets. Several log quality problems were noted and resulted in the following normalizations of intermediate-run log data: (a) MWX-1 compensated neutron data was normalized by -1.5 porosity units; (b) MWX-1 bulk density data was normalized by -0.01 gm/cc; and (c) MWX-2 compensated neutron data was normalized by -0.5 porosity unit.

The MWX basic logs are presented in Figures 4.5 through 4.19 according to the following format:

	MWX-1	MWX-2	MWX-3
Resistivity	Figure 4.5	Figure 4.10	Figure 4.15
Density-Neutron Porosity	4.6	4.11	4.16
Bulk Density-Photoelectric	4.7	4.12	4.17
Spectral Gamma	4.8	4.13	4.18
Long-Spaced Sonic	4.9	4.14	4.19

4.4 ANALYSIS OF COASTAL RESERVOIRS

Analysis of the coastal interval was performed using TITEGAS, a sandstone log analysis model developed by CER Corporation, and procedures given in detail elsewhere.[2-5] The format and description of TITEGAS computed log output is presented in Figure 4.20. The output includes both curves from log analysis computations and plotted core data. The computed logs for MWX-1, MWX-2 and MWX-3 are presented in Figures 4.21, 4.22 and 4.23, respectively.

4.4.1 Overall Quality and Characteristics

Fourteen distinct sand bodies are identified as potential reservoirs in the coastal interval. Using model results from the TITEGAS log analysis program, each sand or zone is classified and labeled on the computed log as being one of the following types:

- Type 1: These reservoirs have the best matrix reservoir quality. This type of zone is interpreted as capable of gas flow from matrix after a perforation breakdown and does not necessarily depend upon natural fractures for flow. A stimulation candidate.

- Type 1a: Matrix permeability is developed as in Type 1 and the unit is also naturally fractured.

- Type 2: These reservoirs are naturally fractured but generally do not have good matrix permeability.

- Type 3: Marginal matrix permeability; secondary stimulation candidate.

- Type 4: These reservoirs are too tight for significant production.

- Type 5: These reservoirs are very marginal gas zones. Water saturation is very high and completion could possibly cause water production problems.

- Type 6: These reservoirs are sands which have very high water saturation. This type of zone will contribute substantial water production.

Some general statements can be made about the relative quality of the units in the coastal interval:

- The best reservoir appears to be the Orange sand. Although the unit is thin in MWX-1 and MWX-2, matrix permeability is relatively high.

- The Red and Yellow sands are relatively fair to poor reservoirs, but are fairly thick and continuous.

- The Blue and Purple sands are also relatively fair to poor reservoirs, but in addition are much thinner units than the Red and Yellow sands. However, they are probably more fractured.

- The Brown and Green sands are the worst quality reservoirs. Generally they are laterally discontinuous and very tight, but may be naturally fractured.

Reservoir quality varies between the three wells. MWX-2 overall has the best quality reservoirs; MWX-1, the worst. Tables 4.4, 4.5 and 4.6 list zone-averaged reservoir characteristics of the coastal reservoirs for all three wells.

4.4.2 Matrix Permeability Analysis

Two methods are available in TITEGAS for determining matrix permeability. The first is a qualitative estimate based on the difference between near-zone water saturation (S_{xo}) and deep formation water saturation (S_w). If the saturation curves are separate but track each other, the discrepancy is attributable to a local water resistivity variation. If the curves travel oppositely, then a permeable interval is interpreted. If the curves stack, then the zone is tight and uninvaded. The TITEGAS computed logs show the S_w difference, or ΔS_w.

The second method is a direct simulation of net stress corrected absolute permeability shown on the TITEGAS logs as the curve labeled KI. When KI, or the permeability index, is corrected for formation water saturation, the resultant effective gas permeability will be one to two orders of magnitude lower.

Visual analysis of the two permeability indicators allows reliable estimation of matrix permeability. Generally when ΔS_w is larger and the saturation curves are swinging in an opposite direction, the calculated KI is high. When thickness of zone is factored in, the permeability-feet parameter (kh on the log) becomes a useful tool to judge zone merit. In the coastal interval, the most permeable zones are the Purple, Orange and Blue sands. The Green, Red and Yellow sands have isolated permeable streaks. In general, the coastal sand lenses have poor matrix permeability and significant gas production would be contingent upon the presence of natural fractures.

4.4.3 Natural Fracture Detection

Several natural fracture indicators are available in the MWX database. Fractures observed in cores are the most direct method of indication. (The core fracture data used in this analysis were those derived from the initial field core description, and may differ from the more recent, comprehensive natural fracture data given in Section 3.4.) A second method relies on various so-called fracture logs, e.g., borehole televiewer (BHTV), circumferential acoustilog (CMA), fracture identification log (FIL), borehole compensated variable density log (BHC-VDL), and the frac ture probability log (FPL). This log suite was run in MWX-3. The oil-base mud used in MWX-1 and MWX-2 prevented the majority of fracture log measurements from being useful in those wells; only the VDL logs were available.

Figure 4.24 is a digitized interpretation of each fracture log for MWX-3, combined into a single trace plot. Shading indicates a log-interpreted fracture. Zones where most or all of the fracture logs exhibit a fracture response can reliably be assumed to be naturally fractured. In MWX-3, these zones are the Orange, Blue, Green C, Green E and Red B sands. In addition, core descriptions show a fracture in the Yellow C sand.

Figures 4.25, 4.26 and 4.27 are composite illustrations for each well which include natural fracture and mud log data for the coastal interval. Cored intervals and core fractures are depicted. Also, fractures identified via fracture logs are shown. For MWX-1 and MWX-2, the variable density log (VDL) was the primary indicator. For MWX-3, all fracture logs described above were used. The mud log portions of the figures show total units of gas and mud weight.

Other methods have been investigated for natural fracture detection. The first method utilizes various logs with different depths of investigation, such as the density-neutron, electromagnetic propagation, micro-SFL, dielectric constant and deep induction log. Water saturations are calculated from each curve and pairs of curves are plotted. When an anomalous relationship occurs, a fracture is suspected. By displaying numerous such pairs of curves, a tool for identifying fractures is created. The saturation curve method (NATUFRAC) is shown for the coastal interval in Figure 4.28. A description of the reasoning behind the interpretation of the saturation curves for natural fractures is given in another report.[1]

Another fracture detection method based on curve comparisons is the multiple density pass (MDP) method. All available bulk density data for an interval, including different log runs and repeat run data, is compared for differences in the readings. If a density tool pad passes over a fracture, the measurement can be significantly different than from a run where the pad missed the fracture (it is possible to miss a fracture in the borehole in the case of a vertical fracture). Also, in different log runs, a lower density on a later run indicates fracture presence since this is opposite to the effect of additional invasion with time. Figure 4.29 presents a trace plot of all density data on MWX-1 in the coastal interval. To the left, fractures are flagged in three columns: those anomalies detected on the same run, those detected between runs, and core-identified fractures (righthand column).

The MDP fracture identification technique is supplementary to other fracture identification techniques. The MDP technique can overlook a fracture present in the borehole and can also indicate a fracture when none is present. There are several reasons why the technique is not reliable by itself. Fractures may be overlooked because pad tools tend to "channel" along the borehole, causing multiple passes to traverse the same paths. Also complex infiltration conditions may mask fractures on the early-late run comparisons. Fractures may be erroneously indicated due to various mechanical reasons associated with logging pad-borehole contact. Approximately 40 percent of MWX-1 core observed fractures were identified by the MDP technique.

Additional fracture verification methods include late versus early resistivity log run comparisons, and computed log versus core porosity comparisons. Abrupt anomalies are suspected fractures. Table 4.7 lists fractures identified on MWX-1 by a combination of core, fracture log, MDP, resistivity log and porosity comparisons. Table 4.8 lists fractures identified on MWX-3 by core, NATUFRAC porosity comparisons and fracture log techniques. Fracture detection data is less available on MWX-2.

4.4.4 Cement Bond Quality

The composite Figures 4.25, 4.26 and 4.27 show the cement bond log interpretation for each well in the left column. A shaded interval indicates adequate cement bonding. In MWX-1, cement quality appears good below 6100 ft. The Brown, Blue, Green, Yellow and Red sands are well isolated in terms of communication via the cement. The uppermost Purple and Orange sands are not isolated.

MWX-2 cement bond quality is generally good throughout the coastal interval. Each unit is well isolated except the Purple sand, which is not isolated on the top. MWX-3 cement quality is similar to MWX-2 in that all zones are isolated except the Purple sand, which is not isolated on the top. In addition, the Yellow A and B sands are not isolated from each other in MWX-3.

4.4.5 Closure Stress Estimates

Closure stress logs were computed for each well to interpret vertical barriers to contain hydraulic fracture treatments.[1] Closure stress is generally higher for shales than for the less elastic reservoir rock; since the sand lenses are enveloped by shalier material, this should promote vertical hydraulic fracture containment. Analysis of the closure stress logs revealed that almost all reservoir units appear to be bounded by rocks with higher closure stresses. Where the adjacent strata are thinner, a less effective barrier is anticipated. Barriers in question are: in MWX-1, between the Red A and Red B and above the Brown; in MWX-3, between the Yellow A and Yellow B, and above the Red A sandstone.

4.5 PETROPHYSICAL RELATIONSHIPS IN THE COASTAL INTERVAL

Two and three-dimensional crossplots offer an opportunity to observe pertinent petrophysical relationships in a specified interval. Log, core and petrographic data are crossplotted and the resultant trends are significant descriptors of the reservoirs. Such an analysis and resulting observations are presented in Appendix 11.3.

4.6 REFERENCES

1. Kukal, G. C. and K. E. Simons, "Multiwell Experiment, Well Log Analysis of Coastal Interval, MWX-1, MWX-2 and MWX-3," CER Corporation Report, February 14, 1986.

2. Kukal, G. C., "A Systematic Approach for the Effective Log Analysis of Tight Gas Sands," SPE 12851, Proceedings of the 1984 SPE/DOE/GRI Unconventional Gas Recovery Symposium, May 1984, pp. 209-220.

3. Kukal, G. C. and R. E. Hill, "Log Analysis of Clay Volume: An Evaluation of Techniques and Assumptions Used in An Upper Cretaceous Sand-Shale Sequence," Paper RR, SPWLA Twenty-Seventh Annual Logging Symposium, June 9-13, 1986.

4. Kukal, G. C. and R. E. Hill, "Improved Shaly Sand Analysis in Heavy Drilling Muds: A Simple Technique for Using the Photoelectric Measurement," Paper U, Transactions of the SPWLA Twenty-Sixth Annual Logging Symposium, June 1985.

5. Kukal, G. C. and Simons, K. E., "Log Analysis Techniques for Quantifying the Permeability of Sub-Millidarcy Sandstone Reservoirs," SPE Formation Evaluation, December 1986, pp. 609-622.

Table 4.1 Coastal Interval Sand Units

UNIT	DEPTH		
	MWX-1	MWX-2	MWX-3
Purple	6,023.0-6,031.0	6,025.0-6,036.0	6,029.0-6,036.0
Orange	6,061.0-6,081.0	6,065.5-6,080.5	6,067.5-6,096.0
Brown	6,179.0-6,197.0	6,177.5-6,188.5	–
Blue	6,242.5-6,253.0	6,239.0-6,252.5	6,240.5-6,263.0
Green A	–	–	6,294.5-6,309.0
Green B	6,324.0-6,343.5	6,324.5-6,336.0	–
Green C	6,350.5-6,359.5	–	6,342.5-6,370.5
Green D	6,375.5-6,380.5	6,375.5-6,380.5	–
Green E	–	–	6,386.0-6,395.0
Yellow A	6,425.0-6,440.0	6,422.5-6,457.5	6,436.0-6,450.5
Yellow B	6,442.5-6,461.5	(combined with A)	6,454.0-6,471.0
Yellow C	6,466.0-6,470.0	6,466.0-6,474.0	6,474.5-6,479.0
Red A	6,498.5-6,521.5	6,496.0-6,534.5	6,504.0-6,520.0
Red B	6,534.5-6,550.5	6,536.0-6,552.0	6,533.0-6,561.5
Net Sand[1] Thickness:	123.5 ft	159.0 ft	170.0 ft

[1] Includes sand with less than 25% clay and greater than 3% porosity.

Table 4.2 MWX Log Database

MWX-1 LOGS

4,130 ft to Surface

Borehole Compensated Sonic/Gamma Ray/
Caliper/Dual Induction

6,827 to 4,130 ft

Dual Induction/Gamma Ray
Lithodensity/Caliper
Compensated Formation Density
Compensated Neutron/Gamma Ray/Caliper
Natural Gamma Spectroscopy
Long Spaced Sonic
Repeat Formation Tester

8,350 to 4,130 ft

Dual Induction/Gamma Ray/SP
Lithodensity/Compensated Neutron/Gamma
Ray/Caliper
Long Spaced Sonic
Epithermal Sidewall Neutron/Gamma Ray/
Caliper
Electromagnetic Propagation/Gamma Ray/
Caliper
Amoco Sonic Tool
Dipmeter - Structural and Stratigraphic
Computed Logs
Geo Dip
Standard Cluster
Directional Survey
Fracture Identification Log
Repeat Formation Tester (12 tests)

MWX-2 LOGS

5,438 to 4,094 ft

Formation Density/Compensated Neutron/
GR/Caliper

6,692 to 4,094 ft

Dual Induction/GR/SP
Formation Density/Compensated Neutron/
GR/Caliper
Lithodensity/GR/Caliper
Sidewall Neutron/GR/Caliper
Natural Gamma Spectroscopy

8,291 to 4,094 ft

Dual Induction/GR/SP
Circumferential Micro Sonic/GR
Digitized Waveforms
Formaton Density/Compensated Neutron/
Natural Gamma Spectroscopy/Caliper
Long Spaced Sonic
Digitized LS Waveforms
Amoco Multiple Spaced Sonic/Waveforms
Sidewall Neutron/GR/Caliper
Dipmeter

8,230 to 4,294 ft

Fracture Identification Log

Table 4.2, Cont.

MWX-3 LOGS

4,134 ft to Surface

Borehole Compensated Sonic/Gamma Ray/ Caliper
Formation Density/Compensated Neutron/ Gamma Ray/Caliper

5,875 to 4,129 ft

Lithodensity/Compensated Neutron Log/ Gamma Ray/Caliper

5,840 to 4,900 ft

Borehole Televiewer

6,875 to 4,130 ft

Lithodensity/Compensated Neutron Log/ Gamma Ray/Caliper
Micro SFL/SP/Caliper

7,474 to 4,129 ft

Dual Induction Log/Gamma Ray/SP
Lithodensity/Compensated Neutron Log/ Natural Gamma Spectroscopy/Caliper
Sidewall Neutron Porosity/Gamma Ray/ Caliper
High Resolution Dipmeter/Gamma Ray/ Caliper
Fracture Identification Log/Gamma Ray/ Caliper
Borehole Compensated Sonic (Digital Sonic) Shear and Compressional Travel Times
Variable Density Log (3 ft spacing)
Mechanical Properties Quick Look (Computed Log)
Dual Laterolog/Microspherically Focused Log/Gamma Ray/Caliper
Electromagnetic Propagation Tool/Gamma Ray/Caliper
Dual Porosity Compensated Neutron Log (CNT-G)/Gamma Ray/Micro Log
Formation Density Compensated/Gamma Ray/Caliper
Amoco Multiple Spaced Sonic
Mobil Multiple Spaced Sonic
Mobil Borehole Televiewer
Spectralog
Borehole Compensated Acoustilog/Gamma Ray/Caliper
BHC Acoustic Fraclog/Gamma Ray/Caliper
Sonic Waveforms Digitized
Dielectric Constant Log
Circumferential Acoustilog

7,300 to 4,130 ft

Cement Bond Log/Variable Density Log/ Gamma Ray/Casing Collar Locator
Cement Evaluation Log/Gamma Ray
Compensated Neutron Log
Thermal Decay Tool/Gamma Ray/Casing Collar Locator

Table 4.3 MWX Core Database

CORED INTERVALS

MWX-1	MWX-2	MWX-3
4,170 - 6,827	4,870 - 4,956	4,887 - 4,928
7,810 - 7,960	5,485 - 5,500[1]	5,690 - 5,870
	5,551 - 5,581[1]	6,431 - 6,530
Total: 2,807 ft	5,700 - 5,880	6,875 - 6,910
	6,390 - 6,568	7,071 - 7,160
	7,080 - 7,388	7,536 - 7,564[2]
	7,817 - 7,907	
	8,100 - 8,141	Total: 500 ft
	Total: 928 ft	

STANDARD ANALYSES

Permeability, Porosity, Water Saturation, Oil Saturation, Grain Density, Cation Exchange Capacity[3]

SPECIAL ANALYSES

Stressed Permeability,[3] Petrographic Thin Section Analysis[3]

[1] Pressure Core
[2] 2 in. diameter core
[3] Not on all samples

Table 4.4 MWX-1 Coastal Reservoir Characteristics

Unit	Zone Depth, ft	Pay Sand (h),* ft	Porosity (ϕ), fraction	Porosity-feet (ϕ x h), ft	Water Saturation (S_w), fraction	Hydrocarbon-feet, (ϕ x (1-S_w) x h), ft	S_{xo} - S_w (ΔS_w), fraction	Permeability-feet (kh), md-ft	Volume Clay (V_{cl}), fraction	Volume Carbonate (V_{CO3}), fraction	Core Porosity, fraction	Stressed Core Permeability, md	Core Water Saturation, fraction	Core Grain Density, gm/cc	Cation Exchange Capacity, meq/100 gm
Purple	6,025.0-6,031.0	6.0	.066	0.39	.653	.16	.147	.0258	.112	.080	.072	.0009	.387	2.66	–
Orange	6,061.0-6,081.0	11.5	.088	1.01	.526	.51	.265	.2397	.070	.104	.075	.0083	.382	2.65	–
Brown	6,179.0-6,197.0	6.0	.057	0.34	.973	.04	.046	.0052	.161	.181	.045	.0034	.588	2.68	–
Blue	6,242.5-6,253.0	10.5	.076	0.80	.651	.32	.148	.0837	.090	.120	.065	–	.452	2.66	–
Green A	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Green B	6,324.0-6,343.5	4.5	.048	0.22	.885	.04	.000	.0027	.189	.138	.043	–	.637	2.68	–
Green C	6,350.5-6,359.5	9.0	.067	0.60	.770	.19	.026	.0378	.144	.059	.061	–	.476	2.66	–
Green D	6,375.5-6,380.5	5.0	.070	0.35	.722	.13	.007	.0193	.149	.103	.070	–	.302	2.67	–
Green E	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Yellow A	6,425.0-6,440.0	13.0	.067	0.87	.636	.34	.099	.0555	.101	.083	.059	.0053	.458	2.67	3.25
Yellow B	6,442.5-6,461.5	19.0	.074	1.41	.628	.55	.069	.0995	.091	.049	.077	.0106	.322	2.66	2.65
Yellow C	6,466.0-6,470.0	0.0	–	–	–	–	–	–	–	–	–	–	–	–	–
Red A	6,498.5-6,521.5	23.0	.067	1.55	.548	.73	.038	.1075	.144	.138	.072	.0059	.371	2.66	2.99
Red B	6,524.0-6,550.5	16.0	.069	1.10	.626	.44	.079	.0730	.091	.142	.070	.0081	.397	2.67	2.35

*Includes sand with less than 25% clay and greater than 3% porosity. Zone averages computed using these footages.

Table 4.5 MWX-2 Coastal Reservoir Characteristics

Unit	Zone Depth, ft	Pay Sand (h),* ft	Porosity (ϕ), fraction	Porosity-feet (ϕ x h), ft	Water Saturation (S_w), fraction	Hydrocarbon-feet, (ϕ x (1-S_w) x h), ft	S_{xo} - S_w (ΔS_w), fraction	Permeability-feet (kh), md-ft	Volume Clay (V_{cl}), fraction	Volume Carbonate (V_{CO3}), fraction	Core Porosity, fraction	Stressed Core Permeability, md	Core Water Saturation, fraction	Core Grain Density, gm/cc	Cation Exchange Capacity, meq/100 gm
Purple	6,025.0-6,036.0	5.5	.071	0.39	.631	0.17	.209	.0296	.128	.083	–	–	–	–	–
Orange	6,065.5-6,080.5	15.0	.082	1.24	.614	0.54	.133	.1576	.086	.040	–	–	–	–	–
Brown	6,177.5-6,188.5	11.0	.076	0.83	.737	0.26	.037	.0460	.137	.073	–	–	–	–	–
Blue	6,239.0-6,252.5	13.5	.077	1.03	.705	0.35	.095	.0734	.067	.072	–	–	–	–	–
Green A	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Green B	6,324.5-6,336.0	11.5	.089	1.02	.608	0.45	.067	.1389	.095	.041	–	–	–	–	–
Green C	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Green D	6,375.5-6,380.5	5.0	.067	0.34	.772	0.10	.002	.0116	.175	.146	–	–	–	–	–
Green E	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Yellow A & B	6,422.5-6,457.5	35.0	.071	2.50	.641	0.95	.129	.1949	.074	.089	.068	.0073	.377	2.66	1.06
Yellow C	6,466.0-6,474.0	8.0	.066	0.53	.697	0.19	.080	.0237	.146	.041	–	–	–	–	–
Red A	6,496.0-6,534.5	38.5	.071	2.72	.555	1.26	.126	.2252	.123	.037	.072	.0073	.365	2.66	0.86
Red B	6,536.0-6,552.0	16.0	.070	1.12	.603	0.46	.131	.0741	.102	.070	.067	.0081	.373	2.67	1.32

*Includes sand with less than 25% clay and greater than 3% porosity. Zone averages computed using these footages.

Table 4.6 MWX-3 Coastal Reservoir Characteristics

Unit	Zone Depth, ft	Pay Sand (h),* ft	Porosity (ϕ), fraction	Porosity-feet (ϕ x h), ft	Water Saturation (S_w), fraction	Hydrocarbon-feet, (ϕ x (1-S_w) x h), ft	Sxo - Sw (Δ Sw), fraction	Permeability-feet (kh), md-ft	Volume Clay (V_{cl}), fraction	Volume Carbonate (VCO_3), fraction	Core Porosity, fraction	Stressed Core Permeability, md	Core Water Saturation, fraction	Core Grain Density, gm/cc	Cation Exchange Capacity, meq/100 gm
Purple	6,029.0-6,036.0	7.0	.062	0.43	.620	.20	.092	.0360	.142	.118	–	–	–	–	–
Orange	6,067.5-6,096.0	28.5	.068	1.95	.620	.78	.102	.1338	.104	.065	–	–	–	–	–
Brown	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Blue	6,240.5-6,263.0	22.5	.074	1.66	.642	.64	.108	.1351	.093	.110	–	–	–	–	–
Green A	6,294.5-6,309.0	14.5	.081	1.17	.635	.46	.025	.0885	.127	.071	–	–	–	–	–
Green B	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Green C	6,342.5-6,370.5	28.0	.079	2.21	.582	.98	.022	.2068	.134	.049	–	–	–	–	–
Green D	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Green E	6,386.0-6,395.0	7.0	.073	0.51	.687	.20	.009	.0342	.126	.062	–	–	–	–	–
Yellow A	6,436.0-6,450.5	11.0	.056	0.61	.733	.21	.055	.0208	.134	.145	.056	.0028	.621	2.68	–
Yellow B	6,454.0-6,471.0	17.0		1.31	.540	.62	.085	.1195	.119	.143	.076	.0065	.423	2.66	–
Yellow C	6,474.5-6,479.0	4.5	.051	0.23	.653	.09	.067	.0057	.198	.222	.047	.0012	.652	2.67	–
Red A	6,504.0-6,520.0	10.5	.053	0.55	.535	.27	.051	.0208	.208	.143	.060	.0023	.574	2.67	–
Red B	6,533.0-6,561.5	19.5	.061	1.19	.558	.56	.045	.0716	.149	.115	–	–	–	–	–

*Includes sand with less than 25% clay and greater than 3% porosity. Zone averages computed using these footages.

Table 4.7 MWX-1 Fracture Detection Summary

Zone	Depth	Fracture Indicator(s)[1]
Purple	6,023.0-6,031.0	Core, Fracture logs,[2] MDP log
Orange	6,061.0-6,081.0	Resistivity Anomaly, Porosity Comparison, Core, MDP log, Fracture logs[2]
Brown	6,179.0-6,197.0	Core, MDP log, Fracture logs[2]
Blue	6,242.5-6,253.0	Core, MDP log, Porosity Comparison, Fracture logs[2]

1 Indicators listed gave positive fracture identification. Indicators reviewed include: MDP log, Fracture logs,[2] core data, porosity comparisons, resistivity anomalies. Zones listed are only those which are positively identified as fractured.

2 Consist of: Variable Density Log (VDL)

Table 4.8 MWX-3 Fracture Detection Summary

Zone	Depth	Fracture Indicator(s)[1]
Orange	6,067.5-6,096.0	NATUFRAC, Fracture logs[2]
Blue	6,240.5-6,263.0	NATUFRAC, Fracture logs[2]
Green C	6,342.5-6,370.5	NATUFRAC, Fracture logs[2]
Red B	6,533.0-6,561.5	NATUFRAC, Fracture logs[2]

1 Indicators listed gave positive fracture identification. Indicators reviewed include: NATUFRAC, Fracture logs,[2] core data, porosity comparisons, resistivity anomalies. Zones listed are only those which are positively identified as fractured.

2 Consist of: Borehole Televiewer (BHTV), Circumferential Acoustic Log (CMA), Fracture Identification Log (FIL), Borehole Compensated Variable Density Log (BHC-VDL), Variable Density Log, 3-ft spacing (VDL), Fracture Probability Log (FPL)

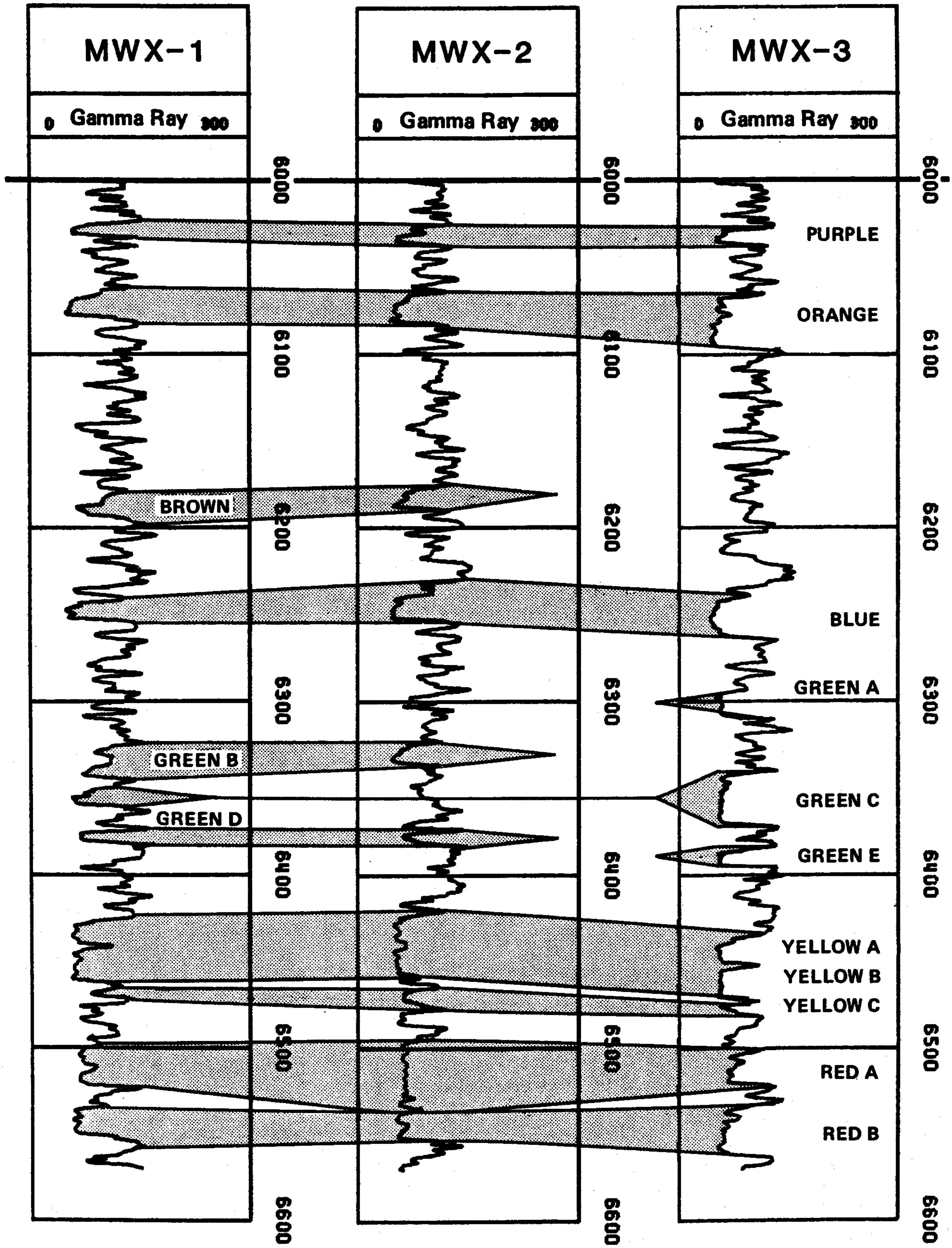


Figure 4.1 Correlation of Units Within the MWX Coastal Interval

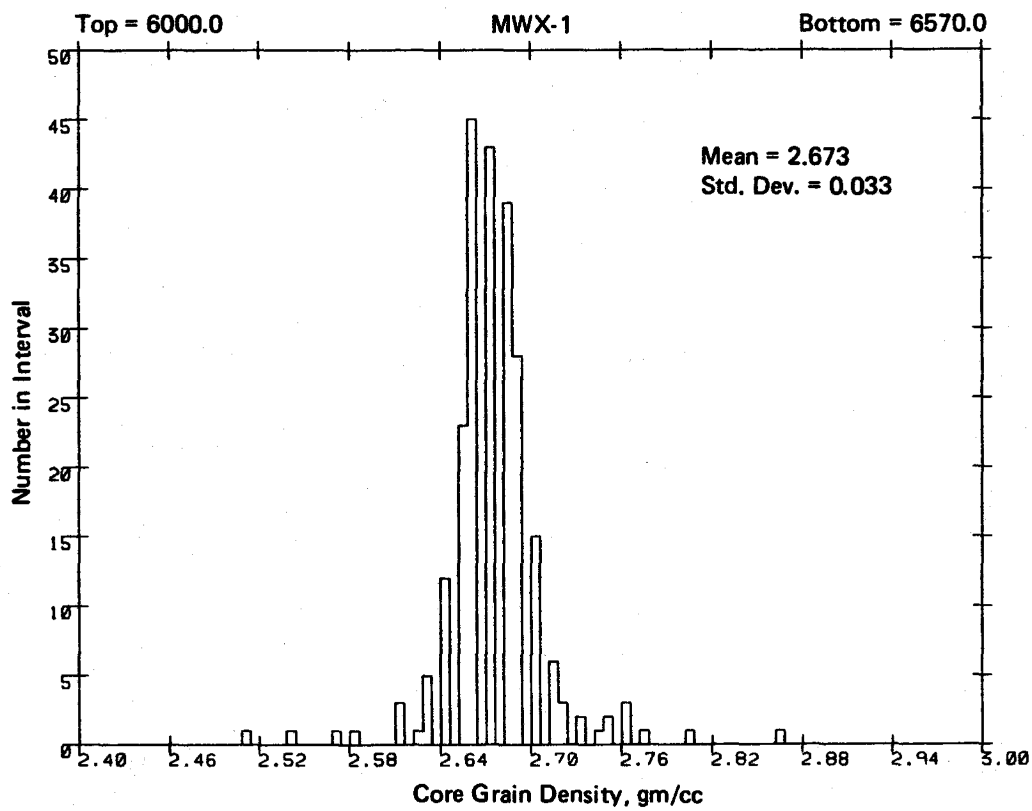


Figure 4.2 Range in Grain Density, MWX-1 Coastal Interval

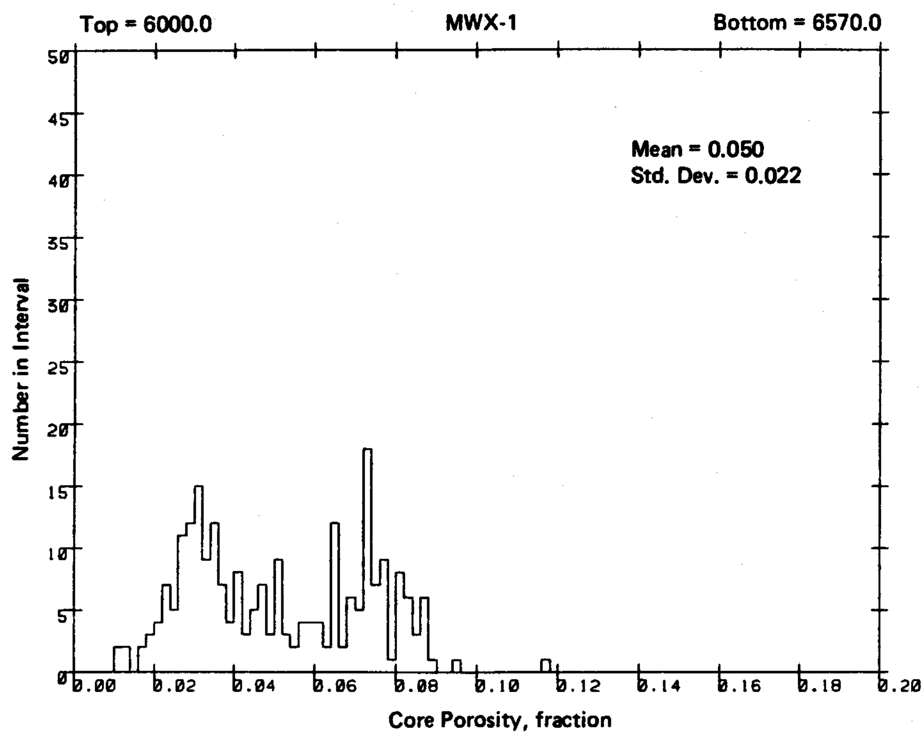


Figure 4.3 Range in Core Porosity, MWX-1 Coastal Interval

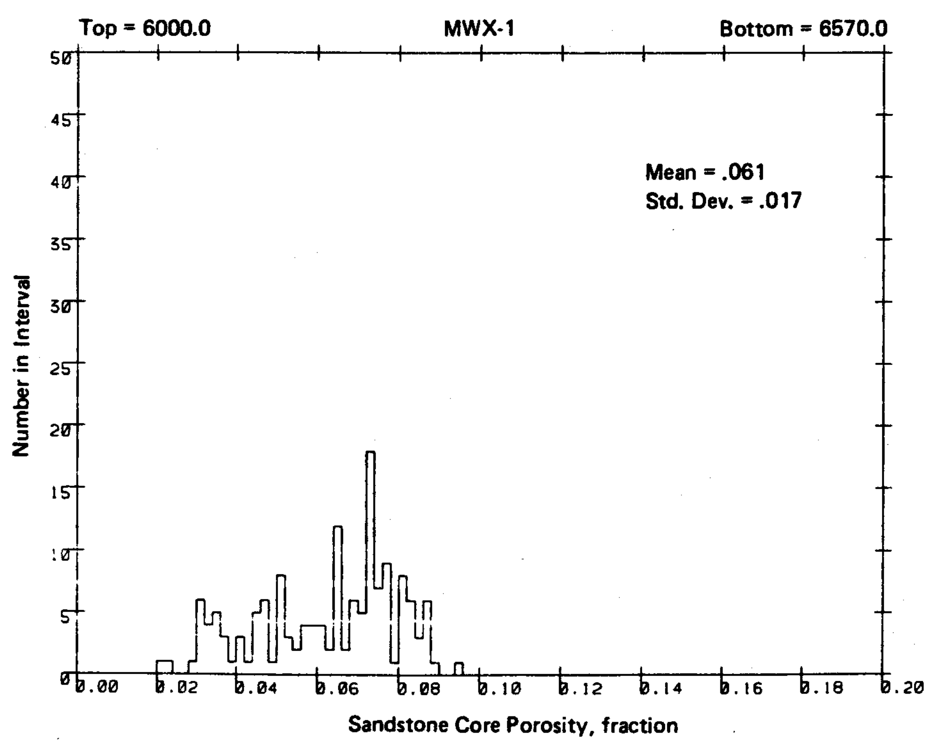


Figure 4.4 Range in Sandstone Core Porosity, MWX-1 Coastal Interval

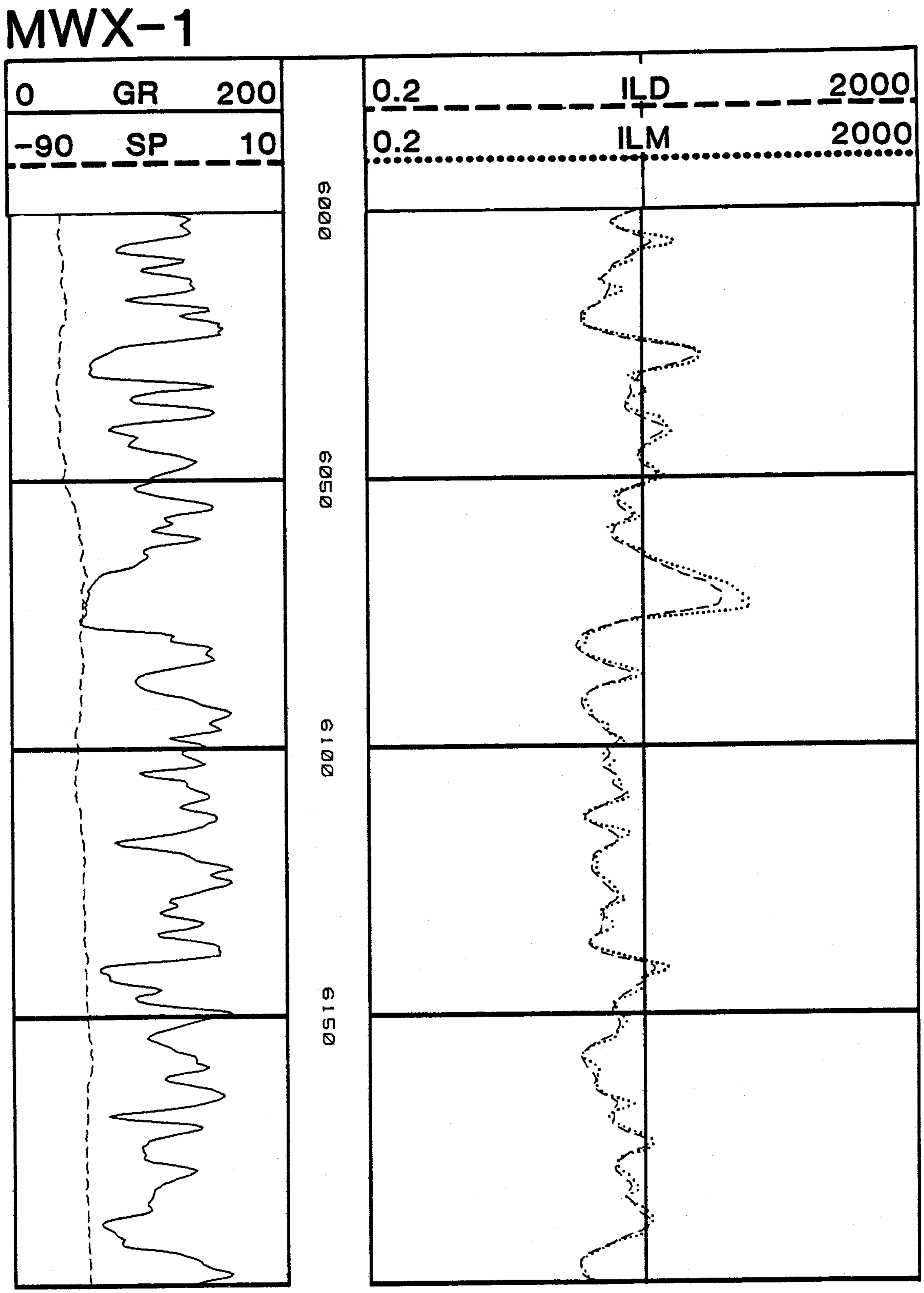


Figure 4.5 MWX-1 Resistivity Log

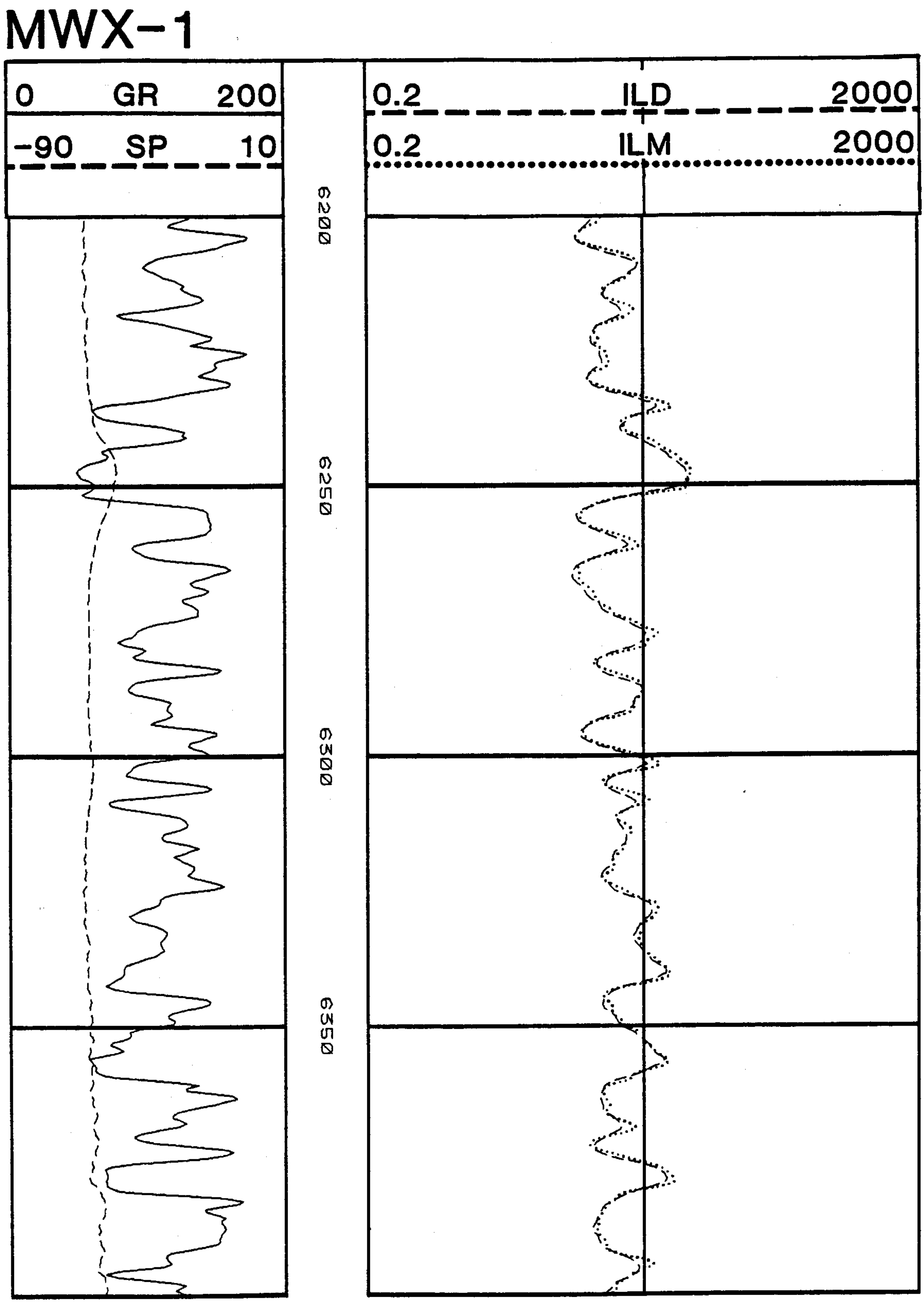


Figure 4.5, Cont.

MWX-1

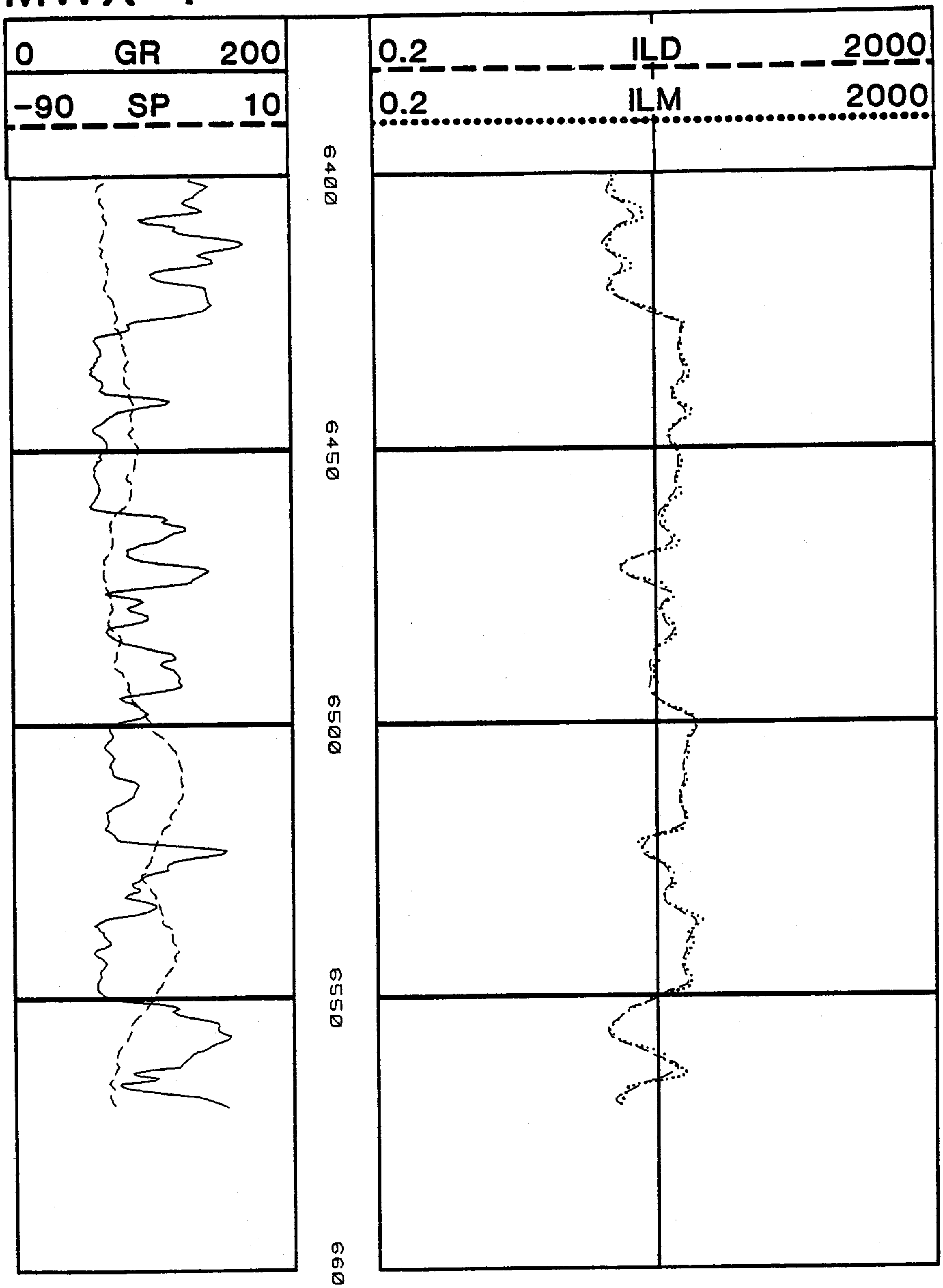


Figure 4.5, Cont.

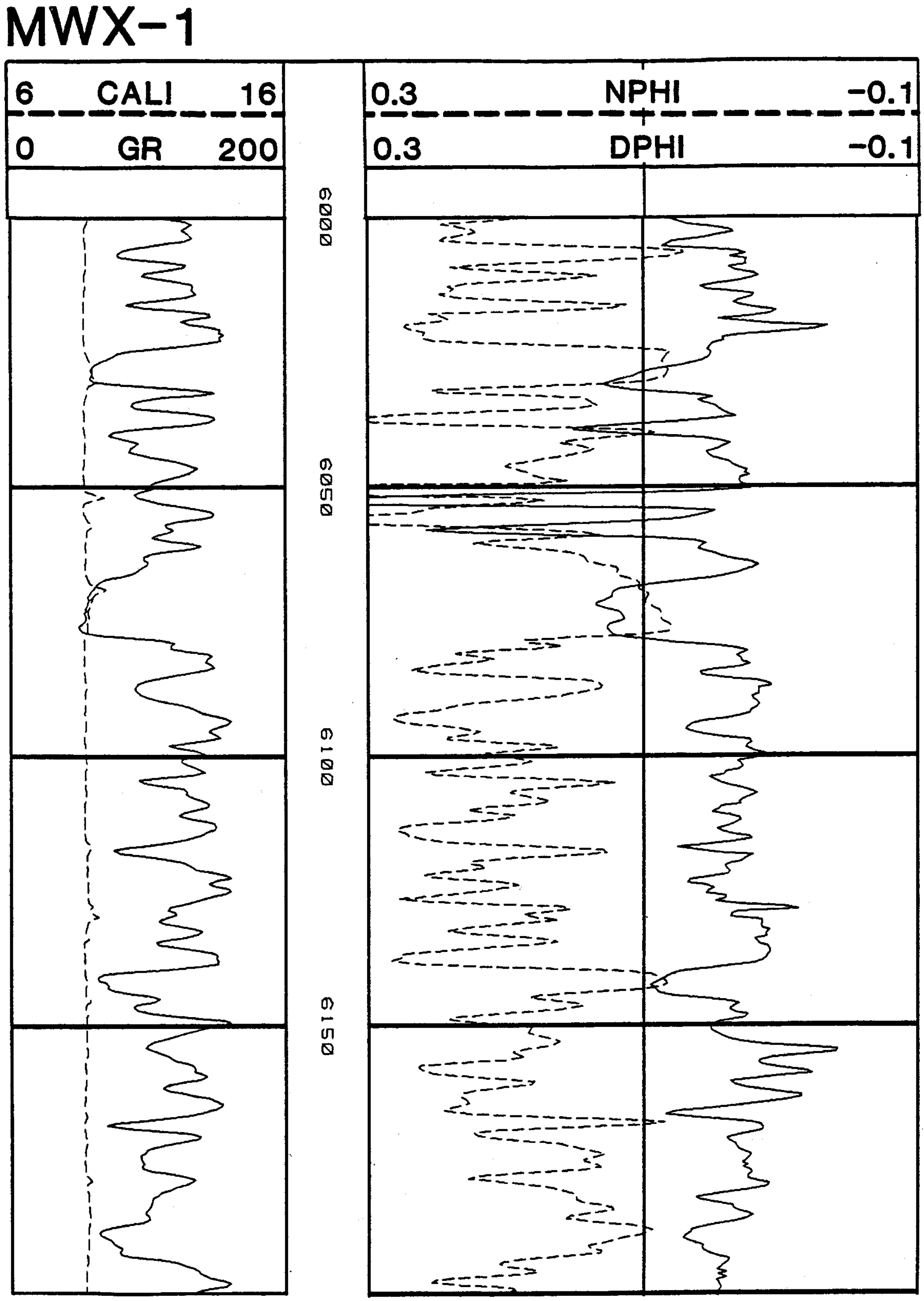


Figure 4.6 MWX-1 Density and Neutron Porosity Logs

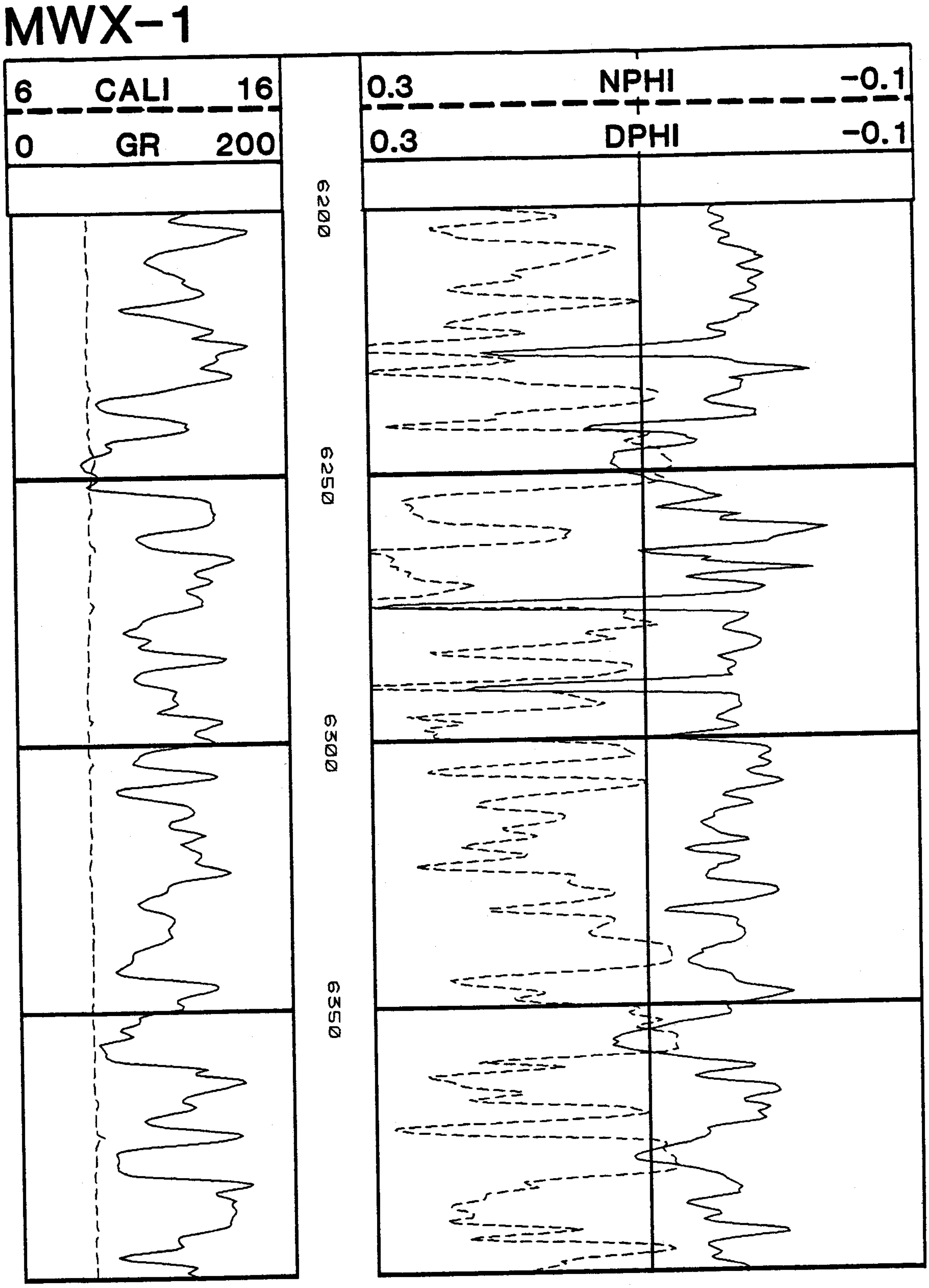


Figure 4.6, Cont.

MWX-1

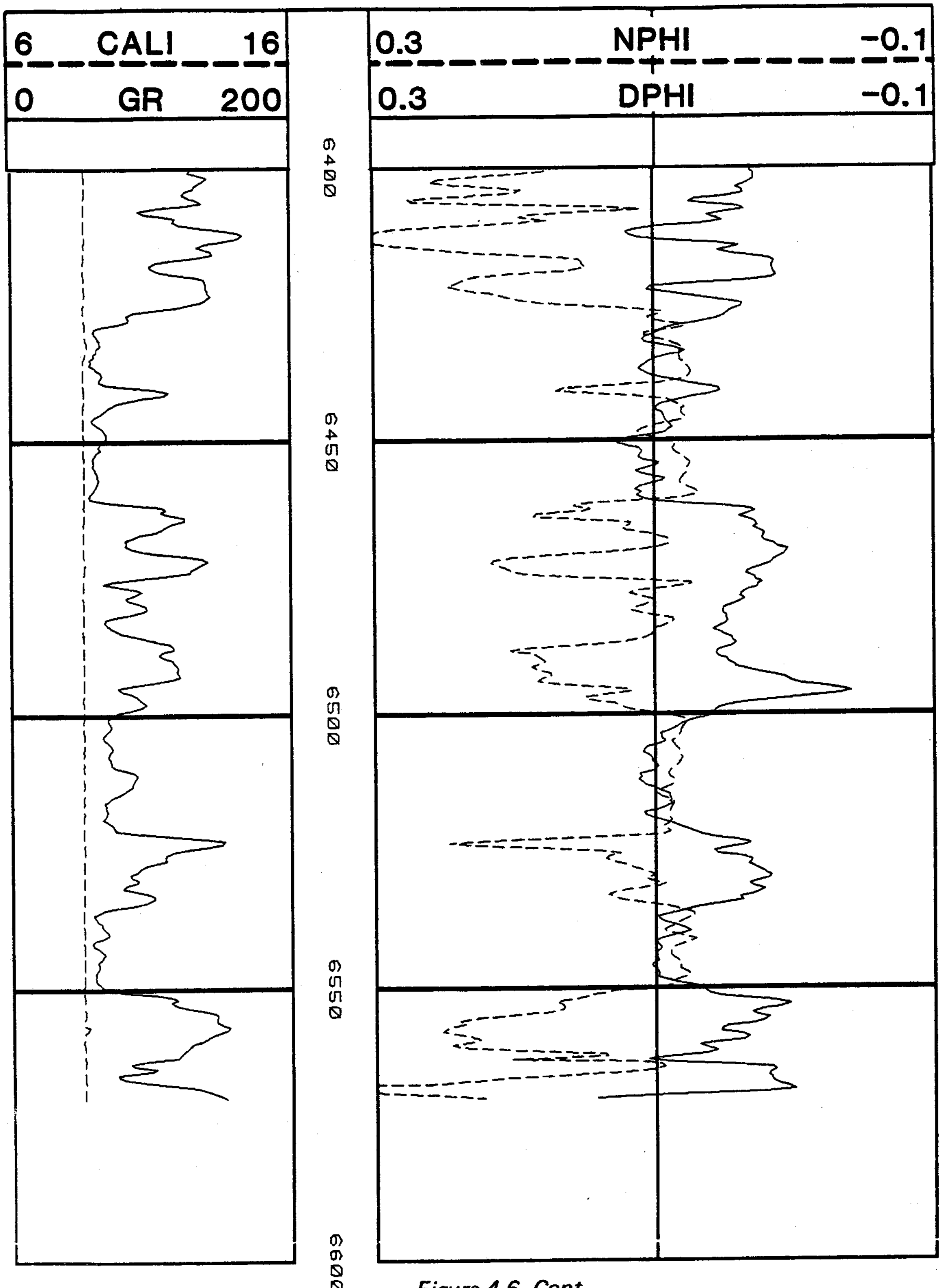


Figure 4.6, Cont.

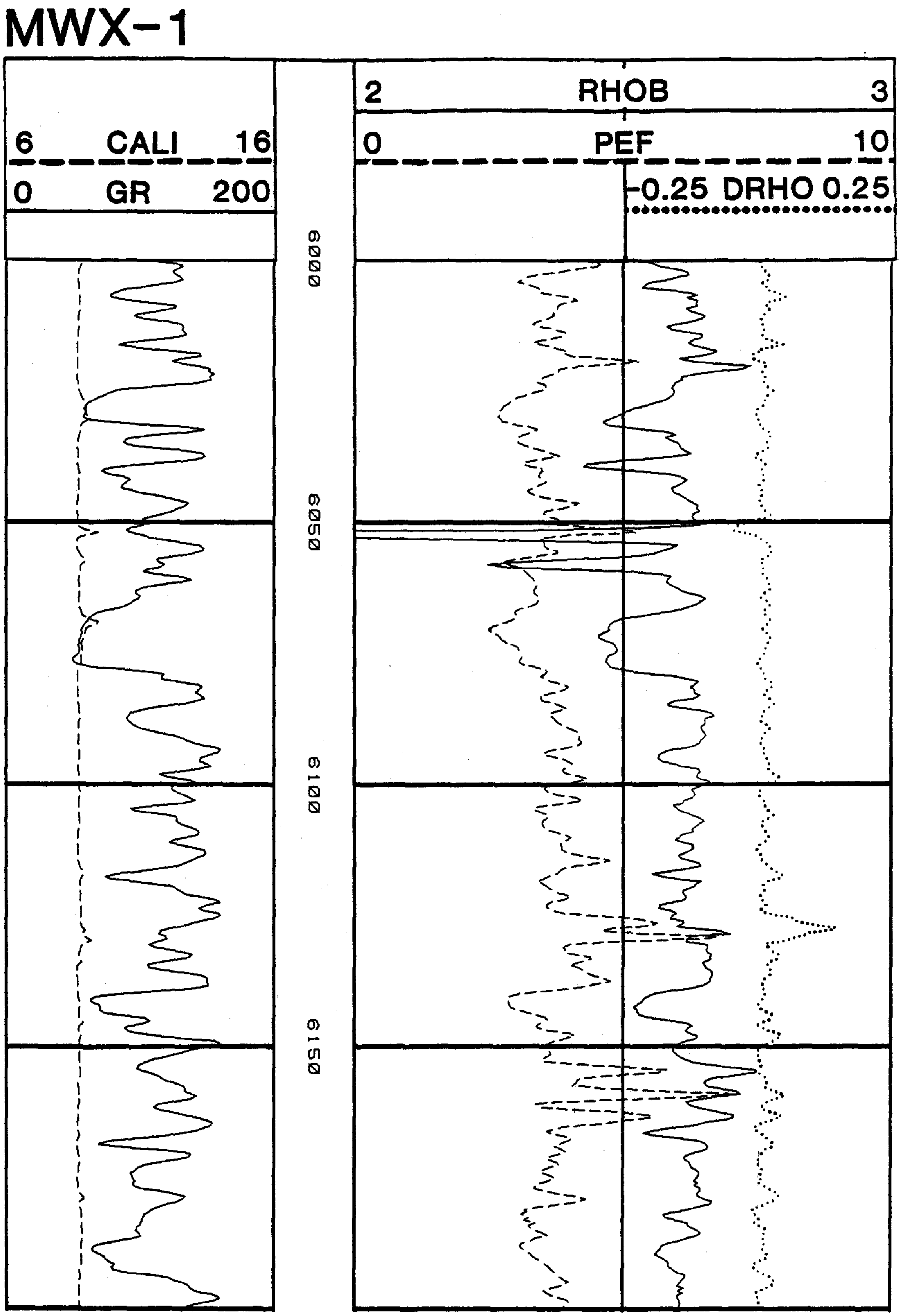


Figure 4.7 MWX-1 Bulk Density and Photoelectric Absorption Logs

MWX-1

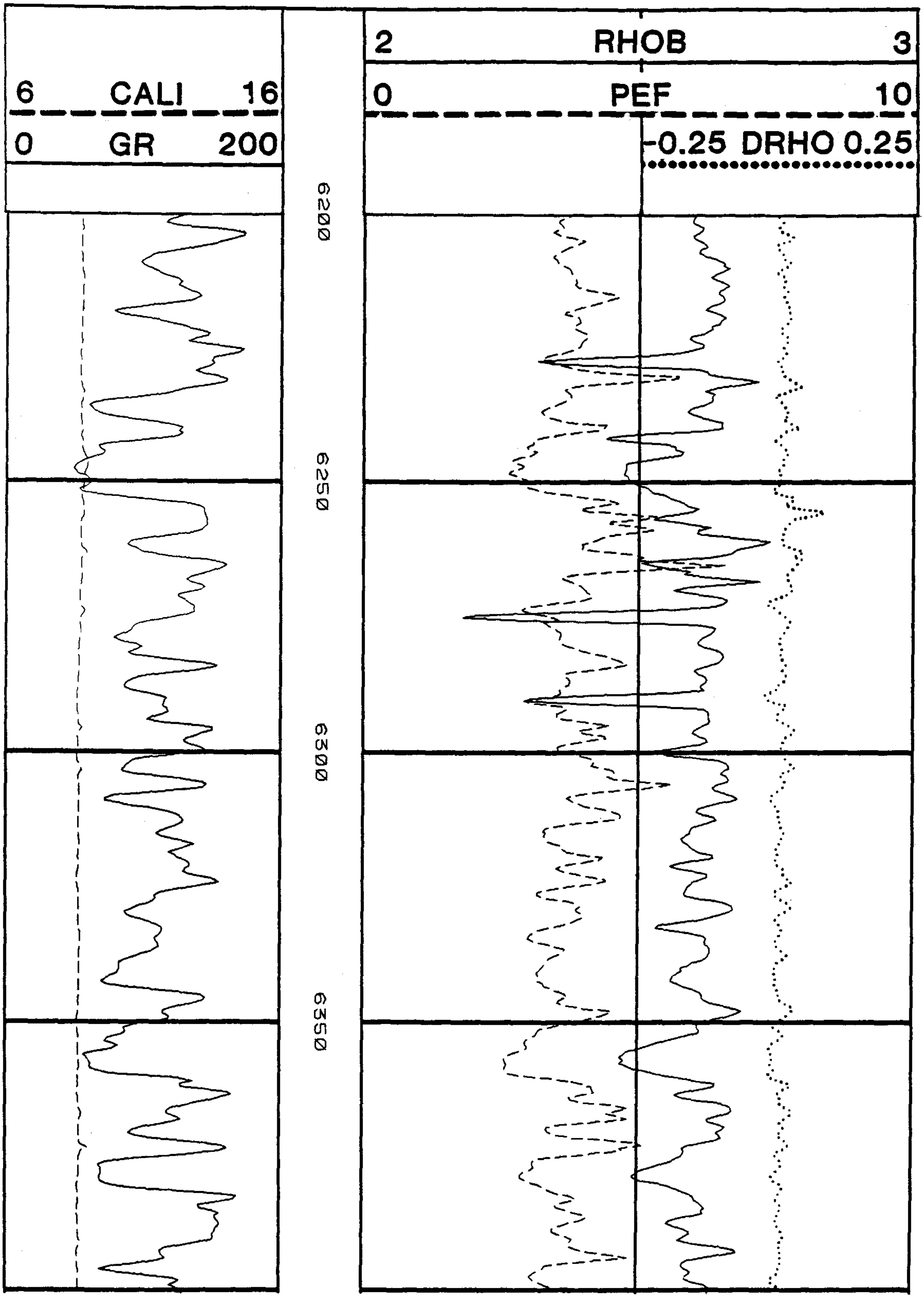


Figure 4.7, Cont.

MWX-1

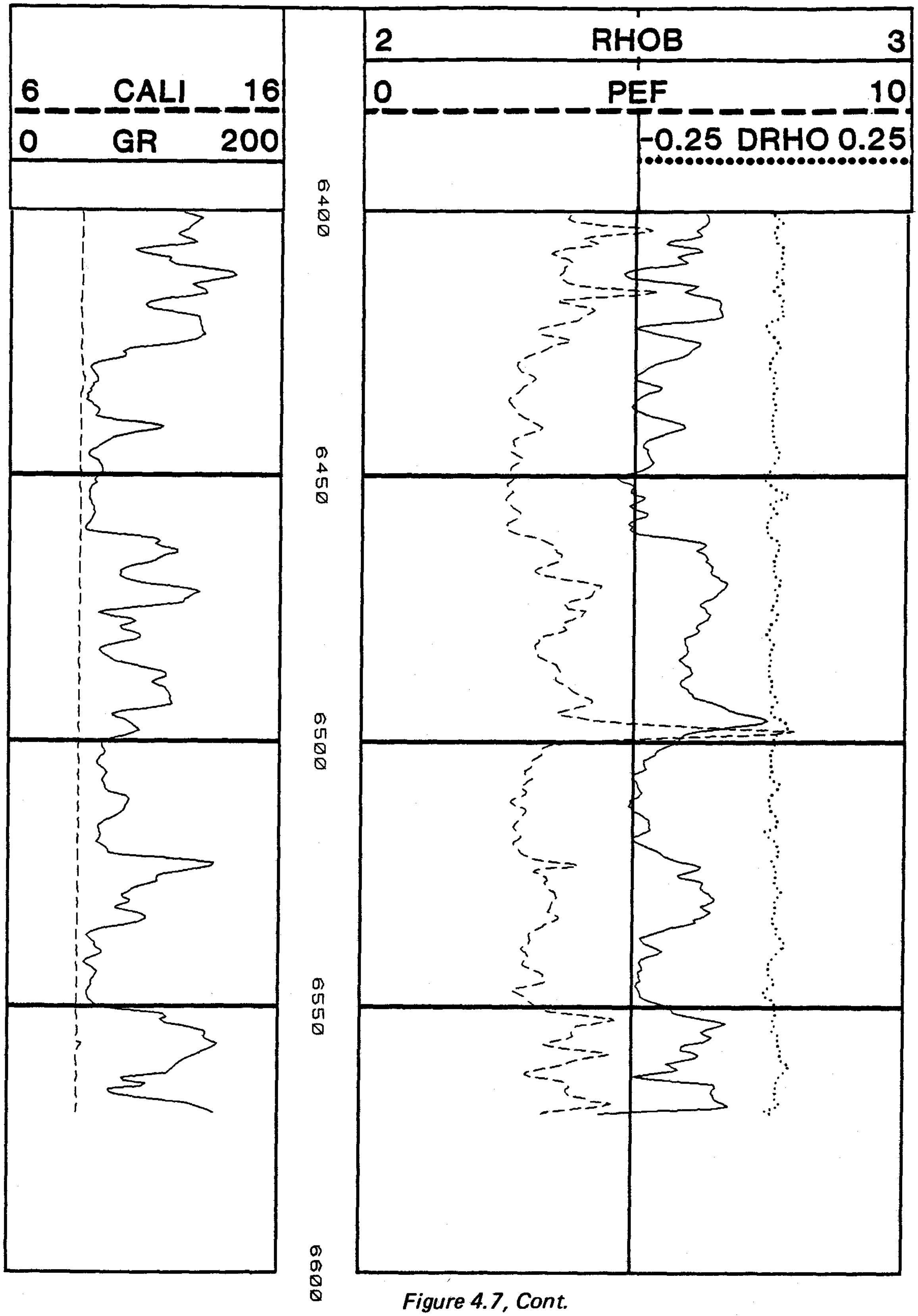


Figure 4.7, Cont.

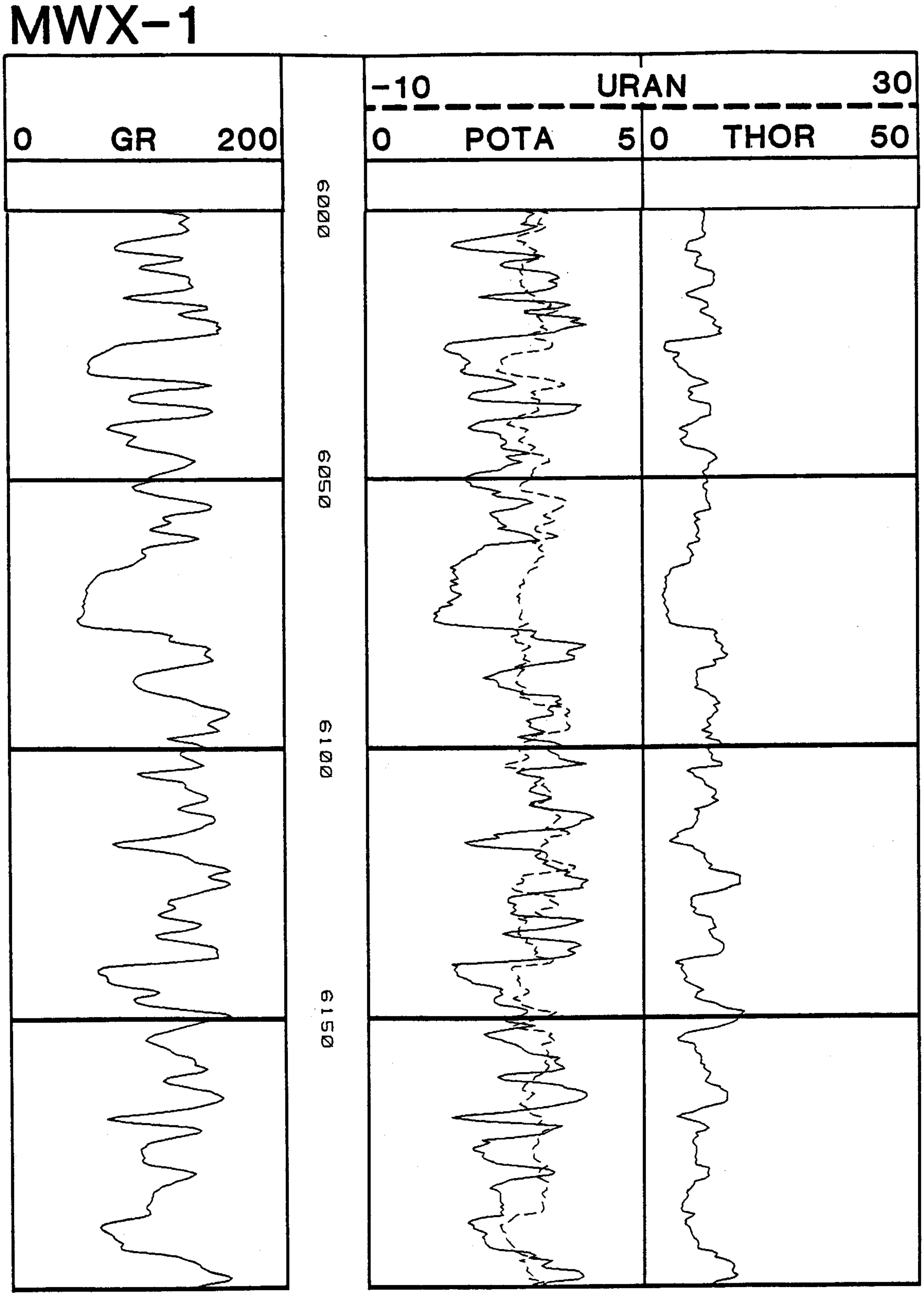


Figure 4.8 MWX-1 Spectral Gamma Log

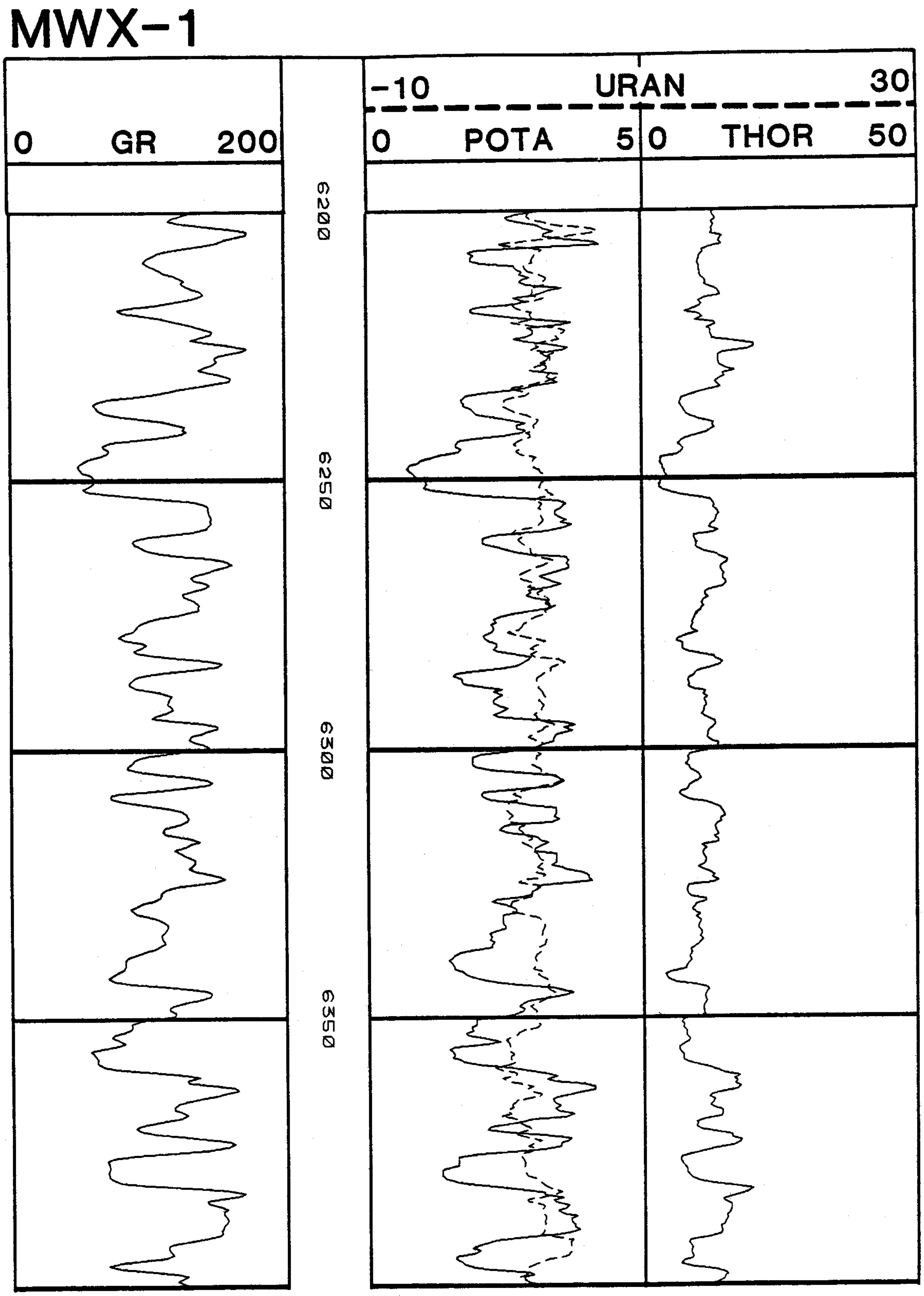


Figure 4.8, Cont.

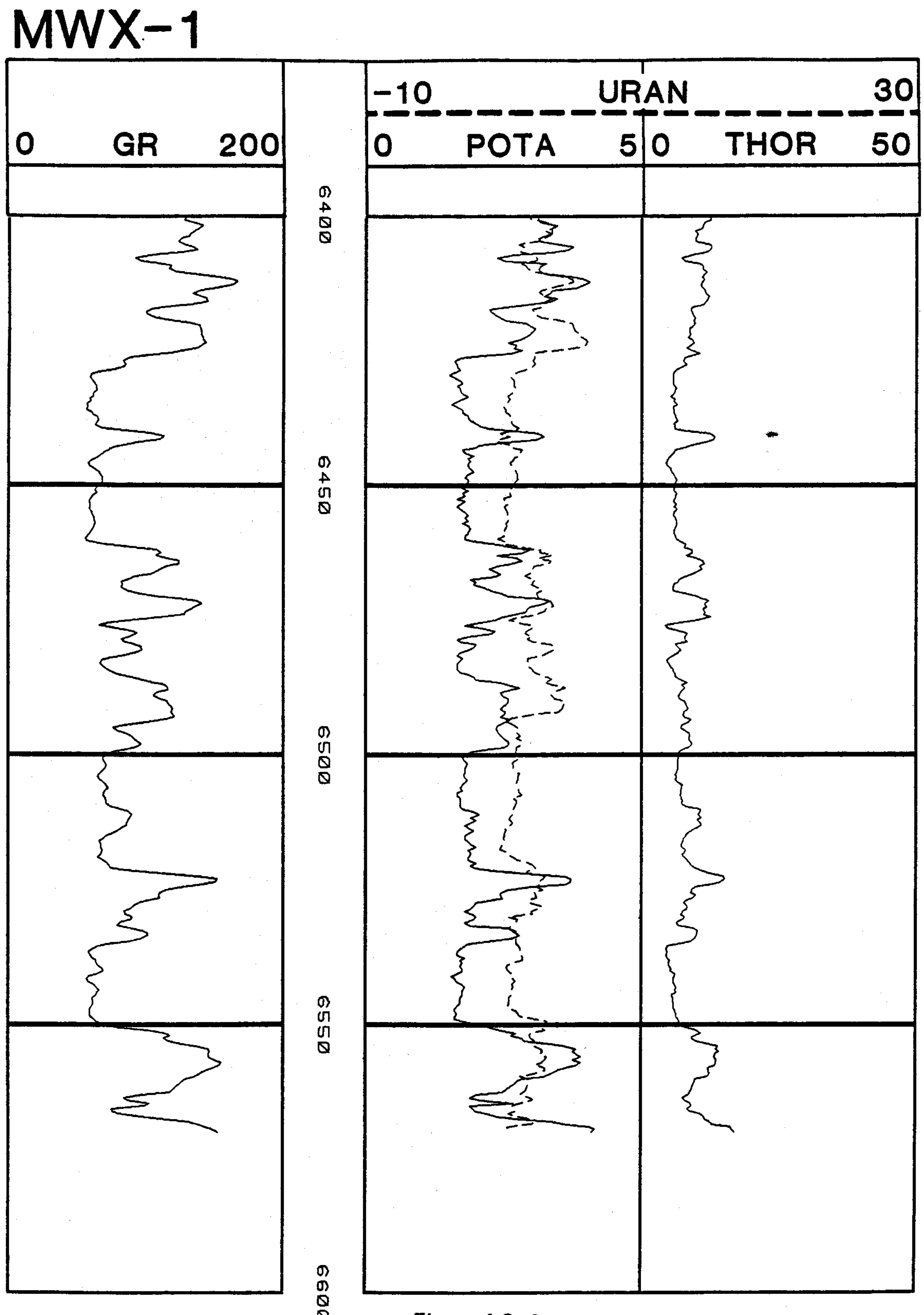


Figure 4.8, Cont.

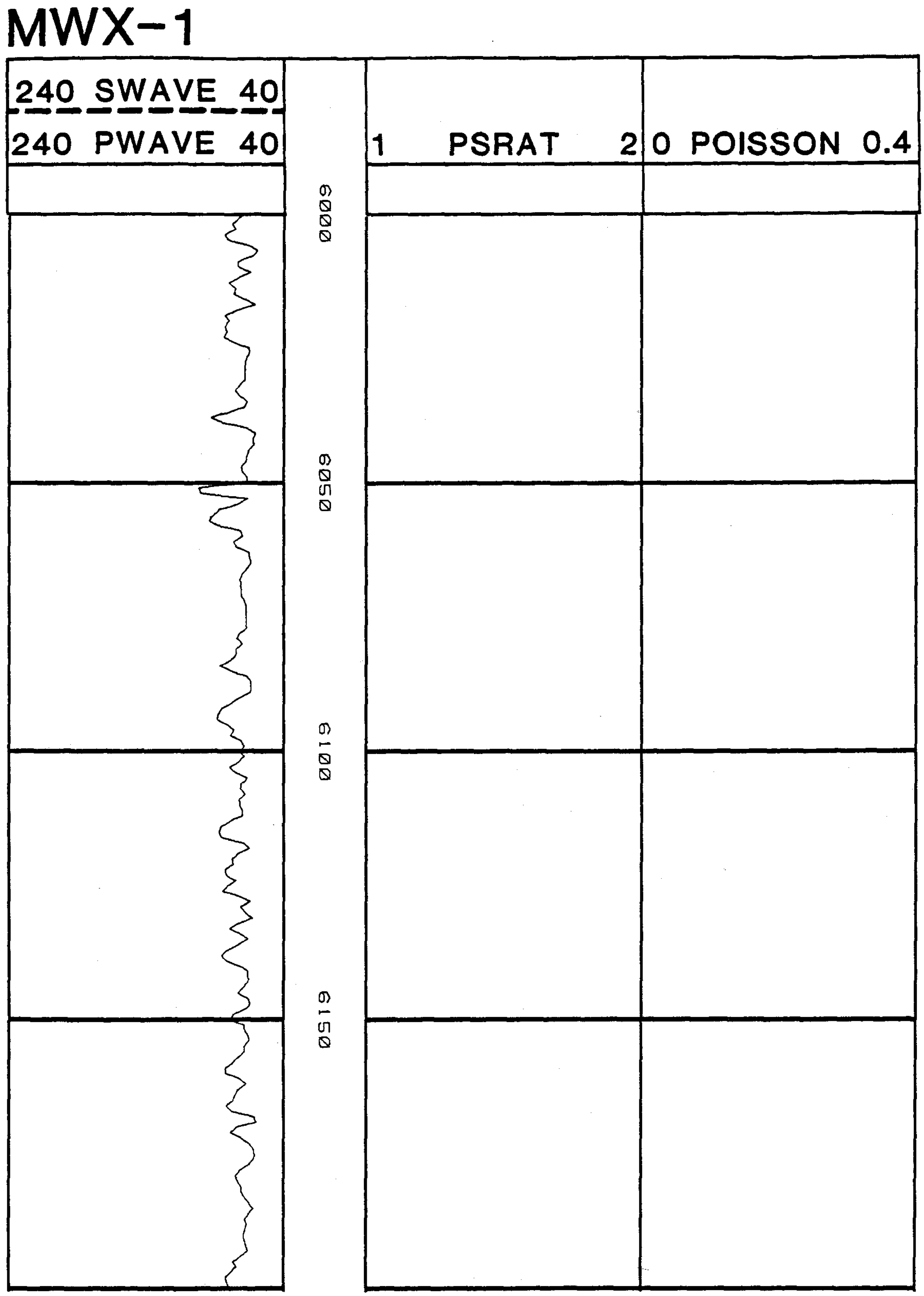


Figure 4.9 MWX-1 Long Spaced Sonic Log

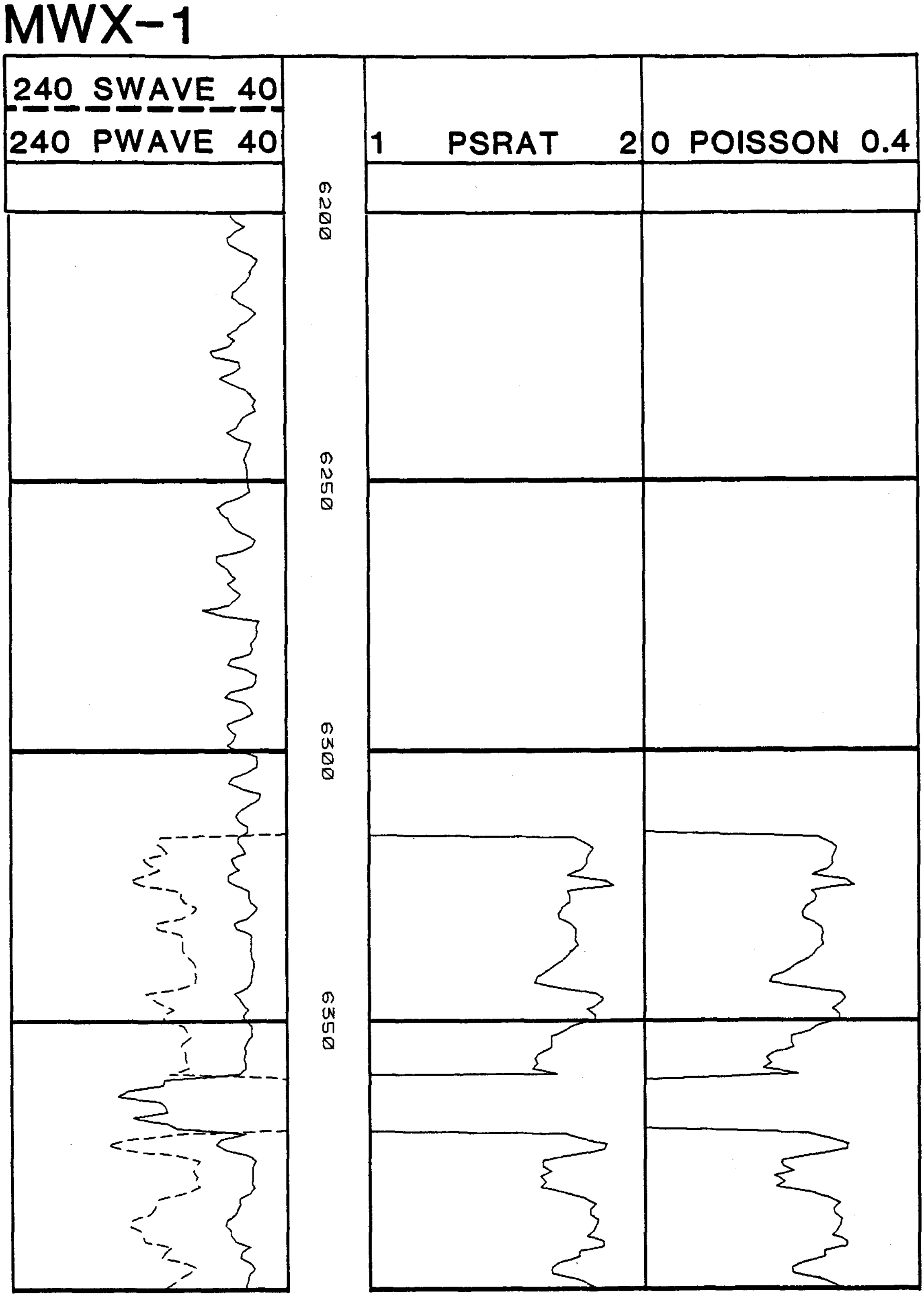


Figure 4.9, Cont.

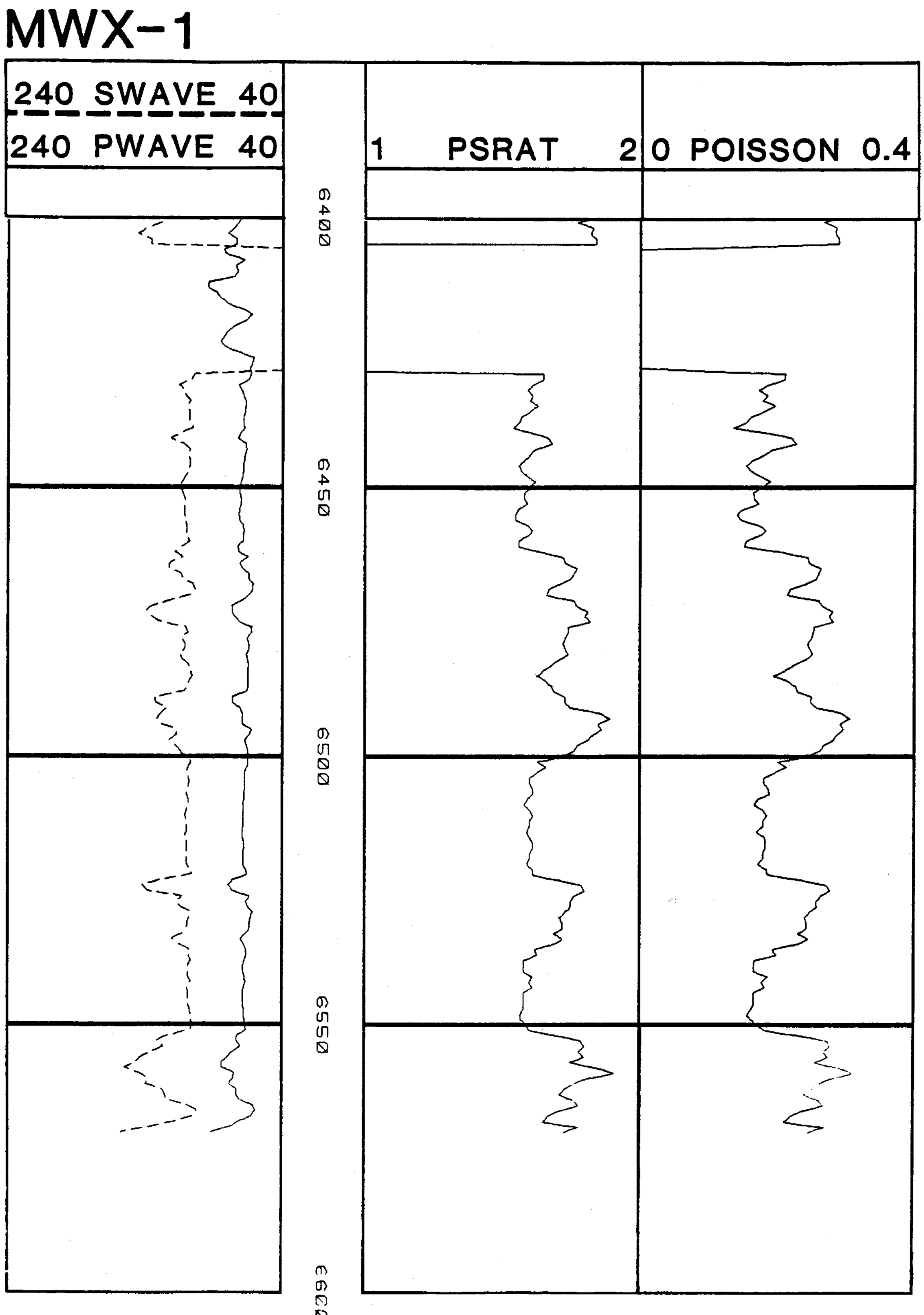


Figure 4.9, Cont.

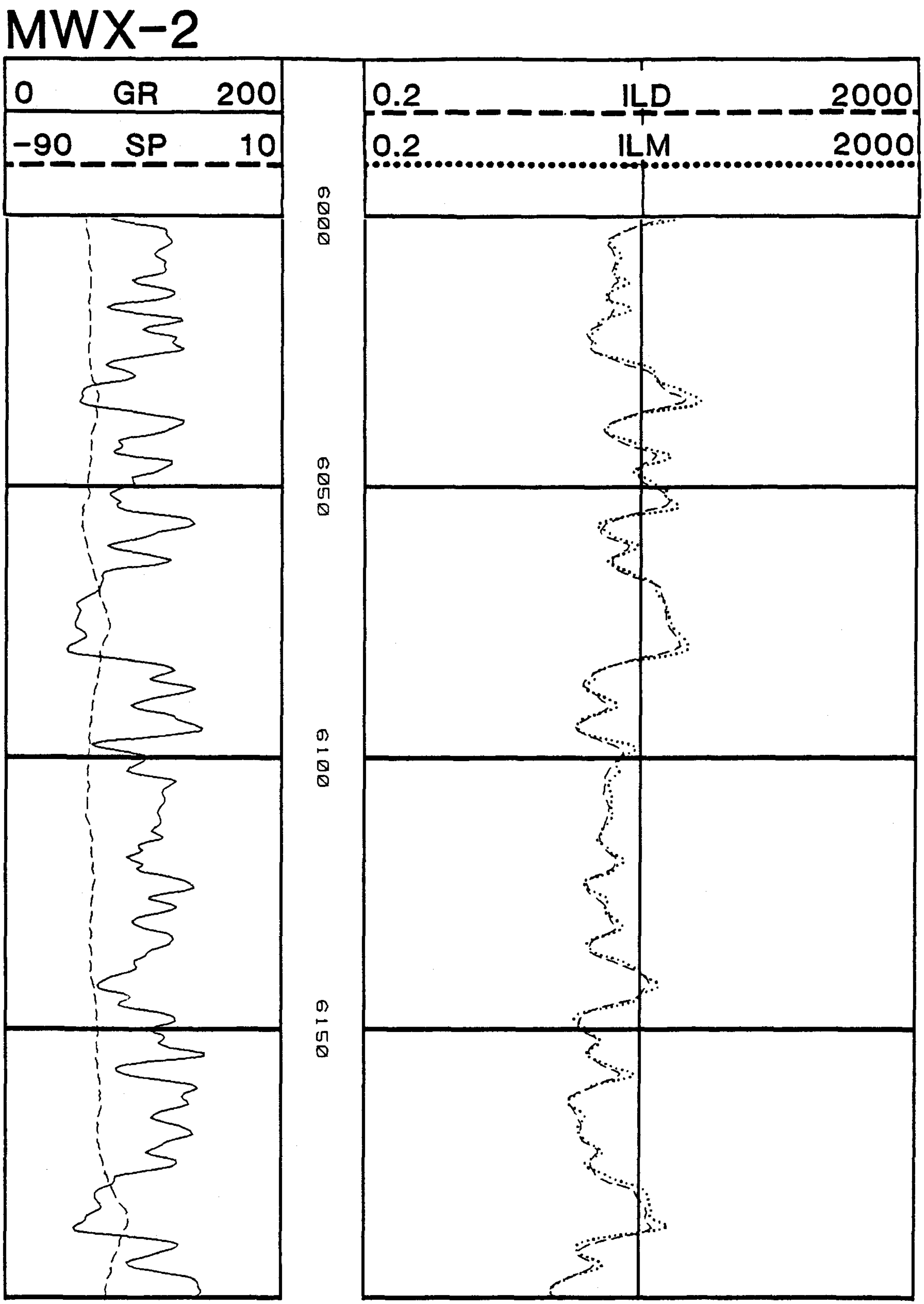


Figure 4.10 MWX-2 Resistivity Log

MWX-2

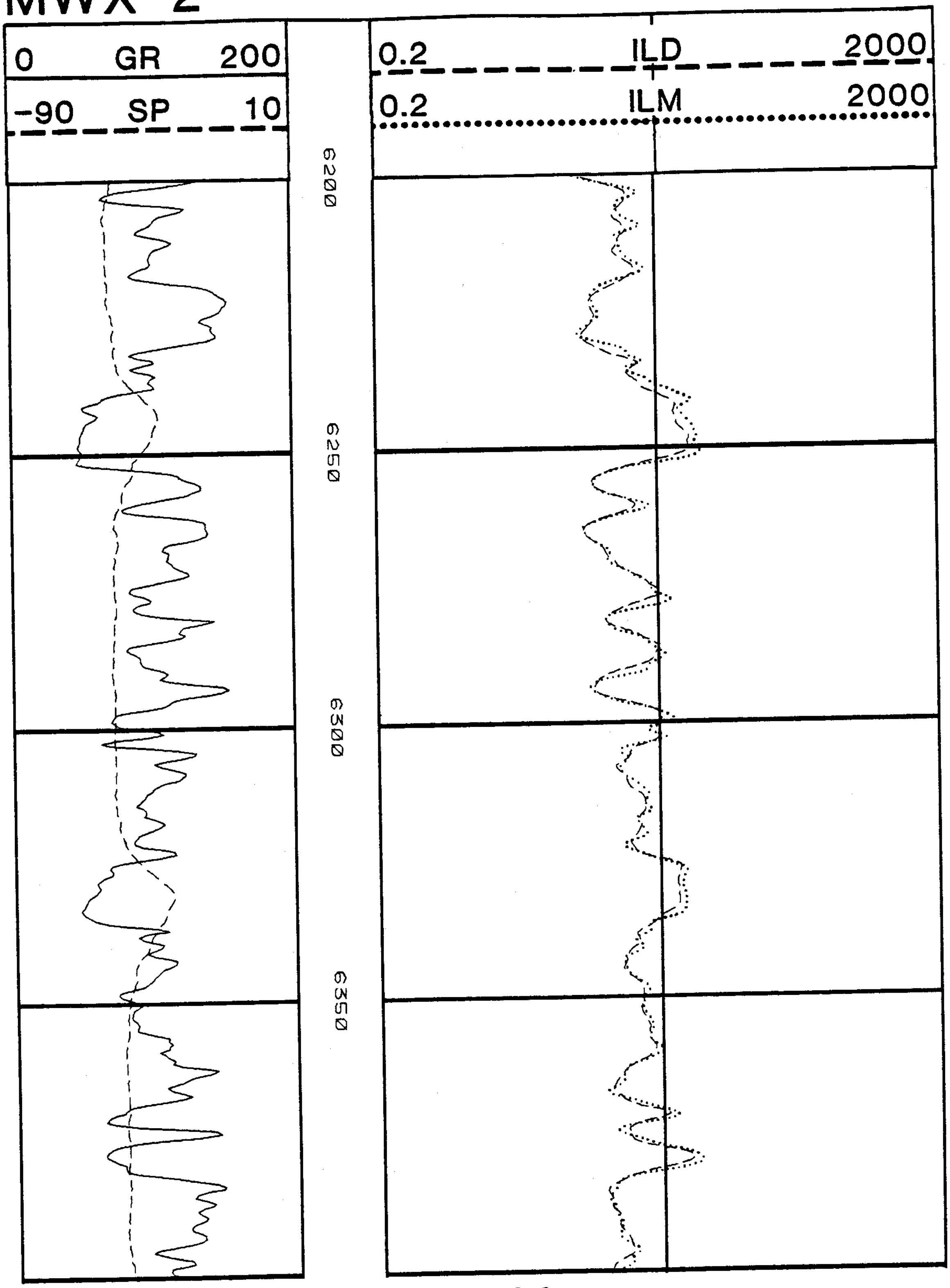


Figure 4.10, Cont.

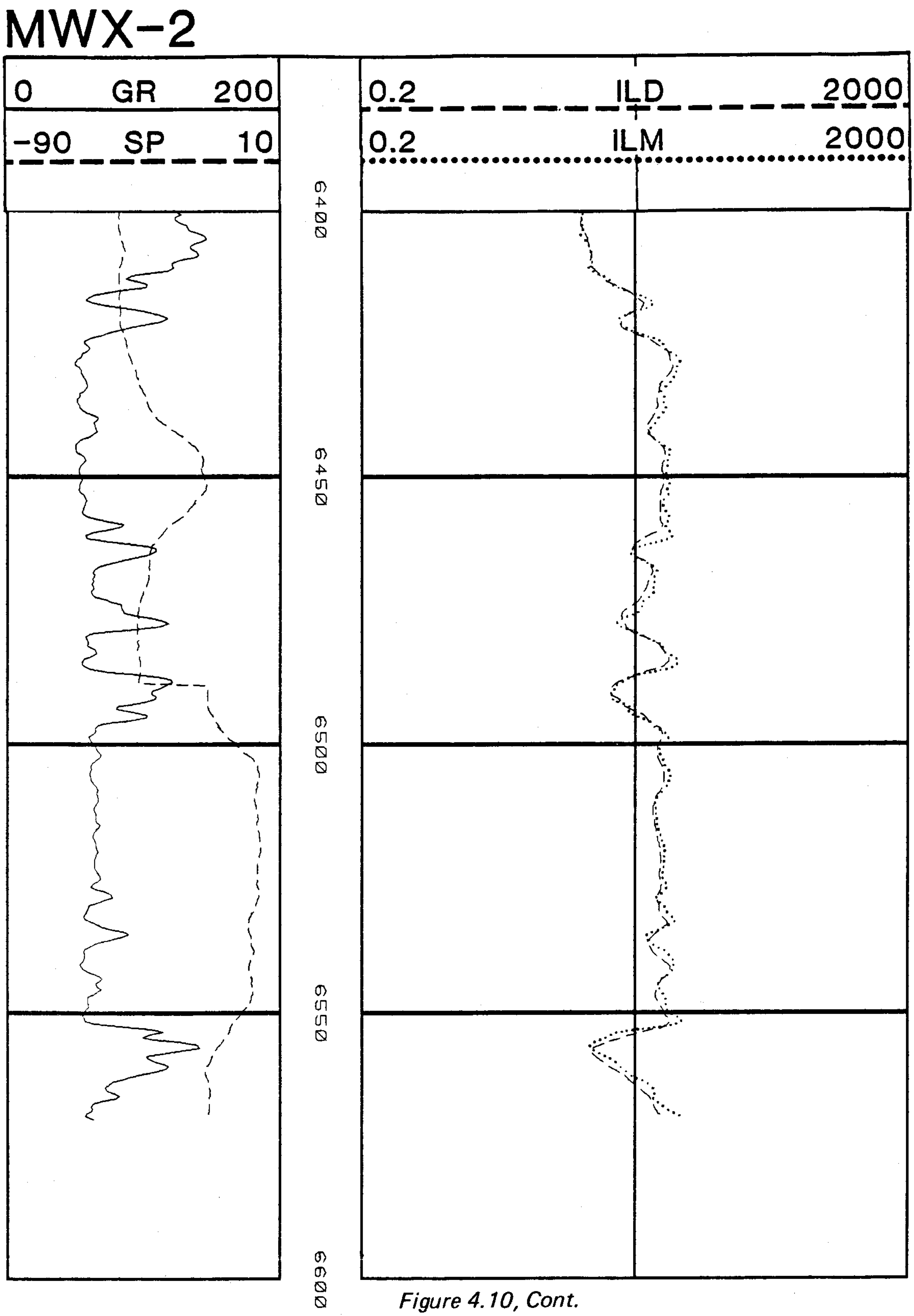


Figure 4.10, Cont.

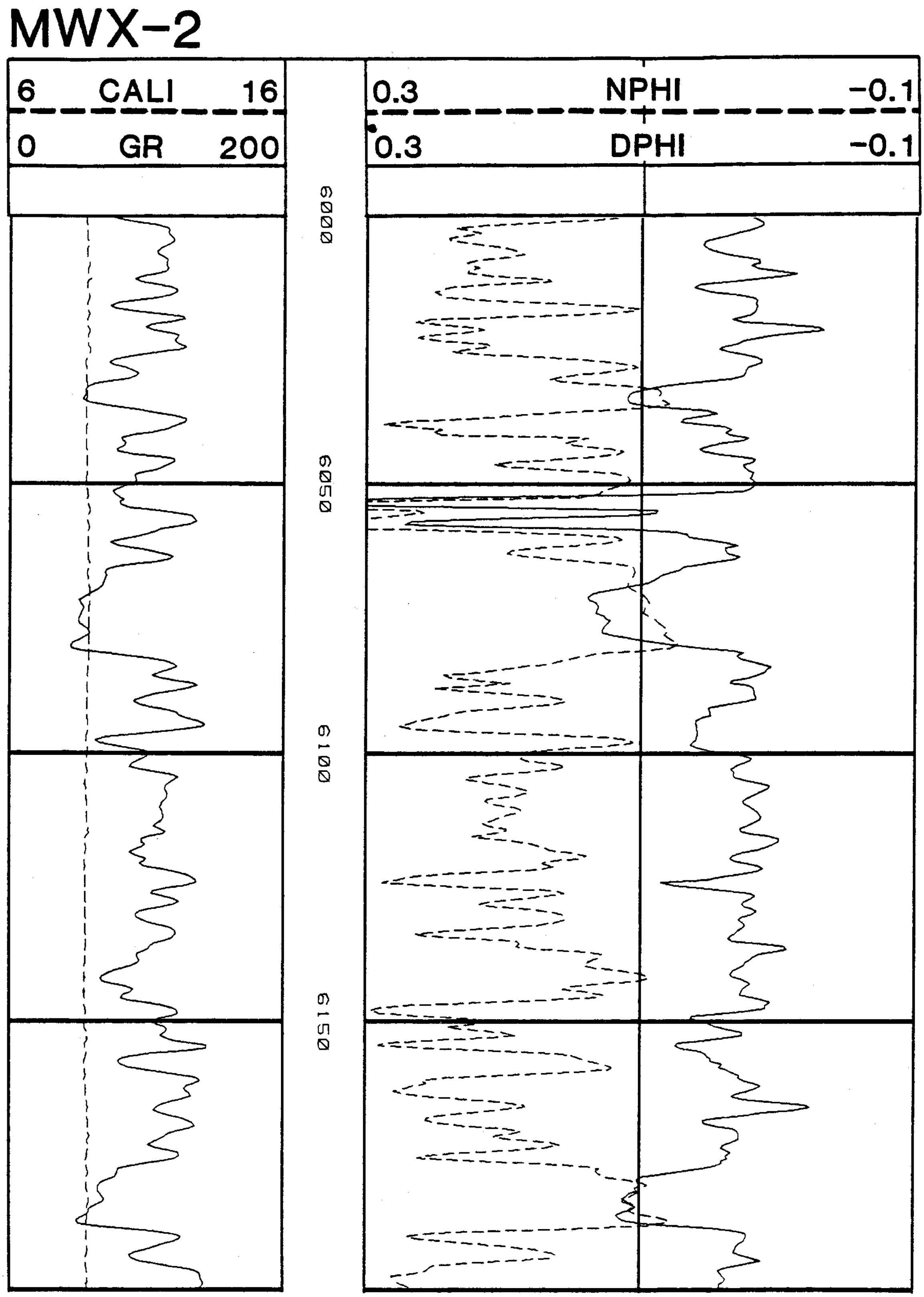


Figure 4.11 MWX-2 Density and Neutron Porosity Logs

MWX-2

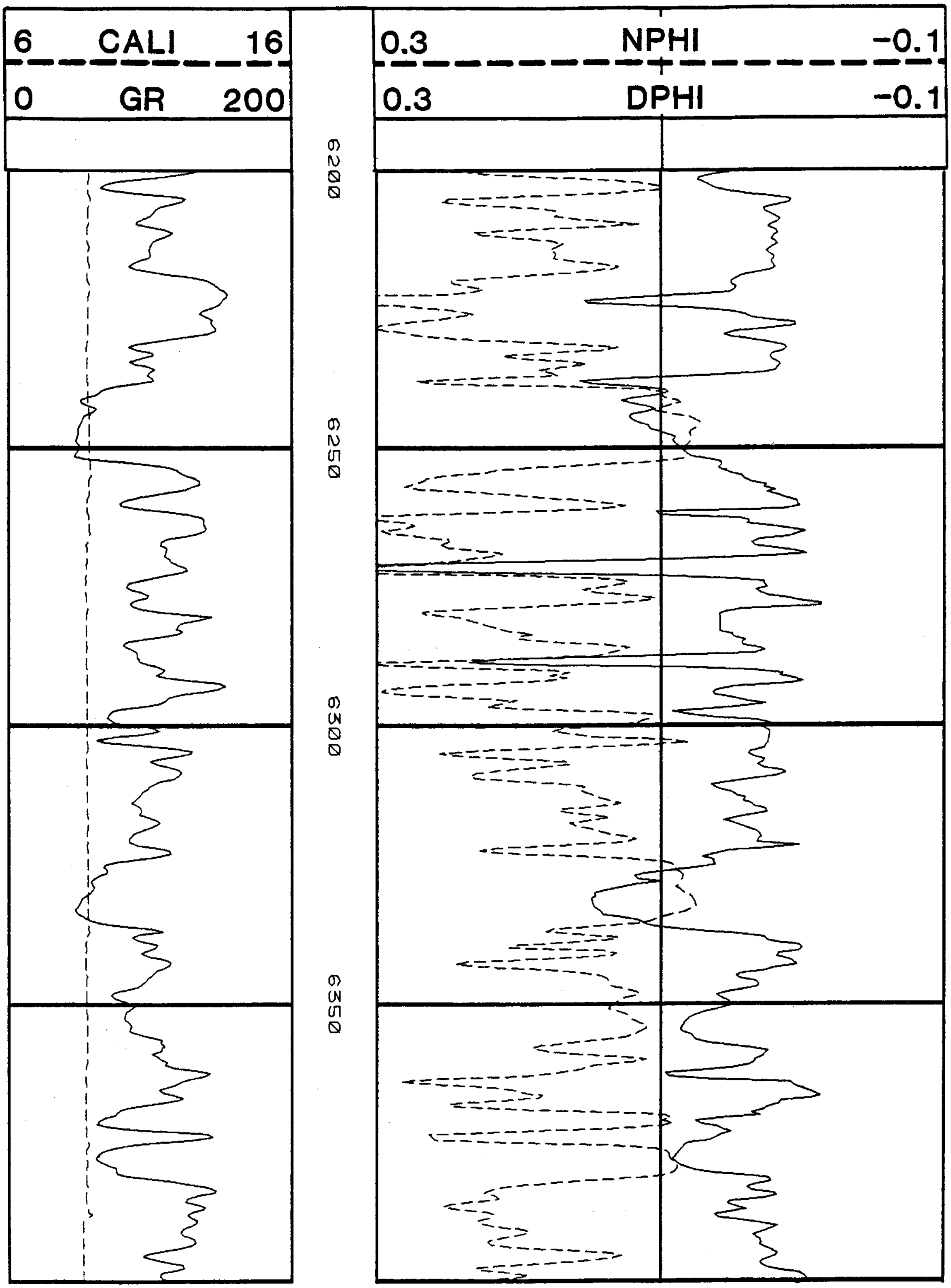


Figure 4.11, Cont.

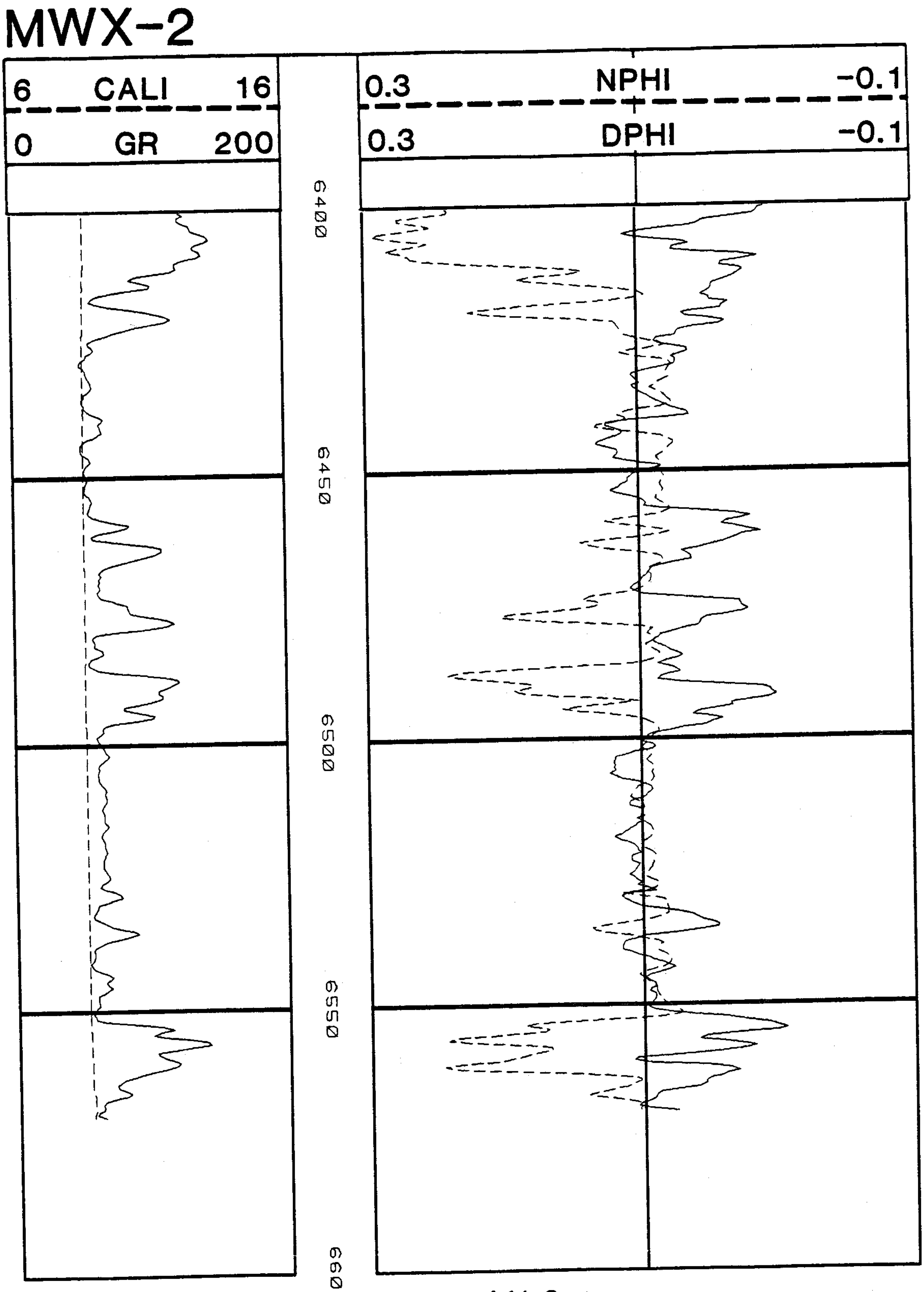


Figure 4.11, Cont.

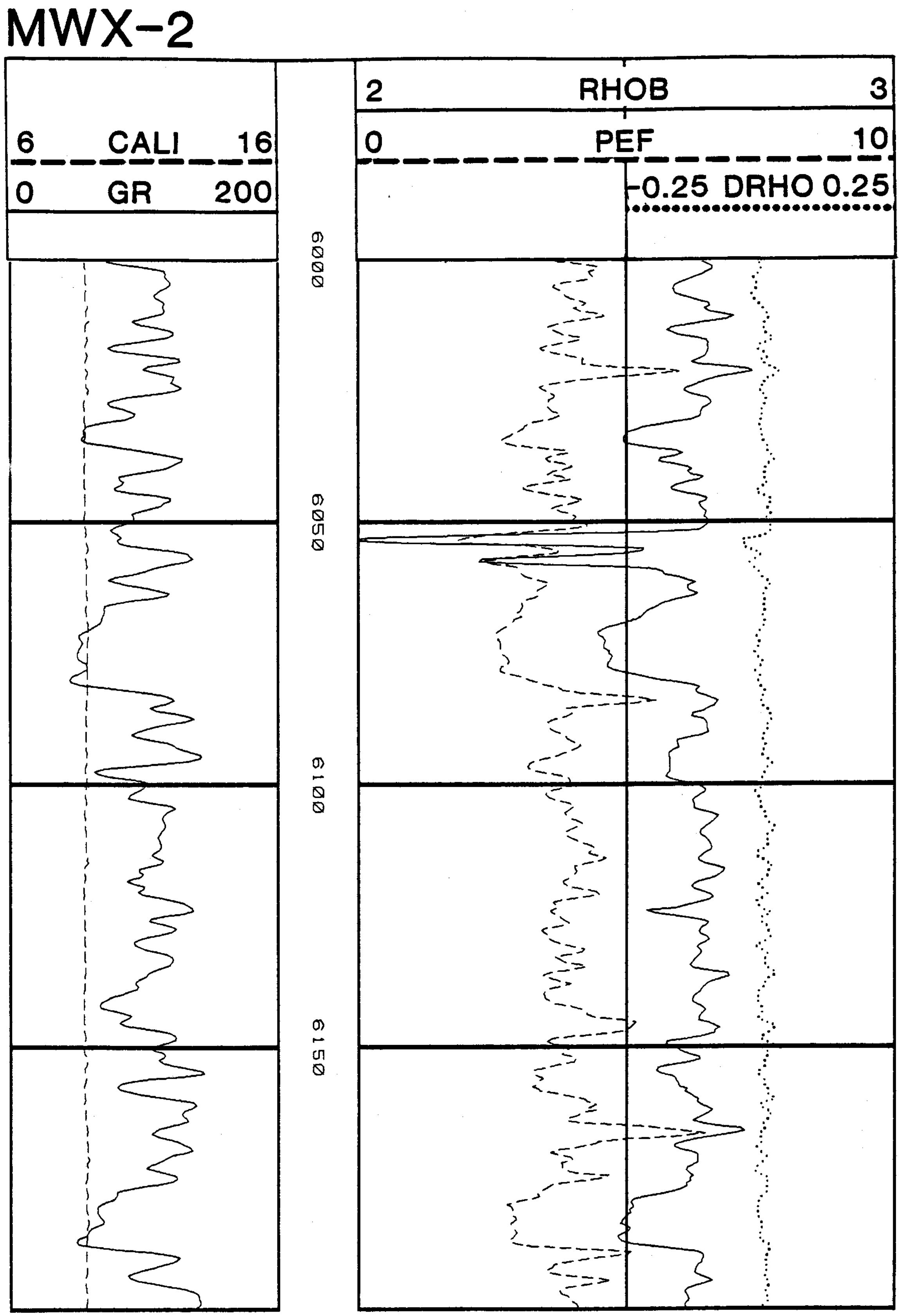


Figure 4.12 MWX-2 Bulk Density and Photoelectric Absorption Logs

MWX-2

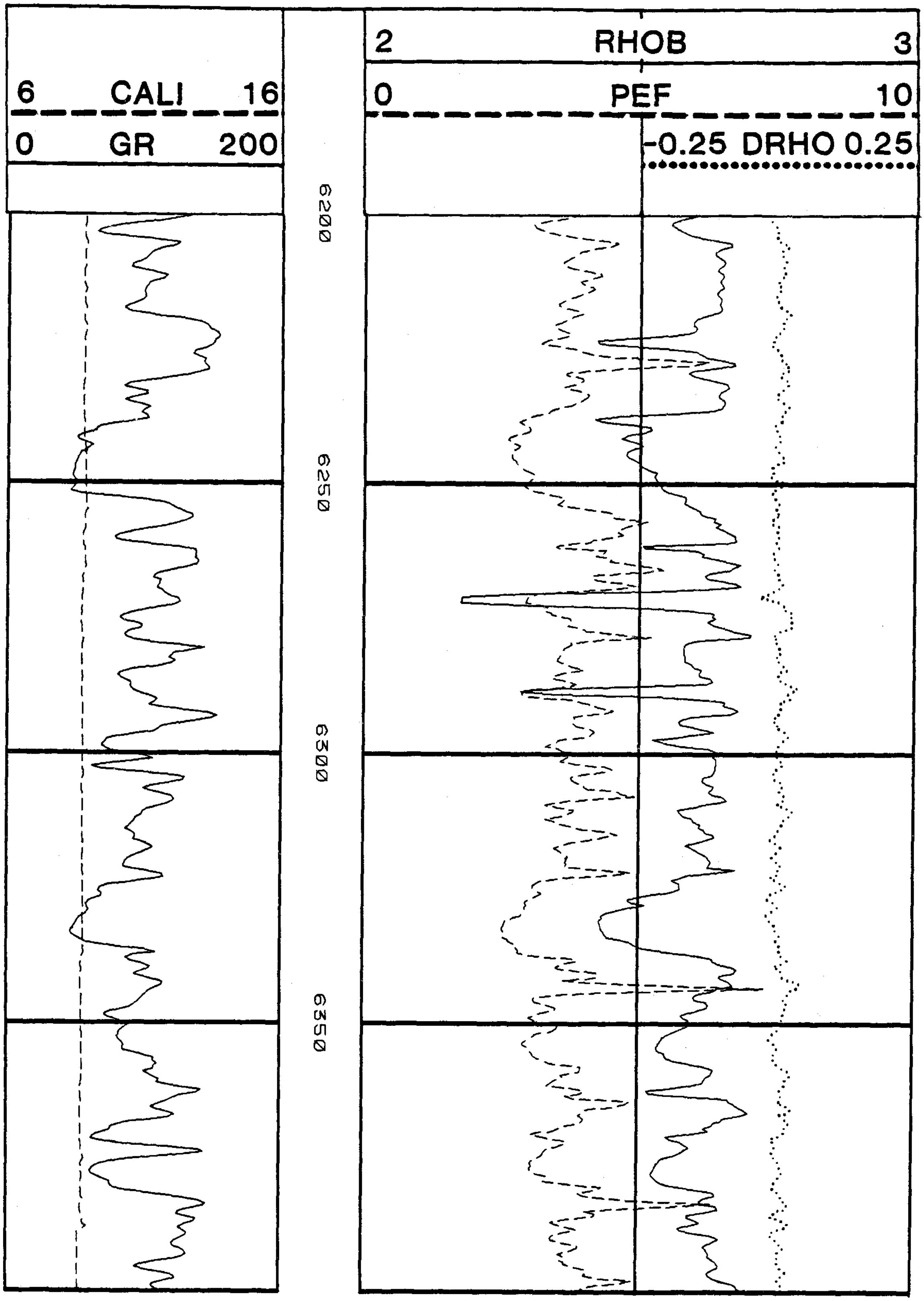
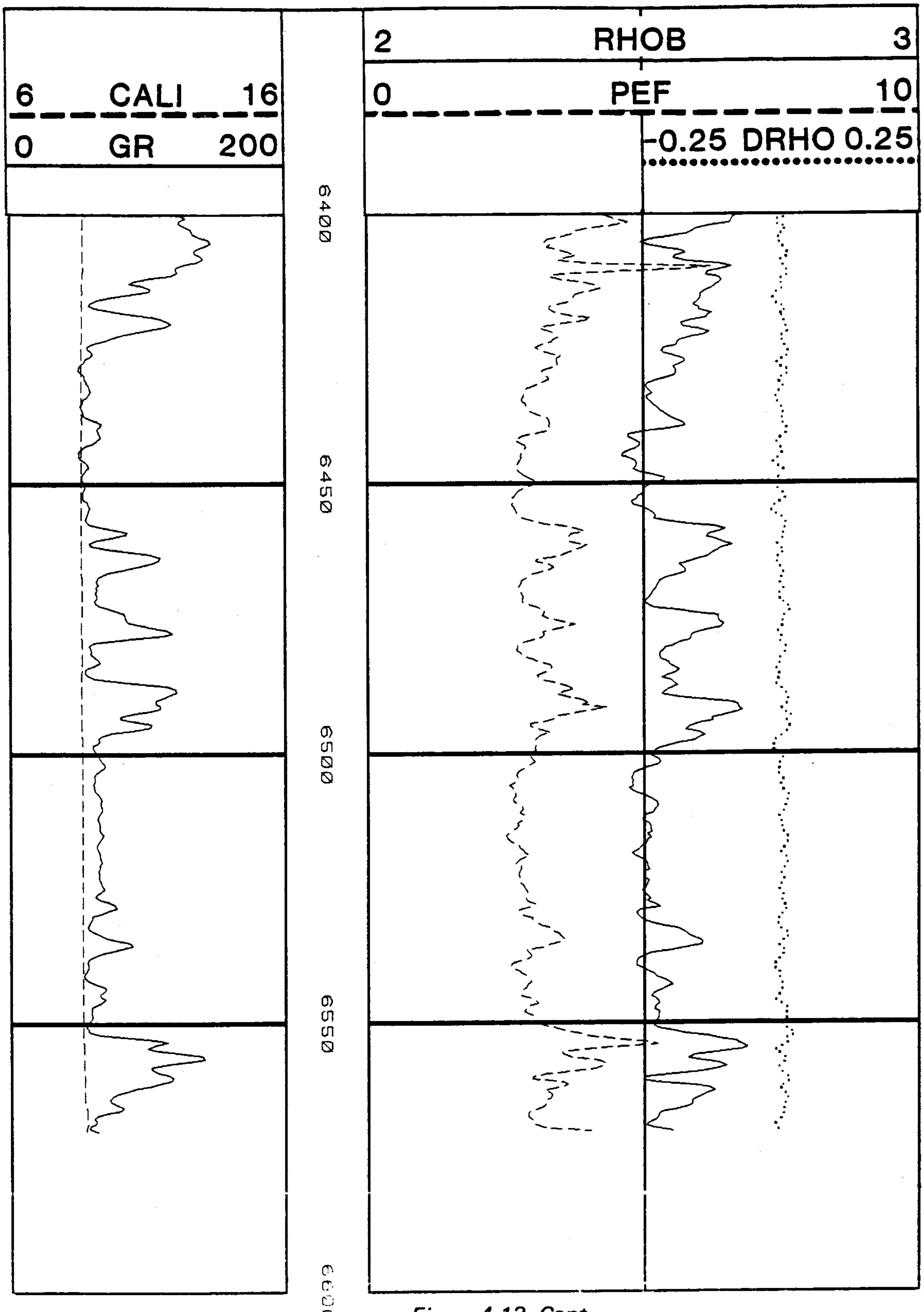


Figure 4.12, Cont.

MWX-2



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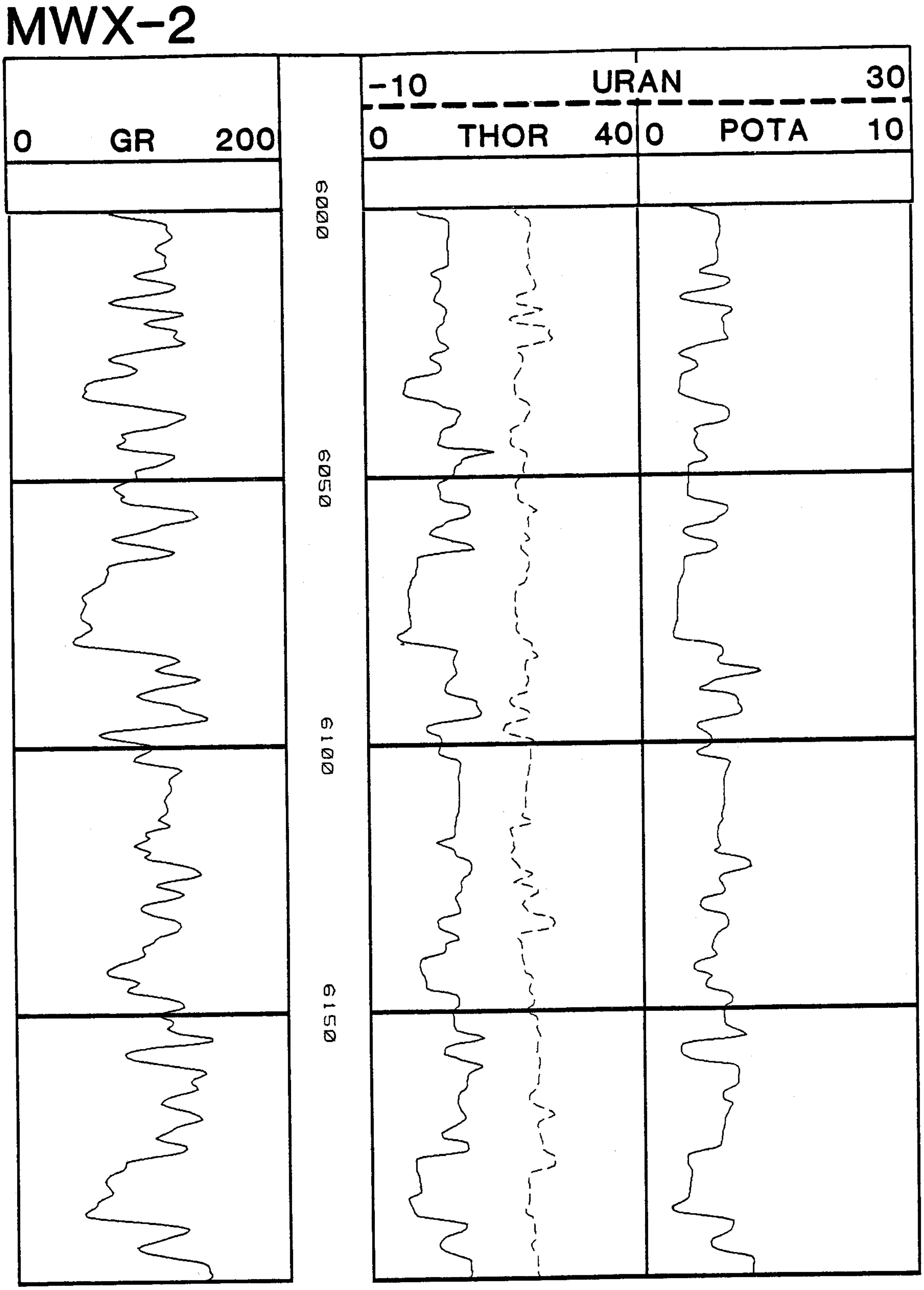


Figure 4.13 MWX-2 Spectral Gamma Log

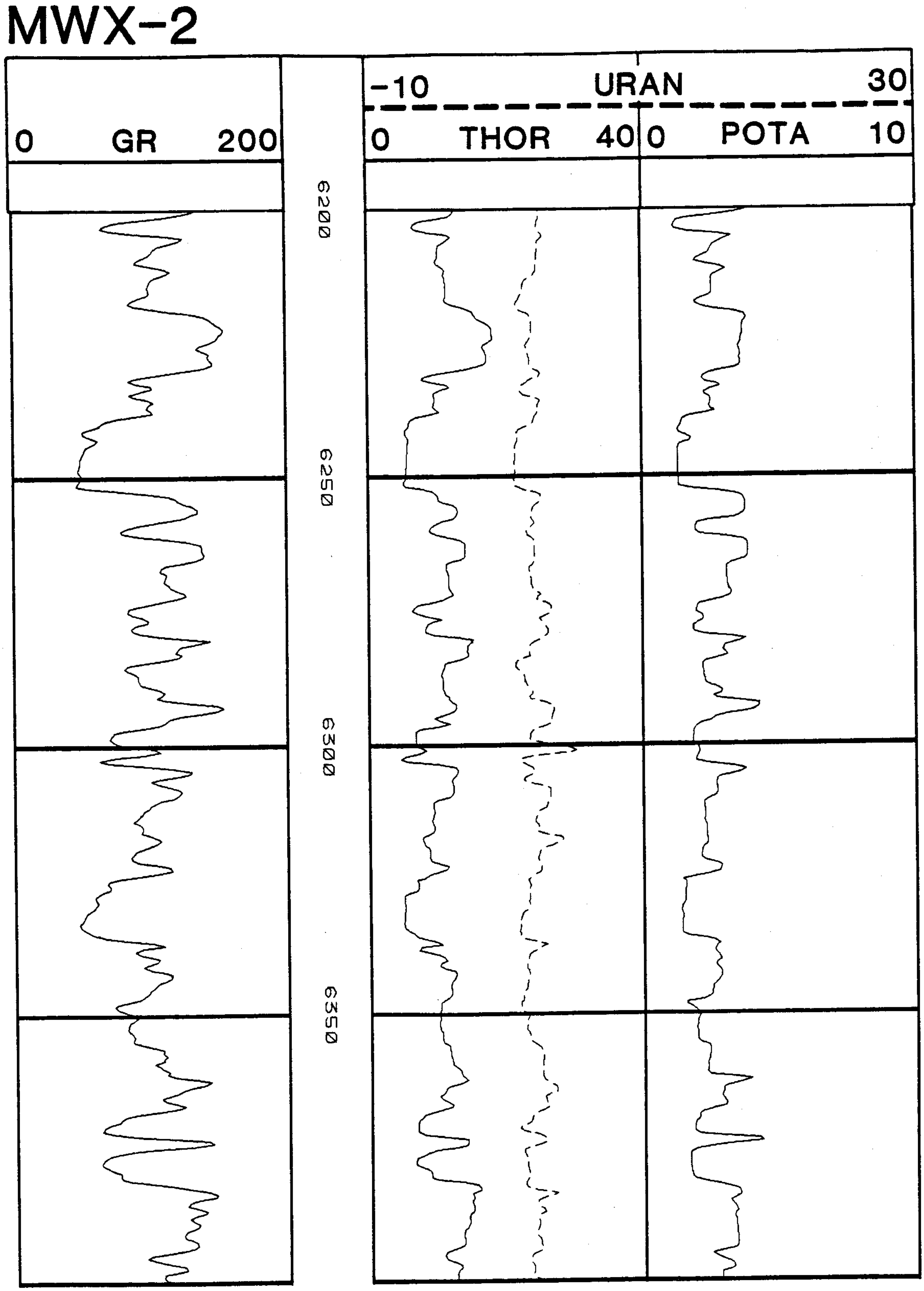


Figure 4.13, Cont.

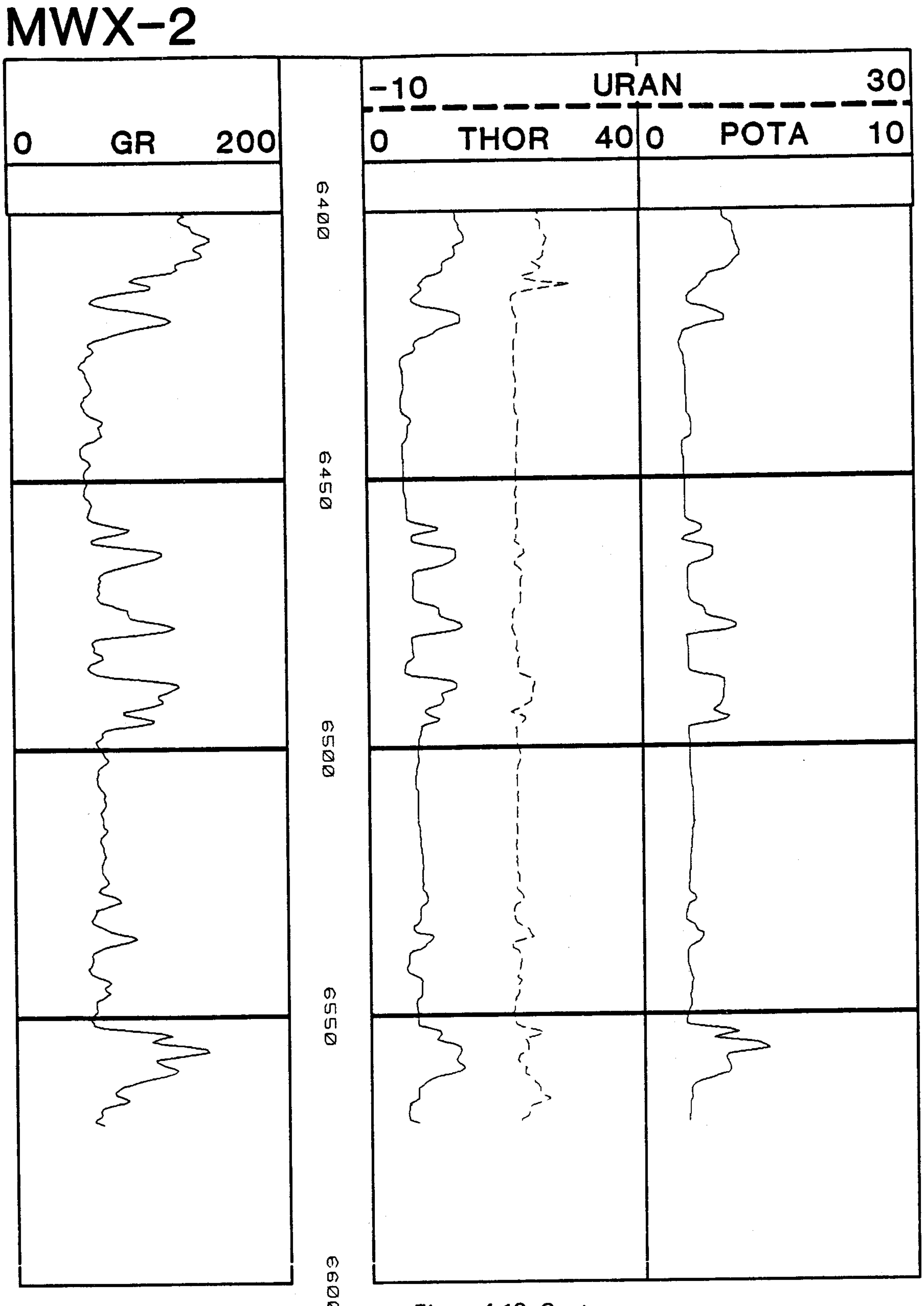


Figure 4.13, Cont.

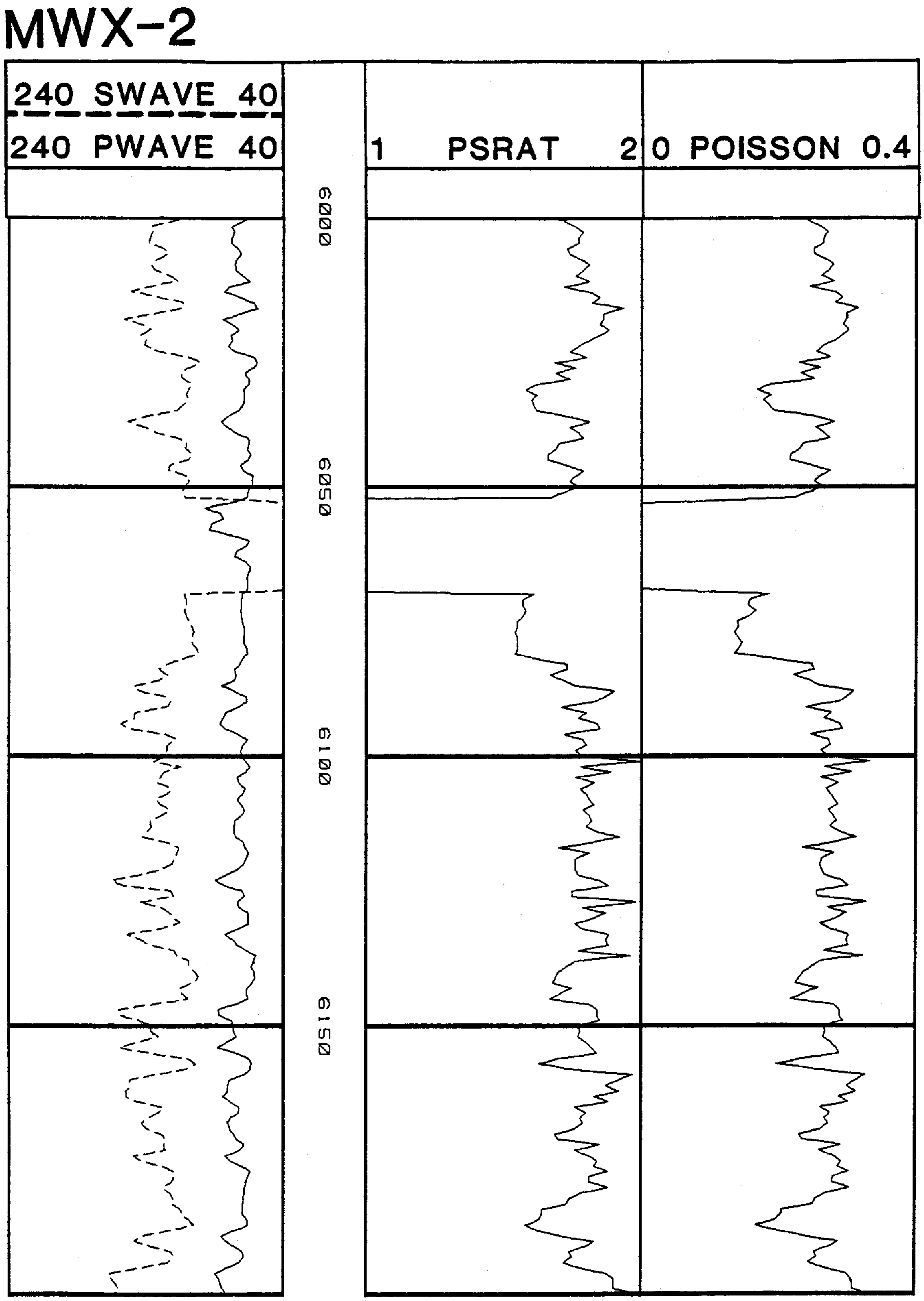


Figure 4.14 MWX-2 Long Spaced Sonic Log

MWX-2

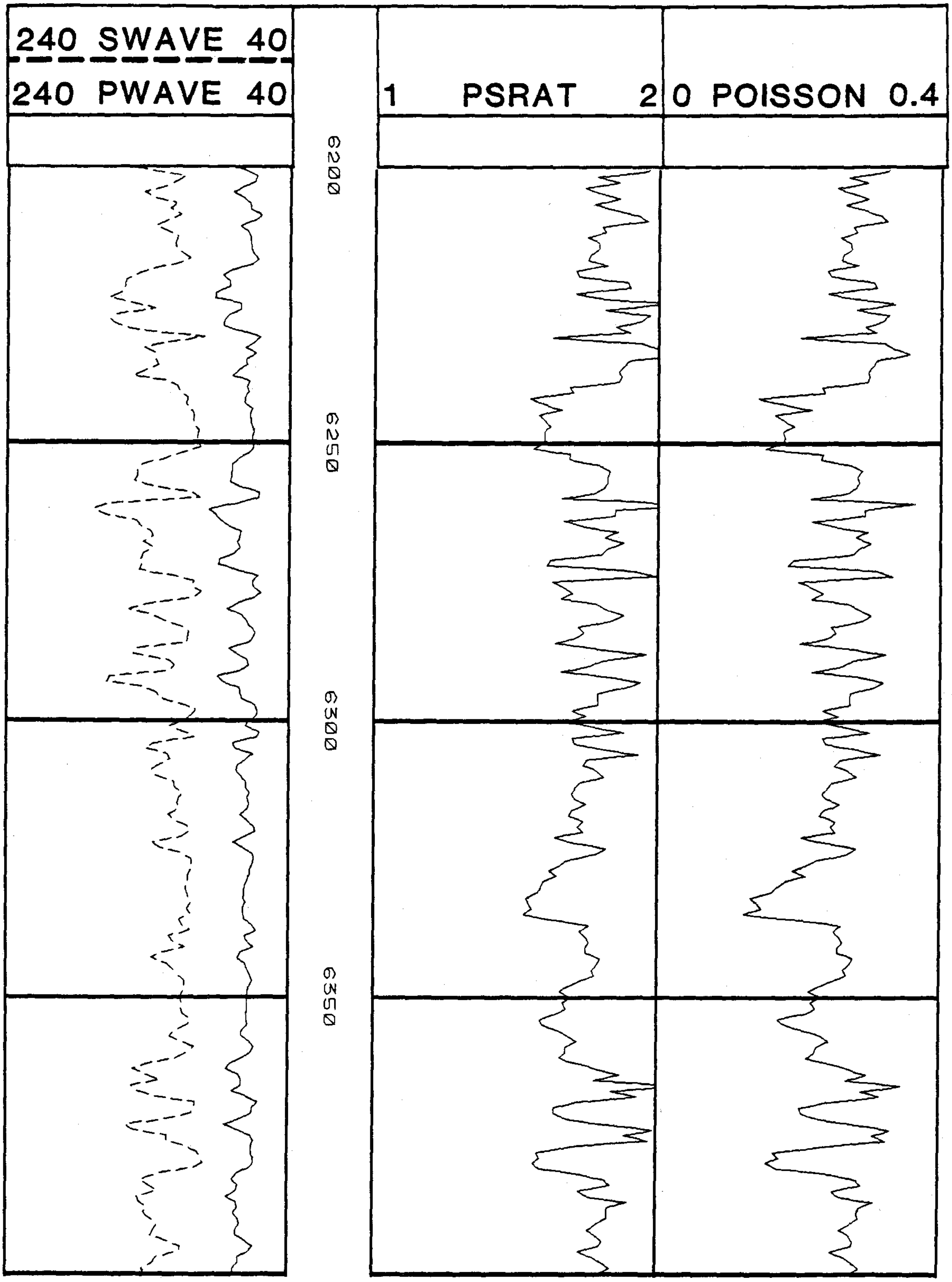


Figure 4.14, Cont.

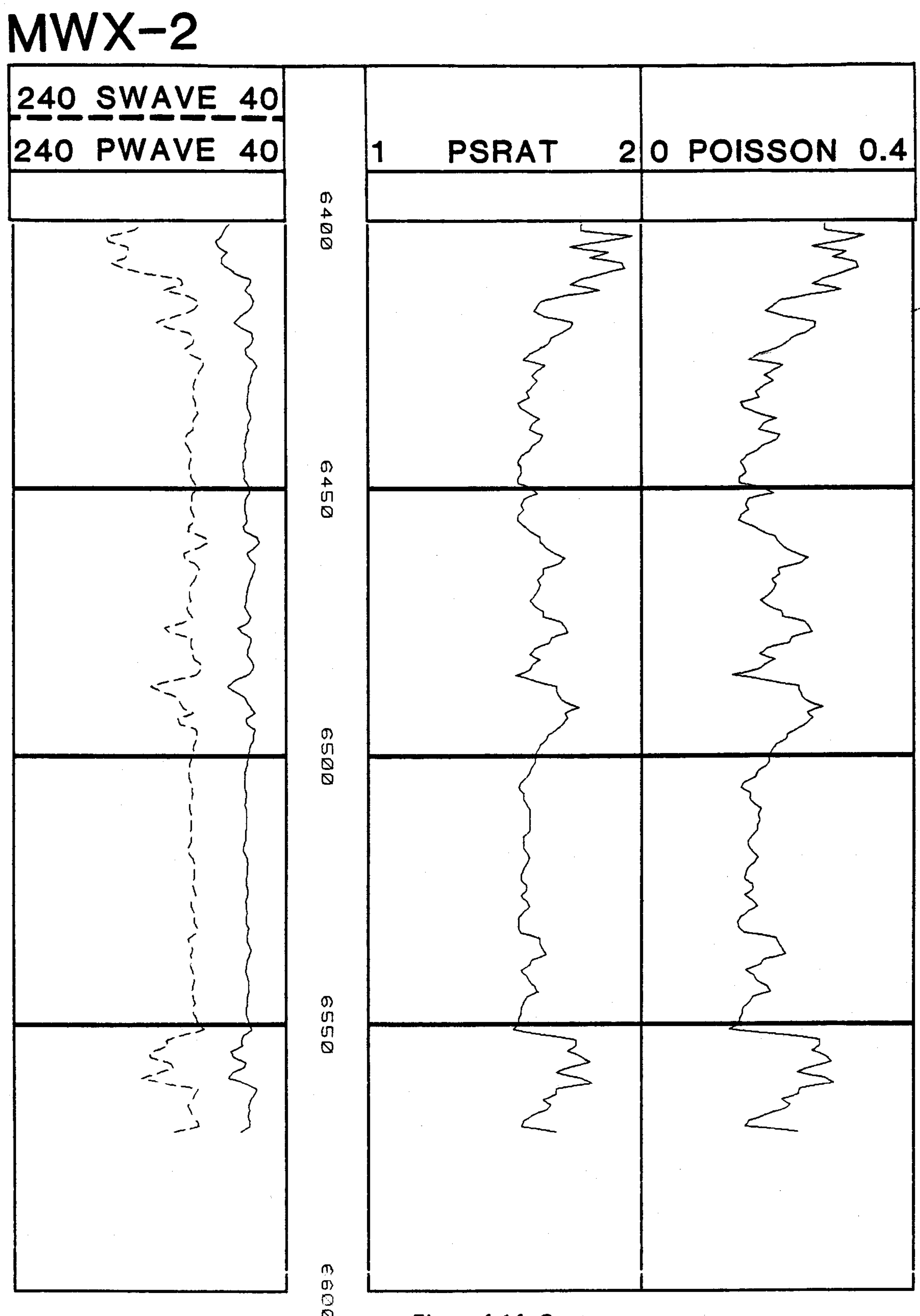


Figure 4.14, Cont.

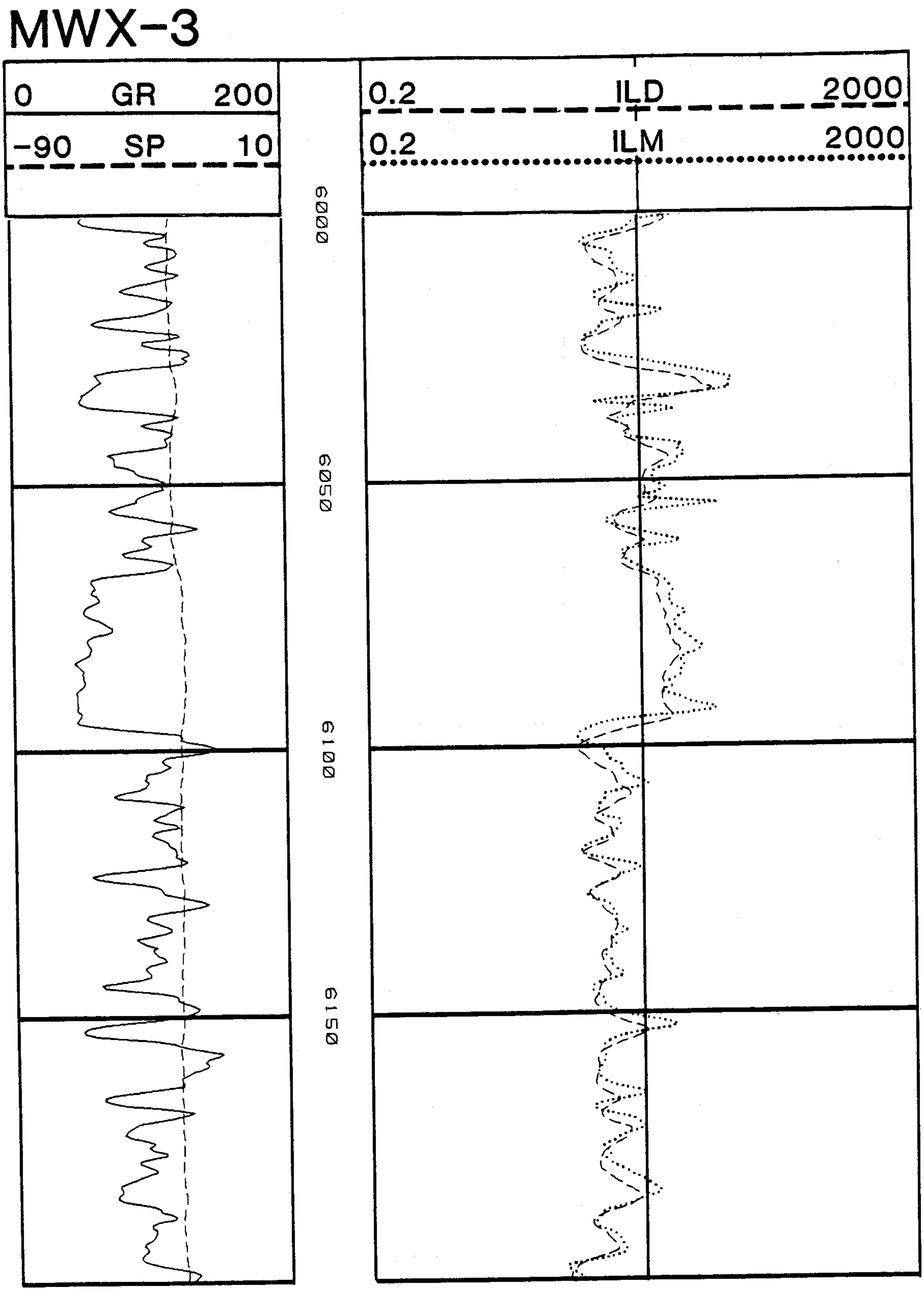


Figure 4.15 MWX-3 Resistivity Log

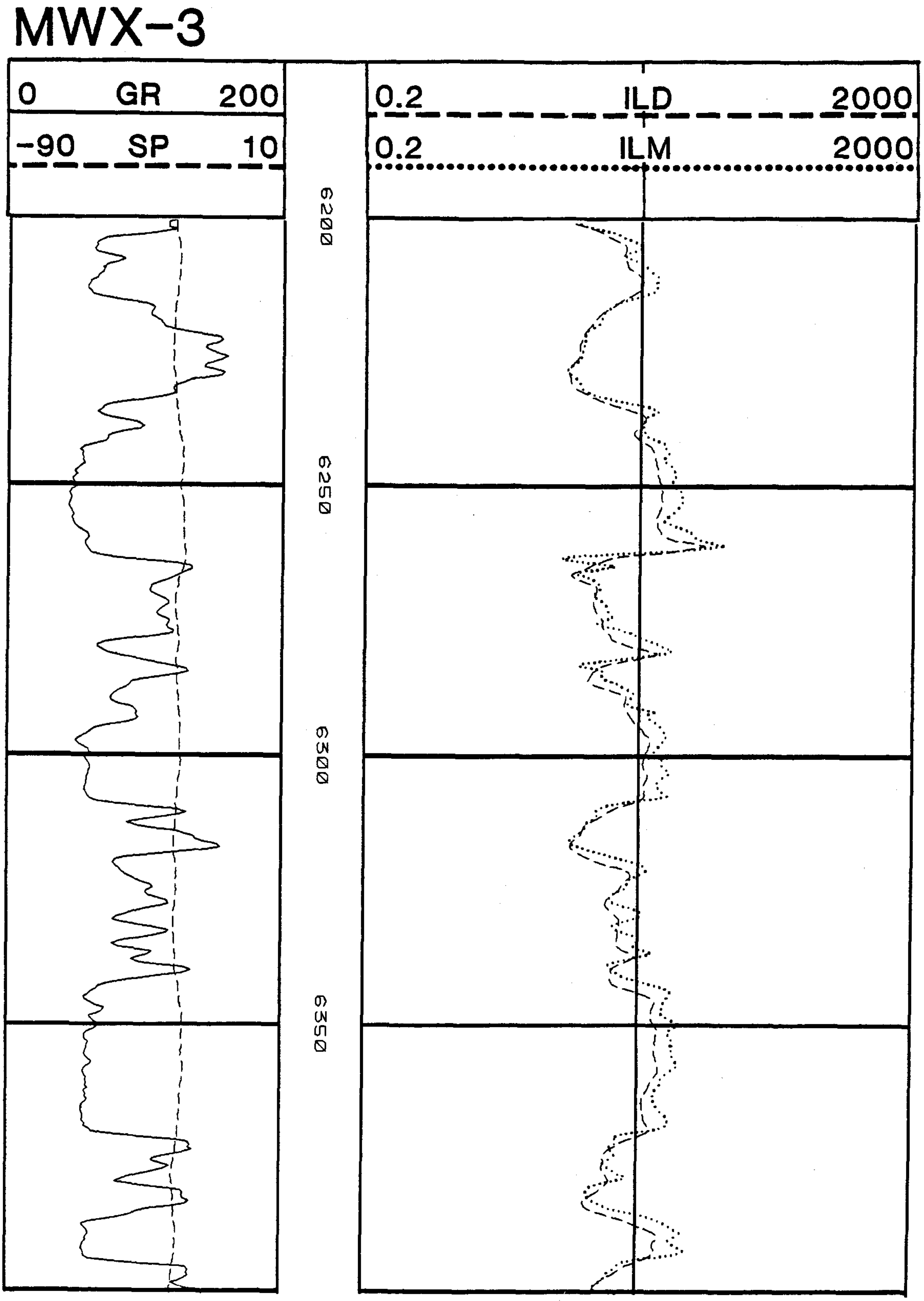


Figure 4.15, Cont.

MWX-3

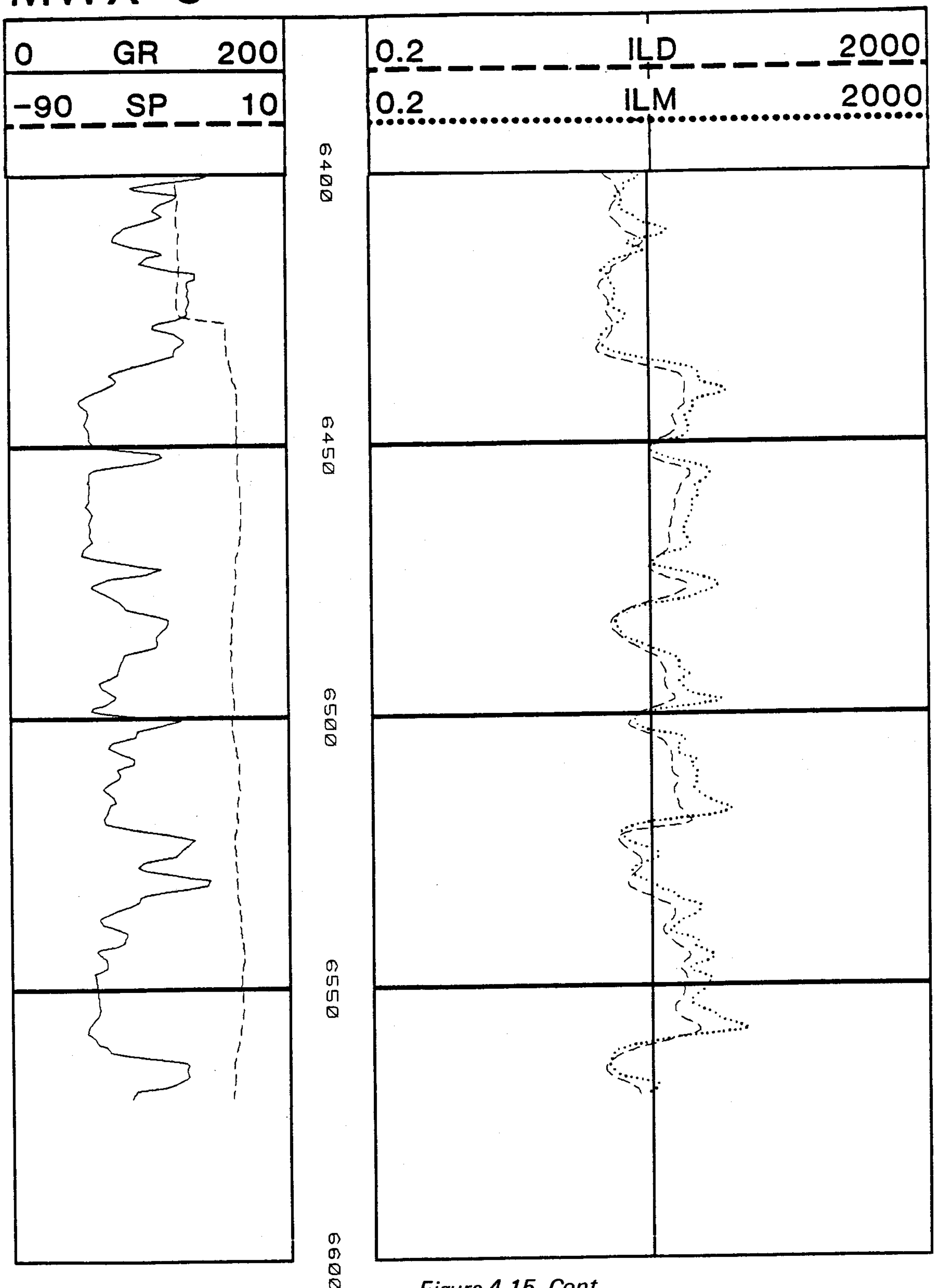


Figure 4.15, Cont.

MWX-3

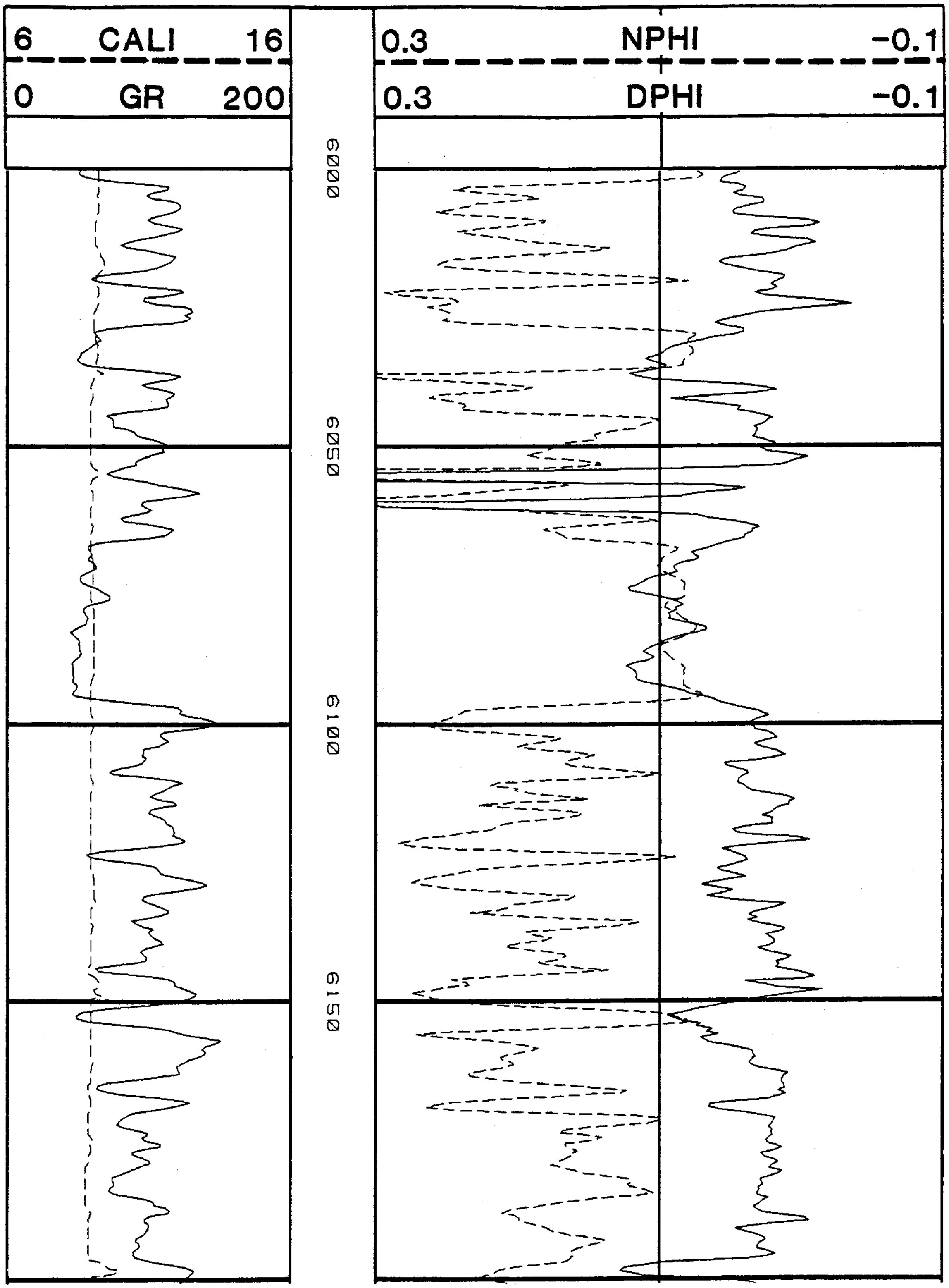


Figure 4.16 MWX-3 Density and Neutron Porosity Logs

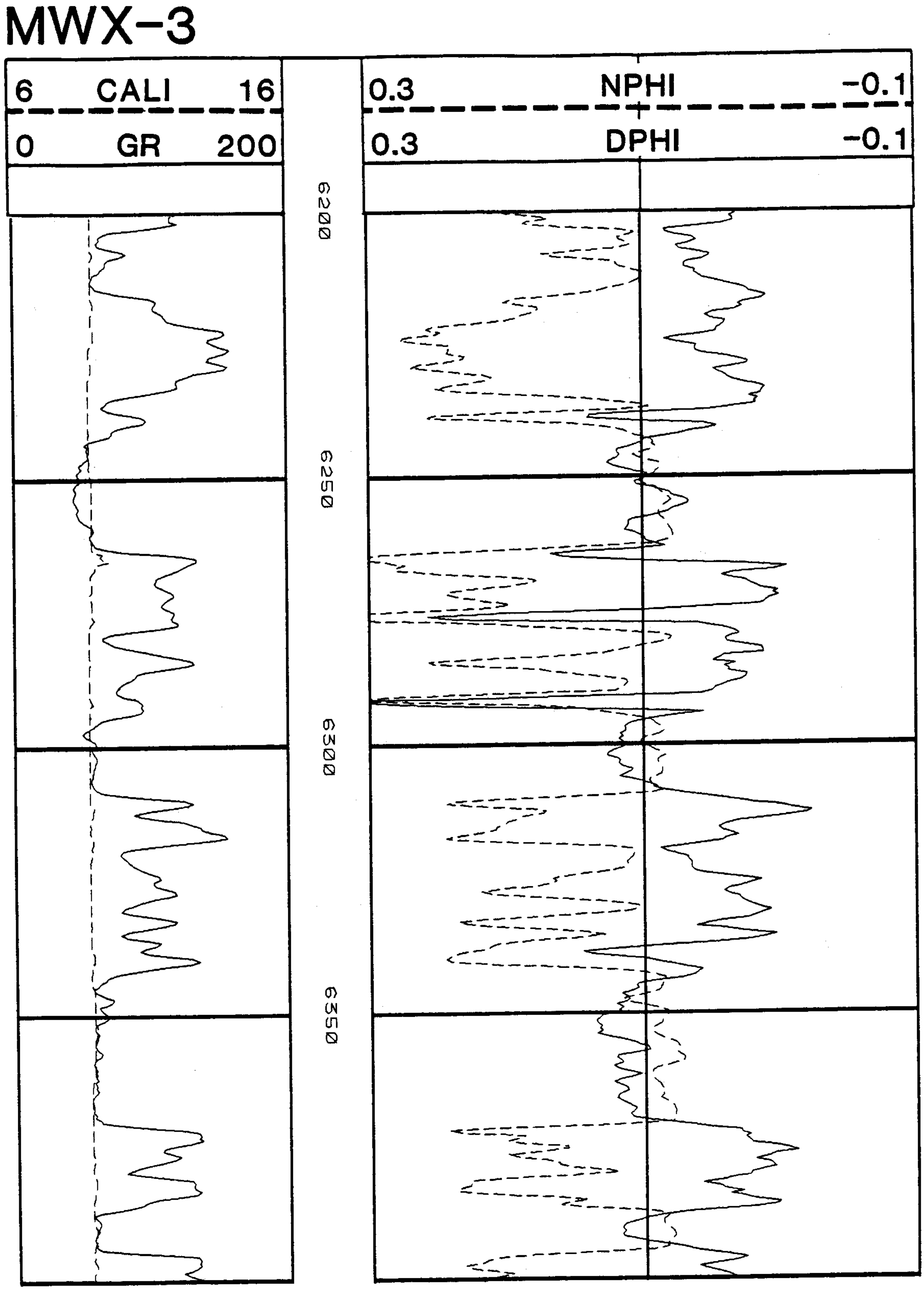


Figure 4.16, Cont.

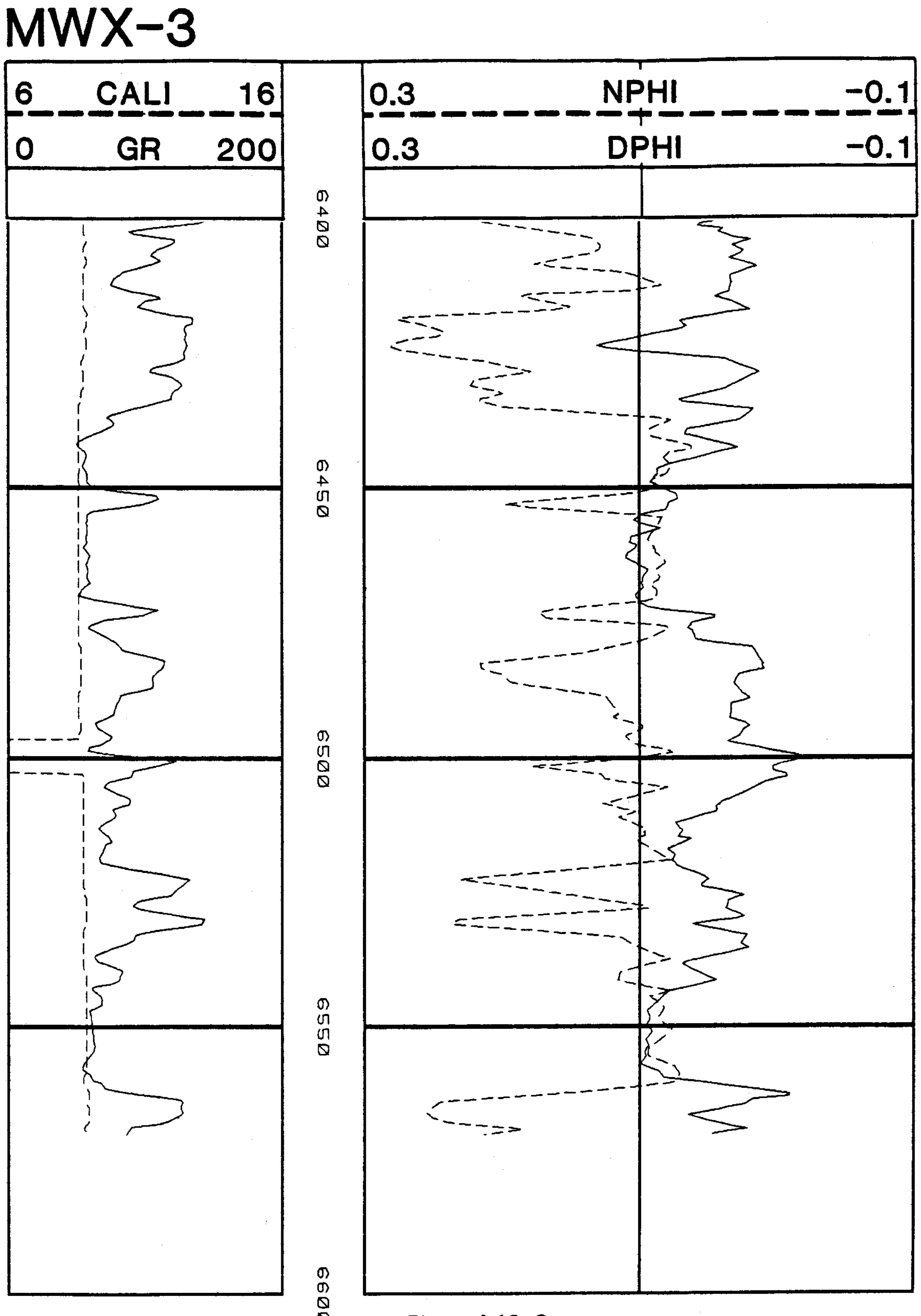


Figure 4.16, Cont.

MWX-3

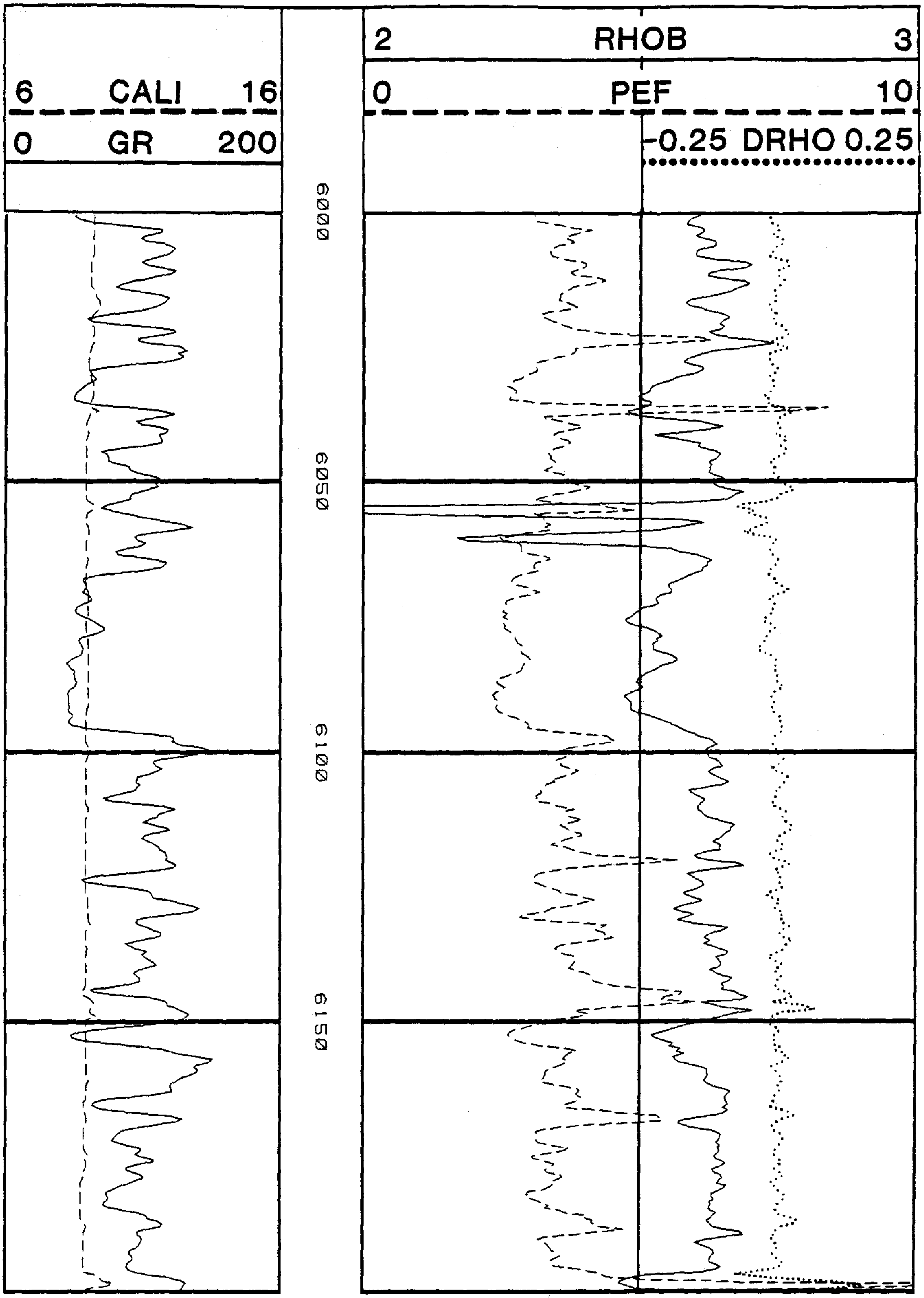
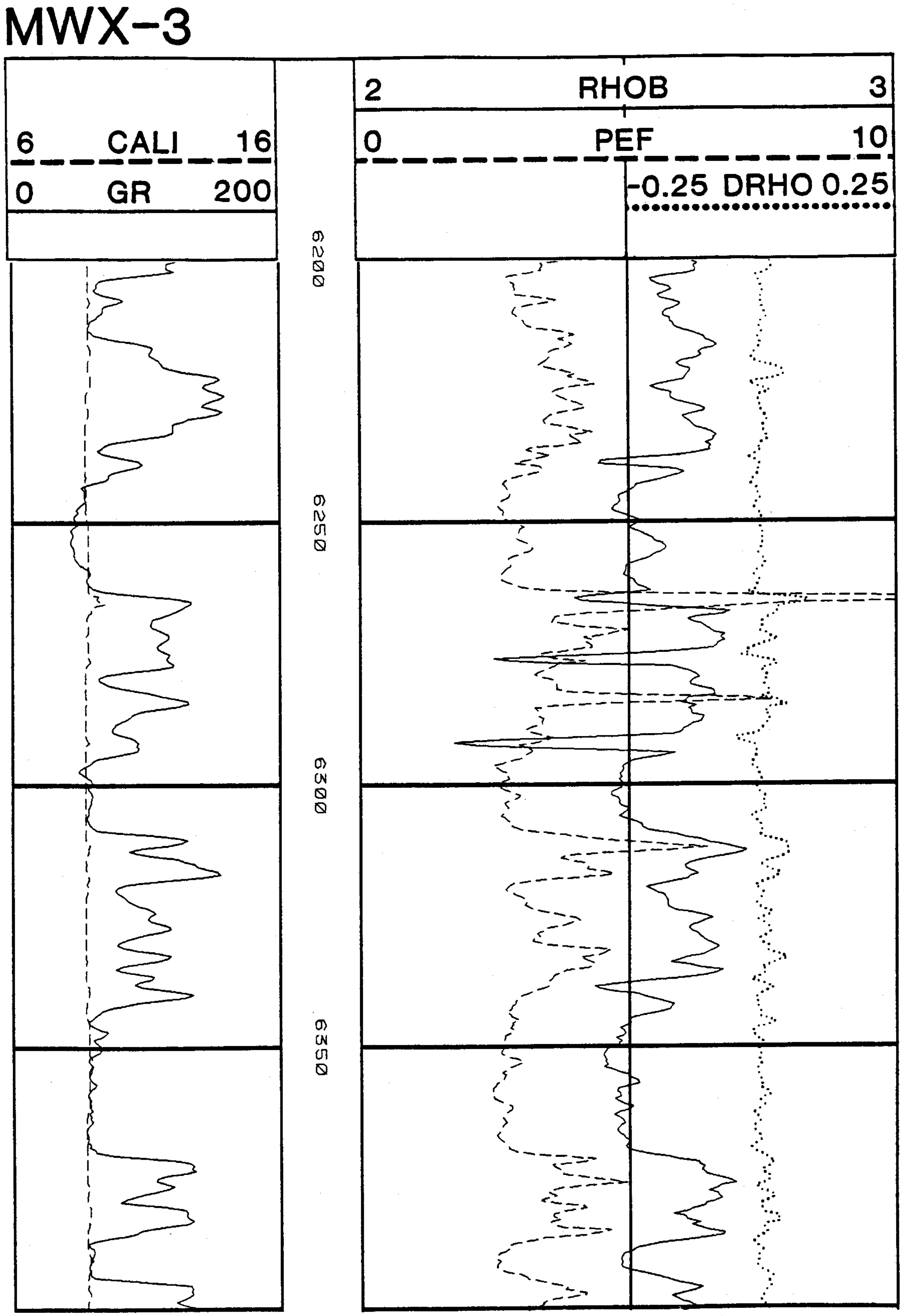


Figure 4.17 MWX-3 Bulk Density and Photoelectric Absorption Logs



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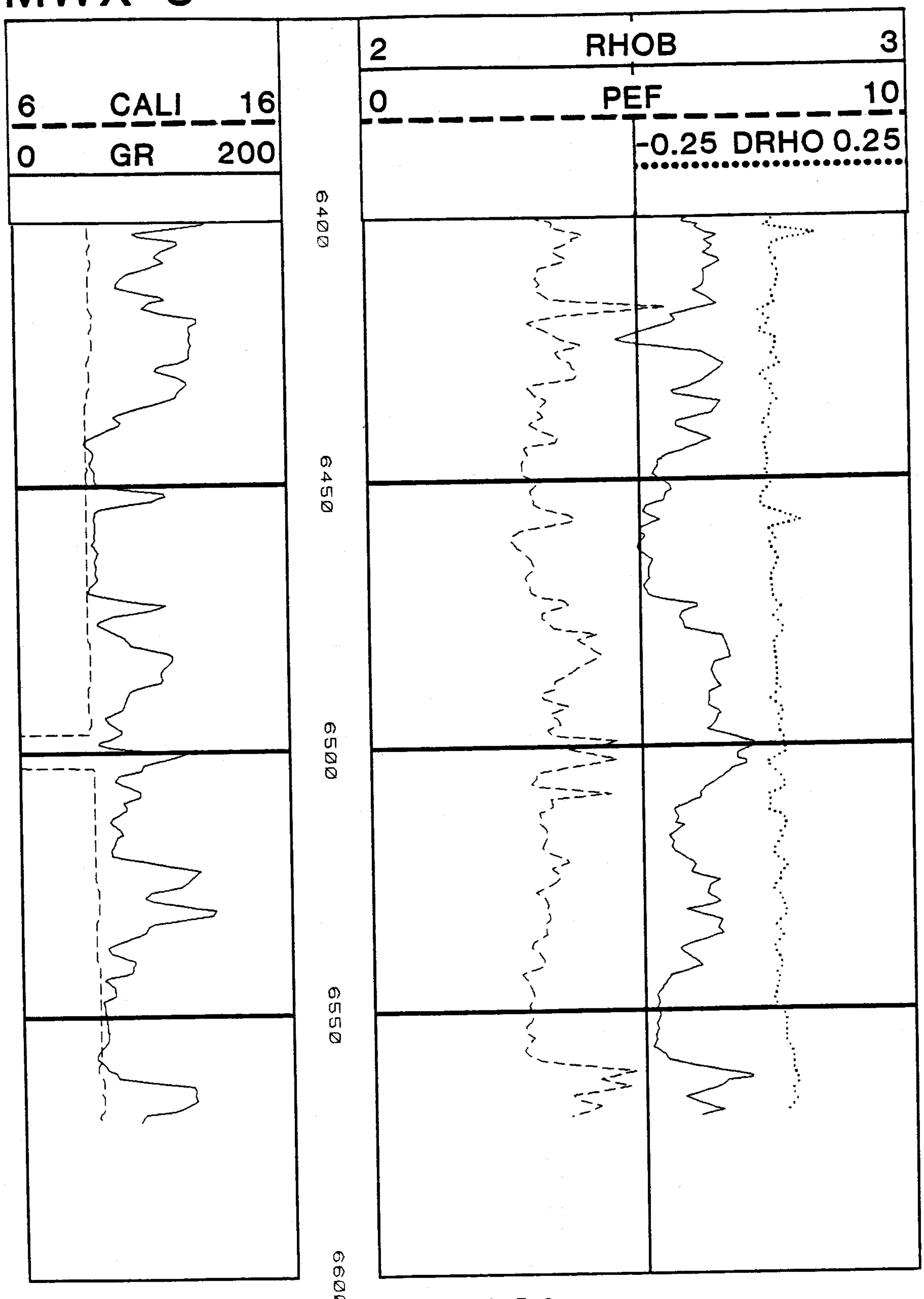
MWX-3



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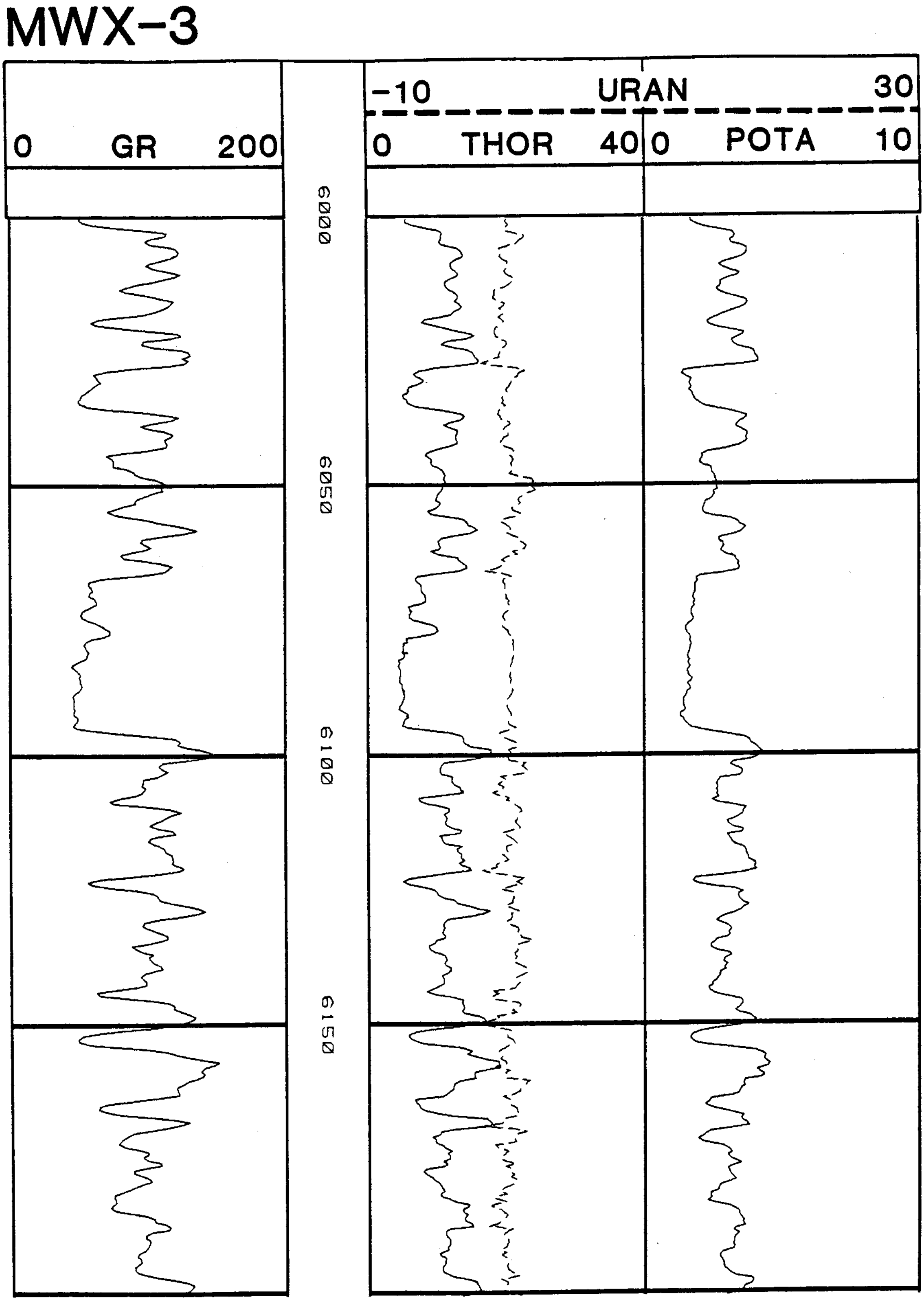
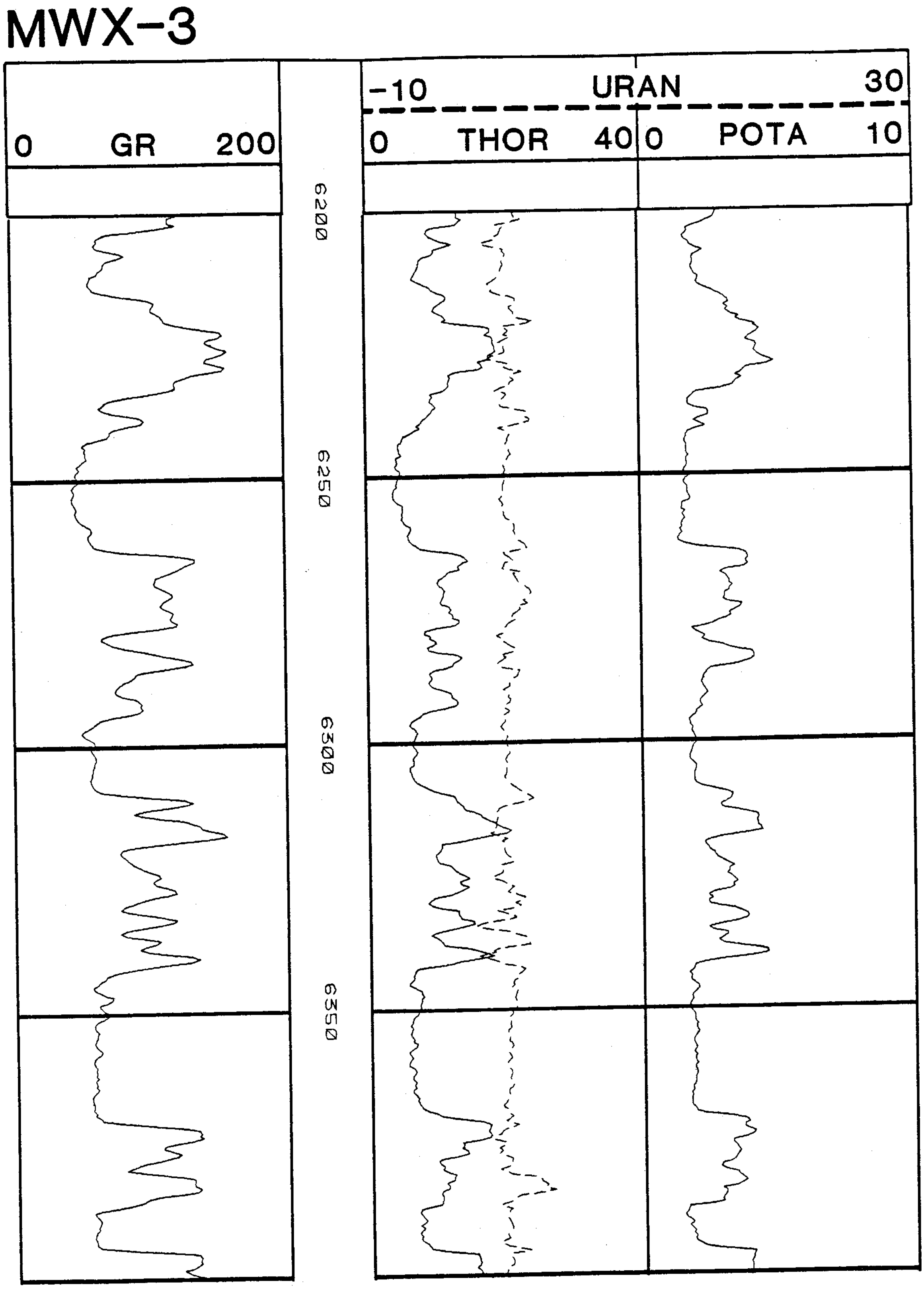


Figure 4.18 MWX-3 Spectral Gamma Log



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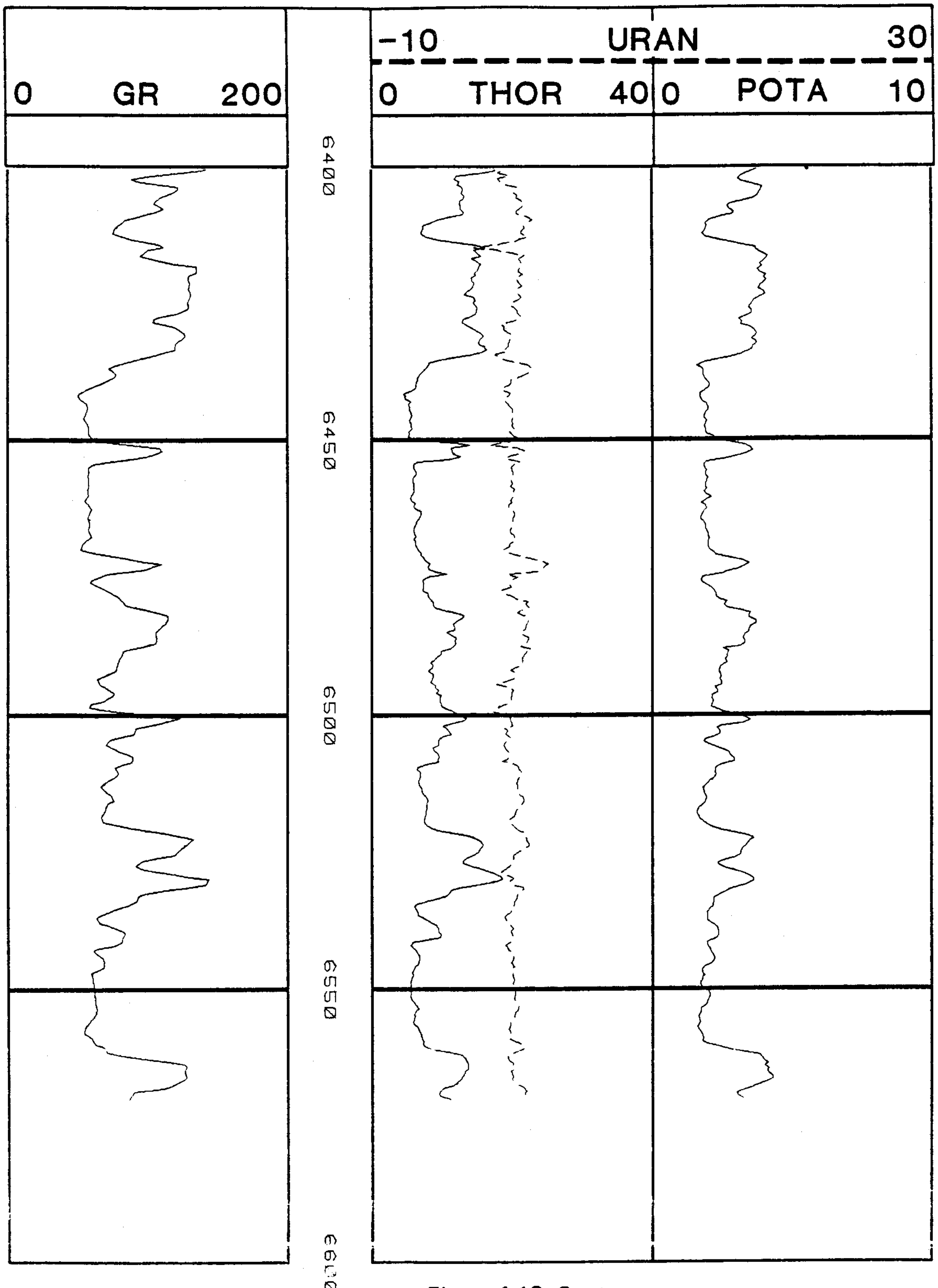
MWX-3



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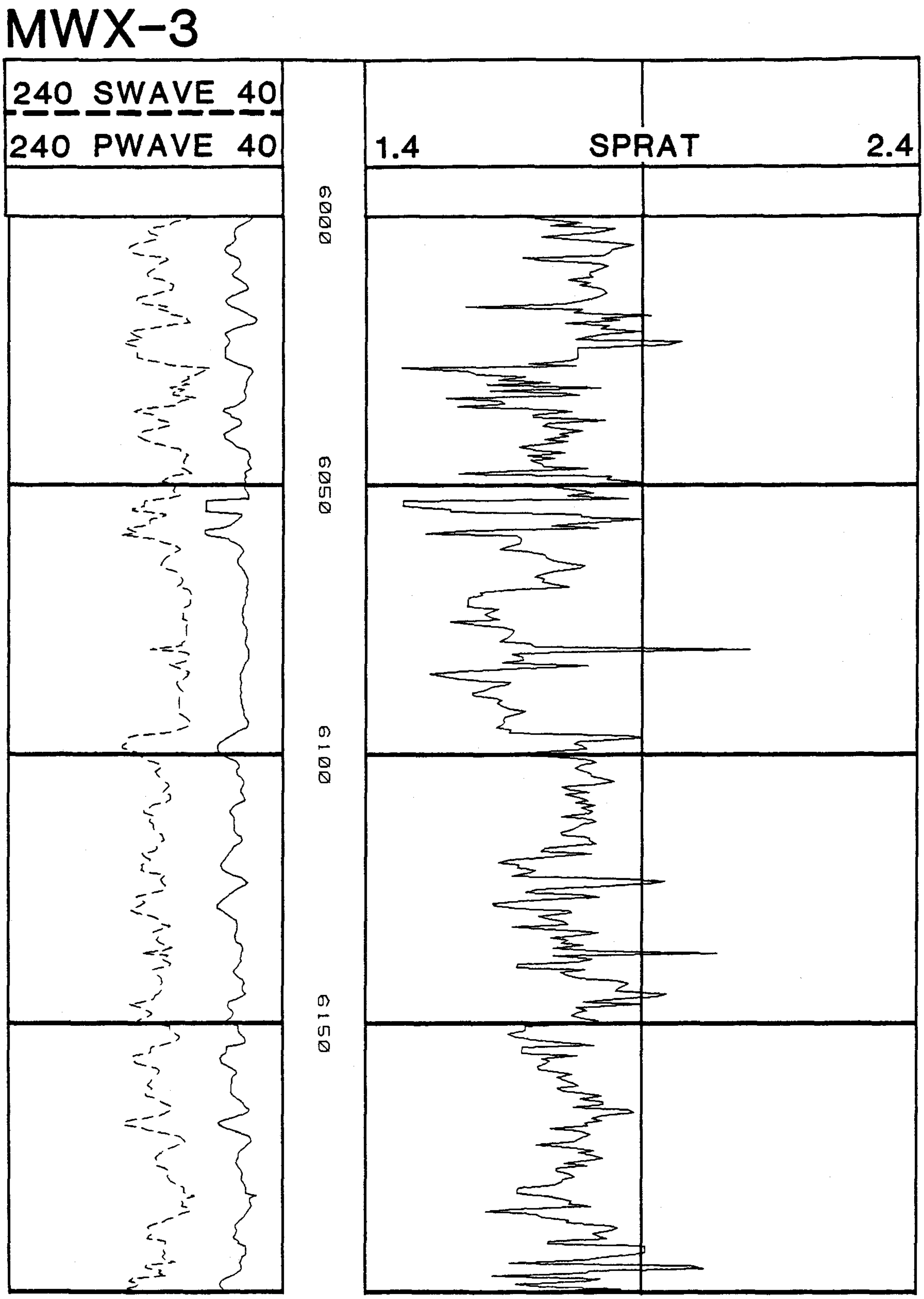
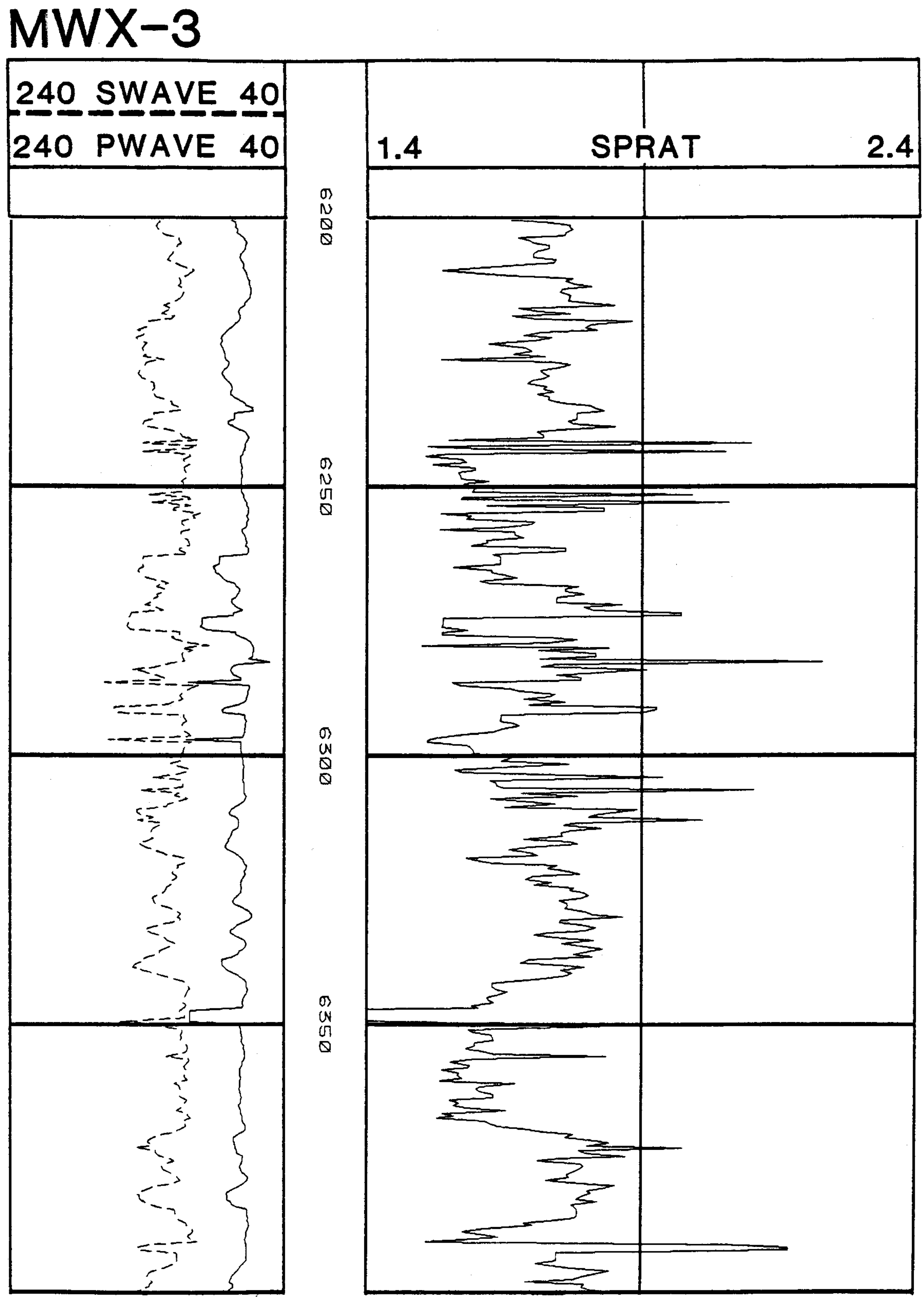


Figure 4.19 MWX-3 Long Spaced Sonic Log



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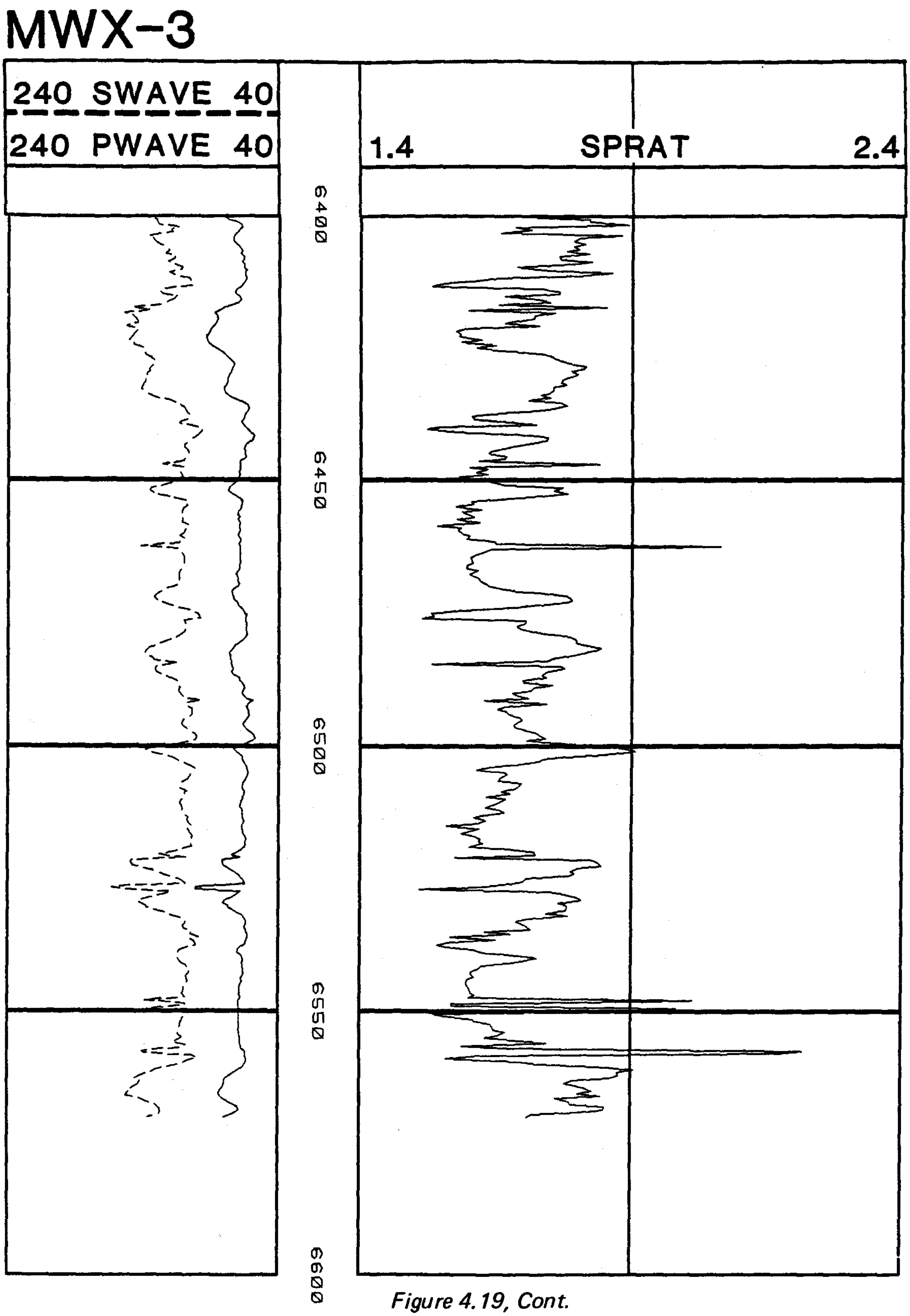

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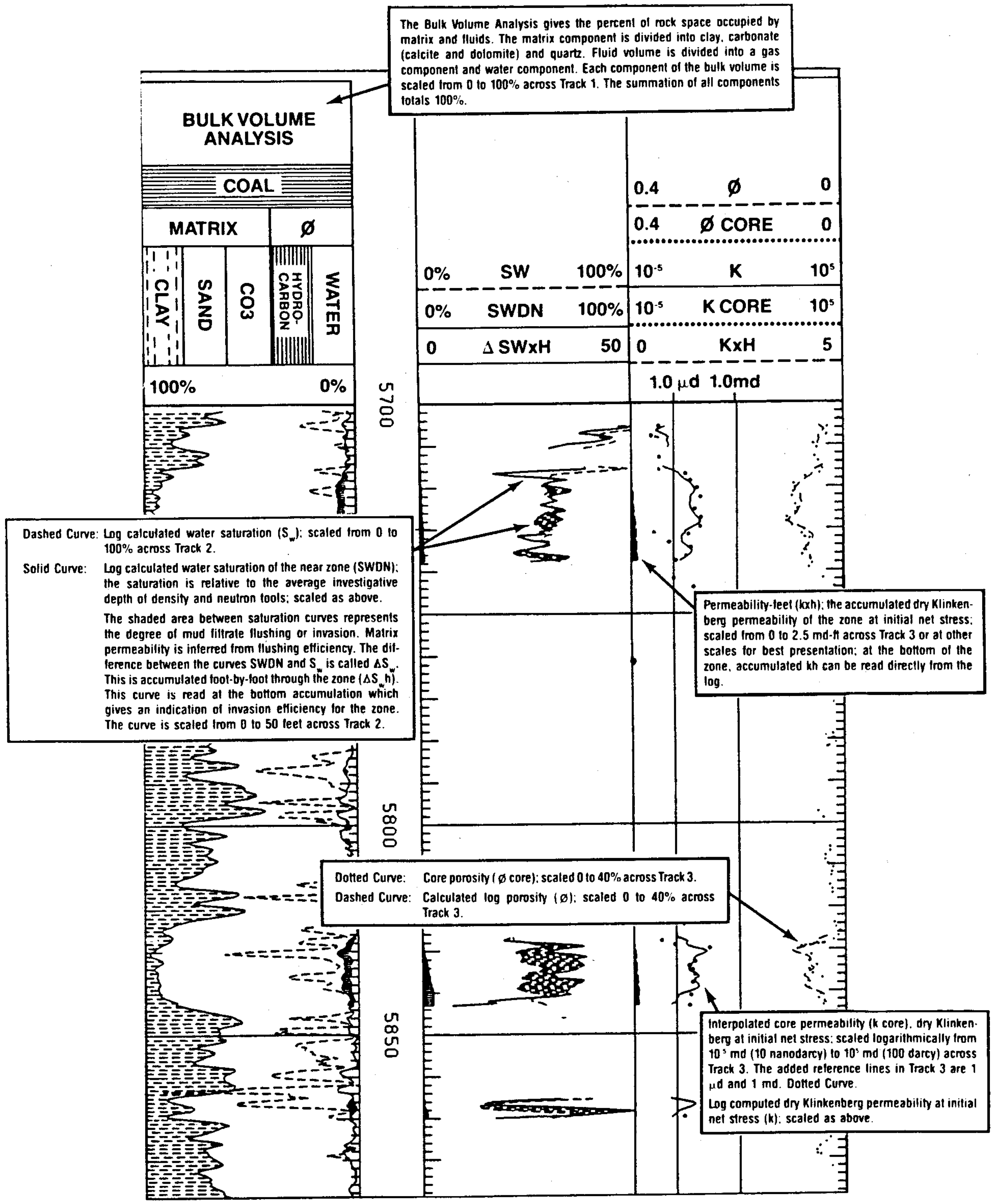


Figure 4.20 Format for TITEGAS Traceplot Output

CER

COMPUTER PROCESSED ANALYSIS

CER TIGHT GAS SANDSTONE ANALYSIS

A COMPREHENSIVE MODEL FOR THE LOG INTERPRETATION OF LOW-PERMEABILITY GAS RESERVOIRS

CER Corp. Post Office Box 15090 Las Vegas, Nevada 89114 Phone (702) 735-7136

COMPANY CER CORP.

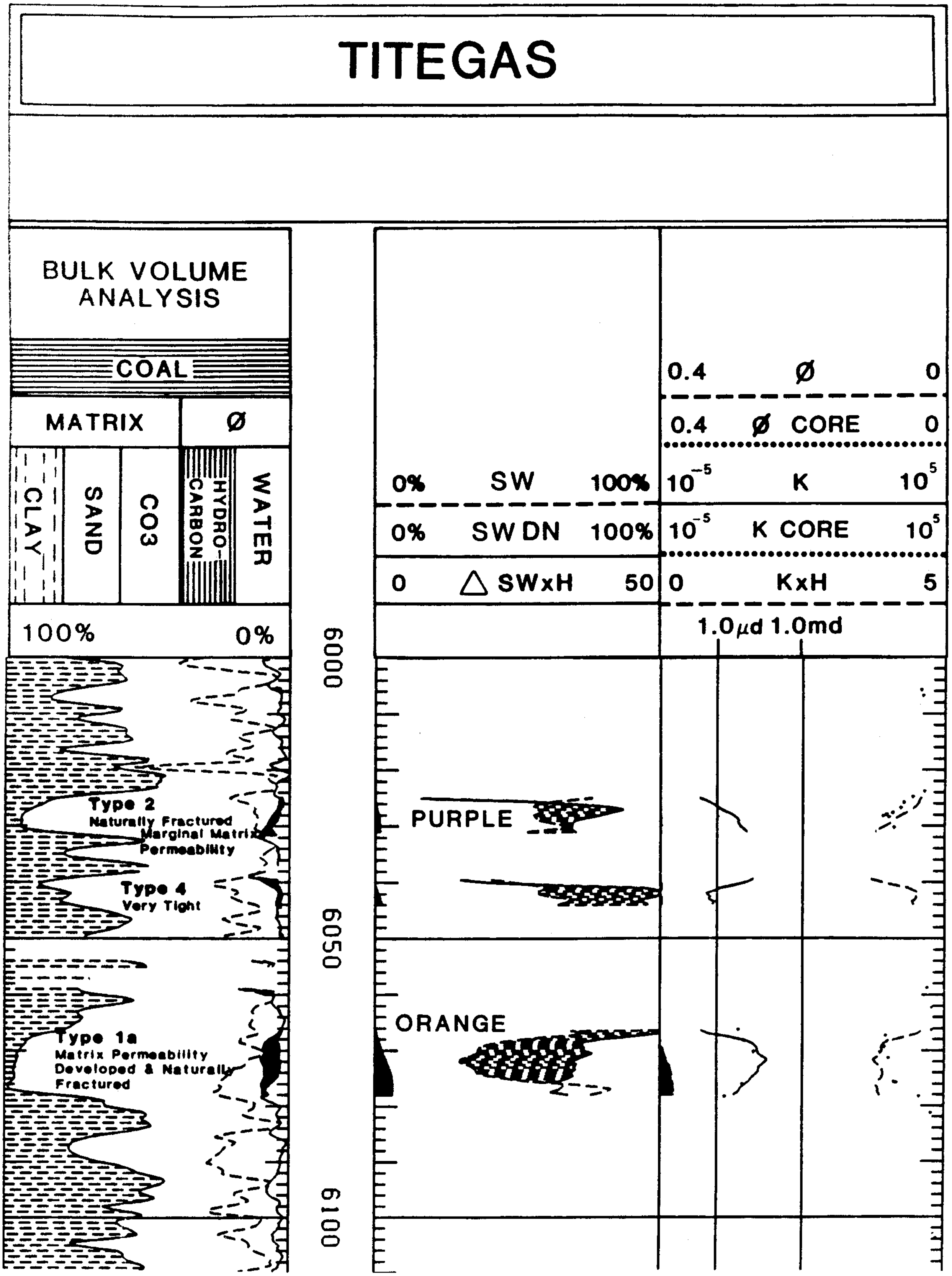
WELL MWX-1

FIELD RULISON

COUNTY GARFIELD STATE CO

DATE 1/15/86	LOCATION SW/SW	ELEVATION 5372.0 KB
		– DF
ANALYST SIMONS/HILL	SEC. 34 TWP. 6S RGE. 94W	5355.0 GL

Figure 4.21 MWX-1 Computer Processed Analysis



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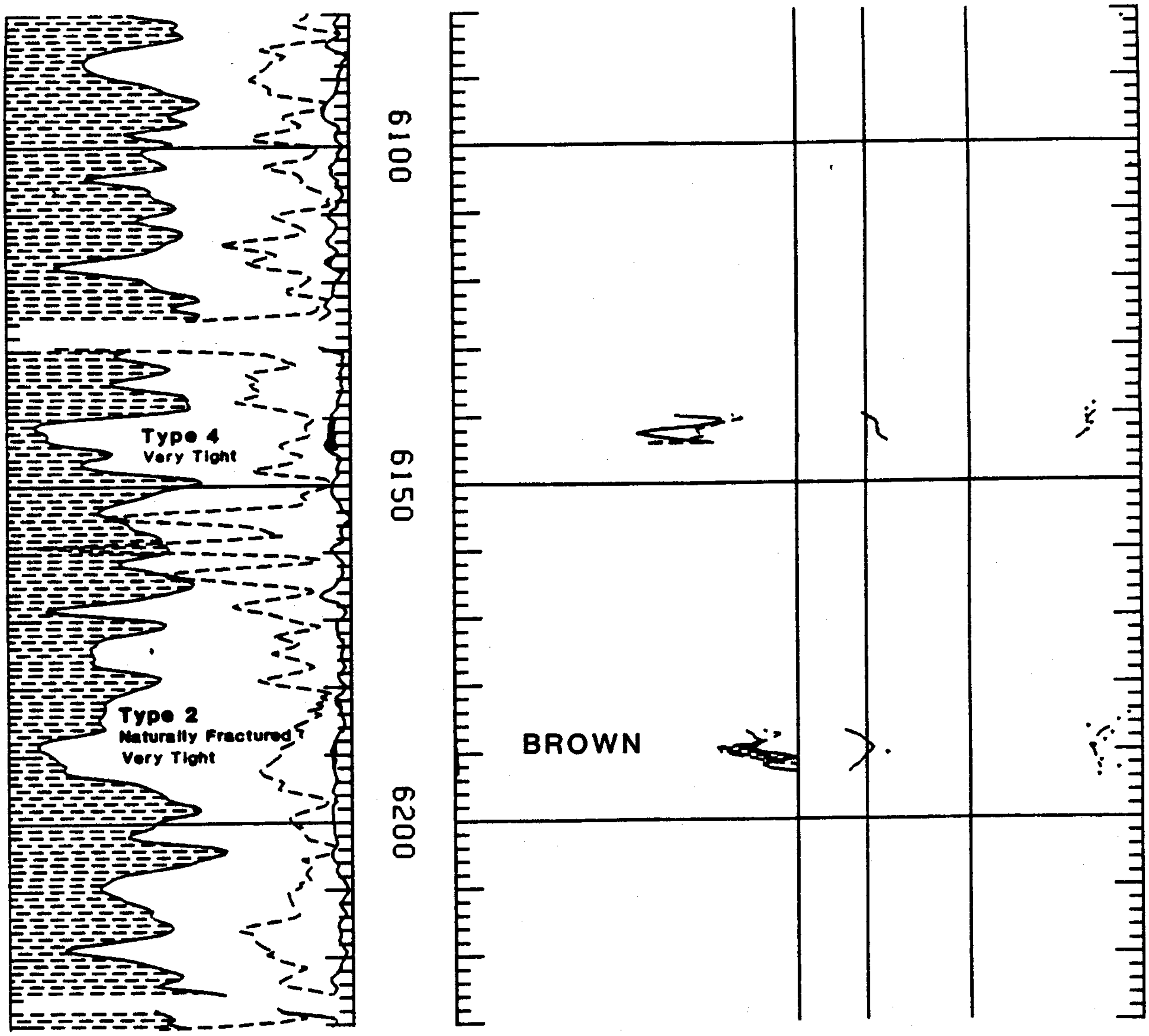

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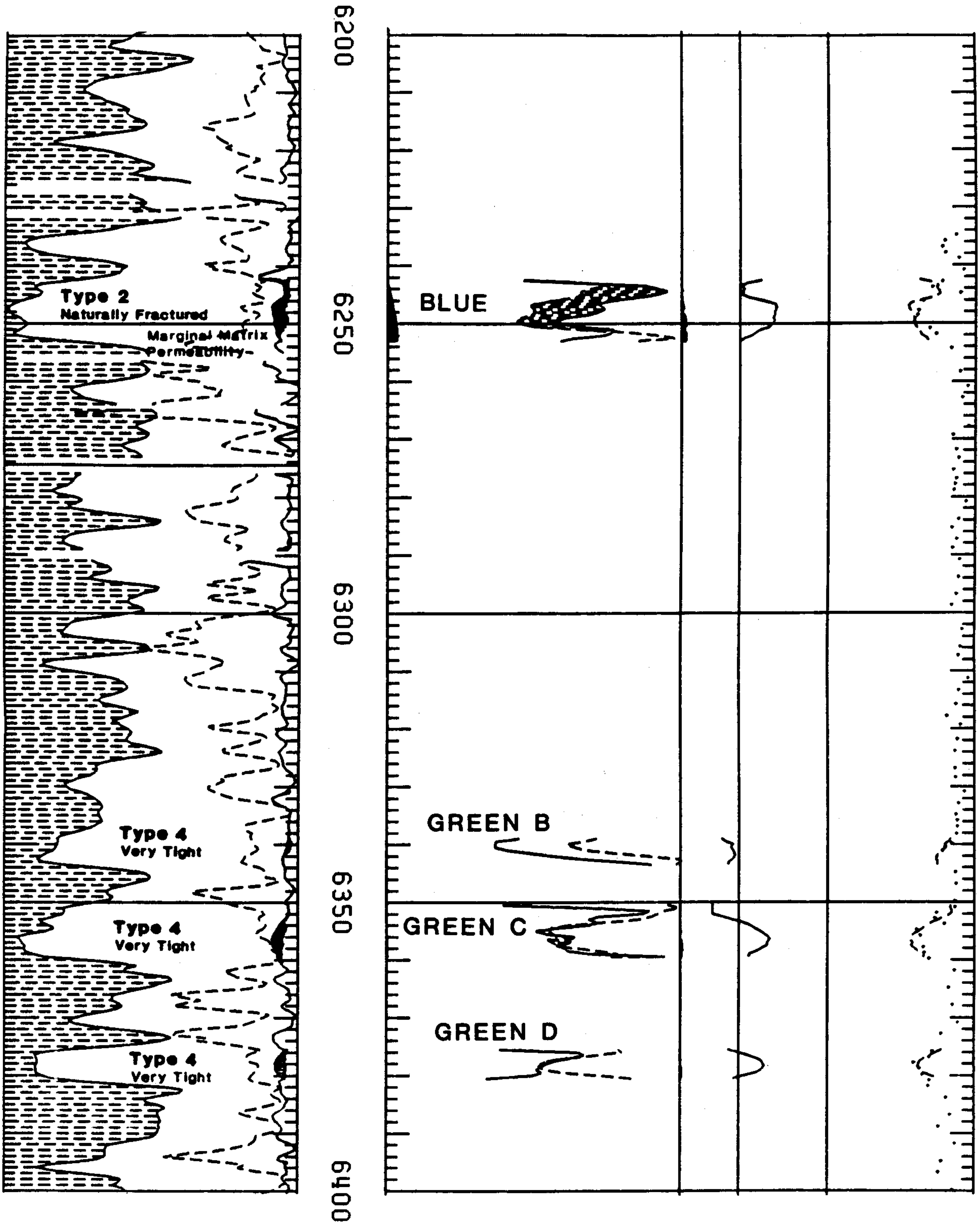

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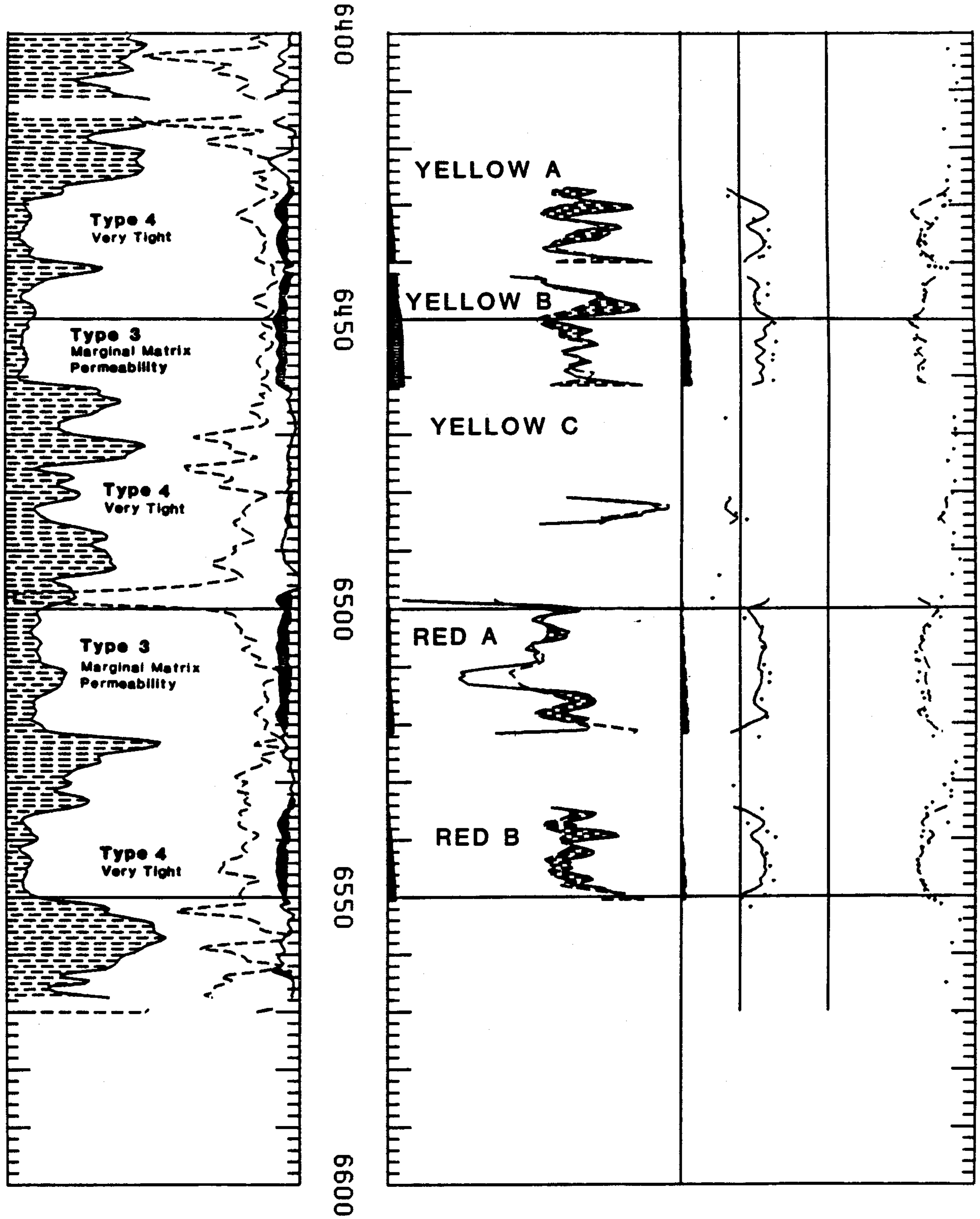


Figure 4.21, Cont.

CER

COMPUTER PROCESSED ANALYSIS

CER TIGHT GAS SANDSTONE ANALYSIS

A COMPREHENSIVE MODEL FOR THE LOG INTERPRETATION OF LOW-PERMEABILITY GAS RESERVOIRS

CER Corp. Post Office Box 15090 Las Vegas, Nevada 89114 Phone (702) 735-7136

COMPANY CER CORP.

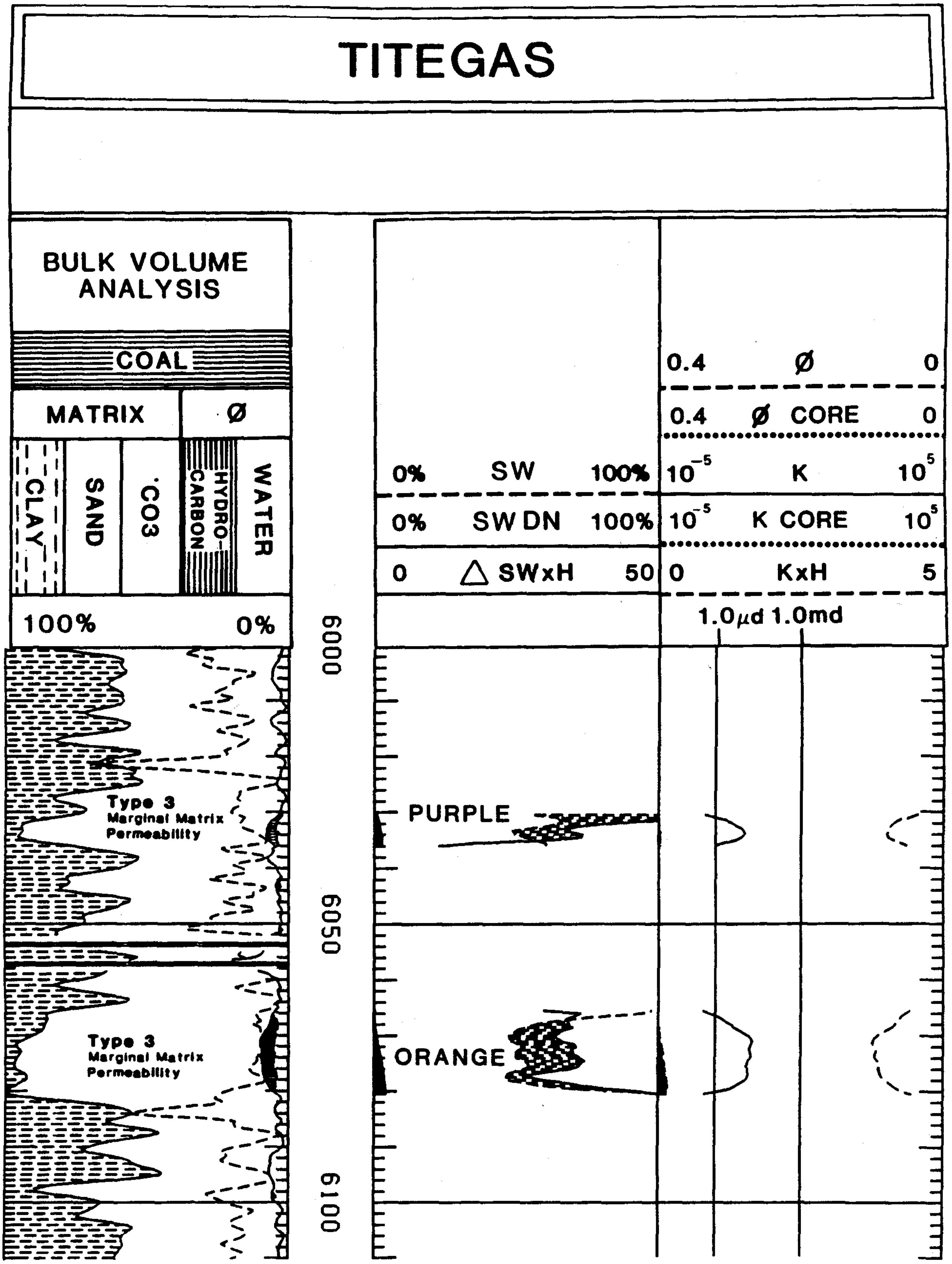
WELL MWX-2

FIELD RULISON

COUNTY GARFIELD STATE CO

DATE 1/15/86	LOCATION SW/SW	ELEVATION 5374.0 KB 5372.5 DF 5355.0 GL
ANALYST SIMONS/HILL	SEC. 34 TWP. 6S RGE. 94W	

Figure 4.22 MWX-2 Computer Processed Analysis



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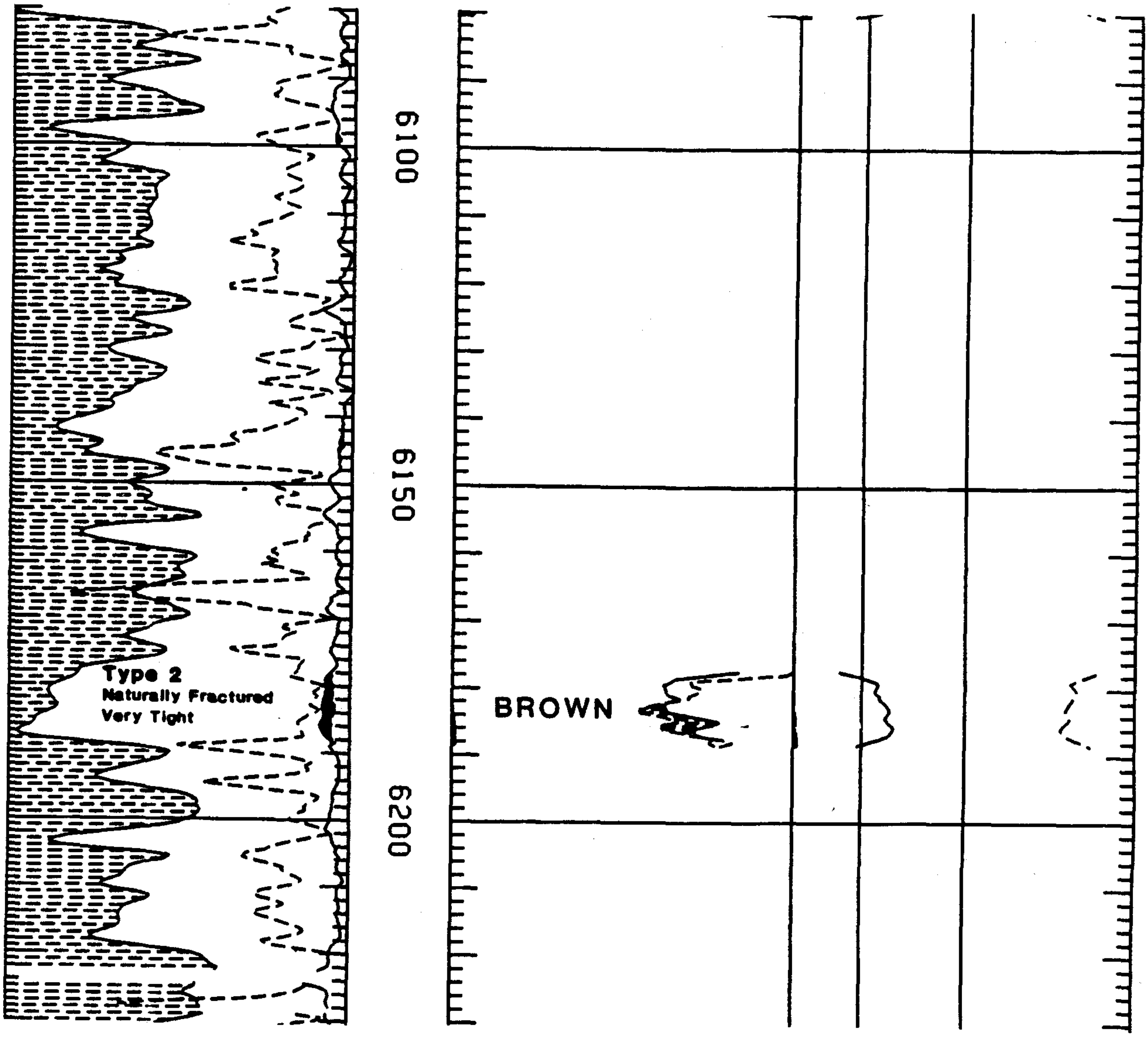

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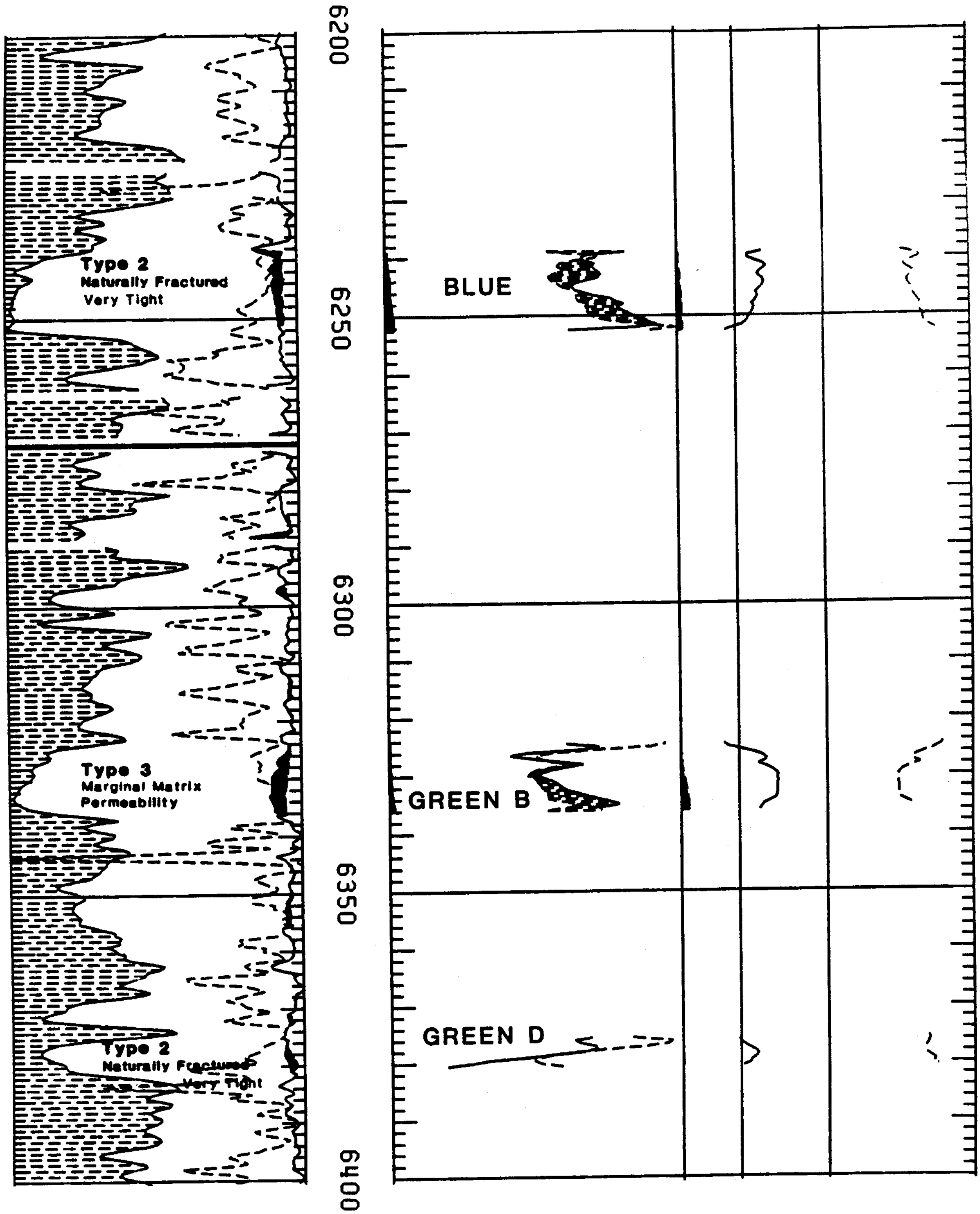

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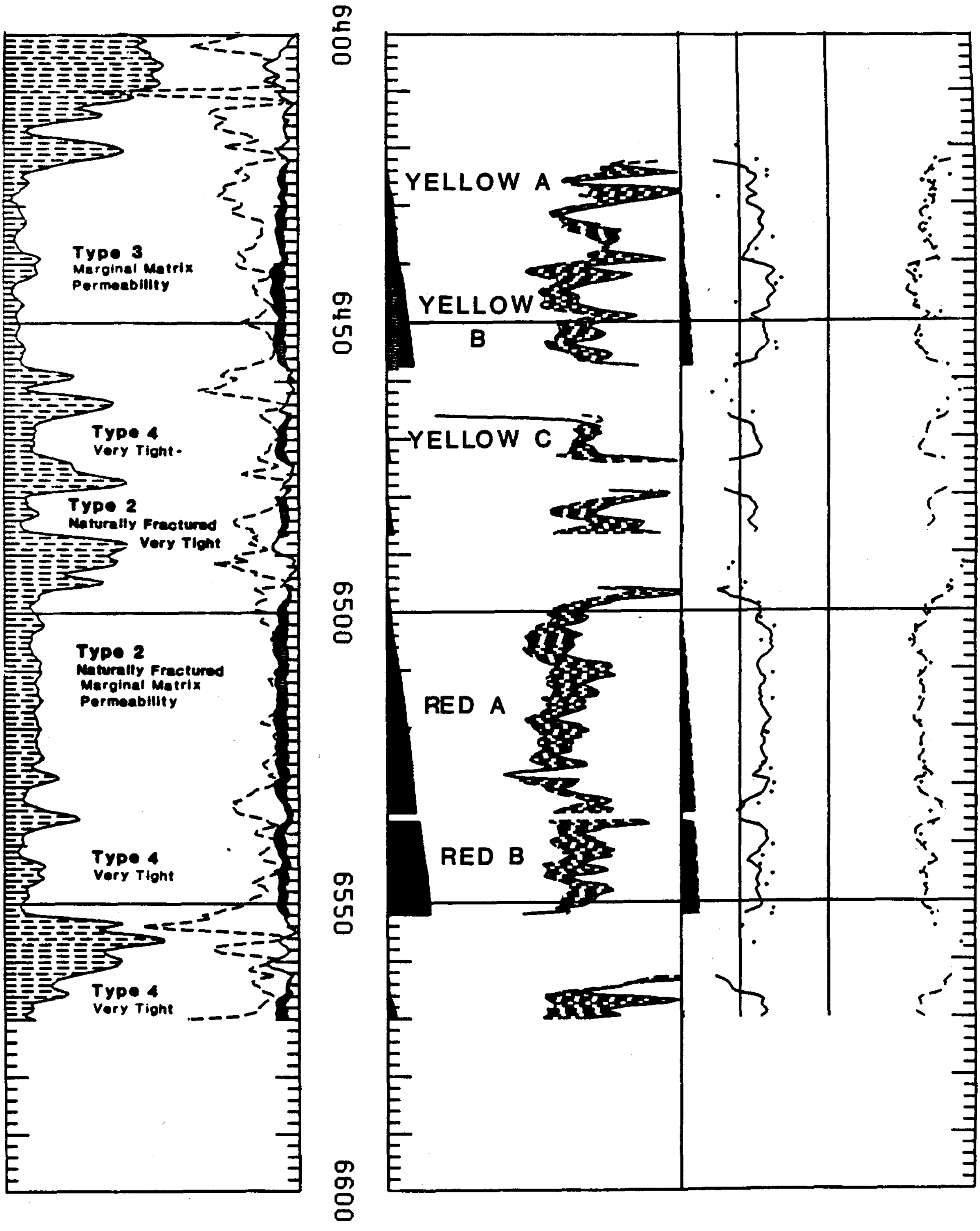


Figure 4.22, Cont.

COMPUTER PROCESSED ANALYSIS

CER

CER TIGHT GAS SANDSTONE ANALYSIS

A COMPREHENSIVE MODEL FOR THE LOG INTERPRETATION OF LOW-PERMEABILITY GAS RESERVOIRS

CER Corp. Post Office Box 15090 Las Vegas, Nevada 89114 Phone (702) 735-7136

COMPANY CER CORP.

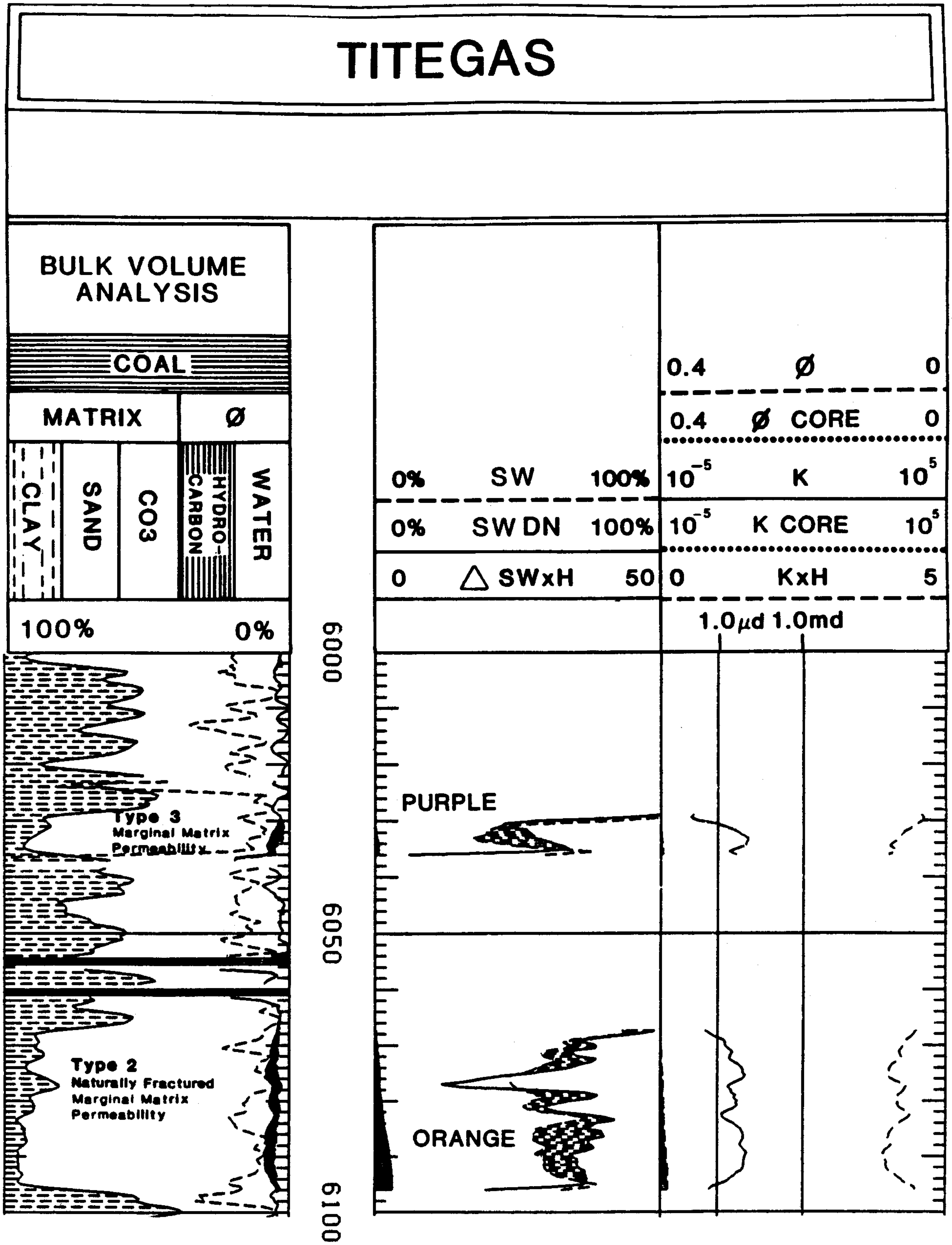
WELL MWX-3

FIELD RULISON

COUNTY GARFIELD STATE CO

DATE 1/15/86	LOCATION SW/SW	ELEVATION 5379.0 KB 5378.0 DF 5359.5 GL
ANALYST SIMONS/HILL	SEC. 34 TWP. 6S RGE. 94W	

Figure 4.23 MWX-3 Computer Processed Analysis



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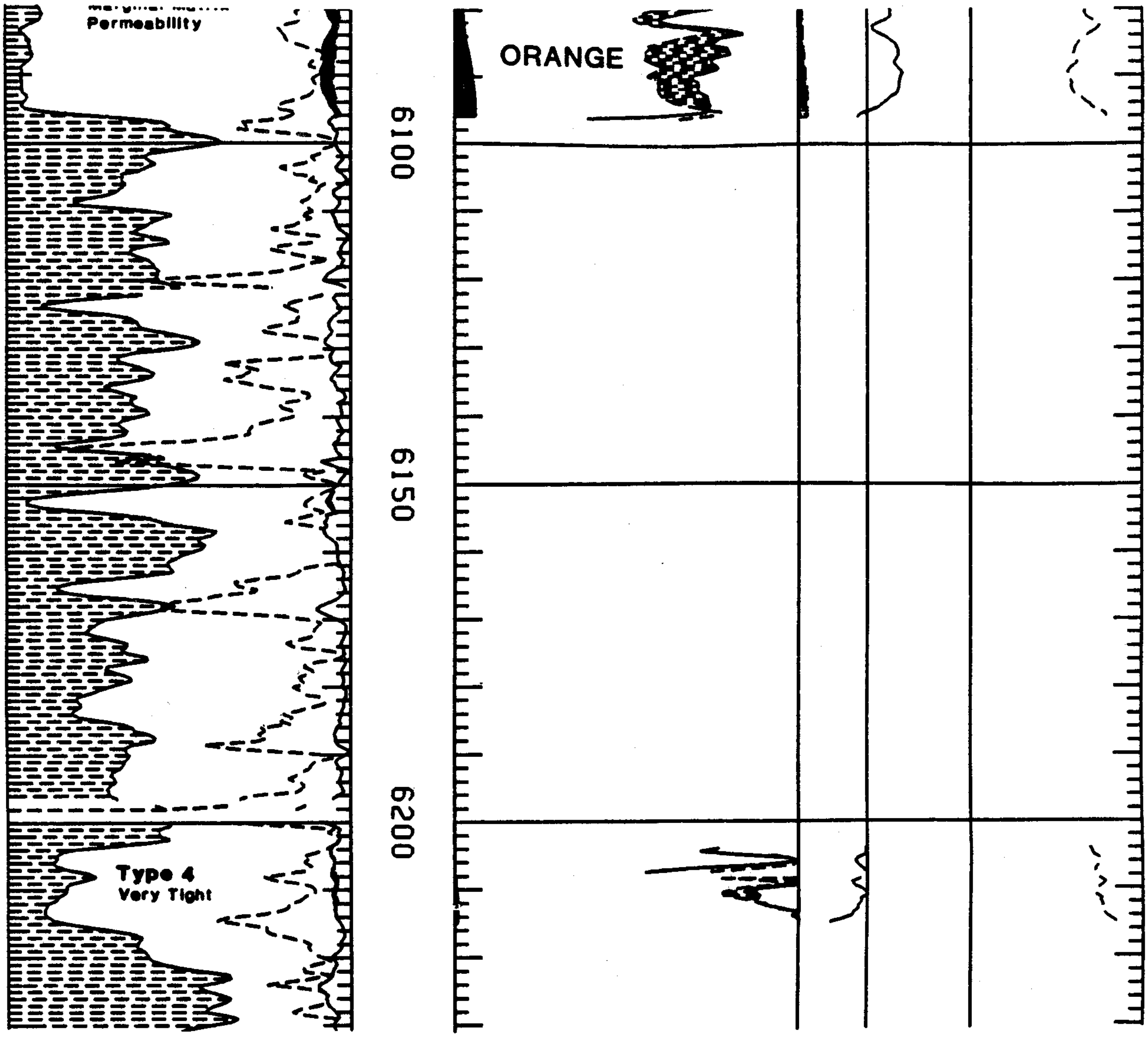

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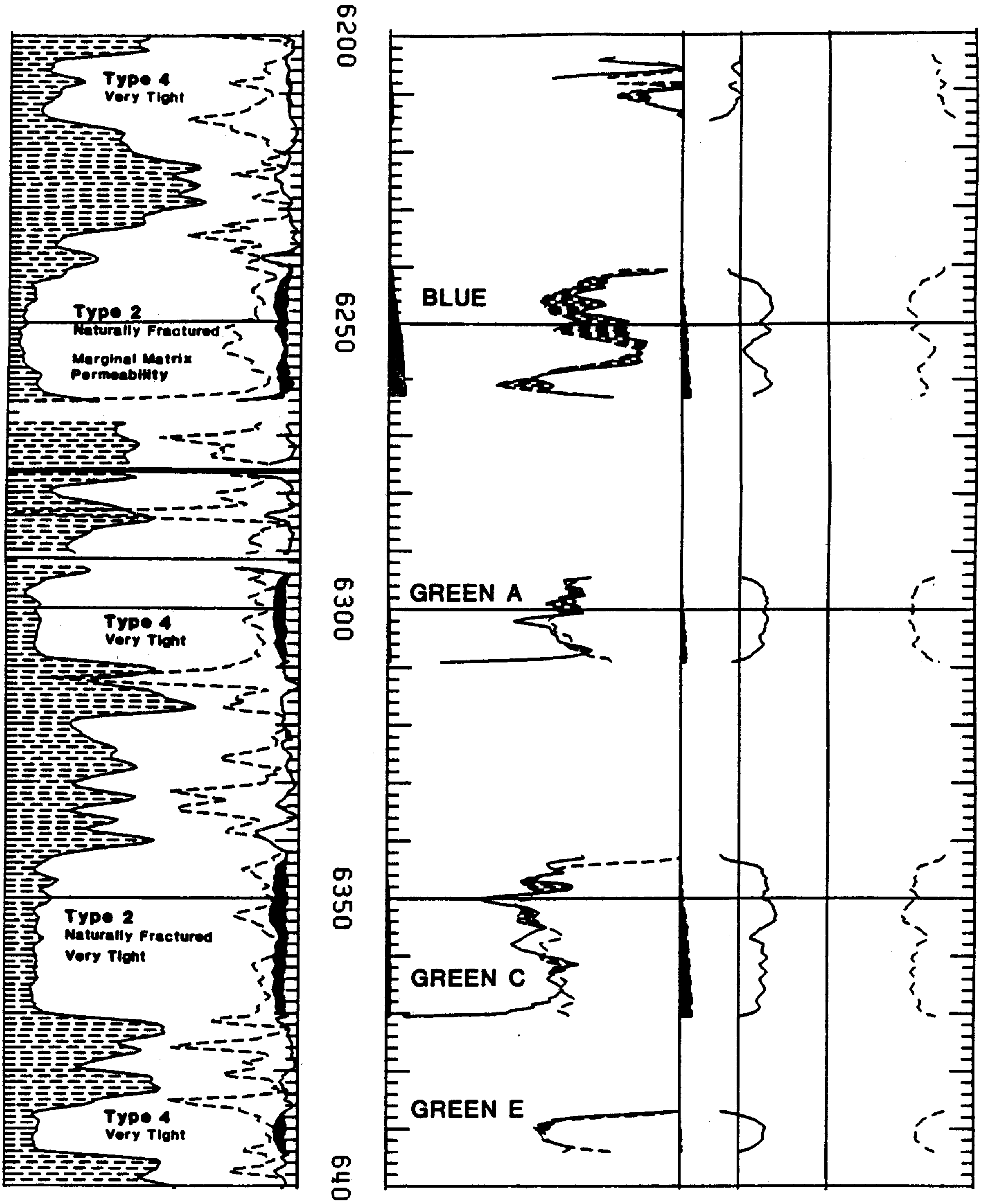

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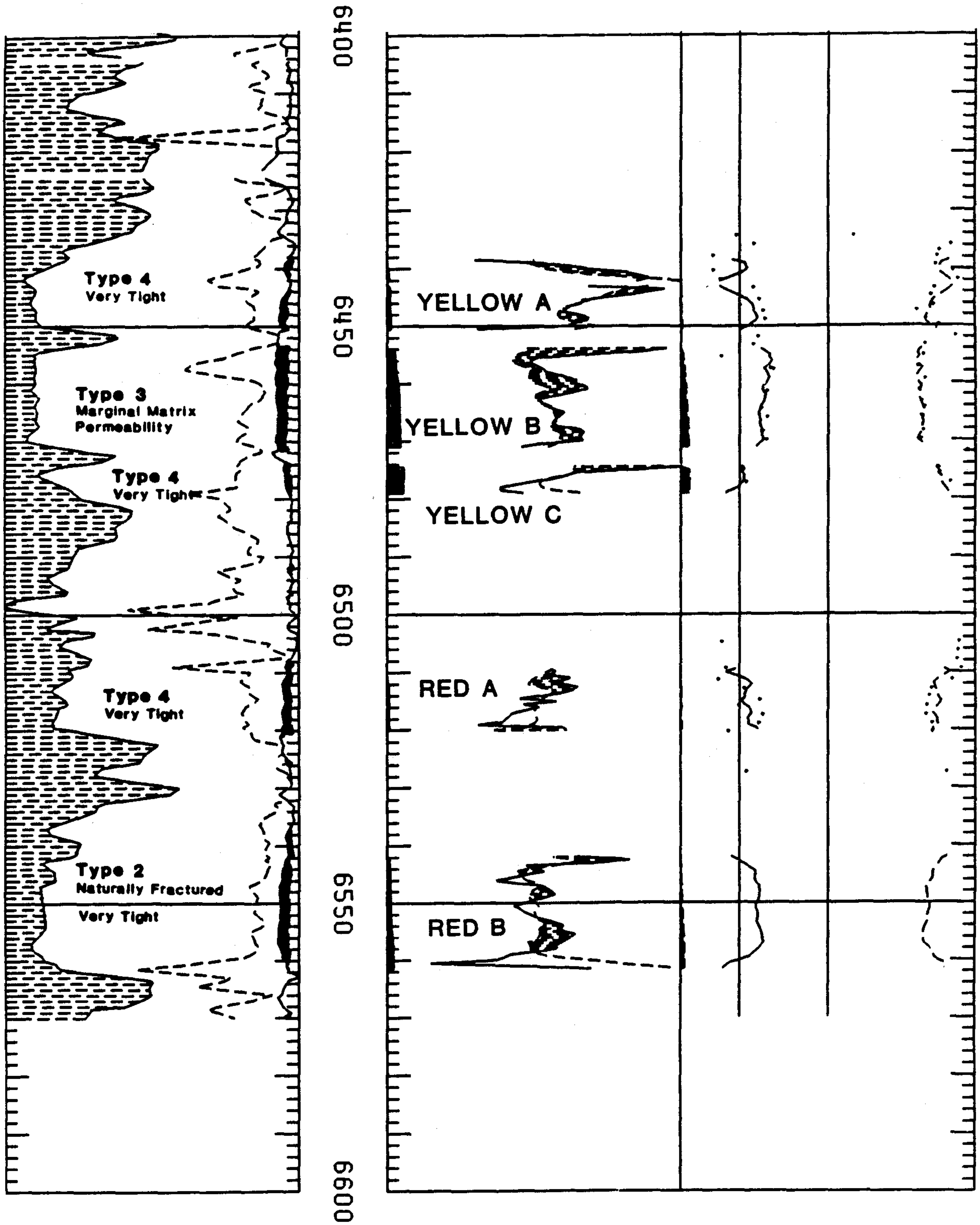


Figure 4.23, Cont.

CER COMPUTER PROCESSED ANALYSIS

CER TIGHT GAS SANDSTONE ANALYSIS

FRACTURE LOGS

CER Corp. Post Office Box 15090 Las Vegas, Nevada 89114 Phone (702) 735-7136

COMPANY CER CORP.

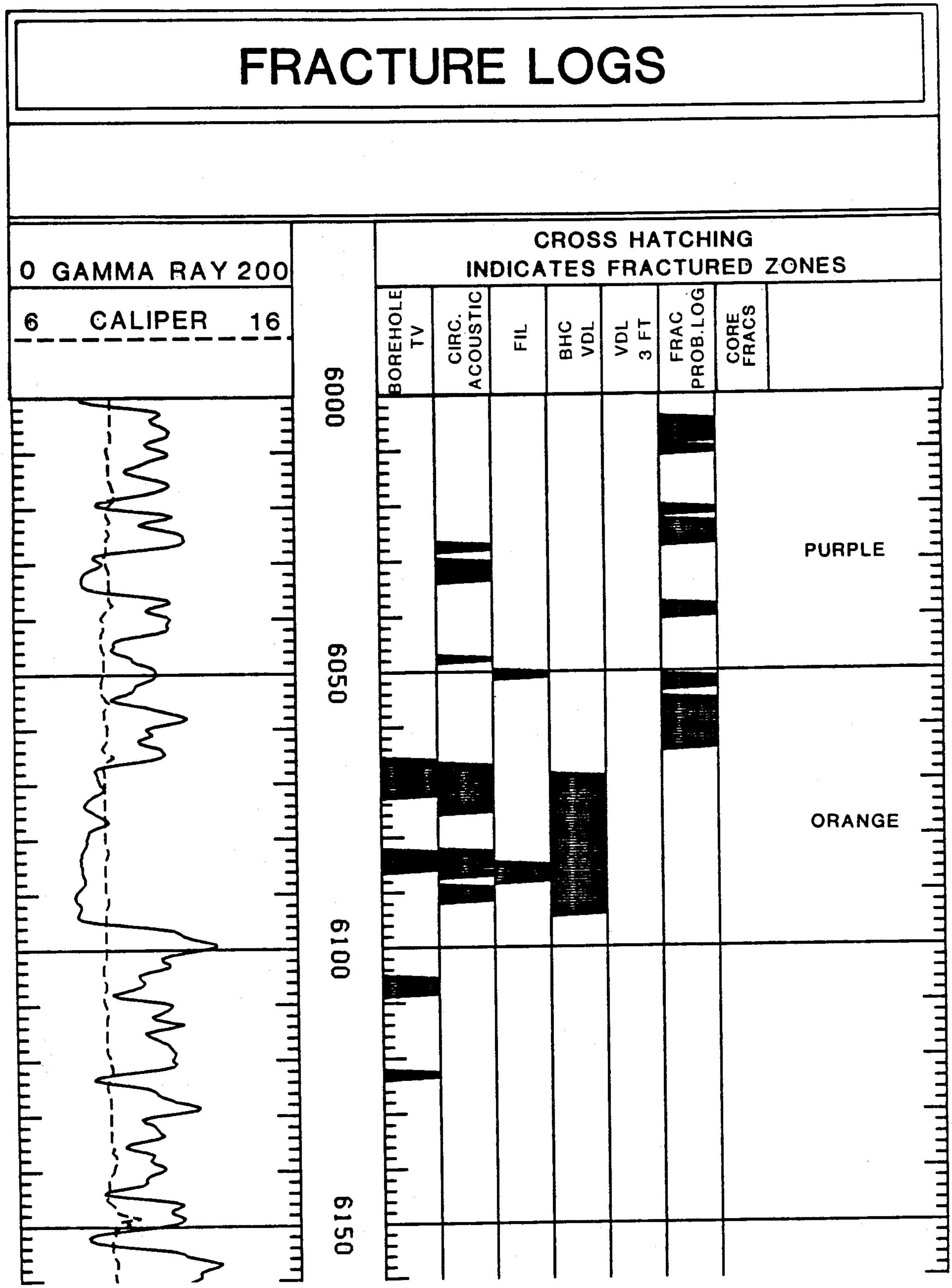
WELL MWX-3

FIELD RULISON

COUNTY GARFIELD STATE CO

DATE 1/25/84	LOCATION SW/NW	ELEVATION
		5379 KB
		5378 DF
ANALYST MONSON	SEC. 34 TWP. 6S RGE. 94W	5359.5 GL

Figure 4.24 MWX-3 Interpretation of Fracture Logs



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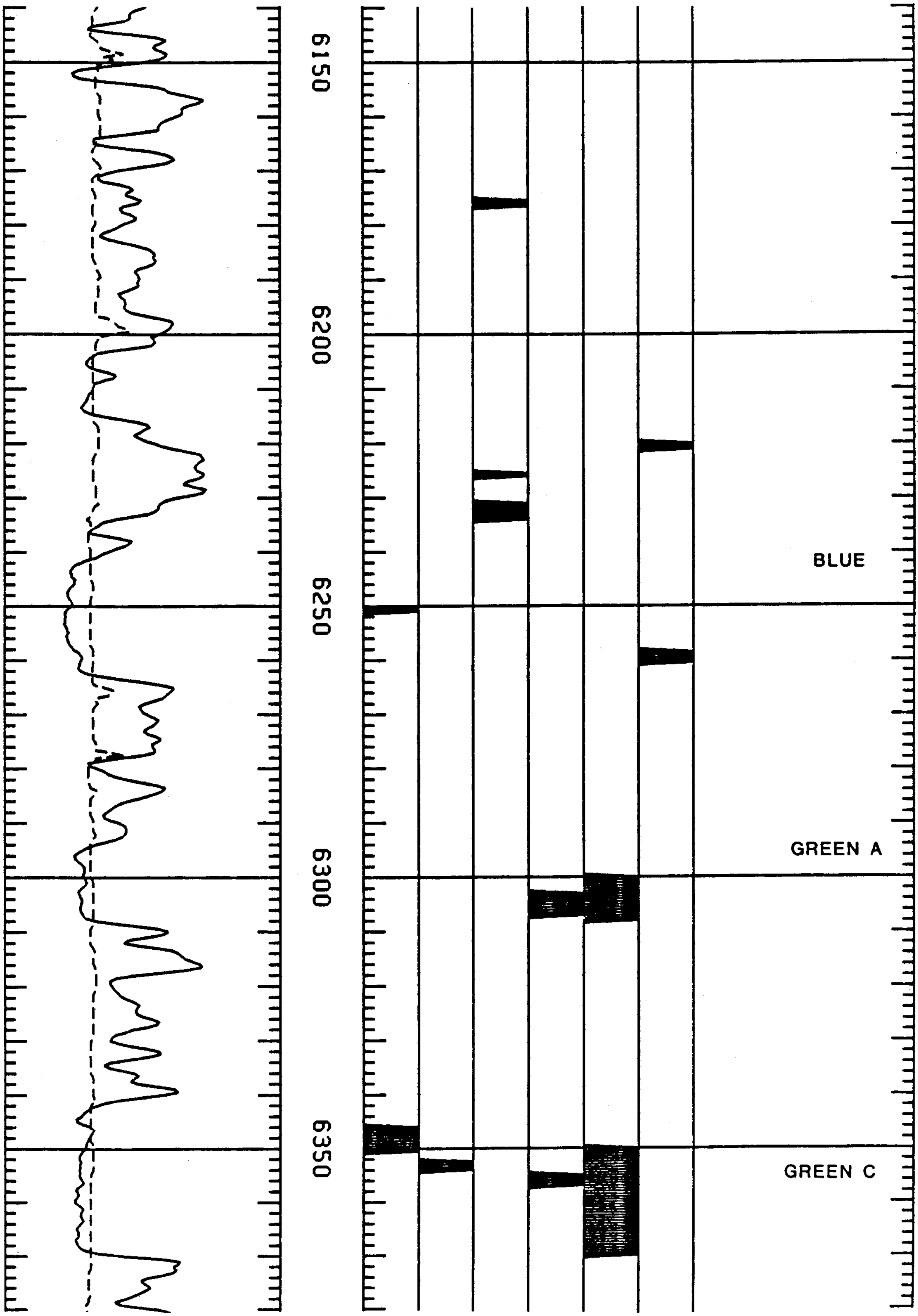


Figure 4.24, Cont.

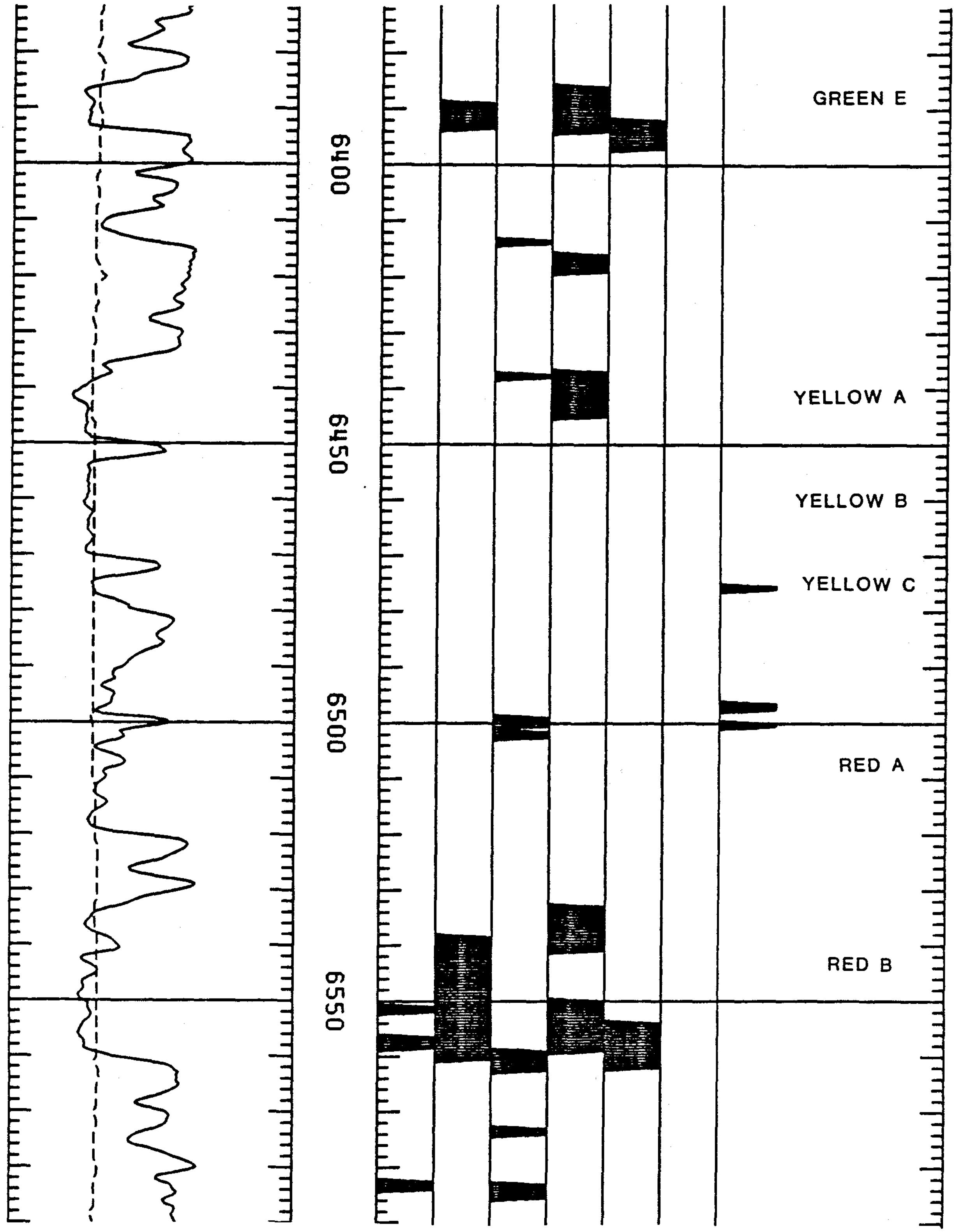
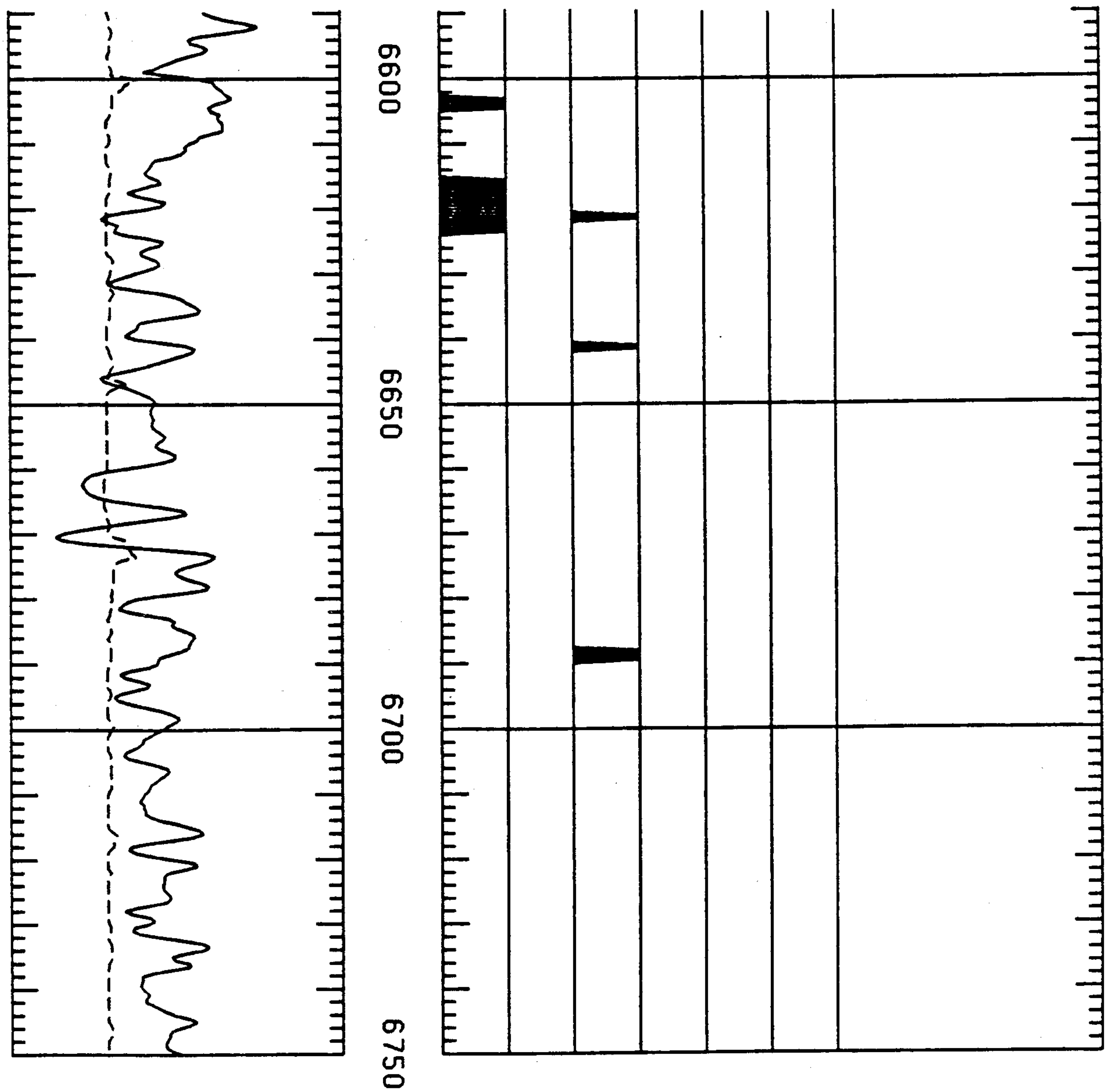


Figure 4.24, Cont.



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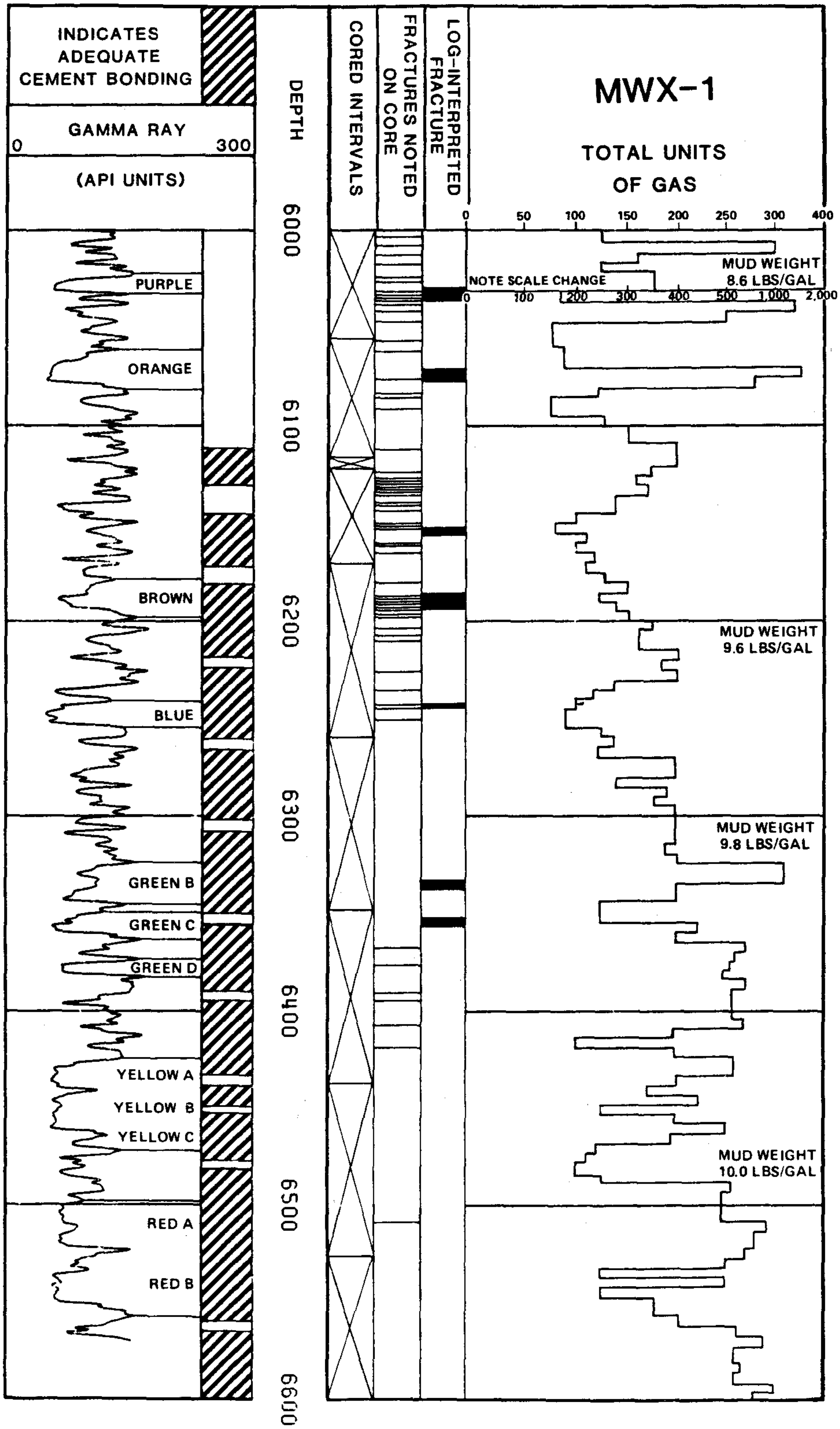


Figure 4.25 Composite Mud Log Including Natural Fracture Data, MWX-1 Coastal Interval

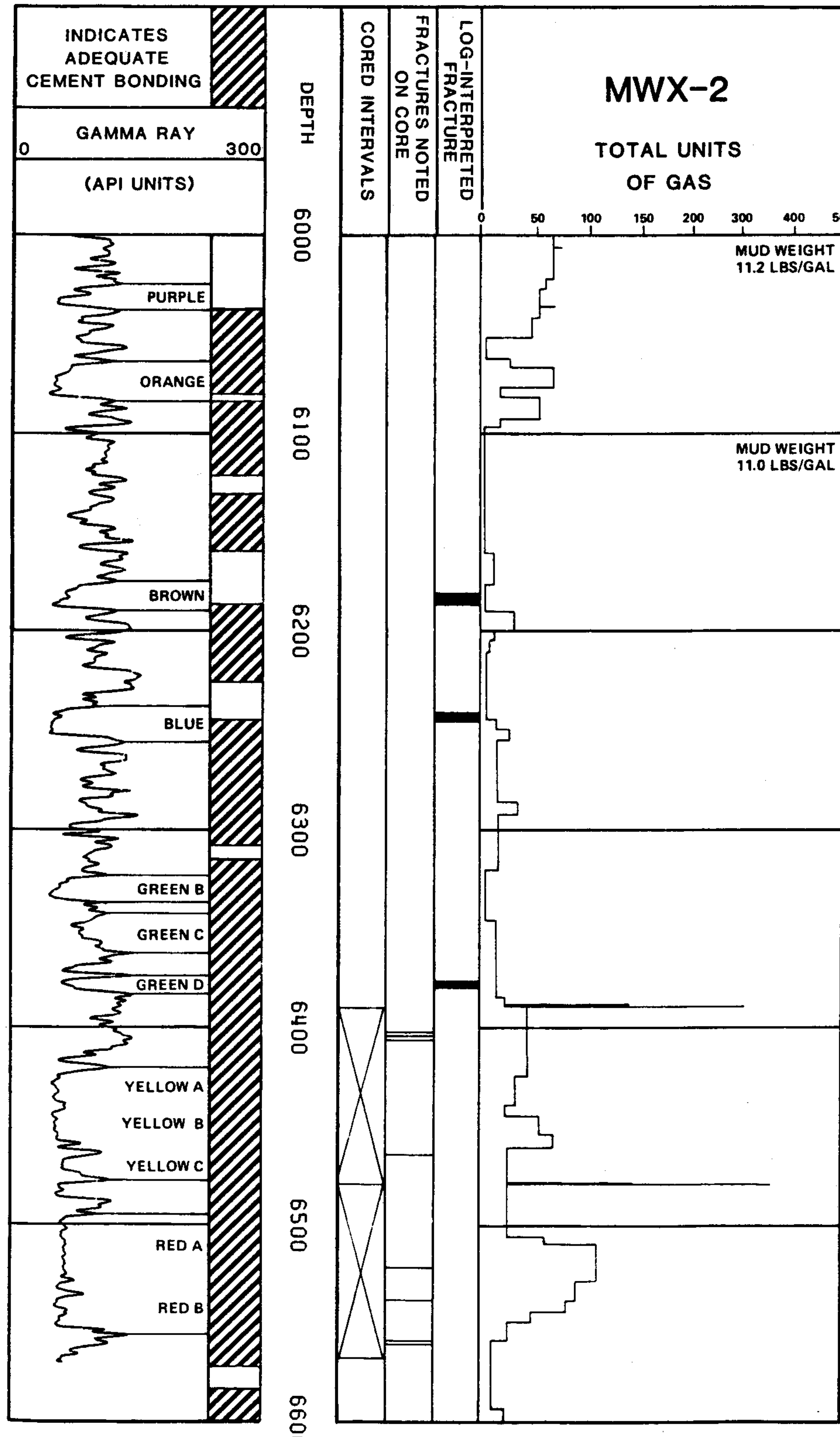


Figure 4.26 Composite Mud Log Including Natural Fracture Data, MWX-2 Coastal Interval

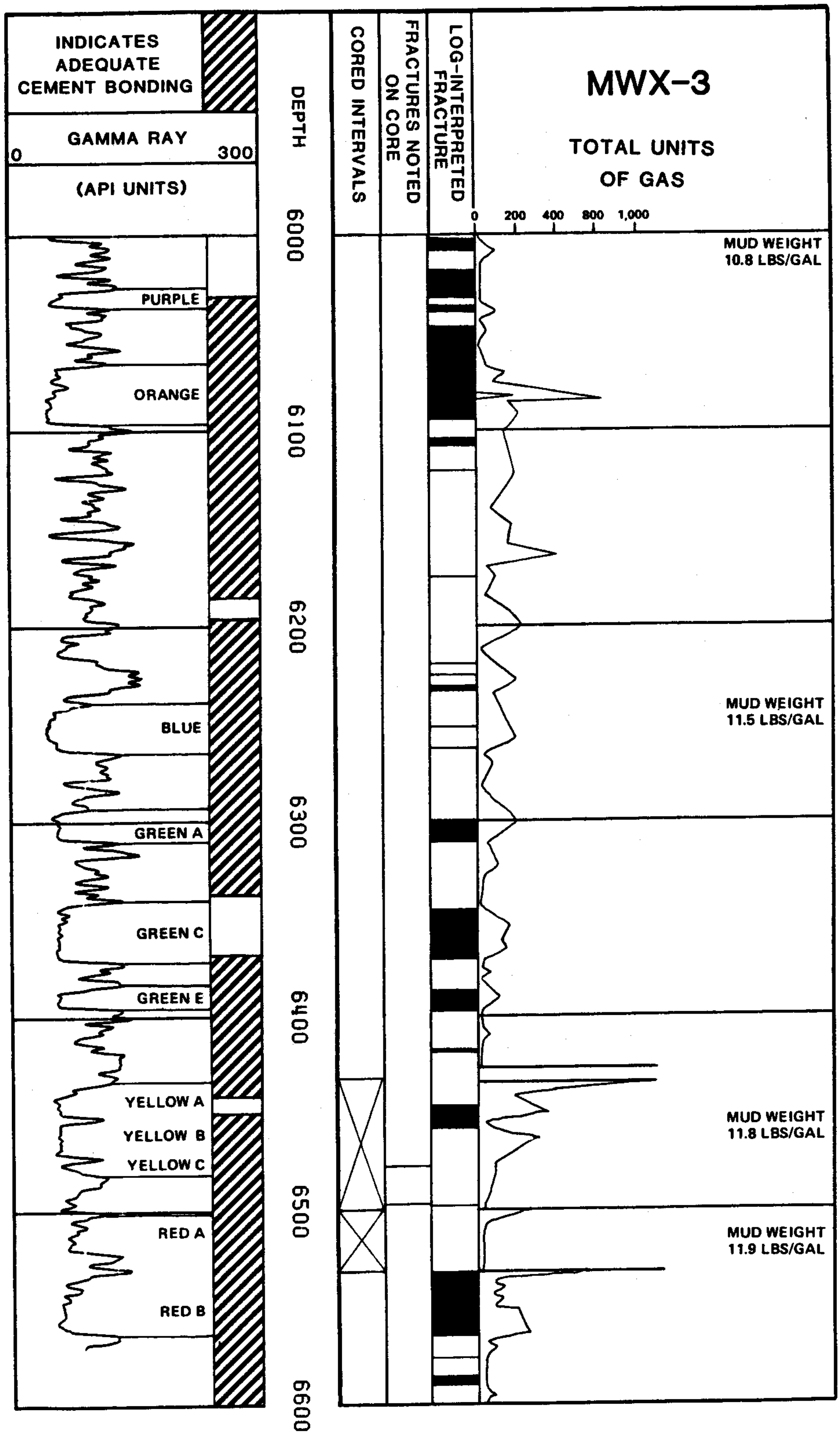


Figure 4.27 Composite Mud Log Including Natural Fracture Data, MWX-3 Coastal Interval

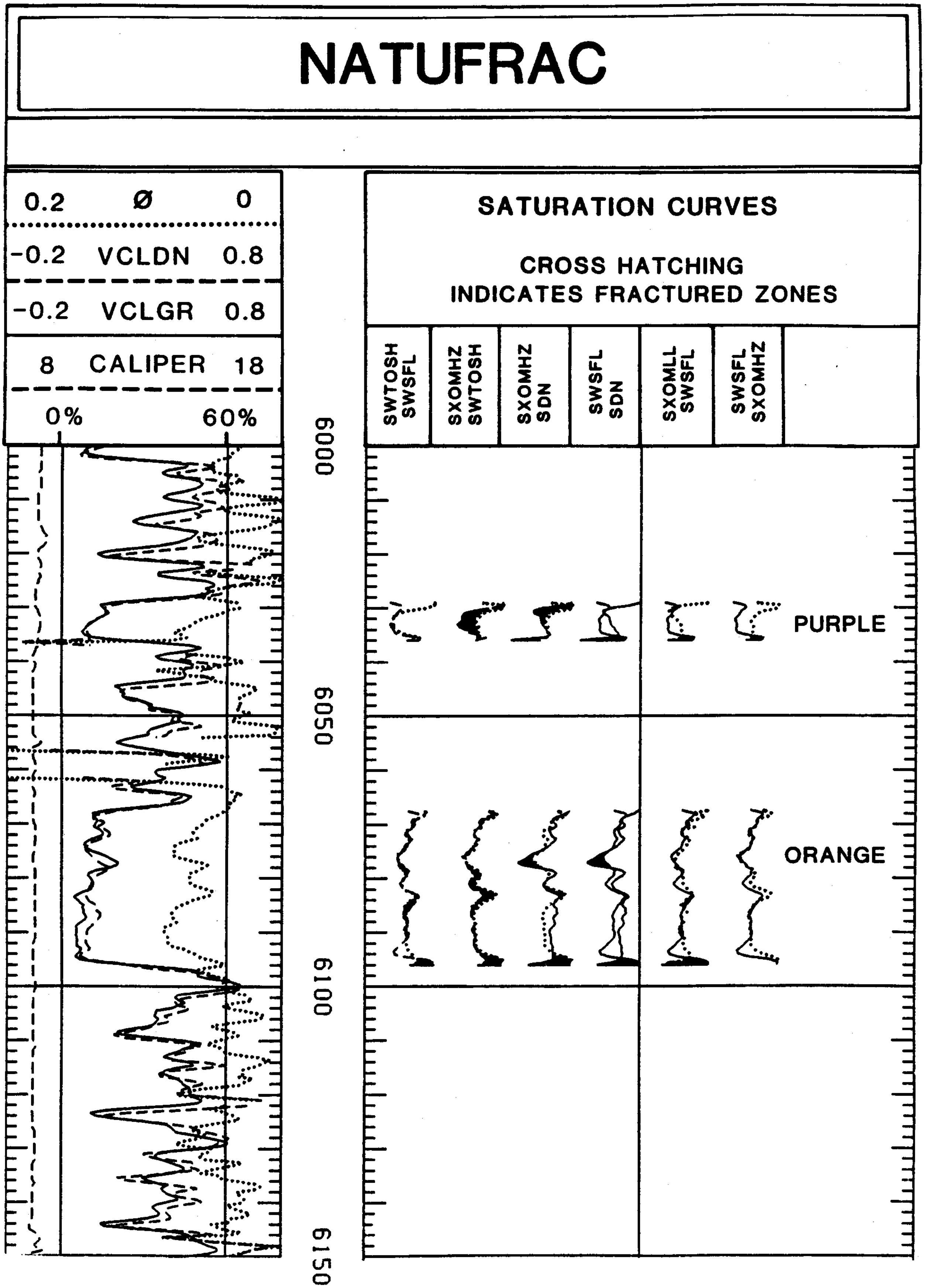


Figure 4.28 MWX-3 NATUFRAC Computed Log

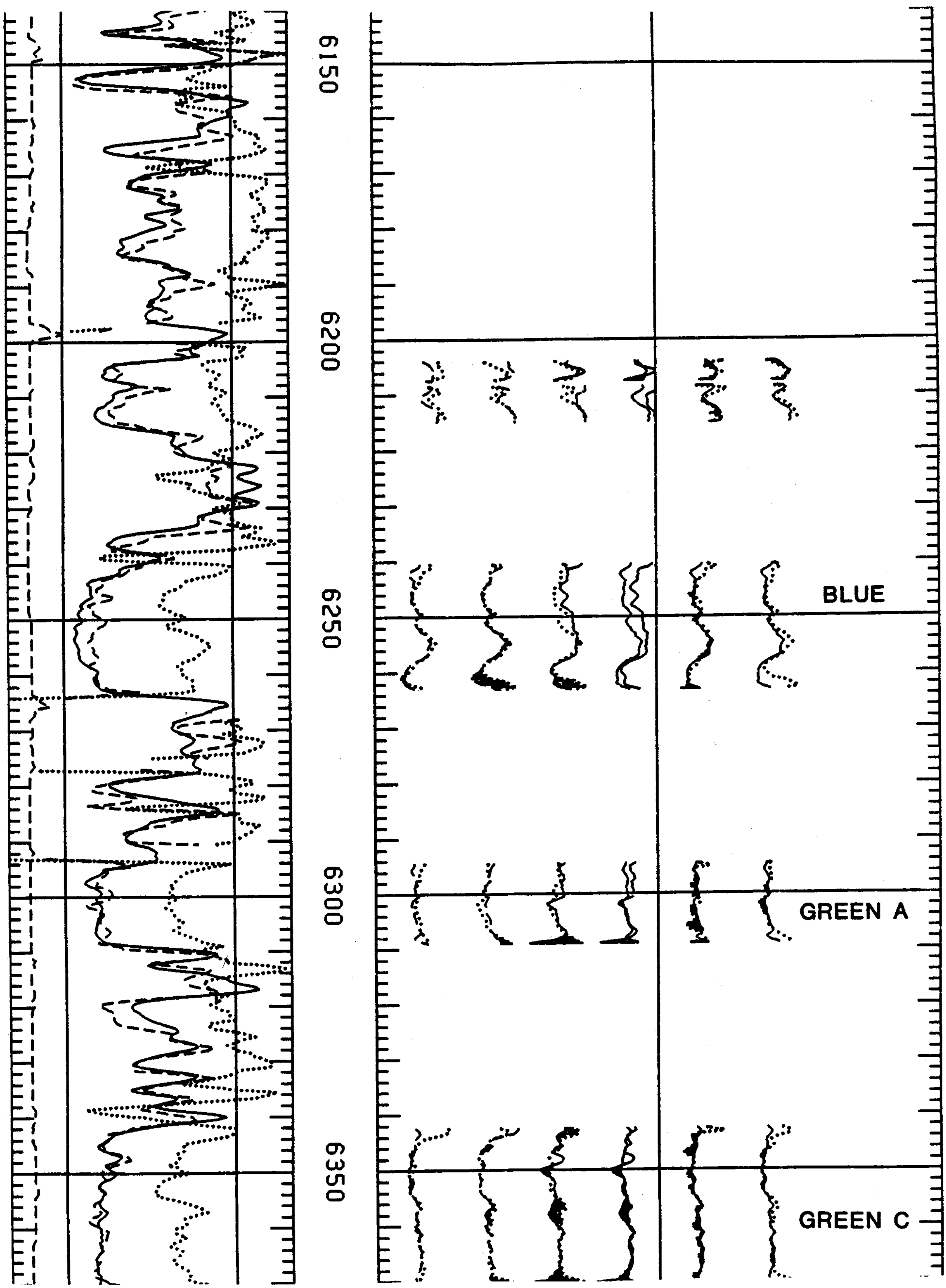


Figure 4.28, Cont.

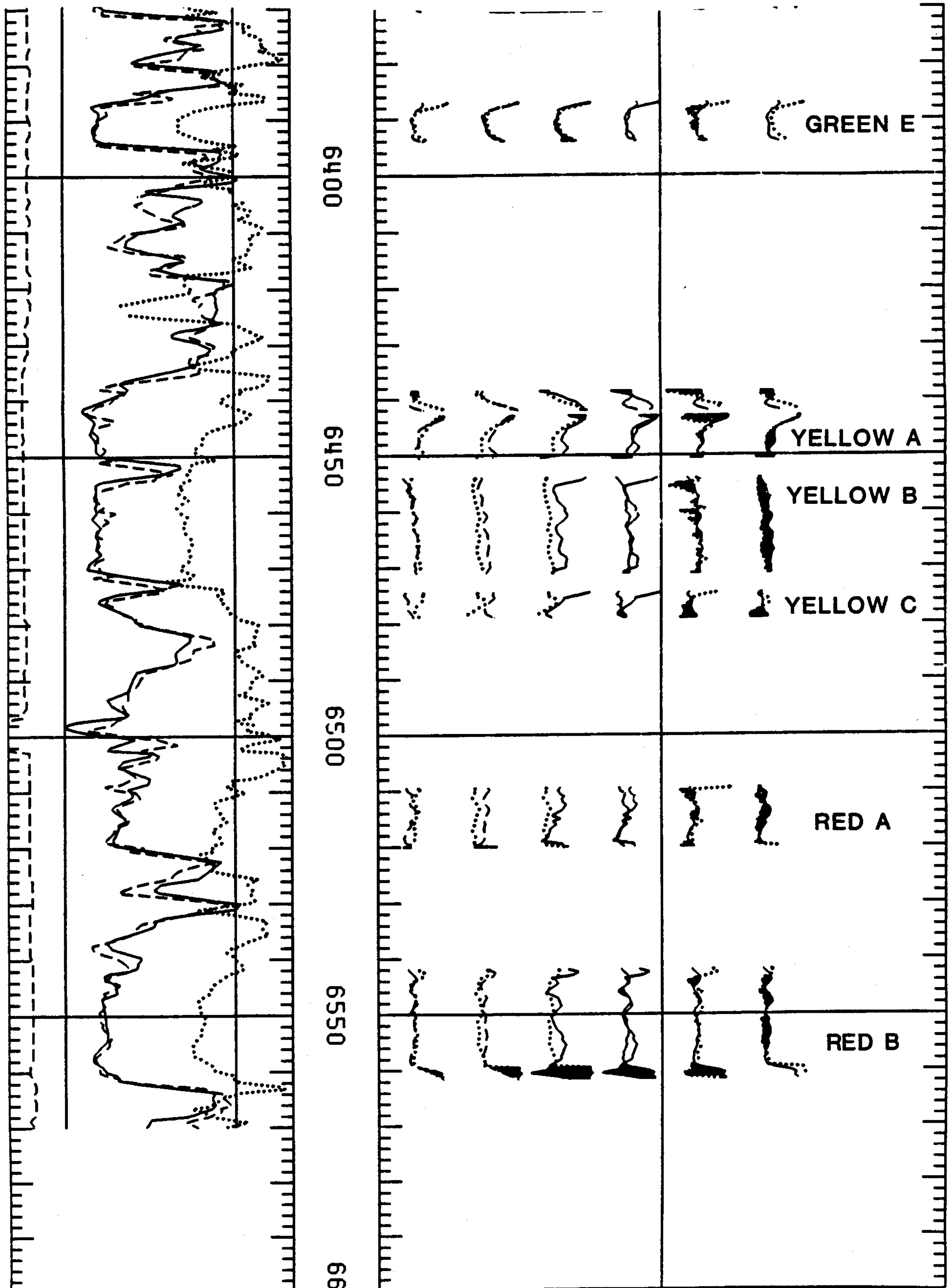


Figure 4.28, Cont.

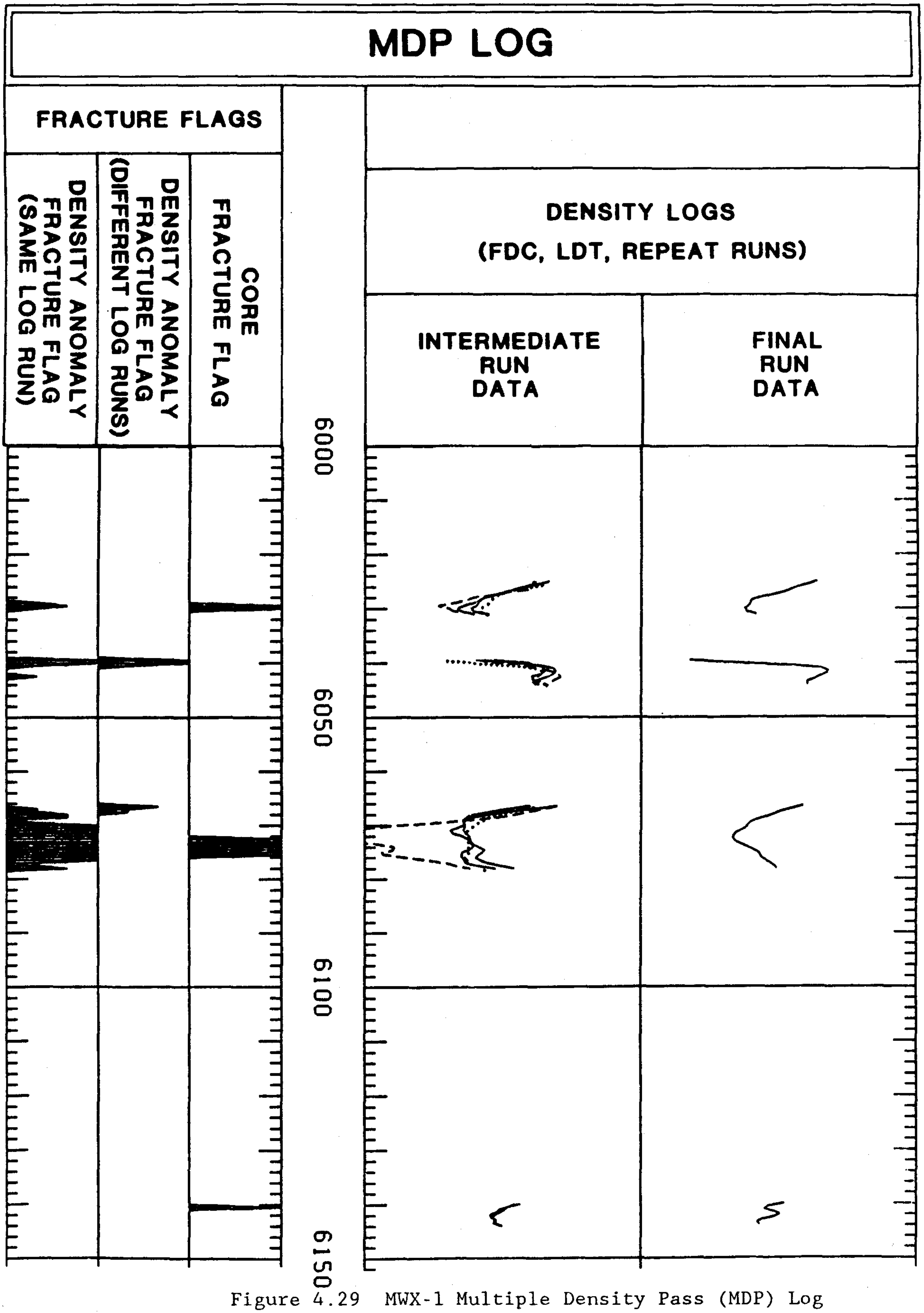


Figure 4.29 MWX-1 Multiple Density Pass (MDP) Log

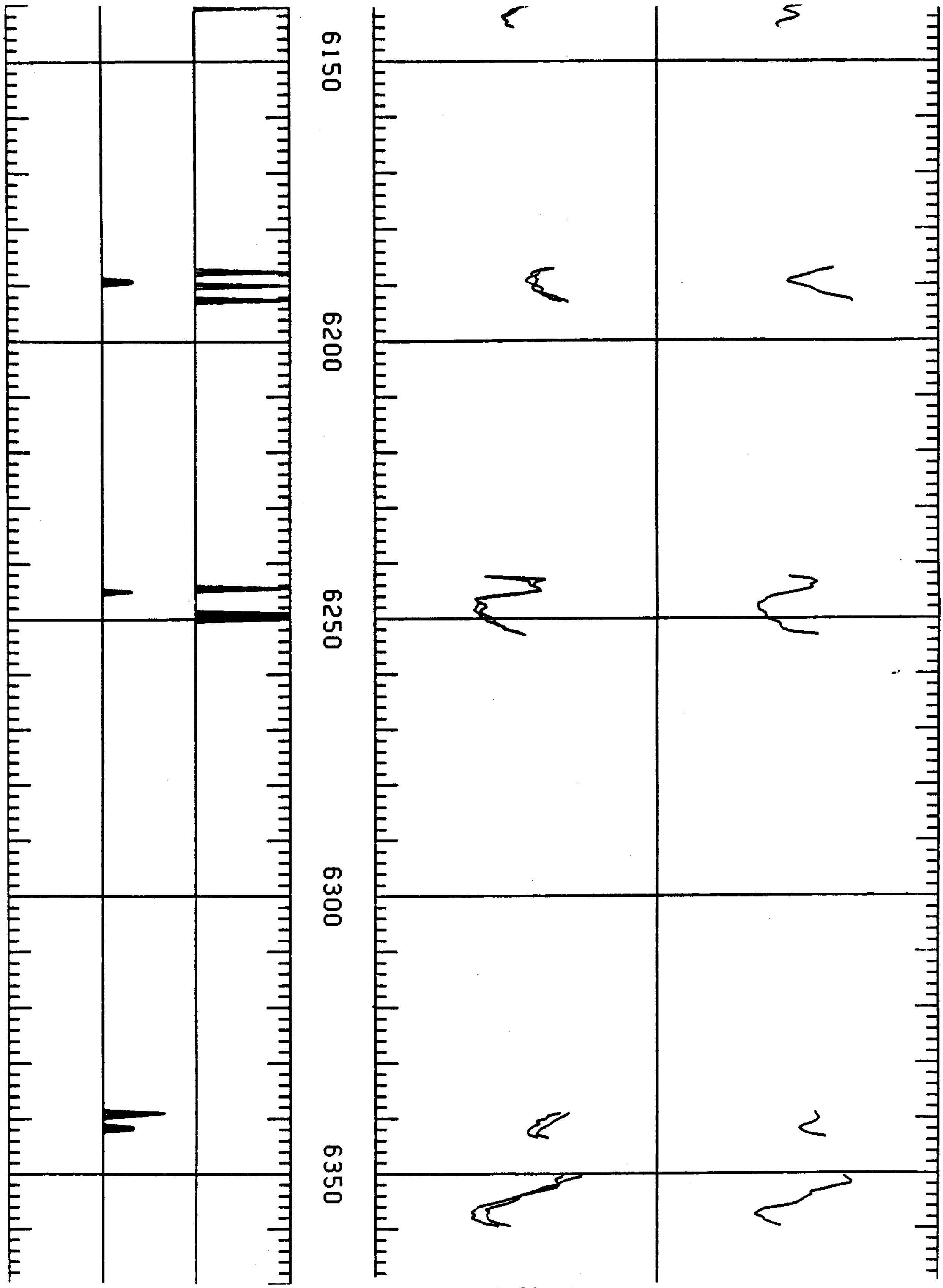


Figure 4.29, Cont.

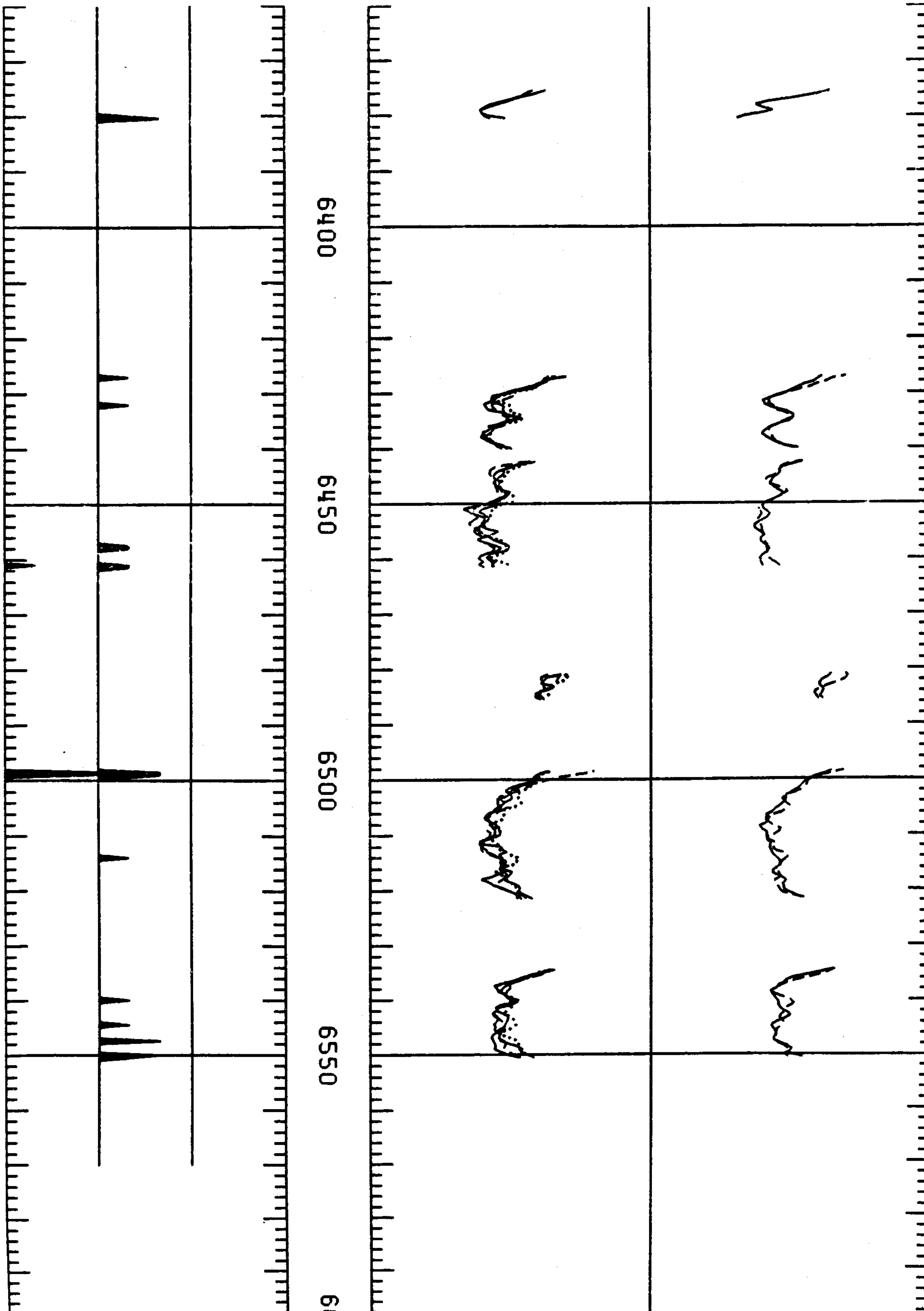


Figure 4.29, Cont.

5.0 CORE ANALYSIS

Allan R. Sattler
Sandia National Laboratories

5.1 INTRODUCTION

The coastal zone occurs at a depth of about 6000 to 6600 ft at the MWX site (Figure 5.1). The core data help describe the formations and the reservoir rock, and they provide input data to all MWX activities. In this section examples of the core data are presented and discussion is given to put the data in perspective. Specifically these remarks indicate:

- what core was taken and what analyses were made;
- typical values of reservoir parameters, rock properties and other measurements;
- implications of the core data; and
- some comparisons of the core data with that of other geologic sections of interest in the Mesaverde.

As described in Section 3.0, the coastal interval is at the upper part of a delta plain. Sandstones in this interval generally are lenticular, distributary channel and splay deposits. These are interspersed with carbonaceous mudstones, shales, and siltstones. There are a few thin beds and lenses of coal, but the coastal is differentiated from the underlying paludal interval by the absence of thick coals and very organic-rich sediments. The pore pressure is about 4400 psi at the bottom of the coastal and the net confining stress is about 2000 psi for an unperturbed reservoir.

After the drilling and coring of MWX-1, interest immediately focused upon the relatively thick Red and Yellow sands at the bottom of the coastal. These sands correlate quite well between the three wells. Both the Red and Yellow sands were originally stimulation targets, but only the Yellow sands were eventually stimulated (Section 7.2). The first sands on which special core analyses were performed were the Red and Yellow sands. Most of the coastal core analyses were concentrated on these two sands because of the interest in them.

A total of 876 ft of 4 inch-diameter core were taken from the three wells in the coastal interval as follows:

- MWX-1: Continuous core was taken through the coastal from 6000 to 6600 ft. Core from 6480 to 6569 ft was oriented.

- MWX-2: Core was taken from 6390 to 6569 ft which included the Red and Yellow sands. Core from 6438 to 6528 ft was oriented.

- MWX-3: Core was taken from 6431 to 6528 ft which included the Yellow and top of the Red sands. The entire core was oriented.

5.2 CORE PROGRAM

The MWX core analysis program is described in detail elsewhere.[1,2] The results of analyses presented in this section have been taken from the reports submitted by the participants. These reports are specifically referenced where used in this section, and more comprehensive listings are found in Section 10.0 and Appendix 11.14. This section presents reservoir, mechanical, and organic properties obtained from core. Other core-derived properties are reported in other sections: lithology (3.2), mineralogy/petrology (3.2.3), sedimentology (3.3), natural fractures (3.4), and estimates of in situ stresses from core (6.4). Core-log correlations are displayed with the log analyses formalisms in Section 4.0, although correlations made with respect to the televiewer and caliper logs are in Section 5.6.

There were over 25 participants in the core program. The major ones involved in coastal analyses were Core Laboratories, Institute of Gas Technology (IGT), and New Mexico Petroleum Recovery Research Center (PRRC) (reservoir and electrical properties, caprock analysis); RE/SPEC (mechanical rock properties); Bendix Field Engineering Corp. and the US Geological Survey (mineralogy/petrology); Colorado Geological Survey and Amoco (organic maturation); and National Institute of Petroleum and Energy Research (NIPER) and Dowell-Schlumberger (laboratory work supporting completions, Section 8.0). Much of the coastal core analysis data from Core Laboratories, IGT, and RE/SPEC are given as Appendices 11.4, 11.5, and 11.6, respectively.

In many core studies, analyses are confined to the reservoir rock only. In MWX, however, the material abutting the sands was studied to obtain properties useful for hydraulic fracture design and analyses of stress test data; for example, mechanical property measurements were made on both sandstone and confining rock samples. In addition, caprock analyses and cation exchange capacity (CEC) measurements were often made to help determine the vertical extent of the reservoir.

5.3 CORE HANDLING AND PREPARATION

A special core processing facility was established in a building at the Department of Energy's Anvil Points Facility across the Colorado River and about 15 road miles from the MWX site. When the core came to the surface, it was removed from the core barrel by project geologists and placed in trays. After a quick preliminary inspection and removal of samples for special measurements, such as anelastic strain recovery (ASR), the core was first covered with plastic to prevent evaporation, and then with thick canvas to protect it from the elements. The core was then transported to Anvil Points for processing. Field processing of the core entailed many special procedures that included the following:

- Construction and use of a six-detector core gamma assembly. The core gamma assembly provided for well control during drilling and for core-log depth correlations after logging. The core gamma assembly also had better spatial resolution than the open-hole gamma ray log.

- Marking the positions and magnitude of scribe line deviation and locations of connections and other breaks in core.

- Photographing the entire amount of core in color.

- Taking core plugs and sealing and preserving selected sections.

- Making a visual core log (which was subsequently followed by a detailed lithology/sedimentology log from slabbed core).

- A special no-freeze freight service was used in the winter to ship samples selected for measurements of reservoir parameter or mechanical rock properties.

Because there were so many conflicting requirements for the MWX core, many of the routine and special core analyses were performed on plugs. This allowed most of the whole core to be available for studies of sedimentology and depositional environment, mechanical rock properties, and organic maturation. Thin sections were taken by facing off the ends of the same core plugs. Preference for thin section analyses was given to the plug ends corresponding to the plugs selected for the restored state permeability measurements. This allowed correlations of sandstone reservoir properties with mineralogy/petrology. Since properties can often vary rapidly in a lenticular sequence, it was necessary to make the correlations from the same sample.

5.4 CORE ANALYSES, RESULTS, AND DISCUSSION

Reservoir properties (water saturation, capillary pressure, permeability and porosity) are used in production testing. Caprock analyses can help define the vertical limits of the reservoir and give an idea of the ability of abutting materials to contain gas. Mineralogy/petrology data provide checks of the frac fluid/formation compatibility (Section 8.0), information on the paragenesis of the formation, and details on the formation of the pore structure. Electrical data (formation factor, resistivity index, and cation exchange capacity, (CEC)) are used in the Archie/Waxman Smits formalisms of log analysis. Mechanical rock properties provide inputs to the analysis of hydraulic fracture length, width, azimuth, and frac containment. Stress-related mechanical property measurements are used for predicting hydraulic fracture azimuth and for modeling the existing in situ stresses (Section 6.0). Organic maturation data are necessary to determine origin and migration of the gas and provide inputs to burial history hypotheses and paleostress information through paleo-pore-pressure estimates. The televiewer and oriented caliper logs can also be used to predict hydraulic fracture azimuth. The display of fractures from the televiewer can be compared with those from oriented core.

5.4.1 Reservoir Parameters

Many reservoir parameter measurements were made at frequent intervals in the sands. For example, routine core analyses providing porosity and water saturation information were taken every foot in the sands and at every other foot for four to six feet into the material abutting the sands.[3-5] Routine core analysis data across the Purple, Orange, Yellow and Red coastal sands are displayed in Figures 5.2-5.8.

Water saturations are very important in tight sandstone. The drilling/coring was actually done "at or near balanced" conditions (i.e., weight of the column of drilling fluid is made about the same as formation gas pressure) to minimize invasion of core and formation by drilling fluid. (It was later determined that the mud weights were about 500 psi less than the measured reservoir pressures.) Oil-base drilling fluid was used in drilling MWX-1 and MWX-2, in part to further prevent invasion of core and formation by water-base drilling fluids. These steps would result in more accurate water saturation measurements. Water-base drilling fluid was used in MWX-3 so a more thorough suite of electrical logs could be run. An ammonium nitrate tag was used in the drilling of MWX-3 in an attempt to correct the water saturations from invasion. Differences in nitrate concentration reported by the mud logger and Core Laboratories, plus the rapid variation of properties in these lenticular sandstone lenses over short distances, made an accurate assessment of these correction factors impossible.[6] As a result, each saturation value for MWX-3 may be from 5%-15% high due to invasion.

The water saturation values were determined by the Dean Stark distillation method in MWX-1 and MWX-2, and by the summation of fluids method in MWX-3 because results from the MWX pressure core data suggested that the Dean Stark method may not be the water extraction method of choice.[7] Water saturations average in the 40-50% range over the Red and Yellow sands.

Porosities were determined by Boyle's Law method. There had been questions whether the pressure of the helium entering the tight whole core would equilibrate during these routine measurements; plugs had an advantage of equilibrating in a shorter time. Because this core was so tight, additional time was allowed for pressure equilibration in determining the porosity of these tight plugs.

The porosities average 5%-7% in the Red and Yellow sands. Porosity as a function of confining pressure was measured by Core Laboratories (Table 5.1)[8,9] and IGT.[10-12] There is little change in porosity with confining pressure.

Core Laboratories used the non-steady state, pulsed method to determine Klinkenberg (gas slippage corrected) permeabilities. IGT used the steady state method to determine their Klinkenberg permeabilities and they performed all of their restored pressure state permeabilities without cleaning. Before measuring their Klinkenberg permeabilities, Core Laboratories subjected each of the core plugs to toluene extraction to remove any residue from oil-base drilling fluid and they leached precipitated salts out of the pores with hot methyl alcohol.

Selection of the plugs for dry, restored-pressure-state, Klinkenberg permeability measurements were made after inspection of the routine core analysis data and re-examination of the core plugs. Core Laboratories provided restored-pressure-state permeability data across the Red and Yellow sands on core from all three wells (Figures 5.3-5.8).[13-15] A few vertical permeability measurements were also made (Figures 5.3-5.6).[16-17] Limited restored state permeability measurements were performed on MWX-1 core in both the Orange and Purple sands (Figure 5.2).[18] IGT[10-12] and PRRC[19] were provided some of the "cleanest" sandstones in the Red and Yellow sand lenses for their detailed studies (Table 5.2).

The average dry Klinkenberg permeabilities for the sandstone are in the 3-8 microdarcy range. The majority of the permeabilities across these coastal sands measured by Core Laboratories were at 1000 and 3000 psi confining pressure, while IGT used 4000 psi. The values at 2000 psi were obtained by interpolation. The vertical and horizontal permeabilities in the Red and Yellow sands have about the same values.

The dry permeabilities over these sandstone lenses are not uniform. They peak in the interior of the lens and decrease at the edges. There are hints of permeability streaks here in the coastal as well as in the fluvial zone. Permeability streaks are defined as thin regions in sandstone where the matrix permeability of the core samples is substantially higher than in most other portions of the sandstone lens.

The Bendix mineralogy data[20] (Appendix 11-1) suggest some open porosity in these more permeable samples and often the total clay content of the higher permeability samples is low. But it is very difficult to make any quantitative correlations with the mineralogical properties.

Often the most permeable of the core plugs were selected for additional analyses such as specific permeability to water, capillary pressure, formation factor, and resistivity index measurements. IGT performed specific permeability to water measurements for a number of core samples (Figure 5.9).[21-22] Core Laboratories also performed specific permeability to brine measurements (Table 5.3).[9] PRRC performed permeability to brine[19] and relative permeability measurements on preserved core (Figures 5.10-5.11).[23]

Corrections for realistic water saturations would result in average permeabilities around 0.5-0.6 microdarcys for the Red and Yellow sands. These permeabilities are one tenth or less than the dry values at 4000 psi confining pressure shown in Figure 5.9. These values adjusted for water saturation effects are, on the average, a factor of five less than similar permeabilities in the paludal zone, are about the same as the marine sandstones, and about two to four times higher than the fluvial B and E sands.

Recent measurements made on selected core show that permeabilities of preserved core are significantly less than those obtained from re-saturated over-dried core. Such measurements made by PRRC on preserved coastal core showed the following:

- Much of the preserved core retained its water content for over five years.

- At low confining pressures (~500 psi), the permeability to brine for preserved core is only about half that of re-saturated oven-dried core. However, at the ~2000 psi confining pressures existing in the coastal zone, this difference is somewhat smaller at ~20%.

- Permeabilities of the preserved core are less than the corresponding oven-dried core at all water saturations, and the differences become quite small below 30% water saturation.

The early capillary pressure measurements performed both by Core Laboratories[24] and IGT[10-12] were by the mercury injection method. Later, capillary pressure measurements were made with the centrifuge using the best available estimates of formation brine (Table 5.4).[9] Extensive capillary pressure measurements, as well as extensions of the capillary pressure curve to very low water saturations by adsorption measurements, were done by PRRC.[25]

The capillary pressures of the coastal zone core to brine are high (>500 psi) at realistic saturations. Capillary pressure data are available from both centrifuge and mercury injection and are compared in Figure 5.12 for neighboring samples. At high saturations, the air-brine curve is lower than the mercury injection curve, even with the use of the 5-to-1 scaling factor between the mercury and water data. At lower saturations, the mercury injection curve is lower. More recent work shows that the capillary pressures for tight sandstones for the different techniques are much closer to each other.[23,26] This may have something to do with slower mercury injection rates.[27]

5.4.2 Caprock Analyses

The caprock analyses included permeability to brine and the minimum gas threshold necessary to displace water (Table 5.5).[28-31] A combination of very low permeability plus a large threshold pressure for gas displacement would indicate a good caprock and stratigraphic barrier.

The caprock analyses on the rock abutting the Red and Yellow sands indicates, for the most part, that the permeabilities to brine are quite low, often in the sub-nanodarcy range. However, the caprock testers could only go to a maximum of about 1000 psi for the threshold pressures, well below the pore pressures in the Red and Yellow sands. (What pore pressures actually exist in these siltstones/mudstones/shales can not really be defined.) Thus, these tests probably should only be considered as a qualitative indicator of the worth of the caprock.

5.4.3 Permeabilities of Core Samples Containing Natural Fractures

The frequency of all natural fractures vs depth is given in Figure 5.13 and the frequency of filled, extension fractures vs depth is given in Figure 5.14. The reservoir permeabilities derived from production testing are compared with the matrix rock in Figure 5.15. In all regions of the Mesaverde, natural fractures dominate pre-frac production: the resulting formation production is at least one, and more often two or more orders of magnitude higher than can be accounted for by matrix rock alone (Figure 5.15).[32,33] There are numerous fractures in the region around and just below the Orange and Purple sands. That area has the highest fracture frequency in the Mesaverde. Relatively few fractures are seen in the Red and Yellow sands and they appear to be rather narrow (Table 3.2). Nonetheless, data given in Figures 5.15 and Section 7.1 show that fractures dominate pre-frac production for these sands also.

Measurements of permeabilities of coastal core samples containing natural calcite-filled extension fractures (Figure 5.16) and carbonaceous stringers were made (Table 5.6).[9,34-36] There is general permeability enhancement along the fracture direction in the cemented fractures. Moreover, only the well-cemented fractures survived the coring and machining process; core with more open fractures often did not. Figure 5.16 shows that fractured core samples and matrix samples have different permeability dependencies on water saturation. In fact, it appears as if water saturation effects enhance the ratio of permeability of fractured core to that of the matrix rock. Perhaps the large capillary forces tend to keep the narrow natural fractures free of water at normal reservoir conditions.

5.4.4 Mechanical Properties

The mechanical rock property measurements were made by RE/SPEC (Figures 5.17-5.19)[37-39] and by Dowell Schlumberger (Table 5.7)[40] in the Red and Yellow sands and in the rock abutting these sands. A few measurements were made in the Orange and Purple sands and in the material abutting these sands.[41] Poisson's ratio (Figure 5.20) and fracture toughness data (Table 5.8) are also given. In both MWX-2 and MWX-3, these measurements were made on the cleanest, least shaly sands and on the most-shaly abutting material. The plugs cut by RE/SPEC were vertical, while the plugs cut by Dowell Schlumberger were both horizontal and vertical.

Young's moduli range from about 11 to 56 GPa for rock abutting the coastal sandstone lenses (siltstone/mudstone/shales) and about 24 to 40 GPa for the sandstones. It is interesting that the abutting materials have a wider range of stiffnesses and compressive strengths which span values found for the sandstones. In fact within a 10-ft increment in the MWX-1 coastal interval, between 6420 and 6430 ft (Figure 5.17), there exist fine-grained siltstones and mudstones that have some of the highest and lowest moduli values measured in the entire Mesaverde column at the MWX site. This behavior is quite unlike marine formations, where the properties tend to be much more uniform over the formation. The moduli in the coastal sandstones are about the same as those found in other lenticular regions, but are somewhat lower than those seen in the Corcoran and Cozzette marine sandstones. It is difficult to make more precise correlations of the mechanical rock properties with lithology, but there are some fundamental differences in the behavior of both the stress-strain curves and the fracture toughness curves between sands and the abutting materials.[37-39,42]

5.4.5 Electrical Properties

Cation exchange coefficients (CEC) were measured using the adsorbed water method (Figures 5.3 and 5.4).[13,14] Formation factor and resistivity index measurements were made (Figures 5.21 and 5.22).[43]

The CEC values in the coastal zone are higher than those values in the marine sandstones. In fact these coastal zone CEC values are among the highest of those for sandstones in the Mesaverde and they average about 2.7 meg/100 g in the Yellow sand. Cementation exponent values were derived from the porosity dependence of the formation factor measurements. The cementation exponent values, m and m* (clay corrected), are about 1.9 and 2.1 at 3000 psi confining pressure (Table 5.9). These values do not seem to depend strongly on depositional environment. Saturation exponent values were derived from the saturation dependence of resistivity index measurements (Table 5.9). Saturation exponent values, n and n* (clay corrected), were about 1.9 and 2.6. Resistivity index values appear to vary with depositional environment. These values were obtained with the aid of a centrifuge and removal of such small amounts of water from a plug are difficult. Moreover, the distribution of the brine remaining after centrifugation may not be the same as would be found in situ resulting in different measured electrical characteristics. Therefore, it is difficult to assess the reliability of the resistivity index data.

5.4.6 Organic Content and Maturation

Vitrinite reflectance measurements were made on some coastal samples by Amoco (Figure 5.23).[44] These measurements were performed not only on the coal, but on rock containing any organic material. The vitrinite reflectance curve vs depth has the same general shape as is seen from other data in this part of the basin. The Colorado Geological Survey (CGS) performed analyses on carbonaceous rock throughout the Mesaverde column and the data for the coastal is given in Table 5.10.[45] The analysis of a number of carbonaceous samples by the CGS shows a fair amount of organic matter interspersed throughout the coastal zone and the Mesaverde above the paludal zone. Total organic carbon, rock evaluation pyrolysis, and C1-C5+ gas analyses were performed on coastal zone samples by Core Laboratories (Tables 5.11 and 5.12).[46, 47]

5.4.7 Directional Permeabilities of Oriented Core

Permeability measurements were made on oriented coastal core and core from other zones at N80°W and N10°E (Table 5.13).[48] These directions are close to the maximum and minimum horizontal stress existing in the coastal zone (Sections 6.0 and 9.0). The following observations are made:

- In all cases, the permeabilities in the direction of minimum principal, horizontal stress (N10°E) are greater than those in the direction of maximum principal horizontal stress (N80°W). Microcracks resulting from stress relaxation would be aligned along the minimum rather than along the maximum horizontal stress, and thus, the permeability would be higher in the direction of the microcracks.

- Using the reasoning above, the vertical permeabilities would be expected to be the smallest because the vertical stresses are the predominant ones in these zones. This is true for the paludal and coastal sandstones. In the vertical direction, effects of bedding on permeability may be important.

- The difference in the horizontal permeabilities are the least for the coastal, suggesting that the degree of horizontal anisotropy may be smaller there than in other zones.

5.4.8 Permeability as a Function of Net Confining Stress

The permeabilities of one coastal and one fluvial core plug were measured as a function of pore pressure and confining stress such that the net confining stress was constant at 2900 psi.[49-51] At the time these measurements were made, the net confining stress in the coastal/fluvial region was estimated to be around 2900 psi and was based on: (1) the measured pore pressure, (2) the measured minimum horizontal stress from in situ stress tests (Section 6.0),[52] (3) the maximum horizontal stress, which was estimated as about 800 psi higher than the minimum horizontal stress from open-hole stress measurement[53] and the modeling of ASR data,[54] and (4) an estimate of 1 psi/ft for vertical, overburden stress. Five pore pressures were chosen, with the initial pore pressure chosen to be close to that existing in the coastal interval (4400 psi). The results are given in Figure 5.24. For both samples it appears that gas permeability is constant at a pore pressure of 1500 psi and above. Presumably, the increase in gas permeability at low pore pressures is due to reduction in Klinkenberg slippage effects. This curve suggests that permeability in these tight sands depends more on the value of the net stress rather than on the individual values of pore or confining pressure.

5.5 CORRELATIONS OF CORE DATA WITH TELEVIEWER AND CALIPER LOGS

Stress-related core data (e.g., anelastic strain relaxation (ASR) and differential strain curve analyses (DSCA)), the MWX-3 televiewer log, and the MWX-3 oriented caliper log all provided predictions of the maximum horizontal stress azimuth with depth. It is assumed that the breakouts identified in the nearly-vertical MWX-3 well are orthogonal to the maximum principal stress.[55] Predictions of the direction of maximum principle horizontal stress (frac azimuth) from the three methods for the coastal zone are given below. Within the spread and uncertainties of the data, the correlation of the three types of measurements is considered fair.

- The ASR/DSCA data (Section 6.4) gives a prediction between 85° and 120°[54] with an uncertainty of at least 10° due to inherent inaccuracies in orienting. These measurements were taken in the Red and Yellow sands.

- The display of breakouts from the borehole televiewer gives a rough prediction between 105° and 125° between 6300 and 6600 ft (Figure 5.25). It is difficult to read breakouts from the televiewer log to better than 15°. A preferred stress direction in the upper half of the coastal zone is not evident from the televiewer log.

- The display of breakouts from the oriented caliper log (Table 5.14) gives a prediction for the maximum horizontal stress roughly between 90° and 228°, although most of these data points lie between 90° and 152°. The oriented caliper can be read within 4-5°, but more important is the fact that the oriented caliper log may not seat squarely along the direction of maximum elongation. Furthermore, in some regions, washouts and stress breakouts may coincide, making interpretations from this log difficult.

The ratio of the minor-to-major wellbore axes was obtained from the oriented caliper logs for the coastal and other lenticular zones (Figure 5.26). There is little deviation from unity in the coastal zone suggesting that the degree of horizontal anisotropy may be small.

5.6 REFERENCES

1. Sattler, A. R., "The Multiwell Experiment Core Program," SPE 11763, Proceedings of the 1983 SPE/DOE Symposium on Low Permeability, Denver, CO, March 14-18, 1983.

2. Sattler, A. R., "The Multiwell Experiment Core Program, II," SPE 11763, Proceedings of the 1984 SPE/DOE Unconventional Gas Recovery Symposium, Pittsburgh, PA, May 16-18, 1984.

3. Core Laboratories, Report RP-2-6714, November 1981.

4. Core Laboratories, Report RP-2-6806, March 1982.

5. Core Laboratories, Report 3806-7199, July 1983.

6. Core Laboratories, Report P83012, January 1984.

7. Sattler, A. R., A. A. Heckes and J. A. Clark, "Pressure Core Measurements in Tight Sandstone Lenses During the Multiwell Experiment," Proceedings of the SPE/DOE/GRI Unconventional Gas Recovery Symposium, Pittsburgh, PA, SPE/DOE/GRI 12853, May 1984.

8. Core Laboratories, SCAL Report 203-830019, June 24, 1983.

9. Core Laboratories, SCAL Report 203-830024, March 15, 1984.

10-12. Institute of Gas Technology, Project 6506 Reports, "Sandstone Permeability and Porosity Measurements," July 1982, August 1982, and October 1982.

13. Core Laboratories, SCAL Report 203-820007, February 1982.

14. Core Laboratories, SCAL Report 203-820075, February 9, 1983.

15. Core Laboratories, SCAL Report 203-84026, August 1984.

16. Core Laboratories, SCAL Report 203-820027, September 14, 1982.

17. Core Laboratories, SCAL Report 203-840077, November 1984.

18. Core Laboratories, SCAL Report 203-830070, November 1983.

19. Wei, K. K., N. R. Morrow and K. R. Brower, "Effect of Fluid, Confining Pressure, and Temperature on Absolute Permeabilities of Low Permeability Sandstones," SPE Formation Evaluation, pp 413-422, August 1986.

20. Bendix Field Engineering, Series of Contractor Reports on Mineralogic and Petrographic Analyses of Multiwell Experiment Samples, 1982-1984 (Data given in Appendix 11.1 for all coastal samples).

21-22. Institute of Gas Technology, Project 65056 Reports, "Sandstone Permeability and Porosity Measurements: Relative Permeability Data," October 1982 and November 1982.

23. New Mexico Petroleum Research Recovery Center, New Mexico Institute of Mining and Technology, Project 2-75-7339, Reports for Morgantown Energy Technology Center, 1987, 1988 (To be published).

24. Core Laboratories, SCAL Report 203-82023, July 1982.

25. Ward, J. S. and N. R. Morrow, "Capillary Pressures and Gas Relative Permeabilities of Low Permeability Sandstones," SPE Formation Evaluation, pp 345-346, September 1987.

26. Walls, J. D. and J. O. Amaefule, "Capillary Pressure and Permeability Relationships in Tight Gas Sands," SPE/DOE 13879, Proceedings of the 1985 SPE/DOE Joint Symposium On Low Permeability Reservoirs, May 1985.

27. Wardlow, N. C. and Taylor, R. P., "Mercury Capillary Pressure Curves and Interpretation of Pore Structure and Capillary Behavior in Reservoir Rock," Bull. Can. Pet. Geol., 24, pp 225-262, 1976.

28. Core Laboratories, SCAL Report 203-840055, March 27, 1984.

29-30. Institute of Gas Technology, Project 65056 Reports, "Caprock Analysis," June 1982 and September 1982.

31. Institute of Gas Technology, Project 61071 Report, "Analysis of Stratigraphic Barriers (Caprock) between Sands in the Cretaceous Mesaverde Formation--US DOE Multiwell Experiment, Garfield County, Colorado," June 1984.

32. Lorenz, J. C., P. T. Branagan, N. R. Warpinski and A. R. Sattler, "Fracture Characteristics and Reservoir Behavior of Stress-Sensitive Fracture Systems in Flat-Lying Lenticular Formations," SPE 15244, Proceedings of the SPE Unconventional Gas Technology Symposium, Louisville, KY, May 18-21, 1986, pp 423-436.

33. Northrop, D. A., "Insights into Natural Gas Production from Low Permeability Reservoirs," SPE 17706, Proceedings of the 1988 Gas Technology Symposium, Dallas, TX, June 13-15, 1988.

34. Core Laboratories, SCAL Report 203-850062, December 1985.

35. Litton Core Research (Core Laboratories) Report 308-87609, July 1987.

36. Core Laboratories SCAL Report 203-87005, April 1987.

37. RE/SPEC Inc., Data Report RSI-0226, September 1983.

38. RE/SPEC Inc., Data Report RSI-0234, October 1983.

39. RE/SPEC Inc., Data Report RSI-0238, November 1983.

40. Dowell Schlumberger Formation Analysis Laboratory (Tulsa) Reports, "Multiwell Experiment Core Analyses of the MWX-1, MWX-2, and MWX-3 Wells, Interim Report, August 1985.

41. RE/SPEC Inc., Progress Report RSI(RCO)-046/5-85/200, May 1985.

42. Senseny, P. E. and Pfeirfle, T. W., "Fracture Toughness of Sandstones and Shales," Proceedings of the 25th Symposium in Rock Mechanics, Evanston, IL, June 1984.

43. Core Laboratories, SCAL Report 203-870050, November 1987.

44. Hemmler, T., "MWX-1 and MWX-2 Cores; Vitrinite Reflectance Data," Letter Report to A. R. Sattler, Sandia National Laboratories, November 1982.

45. Tremain, C. L., Colorado Geological Survey Letter Reports to A. R. Sattler, Sandia National Laboratories; January 1982, March 1982, July 1982, November 1982, February 1983, March 1983, and January 1984.

46. Core Laboratories, Geochemical Services Report 84012, March 1984.

47. Core Laboratories, Geochemical Services Report 84137, August 1984.

48. Institute of Gas Technology, Project 61071 Report, "Directional Core Analysis of the Mesaverde Formation, US DOE Multiwell Experiment, Garfield County, Colorado," September 1984.

49. Walls, J. D., "Tight Gas Sands-Permeability, Pore Structure and Clay," Jour. Pet. Tech., pp 2708-2714, November 1982.

50. Litton Core Research (Petrophysical Services/Core Laboratories) Report, "Gas Permeability of Sandstone Samples," Contract No. 04-4594, July 1986.

51. Litton Core Research (Petrophysical Services/Core Laboratories) Report 38B, "Gas Permeability of Fractured Whole Core and Matrix Plugs at Reservoir Pressures," April 1987.

52. Warpinski, N. R., P. Branagan and R. Wilmer, "In Situ Stress Measurements at DOE's Multiwell Experiment Site, Mesaverde Group, Rifle, Colorado," Jour. Pet. Tech., pp 527-535, March 1985.

53. Warpinski, N. R., "Determining the Minimum In Situ Stresses from Hydraulic Fracturing Through Perforations," Proceedings of the 2nd International Workshop on Hydraulic Fracture Stress Measurements, Minneapolis, Minnesota, June 1988.

54. Warpinski, N. R. and L. W. Teufel, "In Situ Stresses in Low Permeability, Nonmarine Rocks," Proceedings of the 1987 SPE/DOE Joint Symposium on Low Permeability Reservoirs, Denver, CO, SPE/DOE 16402, May 1987.

55. Bell, J. S. and D. T. Gaugh, "The Use of Borehole Breakouts in the Study of Crustal Stress," Proceedings of Hydraulic Fracturing Stress Measurements, USGS Open File Report 82-1075, 1982.

Table 5.1 Porosity as a Function of Overburden Pressure (MWX-2)

Sample Depth (ft)	Porosity (%) at Overburden Pressure (psi) of:			
	200	1000	2000	3000
6504.4	6.1	6.0	6.0	5.9
6536.9	8.2	8.0	8.0	7.9
6549.7	6.8	6.7	6.7	6.6

Table 5.2 Results From Analysis of Dry Coastal Core (IGT)

			Values at Net Confining Stress*					
Well	Core Depth (ft)	Lab Net Confining Stress* (psi)	Porosity (%)	As Received Water. Sat. (%)	Klinkenberg Permeability (μd)	Klinkenberg "B" (psi/μd)	Pore Volume** Compressibility (microsips)	Mercury Capillary Entry Pressure (psia)
MWX-1	6434.1	4310	5.55	35	0.67	111.0	13.8	420
	6453.7	4270	7.09	36	1.35	56.9	18.0	170
	6502.0	4310	4.83	95	0.10	1677.0	11.9	560
	6537.8	4330	6.12	22	1.40	74.9	11.0	230
MWX-2	6429.0	4110	4.42	45	0.15	235.0	13.5	670
	6503.9	4160	5.68	53	0.64	128.0	20.2	320
	6538.0	4180	7.14	35	1.96	76.2	15.4	270
	6548.7	4190	6.56	43	1.40	83.3	15.8	260

*Calculated using (0.925) (sample depth) - (0.5) (pore pressure estimated from mud weight).

**Pore Volume compressibility ($\Delta V/V\Delta P$) determined by fractional changes in pore volume per psi of stepwise increase in confining pressure on the first compression of the rock from about 2,000 psi net stress to the net stress used for testing. Lower values would probably result from cycling of net stress to the maximum that would be experienced in reservoir depletion.

Table 5.3 Permeability to Air and Brine

Depth (ft)	Porosity (%)	Confining Pressure (psi)	Permeability to Air (md)	Specific Permeability to Brine* (nd)
6433.5	5.3	0	0.01	--
		2000	--	0.053
		3000	--	0.037
6435.5	7.8	0	0.04	--
		3000	--	0.138
6503.5	6.1	0	0.02	--
		2000	--	0.128
		3000	--	0.098
6536.7	7.1	0	0.02	--
		2000	--	0.105
		3000	--	0.088

*18,000 ppm sodium chloride.

Table 5.4 Summary of Capillary Test Results*

MWX-1 Core Depth (ft)	Permeability to Air (md)	Porosity (%)	Brine Saturation (% pore space) at Pressure (psi) of: 10	30	70	150	300	600	1000	1300
6433.5	0.01	5.2	100.0	100.0	56.0	54.0	49.0	43.6	40.6	40.4
6435.5	0.04	7.2	100.0	50.0	47.5	42.7	39.4	37.1	35.5	35.3
6536.7	0.02	6.9	100.0	66.0	63.2	57.3	53.0	50.0	45.8	45.6

*Fluid System: Air-Water
Test Method: High-Speed Centrifuge

Table 5.5 Caprock Data (IGT)

Well	Depth (ft)	Rock Type	Vertical K_w (nanodarcies)	Threshold Pressure (psi)
2	6417	Siltstone	7.9	710
2	6420	Shaly Siltstone	0.2	840
2	6421	Siltstone and Silty Shale	<0.1	750
2	6454	Sandy Siltstone	58.8	225
3	6480	Shale	0.4	790
2	6497	Silty Shale	0.3	760
1	6567	Black Silty Shale	0.05	760
1	6569	Shaly Siltstone	17.5	450

Table 5.6 Core Plugs With Carbonaceous Stringers

MWX-1 Depth (ft)	Permeability to Air (md)	Porosity (%)	Klinkenberg Permeability (μd) at overburden pressure (psi) of: 1000	3000
6084.5	<0.01	1.9	0.21	0.08
6191.4	0.02	5.0	1.08	0.22
6195.5	0.01	3.3	0.20	0.09
6242.7	0.24	2.7	14.96	1.28
6342.5	0.01	3.9	0.75	0.40
6430.7	0.01	3.6	0.89	0.27
6451.5	0.11	8.5	9.88	0.56
6502.5	0.18	5.2	18.53	1.12
6564.2	0.01	4.1	0.48	0.14

Table 5.7 Mechanical Properties (Dowell-Schlumberger)

Well	Depth (ft)	Lithology (Location)	Confining Pressure (MPa)	Young's Modulus (GPa)	Poisson's Ratio	Compressive Strength (MPa)
MWX-1	6417.5-H	Shale	12.4	26.6	0.34	--
		(Above Yellow)	17.9	28.5	0.33	233.0
	6417.6-V		12.4	36.2	0.25	--
			17.9	37.8	0.23	319.8
	6427.3-H	Siltstone	12.4	52.7	0.21	--
		(Upper Yellow A)	17.9	53.9	0.18	382.0
	6427.4-V		12.4	55.0	0.19	--
			17.9	55.6	0.17	360.6
	6446.7-H	Sandstone	12.4	27.8	0.22	--
		(Middle Yellow A)	17.9	30.5	0.20	223.7
	6446.8-V		12.4	40.2	0.20	--
			17.9	44.3	0.18	256.9
	6506.4-H	Sandstone	12.4	31.0	0.22	--
		(Middle Red A)	17.9	31.9	0.24	287.5
	6506.4-V		12.4	35.4	0.20	--
			17.9	--	0.19	294.1
	6518.4-H	Sandstone	12.4	33.5	0.24	--
		(Lower Red A)	17.9	34.7	0.23	240.1
	6518.6-V		12.4	37.2	0.20	--
			17.9	37.9	0.19	256.5
	6569.3-H	Shale	12.4	28.9	0.25	--
		(Below Red)	17.9	30.9	0.21	204.4
	6569.5-V		12.4	39.9	0.19	--
			17.9	40.3	0.18	250.0
MWX-2	6419.5-H	Shale	12.4	24.9	0.26	--
		(Above Yellow)	17.9	25.7	0.26	235.5
	6436.1-H	Sandstone	12.4	41.0	0.24	--
		(Middle Yellow A)	17.9	44.7	0.26	301.0
	6502.4-H	Sandstone	12.7	32.1	0.24	--
		(Upper Red A)	17.9	34.1	0.21	253.0
	6502.6-V		12.4	31.0	0.21	--
			17.9	34.3	0.19	274.4
MWX-3	6465.1-H	Sandstone	12.4	29.3	0.21	--
		(Lower Yellow B)	17.9	29.9	0.22	264.1
	6481.5-H	Shale	12.4	23.3	0.28	--
		(Between Yellow, Red)	17.9	24.1	0.28	183.1
	6481.6-V		12.4	35.6	0.23	--
			17.9	36.4	0.22	330.3

Table 5.8 Fracture Toughness Measurements

Well	Lithology	Core Depth (Log Depth) (ft)	Fracture Toughness ($MPa \bullet m^{1/2}$)
MWX-1	Sandy Siltstone	6423.7 - 4.2 (6421.9 - 2.6)	2.61 ± 0.40
	Carbonaceous Mudstone	6426.8 - 7.8 (6425.0 - 6.0)	0.17
	Sandstone (with carbonaceous stringers)	6434.6 - 5.3 (6433.2 - 3.9)	1.45 ± 0.14
	Sandstone	6438.0 - 8.9 (6436.3 - 7.2)	1.25 ± 0.10
	Silty Mudstone	6491.5 - 2.6 (6488.7 - 9.8)	0.99
	Sandstone	6513.6 - 4.8 (6511.6 - 2.8)	1.29 ± 0.12
	Mudstone	6562.8 - 3.8 (6564.5 - 5.5)	1.38 ± 0.44
MWX-2	Sandstone (with carbonaceous stringers)	6418.9 - 9.4 (6414.7 - 5.2)	1.61 ± 0.30
	Sandstone	6431.3 - 2.6 (6427.3 - 8.6)	1.45 ± 0.13
	Sandstone	6437.7 - 8.8 (6434.7 - 5.8)	1.17 ± 0.04
	Sandstone	6519.0 - 0.0 (6513.1 - 4.1)	1.31 ± 0.08
	Carbonaceous, Muddy Siltstone	6565.5 - 6.1 (6559.7 - 0.3)	1.26 ± 0.16
MWX-3	Silty Mudstone	6431.8 - 2.7 (6431.8 - 2.7)	0.44
	Sandstone	6442.3 - 3.4 (6442.3 - 3.4)	1.39 ± 0.07
	Mudstone	6519.7 - 0.3 (6521.2 - 1.8)	1.41 ± 0.06

Table 5.9 Normal and Clay-Corrected Cementation and Saturation Exponents Obtained From Electrical Resistivity Studies

Interval	Well	Effective Overburden Pressure (psi)	Cementation Exponent m	Cementation Exponent m*	Saturation Exponent n	Saturation Exponent n*
Fluvial	MWX-1	0	1.72	1.92	1.37	1.83
		200	1.79	2.00		
		3000	1.89	2.08		
Coastal	MWX-1	0	1.74	1.96	1.85	2.55
		200	1.79	1.98		
		3200	1.88	2.09		
Paludal	MWX-2	0	1.82	2.03	1.08	1.47
		200	1.92	2.12		
		3600	1.95	2.17		

Table 5.10 Lithology of Organic-Rich Coastal Rocks

MWX-1 Depth (ft)	Sample Description
6041.5*	carbonaceous shale and ashy coal
6062.7*	grey brown carbonaceous shale with thin coal stringers
6113.0*	dark grey mudstone
6245.0*	black coal, some fusinite?
6279.0 - 6279.4	bright shiny coal
6601.3 - 6601.5	bright shiny coal, attrital and vitrain
6611.3 - 6611.7	bright shiny coal

*Chips

Table 5.11 Rock Evaluation Pyroxysis Data From the Coastal Interval

Well	Depth (ft)	Total Organic Carbon (%)	Gas Evolved (mg/gm rock)* S_1	S_2	S_3
MWX-1	6006.0	2.36	0.92	2.05	0.25
	6041.0	1.58	0.38	0.46	0.56
	6059.7	4.43	1.97	10.74	0.35
	6060.0	5.21	1.49	6.99	0.60
	6099.0	1.01	0.22	0.10	0.45
	6134.0	0.78	0.09	--	0.37
	6200.0	0.33	0.03	--	0.40
	6231.0	7.93	1.71	10.39	0.33
	6259.0	1.02	0.17	0.19	0.46
	6294.7	23.76	13.15	93.86	2.85
	6294.8	14.90	3.45	20.50	1.39
	6324.0	1.56	0.28	0.30	0.69
	6395.0	0.91	0.68	0.74	0.34
	6398.0	0.60	0.29	--	1.87
	6443.0	1.35	0.86	0.90	0.35
	6478.0	0.42	0.36	--	0.52
	6562.0	0.60	0.59	--	1.31
MWX-2	6390.0	0.35	0.22	0.06	0.41
	6401.0	0.97	0.16	0.35	0.25
	6408.0	4.32	1.03	2.90	0.38
	6492.0	0.33	1.03	0.12	0.33
	6570.0	5.59	1.88	9.98	0.46
MWX-3	6431.4	2.10	0.37	1.30	0.15
	6480.2	1.10	0.25	0.39	0.35
	6504.0	0.21	0.02	0.02	0.04
	6433.2	0.93	0.38	0.37	0.42
	6433.2	0.99	0.46	0.48	0.39
	6493.2	0.73	0.38	0.36	0.25
	6519.2	1.38	0.44	0.64	1.30
	6520.5	3.40	0.79	2.83	0.16
	6528.3	2.91	0.64	2.04	0.10

*S_1 Free hydrocarbons percent.
S_2 Hydrocarbons produced by thermal conversion of kerogen.
S_3 Organic carbon dioxide produced by pyrolysis of kerogen.

Table 5.12 Concentration (Volume ppm of Total Solids) of C1-C5+ Hydrocarbons

Component		MWX-1 Sample (depth, ft)			
		6059.7	6060.0	6294.8	6398.0
Methane	C1	3672	2116	156	2438
Ethane	C2	3454	3565	15	383
Propane	C3	2751	2843	693	116
Isobutane	iC4	871	922	258	32
Butane	nC4	444	480	87	32
	C5+	220	279	89	243

Table 5.13 Directional Permeabilities (MWX-2)

Interval	Depth (ft)	Net Confining Stress (psi)	Dry Klinkenberg Permeability to Air (μd) N80°W	N10°E	Vertical	N10°E / N80°W
Fluvial	5737	3800	1.22	2.16	1.88	1.77
	5830	3800	2.51	3.75	4.93	1.49
Coastal	6446	4000	1.77	1.88	1.16	1.06
	6514	4000	0.89	1.20	0.74	1.35
Paludal	7090	4200	1.40	1.95	0.56	1.39
	7131	4200	9.2	11.3	7.0	1.23

Table 5.14 Coastal Breakout Data: MWX-3 Oriented Caliper Log

Depth (ft)	Observed Breakout Orientation (degrees)	Inferred Direction of Maximum Horizontal Stress (degrees)
6050	62	152
6075	34	124
6125	18	108
6150	12	102
6175	17	107
6200	28	118
6225	26	116
6250	40	130
6275	36	126
6300	46	136
6325	86	176
6350	58	148
6425	138	228
6500	54	144
6525	20	110
6600	0	90

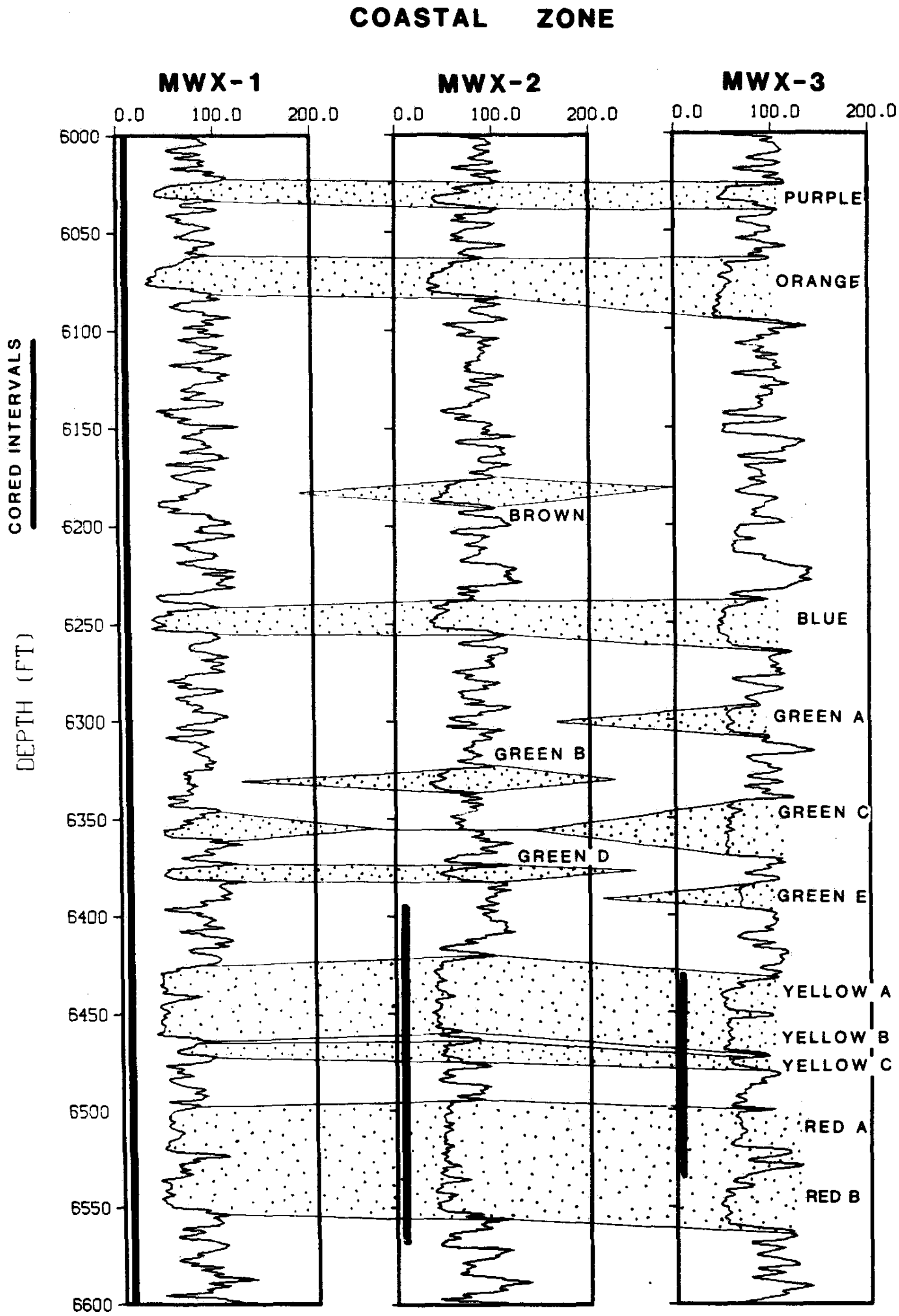


Figure 5.1 Gamma Log Definition of the Coastal Zone

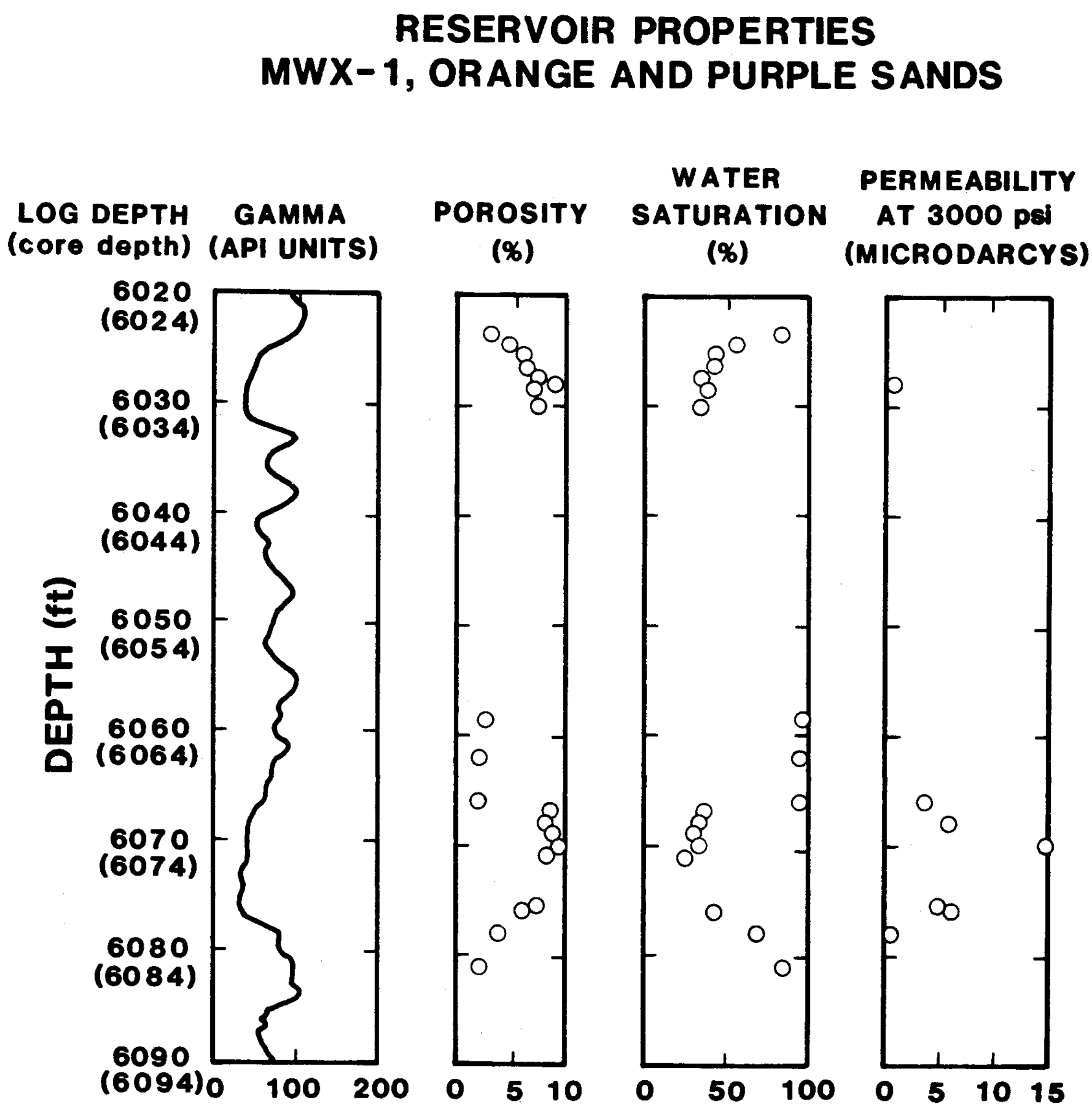

RESERVOIR PROPERTIES
MWX-1, ORANGE AND PURPLE SANDS
LOG DEPTH
(core depth)
GAMMA
(API UNITS)
POROSITY
(%)
WATER
SATURATION
(%)
PERMEABILITY
AT 3000 psi
(MICRODARCYS)
DEPTH (ft)
6020
(6024)
6030
(6034)
6040
(6044)
6050
(6054)
6060
(6064)
6070
(6074)
6080
(6084)
6090
(6094)
0 100 200
0 5 10
0 50 100
0 5 10 15

Figure 5.2

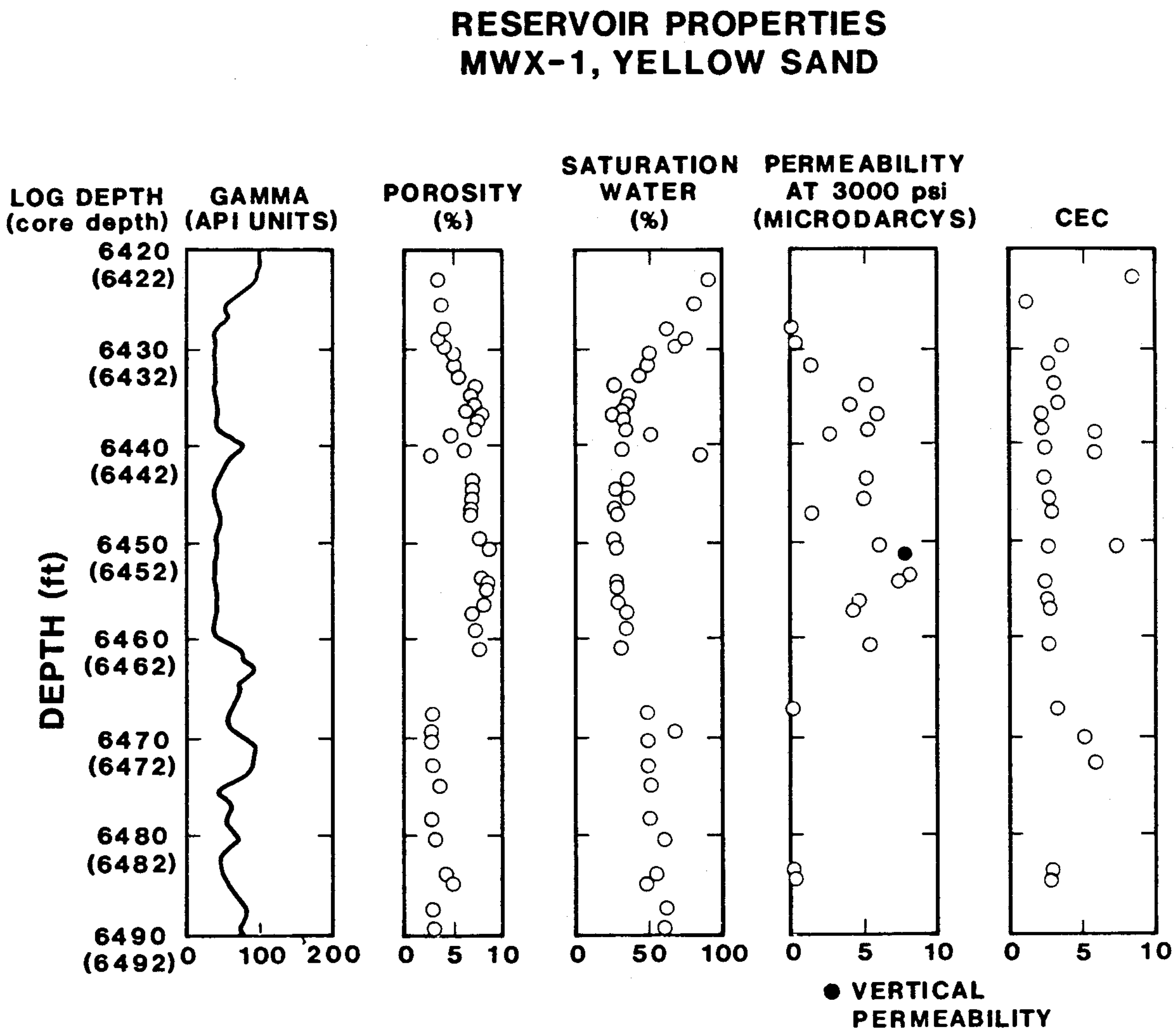

RESERVOIR PROPERTIES
MWX-1, YELLOW SAND
LOG DEPTH
(core depth)
GAMMA
(API UNITS)
POROSITY
(%)
SATURATION
WATER
(%)
PERMEABILITY
AT 3000 psi
(MICRODARCYS)
CEC
DEPTH (ft)
6420
(6422)
6430
(6432)
6440
(6442)
6450
(6452)
6460
(6462)
6470
(6472)
6480
(6482)
6490
(6492)
0
100
200
0
5
10
0
50
100
0
5
10
0
5
10
● VERTICAL
PERMEABILITY

Figure 5.3

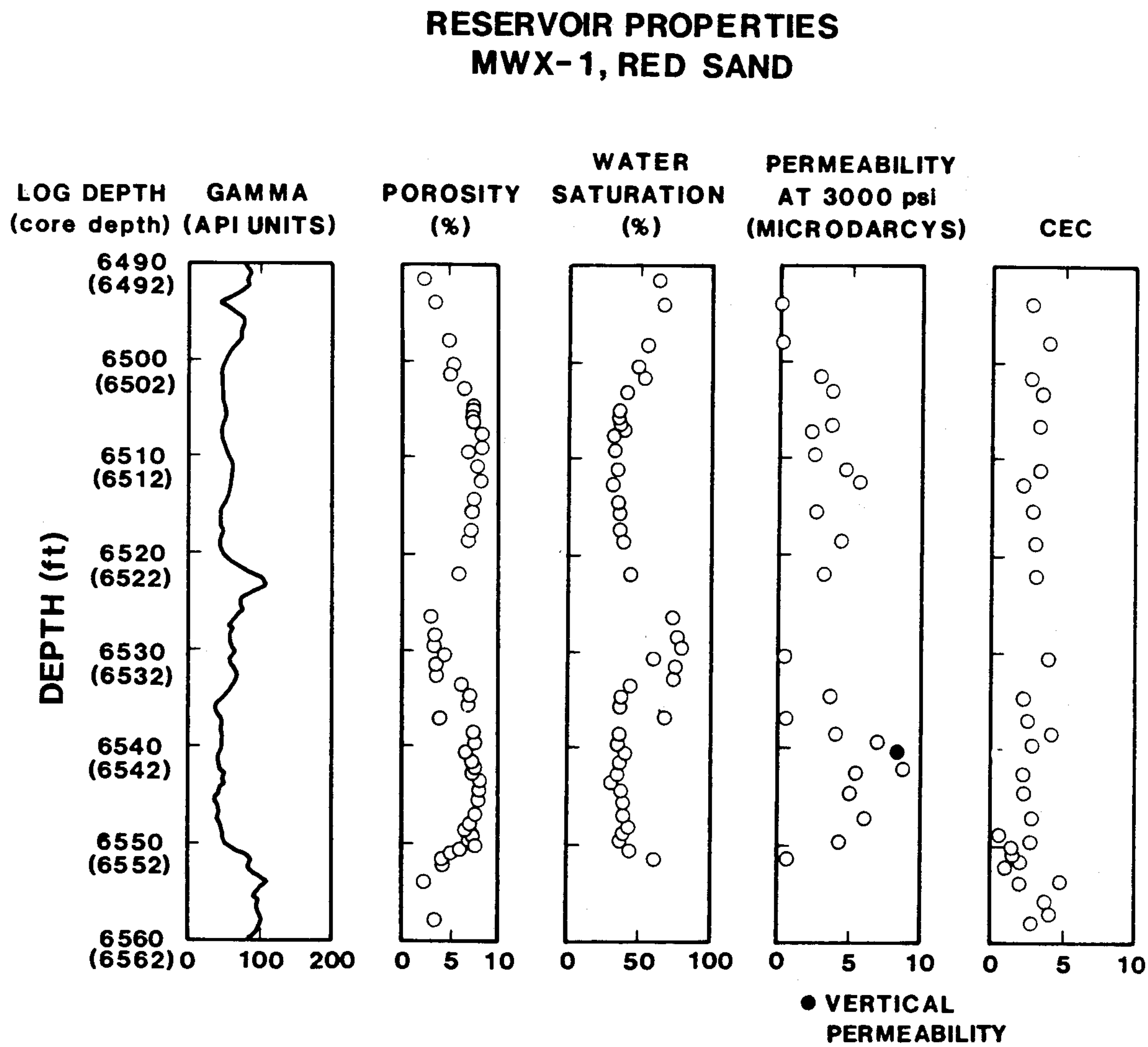

RESERVOIR PROPERTIES
MWX-1, RED SAND
LOG DEPTH (core depth)
GAMMA (API UNITS)
POROSITY (%)
WATER SATURATION (%)
PERMEABILITY AT 3000 psi (MICRODARCYS)
CEC
DEPTH (ft)
6490 (6492)
6500 (6502)
6510 (6512)
6520 (6522)
6530 (6532)
6540 (6542)
6550 (6552)
6560 (6562)
0 100 200
0 5 10
0 50 100
0 5 10
0 5 10
● VERTICAL PERMEABILITY

Figure 5.4

RESERVOIR PROPERTIES
MWX-2, YELLOW SAND

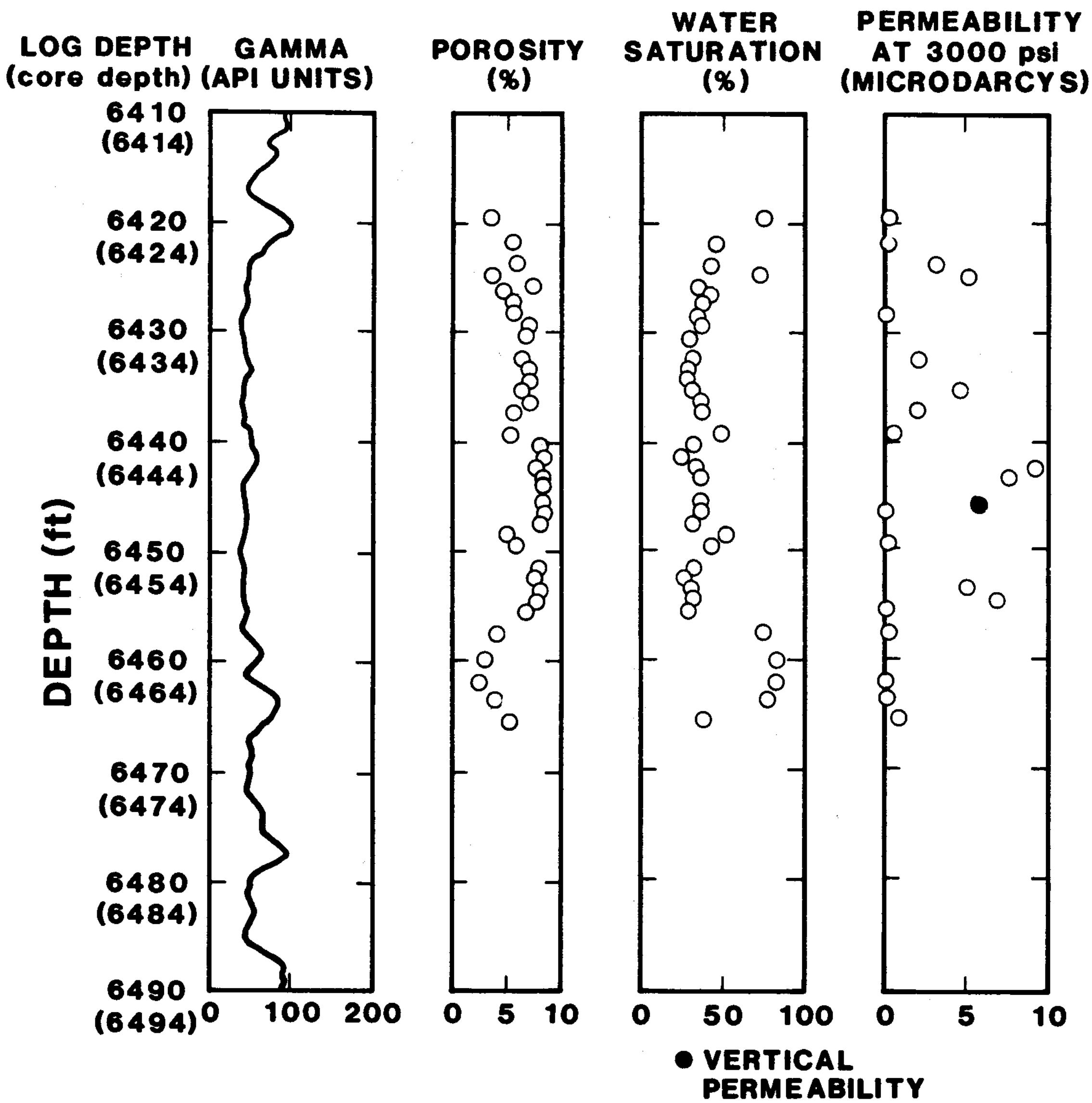


Figure 5.5

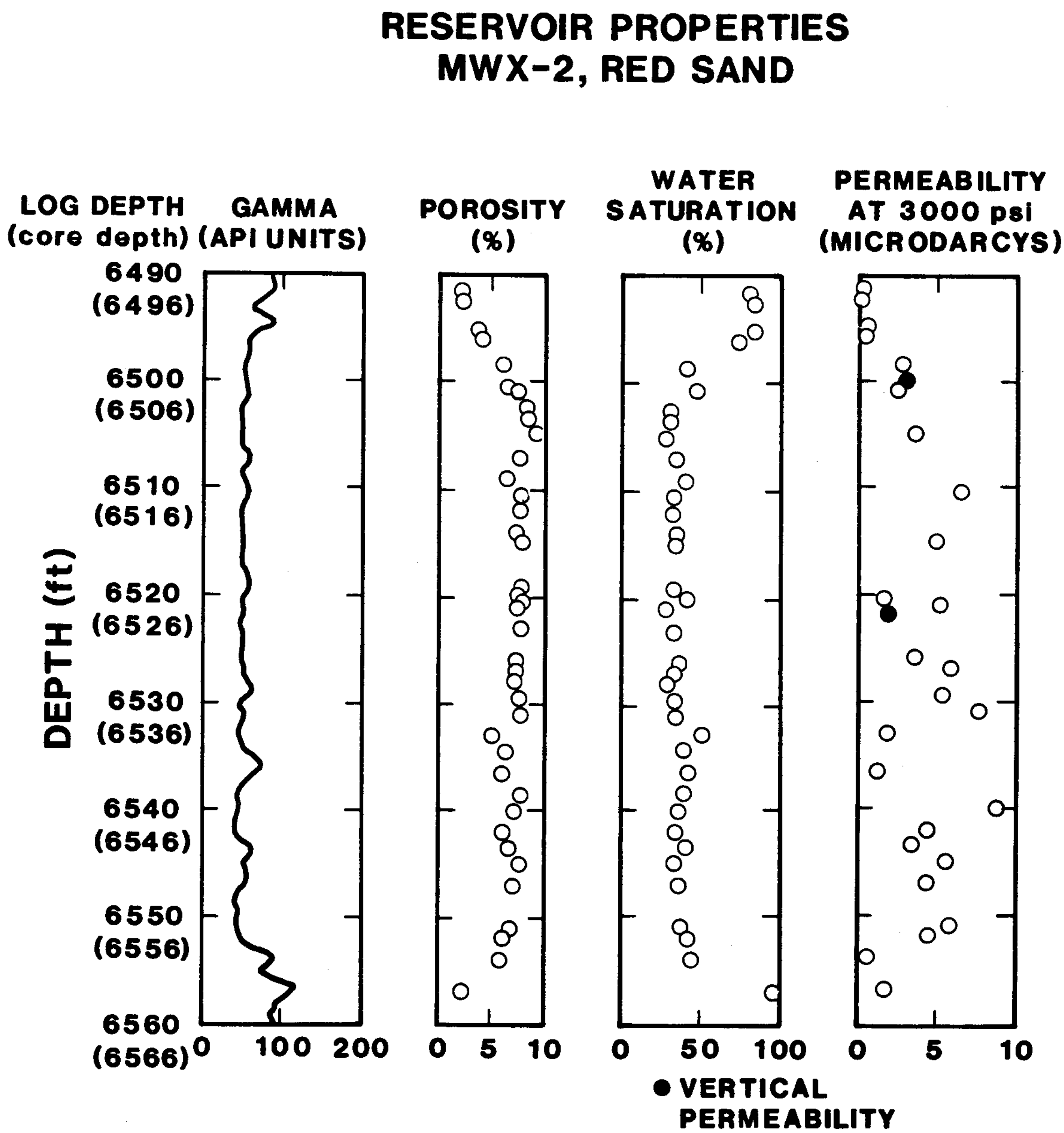

RESERVOIR PROPERTIES
MWX-2, RED SAND
LOG DEPTH
(core depth)
GAMMA
(API UNITS)
POROSITY
(%)
WATER
SATURATION
(%)
PERMEABILITY
AT 3000 psi
(MICRODARCYS)
DEPTH (ft)
6490
(6496)
6500
(6506)
6510
(6516)
6520
(6526)
6530
(6536)
6540
(6546)
6550
(6556)
6560
(6566)
0
100
200
0
5
10
0
50
100
0
5
10
● VERTICAL
PERMEABILITY

Figure 5.6

RESERVOIR PROPERTIES
MWX-3, YELLOW SAND

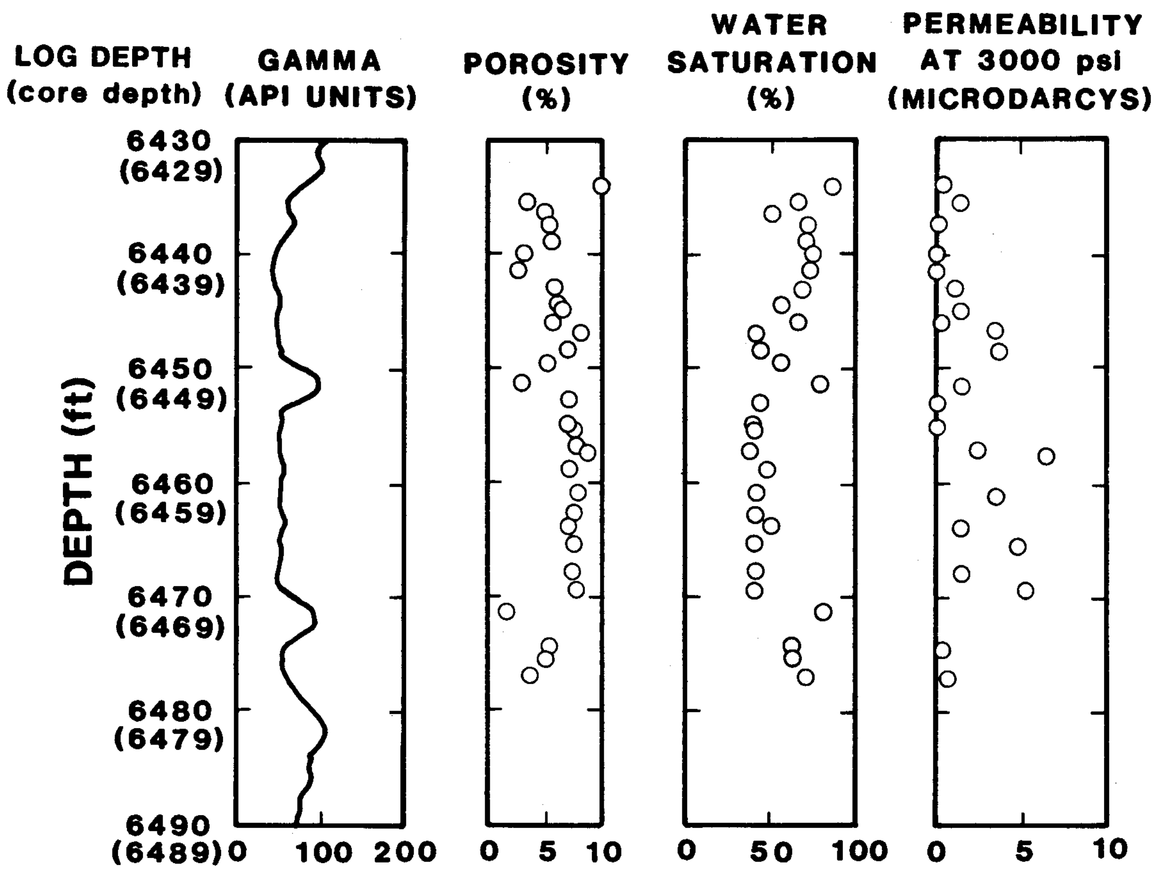


Figure 5.7

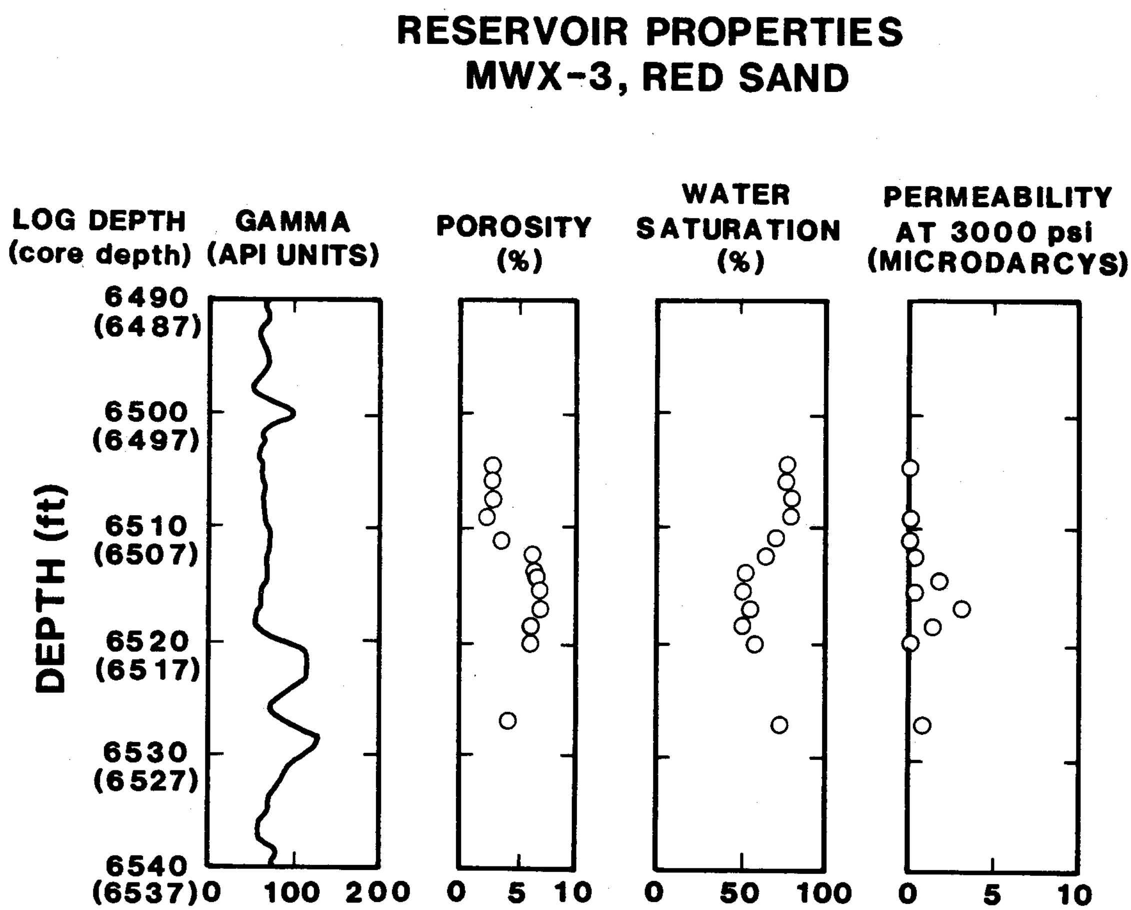

RESERVOIR PROPERTIES
MWX-3, RED SAND
LOG DEPTH
(core depth)
GAMMA
(API UNITS)
POROSITY
(%)
WATER
SATURATION
(%)
PERMEABILITY
AT 3000 psi
(MICRODARCYS)
DEPTH (ft)
6490
(6487)
6500
(6497)
6510
(6507)
6520
(6517)
6530
(6527)
6540
(6537)
0 100 200
0 5 10
0 50 100
0 5 10

Figure 5.8

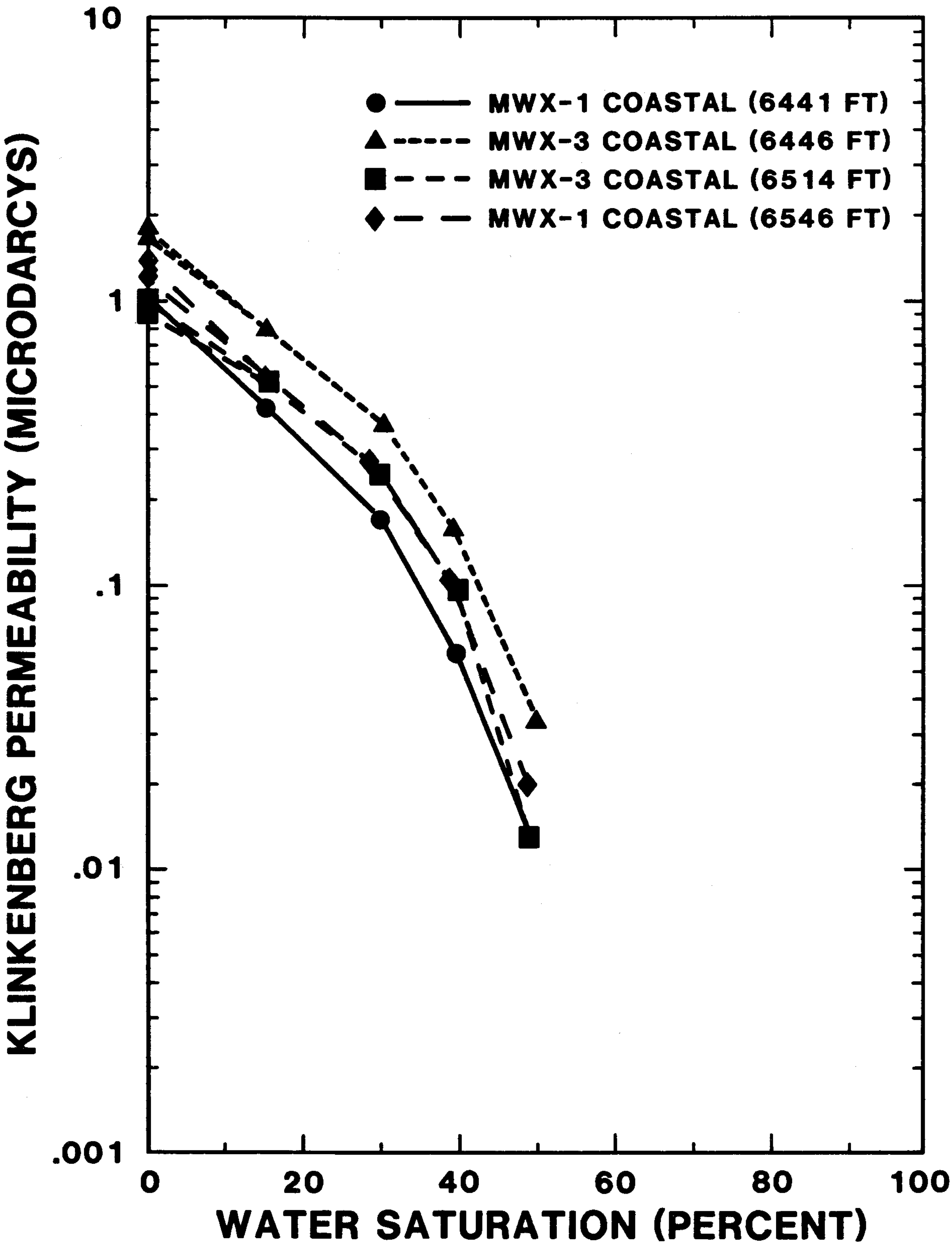


Figure 5.9 Permeability as Function of Water Saturation (at 4000 psi confining pressure)

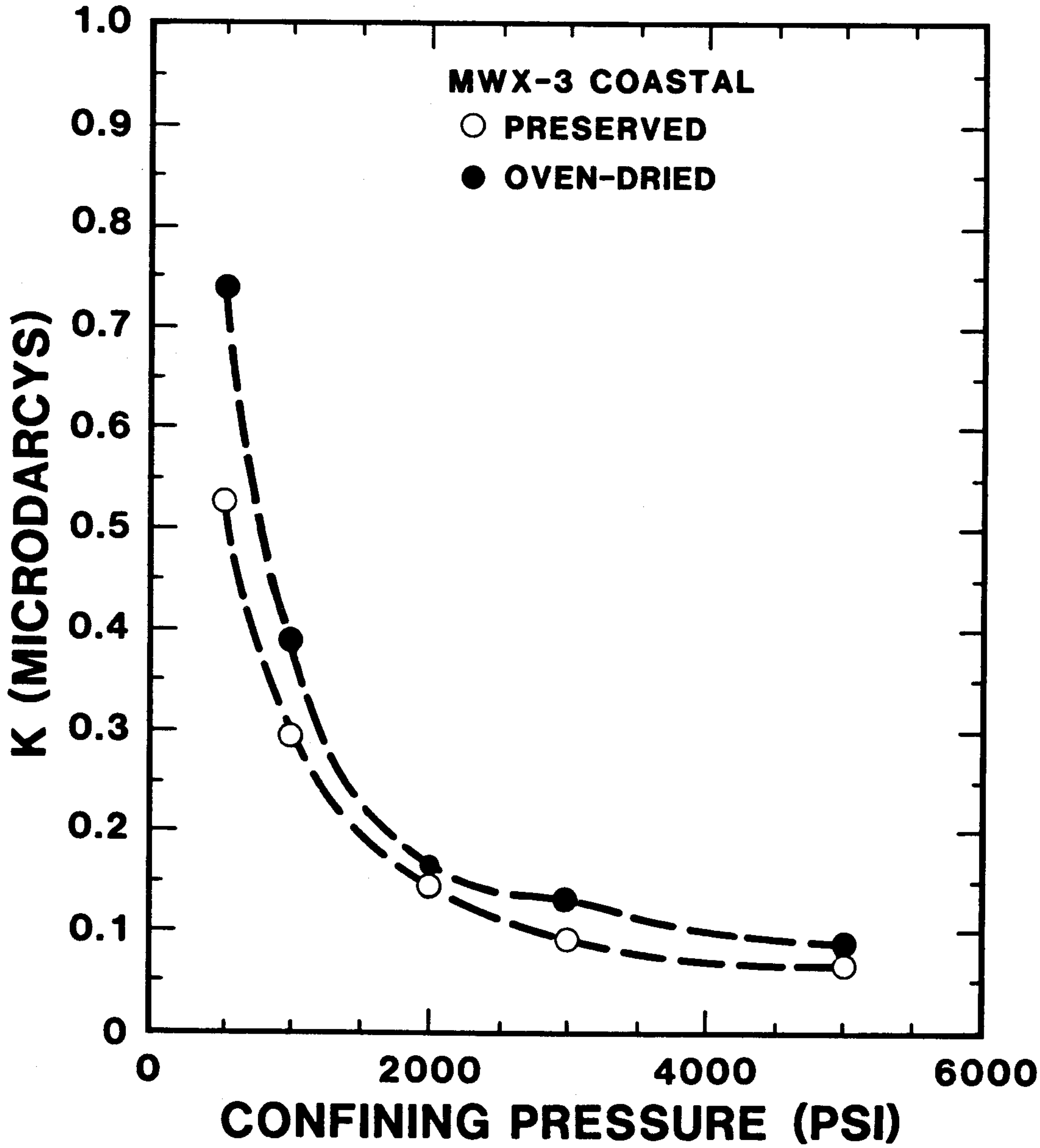


Figure 5.10 Comparison of Brine Permeabilities of Preserved and Oven Dried Coastal Core

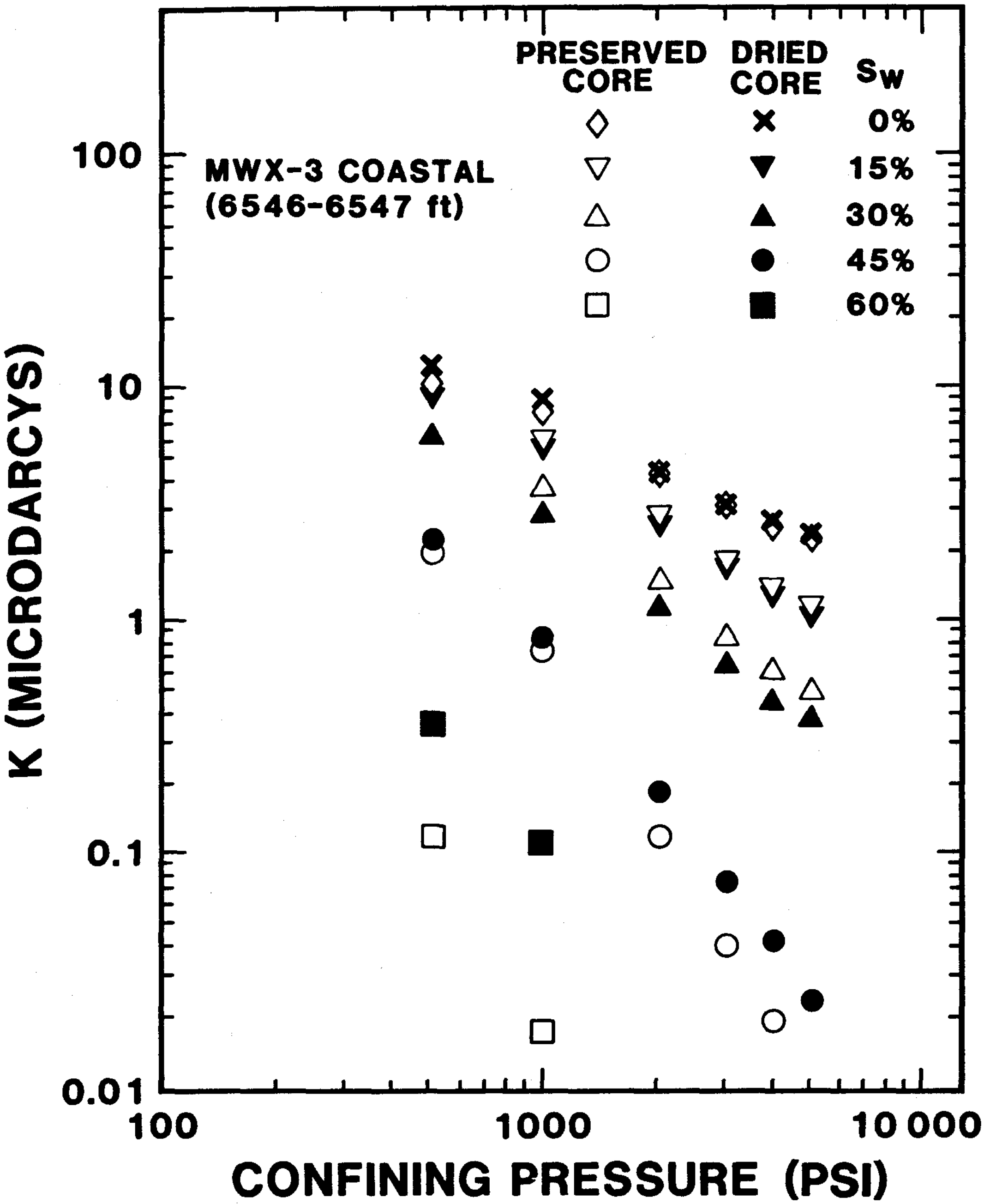


Figure 5.11 Comparison of Relative Permeabilities of Preserved and Oven Dried Coastal Core

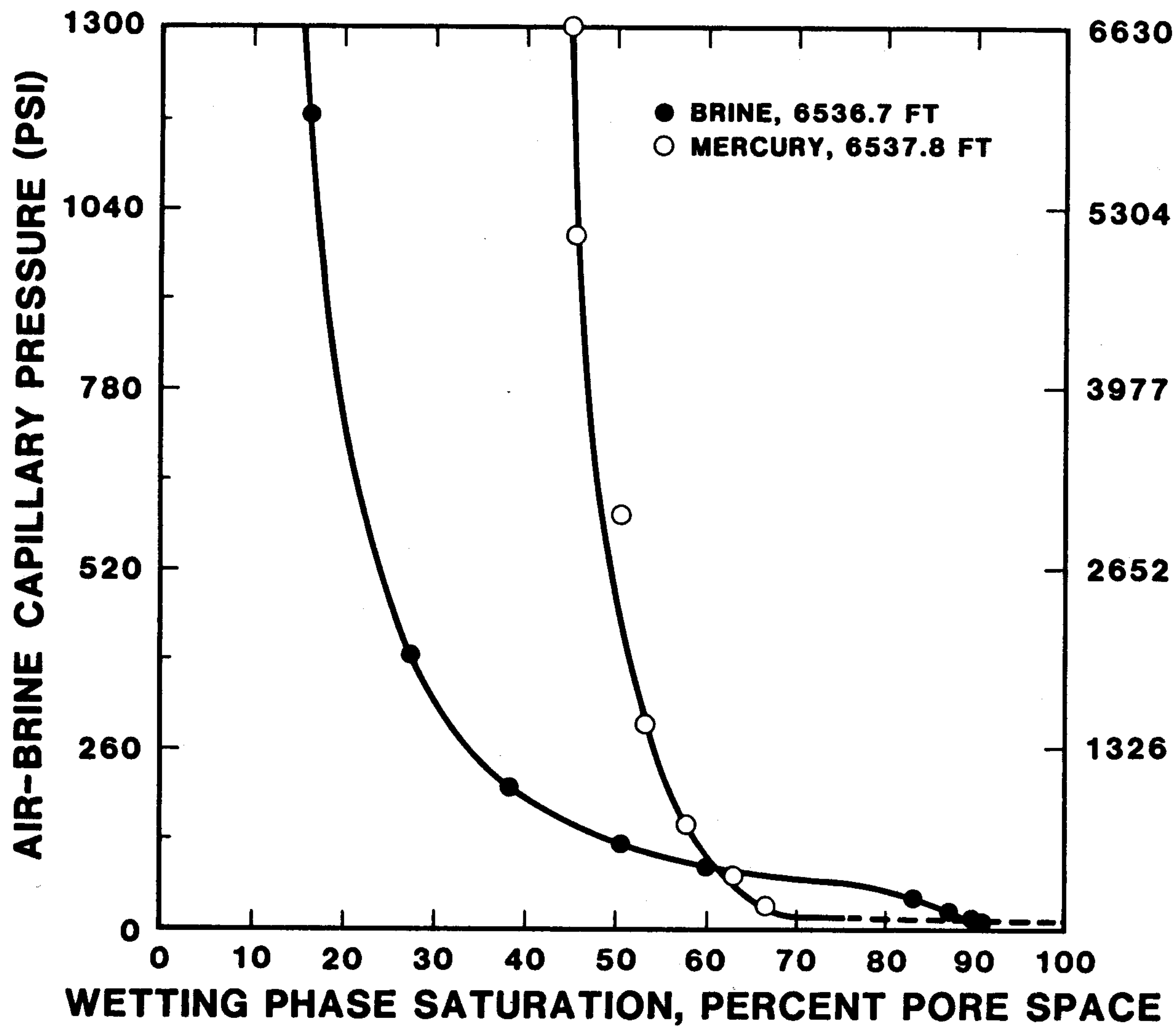


Figure 5.12 Capillary Pressures of Coastal Core by Two Methods

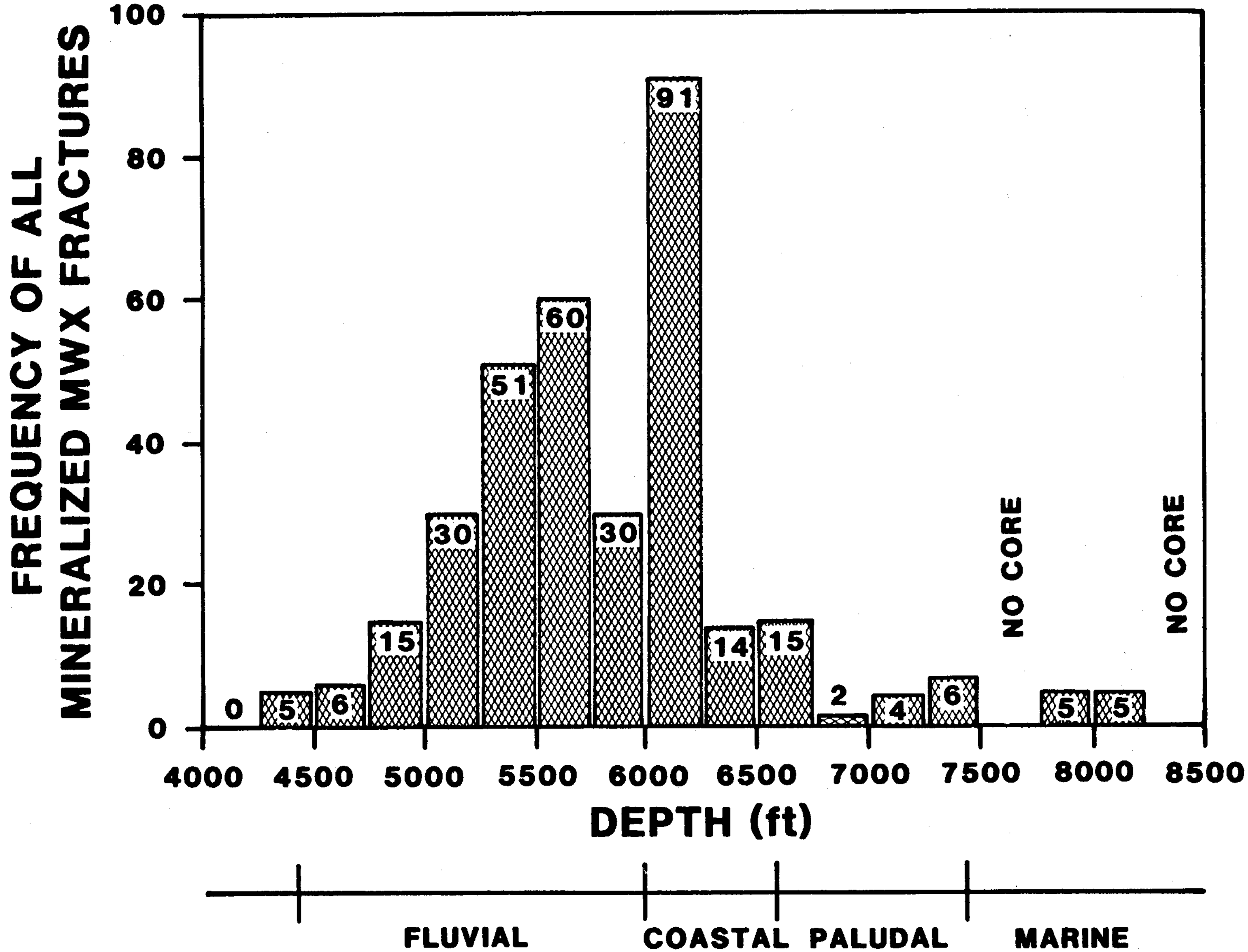


Figure 5.13 Distribution of All Mineralized Fractures in MWX Core

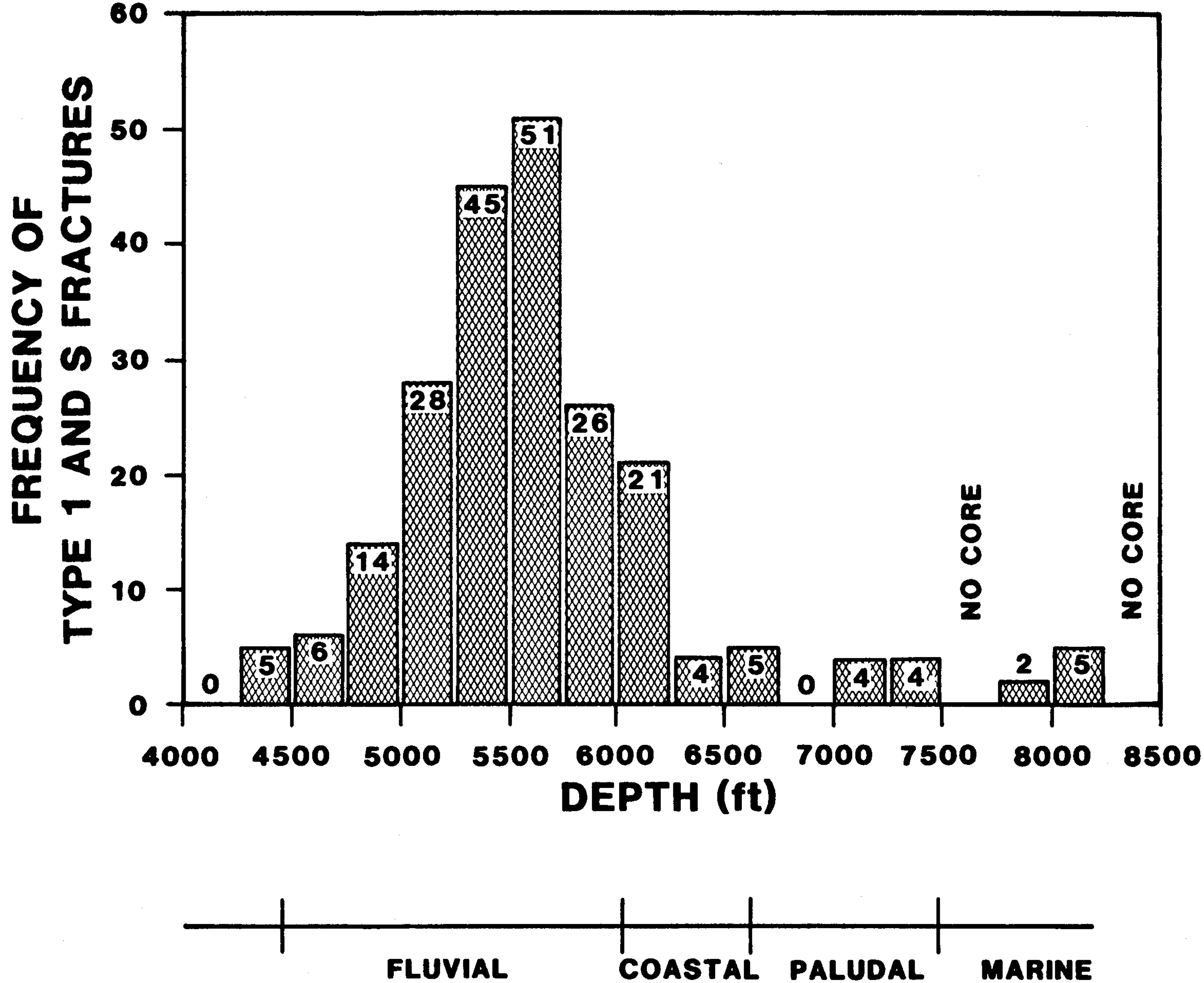


Figure 5.14 Distribution of Mineralized Extension Fractures in MWX Core

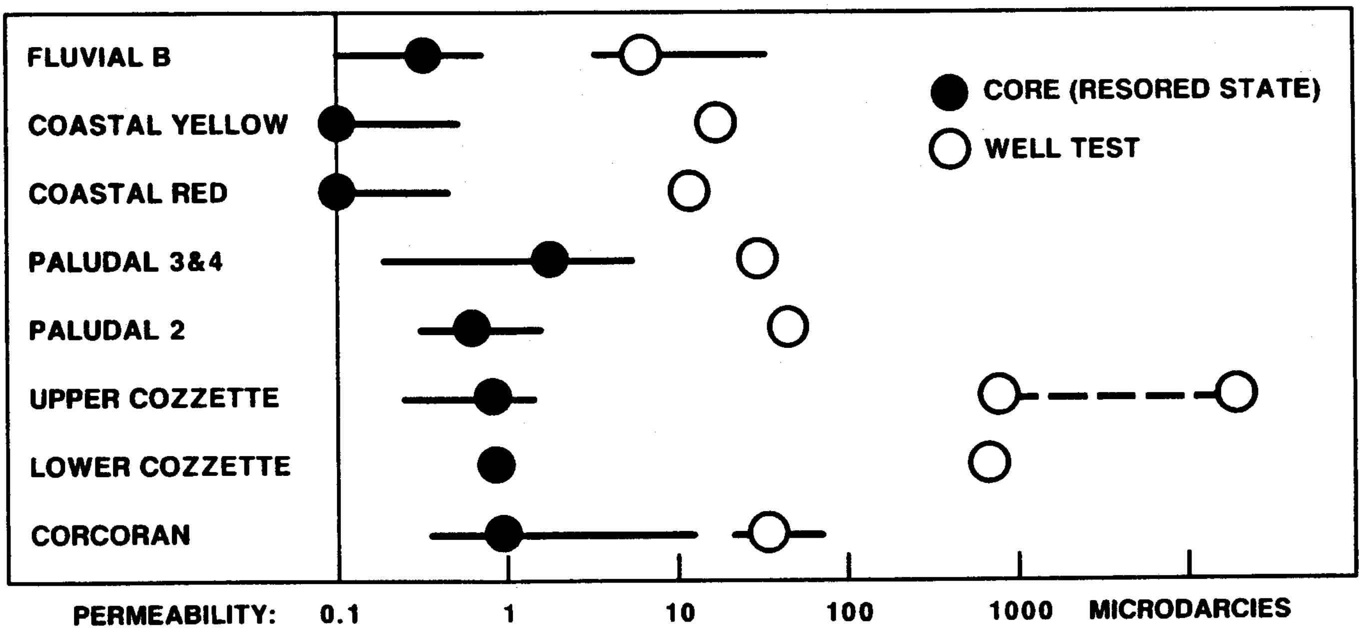


Figure 5.15 Comparison of Restored State (Matrix) and Well Test (Reservoir) Permeabilities Showing the Influence of Natural Fractures on Reservoir Permeability

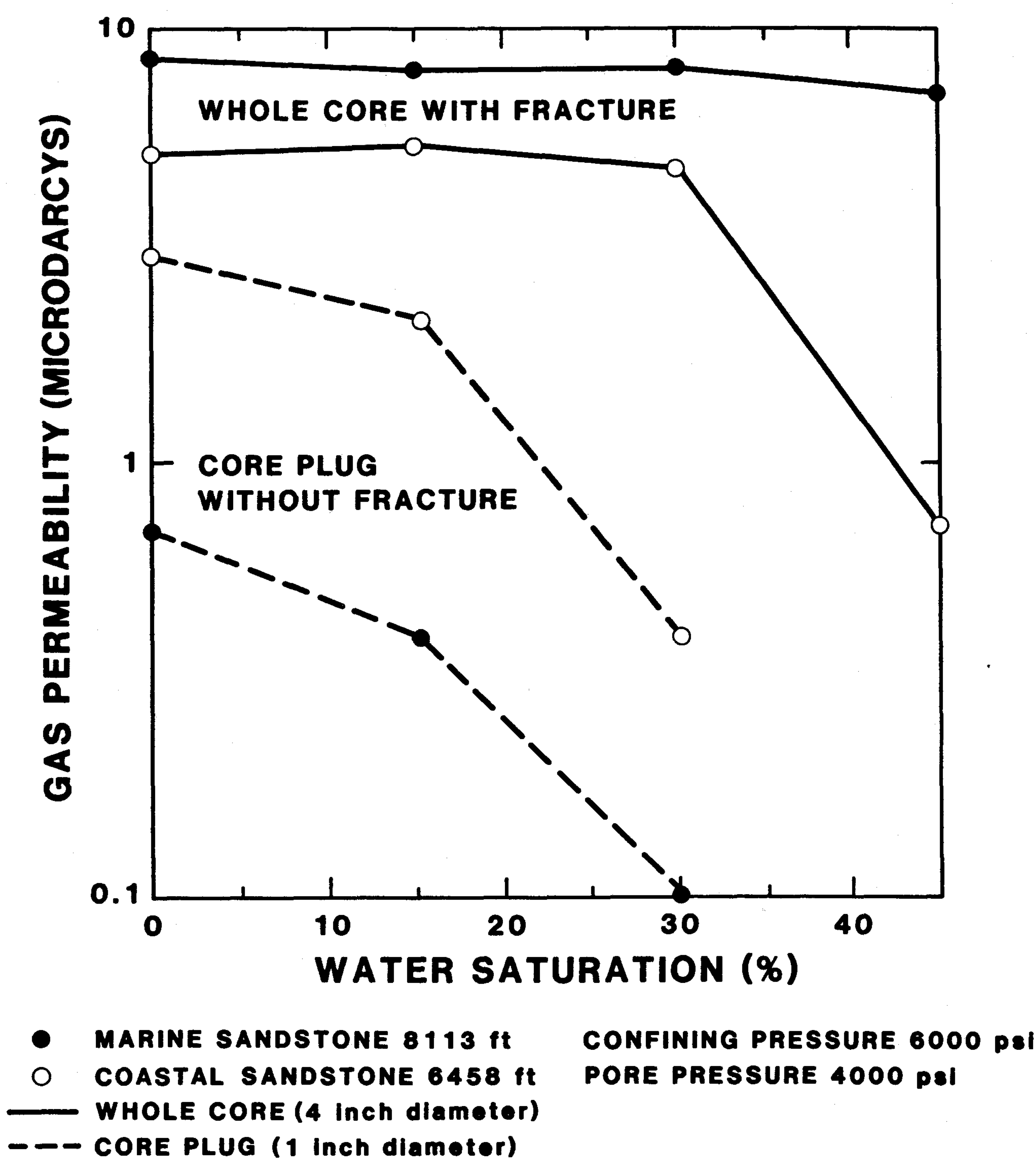
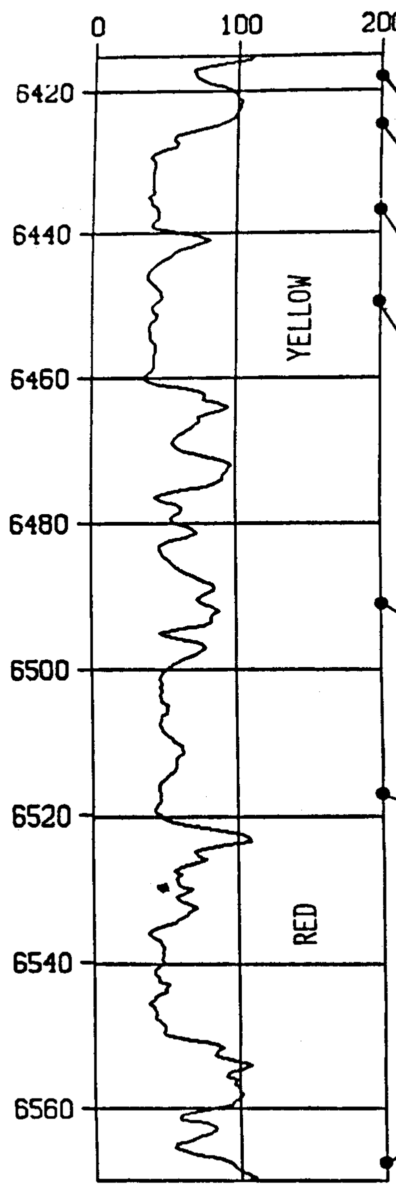


Figure 5.16 Comparison of Permeabilities of Whole Core Containing Natural Fractures with Core Samples of the Associated Matrix Rock as a Function of Water Saturation

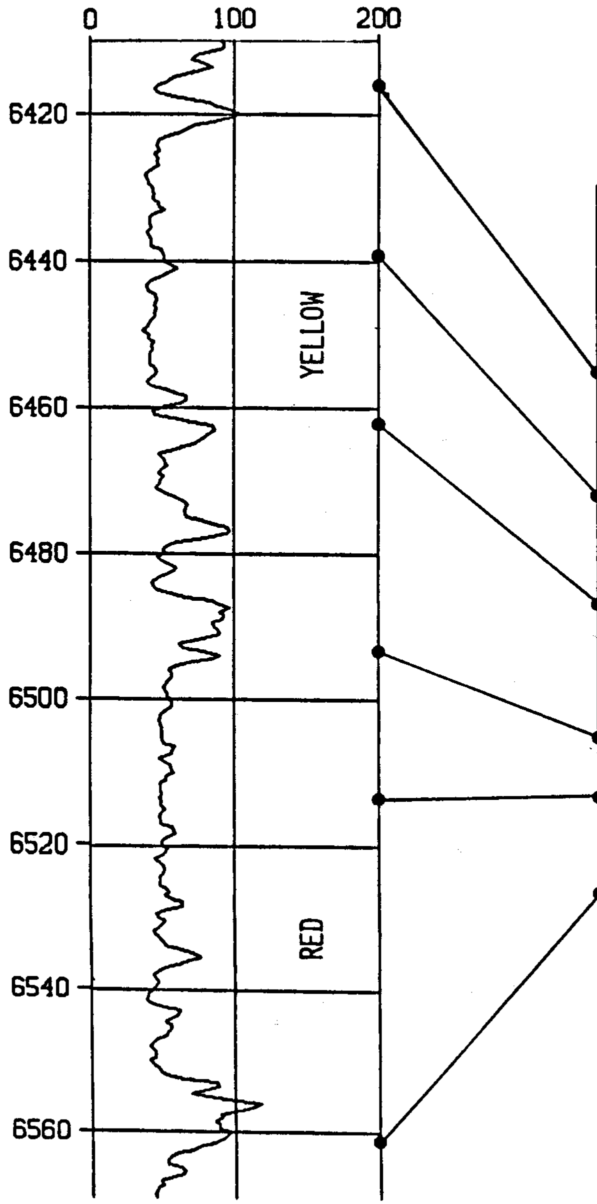


MWX-1 CORE DATA: YELLOW AND RED ZONES

LITHOLOGY	INTERVAL (FT.) (LOG DEPTH)	BRAZILIAN TESTS TENSILE STRENGTH (MPa)	TRIAXIAL TESTS CONFINING PRESSURE (MPa)	COMPRESSIVE STRENGTH[a] (MPa)	E^b (GPa)	b
Siltstone	(6419.5-6420)	-	0	145.7	51.2	.15
	6423.7-6424.2*		10	273.0	54.0	.17
		-	20	360.2	55.5	.19
Shale	(6424.3-6425.2)	-	0	67.4	16.4	.24
	6428.5-6429.4*		10	81.3	14.6	.28
			20	102.2	16.4	.28
			30	104.0	14.6	.22
			50	157.6	18.1	.33
Sandstone	(1)6437.0-6437.9	-9.07 ±0.68(1)	0(2)	104.7	21.0	.21
	(2)6438.0-6438.9		10(2)	170.5	28.2	.18
	(6434.0-6434.9)		20(2)	210.7	31.1	.19
			30(1)	274.7	34.6	.21
Sandstone	(1)6434.6-6435.3	-8.04 ±0.31(1)	0(2)	83.7	16.5	.21
	(2)6451.5-6452.6*		10(2)	137.9	24.2	.18
	(6447.5-6448.6)		20(2)	168.0	27.6	.22
			30(2)	197.4	27.0	.17
			50(2)	257.8	31.3	.20
Sandstone	(1)6491.5-6492.6*	-11.44 ±1.07(1)	0(1)	104.4	24.7	.14
	(6487.5-6488.6)		10(1)	154.6	25.6	.17
	(2)6493.9-6495.1		20(1)	144.2	24.2	.15
			30(1)	149.6	24.4	.15
			50(2)	324.7	36.1	.28
Sandstone	(1)6513.6-6514.8	-8.44 ±0.50(2)	0(2)	97.5	18.1	.29
	(2)6517.3-6518.5		10(2)	147.3	24.9	29
	(6513.3-6514.5)		20(2)	179.4	27.7	.24
			30(2)	227.0	30.6	.23
			50(2)	267.8	33.5	.23
Shale/	(1)6551.9-6552.4		0(2)	104.9	15.5	.11
Sandstone	(2)6562.4-6562.8	-9.86 ±0.26(1)	10(4)	244.1	40.4	.21
	(3)6562.8-6563.8		20(4)	301.8	40.4	.18
	(4)6564.3-6564.8*		20(2)	97.3	10.8	.18
	(6565.6-6566.8)		30(4)	275.6	42.2	.17

* Sealed at well
[a] Ultimate Axial Stress Difference
[b] Calculated for Stresses Between 20 and 60 Percent of Ultimate Axial Stress Difference.

Figure 5.17 Mechanical Properties of Coastal Zone Core from MWX-1

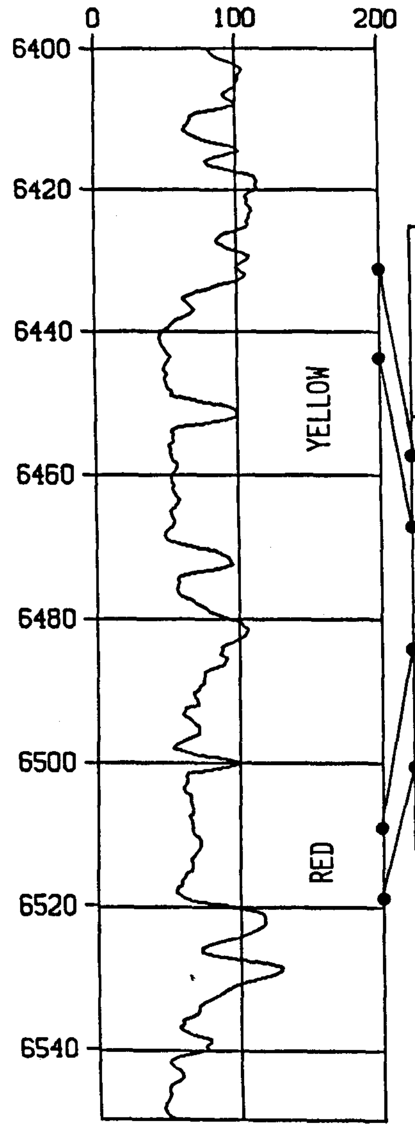


MWX-2 CORE DATA: YELLOW AND RED ZONES

LITHOLOGY	INTERVAL (FT.) (LOG DEPTH)	BRAZILIAN TESTS: TENSILE STRENGTH (MPa)	TRIAXIAL TESTS: CONFINING PRESSURE (MPa)	COMPRESSIVE STRENGTH[a] (MPa)	E^b (GPa)	b
Siltstone/ Mudstone	(6416.3-6417.4) (6418.9-6419.4	-10.81 ±1.84(1)	0(1) 10(1) 20(1) 30(1) 50(1)	146.9 210.2 256.0 282.8 378.8	34.9 34.5 36.3 36.3 38.8	.22 .19 .20 .26 .24
Sandstone	(1)6431.3-6432.6* (2)6439.7-6440.7* (6437.7-6438.7)	-8.04 ±2.26 (1 & 2)	0(2) 10(2) 20(2) 30(2) 50(1)	91.1 170.5 213.5 242.8 343.1	15.4 25.4 31.7 32.4 36.4	.29 .16 .16 .18 .24
Sandstone	(1)6437.7-6438.8 (2)6462.0-6463.0* (6461.0-6462.0)	-13.77 ±0.79(2)	0(2) 10(2) 20(2) 30(2) 50(2)	175.6 200.5 240.2 277.1 427.6	39.6 36.2 36.3 37.5 44.8	.26 .18 .20 .19 .26
Siltstone	(1)6493.0-6493.4* (6487.3-6488.0) (2)6493.4-6494.0	-6.08 ±0.39(1)	0(2) 10(2) 30(2)	62.0 79.1 95.7	17.6 17.0 15.9	.21 .17 .25
Sandstone	(1)6519.0-6520.0 (2)6520.0-6521.0* (6515.06516.0)	-7.16 ±0.91(2)	0(2) 10(2) 20(2) 30(2) 50(2)	87.4 143.5 177.8 201.2 289.2	18.4 25.6 27.9 28.0 33.2	.24 .18 .19 .19 .25
Siltstone	(1)6561.1-6562.2* (2)6564.7-6565.5 (3)6565.5-6566.1*	-7.07 ±0.90(1)	0(1) 10(1) 20(1) 30(1) 50(1)	86.5 82.8 90.9 94.4 120.2	21.7 15.3 15.2 15.3 13.1	.28 .23 .21 .29 .35

* Sealed at well
[a] Ultimate Axial Stress Difference
[b] Calculated for Stresses Between 20 and 60 Percent of Ultimate Axial Stress Difference.

Figure 5.18 Mechanical Properties of Coastal Zone Core from MWX-2



MWX 3 CORE DATA: YELLOW AND RED ZONES

LITHOLOGY	INTERVAL (FT.) (LOG DEPTH)	BRAZILIAN TESTS	TRIAXIAL TESTS			
		TENSILE STRENGTH (MPa)	CONFINING PRESSURE (MPa)	COMPRESSIVE STRENGTH[a] (MPa)	E^b (GPa)	ν^b
Shale	(same) 6431.8-6432.7*	-6.4 ±0.3	20	108.9	17.9	.28
			30	121.4	17.6	.27
Sandstone	(same) 6442.3-6443.4*	-8.2 ±0.5	0	101.6	17.5	.21
			10	166.0	24.5	.21
			20	202.8	27.0	.20
			30	235.6	28.2	.21
Sandstone	6509.7-6510.8* (6511.2-6512.3)	-9.4 ±0.8	0	107.8	22.9	.23
			10	164.3	26.7	.19
			20	198.6	29.2	.19
			30	226.9	29.6	.20
Shale	6519.7-6520.3*	-3.6 ±2.4	20	85.9	13.9	.31
	(6521.2-6521.8)	30	90.3	13.6	.32	

* Sealed at Well
[a] Ultimate Axial Stress Difference
[b] Calculated for Stresses Between 20 and 60 Percent of Ultimate Axial Stress Difference

Figure 5.19 Mechanical Properties of Coastal Zone Core from MWX-3

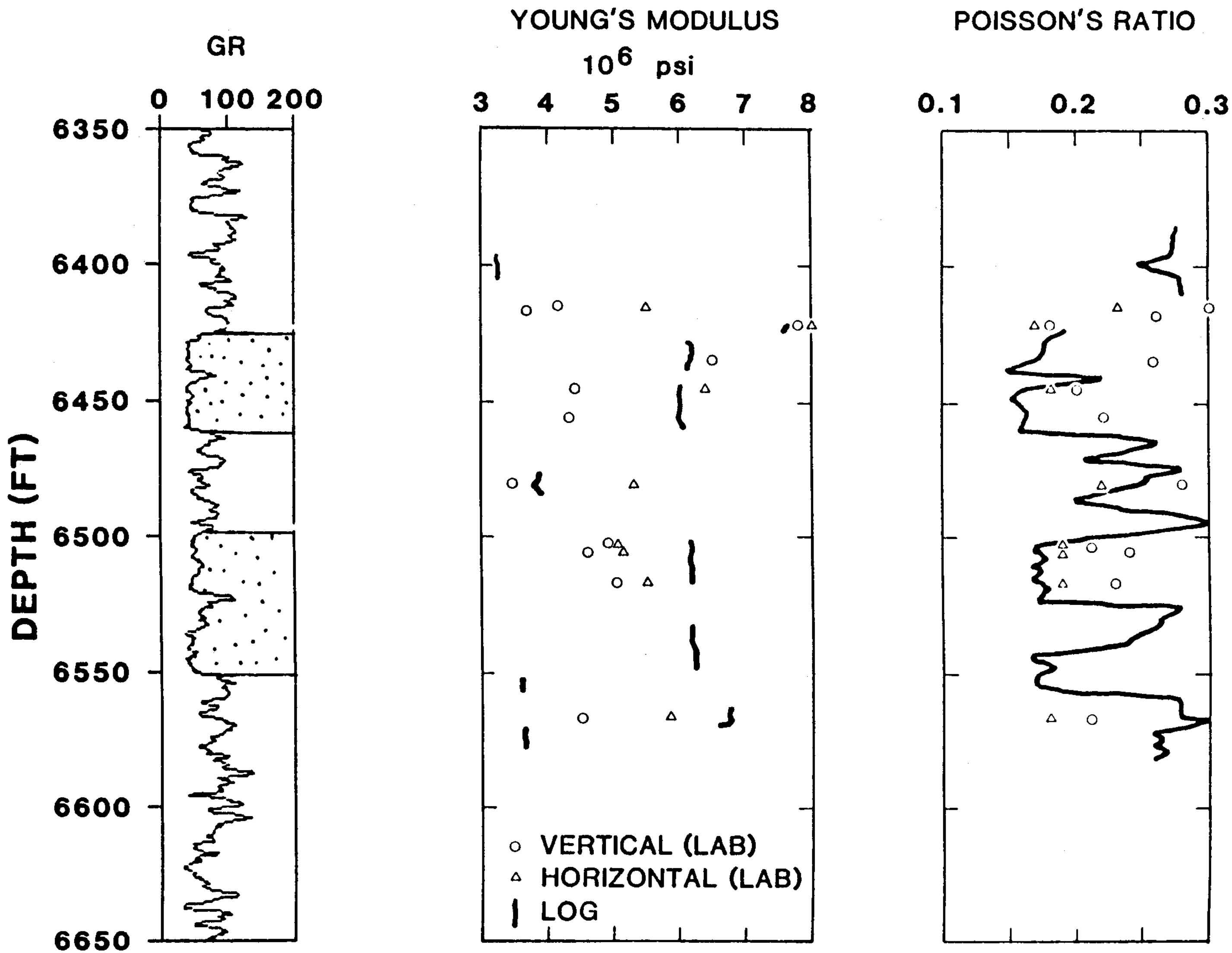


Figure 5.20 Comparison of Young's Modulus and Poisson's Ratio as Function of Depth and Lithology

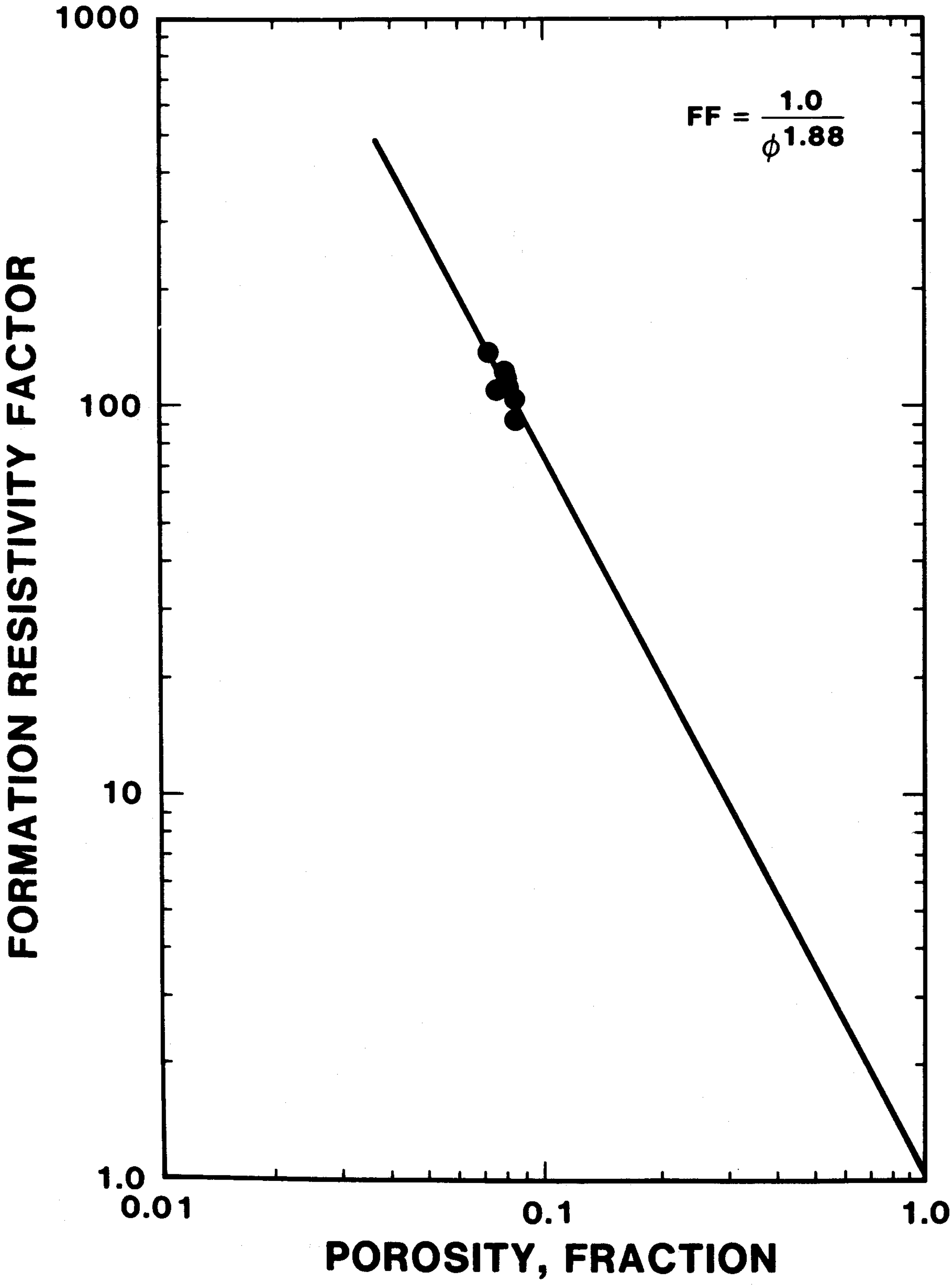


Figure 5.21 Formation Factor

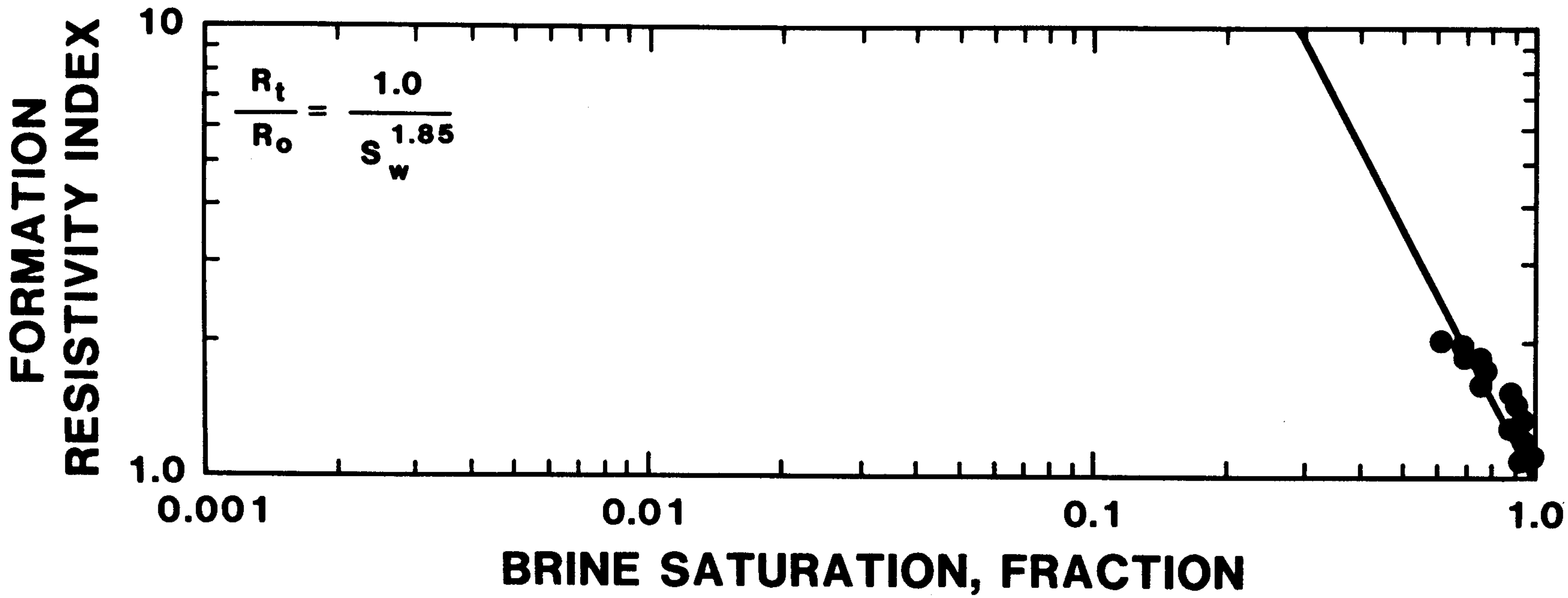


Figure 5.22 Resistivity Index

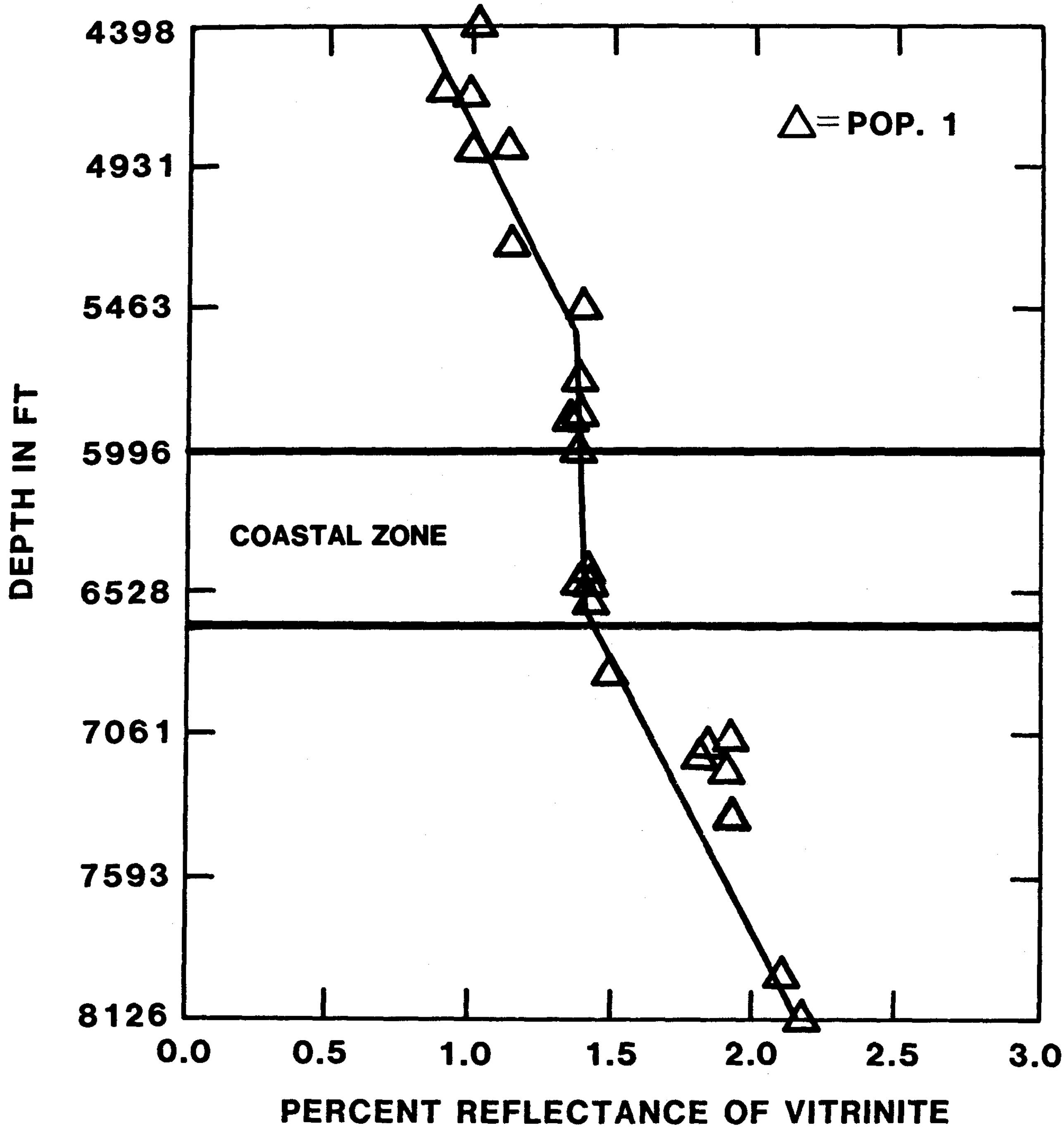


Figure 5.23 Vitrinite Reflectance as Function of Depth

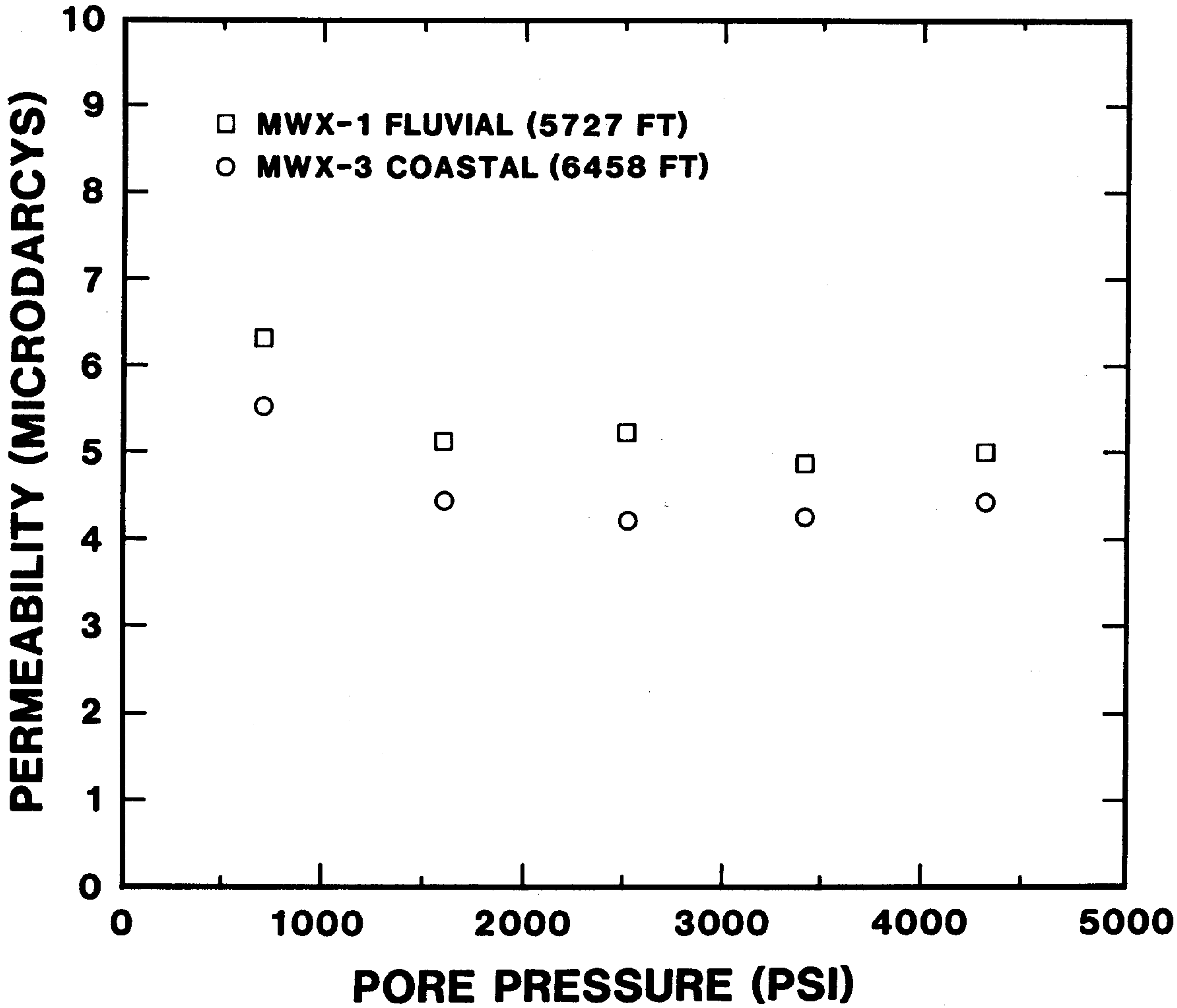
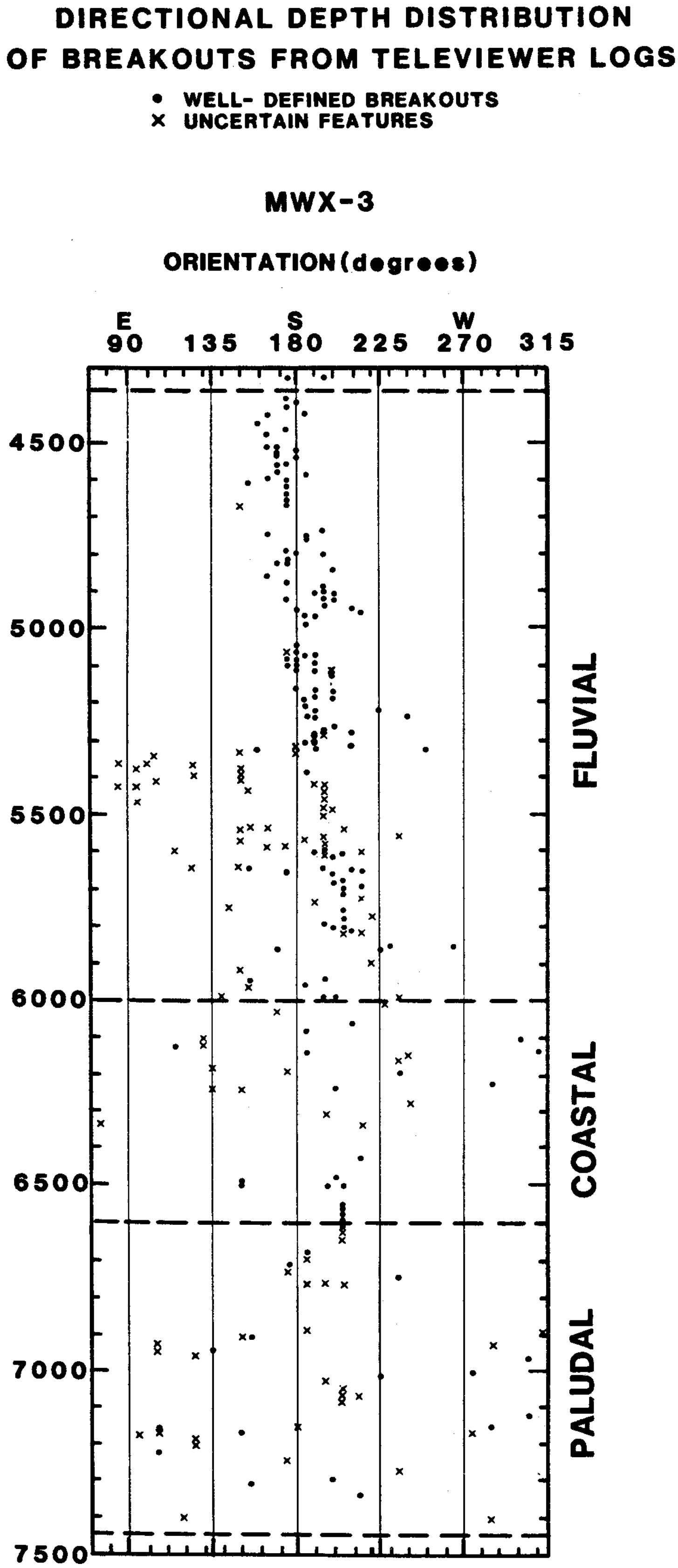


Figure 5.24 Permeability as Function of Pore Pressure at Constant Net Confining Stress of 2900 psi



DIRECTIONAL DEPTH DISTRIBUTION
OF BREAKOUTS FROM TELEVIEWER LOGS
• WELL- DEFINED BREAKOUTS
× UNCERTAIN FEATURES
MWX-3
ORIENTATION (degrees)
E
S
W
90
135
180
225
270
315
4500
5000
5500
6000
6500
7000
7500
FLUVIAL
COASTAL
PALUDAL

Figure 5.25

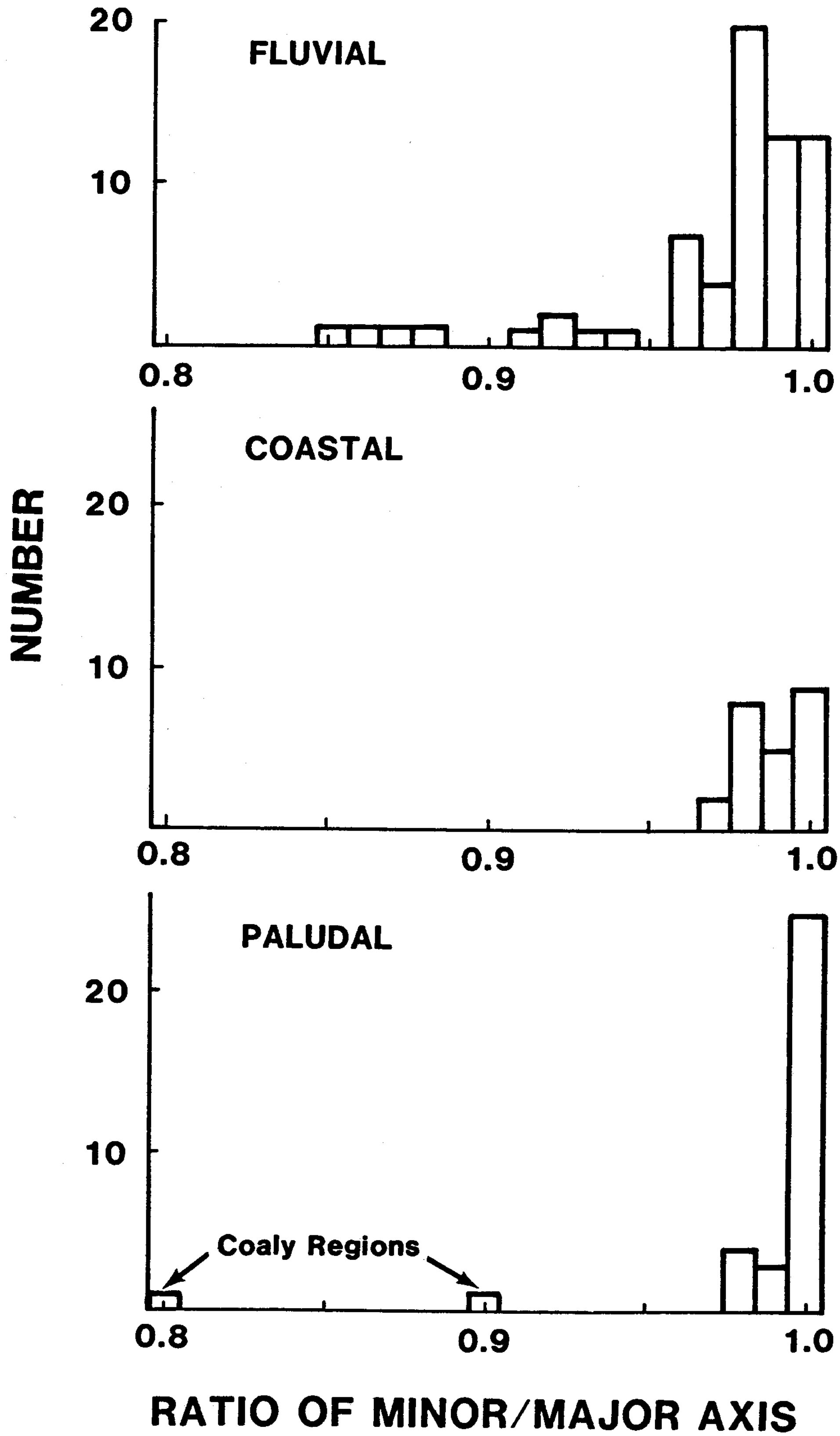


Figure 5.26 Borehole Eccentricity From Four-Arm Oriented Caliper Log

6.0 IN SITU STRESS

Norman R. Warpinski
Sandia National Laboratories

6.1 OBJECTIVE

The objective of the in situ stress testing program is to determine the vertical distribution of the minimum, principal, horizontal in situ stress for the purpose of evaluating hydraulic fracture containment. In addition, these stress data are important for estimating net stresses on reservoir rocks (for property measurements), on proppant packs, and on natural fracture systems. Anelastic strain recovery (ASR) measurements are made to provide the orientation of the stress field and information on the maximum, principal horizontal in situ stress.

6.2 IN SITU STRESS MEASUREMENTS

The vertical distribution of the minimum principal horizontal in situ stress is now known to have a significant influence on hydraulic fracture geometry. Perkins and Kern[1] noted its importance with respect to fracture height and Simonson et al.[2] demonstrated how to calculate fracture height in a nonuniform, but symmetric, stress field. Laboratory[3-5] and mineback[6] experiments have proven the effect of minimum in situ stress differences on fracture height, but, as yet, little field evidence is available, mostly due to the lack of both stress and diagnostic data.

Previous results[7-11] have shown that large stress contrasts exist between sandstones and the abutting mudstone or shale material. These high stresses have apparently kept hydraulic fractures well-contained, but have also resulted in relatively high treatment pressures. Detailed measurements of the stress distribution are essential for understanding hydraulic fracture behavior in this environment.

Additionally, the magnitude of the maximum horizontal in situ stress may be significant for coastal treatments because of the possibility of interactions with the natural fracture system during hydraulic fracture treatments. In such cases, the orientation of the stress field with respect to the natural fractures is also important.

Hydraulic fracturing stress measurements are used to determine the vertical distribution of the minimum principal in situ stress. Anelastic strain recovery (ASR) techniques provide the stress orientation and, when calibrated using measured minimum stress data and log-derived overburden stresses, provide an estimate of the maximum horizontal principal in situ stress. A number of differential strain curve analysis (DSCA) tests were also provided by Dowell-Schlumberger.

6.2.1 Hydraulic Fracturing Measurements

The stress testing technique and the instrumentation and equipment used are fully described in Reference 8. Briefly, small volume hydraulic fractures (5-200 gal) are conducted through a 2-ft perforated interval. Pressure is measured with a quartz crystal oscillator gage for accurate instantaeous shut-in pressure (ISIP) determinations. A bottomhole closure tool is employed to provide fast shut-ins with no wave or storage effects. Typically, three to six repeat injections are performed for each zone. The instantaneous shut-in pressure as determined from the pressure record is taken to be equal to the minimum principal horizontal in situ stress, σ_{Hmin}. In these tests, no information can be obtained about the maximum principal horizontal in situ stress. Stress tests were conducted in MWX-3, because of a fault close to MWX-2 at this depth.

6.2.2 Strain Recovery Measurements

The ASR technique used in these experiments is described in References 12-14. Briefly, it consists of mounting clip-on displacement gages on a piece of sealed, oriented core and recording the time-dependent relaxation of that core. In vertical holes in flat-lying beds, as in these experiments, only four gages are used (one vertical, three horizontal).

Determination of the orientation of the stress field has been shown to be straightforward[15,16] for many sedimentary rocks and is readily calculated by determining the principal strain orientations. If there is no rock fabric to distort the results, the maximum strain direction is coincident with the maximum stress direction.

The determination of the stress magnitudes is more complicated and requires a model for the ASR process. Blanton[17] and Warpinski and Teufel[18] have developed different types of viscoelastic models to explain the behavior. Both models will be used in the analyses of these data.

Blanton's[17] solution, referred to as the direct model, is the easiest to apply and yields a direct calculation of the stresses from the principal strains as

$$\sigma_1 = (\sigma_v - \alpha P) \frac{(1-\nu)\Delta\varepsilon_1 + \nu(\Delta\varepsilon_2 + \Delta\varepsilon_v)}{(1-\nu)\Delta\varepsilon_v + \nu(\Delta\varepsilon_1 + \Delta\varepsilon_2)} + \alpha P \tag{1}$$

and

$$\sigma_2 = (\sigma_v - \alpha P) \frac{(1-\nu)\Delta\varepsilon_2 + \nu(\Delta\varepsilon_1 + \Delta\varepsilon_v)}{(1-\nu)\Delta\varepsilon_v + \nu(\Delta\varepsilon_2 + \Delta\varepsilon_1)} + \alpha P \tag{2}$$

where the $\Delta\varepsilon$ are the change in the principal strains between any two times, ν is Poisson's ratio, P is the pore pressure, α is a poroelastic constant (approximately unity for Mesaverde rocks at the MWX site) and the subscripts 1 and 2 refer to the maximum horizontal and minimum horizontal directions, respectively, while v refers to the overburden. Important assumptions for the direct model include (1) linearly viscoelastic behavior, (2) constant Poisson's ratio throughout the relaxation process, (3) step unloading of the in situ stresses at the moment of coring, (4) a constant α throughout the process, (5) a vertical overburden stress and wellbore, and (6) isotropic behavior.

Warpinski and Teufel's model,[18] referred to as the strain-history model (because it requires fitting a theoretical model to the measured strain history), requires a least-squares fit of the entire strain data set to an expected relaxation behavior of the form

$$\varepsilon_r(t) = (2\sigma_1 \cos^2\theta + 2\sigma_2 \sin^2\theta - \sigma_1 \sin^2\theta - \sigma_2 \cos^2\theta - \sigma_v) J_1 (1-e^{-t/t_1})$$
$$+ (\sigma_1 + \sigma_2 + \sigma_v - 3P) J_2 (1 - e^{-t/t_2}) \tag{3}$$

and

$$\varepsilon_v(t) = (2\sigma_v - \sigma_1 - \sigma_2) J_1 (1 - e^{-t/t_1})$$
$$+ (\sigma_1 + \sigma_2 + \sigma_v - 3P) J_2 (1 - e^{-t/t_2}) \tag{4}$$

where θ is the gage angle orientation with respect to the maximum stress, J_1 and J_2 are distortional and dilatational creep compliance arguments (i.e., equilibrium values of the creep compliance), t is the time, t_1 and t_2 are deviatoric and dilatational time constants, respectively, and the subscript r refers to radial direction in the horizontal plane. Important assumptions for this model are (1) the rock behaves as if it is linearly viscoelastic, (2) the behavior is exponential and can be described using standard models, (3) the overburden stress and wellbore are vertical, (4) the rock is isotropic, (5) the bulk modulus of the grain material is not a viscoelastic parameter (since the process appears to be a fracturing phenomenon), and (6) step unloading of the in situ stresses at the moment of coring.

Once the data are least-squares fitted, estimates of the stresses can be made if J_1 is known. Alternately, a minifrac in tandem with the ASR data (so σ_2 is known) allows J_1 to be determined. In this study, data are still being acquired on J_1 and thus it cannot be used to determine σ_2. We currently use the minifrac data to calculate σ_1 and J_1.

The primary problems with ASR are (1) to ascertain that rock fabric is not distorting the results and (2) obtaining sufficient data to use either viscoelastic model to calculate stress magnitudes.

6.2.3 Differential Strain Curve Analysis

Dowell-Schlumberger has performed DSCA measurements[19-21] on several MWX cores from the coastal zone, as well as the variant, differential wave velocity analysis[22] (DWVA). Using DSCA, DWVA and suitable estimates of important rock properties and reservoir parameters, the magnitudes of the horizontal in situ stresses can be estimated. The orientation of the stress field also proceeds directly from the measurement process (as in ASR).

6.3 HYDRAULIC FRACTURE STRESS MEASUREMENT RESULTS

Fourteen stress tests were attempted: eleven yielded stress results, two failed due to communication problems, and one was inconclusive due to undecipherable pressure behavior.

These stress tests were conducted in MWX-3 using the standard technique. Two-foot intervals were perforated with four jet shots per foot (19 gm charges were used because of the heavy casing in this well), and fractured with small volumes (5 to 100 gal) of 3% KCl water at low flow rates (4 to 14 gpm). Shut-in was performed with a bottomhole closure tool to obtain accurate ISIPs.

Figure 6.1 and Table 6.1 give the results of these stress tests. The most obvious result is the contrast in stresses between the sandstones and the shales. These contrasts range from 700 to 1300 psi and bode well for hydraulic fracture containment. Even the thin shale stringer at 6527-29 ft between the two Red sands has 800 to 1000 psi higher stress than the nearby sands. Unfortunately no measurement of the stress in the shale/siltstone between the Red and the Yellow sands was possible. Stress tests were attempted in both MWX-3 and MWX-2, but were unsuccessful due to communication into nearby perforated intervals.

The stresses in the sands are all around 5700 to 5800 psi at an initial reservoir pressure around 4100 psi. These reservoirs were drawn down to

3800 to 3900 psi in the near wellbore area and some evidence during the nitrogen frac (Section 7.2.3) indicated that the closure stress in the Yellow sands had dropped to below 5500 psi.

Figure 6.2 shows an example pressure record from the combined test at 6765-67 ft and 6706-08 ft. (This test is actually in the top of the paludal zone.) These two zones were tested together because the packer could not be run through a tight spot in the casing at about 6700 ft. This is the second pump in this zone and it was conducted at 12 gpm. The ISIP is difficult to discern, possibly because two zones are being shut-in at the same time. The ISIP is about 6950 ± 50 psi, but 160 psi needs to be added to this result because the bottom hole pressure tool is well above the zone. This results in an ISIP of about 7110 psi. (This number, as well as most of the following test results will not exactly match Table 6.1 because Table 6.1 gives an average of the valid stress tests for each zone. A valid test is one in which there is a reasonably clear ISIP and no strange behavior during or after fracturing.)

Figure 6.3 shows the pressure response of the second pump into the zone at 6606-08 ft. This is one of the good mudstones below the Red B sand and the high stress in this zone is readily apparent. The treatment pressure reached 7320 psi before stabilizing at 7280 psi. The flow rate was about 12 gpm and the ISIP is about 7120 with an error of ±20 psi. For the final stress value, 10 psi needs to be added to these numbers to account for the hydrostatic stress difference between the frac interval and the pressure transducer which is 22 ft higher.

Figure 6.4 shows the pressure record for the third pump at 6565-67 ft. This test was conducted at 20 gpm in a mudstone just below the Red sand. This is one of those cases where there is a very large drop in pressure at shut in. This is most likely caused by an entrance restriction from the perforation into the fracture. Although the ISIP looks to be fairly clear at about 6970 psi, this is considered to be in error by as much as ±100 psi because of the possibility of the large pressure drop masking the closure. Again, 10 psi hydrostatic head needs to be added to this value.

Figure 6.5 shows the fourth pump of the test in the Red B sand at 6548-50 ft. This test was performed at 12 gpm. The treatment pressure is on the order of 5920 psi with an ISIP of 5630 ±20 psi. Again, 10 psi needs to be added to these values.

Figure 6.6 shows the fourth pump of the stress test at 6527-29 ft, in the shale between the two Red sands. The flow rate was about 12 gpm and the ISIP is about 6675 psi plus 10 psi hydrostatic. Even in this thin shale between the two lenses, the stress is very high, with about a 1.02 psi/ft gradient.

The breakdown pump of the upper Red sand, at 6512-14 ft, is shown in Figure 6.7. The injection rate is again 12 gpm. The ISIP for this test is about 5860 psi plus 10 psi hydrostatic.

Figure 6.8 shows the pressure record for the second pump into the lower Yellow sand at 6460-62 ft. This test was also conducted at 12 gpm. The ISIP is 5650 plus 10 psi hydrostatic.

The sixth pump into the upper Yellow sand at 6442-44 ft is shown in Figure 6.9 for a 10 gpm flow rate. The ISIP is about 5740 psi plus 10 psi hydrostatic.

Figure 6.10 shows the fourth pump into a mudstone above the Yellow sands at a depth of 6420-22 ft. The ISIP, although not as clear as the previous examples, is just below 6800 psi. This test was pumped at 14 gpm and 25 psi hydrostatic head needs to be added to these data.

Figure 6.11 is another case of a large pressure drop at shut in. This is a mudstone at 6398 to 6400 ft, with an injection rate of 14 gpm. A rate test conducted in this interval showed that the pressure was highly rate sensitive, indicating an entrance restriction problem. The ISIP is about 6450 plus 25 psi hydrostatic.

Figure 6.12 is an example of the test at 6374-76 ft. The ISIP is somewhat less than 6600 psi and there appears to be some indication of multiple closure behavior. This is one of the tests conducted in a complex layering (siltstones and shales) environment and it is believed that the behavior is due to this lithology. Every stress test in this zone had a different ISIPs, usually differing by 40 to 50 psi.

6.4 CORE STRESS MEASUREMENT RESULTS

In the Multiwell Experiment, there are ASR data from core in all three wells, but only the MWX-3 well data were obtained with the latest improved gages. These MWX-3 data are more accurate and reliable than earlier data. Hence, only the MWX-3 data are used for these analyses. Additionally, any data where the rock showed a pre-existing fabric were not included.

The ASR strain and orientation data are given in Table 6.2. In the sandstones, the maximum compressive horizontal stress direction, the hydraulic fracture azimuth, varies from N58°W to N88°W with an average of about N73°W. This is consistent with other data in the well.[7] In the mudstones there is no preferred stress orientation.

The magnitudes of the stresses, determined from the direct and strain history model, are given in Table 6.3 and shown in Figure 6.13 along with hydraulic fracture and DSCA results. The DSCA results are also given in Table 6.4. Maximum stresses in the sandstones are roughly 600 psi greater than the measured minimum stresses. This agrees well with an open-hole, hydraulic-fracture measurement[14] of the maximum stress in the Rollins sandstone at 7550 ft. In the mudstone, the horizontal stresses are nearly identical, as they must be if there is no preferred stress orientation.

A comparison of ASR and DSCA to hydraulic fracturing can also be gleamed from Figure 6.13. Errors in the minimum in situ stress estimates are typically a few hundred psi. Figures 6.14 through 6.21 show the ASR data for these coastal tests including both the actual ASR data for the four gages taken at one hour intervals and the calculated strain-history fits of the data using the strain-history model.[18] Using this model, the total strain which the piece of core has undergone is estimated. (The format for these figures does not imply that the rock has experienced negative strains in early times. For convenience, the original form of the data is preserved, i.e., all strains start at zero at the time the core is first instrumented, and the early negative strains represent the anelastic strains that the core experienced before being instrumented.)

The data quality is excellent for these Mesaverde sandstones and the theoretical viscoelastic strain-history model[18] fits the measured response very well. It is clear in all of these tests that the vertical strain relaxation is considerably greater than the horizontal strain relaxation, implying that the maximum principal stress is the overburden stress. A comparison of these figures shows that the total anelastic strain undergone by the rock in any gage direction, as determined by the strain-history model, increases with increasing depth for sandstones at the MWX site.

6.5 DISCUSSION

6.5.1 Comparison With Rock Properties

Included in Table 6.1 are rock properties at four stress test locations. They indicate, as one would expect, that the high stress regions are low modulus, high Poisson's ratio materials while the low stress regions are high modulus, low Poisson's ratio materials. However, the data are somewhat more complicated than indicated in Table 6.1. Figure 6.22 shows a plot of rock property measurements made on core from MWX-1. While these cannot be correlated directly with the stress test data in MWX-3 because of the lateral variations common in these lenticular sands, the data show some important features concerning the shales. One of the shale points has a very low modulus similar to the values in Table 6.1, but two others have moduli considerably higher than the sandstones. These rocks are more likely thin siltstone stringers that may appear clay rich but are probably also well cemented, resulting in the high moduli. It is not clear what the stress values in these stringers are, but the variations in stress in the upper three data points, as well as the difficulty in making those measurements (note the large uncertainty), may be because the tests were conducted on or near such stringers. The complex lithology of the "shales" makes measurement and interpretation difficult.

6.5.2 Large Stress Contrasts

One of the important, as well as perplexing, results of these studies is the high stress in the mudstones and shales compared to the sandstones. These large stress contrasts are useful for hydraulic fracture containment, but it is difficult to theorize how the stresses in the mudstones are isotropic at nearly the lithostatic value while the stresses in the sands are much lower and show a strong preferred orientation. It is hard to explain these contrasts in terms of rock properties, particularly when some of the high-stress mudstones have higher moduli and lower Poisson's ratios than the sands. Yet some of the stress must be transmitted through a solid mechanics mechanism (as opposed to pore pressure) because the sands show preferred stress orientation (from anelastic strain recovery, differential strain curve analysis, and fracture diagnostics). Creep can help but it requires large differential relaxation times between sands and mudstones and relatively recent tectonic perturbations. Most likely, a good stress model will need to invoke all of these factors--material property contrasts, differences in pore pressure between sands and mudstones, creep, tectonics--to effectively model the current stresses.

6.5.3 Hydraulic Fracturing

These stress data were used in the design and analysis of hydraulic fracture treatments in these sands. An equilibrium fracture model attributed first to Simonson et al.,[2] can be used to predict maximum height growth vs. wellbore pressure for these stresses. Unfortunately, stress values for the shale between the Red and Yellow sands and for the shale between the two Yellow sands must be assumed. Based on surrounding shale data, a value of 6500 psi has been chosen for both shales; this value should be conservative.

The plan was to frac the Yellow sands while monitoring the Red sands for fracture penetration. Figure 6.23 shows the calculated fracture height for a given treatment pressure above closure stress. Containment is adequate for pressures below 700 psi; higher pressures result in fracture growth into the Red A sand. This case uses the originally measured stresses in the sands.

The same calculation was also made under the assumption that reservoir drawdown had decreased the stresses in the sands--in this case by 200 psi. This is shown in Figure 6.24 and here containment is adequate for treatment pressures up to 875 psi.

Of course, both of these calculations are estimates of the true fracture condition because they neglect material property variations (small effect) and, more importantly, pressure drops in the vertical direction. Actual fracture heights should be less than shown in Figures 6.23 and 6.24 unless the stress data are wrong.

6.6 CONCLUSIONS

These stress results in the coastal zone show that large stress contrasts exist between the sands and mudstones. This is favorable for hydraulic fracture containment.

Stress gradients for the sands are typically 0.88 psi/ft while they range from 1.0 to 1.08 psi/ft for the mudstones. The mudstones are approximately lithostatic and probably nearly hydrostatic (all stresses equal).

There is no clear correlation between rock properties and stress. A better correlation exists between lithology (perhaps measured by the gamma ray response) and stress.

There is good agreement between ASR, DSCA and hydraulic fracture stress measurements. ASR and DSCA results suggest that the difference in horizontal stress is about 600 psi and the maximum stress orientation is about N70°W.

These stress results, while clearer than the paludal results, are still not as reproducible and accurate as the marine data. This is probably due to the lithology; marine rocks tend to be massive and stress test fractures propagate over a fairly uniform zone. The complex layering in nonmarine sequences makes interpretation much more difficult.

6.7 REFERENCES

1. Perkins, T. K., and L. R. Kern, "Widths of Hydraulic Fractures," Journal of Petroleum Technology, Vol. 13, September 1961, p. 937.

2. Simonson, E. R., A. S. Abou-Sayed, and R. J. Clifton, "Containment of Massive Hydraulic Fractures," Society of Petroleum Engineers Journal, Vol. 18, February 1978, p. 27.

3. Warpinski, N. R., J. A. Clark, R. A. Schmidt, and C. W. Huddle, "Laboratory Investigation on the Effect of In Situ Stresses on Hydraulic Fractures Containment," Society of Petroleum Engineers Journal, Vol. 22, No. 3, June 1982, p. 333.

4. Teufel, L. W. and J. A. Clark, "Hydraulic Fracture Propagation in Layered Rock: Experimental Studies of Fracture Containment," SPE/DOE 9878, Proceedings, 1981 SPE/DOE Symposium on Low Permeability Gas Reservoirs, May 1981, Denver, Colorado, p. 449.

5. Hanson, M. E., G. D. Anderson, R. J. Shaffer, and L. D. Thorson, "Some Effects of Stress Friction, and Fluid Flow on Hydraulic Fracturing," Society of Petroleum Engineers Journal, Vol. 22, No. 3, June 1982, p. 321.

6. Warpinski, N. R., R. A. Schmidt, and D. A. Northrop, "In Situ Stresses: The Predominant Influence on Hydraulic Fracture Containment," Journal of Petroleum Technology, Vol. 34, March 1982, pp. 653-664.

7. Warpinski, N. R. and L. W. Teufel, "In Situ Stresses in Low-Permeability, Nomarine Rocks," SPE 16402, Proceedings 1987 SPE/DOE Joint Symposium on Low Permeability Reservoirs, Denver, CO, pp. 125-138, May 1987.

8. Warpinski, N. R., P. T. Branagan, and R. Wilmer, "In Situ Measurements at U.S. DOE's Multiwell Experiment Site, Mesaverde Group, Rifle, Colorado," Journal of Petroleum Technology, Vol. 37, March 1985.

9. Northrop, D. A., ed., "Multiwell Experiment Final Report: 1. The Marine Interval of the Mesaverde Formation," Sandia National Laboratories Report, SAND87-0327, April 1987.

10. Northrop, D. A., ed., "Multiwell Experiment Final Report: 2. The Paludal Interval of the Mesaverde Formation," Sandia National Laboratories Report, in preparation.

11. Warpinski, N. R., P. T. Branagan, A. R. Sattler, J. C. Lorenz, D. A. Northrop, R. L. Mann, and K. H. Frolme, "Fracturing and Testing Case Study of Poludal, Tight, Lenticular, Gas Sands," SPE Formation Evaluation, Vol. 2, No. 4, pp. 535-545, December 1987.

12. Teufel, L. W., "Prediction of Hydraulic Fracture Azimuth from Anelastic Strain Recovery Measurements of Oriented Core," in 23rd U.S. National Rock Mechanics Symposium, Berkeley, CA, ed. R. Goodman and F. Heuez, pp. 238-246, 1982.

13. Teufel, L. W., "Determination of In Situ Stress from Anelastic Strain Recovery Measurement of Oriented Core," SPE 11649, Proceedings, SPE/DOE Symposium on Low Permeability, pp. 421-430, Denver, CO, March 1983.

14. Teufel, L. W., and N. R. Warpinski, "Determination of In Situ Stress from Anelastic Strain Recovery Measurements of Oriented Core: Comparison to Hydraulic Fracture Stress Measurements," Proceedings 25th U.S. Symposium on Rock Mechanics, Northwestern University, Evanston, IL, pp. 176-185, June 1984.

15. Teufel, L. W. C. Hart, A. R. Sattler, and J. A. Clark, "Determination of Hydraulic Fracture Azimuth by Geophysical, Geological and Oriented-Core Methods at the Multiwell Experiment Site, Rifle, CO," SPE 13226, presented at 59th Annual SPE Technical Conference, Houston, TX, September 16-19, 1984.

16. Lacy, L. L., "Comparison of Hydraulic Fracture Azimuth by Geophysical, Geological and Oriented-Core Methods at the Multiwell Experiment Site, Rifle, CO," SPE 13226, presented at 59th Annual SPE Technical Conference, Houston, TX, September 16-19, 1984.

17. Blanton, T. L., "The Relation Between Recovery Deformation and In Situ Stress Magnitudes," SPE 11624, Proceedings, 1983 SPE/DOE Symposium on Low Permeability Gas Reservoirs, Denver, CO, pp. 213-218, March 14-16, 1983.

18. Warpinski, N. R. and L. W. Teufel, "A Viscoelastic Constitutive Model for Determining In Situ Stress Magnitudes from Anelastic Strain Recovery of Core," SPE 15368, presented at 61st Annual SPE Technical Conference, New Orleans, LA, October 5-8, 1986.

19. Strickland, F. and N. Ren, "Predicting the In Situ Stress for Deep Wells Using the Differential Strain Curve Analysis," SPE 8954, Proceedings, SPE/DOE Symposium on Unconventional Gas Recovery, Pittsburgh, PA, pp. 251-258, May 1980.

20. Strickland, F. G. and N. K. Ren, "Predicting the In Situ Stress State for Deep Wells Using Differential Strain Curve Analysis," presented at the 31st Ann. Tech. Meeting of the Pet. Soc. of CIM: Calgary, paper no. 80-31-33, May 1980.

21. Ren, N. K. and J. C. Roegiers, "Differential Strain Curve Analysis--A New Method for Determining the Preexisting In Situ Stress State from Rock Core Measurements," presented at the 5th ISRM Congress, Melbourne, April 1983.

22. Ren, N. K. and P. J. Hudson, "Predicting the In Situ Stress State Using Differential Wave Velocity Analysis," Proceedings, 26th U.S. Symposium on Rock Mechanics, pp. 1235-1246, E. Ashworth, ed., Rapid City, SD, June 26-28, 1985.

Table 6.1

Stress Data and Rock Properties

Well	Depth (ft)	Lithology	σ_{min} (psi)	Estimated Error (psi)	Gradient (psi/ft)	νLaboratory	E (10^6 psi)
MWX-3	6765-67$^+$ 6706-08$^+$	Mudstone	7100	50	1.05	--	--
	6606-08	Mudstone	7130	20	1.08	--	--
	6586-88	Mudstone	*				
	6565-67	Mudstone	6980	100	1.06	--	--
	6548-50	Sandstone	5640	20	0.86	--	--
	6527-29	Mudstone	6665	30	1.02	0.31	2.0
	6512-14	Sandstone	5845	30	0.9	0.19	4.2
	6483-85	Mudstone	**				
	6460-62	Sandstone	5670	30	0.88		
	6442-44	Sandstone	5720	30	0.89	0.21	3.9
	6420-22	Mudstone	6805	30	1.06	0.27	2.6
	6398-6400	Mudstone	6445	120	1.01	--	--
	6374-76	Mudstone	6540	150	1.03	--	--
MWX-2	6488-90	Mudstone	**			--	--
	6496-6553^{++}	Sandstone	5740	50	0.88	0.19	4.2

*Inconclusive
**Communication
$^+$Paludal Zone
$^{++}$Breakdown test

Table 6.2

ASR Strain and Orientation Data

Depth (ft)	Lithology	Core Age* (hrs)	ε_1	ε_2	ε_v	θ	Maximum Horizontal Stress Direction
6466	Sandstone	7-48	138	12	274	-42.3	N88°W
6473	Sandstone	6-48	213	79	288	-7.5	N83°W
6474	Sandstone	6-48	184	96	252	-5.1	N70°W
6482	Mudstone	6-48	166	156	224	--	--
6483	Mudstone	6-48	200	183	298	--	--
6487	Sandstone	6-48	166	60	240	11.9	N60°W
6489	Sandstone	6-48	147	76	290	13.5	N58°W
6517	Sandstone	6-48	237	101	364	-30.2	N77°W

*Core age is the elapsed time interval (to within 1 hour) from when the core was cut and strain relief monitoring began to when monitoring ended.

Table 6.3

ASR Stress Data

Depth (ft)	Lithology	Input Parameters σ_v (psi)	σ_{2meas} (psi)	P (psi)	Direct Model σ_1 (psi)	σ_2 (psi)	Strain-History Model σ_1 (psi)	J_1 (10^6 psi^{-1})
6466	Sandstone	6790	5670	4400	6010	5280	6204	.153
6473	Sandstone	6800	5670	4400	6426	5757	6334	.101
6474	Sandstone	6800	5670	4400	6422	5926	6311	.084
6482	Mudstone	6805	6600*	4400	6462	6402	6643	.207
6483	Mudstone	6805	6600*	4400	6437	6375	6643	.360
6487	Sandstone	6810	5845	4400	6361	5711	6379	.133
6489	Sandstone	6815	5845	4400	6063	5691	6184	.140
6517	Sandstone	6845	5845	4400	6324	5771	6380	.149

*Interpolated from nearby zones of similar lithology.

Table 6.4

Summary of MWX DSCA Results

Sample	Azimuth	Total $\sigma_1:\sigma_2:\sigma_3$	α	Fracture Gradient
MWX-1 6490'	N86E;V	1.199:1.012:1.0	.78	.86
MWX-1 6519'	N77W;V	1.241:1.117:1.0	.95	.85
MWX-2 6501'	N85W;V	1.253:1.128:1.0	.90	.84
MWX-3 6465'	E-W;V	1.175:1.122:1.0	.90	.89
MWX-3 6509'	N89W;V	1.172:1.086:1.0	.90	.90
MWX-3 6520'	N79W;V	1.189:1.029:1.0	.72	.88

Explanation: Azimuth is with respect to the (σ_2 - σ_3) plane (and thus the fracture), while "V" denotes a vertical inclination. "α" is the poroelastic constant used in converting effective stress ratios to subsurface stress magnitudes. Fracture gradients are listed in psi/foot of depth.

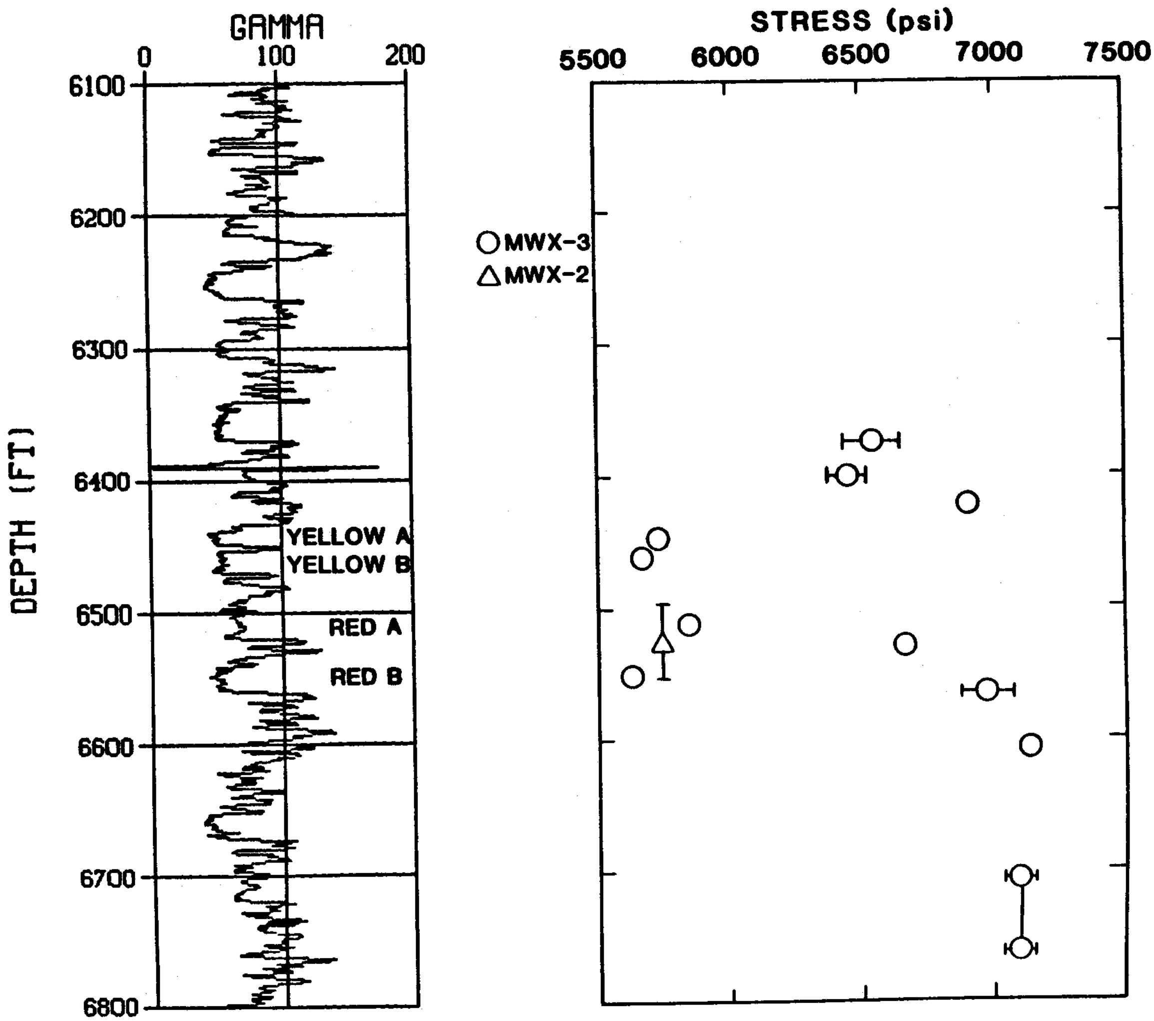


Figure 6.1 Stress Test Results

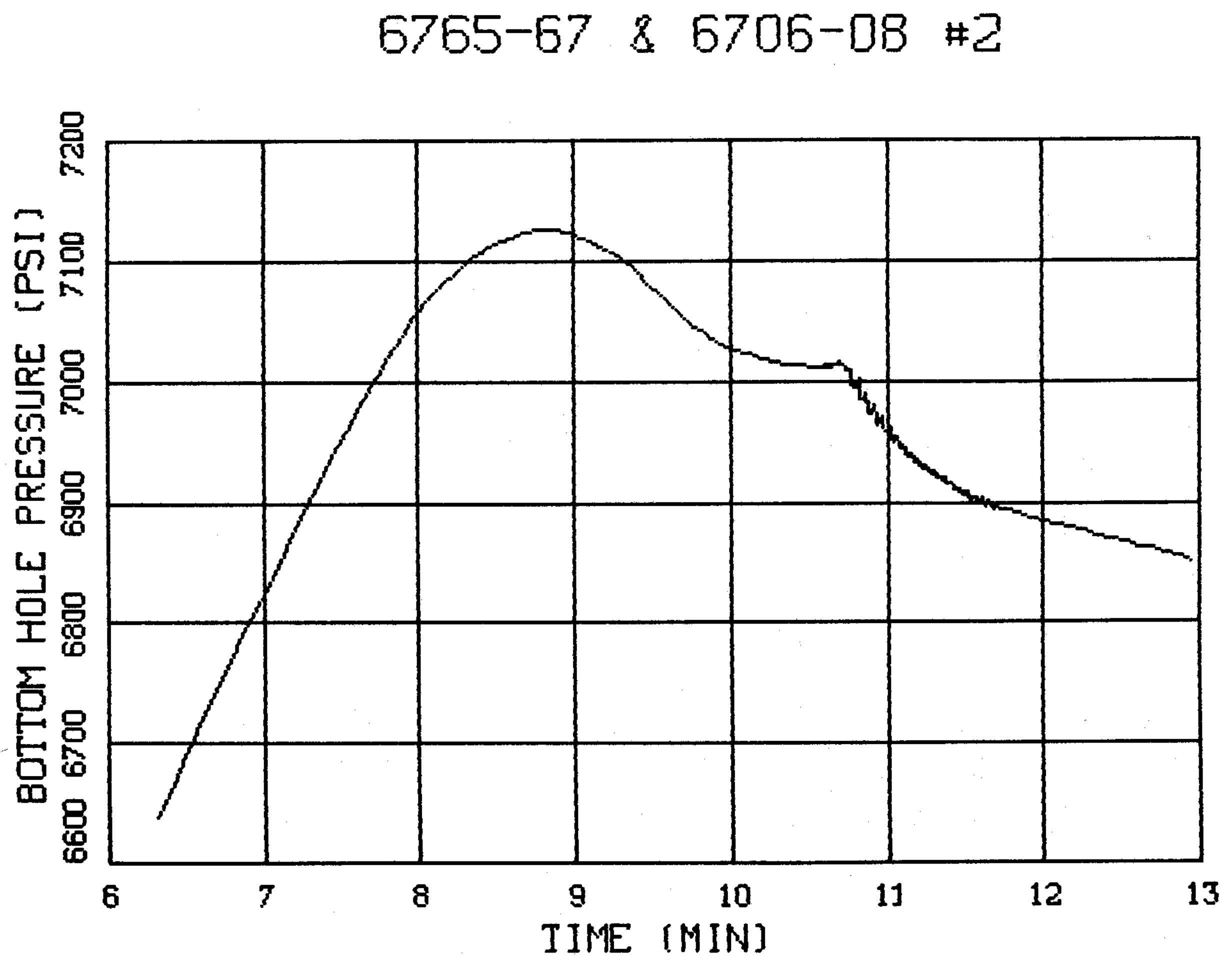


Figure 6.2 Example Stress Data

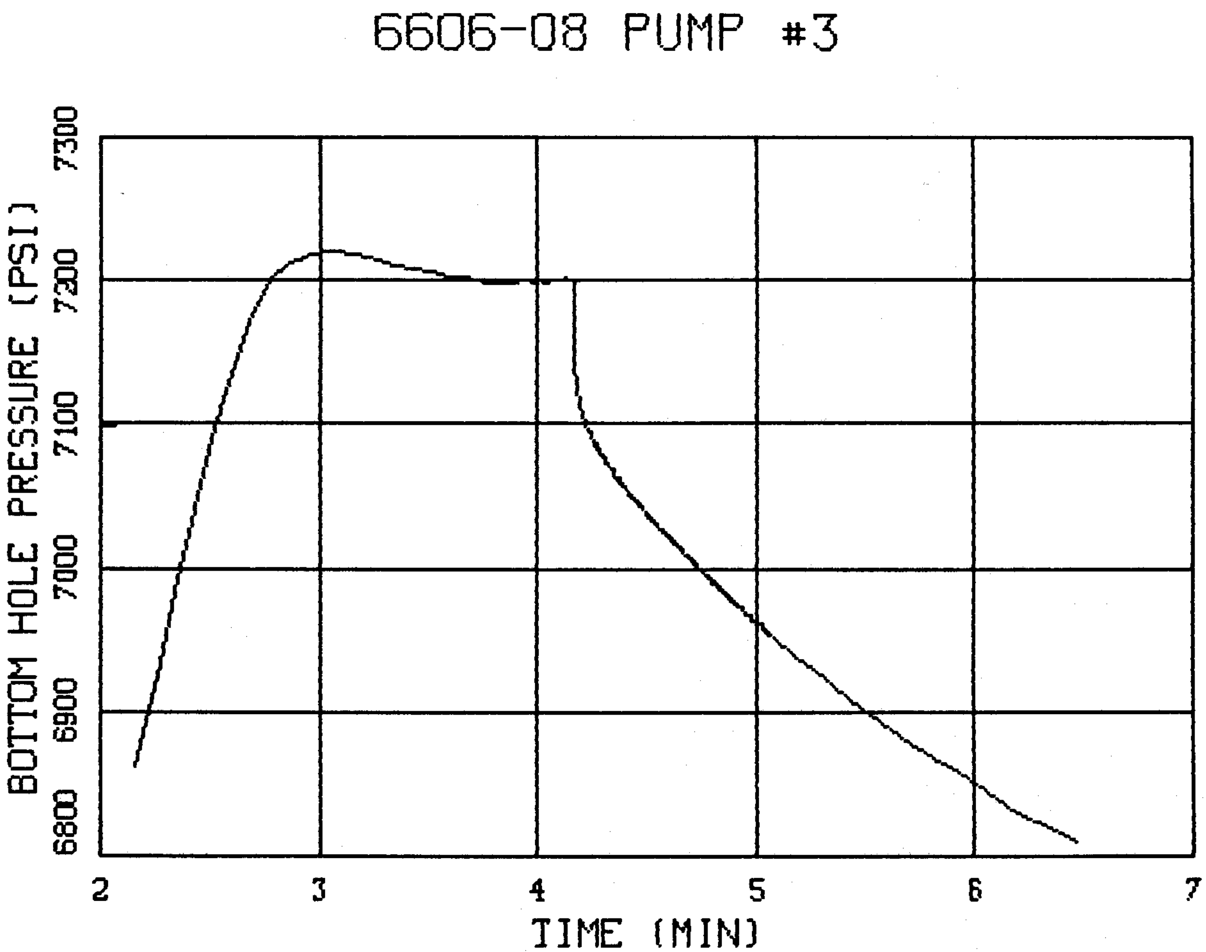


Figure 6.3 Example Stress Data

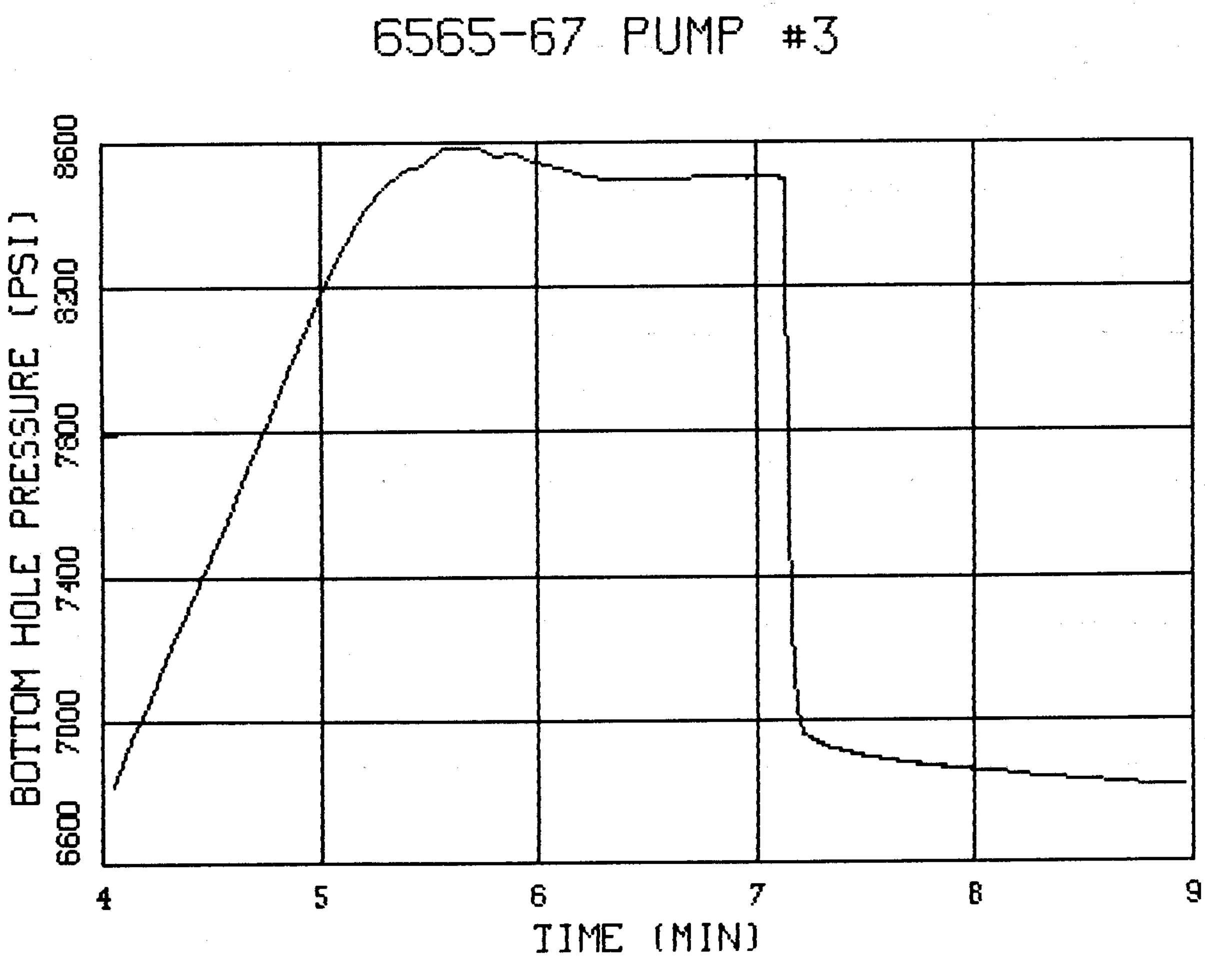


Figure 6.4 Example Stress Data

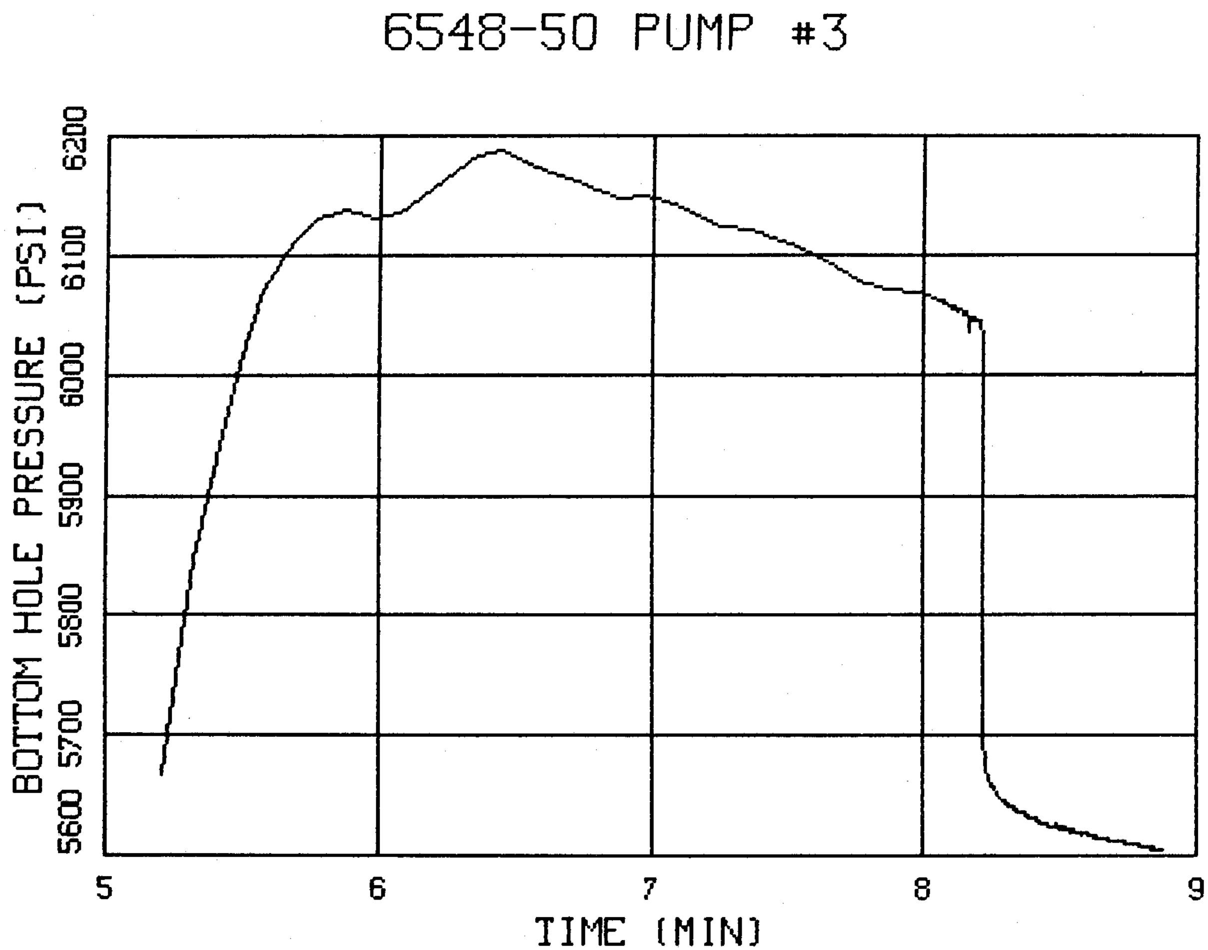


Figure 6.5 Example Stress Data

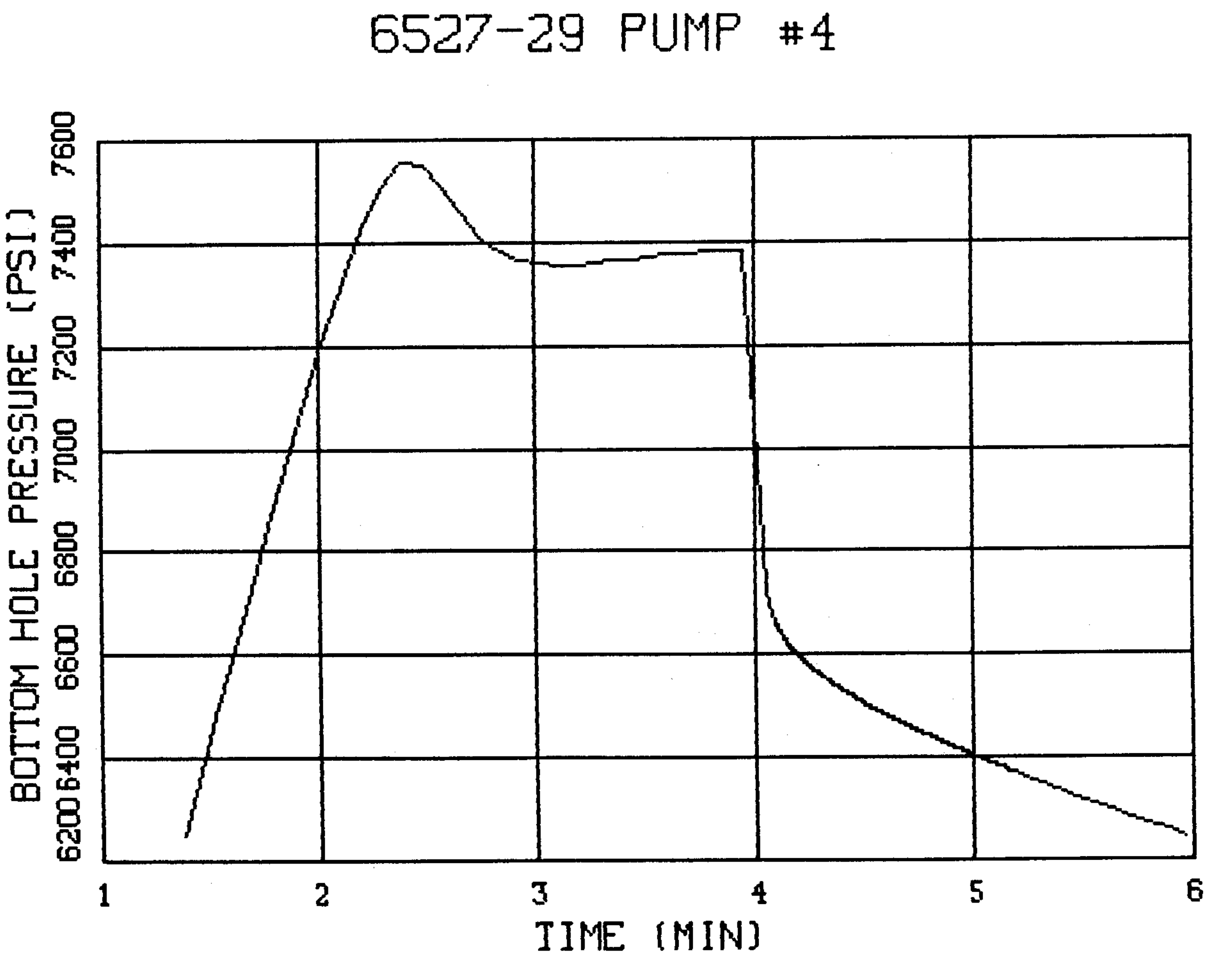


Figure 6.6 Example Stress Data

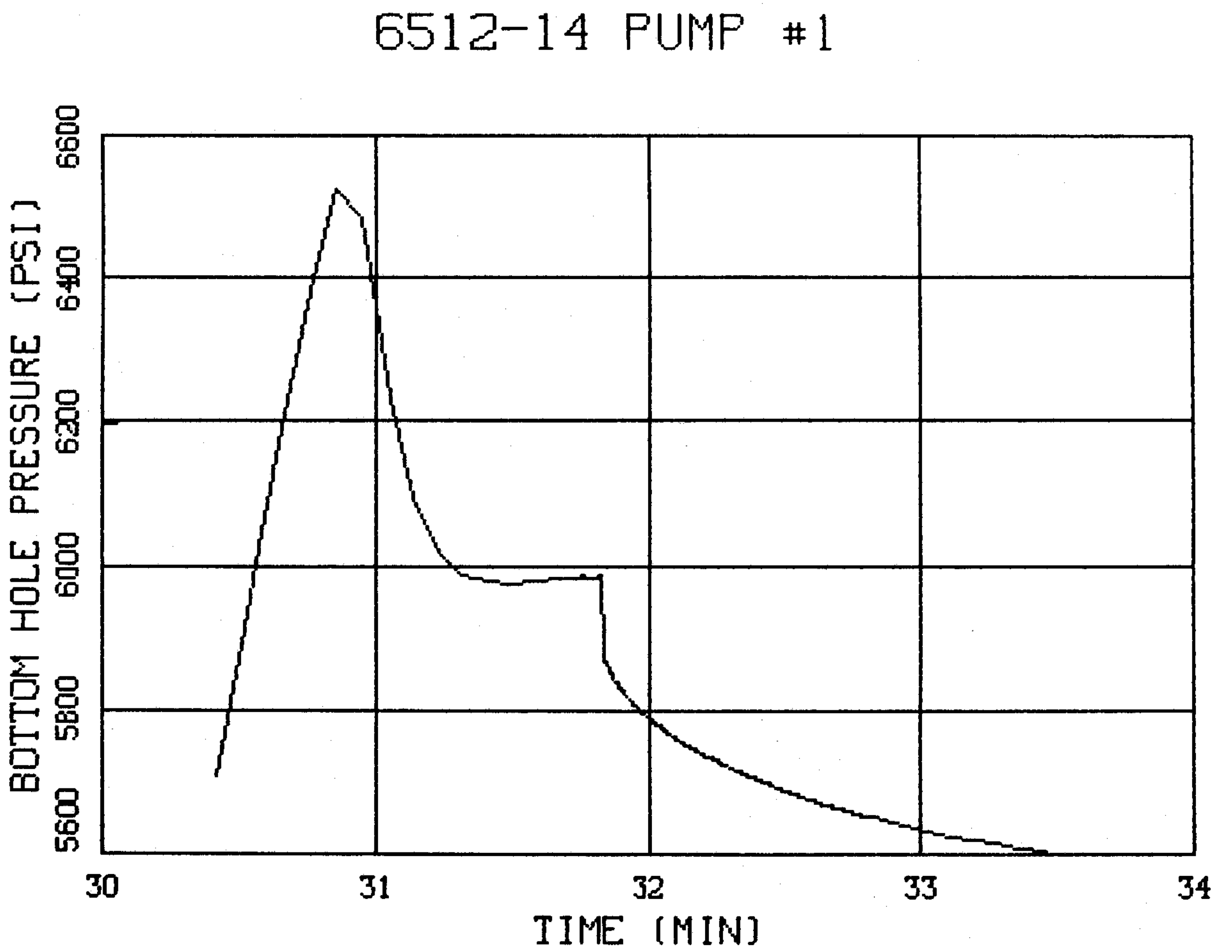


Figure 6.7 Example Stress Data

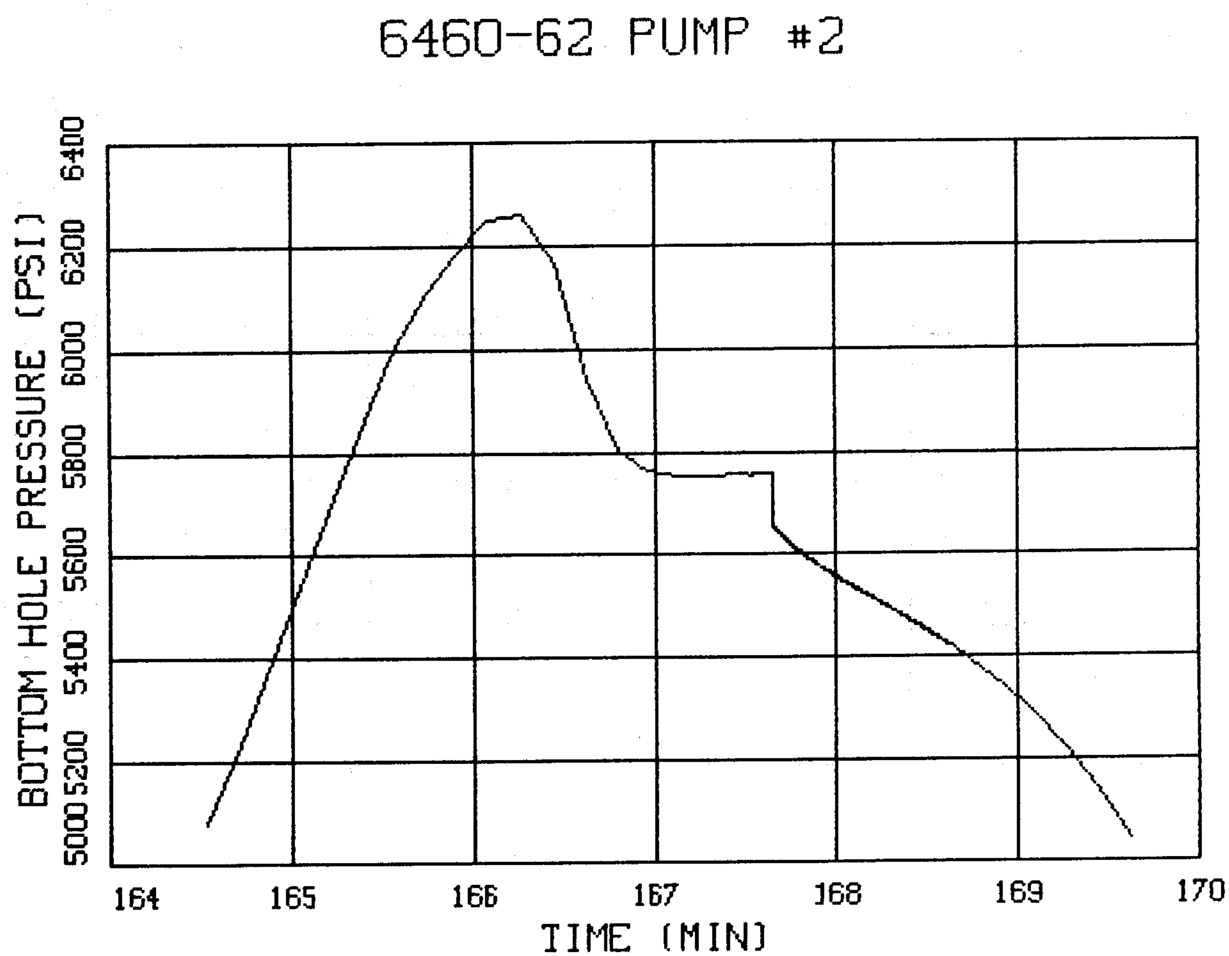


Figure 6.8 Example Stress Data

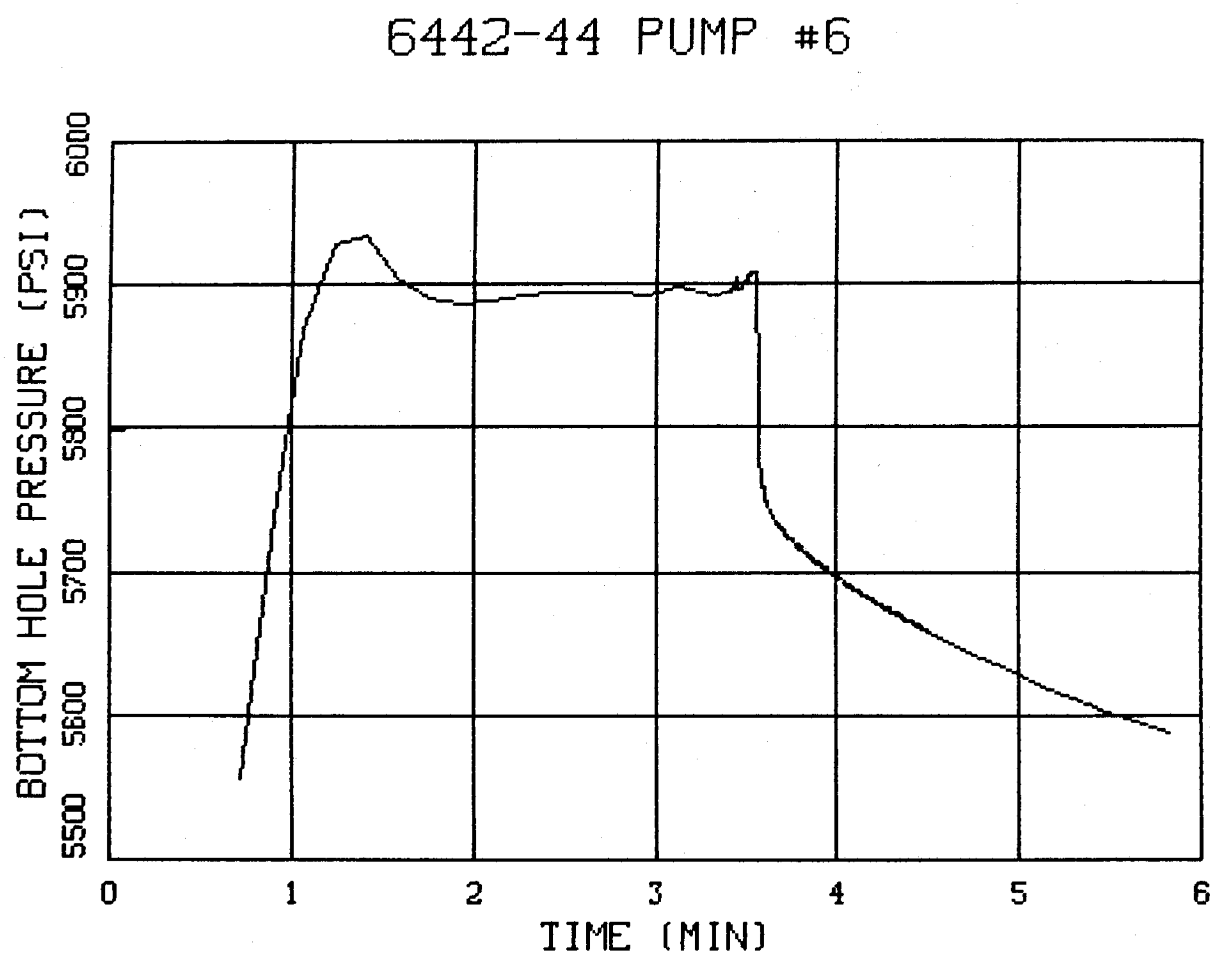


Figure 6.9 Example Stress Data

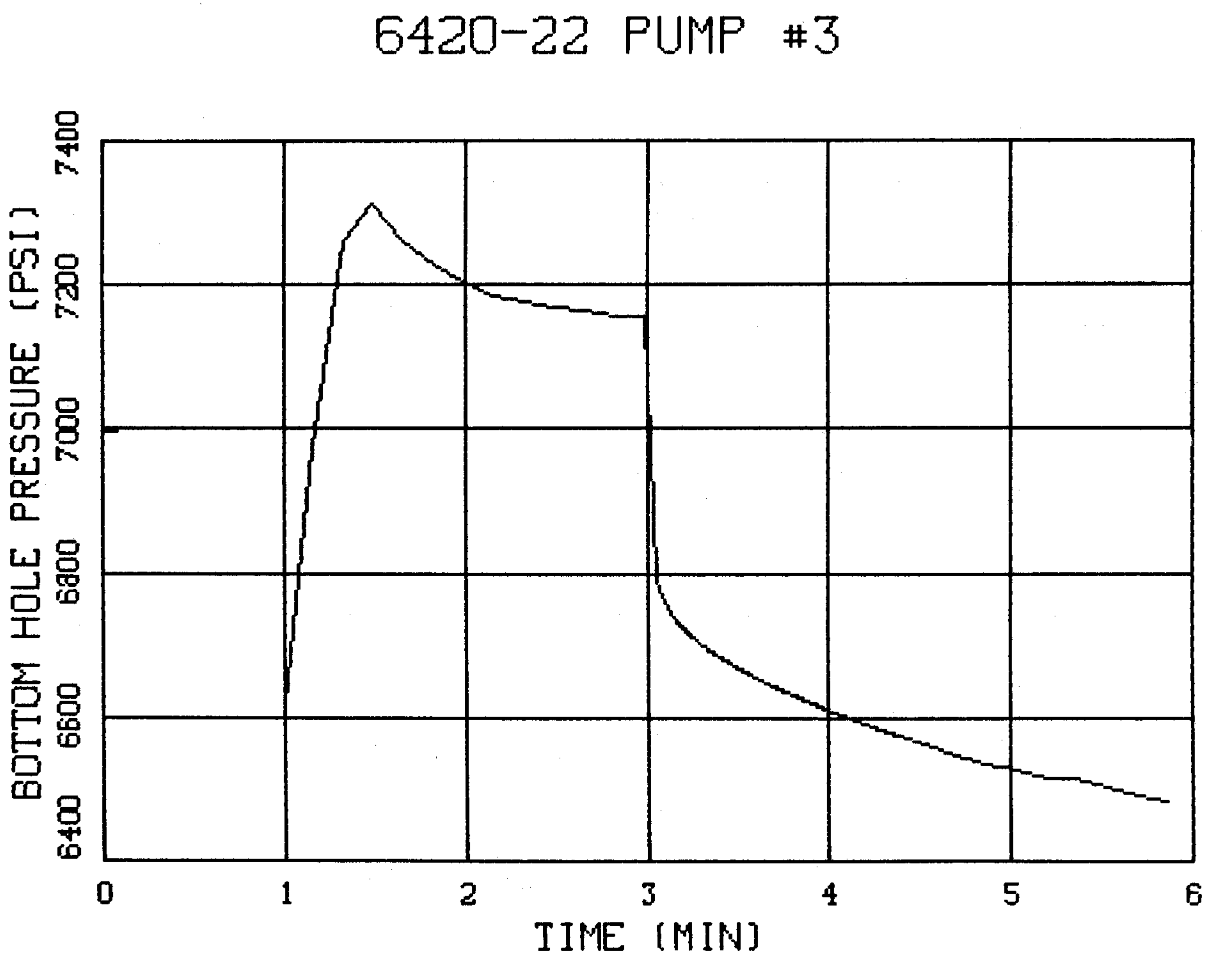


Figure 6.10 Example Stress Data

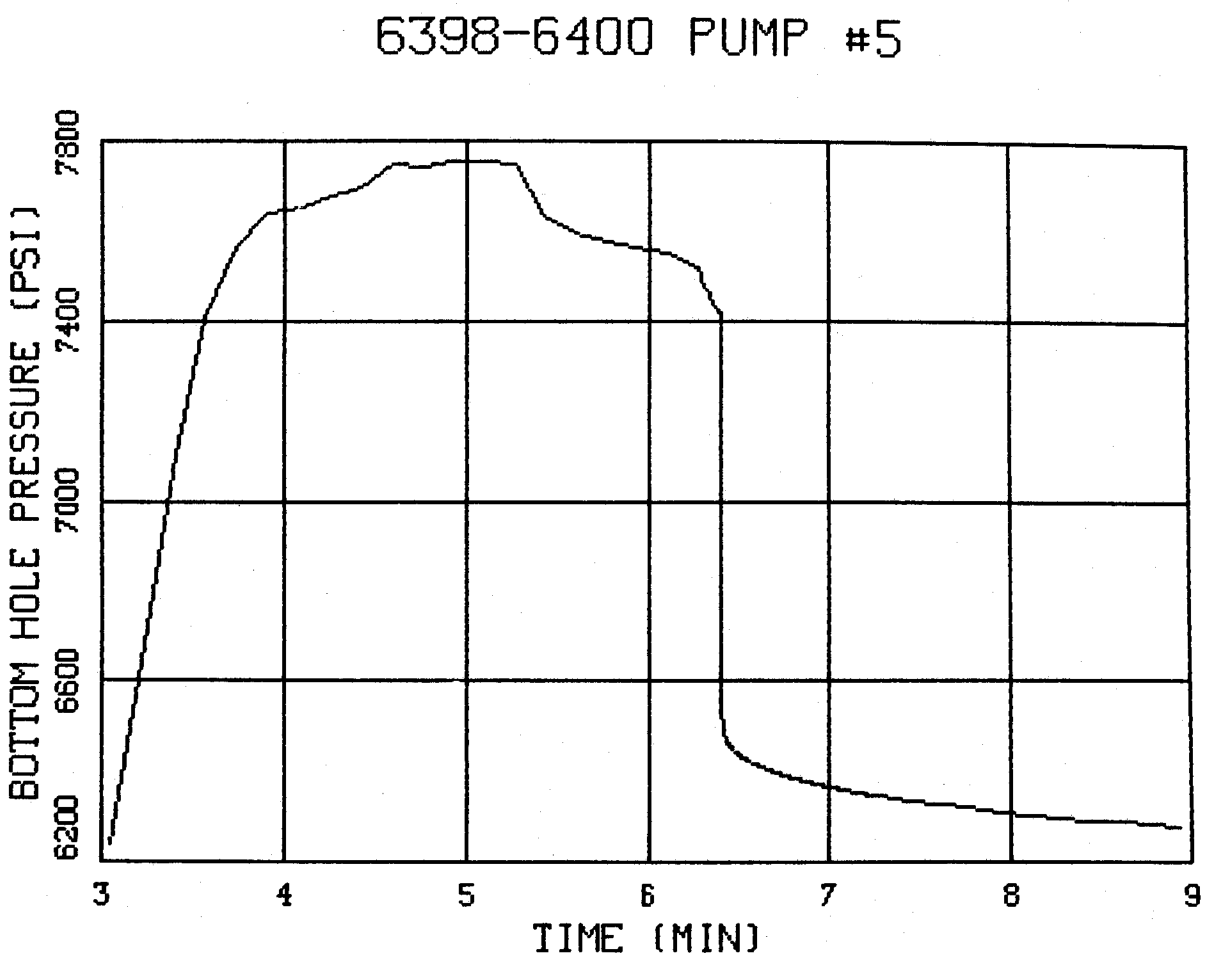


Figure 6.11 Example Stress Data

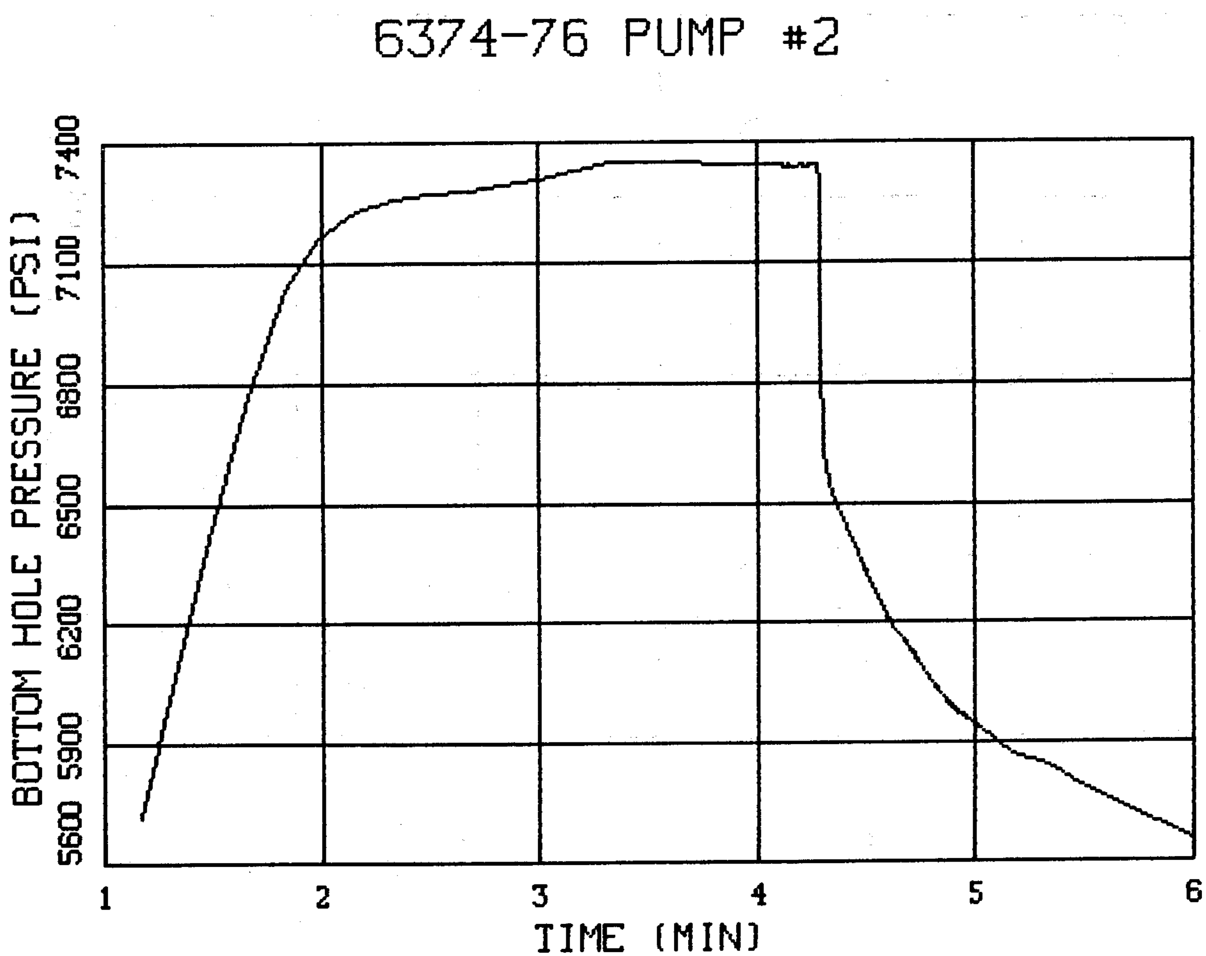


Figure 6.12 Example Stress Data

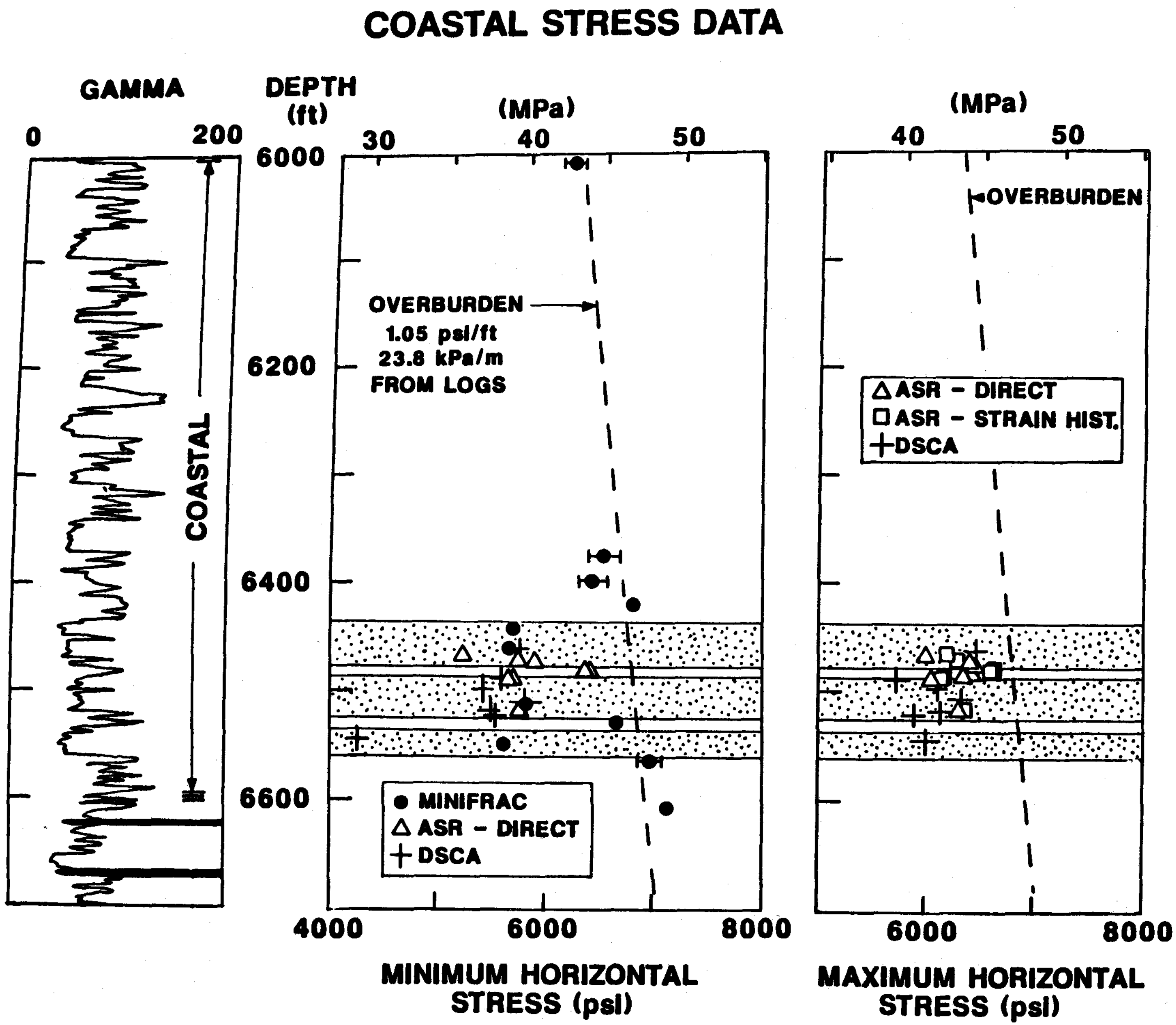


Figure 6.13 Stress Magnitudes from ASR and DSCA Compared to Hydraulic Fracturing

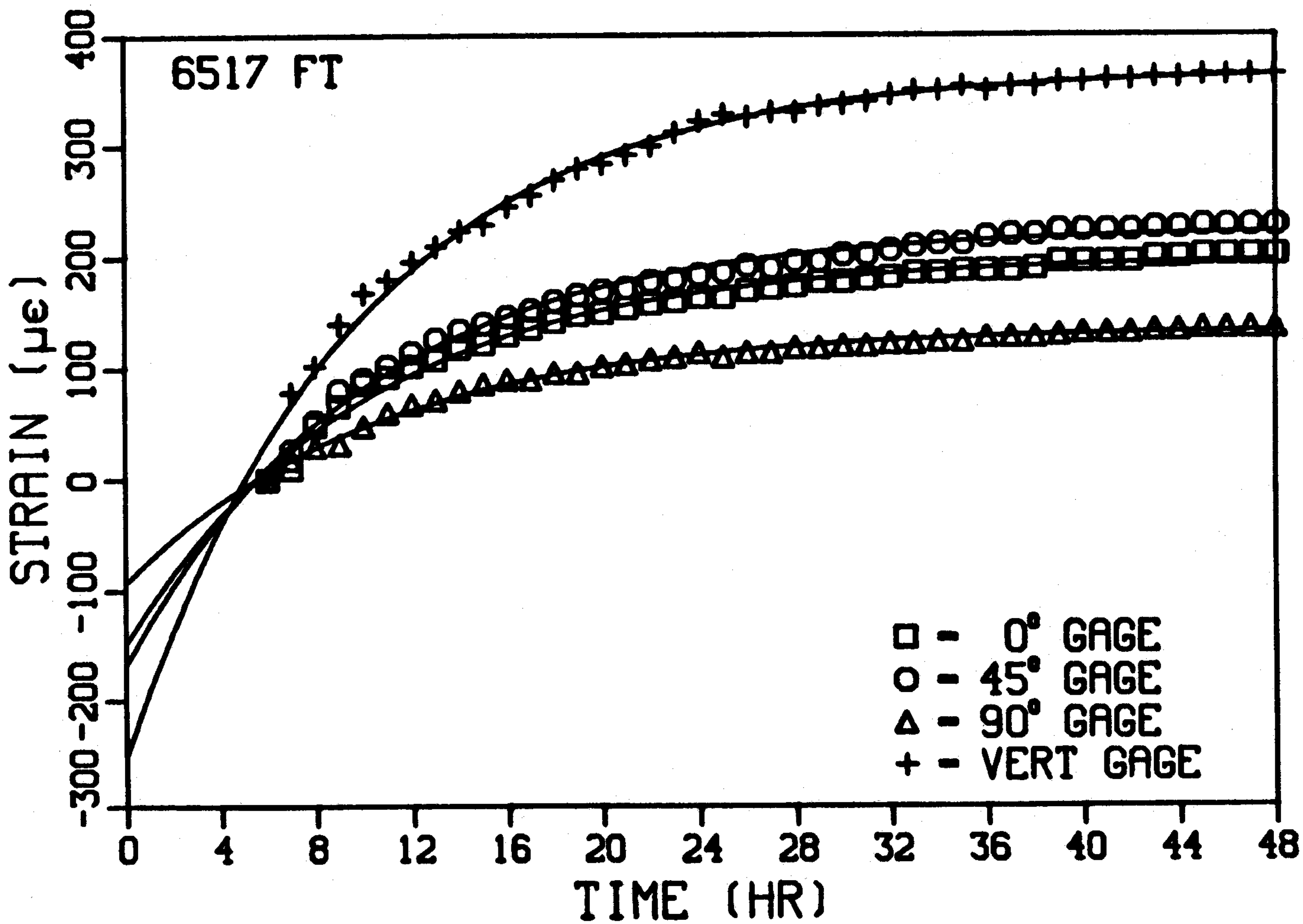


Figure 6.14 ASR Data at 6517 ft

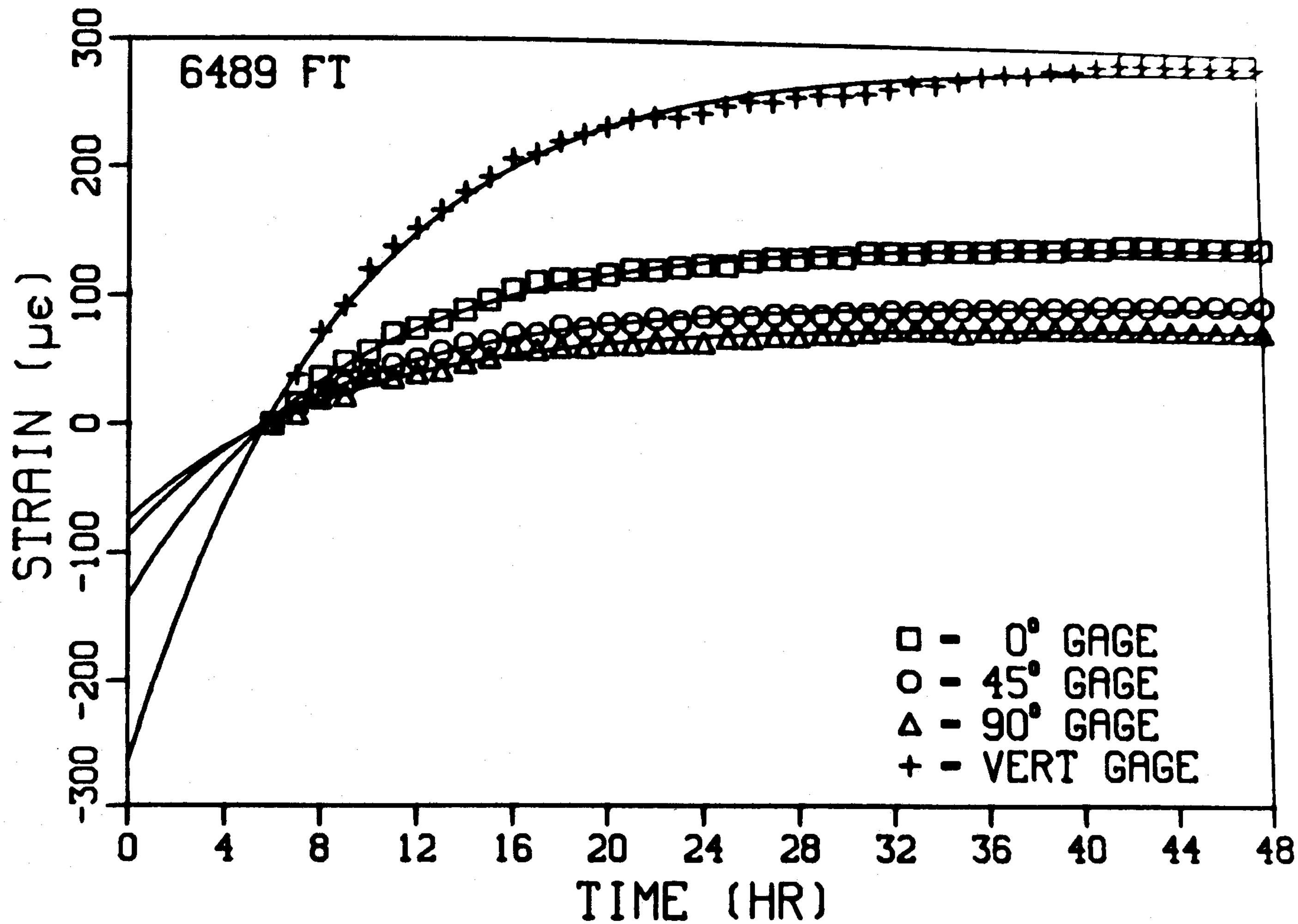


Figure 6.15 ASR Data at 6489 ft

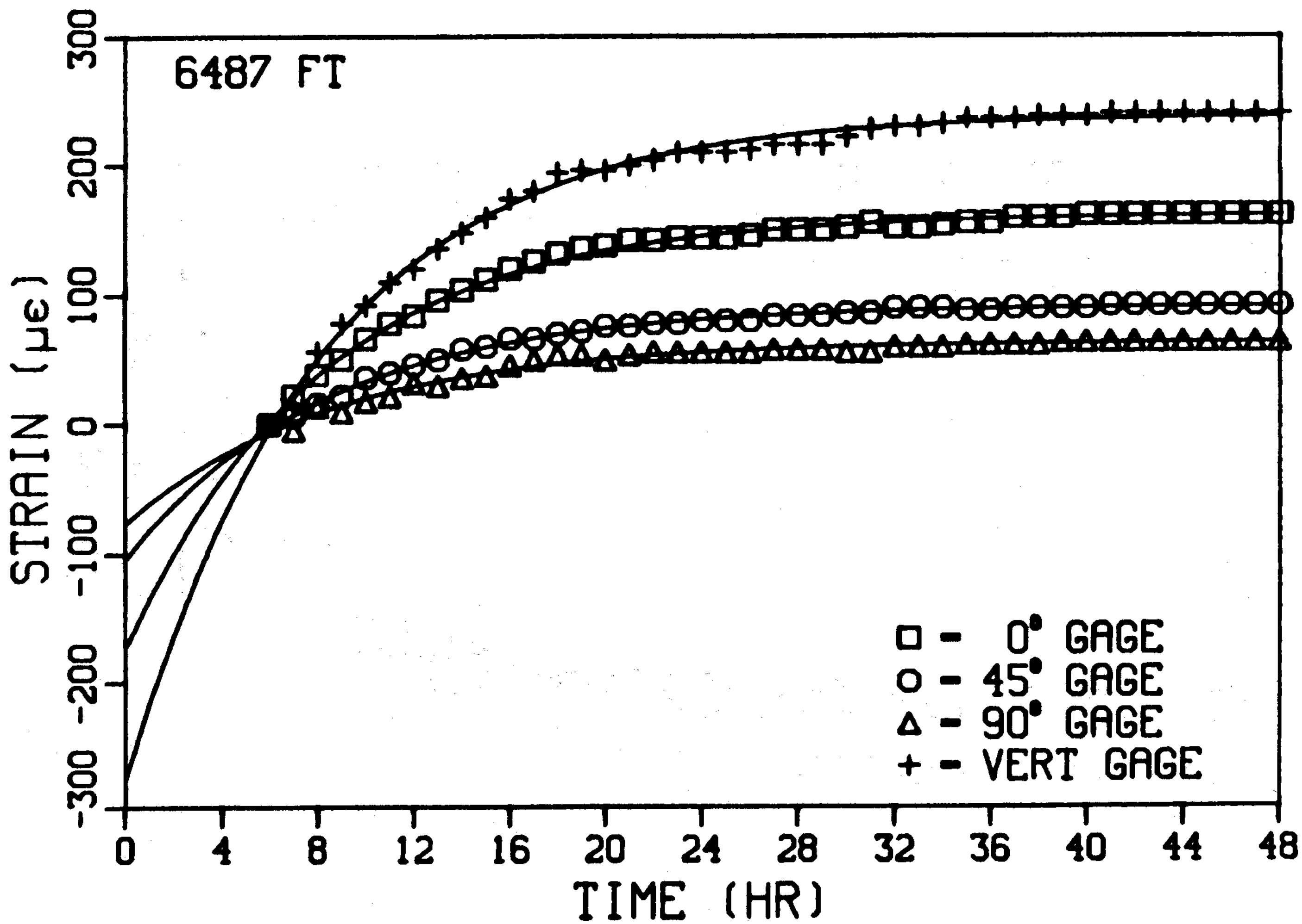


Figure 6.16 ASR Data at 6487 ft

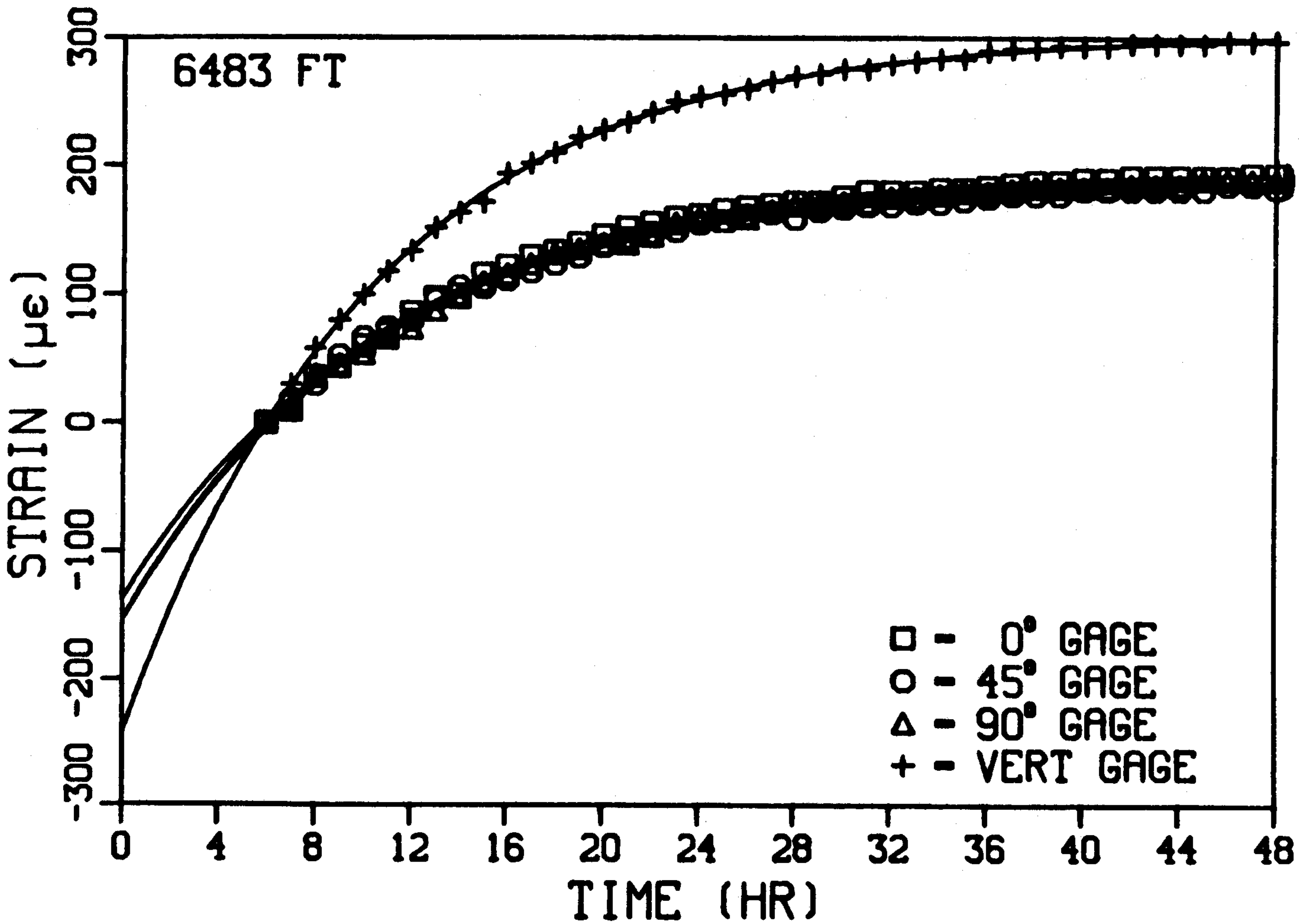


Figure 6.17 ASR Data at 6483 ft

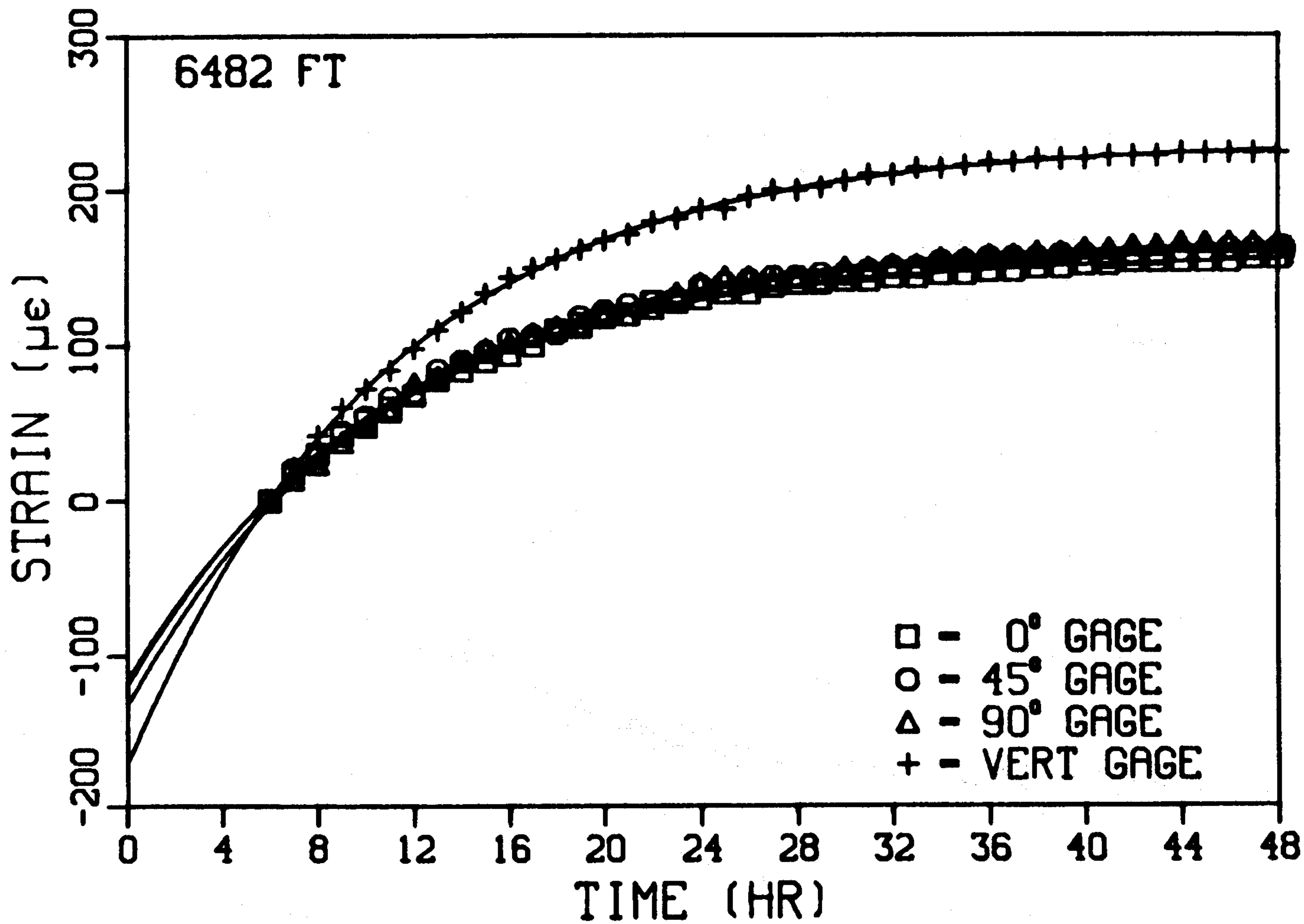


Figure 6.18 ASR Data at 6482 ft

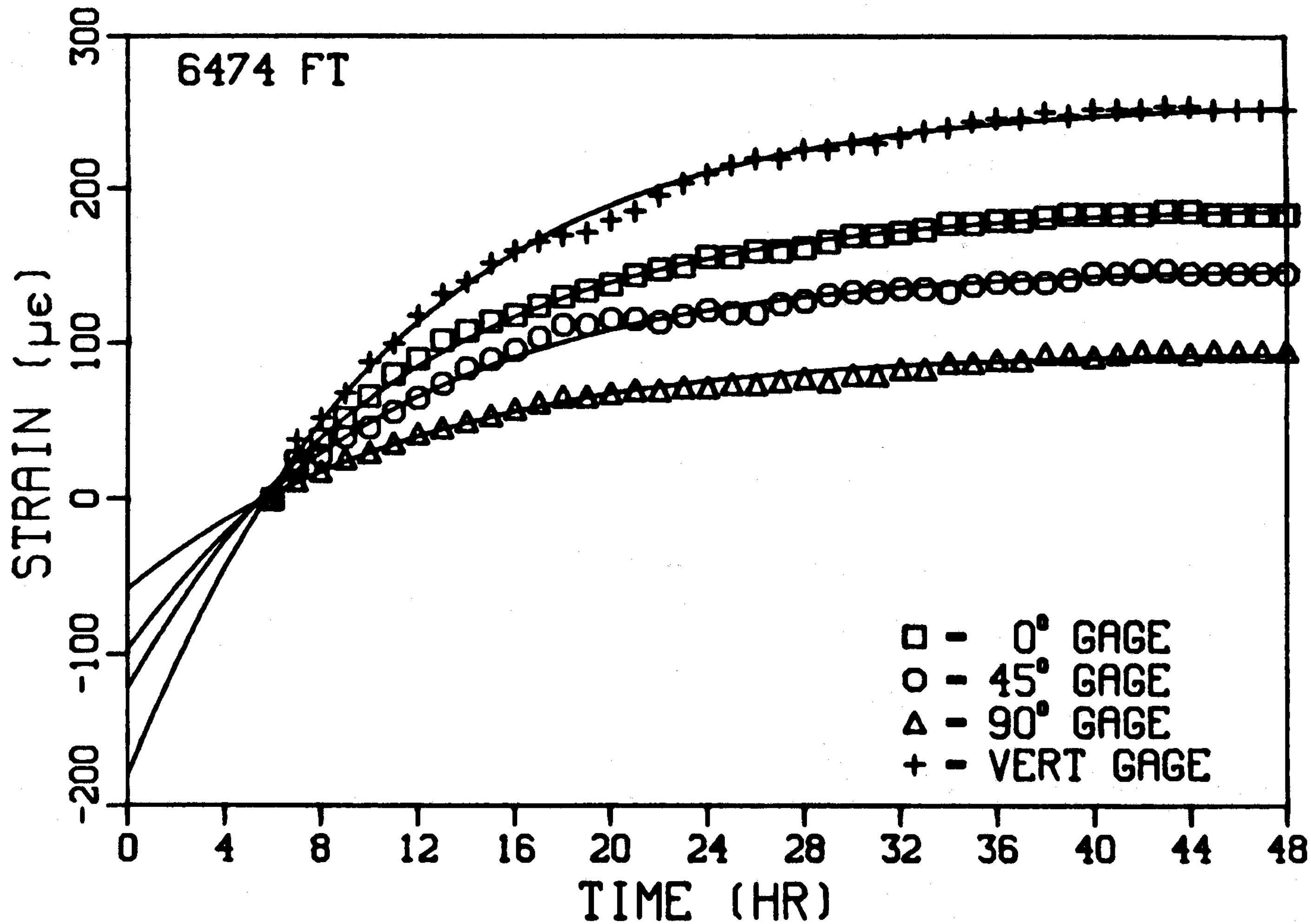


Figure 6.19 ASR Data at 6474 ft

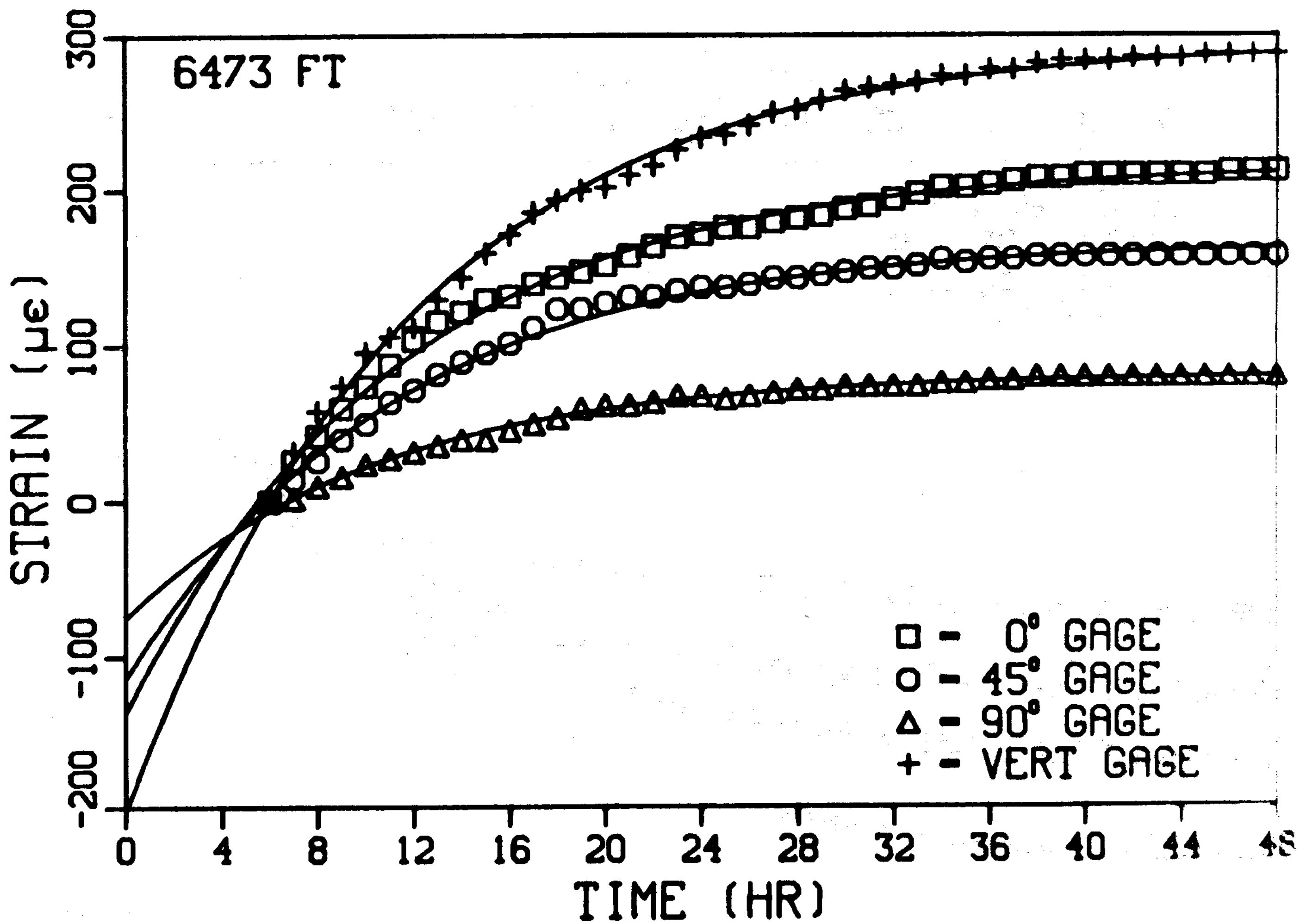


Figure 6.20 ASR Data at 6473 ft

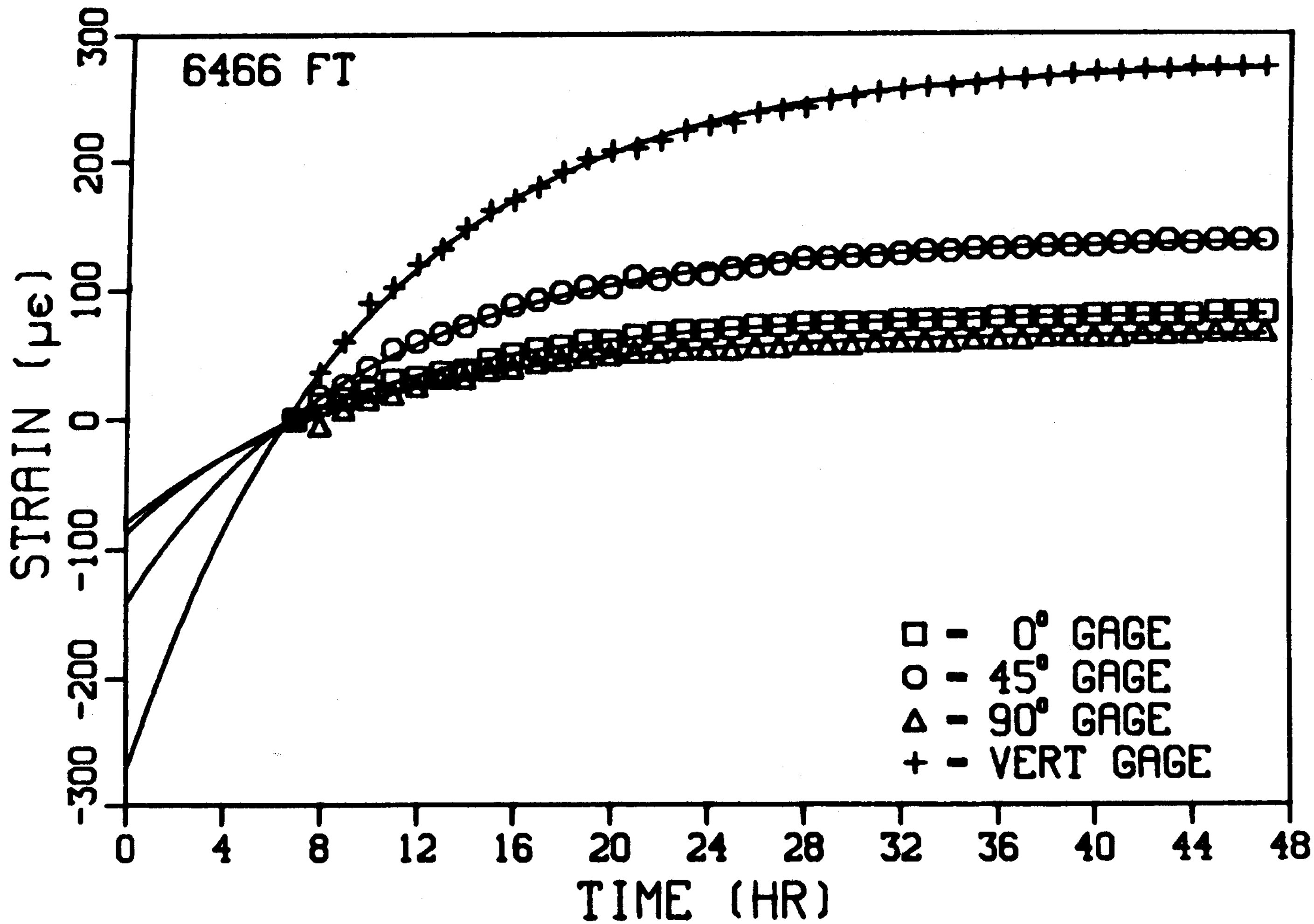


Figure 6.21 ASR Data at 6466 ft

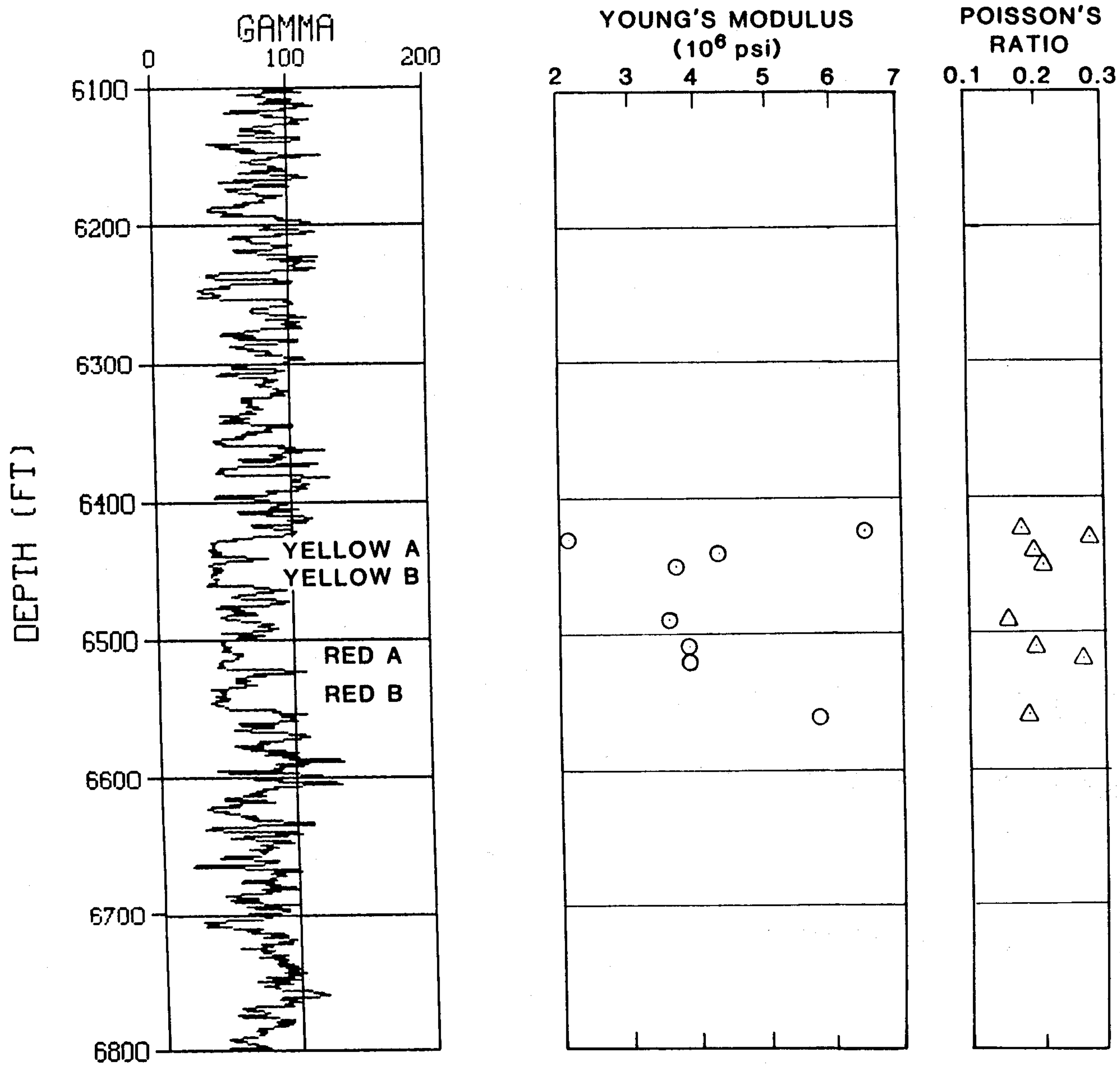


Figure 6.22 Rock Properties for Coastal Zone, MWX-1

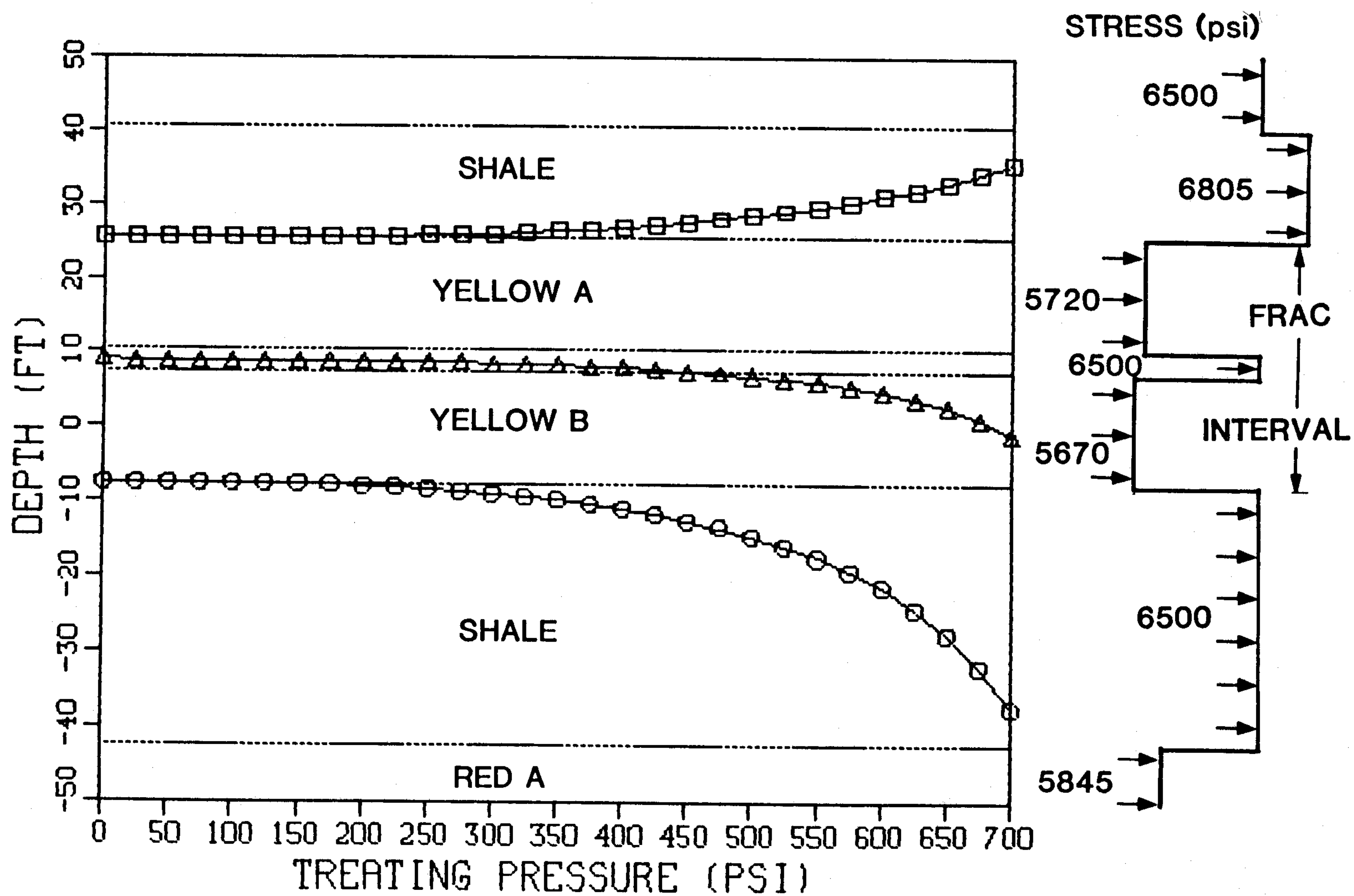


Figure 6.23 Fracture Height vs Treating Pressure (Above Closure Stress) for Initial Stress Levels

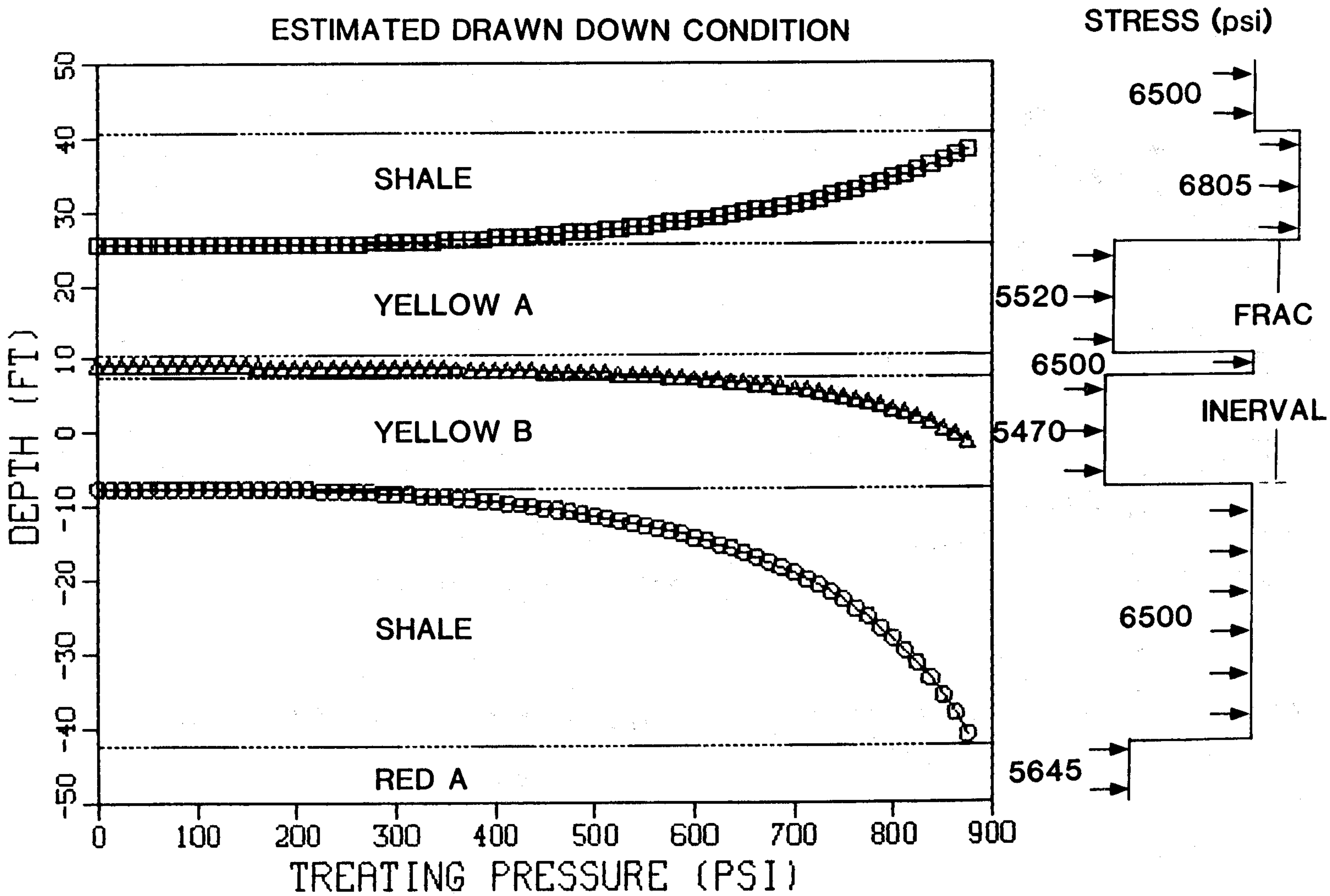


Figure 6.24 Fracture Height vs Treating Pressures (Above Closure Stress) for Drawn-Down Conditions

7.0 STIMULATION EXPERIMENT

7.1 PRE-FRACTURE WELL TESTING AND ANALYSIS

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CER Corporation

7.1.1 INTRODUCTION

Pre-fracture well tests were performed in the coastal interval on the Red sandstones, designated A and B, and the Yellow sandstones, designated A, B and C. Each of the well tests typically consisted of an extended drawdown test period followed by a long-term shut-in period. During critical buildup tests, a bottomhole shut-in was used to minimize wellbore storage volume. In addition to the single well drawdown and buildup tests, pressure interference data were acquired using one or both of the available MWX observation wells. Each of the wells was instrumented with surface transducers and high accuracy, quartz bottomhole pressure/temperature gauges.

The Red sandstone tests were conducted during September and October, 1984, while the Yellow sandstones were subsequently tested during November and December, 1984. The initial, pre-fracture well testing of the Red and Yellow sandstones were performed separately and then commingled for pipeline production during the winter of 1985. Following winter production, a nitrogen injection/tracer test in the commingled sandstones was conducted in April, 1985, in an attempt to better quantify reservoir parameters and to establish communication between the production well, MWX-1, and the two observation wells, MWX-2 and MWX-3.

The testing and analysis of each sandstone are detailed in the following subsections. The analyses of the well testing and interference data were conducted using both analytical and computer reservoir modeling techniques. The analytical methods included Horner analysis, standard superposition type curve plotting techniques and advanced log-log pressure and pressure derivative analysis. Log-log pressure derivative plots were especially useful for identifying complex reservoir flow regimes such as anisotropic natural fracture flow. The reservoir modeling was performed using a naturally fractured reservoir simulator that permits the use of an anisotropic natural fracture set and fully transient matrix properties.

7.1.2 BASELINE RESERVOIR PROPERTIES FOR THE COASTAL RED AND YELLOW SANDSTONES

Prior to initiating the well tests, the comprehensive set of core, log, and geological data that had previously been gathered and analyzed were evaluated for inclusion into a physical model of the reservoir. From that evaluation, a baseline set of reservoir parameters were established from which the well tests could be designed and analyzed. Core-derived matrix permeabilities were used, along with log-calculated porosity, water saturation and net reservoir thickness as initial values for well testing and reservoir modeling information. Figure 7.1.1 illustrates the dry Klinkenberg permeabilities for the Red and Yellow sandstones measured in core from MWX-3. Note that there is considerable variation in the foot by foot measured values, with permeability ranging from about 0.0003-0.006 md. However, the productive intervals appear to exhibit dry gas permeabilities in the range of 0.001-0.003 md, with an average near 0.002 md. To estimate in situ reservoir permeability, core flow studies were conducted at 3000 psi net confining stress and water saturations from 0-50%. The results of selected core tests are presented in Figure 7.1.2. The data shows the extreme variation of matrix permeability with in situ water saturations. For initial water saturations in the range of 40-50%, matrix permeability at a net stress of 4000 psi is seen to be less than 0.0001 md.

Table 7.1.1 summarizes the core and log derived baseline reservoir properties for the Red and Yellow sandstones, and these data represent an estimate of matrix properties. It is obvious that if substantial production is to occur, it must depend heavily upon a natural fracture set since these matrix properties alone represent a very poor productive interval.

The areal extent of the coastal sandstones was estimated from sedimentological analysis of core and nearby outcrop studies.[1] Figure 7.1.3 is a schematic illustration of the areal dimensions for the Red sandstones. Both Red A and B are channel deposits with relatively narrow widths of 300-500 ft. Red A is oriented southwest to northeast and Red B is oriented in an east to west direction; there is a suggestion of channel thinning toward the east. Figure 7.1.4 illustrates the most probable areal dimensions for the Yellow sandstones. Yellow A and B are characterized as channel deposits with widths similar to those found in the Red sandstones. Yellow A is oriented in a southeast to northwest direction, while Yellow B probably has an east to west orientation. The Yellow C is characterized as a splay deposit of undefined areal dimensions.

7.1.3 PRE-FRACTURE WELL TESTS OF THE RED SANDSTONES

The well testing and conventional analysis of the Red sandstones are detailed within this section. Certain critical aspects of well completions for the three MWX wells are detailed in Section 2.2 and should be considered, since they potentially impact interference data. Reservoir modeling results and history matching (Section 7.1.6) and performance predictions for a variety of stimulation scenaria (Section 7.1.7) are presented later.

7.1.3.1 Well and Interference Testing

The prefrac, well/interference testing of the Red sandstones consisted of drawdown and buildup testing in MWX-1 while observing interference pressure in MWX-2 and MWX-3. Bottomhole pressures (BHP) were acquired in all three wells throughout the test and bottomhole shut-in tools were used in the observation wells to minimize wellbore volumes and thus eliminate the effects of storage on the anticipated small pressure transients.

The initial prefrac tests were conducted from September 17 to November 4, 1984. Figure 7.1.5 illustrates the gas flow rate and BHP acquired from MWX-1 and the BHP in the two observation wells. (Data for Figure 7.1.5 are given in Appendix 11.7.) The well testing consisted of three drawdown and buildup sequences, with the final buildup lasting almost 10 days. Gas flow rates during the drawdown periods ranged from 40-100 MCFD and stabilized near 45 MCFD during the later portions of the testing. Flowing BHP ranged from 1200-1800 psi, while buildup pressures reached a maximum of near 4100 psi. Final buildup pressure in MWX-2 and MWX-3 climbed to near 4320 and 4365 psi, respectively. Qualitative examination of Figure 7.1.5 shows no clear indication of pressure interference in either MWX-2 or MWX-3 that could be correlated to the transients generated in MWX-1.

7.1.3.2 Conventional Well Test Analysis

The conventional analysis of the Red prefrac test data consists of Horner plot analysis, an evaluation of interference pressures and log-log/derivative type curve matching. Figure 7.1.6 is a composite Horner plot of the three buildup periods introduced during well testing of the Red sandstones. These periods begin at about 7 days, 16 days, and 25.5 days as seen in Figure 7.1.5. The last buildup (Number 3) was conducted using a bottomhole shut-in tool which virtually eliminated wellbore storage effects and thus permitted an analysis of early time pressure buildup data. Figure 7.1.7 is an expanded view of the Number 3 buildup and illustrates the usefulness of early time pressure data. Two straight line slopes are detectable, indicating the possible existence of boundaries or flow regime variations due to the natural fractures. Note the slope ratio is very close to 2:1. The existence of these two distinct slopes in the first two buildup periods was masked by wellbore storage/afterflow effects.

Horner analysis of the MWX-1 buildup data indicates an average in situ reservoir capacity of 0.38 md-ft, corresponding to a permeability of 0.011 md, an extrapolated initial reservoir pressure of 4240 psi, and a skin of +1.8. The calculated average reservoir permeability of 0.011 md is at least two orders of magnitude larger than the in situ matrix permeability derived from core analysis. If the slope change during the last buildup is assumed to be caused by a reservoir boundary, then the location of the boundary calculates to be approximately 45 ft from MWX-1. This is considerably closer than suggested by geologic data and thus the slope change is probably not an indicator of a boundary.

Figure 7.1.8 is a composite log-log/derivative plot for the three buildups shown in Figure 7.6. For a homogeneous, isotropic reservoir, the line source solution type curves matched to these data suggest a kh = 0.80 md-ft, which is almost twice that derived from the Horner analysis above. This occurs because the flat portion of the derivative curve used in the type curve match corresponds to the slope on the Horner plot of 170 psi/cycle. The last slope of 355 psi/cycle is more representative of the pseudoradial flow regime, and thus flow capacity calculations would be in the ratio of 355:170, or about 2:1.

Figure 7.1.8 also provides another clear illustration of how the use of the bottomhole shut-in technique affects analysis. Note that for both buildups 1 and 2, when shut-in occurs at the surface, storage effects dominate the pressure distribution for almost the entire test period, even though the late derivative data appears to be flattening. However, when the bottomhole shut-in was used, the early time portion of the derivative (3-30 hrs) seen in buildup 3, provides a clear indication that a flow transition period is occurring at about 100 hrs. This is further evidence that production is not controlled by a homogeneous, single porosity/ permeability type of reservoir. Since reservoir production is undoubtedly dominated by natural fracture flow, then radial or pseudo-radial analytic techniques may prove useful, but do not necessarily provide correct solutions.

Because natural fractures in the Red sandstones play such a dominant and significant part in overall reservoir production, analytic techniques that assume dual porosity/permeability were considered more appropriate for the problem. The transition period seen in the data, at about 100 hrs, which was quite visible in the Horner and derivative plots, suggests that a history match may be found using the natural fracture or dual porosity transient type curves of Bourdet.[2] The average flow capacity from that type curve yields a flow capacity of kh = 0.40 md-ft, which corresponds to an average permeability of 0.011 md. With a matrix permeability of 0.00005 md, the fracture-to-matrix permeability ratio is about 220 to 1.

The lack of observable pressure interference in MWX-2 and MWX-3 during the well testing in MWX-1 was disappointing and required considering several possible mechanisms that could account for the observed pressure behavior such as: no areal communication between wells; anisotropic permeability behavior creating a very elliptical pressure distribution; stress sensitive natural fracture permeability; and/or water blocking in observation wells. All of these effects were considered in the reservoir modeling presented in Section 7.1.6.

7.1.4 PRE-FRACTURE WELL TESTS OF THE YELLOW SANDSTONES

This section presents the results of pre-fracture well testing, analysis and reservoir modeling of the Yellow sandstones. As with the Red sandstones, details of the well completion for the Yellow sandstones are provided in Section 2.2. Reservoir modeling results and history matching (Section 7.1.6) and performance predictions for various stimulation scenaria (Section 7.1.7) are presented later.

7.1.4.1 Well and Interference Testing

The Yellow sandstone intervals in MWX-1, 2 and 3 were completed for testing by November 6, 1984. The testing of the Yellow sandstones in MWX-1 began November 12, 1984 and continued for almost 31 days. The testing consisted of a sustained drawdown period of about 17 days, two short pulses that were designed to aid in establishing pressure interference, and a final 10-day buildup test. Figure 7.1.9 illustrates the MWX-1 BHP and surface flow rate along with the BHP in the two observation wells. (Data for Figure 7.1.9 are given in Appendix 11.8.)

The initial production rate was about 100 MCFD, which decreased to 70-80 MCFD after several days. Flowing bottomhole pressures ranged from 1400-2000 psi during the initial flow period. The final two flow periods exhibited rates of approximately 50 MCFD at a BHP of 1600 psi. Final buildup pressure in MWX-1 was slightly above 3800 psi.

Pressures were recorded in the observation wells during the MWX-1 testing period. Final buildup pressures in MWX-2 and MWX-3 were 4266 and 4290 psi, respectively. Although no production testing was conducted in MWX-2 or MWX-3, perforation operations and post-completion clean-up invariably resulted in the introduction of pressure transients into the observation wells, and both wells were exhibiting pressure buildup behavior during the main testing period. As with previous tests in the Red sandstones, the observation wells were shut in bottomhole to minimize wellbore storage effects. Although there appears to be pressure disturbances in the observation wells, no correlation can be made with the MWX-1 production/shut-in sequences.

7.1.4.2 Conventional Well Test Analysis

Figure 7.1.10 is a composite Horner plot of the last two pressure buildup data sets from MWX-1 testing of the Yellow sandstones; the last buildup test (Number 3) was conducted using a bottomhole shut-in. The calculated bulk reservoir permeability from Horner analysis was found to be 0.022 md (0.67 md-ft), an extrapolated initial reservoir pressure of 3950 psi and a skin of 6.1. As observed in the Red sandstones, slope variations in the Horner plot suggest the possible existence of a nearby boundary or dual porosity/permeability behavior. This late time slope variation in the Yellow sandstones is not nearly as definitive as was seen in the Red sandstones, but is present. If it is assumed that this slope change represents a boundary, then the calculated minimum distance to that boundary is 55 ft.

The pressure drop occurring in the data at a Horner time of 2. This is a real formation occurrence since it was not viewed in the annulus pressure. The tubing was isolated from the reservoir and the pressure gauge with the bottomhole shut-in tool and was at a higher pressure than bottomhole and therefore could not contribute to a pressure decrease. One possible explanation for this pressure drop is water imbibing into the reservoir which creates a localized pressure loss in the wellbore. The time during which pressure continues to fall is, however, almost 3 days and suggests that imbibition is not a very probable explanation. Other than leakage to some other formation within the reservoir, the possible explanations are very limited and uncertain.

The log-log/derivative plot of the last buildup is shown in Figure 7.1.11. Note the similarity with the Red data shown in Figure 7.1.8. An alternate explanation for the Horner slope variation, rather than a boundary effect, is the dual porosity behavior caused by flow regime changes in the natural fractures and matrix. The dual porosity type curve match suggests a naturally fractured system with an average flow capacity of 0.38 md-ft, or a permeability of 0.013 md, which is half the value derived from the Horner analysis. However, as detailed in the Red analysis of Section 7.1.3.2, this result is more appropriate than Horner analysis and the factor of 2 variation with the early slope used in Horner analysis is predictable.

7.1.5 SUMMARY OF CONVENTIONAL ANALYSES FOR RED AND YELLOW SANDSTONES

The analytic results of the well tests performed in the Red and Yellow sandstones are presented in Table 7.1.2. These data represent the average values for the reservoir and only qualitatively suggest that the primary reservoir production mechanism is controlled by natural fractures. A comparison of the measured core permeabilities at in situ conditions (0.00005 md), to average well test (0.012 md), results in about a 240 times increase. Although natural fractures were present in cores, their areal extent and connection within the reservoirs were nevertheless uncertain. The well test data, however, with its high production capacity indicates that the fracture system must be extensive and interconnected.

The lack of correlatable pressure interference in the observation wells during both Red and Yellow well tests suggests that the natural fractures exhibit significant anisotropic flow capacity. Without clear transit times and interference pressure values, the derivation of reservoir anisotropy remained ambiguous.

The extent and nature of these natural fractures is of primary consideration for the design of a hydraulic fracturing treatment. Depending on the orientation of a hydraulic fracture relative to the natural fractures and the amount of degradation that may occur to the natural fractures intersected by the hydraulic fracture, post-fracture production enhancement could be significantly altered from simple predictions for a homogeneous reservoir. Predicted production enhancement following simulated hydraulic fracture treatments are presented in Section 7.1.7.

7.1.6 INITIAL PREFRAC RESERVOIR MODELING

Computer reservoir simulations were performed using a 3-D, single phase, naturally fractured reservoir model to determine a sound and acceptable representation of the Red and Yellow reservoirs. A number of reservoir matrix and natural fracture parameters were varied in order to determine their sensitivity and to ultimately provide a most probable value for fracture spacing and anisotropy. In addition, the model was then used to assess the potential enhanced gas production that could occur for various proposed hydraulic fracturing treatments considered for the coastal zone.

The prefrac well test data from the Red and Yellow sandstones were analyzed and a reasonably good approximation was made with the model of basic reservoir behavior by history matching model and field data. Once this was established, the simulated reservoir was modified by incorporating any of the proposed propped hydraulic fractures and then comparing production for the propped fracture case with the base case for both short (2 months) and long (1 year) production periods. This same model was then used to assess the real post-fracture reservoir behavior.

7.1.6.1 Simulating the Well Test Data From Red Sandstones

The model or simulator parameters used to describe the Red reservoir characteristics were optimized to provide the best history match to the prefrac test data presented in Figure 7.1.5. Parameter constraints were imposed from data gathered or derived from the geophysical and geological investigations. Table 7.1.3 lists some of the initial reservoir properties that were used in the simulator.

Neither analytic nor numerical simulation could account for the observed elevated gas production (50-70 MCFD) for a homogeneous reservoir with the assumptions of Table 7.1.3, particularly kg = 0.05 μd. This supports the premise that an interconnected set of highly permeable natural fractures, that crisscross the reservoir and connect a large volume of matrix rock with the wellbore, dominates production capacity. Figure 7.1.12 is a schematic of the model that was used to represent these fractured coastal reservoirs. This model includes the very tight, low porosity matrix and a cross-connected anisotropic set of fractures that extend over the entire reservoir. Natural fracture permeability was spatially variable and could thus be altered to simulate any desired degree of anisotropy. As an example, the natural fracture permeability value in Figure 7.1.12 represents an anisotropic fracture set with a 100:1 ratio.

Figure 7.1.13 is a set of model derived bottomhole pressures used to simulate the MWX-1 field data shown in Figure 7.1.5. The field-measured surface flow rates, shown in Figure 7.1.5, were used as input to the model along with Table 7.1.3 data and the following natural fracture parameters: natural fracture permeability in x,y direction (k_{fx}, k_{fy}) of 6.5 darcies, natural fracture width (w_f) of 0.0005 in., and natural fracture porosity (ϕ_f) of 0.80.

Although this match of the MWX-1 bottomhole pressure between Figures 7.1.5 and 7.1.13 is not exact, it is very reasonable. This is one very possible and physically probable interpretation of the Red sandstone reservoir. However, it can be seen in the upper portion of Figure 7.1.13 that a substantial pressure transient should have been present at the location of the observation well, MWX-2, and to a lesser degree, a transient at MWX-3. The observed pressures from the field data gathered at MWX-2 and

MWX-3 do not substantiate the suggestion that these are transients resulting from perturbances induced at MWX-1. Therefore, although a fairly permeable cross-connected set of natural fractures exists in the Red sandstones, they may not exhibit equivalent flow capacities and could be considered as an anisotropic set.

Natural fracture anisotropy is reasonable, considering the fact that the normal stresses on the fracture set are directionally applied and probably differ in magnitude. Since natural fracture flow capacity can be approximated by a width-cubed function, that is $k_f = \alpha w_f^3$, then the fractures that cross the maximum principle stress may be only slightly more narrow, but would be considerably less conductive than those that cross the minimum principle stress. Previous interference pressure measurements made at MWX in the Cozzette marine sandstones indicated a substantial directional variation in flow capacities for that set of natural fractures, further corroborating the argument of an anisotropic natural fracture set.[3]

In order to provide the simulated MWX-1 well with the required gas flow rates at measured bottomhole pressures, and yet essentially eliminate the pressure transients at either/or both MWX-2 and MWX-3, the natural fractures were altered in order to reflect non-equivalent or anisotropic flow capacities, but while maintaining the same average value.

The direction of the primary fracture set was taken to be parallel to the maximum principle stress direction N74°W (x-axis). The cross or secondary natural fracture set was taken to be orthogonal to the primary set and thus be in the assumed minimum principle stress direction, N16°E (y-axis). The spacing between the fractures was 10 ft, and seen in plan view appears as a square grid (Figure 7.1.12). The flow capacity, $k_f w_f$, for the primary fractures along the maximum principle stress direction was taken to be the larger of the two sets, due to the fact that there is less stress across the fracture face. This anisotropic, fractured reservoir configuration would then provide smaller and smaller pressure transients at the observation wells as the ratio of primary and secondary fracture flow capacities increases. Figure 7.1.14 is a plot of bottomhole pressures for the simulated Red well test, where the fracture permeabilities for the two cases were:

Case I: k_{fx} = 37 darcies, k_{fy} = 0.75 darcies, a 50:1 ratio; and

Case II: k_{fx} = 65 darcies, k_{fy} = 0.65 darcies, a 100:1 ratio.

For the simulated MWX-2 well location, an additional early time transient was introduced to more appropriately describe the real field data; that is, the pressure in the observation well was rising from some previous self-induced transient, and then had superimposed on it a remnant of a transient resulting from production at MWX-1. It is clear from Figure 7.1.14 that for Case I, there should have been a distinguishable pressure transient at MWX-2 during MWX-1 testing. However, Case II, with a 100 to 1 permeability ratio (schematically shown in Figure 7.1.12), indicates that the transient would have been so small that it would have been imperceptible during the field testing period.

Note however, that although Case II provides a reasonable case for matching specific field test data (i.e., measured flow rate, bottomhole pressure in MWX-1, and no observable pressure transient at MWX-2 or MWX-3), it is not a unique solution nor was it intended to be. These cases do, however, indicate that a rather large anisotropy in fracture flow capacity must exist in the natural fractures of the coastal sandstones. Therefore stimulation of these reservoirs under those conditions will yield a considerably different enhancement ratio than would be found from a comparable stimulation in an isotropic, naturally fractured reservoir. Figure 7.1.15 overlays Case II on the field data shown in Figure 7.1.5.

7.1.6.2 Simulating the Well Test Data from Yellow Sandstones

The modeling of the Yellow sandstone prefrac well testing was performed using the same strategy as was used in the Red sandstone modeling. Several different values for anisotropic fracture permeability ratios were attempted with the final value of 80:1 being a fit comparable to that found for the Red sandstone modeling. Table 7.1.3 lists the set of model variables that best simulates the Yellow prefrac test data, while Figure 7.1.16 is the composite overlay of model data and field data.

Figure 7.1.17 is an overlay of the field and model log-log/derivative data. Once again, note the anisotropic value of 80:1 for natural fracture permeability stems from the imperceptible pressure transients at the observation wells. Furthermore, both the Red and Yellow sandstone reservoirs appear to possess very similar characteristics (Table 7.1.3). This is of course not very surprising since both reservoirs have a similar depositional origin, and being in such close proximity, the natural fracture systems were most probably formed at the same time and under the same influences.

7.1.7 SIMULATED PRODUCTION ENHANCEMENT FOR PROPOSED COASTAL STIMULATIONS

To assess the production enhancement that might result from hydraulically fracturing these naturally fractured coastal reservoirs, a series of model simulations were performed. These simulations incorporated several different length propped hydraulic fractures that were coupled to the existing natural fracture model discussed in Section 7.1.6. Prefrac model Case II, the reservoir with a 100 to 1 natural fracture permeability ratio, was chosen as the model base case. A simulated one-year production forecast was performed using that base case model. Figure 7.1.18 shows the results of that model run.

Several other cases that involved the inclusion of propped fracture lengths of 150 ft, 250 ft and 500 ft are also shown in Figure 7.1.18. Each of the propped fractures, except for fracture length variations, had the same following properties: propped fracture height (h) of 30 ft, fracture permeability (k_f) of 50 darcies, and a propped fracture width (w_f) of 0.2 in. Figure 7.1.19 is a schematic of the propped hydraulic natural fractured model. The alignment of the propped fracture was assumed to be along the direction of maximum principle stress N74°W. The propped fractures were then parallel to the highest flow capacity natural fractures, the primary set, and intersected or crossed the natural fractures having the minimum flow capacity, the secondary set. Each of these cases depicts the surface flow ratio for a constant bottomhole pressure of 600 psi. Table 7.1.4 lists the flow rates and production enhancements at 30 days, along with the totals at one year.

The 30-day enhancement ratios were chosen because they would probably represent the preliminary field assessment of the stimulation job that generally results from postfrac tests. Note that these 30-day ratios are between about 2 and 3. These enhancement ratios are substantially smaller than the 10 to 20 that would be predicted for propped fractures of the same length and characteristics were they to be created in a homogeneous reservoir. These three cases, however, are very optimistic in that they include

- a propped fracture length that is totally confined to the productive portion of the reservoir (i.e., no boundaries);

- no deterioration to the original natural fractures flow capacity as a result of the hydraulic stimulation;

- propped hydraulic fracture capacity derived from laboratory data, which is considered to be invariant along its entire length; and

- a propped hydraulic fracture height that extends over the whole net reservoir.

In order to estimate the potential degrading effects that may occur to the natural fracture system due to the hydraulic stimulation process, a new series of model simulations were performed. These model simulations were similar to those described above, except that the original natural fracture system directly adjacent to the propped frac, the secondary set, was partially blocked. Therefore, production into the propped fracture, and thus the wellbore, could only occur by passing through the 10-ft matrix (0.05 μd) blocks that contacted the propped frac. The remaining natural fractures throughout the reservoir were not assumed to be affected by the hydraulic fracturing and thus were not altered. Figure 7.1.20 is a schematic of this model for the 500-ft case which shows the damaged interval along the hydraulic fracture.

Figure 7.1.21 shows the results of two such simulations, 250-ft and 500-ft hydraulic propped fractures, along with the original undisturbed naturally fractured reservoir, or the base case. It is clear from these simulations that the benefits from even long-length induced fractures are marginal, at best, if the existing natural fractures are damaged by the stimulation process.

7.1.8 COASTAL RESERVOIR ANALYSIS SUMMARY FROM THE PREFRAC WELL TESTS

A large set of naturally fractured reservoir simulations were performed that used geophysical, geological and well test data to establish a base case reservoir for the coastal sandstones. Field production rates indicated that the average reservoir flow capacity (0.012 md-66 ft) for the combined Red and Yellow sandstone reservoirs was considerably in excess of the core derived matrix capacity (0.00005 md-66 ft). Therefore, the enhanced production was considered to be the result of an interconnected set of natural fractures that extended well beyond the production well, MWX-1. The interference test data gathered in MWX-2 and MWX-3 during the well tests of the Red and Yellow sandstones, however, requires that a large flow capacity anisotropy, about 80 or 100 to 1, must exist within this naturally fractured system. The case of simulated or model permeability values for the primary and secondary natural fractures of 65 darcies and 0.65 darcies, respectively, which for widths of 0.0005 in., provides flow capacities for each fracture set of 2.7 md-ft and 0.027 md-ft, respectively.

Additional simulations were performed using the anisotropic naturally fracture base case and an optimistic set of characteristics for a variety of propped hydraulic fractures to simulate the effects of stimulation on near term production. These results suggest that although an enhancement of about 2 to 5 times may occur, that in reality the best that could be expected for a 500-ft fracture would be threefold increase. Further reductions to this optimistic enhancement would result if real adjustments are made for other unknowns, such as boundaries for fractures greater than 500 ft, and degradation of the existing natural fracture flow capacity resulting from the stimulation process. If natural fracture degradation occurs, little if any enhancement may occur for even the 500-ft fracture. Thus the selection of a proper and useful hydraulic stimulation must carefully consider both of these factors.

7.1.9 COMMINGLED WINTER PRODUCTION OF THE RED AND YELLOW SANDSTONES

The Red and Yellow sandstone reservoirs in MWX-1 were commingled and produced into the local pipeline system during the winter months of 1984-85. Production commenced on December 26, 1984 with the initial rates averaging between 50 to 60 MCFD. At these low flow rates, the ability for gas to lift water through the 2.875-in. tubing was severely limited and gas production decreased rapidly. On January 15, 1985, the well was opened to the flare pit in an attempt to purge the wellbore of as much liquid as possible. The well was then reconnected to the pipeline and gas rates increased to approximately 45 MCFD at a flowing tubing pressure of 500 psi. Figure 7.1.22 illustrates the MWX-1 winter pipeline production for the commingled Red and Yellow sandstones.

7.1.10 NITROGEN INJECTION EXPERIMENTS

Following the commingled winter production of the Red and Yellow sandstones, a nitrogen (N_2) injection test was performed as part of the prestimulation reservoir assessment. MWX-2 was utilized as the injection well, and MWX-1 and MWX-3 were production/observation wells through which the gaseous effluent was sampled and analyzed for traces of N_2 that might have been transported across the reservoir. The primary objectives of this N_2 injection test were:

- Determine the transit time for N_2 from the injection well to the observation well to quantify the flow capacity of the natural fractures.

- Provide additional insight into the transient flow mechanisms of naturally fractured reservoirs.

7.1.10.1 N_2 Injection Field Procedures

All three MWX wells were prepared for commingled production of the Red and Yellow sandstones during the latter part of March, 1985, and the nitrogen injection test began on April 16, 1985. MWX-2 was selected as the injection well because the pressure gradient between the closest other well, MWX-1, was such as to readily permit injected gas to flow toward MWX-1. This well configuration should provide the best possible case for N_2 transport between any pair of MWX wells. Since MWX-1 had been producing into the pipeline over the winter months, it was clearly not the appropriate candidate well for injection. MWX-3 was not considered seriously as it was the most distant from either of the remaining potential observation locations.

A specially designed GC system, assembled and tested at Sandia, was connected to the tubing of MWX-1 and was set to collect a gas sample from the flow line every 15 minutes, perform a limited GC analysis of gas constituency, and provide a computer printout of the results. This system was essentially self-contained and operated in a semiautomatic fashion.

In addition to the on-line GC system, gas samples from both observation wells, MWX-1 and MWX-3, were taken in 0.3-liter plastic bags for future analysis. A second GC that was scheduled to provide quasi-real-time analysis of the MWX-3 gas bag samples remained operational for only a few hours into the test when one of the flow loops became contaminated and thus provided little usable data. Subsequently, Bendix Corporation of Grand Junction, Colorado, was utilized to perform laboratory GC analysis from a selective group of gas samples taken from MWX-1 and MWX-3 in high pressure canisters. Both gas chromatography systems are described in more detail in Appendix 11.9.

Nitrogen pumping service was provided by Dowell of Vernal, Utah. The N_2 pumper was connected to MWX-2 and injection commenced at 1309 hours on Tuesday, April 16, 1985. A series of N_2 injections, designated A through D, occurred over a 2-day period with the final injection occurring between 1310 and 1355 hours on Thursday, April 18, 1985. Table 7.1.5 provides a listing of the injection series, including injection times, rates and injected volumes. A total of 361,292 SCF of N_2 were injected into the tubing at the wellhead of MWX-2. Approximately 50,000 SCF remained in the 2.875-in. tubing essentially as storage, and thus about 311,300 SCF were injected into the Red and Yellow sandstones. Figure 7.1.23 is a composite plot showing the MWX-2 N_2 injection rate and surface tubing and bottomhole pressures. (The data for this plot are given in Appendix 11.10.)

Bottomhole pressure measurements were made in all three MWX wells using H.P. quartz pressure gauges. Except for an early failure of the H.P. in the injection well, MWX-2, bottomhole pressures were recorded throughout the injection test and subsequently into the flowback/interference test that followed. Pressure testing continued through the end of May, 1985.

In order to maintain temporal continuity throughout the testing period, an initial testing time (t_o) was selected as a zero reference and taken to be 0.00 hrs at 1544 hrs, April 12, 1985, and therefore all the data are referenced to that date and time.

7.1.10.2 N_2 Injection Well, MWX-2

The initial injection schedule called for a semi-continuous injection of N_2 gas into the Red and Yellow sandstones that would occur over a 24- to 36-hour period. The intent of the injection was to permit the N_2 tracer to transverse the distance between MWX-2 and the other two wells through existing natural fractures and thus care was taken not to intentionally create new fractures that might stimulate or enhance the process. This process would be accomplished by injecting at reasonably low rates, about 1000-2000 SCFM, at bottomhole pressures not to exceed the measured minimum horizontal stress of about 5650 psi. The 6450 ft of tubing acted as a buffer and storage vessel during periods when the pumper was shut down. Therefore, as long as the bottomhole pressure exceeded the average reservoir pressure of about 4100 psi, injection into the formation would appear to be a rather continuous process. This scenario assumed that N_2 would traverse the roughly 125 ft between MWX-2 and MWX-1 in a reasonably short time, about 15-30 minutes, and that the amount of N_2 in the gaseous production at MWX-1 could as large as 10%.

Initial N_2 injection began at 1309 hours, April 16, 1985 (93.403 hours), at a rate of 5000 SCFM. This high rate was designed primarily as a means of rapidly filling the tubing wellbore with high pressured N_2. The injection continued for about 7.8 minutes, when the bottomhole H.P. gauge became inoperable and pumping was temporarily suspended in order to ascertain the condition of the gauge. Three additional short injections followed over the next 3.5 hours, during which time, the H.P. gauge was retrieved from MWX-2 and replaced. (Bottomhole pressures are absent during the first 7 hours until the malfunctioning gauge was replaced.)

The subsequent pulses over the next two days are given in Table 7.1.5 and Figure 7.1.23. Assuming the average reservoir pressure in the vicinity of MWX-2 to be 4100 psi, then it can be seen from the bottomhole pressure data that injection continued throughout the entire test period since bottomhole injection pressure, although declining, never dropped below average reservoir pressure.

Note that the surface tubing pressures during the end of the last two shut-in periods (C and D), do not follow bottomhole pressure. This is because the bottomhole pressure gauge was seated into the bottomhole shut-in tool in order to effectively isolate the reservoir and gauge from the bulk of the 6400 ft of tubing. The higher tubing pressure is required to maintain the gauge in the tool seat during these shut-in periods. Therefore, during these shut-in periods, bottomhole pressure data reflects only the pressure associated with the reservoir and the small remaining wellbore volume between the shut-in tool located at 6400 ft and the perfs at 6450 ft. This period of bottomhole isolation provides the best set of pressure falloff transient data that is indicative of the average reservoir behavior.

7.1.10.3 Injection Pressure Analysis

Initial attempts at analyzing the injection pressures involved performing semilog analysis during several of the injection periods. Figure 7.1.24 is a composite graph of the bottomhole pressure for three of the injection periods labeled as A, B, C and D in Figure 7.1.23. For each of these injection periods, zero time corresponds to the beginning of each new injection rate and thus the pressures shown in Figure 7.1.24 have common zero starting times. For these cases, the average reservoir injection flow capacity can be obtained from semilog analysis as,

$$\overline{kh} = 162.6\ q\mu B/m \tag{1}$$

where:

$\overline{kh}$ = average reservoir injection flow capacity, md-ft
q = average flow rate, MSCFD
μ = viscosity, cp
B = formation volume factor, bbl/MSCFD
m = slope from semilog injection plot, psi/cycle

Note that for each of the injections, the slope of bottomhole pressure versus injection time on the semilog plot became straight rather quickly and thus allows a reasonably accurate selection of slope to be made. Only the top of the injection pressures are shown in Figure 7.1.24, in order to visually enhance pressure sensitivity and selection of the slope. The fluid and reservoir properties were taken at an average reservoir pressure of 5500 psi, and using Equation (1) for the periods given above, the kh values derived are between 50 and 75 md-ft as shown in Table 7.1.6. The two values for the D curve are for the early slope when the injection rate was 2000 SCFM and the late slope when the injection rate was reduced to 1800 SCFM.

Semilog analysis is based on flow equations for radial fluid flow within a single porous medium. Thus for the early time injection periods, the assumption of radial flow is probably not a correct one for this naturally fractured system. These inflated values of flow capacity, 50 to 75 md-ft, are most probably representative of the natural fracture system alone, since the tight (0.00005 md) matrix would be unable to respond to these short 20- to 30-minute injection pulses.

If the early flow regimes are dominated by linear, as opposed to radial flow, then the injection periods may be considered as linear fracture flow and/or bilinear flow periods. Linear fracture flow involves a period when gas moves linearly into a fracture and involves only the compression of the gas within the fracture. Essentially, nothing is lost to the surrounding matrix. The bilinear flow period discussed by Cinco[4], involves linear flow within a fracture as well as linear injection into the surrounding media; thus the term bilinear. The period of linear fracture flow is presumed to occur very early in the injection process, after which time flow changes quickly to become bilinear.

The log-log/derivative plot of pressure versus time generally provides an indication of each of the flow regimes. A unit slope on the log-log plot denotes a period of wellbore storage, linear fracture flow appears as a 1/2 slope and bilinear flow would show a 1/4 slope. Figure 7.1.25 is a log-log/derivative graph of the bottomhole injection pressure as a function of injection time for the B injection period. Slopes of 1, 1/2 and 1/4 are shown for reference purposes.

Referring to Figure 7.1.25, it can be seen from the slopes that wellbore storage appears to dominate the injection process from the beginning of injection until about 0.1 hours (6 minutes), and then the slope very abruptly becomes almost flat. Thus, there does not seem to be the manifestations of linear or bilinear flow periods from observing the slopes using the log-log plot. Virtually identical results are obtained using pseudo pressure, which accounts for variations in viscosity and gas compressibility. If, however, it is assumed that the period of linear fracture flow is too short to be observed or is masked by the relatively long wellbore storage period, then the flat portion of the log-log plot may include or represent the period of bilinear flow. Utilizing the analysis technique for bilinear flow provided by Cinco[4] that relates fracture parameters and the slope of the fourth root of time pressure plot, a value for fracture flow capacity can be derived from the following equation:

$$k_f w_f = \left[\frac{44.1 \mu B}{h(\phi_m \, \mu c_m \, k_m)^{1/4}} \right]^2 \left(\frac{q}{m_b} \right)^2 \tag{2}$$

where:

k_f = fracture permeability, md
w_f = fracture width, ft
k_m = matrix permeability, md
h = net height, ft
ϕ_m = matrix gas porosity
c_m = matrix compressibility, psi^{-1}
m_b = slope of straight line for bilinear flow, $psi/hr^{1/4}$

and q, μ and B are as given in Equation (1).

If the primary natural fractures are assumed to be planar and devoid of liquids, with fluid compressibility and viscosity dominated by the injected gas, then conversion factors and fluid properties evaluated at a constant 5500 psi are as follows:

c_m = 0.000109 psi^{-1}
B = 0.625 bbl/MSCFD
μ = 0.0267 cp.

The net pay, h, for the combined Red and Yellow sandstones was taken to be 66 ft and the porosity ϕ_m was taken to be 0.05. Solving Equation (2) with the above properties, we have,

$$k_f w_f = 0.283/\sqrt{k_m}\,(q/m_b)^2$$

Figure 7.1.26 is a plot of the bottomhole injection pressure versus the fourth root of time for the B injection period. Taking the slope during the late time period as indicated by the log-log plot, the primary fracture flow capacity will be given by:

$$k_f w_f = 0.283/\sqrt{k_m}\,(2160/182)^2 \text{ md-ft}$$

or, (3)

$$k_f w_f = 39.86/\sqrt{k_m} \text{ md-ft}$$

If the N_2 injection is assumed to occur from the wellbore through one or two of the primary fractures, k_{fmax}, and that the cross or secondary fracture set, k_{fmin}, dominates and thus represents the surrounding media, then the average reservoir permeability in that direction, k_{min}, will be given by:

$$\bar{k}_{min} = (k_{fmin} \times w_f + k_m \times S)/S \qquad (4)$$

or,

$$\bar{k}_{min} = [(710 \text{ md})(.00024 \text{ in})/(12 \text{ in/ft}) + (.00005 \text{ md})(10 \text{ ft})]/10 \text{ ft}$$

$$\bar{k}_{min} = 0.00147 \text{ md}$$

Equating $k_m = \bar{k}_{min}$ in Equation (3), yields

$$k_f w_f = 39.86/\sqrt{0.00147} \text{ md-ft},$$

or,

$$k_f w_f = 1037 \text{ md-ft.} \tag{5}$$

This represents a very conductive primary fracture set. In fact, when compared to the prefrac well test model data of 0.78 md-ft, it is over 1300 times more conductive. This clearly suggests a fracture enhancement process of some kind.

During each of these N_2 injections, the bottomhole pressure was never permitted to exceed the presumed minimum in situ stress of 5650 psi. Therefore, it seemed highly improbable that additional fracture length to the primary natural fractures was being created during these injection periods.

Since the permeability of a planar fracture is width cubed, αw_f^3, dependent; then, an average 11-fold increase in natural fracture width, that is from 0.00024 to 0.0026 in., would be required to increase the primary natural fracture model data from 0.71 to 1037 md-ft. It is difficult to imagine a physical process, other than natural fracture dilatancy or shear slippage, that could account for an average increase in fracture width of this magnitude. This suggests that the minimum horizontal in situ stress may have decreased from the time that the in situ stress tests were performed to the time that these N_2 injection tests occurred.

7.1.10.4 Falloff Pressure Analysis

The total injection time, that is the period when bottomhole pressure exceeded the current reservoir pressure of about 4100 psi in MWX-2, was 48.9 hrs. This amounts to essentially the whole period of the N_2 injection test, and not just those times when the pump trucks were injecting at the surface. Utilizing falloff analysis for the bottomhole pressure data following the last injection (D), when the well was shut in with the bottomhole shut-in tool, the average reservoir flow capacity, kh, can be estimated.

Figure 7.1.27 is a semilog plot of the bottomhole pressure versus falloff time, t_{f1}, where:

$t_{f1} = (t_f + \Delta t)/\Delta t$

t_f = N_2 injection time, 48.9 hrs

Δt = time since shut in, hrs

Average reservoir flow capacity, kh, is found from the slope of the straight line portion of the curve, shown in Figure 7.1.27 and Equation (1), or

$$\overline{kh} = 162.6 * q\mu B/m_{f1} \tag{6}$$

where the terms are as given in Equation (2), except

m_{f1} = slope from semilog shut-in plot, psi/cycle.

The average flow rate, q, for this falloff test was taken to be the total injected volume, 311,300 SCF, divided by the 48.9 hrs of injection, or q = 153 MSCFD. The value of kh, from Equation (6), is then given by,

$\overline{kh}$ = 1.30 md-ft

This is substantially lower then the average conductivity from a similar analysis performed on the injection data, where kh = 50-75 md-ft. Thus, there appears to be strong evidence to suggest that natural fracture conductivity was enhanced during injection. The falloff kh, however, compares reasonably with the combined kh value for the Red and Yellow sandstones derived from prefrac well test analysis where kh = 0.78 md-ft. This suggests that the fracture system has returned to nearly the same average system when reservoir pressure is permitted to relax.

The early falloff data after the A and B injections did not lend themselves to this kind of semilog analysis because the pressure falloffs are dominated by the effects of wellbore storage. Although the bottomhole shut-in technique was used during the C injection/falloff, it was designed to only test the seating techniques for the final shut-in, and therefore was not continued for a sufficiently long enough period to allow the pressure to get on the semilog straight line, and thus that data was also not usable for semilog analysis.

One additional caveat to this falloff analysis should be made clear. Figure 7.1.28 is a log-log/derivative plot of the D falloff data. Note that the derivative data at 100 hrs after shut-in takes an abrupt drop. This time corresponds to the shut-in of MWX-1 and MWX-3, which had been on continuous production in an attempt to acquire the N_2 tracer. This provides clear evidence that pressure interference does occur between the MWX wells and that the falloff data has been under the perturbing influence of the production occurring in both observation wells, MWX-1 and MWX-3.

7.1.10.5 Tracer Analysis

Figure 7.1.12 provides a graphic model interpretation of the MWX site well locations in conjunction with scaled fracture spacing for one of the coastal sandstones. From prefrac well tests, it was postulated that the principle production mechanism was the result of a highly contiguous and interconnected set of orthogonal, anisotropic natural fractures. The direction of the primary fracture set was taken to be the direction of maximum principle horizontal stress, N76°W, and designated, k_{fmax}. While the secondary fracture set, designated as k_{fmin}, was taken to be orthogonal to that of the primary set. The ratio of fracture flow capacity for the primary and secondary sets was found to be about 80 to 100:1.

For natural fractures with permeabilities on the order of 0.7 darcies, transit time across the reservoir would be about 15 minutes or less, and the amplitude of the N_2 response could be as large as 10-20%. This is based on Darcy's Law for laminar, horizontal flow through a planar vertical fracture that relates the pressure gradient and flow rate of a viscous fluid through a porous media of known permeability and length. For a simple case, fluid velocity can be given by,

$$v = dx/dt = \bar{k}/\mu * dp/dx \tag{7}$$

where:

v = instantaneous fluid velocity, cm/sec

$\bar{k}$ = average permeability, darcies

μ = viscosity, cp

dp/dx = pressure gradient along the direction of velocity, atm/cm

Assuming this function to be linear and continuous, then Equation (7) can be rearranged and solved for the average transit time, Δt, in standard oil field terms,

$$\overline{\Delta t} = 3741.9 * \mu * \Delta x^2 / (\Delta p * \bar{k}) \tag{8}$$

where:

$\overline{\Delta t}$ = average transit time, hrs

Δp = average pressure drop across the length, x, psi

Δx = path length, ft

$\bar{k}$ = average secondary fracture permeability, md

The minimum, secondary natural fracture path length from MWX-2 to MWX-1 is about 75 ft. For the periods when MWX-1 was producing gas while gas was being injected in MWX-2, the average pressure drop, Δp, was about 3500 psi. Inserting these values in Equation (8) yields,

$$\overline{\Delta t} = 3741.9 * 0.0267 * (75)^2 / (3500 * 700)$$

or,

$\Delta t = 0.23$ hrs $= 13.8$ min

From the tubing volumes in the injection and observation wells and the flow and injection rates scheduled during the test, it can be calculated that an additional 10-12 minutes is required to transport gas through the tubular system, connecting the wellhead with the bottomhole reservoir. Thus, a total time lag from surface injection to response at the GC is expected to be about 25 min. Although diffusion was not considered, it would tend to diminish the amplitude but decrease transit time. Losses due to injection into the rock matrix may, on the other hand, tend to increase the transit time. From the above considerations, it was anticipated that a fairly rapid N_2 response at the observation wells would be seen.

Figure 7.1.29 is a composite time plot showing the N_2 injection rates in MWX-2, the percent of free N_2 in MWX-1 gases derived from the semi-automatic GC system and portions of the GC analysis results provided by Bendix Corporation. Both sets of free N_2 data have been corrected for the presence of N_2 corresponding to air contaminants. This process involved measuring the amount of oxygen present in the sample and then subtracting the corresponding value of N_2 that would be present in that quantity of air. This corrected value of N_2 is then considered to be the amount of free N_2 present within that particular sample and presumed to have originated from injection through MWX-2.

If the transit time calculations described above were correct, then N_2 should have been present at the observation wells within about 25-30 minutes. The percentage and time history of N_2 as shown in Figure 7.1.29 do not readily permit a precise selection of N_2 arrival times and/or peak values. Nitrogen response in the observation wells appears to be uneven, possibly due to small isolated pockets of nitrogen. In addition, air contaminated the GC system during the early portions of the experiment, especially between 93 and 103 hrs, and thus the corrected N_2 percentages during that period are extremely suspect. (Note the oscillatory behavior of the corrected data between 93 and 103 hours.) Also, air leaks in the gas bag samples introduced quantities of N_2 that were often ten times as large as the final corrected data. The MWX-1 gas sampling and GC analysis continued for almost 10 days and that only a portion of which is shown in Figure 7.1.29.

If the most immediate N_2 peak following an injection period is assumed to be the response from that injection at the observation well, then the transit times seen in Figure 7.1.29 range from 1 hour for the last injection to about 5 hrs for the injection at 103 hrs. Once again, it must be emphasized that the amplitudes of the N_2 responses are obviously small and may well be within the range of error for trace analysis of N_2 in natural gas using this type of gas chromatographic technique.

If, however, the transit times are in fact between 1 hr and 5 hrs, then rearranging Equation (8) and solving for average minimum fracture permeability, k_{fmin}, the range would be,

$$160 \text{ md} > \overline{k_{fmin}} > 32 \text{ md} \tag{9}$$

Certainly a more accurate evaluation of fracture permeability could be made using a distributed pressure along the crack or making use of a trace simulator. However, because of the limited and often ambiguous transit times, these more sophisticated approaches would not significantly reduce the uncertainty of the results. The limited, questionable data provided by the Bendix GC analysis at best corroborates the 1 to 5 hr transit times.

7.1.10.6 Summary of the Nitrogen Injection Test

During a three-day period in this experiment, several large pulses of gaseous N_2 were injected in MWX-2 while the production/observation wells, MWX-1 and MWX-3, were continuously produced. The produced gases were sampled and monitored for traces of N_2 using standard gas chromatographic (GC) techniques. During the period when N_2 was being injected into MWX-2, there were reasonably good indications from GC data that sporadic traces of N_2 were being observed at both MWX-1 and MWX-3. Thus, there appeared to be additional evidence that an enhanced permeability connection, probably a rather torturous natural fracture path existed within the Red and/or Yellow sandstones. Furthermore, the extent of the fracture system was large and extended at least over the area of the MWX site. The quantities of N_2 that reached the production wells were considerably smaller than anticipated and the transit times, although somewhat difficult to quantify, were longer than expected.

Data and analysis from the nitrogen injection experiments have provided some new and extremely interesting results concerning the extent and flow capacity of the natural fractures that dominate the production mechanism in these very tight lenticular, coastal sandstones. In summary, the more pertinent data derived from this experiment are:

- Semilog analysis of the injection pressures during the injection, pulses showed that average reservoir flow capacity (kh) was large, between 50-75 md-ft. This represents a substantial increase over the initial average value of 0.78 md-ft derived from the combined drawdown/buildup prefrac tests conducted during the fall of 1984 in MWX-1, and orders of magnitude beyond the restored state core matrix values of about 0.0033 md-ft. Thus, these semilog derived values most probably represent the flow capacity of the natural fracture alone, since the tight matrix would be virtually unable to respond to these transients during the short 20 to 30 minute injection periods.

- Bilinear fracture flow analysis provides a lumped equivalent primary fracture flow capacity, $k_f w_f$ = 1037 md-ft. This apparent increase in natural fracture conductivity is most probably the result of small increases in fracture width, w_f, caused by dilatancy or shear slippage during the injection process. This pressure/stress dependence of flow capacity is not surprising since this phenomenon was experienced while testing most of the zones at MWX. However, this experiment was the first attempt to quantify variations in flow capacity at pressures above reservoir pressure.

- Analysis of the falloff data indicated that when the natural fractures were returned to their relaxed position, i.e., when wellbore pressure returns to near average reservoir pressure, the average flow capacity of the reservoir, kh = 1.38 md-ft, almost returned to the pre-injection value, kh = 0.78 md-ft. Further, the derivative analysis of the MWX-2 falloff data shows clear evidence of pressure interference from either or both MWX-1 and MWX-3.

- GC analysis of the flowing gases from the observation wells provides clear indications that N_2 traversed the reservoir from injection well to remote observation wells. The transit time from MWX-2-MWX-1 was found to be between 1-5 hours, and corresponds to a minimum fracture permeability in the range of 32 md to 160 md. These values are reasonably comparable to the value used in the pre-fracture reservoir simulator.

- Although the amplitude and time of arrival of N_2 at the observation wells do not presently permit an unambiguous estimation of transit time or average natural fracture flow capacity, the pressure response of the reservoir in MWX-2 during the injection and falloff revealed that the average macroscopic reservoir flow capacity was functionally dependent on pressure and/or injection flow rate. This kh enhancement, that is particularly evident during injection, is most probably the result of changes occurring within the natural fractures, possibly dilatancy, shear slippage, dewatering, or other phenomena, either individually or in concert.

7.1.11 REFERENCES

1. Lorenz, J. C., "Sedimentology of the Mesaverde Formation at Rifle Gap, Colorado, and Implications for Gas-Bearing Intervals in the Subsurface," Report SAND82-0604, March 1982.

2. Bourdet, D. et al., "New Type Curves and Analysis of Fissured Zone Well Tests," Work Oil (April, 1984) 111-124.

3. Multiwell Experiment Project Groups at Sandia National Laboratories and CER Corporation, "Multiwell Experiment Final Report I: The Marine Interval of the Mesaverde Formation," Sandia National Laboratories Report, SAND87-0327, April 1987.

4. Cinco-Ley, H. and Samaniego-V. F., "Transient Pressure Analysis for Fractured Wells," J. Pet. Tech. (Sept. 1981) 1749-66.

Table 7.1.1 Core and Log Derived Reservoir Characteristics for the Coastal Red and Yellow Sandstones

		Yellow	Red
ϕ_t, Total Matrix Porosity		8.0%	7.5%
s_w, Water Saturation		45.0%	45.0%
k_g, Relative Matrix Gas Permeability (s_w = 45%)		0.05 μd	0.05 μd
h, Productive Channel Thickness			
	MWX-1	30 ft	36 ft
	MWX-2	36 ft	48 ft
	MWX-3	28 ft	22 ft
μ, Gas Viscosity		0.02 cp	0.02 cp
t, Reservoir Temperature		185°F	185°F

Table 7.1.2 Coastal Red and Yellow Average Reservoir Parameters Derived from Conventional Analytic Techniques

Reservoir Parameters	Red	Yellow
$\overline{kh}$	0.40 md-ft	0.38 md-ft
$\bar{k}$	0.011 md	0.013 md
P*	4240 psi	3950 psi
Skin	1.8	1.0
Nearest Boundary	45 ft	55 ft

Table 7.1.3 Input and Derived Reservoir Parameters for Pre-Fracture Simulation

Reservoir Property	Source of Information	Red Sandstone	Yellow Sandstone
Net production height, h	Logs	36 ft	30 ft
Total porosity, ϕ_t	Logs and core	0.075	0.075
Initial water saturation, S_w	Logs and core	0.50	0.50
Initial reservoir temperature, T	Logs	185°F	183°F
Natural fracture spacing, S	Outcrop studies	10 ft	10 ft
Relative matrix gas permeability, k_g	Core analyses	0.05 μd	0.05 μd
Gas gravity, G	Gas analyses	0.63	0.63
Initial reservoir pressure, P_i	Well, Interference tests	4370 psi	4350 psi
Natural fracture permeability x - direction, k_{fx}	Modeling	65d	48d
Natural fracture permeability y - direction, k_{fy}	Modeling	0.65d	0.60d
Anisotropy	Ratio	100:1	80:1
Natural fracture width, w_f	Modeling	0.0005 in	0.0005 in

Table 7.1.4 Simulated Potential Production Enhancement for Various Propped Fracture Lengths

Fracture Length (ft)	30-Day Flow Rate (MCFD)	30-Day Enhancement Ratio	1-Year Cum. Production (MMCF)	1-Year Enhancement Ratio
0	62	1	20	1
150	144	2.3	38	1.9
250	176	2.8	46	2.3
500	193	3.1	53	2.7

Table 7.1.5 MWX-2 N_2 Tracer Injection Series, With Times, Rates and Volumes

Injection Series	Date	Start Time (hrs)	Pump Time (min)	Rate (SCFM)	Volume (SCF)	Series Total (SCF)
wellbore filling	16-APR	93.403	7.82	5000	39,099	39,099
A[1]	16-APR	93.998	10.97	1500	16,455	
	16-APR	94.182	4.97	1100	5,466	
	16-APR	95.075	3.98	1100	4,380	
	16-APR	96.047	4.99	1200	5,985	32,286
A	16-APR	100.002	4.97	1500	7,454	
	16-APR	100.085	13.99	2500	34,966	
	16-APR	100.519	2.97	2500	7,425	
	16-APR	100.569	3.97	1500	5,955	
	16-APR	100.836	4.97	2500	12,424	
	16-APR	100.919	20.04	800	16,029	
	16-APR	101.833	5.97	2500	14,925	
	16-APR	101.933	7.97	1500	11,954	106,135
B	16-APR	103.317	29.97	1500	49,955	49,955
C	17-APR	113.596	5.43	1500	8,149	
	17-APR	113.687	0.29	2000	582	
	17-APR	113.692	4.19	2500	10,465	
	17-APR	113.762	13.50	2000	27,002	46,198
D	18-APR	141.399	8.47	2500	21,175	
	18-APR	141.540	7.47	2000	14,940	
	18-APR	141.665	28.61	1800	51,504	87,619

Total: 361,292

Table 7.1.6 Semilog Analysis During N_2 Injection Periods in MWX-2

Injection Series	Injection Rate (SCFM)	Average Reservoir/ Injection Flow Capacity kh (md-ft)
A	800	65.7
B	1500	65.3
C	2000	56.6
D1	2000	52.5
D2	1800	76.5

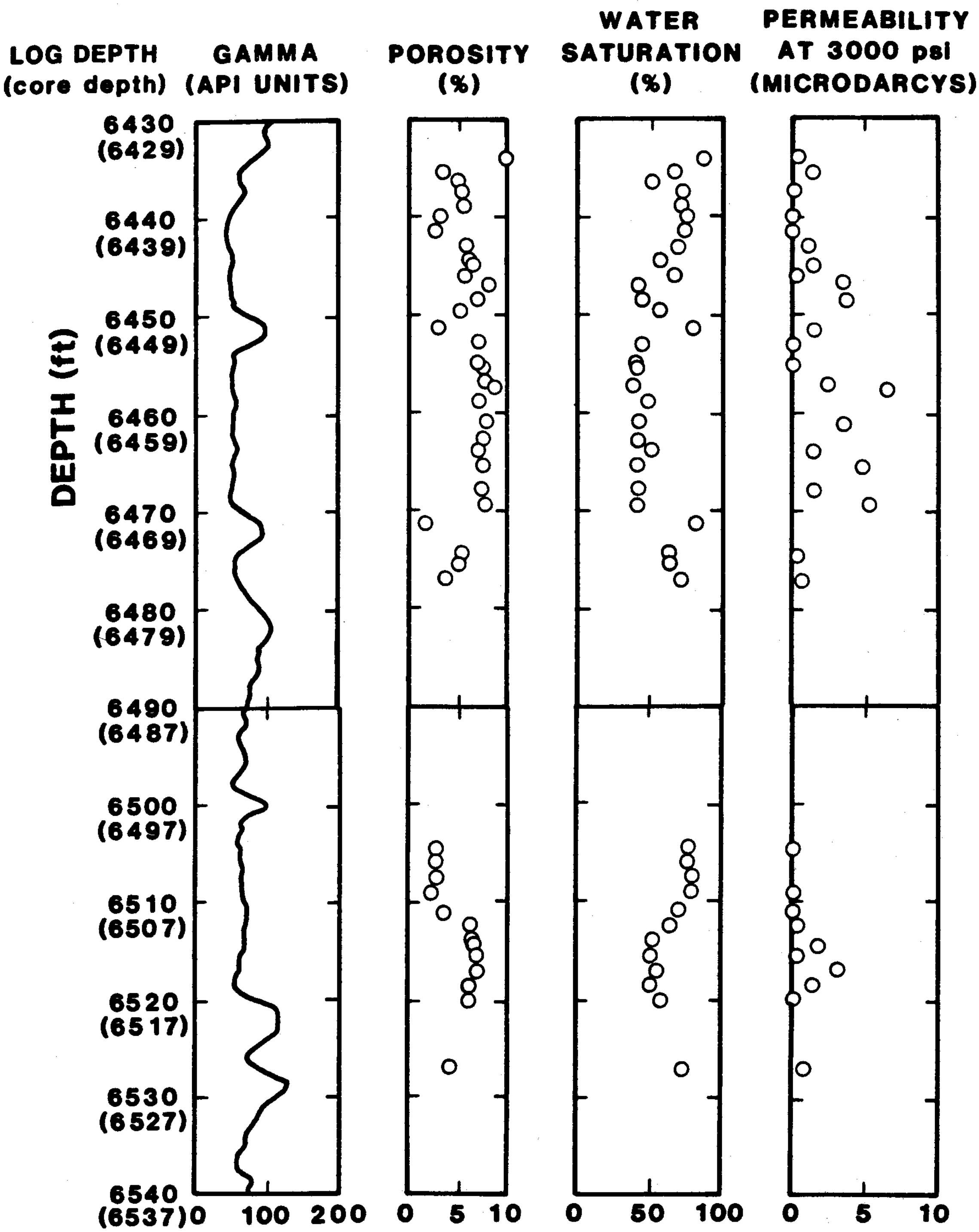

Figure 7.1.1 MWX-3 Core Derived Properties for the Red and Yellow Sandstones

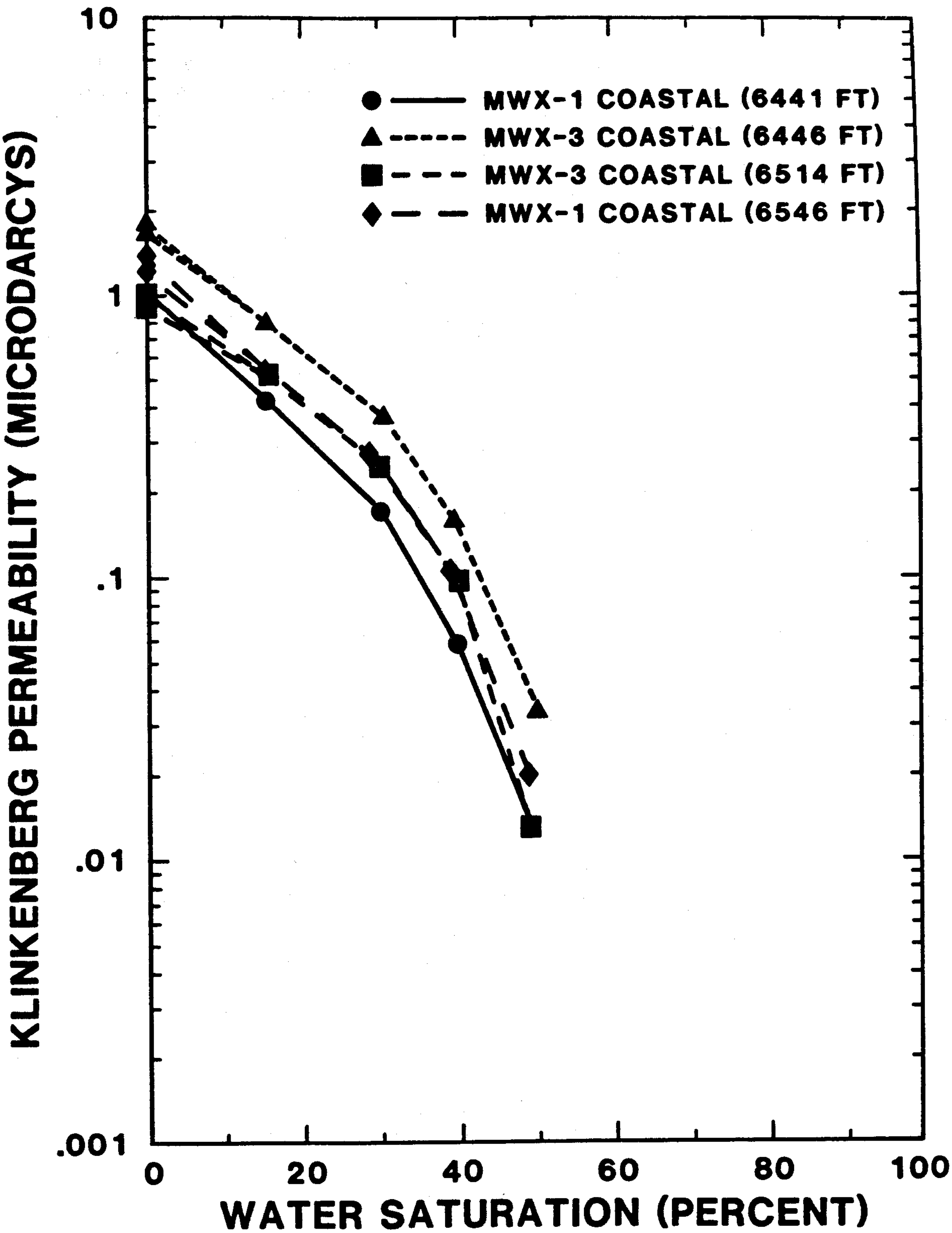

Figure 7.1.2 Restored State Core Permeabilities for Various In Situ Water Saturations

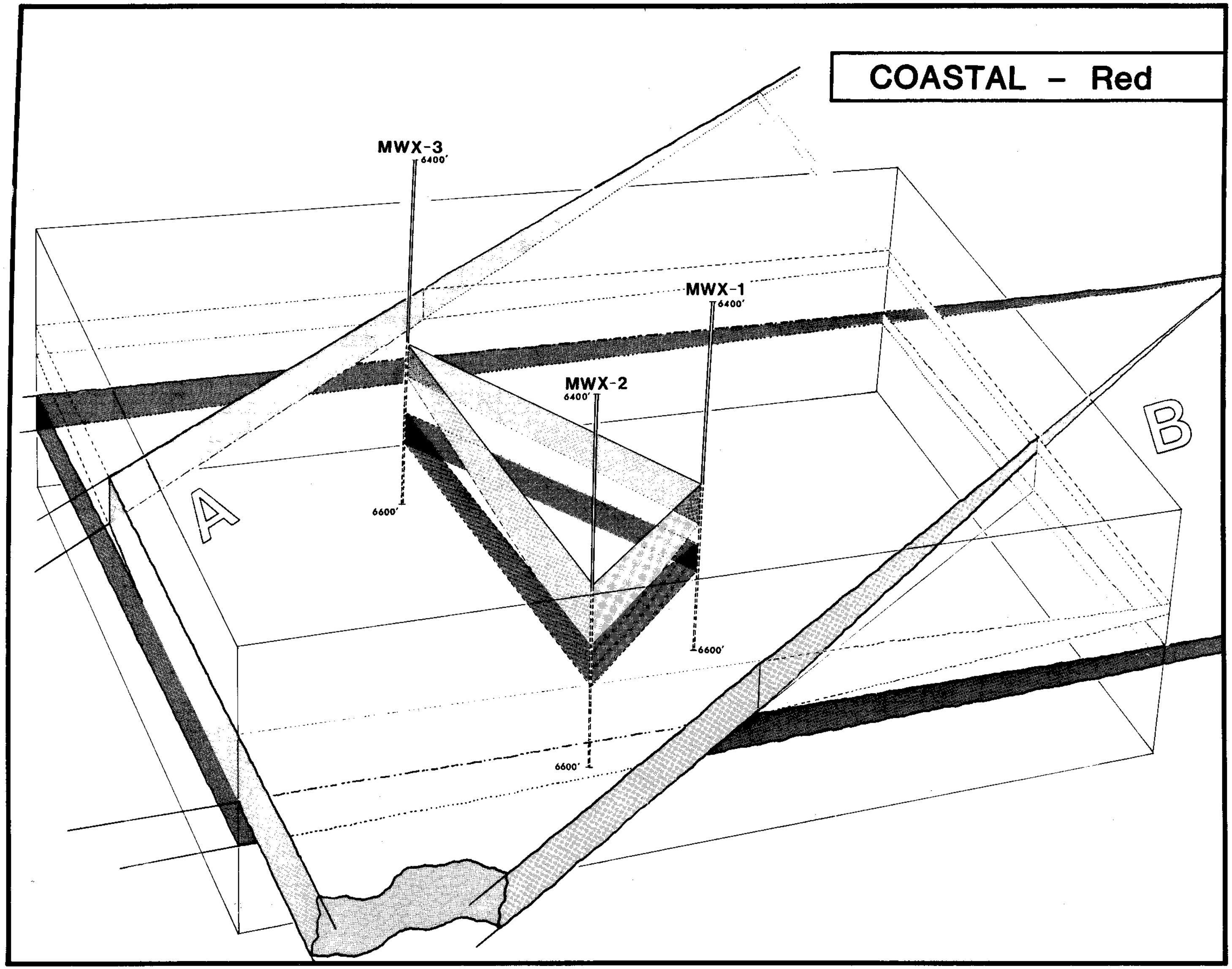

Figure 7.1.3 Cross Section of Coastal Red Sandstones at the MWX Site

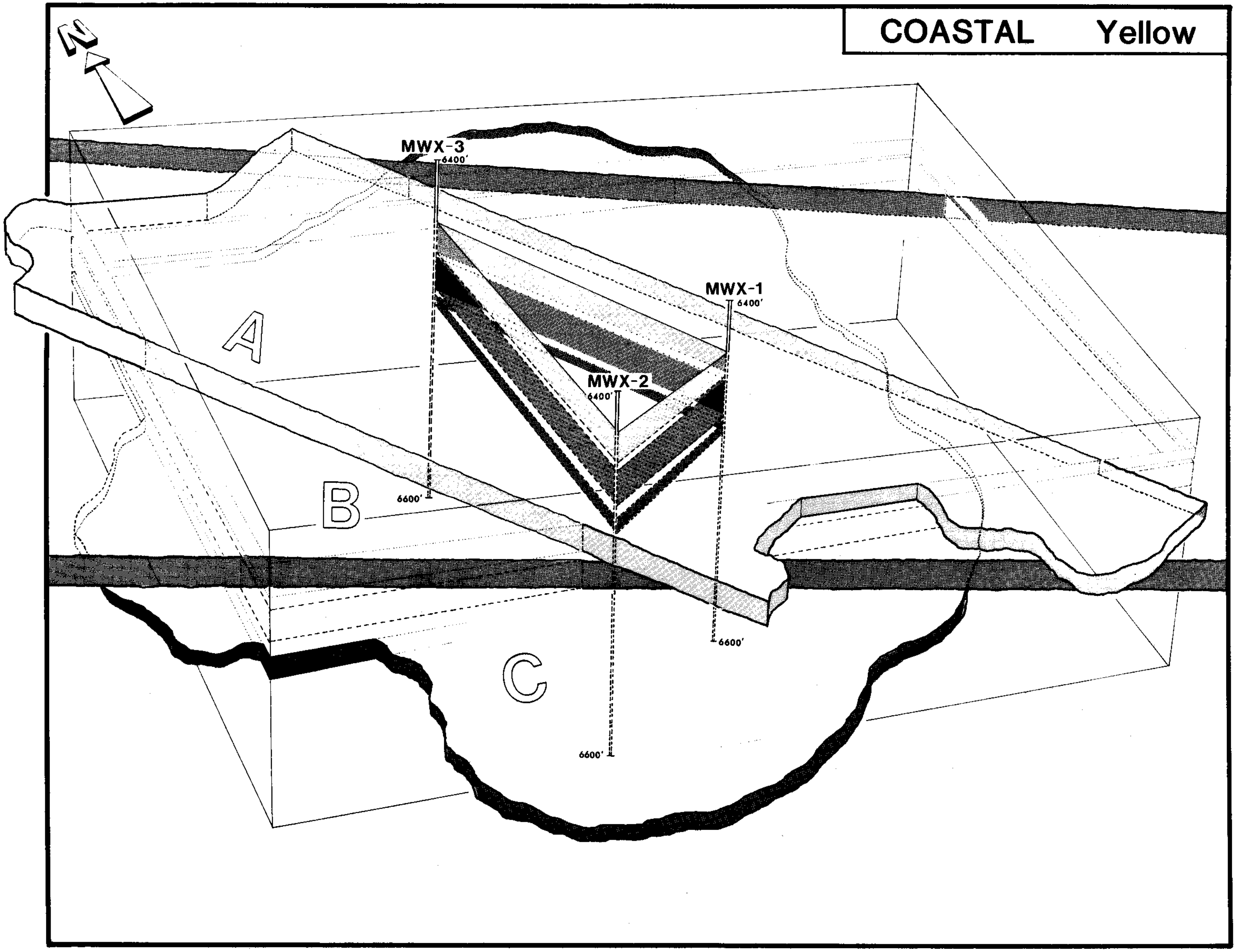

Figure 7.1.4 Cross Section of Coastal Yellow Sandstones at the MWX Site

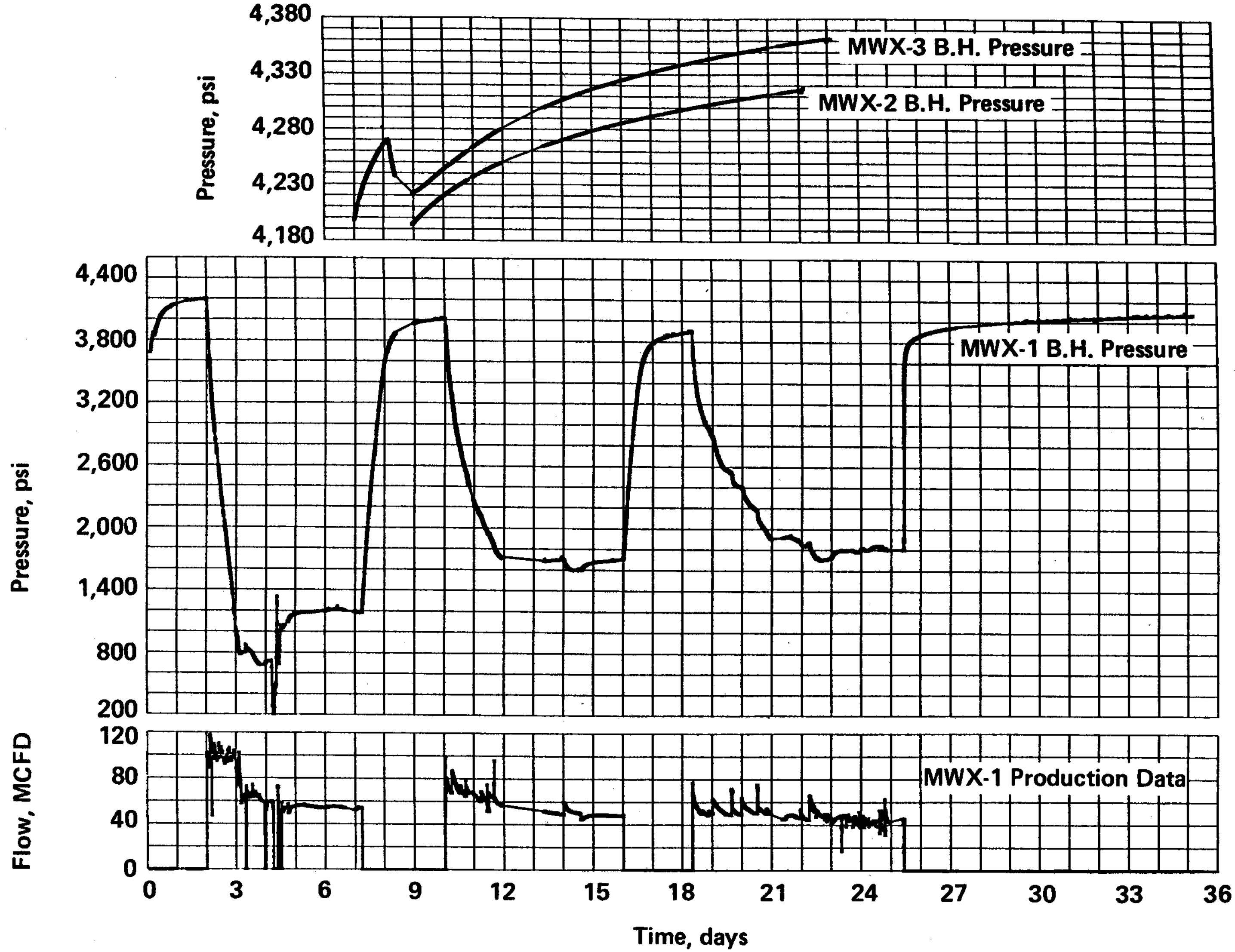

Figure 7.1.5 Pre-Frac Well Test and Interference Data from the Coastal Red Sandstone. (Data given Appendix 11.7)

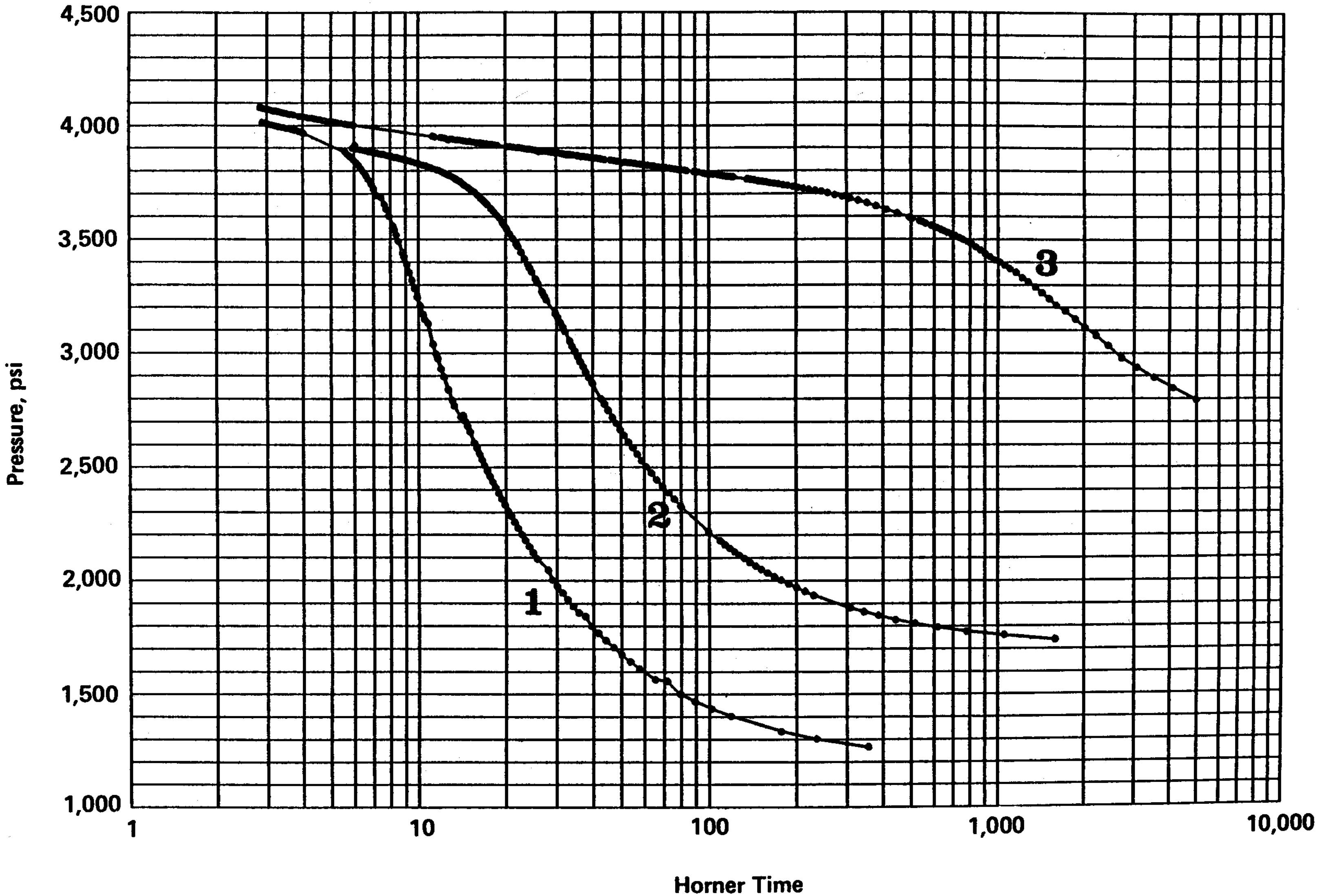

Figure 7.1.6 Composite Horner Plot for Three Buildup Periods from Coastal Red Sandstones Pre-Frac Well Test

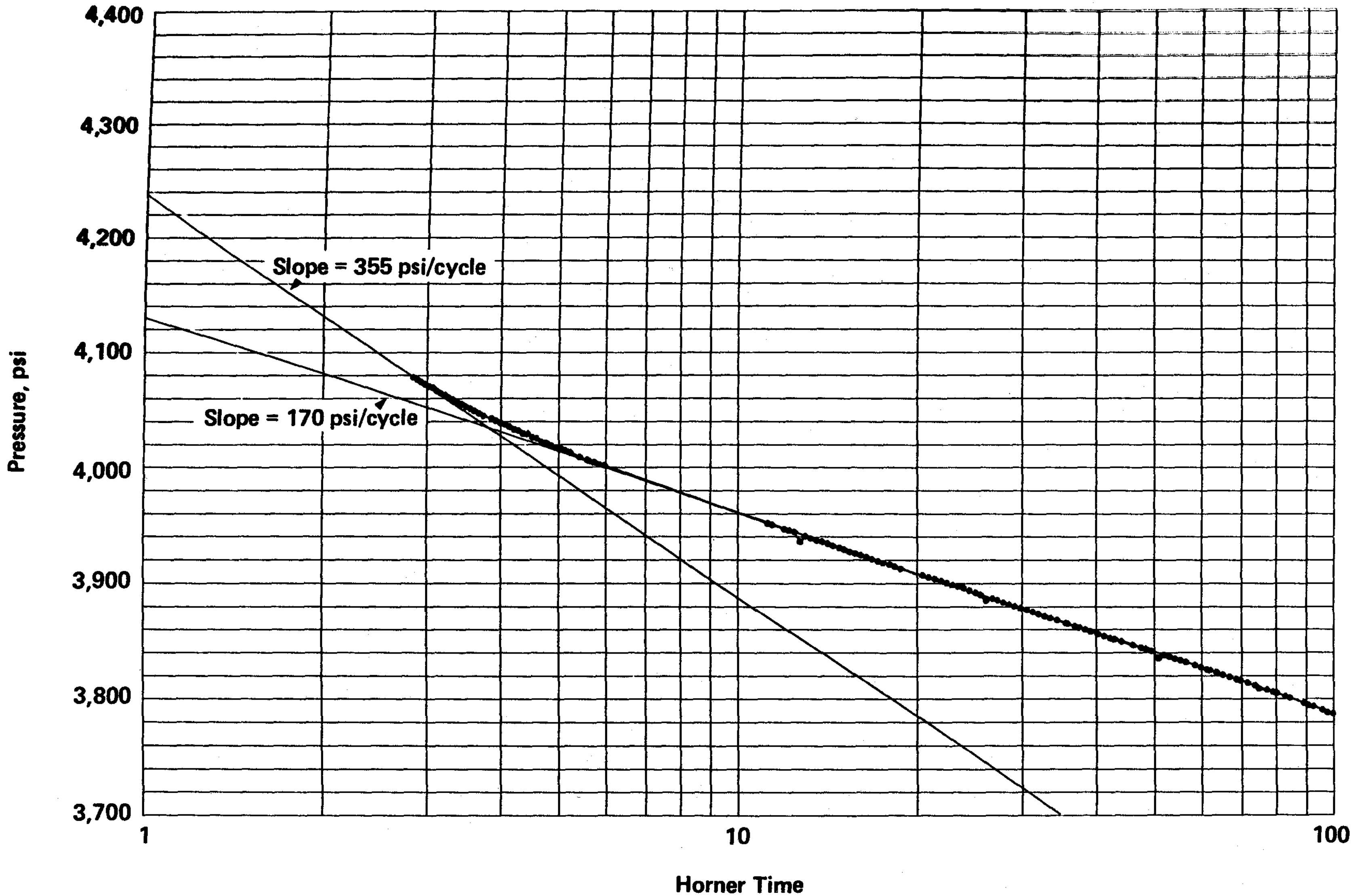

Figure 7.1.7 Expanded of Third and Final Buildup Period from Figure 7.1.6

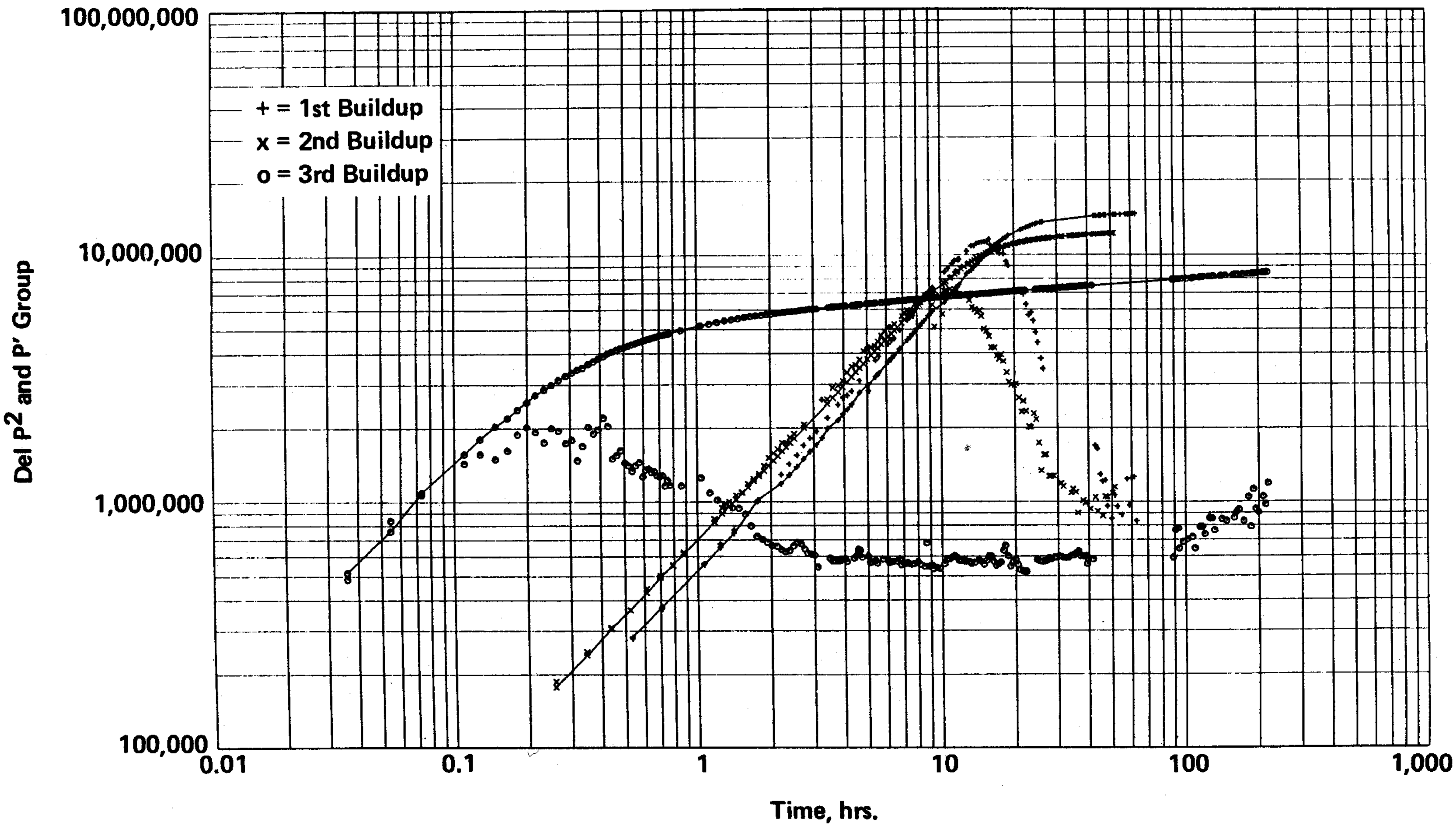

Figure 7.1.8 Composite Log-Log/Derivative Pressure Plot for the Three Buildup Periods from Figure 7.1.5. (+ = First, x = Second, o = Third Buildup, Respectively)

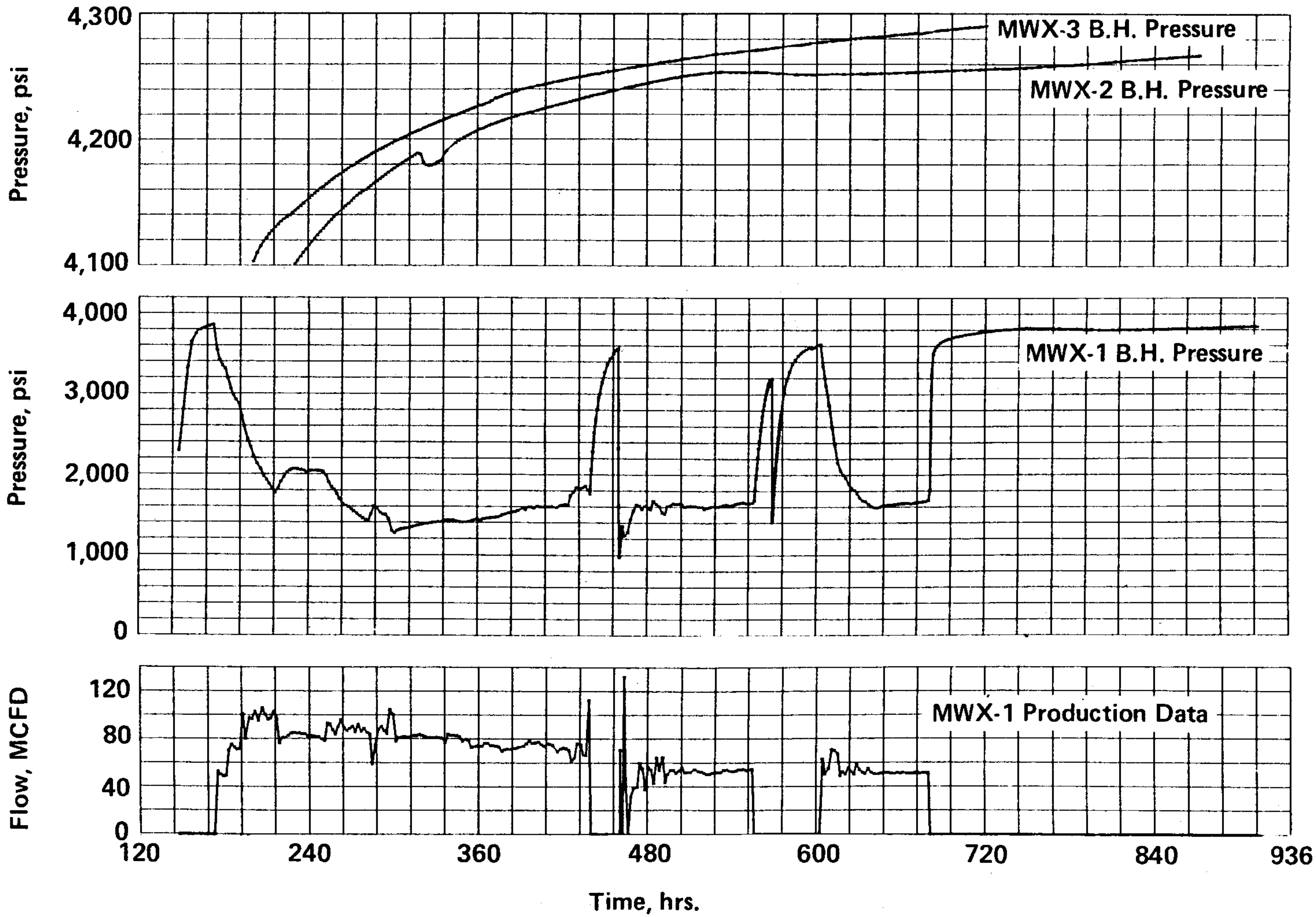

Figure 7.1.9 Prefrac Well Test and Interference Test Data for the Coastal Yellow Sandstones (Data Given in Appendix 11.8)

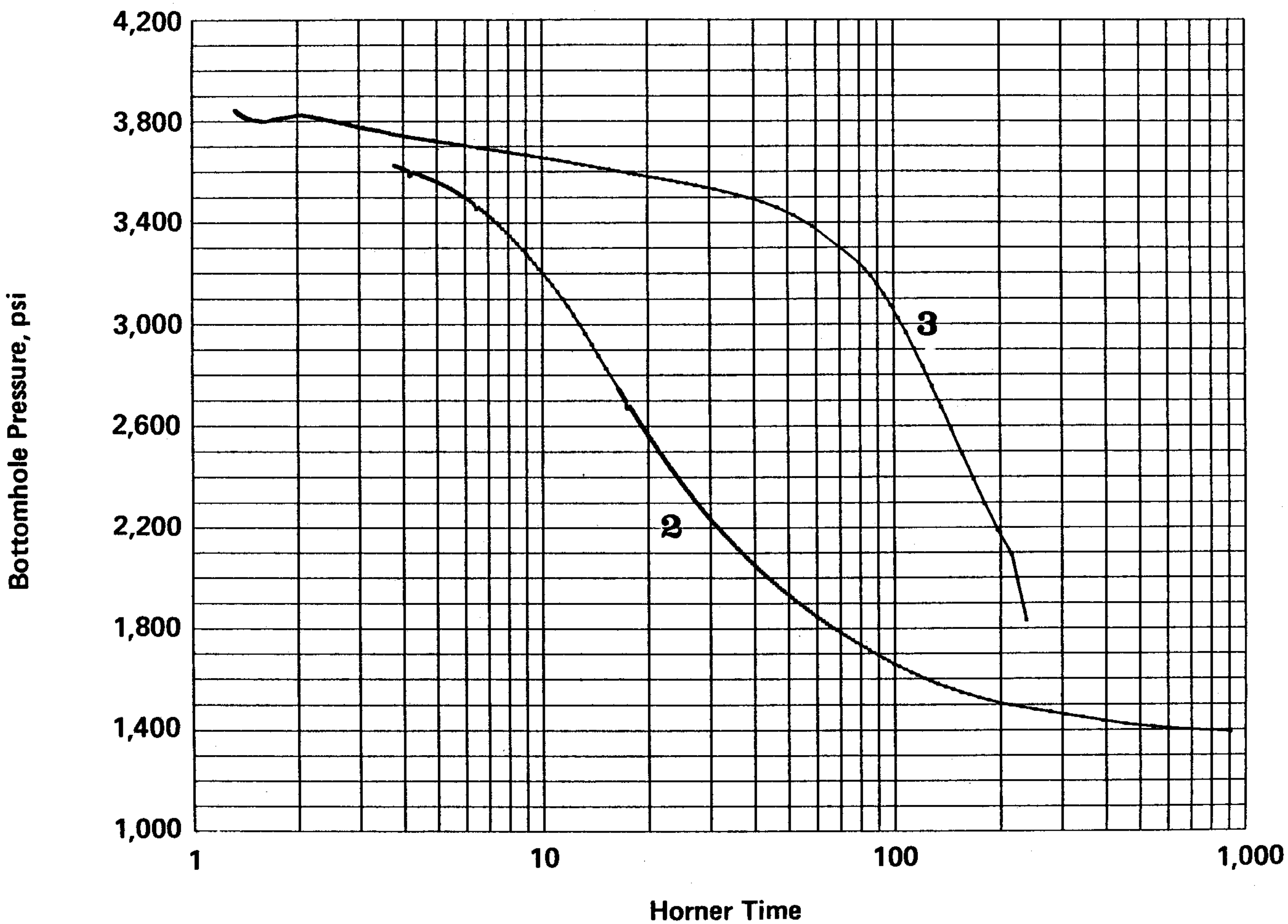

Figure 7.1.10 Horner Plots of the Second and Third Buildup Pressure Tests Performed in the Coastal Yellow Sandstones

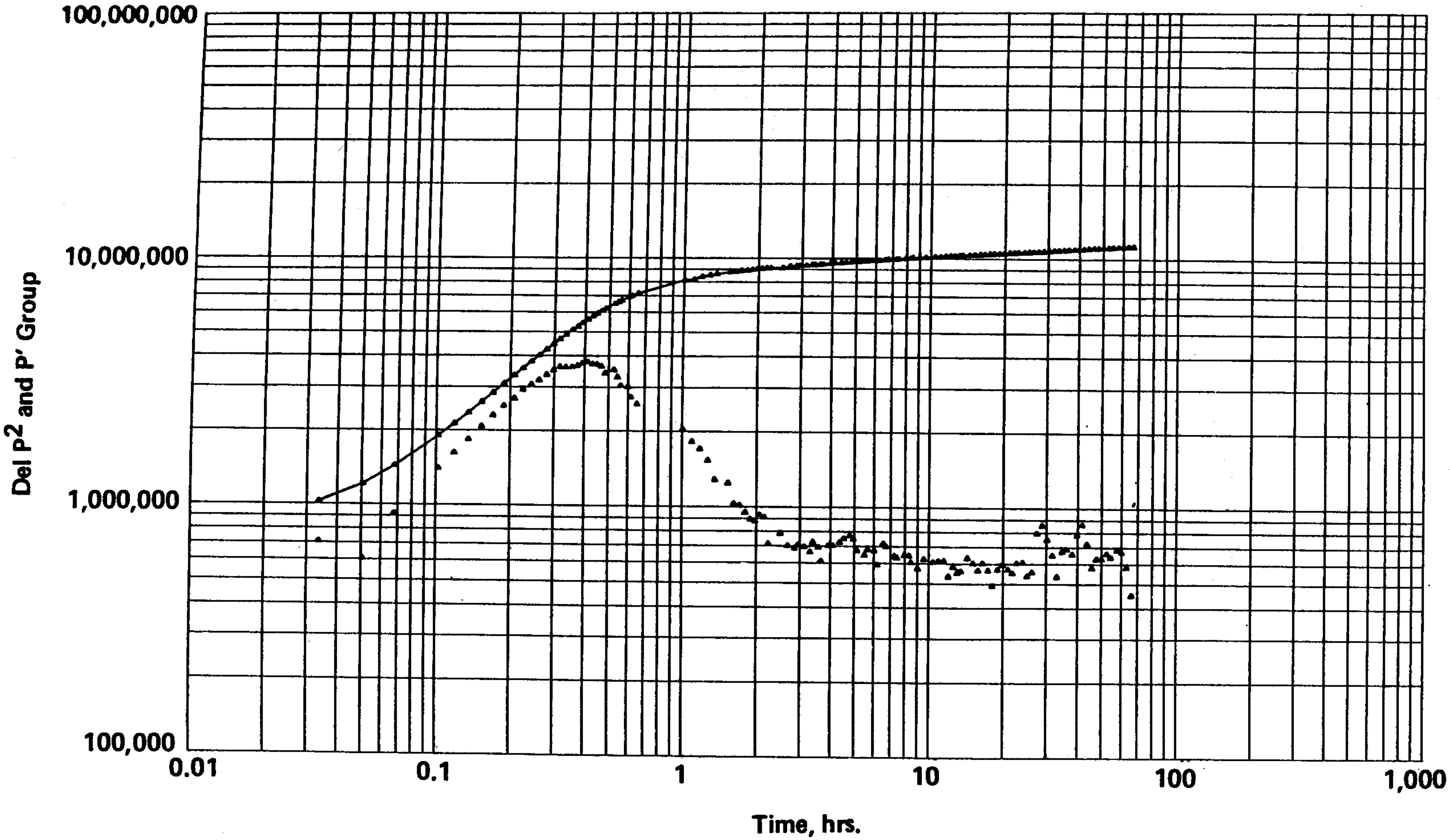

Figure 7.1.11 Log-Log/Derivative Pressure Data from the Final Buildup Test Shown in Figure 7.1.9

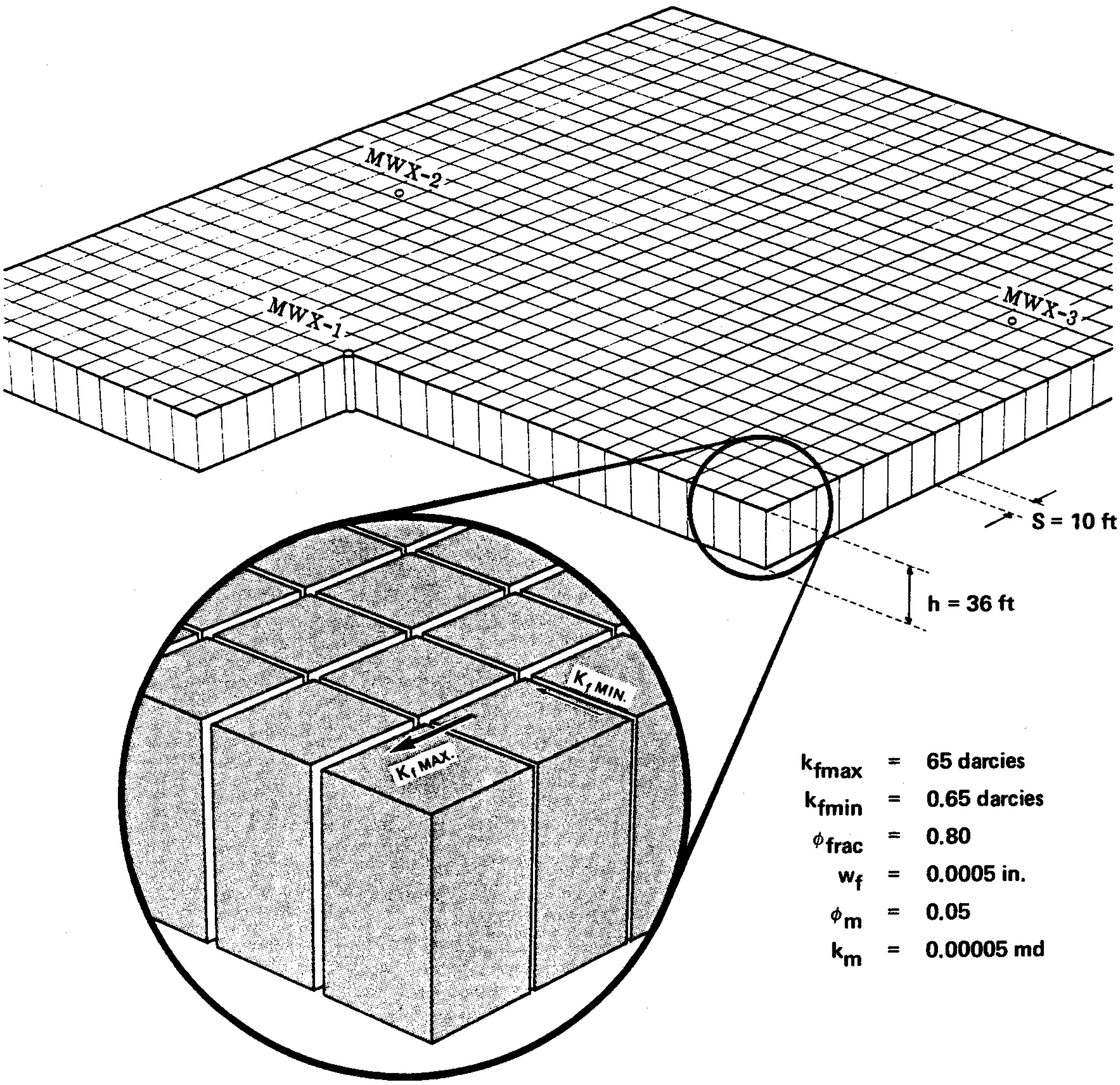

Figure 7.1.12 Schematic of Fully Transient, Naturally Fractured Reservoir Model With a 100:1 Anisotropic Natural Fracture Permeability Ratio

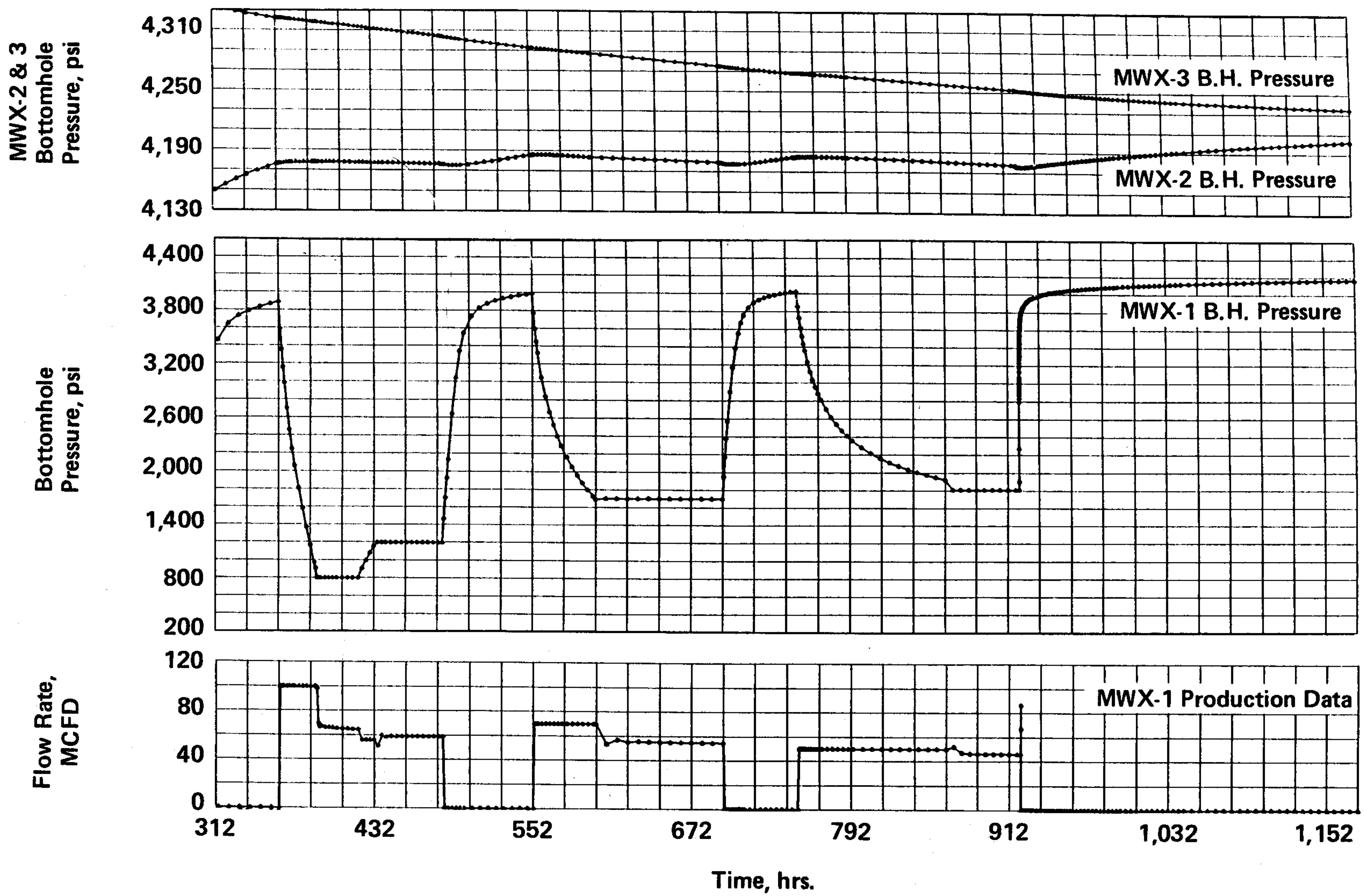

Figure 7.1.13 Model-Derived Bottomhole Pressures Used to Simulate the MWX-1 Field Data

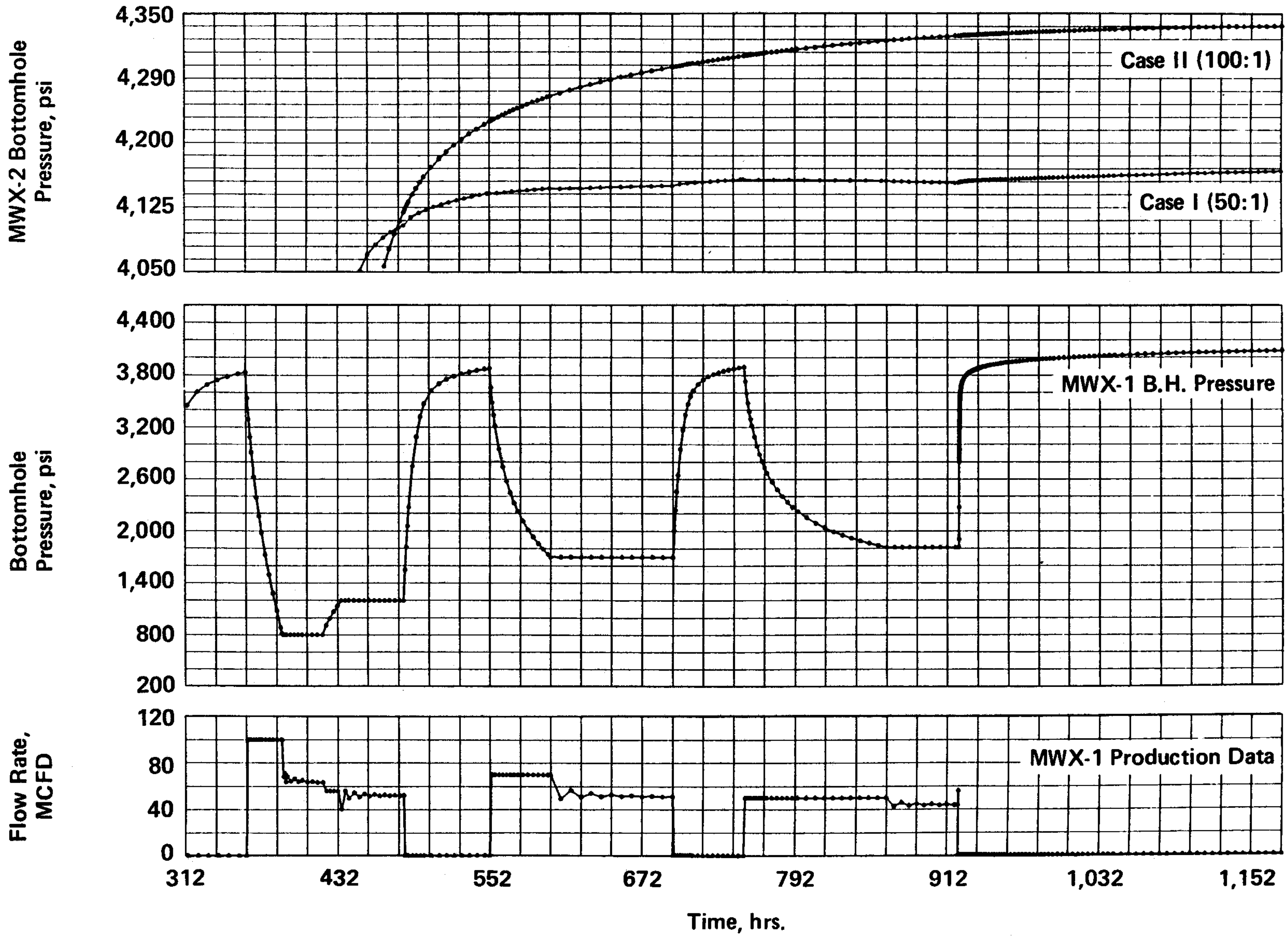

Figure 7.1.14 Simulated Bottomhole Pressures for Two Cases in the Red Sandstones

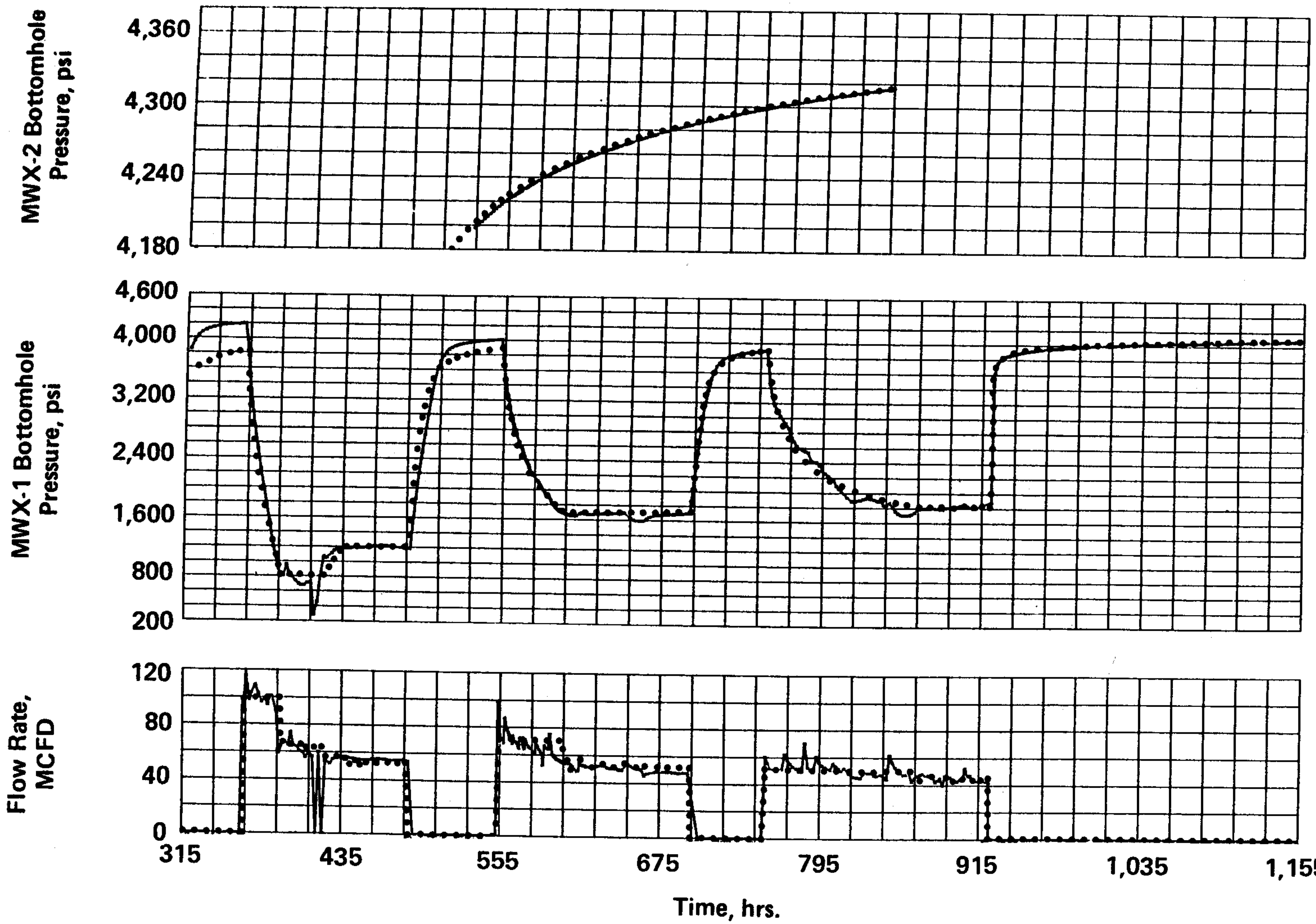

Figure 7.1.15 Overlay of Simulated Model Pressures from Case II With the Field Data from the Red Sandstones

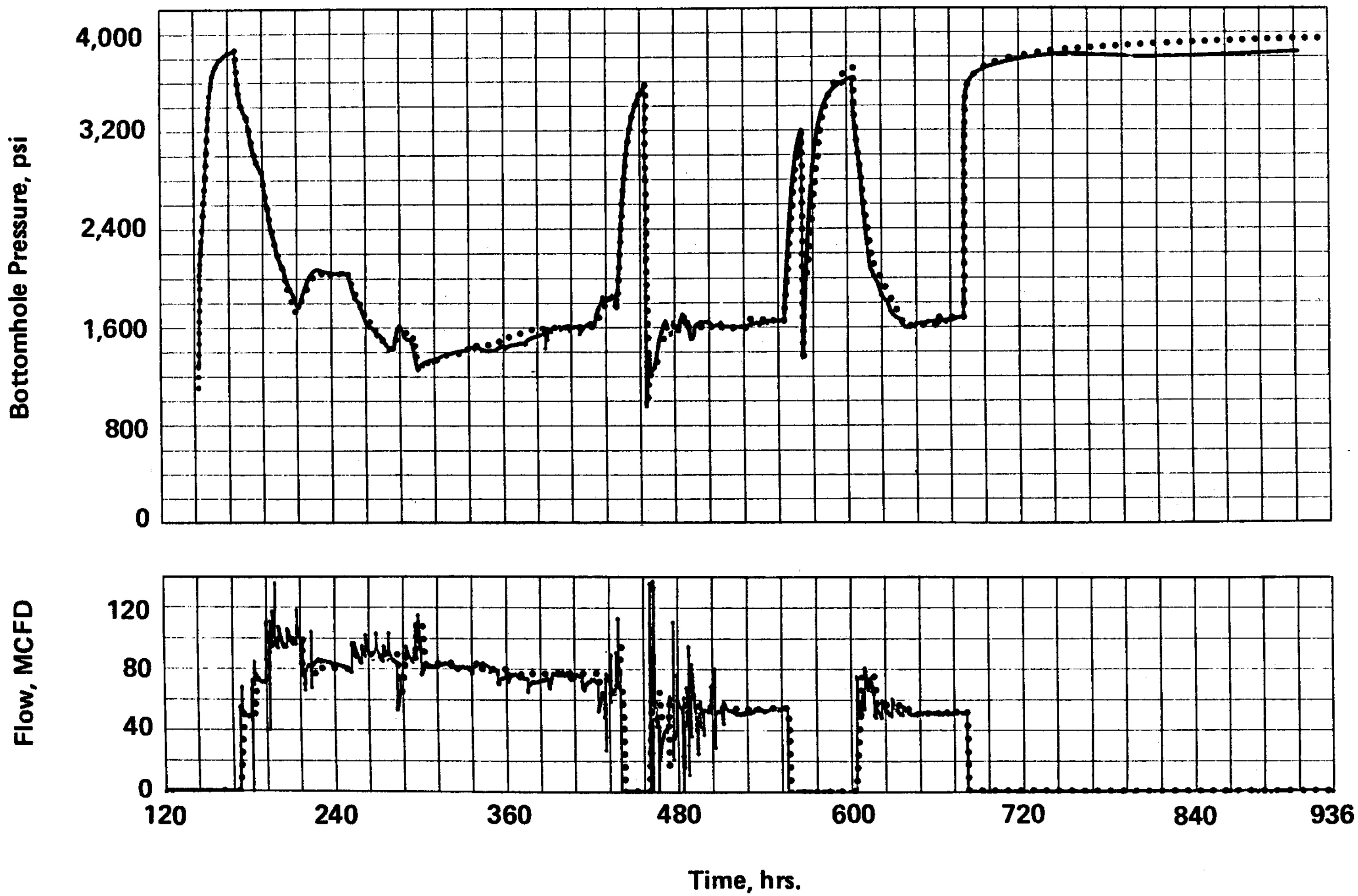

Figure 7.1.16 Overlay of Simulated Model Pressures on the Field Data from the Yellow Sandstones

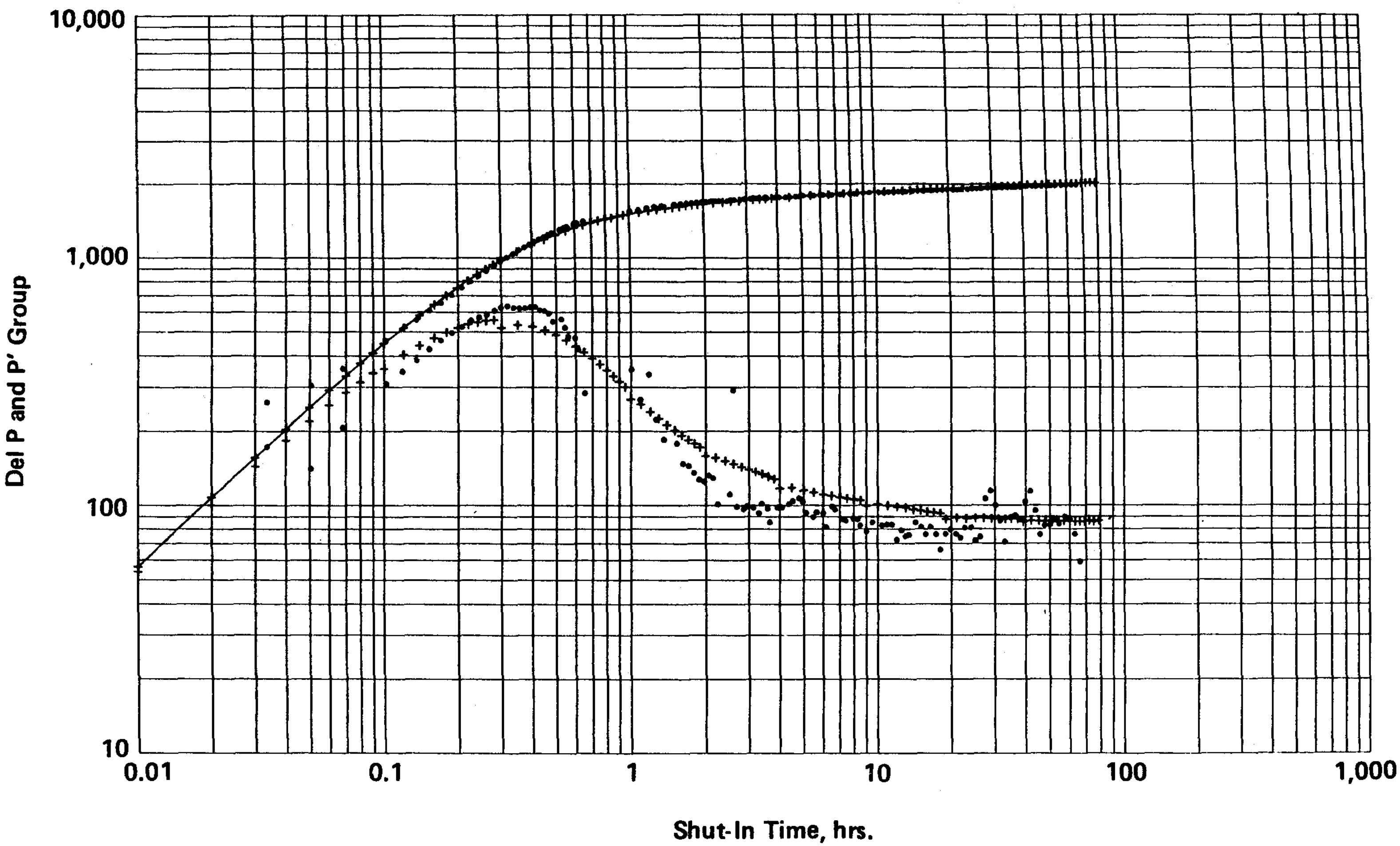

Figure 7.1.17 Overlay of Field and Model Log-Log/Derivative Data for the Yellow Sandstones

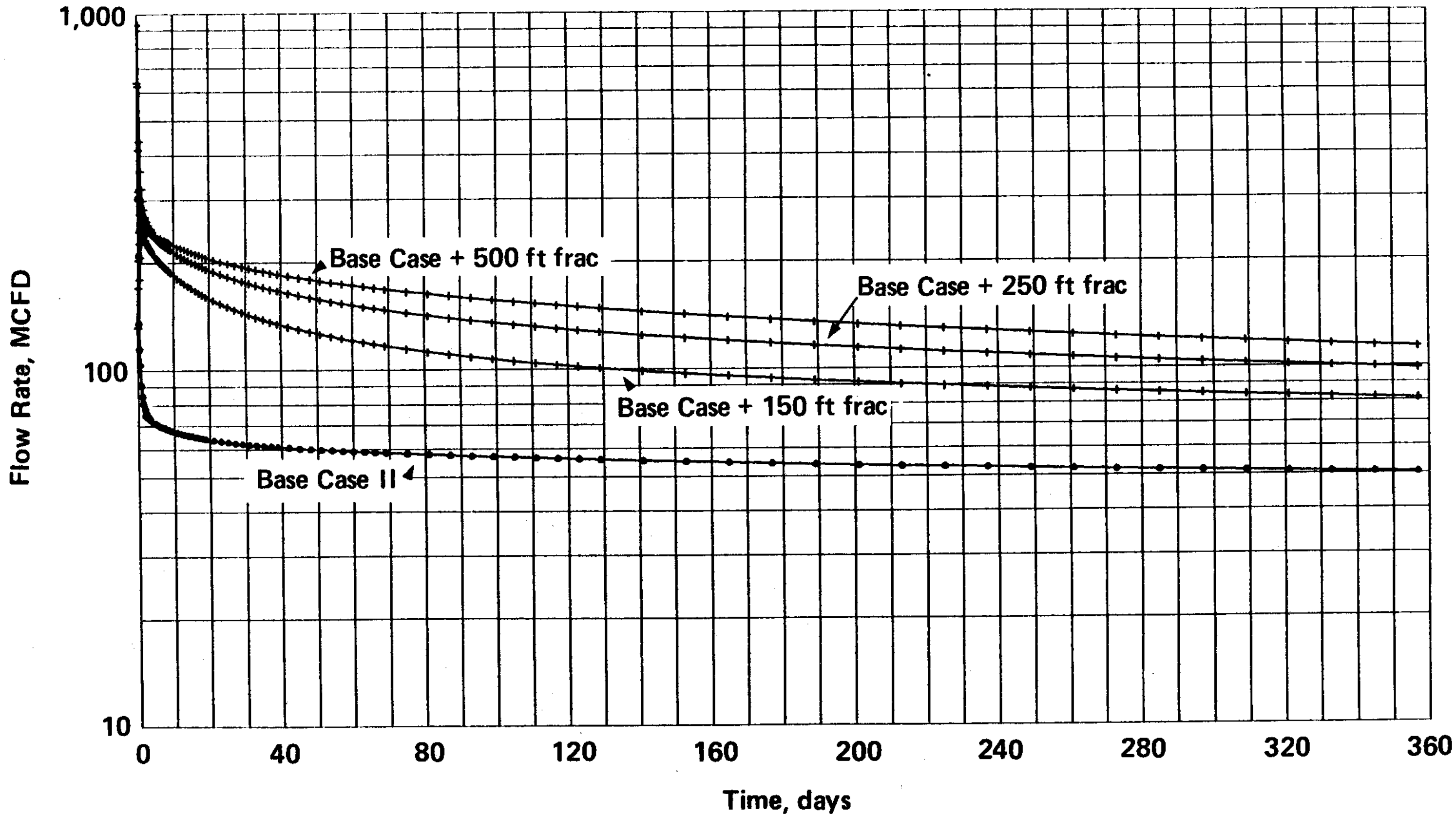

Figure 7.1.18 Simulated Production Histories for a Naturally Fractured Reservoir (Case II) and the Same Reservoir Containing Three Different Length Propped Fractures

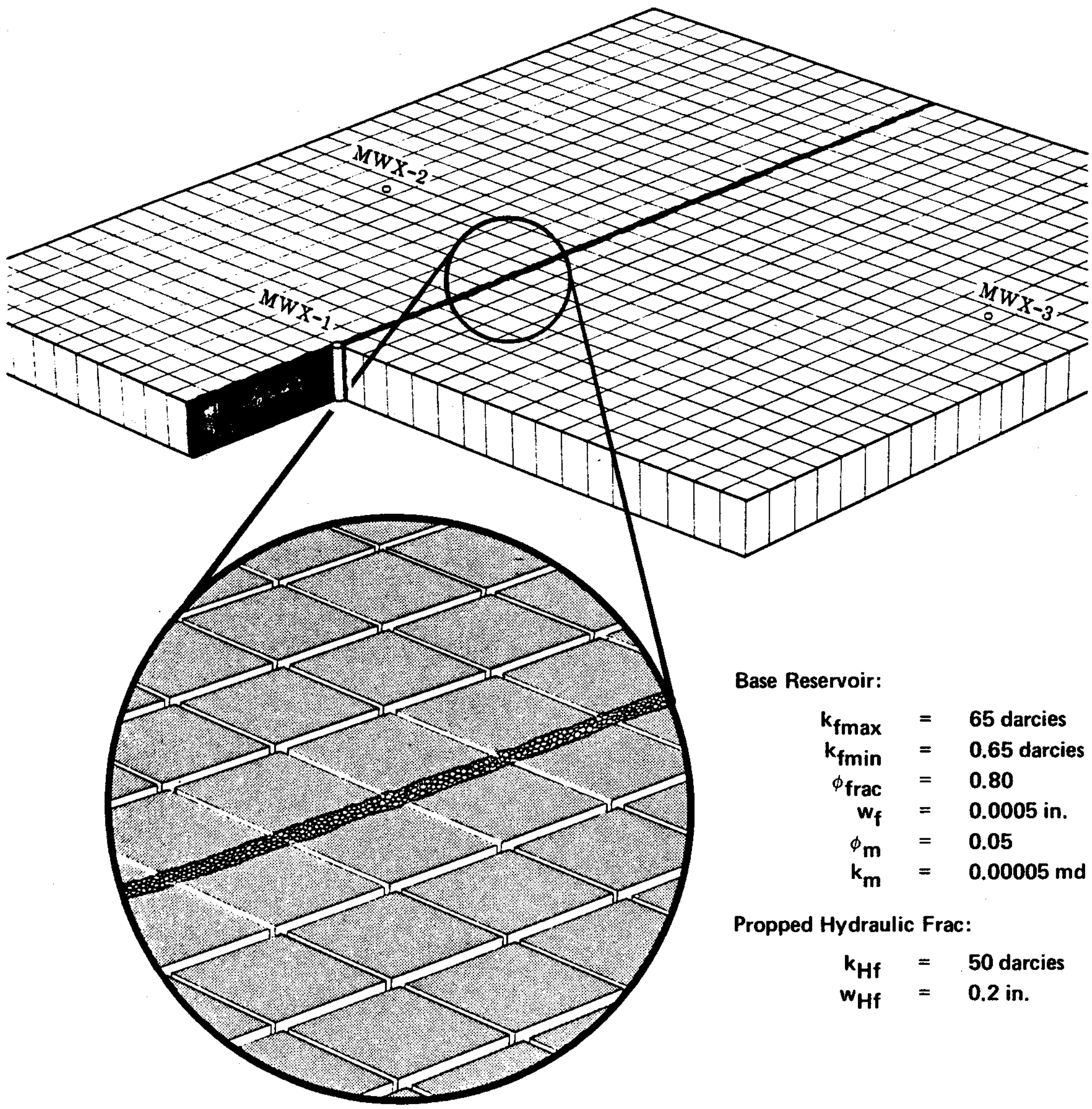

Figure 7.1.19 Schematic of the Propped Hydraulic Fracture in the Naturally Fractured Model

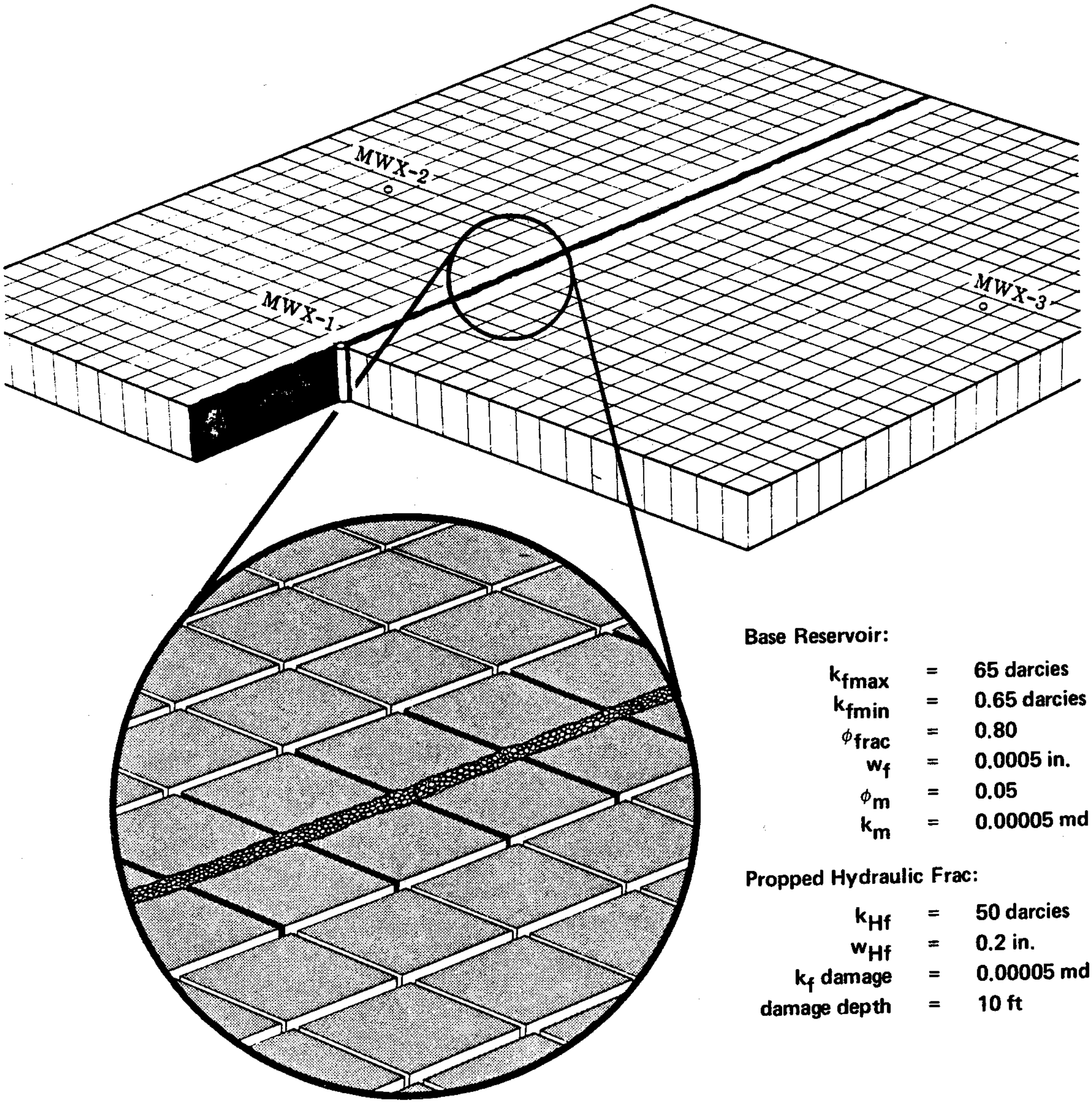

Figure 7.1.20 Schematic of the Propped Hydraulic Fracture With Damage in the Naturally Fractured Model

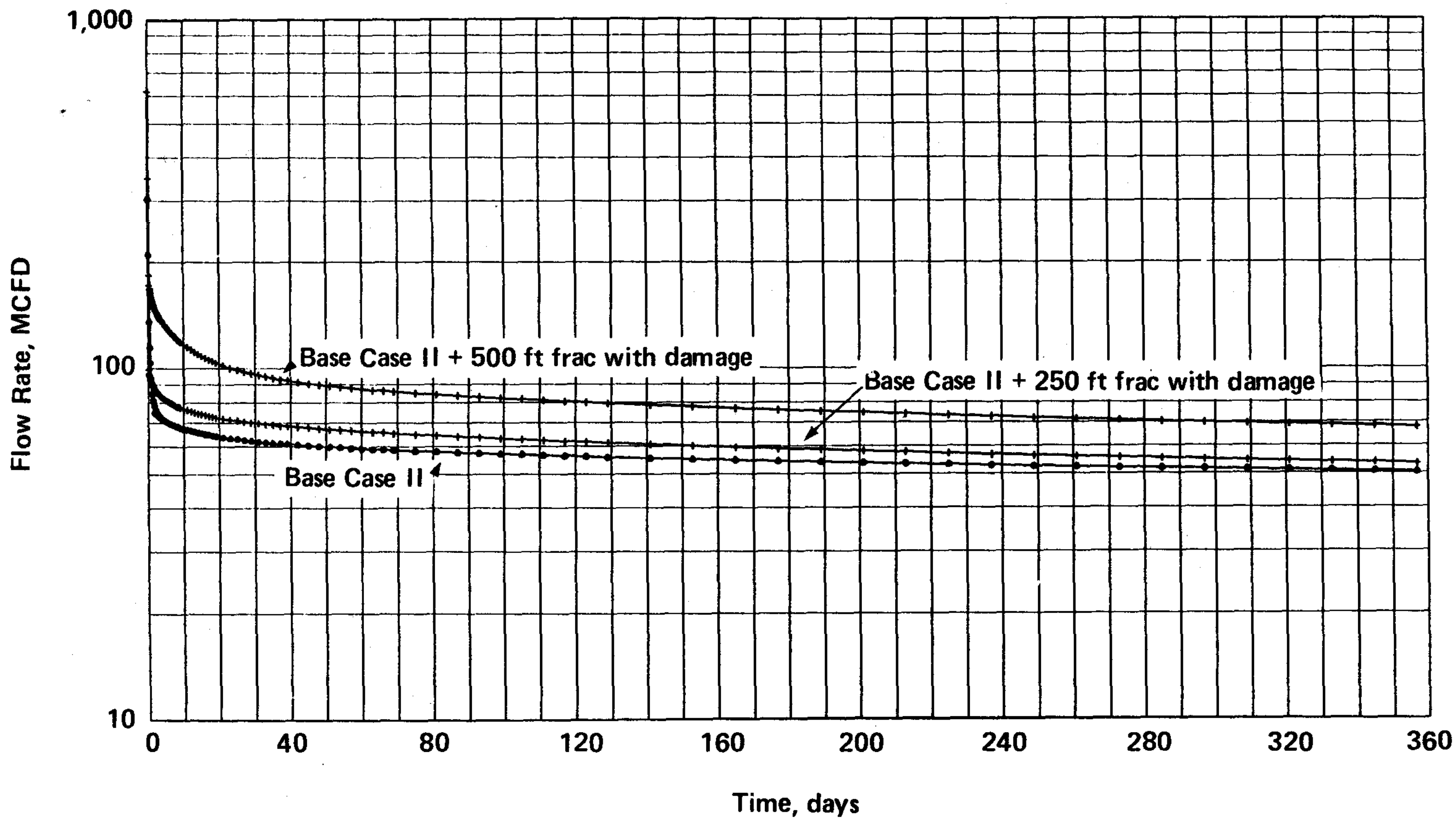

Figure 7.1.21 Simulated Production Histories for a Naturally Fractured Reservoir (Case II) Containing Two Different Length Propped Fractures With Damage Along Them

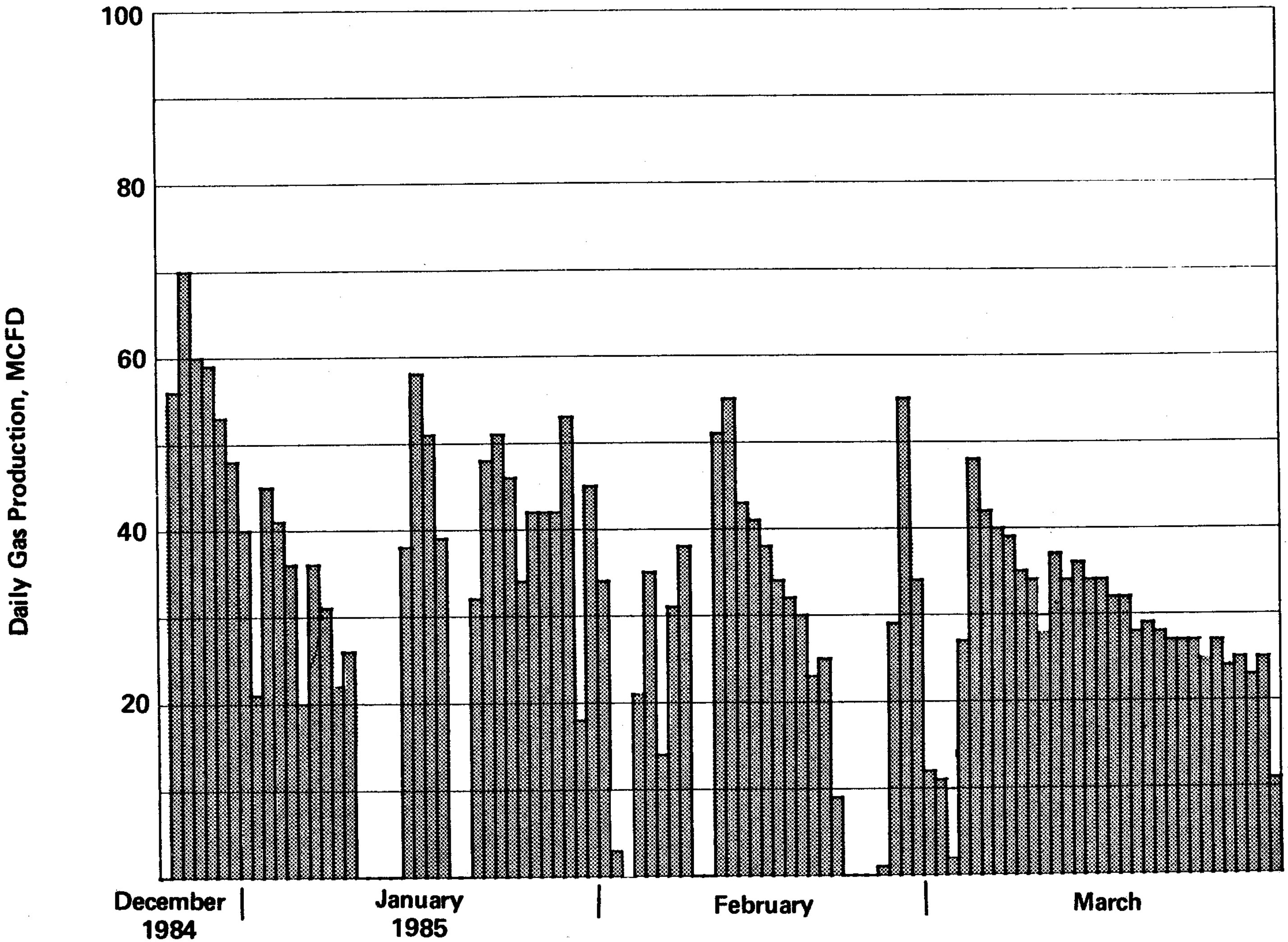

Figure 7.1.22 MWX-1 Winter Production from Commingled Red and Yellow Sandstones

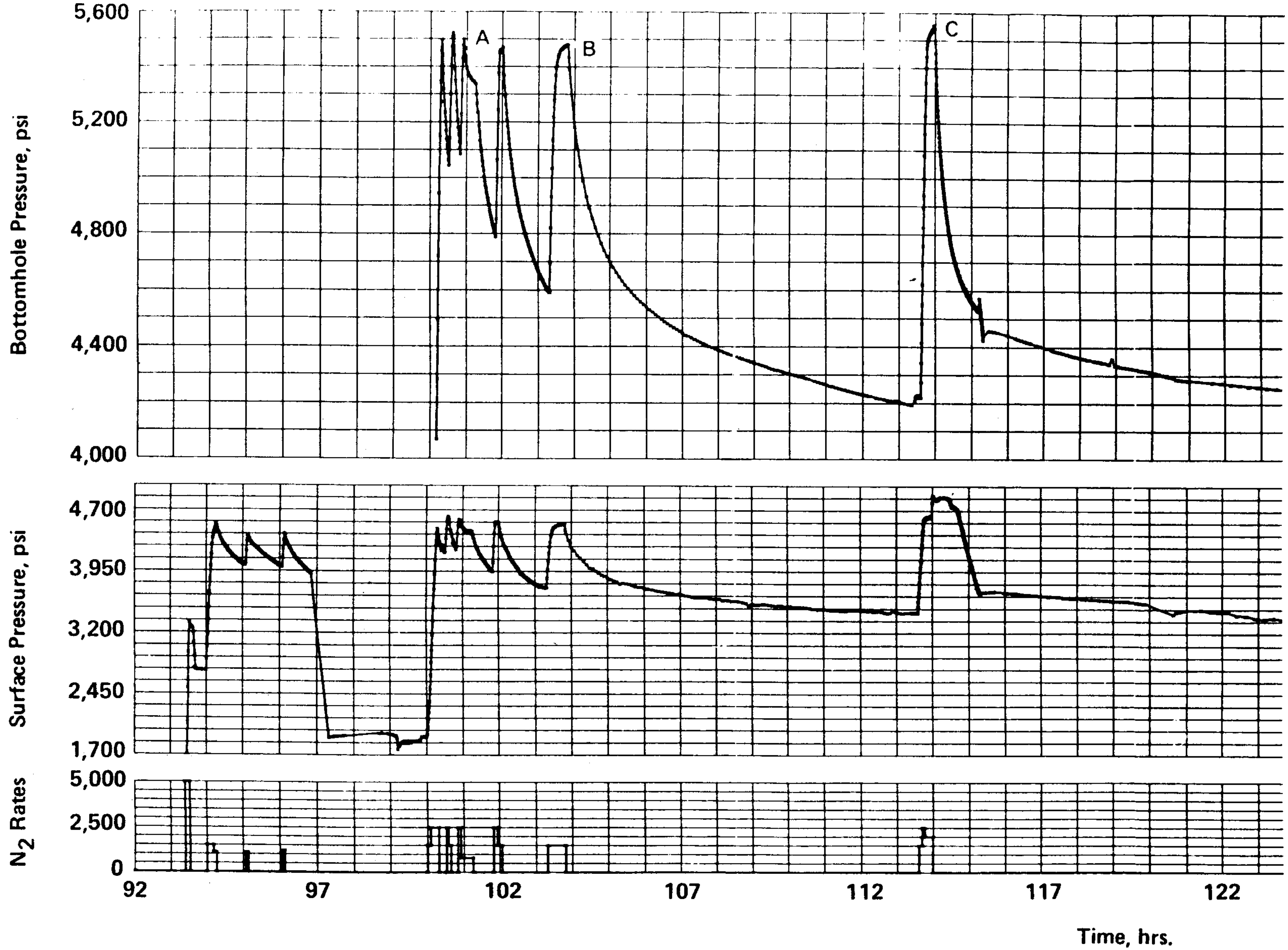

Figure 7.1.23 Nitrogen Tracer Injection Test Data for MWX-2; Time = 0 at 1544 hrs, April 12, 1985. (Plot continued on next page)

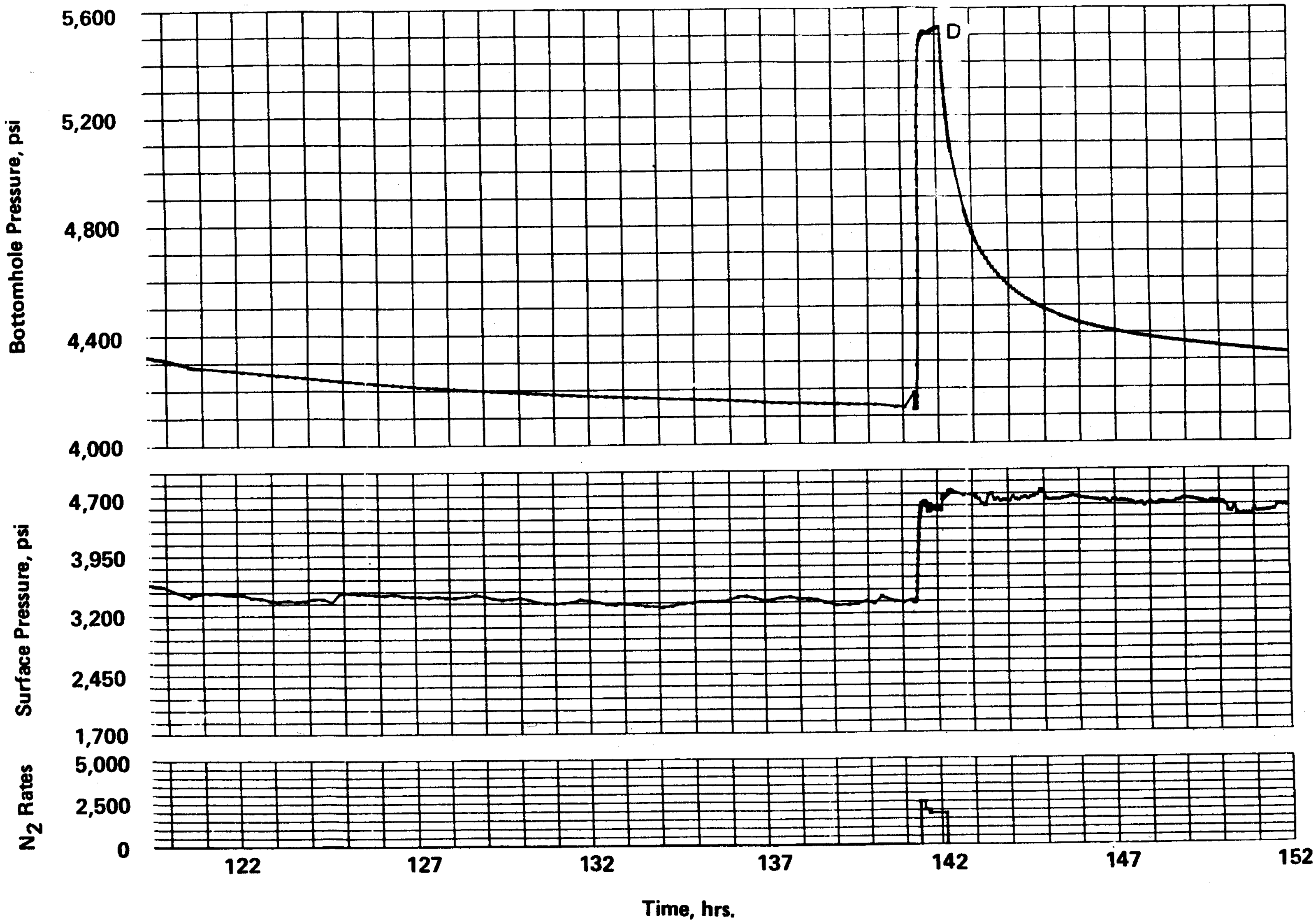

Figure 7.1.23 Nitrogen Tracer Injection Test Data for MWX-2. (Continued from previous page; note overlap)

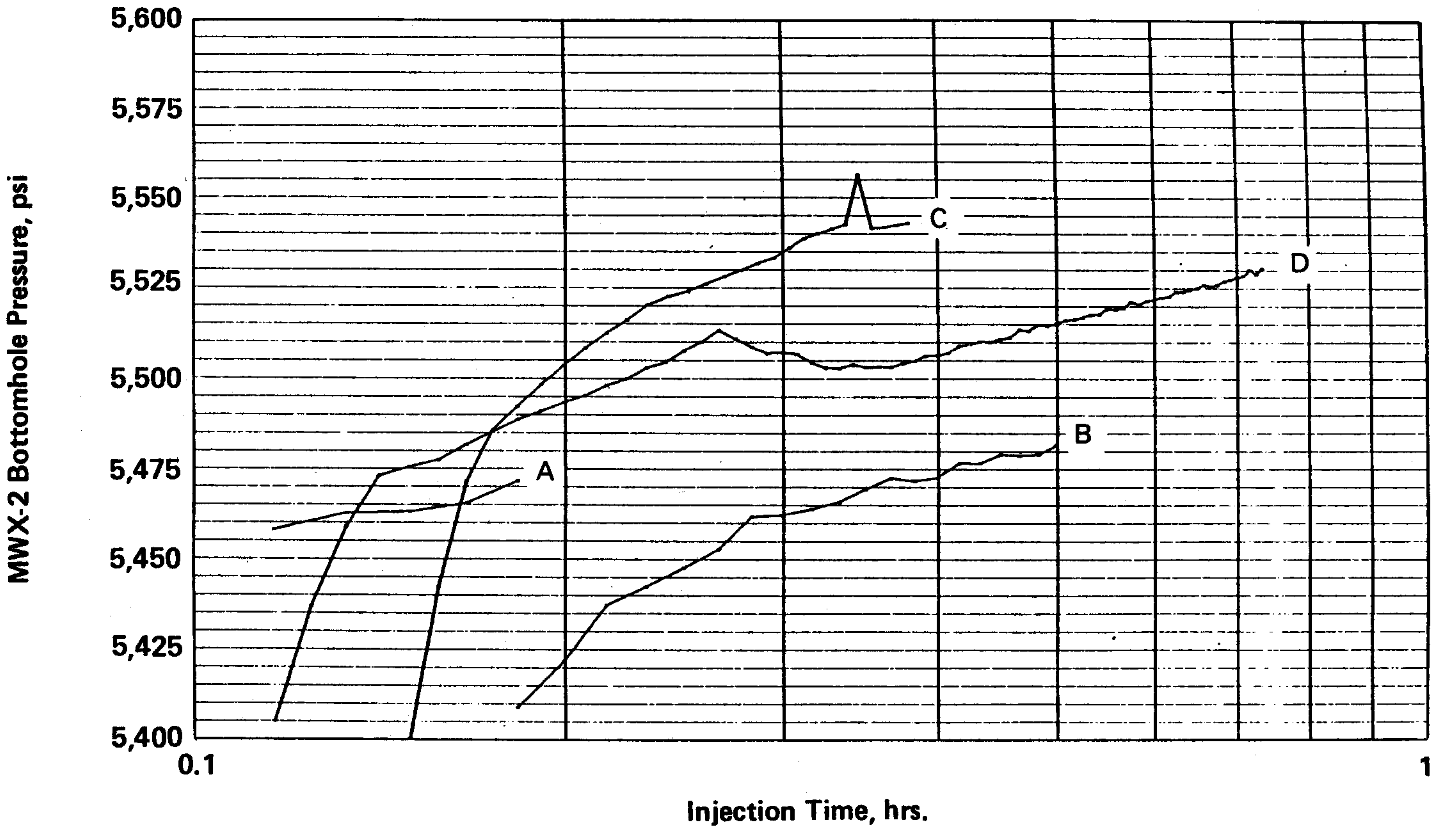

Figure 7.1.24 MWX-2 Bottomhole Pressures for Four Injection Periods

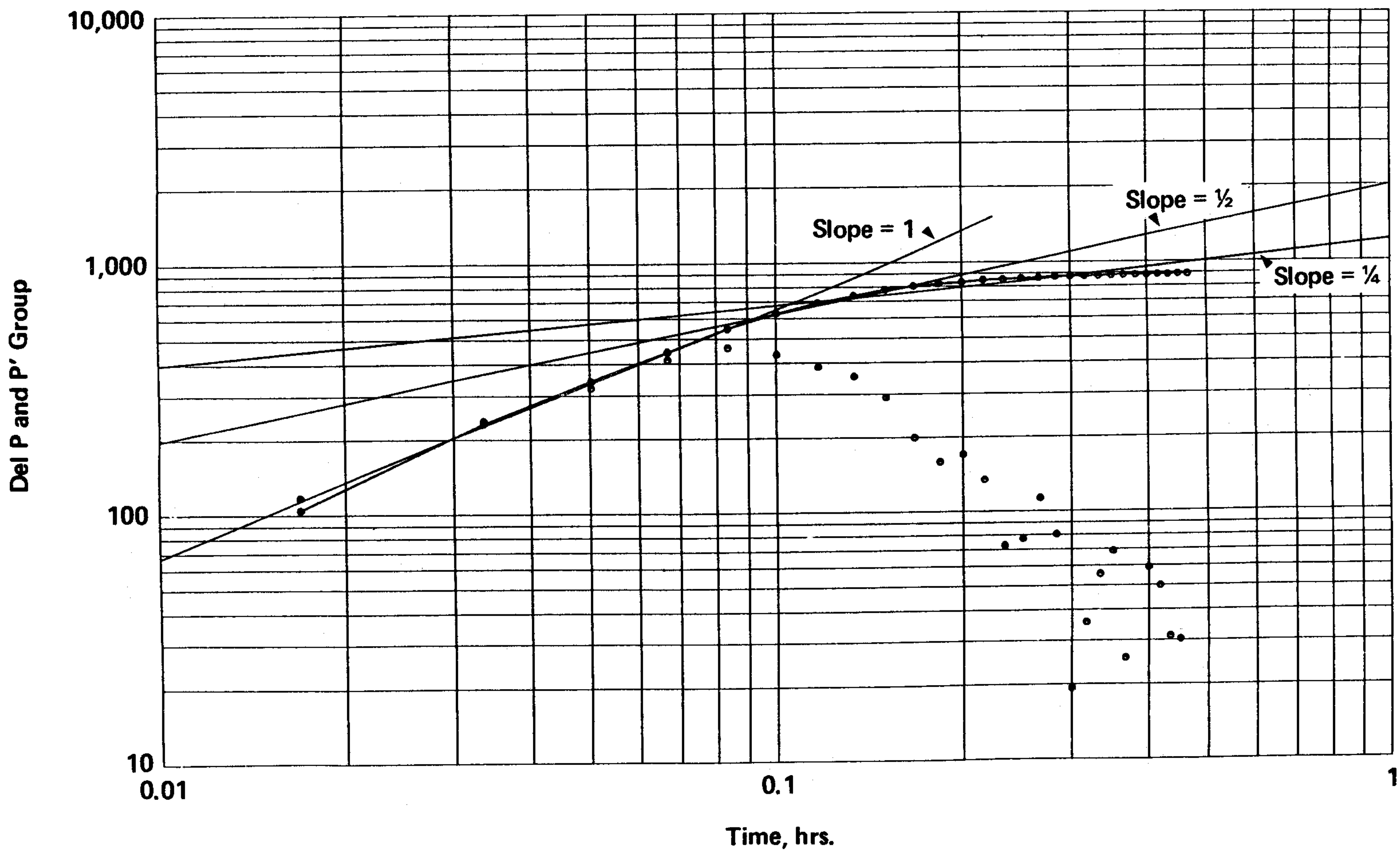

Figure 7.1.25 Log Pressure vs Log Injection Time During the B Injection Period

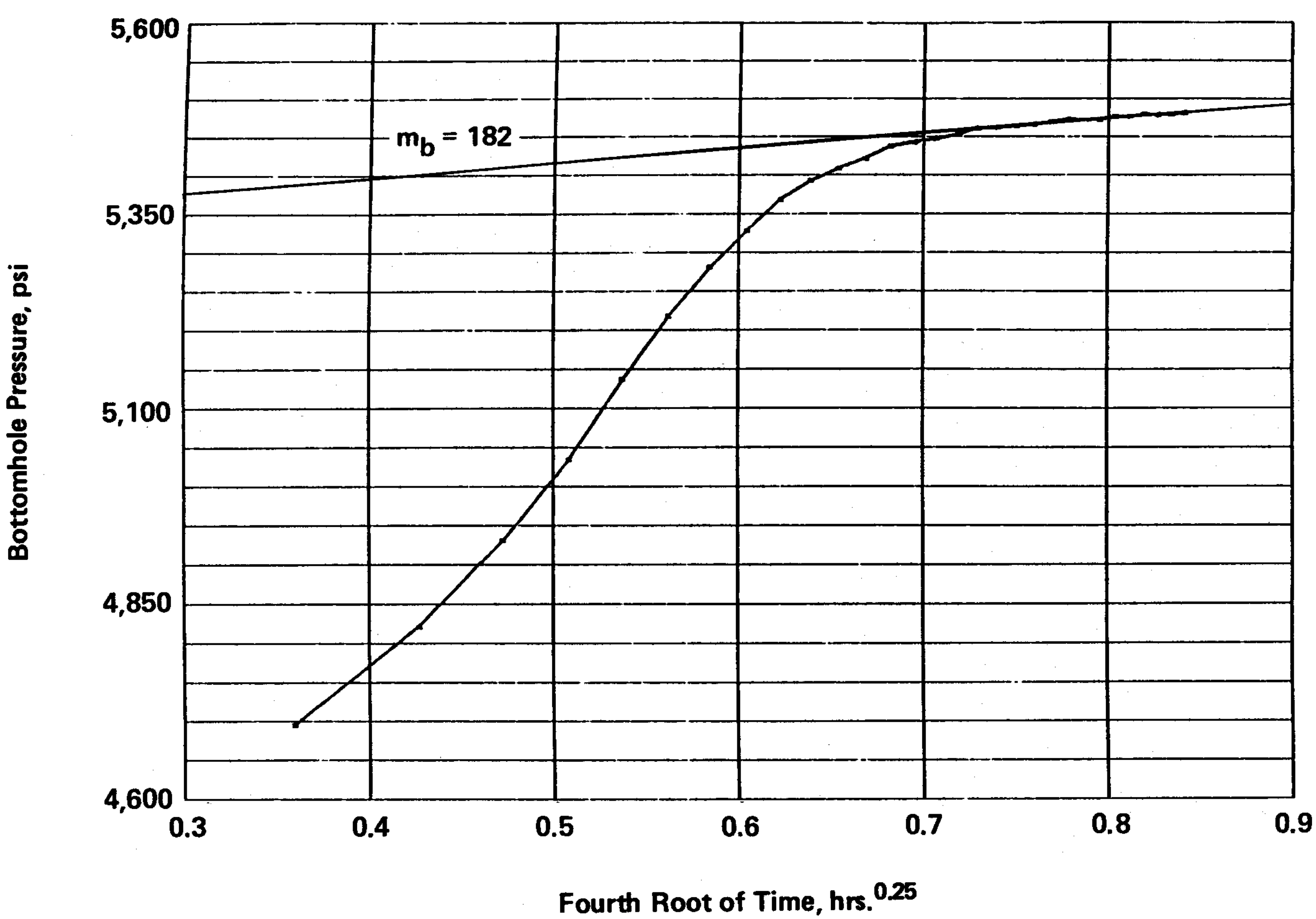

Figure 7.1.26 Fourth Root of Time Pressure Plot for B Injection Period to Evaluate Bilinear Flow Period

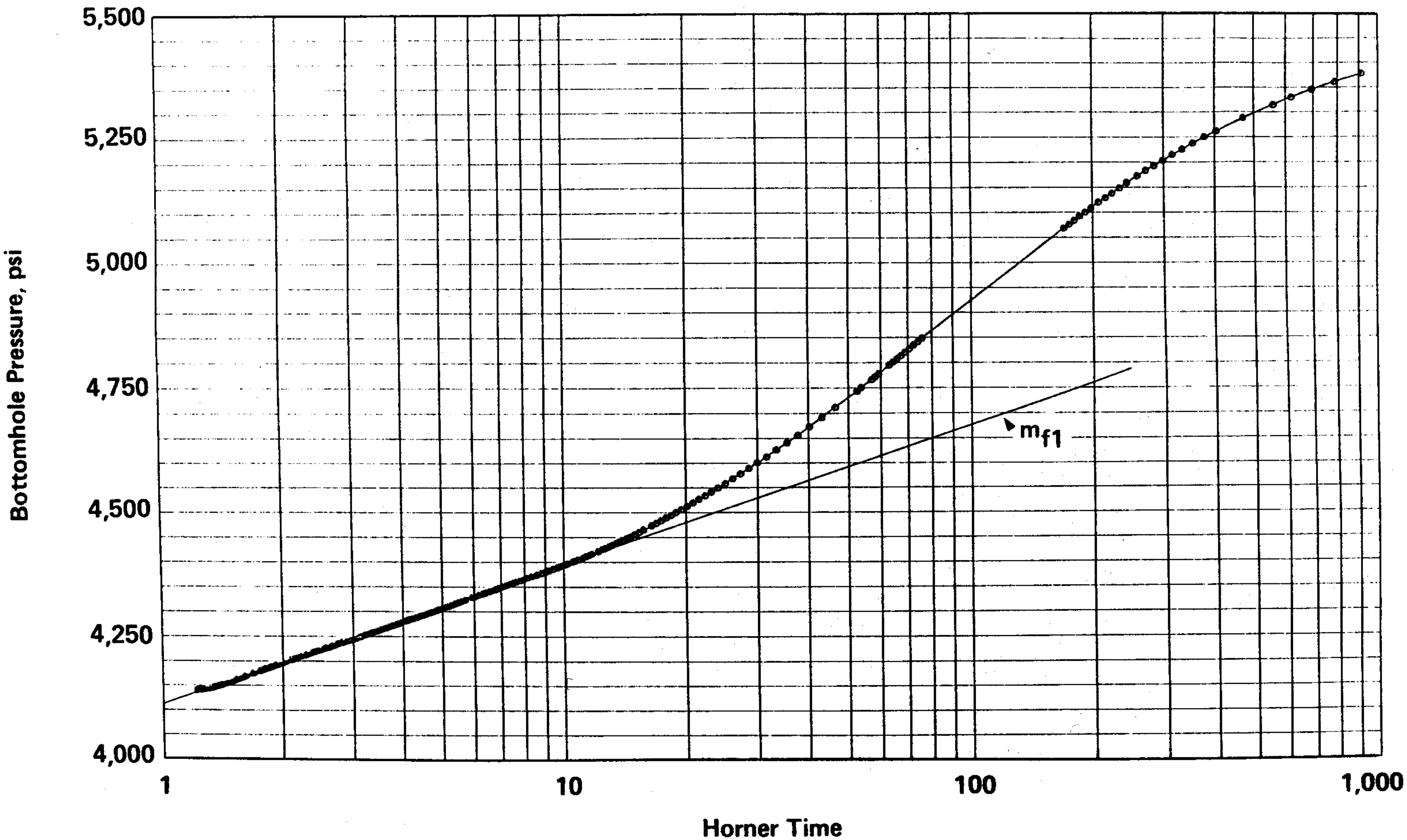

Figure 7.1.27 Horner Plot of Falloff Pressure Data After the D Injection Period. (t_f = 48.9 hrs)

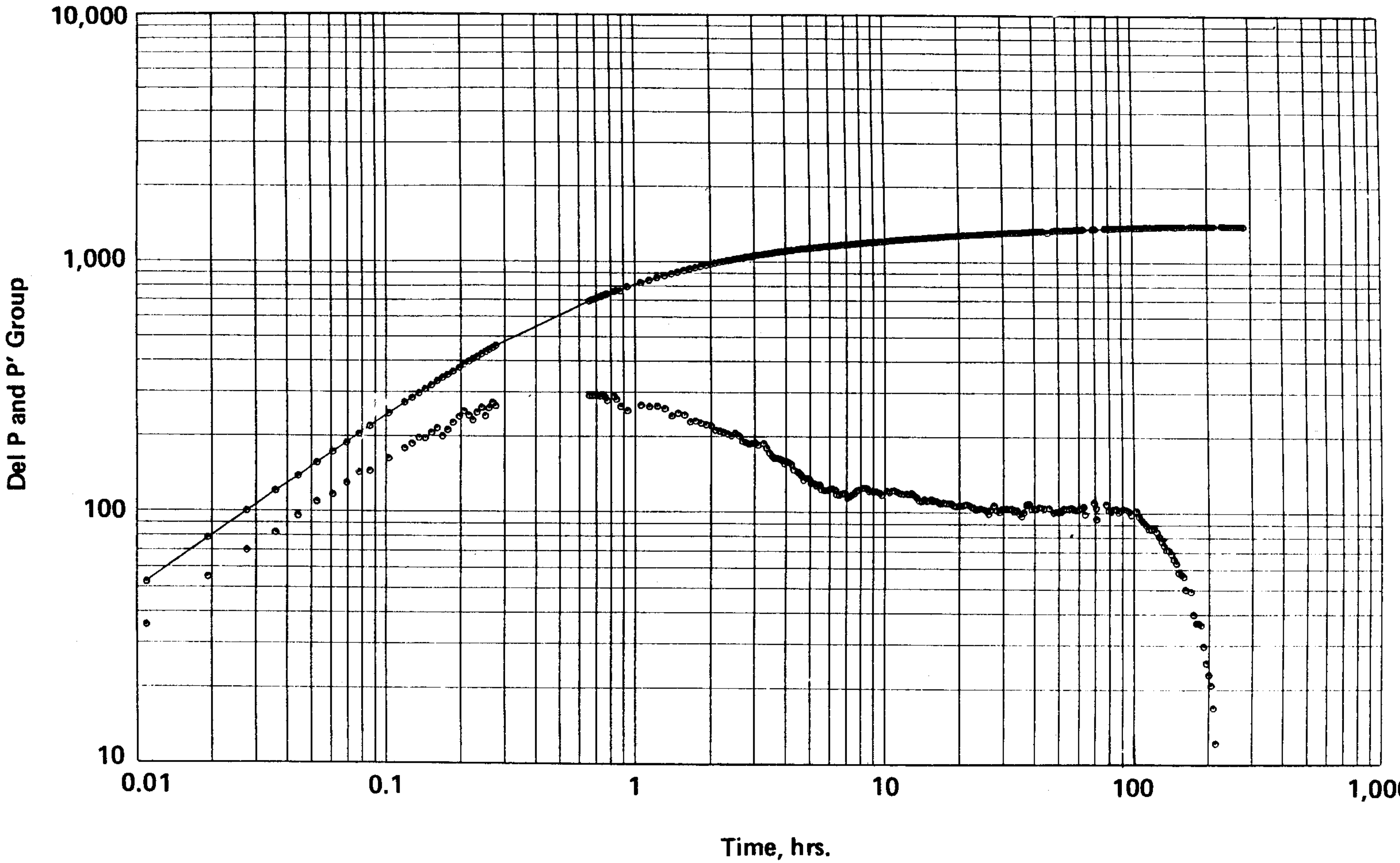

Figure 7.1.28 Log-Log/Derivative Plot of Falloff Pressure Data After the D Injection Period

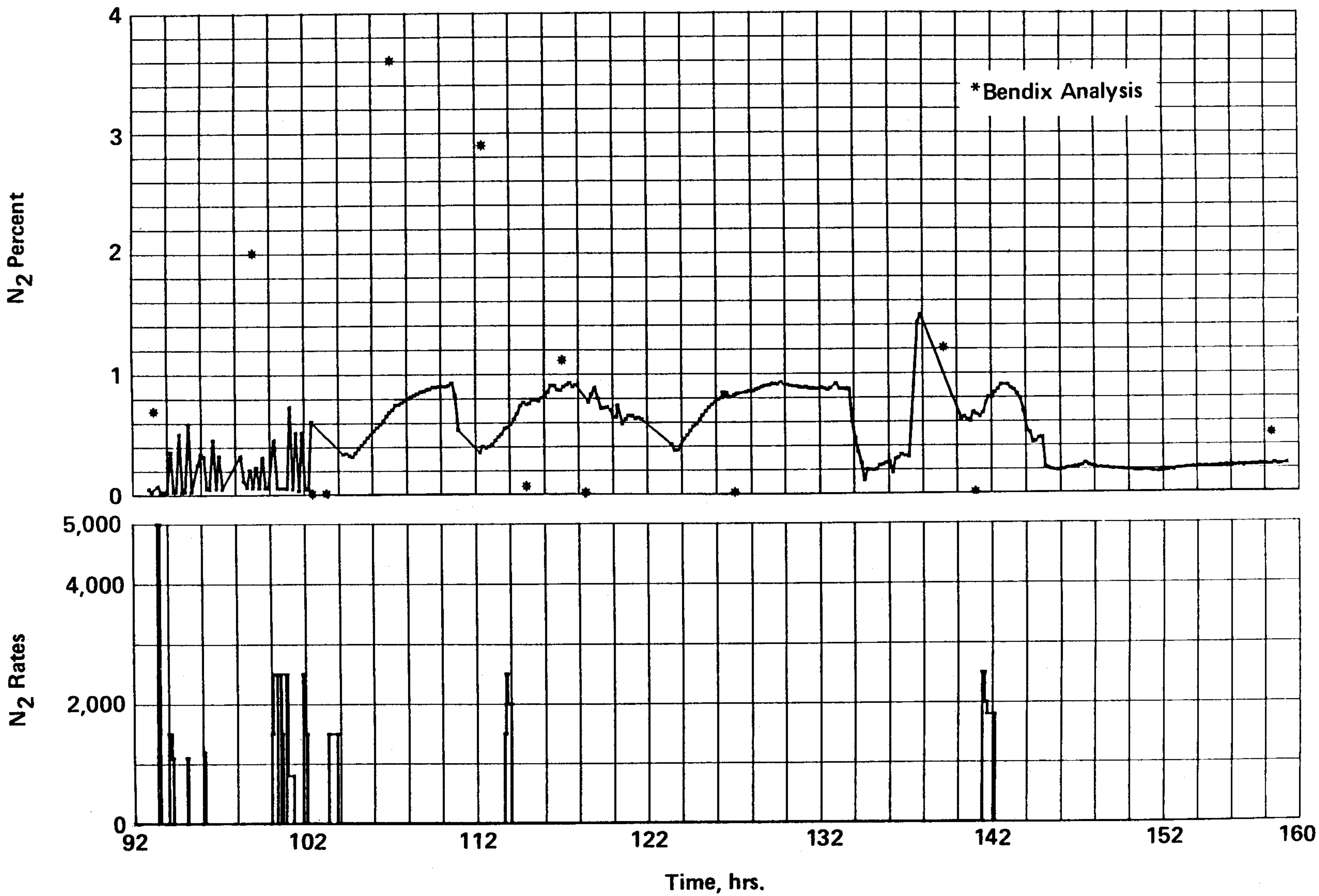

Figure 7.1.29 Nitrogen Injection Rates into MWX-2 and Measured Nitrogen Concentrations at MWX-1

7.2 COASTAL STIMULATION EXPERIMENTS

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Sandia National Laboratories

7.2.1 COASTAL TEST METHODOLOGY

Because of the apparent damage to the natural fractures in the paludal zone as a result of the fracture treatments, a more discerning test methodology was developed for the coastal reservoirs. The basic plan was to conduct a small, totally nondamaging hydraulic fracture in the Yellow sands, to be followed by a small, minimum-damage, propped fracture in the Yellow sands, and, if successful, followed again by a large treatment in both the Red and Yellow sands.

The nondamaging fracture treatment was a nitrogen step-rate fracture with no sand or liquids. Next, a minimum damage treatment was conducted with a 75 quality nitrogen foam and intermediate strength proppant. Based on the results from this small treatment, no large stimulation was conducted.

7.2.2 COASTAL ROCK/RESERVOIR DATA

Gamma logs for the coastal zone are shown in Figure 5.1. The Yellow A and B sands consist of two 15-ft-thick sand channels separated by a thin (~5 ft) shale. Matrix permeabilities for both sands range from 0.1 to 0.5 μd under in situ conditions, with porosities of 6 to 8% and water saturations of 50% or less. Reservoir testing yielded effective permeabilities of about 12 μd, an initial reservoir pressure of about 4300 psi, and a bottomhole temperature of about 185°F. Dowell-Schlumberger ran several rock property measurements, shown in Figure 5.20, that indicate that Young's modulus for the sands is about 5 million psi and Poisson's ratio is about 0.2.

Stress test data are shown in Figure 6.1. The stress contrasts between the sands and shales vary from about 800 to 1400 psi, which should result in good containment of the fracture. Unfortunately, no stress measurement was possible in the shale between the Red and Yellow sands, so only an estimate of the stress is given there. Based on the stresses above and below the sands, the stress in this zone should be about 6850 psi (1.06 psi/ft gradient). With this stress distribution, the ideal, stress-controlled, containment situation is shown in Figure 6.23. Good containment is expected if treatment pressures stay below about 6600 psi. Lens widths for the coastal sands are thought to be 300 to 500 ft, and the best estimate of the lens geometry is shown in Figure 7.2.1.

7.2.3 NITROGEN FRAC

7.2.3.1 Design

During the week of June 10, 1985, a series of stimulation and production tests were conducted in the Yellow sands of the coastal zone in MWX-1. The objectives of this test series were:

(1) Create a fracture of about 200 ft length using a nondamaging fluid at the lowest possible pressures. This is necessary for accurate production data on the reservoir under conditions in which the natural fractures are <u>not</u> damaged or plugged in any way. These conditions can best be achieved by using nitrogen gas (no sand) as the frac fluid. The special concern with damage to the natural fractures is a result of previous stimulation tests in the paludal zone where such damage seriously impaired production.

(2) Investigate reservoir properties (and the fault) on the global reservoir scale by searching for pressure interference and nitrogen production in the offset wells during and after injection.

(3) Search for interference in the "remote" Red sands to determine if sufficient height growth occurred.

(4) Investigate the pressure sensitivity of the natural fractures by flowing back at varying rates and pressures and determining the apparent kh as a function of pressure level during these drawdown periods.

The test series consisted of the following schedule:

Date	Stimulation	Production
June 11	N_2 Step Rate Test and Frac, MWX-1	Start Flowback MWX-1
June 12	--	Shut in MWX-1, Start Production MWX-2, MWX-3
June 13	N_2 Injection	Production MWX-2, MWX-3
June 14-15	--	Production MWX-2, MWX-3

The nitrogen frac conducted on June 11 is of principal concern in this section. The following injection on June 13 was much smaller and probably did no more than reopen part of the fracture created on June 11.

The well configuration for the nitrogen frac is shown in Figure 7.2.2. A bridge plug was set below the Red zone and a retrievable bridge plug with a pressure bomb below it was set below the Yellow zone. A packer was set at about 6400 ft to isolate the Yellow sand. Two joints of 4 1/2 in casing were inserted in the tubing string just above the packer to provide a lower flow-velocity setting for the bottomhole pressure gage than the 2 7/8 in tubing would provide. The Yellow zone was perforated from 6428 to 6460 ft with 2 shots/ft, 14 gm charges, 0.38 in. diameter holes.

During the nitrogen step-rate frac, MWX-2 and MWX-3 were shut in bottomhole with the quartz pressure gages in order to search for pressure interference during or after the frac. Afterwards, both MWX-2 and MWX-3 were put on production to look for traces of nitrogen using gas chromatography.

The nitrogen frac schedule consisted of an initial step rate test followed by a constant-rate pump. The actual pumping schedule is given in Table 7.2.1. The purpose of the step rate test was to provide data on the pressure at which fracturing actually began. Because of expectations of a high leakoff rate into the natural fracture system and low fracture pressures due to the low fluid viscosity, it was felt that a step rate test was the only way to ascertain the effectiveness of the treatment. This total design is based on an estimated leakoff coefficient of 0.01 ft/$\sqrt{}$min.

7.2.3.2 Treatment Data

The bottomhole pressure and flow rate for the nitrogen frac are given in Figure 7.2.3. The purpose of the initial step was to remove any wellbore fluid that remained downhole so that there would not be a liquid spearhead ahead of the gas. Fracturing appears to begin at the 5000 SCFM stage at a pressure of about 5700 psi. The main fracturing stage is the 20,000 SCFM stage, lasting about 20 min. Toward the end of the 20,000 SCFM stage, the bottomhole pressure transducer was pulled up higher into the tubing because excessive flow turbulence was causing problems with the tool signal. This is the reason for the drop in pressure at 4.75 hr. Subsequently, the rate was dropped to 10,000 SCFM in preparation for an attempt at a bottomhole closure. At the same time the rate was lowered, the bottomhole pressure gage was also lowered back near the shut-in nipple. Unfortunately, at shut-in the bottomhole tool signal was lost and no pressure decline data were obtained.

Figure 7.2.4 shows the interference pressures in MWX-2 and MWX-3 correlated with the flow rate into MWX-1. Interference in MWX-2 first becomes clear about when fracturing conditions occur in MWX-1 (5000 SCFM), and slightly later in MWX-3.

The bottomhole pressure and injection rate for the second nitrogen injection on June 13 is shown in Figure 7.2.5. Again, the tool signal was lost when shut-in was attempted. These data were not analyzed in terms of fracture behavior.

The results of the step-rate test are shown in Figure 7.2.6. As was evident in the pressure record, fracturing occurs at the 5000 SCFM rate with a fracture extension pressure of about 5600 psi. Rates are shown as bottom-hole equivalent bpm using the measured pressure at each step, a bottomhole temperature of 170°F, and the gas compressibility factors given in the figure insert.

For comparison, the lowest measured stress in this Yellow zone was 5670 psi, but that stress measurement was performed in MWX-3 before any well testing or production operations. The closure stress here seems to be somewhat lower, possibly due to either lateral variability or removal of gas during prefrac testing.

7.2.3.3 Pressure History Match

A history match of the bottomhole pressure was made in order to estimate the size of the fracture created during the step-rate test. A finite-difference, Perkins and Kern type simulator was used for this analysis; this should be the most appropriate model under these conditions of large confining stress contrasts. This model uses the full, time-dependent momentum and continuity equations, accepts any pressure drop formulation (in this case, turbulent flow) as well as leakoff and spurt, and can be used in either constant or variable height modes.

Before attempting a history match of the pressure, it was first necessary to determine if the back stresses were responsible in large part for the observed pressure behavior. A quick calculation (similar to one by Smith[1]) would indicate that the effect is small (20 to 30 psi over the entire test) and this seems to be born out by the actual data. The pressures do not seem to be increasing dramatically during the constant-flow-rate segments of either the frac or the injection test. Back stress effects have been ignored in this analysis.

Figure 7.2.7 shows an example of some of the initial model runs. While the pressure at the frac stage (20,000 SCFM) could be matched, the step rate pressure levels could not be achieved.

Trying to decrease the pressure sufficiently to match the steps resulted in too low a pressure during the frac. Basically, all reasonable histories passed through the actual data. From these and other results, it was concluded that the closure stress was significantly lower than 5670 psi, the value measured in MWX-3 before testing. The reservoir has since been drawn down near the wellbore from an initial value above 4100 psi to a pre-nitrogen-frac value below 3800 psi. According to Geertsma,[2] a good approximation of the change in closure stress with drawdown is given by

$$\Delta\sigma_c = \frac{(1 - \frac{K}{K_s})(1 - 2\nu)}{1 - \nu} \Delta P_{res}$$

Where K is the bulk modulus of the rock, K_s is associated with the bulk modulus of the solid material in the rock, ν is Poisson's ratio and ΔP_{res} is the change in reservoir pressure. This results in $\Delta\sigma_c \approx 0.45\ \Delta P_{res}$ for coastal rocks. This predicts about a 150 to 180 psi drop in closure stress for a 300 to 400 psi drop in reservoir pressure in the near-frac region.

Model runs using several combinations of leakoff, spurt, fracture roughness and enhanced pressure drop were calculated for values of closure stress varying from 5475 to 5575 psi. The best fit of these runs is shown in Figure 7.2.8. This is by no means a unique answer for the nitrogen frac, but most parameters cannot vary significantly without distorting the results. The step-rate part of the test puts constraints on many of these parameters.

The best match on closure stress was 5475, which is clearly reasonable as discussed earlier. Leakoff is lower than anticipated pre-frac with a match value of 0.005 ft/$\sqrt{}$min and uncertainty of roughly -0.001 to +0.002. The spurt loss does not significantly affect the final pressure levels but helps in the overall shapes of the curves. The accuracy of this number is questionable. A very rough fracture wall was needed to get large pressure drops (using Huitt's[3] relationships adapted to elliptic cross sections) and then an increase in the wall shear stress by a factor of 4 was also required. A reasonable pressure match could not be obtained any other way.

Decreasing leakoff would help raise the pressure but the shapes of the curves would not match the entire step rate process on the simulator. This implies that high treatment pressures are again likely when this zone is treated with a conventional frac fluid.

The simulated length is 285 ft for a constant height fracture of 40 ft. While the model could be used in the variable height mode, little height growth was calculated at these pressures and the numerous calculations were simplified by running in a constant height mode. The uncertainty of this length measurement is probably ±50 ft, if the assumptions about back stresses and rock property values are correct. The efficiency of this fluid was only 6%.

The lack of a good pressure match at the beginning of the treatment may have been due to water in the fracture, which then became the spearhead fluid. The discrepancy at the end results from the bottomhole-pressure tool being moved into position for a downhole shut-in; unfortunately, the tool failed when shut-in was achieved. Before shut-in the rate was reduced to 10,000 SCFM, and the discrepancy at this last stage is primarily tool re-positioning, but may also be partly due to a change in back stresses.

7.2.3.4 Analysis of Pressure at Offset Wells

There was a distinct pressure interference measured in MWX-2 and MWX-3 as seen in Figure 7.2.4. The level of this interference was 1 to 2 psi and it was first detected at the same time the step-rate test reached 5000 SCFM, the rate at which fracturing started. It is likely that this pressure interference is entirely poromechanical; once the pressure in the crack exceeds the closure stress, the fracture begins to dilate and thus strain the rock mass for large distances. This strain (or stress) causes a slight volumetric compression of the rocks at MWX-2 and MWX-3, which in turn squeezes some fluid out of the pore space and into the wellbore causing the pressure to increase slightly. Since there is a bottomhole closure in these wells, the small bottomhole volume and the accurate pressure gages allow the measurement of the small response.

The pressure response in the offset wells can be estimated theoretically by calculating the induced stress due to the hydraulic fracture at the offset well and then determining the volumetric shrinkage due to that stress and required pressure increase due the pore volume decrease. However, a precise calculation requires a knowledge of the fluid distribution in the pore space around the offset wells as well as the compressibility of the fluid in the wellbore. Neither of these are known but limits can be set based on two cases of pore fluids--all gas or all water--and an incompressible wellbore volume. For an infinite length crack, the response should be between 0.5 and 20 psi in MWX-2 and 0.4 and 15 psi in MWX-3 during the 20,000 SCFM step. Compressibility of the wellbore volume will reduce these somewhat, as will a shorter crack length.

These calculated numbers are in agreement with the measured pressures, but a more convincing argument for this mechanical coupling is the instantaneous responses that are observed with the rate changes. It is difficult to understand how the pressure response could be so prompt unless it is mechanical.

7.2.3.5 Conclusions

The analysis of the nitrogen frac data yields a fracture length of 250 to 300 ft with a nitrogen leakoff coefficient in the range of 0.005 ft/$\sqrt{\text{min}}$. Fracturing appeared to initiate at 5000 SCFM at a pressure of about 5700 psi. The closure stress probably has dropped about 200 psi because of the large volume of gas removed during prefrac testing. The high pressures experienced during this treatment show that any conventional fracture will result in very high treatment pressures, and possibly similar damage to the natural fractures as was observed in the paludal.

Interference was observed in both offset wells during the nitrogen fracturing. This interference is most likely a poromechanical coupling, based on the rapid pressure response.

7.2.4 NITROGEN FOAM FRAC

7.2.4.1 Design

The Yellow foam frac was designed to be a small, minimal damage treatment using a 75 quality nitrogen foam with a 20 lb/1000 gal linear gel for the liquid phase. The desired, propped, fracture length was 200 to 300 ft in order to keep the fracture within the lens and within range of borehole geophones. Foam was used to minimize liquids and possible damage. A small volume was used in order to minimize total fluid volumes and treatment pressures. The smallest possible pad was used so that the total fluid length of the fracture (the length measured by the geophones) would not be too much greater than the propped length. The final job design is shown in Table 7.2.2.

Estimated frac fluid parameters are shown in Table 7.2.3. The rheology is for a 20 lb/1000 gal gel at about 150°F. The leakoff coefficient was based on previous treatments in the paludal zone. With these input parameters and a rate of 10 bpm, design calculations showed an expected total frac length of 350 ft, a propped length of 255 ft, and an average prop concentration in the frac of about 0.26 lb/ft^2. The calculated height was 62 ft. The proppant was 12,000 lb of 20/40-mesh Proflow, an intermediate-strength proppant. It was tagged with 10 millicuries of iodine 131 with an 8-day half life.

The bottomhole configuration is shown in Figure 7.2.9. A bridge plug was set over the Red sand with bottomhole pressure bombs to monitor for leaks. The 2-7/8-in. tubing was landed open-ended at 6349 ft and a quartz-crystal, HP pressure gage was lowered to 6300 ft. Perforations, at 2 shots per foot, spanned the Yellow sands between at 6,428 and 6,460 ft. Since the HP pressure gage was about 145 ft above the center of the perforations, the difference between true bottomhole pressure and the gage reading would vary from about 20 to 55 psi depending on the fluid in the hole. All fluids were pumped down the annulus.

7.2.4.2 Treatment Data

The night before the frac (July 31, 1985), N_2 was circulated and the wellbore pressured up to 3500 psi and shut it in for several hours. 150,000 SCF N_2 was injected to test equipment and diagnostics. Maximum surface pressure during this test was about 5200 psi. The well was shut in for the night with surface nitrogen pressure of about 4500 psi, which dropped to about 3400 psi surface by frac time of the next day. This volume of N_2 may have altered the closure stress somewhat (probably not more than a few tens of psi).

The treatment was conducted on August 1 as designed and complete temperature/pressure/flow-rate data were obtained. Selected data for the treatment are given in Appendix 11.11. Figure 7.2.10 shows the surface flow rate and surface density measured during the treatment. The job was started by pumping N_2 at its prescribed rate of 13,000 SCFM until the bottomhole pressure reached 6000 psi. Some of the initial N_2 flow rate data are missing (0 to 7 min) because the nitrogen flow meter did not reach operating pressure/flow-rate conditions. When the bottomhole pressure reached about 6000 psi at 9 min, gelled water - surfactant pad was added at 2.5 bpm. This pad was pumped for about 7 to 8 min, at which time Proflow was added at 4 ppg. Since the N_2 rate did not change, this kept a constant foam quality in terms of the liquid phase, but the foam quality in terms of the slurry (liquid + prop) dropped to 60 to 65%. After 7 to 8 min, sand was stopped and the well was flushed with the 75 quality foam. At the time the flush started at the surface, the pad had not yet reached the perforations as the annular residence time was about 17 to 18 min. It was very important to obtain the most accurate possible flush volume. By monitoring both bottomhole and injection pressure during the flush, calculations of the flush volume were made and updated every minute based on the latest pressure and temperature data. The treatment was pumped per design with a total injected volume of 6000 gal of foam and 12300 lb of prop.

The bottomhole pressure for the entire job + shut-in is shown in Figure 7.2.11 and includes the initial pump-up and injection with N_2 (0 to 28 min), the treatment on the perfs (28 to 41 min) and the 70-min pressure decline.

The injection portion of the test is expanded and shown in Figure 7.2.12. The initial fracturing (9 to 16 min) is with N_2 at about 10.5 bpm. From 16 to 24 min, the rate at the surface has increased to 12.5 bpm but the fluid entering the perfs is still N_2. The rate drops to about 11 bpm at 24 min causing the slight decrease in pressure. Finally at about 27 min the pad hits the perfs. At 34 min the sand hits the perfs and at 39 min it appears to start a tip screenout.

The Nolte-Smith plot[4] of just the liquid fracturing part (28 to 41 min) is shown in Figure 7.2.13. The slope of the curve is about 0.14, which is slightly low for an n' of 0.5, but this may be due to neglecting the initial gas fracturing. After about 12 min, the near-unit slope characteristic of screenouts is observed. This curve suggests reasonably bounded fracture growth throughout the treatment.

The pressure decline part of the test is shown in Figure 7.2.14. However, the Nolte pressure decline analysis will not be meaningful if the crack is already closed on the prop due to the screenout. Thus, there may not be an in situ measurement of fluid leakoff.

The static, surface, tubing pressure for the entire test is shown in Figure 7.2.15, and an expanded plot of just the pumping phase is shown in Figure 7.2.16. This pressure tracks the bottomhole pressure fairly closely, when the compressibility of the N_2 in the tubing is accounted for.

The surface injection pressure (into the annulus) is shown in Figure 7.2.17 for the entire test and Figure 7.2.18 for only the pumping part. Of course, the changing densities of the various stages give these curves their character. Figure 7.2.19 gives the average hydrostatic pressure of the column of fluid in the well during nonflow periods and the hydrostatic pressure plus the friction pressure drop during pump periods.

Finally, the bottomhole temperature during the test is shown in Figure 7.2.20. The initial heating is due to compression of the nitrogen, the slight cooling due to the flow of N_2 past the tool (once fracturing starts), and the rapid cooling when the liquid phase reaches the temperature tool.

The tool continues to cool after shut-in (41 min), probably as a result of slow heat transfer from the warmer nitrogen in the annulus to the cooler foam. The sharp break in the temperature curve at about 70 min when the tool begins to heat up is not understood. It may be due to a separation of phases in the foam.

7.2.4.3 Diagnostic Results

After the treatment, a temperature log was attempted, but sand was tagged at 6370 to 6380 ft. This would correspond to about 2000 lb of sand left in the wellbore and is consistent with the Nolte-Smith plot showing a screenout in the last 2 to 3 minutes of pumping. No temperature anomaly was seen above the sand, which suggests that height growth did not exceed 50 ft into the overlying barrier.

Gamma logs were run to search for radioactive sand and, as seen in Figure 7.2.21, radioactive sand was only detected near the perforations. There is no indication in these data of any significant height growth.

Borehole geophones were used to determine the length and height of the fracture, but the observed signals were too complex to yield a meaningful map of the fracture as discussed in Section 9.0.

The data from the pressure sondes located below the bridge plug at 6482 ft were generally not useful since tool malfunctions resulted in loss of data.

7.2.4.4 Nolte Analysis

Since it is believed that a tip screen-out occurred, the Nolte pressure decline analysis[5] is not appropriate. This is because the crack walls should immediately close on the prop pack, at least near the tip. However, since other interpretations of the pressure increase at the end of the job are possible, the Nolte analysis is included for completeness.

Figure 7.2.22 shows the Nolte plot with a match pressure of about 180 psi. Calculations with this match yield a leakoff coefficient of 0.00036 ft/$\sqrt{}$min, a wing length of 620 ft, a width of 0.12 in., and fluid efficiency of 80%.

7.2.4.5 Treatment Pressure History Match

Without diagnostics and a Nolte analysis, the only other technique to analyze the frac is through history matching the pressure during the job. Unfortunately, without any length or height estimates or independent leakoff data, any match solution is not unique. However, with the variety of fluids and flow rate in the treatment and the screenout near the end of the job, a fairly good representation of the frac is possible.

A first solution was a constant height case, with an assumed height of 40 ft. The history match for this case is shown in Figure 7.2.23. With the exception of the initial nitrogen pump-up (which is dominated by flow into the reservoir rather than fracturing), an accurate match of the pressures can be obtained. However, to do so required an initial closure stress of 5800 psi. This is rather high in view of the amount of gas that was produced from the reservoir. It is estimated that the decrease in reservoir pressure from about 4300 psi to the current (at the time of this frac) 3800 to 3900 psi in the region around the well should have reduced the minimum stress to about 5500 to 5600 psi.

To arrive at the match in Figure 7.2.23, the same nitrogen parameters were used for the initial nitrogen frac as were deduced from the earlier nitrogen step rate test. To achieve a screen out, it was required that width at the sand front be less than 1.5 times the average sand diameter. The changes in fluids and rates help put additional constraints on the fracture parameters so that only a limited range of values can yield a suitable match. The length in this case is 388 ft total and 375 ft propped. The beginning of the nitrogen fracturing is not matched very well because the actual rate entering the perforation is much lower than the calculated bottomhole rate. As the pressure increases, a significant fraction of the nitrogen flow only goes into wellbore storage.

The second solution was a variable height simulation where the height vs pressure data shown in Figure 7.2.24 were used. These data are identical to the initial stress data shown in Figure 6.23, except that the sands have a lower stress due to drawdown. The pressure match is shown in Figure 7.2.25 and while it appears similar to Figure 7.2.23, the results are considerably different. The total length here is 295 ft and the propped length is 275 ft. The maximum height is 96 ft with 33 ft of growth above the top of the Yellow sands and 28 ft of growth below. The lower growth does not break into the Red sands.

As with the constant-height case, this history match is very good and meets all the observed pressure changes. At the end of the job, the calculated bottomhole pressure is somewhat above the measured value, but the measured pressure, with the gauge at 6300 ft is low because of the increased weight of the fluid column due to the sand.

In this case the leakoff coefficient is fairly high at 0.0019 ft/$\sqrt{}$min for this tight zone. This is undoubtedly due to leakoff into the natural fractures. The efficiency of the fluid appears to be a little less than 30%.

7.2.4.6 Conclusions

The best estimate of the treatment result is that the fracture was approximately the desired size, with a propped length of about 275 ft. Height growth was significant, but not excessive. The leakoff coefficient was somewhat higher than anticipated, thus resulting in the tip screenout. However, the tip screenout did not jeopardize any of the treatment objectives and resulted in several desirable features. These include: (1) a total length close to the propped length (so fracture diagnostic lengths should be the same as well-test lengths); (2) a well-propped fracture along the entire length (no overflushing or near-wellbore flowback); and (3) conditions which allowed an estimate of the leakoff coefficient in the history match.

The loss of temperature log and borehole geophone data also points out the need to perform a complete suite of tests for every fracture experiment. Stimulation experiments should always start with a step-rate/flowback sequence to measure the true closure stress at the time of the treatment. A minifrac needs to be performed to yield an independent estimate of the leakoff coefficient. Only then should a propped-frac treatment be attempted. If this entire procedure is not performed there is a good chance of not knowing anything about the frac, particularly when the diagnostics are lost.

This test shows the value of the history-matching procedure for estimating the fracture behavior. This requires a versatile, multistage, multirate, height-growth simulator. Of course any such results are nonunique unless there are some other independent information or several rate changes, fluid changes and even a screenout. The procedure is strengthened if diagnostics can provide a height or even a length or if a leakoff coefficient can be obtained from the minifrac. The correct closure stress is also needed.

7.3 REFERENCES

1. Smith, M. B., "Stimulation Design for Short, Precise Hydraulic Fractures--MHF," SPE 10313, presented at 56th Annual SPE Technical Conf., San Antonio, TX, October 5-7, 1981.

2. Geertsma, J., "Some Rock-Mechanical Aspects of Oil and Gas Well Completions," EUR 38, presented at European Offshore Petroleum Conference and Exhibit, London, October 24-27, 1978.

3. Huitt, J., "Fluid Flow in Simulated Fractures," AIChE Journal, Vol. 2, No. 2, pp. 259-264, June 1956.

4. Nolte, K. G. and M. G. Smith, "Interpretation of Fracturing Pressures," Jour. Pet. Tech., 33, 1767-1775, September 1981.

5. Nolte, K. G., "Determination of Fracture Parameters from Fracturing Pressure Decline," SPE 8341, 54th Annual Fall SPE Technical Conference and Exhibition, Las Vegas, NV, September 23-26, 1979.

Table 7.2.1

Nitrogen Frac Schedule

Test	Rate (SCFM)	Time Period (min)	Total Stage Volume SCF
Remove Wellbore Fluid	<2,000	~60	~50,000
Step Rate	1,000	10	10,000
Step Rate	2,000	10	20,000
Step Rate	5,000	10	50,000
Step Rate	7,500	5	37,500
Step Rate	10,000	5	50,000
Step Rate	15,000	7	105,000
Constant Frac Rate	20,000	20	400,000
Reduce Rate, Seat BHP	10,000	7-8	~75,000
			~800,000 Total

Table 7.2.2

Foam Frac Treatment Design

Stage	Vol. (gal)	N_2 Rate (SCFM)	Slurry Rate (bpm)	Sand (ppg)	Total Rate (bpm)
Pad	3000	13000	2.5	-	10
Sand	3000	13000	4.25	4	12.25
Flush	7880	13000	2.5	-	10

Table 7.2.3

Foam Frac Parameters

$n' = 0.5$
$k' = 0.007$ lb-sec$^{n'}$/ft^2
$c = 0.001$ ft/$\sqrt{\text{min}}$
$Sp = 0.01$ gal/ft^2

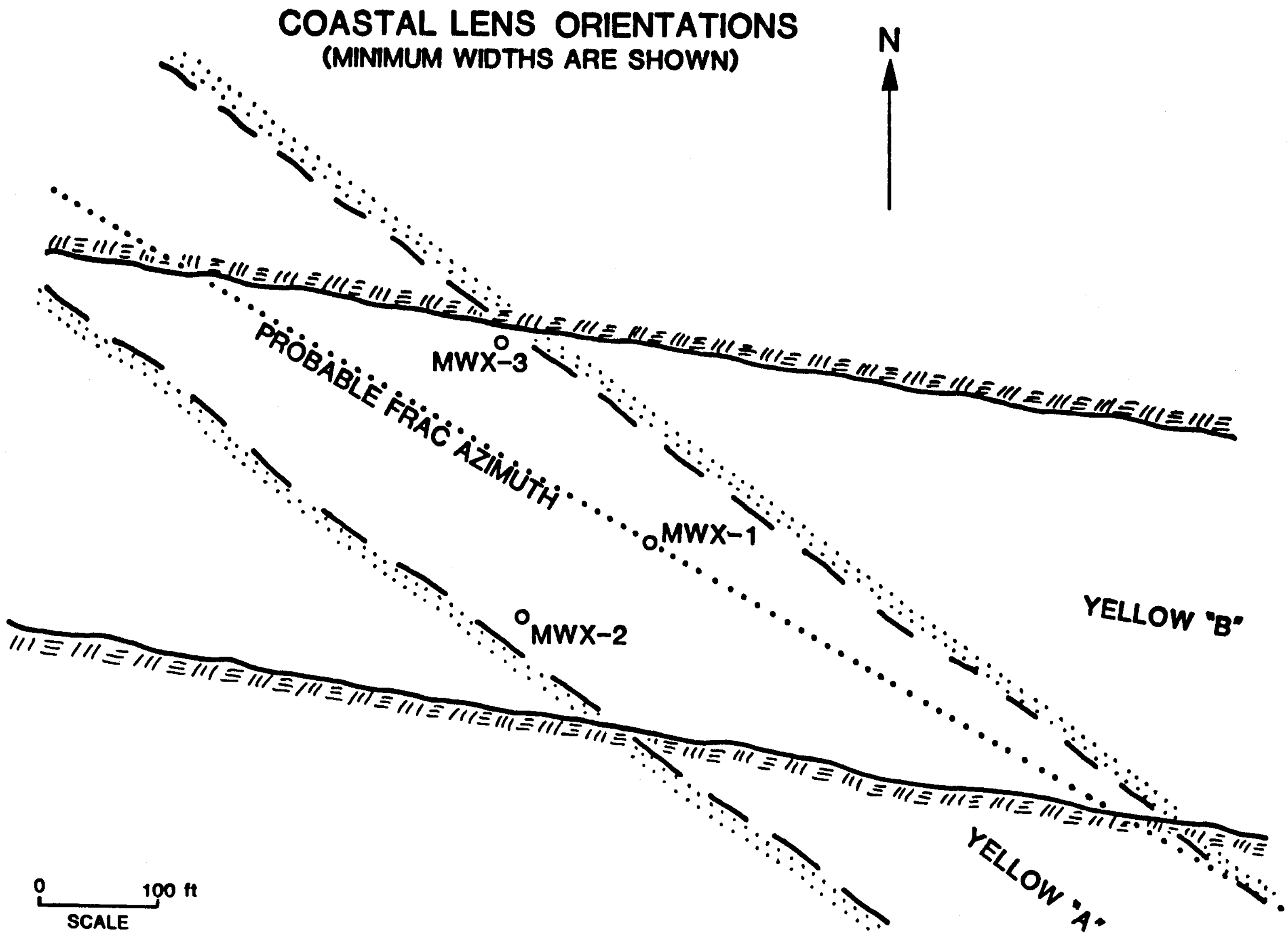


Figure 7.2.1 Channel Geometry

MWX #1
Well Status
6-8-85

Bottomhole Assembly

Let Down	17.00
89 Jts. 2⅞ 6.5# N-80 Tbg.	6264.23
2⅞" Coupling	.44
2⅞ x 4½ Xover	.49
2 Jts 4½ 11.6# N-80 Csg.	80.74
4½" Coupling	.62
4½ x 2⅞ Xover	.49
DHSIN	.82
1 Jt 2⅞ 6.5# N-80 Tbg.	33.48
Tubing Stretch	2.90
Top RTTS	6401.21
Tubing Tail	6413.

Summary

DHSIN	6367
Top of RTTS	6401
Tubing Tail	6413
Top of B-V B.P.	6480
B.P. Tail	6487
Top Sand	7034
Top Go "Elite" WLBP	7040

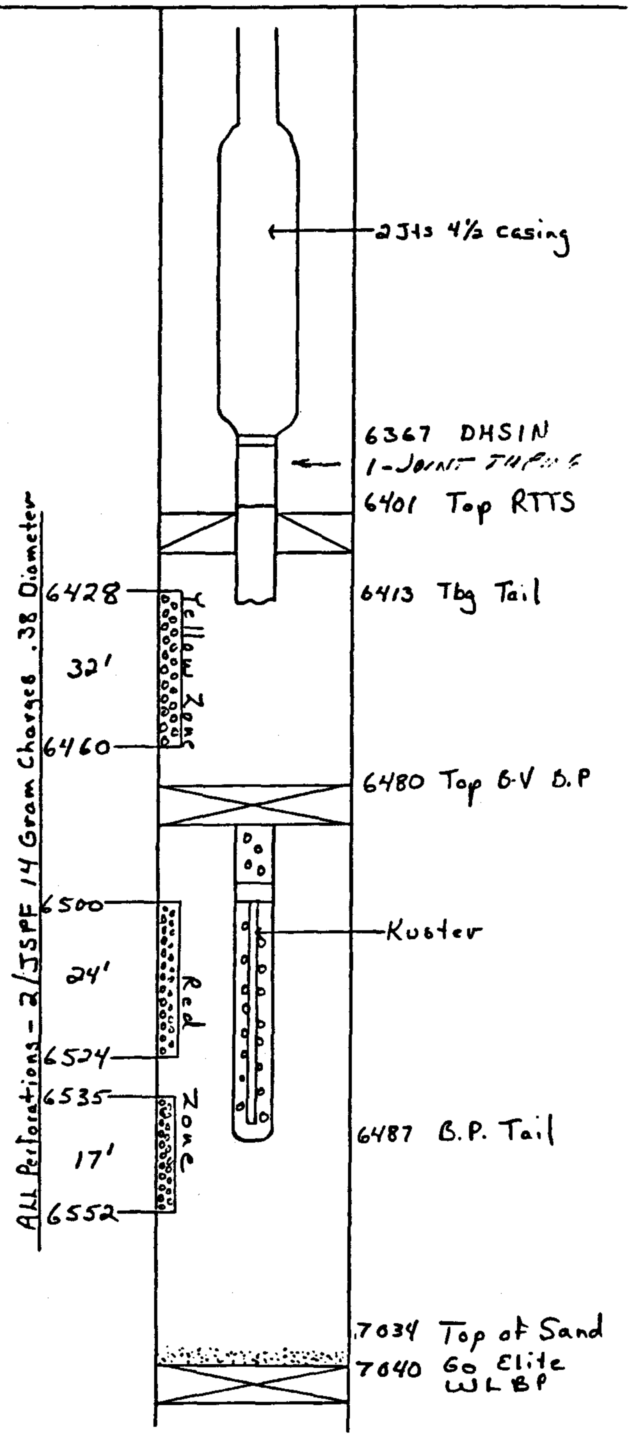


Figure 7.2.2 Wellbore Configuration

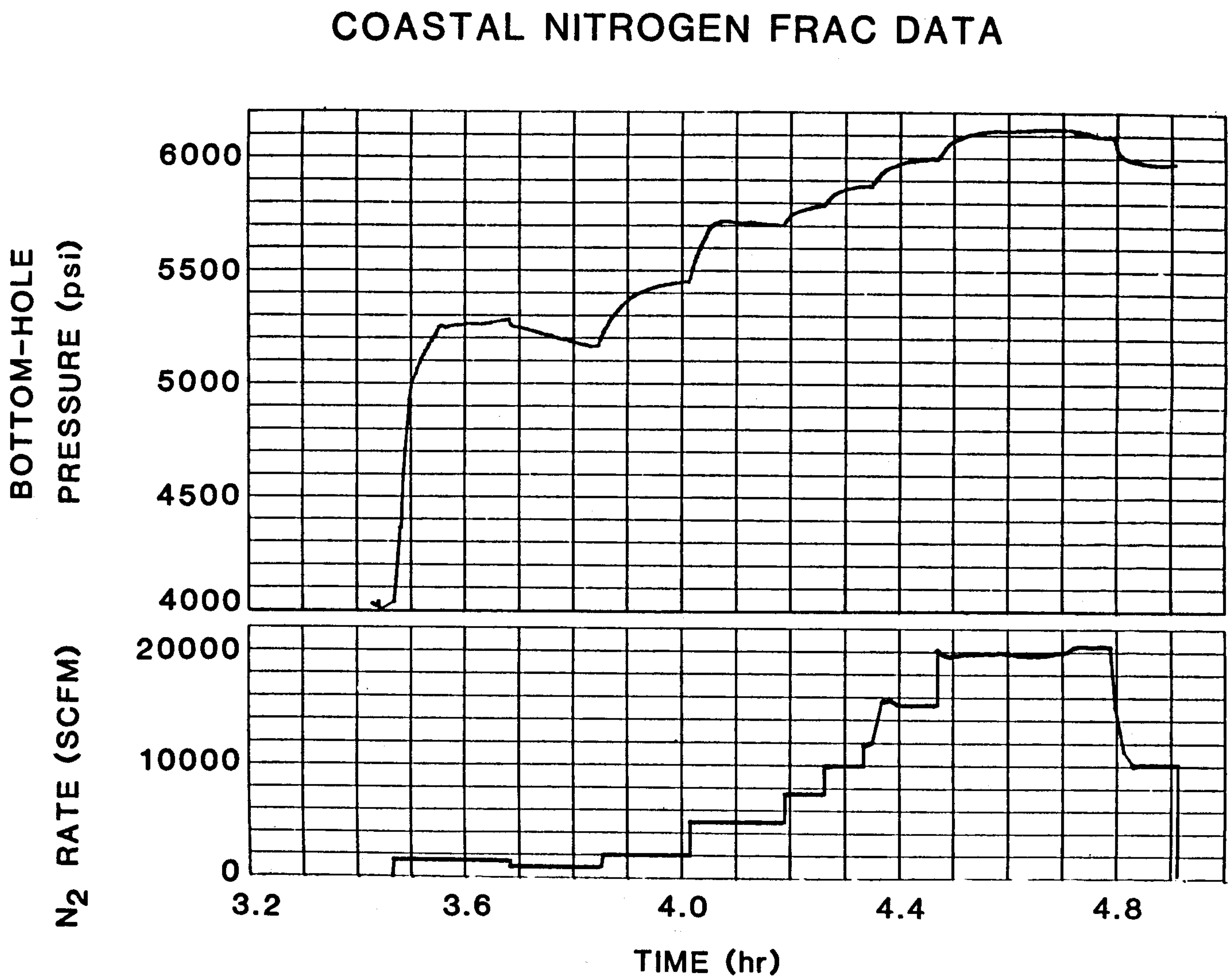


Figure 7.2.3 Nitrogen Injection Data

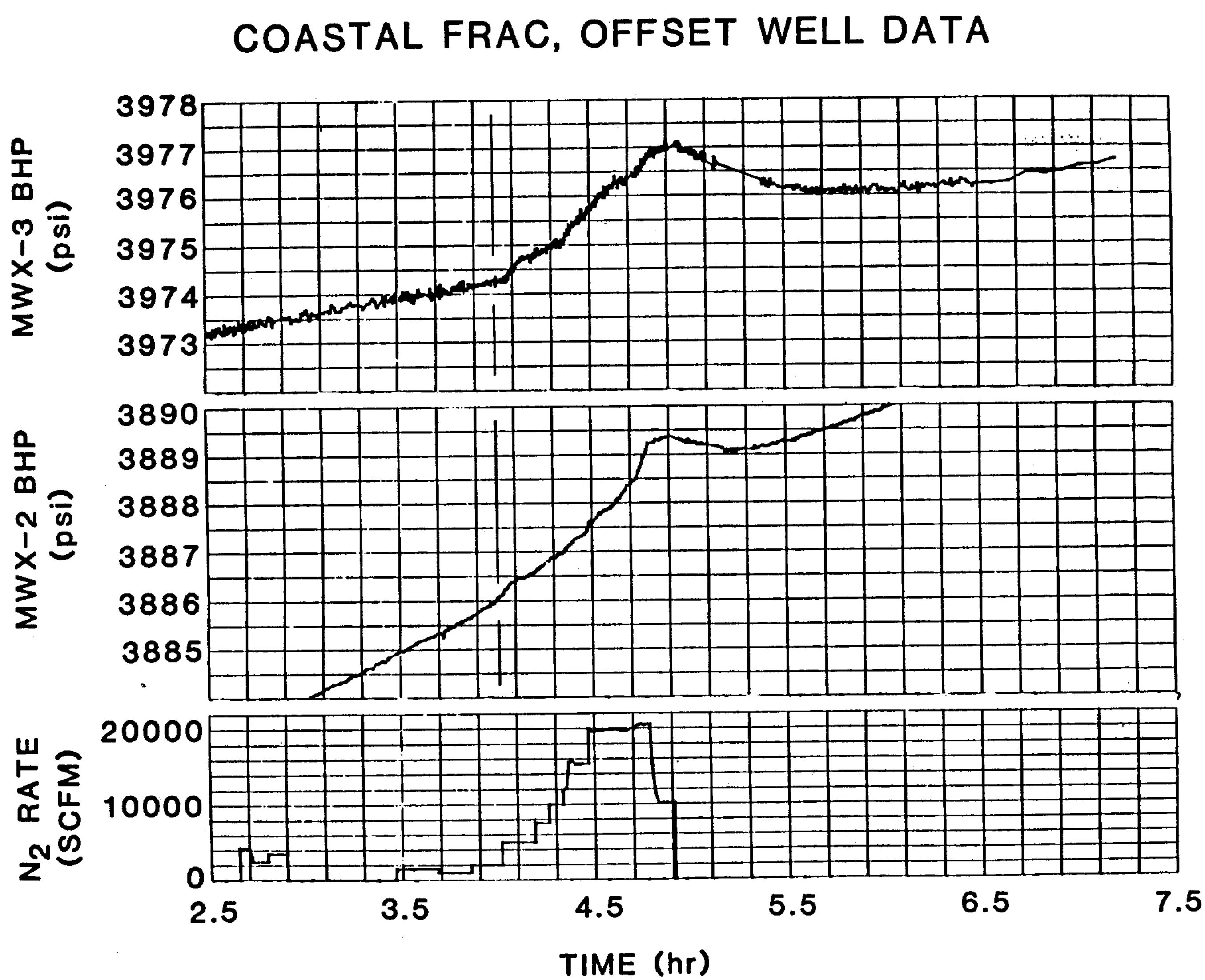


Figure 7.2.4 Nitrogen Frac Interference Data

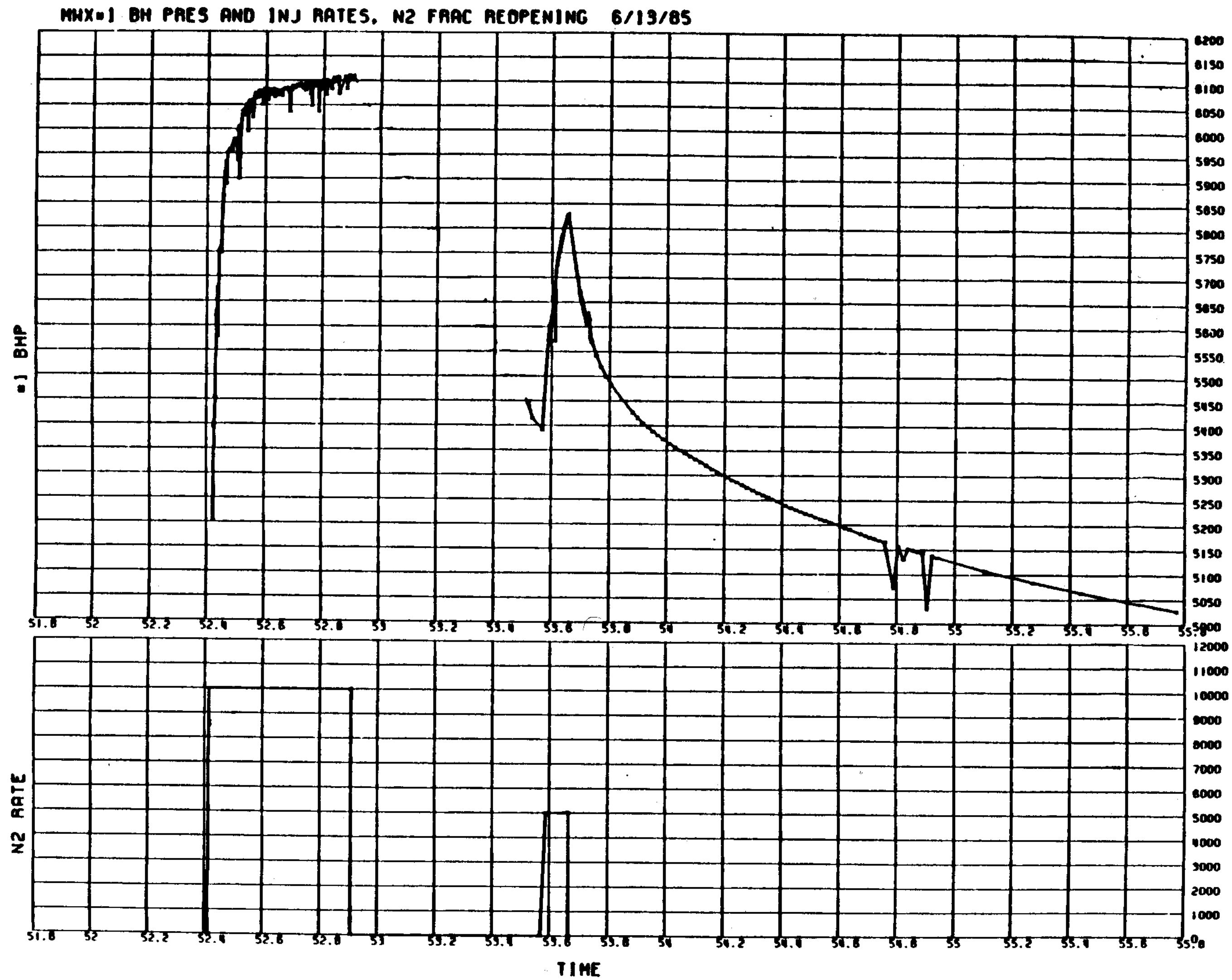


Figure 7.2.5 Second Nitrogen Injection Data

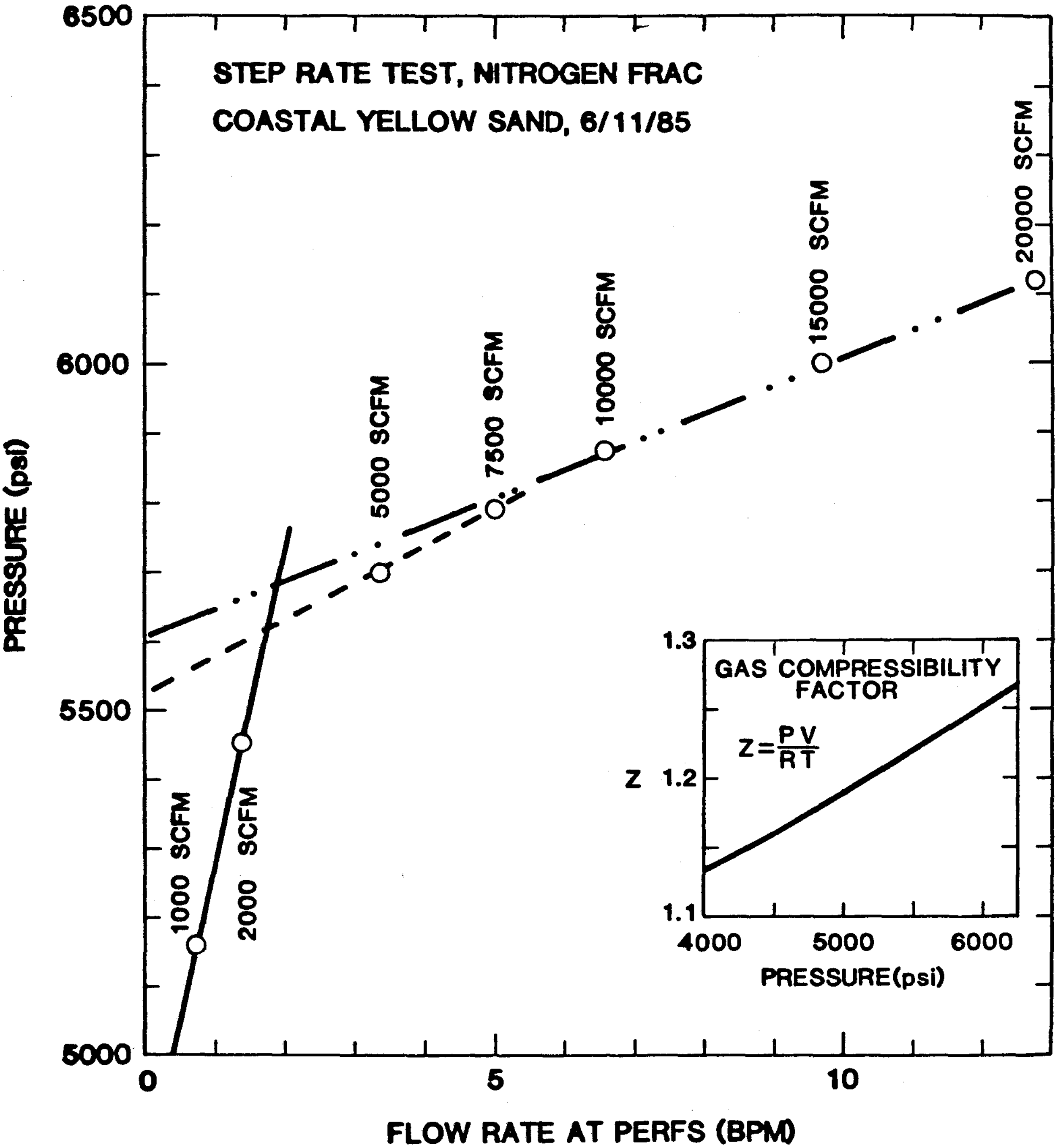


Figure 7.2.6 Nitrogen Step Rate Data

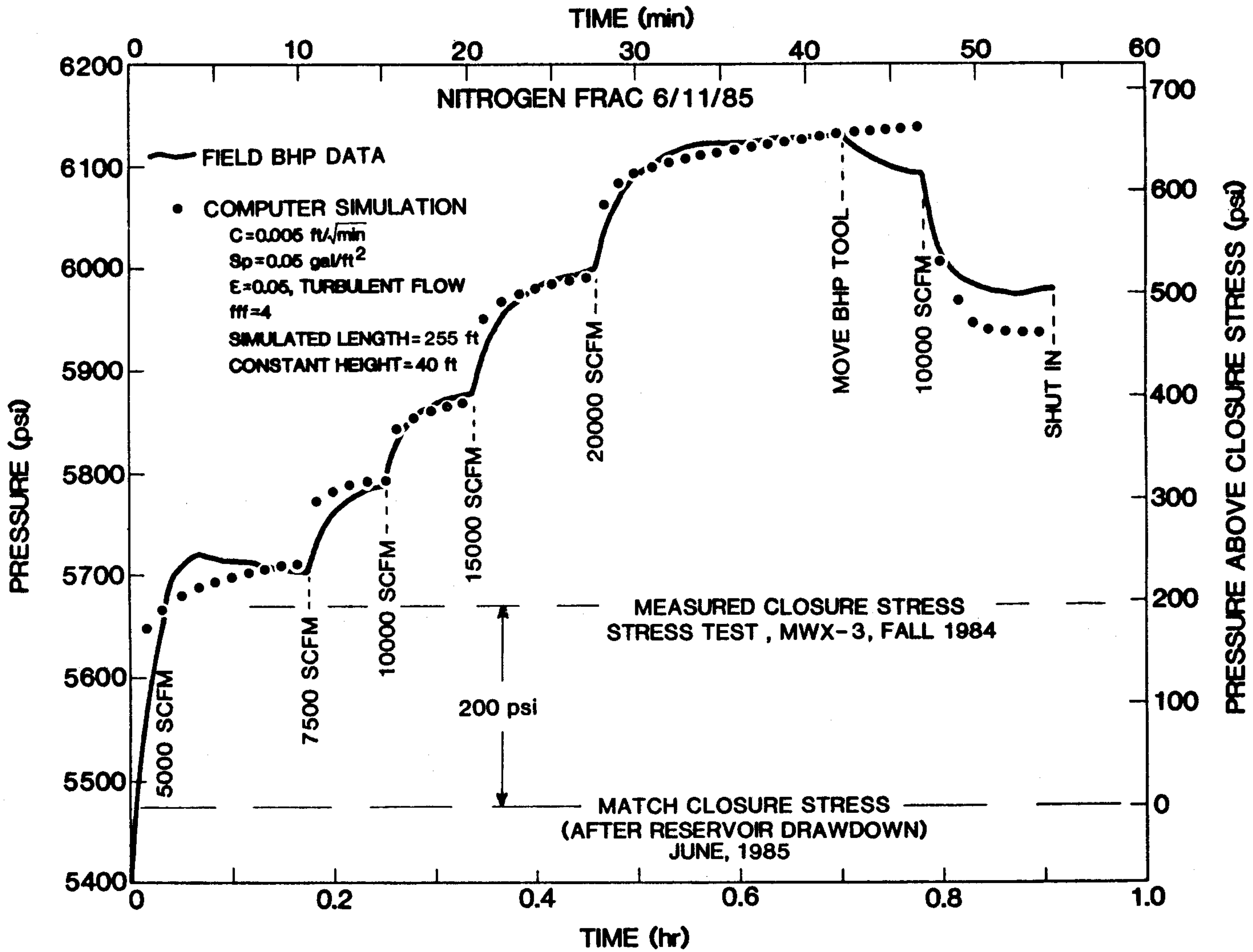


Figure 7.2.8 Nitrogen Frac Pressure History Match

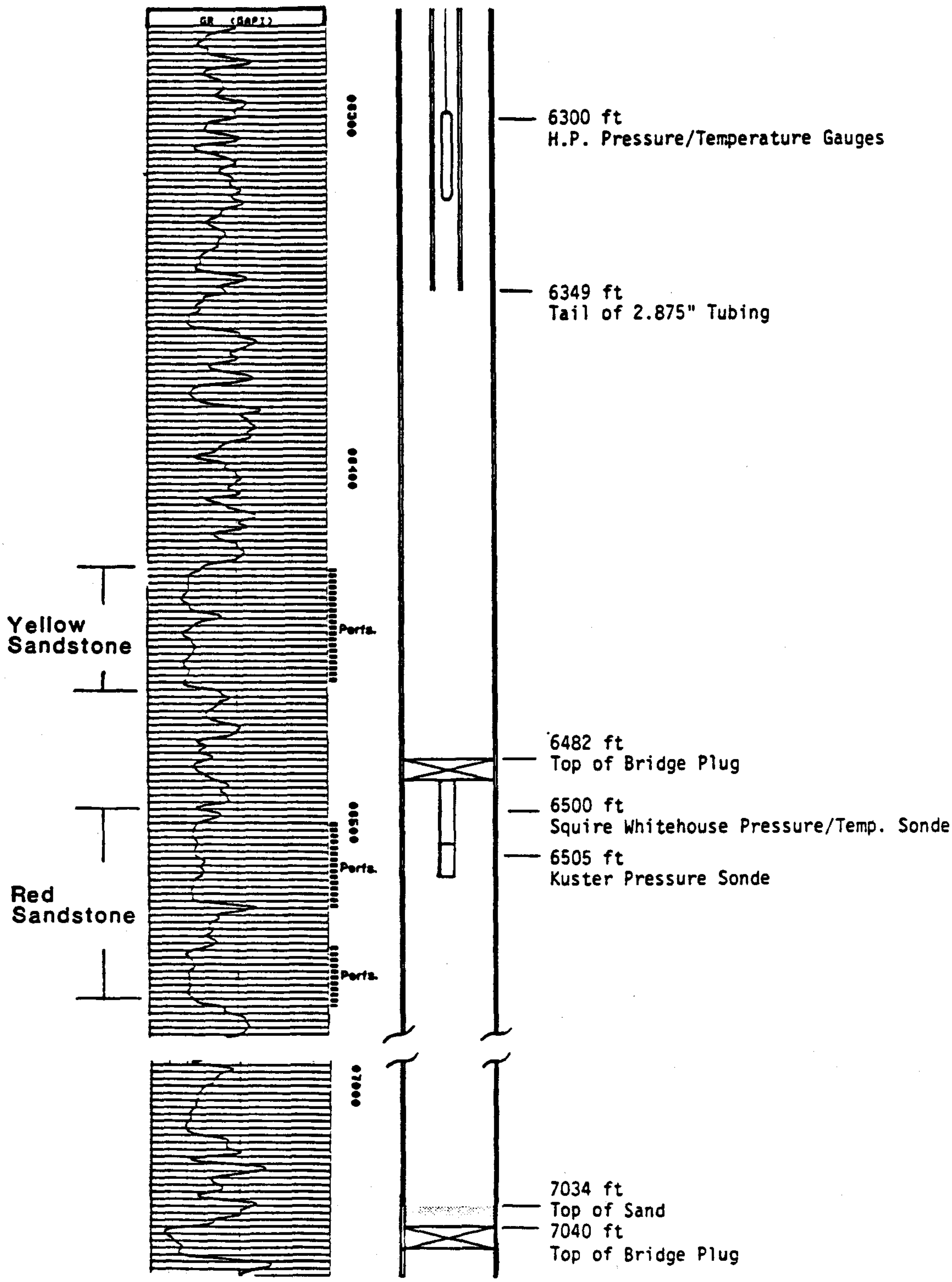


Figure 7.2.9 Bottomhole Configuration

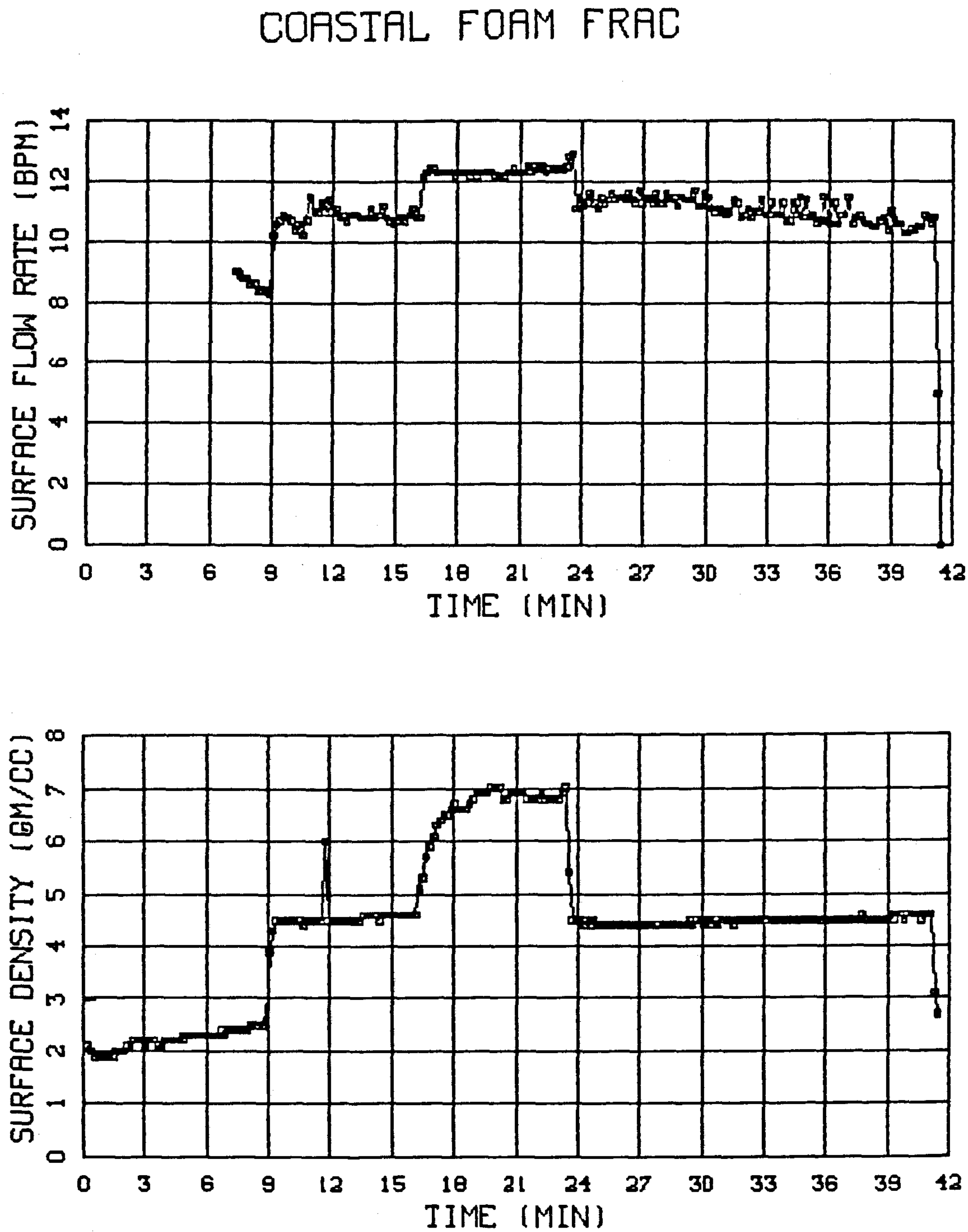


Figure 7.2.10 Flow Rate and Density

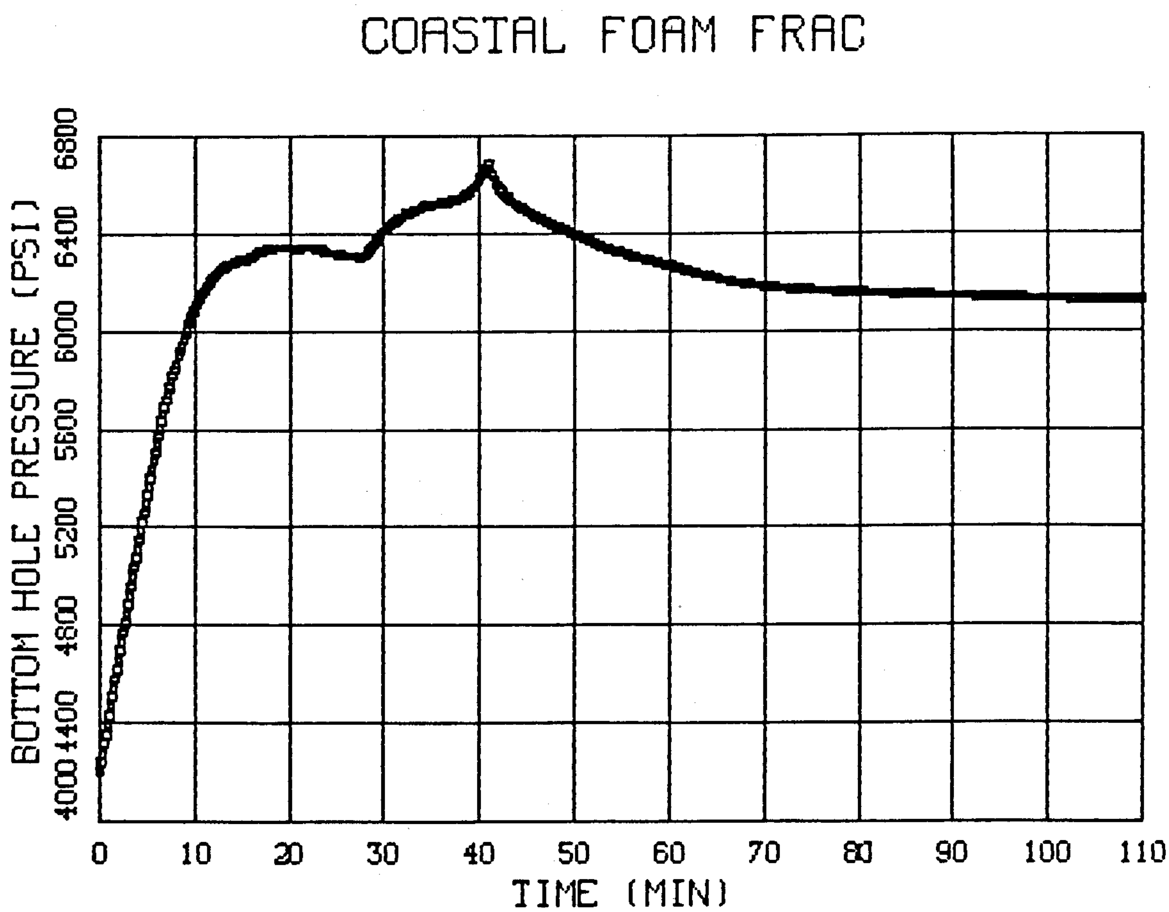


Figure 7.2.11 Bottomhole Pressure

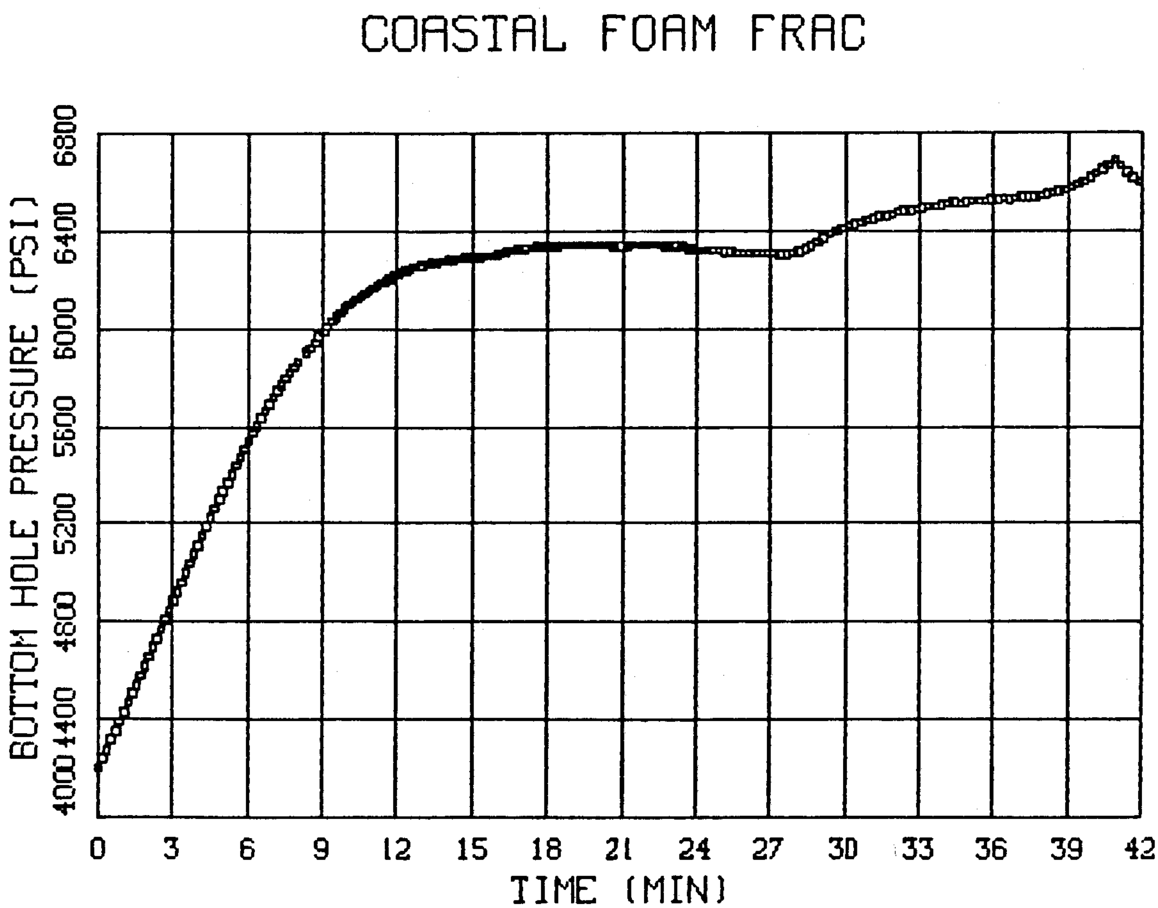


Figure 7.2.12 Bottomhole Pressure for Injection

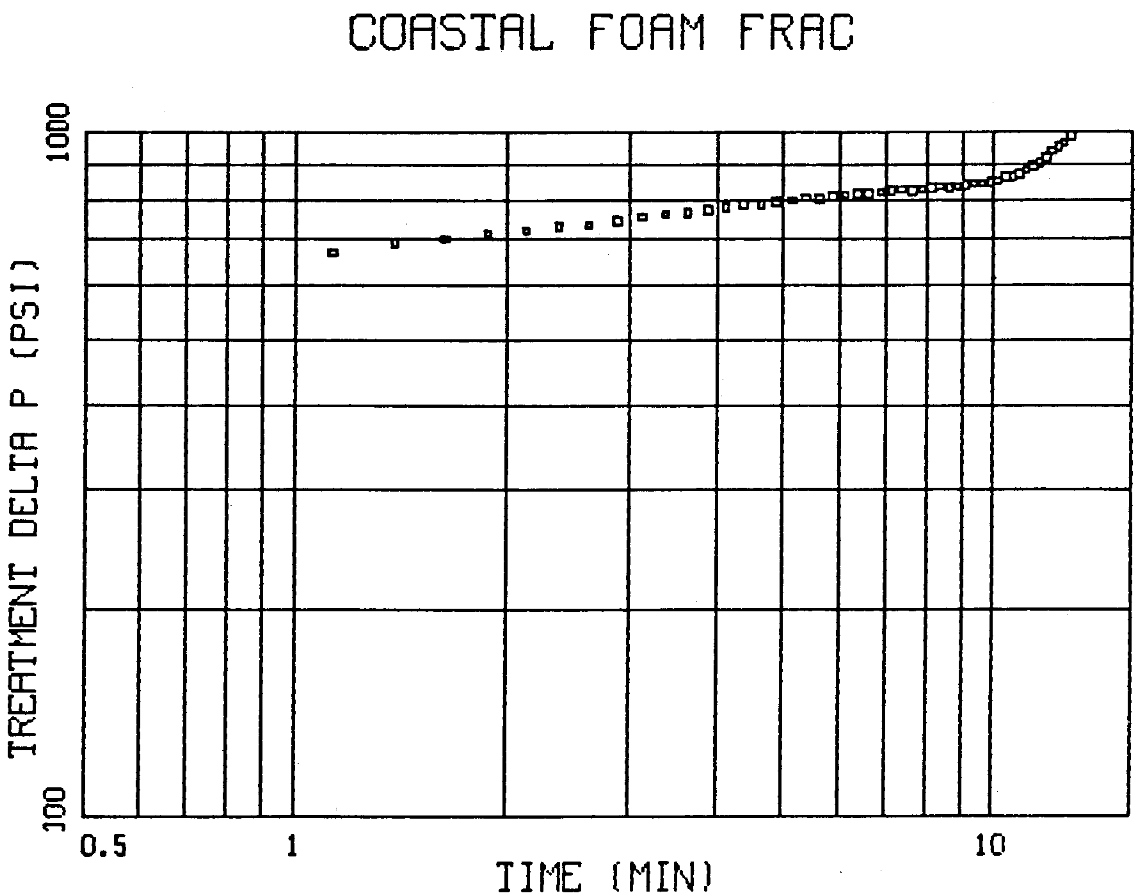


Figure 7.2.13 Nolte-Smith Plot

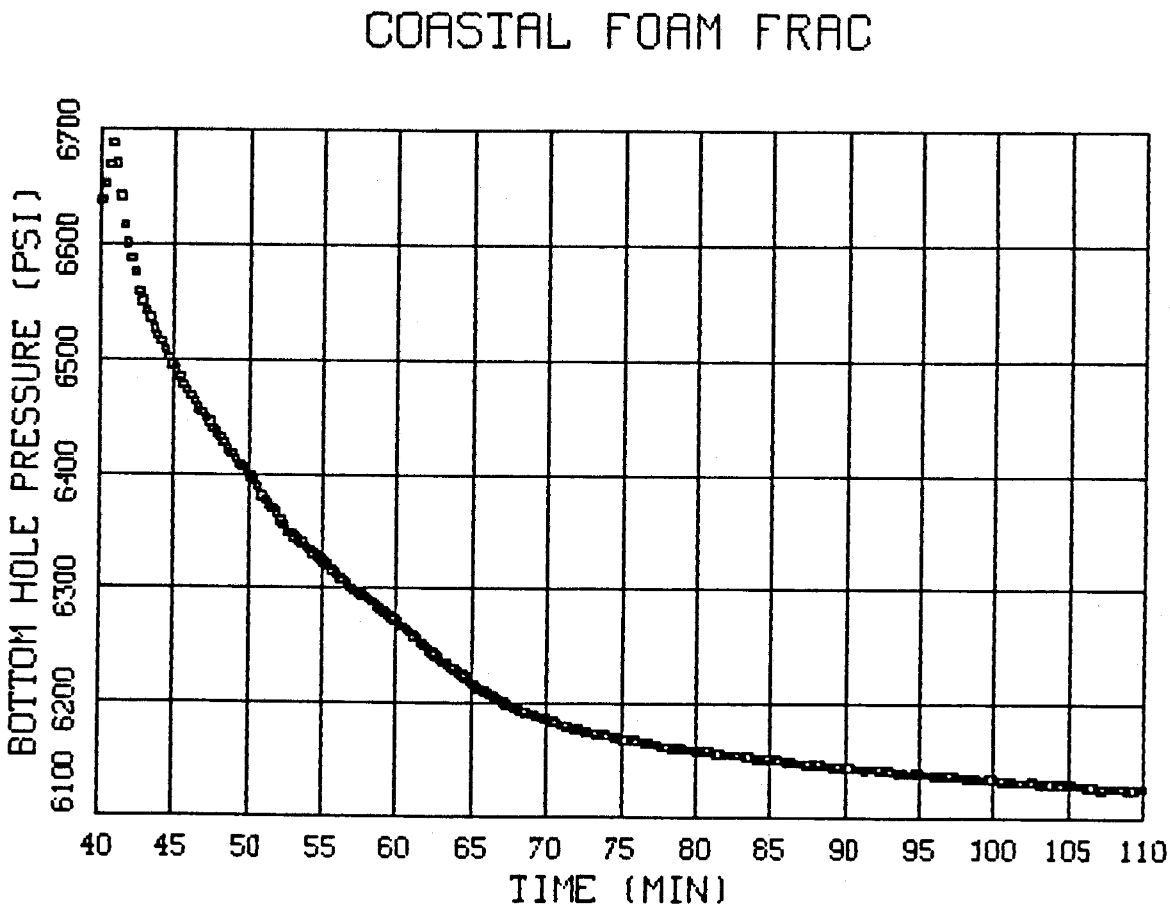


Figure 7.2.14 Bottomhole Pressure for Decline

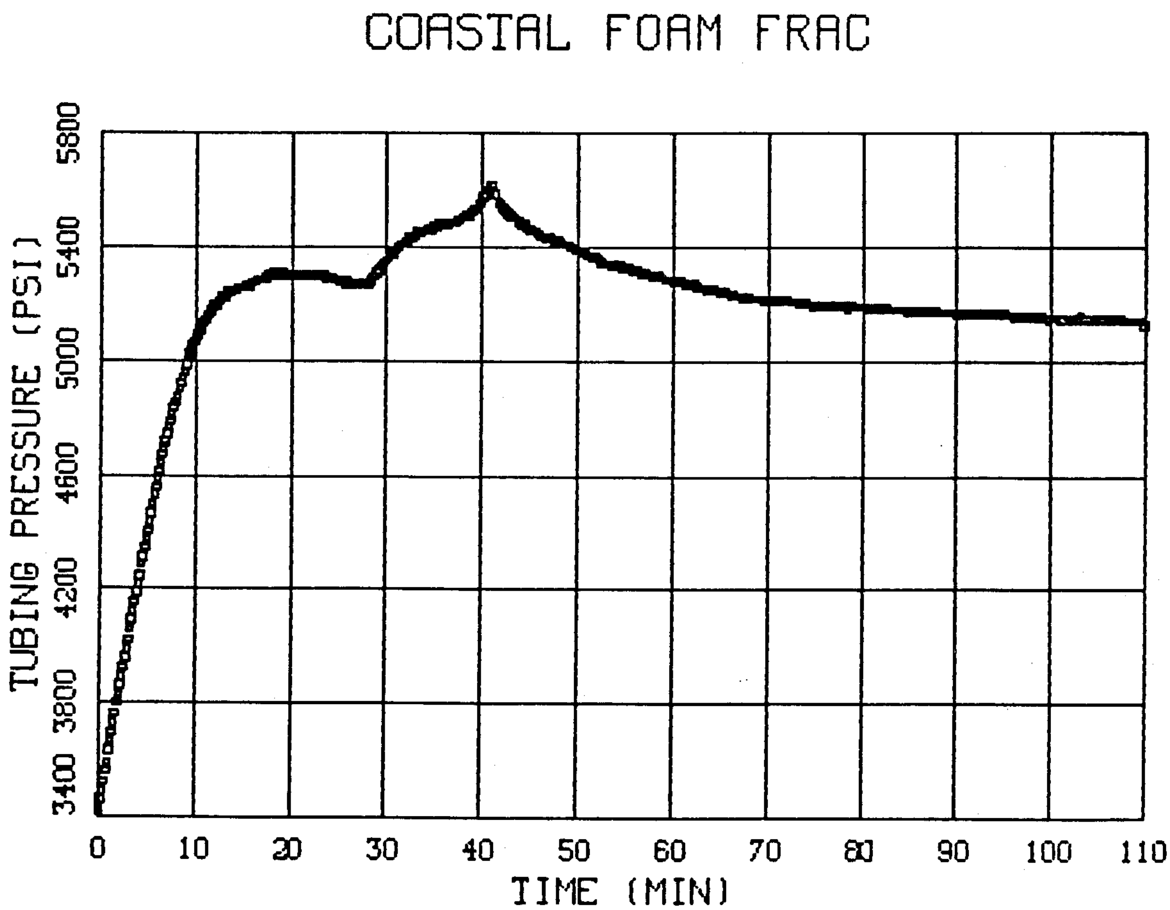


Figure 7.2.15 Tubing Static Pressure

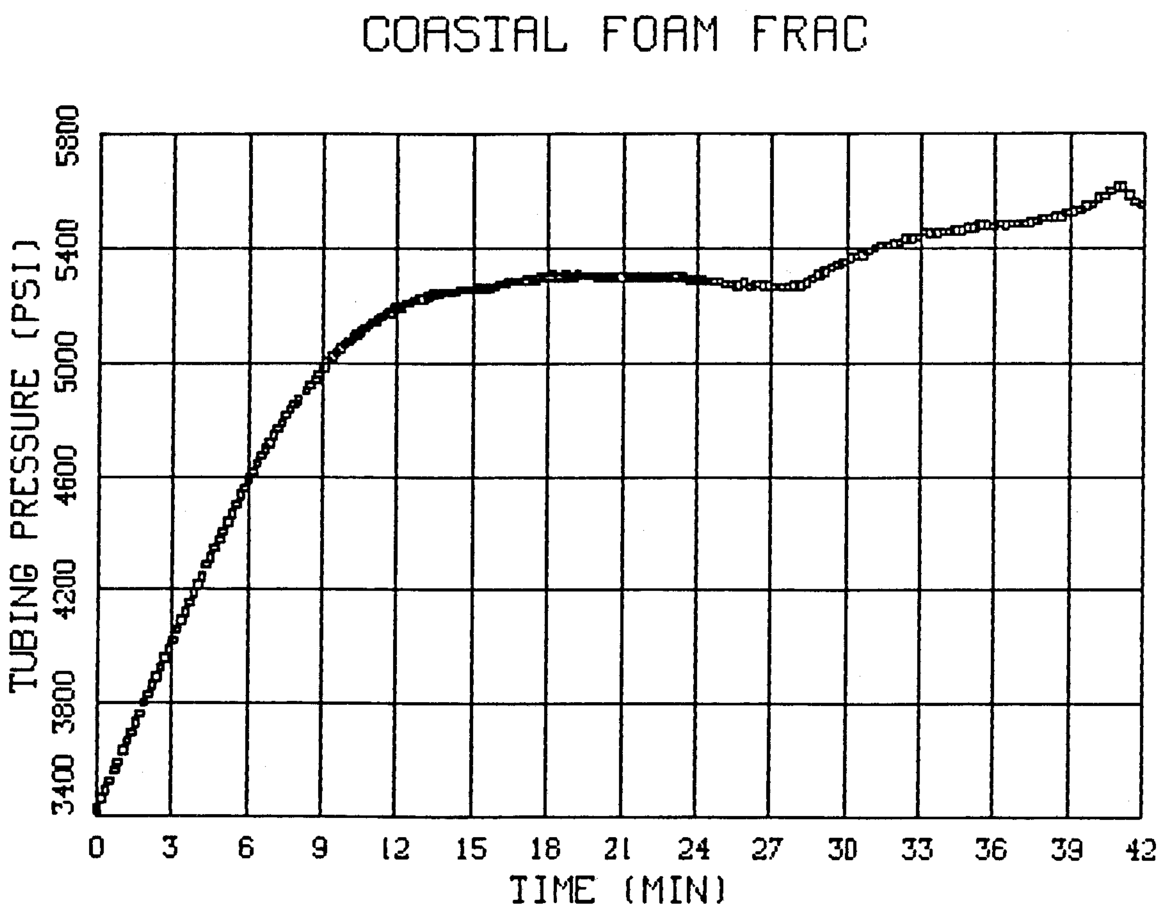


Figure 7.2.16 Tubing Static Pressure for Injection

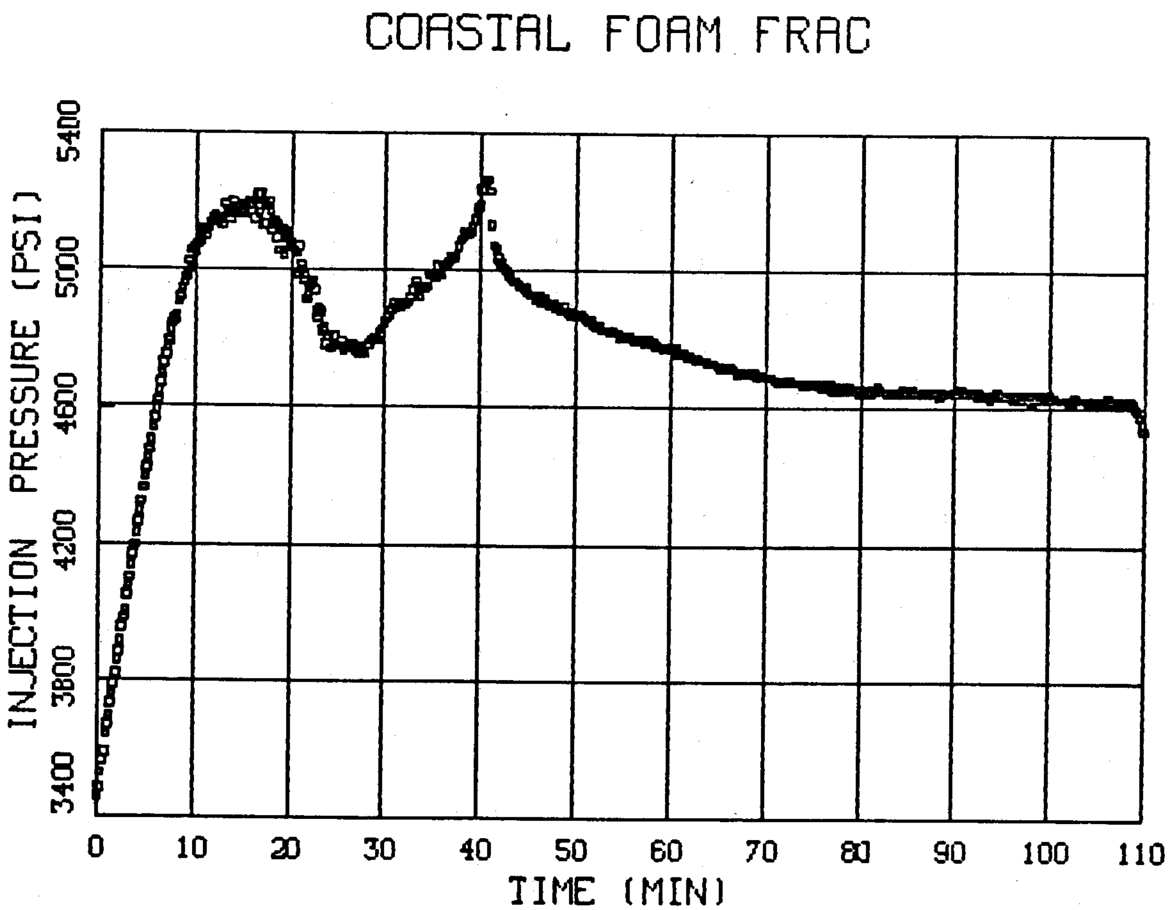


Figure 7.2.17 Surface Injection Pressure

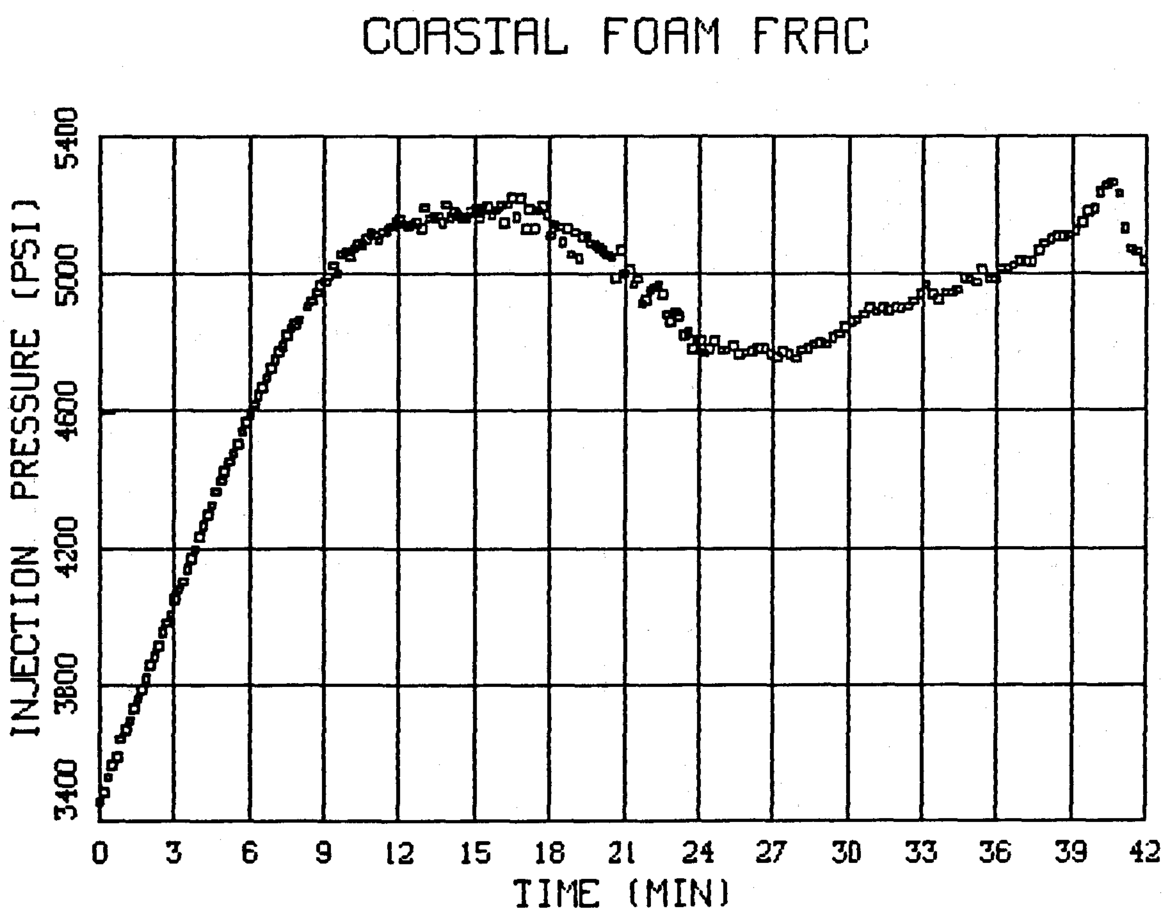


Figure 7.2.18 Surface Pressure for Injection

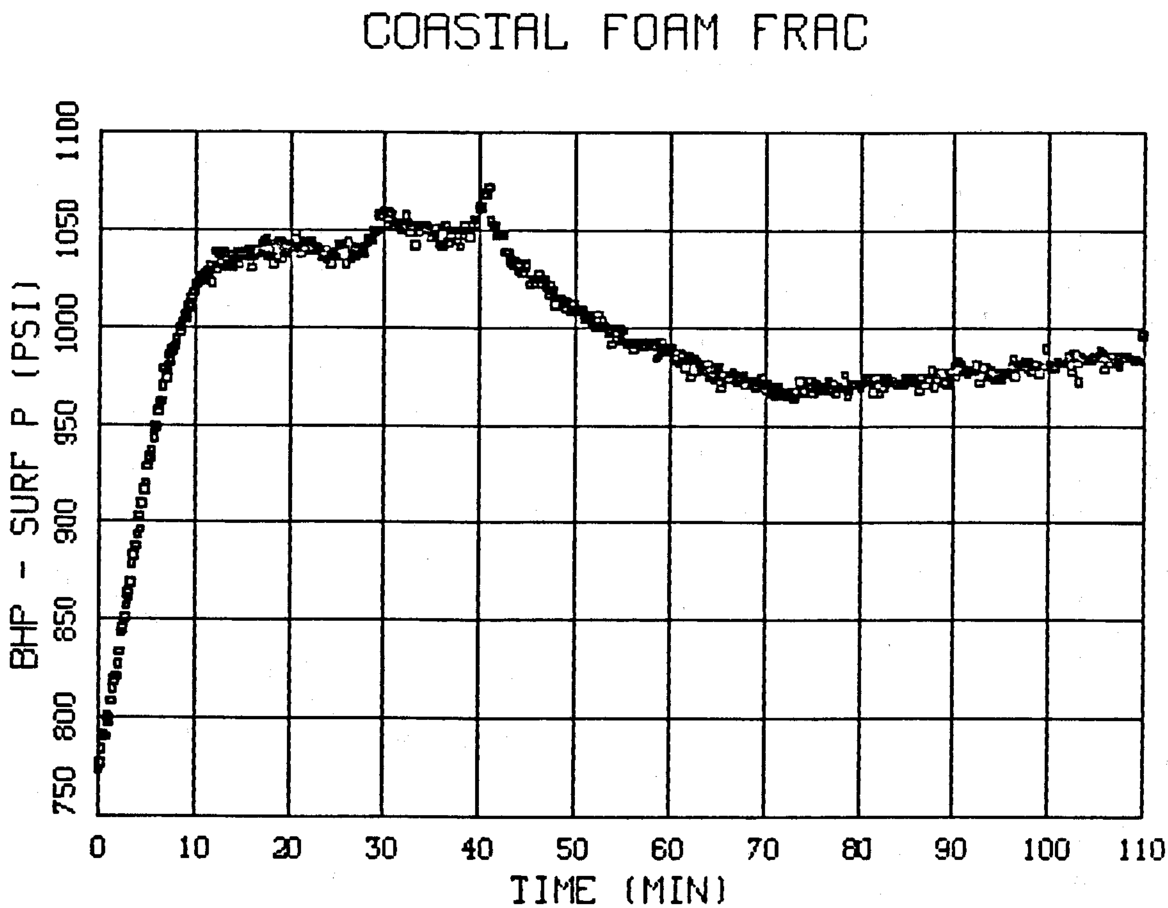


Figure 7.2.19 Bottomhole Minus Surface Pressure

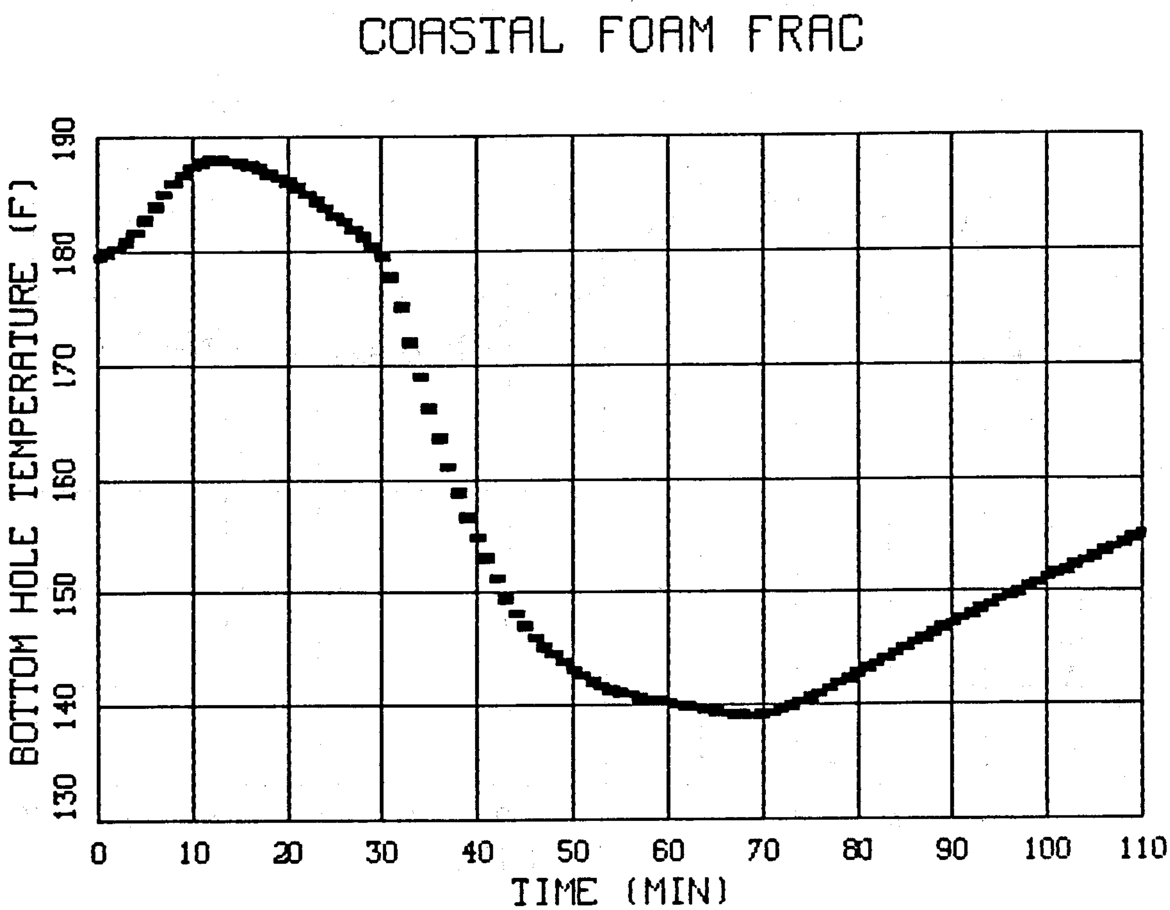
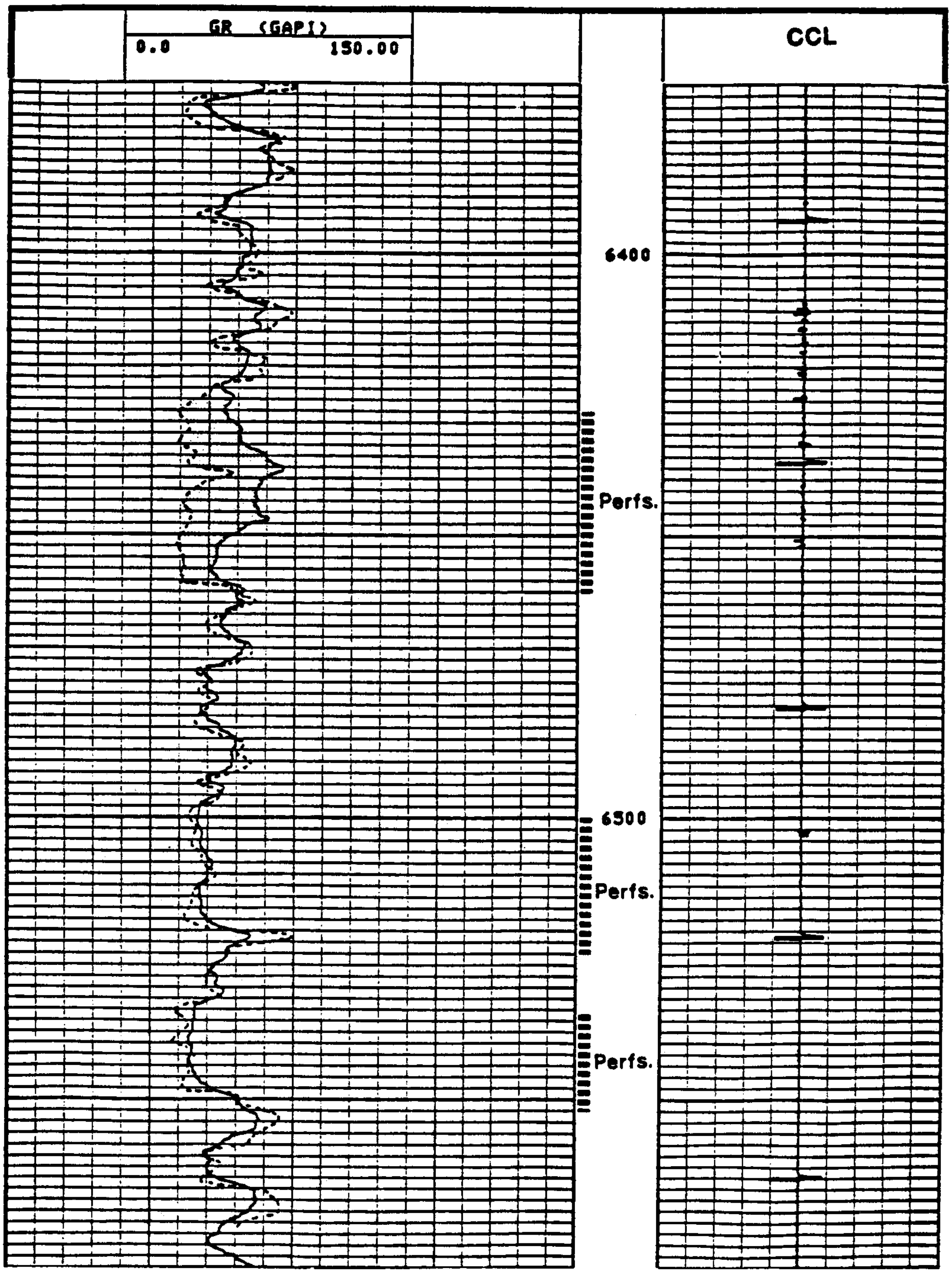


Figure 7.2.20 Bottomhole Temperature

Pre & Post Fracture Composite Gamma Ray Surveys Used to Locate Proppant Tracer Following Wellbore Clean out.



Post Foam Frac Gamma Ray, 8/5/85

Original Cement Evaluation Log, 5/8/82

Figure 7.2.21 Post-frac Gamma Survey

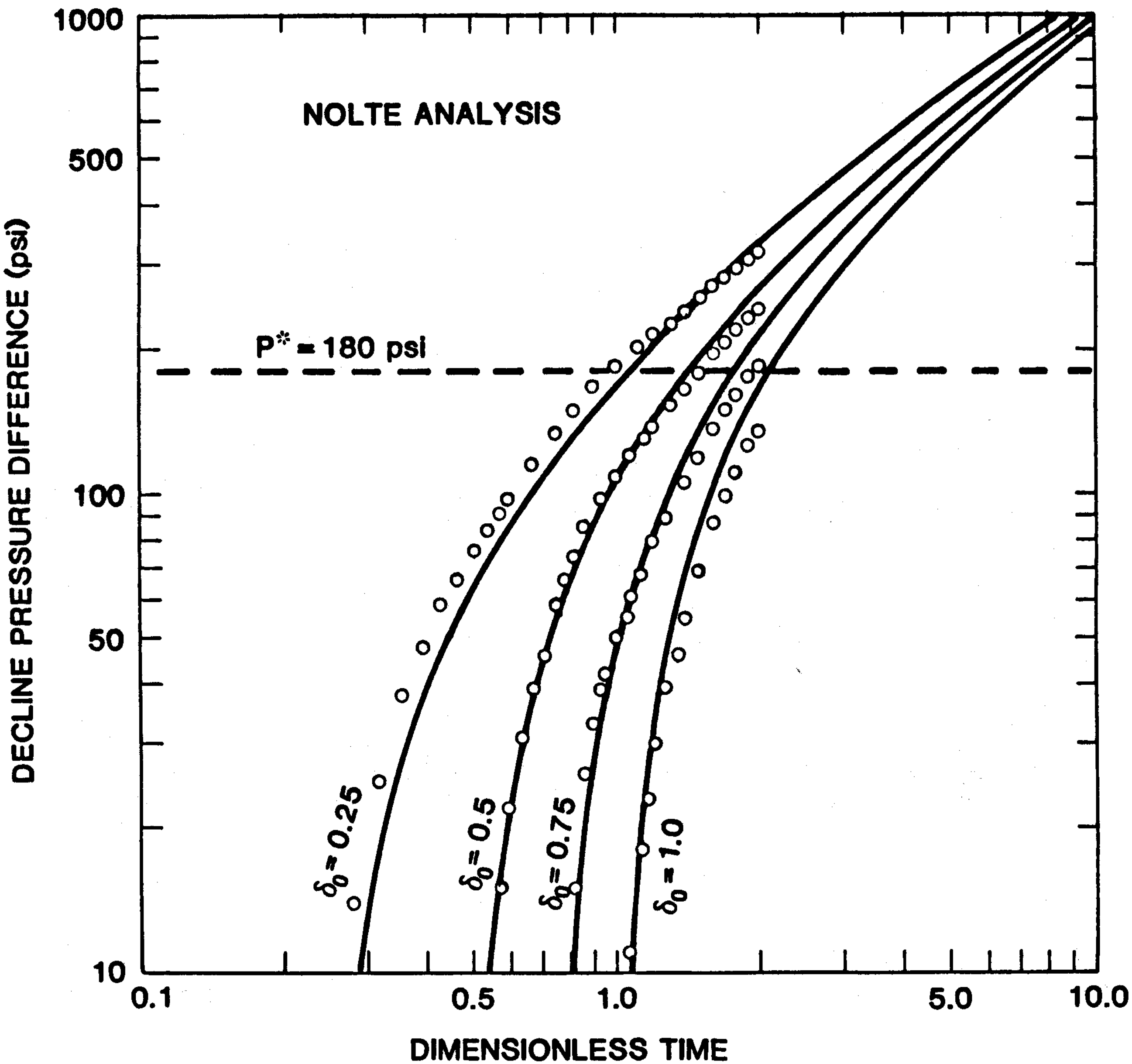


Figure 7.2.22 Nolte Pressure Decline Plot

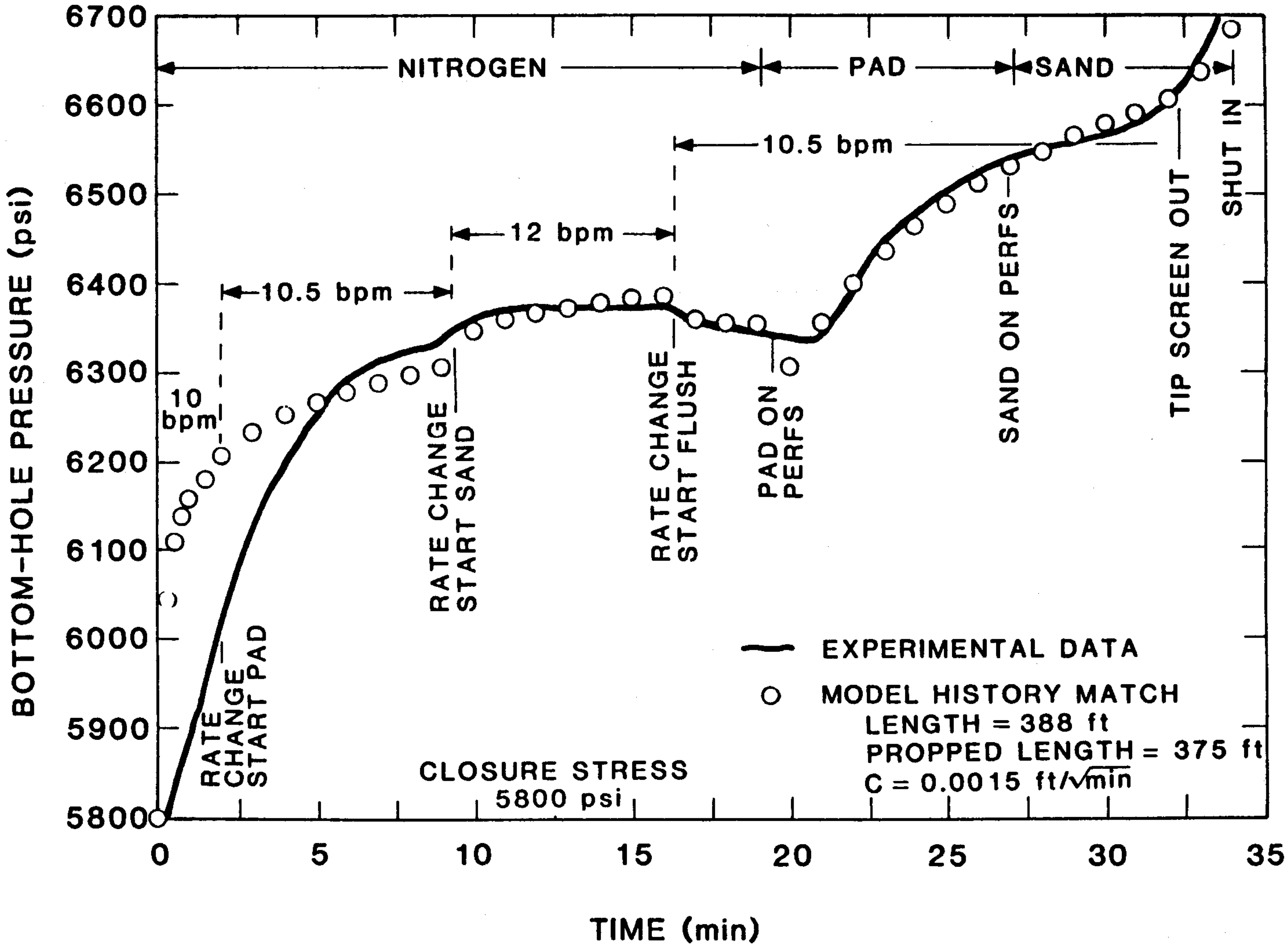


Figure 7.2.23 Constant-Height History Match

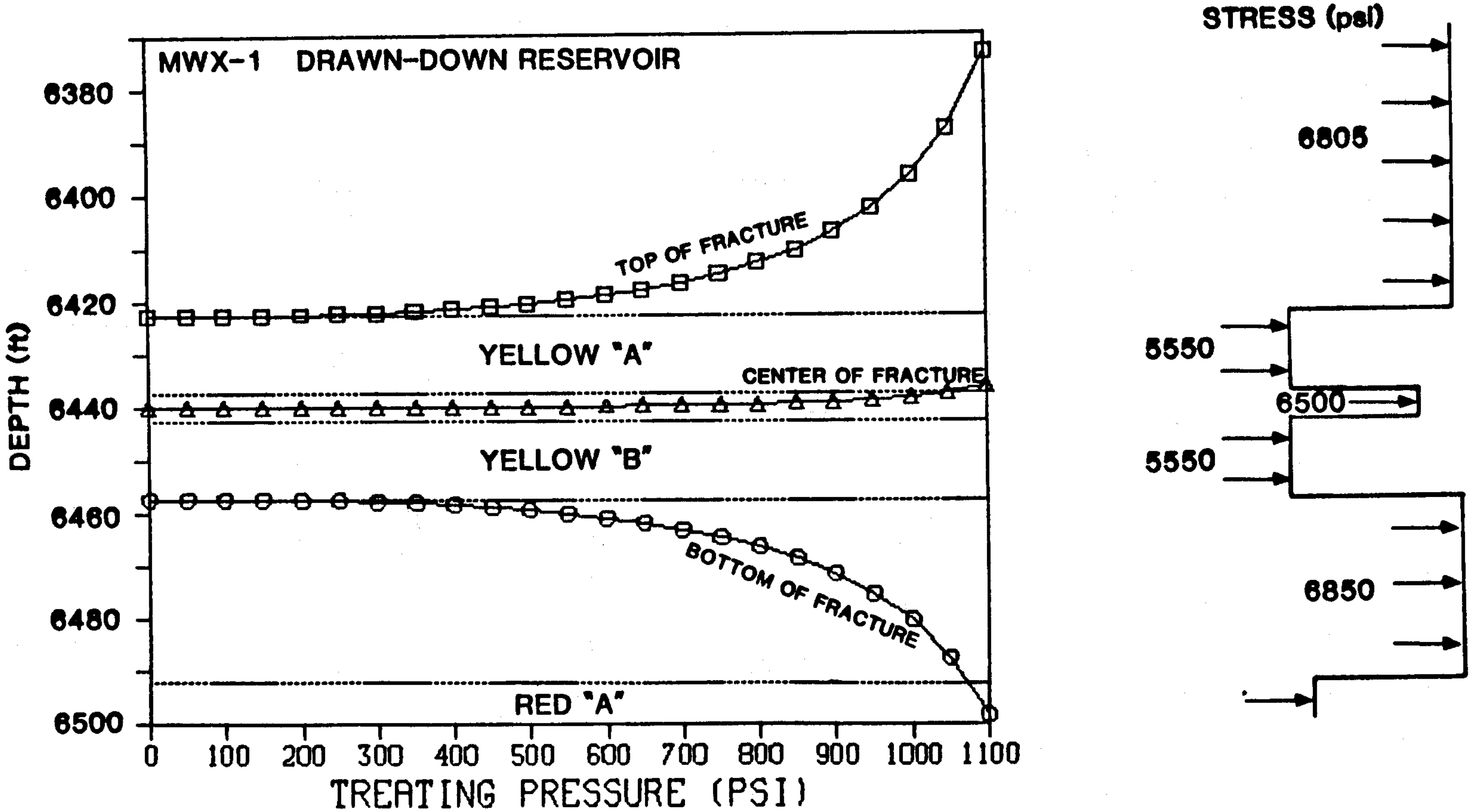


Figure 7.2.24 Drawndown Stress Distribution and Containment

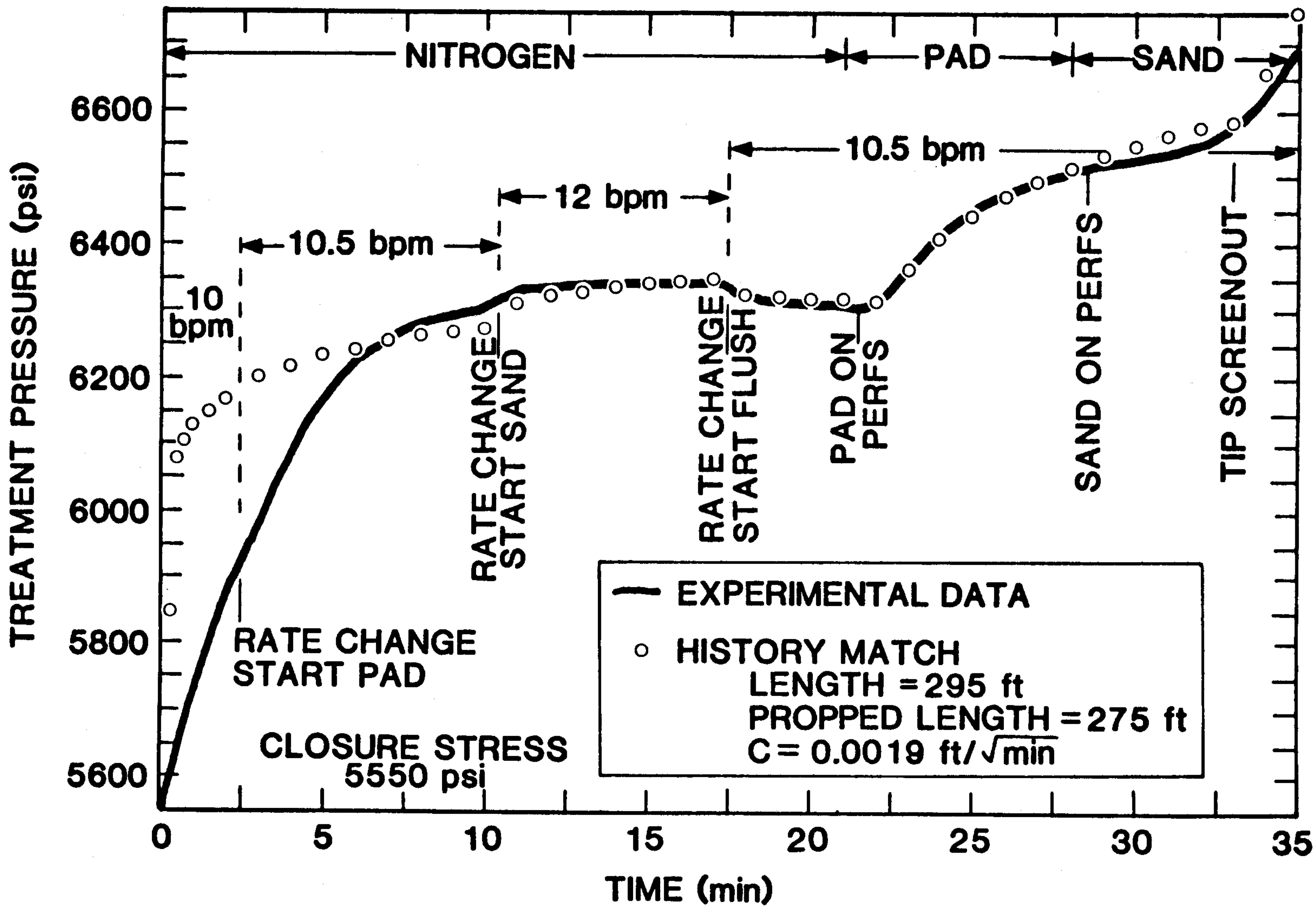


Figure 7.2.25 Variable-Height History Match

7.3 POST-FRACTURE WELL TESTING AND ANALYSIS

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A series of nitrogen fracturing experiments were performed in MWX-1 in the naturally fractured Yellow sandstone. These experiments, detailed in Section 7.2, included a two-part, unpropped nitrogen fracturing and injection test that led to a stimulation treatment involving a propped nitrogen foam fracture. Single and multiple well interference tests were conducted in conjunction with each of the fracturing experiments. The duration and extent of the tests varied depending on available time and the objectives of each experiment. A variety of measurements were made during and following each experiment that included surface pressure, rates and gas compositions, and bottomhole pressure. Additional reservoir and production data were gathered during a production test of the Red and Yellow sands in the Fall of 1985 and again during a reentry test in June, 1986.

7.3.1 UNPROPPED NITROGEN FRACTURING TESTING

The details concerning the overall objectives and analysis of the nitrogen fracturing experiments are discussed in Section 7.2.3. The reservoir engineering portion of these experiments dealt mainly with attempts to measure transient properties of this lenticular reservoir during and after each fracturing experiment.

7.3.1.1 Step Rate Test

The nitrogen step rate fracturing experiment was conducted in the Yellow sandstone in the MWX-1 well on June 11, 1985. Figure 7.2.2 is a schematic of the bottomhole well configuration for the test, and Figure 7.2.3 provides a record of the nitrogen surface injection rates and bottomhole pressure measured in MWX-1 during the test. The two remaining wells, MWX-2 and MWX-3, were configured with surface recording, bottomhole shut-in quartz pressure gauges in order to monitor the pressure transients at their respective locations during the test. Figure 7.2.4 is a composite graph showing the nitrogen injection step rates in MWX-1 and the concurrent bottomhole pressure records from MWX-2 and MWX-3.

As discussed in Section 7.2.3.4, the interference pressures in MWX-2 and MWX-3 closely reflect the N_2 fracturing pressure in MWX-1. Although there was a slightly longer delay time (3 min) for a pressure transient to be observed in MWX-3 than in MWX-2, the absolute arrival time for both wells was much faster than could be accounted for if the reservoir had consisted of just a homogeneous reservoir with an average pre-frac permeability of 0.11 md (Section 7.1.3.2). These observations suggest that either the natural fracture system that dominated the production process was enhanced at high pressure or that the observed interference was a poromechanical response, as suggested in Section 7.2.3.

Although the poromechanical response represents a credible hypothesis, natural fracture conductivity was shown in Section 7.1.10 to be pressure dependent. Thus, a pressure transient acting through a set of natural fractures with enhanced conductivity represents a plausible scenario. Because of uncertainties in natural fracture anisotropy and their conductivity as a function of pressure, as well as the spatial and temporal properties of the induced nitrogen fracture originating from MWX-1, modeling the data would provide significant uncertainty and would most probably reflect the bias associated with selected input parameters. If the response was poromechanical, then this interference data would not be representative of, nor influence, reservoir production parameters. If, however, the response is an actual transient transmitted through the natural fracture system, then the conductivity of the natural fractures must have increased during fracturing. Also note that reservoir pressures in MWX-2 and MWX-3 appeared to return to their pre-frac values as fracturing pressure in MWX-1 decreased (Figure 7.2.4). This implies that the interference response depends on pressures being at or slightly above frac pressure and thus strengthens the poromechanical hypothesis.

As shown in Figure 7.2.2, a Kuster pressure sonde was located below the bridge plug in MWX-1 in order to monitor the pressure response of the underlying Red sandstone during the fracturing occurring in the Yellow sandstone. Figure 7.3.1 is a composite plot of bottomhole pressure from the quartz pressure gauge that was observing the fracturing pressure in the Yellow sandstone and the Kuster data representing pressure in the Red sandstone. There is general correlation between the two bottomhole pressure records. The interference appears to be concurrent with nitrogen injection and the records appear to be coincidental within the limits of correlating time between the Kuster clock and real time bottomhole quartz pressure data. There are several possible reasons for such fast response: (a), the bridge plug may not have provided a continuous, gas-tight seal within the wellbore; (b) the injection nitrogen may have been transported through pre-existing natural fractures that connected the Red and Yellow sandstones together; and (c) a microannular leak may have existed between the casing, cement, and formation.

Whatever the cause of this interference, it most certainly would influence hydraulic fracture parameters and complicate modeling of observation pressure data. Unfortunately, these Kuster data were not available until the bridge plug was removed following the fracturing experiment, and therefore, this obvious connection between the Red and Yellow sandstones was not evident until that time. Although these data sets are correlatable, there are some periods when pressures between the Red and Yellow sands diverge, such as at 4.2 hours when the Kuster data drop rapidly and Yellow fracture pressure rises. Further, note that during the post-fracturing period, from 5.5 hrs on, the difference in pressure between the Yellow and Red sands also diverges, which suggests that the difference is pressure sensitive.

7.3.1.2 Reopening/Injection Test

On June 13, 1985, two days after the step rate fracture tests, a second injection of nitrogen into the existing fracture in MWX-1 was conducted. The data for this second injection, which includes bottomhole pressure and surface injection rate, are shown in Figure 7.2.5.

Figure 7.3.2 presents a continuous record of the bottomhole pressure and surface injection rate for both the step rate test on June 11 (hours 3-6) and the subsequent reopening test on June 13 (hours 52-54).

Since the pressure interference observed in wells MWX-2 and MWX-3 during the step rate fracturing test may have been the result of a poro-mechanical pressure perturbation, an attempt was made during this second test to observe mass flow between wells using nitrogen as the tracer gas. This test was a complement to the pre-frac nitrogen injection and tracer experiments conducted in the commingled Red and Yellow sandstone described in Section 7.1.10. The main differences were that this time nitrogen was injected into the Yellow reservoir alone and through the newly created fracture in MWX-1, whereas earlier, nitrogen was injected in both Red and Yellow sandstones through MWX-2.

Both observation wells were put into production following the acquisition of the interference data from the step rate fracture test. The produced gases were sampled for traces of nitrogen with a GC system similar to that used in the pre-frac tracer tests and described in Appendix 11.9. The initial flow rates from both MWX-2 and MWX-3 were very low, <10 MSCFD. However, after several hours MWX-2 was capable of producing between 50 and 60 MSCFD. Production from MWX-3 was somewhat sporadic, varying between about 10 and 30 MSCFD.

Figure 7.3.3 shows the nitrogen gas analysis from the observation well, MWX-3. The percent nitrogen has been corrected for the presence of air and thus the data in Figure 7.2.3 represents only nitrogen produced from MWX-3. For timing purposes, the nitrogen fracture and injection rates into MWX-1 are shown on the bottom of the figure. Nitrogen background values from MWX-3 were acquired for about 28 hours before nitrogen was injected into MWX-1. These background data on June 12 are an average of 0.2%.

Continuous gas sample analysis during and for two days following the nitrogen injection in MWX-1 on June 13 did not provide sufficient evidence that nitrogen had traversed the reservoir from MWX-1 to MWX-3. GC data were unavailable from June 15 until June 18 because of the low production rate. After that 3-day hiatus, MWX-3 was again produced and intermittent quantities of nitrogen were present in the produced gas with peaks ranging from 1.5% to 3.7%. Thus, the path and or streamlines from the injection well MWX-1 to MWX-3 must have been extremely tortuous and/or constricted.

Since MWX-2 had been used as the injection well for the pre-frac nitrogen injection test performed in April, residual quantities of about 3% to 5% N_2 were found to be still present in this well. Thus, GC data were only intermittently obtained from MWX-2 and were not found to be of sufficient quality to determine whether the measured nitrogen was residual gas or tracer gas originating from MWX-1.

7.3.1.3 Post Nitrogen Fracture Production Test

At the end of the nitrogen fracturing experiments, MWX-1 was produced for approximately 9 days at an average flow rate of 90 MCFD, and then shut in for a short five-day buildup test. Figure 7.3.4 is a Horner plot of that bottomhole pressure buildup data. Analysis of the Horner plot yields an average reservoir permeability of 0.047 md, which is more than twice the pre-frac average permeability of 0.022 md (Section 7.1.4.2). This should not be construed to mean that the average reservoir permeability has been increased, but only that the early time flow regime has been altered. Figure 7.3.5 is a log-log/derivative plot of the buildup pressure. Comparing this post nitrogen frac pressure buildup data with the pre-frac log-log/derivative shown in Figure 7.1.11 demonstrates the significant profile differences. The post-nitrogen-frac log-log slope is approximately 1/4 suggesting a long period of bilinear flow. This implies that the newly created, unpropped nitrogen fracture is significantly more conductive than the original natural fractures, and thus is the primary cause of this enhanced production.

Although the post-nitrogen-frac production rates were somewhat higher than the pre-fracture rates (90 MSCFD versus 55-60 MSCFD), the reservoir had been supercharged with nitrogen during the fracture and injection periods. Thus the enhancement ratio is uncertain, although the maximum value is probably not larger than 1.6. Thus, the newly created, unpropped fracture has provided a reasonable production enhancement to this naturally fractured reservoir.

7.3.2 POST STIMULATION TESTING

The stimulation experiment in the Yellow sandstone was designed to create a short (200-300 ft), propped fracture that would enhance production from this lenticular reservoir. In order to minimize liquid damage to the existing natural fractures, a 75% quality nitrogen foam was used as the transport media for the emplacement of about 12,000 lbs of intermediate strength 20/40 proppant. The objectives, design criteria, actual treatment parameters and analysis are discussed in Section 7.2.4.

The treatment was performed as designed on August 1, 1985 and all diagnostic data and analysis suggest that the final propped fracture length was about 275 ft. Pressure sondes placed below the bridge plug separating the Yellow and Red sandstones were found to have been damaged and thus could not supply information to confirm or deny whether the stimulation treatment extended down into the Red sandstone. Recall that a significant interference pressure was observed in the Red sandstone during the nitrogen fracturing experiments in the Yellow sandstone (Figure 7.3.1).

MWX-1 was intermittently produced following the treatment in order to recover as much of the residual treatment fluids as possible. A post-frac temperature log was attempted but proppant in the wellbore would not permit the tool to reach deep enough to provide useful data. A gamma ray survey was performed after the wellbore was cleaned of excess fluids and proppant and it provided evidence that the fracture was well confined in the Yellow sandstone, at least near the wellbore. The well was then reconfigured with a tubing packer and bottomhole shut-in tool in preparation for a production and well test of the newly stimulated Yellow sandstone reservoir.

Figure 7.3.6 provides a continuous record of the surface flow rate and bottomhole pressure for the entire post-stimulation test period. (Data for Figure 7.3.6 are given in Appendix 11.12.) Early production flow rate was 150 MSCFD but was cut back to about 90 MSCFD as the bottomhole pressure fell below 1000 psi. The final drawdown that began at 384 hrs lasted 8 days with an average flow rate of 100 MSCFD. This post-stimulation production represents about a 1.7 times increase over the pre-frac production flow rates, but is only about a 10% increase in the production flow rates that were measured after the unpropped nitrogen fracture experiments conducted in June. A summary of Yellow sandstone production performance is given in Table 7.3.1.

If the simulated enhancement ratios presented in Table 7.1.4 are accurate, then scaling of these simulated propped frac length suggests that the effective frac length is probably less than 150 ft. This short effective frac length may be attributed to several possible mechanisms:

- the real propped length may be actually only 150 ft,
- only 150 ft of a longer frac contacts productive reservoir rock, or
- the conductivity of the propped frac and adjacent natural fracture is considerably less than optimum.

Figure 7.3.7 is a log-log/derivative plot of the bottomhole pressure buildup that began at 576 hours (Figure 7.3.6); Figure 7.3.8 is the Horner plot of the same data. A comparison of the log-log/derivative plots from the pre-frac buildup (Figure 7.1.11), the post-nitrogen fracturing buildup (Figure 7.3.5), and the post-stimulation buildup (Figure 7.3.7) provides a qualitative assessment of the flow regimes. Clearly the post-stimulation plot shows a significant difference with respect to the pre-frac plot, but very little change when compared to the post-nitrogen-frac plot. Both the post-nitrogen-frac and the post-stimulation pressure buildup histories suggest that the presence of a newly created frac, propped or unpropped, leads to an early flow period that is marked by near-linear flow. However, since the flow regime is not entirely linear and the enhancement ratio is only about 1.5, this implies that the fracture is not as highly conductive as it should be. Whether this less-than-optimum conductivity is the result of damage to the propped frac itself or to the natural fractures that support the propped frac is not clear from these data.

Previous fracturing and stimulation experiments in the paludal interval showed that residual treatment liquids resulted in transitory damage to the conductivity of the natural fractures.[1] Thus, the liquid impairment that primarily effects the natural fracture system was again considered a deterrent to optimum production in the coastal Yellow sandstone.

One further complication to an already complex problem involved a review of the Kuster pressure data acquired from the Red sandstone during the early portion of the post-stimulation testing in the Yellow sandstone. The Kuster sonde was emplaced below a bridge plug in a manner similar to that shown in the well schematic of Figure 7.2.2, and was thus isolated from the Yellow sandstone. Figure 7.3.9 is a composite plot that shows the flow rate and bottomhole pressure for the Yellow sandstone (an expansion of the early data shown in Figure 7.3.6) along with the Kuster pressure data from the supposedly isolated Red sandstone. It is clear that the Red sandstone pressure responded in an almost one-to-one fashion to changes in the Yellow sandstone. Thus, the two reservoirs were obviously communicating and isolation had been breached, if it ever had been achieved. Note that whatever path existed between Red and Yellow sandstones it was certainly a tortuous one since the pressure drop during production was about 600 psi as opposed to about 100 psi during the latter part of the buildup.

7.3.3 TRACER TESTING BETWEEN THE RED AND YELLOW SANDSTONES

Since data acquired on two separate occasions showed that pressure communication existed between the Red and Yellow sandstones in MWX-1, a tracer interference test was designed that might provide information concerning the nature and extent of the leak mechanism. The primary intent of this test was to determine whether the produced gases measured during the post-stimulation test in the Yellow sandstone were the result of enhanced production stemming from the propped stimulation or whether there was sufficient communication with the Red sandstone to allow the Red sandstone to enhance production. A series of flow/interference pressure and tracer tests was scheduled that used a set of Lynes inflatable packers as shown in Figure 7.3.10. This configuration was intended: (a) to provide complete wellbore isolation between the Red and Yellow sandstones; (b) permit independent bottomhole pressure measurements of both sandstones, and (c) enable separate or commingled production through tubing and annular regions. Each of the packers was individually controlled, which permitted the Red and Yellow intervals to be individually or collectively produced or pressurized. A nitrogen tracer test was performed that involved injecting nitrogen through the annulus and into the Yellow sandstone while the Red sandstone was being produced.

Although there were significant and often frustrating operational problems that reduced the amount of quality data, there was sufficient information available to indicate that the leak between the Red and Yellow was small and had little effect on the post-stimulation testing of the Yellow sandstone. Independent production and pressure measurements of the Red and Yellow sandstones suggested that some form of pressure communication existed between the intervals, but that the flow path was very small. Further, this small leak appeared to be time-dependent and contingent on wellbore pressure, indicating that the leak might be a microannular region at the wellbore. Tracer monitoring of gas from the Red sands using a GC system while injecting nitrogen into the Yellow sands indicated that little if any nitrogen passed from the higher pressured Yellow sands into the lower pressured Red sands that were being produced.

7.3.4 REENTRY WELL TESTING OF THE COMMINGLED YELLOW AND RED SANDSTONES

In June, 1986, after an almost continuous 6-month shut-in period, the commingled Yellow and Red sandstones were produced into the local pipeline. The primary intent of this brief reentry test was to assess the short-term production changes that may have occurred in the stimulated Yellow sandstone. A previous test of a paludal interval that appeared to have impaired production following stimulation demonstrated that the damage mechanism was temporary and probably the result of entrapped liquids in the fracture system.[1] The paludal reentry test was conducted after an 18-month shut-in and showed a significant production increase indicating that the effects of the damage significantly diminished during this 18-month shut-in. Thus, the reentry test of the coastal sands was aimed at determining whether potential damage mechanisms similar to those found in the paludal interval would be sufficiently diminished during only a 6-month shut-in.

Figure 7.3.11 shows the wellbore configuration used to test both the paludal and coastal intervals. A tubing packer at 6998 ft separated and isolated the paludal and coastal perforations. Initially, the paludal was tested through the bottom of the integral tubing string. Following the paludal reentry test, a tubing plug was placed at 6950 ft, thus isolating the paludal reservoir. The tubing was then perforated near the bottom of the coastal interval and then the commingled Red and Yellow sandstones were produced through the tubing.

Figure 7.3.12 is a composite plot of the surface gas flow rate, and tubing and casing pressure for this coastal reentry test. The initial high flow rate of 300 MSCFD was intended to produce the wellbore storage volume while reducing the bottomhole pressure to previous test pressure values of 900-1000 psi. That the flow rate had to be reduced to about 110 MCFD to maintain a steady surface pressure of 750-800 psi suggests that no real increase in producibility had occurred during this 6-month shut-in period. Further, since this test involved commingled production from both the Red and Yellow sandstones, the production from the Yellow alone was probably no greater than 75-85 MSCFD.

7.3.5 CONCLUSIONS

The stimulation of the coastal Yellow sandstone was conducted in two parts: a series of unpropped nitrogen fracture experiments followed by the main propped stimulation treatment.

A series of unpropped nitrogen fracture experiments was successfully conducted in MWX-1 in order to assess certain reservoir and fracture parameters for the impending stimulation of the coastal Yellow sandstone. Well testing of this naturally fractured lenticular reservoir following the nitrogen fracturing experiments showed that the early time flow regime in the reservoir had been noticeably altered when compared with pre-frac data and now resembled a linear system representative of a created fracture. Furthermore, production had been increased by about 50% over pre-frac production. Thus, this unpropped nitrogen hydraulic fracture was found to be significantly more conductive than the original natural fractures and was therefore draining a notably larger area of the reservoir.

The hydraulic stimulation of the Yellow sandstone was a relatively small nitrogen foam treatment designed to create a frac with a propped length of about 200-300 ft. Following the successful execution of this frac, a well test was performed to measure the extent of production enhancement. When pre- and post-stimulation production are compared, the amount of increased production suggests that the effective propped frac length is no more than 150 ft. In fact, when comparing the unpropped and propped production rates there is little additional enhancement. Table 7.3.1 presents a summary of the production performance from the pre-frac, post-nitrogen-frac, post-stimulation and reentry well tests. When the added complication of a small but finite leak between the Red and Yellow reservoirs is included in this comparison, then differences of 10-15 MSCFD are probably well within the overall uncertainty. Therefore it is difficult to state the exact nature and length of the induced fractures.

The log-log/derivative data show that a significant change occurred in the early flow regime following each of the fracturing experiments. The flow regime after the nitrogen fracs was considerably more linear than the pre-frac, but somewhat less than that seen after the creation of the propped frac. This implies that both the unpropped and propped fractures exhibit relatively high, dimensionless frac conductivities. Since no apparent production increase was seen to occur between the unpropped and propped tests this implies that the effective length of the propped frac is shorter than the unpropped length or that there had been a decrease in the average conductivity of the reservoir adjacent to the propped fracture. Damage mechanisms to the natural fractures that connect the reservoir and the newly created frac have been postulated and tested.

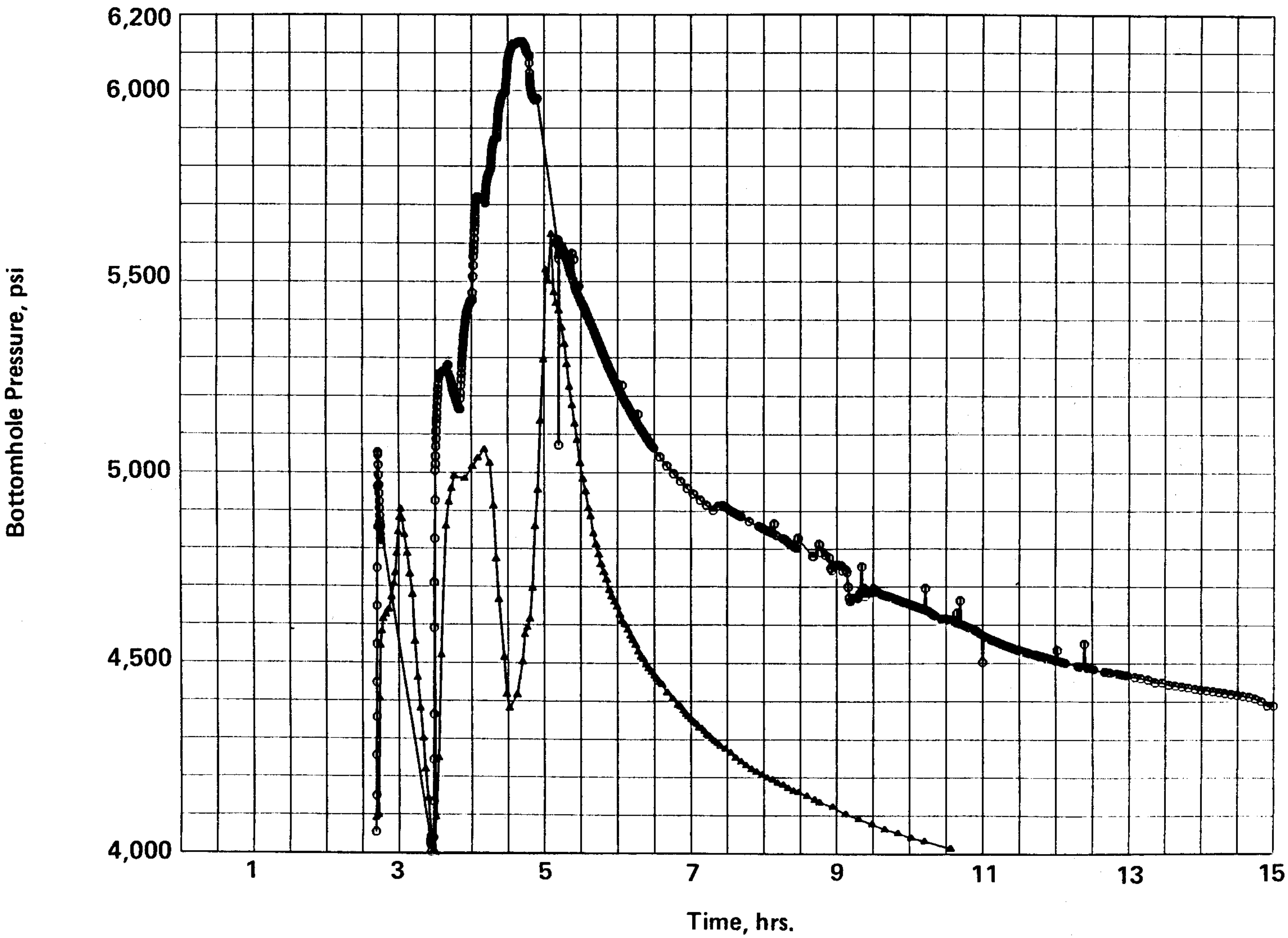
A reentry test of the stimulated Yellow sandstone following a 6-month shut-in period did not provide evidence of any increase in production that may have resulted from reducing the effects of reservoir damage. Thus, the damage mechanism in this coastal interval might either be different from that found in the paludal interval or the time to effectively clean up the damage is in excess of 6 months.

7.3.6 REFERENCES

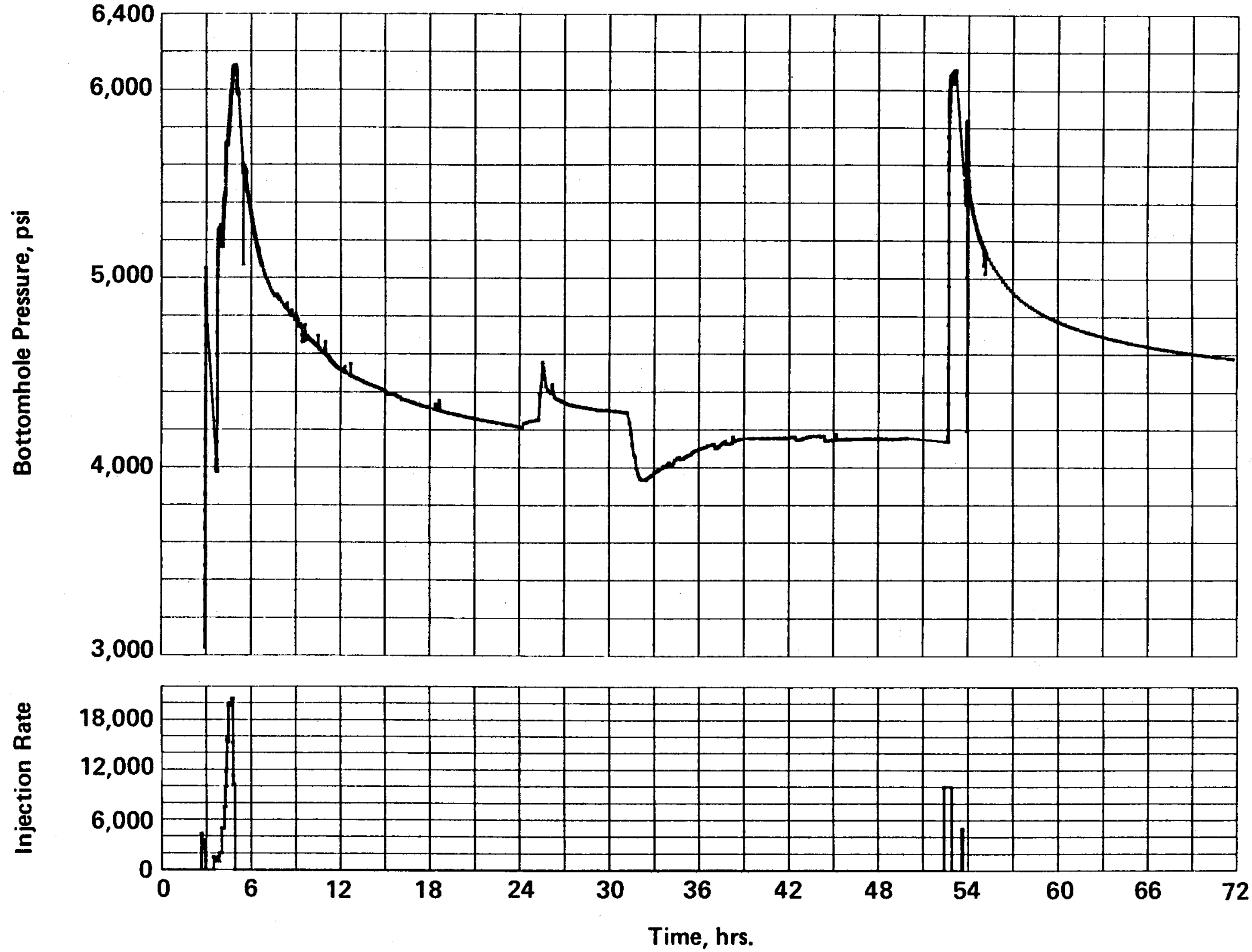
1. Branagan, P. T., C. L. Cippola, S. J. Lee, and L. Yan, "Case History of Hydraulic Fracture Performance in the Naturally Fractured Paludal Zone: The Transitory Effects of Damage," SPE/DOE 16397, Proceedings of the 1987 SPE/DOE Joint Symposium on Low Permeability Reservoirs, Denver, CO, May 18-19, 1987, pp 61-71.

Table 7.3.1 Summary of Coastal Yellow Sandstone Production Performance

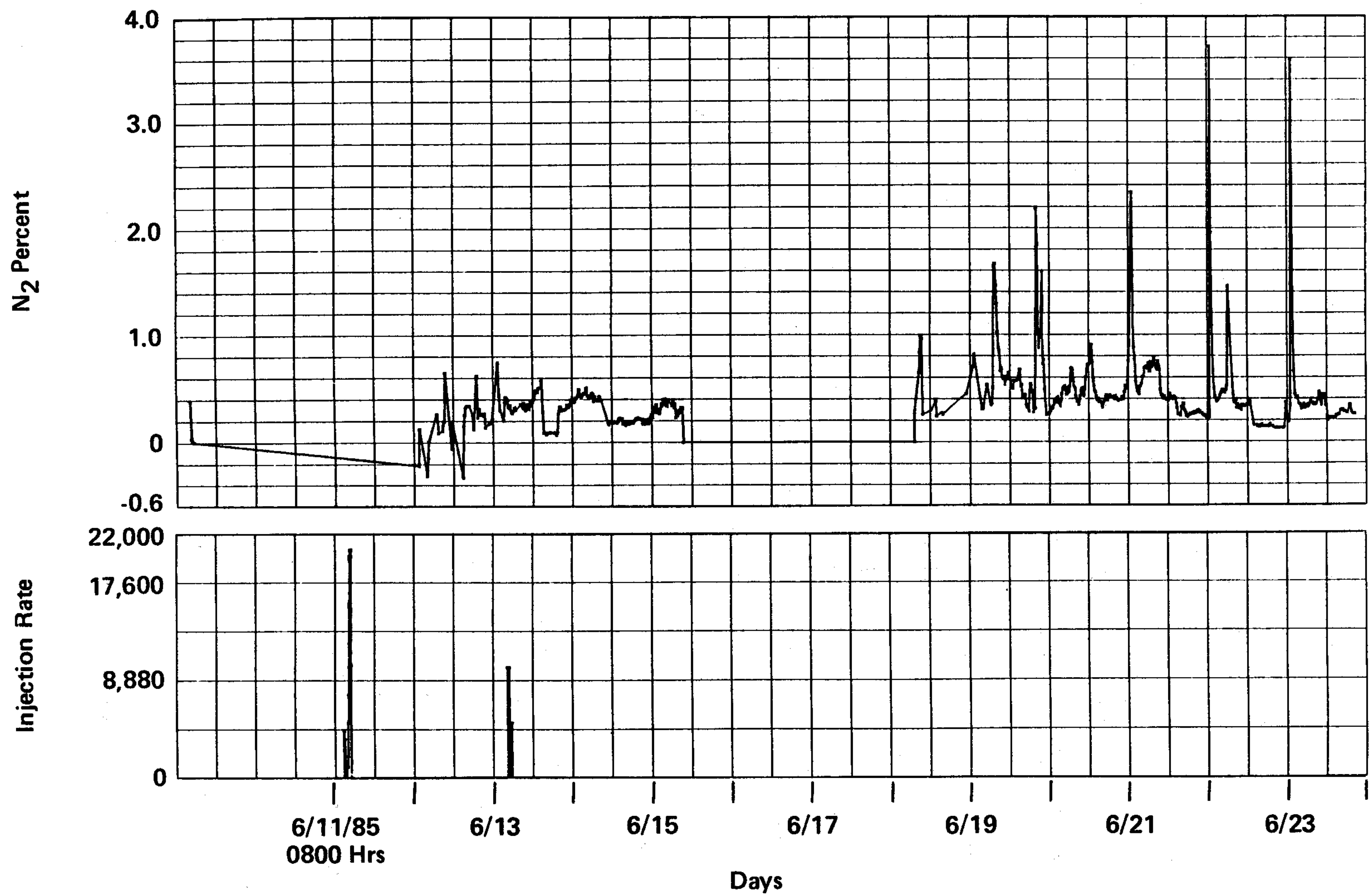
	Test Date	Maximum Flow Rate (MSCFD)
Pre-Frac	November 1984	55-60
Post Nitrogen Frac, Unpropped	June 1985	90
Post Nitrogen Foam Frac, Propped	August 1985	100
Reentry	June 1986	75-85



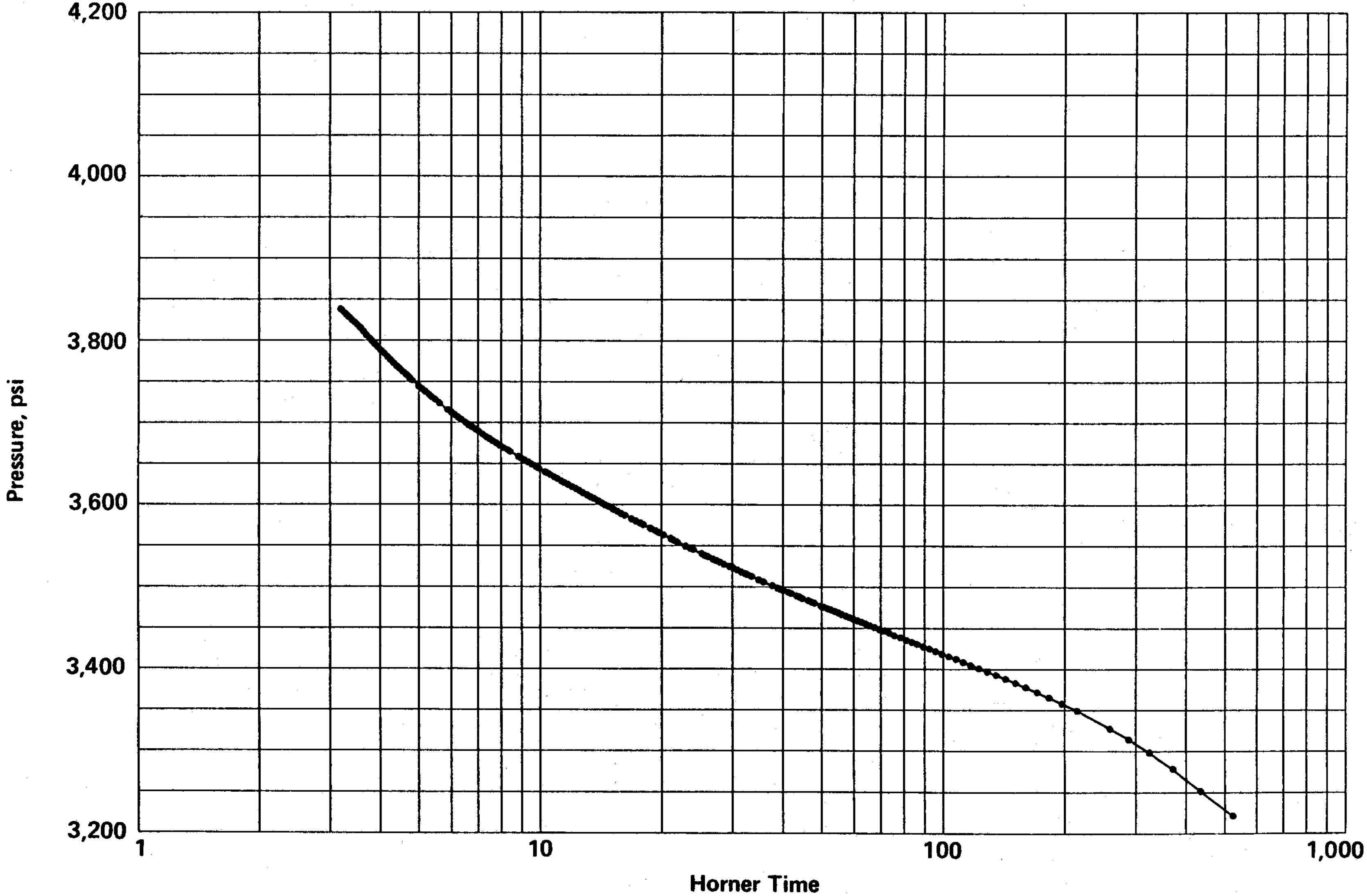
7.3.1 Composite plot of the bottomhole pressure in Yellow sandstones (circles) and Kuster sonde pressure in the Red sandstones (triangles) for the nitrogen step rate test.



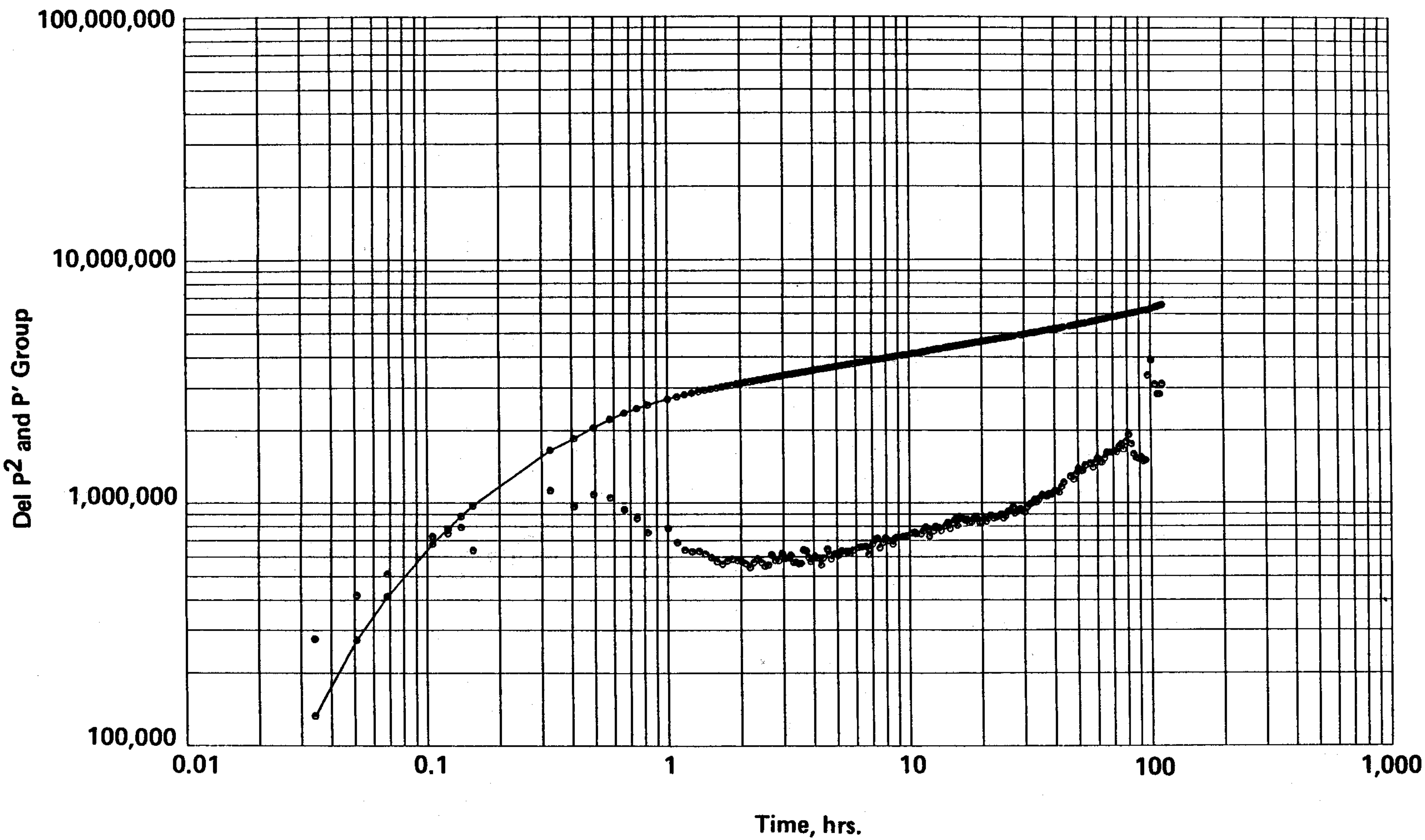
7.3.2 Bottomhole pressure and injection rate for the unpropped nitrogen fracturing tests.



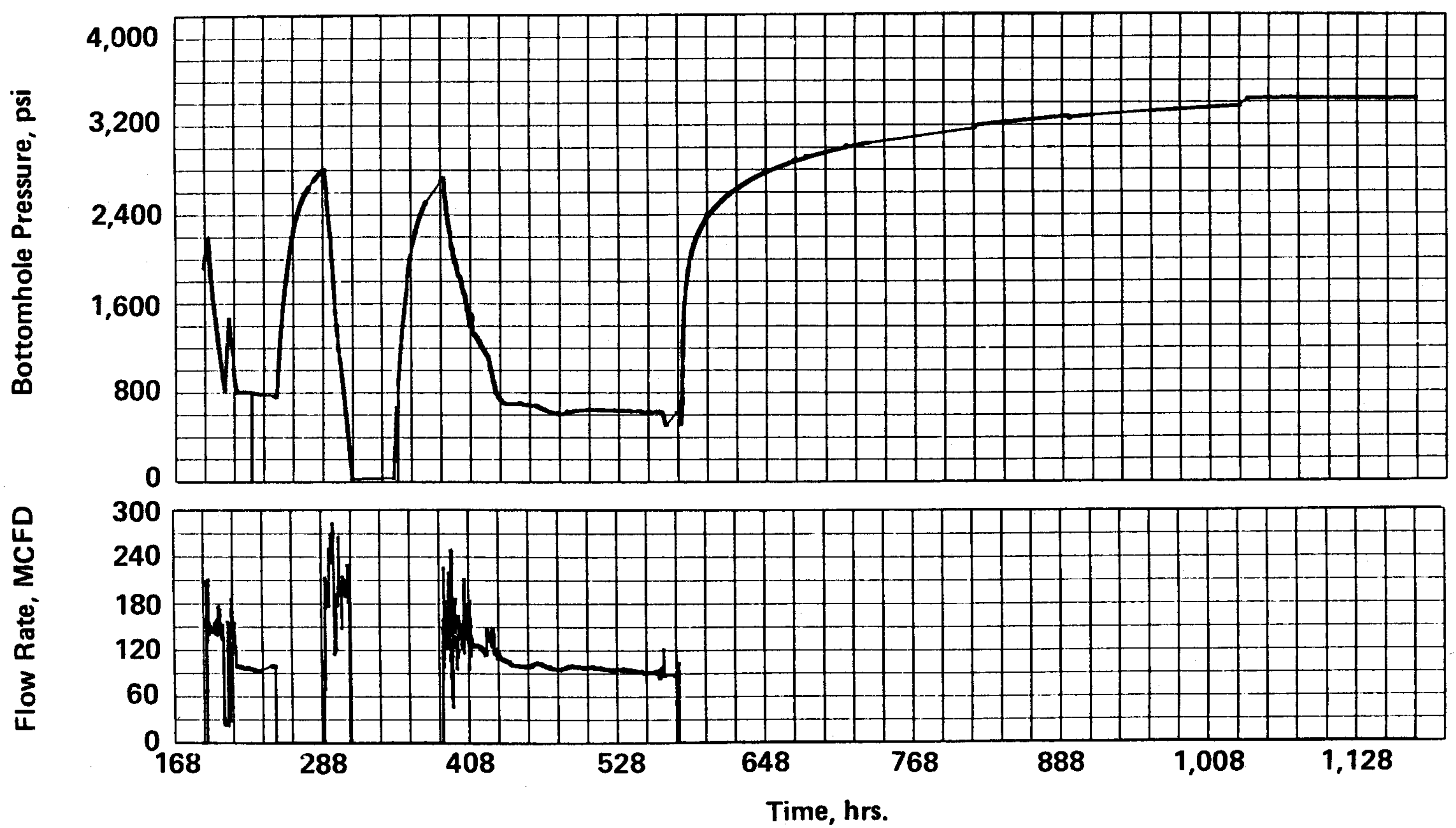
7.3.3 Nitrogen gas analyses from MWX-3 during the unpropped nitrogen fracturing tests.



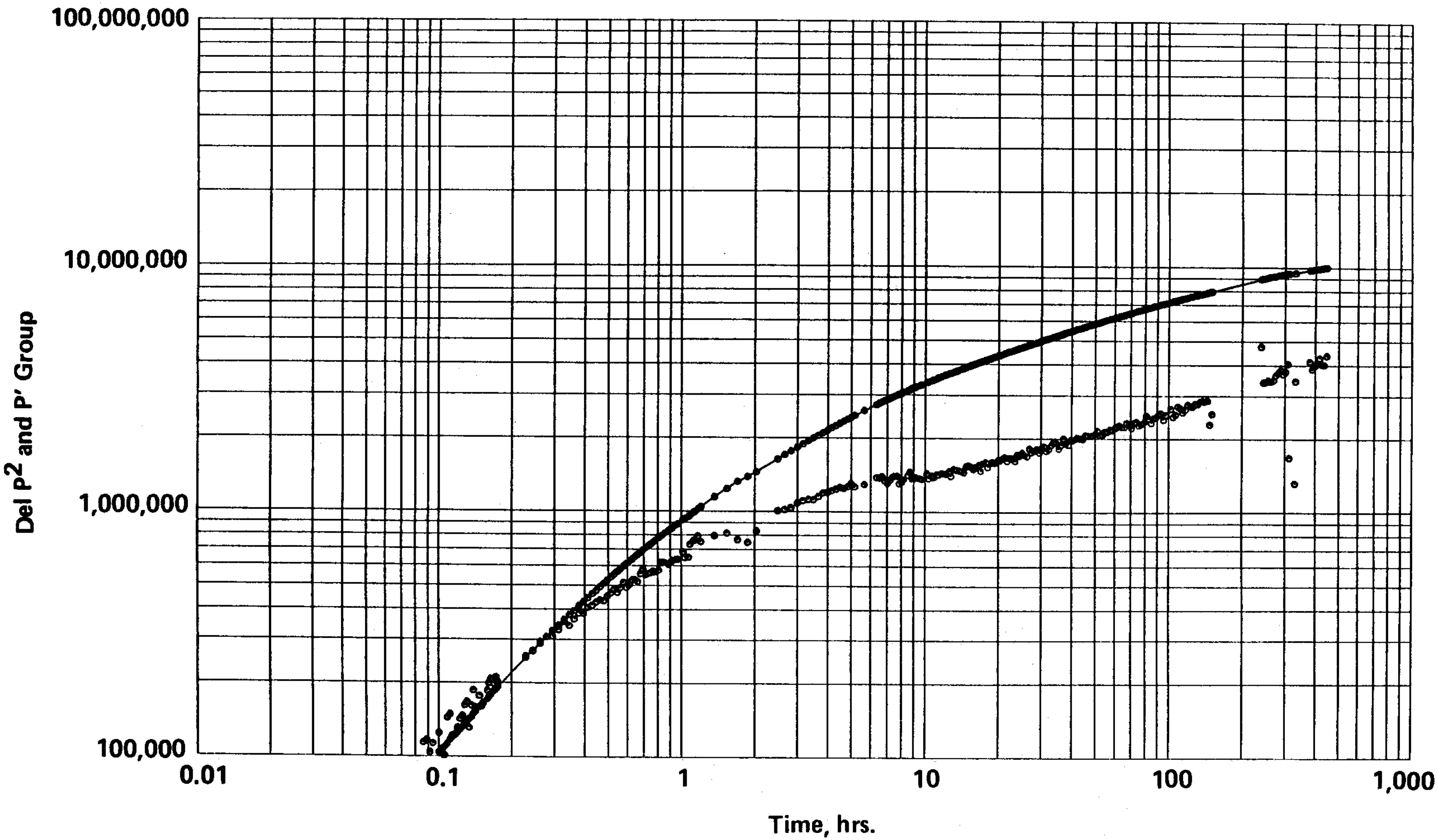
7.3.4 Horner plot of the pressure buildup data from the testing of the Yellow sandstone following the unpropped nitrogen fracturing experiments.



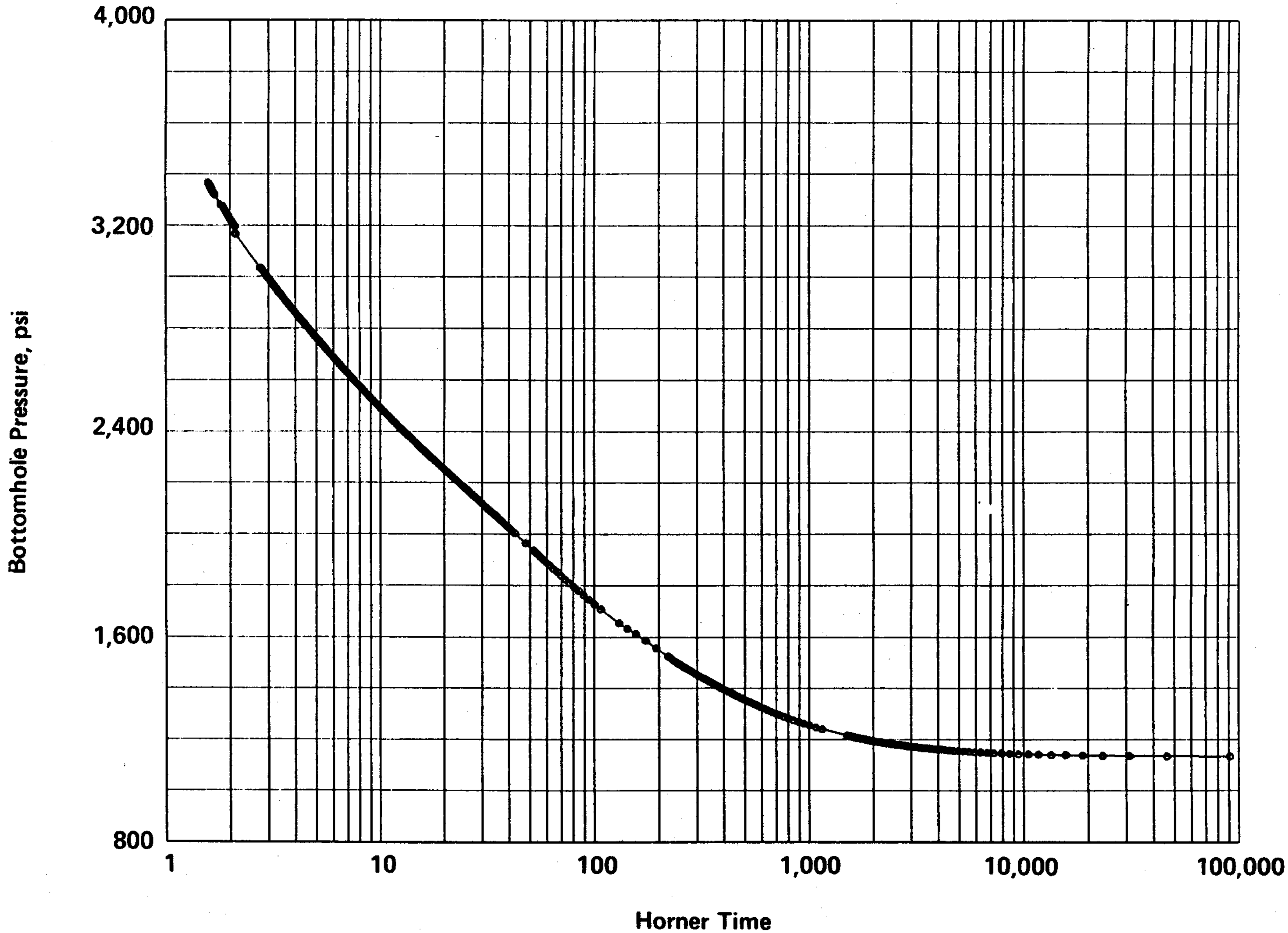
7.3.5 Log-log/derivative pressure buildup data from the testing of the Yellow sandstone following the unpropped nitrogen fracturing experiments.



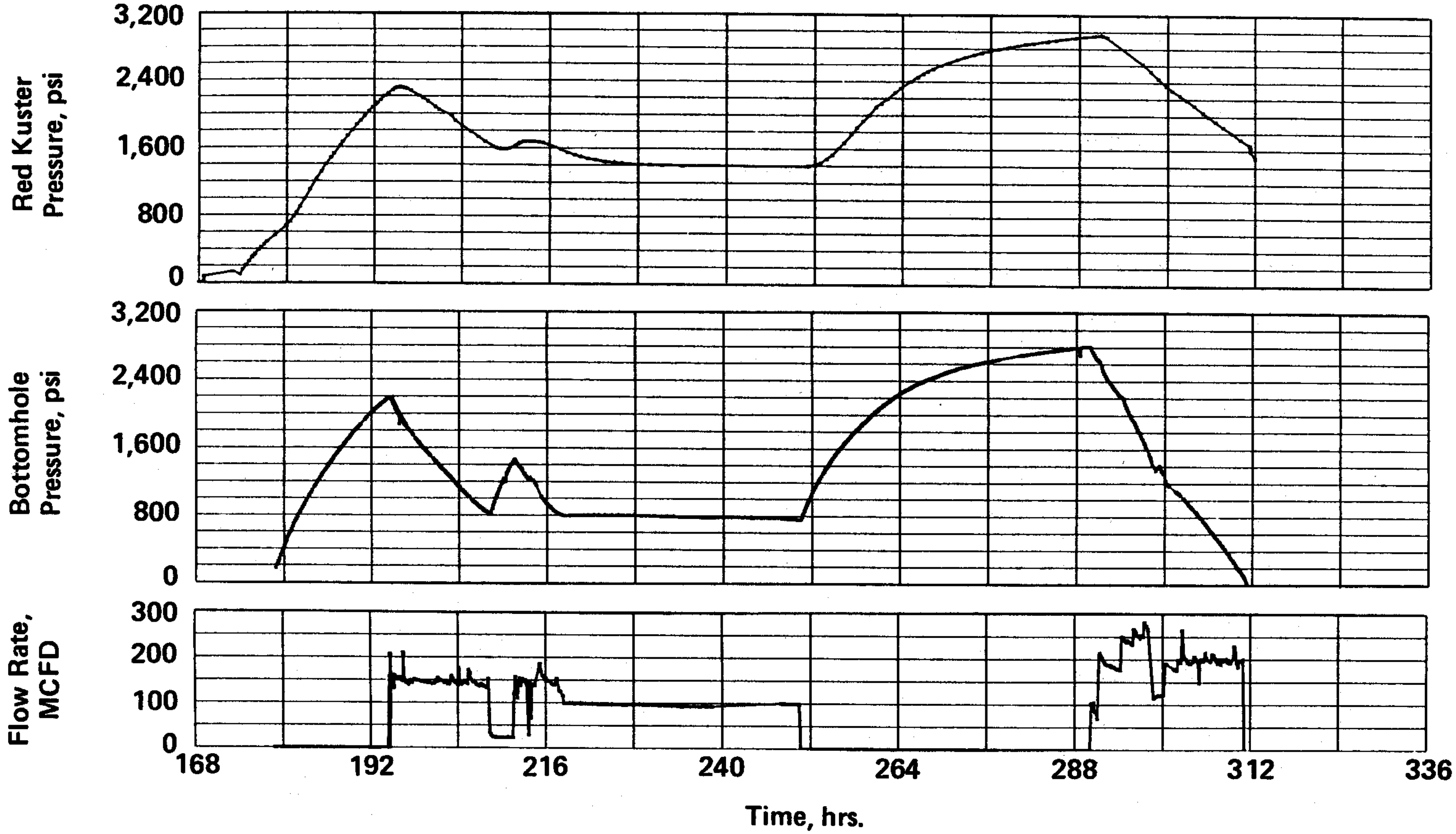
7.3.6 Post stimulation production and well testing of the Yellow sandstone, showing surface flow rate and bottomhole pressure.



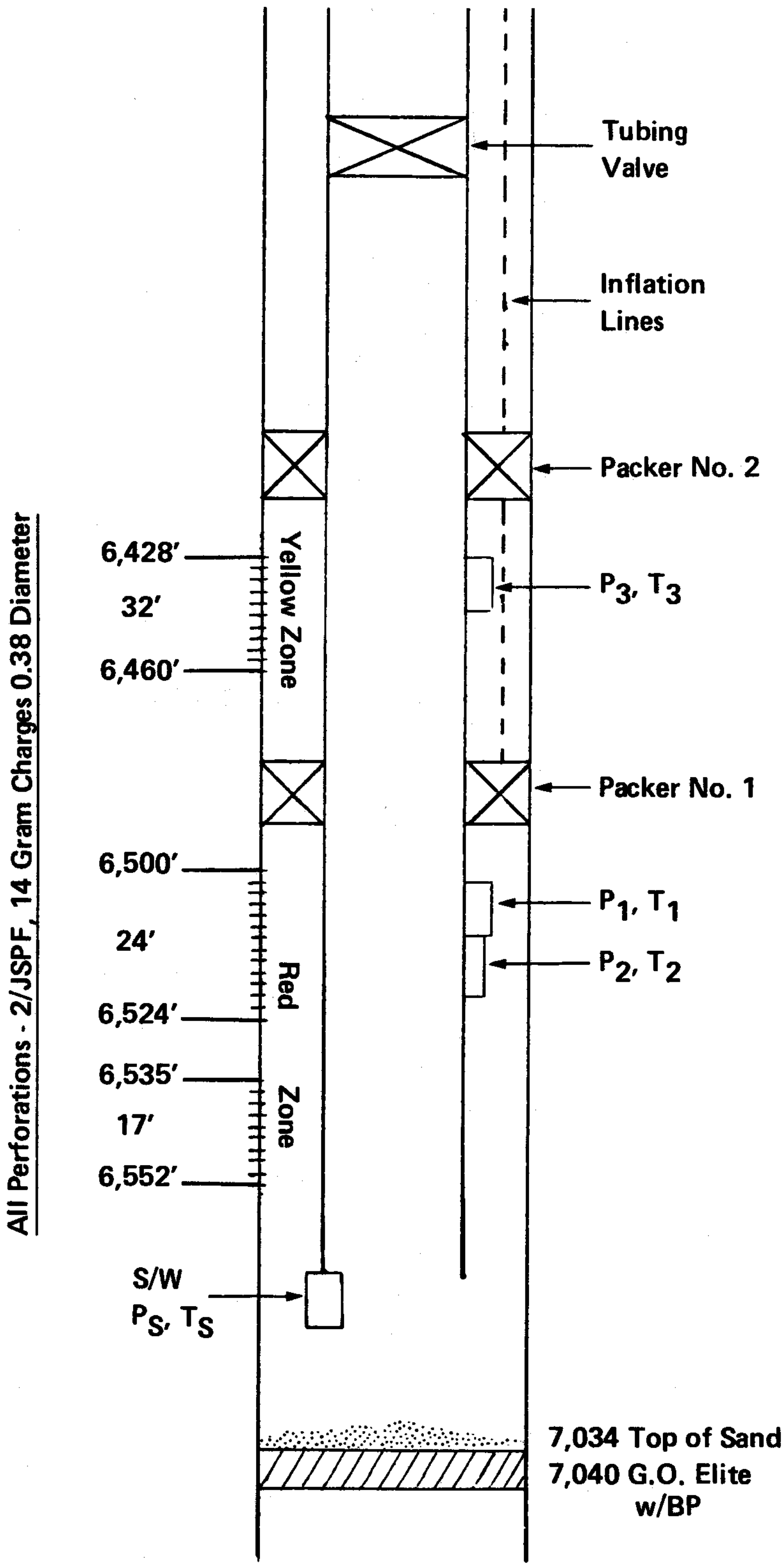
7.3.7 Log-log/derivative pressure buildup data from the testing of the Yellow sandstone following the propped stimulation treatment.



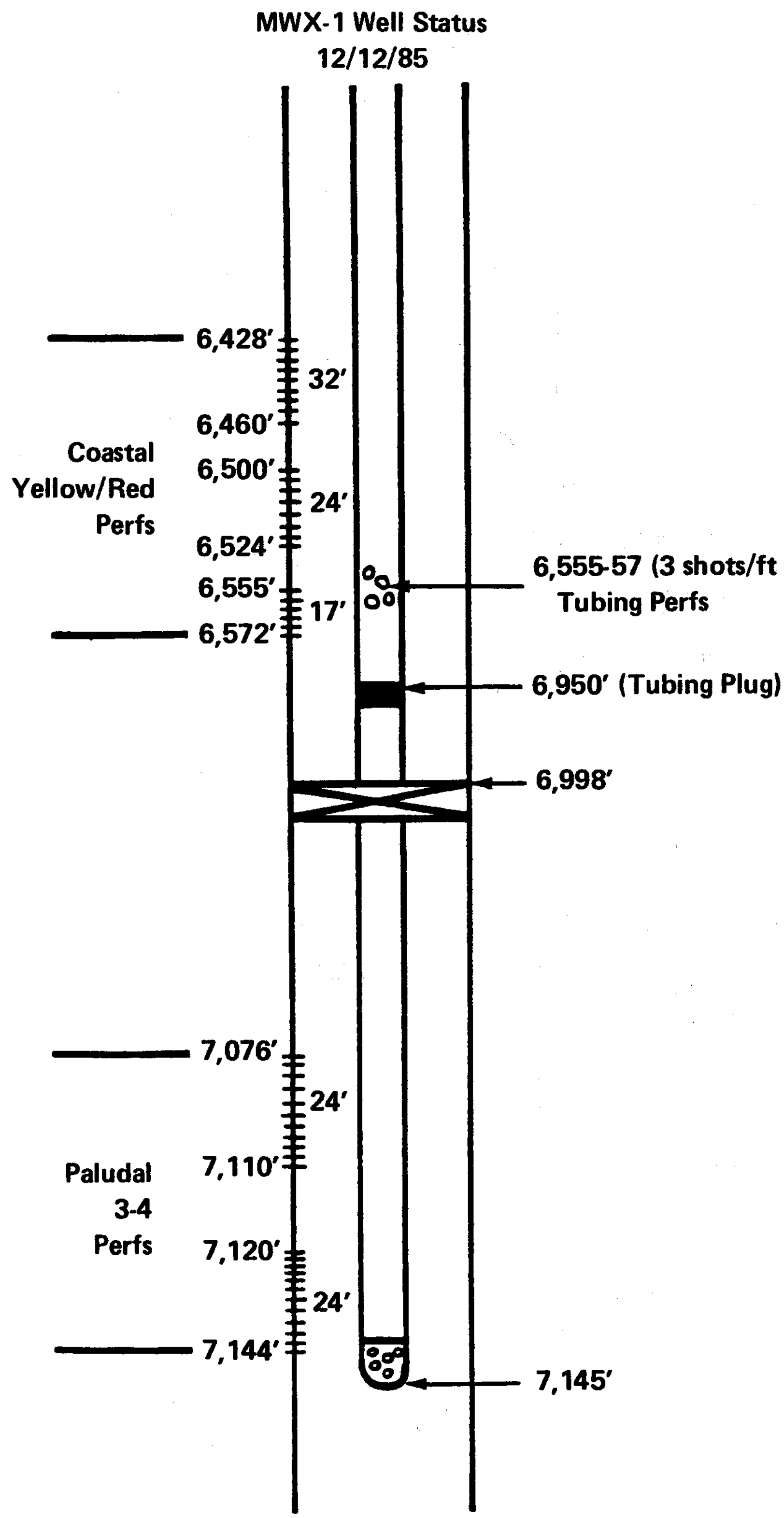
7.3.8 Horner plot of the pressure buildup data from the testing of the Yellow sandstone following the propped stimulation treatment.



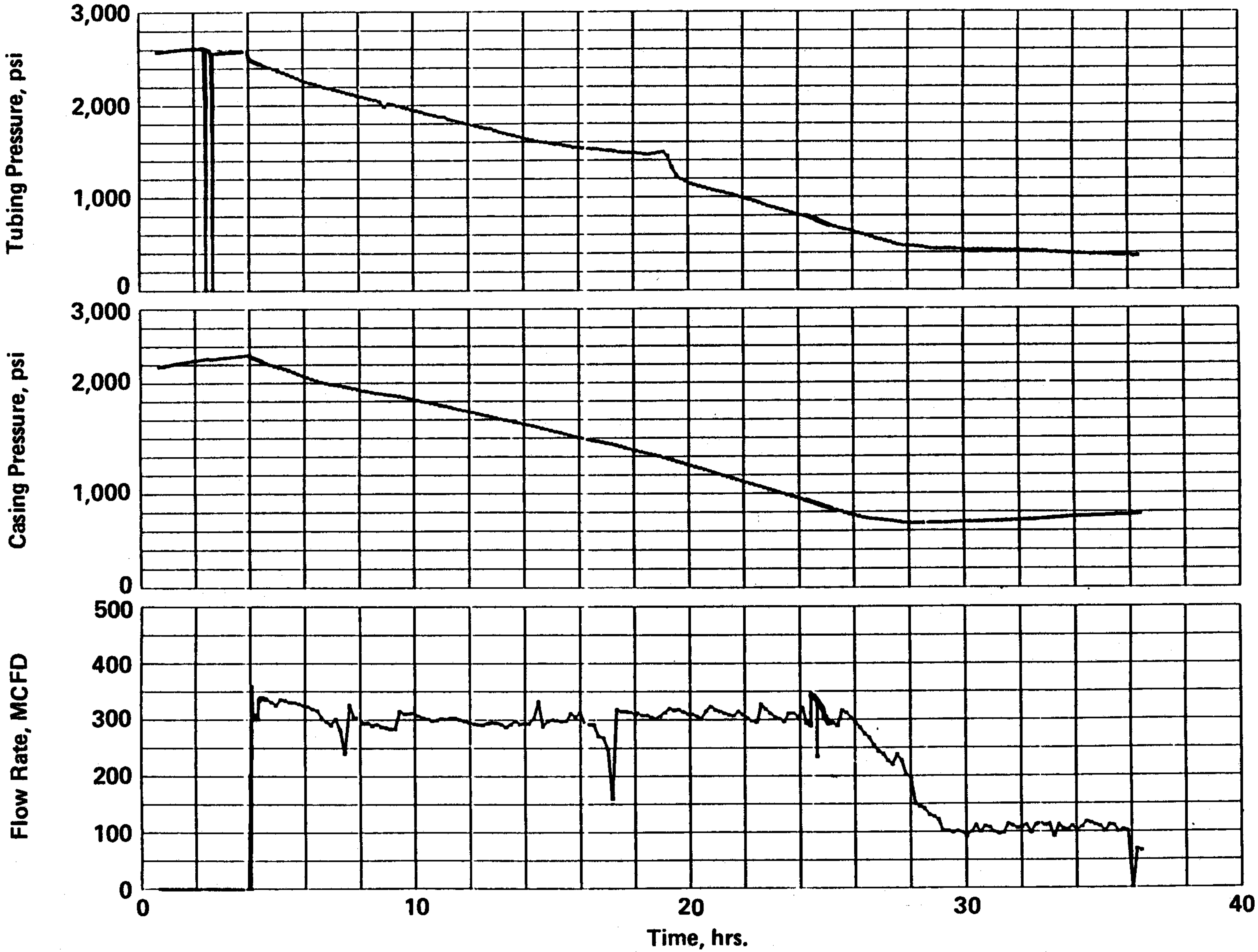
7.3.9 Composite plot of the post-stimulation pressure and flow rate in the Yellow sandstone, along with the Kuster sonde pressure data from the "isolated" Red sandstone.



7.3.10 Schematic of the bottomhole packer assembly used during the interference and tracer testing of the Yellow and Red sandstones.



7.3.11 Wellbore configuration used during the independent reentry testing of stimulated paludal and coastal reservoirs.



7.3.12 A composite plot of the surface flow rate, tubing, and casing pressure during the reentry testing of the coastal sandstone.

8.0 LABORATORY STUDIES

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8.1 INTRODUCTION

Pre- and postfrac laboratory studies were done as an integral part of the coastal zone operations described in Sections 2.0 and 7.0. A thorough description of the laboratory studies as well as attendant discussions are found in Reference 1.

The stimulation operations were conducted in the Yellow sandstone of MWX-1 at 6425-6475 ft. The sandstone is extremely tight as permeabilities are in the few tenths of a microdarcy range, and it is among the least permeable sands studied in the Mesaverde. Capillary pressures range around 500 psi and higher, and this rock is prone to imbibition and increased saturation from water-based fluids (Section 5.0).

Very extensive pre- and postfrac production testing was conducted (Sections 7.1 and 7.3). Prefrac tests indicate an effective formation permeability of about 12 microdarcies, well above the permeability existing in the matrix sandstone rock. Natural fractures are believed to account for this discrepancy between the formation and matrix permeabilities. Core and outcrop studies suggest that the natural fractures occurring in the coastal zone are very narrow (Section 3.0).

Previously, stimulation operations were conducted in the paludal interval some 600 ft below the Red and Yellow coastal sandstones.[2,3] There are similarities in properties of the coastal and paludal zones; matrix permeabilities are in the microdarcy range with formation permeabilities about two orders of magnitude higher than that of the matrix rock. Our experience in stimulating the paludal zone with HPG gel suggested that the fracturing fluid used in the paludal zone stimulations may have caused intermediate to long-term formation damage. This damage is reversible, at least in part.[4,5]

Because of the apparent damage to the paludal zone from the stimulation, a staged plan was developed for stimulating the coastal zone (Section 7.2.1). A major aspect in the propped coastal zone stimulation was the use of a nitrogen foam rather than the more conventional water-based gel. The liquid phase contained 20 lb./1000 gal of a "relatively clean" biopolymer. It was hoped that the use of foam with the biopolymer would minimize formation damage. Two small hydraulic fracture treatments were conducted in the coastal zone: one unpropped with nitrogen gas, the other with 70 quality nitrogen foam with proppant (Section 7.2). We desired to make a comparison between the unpropped, "nondamaging" nitrogen gas frac and the propped nitrogen foam frac (Tables 7.2.1 and 7.2.2). The results of the foam stimulation were less then expected: about a 60 percent increase in production from the prefrac value, slightly more than the production increase that was realized from the N_2 gas stimulation.

The laboratory data presented in this section were used to help explain the production results from the coastal stimulation. This section, in effect, takes this laboratory data and integrates it with field data, the earlier core data, and results from the paludal zone stimulation in an attempt to clarify the results of the propped coastal zone stimulation.[1]

8.2 LABORATORY MEASUREMENTS SUPPORTING THE COASTAL STIMULATION

From the paludal zone experience, it was felt that a fairly complete series of both pre- and postfrac lab tests was needed to help design the propped stimulation and to be in a position to provide information about postfrac production. These laboratory tests included:

- Estimates of permeability degradation and leakoff from foam frac fluids in tight sandstone. These included measurements with matrix rock and artificially fractured core used to simulate effects on natural fractures.

- Core analysis in rock adjacent to the sandstones, mainly mechanical rock properties (Section 5.4.4) and proppant-related effects.

- Stress-related mechanical rock property measurements to predict fracture azimuth and the in situ stress state (Section 6.0).

- Proppant-closure stress cycling to stimulate production shut-in test sequences which occur in postfrac well testing.

- Study of creep effects on the conductivity of the created fracture and related long-term proppant embedment.

- Analysis of frac and returned fluids for polymers and decomposition products in order to estimate the amount and state of the gel still in the formation.

- Water analysis of prefrac and postfrac fluids to look for evidence of formation water production.

The laboratory work supporting Multiwell Experiment stimulations has continued almost uninterrupted from the time before the paludal stimulations through the final fluvial stimulations. There are some results pertinent to the coastal zone stimulation that were done in support of the later fluvial zone stimulation. Since a biopolymer foam was used in both the coastal and fluvial stimulations, much of the laboratory work centered about the biopolymer is relevant to operations in both zones. In addition, as work progressed, a larger portion of the laboratory program focused on damage mechanisms to these narrow natural fractures. This work was centered around artificially fractured core to estimate effects of frac fluids and additives on natural fractures. Much of this work is relevant to the stimulations of all three lenticular formations (paludal, coastal and fluvial). Inclusion of some of these data make a more complete story.

A broad group of studies was undertaken. Dowell-Schlumberger (DS) conducted mineralogy/petrology studies for frac fluid/matrix rock compatibility, matrix rock permeability measurements, leakoff estimates and permeability damage due to the foam fluid, electrical conductivity measurements, mechanical rock property and differential strain curve analyses, proppant strength/embedment/pressure cycling/creep measurements, proppant conductivity measurements, and pre- and postfrac fluid sample analyses (water chemistry, total organic carbon, and carbohydrates).[6,7] The National Institute for Petroleum and Energy Research (NIPER) conducted matrix rock and cracked core (artificial fracture) permeability and clean-up measurements, permeability degradation from the frac fluid, leakoff, and proppant strength/embedment/cycling measurements, fracture conductivity measurements, and postfrac fluid sample analyses (presence of polymer).[8-14] Core Laboratories, Midland, performed water chemistry on pre- and postfrac samples.[15] In addition, there are extensive core data for the coastal zone (Section 5.0).

8.3 RESULTS

8.3.1 Matrix Rock

Dry Klinkenberg gas permeabilities of undamaged coastal core are of the order of a few microdarcies. Gas permeabilities at various water saturations were also measured. The presence of water reduces effective gas permeabilities about an order of magnitude at realistic water saturations (Figure 5.9). Permeabilities to brine are quite low, around one-tenth of a microdarcy or less. Capillary pressures at expected water saturations are greater that 500 psi. (The above data are given in Section 5.0.)

The rock is prone to brine imbibition and is difficult to clean up. Clean-up times for such tight rock are considerable, even when undamaged. Brine clean-up times for undamaged coastal zone core are from 100 to 200 hours for liquid invasion depths of one inch and for gas pressure differentials of ~400 psi/in.[9,16]

Attempts to measure leakoff of foam fluid into such low permeability core were not successful. Leakoff had to be estimated from laboratory values by extrapolating some of the earlier data on other core samples in the 10 microdarcy to 100 millidarcy range. An estimated fluid loss coefficient of 0.00002 ft/$\sqrt{}$min was obtained. Leakoff measurements with the nonfoamed base fluid were made and gave an estimated fluid loss coefficient of 0.0006 ft/$\sqrt{}$min for the foam. These numbers are smaller than those estimated from the foam frac.

Little permanent damage to core samples was found with the foam frac fluids used in the frac. Gas permeability reductions were around 15 percent using 70 quality foam similar to that used in the frac (Table 8.1). Brine permeability reduction from exposing the core to the foam frac fluid was not measured. Previously, very low permeability core, such as the coastal zone core, showed about a factor of three reduction in brine permeability because of damage from water-based gels.[16] Any damage from the frac fluid would make the already long brine clean-up times longer.

8.3.2 Artificially Fractured Core

The effect of fluids upon the narrow natural fractures believed to exist in Mesaverde rock was simulated by using cracked core to create artificial "natural" fractures. These artificial fractures are susceptible to fluid damage. Fracture fluids in the cracked paludal zone core reduced its permeability.[14] In addition, the exposure of these created fractures to brine alone may create some permanent damage in some coastal zone core. Brine and gas were cycled through a piece of cracked Yellow sandstone core that had an original effective gas permeability (matrix plus crack) of 0.068 md and an original matrix permeability of 0.002 md at 3000 psi confining pressure. After two and thirty hours' exposure to brine, gas permeability was reduced by 22 percent and 50 percent respectively.

In other work with cracked core, gas permeability reductions of 40 percent to 70 percent were seen in artificial fractures when gelled fluids were pumped through the samples. The amount of reduction depended upon the core and particular treatment conditions. A large liquid flow reduction was also observed as a result of pumping gel through an artificial fracture.[14]

In recent work,[17] it appears that not only the biopolymer used can degrade the permeability of these artificial fractures significantly, but HPG (hydroxypropylguar) gels and even HEC (hydroxyethylcellulose) gels also cause the same problem (Table 8.2). This is illustrated by SEM photos taken of some samples after impregnation with the polymer fluid (Figures 8.1 and 8.2). It seems as if biopolymer covers the interior of the crack and also collects at the crack entrance. (While fluvial core was used in this recent work,[17] the data are considered relevant to the coastal situation as well.)

8.3.3 Proppant Related Effects

Proppant embedment and fracture conductivity measurements were conducted on the Yellow and Red sandstones and on the rocks abutting these sands. Little proppant embedment was evident and only a small difference in estimated fracture conductivity was noted in any of the coastal zone samples tested (Table 8.3). The fracture conductivity estimates included determining proppant pack permeability and estimating reduction of fracture width from both proppant embedment and proppant characteristics (crushing, packing, and permeability vs closure stress). At these depths and stresses, there seems to be no short-term problem of diminished fracture conductivity from embedment of the intermediate strength proppant. Fracture conductivity was estimated for a concentration of 0.8 lb/ft^2 in these tests.

However, the proppant embedment characteristics of the formations abutting these sands do change when the core is wet, i.e., embedment increases (Table 8.4). Also, continuous exposure of some coastal sands to brine saturation caused the sands to soften and break more easily under stress. This is consistent with measured decreases of rock strength with saturation and consistent with observing permeability degradation of cracked coastal zone core when exposing it to brine.

Proppant creep tests were also conducted on a coastal zone sandstone. Over a 14-hour period there was only a 2 to 3 percent decrease in fracture conductivity due to proppant embedment in the sand. A somewhat longer embedment/creep test (18 day) on coastal zone core propped with sintered bauxite showed little additional frac closure after the initial loading (4000 psi) the first day.[18] That loading pressure should represent a reasonably well drawn-down reservoir in the coastal zone. The sintered bauxite is a high strength proppant. Since this is well below the crush strength of either the bauxite or the intermediate strength proppant used, this is a valid test for longer term proppant embedment on a coastal sand.

Crush tests were conducted on the intermediate strength proppant used in the frac. The 20/40 size proppant should be usable at closure stresses up to 10,000 psi. Fines generated at 10,000 psi were less that 7 percent. Two related series of crush resistance tests were conducted on the proppant. These were to stimulate production/shut-in cycling used in production cycling of MWX-1. Nine cycles were run between 7000 and 3000 psi and six cycles between 5500 psi and 1000 psi. The amount of fines generated in both tests was less than 3 percent. Decrease in fracture conductivity from pressure cycling was also minimal.

More recent stressed proppant pack slurry tests were also conducted using the intermediate strength proppant.[18] Proppant pack liquid permeability measurements were made for KCl brine, non-degraded biopolymer gel, and degraded biopolymer gel at closure stresses ranging from 2000-10000 psi. Very little difference in liquid permeability was measured for the three liquids.

8.3.4 Fluid Analyses

Chemical analyses were made on the prefrac water samples taken after the long 1984-1985 winter production run, on samples from the water well used in the foam frac fluid, and on samples of returned fluids following the foam frac.[7,15] These analyses indicate a rise in the concentration of the sodium and bicarbonate ion after the foam frac. This would be expected if formation water is being produced in the returned fluids. There was no corresponding decrease in the concentration of the potassium ion; exchange effects may not be the dominant sodium source. MWX-1 failed to produce any additional water in subsequent coastal zone operations.

The chemistry data were combined with those from fluid load balance estimates and analyses of organic products, total organic carbon and carbohydrates (original gel plus decomposition products).[7] These indicate that about one half of the organic material in the foam frac treatment was not recovered. The remaining frac fluid may be in either the natural fractures or the matrix rock or both.

Molecular weight studies were performed on both samples of the frac fluid and the returned fluid samples. The results of this study are:

- The molecular weights of the xanthan gum polymer used in the foam frac are greater than those of unbroken HPG. The are no weight standards available to determine the molecular weight of this polymer quantitatively.

- The biogel has extremely good temperature stability.[18] After the coastal zone frac, a 20 lb. 1000 sample of biopolymer was kept in a water bath at 195°F and sampled periodically (Figure 8.3). The molecular weight showed only a slight decrease over the 56 day period. Further, the test temperature was ~10°F higher than coastal zone temperatures.

- No original polymer was detected in the returned fluids from the stimulation. The detection limit was about 5 lb/1000 gal, or 25 percent of the original frac fluid concentration.

- Analyses of frac fluid and returned fluid samples suggest that at least some of the returned fluid samples had organic concentrations close to 50 percent of the frac fluid concentration. It is not understood why original polymer was not detected in returned fluids in view of its temperature stability.

8.4 DISCUSSION

The basic stimulation design was supported by mineralogy/petrology analyses, permeability related measurements, rock property studies and studies of proppant effects. The purpose of much of the prefrac laboratory work was to help avoid or minimize damage. The compatibility of the treatment and the matrix rock was verified by the mineralogy studies. The fact that the rock had very low permeabilities and attendant high capillary pressures reinforced the decision to minimize liquid in the frac design. The fluids chosen did not appear to cause excessive damage or leakoff in the matrix rock. The mechanical rock properties were used in fracture width and length calculations and the estimate of frac wing length is in fair agreement with the design length. The extensive group of proppant tests showed that the intermediate strength proppant chosen was more than adequate for the coastal stimulation. Prefrac fluid samples from the well were analyzed for comparison with postfrac fluid samples.

The above group of experiments provided insufficient information to pinpoint why MWX-1 production was less than expected following the propped frac. The addition of results from the postfrac fluid experiments still did not pinpoint the cause. However, laboratory and field data did help eliminate several possible causes of production problems.[1] These include:

- Degradation of permeability to gas of the matrix rock.

- Leakoff directly into the matrix during the frac. Estimates of formation leakoff (history matching) and laboratory derived leakoff are 0.0015 and 0.0006 ft/$\sqrt{}$min, respectively. (However, imbibition of frac fluids into the matrix adjoining the natural fractures may be important.)

- Polymer block in the proppant pack. Only 60 lb. of polymer were used in the entire operation, and these were distributed over the large frac area because the foam frac pressure history indicated a tip screenout.

- Proppant-related effects.

- Imbibition of water from pre- and postfrac operations. Except for the frac fluid, there was no exposure of this formation to water from well operations.

- Lowered reservoir pressures. These changed little throughout the coastal zone operations.

- Frac design. The wing length of the propped frac (Section 7.2.4) was estimated to be at least as long as that of the unpropped frac.

The addition of more recent data, especially the work with biopolymer and artificial fractures provide a basis for explaining the poststimulation production. Some degree of formation damage to the narrow natural fractures occurring in the coastal zone seem to be involved. Natural fractures dominate unstimulated production in the blanket and lenticular sands tested at the MWX site. Damage to these natural fracture systems seemed to be a very important, if not controlling, factor in some of the stimulations, and it appeared to be the dominant effect in the paludal zone. There were many similarities in the geologic properties and operational results from the coastal and paludal zones. These include:

- The fracture systems are similar as seen in core and outcrop.

- Prefrac production appears to be predominantly from fractures.

- Flowback was >50 percent of initial load.

- There was less than expected production enhancement for several months following stimulation.

- Laboratory work eliminated the same matrix rock centered mechanisms as primary causes of the damage (permeability degradation, leakoff, proppant effects, frac fluid-formation rock incompatibility).

The natural fractures observed in core have widths varying from microscopic to 1/2 inch and are usually filled with calcite. The permeability of the fractures is dependent on an effective width of the unfilled portion of the mineralized fracture. Core observations and well tests suggest that such open widths must be extremely narrow, <0.001 in. Such narrow fractures must be very prone to damage from fluids or from stresses from hydraulic fracture or drawdown. Laboratory evidence pertinent to fluid damage in natural fractures includes:

- Brine in some artificially created fractures caused some permeability loss. There is a large percentage of clays in the core and they may move and swell.

- Permeabilities in artificially created fractures often were significantly reduced by exposure to biopolymer and other gels.

- The biopolymer is extremely temperature stable. Any fluid entering these fractures would not degrade readily.

- SEM photos of core samples exposed to the biopolymer show coating of the entrance and sides of the fractures.

- The high treating pressures encountered during the main coastal zone frac (Section 7.2.4) suggest that this stable fluid probably entered these narrow fractures. The maximum pumping pressures were 6700 psi, well above a closure stress of ~5500 psi, and a tip screenout occurred.

- There are also other possible forms of damage to the narrow natural fractures: trapping of fines within the narrow fractures; shearing of asperities on the fracture wall during the stimulation; closure of natural fractures due to stresses in the formation induced by the proppant; and the closure of natural fractures due to drawdown during production. All of these effects would make the narrow natural fractures more narrow and aggravate the fluid effects discussed.

8.5 CONCLUSIONS

Laboratory work provided valuable data for the design and analysis of the coastal zone stimulation from the following aspects:

- Frac fluid-matrix rock compatibility.

- Gas permeability degradation by frac fluids.

- Leakoff into the matrix rock.

- Near-term proppant effects.

- Mechanical rock properties.

It appears that formation damage is present and it is extremely likely that this damage is centered about the natural fracture system. Numerous possible causes of formation damage were either eliminated or qualified by the laboratory work. Other causes were eliminated based on operational data or procedures.

Some degree of fluid damage to the narrow natural fractures is postulated to account for the postfrac performance of the Yellow sand in the coastal. The frac fluid that is forced into the narrow fractures at high pumping pressures may remain there and degrade only very slowly. Effects of fines and stress probably exacerbate the fluid-related damage effects.

8.6 REFERENCES

1. Sattler, A. R., P. J. Hudson, C. J. Raible, B. L. Gall, and D. R. Maloney, "Laboratory Studies for the Design and Analysis of Hydraulic Fracture Stimulations in Lenticular, Tight, Gas Reservoirs," SPE/DOE/GRI 15425, Proceedings of the Unconventional Gas Technology Symposium, Louisville, Kentucky, May 1986.

2. Warpinski, N. R., P. T. Branagen, A. R. Sattler, J. C. Lorenz, D. A. Northrop, R. L. Mann, and K. H. Frohne, "Fracturing and Testing Case Study of Paludal, Tight, Lenticular Gas Sands," SPE Formation Evaluation, pp 535-545, December 1987.

3. "Multiwell Experiment Final Report: II, The Paludal Interval of the Mesaverde Formation," Sandia National Laboratories Report, SAND 88-1008, June 1988.

4. Branagen, P. T., C. L. Cipolla, S. J. Lee and L. Yan, "Case History of Hydraulic Fracture Performance in the Naturally Fractured Paludal Zone: The Transitory Effects of Damage," SPE/DOE 16397, Proceedings of the 1987 SPE/DOE Joint Symposium on Low Permeability Reservoirs, Denver, Colorado, May 1987.

5. Sattler, A. R., C. J. Raible, B. L. Gall and P. J. Gill, "Stimulation Fluid Systems for Naturally Fractured Tight Gas Sandstones: A General Case Study From Multiwell Experiment Stimulations," SPE 17717, 1988 SPE Gas Technology Symposium, Dallas, Texas, June 13-15, 1988.

6. Hudson, P., et al., "Multiwell Experiment Core Analysis of the MWX-1, MWX-2, MWX-3, Dowell-Schlumberger Interim Report," August 1985.

7. Hudson, P., et al., Multiwell Core and Fluid Analyses of the MWX-1, MWX-2, and MWX-3, Dowell-Schlumberger Supplemental Report, February, 1986.

8. "Fracture Conductivity Studies," NIPER monthly report, January 1985.

9. Raible, C. J. and Gall, B. L., "MWX Coastal Core Evaluation: Gas Permeability and Cleanup Time as a Function of Liquid Saturation," NIPER topical report, 1985.

10. Maloney, D., "MWX Coastal Zone Fracture Flow Capacity Predictions," NIPER Memo Report, July 1985.

11. Maloney, D., "Results of Tests Conducted on MWX-1 Proppant Sample #58," NIPER Memo Report, August 1985.

12. Gall, B. L., "Laboratory Studies of the Fracturing Fluid Base Gel Used in the MWX Stimulation of the Yellow Sands (Coastal Zone 8/1/85)," NIPER Memo Report, August, 1985.

13. NIPER Quarterly Report, Contract No. NIPER 85-688, November, December 1985.

14. Gall, B. L., "Permeability Damage to Cracked Core by Fracturing Fluids," NIPER Memo Report, January, 1986.

15. Core Laboratories Inc. (Midland), Water Analysis Reports for Sandia, July, August, October 1985.

16. Raible, C. L. and Gall, B. L., "Laboratory Formation Studies of the Western Tight Sands," SPE 13903, Proceedings of the 1985 SPE/DOE Symposium on Low Permeability Reservoirs, Denver, Colorado, May 1985.

17. Gall, B. L., A. R. Sattler, D. R. Maloney and G. J. Raible, "Permeability Damage to Natural Fractures Caused by Fracturing Fluid Polymers," SPE 17542, Proceedings of the 1988 SPE Rocky Mountain Regional Meeting and Exhibition, Casper, Wyoming, May 1988.

18. Raible, C. J., NIPER Quarterly Reports to Sandia National Laboratories, Contract NIPER 85-683, January-March 1986 and April-June 1986.

Table 8.1 Horizontal Permeability Degradation of Coastal Zone Core After Exposure in Foam Frac Fluid

Depth (ft)	Treatment Phase	Nitrogen Permeability (μd) Pore Volumes of Gas Through Core 0	10	20	50	100
6446.6	Before Treatment	.003	.009	.011	.016	.021
	After Treatment	*	.006	.010	.015	.018
	% Permeability Recovery	*	67	91	94	86
6507	Before Treatment	.006	.013	.017	.025	.029
	After Treatment	.001	.008	.015	.022	.024
	% Permeability Recovery	17	62	88	88	83

* Value below measurable limits

Injection Pressure: 1000 psi
Injection Period: 2 hours
Treatment Temperature: 160°F
Treating Fluid: Water-base, 70-Quality stabilized foam prepared with 20 lb foam stabilizer in a base fluid of 2 percent KCl
Shut-In Time: 16 hours @ 160°F

Table 8.2 Permeability to Gas of Cracked Core Before and After Exposure to GELS*

Gel Type	Sample		Additive	Permeability (md)		Reduction (%)
	Well	Depth		Before	After	
HPG	MWX-1	5842.0-C	-	0.042	0.022	48
Biopolymer*	MWX-3	5727.1-A	-	0.190	0.020	90
	MWX-1	5842.0-A	Breaker	0.045	0.019	58
	MWX-3	5727.1-B1	100 mesh sand	0.052	0.024	54
	MWX-3	5727.1-B2	100 mesh sand	0.107	0.023	79
	MWX-1	5548.7-B	100 mesh sand	0.136	0.017	88
	MWX-1	5548.7-C2	100 mesh sand	0.239	0.024	90
	MWX-1	5548.7-C3	100 mesh sand	0.372	0.020	94
	MWX-2	5736.1-B	Breaker	0.072	0.024	66
	MWX-2	5736.1-A	Breaker + 100 mesh sand	0.076	0.030	61
	MWX-1	5727.4-B	Breaker	0.041	0.013	68
HEC	MWX-2	5736.1	Breaker	0.073	0.034	53
	MWX-1	5836.8-B	Breaker (3 day test)	0.153	0.030	80
	MWX-1	5836.8-A	Breaker (8 day test)	0.063	0.013	78

* Xanthan gum

Table 8.3 Estimated Fracture Conductivity in MWX-1 Core in and Around the Yellow Sand (Darcy-ft)

Sample	Depth (ft)	Closure Stress (psi)			
		2000	4000	6000	8000
Shale	6400	3.7	3.0	2.2	1.6
Sandstone	6347	3.8	3.0	2.7	1.7
Sandstone	6459	3.7	3.0	2.3	1.7
Sandstone	6464	3.7	3.0	2.3	1.7
Shale	6476	3.7	3.0	2.3	1.7

Notes:

1. Permeability using proposed API conductivity test procedures for a 2 lb/ft^2 proppant placement in a linear flow cell.
2. Frac width w/o embedment measured using a 0.8 lb/ft^2 proppant placement in a 2-inch ID API crush cell.
3. Embedment estimated from proppant and rock penetration test results.
4. Does not account for proppant pack damage due to frac fluid residue, rock creep, long-term proppant crushing, or damage due to fines generated during the fracturing process.

Table 8.4 Proppant Embedment Characteristics of Formations Abutting Yellow Sandstone

Well	Depth (ft)	Description	Test Condition	Embedment Strength (psi)
MWX-2	6399.5	Shale above Yellow sandstones	Dry	56,600
			Wet	17,300
MWX-1	6475.8	Shale between Yellow and Red sandstones	Dry	120,500
			Wet	29,200
MWX-2	6569.7	Shale below Red sandstones	Dry	60,000
			Wet	24,000

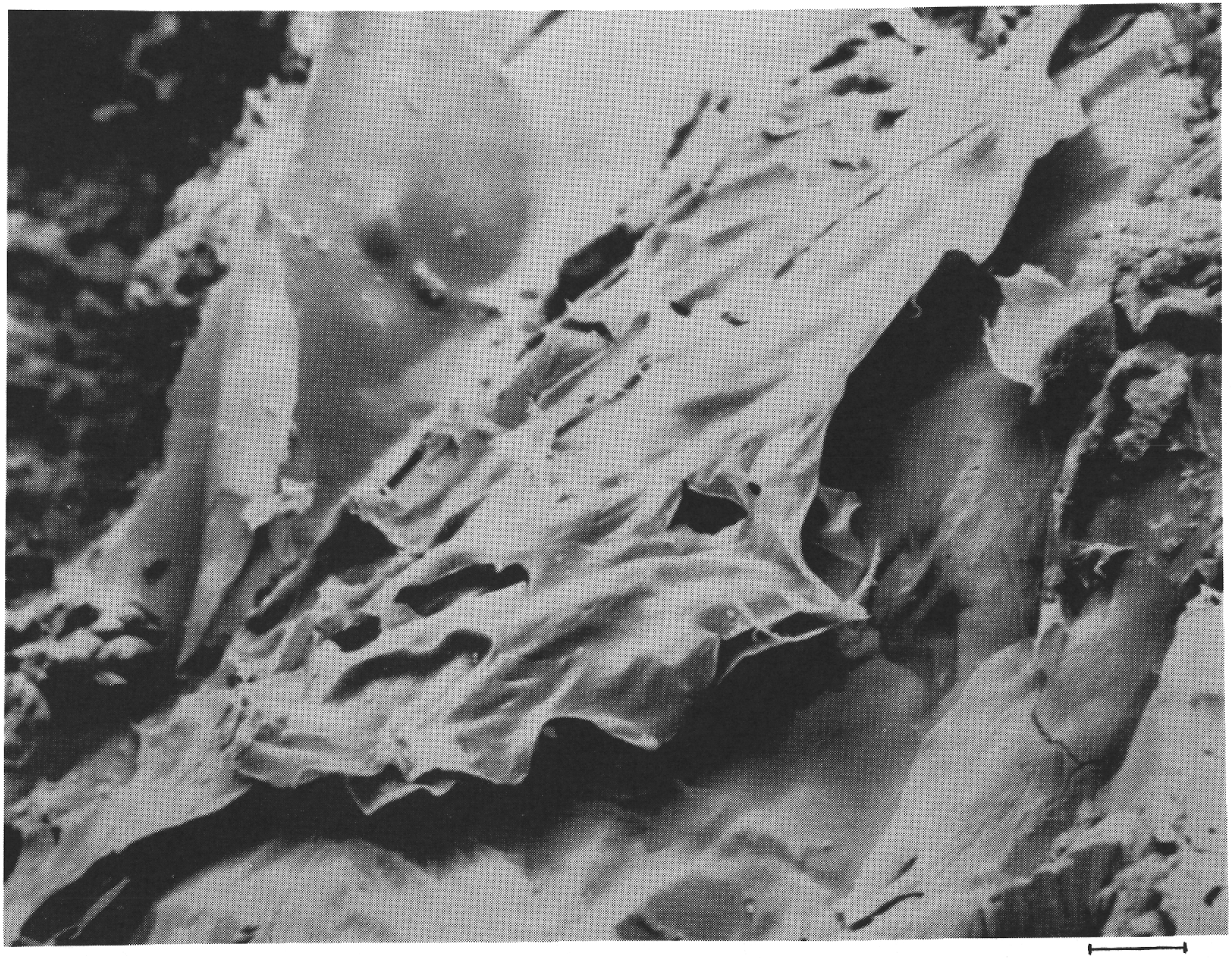
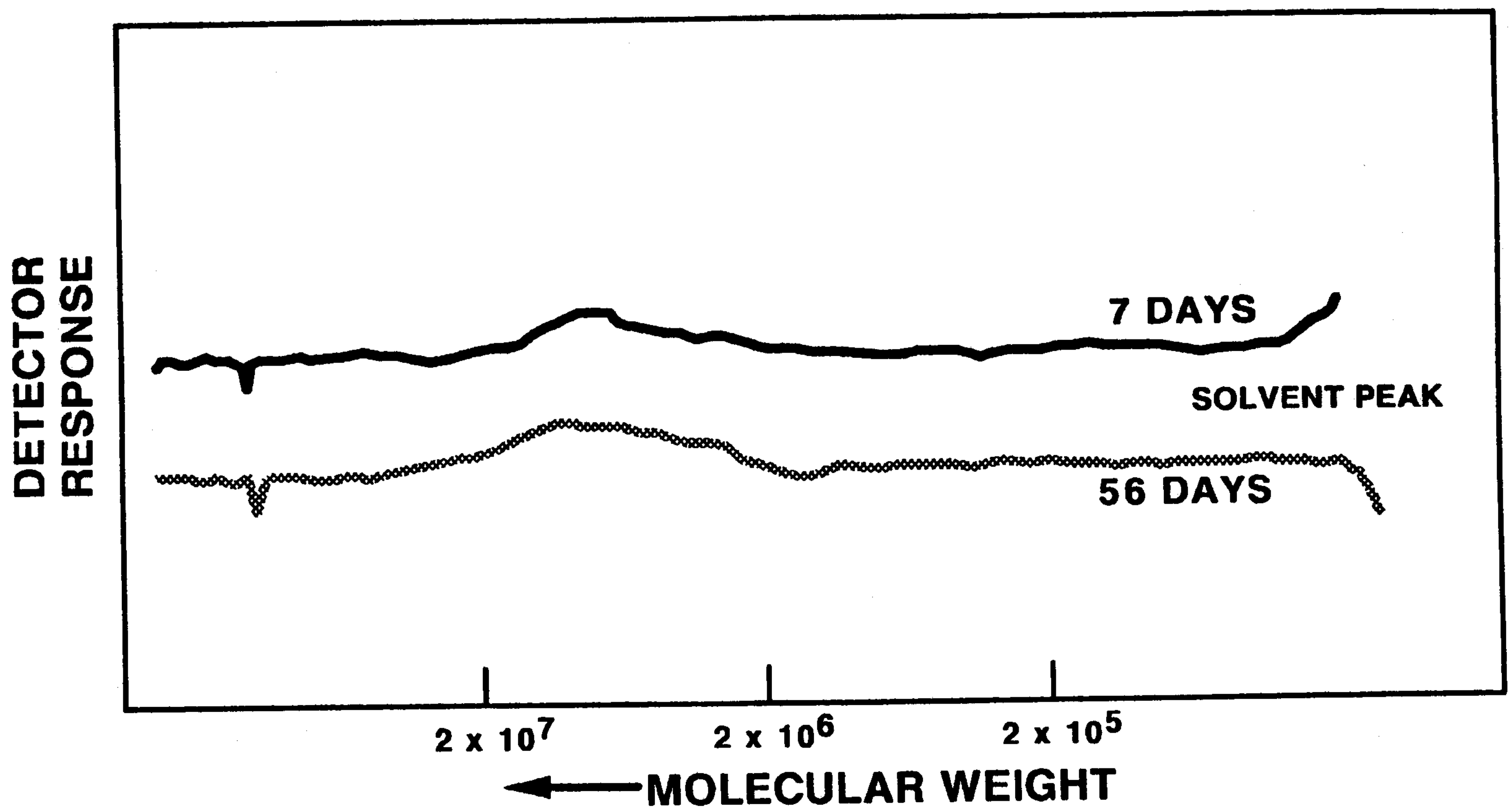


Figure 8.1 Dried Polymer at Crack Entrance (Scale = 20 μm)

Figure 8.2 Dried Polymer on Crack Interior (Scale = 100 μm)



MOLECULAR WEIGHT DISTRIBUTIONS
FOR BIPOLYMER VS TIME AT 150° F

Figure 8.3

9.0 BOREHOLE SEISMIC SYSTEM ANALYSES

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9.1 INTRODUCTION

A redesigned prototype borehole seismic system was fielded at the Multiwell Experiment (MWX) site to provide fracture diagnostics for the August 1, 1985, coastal zone stimulation. Although the system performed very well, the complexity of the orientation and fracture data sets from MWX-2 prohibited immediate analyses. Thus, an extensive system evaluation was performed to insure that each element of the surface hardware was functioning as expected and not distorting the received waveform. After several months of effort, several attempts at data analysis, and multiple hardware and software modifications, there was reasonable confidence that the existing instrumentation system and available analysis techniques were performing correctly. However, data analysis was still not possible and no map of the coastal zone hydraulic fracture could be derived. The seismic data set contained complexities that precluded analysis and remain unexplained.

This effort was documented in a draft report by Carolyne M. Hart, Richard A. Newell, and Harry E. Morris.[1] This section was extracted from that lengthy report.

9.2 SYSTEM IMPROVEMENTS

9.2.1 Hardware

Table 9.1 summarizes a comparison of the redesigned borehole seismic system to that of the "old" system.[2] A block diagram of the system is shown in Figure 9.1. The upgraded borehole seismic tools performed well during the coastal stimulation experiment. The newly implemented package diagnostics and calibration procedures proved to be valuable. Downtime was virtually nonexistent; the new packages were able to withstand downhole pressures and temperatures for a continuous 72-hour interval.

The test data show dramatic improvement in both peak signal amplitudes and signal-to-noise ratios as a result of the upgrades. Prior to the coastal stimulation, the tools had a maximum downhole gain of 80 dB, a factor of 10,000 (Figure 9.2a). The three geophone stack increases the peak amplitudes by a factor of three. An additional 20 dB of downhole gain further enhances the signal amplitude by a factor of ten. Thus, the resultant coastal frac signal is multiplied by a factor of 300,000 downhole (Figure 9.2b). The event shown could not have been detected using pre-coastal instrumentation.

9.2.2 Software

In a homogeneous isotropic elastic medium, two waves result from a perturbation: a simple longitudinal wave (P-wave), linearly polarized in the direction of propagation, and a shear wave (S-wave), linearly polarized perpendicular to the direction of propagation. In a real media the polarization parameters also depend on the inhomogeneities and anisotropies of the formation. During the passage of the wave, the particles of the earth move in intricate trajectories. The resultant polarization is often represented by ellipsoids. A basic assumption of the polarization method is that phase and amplitude parity can be maintained between the triaxial components. Without 1:1:1 phase and amplitude output ratios between the three channels, the resultant polarization direction cannot be determined.

Simple extremum estimates of polarization directions were employed in the paludal phase I stimulation analysis.[3] The mode of the polarization ellipsoid was used to determine the direction to the seismic source. The distance to the source from the receiver was determined by using the separation between the P- and S-wave arrival times, T_p and T_s, according to the formula:

$$D = V_c \ (T_s - T_p)$$

where the velocity coefficient

$$V_c = V_s V_p / (V_p - V_s)$$

was determined by measuring T_p and T_s for tubing shots fired at a known distance without knowledge of the P- and S-wave velocities V_p and V_s.

Because previous waves have closely resembled elliptical polarization, an algorithm was developed based on directional statistics and a weighting factor commensurate with the signal-to-noise ratio.[4] Distribution-free mode and first and second moments of the directional random variables are computed from the polarized data, thereby describing the angle from a borehole seismic tool to a microseismic event in spherical coordinates. Samples for the random variables of interest are calculated from the digitized records of the waveforms measured by the triaxial geophones. The algorithm then computes the minimum and maximum values of the linearly transformed, triangularly distributed, random variables characterized by the three distribution-free parameters. This algorithm removes much of the human judgment and also provides an estimate of error commensurate with tightness of fit. Since event locations are most easily understood in cartesian coordinates, an algorithm was developed to trigonometrically transform the spherical coordinates of the location and the first and second moments into cartesian coordinates for the event locations from individual tools, and to combine these locations into a minimum-error location should data from two packages be acquired.

9.3 PERFORATION SHOT DATA

9.3.1 Pretest MWX-2 to MWX-3 Tubing Shots

An initial test of the borehole seismic system was conducted on July 23 and 24, 1985. With a borehole seismic tool positioned and clamped at 6350 ft in MWX-3, a pre-test series of ten 6-gram decentralized tubing shots were fired in MWX-2 between 6454 ft and 6444 ft. Approximate horizontal distances between the three wells at 6400 ft are shown in Figure 9.3. Using the downhole distance between MWX-2 and MWX-3 and the tool depths in each well, the direct seismic wave generated by each detonation traveled about 235 ft. The most distant detectable event from the paludal zone stimulation[3] was 228 ft from the source to the receiver.

A PDP-11/34 analog to digital converter sampled the signals at 2.15 kHz per channel, utilizing a sample and hold capability so that all eight channels could be sampled simultaneously. An HP-6420A digital signal analyzer was used in parallel with the PDP-11/34 to display the spectral power density of the detected events. Wavetek filters were used to limit the spectral content of the events to a 100 to 500 Hz band. This bandpass was chosen based on measured frequency content of the paludal zone data. Spectral displays of the tubing shot data verified that the fundamental 388 Hz spectral content was indeed within this band.

As illustrated in Figure 9.4, the P-wave arrivals for these tubing shot data were very distinct, and the S-wave arrival was detectable from superimposed traces. However, the horizontal polarization plots were open and offset, and there was no apparent polarization direction in the vertical projection.

9.3.2 Orientation Tubing Shots

Decentralized tubing shots were also used for orienting the tools prior to the frac. With borehole seismic units clamped in MWX-2 and MWX-3 at well log depths of 6386 and 6338 ft, respectively, two series of ten 6-gram charges were fired into the MWX-1 wellbore between 6447 and 6438 ft (July 30, 1985). Direct seismic waves traveled 125 ft from the source to the receiver in MWX-2 and 215 ft to the receiver in MWX-3. Both distances are less than 235 ft direct ray path from MWX-2 to MWX-3 in the pre-test experiment.

Although signal-to-noise ratios in MWX-2 were good, the first arrivals were not as distinct as those from the pre-test experiment as seen in a comparison of Figures 9.4 and Figure 9.5. Peak-to-peak amplitudes were about the same as those from the pre-test data even though the direct ray path distance has been reduced by a factor of almost two. Horizontal polarization plots were again offset and appeared to be more open and erratic than the pre-test results. The S-wave arrival could not be determined by superimposing the horizontal traces. The polarization plot did break from the dominant P-wave direction after a period of time, but the expected S-wave break-out angle of 90° from the P-wave polarization direction was not observed. An S-wave arrival time was picked from the apparent break in the horizontal hodograms and the time interval appeared to be consistent throughout the 20 tubing shots. An orientation angle of 64° ± 13° clockwise from H2 and a velocity coefficient of 22 ft/ms were computed. The velocity coefficients from the paludal stimulation orientation data ranged from 23 ft/ms to 30 ft/ms, so the computed coastal orientation velocity coefficient appeared to be in the correct range. Again, the vertical polarization projections were unusable.

The background noise in MWX-3 increased substantially since the pretest series a week earlier and was now large enough to prohibit acquisition of analyzable data. Gas leaks and the resultant bubbling in the wellbore were the probable noise source. It had been demonstrated during the paludal test that well pressurization could attenuate such noise significantly, so MWX-3 was pressurized 1000 psi above the in situ pressure. The noise level was reduced, but not enough to allow event detection and analysis. None of the 20 orientation tubing shot waveforms received in MWX-3 exhibited amplitudes of sufficient magnitude for analysis. The seismic tool depth was varied between 6200 and 6338 ft, but signal amplitude did not appear to be depth dependent.

9.4 STIMULATION DATA

It was recognized during the paludal phase II stimulation experiment that fluid flow and pumping noise in the stimulation well could create a background noise level great enough to mask the microseismic activity created by the fracture. This conclusion was reinforced during pumping periods in the coastal zone. The spectrum analyzer showed that there is a very dominant 400 Hz content in the pumping and flow noise. Since the microseismic spectrum was expected to be in the same range, bandpass filtering to reject the flow noise would not be applicable. No waveforms with sufficient signal-to-noise ratios for analysis were detected during pumping.

After shut-in, the signal-to-noise ratio, as well as the peak-to-peak amplitudes for the microseismic signals recorded in MWX-2 were comparable to those in the orientation data. The horizontal polarization ellipsoids were again very open and somewhat offset. The vertical plots were still erratic. No microseisms displaying substantial amplitudes or distinct P- or S-wave characteristics were detected in MWX-3 due to the continually high noise level, and no further attempts were made to analyze the MWX-3 data set.

It was concluded from this first look at field data that on-site data analyses were impossible. Unraveling the causes of the observed complications in the data set would take time and an organized approach.

9.5 ANALYSIS OF COASTAL STIMULATION DATA

A summary of the subsequent efforts to analyze the coastal seismic data set is given in Appendix 11.13. These efforts included: development of a synthetic event generator and a null balance system; recalibration of the borehole seismic system; recalibration to include higher frequencies; investigations to achieve phase and amplitude parity both within and between channels; and several analog playbacks and redigitizations of the data. These efforts essentially eliminated electronic-related phenomena affecting the seismic signal analysis. Nevertheless, distortions and other complications remained.

9.5.1 Phase Disparity

An attempt to evaluate the distortion that was still prohibiting data analysis was made by choosing one of the "better" post-flow events and examining its properties in detail. The data set was searched for an event that was not normal to any of the sensors, providing good signal strength in all three planes. A close look at the arrival times of the longitudinal wave on the three axes indicated that there were substantial phase shifts between channels. The H1 channel led the H2 channel by just over 200 microseconds while H1 led V by approximately 500 microseconds,

Figure 9.6. Other post-flow events displaying signal strength on all three channels were scanned to see if this phase shift occurred in all of the data. There did appear to be phase disparity in all events, but the phase relationship between channels varied widely. That is, in not all events did the H1 channel lead, nor was the phase separation between channels consistent.

The orientation data were examined again to see if the phase shifting was present prior to stimulation. Because the orientation to MWX-1 was orthogonal to one of the horizontal channels, the orthogonal axis contained little of the longitudinal component. Thus, it was impossible to determine the phase relationships between the horizontal components. The vertical time series was, however, significantly out of phase with the horizontal channel.

If the BSS was introducing the phase disparity, the pre-test tubing shot data from MWX-2 to MWX-3 would also exhibit this characteristic. Under the same calibrated system configuration for which the MWX-2 event data displayed phase disparity, all pre-test data from MWX-2 to MWX-3 exhibited phase parity. The phase relationships between the two horizontal channels for one of the pre-test events is shown in Figure 9.7.

9.5.2 Uniqueness of MWX-2 Data

The data received in MWX-2 differed from data received during the pre-test experiments in which the receiver was in MWX-3. The following characteristics are unique to this MWX-2 data set and had not been observed in previous data acquired from MWX experimentation:

(1) Amplitudes from tubing shots in MWX-1 acquired in MWX-2 were smaller than those from data received in MWX-3 during pre-test tubing shots in MWX-2, despite the closer proximity of MWX-2 to MWX-1.

(2) All of the MWX-2 data were unique in that their low signal strengths would have prevented detection previously. An investigation into the low gain (80 dB) data showed that none of the data could have been acquired with the borehole seismic tools before redesign.

(3) The spectral content of the data acquired in MWX-2 differed significantly from that received in MWX-3. The spectral distribution of the MWX-2 data was more complex than the spectra of the MWX-3 data. The MWX-2 spectral content was consistent between both tubing shots and fracture events.

(4) There were multiple, distinctly polarized, waveforms in the MWX-2 data set perhaps indicating the existence of two P-waves and two S-waves. Only two distinctly polarized waveforms were identified in the MWX-3 data and the previous MWX data set. Time between arrivals and polarization directions indicate that the first and third arrivals in the MWX-2 data are the direct P- and S-wave arrivals, respectively.

(5) Phase disparity between channels existed in the MWX-2 data set, but not in the MWX-3 data set. The phase disparity alone was significant enough to render the data nonanalyzable. No inclinations could be computed from the data. The cause of the anomalous phase relationships in the MWX-2 data is unknown, but it is suspected that inhomogeneities near wellbore MWX-2 were phase shifting the data.

9.6 SUMMARY OF COASTAL BOREHOLE SEISMIC ANALYSES

A major redesign of the borehole seismic system was completed prior to the August 1, 1985, MWX coastal stimulation experiment. The upgraded system performed well during the test, and its field performance indicated a major advancement in the development of BSS. Newly developed package diagnostics and calibration procedures proved to be valuable. Confidence in the seismic package integrity was high, and the electrical package upgrades noticeably enhanced the overall reliability of the BSS by reducing system downtime due to troubleshooting and repairs. Most importantly, a large increase in the data signal-to-noise ratios was evident; microseismic signals that would have been discarded prior to system redesign were acquired in quantity with excellent signal-to-noise ratios. Finally, the following analysis and instrumentation improvements were made.

(1) A maximum likelihood event location scheme based on directional statistics has become an integral part of the system. The newly developed algorithm provides source locations and an error estimate for those locations.

(2) Higher frequency content of the microseismic data will be included in the digitized data set.

(3) The digitization rate has been increased to 4.76 kHz per channel, but only 3 channels can be digitized simultaneously at this rate.

(4) The null system was essential to maintaining system balance which was, in turn, essential to data analysis. This system will continue to be an integral part of the surface hardware.

(5) The synthetic event generator developed to generate three-component sinusoidal signals of specified amplitude, frequency and phase will be used for future system calibration inputs.

However, in spite of these improvements and insights, the source locations of seismic signals associated with the coastal fracturing experiment could not be determined. Thus, there is no map of fracture azimuth or height and no estimate of fracture length of the coastal nitrogen foam frac. The inability to analyze this data set was disappointing and extremely frustrating. Clearly, a major factor was the uniqueness of the signals recorded in MWX-2. The reduced amplitudes, different spectral content, multiple polarized waveforms with overlapping P- and S-wave arrivals, and distinct phase disparity on the different channels had not been observed before and their causes are not yet understood.

Some insight has been gained in subsequent, more extensive tests at the MWX site.[5,6] The complexity of the geologic environment is important as different signal velocities and attenuations have been noted along different signal directions. Also, the overall character and quality of the received signals and accuracy in measuring known source locations (e.g., perforation shots) is a strong function of where the tool is clamped in the well. Some locations have produced some of the effects first noted in the MWX-2 coastal data set. Finally, the true response of the clamped downhole seismic tool is unknown. Resonances inherent in the tool and its clamping scheme are not known, especially with respect to the three orthogonal geophone axes. However, the improvements given above and the understanding gained during the efforts associated with the coastal stimulation experiment spurred further diagnostic advances which were successful during the subsequent fluvial stimulations.[5,6]

9.7 REFERENCES

(1) Hart, C. M., R. A. Newell and H. E. Morris, "Borehole Seismic System Analysis for a Complex Data Set," Draft Report, Sandia National Laboratories, Albuquerque, NM, April 1986.

(2) Seavey, R. W., "Borehole Seismic Unit," Sandia National Laboratories Report, SAND82-0373, May 1982.

(3) Hart, C. M., D. Engi, R. P. Fleming, and H. E., Morris, "Fracture Diagnostics Results for the Multiwell Experiment Paludal Zone Stimulation," SPE/DOE/GRI 12852 presented at the 1984 Unconventional Gas Recovery Symposium, Pittsburgh, PA, May 1984.

(4) Engi, D., "A Numerical Signal Processing Technique for Borehole Seismic Fracture Diagnostics," Sandia National Laboratories Report, SAND 86-1865, January 1987.

(5) Thorne, B. J. and H. E. Morris, "An Assessment of Borehole Seismic Fracture Diagnostics," SPE 18193, presented at 63rd Annual Technical Conference and Exhibition of the Society of Petroleum Engineers of AIME, Houston, TX, October 2-5, 1988.

(6) Thorne, B. J., and H. E. Morris, "Passive Seismic Monitoring of Hydraulic Fracture Experiments at the Multiwell Experiment Site," Sandia National Laboratories Report, SAND88-1284, June 1988.

TABLE 9.1

"Old" Versus Redesigned System Performance Comparison

Item	"Old" System	Redesigned System
Maximum signal-to-noise Ratio	4 to 1	10 to 1
Temperature stability	Gain and DC offset drift	No drift during 72 hours of continuous operation in a well.
Clamp control	Often would not operate.	More than 20 successful operations without failure.
Clamp stability	Seldom rigidly locked in well	Always rigidly locked in well.
Diagnostics	1. Temperature 2. Uncertain clamp position	1. Temperature 2. Known clamp position 3. Clamp force 4. Operation mode
Downhole checks	None	1. Electrical calibration 2. System functional check
Sensor array	Single geophone per axis	3 geophones per axis plus geophone at 45° to horizontals.

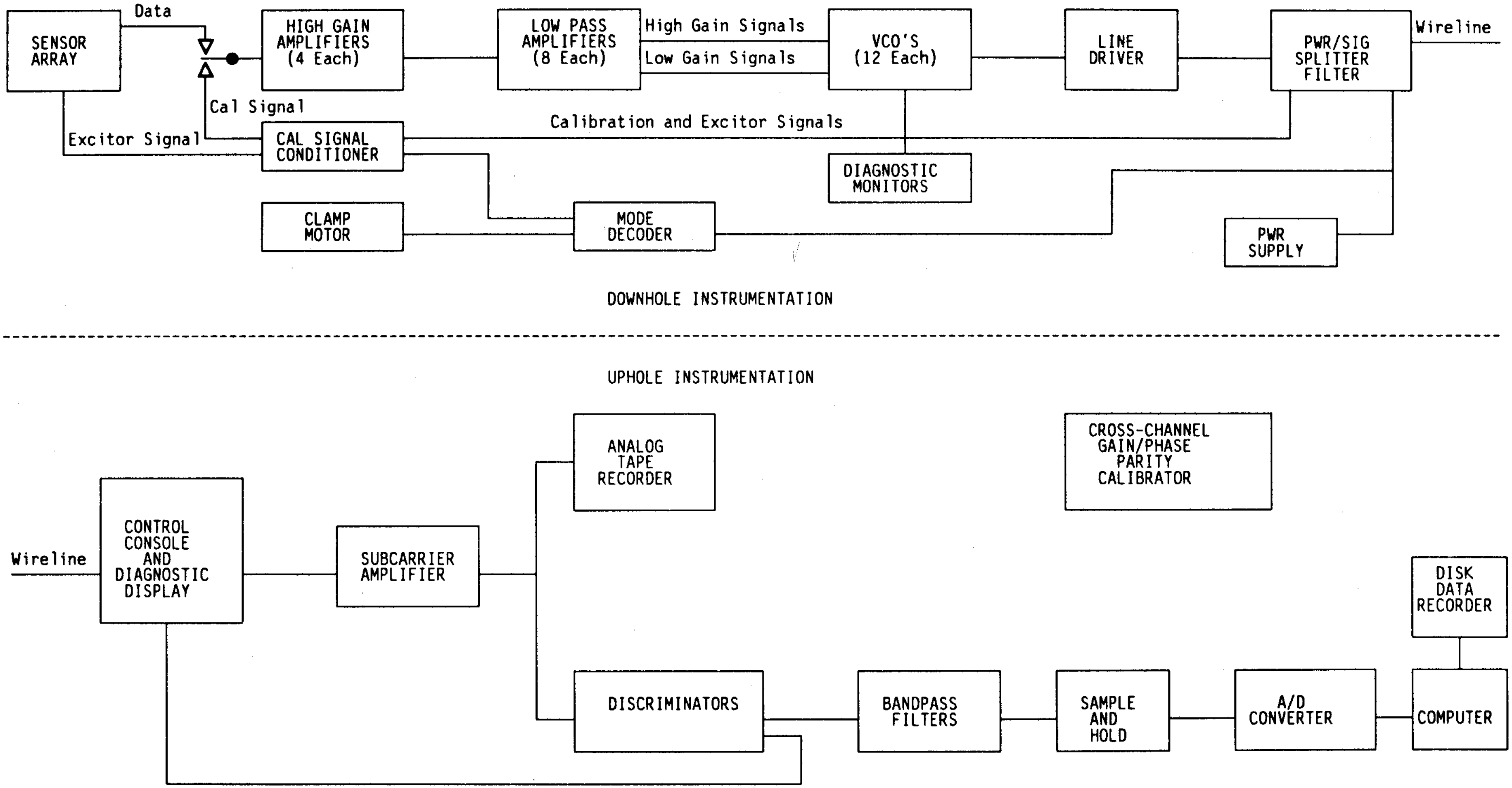

Figure 9.1. Borehole Seismic System Block Diagram

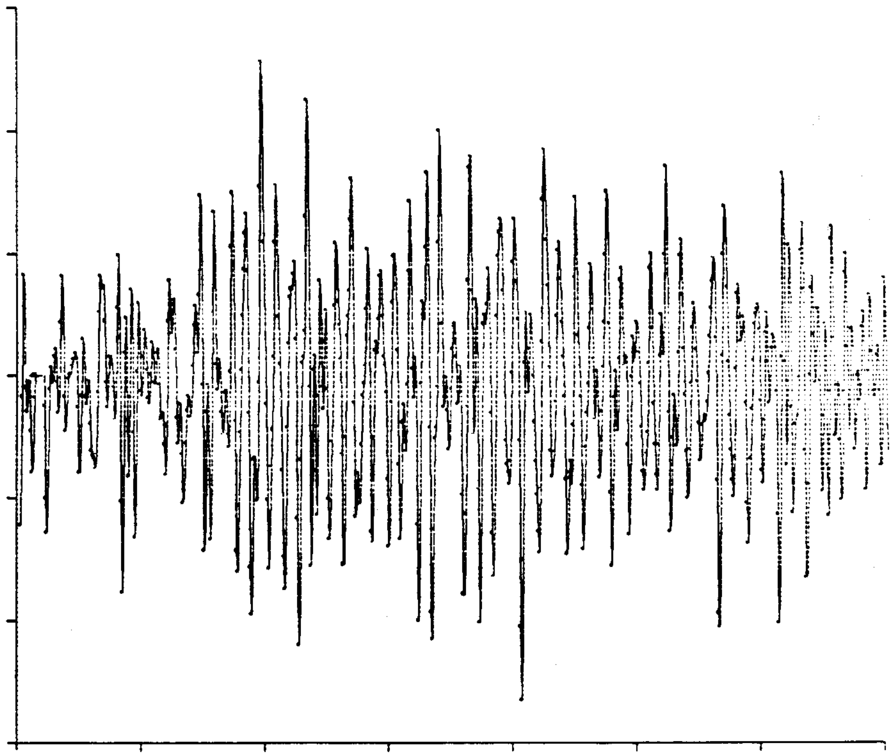

Figure 9.2(a). Event Signal-to-Noise Comparison, Gain = 10,000.

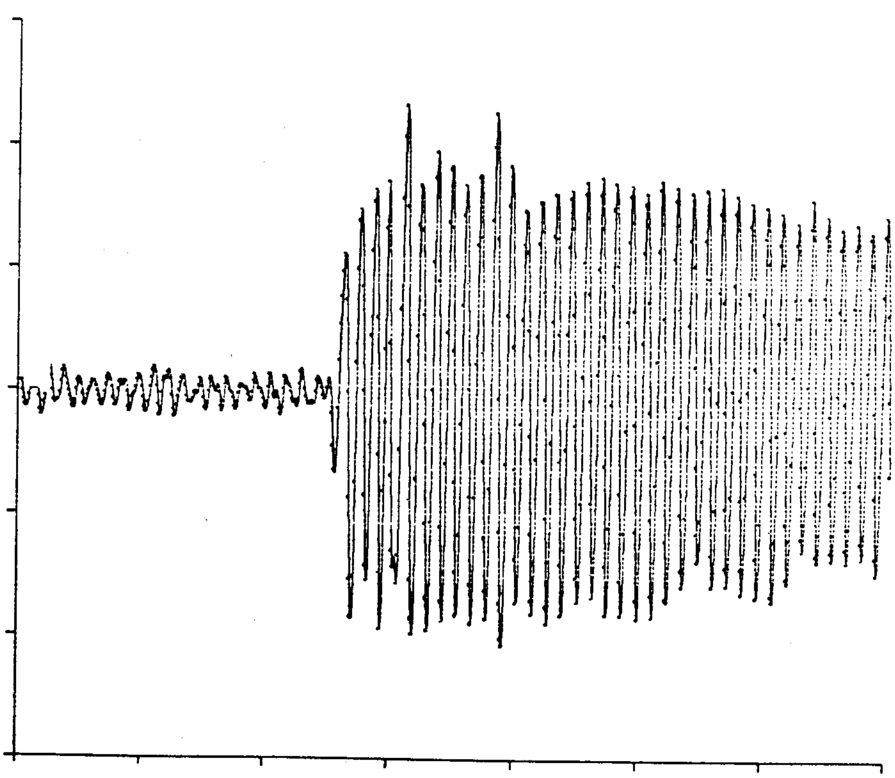

Figure 9.2(b). Event Signal-to-Noise Comparison, Gain = 300,000.

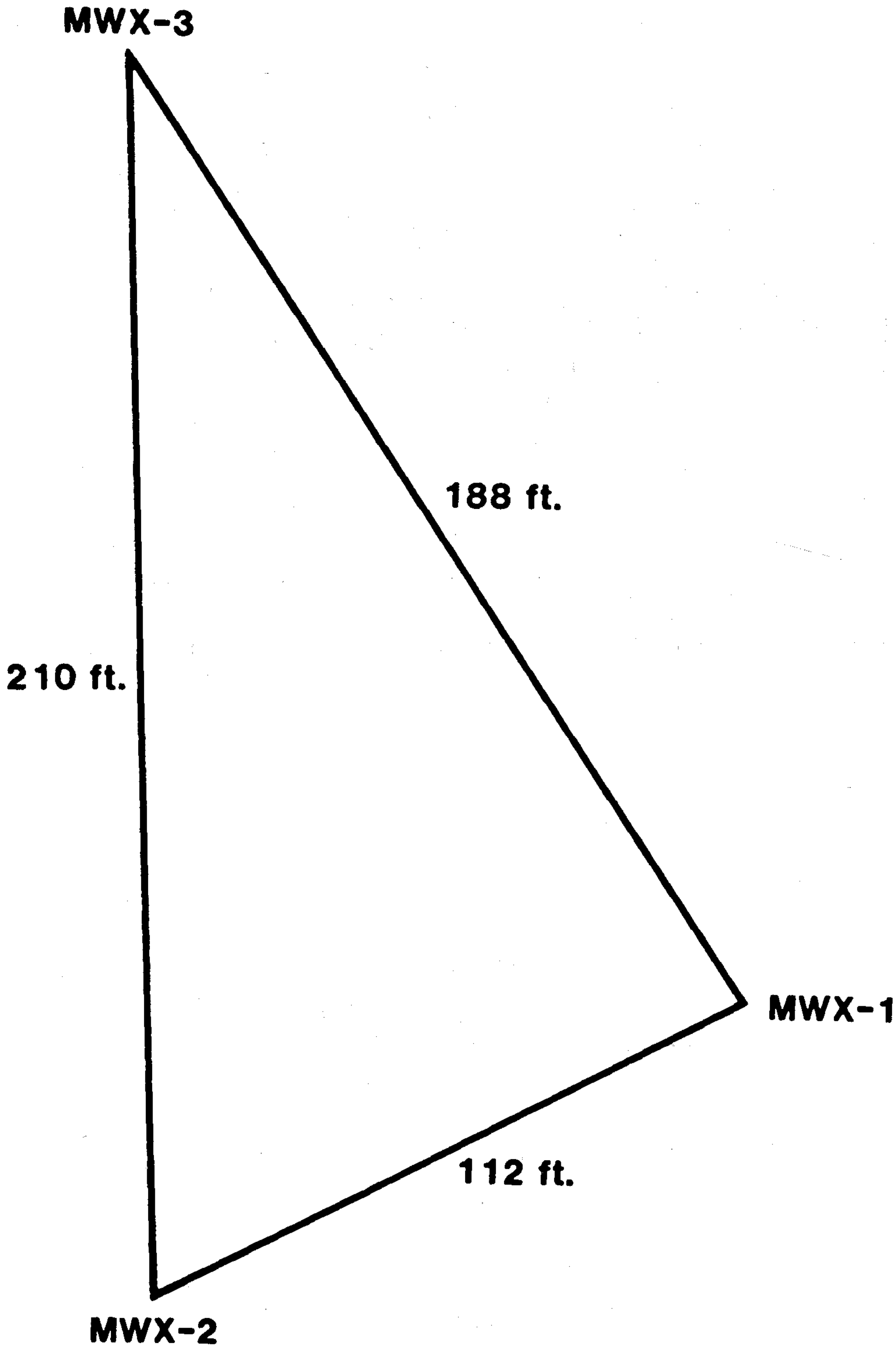

Figure 9.3. Well Spacing at 6400 feet.

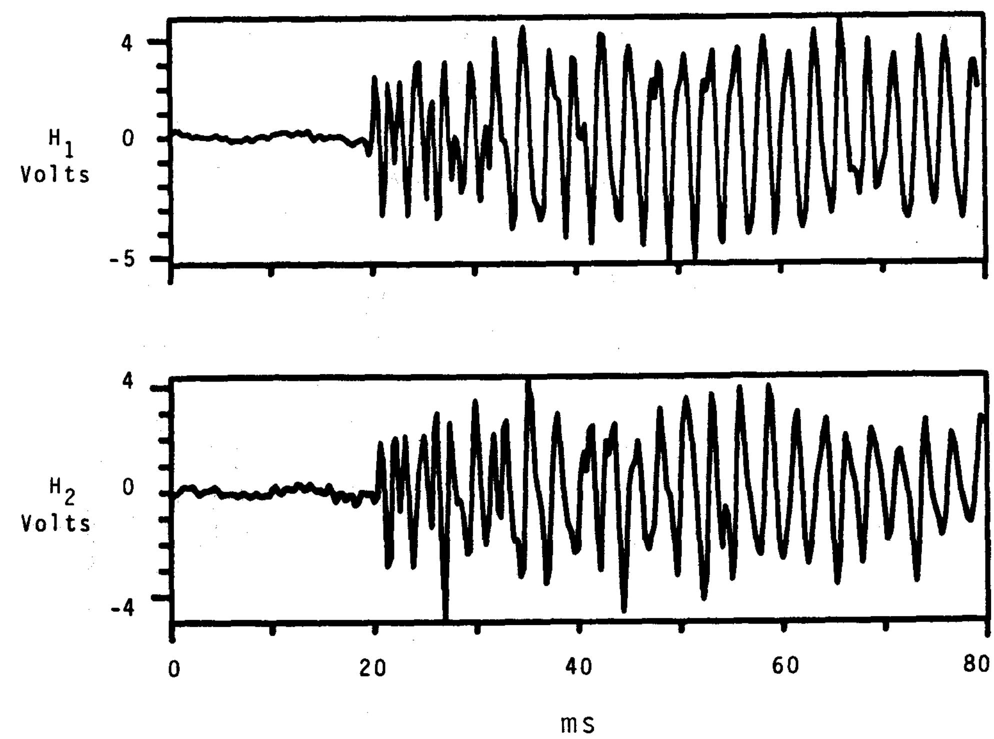

Figure 9.4. Pre-test Tubing Shot Time Series.

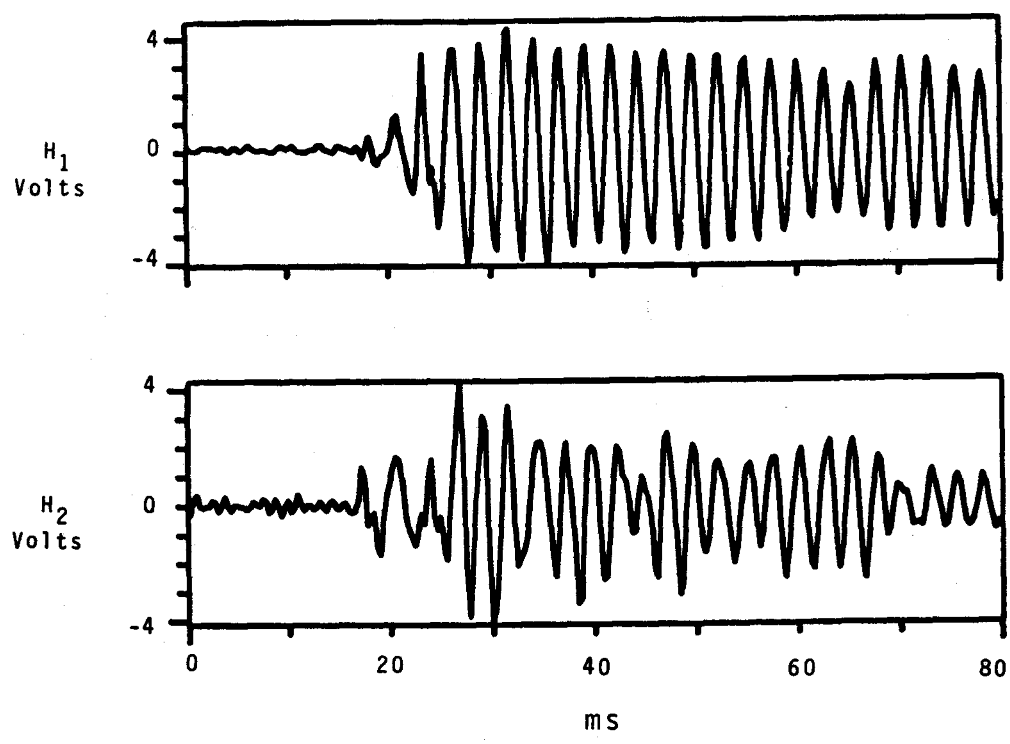

Figure 9.5. MWX-2 Orientation Shot Time Series.

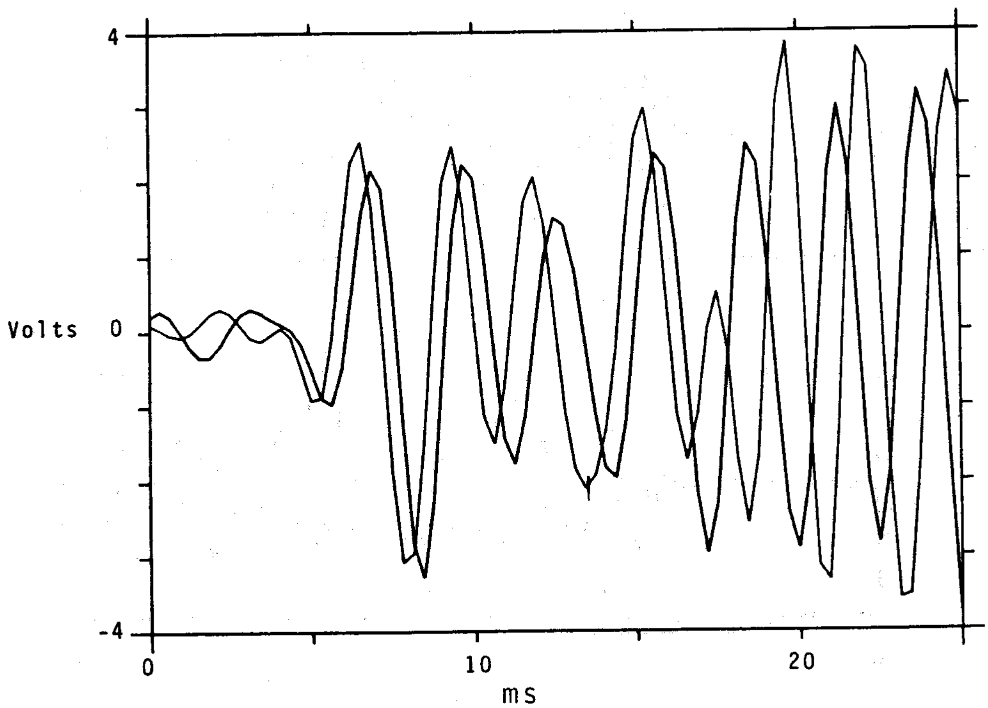

Figure 9.6. Event Data Phase Delay (H1 to V).

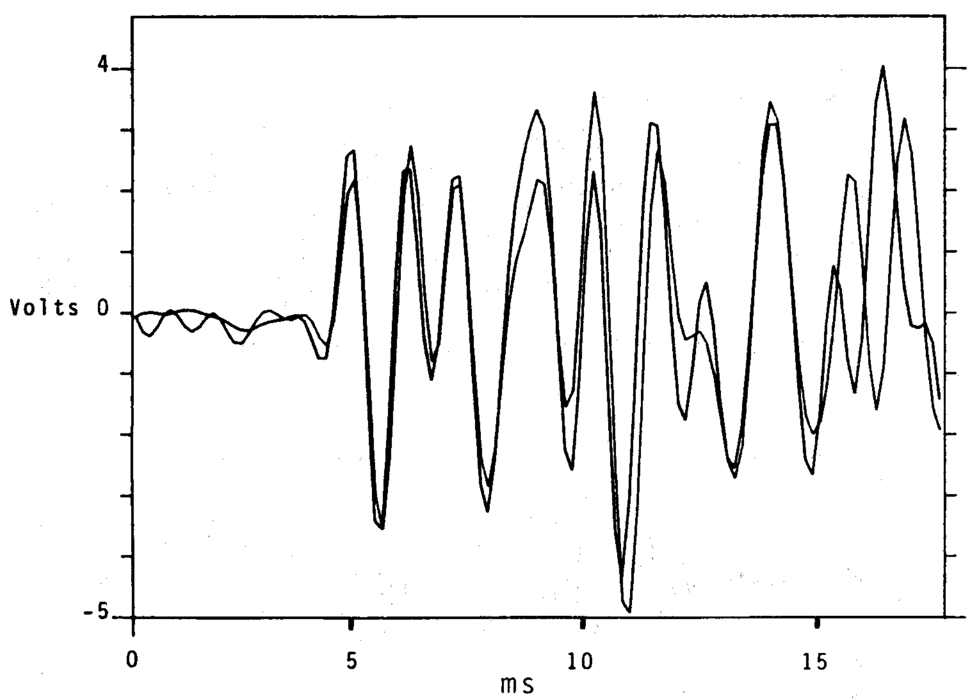

Figure 9.7. Pre-test tubing Shot Data Phase Delay (H1 to H2).

10.0 BIBLIOGRAPHY

S. J. Finley
Sandia National Laboratories

The technical output from the Multiwell Experiment resides in an MWX Data File which is maintained in the project office at Sandia National Laboratories in Albuquerque, NM.

The MWX Data File is intended to be "results-oriented." Thus, it includes such entries as (1) data reports from contractors and others, (2) memoranda, informal reports and compilations of results and analyses, (3) formal publications and reports, and (4) in limited cases, planning documents, review meeting summaries, etc. It is not intended to include every sheet of paper ever written on MWX or every bit of data taken. In general these are entries which are referenceable and which convey data.

The MWX Data File has the following overall organization:

1.0 Well data by well
1.1 Well logs by well and logging program; analyses
1.2 Core and fluid analyses by type and performer
1.3 Core-log correlation
1.4 Geology by topic
1.5 Environmental
1.6 Geophysics by type
1.7 Stress testing by interval
1.8 Well testing by interval
1.9 Stimulation and fracture diagnostics by interval
3.1 General reviews and status reports
3.3 Quarterly reports
3.5 Topical meetings, displays and workshops
3.7 Technical Review Panel
3.8 Plans

A computer-based index to the MWX Data File is also maintained in which each entry is indexed by accession number, data file number, author(s), title, company, date, alternate report number, key word(s), and comments/notes. Thus, searches, retrieval, and summaries of various types can be made readily. Two listings from this index are presented:

(A) A listing is given in this section of publications and formal reports which include information on the coastal interval. (These are selected from the index through the key words "formal" and "coastal.")

(B) A listing of the complete MWX Data File index data is given in Appendix 11.14 for those entries which contain results for the coastal interval.

****
ACCES NUM   N00641
REPORT NUM 1.6.3.012
AUTHOR   ALBRIGHT,JN
AUTHOR   JOHNSON,PA
TITLE   CROSSWELL ACOUSTIC SURVEYING OF GAS SANDS: TRAVEL-TIME PATTERN
            RECOGNITION, SEISMIC Q, AND CHANNEL WAVES
CORP AUTH   LANL
DATE   850619
NOTES   PRESENTED AT ANNUAL MEETING OF THE SOCIETY OF PROFESSIONAL WELL
            LOG ANALYSTS (SPWLA) JUNE 19,1985 DALLAS,TEXAS.
****
ACCES NUM   N00640
REPORT NUM 1.6.3.011
AUTHOR   ALBRIGHT,JN
AUTHOR   TERRY,DA
AUTHOR   BRADLEY,CR
TITLE   PATTERN RECOGNITION AND TOMOGRAPHY USING CROSSWELL ACOUSTIC DATA
CORP AUTH   LANL
DATE   850500
ALT NUMBER SPE13854
NOTES   PRESENTED AT 1985 SPE/DOE SYMPOSIUM ON LOW PERMEABILITY
            RESERVOIRS, MAY 19-22,1985, DENVER,CO.
****
ACCES NUM   N00301
REPORT NUM 1.4.2.012
AUTHOR   EATOUGH,MO
TITLE   MINERALOGIC AND PETROLOGIC OVERVIEW OF CORE SAMPLES FROM THE
            DEPT. OF ENERGY'S WESTERN GAS SANDS PROJECT MULTIWELL EXPERIMENT,
            PICEANCE BASIN, COLORADO
CORP AUTH   BENDIX
DATE   830300
ALT NUMBER SPEDOE11764
NOTES   THIS PAPER WAS PRESENTED AT THE 1983 SPE/DOE SYMPOSIUM ON LOW
            PERMEABILITY HELD IN DENVER, COLORADO, MARCH 14-16, 1983
****
ACCES NUM   N00308
REPORT NUM 1.4.2.013
AUTHOR   HEINZE,DM
TITLE   MINERALOGY AND PETROLOGY ASPECTS OF THE MESAVERDE FORMATION AT
            RIFLE GAP, COLORADO, SPECIFIC TO THE SEDIMENTOLOGY AND
            GAS-BEARING INTERVALS IN THE SUBSURFACE
DATE   830300
ALT NUMBER SAND830287
****
ACCES NUM   N00639
REPORT NUM 1.6.3.010
AUTHOR   JOHNSON,PA
AUTHOR   ALBRIGHT,JN
TITLE   IN SITU PHYSICAL PROPERTIES MEASUREMENTS USING CROSSWELL
            ACOUSTIC DATA
CORP AUTH   LANL
DATE   850500
ALT NUMBER SPE13881
NOTES   PRESENTED AT 1985 SPE/DOE SYMPOSIUM ON LOW PERMEABILITY GAS
            RESERVOIRS, DENVER,CO. MAY 19-20,1985.
****
ACCES NUM   N00630
REPORT NUM 3.1.004
AUTHOR   KOMAR,CA
TITLE   PROCEEDINGS OF THE UNCONVENTIONAL GAS RECOVERY CONTRACTORS MEETING
CORP AUTH   DOE
DATE   851100
ALT NUMBER DOE/METC-86/6034
****
ACCES NUM   N00575

REPORT NUM 1.1.4.012
AUTHOR KUKAL,GC
TITLE A SYSTEMATIC APPROACH FOR THE EFFECTIVE LOG ANALYSIS OF TIGHT GAS SANDS
CORP AUTH CER
DATE 840500
ALT NUMBER SPEDOE12851
NOTES PRESENTED AT SPE/DOE/GRI UNCONVENTIONAL GAS RECOVERY SYMPOSIUM, MAY 13-15,1984-PITTSBURGH PA.

****

ACCES NUM N00574
REPORT NUM 1.1.4.011
AUTHOR KUKAL,GC
AUTHOR SIMONS,KE
TITLE LOG ANALYSIS TECHNIQUES FOR QUANTIFYING THE PERMEABILITY OF SUB-MILLIDARCY SANDSTONE RESERVOIRS
CORP AUTH CER
DATE 850500
ALT NUMBER SPEDOE13880
NOTES PRESENTED AT THE SPE/DOE 1985 LOW PERMEABILITY GAS RESERVOIR SYMPOSIUM DENVER,COLORADO-MAY 19-22 1985.

****

ACCES NUM N00160
REPORT NUM 1.6.2.002
AUTHOR LEE,MW
TITLE VERTICAL SEISMIC PROFILES AT MULTI-WELL EXPERIMENT SITE, GARFIELD COUNTY, COLORADO
CORP AUTH USGS
DATE 831100
ALT NUMBER USGS OPEN FILE REPORT 84-168

****

ACCES NUM N00161
REPORT NUM 1.6.2.003
AUTHOR LEE,MW
TITLE DELINEATION OF LENTICULAR-TYPE SAND BODIES BY VERTICAL SEISMIC PROFILING METHOD
CORP AUTH USGS
DATE 831100
ALT NUMBER USGS OPEN FILE REPORT 84-265

****

ACCES NUM N00501
REPORT NUM 1.6.2.005
AUTHOR LEE,MW
TITLE INTERPRETATION OF AZIMUTHAL VERTICAL SEISMIC PROFILE SURVEY AT MULTIWELL EXPERIMENT SITE, GARFIELD COUNTY, COLORADO
CORP AUTH USGS
DATE 850400
ALT NUMBER USGS OPEN FILE REPORT 85-428

****

ACCES NUM N00500
REPORT NUM 1.6.2.004
AUTHOR LEE,MW
AUTHOR MILLER,JJ
TITLE ACQUISITION AND PROCESSING OF AZIMUTHAL VERTICAL SEISMIC PROFILES AT MULTIWELL EXPERIMENT SITE, GARFIELD COUNTY, COLORADO
CORP AUTH USGS
DATE 850400
ALT NUMBER USGS OPEN FILE REPORT 85-427

****

ACCES NUM N00511
REPORT NUM 1.4.3.030
AUTHOR LORENZ,JC
TITLE PREDICTIONS OF SIZE AND ORIENTATIONS OF LENTICULAR RESERVOIRS IN THE MESAVERDE GROUP, NORTHWESTERN COLORADO
CORP AUTH SAND
DATE 850519

ALT NUMBER SPEDOE13851
NOTES PRESENTED AT THE SPE/DOE 1985 LOW PERMEABILITY GAS RESERVOIRS SYMPOSIUM, DENVER,CO.-MAY 19-20,1985.
****
ACCES NUM N00294
REPORT NUM 1.4.3.033
AUTHOR LORENZ,JC
TITLE SEDIMENTOLOGY OF THE MESAVERDE FORMATION AT RIFLE GAP, COLORADO AND IMPLICATIONS FOR GAS-BEARING INTERVALS IN THE SUBSURFACE
DATE 820300
ALT NUMBER SAND820604
****
ACCES NUM N00309
REPORT NUM 1.4.3.037
AUTHOR LORENZ,JC
TITLE RESERVOIR SEDIMENTOLOGY IN MESAVERDE ROCKS AT THE MULTI-WELL EXPERIMENT SITE
DATE 830600
ALT NUMBER SAND83-1078
****
ACCES NUM N00671
REPORT NUM 1.4.5.013
AUTHOR LORENZ,JC
AUTHOR BRANAGAN,P
AUTHOR WARPINSKI,NR
AUTHOR SATTLER,AR
TITLE FRACTURE CHARACTERISTICS AND RESERVOIR BEHAVIOR OF STRESS-SENSITIVE FRACTURE SYSTEMS IN FLAT-LYING LENTICULAR FORMATIONS
CORP AUTH SAND
CORP AUTH CER
DATE 860518
ALT NUMBER SPE 15244
NOTES PRESENTED AT THE UNCONVENTIONAL GAS TECHNOLOGY SYMPOSIUM OF THE SOCIETY OF PETROLEUM ENGINEERS, LOUISVILLE, KY, MAY 18-21,1986
****
ACCES NUM N00793
REPORT NUM 1.4.4.041
AUTHOR LORENZ,JC
AUTHOR FINLEY,SJ
TITLE DIFFERENCES IN FRACTURE CHARACTERISTICS AND RELATED PRODUCTION OF NATURAL GAS IN DIFFERENT ZONES OF THE MESAVERDE FORMATION, NORTHWESTERN, COLORADO
CORP AUTH SAND
DATE 870927
ALT NUMBER SPE16809
NOTES PRESENTED AT THE ANNUAL SPE CONFERENCE IN DALLAS,TX SEPT. 27-30,1987
****
ACCES NUM N00845
REPORT NUM 1.4.5.016
AUTHOR LORENZ,JC
AUTHOR FINLEY,SJ
TITLE SIGNIFICANCE OF DRILLING- AND CORING-INDUCED FRACTURES IN MESAVERDE CORE, NORTHWESTERN COLORADO
CORP AUTH SAND
DATE 880600
ALT NUMBER SAND 88-1623
****
ACCES NUM N00780
REPORT NUM 1.4.3.040
AUTHOR LORENZ,JC
AUTHOR RUTLEDGE,AK
TITLE LATE CRETACEOUS MESAVERDE GROUP OUTCROPS AT RIFLE GAP, PICEANCE CREEK BASIN, NORTHWESTERN COLORADO
CORP AUTH SAND

DATE 870000
ALT NUMBER 68
NOTES GEOLOGICAL SOCIETY OF AMERICA CENTENNIAL FIELD GUIDE - ROCKY MOUNTAIN SECTION, 1987
****
ACCES NUM 00847
REPORT NUM 3.1.021
AUTHOR LORENZ,JC
AUTHOR WARPINSKI,NR
AUTHOR TEUFEL,LW
AUTHOR BRANAGAN,PT
AUTHOR SATTLER,AR
AUTHOR NORTHROP,DA
TITLE RESULTS OF THE MULTIWELL EXPERIMENT, IN SITU STRESSES, NATURAL FRACTURES, AND OTHER GEOLOGICAL CONTROLS ON RESERVOIRS
CORP AUTH SAND
CORP AUTH CER
DATE 880830
NOTES EOS VOL. 69 NO.35 P817,825-826
****
ACCES NUM N00104
REPORT NUM 1.2.55.001
AUTHOR MORROW,NR
TITLE RELATIONSHIP OF PORE STRUCTURE TO FLUID BEHAVIOR IN LOW PERMEABILITY GAS SANDS, FIRST ANNUAL REPORT
CORP AUTH NMPRRC
DATE 831000
ALT NUMBER DOEBC10216-13
****
ACCES NUM N00328
REPORT NUM 1.2.55.005
AUTHOR MORROW,NR
TITLE RELATIONSHIP OF PORE STRUCTURE TO FLUID BEHAVIOR IN LOW PERMEABILITY GAS SANDS
CORP AUTH NMPRRC
DATE 840500
ALT NUMBER NMERDI2703303
****
ACCES NUM N00705
REPORT NUM 1.2.55.012
AUTHOR MORROW,NR
TITLE RELATIONSHIP OF PORE STRUCTURE TO FLUID BEHAVIOR IN LOW PERMEABILITY GAS SANDS: YEAR THREE
CORP AUTH NMPRRC
DATE 850200
ALT NUMBER NMERDI 2-72-4309
****
ACCES NUM N00447
REPORT NUM 1.2.55.004
AUTHOR MORROW,NR
AUTHOR BROWER,KR
AUTHOR KILMER,NH
TITLE RELATIONSHIP OF PORE STRUCTURE TO FLUID BEHAVIOR IN LOW PERMEABILITY GAS SANDS
CORP AUTH NMPRRC
DATE 820000
ALT NUMBER DOE BC 10216-14
****
ACCES NUM N00704
REPORT NUM 1.2.55.011
AUTHOR MORROW,NR
AUTHOR BROWER,KR
AUTHOR KILMER,NH
TITLE RELATIONSHIP OF PORE STRUCTURE TO FLUID BEHAVIOR IN LOW PERMEABILITY GAS SANDS, 1984 FINAL REPORT
CORP AUTH NMPRRC

DATE   840900
ALT NUMBER DOEBC10216-13
****
ACCES NUM   N00669
REPORT NUM 1.2.55.009
AUTHOR   MORROW,NR
AUTHOR   WARD,J
AUTHOR   BROWER,KR
TITLE   ROCK MATRIX AND FRACTURE ANALYSIS OF FLOW IN WESTERN TIGHT GAS SANDS, 1985 ANNUAL REPORT
CORP AUTH   NMPRRC
DATE   860200
ALT NUMBER DOEMC21179-2032
****
ACCES NUM   N00470
REPORT NUM 1.4.3.026
AUTHOR   PETERSON,RE
TITLE   GEOLOGICAL AND PRODUCTION CHARACTERISTICS OF THE NON-MARINE PART OF THE MESAVERDE GROUP, RULISON FIELD AREA,PICEANCE BASIN, COLORADO
CORP AUTH   CER
DATE   840514
ALT NUMBER SPE 12835
NOTES   PRESENTED AT THE 1984 SPE/DOE/GRI UNCONVENTIONAL GAS RECOVERY SYMPOSIUM HELD IN PITTSBURGH PA, MAY 13-15,1984.
****
ACCES NUM   N00295
REPORT NUM 1.4.3.034
AUTHOR   PETERSON,RE
TITLE   WESTERN GAS SANDS PROJECT: AN APPROXIMATION OF CONTINUITY OF LENTICULAR MESAVERDE SANDSTONE LENSES, UTILIZING CLOSE WELL CORRELATIONS, PICEANCE BASIN, NORTHWEST COLORADO
CORP AUTH   CER
DATE   821100
ALT NUMBER DOENV102493
****
ACCES NUM   N00305
REPORT NUM 1.4.3.035
AUTHOR   PETERSON,RE
AUTHOR   KOHOUT,J
TITLE   AN APPROXIMATION OF CONTINIUITY OF LENTICULAR MESAVERDE SANDSTONE LENSES UTILIZING CLOSE-WELL CORRELATIONS, PICEANCE BASIN, NORTHWESTERN COLORADO
CORP AUTH   CER
DATE   830300
ALT NUMBER SPEDOE11610
NOTES   THIS PAPER WAS PRESENTED AT THE 1983 SPE/DOE SYMPOSIUM ON LOW PERMEABILITY HELD IN DENVER, COLORADO, MARCH 14-16, 1983
****
ACCES NUM   N00300
REPORT NUM 1.2.12.020
AUTHOR   RANDOLPH,PL
TITLE   POROSITY AND PERMEABILITY OF MESAVERDE SANDSTONE CORE FROM THE U.S. DOE MULTIWELL EXPERIMENT, GARFIELD COUNTRY, COLORADO
CORP AUTH   IGT
DATE   830300
ALT NUMBER SPEDOE11765
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****
ACCES NUM   N00496
REPORT NUM 1.2.12.019
AUTHOR   RANDOLPH,PL
AUTHOR   SOEDER,DJ
AUTHOR   CHOWDIAH,P
TITLE   EFFECTS OF WATER AND STRESS UPON PERMEABILITY TO GAS OF PALUDAL

AND COASTAL SANDS; U.S. DOE MULTIWELL EXPERIMENT
EXPERIMENT
CORP AUTH IGT
DATE 850200
ALT NUMBER DOE/MC/20342-1838
****
ACCES NUM N00326
REPORT NUM 1.2.12.021
AUTHOR RANDOLPH,PL
AUTHOR SOEDER,DJ
AUTHOR CHOWDIAH,P
TITLE POROSITY AND PERMEABILITY OF TIGHT SANDS
CORP AUTH IGT
DATE 840513
ALT NUMBER SPEDOEGRI12836
NOTES PRESENTED AT THE 1984 SPE/DOE/GRI UNCONVENTIONAL GAS RECOVERY SYMPOSIUM, PITTSBURGH, PENNSYLVANIA, MAY 13-15, 1984
****
ACCES NUM N00672
REPORT NUM 1.2.62.017
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CORP AUTH SAND
CORP AUTH DOWELL
CORP AUTH NIPER
DATE 860518
ALT NUMBER SPE 15245
NOTES THIS PAPER WAS PRESENTED AT THE UNCONVENTIONAL GAS TECHNOLOGY SYMPOSIUM OF THE SOCIETY OF PETROLEUM ENGINEERS HELD IN LOUISVILLE, KENTUCKY, MAY 18-21,1986.
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ACCES NUM N00572
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REPORT NUM 1.2.25.018
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ALT NUMBER SPE13134
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ALT NUMBER OFR 84757
NOTES SUMMARY OF USGS WORK ON MWX
****
ACCES NUM N00513
REPORT NUM 1.9.5.004
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TITLE DETERMINATION OF HYDRAULIC FRACTURE AZIMUTH BY GEOPHYSICAL, GEOLOGICAL, AND ORIENTED CORE METHODS AT THE MULTI-WELL EXPERIMENT SITE, RIFLE, CO.
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CORP AUTH NMPRRC
DATE 841001
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ACCES NUM N00647
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TITLE CAPILLARY PRESSURES AND GAS RELATIVE PERMEABILITIES OF LOW PERMEABILITY SANDSTONE
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ACCES NUM N00759

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CORP AUTH NMPRRC
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ALT NUMBER SPE 13093
NOTES PRESENTED AT THE 59TH ANNUAL TECHNICAL CONFERENCE AND EXHIBITION HELD IN HOUSTON, TEXAS SEPT 16-19,1984
****

11.0 APPENDICES

The following appendices appear as microfiche in a pocket on the back cover:

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11.11 Treatment Data for Coastal Nitrogen Foam Fracture (Sandia)

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APPENDIX 11.1

PETROGRAPHIC DATA SHEETS

BENDIX

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6345.6
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: May 25, 1982

Rock Type: Calcareous Subarkose
Mean Grain Size (mm): 0.06
Grain Size Range (mm): 0.02 - 0.15

% Pore Space: 8
Sorting (est.): Well Sorted
Angularity (est.): A to SR

GENERAL DESCRIPTION: Well indurated; grain contacts are mostly concavo-convex sutured; no floating grains; porosity is about 50/50 intergranular pore space and pore throats which are mostly filled with clay. Blue epoxy also penetrated along cleavages in altered feldspars and carbonates; quartz overgrowths are not readily distinguishable.

COMPOSITION	%	COMMENTS
Quartz	50	Mostly monocrystalline; few polycrystalline grains; overgrowths common
K-feldspar	tr	Microcline
Plagioclase	7	Nearly fresh to almost totally altered
Chert	1	Many grains are squashed
Lithics	6	Mostly sedimentary rock fragments and fewer plutonic and volcanic rock fragments
Authigenic Minerals		
Silica O. gr.	2	Could possibly be more abundant; calcite and clay under some
Calcite	7	Some twinning; few could be clasts; many irregular grains
Dolomite	14	Twinned; rhombs and irregular grains
Muscovite	tr	Few shredded and contorted flakes
Biotite	tr	Shredded flakes
Opaques	tr	Few detrital grains; some could be alteration product
Accessory Minerals		
Zircon	tr	Some fairly large 0.05 mm
Tourmaline	tr	
Unknown	tr	Brown globular grains; could be altered mafics
Voids w/o Clay	1	
Voids w/Clay	7	Contain matted illite
Clay Minerals	1	Not included in pore space
Mixed Layer (By XRD)	Dom	Illite/montmorillonite (mostly illite)

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6346.4
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: May 26, 1982

Rock Type: Calcareous Subarkose
Mean Grain Size (mm): 0.07
Grain Size Range: 0.02 - 0.15

% Pore Space: 8
Sorting (est.): Well Sorted
Angularity (est.): A to SR

GENERAL DESCRIPTION: Similar to Sample MWX-6345.6; porosity is about 50/50 clay-filled pores and pore throats. Some micritic blobs of carbonate were impregnated by blue epoxy.

COMPOSITION	%	COMMENTS
Quartz	53	
K-feldspar	1	
Plagioclase	7	
Chert	2	
Lithics	5	
Authigenic Minerals		
Silica O. gr.	2	
Calcite	7	Some twinned
Dolomite	14	Twinned
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Tourmaline	tr	
Unknown	tr	
Voids w/o Clay	1	
Voids w/Clay	7	
Clay Minerals	tr	Not included in pore space
Mixed Layer		Should be similar to previous sample

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6355.5
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: May 26, 1982

Rock Type: Calc. Feldspathic Litharenite
Mean Grain Size (mm): 0.14
Grain Size Range (mm): 0.05 - 0.25

% Pore Sapce: 10
Sorting (est.): Moderately Sorted
Angularity (est.): A to SR

GENERAL DESCRIPTION: Mineralogically similar to previous smaples with distinct increase in grain size. Well indurated; grain contacts are mostly concavo-convex or sutured; very few floating grains. Floating grains occur in pockets dominated by clay, carbonate and silt-sized grains. Pore space is dominated by clay-filled pores; some pore throats; some microporosity in altered feldspars.

COMPOSITION	%	COMMENTS
Quartz	47	Mostly monocrystalline; few metamorphic; rutilated grains common
K-feldspar	1	Microcline and orthoclase
Plagioclase	5	Nearly fresh to totally altered
Chert	4	Few squashed grains
Lithics	9	Mostly sedimentary few possibly volcanic
Authigenic Minerals		
Silica O. gr.	3	Some clay and carbonate under the overgrowths
Calcite	13	Twinned; irregular grains and rhombs; some poikilotopic cement
Dolomite	6	Twinned; rhombs and irregular grains
Muscovite	tr	
Biotite	tr	
Opaques	tr	Very few detrital grains; some could be alteration product
Accessory Minerals		
Tourmaline	tr	
Zircon	tr	
Unknown	tr	Brown globular masses; could be altered mafics
Voids w/o Clay	1	
Voids w/Clay	9	Contain illite
Clay Minerals	2	Not included in clay filled voids (Illite and kaolinite)
Kaolinite (Optically)	tr	Authigenic in pore space
Mixed Layer (By XRD)	Dom	Illite/montmorillonite (dominated by illite)

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6357.6
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: May 27, 1982

Rock Type: Sublitharenite
Mean Grain Size (mm): 0.12
Grain Size Range (mm): 0.04 to 0.36

% Pore Space: 12
Sorting (est.): Moderate
Angularity (est.): A to SR

GENERAL DESCRIPTION: Mineralogically and texturally similar to MWX-6355.5. Pore space is also similar, but this sample appear to have more pore throats. This sample also contains some poikilotopic carbonate cement.

COMPOSITION	%	COMMENTS
Quartz	51	
K-feldspar	1	
Plagioclase	7	
Chert	3	
Lithics	10	Also contains few plutonic rock fragments
Authigenic Minerals		
Silica O. gr.	3	
Calcite	5	Few twinned
Dolomite	5	Commonly twinned
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals	tr	
Zircon	tr	
Other	tr	Detrital chalcedony
Unknown	tr	
Voids w/o Clay	2	
Voids w/Clay	10	Mostly filled with illite possibly some kaolinite
Clay Minerals	1	Not included in pore space
Kaolinite (Optically)	tr	
Chlorite (Optically)	tr	One area seen in thin section
Mixed Layer	Dom	Should be similar to previous sample (MWX-6355.5)

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6360.5
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: May 25, 1982

Rock Type: Feldspathic Litharenite
Mean Grain Size (mm): 0.18
Grain Size Range (mm): 0.04 - 0.40

% Pore Space: 12
Sorting (est.): Moderate
Angularity (est.): A to SR

GENERAL DESCRIPTION: Mineralogically and texturally similar to previous samples; pore space is dominated by clay-filled voids in about a 3:1 ratio over open voids. Clay-filled pore throats and microporosity in altered feldspars and carbonate is also common.

COMPOSITION	%	COMMENTS
Quartz	53	
K-feldspar	2	
Plagioclase	7	
Chert	6	
Lithics	9	
Authigenic Minerals		
Silica O. gr.	3	
Calcite	3	Few twinned
Dolomite	3	Commonly twinned; contain some dolomite rhombs
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Other	tr	Detrital chalcedony
Unknown	tr	Possible zeolites in pores. No zeolite found in XRD.
Voids w/o Clay	3	
Voids w/Clay	9	
Clay Minerals	2	Not included in pore space
Kaolinite (Optically)	tr	Lines voids
Mixed Layer	Dom	Should be similar to previous samples

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6362.5
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: May 27, 1982

Rock Type: Feldspathic Litharenite
Mean Grain Size (mm): 0.17
Grain Size Range (mm): 0.03 - 0.35

% Pore Space: 11
Sorting (est.): Moderate
Angularity (est.): A to SR

GENERAL DESCRIPTION: Mineralogically and texturally similar to previous samples; porosity is dominated by clay-filled pores; a few open pores and clay-filled pore throats were also observed; blue epoxy also penetrated altered feldspars.

COMPOSITION	%	COMMENTS
Quartz	58	
K-feldspar	1	
Plagioclase	9	
Chert	4	
Lithics	9	
Authigenic Minerals		
Silica O. gr.	2	
Calcite	2	Few twinned
Dolomite	2	Commonly twinned
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Other	tr	Detrital chalcedony
Unknown	tr	
Voids w/o Clay	1	
Voids w/Clay	10	
Clay Minerals	1	Not included in pore space
Mixed Layer	Dom	Should be similar to previous samples

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6363.5
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: May 27, 1982

Rock Type: Feldspathic Litharenite
Mean Grain Size (mm): 0.14
Grain Size Range (mm): 0.04 - 0.35

% Pore Space: 13
Sorting (est.): Moderate to Well
Angularity (est.): A to SR

GENERAL DESCRIPTION: Mineralogically and texturally similar to previous samples; porosity is dominated by clay-filled pores; a few open voids and clay-filled pore throats were also observed.

COMPOSITION	%	COMMENTS
Quartz	54	
K-feldspar	1	
Plagioclase	8	
Chert	3	
Lithics	9	
Authigenic Minerals		
Silica O. gr.	3	
Calcite	3	Some twinned
Dolomite	5	Commonly twinned
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Other	tr	
Voids w/o Clay	1	
Voids w/Clay	12	
Clay Minerals	1	Not included in pore space
Kaolinite (Optically)	tr	
Mixed Layer (By XRD)	Dom	Illite/montmorillonite (illite dominant)

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6380.4
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: May 27, 1982

Rock Type: Calcareous Sublitharenite
Mean Grain Size (mm): 0.09
Grain Size Range (mm): 0.02 - 0.18

% Pore Space: 15
Sorting (est.): Well
Angularity (est.): A to SR

GENERAL DESCRIPTION: Mineralogically similar to previous samples with a distinct decrease in grain size. Porosity is dominated by small clay-filled pores and, to a lesser degree, clay-filled pore throats; a few open voids are also present.

COMPOSITION	%	COMMENTS
Quartz	49	Mostly monocrystalline, few polycrystalline
K-feldspar	1	Microcline
Plagioclase	4	Nearly fresh to almost totally altered
Chert	3	Microcrystalline; squashed grains common
Lithics	7	Sedimentary and volcanic
Authigenic Minerals		
Silica O. gr.	4	Sometimes difficult to distinguish from detrital quartz
Calcite	5	Some twinned
Dolomite	12	Many twinned
Muscovite	tr	Squashed flakes
Biotite	tr	Bleached
Opaques	tr	Few detrital grains; some globular masses
Accessory Minerals		
Tourmaline	tr	
Zircon	tr	
Other	tr	Detrital chalcedony
Unknown	tr	Brown nearly amorphous
Voids w/o Clay	1	
Voids w/Clay	14	
Clay Minerals	tr	Not included in pore space
Kaolinite (Optically)	tr	Lines pores
Mixed Layer (By XRD)	Dom	Illite/montmorillonite (illite dominant)

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6382.5
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: May 28, 1982

Rock Type: Calcareous Sublitharenite
Mean Grain Size (mm): 0.10
Grain Size Range (mm): 0.02 to 0.20

% Pore Space: 13
Sorting (est.): Well
Angularity (est.): A to SR

GENERAL DESCRIPTION: Mineralogically and texturally similar to previous samples. Porosity is evenly divided between clay-filled pores and clay-filled pore throats around many grains. A few open pores are also present.

COMPOSITION	%	COMMENTS
Quartz	55	
K-feldspar	1	
Plagioclase	6	
Chert	2	
Lithics	6	
Authigenic Minerals		
Silica O. gr.	3	
Calcite	4	Twinned
Dolomite	9	Twinned
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Epidote	tr	
Hornblende	tr	
Other	tr	
Unknown	tr	Could be zeolites in pore space
Voids w/o Clay	1	
Voids w/Clay	12	
Clay Minerals	tr	Not included in pore space
Mixed Layer	Dom	Should be similar to previous samples

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6384.5
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: May 28, 1982

Rock Type: Calcareous Sublitharenite
Mean Grain Size (mm): 0.07
Grain Size Range (mm): 0.02 - 0.15

% Pore Sapce: 4
Sorting (est.): We
Angularity (est.): . 3R

GENERAL DESCRIPTION: Well indurated; finer grained than previous samples; distinct increase in carbonate. Porosity is dominated by clay-filled pores, few pore throats were observed. Open pores more abundant than pore throats. A few pores not filled by clay were filled with calcite and authigenic quartz.

COMPOSITION	%	COMMENTS
Quartz	51	Mostly monocrystalline; few polycrystalline
K-feldspar	tr	Microcline
Plagioclase	4	Nearly fresh to almost totally altered
Chert	1	
Lithics	6	Mostly mudstone; few micritic fragments
Authigenic Minerals		
Silica O. gr.	4	
Calcite	10	Twinned
Dolomite	16	Twinned
Muscovite	1	Shredded and squashed grains
Biotite	tr	
Opaques	tr	Few detrital grains and globular masses
Accessory Minerals		
Zircon	1	
Tourmaline	tr	
Hornblende	tr	Brownish yellow
Other	tr	
Unknown	tr	
Voids w/o Clay	1	
Voids w/Clay	3	
Clay Minerals	tr	Not included in pore space
Kaolinite	tr	Kaolinite fills a few pores, but not detected with XRD
Mixed Layer (By XRD)	Dom	Illite/montmorillonite (illite dominant)

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6400.3
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: May 28, 1982

Rock Type: Calcareous Sublitharenite
Mean Grain Size (mm): 0.10
Grain Size Range (mm): 0.02 - 0.26

% Pore Space: 15
Sorting (est.): Well to Moderate
Angularity (est.): A to SR

GENERAL DESCRIPTION: Mineralogically and texturally similar to the previous sample; may be slightly less well sorted. Porosity is higher in this sample and is dominated by clay-filled pores and pore throats. A few open pores were observed. A small fracture is filled with calcite.

COMPOSITION	%	COMMENTS
Quartz	48	
K-feldspar	tr	
Plagioclase	4	
Chert	2	
Lithics	8	
Authigenic Minerals		
Silica O. gr.	2	
Calcite	7	Twinned
Dolomite	12	Twinned
Muscovite	1	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Other	tr	
Unknown	tr	
Voids w/o Clay	1	
Voids w/Clay	14	
Clay Minerals	1	Not included in pore space
Chlorite (Optically)	tr	
Mixed Layer (By XRD)	Dom	Illite/montmorillonite (illite dominant)

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6431.5
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: April 12, 1982

Rock Type: Calcareous Lithic Arenite
Mean Grain Size (mm): 0.08
Grain Size Range (mm): 0.04 to 0.12

% Pore Space: 8
Sorting (est.): Very well
Angularity (est): A to SR

GENERAL DESCRIPTION: Well indurated; grain contacts are mostly concavo-convex or sutured; porosity is dominated by clay-filled pores and lesser by open pores; pore throats are common.

COMPOSITION	%	COMMENTS
Quartz	37	Mostly monocrystalline; few strongly undulose polycrystalline
K-feldspar	tr	Perthite
Plagioclase	8	Few fresh; most are moderately to very strongly altered
Chert	5	Many squashed grains
Lithics	2	Mostly sedimentary rock fragments (mudstone and claystone. Few volcanic rock fragments (plagioclase phenocrysts in aphanitic groundmass).
Authigenic Minerals		
Silica O. gr.	8	Many indistinguishable from detrital grains
Calcite	20	Cement and pore fillings; commonly replaces feldspars; twinned
Dolomite	7	Rhombs and interlocking anhedra
Orthoclase	tr	Free standing euhedra
Muscovite	tr	Squashed between detrital grains
Biotite	tr	
Opaques	tr	Few detrital; mostly aggregates in interstices
Accessory Minerals		
Zircon	tr	Most nearly as large as other detrital grains
Tourmaline	tr	
Unknown	tr	Cloudy nearly opaque; amorphous; possibly altered mafic
Voids w/o Clay	1	Mostly equidimensional pores with little or no clay
Voids w/Clay	7	
Clay Minerals	4	Did not pick up blue epoxy impregnation
Chlorite (Optically)	tr	
Mixed Layer (By XRD)	Dom	Illite/montmorillonite (dominantly illite)

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6433.5
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: April 12, 1982

Rock Type: Calc. Feldspathic Litharenite
Mean Grain Size (mm): 0.07
Grain Size Range (mm): 0.03 - 0.14

% Pore Space: 5
Sorting (est.): Well Sorted
Angularity (est.): Subangular

GENERAL DESCRIPTION: Well indurated; grain contacts are concavo-convex or sutured; porosity is dominated by equidimensional pores; some are lined by clay; very few pore throats observed; this sample was not impregnated by the Gardner method.

COMPOSITION	%	COMMENTS
Quartz	34	Mostly monocrystalline; few polycrystalline
K-feldspar	tr	
Plagioclase	6	Nearly fresh to extensive alteration to clay and sericite
Chert	6	Some ferruginous stain
Lithics	2	Squashed
Authigenic Minerals		
Silica O. gr.	12	Frequently indistinguishable from detrital grains
Calcite	12	Twinned; commonly surrounds detritus and dolomite
Dolomite	10	Rhombs; round blebs, and fine interlocking anhedra; twinned
Muscovite	tr	Contorted books
Opaques	tr	
Accessory Minerals		
Tourmaline	tr	
Zircon	tr	
Other	tr	Aggregates of light brown spheres; phosphatic pellets?
Unknown	tr	Cloudy; dark brown to nearly opaque
Voids w/o Clay	5	
Voids w/Clay	tr	
Clay Minerals	12	Fills interstices
Chlorite (Optically)	tr	Authigenic patches
Mixed Layer (By XRD)	Dom	Illite/montmorillonite (dominated by illite)

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6435.7
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: April 12, 1982

Rock Type: Calcareous Subarkose
Mean Grain Size (mm): 0.10
Grain Size Range (mm): 0.05 - 0.17

% Pore Space: 7
Sorting (est.): Well Sorted
Angularity (est.): SR to SA

GENERAL DESCRIPTION: Mineralogically and texturally similar to MWX-6433.5, but slightly coarser grained.

COMPOSITION	%	COMMENTS
Quartz	47	
K-feldspar	tr	
Plagioclase	7	
Chert	4	
Lithics	3	
Authigenic Minerals		
Silica O. gr.	7	
Calcite	7	Twinned
Dolomite	6	Some twinned
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Unknown	tr	
Voids w/o Clay	3	
Voids w/Clay	4	
Clay Minerals	9	Not included in voids with clay
Chlorite (Optically)	tr	
Mixed Layer	Dom	Should be similar to MWX-6433.5

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6437.4
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: April 13, 1982

Rock Type: Calc. Feldspathic Litharenite
Mean Grain Size (mm): 0.13
Grain Size Range (mm): 0.05 to 0.24

% Pore Space: 9
Sorting (est.): Well Sorted
Angularity (est.): A to SR

GENERAL DESCRIPTION: Well indurated; mineralogically similar to previous samples; distinct increase in grain size and porosity. Porosity is dominated by pore space without clays. Gardner method of impregnation not used with this sample.

COMPOSITION	%	COMMENTS
Quartz	28	
K-feldspar	1	Perthite
Plagioclase	8	
Chert	11	
Lithics	4	
Authigenic Minerals		
Silica O. gr.	10	
Calcite	8	Some twinning
Dolomite	5	Some twinning
Silica Cement	tr	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Unknown	tr	
Voids w/o Clay	9	
Voids w/Clay	tr	
Clay Minerals	16	Not included in voids
Chlorite (Optically)	tr	
Mixed Layer	Dom	Should be similar to previous samples

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6438.5
INTERVAL: Coastal

Petrologist: M. C. Eatough
Date: April 13, 1982

Rock Type: Calc. Feldspathic Litharenite
Mean Grain Size (mm): 0.11
Grain Size Range (mm): 0.02 - 0.19

% Pore Space: 5
Sorting (est.): Well Sorted
Angularity (est.): SA to SR

GENERAL DESCRIPTION: Mineralogically and texturally similar to previous samples; porosity is dominated by irregular pore space. Gardner method not used on this sample.

COMPOSITION	%	COMMENTS
Quartz	43	
K-feldspar	1	Orthoclase and perthite
Plagioclase	8	
Chert	10	
Lithics	3	
Authigenic Minerals		
Silica O. gr.	7	
Calcite	5	Twinned; surrounds dolomite and detritus
Dolomite	3	Some twinned; broken down micrite is common
Silica Cement	tr	Microcrystalline
Muscovite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Tourmaline	tr	
Other	1	Patches of limonitized/bleached biotite? or clays
Unknown	tr	Brown isotropic clay? patches
Voids w/o Clay	5	
Voids w/Clay	tr	
Clay Minerals	13	Some represent remnant clay clasts
Chlorite (Optically)	tr	
Mixed Layer	Dom	Should be similar to previous samples

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6440.5
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: April 13, 1982

Rock Type: Calc. Feldspathic Litharenite
Mean Grain Size (mm): 0.13
Grain Size Range (mm): 0.06 - 0.28

% Pore Space: 5
Sorting (est.): Well Sorted
Angularity (est.): SA to SR

GENERAL DESCRIPTION: Mineralogically and texturally similar to previous samples; porosity is dominated by equidimensional pores. Gardner method not used on this sample.

COMPOSITION	%	COMMENTS
Quartz	38	
K-feldspar	1	
Plagioclase	6	
Chert	6	
Lithics	3	
Authigenic Minerals		
Silica O. gr.	10	
Calcite	8	Commonly twinned
Dolomite	7	Commonly twinned
Silica Cement(?)	2	Microcrystalline; could represent chert; no grain boundaries
Muscovite	tr	
Opaques	tr	Carbonaceous material(?)
Accessory Minerals		
Zircon	tr	
Tourmaline	tr	
Unknown	tr	
Voids w/o Clay	5	
Voids w/Clay	tr	
Clay Minerals	14	Not included in voids with clays
Chlorite (Optically)	tr	
Mixed Layer (By XRD)	Dom	Illite/montmorillonite (illite dominant)

MULTI-WELL PETROGRAPHIC ASSESSMENT

SAMPLE NO: MWX-6445.5
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: April 14, 1982

Rock Type: Feldspathic Litharenite
Mean Grain Size (mm): 0.12
Grain Size Range (mm): 0.05 - 0.17

% Pore Space: 6
Sorting (est.): Very Well Sorted
Angularity (est.): A to SR

GENERAL DESCRIPTION: Well indurated; grain contacts are concavo-convex and lesser sutured contacts; calcite and dolomite are rarely found together. Very similar to previous samples. Porosity is dominated by equidimensional pores. Gardner method not used on this sample.

COMPOSITION	%	COMMENTS
Quartz	43	Mostly monocrystalline; few polycrystalline
K-feldspar	1	Perthite. Fresh to slight argillic alteration
Plagioclase	5	Nearly fresh to almost totally altered
Chert	13	
Lithics	5	Mostly clay clasts and micritic clasts; few volcanic rock fragments
Authigenic Minerals		
Silica O. gr.	7	Difficult to distinguish from detrital quartz
Calcite	4	Few twinned
Dolomite	3	Commonly twinned
Muscovite	tr	
Biotite	tr	Limonitized
Opaques	tr	
Accessory Minerals		
Tourmaline	tr	
Zircon	tr	Prismatic shapes
Other	tr	Detrital chalcedony with silica overgrowths
Voids w/o Clay	6	
Voids w/Clay	tr	
Clay Minerals	12	
Chlorite (Optically)	tr	Associated with volcanic rock fragments
Mixed Layer (By XRD)	Dom	Illite/montmorillonite (illite dominant)

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6447.5
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: April 14, 1982

Rock Type: Calc. Feldspathic Litharenite
Mean Grain Size (mm): 0.11
Grain Size Range (mm): 0.03 - 0.22

% Pore Space: 4
Sorting (est.): Well Sorted
Angularity (est.): A to SR

GENERAL DESCRIPTION: Mineralogically and texturally similar to the previous sample. Porosity is dominated by pore space.

COMPOSITION	%	COMMENTS
Quartz	41	
K-feldspar	1	
Plagioclase	7	
Chert	7	
Lithics	4	
Authigenic Minerals		
Silica O. gr.	7	
Calcite	8	Commonly twinned
Dolomite	7	Commonly twinned
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Tourmaline	tr	
Unknown	tr	
Voids w/o Clay	4	
Voids w/Clay	tr	
Clay Minerals	14	Not included in pore space
Chlorite (Optically)	tr	
Mixed Layer	Dom	Should be similar to previous samples

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6451.5
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: April 14, 1982

Rock Type: Calc. Feldspathic Litharenite
Mean Grain Size (mm): 0.13
Grain Size Range (mm): 0.02 to 0.22

% Pore Space: 8
Sorting (est.): Moderately Sorted
Angularity (est.): SA to SR

GENERAL DESCRIPTION: Well indurated; discontinuous lenses of silt and clay with floating sand-sized clastics; most grain contacts are concavo-convex. Carbonaceous material(?) along mud lenses. Porosity is dominated by open pores. Gardner method not used on this sample.

COMPOSITION	%	COMMENTS
Quartz	41	Mostly monocrystalline; few polycrystalline
K-feldspar	1	Slightly argillic perthite
Plagioclase	5	Nearly fresh to almost totally altered
Chert	6	Some contain fine-grained dolomite rhombs
Lithics	4	Clay and micrite clasts
Authigenic Minerals		
Silica O. gr.	6	
Calcite	6	Few twinned
Dolomite	5	Few twinned
Muscovite	tr	
Biotite	tr	Bleached flakes
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Other	tr	Contorted carbonaceous? stringers associated with clay lenses
Other	tr	Detrital chalcedony
Voids w/o Clay	8	
Voids w/Clay	tr	
Clay Minerals	17	
Chlorite (Optically)	tr	
Mixed Layer (By XRD)	Dom	Illite/montmorillonite (illite dominant)

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6455.2
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: April 13, 1982

Rock Type: Calc. Feldspathic Litharenite
Mean Grain Size (mm): 0.13
Grain Size Range (mm): 0.03 - 0.25

% Pore Space: 7
Sorting (est.): Moderate
Angularity (est.): A to SR

GENERAL DESCRIPTION: Mineralogically and texturally similar to previous sample; carbonaceous stringers are not always along mud lenses; porosity is dominated by open pore space. Gardner method not used on this sample.

COMPOSITION	%	COMMENTS
Quartz	34	
K-feldspar	2	
Plagioclase	6	
Chert	9	
Lithics	3	
Authigenic Minerals		
Silica O. gr.	7	
Calcite	6	Twinned
Dolomite	4	Twinned
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Tourmaline	tr	
Unknown	1	
Voids w/o Clay	7	
Voids w/Clay	tr	
Clay Minerals	21	Not included in pore space
Mixed Layer	Dom	Should be similar to previous samples

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6458.0
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: April 14, 1982

Rock Type: Calc. Feldspathic Litharenite
Mean Grain Size (mm): 0.12
Grain Size Range (mm): 0.05 - 0.18

% Pore Space: 8
Sorting (est.): Well Sorted
Angularity (est.): SA to SR

GENERAL DESCRIPTION: Very similar to the previous sample. Mudstone lenses are not as predominant. Porosity is predominated by clay-filled voids with pore throats readily visible. Large pores are common.

COMPOSITION	%	COMMENTS
Quartz	48	
K-feldspar	2	
Plagioclase	5	
Chert	9	
Lithics	4	
Authigenic Minerals		
Silica O. gr.	5	
Calcite	5	Twinned
Dolomite	4	Twinned
Muscovite	tr	
Biotite	tr	Bleached
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Tourmaline	tr	
Other	tr	Detrital chalcedony
Unknown	tr	Patches of carbonaceous material
Voids w/o Clay	1	
Voids w/Clay	7	
Clay Minerals	9	Not included in voids with clay
Chlorite (Optically)	tr	Round patches
Mixed Layer	Dom	Should be similar to previous samples

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6463.5
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: April 14, 1982

Rock Type: Calc. Feldspathic Litharenite
Mean Grain Size (mm): 0.12
Grain Size Range (mm): 0.03 - 0.30

% Pore Space: 7
Sorting (est.): Moderately
Angularity (est.): A to SR

GENERAL DESCRIPTION: Very similar to previous samples; elongate patches of micrite and microsparite mixed with limonitic clay are also common; porosity is dominated by irregular shaped pore space.

COMPOSITION	%	COMMENTS
Quartz	36	
K-feldspar	1	
Plagioclase	6	
Chert	9	
Lithics	4	
Authigenic Minerals		
Silica O. gr.	7	
Calcite	5	
Dolomite	7	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Other	tr	Carbonaceous material(?)
Unknown	tr	
Voids w/o Clay	7	
Voids w/Clay	tr	
Clay Minerals	17	Not included in pore space
Chlorite (Optically)	tr	
Mixed Layer	Dom	Should be similar to previous samples

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6477.5
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: April 14, 1982

Rock Type: Mudstone
MEAN GRAIN SIZE (mm): 0.06 of sand-sized grains
GRAIN SIZE RANGE (mm): 0.01 - 0.21

% Pore Space: Microporosity in Clays
SORTING (est.): Poor
Angularity (est.): A to SR

GENERAL DESCRIPTION: This sample is basically a claystone with muddy and sandy lenses and horizons. These layers and lenses show strong deformation due to compaction. Long stringers of carbonaceous material are common; floating grains common; lesser point, long and cancavo-convex contacts. Porosity is due to microporosity in clays.

COMPOSITION	%	COMMENTS
Quartz	17	Mostly monocrystalline; few overgrowths
K-feldspar	tr	Perthite; fresh to moderate argillic alteration
Plagiocalse	1	Cores replaced by calcite; moderate to strong sericitic alteration
Chert	1	Inclusions of pyrite and dolomite rhombs
Lithics	2	Cloudy claystones and carbonate clasts predomiante
Authigenic Minerals		
Silica O. gr.	tr	In some sandy lenses
Calcite	2	Feldspar replacement and finely disseminated patches
Dolomite	2	Scattered rhombs and interlocking anhedra
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Tourmaline	tr	
Other	tr	Detrital chalcedony
Unknown	1	Carbonaceous material(?)
Clay Minerals	74	
Chlorite (Optically)	tr	
Mixed Layer (By XRD)	Dom	Illite/montmorillonite (illite dominant)

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6481.0
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: April 14, 1982

Rock Type: Calc. Feldspathic Litharenite
Mean Grain Size (mm): 0.13
Grain Size Range (mm): 0.02 - 0.24

% Pore Space: Tr + Microporosity
Sorting (est.): Moderate
Angularity (est.): A to SR

GENERAL DESCRIPTION: Well indurated sandstone with large lenses and horizons of sand-sized clastics partially floating in a clay/silt matrix. Stringers of carbonaceous material common in these lenses. Grain contacts are mostly concavo-convex. Porosity is assumed to be microporosity in clays. Gardner method not used on this sample. One small fracture obaserved was filled with calcite.

COMPOSITION	%	COMMENTS
Quartz	39	Mostly monocrystalline; few polycrystalline
K-feldspar	2	Microcline and perthite
Plagioclase	5	Fairly fresh to extremely altered or replaced
Chert	5	Usually deformed
Lithics	7	Mudstones, volcanics and plutonic
Authigenic Minerals		
Silica O. gr.	2	
Calcite	9	Some twinned; commonly replaces feldspars
Dolomite	8	Some twinned; many random rhombs
Muscovite	tr	Scattered flakes
Biotite	tr	Few flakes
Opaques	tr	Irregular masses around grain
Accessory Minerals		
Zircon	tr	Some fairly large (0.10 mm)
Other	tr	Detrital chalcedony
Voids w/o Clay	tr	Very few observed
Clay Minerals	21	
Mixed Layer (By XRD)	Dom	Illite/montmorillonite (illite dominant)

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6487.5
INTERVAL: Coastal

Petrologist: M. L. Dixon
Date: April 15, 1982

Rock Type: Calc. Feldspathic Litharenite
Mean Grain Size (mm): 0.10
Grain Size Range (mm): 0.02 - 0.17

% Pore Space: Tr + Microporosity
Sorting (est.): Moderate
Angularity (est.): A to SR

GENERAL DESCRIPTION: Very fine sand-sized; lenses of ferruginous clay are common and show abundant floating and point detrital grain contacts. Portion of rock with clean matrix has long and concavo-convex contacts common. Much of the porosity is present as micropores in clay matrix.

COMPOSITION	%	COMMENTS
Quartz	39	Mostly monocrystalline; few polycrystalline
K-feldspar	1	Fresh to moderate argillic alteration
Plagioclase	3	Partial replacement by calcite. Minor replacement by limonite in ferruginous areas
Chert	5	Inclusions of dolomite rhombs
Lithics	6	Largely ferruginous claystones and carbonate clasts
Authigenic Minerals		
Silica O. gr.	2	Not as common in areas rich in ferruginous clay
Calcite	4	Fine anhedra, occasionally twinned
Dolomite	8	Rhombs and interlocking anhedra; few twinned
Muscovite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Tourmaline	tr	
Other	2	Carbonaceous material
Voids w/o Clay	tr	
Clay Minerals	29	As matrix in some areas
Chlorite (Optically)	tr	
Mixed Layer (By XRD)	Dom	Illite/montmorillonite (illite dominant)

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6502.5
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: April 13, 1982

Rock Type: Calc. Sublithic Arenite
Mean Grain Size (mm): 0.08
Grain Size Range (mm): 0.02 - 0.15

% Pore Space: 14
Sorting (est.): Moderate
Angularity (est.): A to SR

GENERAL DESCRIPTION: Very fine sand with concavo-convex and sutured grain boundaries; pore space is partially to totally filled with clay and carbonate. Subparallel stringers of carbonaceous material along bedding(?). Porosity is dominated in clay patches and to a lesser degree pore throats are small open pores.

COMPOSITION	%	COMMENTS
Quartz	43	Mostly monocrystalline; few polycrystalline
K-feldspar	2	Microcline
Plagioclase	3	Fresh to totally altered
Chert	4	Generally squashed
Lithics	3	Mostly sedimentary (claystone) few metamorphic
Authigenic Minerals		
Silica O. gr.	3	
Calcite	12	Commonly twinned
Dolomite	10	Many individual rhombs; commonly twinned
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Epidote	tr	May be broken out of altered feldspars
Tourmaline	tr	
Hornblende	tr	
Other	3	Carbonaceous material; subparallel stringers
Unknown	tr	
Voids w/o Clay	2	
Voids w/Clay	12	
Clay Minerals	1	Not included in pore space with clays
Chlorite (Optically)	tr	
Mixed Layer (By XRD)	Dom	Illite/montmorillonite (illite dominant)

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6507.3
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: April 15, 1982

Rock Type. Calc. Feldspathic Litharenite
Mean Grain Size (mm): 0.09
Grain Size Range (mm): 0.03 to 0.20

% Pore Space: 4
Sorting (est.): Moderate
Angularity (est.): A to SR

GENERAL DESCRIPTION: Very similar mineralogically and texturally to earlier samples (MWX-6433.5, etc.). Gardner method was not used on this sample.

COMPOSITION	%	COMMENTS
Quartz	37	
K-feldspar	1	
Plagioclase	5	
Chert	6	
Lithics	5	
Authigenic Minerals		
Silica O. gr.	4	
Calcite	16	Few twinned
Dolomite	9	Mostly twinned
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals	tr	
Zircon	tr	
Epidote	tr	
Tourmaline	tr	
Other	tr	
Unknown	tr	
Voids w/o Clay	4	
Voids w/Clay	tr	
Clay Minerals	13	Not included in pore space
Chlorite (Optically)	tr	
Mixed Layer (By XRD)	Dom	Montmorillonite/illite (illite dominant)

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6508.3
INTERVAL: Coastal

Petrologist: M. L. Dixon
Date: April 15, 1982

Rock Type: Calc. Feldspathic Litharenite
Mean Grain Size (mm): 0.10
Grain Size Range (mm): 0.03 - 0.20

% Pore Space: 7
Sorting (est.): Moderately
Angularity (est.): A to SR

GENERAL DESCRIPTION: Very fine sand-sized; concavo-convex grain contacts predominate with lesser sutured contacts; clay occurs in patches which could represent broken-down rock fragments. Very similar to previous sample. Porosity dominated by open pores. Gardner method not used on this sample.

COMPOSITION	%	COMMENTS
Quartz	44	
K-feldspar	2	
Plagioclase	5	
Chert	7	
Lithics	6	Clay and carbonate clasts. Broken down in place
Authigenic Minerals		
Silica O. gr.	4	
Calcite	6	Twinned
Dolomite	7	Twinned
Muscovite	tr	
Opaques	tr	
Accessory Minerals		
Tourmaline	tr	
Zircon	tr	
Voids w/o Clay	7	
Voids w/Clay	tr	
Clay Minerals	11	Not included in pore space
Chlorite (Optically)	tr	Authigenic patches
Mixed Layer	Dom	Should be similar to MWX-6507.3

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6514.7
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: April 15, 1982

Rock Type: Calc. Feldspathic Litharenite
Mean Grain Size (mm): 0.10
Grain Size Range (mm): 0.05 to 0.24

% Pore Space: 8
Sorting (est.): Well
Angularity (est.): A to SR

GENERAL DESCRIPTION: Mineralogically and texturally similar to previous samples. A very small amount of a zeolite could be present in some pores. Pososity is dominated by clays over open pores and pore throats.

COMPOSITION	%	COMMENTS
Quartz	41	
K-feldsar	2	
Plagioclase	4	
Chert	5	
Lithics	8	
Authigenic Minerals		
Silica O. gr.	4	
Calcite	10	Some twinned
Dolomite	9	Commonly twinned
Muscovite	tr	
Biotite	tr	
Opaques	1	
Accessory Minerals		
Zircon	tr	
Apatite	tr	
Other	tr	
Unknown	tr	Could possibly be zeolite in pore spaces
Voids w/o Clay	3	Some partially filled with carbonate, and quartz overgrowths
Voids w/Clay	5	
Clay Minerals	7	Not included in pore space
Mixed Layer	Dom	Should be similar to previous samples

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6517.5
INTERVAL: Coastal

Petrologist: M. L. Dixon
Date: April 15, 1982

Rock Type: Calc. Feldspathic Litharenite
Mean Grain Size (mm): 0.09
Grain Size Range (mm): 0.02 - 0.17

% Pore Space: 5
Sorting (est.): Moderate
Angularity (est.): A to SR

GENERAL DESCRIPTION: Very fine sand-sized; concavo-convex grain contacts common, lesser sutured. Possible carbonaceous stringers present. Fairly clean matrix Very similar to previous samples. Could possibly have a trace of zeolite in pore space. Porosity dominated by open pores. Gardner method not used on this sample.

COMPOSITION	%	COMMENTS
Quartz	41	Some rutilated grains
K-feldspar	1	
Plagioclase	6	
Chert	7	
Lithics	7	Claystone and carbonate clasts
Authigenic Minerals		
Silica O. gr.	3	
Calcite	7	Twinned
Dolomite	10	Twinned
Muscovite	tr	
Biotite	tr	Bleached contorted books
Opaques	tr	
Accessory Minerals		
Tourmaline	tr	
Zircon	tr	
Other	tr	Carbonaceous(?) material, long stringers
Voids w/o Clay	5	
Voids w/Clay	tr	
Clay Minerals	12	Not included in pore space
Mixed Layer	Dom	Should be similar to previous samples

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6522.5
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: April 15, 1982

Rock Type: Calc. Feldspathic Litharenite
Mean Grain Size (mm): 0.10
Grain Size Range (mm): 0.03 - 0.19

% Pore Space: 6
Sorting (est.): Well
Angularity (est.): A to SR

GENERAL DESCRIPTION: Very fine sand with concavo-convex and sutured grain boundaries. Porosity dominated by intergranular pore space, some of which is partially filled with clay. Gardner method not used on this sample.

COMPOSITION	%	COMMENTS
Quartz	46	Mostly monocrystalline; few polycrystalline
K-felsdpar	2	Microcline
Plagioclase	5	Fresh to extensively altered
Chert	5	Many squashed grains
Lithics	9	Mostly sedimentary (claystones) few volcanics
Authigenic Minerals		
Silica O. gr.	4	Not easily distinguished from detrital quartz
Calcite	7	Mostly twinned
Dolomite	6	Mostly twinned
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals	tr	
Zircon	tr	
Epidote	tr	May be derived from altered feldspars
Unknown	tr	
Voids w/o Clay	6	Some partially filled with clay
Voids w/Clay	tr	Totally filled
Clay Minerals	7	
Chlorite (Optically)	tr	
Mixed Layer (By XRD)	Dom	Illite/montmorillonite (illite dominant)

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6540.5
INTERVAL: Coastal

Petrologist: M. L. Dixon
Date: April 16, 1982

Rock Type: Calcareous Sublitharenite
Mean Grain Size (mm): 0.15
Grain Size Range (mm): 0.05 - 0.21

% Pore Sapce: 6
Sorting (est.): Well Sorted
Angularity (est.): A to SR

GENERAL DESCRIPTION: Fine sand-sized; concavo-convex and sutured grain contacts; quartz overgrowths are very abundant and not always easily distinguished from detrital quartz grains. Porosity is domianted by open pores. Gardner method not used on this sample.

COMPOSITION	%	COMMENTS
Quartz	44	Some rutilated grains
K-feldspar	1	
Plagioclase	4	Bent twinning lamellae
Chert	3	
Lithics	6	Clay and carbonate clasts. Squashed and broken-down
Authigenic Minerals		
Silica O. gr.	8	
Calcite	5	Twinned. Fine granular calcite commonly surrounds dolomite rhombs.
Dolomite	10	Twinned
Muscovite	tr	
Biotite	tr	Bleached and limonitized
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Tourmaline	tr	
Apatite	tr	
Other	tr	Detrital chalcedony
Other	tr	Limonite and thin stringers of carbonaceous material
Voids w/o Clay	6	
Voids w/Clay	tr	
Clay Minerals	12	
Mixed Layer (By XRD)	Dom	Illite/montmorillonite (illite dominant)

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6541.3
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: April 16, 1982

Rock Type: Calc. Feldspathic Litharenite
Mean Grain Size (mm): 0.14
Grain Size Range (mm): 0.05 - 0.25

% Pore Space: 3
Sorting (est.): Well
Angularity (est.): A to SR

GENERAL DESCRIPTION: Very similar to previous sample. Porosity dominated by open pores. Gardner method not used on this sample.

COMPOSITION	%	COMMENTS
Quartz	43	
K-feldspar	1	
Plagioclase	8	
Chert	8	
Lithics	8	
Authigenic Minerals		
Silica O. gr.	4	
Calcite	7	Commonly twinned
Dolomite	6	Commonly twinned
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals	tr	
Zircon	tr	
Tourmaline	tr	
Other	tr	
Unknown	tr	
Voids w/o Clay	3	
Voids w/Clay	tr	
Clay Minerals	12	Not included in pore space
Mixed Layer	Dom	Should be similar to previous samples

MULTI-WELL PETROGRAPHIC ANANYSIS

SAMPLE NO: MWX-6544.4
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: April 16, 1982

Rock Type: Calc. Feldspathic Litharenite
Mean Grain Size (mm): 0.13
Grain Size Range (mm): 0.04 - 0.19

% Pore Space: 3 (microporosity in clay)
Sorting (est.): Well Sorted
Angularity (est.): A to SR

GENERAL DESCRIPTION: Fine sand-sized; concavo-convex and sutured grain contacts. Similar to MWX-6540.5. Porosity is dominated by open pore space. Gardner method not used on this sample.

COMPOSITION	%	COMMENTS
Quartz	46	
K-feldspar	1	
Plagioclase	5	Bent twinning lamellae
Chert	7	
Lithics	5	Carbonate and clay clasts. Possible altered volcanic rock fragments
Authigenic Minerals		
Silica O. gr.	7	
Calcite	5	Twinned
Dolomite	7	Twinned. Some are bent
Muscovite	tr	
Biotite	tr	Bleached and limonitized
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Tourmaline	tr	
Apatite	tr	
Voids w/o Clay	3	
Voids w/Clay	tr	
Clay Minerals	13	Not included in pore space
Mixed Layer	Dom	Should be similar to previous samples

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6546.3
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: April 16, 1982

Rock Type: Calc. Feldspathic Litharenite
Mean Grain Size (mm): 0.11
Grain Size Range (mm): 0.04 - 0.25

% Pore Space: 2
Sorting (est.): Well
Angularity (est.): A to SR

GENERAL DESCRIPTION: Very similar to previous samples. Porosity is dominated by open pore space. Gardner method not used on this sample.

COMPOSITION	%	COMMENTS
Quartz	36	
K-feldspar	1	
Plagioclase	5	
Chert	6	
Lithics	6	
Authigenic Minerals		
Silica O. gr.	9	
Calcite	10	Commonly twinned
Dolomite	11	Commonly twinned
Muscovite	tr	
Biotite	tr	
Opaques		
Accessory Minerals	tr	
Zircon	tr	
Epidote	tr	
Voids w/o Clay	2	
Voids w/Clay	tr	
Clay Minerals	14	Not included in pore space
Chlorite (Optically)	tr	
Mixed Layer	Dom	Should be similar to previous samples

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6548.8
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: April 16, 1982

Rock Type: Calc. Feldspathic Litharenite
Mean Grain Size (mm): 0.15
Grain Size Range (mm): 0.05 - 0.30

% Pore Space: 5
Sorting (est.): Well
Angularity (est.): A to SR

GENERAL DESCRIPTION: Very similar to previous samples. Pore space is dominated by open pores. Gardner method not used in this sample.

COMPOSITION	%	COMMENTS
Quartz	37	
K-feldspar	2	
Plagioclase	4	
Chert	8	
Lithics	15	
Authigenic Minerals		
Silica O. gr.	4	
Calcite	4	Commonly twinned
Dolomite	6	Commonly twinned
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Other	tr	
Unknown	tr	
Voids w/o Clay	5	
Voids w/Clay	tr	
Clay Minerals	14	Not included in pore space
Chlorite (Optically)	tr	
Mixed Layer	Dom	Should be similar to previous samples

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6551.5
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: April 19, 1982

Rock Type: Calcareous Litharenite
Mean Grain Size (mm): 0.12
Grain Size Range (mm): 0.05 - 0.38

% Pore Space: Trace
Sorting (est.): Well
Angularity (est.): A to SR

GENERAL DESCRIPTION: Mineralogically and texturally similar to previous samples with the addition of chalcedony, organic debri, and irregular lenses of clay mixed with carbonate. Distinct lack of pore space. The few pores observed are filled with clay. Gardner method not used in this sample.

COMPOSITION	%	COMMENTS
Quartz	52	
K-feldspar	1	
Plagioclase	4	
Chert	5	
Lithics	12	Sedimentary, volcanic and plutonic
Authigenic Minerals		
Silica O. gr.	2	
Calcite	6	Commonly twinned
Dolomite	9	Commonly twinned
Chalcedony(?)	tr	Radiating from quartz grain
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Epidote(?)	tr	
Other	tr	Organics
Voids w/o Clay	tr	
Voids w/Clay	tr	
Clay Minerals	7	
Chlorite (Optically)	tr	
Mixed Layer (By XRD)	Dom	Illite/montmorillonite (illite dominant)

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6574.1
INTERVAL: Coastal

Petrologist: M. O. Eatough
Date: April 19, 1982

Rock Type: Mudstone

% Pore Space: Microporosity

GENERAL DESCRIPTION: Mudstone with scattered silt-sized clastics and siltstone lenses. Carbonate is mixed throughout the clay and is very fine-grained; thin stringers of organics and limonitic material; some sedimentary deformation around silty lenses. Poor impregnation of microporous clays. Gardner method not used on this sample.

COMPOSITION	%	COMMENTS
Clay Minerals		
Kaolinite (By XRD)	Minor	
Montmorillonite (By XRD)	tr	
Mixed Layer (By XRD)	Dom	Illite/montmorillonite (illite dominant)

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6582.5 | Petrologist: M. O. Eatough
INTERVAL: Coastal | Date: April 19, 1982

Rock Type: Calcareous Subarkose | % Pore Space: 5
Mean Grain Size (mm): 0.07 | Sorting (est.): Very Well
Grain Size Range (mm): 0.03 - 0.15 | Angularity (est.): A to SR

GENERAL DESCRIPTION: Mineralogically and texturally similar to earlier samples (i.e., 6431.5). Kaolinite and montmorillonite content showed distinct increase. Porosity is dominated by clay-filled voids and pore throats.

COMPOSITION	%	COMMENTS
Quartz	48	
K-feldspar	tr	
Plagioclase	5	
Chert	3	
Lithics	2	
Authigenic Minerals		
Silica O. gr.	4	
Calcite	17	Commonly twinned
Dolomite	11	Commonly twinned
Muscovite	tr	
Biotite	tr	
Opaques	tr	Framboidal pyrite in altered grains
Accessory Minerals		
Zircon	tr	
Tourmaline	tr	
Apatite	tr	
Unknown	tr	
Voids w/o Clay	tr	Very few in the thin section
Voids w/Clay	5	
Clay Minerals	3	
Kaolinite (By XRD)	Moderate	
Chlorite (By XRD)	tr	
Montmorillonite (By XRD)	Minor	
Mixed Layer (By XRD)	Dom	Illite/montmorillonite (illite dominant

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6425.8
INTERVAL: Coastal (MWX-2)

Petrologist: M. J. Eatough
Date: January 6, 1983

Rock Type: Feldspathic Litharenite
Mean Grain Size (mm): 0.13
Grain Size Range (mm): 0.04 to 0.27

% Pore Space: 13
Sorting (est.): Well
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	35	
K-Feldspar	tr	
Plagioclase	6	
Chert	4	
Lithics	8	
Authigenic Minerals		
Silica O. gr.	5	
Calcite	10	
Dolomite	4	
Siderite	1	
Muscovite	tr	
Biotite	tr	
Opaques	1	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	1	
Voids w/Clay	12	
Clay Minerals	13	
Illite (X-ray)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6427.8
INTERVAL: Coastal (MWX-2)

Petrologist: M. J. Eatough
Date: January 6, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.16
Grain Size Range (mm): 0.04 to 0.33

% Pore Space: 4
Sorting (est.): Well
Angularity (est.): A to SR

GENERAL DESCRIPTION: The sample is either a contact between a sandstone and shale or contains a large mudstone (shale) clast.

COMPOSITION	%	COMMENTS
Quartz	38	
K-Feldspar	tr	
Plagioclase	4	
Chert	2	
Lithics	10	
Authigenic Minerals		
Silica O. gr.	2	
Calcite	9	
Dolomite	7	
Siderite	1	
Muscovite	1	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	tr	
Voids w/Clay	4	
Clay Minerals	21	
Illite (X-ray)	D	With illite/montmorillonite
Chlorite (Optically)	tr	

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX 6429.2
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 10, 1983

Rock Type: Calcareous Litharenite
Mean Grai Size (mm): 0.13
Grain Size Range (mm): 0.04 to 0.33

% Pore Space: 2
Sorting (est.): Moderate to Well
Angularity (est.): A to SR

GENERAL DESCRIPTION: Detritus is supported by patchy sparitic cement. Carbonates extensively replaces detrital grains. All pore space is secondary.

COMPOSITION	%	COMMENTS
Quartz	43	
K-Feldspar	tr	
Plagioclase	5	
Chert	4	
Lithics	12	
Authigenic Minerals		
Silica O. gr.	1	
Calcite	25	
Dolomite	6	
Siderite	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	tr	
Voids w/Clay	2	
Clay Minerals	2	
Illite (X-ray)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6432.5
INTERVAL: Coastal MWX-2

Petrologist: M. O. Eatough
Date: January 10, 1983

Rock Type: Calcareous Litharenite
Mean Grain Size (mm): 0.14
Grain Size Range (mm): 0.04 to 0.24

% Pore Space: 9
Sorting (est.): Well
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	38	
K-Feldspar	1	
Plagioclase	7	
Chert	4	
Lithics	17	
Authigenic Minerals		
Silica O. gr.	3	
Calcite	15	
Dolomite	4	
Siderite	tr	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	tr	
Voids w/Clay	9	
Clay Minerals	2	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6434.5
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 10, 1983

Rock Type: Sublitharenite
Mean Grain Size (mm): 0.13
Grain Size Range (mm): 0.04 to 0.30

% Pore Space: 12
Sorting (est.): Well
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	58	
K-Feldspar	tr	
Plagioclase	5	
Chert	3	
Lithics	6	
Authigenic Minerals		
Silica O. gr.	3	
Calcite	3	
Dolomite	7	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	1	
Voids w/Clay	11	
Clay Minerals	3	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6436.5
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 10, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.13
Grain Size Range (mm): 0.04 to 0.33

% Pore Space: 10
Sorting (est.): Well
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	51	
K-Feldspar	tr	
Plagioclase	6	
Chert	2	
Lithics	16	
Authigenic Minerals		
Silica O. gr.	2	
Calcite	7	
Dolomite	3	
Siderite	tr	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	tr	
Voids w/Clay	10	
Clay Minerals	2	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6437.5
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 10, 1983

Rock Type: Feldspathic Litharenite
Mean Grain Size (mm): 0.13
Grain Size Range (mm): 0.04 to 0.36

% Pore Space: 10
Sorting (est.): Moderate
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	52	
K-Feldspar	tr	
Plagioclase	9	
Chert	4	
Lithics	14	
Authigenic Minerals		
Silica O. gr.	3	
Calcite	3	
Dolomite	2	
Siderite	1	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	1	
Voids w/Clay	9	
Clay Minerals	2	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6438.5
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 10, 1983

Rock Type: Sublitharenite
Mean Grain Size (mm): 0.15
Grain Size Range (mm): 0.04 to 0.33

% Pore Space: 11
Sorting (est.): Moderate to Well
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	56	
K-Feldspar	tr	
Plagioclase	4	
Chert	3	
Lithics	11	
Authigenic Minerals		
Silica O. gr.	3	
Calcite	7	Some is poikilotopic
Dolomite	3	
Siderite	tr	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	1	
Voids w/Clay	10	
Clay Minerals	2	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6439.5
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 10, 1983

Rock Type: Calcareous Litharenite
Mean Grain Size (mm): 0.14
Grain Size Range (mm): 0.04 to 0.30

% Pore Space: 8
Sorting (est.): Moderate to Well
Angularity (est.): A to R

COMPOSITION	%	COMMENTS
Quartz	49	
K-Feldspar	tr	
Plagioclase	3	
Chert	4	
Lithics	14	
Authigenic Minerals		
Silica O. gr.	3	
Calcite	14	
Dolomite	3	
Siderite	tr	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Epidote	tr	
Voids w/o Clay	1	
Voids w/Clay	7	
Clay Minerals	2	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6440.5
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 10, 1983

Rock Type: Sublitharenite
Mean Grain Size (mm): 0.18
Grain Size Range (mm): 0.04 to 0.45

% Pore Space: 13
Sorting (est.): Moderate
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	59	
K-Feldspar	tr	
Plagioclase	4	
Chert	3	
Lithics	13	
Authigenic Minerals		
Silica O. gr.	2	
Calcite	3	
Dolomite	2	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	1	
Voids w/Clay	12	
Clay Minerals	1	
Illite (X-ray)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6443.5
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 10, 1983

Rock Type: Feldspathic Litharenite
Mean Grain Size (mm): 0.08
Grain Size Range (mm): 0.02 to 0.12

% Pore Space: 11
Sorting (est.): Well
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	42	
K-Feldspar	tr	
Plagioclase	6	
Chert	1	
Lithics	7	
Authigenic Minerals		
Silica O. gr.	1	
Calcite	6	
Dolomite	5	
Siderite	6	In stringers
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Unknown	2	Organic-rich clay?; ferruginous clay? in stringers
Voids w/o Clay	tr	
Voids w/Clay	11	
Clay Minerals	14	
Illite (X-ray)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6444.5
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 10, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.17
Grain Size Range (mm): 0.04 to 0.42

% Pore Space: 8
Sorting (est.): Moderate
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	48	
K-Feldspar	1	
Plagioclase	8	
Chert	5	
Lithics	16	
Authigenic Minerals		
Silica O. gr.	3	
Calcite	4	
Dolomite	2	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	1	
Voids w/Clay	7	
Clay Minerals	5	
Illite (X-ray)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6446.5
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 10, 1983

Rock Type: Sublitharenite
Mean Grain Size (mm): 0.13
Grain Size Range (mm): 0.04 to 0.30

% Pore Space: 6
Sorting (est.): Well
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	59	
K-Feldspar	tr	
Plagioclase	6	
Chert	2	
Lithics	11	
Authigenic Minerals		
Silica O. gr.	2	
Calcite	8	
Dolomite	3	
Siderite	1	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	tr	
Voids w/Clay	6	
Clay Minerals	2	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6449.5
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 11, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.17
Grain Size Range (mm): 0.04 to 0.30

% Pore Space: 12
Sorting (est.): Moderate to Well
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	44	
K-Feldspar	1	
Plagioclase	7	
Chert	4	
Lithics	19	
Authigenic Minerals		
Silica O. gr.	3	
Calcite	3	
Dolomite	1	
Siderite	tr	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	1	
Voids w/Clay	11	
Clay Minerals	6	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6450.5
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 11, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.16
Grain Size Range (mm): 0.04 to 0.33

% Pore Space: 14
Sorting (est.): Moderate
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	45	
K-Feldspar	tr	
Plagioclase	7	
Chert	3	
Lithics	19	
Authigenic Minerals		
Silica O. gr.	4	
Calcite	3	
Dolomite	1	
Siderite	1	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	1	
Voids w/Clay	13	
Clay Minerals	3	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6452.5
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 11, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.18
Grain Size Range (mm): 0.04 to 0.42

% Pore Space: 3
Sorting (est.): Moderate
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	36	
K-Feldspar	1	
Plagioclase	4	
Chert	8	
Lithics	20	
Authigenic Minerals		
Silica O. gr.	tr	
Calcite	17	
Dolomite	5	
Siderite	tr	
Muscovite	1	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	tr	
Voids w/Clay	3	
Clay Minerals	5	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6455.5
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 11, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.13
Grain Size Range (mm): 0.04 to 0.36

% Pore Space: 8
Sorting (est.): Moderate
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	51	
K-Feldspar	tr	
Plagioclase	5	
Chert	3	
Lithics	17	
Authigenic Minerals		
Silica O. gr.	2	
Calcite	5	
Dolomite	4	
Siderite	1	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	tr	
Voids w/Clay	8	
Clay Minerals	4	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6457.5
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 11, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.16
Grain Size Range (mm): 0.04 to 0.36

% Pore Space: 9
Sorting (est.): Moderate
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	46	
K-Feldspar	tr	
Plagioclase	5	
Chert	5	
Lithics	19	
Authigenic Minerals		
Silica O. gr.	2	
Calcite	6	
Dolomite	2	
Siderite	tr	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	1	
Voids w/Clay	8	
Clay Minerals	6	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6459.5
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 11, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.14
Grain Size Range (mm): 0.04 to 0.30

% Pore Space: 7
Sorting (est.): Moderate to Well
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	54	
K-Feldspar	tr	
Plagioclase	4	
Chert	3	
Lithics	18	
Authigenic Minerals		
Silica O. gr.	2	
Calcite	6	
Dolomite	2	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	1	
Voids w/Clay	6	
Clay Minerals	4	
Illite (X-ray)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6467.5
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 11, 198

Rock Type: Litharenite
Mean Grain Size (mm): 0.10
Grain Size Range (mm): 0.02 to 0.18

% Pore Space: 10
Sorting (est.): Well
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	46	
K-Feldspar	tr	
Plagioclase	4	
Chert	3	
Lithics	8	
Authigenic Minerals		
Silica O. gr.	7	
Calcite	11	
Dolomite	7	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Tourmaline	tr	
Voids w/o Clay	tr	
Voids w/Clay	10	
Clay Minerals	3	
Illite (X-ray)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6472.0
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 11, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.09
Grain Size Range (mm): 0.02 to 0.18

% Pore Space: 4
Sorting (est.): Well
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	52	
K-Feldspar	tr	
Plagioclase	5	
Chert	3	
Lithics	14	
Authigenic Minerals		
Silica O. gr.	3	
Calcite	4	
Dolomite	7	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	tr	
Voids w/Clay	4	
Clay Minerals	8	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6474.0
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 11, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.13
Grain Size Range (mm): 0.04 to 0.33

% Pore Space: 7
Sorting (est.): Moderate to Well
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	52	
K-Feldspar	tr	
Plagioclase	3	
Chert	4	
Lithics	18	
Authigenic Minerals		
Silica O. gr.	5	
Calcite	4	
Dolomite	4	
Siderite	tr	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	tr	
Voids w/Clay	7	
Clay Minerals	3	
Illite (X-ray)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6476.0
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 11, 1983

Rock Type: Sandy Siltstone
Mean Grain Size (mm): Silt (<0.06)
Grain Size Range (mm): Clay to 0.12

% Pore Space: tr
Sorting (est.): Very Well
Angularity (est.): A to R

GENERAL DESCRIPTION: Detrital mineralogy is very similar to other samples; dolomite is dominant over calcite; some siderite along bedding planes. Only clay minerals identified are illite and mixed layer illite/montmorillonite.

COMPOSITION	%	COMMENTS
Clay Minerals		
Illite (X-ray)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO:	MWX-6485.5	Petrologist:	M. O. Eatough
INTERVAL:	Coastal (MWX-2)	Date:	January 11, 1983

Rock Type:	Litharenite	% Pore Space:	11
Mean Grain Size (mm):	0.10	Sorting (est.):	Moderate
Grain Size Range (mm):	0.03 to 0.33	Angularity (est.):	A to SR

COMPOSITION	%	COMMENTS
Quartz	46	
K-Feldspar	tr	
Plagioclase	8	
Chert	5	
Lithics	13	
Authigenic Minerals		
Silica O. gr.	1	
Calcite	2	
Dolomite	6	
Siderite	tr	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	tr	
Voids w/Clay	11	
Clay Minerals	8	
Illite (X-ray)	D	With illite/montmorillonite.

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6488.0
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 11, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.13
Grain Size Range (mm): 0.03 to 0.36

% Pore Space: 2
Sorting (est.): Poor to Moderate
Angularity (est.) A to SR

COMPOSITION	%	COMMENTS
Quartz	51	
K-Feldspar	tr	
Plagioclase	4	
Chert	5	
Lithics	15	
Authigenic Minerals		
Silica O. gr.	1	
Calcite	1	
Dolomite	4	
Siderite	tr	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/Clay	2	
Clay Minerals	17	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6491.5
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 11, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.14
Grain Size Range (mm): 0.03 to 0.36

% Pore Space: 5
Sorting (est.): Poor to Moderate
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	51	
K-Feldspar	tr	
Plagioclase	3	
Chert	7	
Lithics	17	
Authigenic Minerals		
Silica O. gr.	2	
Calcite	1	
Dolomite	10	
Siderite	tr	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	tr	
Voids w/Clay	5	
Clay Minerals	3	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6500.9
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 11, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.10
Grain Size Range (mm): 0.03 to 0.30

% Pore Space: 18
Sorting (est.): Moderate
Angularity (est.) A to SR

COMPOSITION	%	COMMENTS
Quartz	38	
K-Feldspar	tr	
Plagioclase	5	
Chert	3	
Lithics	14	
Authigenic Minerals		
Silica O. gr.	1	
Calcite	8	
Dolomite	10	
Siderite	tr	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	tr	
Voids w/Clay	18	
Clay Minerals	3	
Illite (X-ray)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6504.4
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 11, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.09
Grain Size Range (mm): 0.03 to 0.21

% Pore Space: 17
Sorting (est.): Moderate to Well
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	44	
K-Feldspar	tr	
Plagioclase	4	
Chert	3	
Lithics	16	
Authigenic Minerals		
Silica O. gr.	2	
Calcite	3	
Dolomite	8	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	tr	
Voids w/Clay	17	
Clay Minerals	3	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6508.3
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 11, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.12
Grain Size Range (mm): 0.03 to 0.18

% Pore Space: 7
Sorting (est.): Well
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	46	
K-Feldspar	tr	
Plagioclase	8	
Chert	4	
Lithics	13	
Authigenic Minerals		
Silica O. gr.	5	
Calcite	4	
Dolomite	7	
Siderite	tr	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	1	
Voids w/Clay	6	
Clay Minerals	6	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6509.4
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 11, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.10
Grain Size Range (mm): 0.03 to 0.18

% Pore Space: 10
Sorting (est.): Well
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	46	
K-Feldspar	tr	
Plagioclase	4	
Chert	1	
Lithics	13	
Silica O. gr.	4	
Calcite	2	
Dolomite	10	
Siderite	1	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Unknown	tr	High relief low birefringence
Voids w/o Clay	tr	
Voids w/Clay	10	
Clay Minerals	9	
Kaolinite (Optically)	tr	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6511.1
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 11, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.11
Grain Size Range (mm): 0.03 to 0.30

% Pore Space: 6
Sorting (est.): Well
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	47	
K-Feldspar	tr	
Plagioclase	7	
Chert	4	
Lithics	16	
Authigenic Minerals		
Silica O. gr.	2	
Calcite	4	
Dolomite	9	
Siderite	tr	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Unknown	tr	High relief low birefringence
Voids w/o Clay	tr	
Voids w/Clay	6	
Clay Minerals	5	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6512.9
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 11, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.11
Grain Size Range (mm): 0.03 to 0.18

% Pore Space: 5
Sorting (est.): Well
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	52	
K-Feldspar	tr	
Plagioclase	5	
Chert	3	
Lithics	13	
Authigenic Minerals		
Silica O. gr.	2	
Calcite	6	
Dolomite	7	
Siderite	tr	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	tr	
Voids w/Clay	5	
Clay Minerals	7	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6515.1
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 11, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.10
Grain Size Range (mm): 0.03 to 0.21

% Pore Space: 6
Sorting (est.): Well
Angularity (est.): A to SR

GENERAL DESCRIPTION: Thin bedding

COMPOSITION	%	COMMENTS
Quartz	42	
K-Feldspar	tr	
Plagioclase	5	
Chert	3	
Lithics	16	
Authigenic Minerals		
Silica O. gr.	1	
Calcite	4	
Dolomite	9	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Unknown	3	Ferruginous clay/with organics? along bedding planes
Voids w/o Clay	tr	
Voids w/Clay	6	
Clay Minerals	10	
Illite (X-ray)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6517.9
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 12, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.12
Grain Size Range (mm): 0.03 to 0.42

% Pore Space: 3
Sorting (est.): Moderate to Well
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	45	
K-Feldspar	tr	
Plagioclase	5	
Chert	1	
Lithics	24	
Authigenic Minerals		
Silica O. gr.	2	
Calcite	5	
Dolomite	5	
Siderite	tr	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Other	tr	Carbonaceous material
Voids w/o Clay	tr	
Voids w/Clay	3	
Clay Minerals	9	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6519.9
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 12, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.14
Grain Size Range (mm): 0.03 to 0.45

% Pore Space: 8
Sorting (est.): Moderate
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	40	
K-Feldspar	tr	
Plagioclase	6	
Chert	4	
Lithics	21	
Authigenic Minerals		
Silica O. gr.	2	
Calcite	5	
Dolomite	3	
Siderite	tr	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Other	4	Mudstone fragments
Other	tr	Carbonaceous Material
Voids w/o Clay	tr	
Voids w/Clay	8	
Clay Minerals	7	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6521.9
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 12, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.14
Grain Size Range (mm): 0.04 to 0.39

% Pore Space: 8
Sorting (est.): Moderate
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	49	
K-Feldspar	1	
Plagioclase	7	
Chert	5	
Lithics	14	
Authigenic Minerals		
Silica O. gr.	2	
Calcite	6	
Dolomite	4	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	tr	
Voids w/Clay	8	
Clay Minerals	4	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6524.9
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 12, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.10
Grain Size Range (mm): 0.03 to 0.18

% Pore Space: 21
Sorting (est.): Well
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	37	
K-Feldspar	1	
Plagioclase	7	
Chert	2	
Lithics	14	
Authigenic Minerals		
Silica O. gr.	4	
Calcite	6	
Dolomite	4	
Siderite	tr	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	tr	
Voids w/Clay	21	
Clay Minerals	4	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6525.9
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 12, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.14
Grain Size Range (mm): 0.03 to 0.45

% Pore Space: 12
Sorting (est.): Moderate to Poor
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	46	
K-Feldspar	tr	
Plagioclase	5	
Chert	3	
Lithics	20	
Authigenic Minerals		
Silica O. gr.	3	
Calcite	4	
Dolomite	4	
Siderite	tr	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	tr	
Voids w/Clay	12	
Clay Minerals	3	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6528.9
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 12, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.11
Grain Size Range (mm): 0.03 to 0.24

% Pore Space: 5
Sorting (est.): Well
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	42	
K-Feldspar	tr	
Plagioclase	4	
Chert	2	
Lithics	21	
Authigenic Minerals		
Silica O. gr.	1	
Calcite	8	
Dolomite	9	
Siderite	1	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Other	tr	Mudstone clasts
Voids w/o Clay	tr	
Voids w/Clay	6	
Clay Minerals	6	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6531.9
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 12, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.18
Grain Size Range (mm): 0.03 to 0.45

% Pore Space: 11
Sorting (est.): Moderate
Angularity (est.): A to R

COMPOSITION	%	COMMENTS
Quartz	41	
K-Feldspar	tr	
Plagioclase	4	
Chert	6	
Lithics	20	
Authigenic Minerals		
Silica O. gr.	3	
Calcite	8	
Dolomite	4	
Siderite	tr	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Other	tr	Mudstone clasts
Voids w/o Clay	1	
Voids w/Clay	10	
Clay Minerals	3	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6535.3
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 12, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.14
Grain Size Range (mm): 0.03 to 0.30

% Pore Space: 9
Sorting (est.): Well
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	48	
K-Feldspar	tr	
Plagioclase	5	
Chert	3	
Lithics	23	
Authigenic Minerals		
Silica O. gr.	1	
Calcite	6	
Dolomite	3	
Siderite	1	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	1	
Voids w/Clay	8	
Clay Minerals	1	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6539.2
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 12, 1983

Rock Type: Calcareous Litharenite
Mean Grain Size (mm): 0.16
Grain Size Range (mm): 0.03 to 0.33

% Pore Space: 13
Sorting (est.): Moderate to Well
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	36	
K-Feldspar	tr	
Plagioclase	5	
Chert	7	
Lithics	15	
Authigenic Minerals		
Silica O. gr.	1	
Calcite	16	
Dolomite	4	
Siderite	tr	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	tr	
Voids w/Clay	13	
Clay Minerals	3	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6540.7
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 12, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.11
Grain Size Range (mm): 0.03 to 0.33

% Pore Space: 8
Sorting (est.): Moderate to Well
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	49	
K-Feldspar	tr	
Plagioclase	4	
Chert	5	
Lithics	17	
Authigenic Minerals		
Silica O. gr.	1	
Calcite	6	
Dolomite	6	
Siderite	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	tr	
Voids w/Clay	8	
Clay Minerals	4	
Illite (X-ray)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6542.6
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 12, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.13
Grain Size Range (mm): 0.03 to 0.36

% Pore Space: 17
Sorting (est.): Moderate
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	36	
K-Feldspar	tr	
Plagioclase	4	
Chert	3	
Lithics	21	
Authigenic Minerals		
Silica O. gr.	2	
Calcite	8	
Dolomite	5	
Siderite	1	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	tr	
Voids w/Clay	17	
Clay Minerals	2	
Illite (X-ray)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6545.8
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 12, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.18
Grain Size Range (mm): 0.03 to 0.42

% Pore Space: 4
Sorting (est.): Moderate
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	42	
K-Feldspar	tr	
Plagioclase	7	
Chert	7	
Lithics	25	
Authigenic Minerals		
Silica O. gr.	1	
Calcite	5	
Dolomite	4	
Siderite	tr	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	tr	
Voids w/Clay	tr	
Clay Minerals	4	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6547.8
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 12, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.16
Grain Size Range (mm): 0.03 to 0.30

% Pore Space: 9
Sorting (est.): Well
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	47	
K-Feldspar	tr	
Plagioclase	3	
Chert	5	
Lithics	19	
Authigenic Minerals		
Silica O. gr.	1	
Calcite	9	
Dolomite	4	
Siderite	1	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	tr	
Voids w/Clay	9	
Clay Minerals	2	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6549.7
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 12, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.13
Grain Size Range (mm): 0.03 to 0.23

% Pore Space: 2
Sorting (est.): Moderate to Well
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	43	
K-Feldspar	tr	
Plagioclase	4	
Chert	2	
Lithics	23	
Authigenic Minerals		
Silica O. gr.	3	
Calcite	7	
Dolomite	6	
Siderite	1	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	tr	
Voids w/Clay	2	
Clay Minerals	9	
Illite (X-ray)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6551.2
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 12, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.15
Grain Size Range (mm): 0.03 to 0.36

% Pore Space: 13
Sorting (est.): Moderate
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	46	
K-Feldspar	tr	
Plagioclase	6	
Chert	3	
Lithics	19	
Authigenic Minerals		
Silica O. gr.	1	
Calcite	5	
Dolomite	3	
Siderite	1	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	tr	
Voids w/Clay	13	
Clay Minerals	3	
Illite (X-ray)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO: MWX-6556.9
INTERVAL: Coastal (MWX-2)

Petrologist: M. O. Eatough
Date: January 12, 1983

Rock Type: Litharenite
Mean Grain Size (mm): 0.14
Grain Size Range (mm): 0.03 to 0.45

% Pore Space: 9
Sorting (est.): Moderate
Angularity (est.): A to SR

COMPOSITION	%	COMMENTS
Quartz	42	
K-Feldspar	tr	
Plagioclase	5	
Chert	5	
Lithics	21	
Authigenic Minerals		
Silica O. gr.	2	
Calcite	5	
Dolomite	3	
Siderite	2	
Muscovite	tr	
Biotite	tr	
Opaques	tr	
Accessory Minerals		
Zircon	tr	
Voids w/o Clay	tr	
Voids w/Clay	9	
Clay Minerals	5	
Illite (Assumed)	D	With illite/montmorillonite

MULTI-WELL PETROGRAPHIC ANALYSIS

SAMPLE NO:	MWX-6559.9	Petrologist:	M. O. Eatough
INTERVAL:	Coastal (MWX-2)	Date:	January 12, 1983

Rock Type: Micrite % Pore Sapce: tr

GENERAL DESCRIPTION: This limestone consists primarily of micritic carbonate (calcite:dolomite = 8:1). Minor siderite was also detected by XRD. X-ray diffraction analysis indicates significant quartz and feldspar which are probably clay size and were not observed in thin section. The only clay minerals identified were illite and mixed layer illite/montmorillonite, but clays are a very minor constinuent. Fractures in the limestone are healed with microsparite.

COMPOSITION	%	COMMENTS
Clay Minerals		
Illite (X-ray)	D	With illite/montmorillonite

APPENDIX 11.2

LOG ANALYSIS TECHNIQUES AND VERIFICATION OF RESULTS

G. C. Kukal
CER Corporation

APPENDIX 11.2

LOG ANALYSIS TECHNIQUES AND VERIFICATION OF RESULTS

G. C. Kukal
CER Corporation

Analysis of the coastal interval was performed using TITEGAS, a sandstone log analysis model developed by CER Corporation which is documented in detail elsewhere.[1,2] Great effort has gone into utilizing all of the extensive log data available. The log data was first corrected for environmental influences and then used to determine lithologic and critical reservoir characteristics. The calculated model results include: water saturation (S_w); absolute permeability (corrected for net stress), referred to as log calculated permeability (k); total porosity (ϕ); clay volume (v_{cl}); carbonate volume (VCO_3); matrix density (ρma); shallow zone saturation (S_{xo}); and formation water resistivity (R_w).

Clay constants and matrix constants were systematically determined using crossplot techniques as described by recent CER publications.[3,4] The results of the TITEGAS program are graphically displayed in traceplots and crossplots as well as in tabular form.

(1) Porosity

Whenever possible, log model outputs are verified directly by comparison to an independent measurement, such as core and petrographic data. Log calculations are generally plotted on the x-axis versus core data on the y-axis.

TITEGAS model (log) porosity is compared to core porosity in Figures 1, 2, and 3 for MWX-1, MWX-2 and MWX-3, respectively. Correlation coefficients are 0.763, 0.846 and 0.640. Log and core means are within 0.003 for all plots. There is good one-to-one agreement (slope and intercept). Standard error for log model results to simulate core data for the three wells is 0.0094. This is an unusually small error since the precision of the core data itself accounts for 0.005 to 0.007 of this error.[5,6]

(2) Matrix Calculations and Their Impact Upon Porosity Analysis

A three-component system is used to compute matrix density. The model uses three equations and three unknowns to solve for sand (quartz) volume, clay volume and carbonate volume. Two measurements are required: gamma ray and photoelectric absorption cross section index (P_e). Using a procedure outlined elsewhere,[4] clay volume is solved using the gamma ray log and then clay effects are stripped from the P_e response. This leads to a volume percent for three components--quartz, clay and a specified third component. In the case of the coastal interval, petrographic data establishes that the principal accessory component is a 50/50 mixture of the carbonate minerals calcite and dolomite. Once volumes are established, the neutron log matrix is corrected and matrix density is computed using material balance and assumed density of 2.64 for quartz, 2.73 for clay and 2.77 for carbonate.

It is possible to analyze the success of the matrix model as a predictive tool. The standard deviation of matrix density is 0.033. For the multidimensional case (matrix density vs. grain density), the standard error is comparable, at the mean of the data, to the standard deviation in the one-dimensional case (grain density). The success of the model is thus determined from the difference of 0.033 and the various standard errors for the MWX-1, MWX-2 and MWX-3 matrix density results (0.014, 0.007 and 0.011, respectively). The effectiveness of the matrix model is best verified by determining its influence upon the porosity results. The MWX-2 well is used to make this comparison because the MWX-2 core data represents selected sampling from what principally could be considered potential reservoir rock. In contrast, the MWX-1 data consists of all lithologies, including mudstones.

The coastal interval was analyzed with the three-component matrix model described above and compared with an analysis where matrix density was held constant at 2.673, the mean of the interval's core grain density. Histograms were constructed of the difference between core porosity and log interpreted porosity:

$$\Delta P = \left| \phi \text{ core} - \phi \text{ log} \right|$$

The mean difference between core and log porosities using the three-component model is 0.006 whereas the mean porosity difference using a constant matrix density is 0.009. For the three-component matrix model, 50 percent of the distribution has a difference of 0.004 or less and 67 percent has a difference of 0.006 or less. For the constant matrix, 50 percent of the distribution has a difference of 0.008 or less and 67 percent has a difference of 0.0115 or less. Porosity analysis is thus significantly improved using a variable matrix.

(3) Clay Volume

It is important to determine accurate clay volume because clays affect the response of all logging tools. There is a need to properly account for the presence of clay to achieve accuracy in interpreting parameters such as porosity and water saturation. Also, clays generally contribute to permeability reduction. Sandstones having high clay content generally have high irreducible water saturation and poor flow characteristics. Clay quantification therefore enables better inference of reservoir quality.

The MWX database provides an unusual opportunity to verify some of the assumptions used in the log analysis of clay volume. Because of this unusual data set and the sensitivity of accurate clay volumes to the TITEGAS log analysis system, a considerable research effort was geared to the study of these assumptions.

One of the complications of clay analysis is the variability of clay type. Common clays in sand-shale sequences include the minerals illite, smectite, mixed-layer illite-smectite, chlorite and kaolinite. Within the coastal interval of MWX, both scanning electron microscopy (SEM) and quantitative x-ray diffraction (XRD) data suggest that smectite and also perhaps kaolinite have been illitized. Illitization is a normal diagenetic process that is quite prevalent within tight gas sands. Illitization is dependent upon temperature, time and potassium availability.[7] The almost total absence of potassium feldspars in XRD patterns and the presence of relict feldspars, as observed petrographically by Bendix and the USGS, suggest that potassium feldspars have provided a large portion of the potassium needed to form illite. It is interesting to note that while chlorite is common throughout the MWX Mesaverde Group, it is not abundant within the coastal interval. This may be related to the source and specifically may indicate limited original volcanic lithic fragments within this interval.

An additional complicating factor in clay analysis is the similarity between clay minerals and other phyllosilicates such as micas. Spencer has noted that sericite (fine grained muscovite) is a frequently observed alteration product within the coastal interval.[8,9] Since sericite and illite have a similar chemical composition and crystal structure, it is generally difficult to distinguish between the two.

There are four basic assumptions used for the log analysis of clay volume in the MWX coastal interval. A variety of MWX data including x-ray diffraction, chemical and cation exchange capacity data are available and are used to verify these assumptions.

First, there is the assumption that clay volume is related directly to the intensity of natural gamma radiation. Since illite and highly ordered illite-smectite are the dominant clays within the coastal interval, and since illites contain approximately 8 to 9 percent K_2O on average, with K^{40} being a naturally radioactive isotope of potassium, the first assumption seems valid. Heinze provides data to support the correlation of natural gamma radiation with clay.[10] In a study of clay within eight samples taken from the MWX wells over a several thousand foot interval of the Mesaverde Group, he found that K, U and Th core data each have a strong correlation (correlation coefficients 0.92 to 0.95) with clay weight percent as interpreted from XRD patterns. His data also shows a good correlation between K, U and Th and both particle size and cation exchange capacity (CEC), which is an indirect indicator of clay volume.

The second and third clay assumptions used within the coastal analysis relate to the use of shale to calibrate neutron and gamma ray clay response. The second assumes that there are "typical" shales within the section being analyzed and this shale has a "clay constant" which is defined as the fraction of clay within the shale. At MWX, this is uniformly assumed to be 60 percent. Potter et al. (1980) in their discussion of the sedimentology of shale give a worldwide average of 58 percent clay minerals within shale.[11] Yaalon gives a worldwide average of 59 percent clay within shale using 10,000 analyses.[12] The assumption is supported by Pollastro of the USGS who used XRD to analyze the clay content of eight shale samples throughout the Mesaverde section of MWX.[13] The samples averaged 59.6 percent clay.

The third assumption is that clay minerals remain similar in both sands and shales. Pollastro observed this to be the case at MWX.[13] He noted that when chlorite is found in a sandstone, it is always found in a nearby shale. Likewise, when only illite and illite-smectite (I/S) are within a sandstone, then only these clay minerals are found in a nearby shale. Although not published in his MWX report, Pollastro used XRD to measure the percent of illite within mixed-layer I/S. He found that the degree of illitization is identical ($\pm$ 3 percent) in sandstones and nearby shales.[14] The percent of illite within mixed-layer I/S is extremely critical to the third assumption. This is because potassium content varies directly with increasing illite whereas hydrogen index varies inversely with increasing illite. Therefore, an alternative method was applied to interpret the percent illite within mixed-layer I/S. Using Heinze's whole rock chemical data,[10] K_2O and Al_2O_3 was first corrected for XRD quantified plagioclase and potassium feldspar. Then the ratio K_2O/Al_2O_3 of the remaining portion of each of the eight sand and shale samples was calculated. This should be a good technique to determine variation of I/S in the mixed-layer clay because aluminum remains fairly constant, regardless of clay type, whereas potassium varies dramatically. It was found that the ratio remains very constant between 0.205 and 0.231 for seven of the samples and at 0.145 for the one sandstone within the upper fluvial interval which is rich in chlorite (45 percent). The constancy of the ratio verifies Pollastor's results and provides additional support to the third assumption.

The fourth clay assumption relates to determining the minimum clay volume in sandstone. It is unreasonable to assume that every interval analyzed contains a perfectly clean or clay-free zone. The technique adopted to determine the minimum clay volume involves using the computed density-neutron clay volume to refine the gamma ray constants. For consistency flushed zone water saturation is made to equal 100 percent. However, when a flushed zone water saturation of 100 percent is used, a problem arises as shown in Figure 4. Some sandstones contain unflushed gas thus making the clay volumes anomalously low. Gamma ray constants can't be chosen using density and neutron data unless the zones containing gas are removed. The technique used to do this is straightforward. Only points having greater than 20 percent clay are used such as presented in Figure 5. With the exclusion of cleaner rocks, the gas effect is removed. This is because rocks having greater than 20 percent clay have very high irreducible water saturations and therefore do not contain gas.

Attempts were made to verify log calculated clay volumes using chemical data as provided by Heinze.[10] Although the data is limited, there is a good agreement between clay volumes calculated from log data and clay volumes calculated from chemical data and cation exchange capacity data.

(4) Water Saturation

Figures 6, 7, and 8 compare log interpreted water saturation to core water saturations for the three wells. There are several factors that affect core water saturations, including coring conditions, sampling procedures, core preservation and laboratory analytical techniques. For MWX-1 and MWX-2, it is probable that reported core water saturations are generally too low, whereas for MWX-3 they are probably too high. This is due in part to drilling fluid: MWX-1 and MWX-2 were drilled with oil-base mud; MWX-3 was drilled with water-base mud.

For MWX-1 and MWX-2, there are several reasons why core water saturation may be too low:

- Partial flushing of core with diesel during coring, plugging and storage (plugs were stored immersed in diesel). It is not known if the diesel displaced a fraction of the water present or only gas; however, some oil saturations are greater than 75 percent and the original oil saturation was probably zero.

- When the core was brought to surface, the gas within the pore space expanded and forced some water out of the core. Small bubbles were frequently noted coming from a core laid out for examination.

- Within the laboratory, core is at lower net stress than in situ and pores expand. The resulting water saturation is less. As a typical example, assume that porosity in situ is 8 percent, while in the laboratory, it is measured 8.3 percent. If water saturation is measured 67.5 percent in the lab, it would actually be 70 percent with the smaller in situ pore volume.

- Sattler et al. presented data[15] which points out a substantial discrepancy between Dean-Stark saturations and saturations measured by vacuum drying for tight sand core. Figure 9 summarizes this discrepancy. An equation of the best fit RMA line transforms Dean-Stark analysis into total water saturation:

$$S_{wt} = \frac{S_{wds} + 0.1186}{0.9685}$$

where: S_{wt} = total water fraction within pore space; and

S_{wds} = water fraction of pore space resulting from Dean-Stark analysis

It is assumed that the above transform, which was developed using data from the MWX-2 lower fluvial interval, is typical of tight sands in general. The transform was applied to MWX-1 and MWX-2 coastal interval saturation data, which were analyzed using the Dean-Stark method, resulting in Figures 10 and 11. Since the summation of fluids method was used for MWX-3, the transform is not required and Figure 8 shows the relationship between core water saturation and log calculated water saturation. The plots indicate that a reasonably good estimate of water saturation is being obtained from logs.

Water resistivity (R_w) used in the saturation analysis has been explained in previous discussions.[16,17] Interpreted R_w through the interval averages 0.11 Ω-m and remains fairly constant. It should be pointed out that the technique used to determine R_w results in an s_w which is independent of anomalous variation of saturation exponent and cementation exponent except in fractured intervals. In a fractured interval, log interpreted water saturations are likely to be too high.

(5) Permeability

An equation developed for log interpretation of net stress corrected absolute permeability in low permeability sandstone reservoirs[18] was utilized in the coastal interval. The results are illustrated in Figures 12, 13, and 14. Good one-to-one relationships were achieved for MWX-1 and MWX-2. The poorer correlation for MWX-3 appears to be due to two anomalous points and less data.

REFERENCES

1. Kukal, G. C. and K. E. Simons, "Multiwell Experiment, Well Log Analysis of Coastal Interval, MWX-1, MWX-2 and MWX-3," CER Corporation Report, February 14, 1986.

2. Kukal, G. C., "A Systematic Approach for the Effective Log Analysis of Tight Gas Sands," SPE 12851, Proceedings of the 1984 SPE/DOE/GRI Unconventional Gas Recovery Symposium, May 1984, pp. 209-220.

3. Kukal, G. C. and R. E. Hill, "Log Analysis of Clay Volume: An Evaluation of Techniques and Assumptions Used in An Upper Cretaceous Sand-Shale Sequence," Paper RR, SPWLA Twenty-Seventh Annual Logging Symposium, June 9-13, 1986.

4. Kukal, G. C. and R. E. Hill, "Improved Shaly Sand Analysis in Heavy Drilling Muds: A Simple Technique for Using the Photoelectric Measurement," Paper U, Transactions of the SPWLA Twenty-Sixth Annual Logging Symposium, June 1985.

5. Jenkins, R. E., Personal Communication, January 26, 1983.

6. Randolph, P. L., Personal Communication, January 26, 1983.

7. Srodon, J. and D. D. Eberl, "Illite," Reviews in Mineralogy: Micas, edited by S. W. Baily, Mineralogical Society of America, 1984.

8. Spencer, C. W. and J. K. Pitman, "USGS Review of Mesaverde Coastal Interval (6,345-6,582 ft) in CER No. 1 MWX," MWX Project Report, September 1982.

9. Pitman, J. K. and C. W. Spencer, "Petrology of Selected Sandstones in the MWX Wells (Northwest Colorado) and Its Relationship to Borehole Geophysical Log Analysis and Reservoir Quality," Geologic Studies in Support of the U.S. Department of Energy Multiwell Experiment, Garfield County, Colorado: U.S. Geological Survey Open-File Report 84-757, Spencer, C. W. and C. W. Keighin, eds., 1984, pp. 33-66.

10. Heinze, D. M., "Clay Identification and Amount Measured by Laboratory Techniques Compared to Well Log Responses: Application to Tight Gas Sands and Shales," Sandia Report SAND85-0312, March 1985.

11. Potter, P. E., J. B. Maynard and W. A. Pryor, Sedimentology of Shale. Study Guide and Reference Source, Springer-Verlag, New York, Inc., 1980, p. 49.

12. Yaalon, D. H., "Mineral Composition of the Average Shale," Clay Minerals Bulletin, Vol. 5, No. 27, 1962, pp. 31-36.

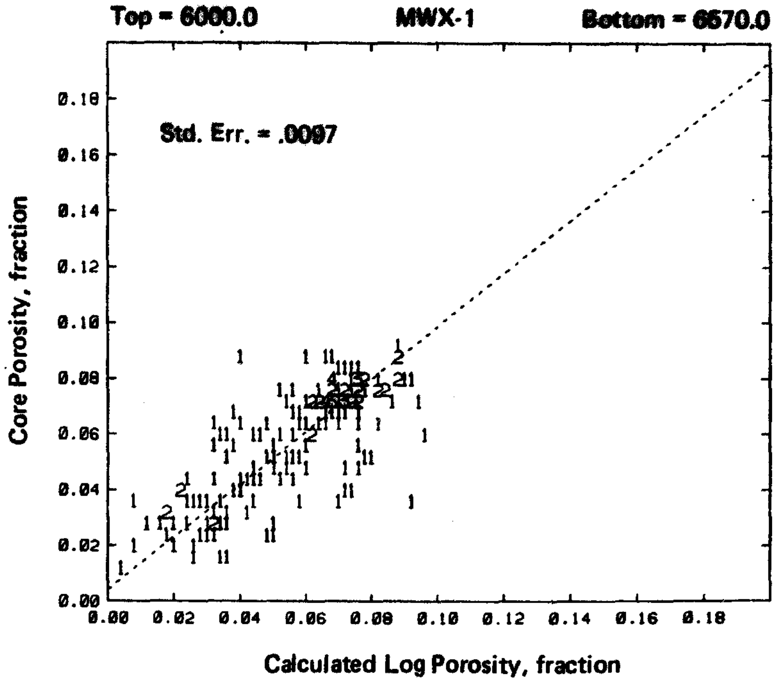
13. Pollastro, R. M., "Mineralogy of Selected Sandstones/Shale Pairs and Sandstones from the Multiwell Experiment-Interpretations from X-Ray Diffraction and Scanning Electron Microscopy Analyses," Geologic Studies in Support of the U.S. Department of Energy Multiwell Experiment, Garfield County, Colorado: U.S. Geological Survey Open-File Report 84-757, Spencer, C. W., and C. W. Keighin, eds., 1984, pp. 67-74.

14. Pollastro, R. M., Personal Communications, December 10, 1985.

15. Sattler, A. R., A. A. Heckes and J. A. Clark, "Pressure Core Measurements in Tight Sandstone Lenses During the Multiwell Experiment," SPE 12853, Proceedings of the 1984 SPE/DOE/GRI Unconventional Gas Recovery Symposium, May 1984, pp. 229-234.

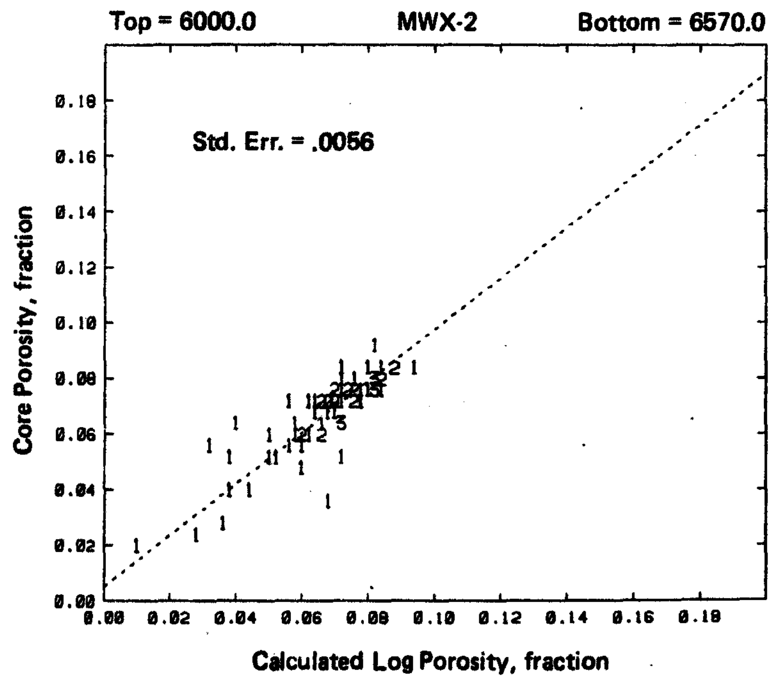
16. Kukal, G. C., "Log Analysis in Low-Permeability Gas Sand Sequences-Correcting for Variable Unflushed Gas Saturation," Paper F, Transactions of the SPWLA Twenty-Fourth Annual Logging Symposium, June 1983.

17. Law, B. E., J. R. Hatch, G. C. Kukal and C. W. Keighin, "Geologic Implications of Coal Dewatering," AAPG Bulletin, Vol. 67, No. 12, December 1983, pp. 2255-2260.



Points Plotted	163
Frequency Drop	0
Offscale X Values	0
Offscale Y Values	0
Offscale X and Y	0
Null X or Y	978
Discriminated Out	0
On Full Spots	0
Beyond Overflow	0
Total Points	1141
X Axis Mean	.0564
X Axis Std. Dev.	.0212
Y Axis Mean	.0574
Y Axis Std. Dev.	.0201
Correlation Coef.	.7634

Figure 1. Calculated Porosity Vs. Core Porosity, MWX-1 Coastal Interval



Points Plotted	70
Frequency Drop	0
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Offscale Y Values	0
Offscale X and Y	0
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Discriminated Out	0
On Full Spots	0
Beyond Overflow	0
Total Points	1141
X Axis Mean	.067
X Axis Std. Dev.	.0157
Y Axis Mean	.067
Y Axis Std. Dev.	.0145
Correlation Coef.	.8458

Figure 2. Calculated Porosity Vs. Core Porosity, MWX-2 Coastal Interval

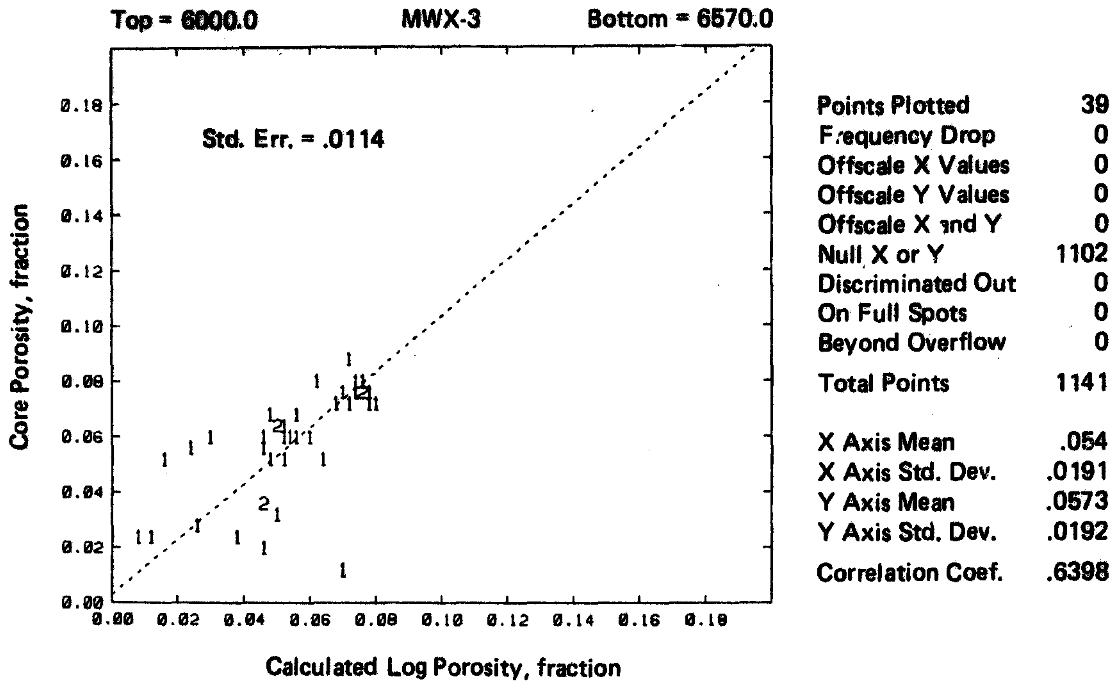


Figure 3. Calculated Porosity Vs. Core Porosity, MWX-3 Coastal Interval

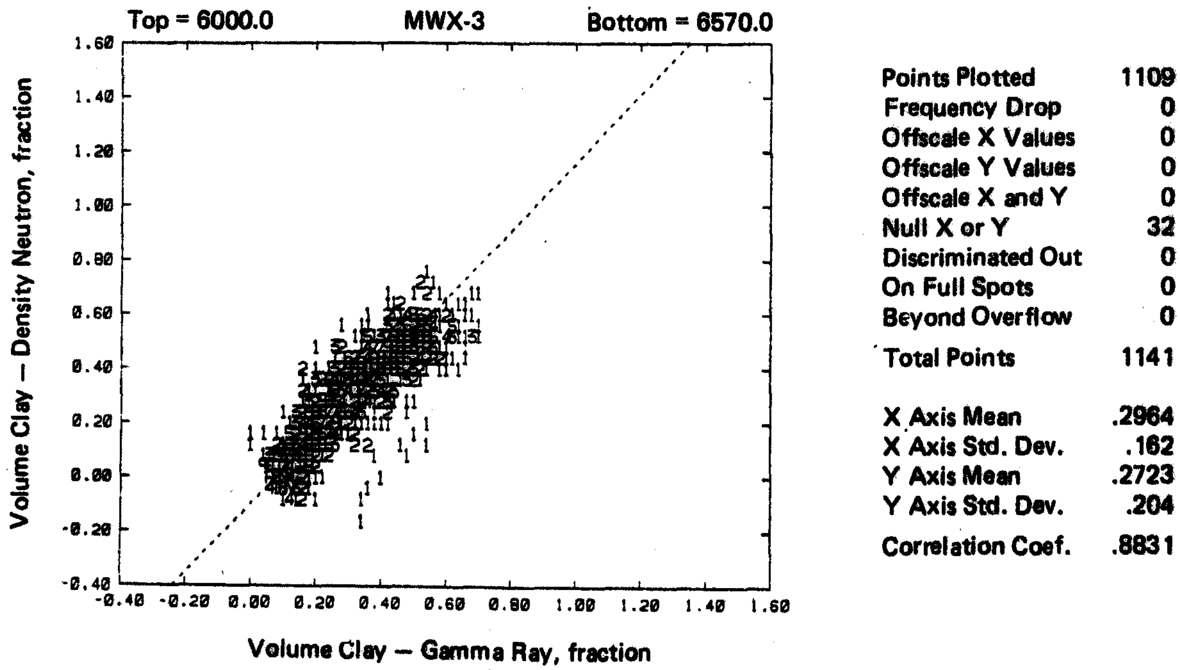
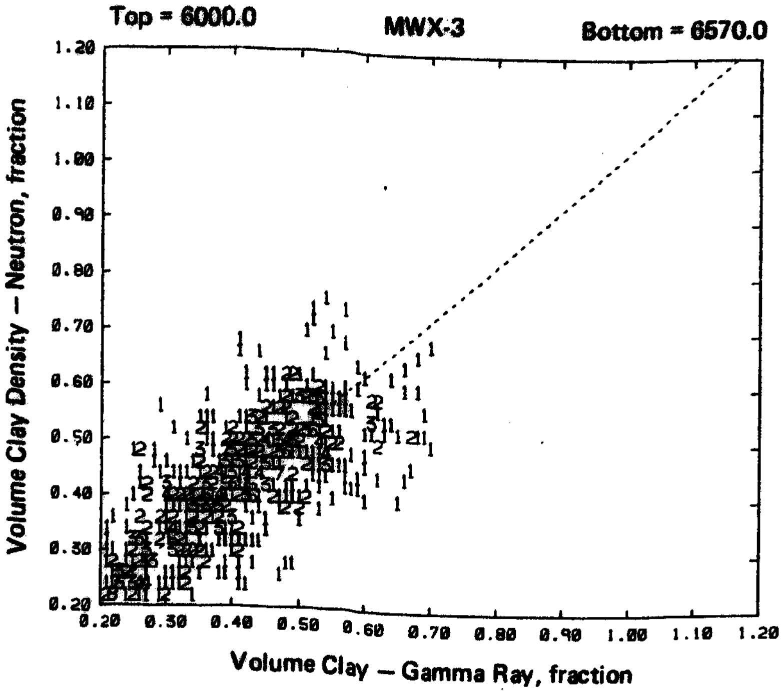
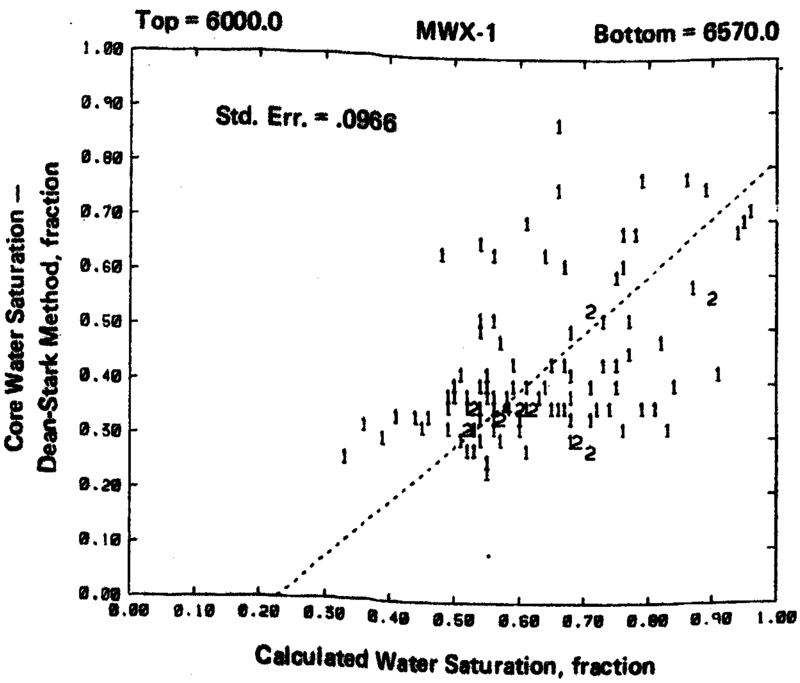


Figure 4. Comparison of Calculated Clay Volumes Showing Gas Effect on Values Computed from Density-Neutron Logs, MWX-3 Coastal Interval



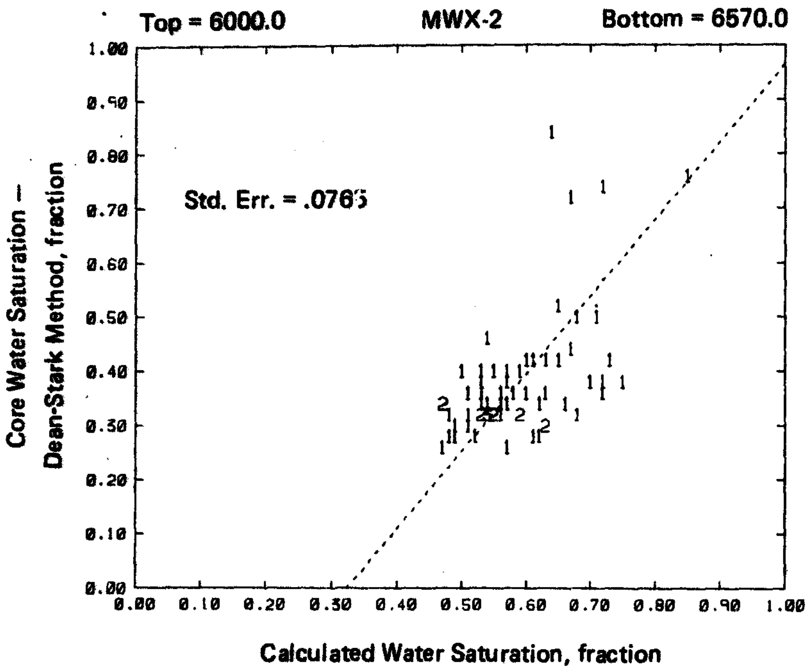
Points Plotted	634
Frequency Drop	0
Offscale X Values	35
Offscale Y Values	72
Offscale X and Y	368
Null X or Y	32
Discriminated Out	0
On Full Spots	0
Beyond Overflow	0
Total Points	1141
X Axis Mean	.4095
X Axis Std. Dev.	.1104
Y Axis Mean	.424
Y Axis Std. Dev.	.1135
Correlation Coef.	.7184

Figure 5. *Volume Clay Calculated from Gamma Ray Log Vs. Volume Clay Calculated from Density-Neutron Logs, MWX-3 Coastal Interval*



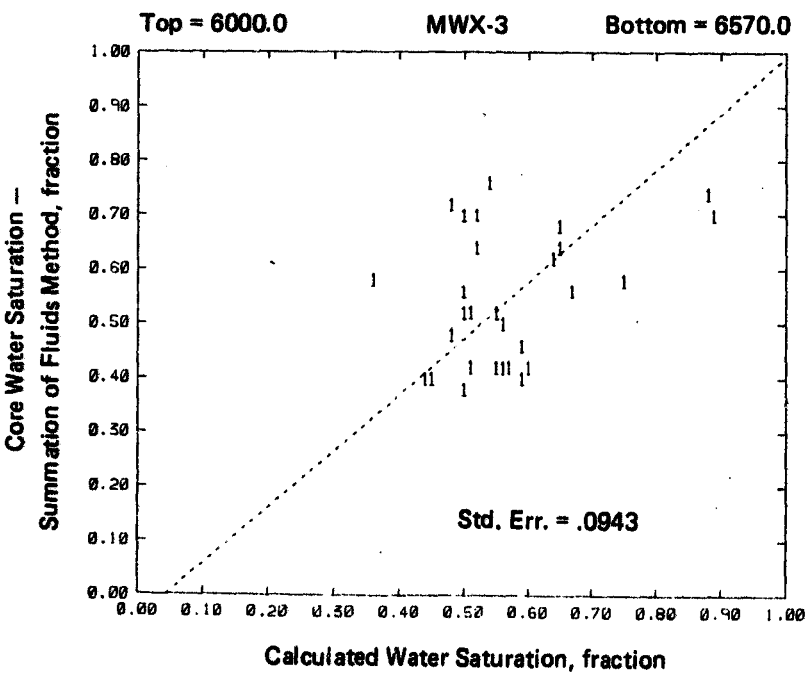
Points Plotted	115
Frequency Drop	0
Offscale X Values	5
Offscale Y Values	0
Offscale X and Y	0
Null X or Y	1021
Discriminated Out	0
On Full Spots	0
Beyond Overflow	0
Total Points	1141
X Axis Mean	.6343
X Axis Std. Dev.	.1309
Y Axis Mean	.427
Y Axis Std. Dev.	.1374
Correlation Coef.	.5017

Figure 6. *Calculated Water Saturation Vs. Core Water Saturation, MWX-1 Coastal Interval*



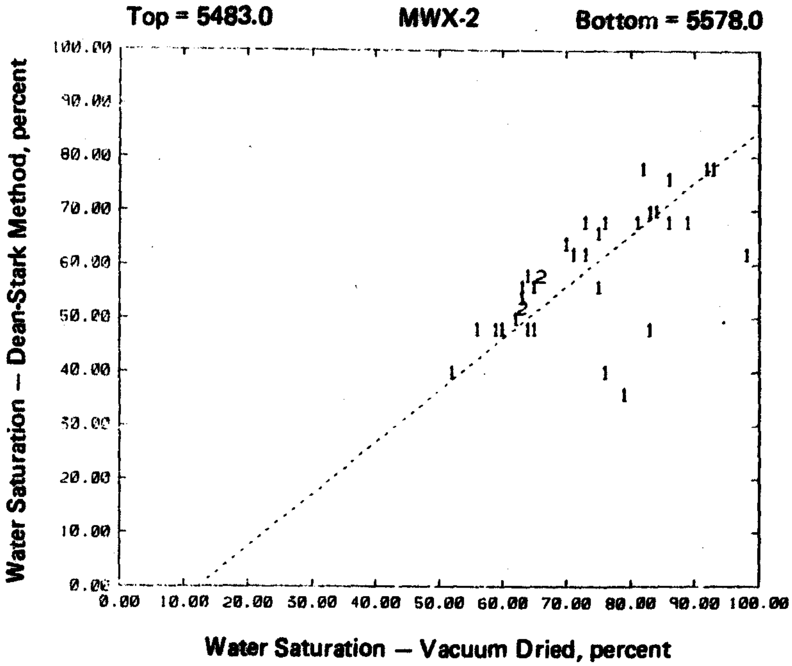
Points Plotted	63
Frequency Drop	0
Offscale X Values	0
Offscale Y Values	0
Offscale X and Y	0
Null X or Y	1078
Discriminated Out	0
On Full Spots	0
Beyond Overflow	0
Total Points	1141
X Axis Mean	.5892
X Axis Std. Dev.	.0805
Y Axis Mean	.3793
Y Axis Std. Dev.	.1148
Correlation Coef.	.5479

Figure 7. Calculated Water Saturation Vs. Core Water Saturation, MWX-2 Coastal Interval



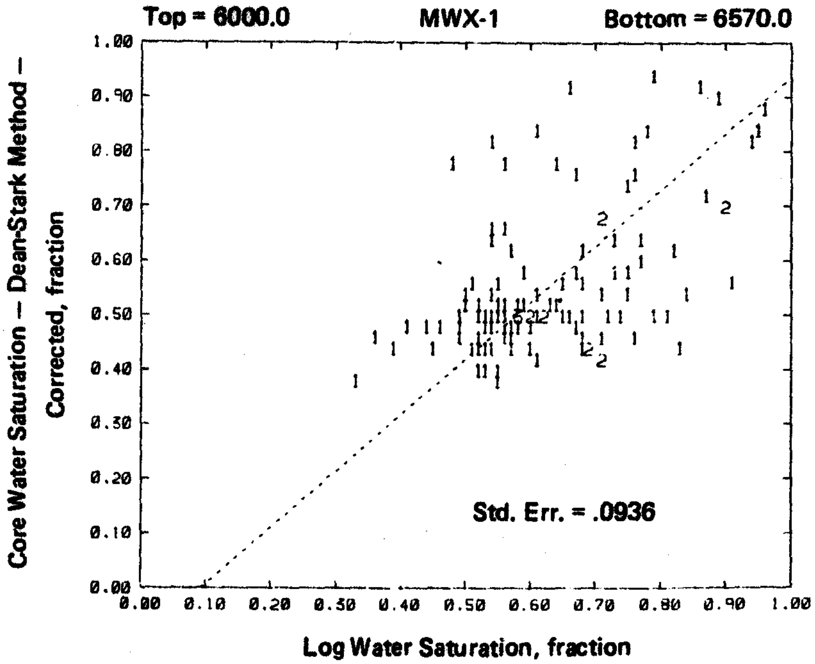
Points Plotted	29
Frequency Drop	0
Offscale X Values	0
Offscale Y Values	0
Offscale X and Y	0
Null X or Y	1112
Discriminated Out	0
On Full Spots	0
Beyond Overflow	0
Total Points	1141
X Axis Mean	.5693
X Axis Std. Dev.	.1167
Y Axis Mean	.5446
Y Axis Std. Dev.	.1211
Correlation Coef.	.3714

Figure 8. Calculated Water Saturation Vs. Core Water Saturation, MWX-3 Coastal Interval



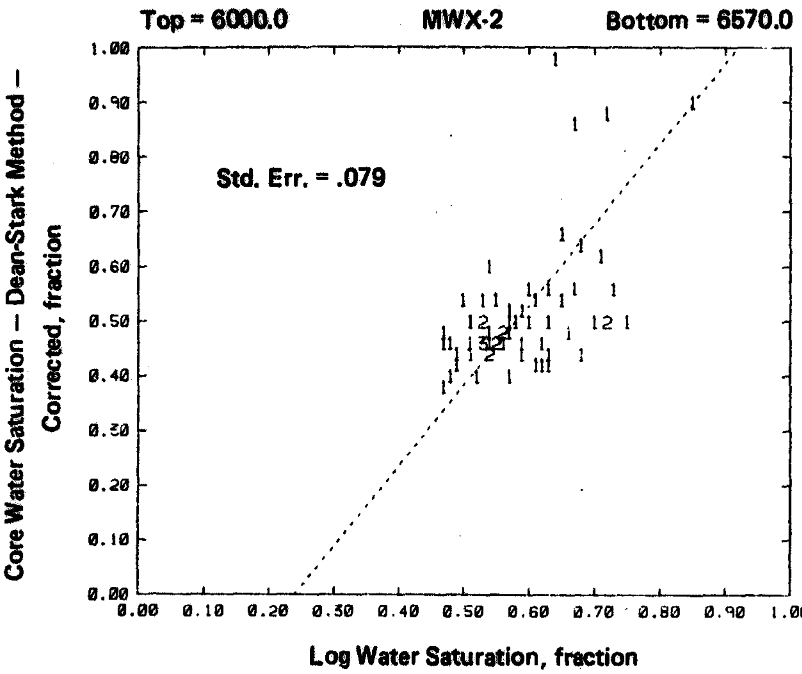
Points Plotted	35
Frequency Drop	0
Offscale X Values	0
Offscale Y Values	0
Offscale X and Y	0
Null X or Y	156
Discriminated Out	0
On Full Spots	0
Beyond Overflow	0
Total Points	191
X Axis Mean	73
X Axis Std. Dev.	11.56
Y Axis Mean	58.85
Y Axis Std. Dev.	11.2
Correlation Coef.	.6666

Figure 9. ***Core Water Saturation Measured by Vacuum Drying Vs. Dean-Stark Method, MWX-2 Lower Fluvial Interval***



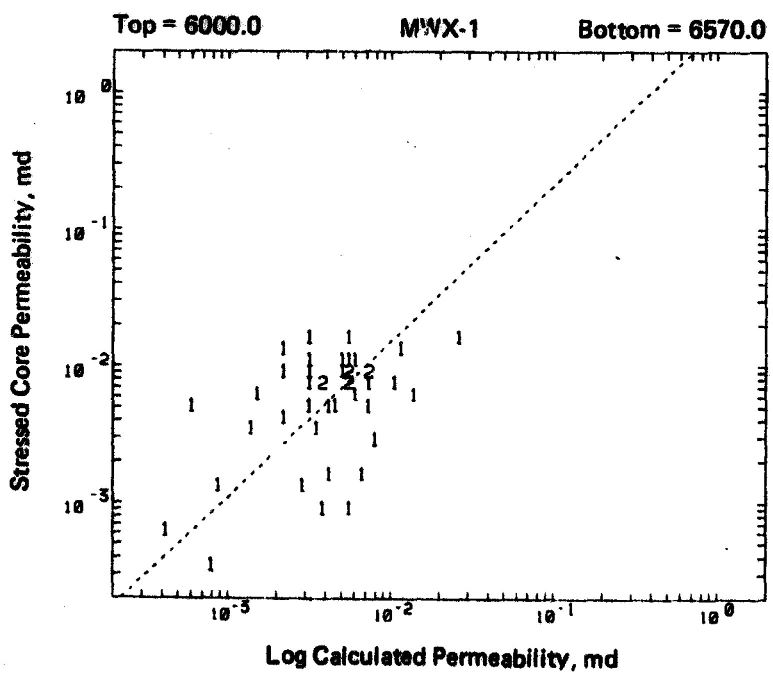
Points Plotted	114
Frequency Drop	0
Offscale X Values	4
Offscale Y Values	1
Offscale X and Y	1
Null X or Y	1021
Discriminated Out	0
On Full Spots	0
Beyond Overflow	0
Total Points	1141
X Axis Mean	.6341
X Axis Std. Dev.	.1314
Y Axis Mean	.5594
Y Axis Std. Dev.	.1358
Correlation Coef.	.5212

Figure 10. ***Calculated Water Saturation Vs. Corrected Core Water Saturation from Dean-Stark Method, MWX-1 Coastal Interval***



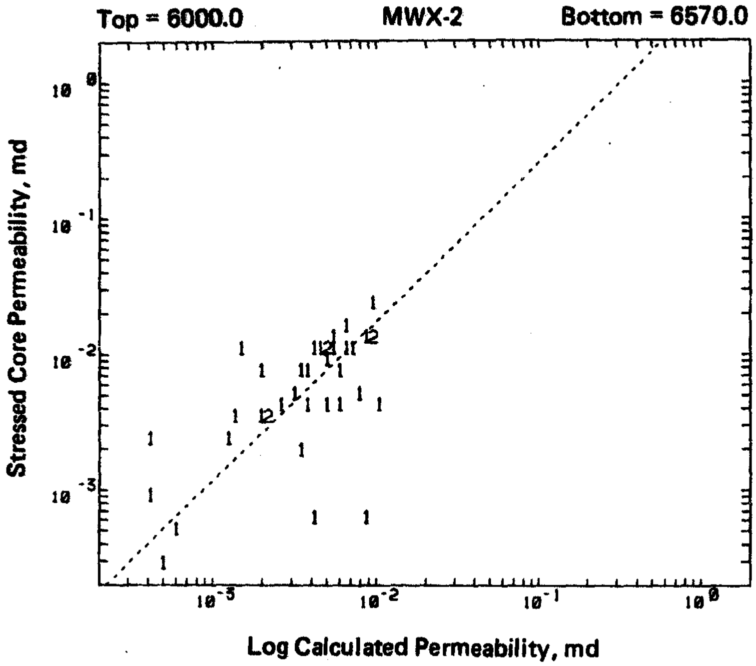
Points Plotted	63
Frequency Drop	0
Offscale X Values	0
Offscale Y Values	0
Offscale X and Y	0
Null X or Y	1078
Discriminated Out	0
On Full Spots	0
Beyond Overflow	0
Total Points	1141
X Axis Mean	.5892
X Axis Std. Dev.	.0805
Y Axis Mean	.5141
Y Axis Std. Dev.	.1185
Correlation Coef.	.5479

Figure 11. Calculated Water Saturation Vs. Corrected Core Water Saturation from Dean-Stark Method, MWX-2 Coastal Interval



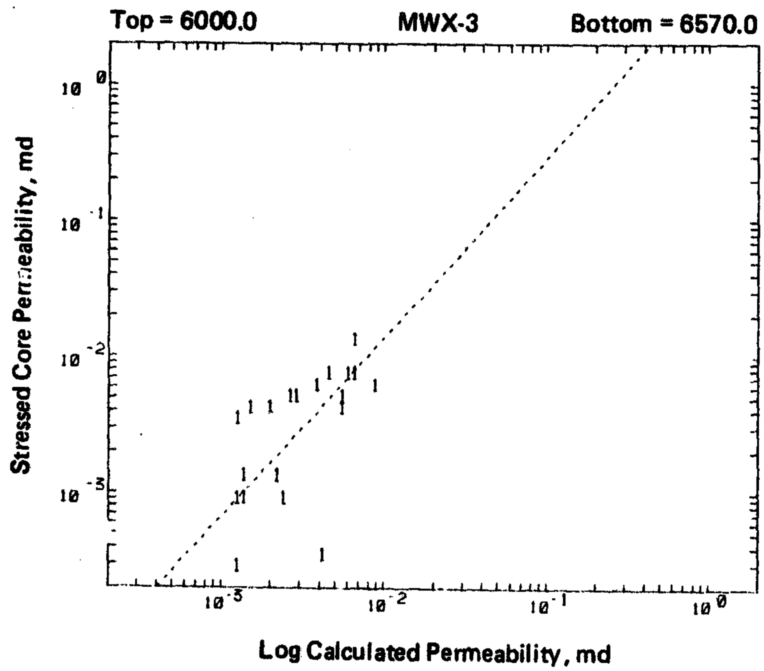
Points Plotted	43
Frequency Drop	0
Offscale X Values	0
Offscale Y Values	1
Offscale X and Y	0
Null X or Y	1097
Discriminated Out	0
On Full Spots	0
Beyond Overflow	0
Total Points	1141
X Axis Mean	-2.404
X Axis Std. Dev.	.3543
Y Axis Mean	-2.278
Y Axis Std. Dev.	.4051
Correlation Coef.	.5063

Figure 12. Log Calculated Net Stress Corrected Absolute Permeability Vs. Stressed Klinkenberg Core Permeability, MWX-1 Coastal Interval



Points Plotted	38
Frequency Drop	0
Offscale X Values	0
Offscale Y Values	1
Offscale X and Y	0
Null X or Y	1102
Discriminated Out	0
On Full Spots	0
Beyond Overflow	0
Total Points	1141
X Axis Mean	-2.458
X Axis Std. Dev.	.3859
Y Axis Mean	-2.297
Y Axis Std. Dev.	.451
Correlation Coef.	.6241

Figure 13. Log Calculated Net Stress Corrected Absolute Permeability Vs. Stressed Klinkenberg Core Permeability, MWX-2 Coastal Interval



Points Plotted	22
Frequency Drop	0
Offscale X Values	0
Offscale Y Values	3
Offscale X and Y	0
Null X or Y	1116
Discriminated Out	0
On Full Spots	0
Beyond Overflow	0
Total Points	1141
X Axis Mean	-2.557
X Axis Std. Dev.	.3884
Y Axis Mean	-2.593
Y Axis Std. Dev.	.5127
Correlation Coef.	.2312

Figure 14. Log Calculated Net Stress Corrected Absolute Permeability Vs. Stressed Klinkenberg Core Permeability, MWX-3 Coastal Interval

APPENDIX 11.3

PETROPHYSICAL RELATIONSHIPS FROM CROSSPLOTS

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APPENDIX 11.3

PETROPHYSICAL RELATIONSHIPS FROM CROSSPLOTS

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Two and three-dimensional crossplots offer an excellent opportunity to observe pertinent petrophysical relationships in the coastal interval. Log, core and petrographic data are crossplotted and the resultant trends are are significant descriptors of the reservoirs. A way to measure the relatedness of the two crossplotted parameters is by a numerical correlation coefficient ranging from -1.0 to 1.0. A value of zero indicates no correlation whatsoever, while a value of 1.0 or -1.0 indicates perfect correlation between the two parameters. Negative coefficients indicate inverse relationships, i.e., as one parameter increases, the other decreases.

Since hundreds of two-dimensional crossplots of log, core and thin section data can be constructed, a data reduction effort termed a crossplot matrix is presented here. This matrix consists of the correlation coefficients of various crossplots with shading intensity representing degree of correlation between the two parameters. The correlation matrix for the coastal interval in MWX-1 is given in Figure 1. An explanation of crossplot variable names is given as Figure 1-A.

In addition to noting relationships (or the lack of) between reservoir parameters measured directly on core or thin section, the matrix is useful to determine which log responses are best suited to model certain reservoir characteristics.

Several observations on the nature of the reservoir rock can be made from Figure 1. In particular:

- Gamma Ray (GRRUN) has a high correlation with compensated neutron (PHINC). This indicates that the gamma ray log is a good clay indicator in this section. Furthermore, total gamma correlates better to PHINC than the potassium curve (POTAR) alone, implying that the total gamma is measuring more than just the potassium-dominant clays. It appears that thorium or uranium components are contributing positively as clay indicators.

- Correlation of sonic travel time (DLT) and core porosity (CORPHI) is minimal. Indeed, cation exchange capacity (CEC), gamma ray (GRRUN) and the neutron logs (PHINC, SNPR) are the only parameters which relate well to DLT, implying that in these rocks, clays restrict the use of DLT as a porosity indicator.

- As expected, core porosity (CORPHI) varies inversely with bulk density (RHOBRC) and directly with density-calculated porosity. Core porosity relates inversely to neutron porosity (PHINC) because the neutron is more responsive to clay than it is to porosity. It is interesting to note that although the correlation coefficients of bulk density and neutron porosity to core porosity are -0.59 and -0.05, respectively, through careful modeling of log response for clay, matrix and fluids, it is possible to achieve high correlations between calculated porosity and core porosity (Figure 1, Appendix 11.2).

- Core saturations (CORESW, CORESO) correlate best to the log parameters gamma ray (GRRUN) and resistivity (RT). RT varies inversely with increasing CORESW. GRRUN varies directly with CORESW: with higher clay content in the rock, water saturation increases for a variety of reasons. Clay-bound water increases and capillary pressure increases, causing more water to be immobile. The same relationship is observed when comparing CORESW to CEC, which is also clay-related.

- Matrix permeability (KPFM) correlates well with log parameters bulk density (RHOBRC) and gamma ray (GRRUN), and both are inverse relationships. The lower densities correspond to rocks with more porosity and less clay. KPFM is seen to have a strong dependence on core porosity (CORPHI) and quartz percentage (QUARTZ). Gamma ray responds primarily to clays and higher clay volumes reduce matrix permeability.

- Matrix permeability (KPFM) is also dependent on grain size (XGRSZE). The larger the grain size, the better the matrix permeability. Rocks with larger grain size also tend to consist of a higher percentage of quartz.

- Core porosity (CORPHI) increases as quartz percentage (QUARTZ) increases and decreases as carbonate volume (CO3) increases. Presumably, the carbonate is an authigenic mineral that fills a portion of the porosity.

- Core saturation (CORESW) is controlled by (among other things) grain size and carbonate volume. As grain size increases, capillary size increases and water is more mobile.

With a correlation matrix, relationships between two variables are seen. By plotting a third variable on the z-axis of the plot, much can be learned about what controls or affects the relationship between x and y. The following interpretations are made from such z-plots:

- Figure 2 shows the influence of clay on the sonic travel time-core porosity relationship. In general, the relationship is seen to hold; however, it breaks down as clay content increases.

- Figure 3 illustrates the typical porosity-saturation relationship that exists in the Coastal Mesaverde reservoirs. Permeability is plotted on the z-axis and it is apparent that the lower permeabilities have higher water saturations and vice versa.

- Figure 4 illustrates the adverse effect carbonate has on permeability. Carbonate is plotted on the z-axis of a permeability-porosity crossplot. A trend is detected whereby increased carbonate implies less permeability and porosity.

- Figure 5, a plot of carbonate vs core porosity, further illustrates the effects of carbonate minerals. A trend relating higher carbonate to lower porosities is seen. Adding grain size on the z-axis reveals some explanation: overall, the rocks with more carbonate are finer grained (and vice versa). Finer grained rocks generally are associated with less porosity.

- Figure 6 emphasizes another aspect of the reservoirs. Grain density versus grain size shows that the larger the grain size, the less the density of the grain. Quartz, one of the least dense materials in these reservoirs, maintains a larger grain size than clays, precipitated minerals and lithic fragments. Carbonate plotted on the z-axis supports this argument: the least dense material has very little carbonate and larger grain size. The rocks with the most carbonate are not only more dense, but also have smaller grain sizes.

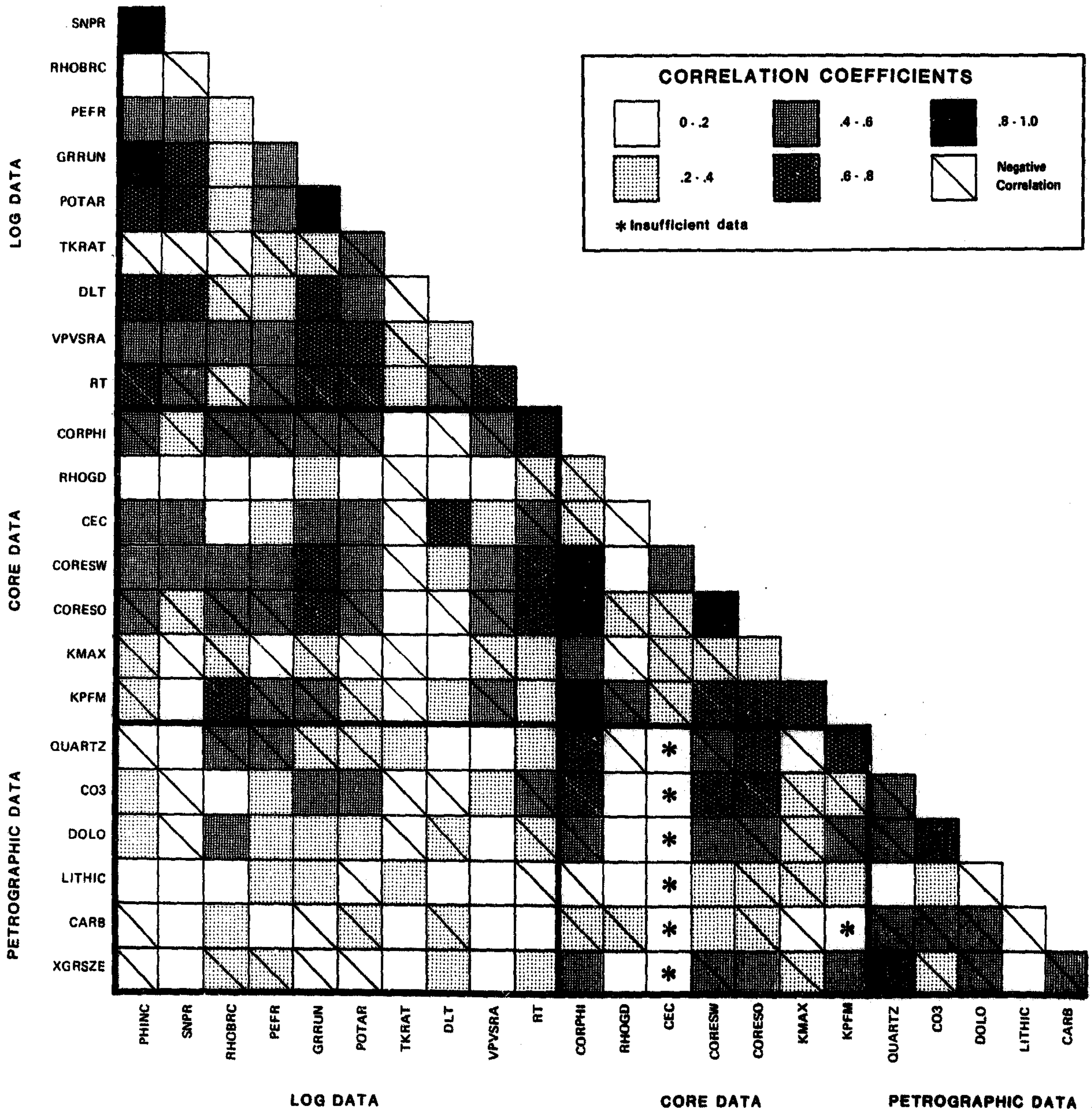

Figure 1. Correlation Coefficient Matrix, MWX-1 Coastal Interval

Figure 1A. Explanation of Crossplot Variables

CARB	:	carbonaceous material, fraction
CEC	:	cation exchange capacity, meq/100 gm
CO3	:	dolomite + calcite (thin-section), fraction
CORESO	:	core oil saturation, fraction
CORESW	:	core water saturation, fraction
CORPHI	:	core porosity, fraction
DLT	:	sonic interval transit time, microseconds/ft
DOLO	:	dolomite (thin-section), fraction
GRRUN	:	gamma ray, borehole corrected, API units
KI	:	calculated gas permeability, not corrected for water saturation, md
KMAX	:	dry core permeability, uncorrected, md
KPFM	:	dry core Klinkenberg permeability, corrected to in situ net stress, md
LITHIC	:	rock fragments (thin-section), fraction
PEFR	:	photoelectric effect, barns/electron
PHI	:	calculated porosity, corrected for variable fluid and matrix density, fraction
PHINC	:	neutron porosity, borehole corrected, fraction
POTAR	:	spectral gamma ray potassium, fraction
QUARTZ	:	quartz (thin-section), fraction
RHOBRC	:	bulk density, borehole corrected, gm/cc
RHOGD	:	core grain density, gm/cc
RHOMA	:	calculated matrix density, gm/cc
RT	:	formation resistivity (deep), ohm-m
SANDSZ	:	visual estimate of grain size from core, dimensionless
SNPR	:	sidewall neutron porosity, uncorrected, fraction
SWTOSH	:	calculated water saturation, deep formation, fraction
TKRAT	:	thorium/potassium ratio
VCAL	:	computed volume carbonate, fraction
VCLDN	:	volume clay from density-neutron logs, fraction
VCLGR	:	volume clay from gamma ray log, fraction
VPVSRA	:	compressional wave velocity/shear wave velocity, dimensionless
XGRSZE	:	mean grain size (thin-section), mm

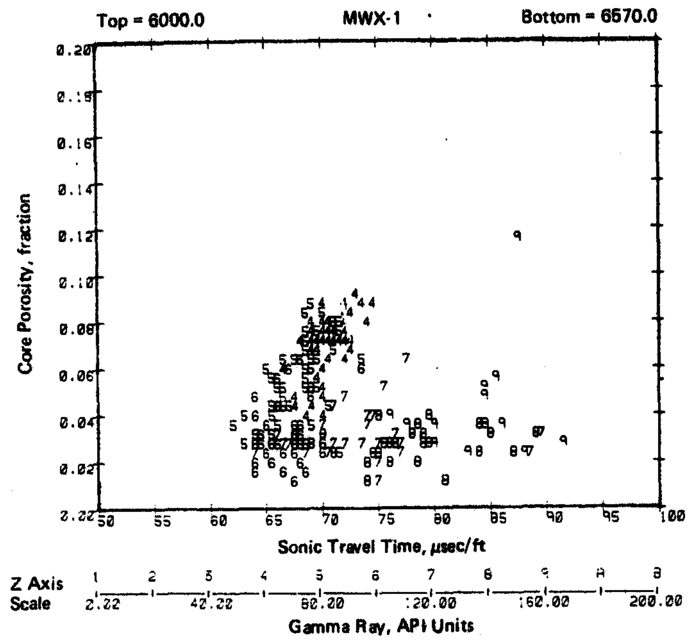

Figure 2. ***Sonic Travel Time Vs. Core Porosity with Gamma Ray on the Z-Axis, MWX-1 Coastal Interval***

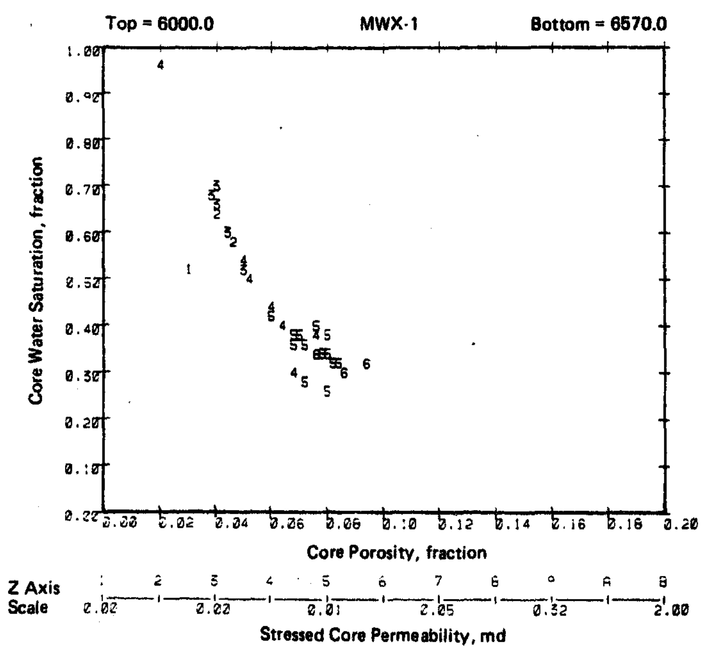

Figure 3. ***Core Porosity Vs. Water Saturation with Stressed Core Permeability on the Z-Axis, MWX-1 Coastal Interval***

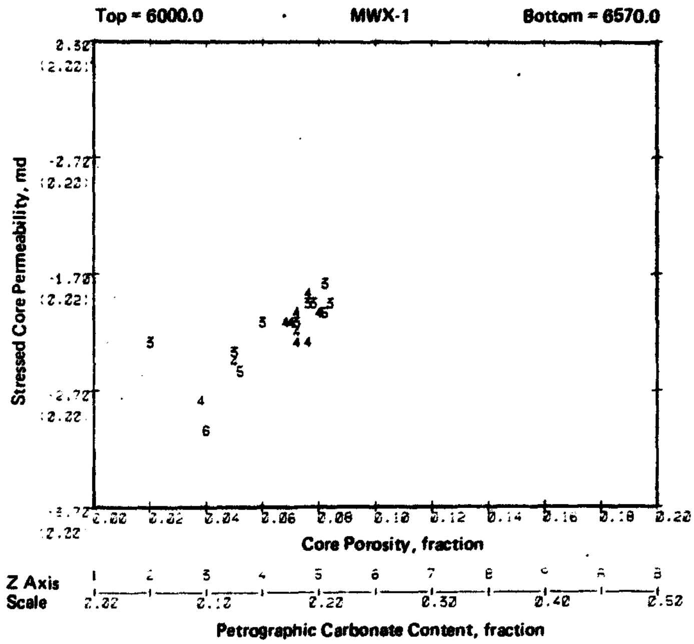

Figure 4. ***Core Porosity Vs. Stressed Core Permeability with Volume Carbonate on the Z-Axis, MWX-1 Coastal Interval***

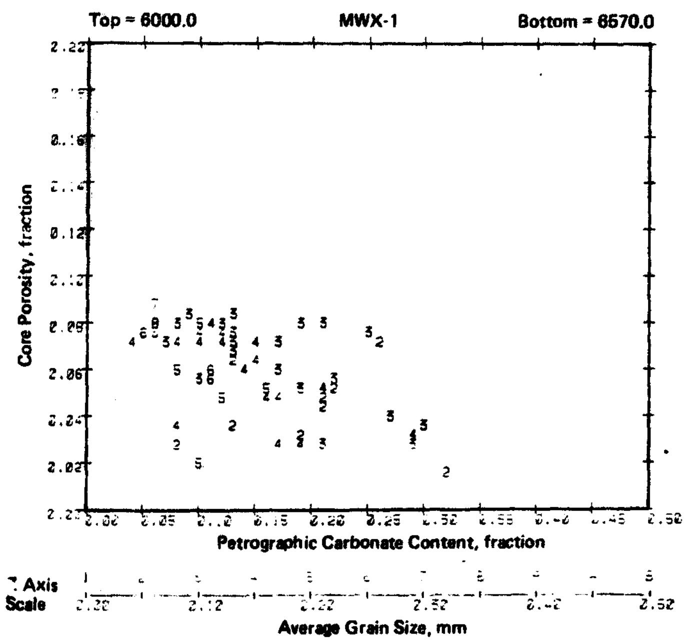

Figure 5. ***Volume Carbonate Vs. Core Porosity with Average Grain Size on the Z-Axis, MWX-1 Coastal Interval***

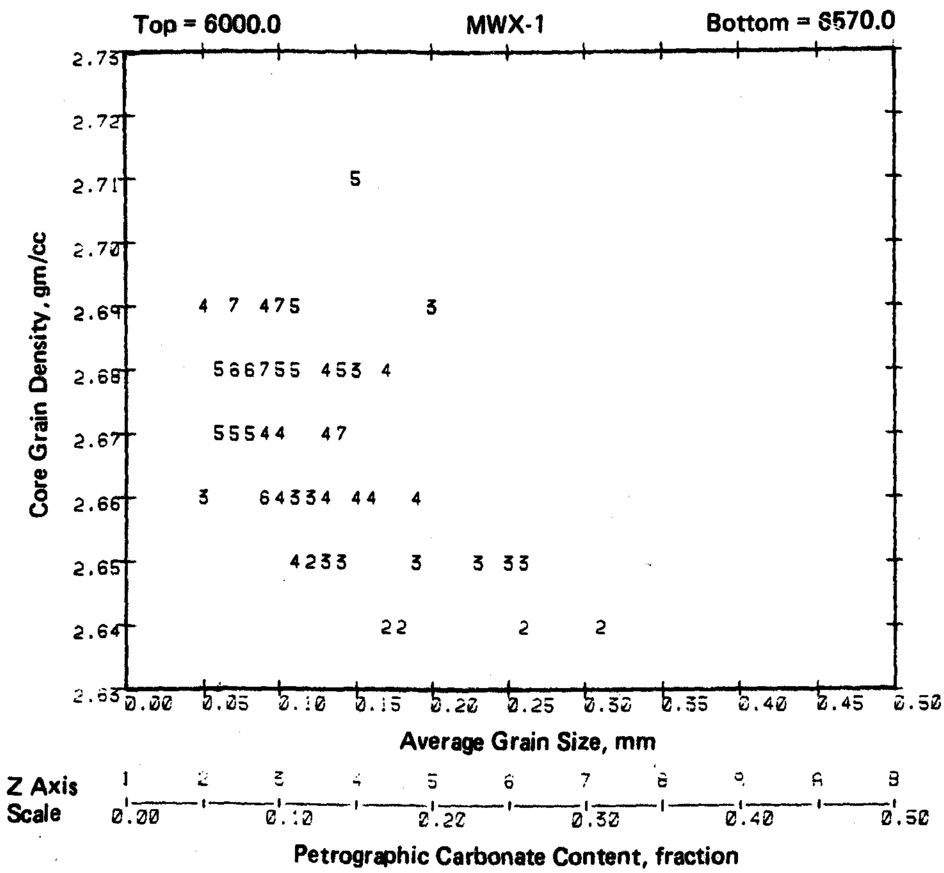

Figure 6. Average Grain Size Vs. Core Grain Density with Volume Carbonate on the Z-Axis, MWX-1 Coastal Interval

APPENDIX 11.4

CORE LABORATORIES DATA

APPENDIX 11.4

CORE LABORATORIES DATA

Core Laboratories, Inc. conducted a number of conventional and special measurements and analyses on MWX core. Copies of all coastal results are included in the appendix in the order: Conventional Dean Stark and Boyle's Law analyses, permeability to air and water, Klinkenberg permeability measurements as a function of overburden pressure, capillary pressure tests, cation exchange capacity measurements, formation resistivity factor and index measurements, caprock analysis, rock-eval pyrolysis, nitrate analysis, and hydrocarbon analysis of fluid and gas samples. Test and analysis procedures and sample descriptions are provided in the MWX data file references listed below.

Conventional Analyses:	1.2.11.001	1.3.001	
	1.2.11.004	1.3.003	
	1.2.11.018		
Special Analysis:	1.2.11.003	1.2.11.014	1.2.11.025
	1.2.11.004	1.2.11.017	1.2.11.026
	1.2.11.006	1.2.11.020	1.2.11.027
	1.2.11.008	1.2.11.021	1.2.11.029
	1.2.11.010	1.2.11.022	1.2.11.033
	1.2.11.013	1.2.11.023	1.2.11.034
Hydrocarbon Analyses:	1.2.35.003	1.2.35.010	
	1.2.35.005	1.2.35.011	
Core Data Summary:	1.2.11.030		

CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

SANDIA LABORATORIES
MWX-2

DATE : 3-1-82
FORMATION :

FILE NO : RP-2-6806
ANALYSTS : AT;BN;CW;FD;TE

DEAN STARK METHOD

SAMPLE NUMBER	DEPTH	PERM Ka MAXIMUM	POR. He	FLUID SATS. OIL	FLUID SATS. WTR	GRAIN DEN	DESCRIPTION
113	6423.7-00.0	<0.01	3.5	14.3	74.3	2.69	
114	6425.8-00.0	0.02	5.5	41.8	45.5	2.66	
115	6427.8-00.0	<0.01	5.9	50.8	42.4	2.67	
116	6429.2-00.0	<0.01	3.6	22.2	72.2	2.68	

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

SANDIA LABORATORIES
MWX-2

DATE : 3-1-82
FORMATION :

FILE NO : RP-2-6806
ANALYSTS : AT;BN;CW;FD;TB

DEAN STARK METHOD

SAMPLE NUMBER	DEPTH	PERM Ka MAXIMUM	POR. He	FLUID SATS. OIL	WTR	GRAIN DEN	DESCRIPTION
117	6430.5-00.0	0.02	4.7	51.1	42.6	2.66	
118	6431.5-00.0	0.03	5.6	53.6	37.5	2.66	
119	6432.5-00.0	0.02	5.8	56.9	34.5	2.67	
120	6433.5-00.0	0.02	7.0	57.1	37.1	2.66	
121	6434.5-00.0	0.03	6.7	61.2	29.9	2.65	
122	6436.5-00.0	0.04	6.4	59.4	31.3	2.65	
123	6437.5-00.0	0.05	7.0	62.9	28.6	2.65	
124	6438.5-00.0	0.09	7.1	66.2	28.2	2.65	
125	6439.5-00.0	0.06	6.4	64.1	31.3	2.66	
126	6440.5-00.0	0.07	7.1	57.7	36.6	2.65	
127	6441.5-00.0	0.01	5.6	57.1	37.5	2.67	
128	6443.5-00.0	0.01	5.3	41.5	49.1	2.68	
129	6444.5-00.0	0.09	8.1	54.3	32.1	2.64	
130	6445.5-00.0	0.09	8.4	64.3	25.0	2.65	
131	6446.5-00.0	0.05	7.7	50.6	33.8	2.66	
132	6447.5-00.0	0.09	8.2	52.4	36.6	2.65	
133	6449.5-00.0	0.09	8.3	51.8	37.3	2.65	
134	6450.5-00.0	0.11	8.4	52.4	36.9	2.65	
135	6451.5-00.0	0.08	8.1	56.8	32.1	2.66	
136	6452.5-00.0	0.03	5.0	40.0	52.0	2.66	
137	6453.5-00.0	0.04	5.8	48.3	43.1	2.66	
138	6455.5-00.0	0.06	7.9	53.2	32.9	2.66	
139	6456.5-00.0	0.05	7.6	65.8	26.3	2.66	
140	6457.5-00.0	0.08	8.0	60.0	31.3	2.66	
141	6458.5-00.0	0.09	7.7	59.7	32.5	2.66	
142	6459.5-00.0	0.05	6.8	64.7	29.4	2.66	
143	6461.7-00.0	<0.01	4.0	17.5	75.0	2.76	
144	6463.9-00.0	<0.01	3.0	3.3	83.3	2.68	
145	6465.8-00.0	<0.01	2.4	0.0	83.3	2.67	
146	6467.5-00.0	<0.01	4.0	12.5	77.5	2.69	

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

SANDIA LABORATORIES
MWX-2

DATE : 3-1-82
FORMATION :

FILE NO : RP-2-6806
ANALYSTS : AT;BH;CW;FD;TI

DEAN STARK METHOD

SAMPLE NUMBER	DEPTH	PERM Ka MAXIMUM	POR. He	FLUID SATS. OIL	FLUID SATS. WTR	GRAIN DEN	DESCRIPTION
147	6469.6-00.0	<0.01	5.3	50.9	39.6	2.68	
148	6497.6-00.0	<0.01	2.0	0.0	80.0	2.69	
149	6498.6-00.0	<0.01	2.2	0.0	81.8	2.68	
150	6500.9-00.0	<0.01	3.6	2.8	83.3	2.67	
151	6501.8-00.0	0.01	4.1	14.6	73.2	2.68	
152	6504.4-00.0	0.02	6.1	52.5	41.0	2.67	
153	6506.5-00.0	0.02	6.4	43.8	46.9	2.66	
154	6508.3-00.0	0.02	8.3	57.8	30.1	2.66	
155	6509.4-00.0	0.01	8.3	55.4	30.1	2.66	
156	6511.1-00.0	0.05	9.1	61.5	27.5	2.66	
157	6512.9-00.0	0.04	7.6	52.6	34.2	2.66	
158	6515.1-00.0	0.01	6.3	50.8	39.7	2.65	
159	6516.3-00.0	0.02	7.7	58.4	32.5	2.66	
160	6517.9-00.0	0.03	7.6	53.9	31.6	2.66	
161	6519.9-00.0	0.06	7.3	56.2	34.2	2.66	
162	6521.9-00.0	0.05	7.8	60.3	33.3	2.66	
163	6524.9-00.0	0.04	7.8	60.3	33.3	2.66	
164	6525.9-00.0	0.05	7.5	46.7	40.0	2.66	
165	6527.2-00.0	0.04	7.3	63.0	27.4	2.66	
166	6528.9-00.0	0.03	7.7	57.1	32.5	2.66	
167	6529.9-00.0	0.03	7.3	56.2	35.6	2.66	
168	6531.9-00.0	0.05	7.3	57.5	32.9	2.66	
169	6534.2-00.0	0.05	7.1	64.8	28.2	2.65	
170	6535.3-00.0	0.06	7.6	59.2	32.9	2.65	
171	6536.9-00.0	0.07	7.7	54.5	33.8	2.66	
172	6539.2-00.0	0.02	5.0	40.0	50.0	2.66	
173	6540.7-00.0	0.02	6.4	51.6	39.1	2.67	
174	6542.6-00.0	0.01	6.0	51.7	41.7	2.67	
175	6544.3-00.0	0.03	7.7	44.2	39.0	2.67	
176	6545.8-00.0	0.05	7.1	50.7	35.2	2.65	

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

SANDIA LABORATORIES
MWX-2

DATE : 3-1-82
FORMATION :
DRLG. FLUID:
LOCATION :

FILE NO : RP-2-6806
ANALYSTS : AT;BN;CW;FD;TE
ELEVATION:

DEAN STARK METHOD

SAMPLE NUMBER	DEPTH	PERM Ka MAXIMUM	POR. He	FLUID SATS. OIL	FLUID SATS. WTR	GRAIN DEN	DESCRIPTION
177	6547.8-00.0	0.03	6.0	51.7	33.3	2.66	
178	6549.7-00.0	0.02	6.5	49.2	40.0	2.68	
179	6551.2-00.0	0.03	7.6	51.3	32.9	2.67	
180	6552.8-00.0	0.03	7.0	50.0	35.7	2.67	
181	6556.9-00.0	0.05	6.7	59.7	37.3	2.66	
182	6558.1-00.0	0.05	6.1	49.2	41.0	2.66	
183	6559.9-00.0	<0.01	5.7	50.9	43.9	2.89	
184	6562.8-00.0	<0.01	2.2	0.0	95.5	2.67	

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SANDIA LABORATORIES
MWX-1

DATE : 11-3-81
FORMATION :

FILE NO : RP-2-6714
ANALYSTS : RN,AT,CW,KS,FD

DEAN STARK METHOD

SAMPLE NUMBER	DEPTH	PERM Ka MAXIMUM	POR. He	FLUID SATS. OIL	FLUID SATS. WTR	GRAIN DEN	DESCRIPTION
800	6009.3-00.0	0.01	3.6	16.7	72.2	2.68	
801	6010.6-00.0	0.01	3.4	11.8	76.5	2.68	
802	6027.3-00.0	0.01	3.1	12.9	83.9	2.67	

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SANDIA LABORATORIES
MWX-1

DATE : 11-3-81
FORMATION :

FILE NO : RP-2-6714
ANALYSTS : BN,AT,CW,KS,FB

DEAN STARK METHOD

SAMPLE NUMBER	DEPTH	PERM Ka MAXIMUM	POR. He	FLUID SATS. OIL	FLUID SATS. WTR	GRAIN DEN	DESCRIPTION
803	6028.6-00.0	0.01	4.7	42.6	55.3	2.65	
804	6029.6-00.0	0.02	6.0	55.0	43.3	2.64	
805	6030.6-00.0	0.03	6.4	50.0	42.2	2.63	
806	6031.6-00.0	0.04	7.4	63.5	35.1	2.63	
807	6032.7-00.0	0.04	7.1	60.6	38.0	2.63	
808	6033.9-00.0	0.01	7.4	63.5	35.1	2.76	
809	6062.2-00.0	0.01	2.7	18.5	96.3	2.67	
810	6065.5-00.0	<0.01	2.1	0.0	95.2	2.69	
811	6069.3-00.0	0.02	7.1	62.0	36.6	2.64	
812	6070.7-00.0	0.03	8.6	59.3	36.0	2.66	
813	6071.7-00.0	0.02	8.3	66.3	32.5	2.65	
814	6072.7-00.0	0.04	8.7	65.5	29.9	2.64	
815	6073.7-00.0	0.06	9.3	61.3	32.3	2.64	
816	6074.7-00.0	0.02	8.2	73.2	25.6	2.65	
817	6079.7-00.0	0.08	6.1	52.5	42.6	2.65	
818	6081.7-00.0	0.10	3.8	23.7	68.4	2.69	
819	6084.5-00.0	0.01	2.1	0.0	85.7	2.69	
820	6141.7-00.0	0.01	5.6	50.0	44.6	2.67	
821	6142.6-00.0	0.01	6.5	55.4	40.0	2.66	
822	6143.5-00.0	0.01	6.5	55.4	40.0	2.66	
823	6144.5-00.0	0.01	5.9	50.8	44.1	2.68	
824	6145.5-00.0	0.01	6.4	51.6	40.6	2.66	
825	6187.6-00.0	0.01	1.8	0.0	88.9	2.69	
826	6188.6-00.0	0.01	3.0	3.3	86.7	2.71	
827	6189.3-00.0	0.01	6.5	56.9	38.5	2.65	FRACTURED PERMEABILITY PLUG
828	6190.6-00.0	0.01	3.7	21.6	70.3	2.68	
829	6191.4-00.0	0.02	4.6	37.0	56.5	2.67	
830	6192.6-00.0	0.01	5.6	46.4	46.4	2.66	
831	6193.2-00.0	0.03	5.1	39.2	51.0	2.66	
832	6194.5-00.0	0.01	5.0	50.0	42.0	2.69	

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MWX-1

DATE : 11-3-81
FORMATION :

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ANALYSTS : BN,AT,CW,KS,FD

DEAN STARK METHOD

SAMPLE NUMBER	DEPTH	PERM Ka MAXIMUM	POR. He	FLUID OIL	SATS. WTR	GRAIN DEN	DESCRIPTION
833	6195.5-00.0	0.01	3.0	6.7	86.7	2.69	
834	6196.5-00.0	0.01	5.2	25.0	40.4	2.71	
835	6238.5-00.0	0.01	3.0	6.7	86.7	2.69	
836	6239.5-00.0	0.01	4.5	33.3	57.8	2.68	
837	6240.7-00.0	<0.01	4.8	31.3	64.6	2.67	
838	6241.6-00.0	<0.01	4.4	25.0	70.5	2.67	
839	6242.7-00.0	0.49	2.6	7.7	80.8	2.71	FRACTURED PERMEABILITY PLUG
840	6244.3-00.0	<0.01	1.9	0.0	89.5	2.69	
841	6246.6-00.0	<0.01	4.8	29.2	64.6	2.67	
842	6247.5-00.0	0.01	6.2	53.2	40.3	2.65	
843	6248.3-00.0	<0.01	2.3	0.0	87.0	2.69	
844	6249.8-00.0	<0.01	7.2	59.7	36.1	2.66	
845	6250.7-00.0	0.01	8.0	57.5	38.8	2.64	
846	6251.5-00.0	0.01	8.0	52.5	40.0	2.65	
847	6252.5-00.0	0.05	8.0	60.0	32.5	2.75	
848	6253.5-00.0	0.04	7.7	59.7	33.8	2.64	
849	6254.5-00.0	0.04	7.5	56.0	34.7	2.64	
850	6255.3-00.0	0.02	6.5	50.8	41.5	2.66	
851	6256.5-00.0	0.01	5.6	41.1	48.2	2.65	
852	6259.5-00.0	0.08	3.5	14.3	71.4	2.80	FRACTURED PERMEABILITY PLUG
853	6260.8-00.0	0.49	11.6	68.1	27.6	2.77	FRACTURED PERMEABILITY PLUG
854	6263.1-00.0	0.02	2.3	0.0	82.6	2.67	FRACTURED PERMEABILITY PLUG
855	6265.6-00.0	<0.01	1.3	0.0	69.2	3.19	
856	6267.5-00.0	<0.01	2.0	0.0	80.0	2.68	
857	6272.6-00.0	<0.01	1.1	0.0	54.5	2.70	
858	6273.9-00.0	0.04	3.3	21.2	66.7	2.61	FRACTURED PERMEABILITY PLUG
859	6276.6-00.0	<0.01	2.8	0.0	82.1	2.64	
860	6278.2-00.0	0.20	2.5	0.0	84.0	2.66	FRACTURED PERMEABILITY PLUG
861	6280.2-00.0	0.01	3.2	0.0	84.4	2.65	
862	6281.7-00.0	0.01	2.8	3.6	92.9	2.68	

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SANDIA LABORATORIES
MWX-1

DATE : 11-3-81
FORMATION :

FILE NO : RP-2-6714
ANALYSTS : BN,AT,CW,KS,FD

DEAN STARK METHOD

SAMPLE NUMBER	DEPTH	PERM Ka MAXIMUM	POR. He	FLUID SATS. OIL	FLUID SATS. WTR	GRAIN DEN	DESCRIPTION
863	6282.4-00.0	0.07	3.0	0.0	90.0	2.68	
864	6283.5-00.0	0.01	3.1	9.7	83.9	2.67	
865	6285.6-00.0	<0.01	1.5	0.0	80.0	2.70	
866	6288.5-00.0		2.5	0.0	96.0	2.65	UNSUITABLE FOR PERMEABILITY MEASUREMENT
867	6290.1-00.0	0.32	3.4	11.8	79.4	2.67	FRACTURED PERMEABILITY PLUG
868	6292.1-00.0	0.01	2.7	7.4	77.8	2.68	
869	6293.5-00.0	0.01	3.3	15.2	78.8	2.67	
870	6295.7-00.0	0.01	2.3	0.0	91.3	2.69	
871	6298.3-00.0	0.02	2.5	12.0	84.0	2.67	
872	6301.4-00.0	0.01	2.7	0.0	88.9	2.65	
873	6303.8-00.0	<0.01	3.2	6.3	84.4	2.74	
874	6303.8-****	0.04	2.4	0.0	91.7	2.68	FRACTURED PERMEABILITY PLUG
875	6307.6-00.0	<0.01	1.9	0.0	94.7	2.70	
876	6309.3-00.0	<0.01	2.2	0.0	90.9	2.72	
877	6310.8-00.0		2.4	8.3	79.2	2.69	UNSUITABLE FOR PERMEABILITY MEASUREMENT
878	6313.3-00.0	<0.01	1.1	0.0	81.8	2.70	
879	6315.8-00.0	0.12	2.4	0.0	83.3	2.64	FRACTURED PERMEABILITY PLUG
880	6318.5-00.0	<0.01	2.7	0.0	92.6	2.63	
881	6320.5-00.0	0.01	4.0	12.5	80.0	2.69	
882	6322.2-00.0	0.11	2.2	9.1	72.7	2.68	FRACTURED PERMEABILITY PLUG
883	6324.3-00.0	1.10	2.6	3.9	80.8	2.68	FRACTURED PERMEABILITY PLUG
884	6326.7-00.0	0.01	2.9	0.0	89.7	2.66	FRACTURED PERMEABILITY PLUG
885	6329.5-00.0	<0.01	2.9	0.0	93.1	2.66	
886	6331.2-00.0	0.01	2.8	10.7	75.0	2.66	
887	6333.5-00.0	<0.01	1.6	0.0	62.5	2.70	
888	6335.7-00.0	0.01	2.4	4.2	66.7	2.70	
889	6337.5-00.0	<0.01	2.7	0.0	74.1	2.64	
890	6338.3-00.0	<0.01	2.6	0.0	69.2	2.66	
891	6339.5-00.0	0.01	2.6	3.8	61.5	2.67	
892	6340.8-00.0	<0.01	2.5	4.0	64.0	2.68	

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SANDIA LABORATORIES
MWX-1

DATE : 11-3-81
FORMATION :

FILE NO : RP-2-6714
ANALYSTS : BN,AT,CW,KS,

DEAN STARK METHOD

SAMPLE NUMBER	DEPTH	PERM Ka MAXIMUM	POR. He	FLUID SATS. OIL	WTR	GRAIN DEN	DESCRIPTION
893	6341.5-00.0	0.01	2.6	11.5	57.7	2.68	
894	6342.5-00.0	0.01	3.4	14.7	61.8	2.67	
895	6343.7-00.0	0.01	4.1	14.6	63.4	2.68	
896	6344.5-00.0	0.01	4.4	22.7	59.1	2.68	
897	6345.6-00.0	<0.01	4.5	11.1	68.9	2.68	
898	6346.4-00.0	<0.01	4.9	18.4	75.5	2.67	
899	6349.3-00.0	<0.01	2.8	0.0	71.4	2.70	
900	6351.6-00.0	<0.01	2.7	0.0	70.4	2.70	
901	6354.6-00.0	<0.01	2.9	0.0	72.4	2.65	
902	6355.5-00.0	<0.01	2.9	0.0	72.4	2.68	
903	6356.6-00.0	<0.01	5.4	27.8	68.5	2.68	
904	6357.6-00.0	0.01	5.6	28.6	55.4	2.66	
905	6358.5-00.0	0.02	4.3	20.9	60.5	2.67	
906	6359.6-00.0	0.03	8.1	53.1	32.1	2.64	
907	6360.5-00.0	0.04	7.6	51.3	34.2	2.64	
908	6362.5-00.0	0.03	7.2	48.6	36.1	2.64	
909	6363.5-00.0	0.03	7.1	47.9	36.6	2.65	
910	6364.3-00.0	0.02	6.4	51.6	32.8	2.68	
911	6366.4-00.0	<0.01	3.0	3.3	70.0	2.70	
912	6369.5-00.0	<0.01	3.8	0.0	78.9	2.70	
913	6372.5-00.0	0.10	3.2	6.3	65.6	2.68	FRACTURED PERMEABILITY PLUG
914	6376.3-00.0	<0.01	2.5	0.0	56.0	2.69	
915	6379.5-00.0	<0.01	4.7	27.7	53.2	2.68	
916	6380.4-00.0	<0.01	5.9	45.8	35.6	2.69	
917	6381.7-00.0	<0.01	6.3	47.6	33.3	2.66	
918	6382.5-00.0	<0.01	8.5	64.7	24.7	2.67	
919	6383.5-00.0	0.01	7.7	59.7	27.3	2.67	
920	6384.5-00.0	0.01	7.3	56.2	28.8	2.68	
921	6385.7-00.0	0.01	6.3	54.0	31.7	2.67	
922	6386.5-00.0	0.02	6.5	55.4	40.0	2.68	

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

SANDIA LABORATORIES
MWX-1

DATE : 11-3-81
FORMATION :

FILE NO : RP-2-6714
ANALYSTS : BN;AT;CW;KS;FB

DEAN STARK METHOD

SAMPLE NUMBER	DEPTH	PERM Ka MAXIMUM	POR. He	FLUID SATS. OIL	FLUID SATS. WTR	GRAIN DEN	DESCRIPTION
923	6388.4-00.0	0.01	4.1	31.7	63.4	2.68	
924	6391.6-00.0	0.01	3.5	29.0	91.4	2.61	
925	6394.6-00.0	0.01	5.1	35.3	60.8	2.75	
926	6397.5-00.0		2.9	10.3	86.2	2.70	
927	6399.5-00.0	0.01	4.7	40.4	55.3	2.69	
928	6400.3-00.0	0.01	5.1	47.1	51.0	2.68	
929	6403.7-00.0	0.01	3.2	18.8	65.6	2.69	
930	6406.3-00.0	0.17	3.6	11.1	86.1	2.70	FRACTURED PERMEABILITY PLUG
931	6409.3-00.0	0.01	2.8	0.0	96.4	2.68	
932	6412.3-00.0	0.01	2.4	4.2	87.5	2.70	
933	6415.4-00.0	0.01	2.6	11.5	80.8	2.71	
934	6420.7-00.0	0.15	4.2	31.0	61.9	2.66	FRACTURED PERMEABILITY PLUG
935	6424.8-00.0	1.20	3.5	5.7	91.4	2.69	FRACTURED PERMEABILITY PLUG
936	6427.7-00.0	0.02	3.8	10.5	81.6	2.57	
937	6429.4-00.0	0.03	4.1	31.7	63.4	2.73	
938	6430.7-00.0	0.02	3.4	5.9	76.5	2.71	
939	6431.5-00.0	0.01	3.9	25.6	69.2	2.68	
940	6432.2-00.0	0.02	5.0	44.0	52.0	2.68	
941	6433.5-00.0	0.02	5.2	48.1	50.0	2.68	
942	6434.4-00.0	0.01	5.8	50.0	44.8	2.66	
943	6435.7-00.0	0.04	7.3	67.1	28.8	2.66	
944	6436.7-00.0	0.03	6.8	55.9	38.2	2.67	
945	6437.4-00.0	0.02	7.3	57.5	35.6	2.66	
946	6438.2-00.0	<0.01	6.3	60.3	33.3	2.66	
947	6438.5-00.0	0.01	7.9	68.4	26.6	2.66	
948	6439.3-00.0	0.01	7.6	60.5	34.2	2.65	
949	6440.5-00.0	0.01	7.2	56.9	36.1	2.66	
950	6441.1-00.0	<0.01	4.9	36.7	53.1	2.66	
951	6441.5-00.0	0.02	6.2	56.5	33.9	2.66	
952	6442.8-00.0	0.01	2.9	0.0	86.2	2.65	

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SANDIA LABORATORIES
MWX-1

DATE : 11-3-81
FORMATION :

FILE NO : RP-2-6714
ANALYSTS : BN,AT,CW,KS,FB

DEAN STARK METHOD

SAMPLE NUMBER	DEPTH	PERM Ka MAXIMUM	POR. He	FLUID SATS. OIL	FLUID SATS. WTR	GRAIN DEN	DESCRIPTION
953	6445.5-00.0	0.05	7.1	54.9	36.6	2.65	
954	6446.5-00.0	0.03	7.0	62.9	30.0	2.67	
955	6447.5-00.0	0.05	7.0	55.7	37.1	2.65	
956	6448.3-00.0	0.04	7.0	61.4	28.6	2.66	
957	6449.1-00.0	0.03	6.9	60.9	30.4	2.67	
958	6451.5-00.0	0.18	7.9	64.6	27.8	2.65	
959	6452.5-00.0	0.07	8.7	59.8	29.9	2.67	
960	6455.9-00.0	0.10	8.7	62.1	29.9	2.65	
961	6456.5-00.0	0.11	8.6	61.6	30.2	2.65	
962	6458.0-00.0	0.07	8.3	60.2	31.3	2.66	
963	6460.0-00.0	0.08	7.1	52.1	36.6	2.66	
964	6461.5-00.0	0.04	7.4	47.3	36.5	2.66	
965	6463.5-00.0	0.08	7.8	28.2	33.3	2.66	
966	6470.0-00.0	<0.01	3.1	6.5	51.6	2.69	
967	6471.8-00.0	1.00	3.0	13.3	70.0	2.51	FRACTURED PERMEABILITY PLUG
968	6473.0-00.0	<0.01	2.9	17.2	51.7	2.69	
969	6475.6-00.0	0.02	3.1	19.4	51.6	2.69	
970	6477.5-00.0	0.04	3.9	17.9	53.8	2.68	
971	6481.0-00.0	<0.01	3.0	23.3	53.3	2.68	
972	6482.8-00.0	0.01	3.3	6.1	63.6	2.67	
973	6486.5-00.0	<0.01	4.5	22.2	57.8	2.67	
974	6487.5-00.0	0.01	5.1	29.4	51.0	2.66	
975	6489.8-00.0	<0.01	3.1	6.5	64.5	2.67	
976	6491.8-00.0	<0.01	3.3	6.1	63.6	2.61	
977	6494.5-00.0	0.01	2.3	0.0	60.9	2.65	FRACTURED PERMEABILITY PLUG
978	6497.0-00.0	<0.01	3.4	8.8	64.7	2.76	
979	6500.0-00.0	<0.01	4.8	29.2	54.2	2.76	
980	6502.5-00.0	0.37	5.4	27.8	48.1	2.67	
981	6503.5-00.0	0.03	5.0	26.0	52.0	2.63	
982	6505.1-00.0	0.03	6.5	49.2	40.0	2.66	

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SANDIA LABORATORIES
MWX-1

DATE : 11-3-81
FORMATION :

FILE NO : RP-2-6714
ANALYSTS : RN,AT,CW,KS,FB

DEAN STARK METHOD

SAMPLE NUMBER	DEPTH	PERM Ka MAXIMUM	POR. He	FLUID SATS. OIL	FLUID SATS. WTR	GRAIN DEN	DESCRIPTION
983	6507.3-00.0	0.03	7.4	54.1	36.5	2.66	
984	6508.0-00.0	0.03	7.4	56.8	35.1	2.67	
985	6508.1-00.0	0.03	7.4	51.4	35.1	2.66	
986	6508.3-00.0	0.04	7.5	53.3	37.3	2.66	
987	6509.3-00.0	0.03	8.3	60.2	31.3	2.67	
988	6511.2-00.0	0.04	8.2	61.0	31.7	2.67	
989	6513.0-00.0	0.05	7.9	58.2	34.2	2.66	
990	6514.7-00.0	0.05	8.2	58.5	31.7	2.67	
991	6516.5-00.0	0.03	7.5	56.0	34.7	2.68	
992	6517.5-00.0	0.03	7.3	56.2	35.6	2.67	
993	6519.5-00.0	0.03	7.2	55.6	36.1	2.67	
994	6522.5-00.0	0.04	6.9	52.2	37.7	2.66	
995	6524.2-00.0	0.03	6.0	43.3	43.3	2.67	
996	6528.7-00.0	0.01	2.9	3.4	72.4	2.68	
997	6530.7-00.0	0.01	3.4	5.9	76.5	2.69	
998	6531.4-00.0	<0.01	3.3	0.0	78.8	2.69	
999	6532.4-00.0	0.01	4.4	22.7	59.1	2.68	
1000	6533.5-00.0	0.01	3.5	2.9	74.3	2.69	
1001	6534.4-00.0	0.01	3.5	8.6	74.3	2.67	
1002	6535.3-00.0	0.01	6.1	45.9	42.6	2.68	
1003	6536.7-00.0	0.03	6.9	52.2	37.7	2.67	
1004	6537.5-00.0	0.05	6.8	50.0	36.8	2.66	
1005	6539.2-00.0	0.02	3.9	17.9	66.7	2.68	
1006	6540.5-00.0	0.04	7.3	53.4	35.6	2.66	
1007	6541.3-00.0	0.09	7.5	54.7	34.7	2.65	
1008	6542.5-00.0	0.02	6.6	48.5	39.4	2.67	
1009	6543.7-00.0	0.05	7.2	54.2	36.1	2.66	
1010	6544.4-00.0	0.05	7.3	53.4	35.6	2.66	
1011	6545.5-00.0	0.04	8.1	58.0	30.9	2.67	
1012	6546.3-00.0	0.04	8.0	55.0	37.5	2.69	

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SANDIA LABORATORIES
MWX-1

DATE : 11-3-81
FORMATION :

FILE NO : RP-2-6714
ANALYSTS : RN,AT,CW,KS,FD

DEAN STARK METHOD

SAMPLE NUMBER	DEPTH	PERM Ka MAXIMUM	POR. He	FLUID SATS. OIL	FLUID SATS. WTR	GRAIN DEN	DESCRIPTION
1013	6547.5-00.0	0.05	7.9	53.2	39.2	2.68	
1014	6548.8-00.0	0.08	7.6	48.7	40.8	2.66	
1015	6549.7-00.0	0.07	7.1	45.1	43.7	2.66	
1016	6550.7-00.0	0.06	6.6	50.0	39.4	2.66	
1017	6551.5-00.0	0.04	6.8	51.5	36.8	2.67	
1018	6552.5-00.0	0.02	5.9	42.4	44.1	2.66	
1019	6553.5-00.0	0.02	4.3	20.9	60.5	2.67	
1020	6563.3-00.0	0.04	4.0	17.5	65.0	2.54	
1021	6564.2-00.0	0.02	4.2	14.3	61.9	2.67	
1022	6566.5-00.0	0.01	2.8	0.0	75.0	2.70	
1023	6568.4-00.0	0.01	2.7	0.0	77.8	2.69	
1024	6570.5-00.0	0.81	1.5	0.0	66.7	2.67	FRACTURED PERMEABILITY PLUG
1025	6574.1-00.0	0.04	4.0	17.5	70.0	2.70	
1026	6577.4-00.0	<0.01	1.7	0.0	41.2	2.70	
1027	6578.8-00.0	0.01	2.8	3.6	17.9	2.68	
1028	6579.9-00.0	0.01	1.5	0.0	73.3	2.70	
1029	6580.7-00.0	<0.01	2.1	9.5	76.2	2.70	
1030	6581.2-00.0	0.01	1.9	5.3	84.2	2.69	
1031	6582.5-00.0	0.01	3.8	7.9	55.3	2.68	
1032	6583.5-00.0	<0.01	3.3	0.0	30.3	2.69	
1033	6596.8-00.0	0.03	2.6	11.5	80.8	2.66	

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

SANDIA NATIONAL LABORATORIES   DATE ON : 18-JUL-83   OFF: 06-OCT-83 FILE NO : 3806-7199
MWX-3   FORMATION : MESA VERDE   LABORATORY: AURORA

CONVENTIONAL CORE ANALYSIS--BOYLE'S LAW POROSITY

SAMPLE NUMBER	DEPTH FEET	PERM MD MAX Ka	He POR	OIL% PORE	WTR% PORE	GRAIN DEN
66	6432.7-32.9	<0.01	16.8	0.0	86.5	3.08
67	6434.4-34.6	<0.01	3.5	0.0	66.5	2.69
68	6435.6-35.8	<0.01	5.1	0.0	51.7	2.68
69	6436.6-36.8	<0.01	5.4	0.0	72.6	2.69
70	6437.8-38.0	<0.01	5.6	0.0	71.6	2.69
71	6438.9-39.1	<0.01	3.2	0.0	75.7	2.69
72	6440.3-40.5	<0.01	2.6	0.0	73.8	2.68
73	6441.8-42.0	<0.01	5.8	0.0	69.4	2.67
74	6443.5-43.7	<0.01	6.1	0.0	57.5	2.67
75	6444.8-45.0	<0.01	5.9	0.0	67.5	2.67
76	6445.8-46.0	0.01	8.2	0.0	42.0	2.69
77	6447.5-47.7	0.02	7.0	0.0	45.0	2.67
78	6448.5-48.7	<0.01	5.2	0.0	56.7	2.68
79	6450.5-50.7	0.05	3.0	0.0	80.3	2.60
80	6452.1-52.3	<0.01	7.1	0.0	44.7	2.68
81	6453.6-53.8	0.01	7.1	0.0	40.7	2.66
82	6454.6-54.8	0.01	7.5	0.0	40.6	2.67
83	6456.5-56.8	0.04	8.7	0.0	38.2	2.65
84	6457.7-57.9	0.03	7.1	0.0	47.5	2.65
85	6460.1-60.3	0.02	7.9	0.0	42.5	2.66
86	6461.8-62.0	0.03	7.5	0.0	41.8	2.66
87	6463.0-63.2	0.02	7.1	0.0	49.9	2.66
88	6464.4-64.5	0.01	7.6	0.0	41.0	2.67

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CORE LABORATORIES, INC.

Petroleum Reservoir Engineering

DALLAS, TEXAS

SANDIA NATIONAL LABORATORIES   DATE ON : 18-JUL-83   OFF: 06-OCT-83   FILE NO : 3806-7199
MWX-3   FORMATION : MESA VERDE   LABORATORY: AURORA

CONVENTIONAL CORE ANALYSIS--BOYLE'S LAW POROSITY

SAMPLE NUMBER	DEPTH FEET	PERM MD MAX Ka	He POR	OIL% PORE	WTR% PORE	GRAIN DEN
89	6466.9-67.1	0.02	7.4	0.0	41.1	2.67
90	6468.5-68.7	0.03	7.7	0.0	40.0	2.67
91	6470.6-70.8	<0.01	1.4	0.0	81.4	2.68
92	6473.4-73.7	0.01	5.3	0.0	61.9	2.67
93	6474.6-74.8	<0.01	5.2	0.0	63.2	2.67
94	6475.7-75.9	0.01	3.7	0.0	70.4	2.67
95	6501.4- 1.6	<0.01	2.4	0.0	76.5	2.68
96	6502.7- 2.9	<0.01	2.6	0.0	76.4	2.67
97	6504.3- 4.5	<0.01	2.7	0.0	78.8	2.67
98	6506.1- 6.3	<0.01	2.1	0.0	78.5	2.69
99	6507.7- 7.9	<0.01	3.4	0.0	69.7	2.63
100	6509.5- 9.7	<0.01	6.2	1.6	63.7	2.67
101	6510.8-10.9	<0.01	6.3	3.2	51.8	2.67
102	6512.3-12.5	0.01	6.8	0.0	51.2	2.67
103	6513.8-14.0	<0.01	6.9	0.0	55.8	2.68
104	6515.4-15.6	<0.01	6.1	0.0	51.1	2.67
105	6516.7-16.9	<0.01	6.0	0.0	58.2	2.68
106	6523.7-23.9	<0.01	4.1	0.0	74.3	2.68

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CORE LABORATORIES, INC.

File 203-830024

SPECIFIC PERMEABILITY TO WATER

Company: Sandia National Laboratories

Well: MWX-1

Formation: Mesa Verde

Field: Rulison

County, State: Garfield, Colorado

Water Identification: 18,000 ppm NaCl

Sample I.D.	Depth, feet	Porosity, percent	Permeability to Air, millidarcys	Specific Permeability to Water, millidarcys	Permeability Ratio water/oil
941	6433.5	5.3	0.01	--------	--------
			2000 O.B.	5.3×10^{-5}	
			3000 O.B.	3.7×10^{-5}	
943	6435.5	7.8	0.04	--------	--------
			3000 O.B.	1.38×10^{-4}	

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CORE LABORATORIES, INC.

Special Core Analysis

File 203-820088

PERMEABILITY, POROSITY, AND GRAIN DENSITY

Company: SANDIA NATIONAL LABORATORIES   Well: MULTI-WELL EXPERIMENT-1

Formation: MESA VERDE -FLUVIAL   Field: RULISON

County (Parish), State: GARFIELD, COLORADO

Sample Identification	Depth, feet	Permeability to Air, millidarcys	Porosity, percent	Grain Density, gm/cm^3
93-S	6259.0		*	2.69
95-S	6260.0		*	2.62
97-S	6261.0		*	2.74
99-S	6267.0		*	2.58
101-S	6263.0		*	2.76
103-S	6264.0		*	2.71
105-S	6551.0		7.0	2.69
107-S	6552.0		7.2	2.68
109-S	6553.0		5.2	2.67
111-S	6554.0		4.2	2.73
113-S	6555.5		*	2.86
115-S	6556.0		2.3	2.72
117-S	6557.0		*	2.70
119-S	6558.0		*	2.69
121-S	6559.0		3.4	2.72

* SAMPLE FAILED

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CORE LABORATORIES, INC.

Special Core Analysis

File 203-82049

VERTICAL PERMEABILITY TO AIR AND GRAIN DENSITY

Company: SANDIA NATIONAL LABORATORIES Well: MULTI-WELL EXPERIMENT #1 & 2

Formation: FLUVIAL MESAVERDE & CORCORAN** Field: RULISON

County (Parish), State: GARFIELD, COLORADO

Sample Identification	Depth, feet	Permeability to Air, millidarcys	Grain Density
MWX-2 WELL			
6	6447 - 6448	0.10	2.66
8	6506.7-6507.4	0.07	2.68
** 10	6526 - 6527	0.07	2.68
MWX-1 WELL			
7	6455.3-6456.2	0.15	2.65
9	6511.0-6511.7	0.06	2.66
** 11	6543.3-6544.4	0.09	2.67

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SPECIFIC PERMEABILITY TO WATER

Company: Sandia National Laboratories Well: MWX-1

Formation: Mesa Verde Field: Rulison

County, State: Garfield, Colorado

Water Identification: 18,000 ppm NaCl

Sample I.D.	Depth, feet	Porosity, percent	Permeability to Air, millidarcys	Specific Permeability to Water, millidarcys	Permeability Ratio water/oil
981	6503.5	6.1	0.02	--------	--------
			2000 O.B.	1.28×10^{-4}	
			3000 O.B.	9.8×10^{-5}	
1003	6536.7	7.1	0.02	---------	--------
			2000 O.B.	1.05×10^{-4}	
			3000 O.B.	8.8×10^{-5}	

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CORE LABORATORIES, INC.

File 203-830024

PERMEABILITY TO AIR AND POROSITY

Company: Sandia National Laboratories

Well: MWX-1 & MWX-2

Formation: Mesa Verde

Field: Rulison

County, State: Garfield, Colorado

Well	Sample Identification	Depth, feet	Permeability to Air, millidarcys	Porosity, percent
MWX-1	941	6433.5	0.01	5.3
MWX-1	943	6435.5	0.04	7.8
MWX-1	981	6503.5	0.02	6.1
MWX-1	1003	6536.7	0.02	7.1

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CORE LABORATORIES, INC.

File 203-830024

PERMEABILITY TO AIR AND POROSITY

Company:	Sandia National Laboratories	Well:	MWX-2
Formation:	Mesa Verde	Field:	Rulison
County, State:	Garfield, Colorado		

CORE PLUGS WITH PERPENDICULAR FRACTURES

Sample Identification	Depth, feet	Permeability to Air, millidarcys	Porosity, percent
38-28M	6193.0-93.4	0.02	4.6
38-28F	6193.0-93.4	0.02	4.7

-The "M" Designation refers to Matrix Permeability.
-The "F" Designation refers to plug permeability across a fracture.
The fractures were generally mineral filled.

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PERMEABILITY TO AIR AND POROSITY

Company: SANDIA NATIONAL LABORATORIES　　Well: MULTI-WELL EXPERIMENT #2
Formation: MESA VERDE-COASTAL　　Field: RULISON
County (Parish), State: GARFIELD COUNTY, COLORADO

Sample Identification	Depth, feet	Permeability to Air, millidarcys	Porosity, percent
113	6423.7	< 0.01	5.5
114	6425.8	0.02	5.7
115	6427.8	0.01	7.4
116	6429.2	0.01	3.6
119	6432.5	0.03	5.7
122	6436.5	0.06	7.2
125	6439.5	0.07	6.5
127	6441.5	0.03	5.9
128	6443.5	0.03	5.8
131	6446.5	0.10	7.4
134	6450.5	0.18	8.6
137	6453.5	0.04	5.9
140	6457.5	0.10	7.4
141	6458.5	0.14	7.5
142	6459.5	0.08	6.8
143	6461.7	0.02	4.5
144	6463.9	0.01	4.0
145	6465.8	0.03	2.3
146	6467.5	0.01	4.0
147	6469.6	0.01	4.9

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PERMEABILITY TO AIR AND POROSITY

Company: SANDIA NATIONAL LABORATORIES Well: MULTI-WELL EXPERIMENT #2
Formation: MESA VERDE-COASTAL Field: RULISON
County (Parish), State: GARFIELD COUNTY, COLORADO

Sample Identification	Depth, feet	Permeability to Air, millidarcys	Porosity, percent
148	6497.6	0.01	1.8
149	6498.6	0.01	4.5
150	6500.9	0.02	3.5
151	6501.8	0.02	4.5
152	6504.4	0.04	6.1
154	6508.3	0.05	7.9
156	6511.1	0.03	7.3
159	6516.3	0.09	9.0
162	6521.9	0.06	7.7
165	6527.2	0.05	7.8
167	6529.9	0.04	7.6
168	6531.9	0.06	7.6
170	6535.3	0.08	8.0
171	6536.9	0.13	8.0
172	6539.2	0.03	5.6
174	6542.6	0.04	6.5
176	6545.8	0.07	8.7
177	6547.8	0.05	7.5
178	6549.7	0.03	6.7
179	6551.2	0.05	8.0

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PERMEABILITY TO AIR AND POROSITY

Company: SANDIA NATIONAL LABORATORIES
Well: MULTI-WELL EXPERIMENT #2
Formation: MESA VERDE-COASTAL
Field: RULISON
County (Parish), State: GARFIELD COUNTY, COLORADO

Sample Identification	Depth, feet	Permeability to Air, millidarcys	Porosity, percent
180	6552.8	0.04	7.6
181	6556.9	0.05	7.0
182	6558.1	0.06	6.4
183	6559.9	0.02*	8.1
184	6562.8	0.09*	3.0

*FRACTURED PLUG

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PERMEABILITY TO AIR, POROSITY, AND GRAIN DENSITY

Sandia National Laboratories
Mesa Verde Formation
Garfield County, Colorado

Multi-Well Experiment No. 1
Rulison Field

Sample Identification	Depth, feet	Permeability to Air, millidarcys	Porosity, percent	Grain Density, gm/cc
819	6084.5	<0.01	1.9	2.70
829	6191.4	0.02	5.0	2.69
833	6195.5	0.01	3.3	2.70
839	6242.7	0.24	2.7	2.72
894	6342.5	0.01	3.9	2.69
938	6430.7	0.01	3.6	2.72
958	6451.5	0.11	8.5	2.67
980	6502.5	0.18	5.2	2.68
1021	6564.2	0.01	4.1	2.69

PERMEABILITY TO AIR, POROSITY, AND GRAIN DENSITY

Sandia National Laboratories
Mesa Verde Formation
Garfield County, Colorado

Multi-Well Experiment No. 3
Rulison Field

Sample Identification	Depth, feet	Permeability to Air, millidarcys	Porosity, percent	Grain Density, gm/cc
74	6443.5-43.7	0.02	6.6	2.69
82	6454.6-54.8	0.04	8.2	2.69

CORE LABORATORIES, INC.

File 203-830055

PERMEABILITY TO AIR AND POROSITY

Company: Sandia National Laboratories — Well: MWX-3

Formation: Mesa Verde — Field: Rulison

County, State: Garfield, Colorado

Sample Identification	Depth, feet	Permeability to Air, millidarcys	Porosity, percent
5	6443.7-44.0	0.06	6.5
6	6556.1-56.66	0.06	7.8
7	6511.1-11.5	0.04	6.4

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PERMEABILITY TO AIR, BOYLE'S LAW POROSITY AND KLINKENBERG PERMEABILITY

Company: Sandia National Laboratories   Well: MWX-1

Formation: Mesa Verde   Field: Rulison

County, State: Garfield, Colorado

Sample Identification	Depth, feet	Permeability to Air millidarcys	Porosity, percent	Klinkenberg Permeability Effective Overburden Pressure, psi		
				1000	2000	3000
4M	6002.5-6002.8	0.01	4.8	0.00038	0.00009	0.00006
4F	6002.5-6002.8	0.01	6.1	0.00211	0.00176	0.00110
5M	6107.6-6107.9	0.01	1.3	0.00014	0.00007	0.00004
5F	6107.6-6107.9	0.02	1.4	0.00221	0.00070	0.00040

M = Matrix Permeability
F = Fracture Permeability

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CORE LABORATORIES, INC.
Special Core Analysis

File 203-840077

SUMMARY OF ROUTINE PERMEABILITY, POROSITY & KLINKENBERG PERMEABILITY AS A FUNCTION OF OVERBURDEN POROSITY

Company: Sandia National Laboratories Well: Multi-Well Experiment No. 1

Formation: Mesa Verde Field: Rulison

County, State: Garfield, Colorado

		Effective Overburden Pressure, psi		1000	2000	3000
Sample Identification	Depth, feet	Permeability to Air Millidarcys	Porosity, Percent	Klinkenberg Permeability Millidarcys		
34-16	6032.3-[illegible].7	1.5	8.9	0.00093	0.00088	0.0006
35-9A	6079.0-79.5	0.09	7.2	0.00836	0.00560	0.0049

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CORE LABORATORIES, INC.

File 203-830070

Company SANDIA NATIONAL LABORATORIES Formation MESA VERDE-UPPER COASTAL ZONE

Well MULTI-WELL EXPERIMENT NO. 1 County GARFIELD

Field RULISON State COLORADO

SUMMARY OF ROUTINE PERMEABILITY, POROSITY & KLINKENBERG PERMEABILITY AS A FUNCTION OF OVERBURDEN PRESSURE

		Effective Overburden Pressure, Psi		1000	2000	3000
Sample Identification	Depth, feet	Permeability to Air Millidarcys	Porosity Percent	Klinkenberg Permeability Millidarcys		
811	6069.3	0.05	8.1	0.0056	0.0046	0.0036
813	6071.7	0.06	9.0	0.0100	0.0062	0.0058
815	6073.7	0.12	9.9	0.0198	0.0162	0.0146
817	6079.7	0.13	6.8	0.0094	0.0064	0.0061
818	6081.7	0.10	3.6	0.0025	0.0011	0.0006

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PERMEABILITY, POROSITY, AND KLINKENBERG PERMEABILITY

Sandia National Laboratories
Mesa Verde Formation
Garfield County, Colorado

Multi-Well Experiment No. 1
Rulison Field

Sample I.D.	Depth, feet	Permeability to Air, millidarcies	Porosity, percent	Klinkenberg Permeability, millidarcies at overburden pressures, psi 1000	2000	3000
819	6084.5	<0.01	1.9	0.00021	0.00015	0.00008
829	6191.4	0.02	5.0	0.00108	0.00081	0.00022
833	6195.5	0.01	3.3	0.00020	0.00014	0.00009
839	6242.7	0.24	2.7	0.01496	0.00492	0.00128
894	6342.5	0.01	3.9	0.00075	0.00056	0.00040
938	6430.7	0.01	3.6	0.00089	0.00046	0.00027
958	6451.5	0.11	8.5	0.00988	0.00241	0.00056
980	6502.5	0.18	5.2	0.01853	0.00513	0.00112
1021	6564.2	0.01	4.1	0.00048	0.00027	0.00014

PERMEABILITY, POROSITY AND KLINKENBERG PERMEABILITY

Company: Sandia National Laboratories
Formation: Mesa Verde
County, State: Garfield, Colorado
Well: MWX-1
Field: Rulison

Sample Identification	Sample Depth	Permeability to Air, Millidarcys	Porosity, percent	Klinkenberg Permeability Millidarcys (Effective Overburden, psi: 1000)	(2000)	(3000)
827	6189.3	0.01	7.0	0.00346	0.00125	0.00071
9VF	6365.5-66.2	<0.01	3.2	0.00026	0.00017	0.00012
9VM	6365.5-66.2	<0.01	3.0	0.00019	0.00017	0.00013
9HF	6365.5-66.2	0.01	3.4	0.00190	0.00059	0.00039
9HM	6365.5-66.2	0.01	3.3	0.00153	0.00058	0.00032

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Company SANDIA NATIONAL LABORATORIES
Well MULTI-WELL EXPERIMENT-1
Field RULISON
Formation MESAVERDE
County GARFIELD
State COLORADO

Summary of Routine Permeability, Porosity and Klinkenberg Permeability as a Function of Overburden Pressure

Effective Overburden Pressure, psi: 1000

Sample Identification	Depth Feet	Permeability to Air Millidarcys	Porosity Percent	Klinkenberg Permeability * Millidarcys
947	6438.5	**	7.9	.0109
949	6440.5	.05	7.2	.0114
953	6445.5	**	7.1	.0095
955	6447.5	.05	7.0	.0086
959	6452.5	**	8.7	.0158
960	6455.9	.09	8.7	.0192
983	6505.1	**	7.4	.0057
986	6508.3	.04	7.5	.0057
989	6513.0	**	7.9	.0112
990	6514.7	.07	8.2	.0105
1007	6541.3	**	7.5	.0173
1010	6544.5	.05	7.3	.0090
1012	6546.3	**	8.0	.0114
1014	6548.8	.07	7.6	.0156

* Permeability to Nitrogen
** Permeability to Air Not Obtained

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File 203820022

Company Sandia National Laboratories Formation N/A
Well No. 1 County Garfield
Field Multi-Well Experiment State Colorado

KLINKENBERG PERMEABILITY AS A FUNCTION OF OVERBURDEN PRESSURE

SAMPLE NUMBER	DEPTH FEET	POROSITY PERCENT	EFFECTIVE OVERBURDEN PRESSURE, PSIG 1000	2000	3000	4000
			PERMEABILITY, KLINKENBERG, MICRO-DARCY			
Vertical Plug Samples, Drilled By Core Laboratories, Inc.						
	6446	9.3	12.3		7.4	3.8
	6456	9.5	17.0		7.9	6.6
	6507	7.6	4.7		1.3	0.9
	6511	9.0	6.8		4.9	3.7
	6526	8.6	7.0		4.4	2.6
	6543	8.2	14.0		6.3	5.5

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Company SANDIA NATIONAL LABORATORIES
Well MULTI-WELL EXPERIMENT NO. 1 & 2
Field RULISON
Formation MESAVERDE-
County GARFIELD
State COLORADO

SUMMARY OF ROUTINE VERTICAL PERMEABILITY, POROSITY AND KLINKENBERG VERTICAL PERMEABILITY AS A FUNCTION OF OVERBURDEN PRESSURE

Sample Number	Depth Feet	Vertical Permeability to Air Millidarcys	Porosity Percent	Vertical Klinkenberg* Permeability Millidarcys — Effective Overburden Pressure, Psi 1000	3000	4000	Grain Density
MWX-2 WELL							
6	6447-6448	0.10	8.3	.0186	.0075	.0068	2.66
8	6506.7-07.4	0.07	7.2	.0053	.0024	.0013	2.68
** 10	6526-6527	0.07	7.6	.0063	.0016	.0011	2.68
MWX-1 WELL							
7	6455.3-56.2	0.15	8.2	.0203	.0082	.0059	2.65
9	6511.0-11.7	0.06	7.0	.0075	.0024	.0014	2.66
** 11	6543.3-44.4	0.09	7.4	.0107	.0086	.0053	2.67

* Permeability to Nitrogen
* Corcoran Zone

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CORE LABORATORIES, INC.

File 203-830024

POROSITY AS A FUNCTION OF OVERBURDEN PRESSURE

Company: Sandia National Laboratories Well: MWX-2

Formation: Mesa Verde - Paludal Zone Field: Rulison

County, State: Garfield, Colorado

		Overburden Pressure, psi				
		200	1000	2000	3000	200
Sample I.D.	Depth, feet	Porosity, percent				
38-28M	6193.0-93.4	4.6	4.5	4.5	4.4	4.5
38-28F	6193.0-93.4	4.7	4.6	4.4	4.3	4.5

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Company: Sandia National Laboratories

Well: MWX-2

Formation: Mesa Verde

Field: Rulison

County, State: Garfield, Colorado

SUMMARY OF ROUTINE PERMEABILITY, POROSITY AND KLINKENBERG PERMEABILITY AS A FUNCTION OF OVERBURDEN PRESSURE

			Effective Overburden Pressure, psi	1000	2000	3000
Sample Number	Depth feet	Permeability to Air Millidarcys	Porosity Percent	Klinkenberg Permeability Millidarcys		
38-28M	6193.0-93.4	0.03	4.6	.0044	.0028	.0015
38-28F	6193.0-93.4	0.02	4.7	.0044	.0029	.0017

-The "M" Designation refers to Matrix Permeability.
-The "F" Designation refers to plug permeability across a fracture.
The fractures were generally mineral filled.

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CORE LABORATORIES, INC.
Special Core Analysis

PERMEABILITY TO AIR AND POROSITY AS A FUNCTION OF OVERBURDEN PRESSURE

Company: SANDIA NATIONAL LABORATORIES
Well: MULTI-WELL EXPERIMENT 2
Formation: MESA VERDE-COASTAL ZONE
Field: RULISON
County (Parish), State: GARFIELD, COLORADO

Sample I.D.	Depth, feet	Overburden Pressure, psi							
		200	1000	2000	3000				
		Porosity, percent							
152	6504.4	6.1	6.0	6.0	5.9				
171	6536.9	8.2	8.0	8.0	7.9				
178	6549.7	6.8	6.7	6.7	6.6				

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CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File 203-820075

Company SANDIA NATIONAL LABORATORIES
Well MULTI-WELL EXPERIMENT #2
Field RULISON
Formation MESA VERDE - COASTAL
County GARFIELD
State COLORADO

SUMMARY OF ROUTINE PERMEABILITY, POROSITY AND KLINKENBERG PERMEABILITY AS A FUNCTION OF OVERBURDEN PRESSURE

		Effective Overburden Pressure, Psi		1000	3000	4000
Sample Identification	Depth Feet	Permeability to Air Millidarcys	Porosity Percent	Klinkenberg Permeability * Millidarcys		
113	6423.7	0.01	5.5	0.0010	0.0002	< 0.0001
114	6425.8	0.02	5.7	0.0050	0.0002	0.0002
115	6427.8	0.01	7.4	0.0100	0.0031	< 0.0001
116	6429.2	0.01	3.6	0.0091	0.0050	0.0038
119	6432.5	0.03	5.7	0.0002	0.0001	< 0.0001
122	6436.5	0.06	7.2	0.0050	0.0021	0.0002
125	6439.5	0.07	6.5	0.0151	0.0046	0.0045
127	6441.5	0.03	5.9	0.0040	0.0020	0.0009
128	6443.5	0.03	5.8	0.0033	0.0005	0.0003
131	6446.5	0.10	7.4	0.0302	0.0091	0.0046
134	6450.5	0.18	8.6	0.0009	< 0.0001	< 0.0001
137	6453.5	0.04	5.9	0.0032	0.0002	0.0001
140	6457.5	0.10	7.4	0.0194	0.0050	0.0048
141	6458.5	0.14	7.5	0.0204	0.0068	0.0050
142	6459.5	0.08	6.8	0.0010	< 0.0001	< 0.0001
143	6461.7	0.02	4.5	0.0007	0.0003	0.0002
144	6463.9	0.01	4.0	0.0004	0.0001	< 0.0001
145	6465.8	0.03	2.3	0.0001	< 0.0001	< 0.0001
146	6467.5	0.01	4.0	0.0006	0.0002	0.0002
147	6469.6	0.01	4.9	0.0031	0.0009	0.0006
148	6497.6	0.01	1.8	0.0006	0.0003	0.0001
149	6498.6	0.01	4.5	0.0005	0.0001	0.0001
150	6500.9	0.02	3.5	0.0017	0.0006	0.0004
151	6501.8	0.02	4.5	0.0013	0.0003	0.0001
152	6504.4	0.04	6.1	0.0045	0.0027	0.0014
154	6508.3	0.05	j.9	0.0130	0.0114	0.0047
156	6511.1	0.03	7.3	0.0051	0.0036	0.0025
159	6516.3	0.09	9.0	0.0132	0.0064	0.0056
162	6521.9	0.06	7.7	0.0138	0.0050	0.0041
165	6527.2	0.05	7.8	0.0099	0.0051	0.0036
167	6529.9	0.04	7.6	0.0061	0.0035	0.0021

*PERMEABILITY TO NITROGEN

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Company: SANDIA NATIONAL LABORATORIES
Well: MULTI-WELL EXPERIMENT #2
Field: RULISON
Formation: MESA VERDE-COASTAL
County: GARFIELD
State: COLORADO

SUMMARY OF ROUTINE PERMEABILITY, POROSITY AND KLINKENBERG PERMEABILITY AS A FUNCTION OF OVERBURDEN PRESSURE

Sample Identification	Depth Feet	Permeability to Air Millidarcys	Porosity Percent	Klinkenberg Permeability* Millidarcys — Effective Overburden Pressure, Psi 1000	3000	4000
168	6531.9	0.06	7.6	0.0118	0.0057	0.0036
170	6535.3	0.08	8.0	0.0163	0.0053	0.0039
171	6536.9	0.13	8.0	0.119	0.0076	0.0046
172	6539.2	0.03	5.6	0.0045	0.0018	0.0010
174	6542.6	0.04	6.5	0.0046	0.0012	0.0004
176	6545.8	0.07	8.7	0.0127	0.0087	0.0059
177	6547.8	0.05	7.5	0.0057	0.0044	0.0033
178	6549.7	0.03	6.7	0.0048	0.0034	0.0023
179	6551.2	0.05	8.0	0.0138	0.0055	0.0051
180	6552.8	0.04	7.6	0.0084	0.0044	0.0036
181	6556.9	0.05	7.0	0.0153	0.0058	0.0037
182	6558.1	0.06	6.4	0.0141	0.0044	0.0037
183	6559.9	0.02**	8.1	0.0013	0.0006	0.0003
184	6562.8	0.09**	3.0	0.0029	0.0018	0.0011

*PERMEABILITY TO NITROGEN
**FRACTURED PERMEABILITY PLUG

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PERMEABILITY TO AIR, BOYLE'S LAW POROSITY AND KLINKENBERG PERMEABILITY

Company: Sandia National Laboratories   Well: MWX-3

Formation: Mesa Verde   Field: Rulison

County, State: Garfield, Colorado

Sample Identification	Depth, feet	Permeability to Air millidarcys	Porosity, percent	Klinkenberg Permeability Effective Overburden Pressure, psi 1000	2000	3000
66	6432.7-6432.9	0.05	5.9	0.00087	0.00055	0.00034
67	6434.4-6434.6	0.03	4.5	0.00303	0.00250	0.00141
69	6436.6-6436.8	0.05	6.4	0.00015	0.00009	0.00005
71	6438.9-6439.1	0.03	4.3	0.00015	0.00009	0.00005
72	6440.3-6440.5	0.02	3.4	0.00028	0.00015	0.00010
73	6441.8-6442.0	0.06	7.1	0.00320	0.00213	0.00109
75	6444.8-6445.0	0.05	6.9	0.00128	0.00074	0.00033
76	6445.8-6446.0	0.06	9.0	0.00876	0.00408	0.00350
77	6447.5-6447.7	0.07	7.8	0.00963	0.00489	0.00358

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CORE LABORATORIES, INC.
Special Core Analysis

File 203-840026

PERMEABILITY TO AIR, BOYLE'S LAW POROSITY AND KLINKENBERG PERMEABILITY

Company: Sandia National Laboratories   Well: MWX-3

Formation: Mesa Verde   Field: Rulison

County, State: Garfield, Colorado

Sample Identification	Depth, feet	Permeability to Air millidarcys	Porosity, percent	Klinkenberg Permeability Effective Overburden Pressure, psi		
				1000	2000	3000
79	6450.5-6450.7	0.10	0.6	0.00446	0.00313	0.00134
80	6452.1-6452.3	0.04	7.9	0.00750	0.00011	0.00008
81	6453.6-6453.8	0.06	8.6	0.00026	0.00018	0.00010
83	6456.5-6456.8	0.13	10.1	0.2134	0.00919	0.00637
85	6460.1-6460.3	0.07	9.1	0.01047	0.00619	0.00345
87	6463.0-6463.2	0.06	8.1	0.00702	0.00360	0.00127
88	6464.4-6464.5	0.07	8.7	0.01314	0.00507	0.00474
89	6466.9-6467.1	0.07	8.9	0.01020	0.00281	0.00140
90	6468.5-6468.7	0.08	8.7	0.01024	0.00580	0.00512
92	6473.4-6473.7	0.03	6.4	0.00176	0.00062	0.00026
94	6475.7-6475.9	0.03	4.7	0.00251	0.00102	0.00052
95	6501.4-6501.6	0.02	3.8	0.00033	0.00017	0.00008
98	6506.1-6506.3	0.01	3.5	0.00054	0.00019	0.00011
99	6507.7-6507.9	0.02	4.7	0.00030	0.00011	0.00006
100	6509.5-6509.7	0.03	7.5	0.00246	0.00076	0.00034
102	6512.3-6512.5	0.05	8.2	0.00102	0.00077	0.00030
103	6513.8-6514.0	0.04	7.7	0.00610	0.00510	0.00302

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PERMEABILITY TO AIR, BOYLE'S LAW POROSITY AND KLINKENBERG PERMEABILITY

Company: Sandia National Laboratories Well: MWX-3

Formation: Mesa Verde Field: Rulison

County, State: Garfield, Colorado

Sample Identification	Depth, feet	Permeability to Air millidarcys	Porosity, percent	Klinkenberg Permeability Effective Overburden Pressure, psi 1000	2000	3000
104	6515.4-6516.6	0.05	7.1	0.00483	0.00363	0.00127
105	6516.7-6516.9	0.03	7.2	0.00065	0.00024	0.00012
106	6523.7-6523.9	<0.01	5.4	0.00230	0.00113	0.00079

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PERMEABILITY, POROSITY, AND KLINKENBERG PERMEABILITY

Sandia National Laboratories
Mesa Verde Formation
Garfield County, Colorado

Multi-Well Experiment No. 3
Rulison Field

Sample I.D.	Depth, feet	Permeability to Air, millidarcies	Porosity, percent	Klinkenberg Permeability, millidarcies at overburden pressures, psi		
				1000	2000	3000
74	6443.5-43.7	0.02	6.6	0.00354	0.00124	0.00067
82	6454.6-54.8	0.04	8.2	0.00970	0.00480	0.00185

CORE LABORATORIES, INC.

File 203-830055

Company: Sandia National Laboratories

Well: MWX-3

Formation: Mesa Verde

Field: Rulison

County, State: Garfield, Colorado

SUMMARY OF ROUTINE VERTICAL PERMEABILITY, POROSITY AND KLINKENBERG VERTICAL PERMEABILITY AS A FUNCTION OF OVERBURDEN PRESSURE

			Effective Overburden Pressure, psi	1000	2000	3000
Sample Number	Depth feet	Vertical Permeability to Air Millidarcys	Porosity Percent	Vertical Klinkenberg Permeability Millidarcys		
5(64-46)	6443.7-44.0	0.06	7.2	0.0064	0.0027	0.0014
6(64-47)	6456.1-56.55	0.06	7.6	0.0097	0.0053	0.0023
7(65-20)	6511.1-11.5	0.04	8.2	0.0058	0.0034	0.0017

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SUMMARY OF CAPILLARY PRESSURE TEST RESULTS

Company: Sandia National Laboratories
Well: MWX-1
Field: Rulison
Formation: Mesa Verde
County, State: Garfield, Colorado

Fluid System: Air-Water

Test Method: High-Speed Centrifuge

Sample I.D.	Depth, feet	Permeability to Air, millidarcys	Porosity, percent	Brine Saturation, percent pore space — Pressure, psi: 10	30	70	150	300	600	1000	1300
941	6433.5	0.01	5.2	100.0	100.0	56.0	54.0	49.0	43.6	40.6	40.4
943	6435.5	0.04	7.2	100.0	50.0	47.5	42.7	39.4	37.1	35.5	35.3
1003	6536.7	0.02	6.9	100.0	66.0	63.2	57.3	53.0	50.0	45.8	45.6

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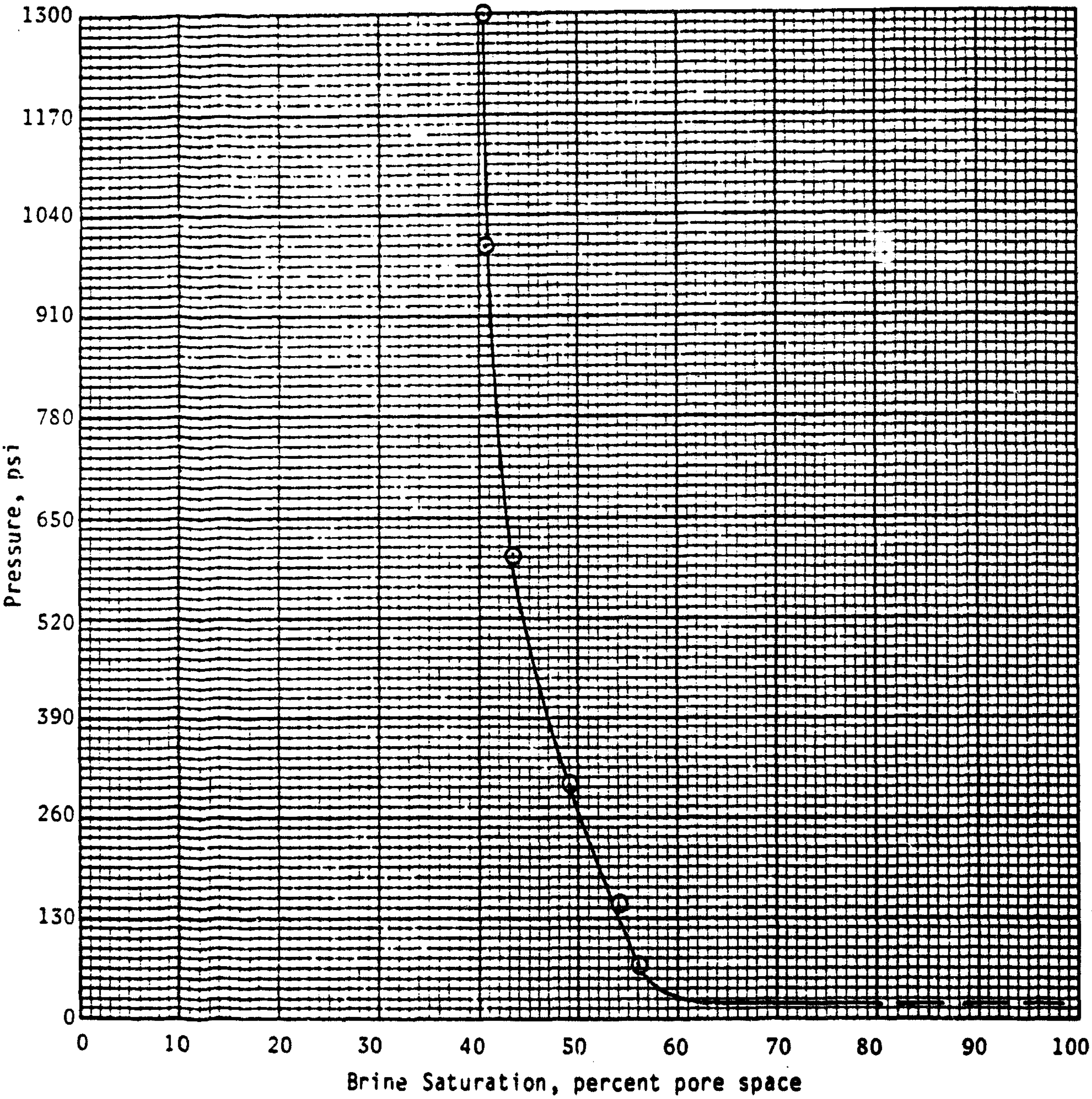
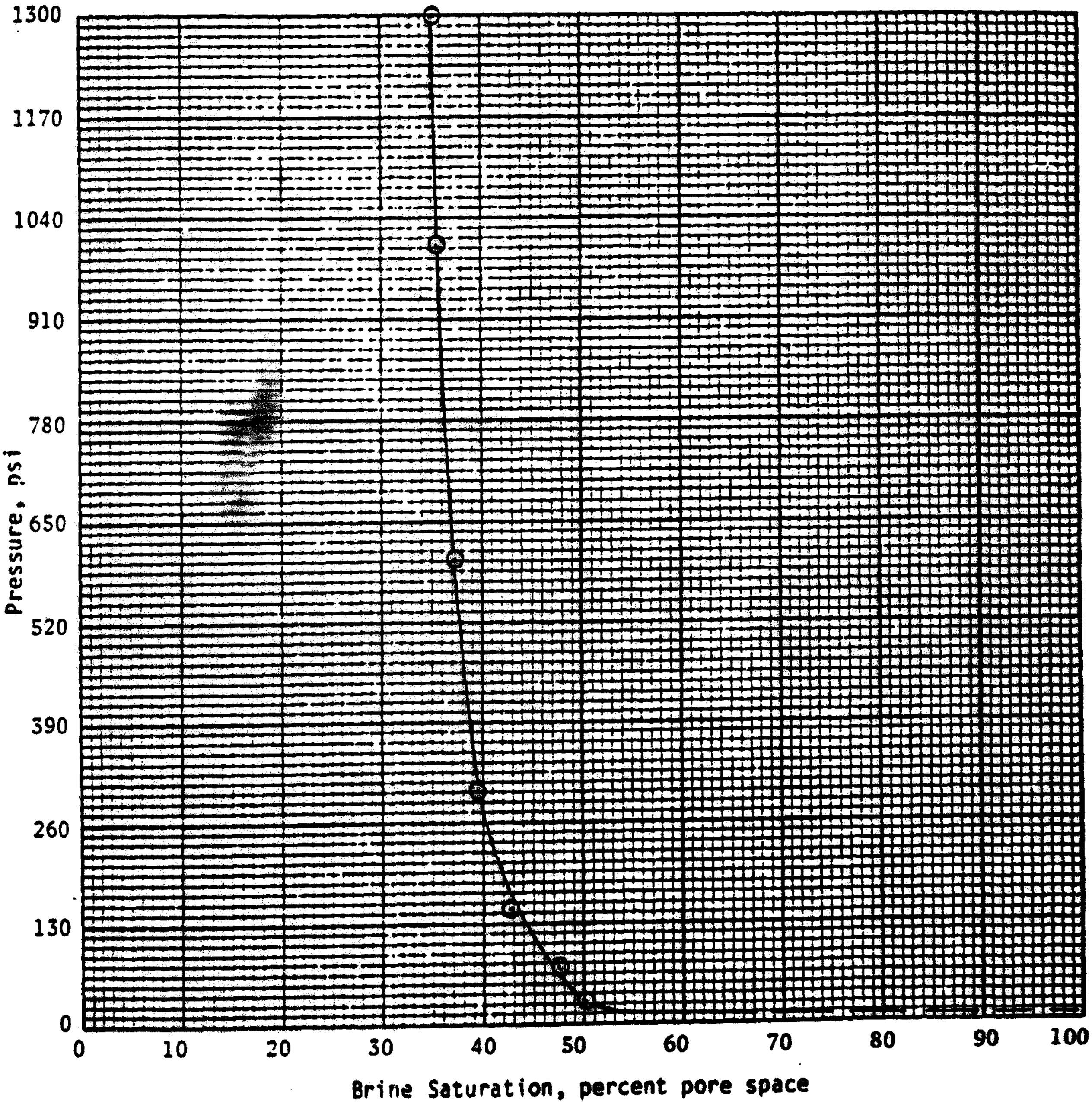
Company Sandia National Laboratories
Well MWX-1
Field Rulison
Formation Mesa Verde
County Garfield
State Colorado

Sample Number: 941
Permeability = 0.01
Porosity = 5.2



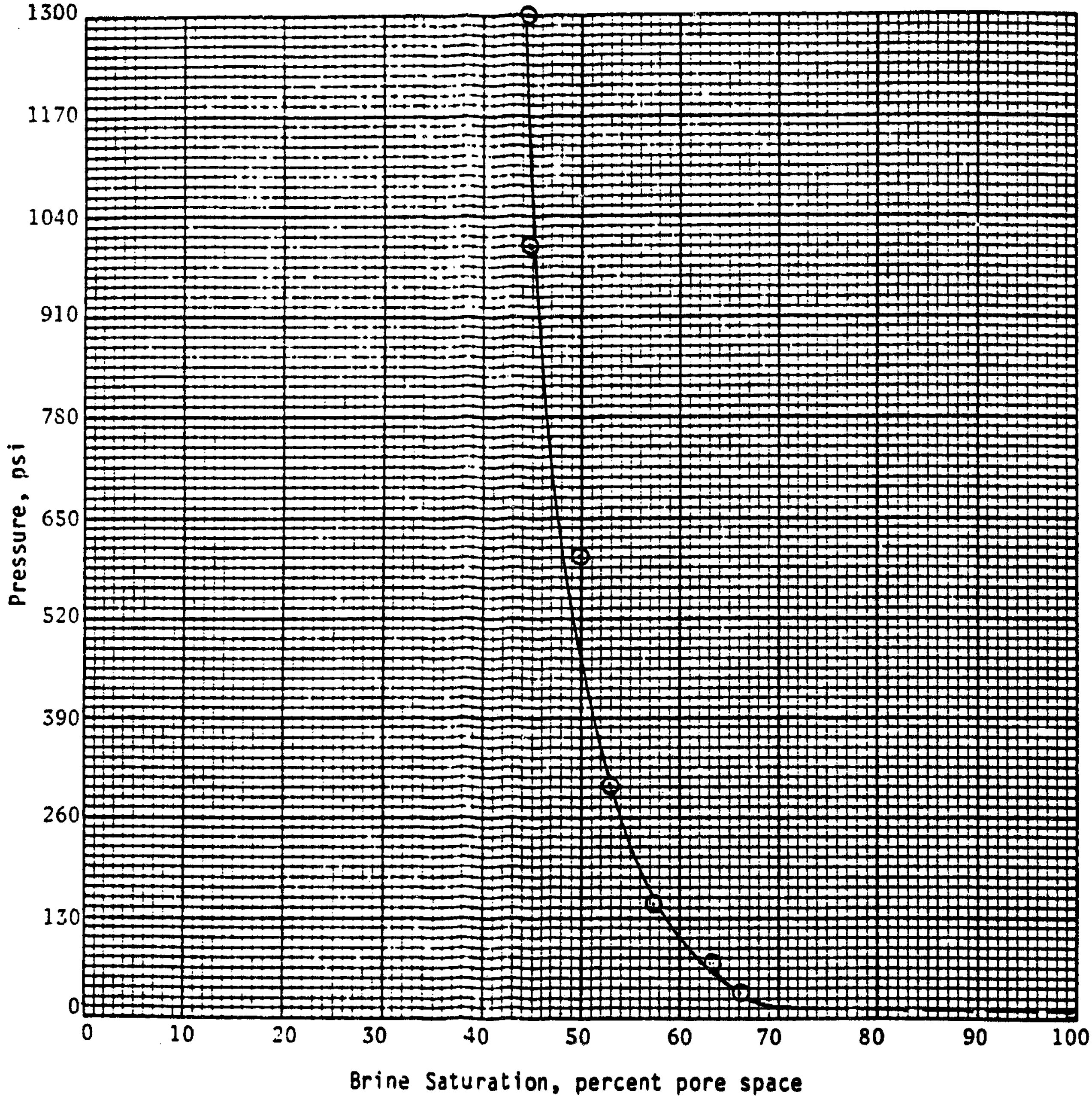
Company Sandia National Laboratories
Well MWX-1
Field Rulison
Formation Mesa Verde
County Garfield
State Colorado

Sample Number: 943
Permeability = 0.04
Porosity = 7.2



Company Sandia National Laboratories
Well MWX-1
Field Rulison
Formation Mesa Verde
County Garfield
State Colorado

Sample Number: 1003
Permeability = 0.02
Porosity = 6.9



CORE LABORATORIES, INC.

Special Core Analysis

File 203-82023

SUMMARY OF MERCURY INJECTION TEST RESULTS

Company: SANDIA NATIONAL LABORATORIES Well: MULTI-WELL EXPERIMENT-1

Formation: MESAVERDE Field: RULISON

County (Parish), State: GARFIELD, COLORADO

Sample Identification:	947	953	959	983	989	1007	1012	
Depth, feet:	6438.5	6445.5	6452.5	6505.1	6513.0	6541.3	6546.3	
Permeability to Air, md:	*	*	*	*	*	*	*	
Porosity, percent:	7.9	7.1	8.7	7.4	7.9	7.5	8.0	

* PERMEABILITY TO AIR MEASUREMENTS NOT OBTAINED

Injection Pressure, psia	Percent Pore Space Occupied by Mercury							
3	0.0	0.0	0.0	0.0		0.0	0.0	
6	0.0	0.0	0.0	0.0		0.0	0.0	
9	0.0	0.0	0.0	0.0		0.0	0.0	
12	0.0	0.0	0.0	0.0		0.0	0.0	
15	0.0	0.0	0.0	0.0		0.0	0.0	
18	0.0	0.0	0.0	0.0		0.0	0.0	
21	0.0	0.0	0.0	0.0		0.0	0.0	
24	0.0	0.0	0.0	0.0		0.0	0.0	
27	0.0	0.0	0.0	0.0		0.0	0.0	
30	0.0	0.0	0.0	0.0		0.0	0.0	
40	0.0	0.0	0.0	0.0		0.0	0.0	
60	0.0	0.0	0.0	0.0		0.0	0.0	
80	0.0	0.0	0.0	0.0		0.0	0.0	
100	0.0	0.0	0.0	0.0		0.0	0.0	
200	0.0	0.0	0.0	0.0	SAMPLE	0.0	0.0	
300	7.0	6.4	11.1	0.0	FAILURE	22.6	0.0	
500	33.5	32.0	36.3	13.6		37.4	22.1	
750	43.2	41.4	46.9	29.7		45.7	37.3	
1000	47.6	47.4	53.4	36.6		50.6	42.9	
1250	50.8	50.1	57.0	41.4		54.3	48.2	
1500	53.4	53.1	59.9	44.9		55.5	49.7	
1750	55.6	55.5	62.6	47.6		56.8	52.6	
2000	57.1	58.4	65.1	49.6		57.1	54.7	
1500								
1250								
1000								
750								
500								
300								
200								
100								
80								
60								
40								
30								
15								
0								

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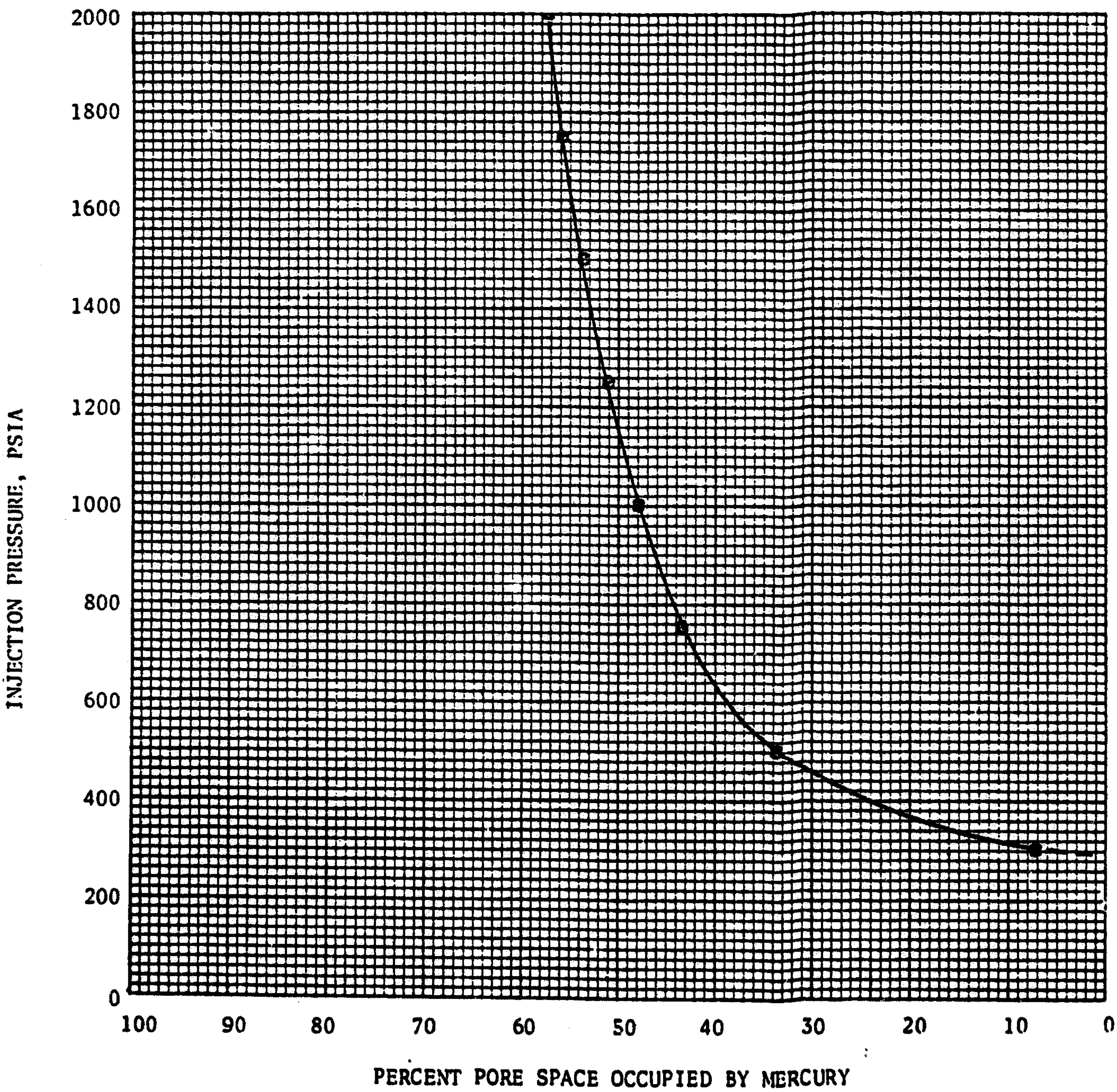
CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

Company SANDIA NATIONAL LABORATORIES Formation MESAVERDE
Well MULTI-WELL EXPERIMENT-1 County GARFIELD
Field RULISON State COLORADO

MERCURY INJECTION CAPILLARY PRESSURE CURVE
SAMPLE NUMBER: 947

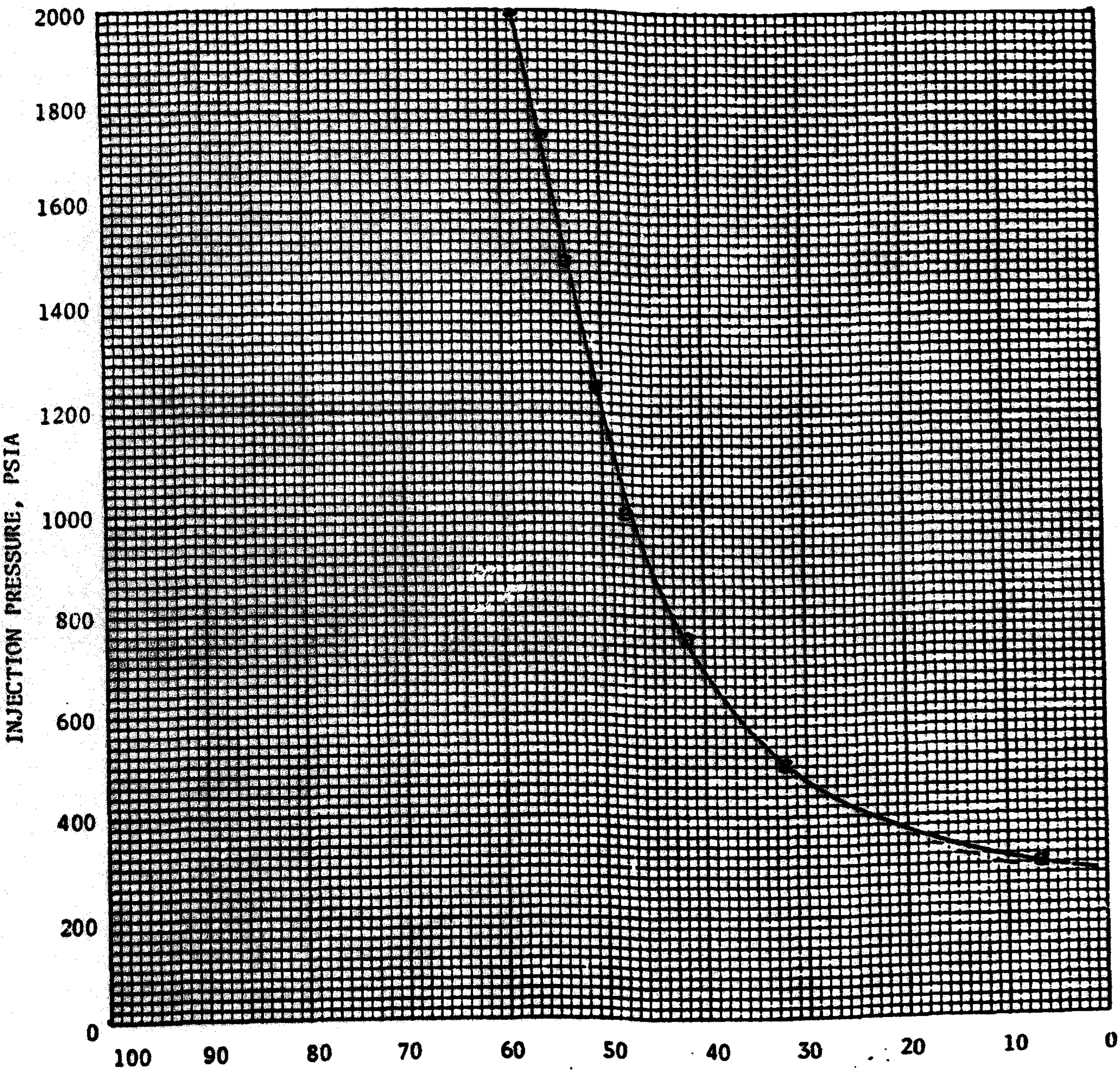


CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File 203-82023

Company SANDIA NATIONAL LABORATORIES Formation MESAVERDE
Well MULTI-WELL EXPERIMENT-1 County GARFIELD
Field RULISON State COLORADO

MERCURY INJECTION CAPILLARY PRESSURE CURVE
SAMPLE NUMBER: 953

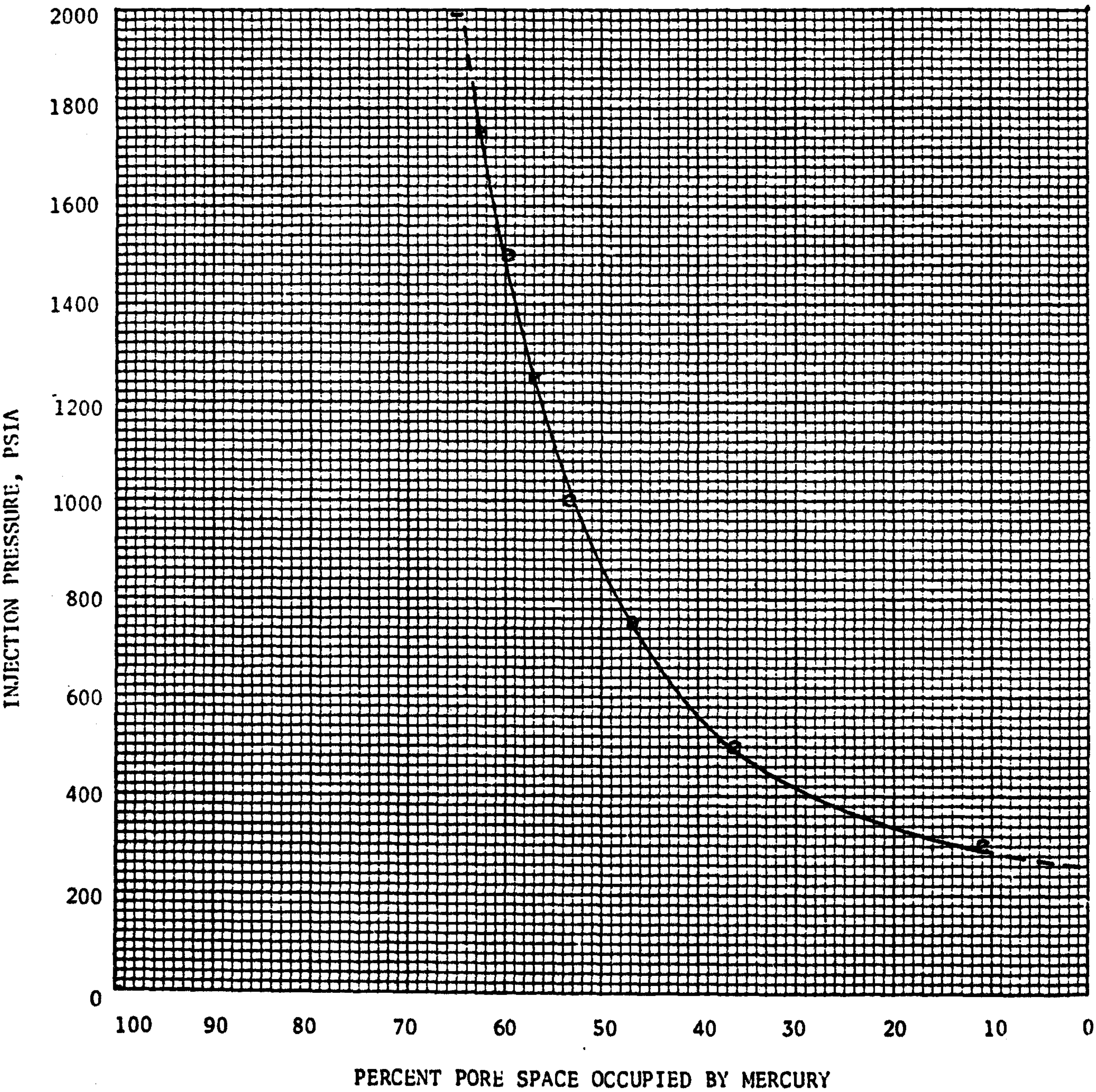


CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File 203-82023

Company SANDIA NATIONAL LABORATORIES Formation MESAVERDE
Well MULTI-WELL EXPERIMENT-1 County GARFIELD
Field RULISON State COLORADO

MERCURY INJECTION CAPILLARY PRESSURE CURVE
SAMPLE NUMBER: 959

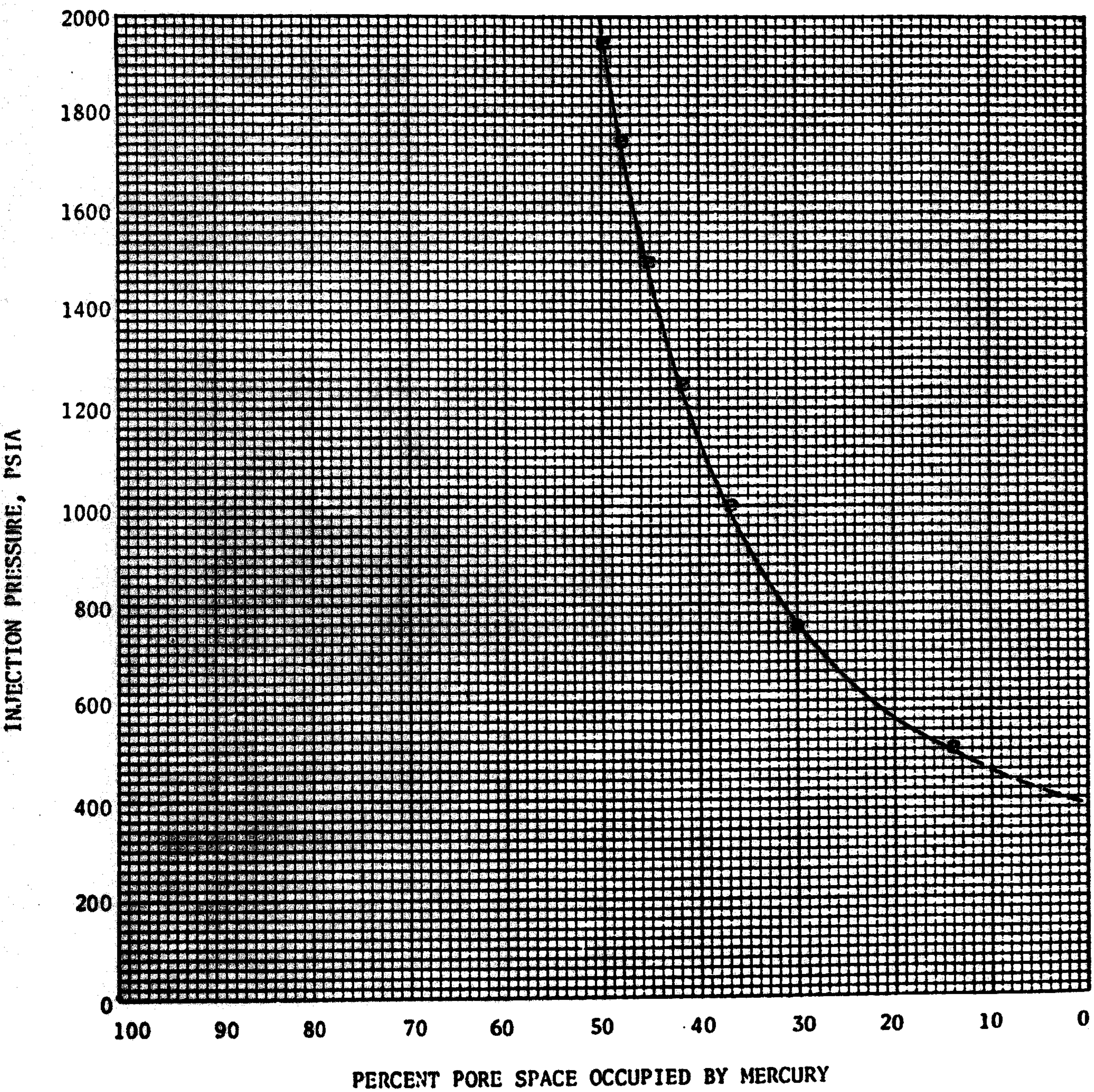


CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File 203-82023

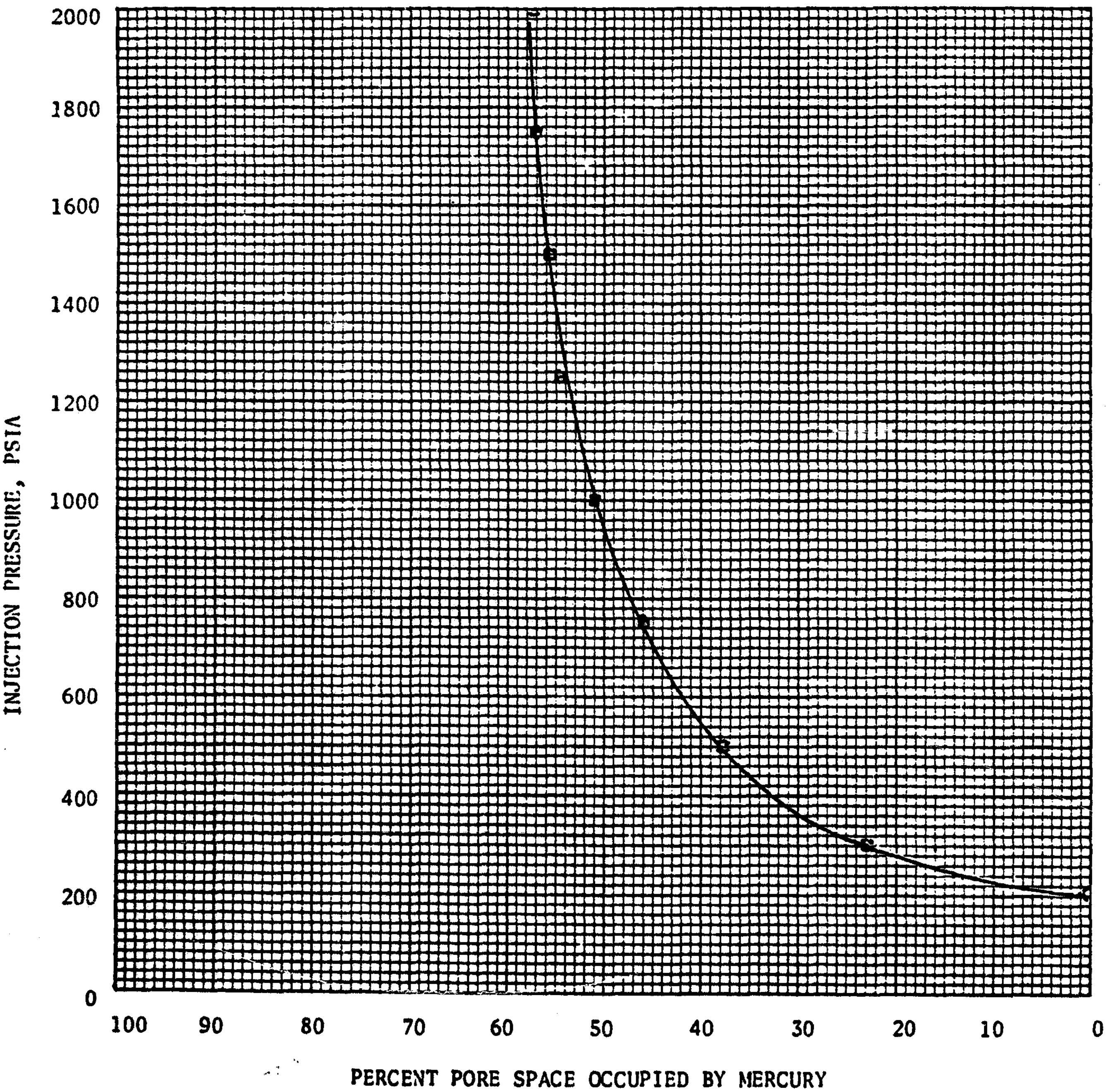
Company SANDIA NATIONAL LABORATORIES Formation MESAVERDE
Well MULTI-WELL EXPERIMENT-1 County GARFIELD
Field RULISON State COLORADO

MERCURY INJECTION CAPILLARY PRESSURE CURVE
SAMPLE NUMBER: 983



Company SANDIA NATIONAL LABORATORIES
Formation MESAVERDE
Well MULTI-WELL EXPERIMENT-1
County GARFIELD
Field RULISON
State COLORADO

MERCURY INJECTION CAPILLARY PRESSURE CURVE
SAMPLE NUMBER: 1007

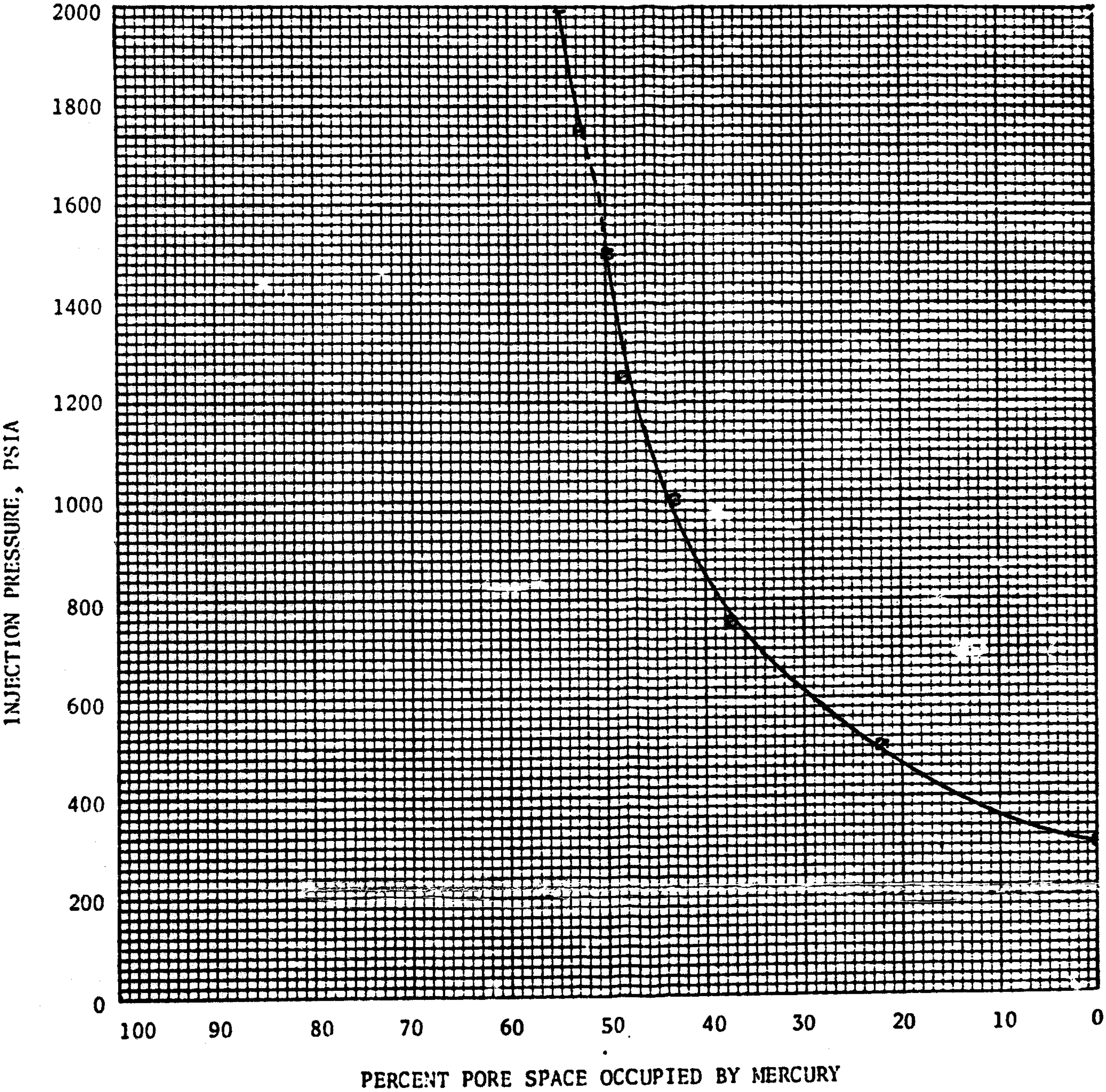


CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File 203-82023

Company SANDIA NATIONAL LABORATORIES
Formation MESAVERDE
Well MULTI-WELL EXPERIMENT-1
County GARFIELD
Field RULISON
State COLORADO

MERCURY INJECTION CAPILLARY PRESSURE CURVE
SAMPLE NUMBER: 1012



SUMMARY OF PORE SIZE DISTRIBUTION

Company: SANDIA NATIONAL LABORATORIES Well: MULTI-WELL EXPERIMENT-1
Formation: MESAVERDE Field: RULISON
County (Parish), State: GARFIELD, COLORADO

Sample Identification:	947	953	959	983	989	1007	1012	
Depth, feet:	6438.5	6445.5	6452.5	6505.1	6513.0	6541.3	6546.3	
Permeability to Air, md:	*	*	*	*	*	*	*	
Porosity, percent:	7.9	7.1	8.7	7.4	7.9	7.5	8.0	

* PERMEABILITY TO AIR MEASUREMENTS NOT OBTAINED

Pore Aperture Radius (Microns)	CUMULATIVE PERCENT PORE SPACE							
35.	100.0	100.0	100.0	100.0		100.0	100.0	
30.	100.0	100.0	100.0	100.0		100.0	100.0	
25.	100.0	100.0	100.0	100.0		100.0	100.0	
20.	100.0	100.0	100.0	100.0		100.0	100.0	
15.	100.0	100.0	100.0	100.0		100.0	100.0	
10.	100.0	100.0	100.0	100.0	SAMPLE	100.0	100.0	
8.	100.0	100.0	100.0	100.0	FAILURE	100.0	100.0	
6.	100.0	100.0	100.0	100.0		100.0	100.0	
4.	100.0	100.0	100.0	100.0		100.0	100.0	
3.	100.0	100.0	100.0	100.0		100.0	100.0	
2.	100.0	100.0	100.0	100.0		100.0	100.0	
1.	100.0	100.0	100.0	100.0		100.0	100.0	
.8	100.0	100.0	100.0	100.0		100.0	100.0	
.6	100.0	100.0	100.0	100.0		100.0	100.0	
.4	100.0	100.0	100.0	100.0		100.0	100.0	
.3	81.7	82.9	78.7	100.0		71.8	100.0	
.2	64.7	66.2	61.7	83.2		61.1	74.8	
.10	51.5	51.7	45.5	62.0		48.3	55.6	
.09	50.0	50.6	43.8	59.8		46.4	52.9	
.08	48.3	48.8	42.0	57.4		45.2	51.2	
.07	46.4	46.7	39.9	54.9		44.4	50.0	
.06	44.2	44.3	37.1	52.1		43.1	47.2	
.055	43.2	42.4	35.5	50.5		42.9	45.8	

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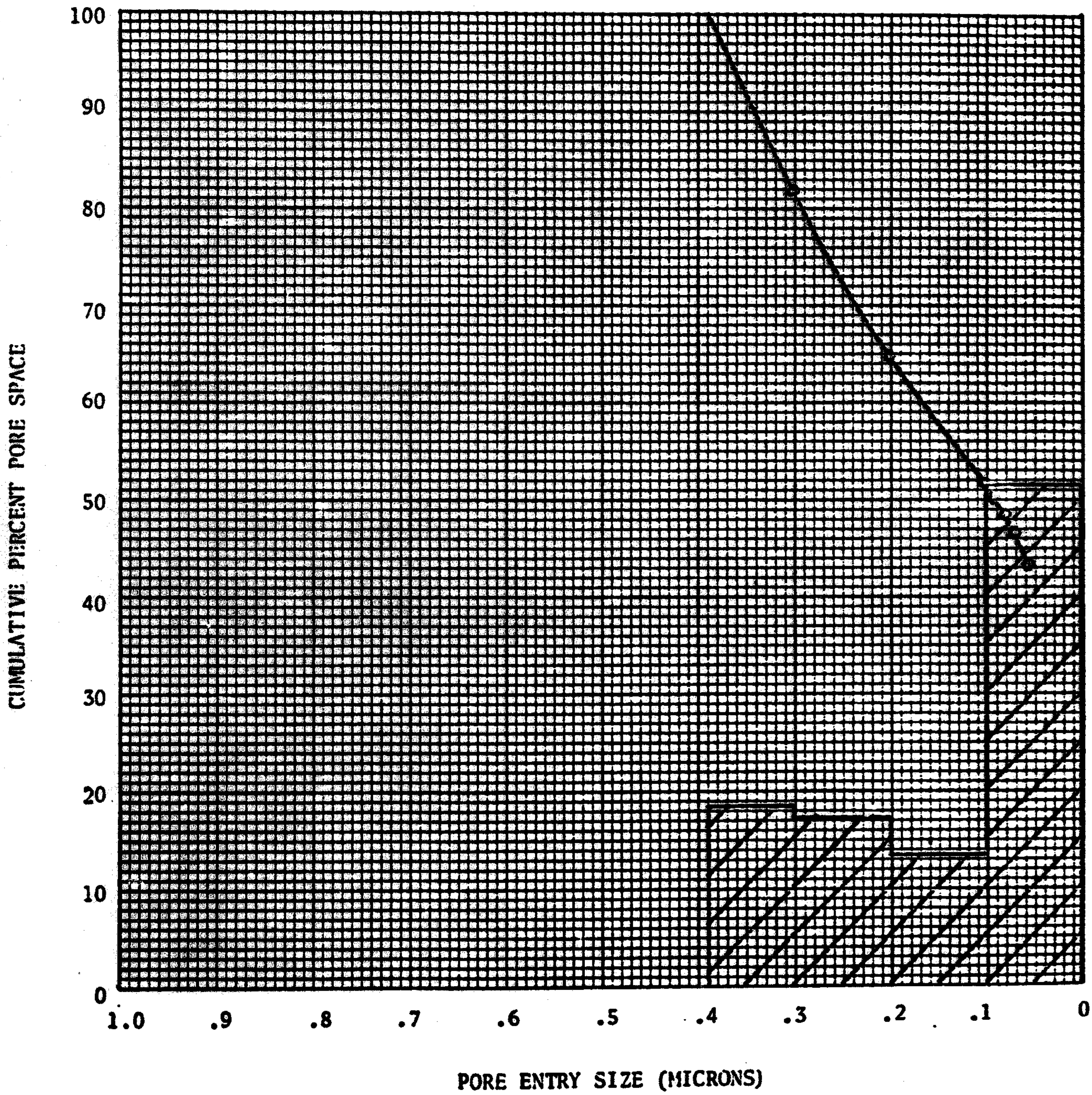
CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File 203-82023

Company SANDIA NATIONAL LABORATORIES
Well MULTI-WELL EXPERIMENT-1
Field RULISON
Formation MESAVERDE
County GARFIELD
State COLORADO

PORE SIZE DISTRIBUTION
SAMPLE NUMBER: 947

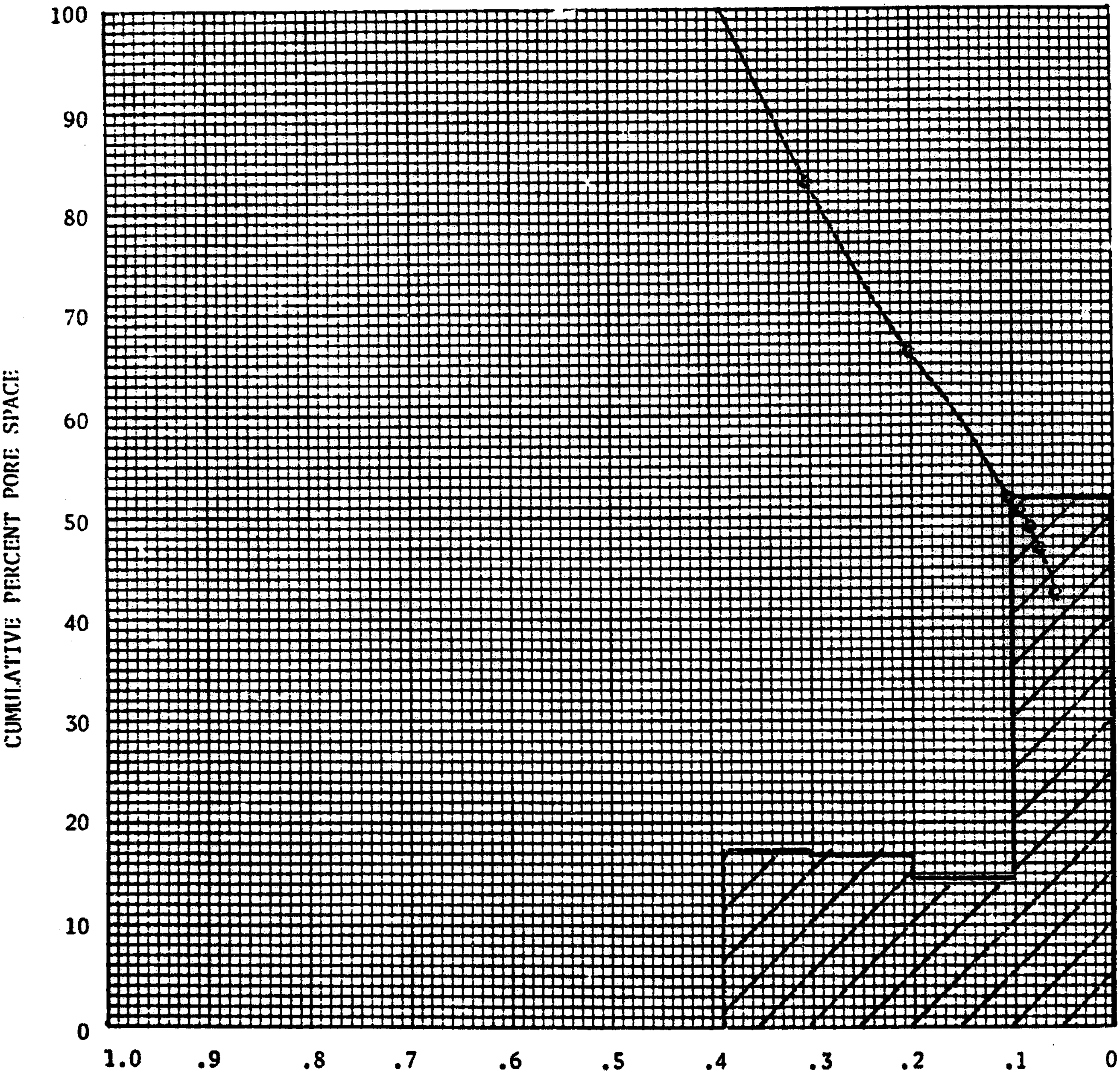


CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File 203-82023

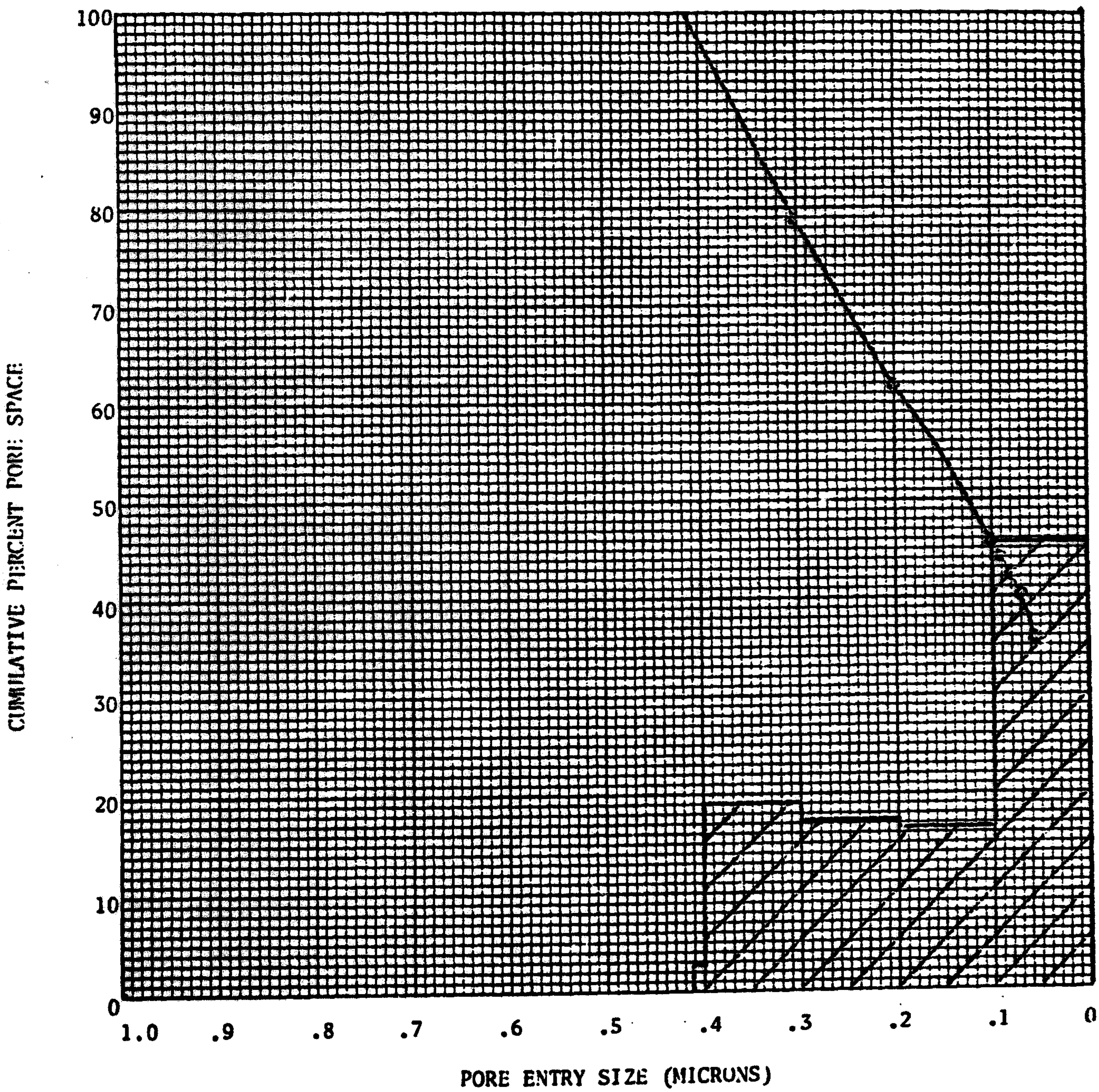
Company SANDIA NATIONAL LABORATORIES Formation MESAVERDE
Well MULTI-WELL EXPERIMENT-1 County GARFIELD
Field RULISON State COLORADO

PORE SIZE DISTRIBUTION
SAMPLE NUMBER: 953



Company	SANDIA NATIONAL LABORATORIES	Formation	MESAVERDE
Well	MULTI-WELL EXPERIMENT-1	County	GARFIELD
Field	RULISON	State	COLORADO

PORE SIZE DISTRIBUTION
SAMPLE NUMBER: 959

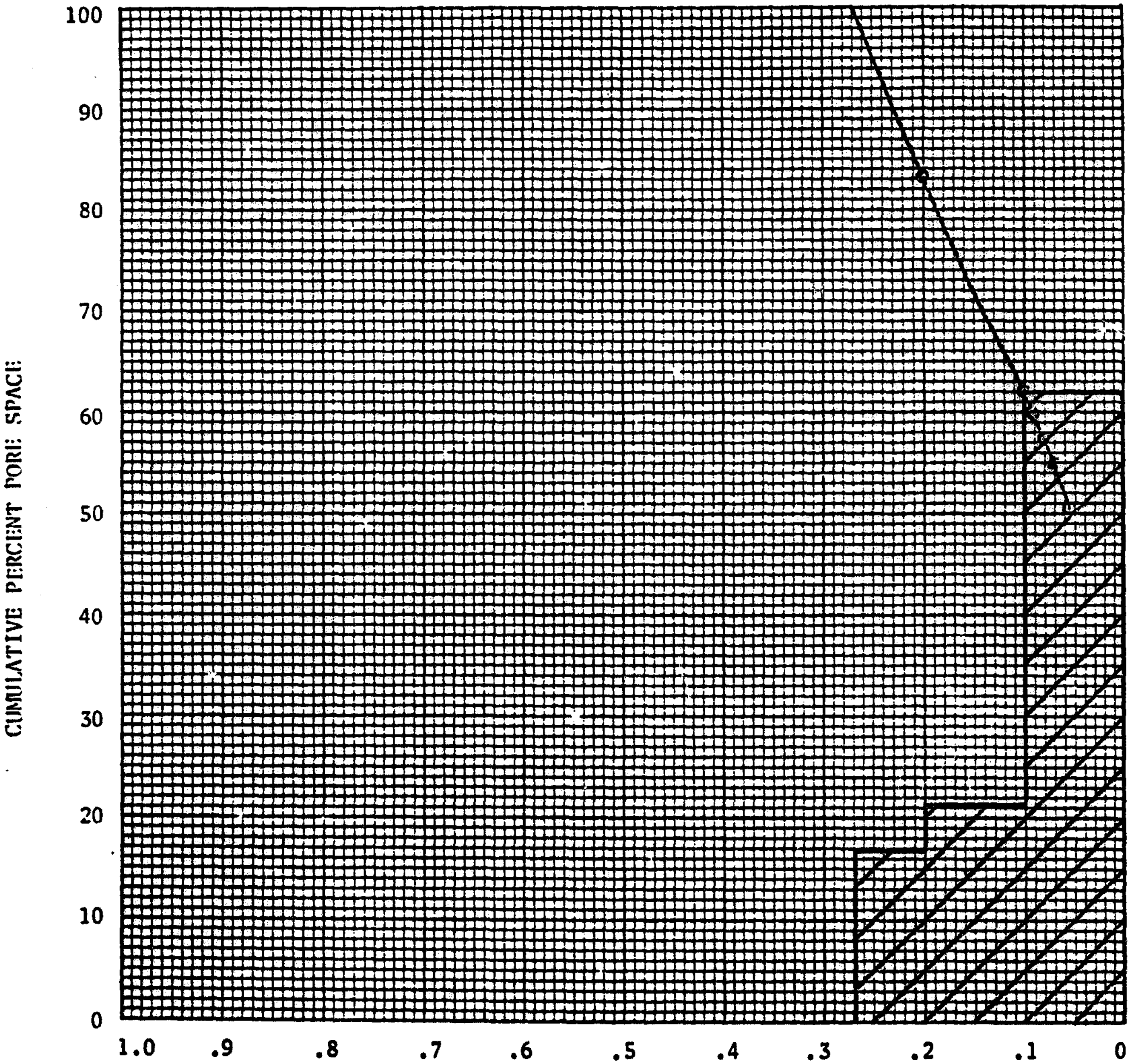


CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File 203-82023

Company SANDIA NATIONAL LABORATORIES Formation MESAVERDE
Well MULTI-WELL EXPERIMENT-1 County GARFIELD
Field RULISON State COLORADO

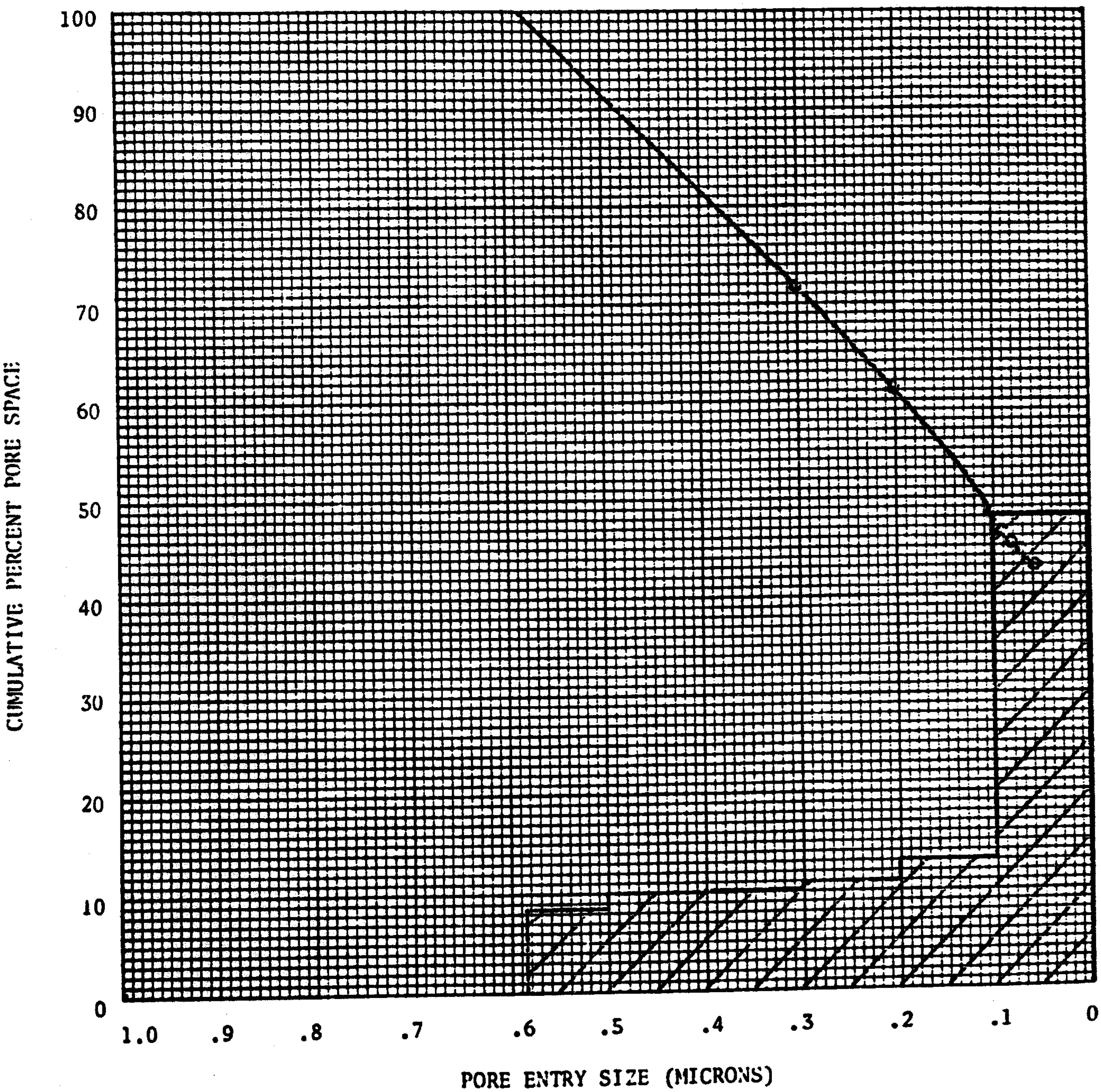
PORE SIZE DISTRIBUTION
SAMPLE NUMBER: 983



PORE ENTRY SIZE (MICRONS)

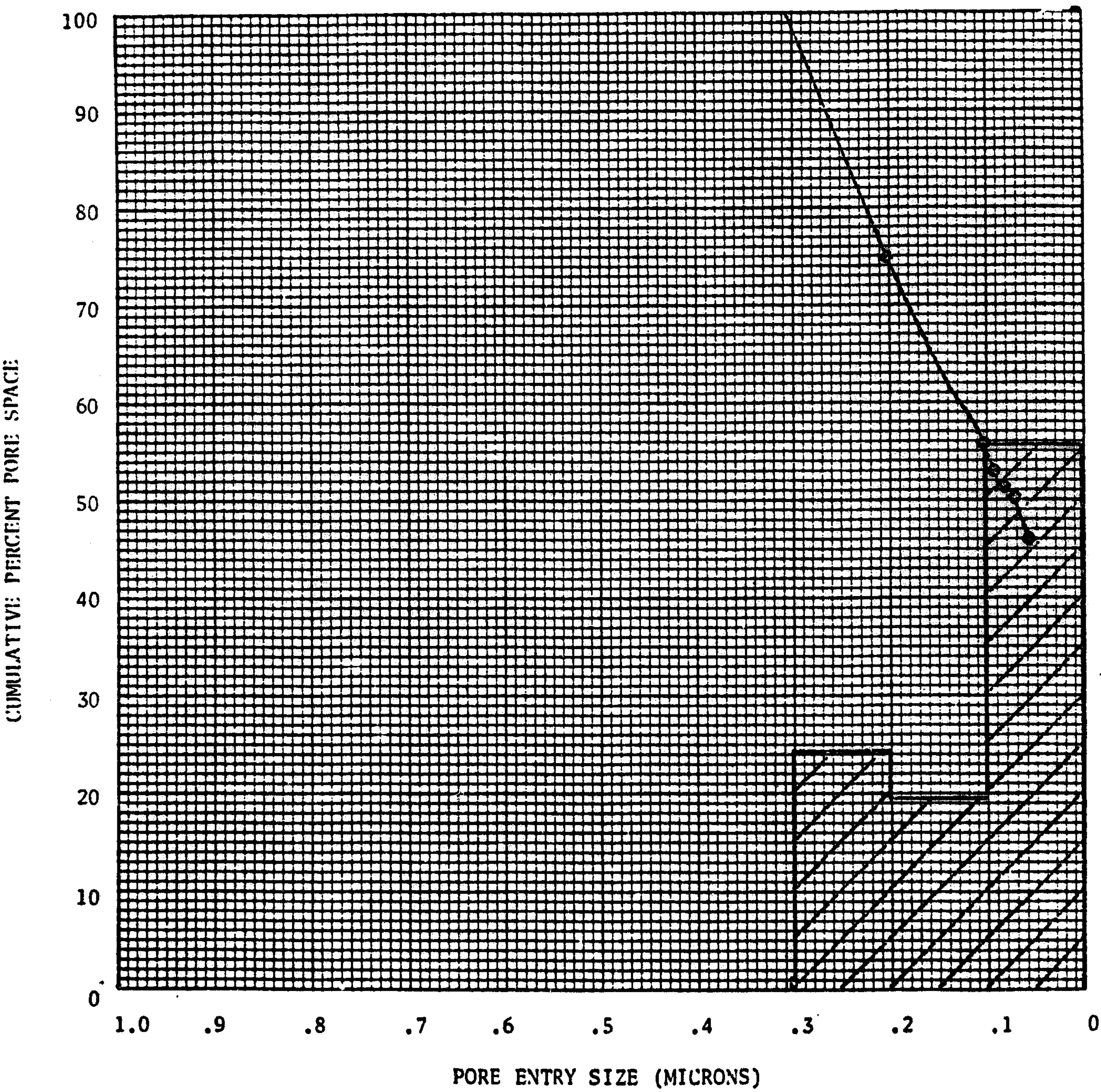
Company SANDIA NATIONAL LABORATORIES Formation MESAVERDE
Well MULTI-WELL EXPERIMENT-1 County GARFIELD
Field RULISON State COLORADO

PORE SIZE DISTRIBUTION
SAMPLE NUMBER: 1007



Company SANDIA NATIONAL LABORATORIES
Formation MESAVERDE
Well MULTI-WELL EXPERIMENT-1
County GARFIELD
Field RULISON
State COLORADO

PORE SIZE DISTRIBUTION
SAMPLE NUMBER: 1012



Company SANDIA NATIONAL LABORATORIES
Well MULTI-WELL EXPERIMENT-1
Field RULISON
Formation MESA VERDE- /COASTAL/
County GARFIELD
State COLORADO

SAMPLE #	DEPTH FEET	CEC; ADSORBED WATER METHOD
93-S	6259.0	9.9
95-S	6260.0	12.5
97-S	6261.0	8.8
99-S	6262.0	11.0
101-S	6263.0	7.3
103-S	6264.0	9.5
105-S	6551.0	0.69
107-S	6552.0	1.2
109-S	6553.0	1.6
111-S	6554.0	1.1
113-S	6555.5	4.8
115-S	6556.0	2.0
117-S	6557.0	3.8
119-S	6558.0	4.0
121-S	6559.0	2.9

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Company SANDIA NATIONAL LABORATORIES
Formation MESAVERDE-.
Well MULTI-WELL EXPERIMENT NO. 1
County GARFIELD
Field RULISON
State COLORADO

Depth Feet	Sample Number	Humidity Weight	Dry Weight	Tare Weight	Adsorbed Water Cation Exchange Capacity
6403.7	929	41.578	41.539	26.256	3.0
6409.3	931	44.621	44.545	29.284	6.0
6415.4	933	38.489	38.436	23.114	4.1
6424.8	935	50.535	50.425	35.231	8.4
6442.8	952	48.828	48.755	33.466	5.8
6473.0	968	49.294	49.230	33.958	5.1
6475.6	969	49.358	49.284	34.047	5.8

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CATION EXCHANGE CAPACITY - ADSORBED WATER METHOD

Company: Sandia National Laboratories
Formation: Mesa Verde
County, State: Garfield, Colorado

Well: As Noted
Field: Rulison

Sample I.D.	Depth, feet	Cation Exchange Capacity meq/100 grams
MWX-I (Coastal)		
949	6440.5	2.2
955	6447.5	2.7
960	6455.9	2.5
986	6508.3	3.3
990	6514.7	2.3
1010	6544.5	2.3
1014	6548.8	2.8

CORE LABORATORIES, INC.
Special Core Analysis

File 203-840016

CATION EXCHANGE CAPACITY MEASUREMENTS

Company: Sandia National Laboratories **Well:** MWX-1

Formation: Mesa Verde **Field:** Rulison

County, State: Garfield, Colorado

SAMPLE IDENTIFICATION		CATION EXCHANGE CAPACITY
Number	Depth, feet	meq/100 g*
** 3	6546.3	4.74
4	6556.1-6556.3	6.99

*meq = milliequivalents

**NOTE: Samples No. 2 and No. 3 were very finely crushed when received, much finer then the 60 mesh which we use as standard.

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Company SANDIA NATIONAL LABORATORIES
Well MULTI-WELL EXPERIMENT #2
Field RULISON
Formation MESA VERDE-COASTAL
County GARFIELD
State COLORADO

Depth Feet	Sample Number	Humidity Weight	Dry Weight	Tare Weight	Adsorbed Water Cation Exchange Capacity
6423.7	113	49.340	49.334	33.957	0.38
6425.8	114	49.343	49.338	34.047	0.30
6427.8	115	52.409	52.401	37.138	0.54
6429.2	116	56.473	56.469	40.820	0.22
6432.5	119	58.694	58.698	43.246	0.03
6436.5	122	59.347	59.334	43.874	0.96
6439.5	125	53.634	53.625	38.203	0.58
6441.5	127	47.898	42.896	33.357	0.12
6443.5	128	54.738	54.713	39.350	3.4
6446.5	131	53.335	53.324	38.085	0.79
6450.5	134	52.397	52.380	36.931	1.4
6453.5	137	57.864	57.848	42.536	1.3
6457.5	140	51.356	5-.333	36.036	2.2
6458.5	141	57.723	57.708	43.209	1.3
6459.5	142	48.397	48.380	32.968	0.86
6461.7	143	53.351	53.336	38.115	1.2
6463.9	144	46.679	46.675	31.102	0.22
6465.8	145	45.245	45.222	29.795	2.1
6467.5	146	45.532	45.528	30.215	0.22
6469.6	147	49.279	49.273	34.184	0.39
6497.6	148	43.563	43.549	28.519	1.1
6498.6	149	43.942	43.934	28.481	0.54
6500.9	150	47.531	47.519	31.965	0.85
6501.8	151	42.247	42.229	27.027	1.6
6504.4	152	54.565	54.554	39.175	0.78
6508.3	154	48.225	48.210	32.804	1.2
6511.1	156	43.687	43.679	28.375	0.54
6516.3	159	45.112	45.100	29.805	0.86
6521.9	162	49.032	49.020	33.882	0.87
6527.2	165	46.884	46.682	31.398	0.11
6529.9	167	42.484	42.478	27.031	0.38
6531.9	168	42.176	42.166	26.908	0.69
6535.3	170	48.386	48.375	33.070	0.79
6536.9	171	42.219	42.209	26.748	0.69
6539.2	172	49.111	49.091	33.582	1.8
6542.6	174	45.659	45.658	30.402	0.04
6545.8	176	45.479	45.456	30.340	2.2
6547.8	177	46.399	46.392	29.817	0.41
6549.7	178	40.862	40.854	25.434	0.58

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Company SANDIA NATIONAL LABORATORIES
Well MULTI-WELL EXPERIMENT #2
Field RULISON
Formation MESA VERDE-COASTAL
County GARFIELD
State COLORADO

Depth Feet	Sample Number	Humidity Weight	Dry Weight	Tare Weight	Adsorbed Water Cation Exchange Capacity
6551.2	179	51.774	51.766	36.713	0.59
6552.8	180	45.962	45.958	32.626	0.25
6556.9	181	43.241	43.235	28.203	0.47
6558.1	182	55.168	55.159	39.639	0.60
6559.2	183	52.500	52.484	37.068	1.3
6562.8	184	49.416	49.405	34.139	0.79

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CORE LABORATORIES, INC.

File 203-830055

Company: Sandia National Laboratories Well: MWX-3

Formation: Mesa Verde Field: Rulison

County, State: Garfield, Colorado

CATION EXCHANGE CAPACITY ANALYSIS
(Wet Chemistry Method)

Sample Number	Depth, feet	Cation Exchange Capacity Milliequivalents/100 grams
64-55	6449.0-49.1	12.4
64-50	6470.8	.45
65-22	6518.7	17.0
65-27	6527.3	21.6

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FORMATION RESISTIVITY FACTOR AND RESISTIVITY INDEX

Company: SANDIA NATIONAL LABORATORIES   Well: MULTI-WELL EXPERIMENT-1
Formation: MESAVERDE   Field: RULISON
County (Parish), State: GARFIELD, COLORADO

Saturant: 20,000 ppm NaCl
Resistivity of Saturant: .324 ohm-meters at 72.4 °F (C)

Sample I.D.	Depth, feet	Permeability to Air, millidarcys	Porosity, percent	Formation Resistivity Factor	Brine Saturation, percent pore space	Resistivity Index
949	6440.5	.05	8.0	83.5	100.0	1.0
					98.8	1.13
					94.4	1.36
					73.7	1.85
955	6447.5	.05	7.6	77.8	100.0	1.0
					97.4	1.18
					92.1	1.41
					73.8	1.86
960	6455.9	.09	8.6	69.7	100.0	1.0
					97.2	1.14
					92.1	1.39
					69.7	1.83
986	6508.3	.04	8.0	84.5	100.0	1.0
					96.1	1.16
					92.1	1.35
					76.2	1.71
990	6514.7	.07	8.6	76.2	100.0	1.0
					89.2	1.09
					84.6	1.33
					75.8	1.61

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FORMATION RESISTIVITY FACTOR AND RESISTIVITY INDEX

Company: SANDIA NATIONAL LABORATORIES Well: MULTI-WELL EXPERIMENT-1
Formation: MESAVERDE Field: RULISON
County (Parish), State: GARFIELD, COLORADO

Saturant: 20,000 ppm NaCl
Resistivity of Saturant: .324 ohm-meters at 72.4 °F (C)

Sample I.D.	Depth, feet	Permeability to Air, millidarcys	Porosity, percent	Formation Resistivity Factor	Brine Saturation, percent pore space	Resistivity Index
1010	6544.5	.05	7.3	93.7	100.0	1.0
					94.3	1.18
					88.6	1.50
					67.6	2.09
1014	6548.8	.07	8.0	76.2	100.0	1.0
					94.8	1.06
					89.6	1.34
					69.3	1.95

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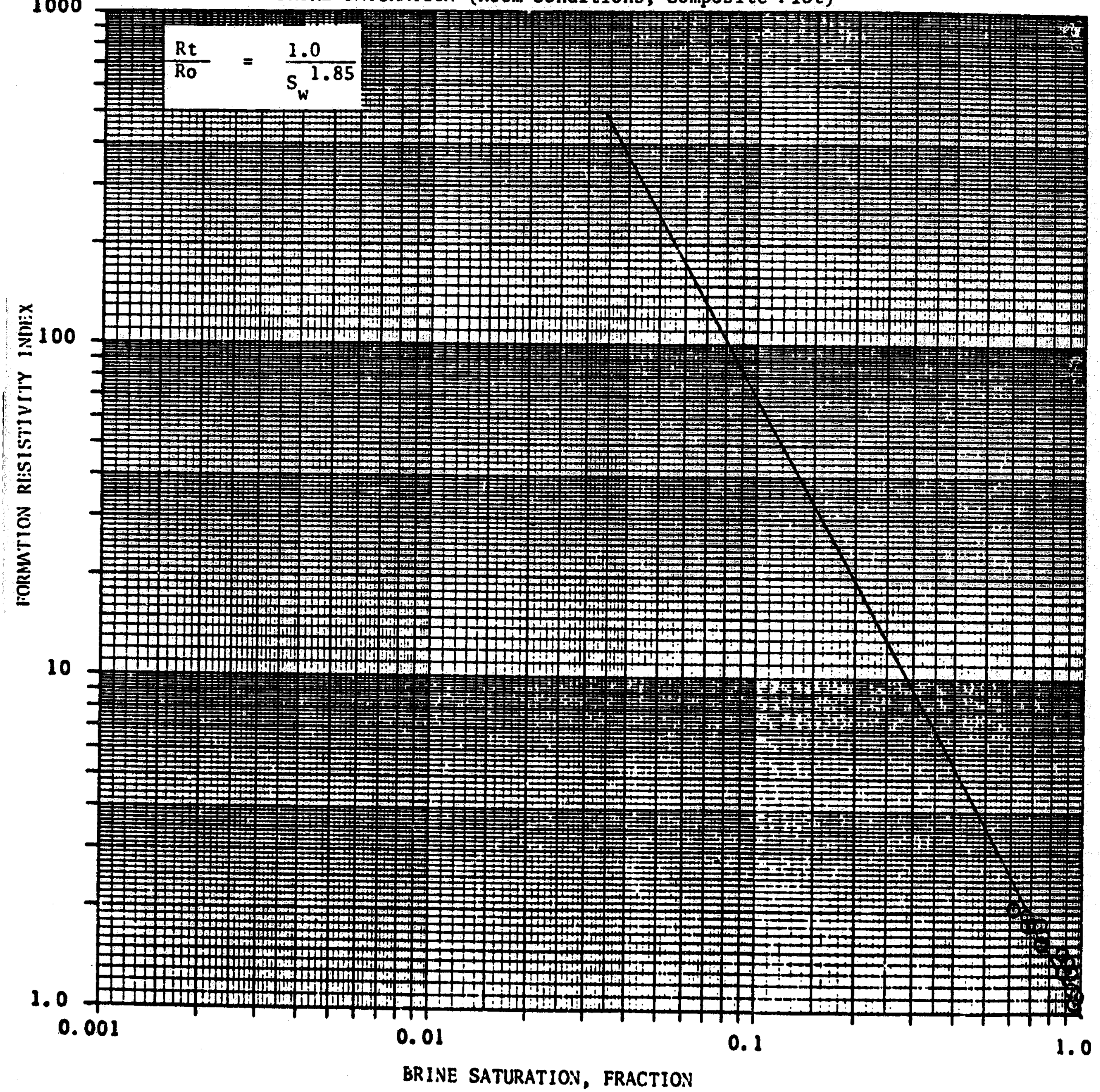
CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

Company SANDIA NATIONAL LABORATORIES
Formation MESAVERDE
Well MULTI-WELL EXPERIMENT-1
County GARFIELD
Field RULISON
State COLORADO

FORMATION RESISTIVITY INDEX
VERSUS
BRINE SATURATION (Room Conditions, Composite Plot)



FORMATION RESISTIVITY FACTOR AS A FUNCTION OF OVERBURDEN PRESSURE

Company: SANDIA NATIONAL LABORATORIES Well: MULTI-WELL EXPERIMENT-1
Formation: MESAVERDE Field: RULISON
County (Parish), State: GARFIELD, COLORADO

Saturant: 20,000 ppm NaCl
Resistivity of Saturant: .324 ohm-meters at 72 °F (C)

Sample I.D.	Depth, feet	Permeability to Air, millidarcys	Porosity, percent	Effective Overburden Pressure, psi					
				0.0	200	3200			
				Formation Resistivity Factor					
949	6440.5	.05	8.0	83.5	86.5	116			
955	6447.5	.05	7.6	77.8	81.5	110			
960	6455.9	.09	8.6	69.7	70.9	94.8			
986	6508.3	.04	8.0	84.5	88.9	119			
990	6514.7	.07	8.6	76.2	77.9	104			
1010	6544.5	.05	7.3	93.7	101	137			
1014	6548.8	.07	8.0	76.2	110	110			

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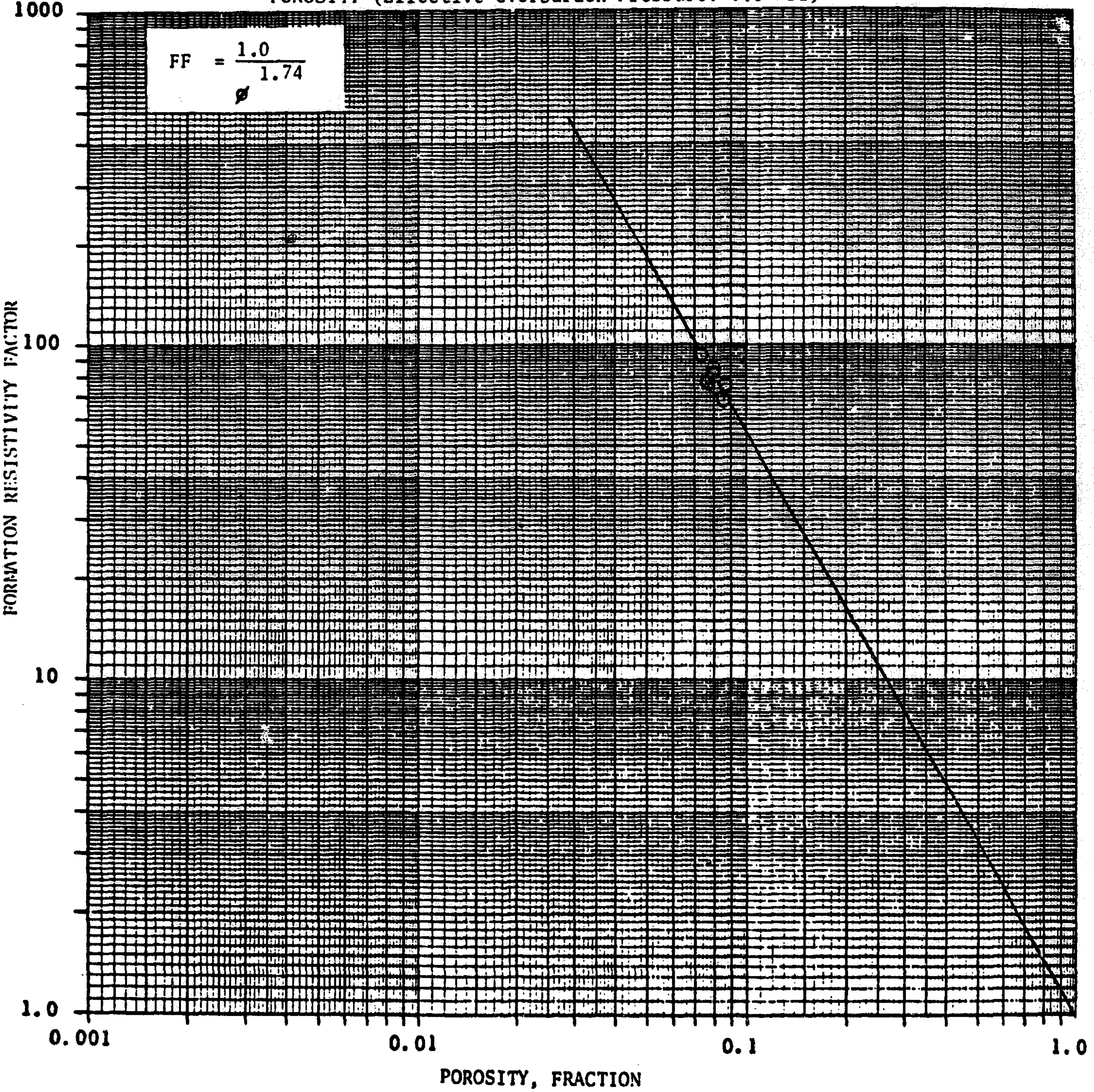
CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File 203-82023

Company SANDIA NATIONAL LABORATORIES Formation MESAVERDE
Well MULTI-WELL EXPERIMENT-1 County GARFIELD
Field RULISON State COLORADO

FORMATION RESISTIVITY FACTOR
VERSUS
POROSITY (Effective Overburden Pressure: 0.0 Psi)

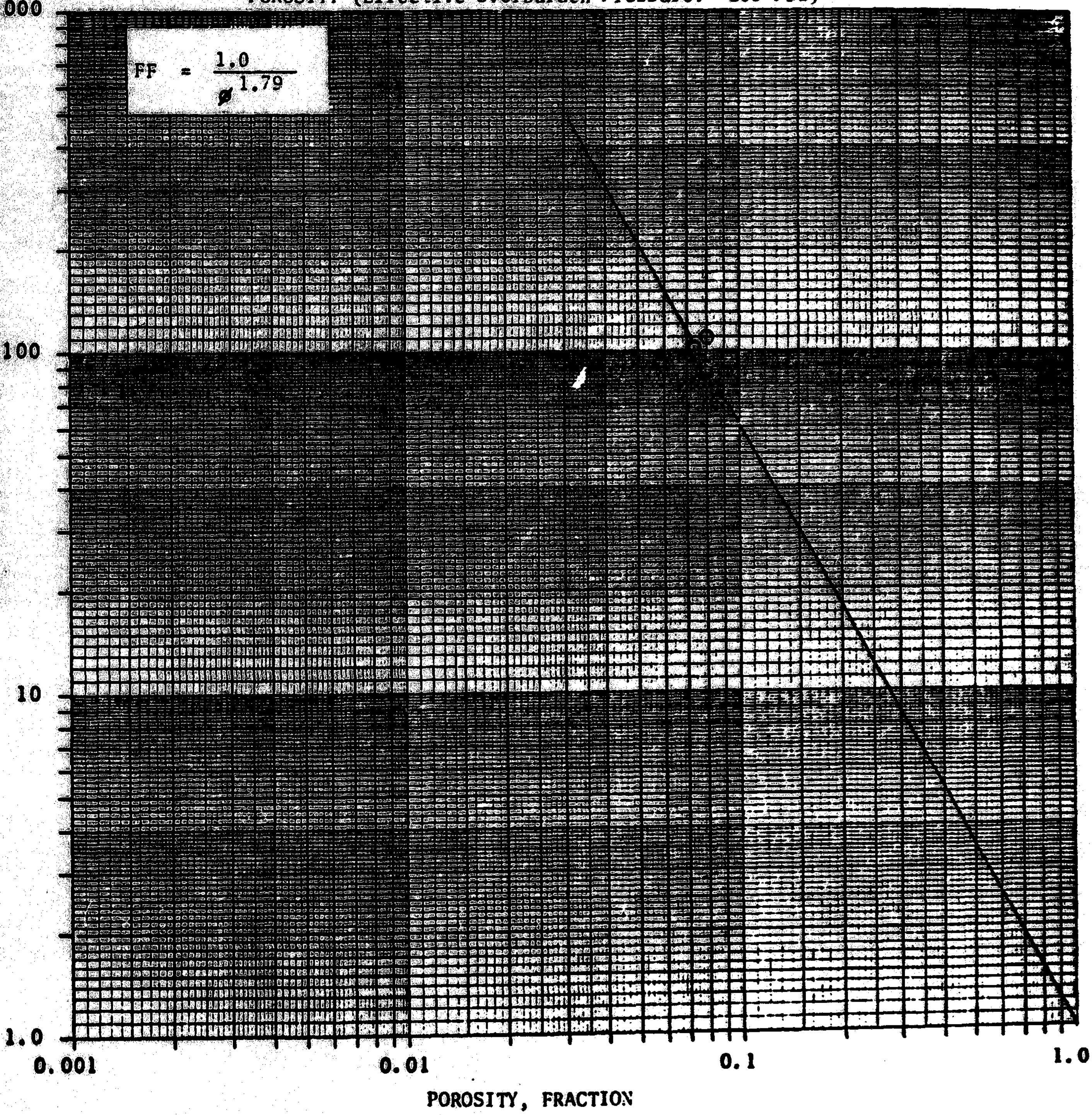


CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

File 203-82023

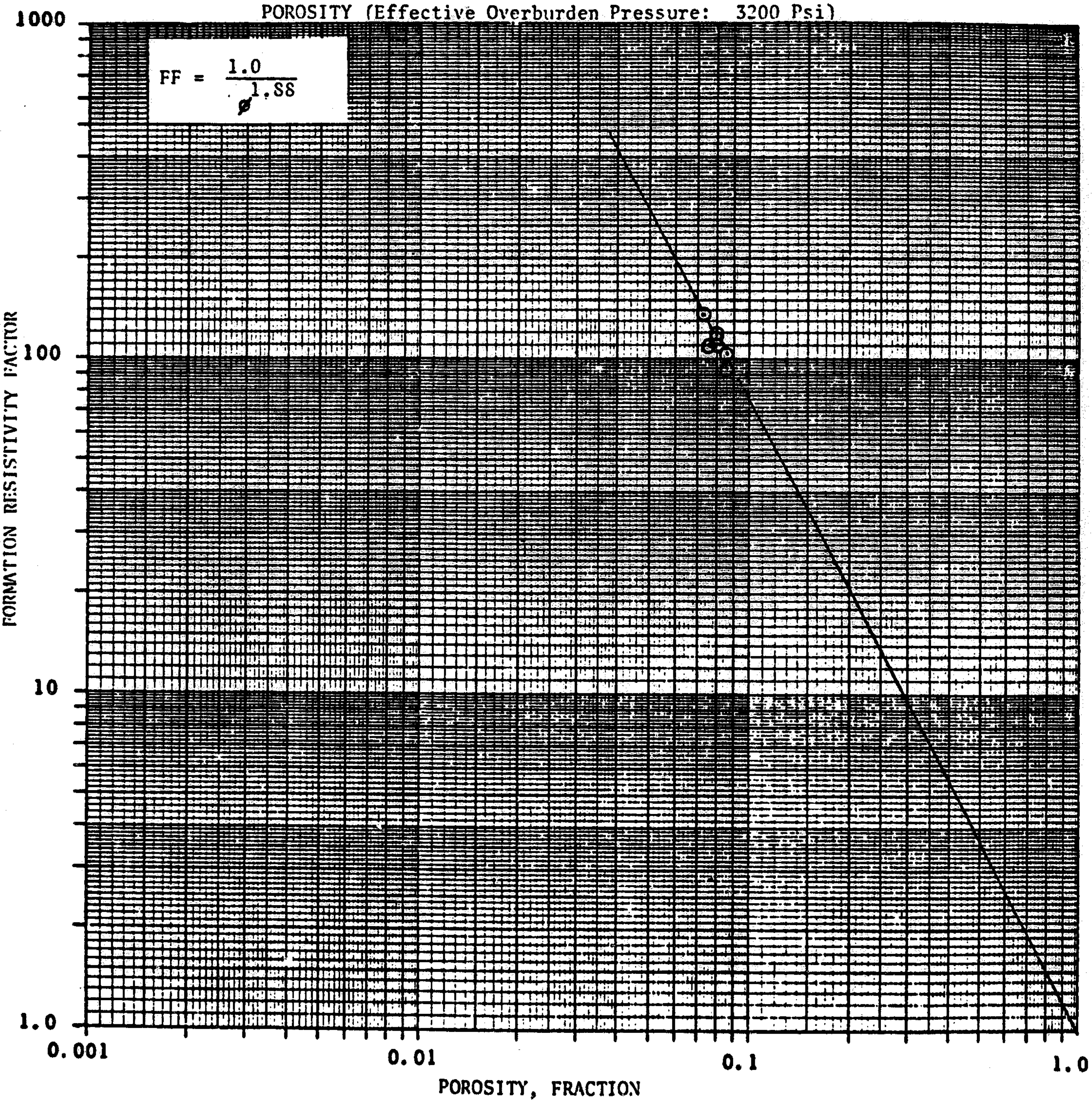
Company SANDIA NATIONAL LABORATORIES Formation MESAVERDE
Well MULTI-WELL EXPERIMENT-1 County GARFIELD
Field RULISON State COLORADO

FORMATION RESISTIVITY FACTOR
VERSUS
POROSITY (Effective Overburden Pressure: 200 Psi)



Company SANDIA NATIONAL LABORATORIES Formation MESAVERDE
Well MULTI-WELL EXPERIMENT-1 County GARFIELD
Field RULISON State COLORADO

FORMATION RESISTIVITY FACTOR
VERSUS
POROSITY (Effective Overburden Pressure: 3200 Psi)



FORMATION RESISTIVITY FACTOR AS A FUNCTION OF OVERBURDEN PRESSURE
Corrected for Clay Effects

Company: Sandia National Laboratories
Formation: Mesa Verde
County, State: Garfield, Colorado
Well: MWX-I (Coastal)
Field: Rulison

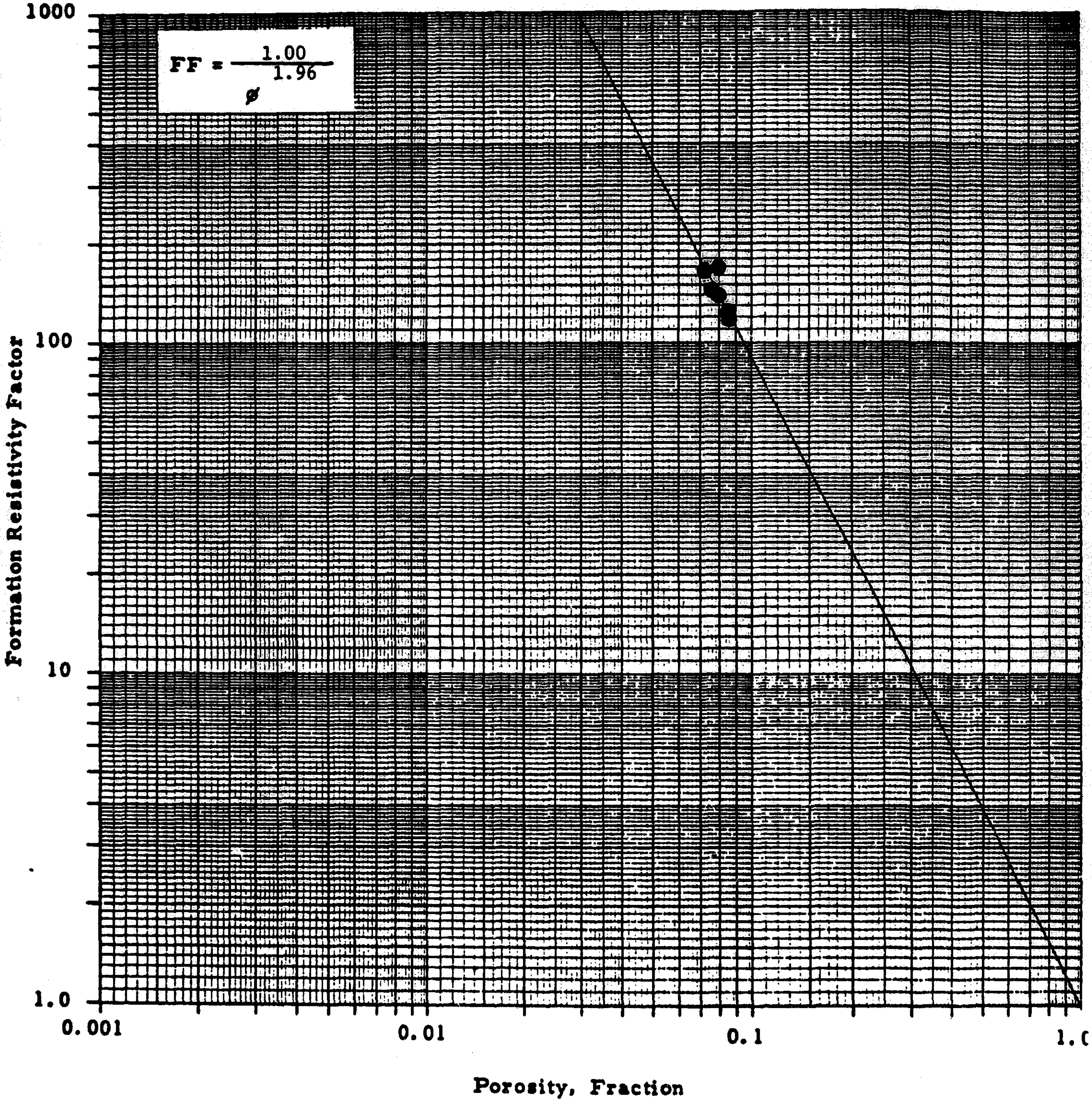
Saturant: 20,000 ppm NaCl
Resistivity of Saturant: 0.324 ohm-meters at 77°F

Sample I.D.	Depth, feet	Permeability to Air, Millidarcys	Porosity, Percent	Formation Resistivity Factor — Overburden Pressure, psi 0.0	200	3200
949	6440.5	0.05	8.0	139	160	
			8.0*			193
955	6447.5	0.05	7.6	144	151	
			7.6*			204
960	6455.9	0.09	8.6	118	120	
			8.6*			160
986	6508.3	0.04	8.0	168	177	
			8.0*			237
990	6514.7	0.07	8.6	125	128	
			8.6*			171
1010	6544.5	0.05	7.3	165	178	
			7.3*			241
1014	6548.8	0.07	8.0	140	149	
			8.0*			203

* Porosity values are not adjusted for overburden reduction.

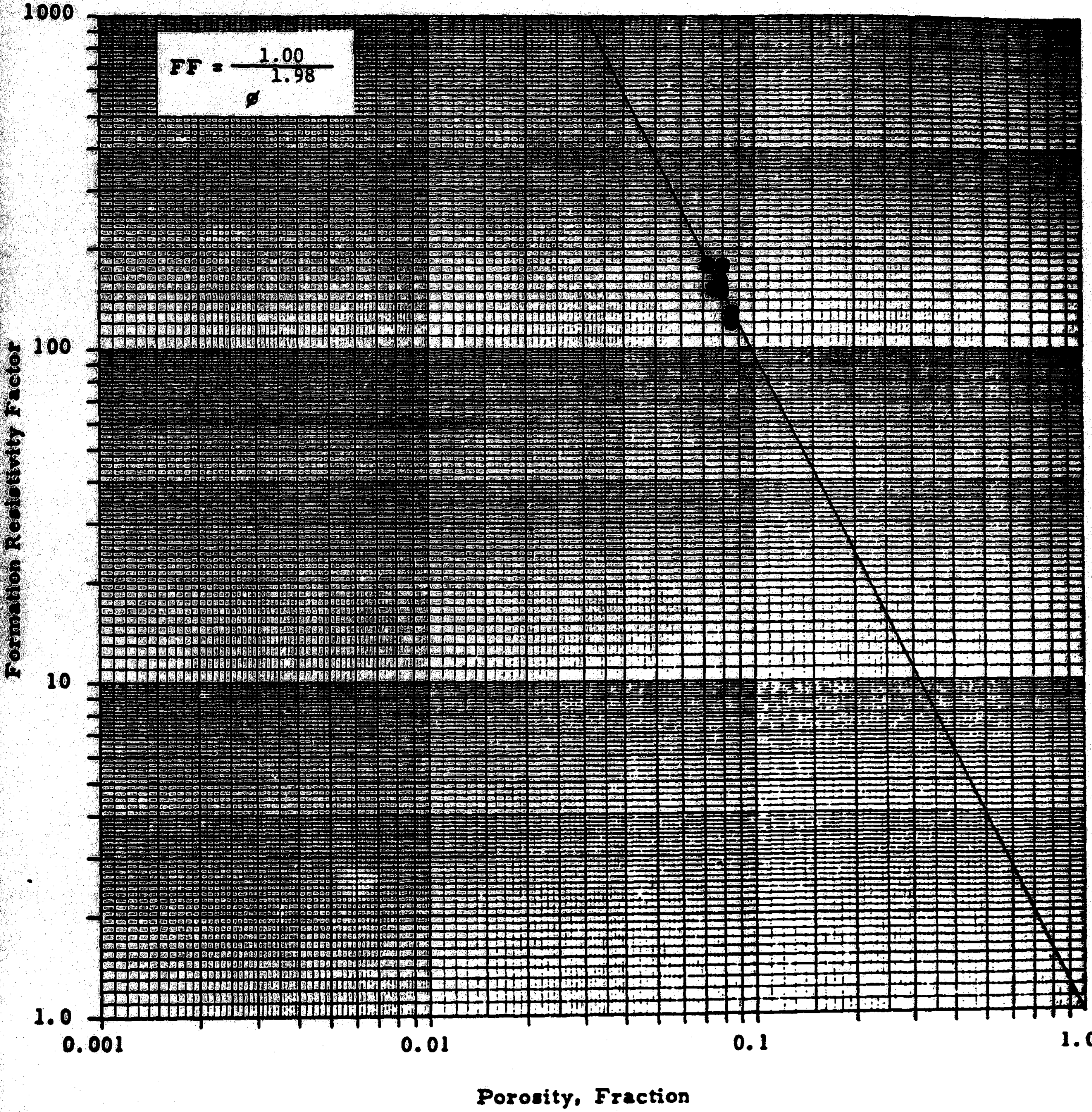
Company Sandia National Laboratories
Well MWX-I (Coastal)
Field Rulison
Formation Mesa Verde
County Garfield
State Colorado

0.0 psi Effective Overburden
Clay-Corrected



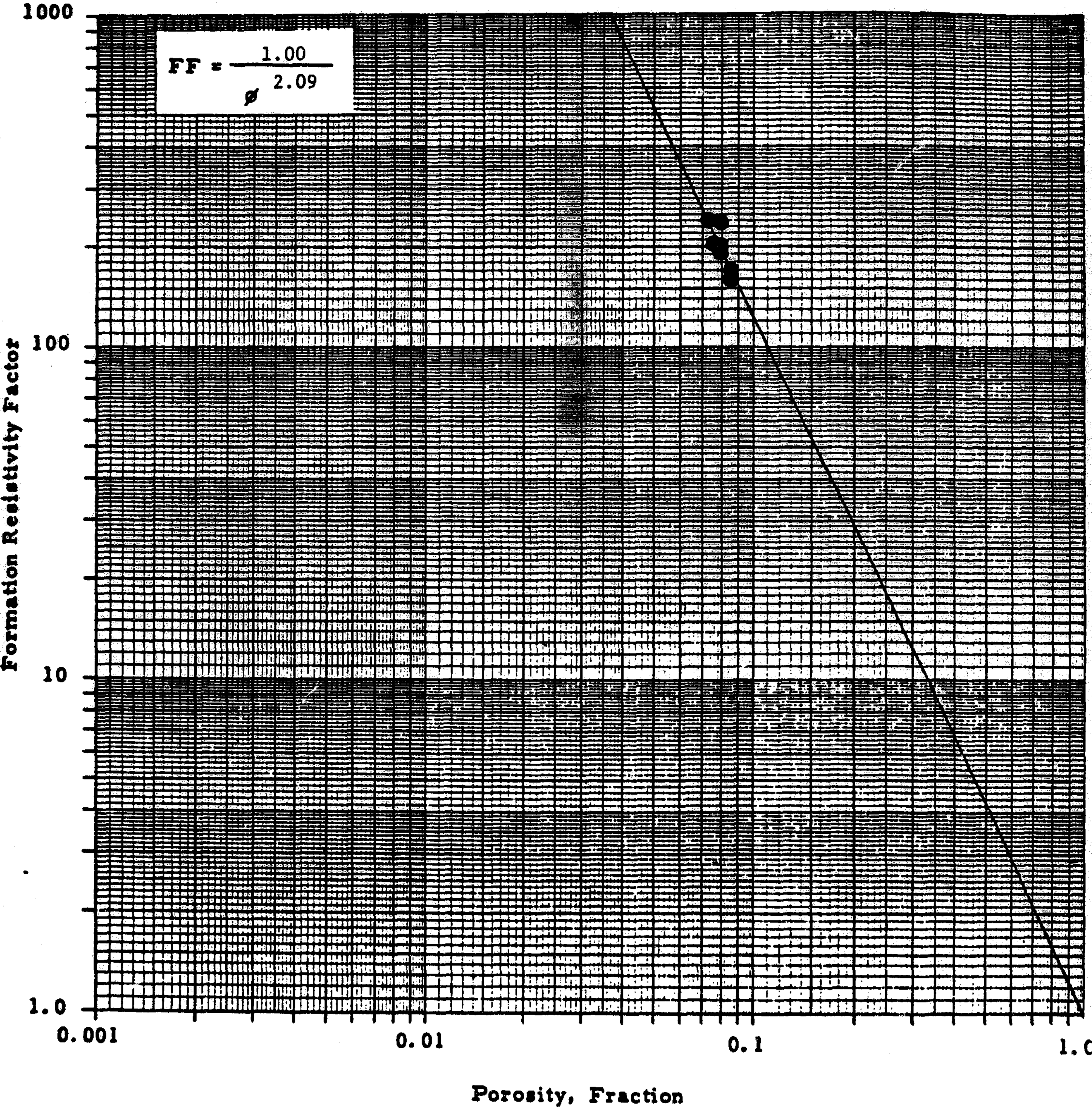
Company Sandia National Laboratories
Well MWX-1 (Coastal)
Field Rulison
Formation Mesa Verde
County Garfield
State Colorado

200 psi Effective Overburden
Clay-Corrected



Company Sandia National Laboratories
Well MWX-I (Coastal)
Field Rulison
Formation Mesa Verde
County Garfield
State Colorado

3200 psi Effective Overburden
Clay-Corrected



FORMATION RESISTIVITY INDEX
Corrected for Clay Effects

Company: Sandia National Laboratories
Formation: Mesa Verde
County, State: Garfield, Colorado

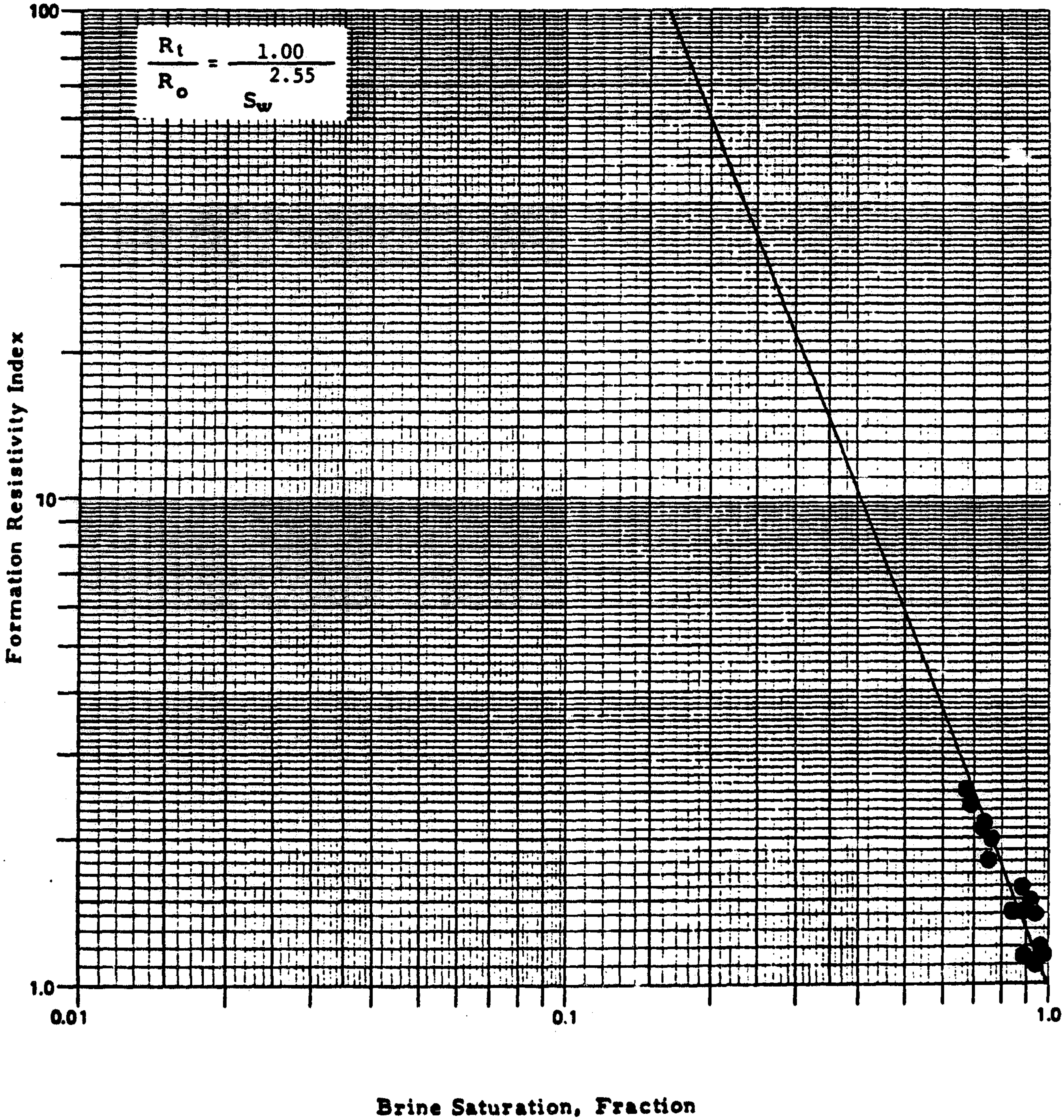
Well: MWX-I (Coastal)
Field: Rulison

Saturant: 20,000 ppm NaCl
Resistivity of Saturant: 0.324 ohm-meters at 77°F

Sample I.D.	Depth, feet	Permeability to Air Millidarcys	Porosity, Percent	Brine Saturation percent pore space	Resistivity Index
949	6440.5	0.05	8.0	98.8	1.14
				94.4	1.39
				73.7	2.11
955	6447.5	0.05	7.6	97.4	1.19
				92.1	1.47
				73.8	2.16
960	6455.9	0.09	8.6	97.2	1.15
				92.1	1.46
				73.8	2.13
986	6508.3	0.04	8.0	96.1	1.18
				92.1	1.41
				76.2	1.98
990	6514.7	0.07	8.6	89.2	1.14
				84.6	1.42
				75.8	1.81
1010	6544.5	0.05	7.3	94.3	1.21
				88.6	1.58
				67.6	2.52
1014	6548.8	0.07	8.0	94.8	1.09
				89.6	1.41
				69.3	2.34

Company Sandia National Laboratories
Formation Mesa Verde
Well MWX-I (Coastal)
County Garfield
Field Rulison
State Colorado

Composite Plot (Clay-Corrected)



CORE LABORATORIES, INC.

File 203-830055

CAPROCK ANALYSIS

Company: Sandia National Laboratories
Well: MWX-3

Formation: Mesa Verde
Field: Rulison

County, State: Garfield, Colorado

Sample Identification	Depth, feet	Permeability to Liquid, millidarcys	Threshold Pressure, psi
64-44	6432.9-33.6	-------------	>1000 psi

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Table 1 FILE NO. 84137

MWX-1

ROCK-EVAL PYROLYSIS

Depth (FT)	TOC	Mg/Gm Rock S1	S2	S3	Hydrogen Index	Oxygen Index	Oil or Gas Shows	Potential	Trans Ratio	TMAX (Deg C)
6006.0	2.36	0.92	2.05	0.25	86.9	10.6	0.92	2.97	0.31	472
6041.0	1.58	0.38	0.46	0.56	29.1	35.4	0.38	0.84	0.45	478
6059.7	4.43	1.97	10.74	0.35	242.4	7.9	1.97	12.71	0.15	468
6060.0	5.21	1.49	6.99	0.60	134.2	11.5	1.49	8.48	0.18	472
6099.0	1.01	0.22	0.10	0.45	9.9	44.6	0.22	0.32	0.69	479
6134.0	0.78	0.09	-	0.37	-	47.4	0.09	0.09	-	-
6200.0	0.33	0.03	-	0.40	-	121.2	0.03	0.03	-	-
6231.0	7.93	1.71	10.39	0.33	131.0	4.2	1.71	12.10	0.14	477
6259.0	1.02	0.17	0.19	0.46	18.6	45.1	0.17	0.36	0.47	481
6294.7	23.76	13.15	93.86	2.85	395.0	12.0	13.15	107.01	0.12	476
6294.8	14.90	3.45	20.50	1.39	137.6	9.3	3.45	23.95	0.14	478
6324.0	1.56	0.28	0.30	0.69	19.2	44.2	0.28	0.58	0.48	489
6395.0	0.91	0.68	0.74	0.34	81.3	37.4	0.68	1.42	0.48	364
6398.0	0.60	0.29	-	1.87	-	311.7	0.29	0.29	-	-
6443.0	1.35	0.86	0.90	0.35	66.7	25.9	0.86	1.76	0.49	480
6478.0	0.42	0.36	-	0.52	-	123.8	0.36	0.36	-	-
6562.0	0.60	0.59	-	1.31	-	218.3	0.59	0.59	-	-
6645.0	7.89	2.20	7.33	0.57	92.9	7.2	2.20	9.53	0.23	486
6653.0	0.58	0.18	-	1.51	-	260.3	0.18	0.18	-	-

TOC = Total Organic Carbon
Hydrogen Index = (S2/TOC)x100
Oxygen Index = (S3/TOC) x 100
Oil or Gas Shows = S1
Oil or Gas Potential = S1+S2
Transformation Ratio = S1/(S1+S2)

File 84137

Table 2

MWX-1

Concentration (Vol PPM of Total Solids) of C_1-C_{5+} Hydrocarbons

Depth (ft)	C1 Methane	C2 Ethane	C3 Propane	iC4 Isobutane	nC4 Butane	Total C_{5+}	Total C_1-C_4	Total C_2-C_4	% Gas Wetness	iC4 / nC4
6059.7	3672	3454	2751	871	444	220	10192	7520	73.4	1.96
6060.0	2116	3565	2843	922	480	279	9926	7810	78.7	1.92
6294.8	156	15	693	258	87	89	1209	1053	87.1	2.97
6398.0	2438	383	116	32	32	243	3001	563	18.8	1.00

Table 1 FILE NO. 84137

MWX-2

ROCK-EVAL PYROLYSIS

Depth (FT)	TOC	Mg/Gm Rock S1	S2	S3	Hydrogen Index	Oxygen Index	Oil or Gas Shows	Potential	Trans Ratio	TMAX (Deg C)
6390.0	0.35	0.22	0.06	0.41	17.1	117.1	0.22	0.28	0.79	354
6401.0	0.97	0.16	0.35	0.25	36.1	25.8	0.16	0.51	0.31	476
6408.0	4.32	1.03	2.90	0.38	67.1	8.8	1.03	3.93	0.26	477
6492.0	0.33	1.03	0.12	0.33	36.4	100.0	1.03	1.15	0.90	361
6570.0	5.59	1.88	9.98	0.46	178.5	8.2	1.88	11.86	0.16	480

TOC = Total Organic Carbon
Hydrogen Index = (S2/TOC)x100
Oxygen Index = (S3/TOC) x 100
Oil or Gas Shows = S1
Oil or Gas Potential = S1+S2
Transformation Ratio = S1/(S1+S2)

FILE NO. 84012

Table 1

ROCK-EVAL PYROLYSIS, MWX-3

depth	Sample Number lith.	TOC %	Mg/Gm Rock S1	S2	S3	Hydrogen Index	Oxygen Index	Oil or Gas Shows	Oil or Gas Potential	Trans Ratio	TMAX (Deg C)
6431.5	3-5 mudst	2.10	0.37	1.30	0.15	61.9	7.1	0.37	1.67	0.22	476
6480.2	3-6 mud, blk	1.10	0.25	0.39	0.35	35.5	31.8	0.25	0.64	0.39	486
6483.2	3-8 blk cly	0.93	0.38	0.37	0.42	39.8	45.2	0.38	0.75	0.51	485
6484.2	3-9 blk mud	0.99	0.46	0.48	0.39	48.5	39.4	0.46	0.94	0.49	484
6493.2	3-10 brn SS, [illegible]	0.73	0.38	0.36	0.25	49.3	34.2	0.38	0.74	0.51	485
6519.2	3-11 blk clay	1.38	0.44	0.64	1.30	46.4	94.2	0.44	1.08	0.41	490
6520.5	3-12 mudst	3.40	0.79	2.83	0.16	83.2	4.7	0.79	3.62	0.22	473
6529.3	3-13 blk clay	2.91	0.64	2.04	0.10	70.1	3.4	0.64	2.68	0.24	476

TOC = Total Organic Carbon
Hydrogen Index = (S2/TOC)x100
Oxygen Index = (S3/TOC) x 100
Oil or Gas Shows = S1
Oil or Gas Potential = S1+S2
Transformation Ratio = S1/(S1+S2)

*Tmax values considered unreliable due to low concentration of S_2.

File 84012

Table 2, MWX-3

Concentration (Vol PPM of Gas in Rock) of C_1-C_{5+} Hydrocarbons

Sample No.	C1 Methane	C2 Ethane	C3 Propane	iC4 Isobutane	nC4 Butane	Total C_{5+}	Total C_1-C_4	Total C_2-C_4	% Gas Wetness	iC4 nC4
6431.5 3-5 mudst	672	2260	1364	250	176	106	4722	4050	85.8	1.42
6520.5 3-12 mudst	1367	6084	4621	780	676	468	13528	12161	89.9	1.15

CORE LABORATORIES, INC.
2001 COMMERCE DRIVE
MIDLAND, TEXAS
(915) 694-7761

Company:	Sandia National Laboratories	Formation:	Mesa Verde
Well :	MWX-3	County :	Garfield
Field :	Rulison	State :	Colorado

NITRATES

Sample Number	Sample Type	Depth, feet	Nitrate, mg/l
9	Plug	6436.8-37.0	158.6
	Donut		117.9
10	Plug	6448.7-49.0	152.6
	Donut		176.5
11	Plug	6457.5-57.7	129.5
	Donut		66.5
12	Plug	6464.1-64.4	66.3
	Donut		130.4
13	Plug	6514.0-14.3	152.2
	Donut		123.9

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CORE LABORATORIES, INC.
2001 COMMERCE DRIVE
MIDLAND, TEXAS
(915) 694-7761

File P83012

VERTICAL PLUG AND DONUT DATA

Sample Number	Sample Type	Depth, feet	Vertical Perm., md	Porosity, Percent	Water Saturation Percent Pore Vol.
9	Plug	6436.8-37.0	L.T. 0.01	6.6	55.3
	Donut			6.4	57.8
10	Plug	6448.7-49.0	L.T. 0.01	5.3	34.6
	Donut			5.1	54.2
11	Plug	6457.5-57.7	0.03	8.2	47.6
	Donut			8.9	51.2
12	Plug	6464.1-64.4	L.T. 0.01	7.6	58.0
	Donut			7.9	55.6
13	Plug	6514.0-14.3	L.T. 0.01	7.0	40.9
	Donut			7.0	51.7

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CORE LABORATORIES, INC.
2001 COMMERCE DRIVE
MIDLAND, TEXAS
(915) 694-7761

File P83012

FILTRATE INVASION DATA

Sample Number	Sample Type	Depth, feet	Filtrate Percent Of Total Water	Filtrate Percent Of Pore Volume
9	Plug	6436.8-37.0	20.6	11.4
	Donut		15.3	8.8
10	Plug	6448.7-49.0	19.8	6.9
	Donut		22.9	12.4
11	Plug	6457.5-57.7	16.8	8.0
	Donut		8.6	4.4
12	Plug	6464.1-64.4	8.6	5.0
	Donut		16.9	9.4
13	Plug	6514.0-14.3	17.3	7.1
	Donut		14.1	7.3

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CORE LABORATORIES, INC.

Reservoir Fluid Analysis

File ARFL-850129

Company Sandia National Laboratories Formation Mesa Verde

Well MWX-1 ~6450ft (yellow coastal) County Garfield

Field State Colorado

HYDROCARBON ANALYSIS OF FLUID SAMPLE

Component	Mol Percent	Weight Percent	Density, Gm/Cc @ 60°F.	°API @ 60°F.	Molecular Weight
Hydrogen Sulfide	0.00	0.00			
Carbon Dioxide	0.00	0.00			
Nitrogen	0.00	0.00			
Methane	trace	0.00			
Ethane	0.10	0.03			
Propane	0.29	0.12			
iso-Butane	0.24	0.13			
n-Butane	0.22	0.12			
iso-Pentane	0.34	0.23			
n-Pentane	0.44	0.30			
Hexanes	4.55	3.58			
Heptanes	22.37	20.13			
Octanes	61.99	62.23			
Nonanes	5.71	6.48			
Decanes	0.52	0.66			
Undecanes plus	3.23	5.99	0.8277	39.3	198
	100.00	100.00			

Properties of Heptanes plus

Density gm/cc @ 60°F.	0.7462
°API @ 60°F.	57.9
Molecular Weight	109

Sampled on 8/12/85 at 15:30 hours.

Sample Number: 101

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1.2.35.011

CORE LABORATORIES, INC.
Reservoir Fluid Analysis

File ARFL-860115

Company Sandia National Laboratories
Formation Mesa Verde-Coastal (Red & Yellow
Well MWX-1
County Garfield
Field Rulison
State Colorado

HYDROCARBON ANALYSIS OF METER RUN GAS SAMPLE

Component	Mol Percent	GPM
Hydrogen Sulfide	0.00	
Carbon Dioxide	4.17	
Nitrogen	1.19	
Methane	86.99	
Ethane	5.51	1.503
Propane	1.22	0.343
iso-Butane	0.30	0.100
n-Butane	0.23	0.074
iso-Pentane	0.11	0.041
n-Pentane	0.08	0.030
Hexanes	0.09	0.036
Heptanes plus	0.11	0.049
	100.00	2.176

Calculated gas gravity (air = 1.000) = 0.654

Calculated gross heating value = 1065 BTU per cubic foot of dry gas at 15.025 psia and 60°F.

Collected at 250 psig on 6/2/86 at 10:00 hours.

CORE LABORATORIES, Inc.

Matthew W Ostrand

Matthew W. Ostrand
Reservoir Fluid Supervisor

MWO/sso
distribution

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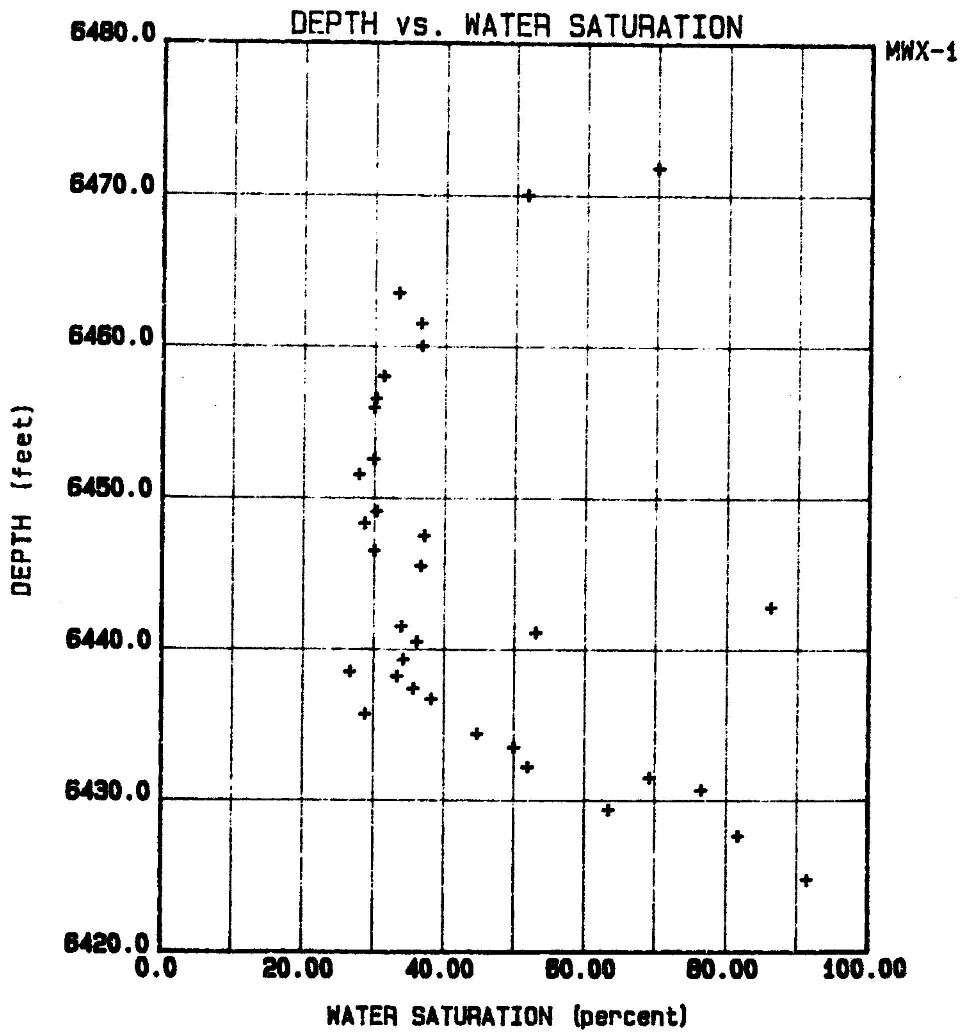

Sandia National Laboratories
Mesa Verde Formation
Rulison Field
Coastal Yellow Sand Zone (6424.8 - 6471.8)

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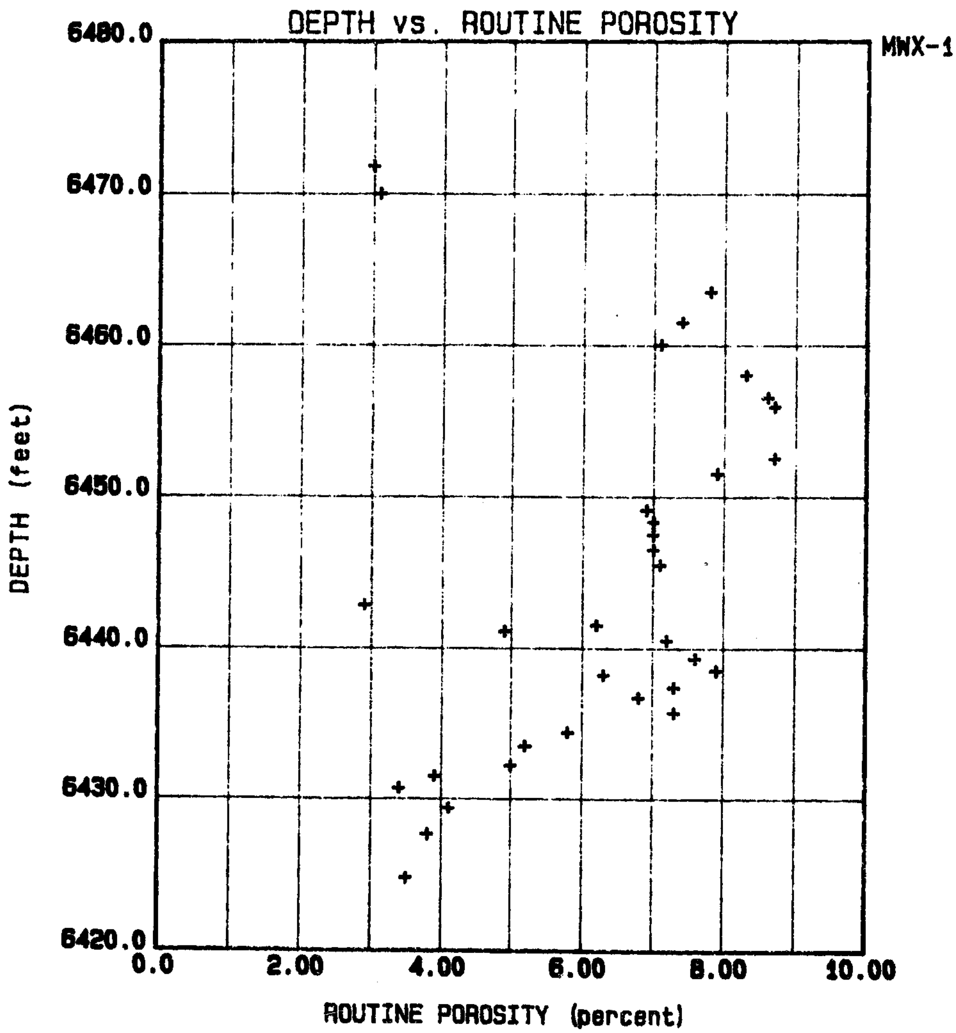

Sandia National Laboratories
Mesa Verde Formation
Rulison Field
Coastal Yellow Sand Zone (6424.8 - 6471.8)

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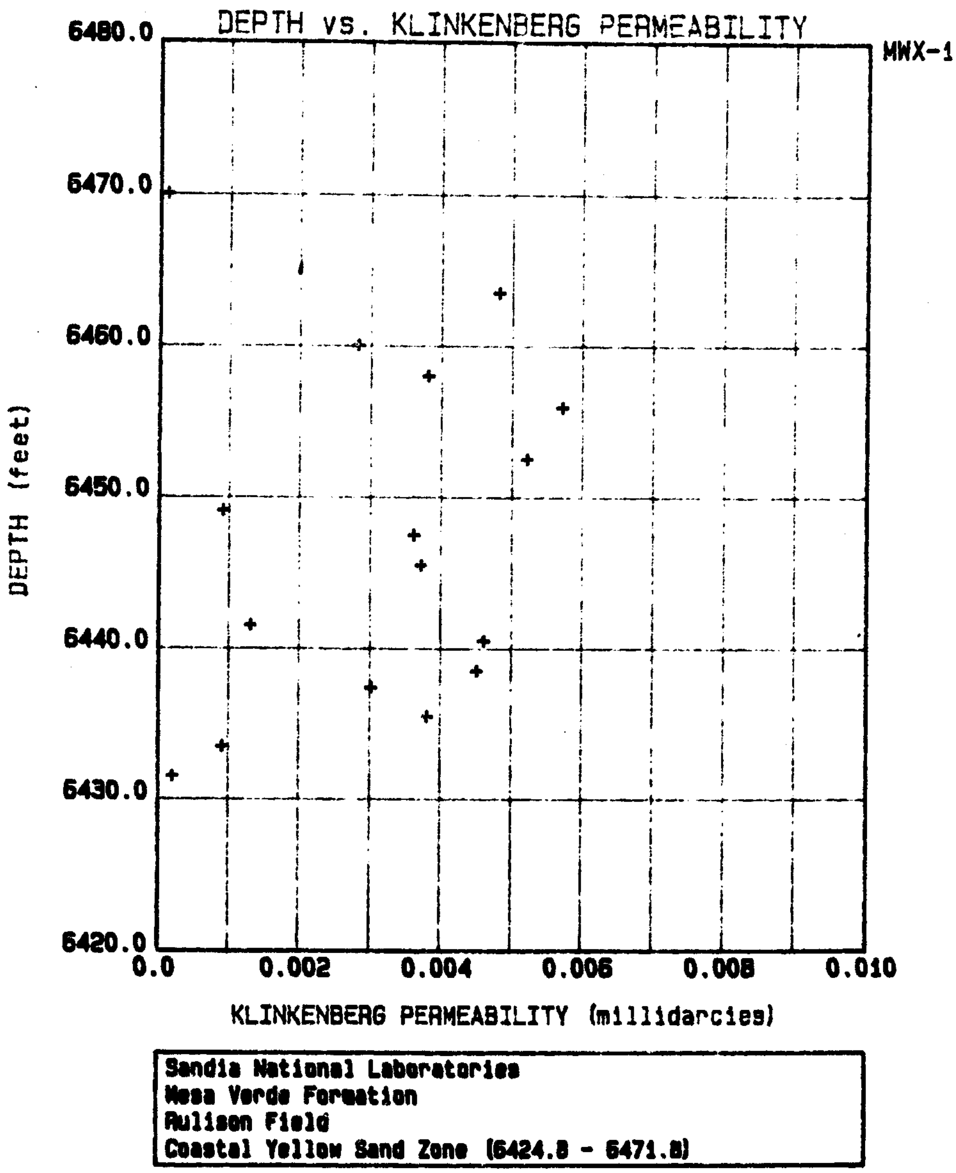

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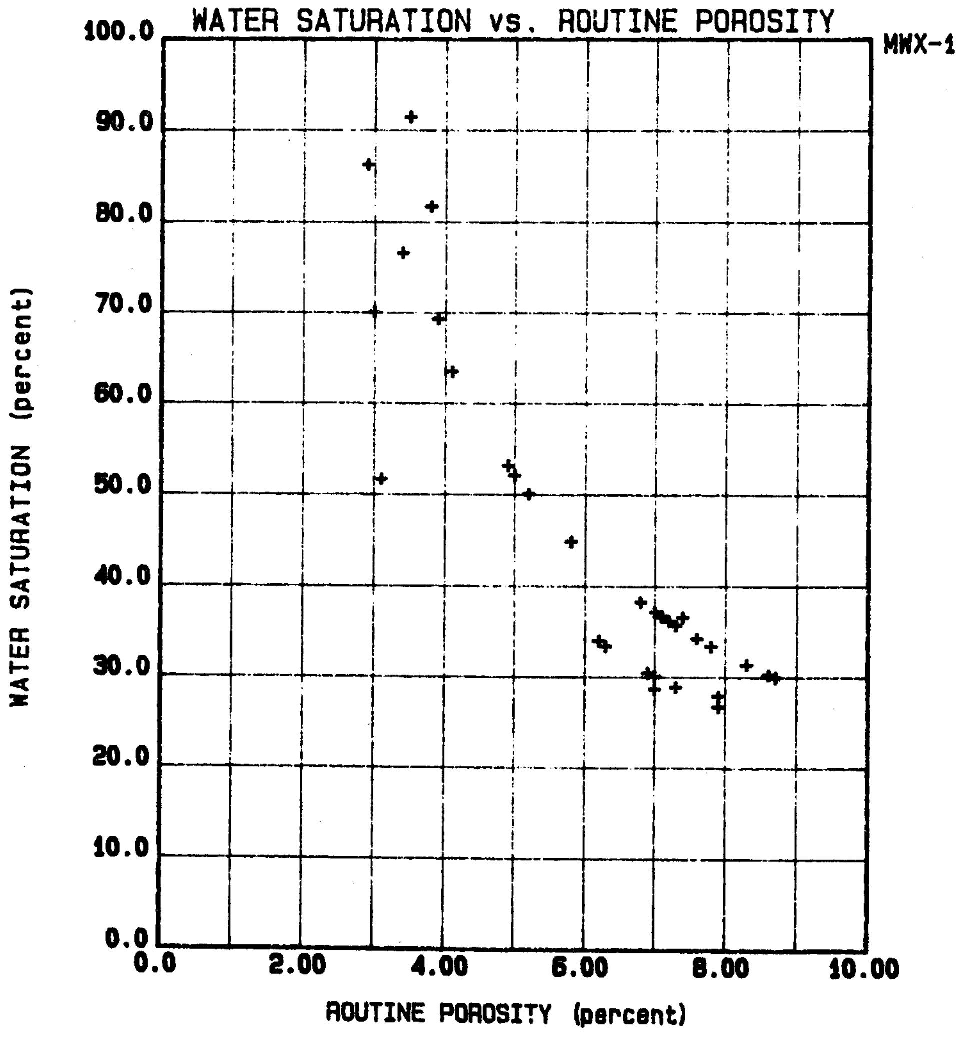

Sandia National Laboratories
Mesa Verde Formation
Rulison Field
Coastal Yellow Sand Zone (6424.8 - 6471.8)

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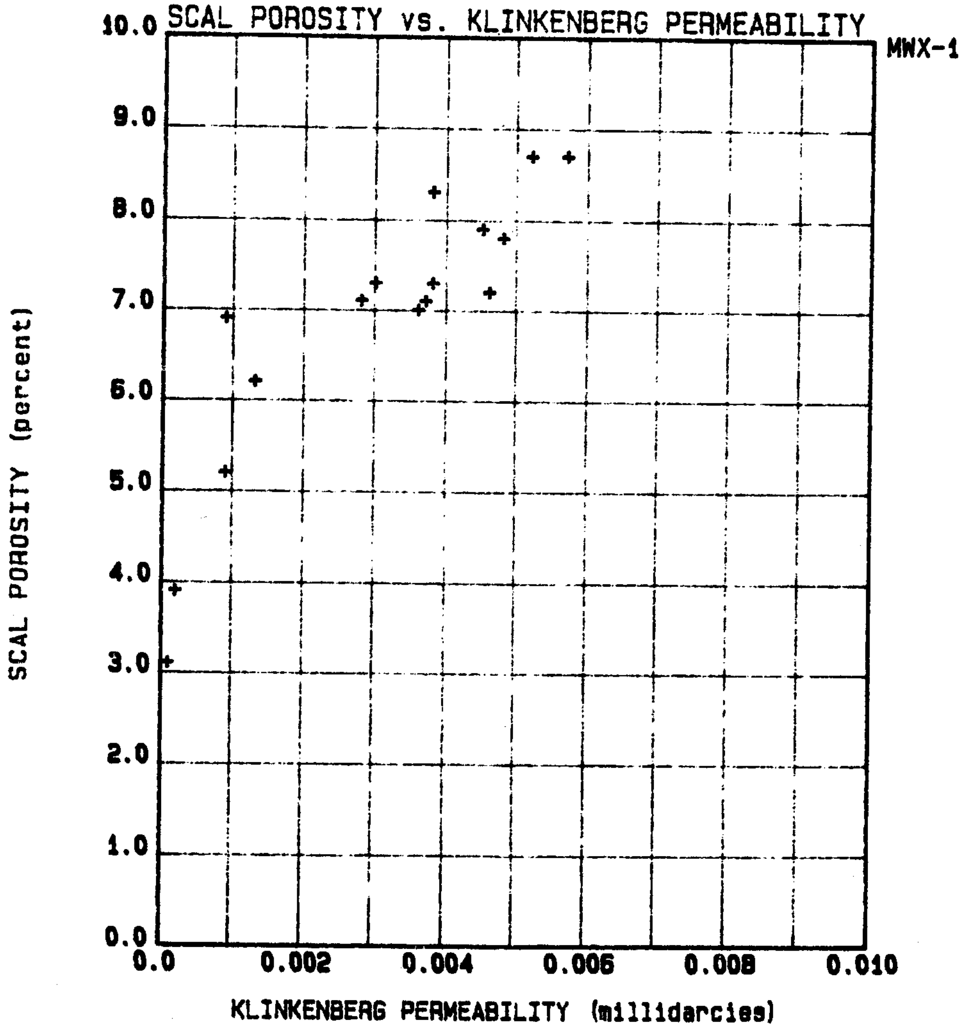

Sandia National Laboratories
Mesa Verde Formation
Rulison Field
Coastal Yellow Sand Zone (6424.8 - 6471.8)

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APPENDIX 11.5

INSTITUTE OF GAS TECHNOLOGY (IGT) DATA

APPENDIX 11.5

INSTITUTE OF GAS TECHNOLOGY (IGT) DATA

This appendix includes data resulting from IGT's permeability analyses. The analysis procedures and results are discussed in the following MWX Data File references:

1.2.12.002	1.2.12.006
1.2.12.003	1.2.12.011
1.2.12.004	1.2.12.013
1.2.12.005	1.2.12.019

Results are presented in the following order:

Well	Sample Number	Core Depth (ft)
MWX-1	40-11C	6421.0-6421.8
	40-14B	6433.7-6434.7
	41-01A	6441
	41-05	6453.5-6454.0
	41-10	6501.4-6502.2
	42-11	6567.3-6567.7
	42-20	6537.2-6538.3
	42-32	6546
MWX-2	50-05	6428.5-6429.3
	51-09	6503.1-6504.0
	51-20	6537.8-6538.4
	51-26	6548.5-6548.9
MWX-3	64-13	6446
	65-11	6514

A. SAMPLE INFORMATION: MWX # 1 RUN # 40 CODE 40 - 11 C

DEPTH: TOP 6421.0 FT BASE 6421.8 FT

LITHOLOGY SILTSTONE AND BLACK SILTY SHALE, THINLY LAMINATED TO THIN BEDDED. ELONGATE COALY FRAGMENTS COMMONLY OCCUR IN THE SHALY ZONES. ORIENTED, RUN UPRIGHT.

B. PERMEABILITY TESTS: DATE CORE WAS TRIMMED 5-24-82

TRIMMED CORE DIAMETER: 10.0 cm LENGTH: 17.6 cm

STATION IN MULTIPLE CORE TESTER: 12 BATCH # 1

DATE RUN WAS STARTED: 5-26-82 DURATION OF RUN 316 Hrs.

CONFINING PRESSURE: 1000 PSIG DIFFERENTIAL PRESSURE: 720 PSID

FLOW RATE: $< 10^{-4}$ CC/HR PERMEABILITY TO WATER: $< 1.16 \times 10^{-4}$ MD

C. THRESHOLD PRESSURE MEASUREMENT: CONFINING PRESSURE: 1000 PSIG

INITIAL GAS PRESSURE: 800 PSIG STABILIATION TIME: 41 HOURS

STABLE GAS PRESSURE: 750 PSIG = THRESHOLD PRESSURE

D. EFFECTIVE POROSITY: WEIGHT OF GLASS DISH: 26.141 g

CHIP DIMENSIONS: THICKNESS: 3.260 CM DIAM: 2.519 CM VOLUME: 16.253 cc

DRIED AT 50 °C AND 42 % RELATIVE HUMIDITY FOR 312 HOURS

CHIP + DISH	CHIP	DATE	TIME
68.612 g	*42.47	8-5	15:30
67.693	41.55	8-6	09:00
67.697	41.56	8-9	10:00
67.688	41.55	8-10	11:30
67.772	41.63	8-18	15:30

WATER CONTENT: 0.924 g x 1g/cc =

PORE VOLUME: 0.924 cc

$\frac{\text{PORE VOL.}}{\text{CHIP VOL.}} \times 100 =$ 5.68 % POROSITY

* SATURATED WEIGHT

IGT

MULTIWELL PROJECT : SANDSTONE SCREENING TESTS

SAMPLE INFORMATION: MWX# 1 RUN# 40 C.E.R. CODE 40 - 14B

DEPTH: TOP 6433.7 ft BASE 6434.7 ft LENGTH 1.0 ft

LITHOLOGY: MEDIUM FINE SANDSTONE, THICK BEDDED WITH POORLY-DEVELOPED SECONDARY LAMINAE (POSSIBLY CROSS LAMINATION). TINY COALY(?) FRAGMENTS ARE DISPERSED THROUGHOUT THE MATRIX. ORIENTED.

AS-RECEIVED WATER SATURATION:

DATE	TIME	CHIP WEIGHT (g)
6-6	15:00	529.52 ← Initial weight
6-8	11:10	527.35
6-11	12:25	525.45 DRY
6-22	16:30	525.7 FINAL

DRIED AT 60 °C AND 45 % RELATIVE HUMIDITY.

WATER CONTENT OF CHIP: 4.07 g

PORE VOLUME OCCUPIED BY WATER: 34.80%

PLUG INFORMATION: DIAMETER 2.540 cm LENGTH 5.182 cm

DEPTH 6434.1 ft ORIENTATION 90° W OF PRIME N 22° W

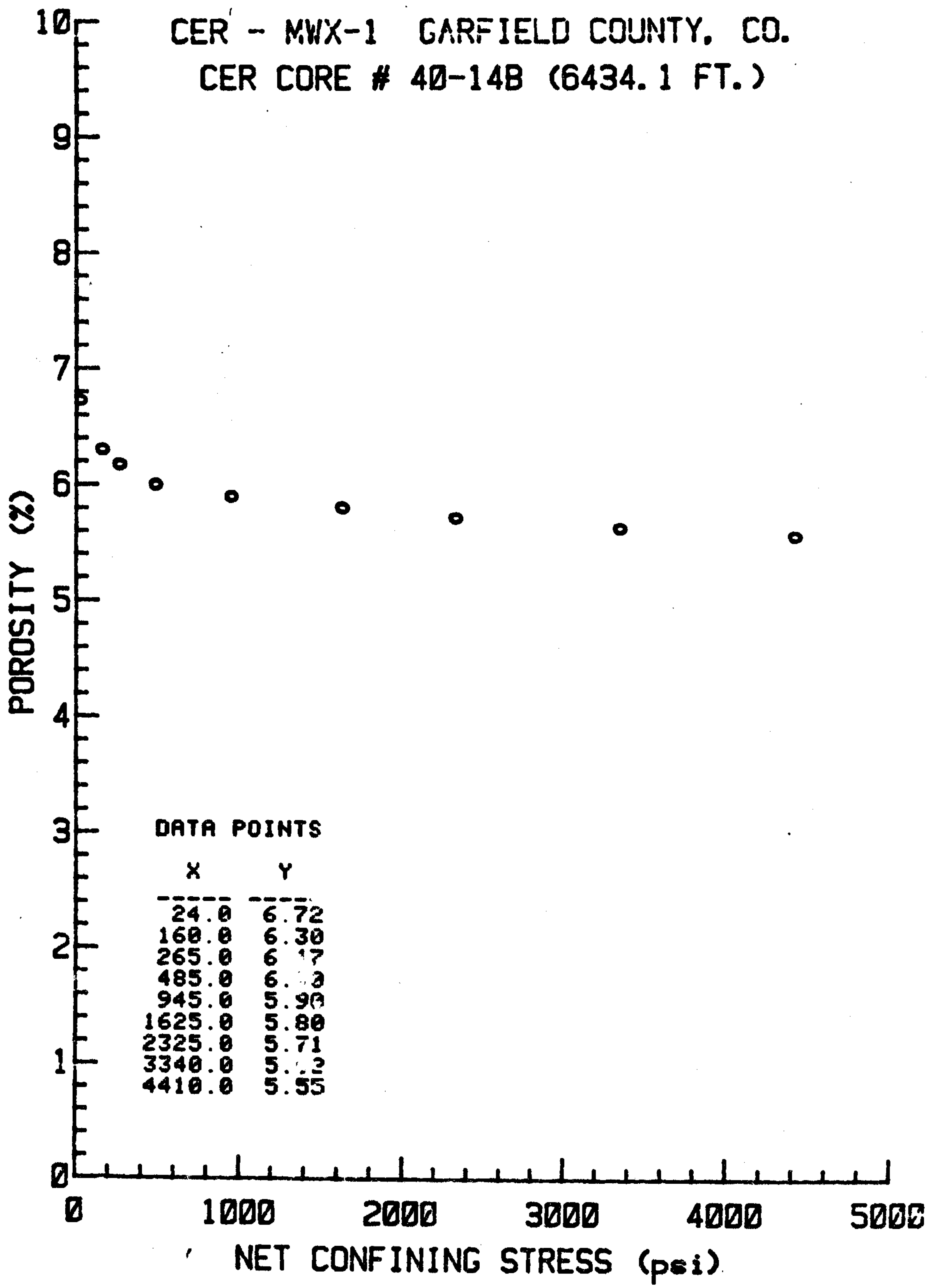
DATE CUT 6-6-82 DRIED AT 60 °C AND 45 % RELATIVE HUMIDITY.

WET WEIGHT 65.525 g DRY WEIGHT 65.497 g VOLUME 26.258 cc

GAS POROSITY UNDER NET CONFINING STRESS 5.55 % TESTING COMPLETE 7-2-82

WEIGHT HISTORY OF PLUG: * WEIGHT AFTER TESTING

DATE	TIME	WEIGHT	DATE	TIME	WEIGHT	
6-8	11:40	65.514	6-28	19:23	65.510	
6-10	18:05	65.512	7-2	23:35	65.524	*
6-11	12:15	65.497				
6-17	10:12	65.518				
6-21	10:00	65.525				
6-24	15:00	65.500				



DATA POINTS

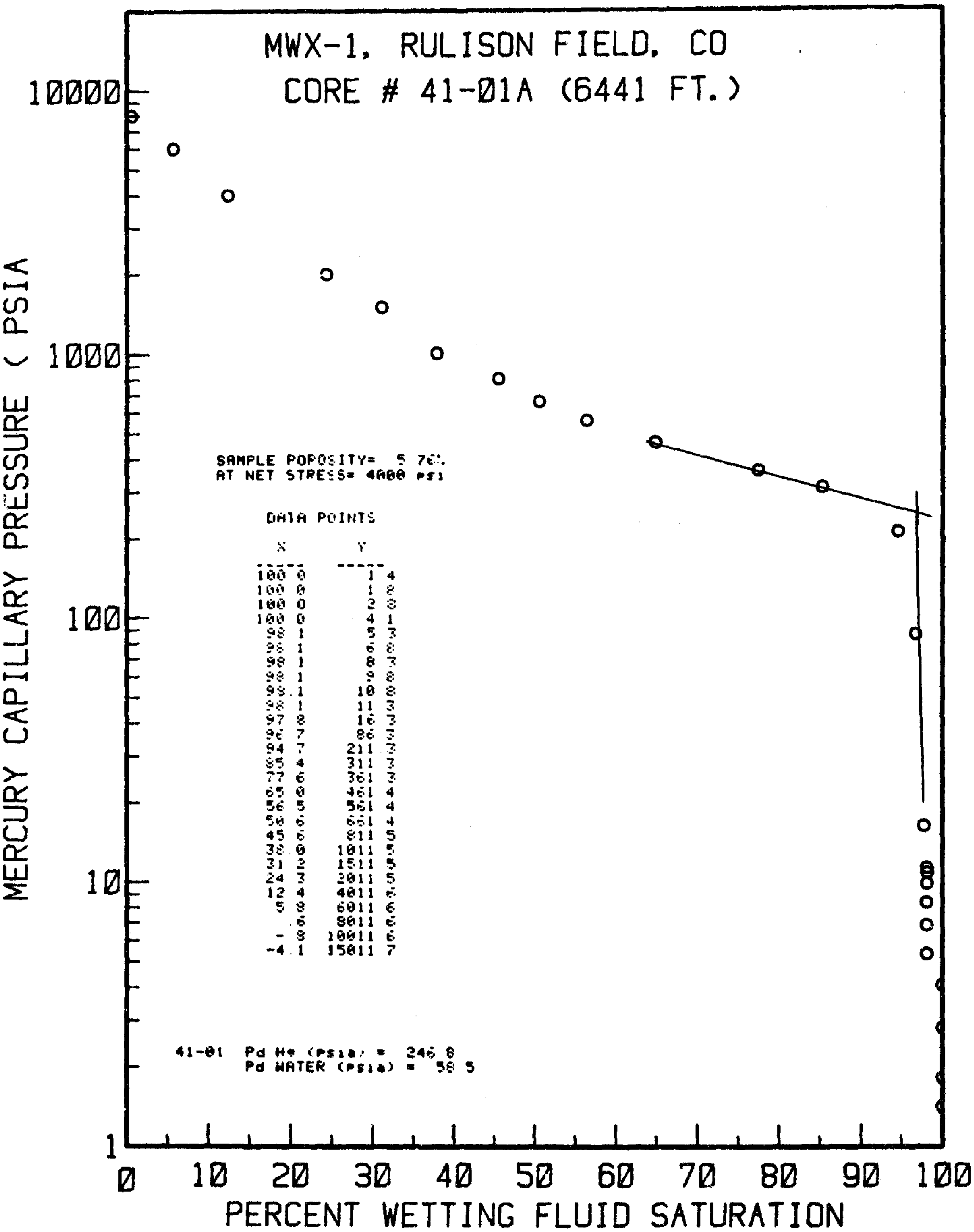
X	Y
24.0	6.72
160.0	6.30
265.0	6.[illegible]7
485.0	6.[illegible]0
945.0	5.90
1625.0	5.80
2325.0	5.71
3340.0	5.[illegible]
4410.0	5.55

INSTITUTE OF GAS TECHNOLOGY

********** WELL NAME:CER - MWX-1 GARFIELD COUNTY, CO. **********

PLUG: CER CORE # 40-14B (6434.1 FT.) PLUG LENTH: 5.182 CM PLUG AREA: 5.067 CM^2

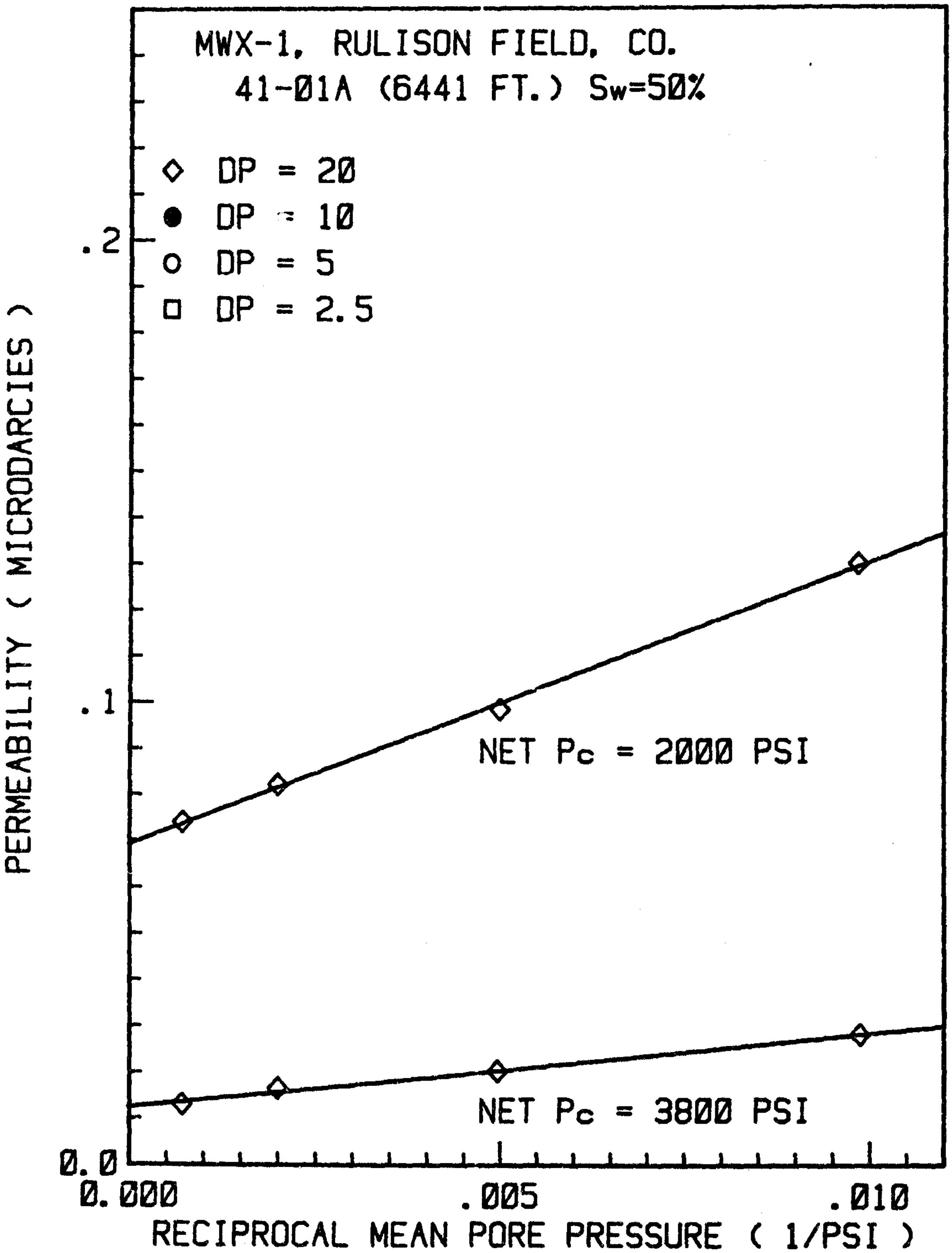
TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY [STD.DEV.] (MICRODARCY)	NO. OF MEAS
06-30	07:57	02:00	4281	50.64	19.64	5.61E-004	90.00	0.01814	0.9994	2.13 [0.10]	24
06-30	10:12	04:00	4251	50.35	9.97	2.90E-004	90.01	0.01814	0.9994	2.18 [0.06]	24
06-30	16:40	02:21	4452	100.72	19.81	7.42E-004	90.01	0.01818	0.9989	1.41 [0.04]	29
06-30	19:02	00:01	4440	100.81	19.65	6.53E-004	90.00	0.01818	0.9989	1.25 [0.00]	1
06-30	19:30	02:52	4425	100.41	9.89	3.71E-004	90.01	0.01818	0.9989	1.42 [0.01]	19
06-30	22:33	16:00	4375	100.30	4.46	1.67E-004	90.01	0.01818	0.9989	1.42 [0.05]	27
07-01	08:30	01:50	4599	200.09	9.39	5.17E-004	90.00	0.01826	0.9979	1.05 [0.06]	14
07-01	13:09	02:57	4563	199.93	4.74	2.56E-004	90.00	0.01826	0.9979	1.03 [0.04]	11
07-01	17:06	05:03	4415	50.23	9.45	2.69E-004	90.00	0.01814	0.9994	2.15 [0.07]	27
07-01	22:20	07:00	4374	50.11	4.66	1.31E-004	90.00	0.01814	0.9994	2.13 [0.07]	19
07-02	08:25	05:25	4323	25.19	4.74	1.11E-004	90.00	0.01812	0.9996	3.52 [0.13]	13


MWX-1, RULISON FIELD, CO
CORE # 41-01A (6441 FT.)
10000
1000
100
10
1
MERCURY CAPILLARY PRESSURE (PSIA
SAMPLE POROSITY= 5 76%
AT NET STRESS= 4000 psi
DATA POINTS
X Y
100 0 1 4
100 0 1 8
100 0 2 8
100 0 4 1
98 1 5 3
98 1 6 8
98 1 8 3
98 1 9 8
99.1 10 8
98 1 11 3
97 8 16 3
96 7 86 3
94 7 211 3
85 4 311 3
77 6 361 3
65 0 461 4
56 5 561 4
50 6 661 4
45 6 811 5
38 0 1011 5
31 2 1511 5
24 3 2011 5
12 4 4011 5
5 8 6011 6
.6 8011 6
- 8 10011 6
-4.1 15011 7
41-01 Pd He (psia) = 246 8
Pd WATER (psia) = 58 5
0 10 20 30 40 50 60 70 80 90 100
PERCENT WETTING FLUID SATURATION

********** WELL NAME: MWX-1, RULISON FIELD, CO. **********

PLUG: 41-01A (6441 FT.) Sw-50% PLUG LENGTH: 3.970 CM PLUG AREA: 5.057 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	PERMEABILITY STD. DEV. (%)
04-15	17:15	15:00	2094	101.73	21.21	8.38E-005	94.00	0.01852	0.9992	1.30E-001	(3.0)
04-16	17:12	14:00	2214	200.51	20.63	1.21E-004	94.00	0.01857	0.9987	9.85E-002	(3.7)
04-18	10:20	08:00	2497	500.94	20.76	2.51E-004	94.00	0.01880	0.9982	8.21E-002	(4.3)
04-19	11:22	07:00	3400	1399.96	19.37	5.54E-004	94.00	0.02010	1.0083	7.41E-002	(6.9)
04-19	21:15	15:00	4296	1400.21	19.89	2.77E-004	94.00	0.02010	1.0084	3.61E-002	(8.3)
04-20	18:00	42:00	5207	1399.77	19.72	9.96E-005	94.00	0.02009	1.0083	1.31E-002	(9.5)
04-23	19:40	37:00	4300	500.75	21.05	5.13E-005	94.00	0.01880	0.9982	1.65E-002	(15.4)
04-27	21:30	32:00	4000	201.59	21.37	2.61E-005	94.00	0.01857	0.9986	2.03E-002	(6.1)
05-01	20:40	36:00	3895	101.39	21.87	1.86E-005	94.00	0.01852	0.9992	2.81E-002	(6.2)

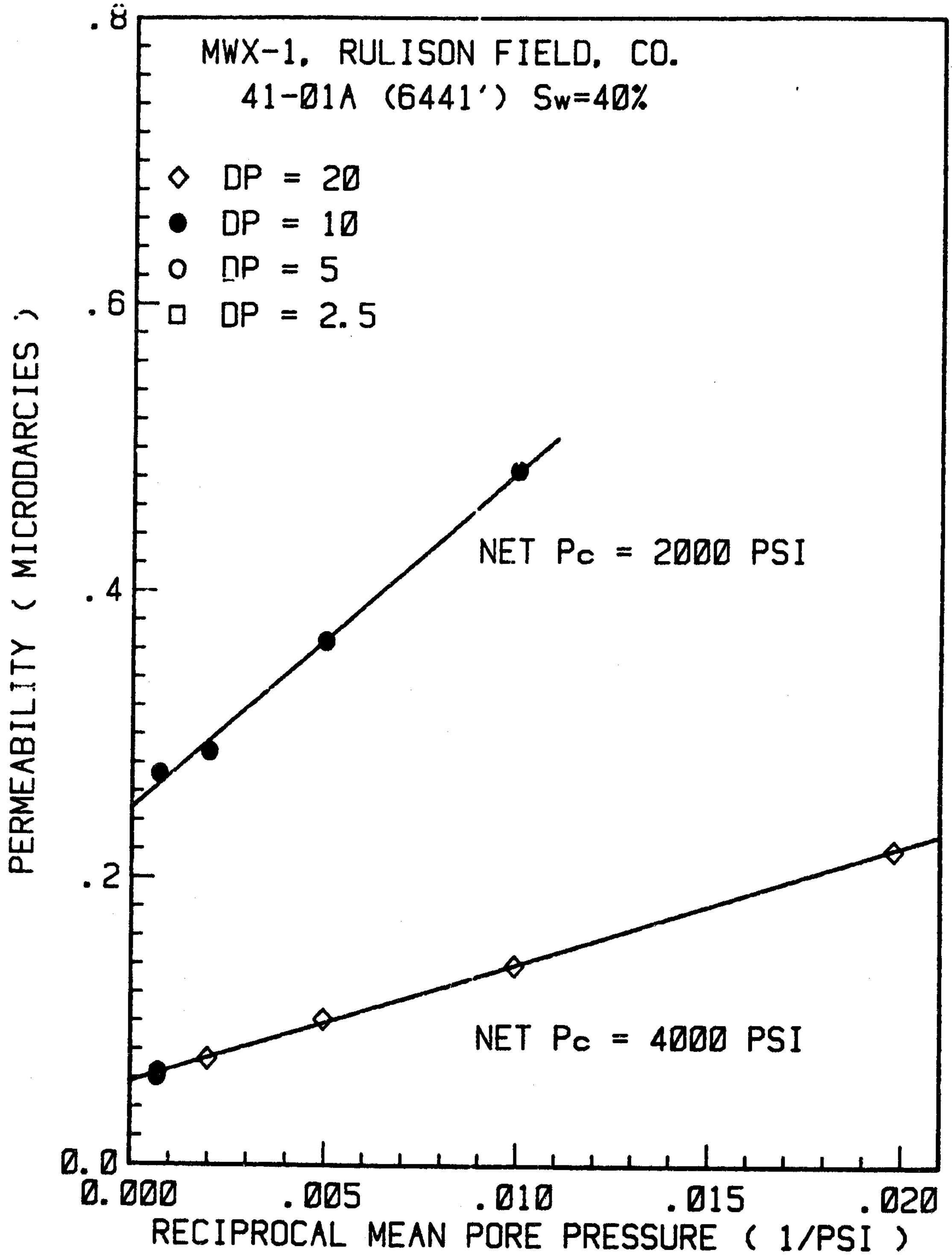


MWX-1, RULISON FIELD, CO.
41-01A (6441 FT.) Sw=50%
DP = 20
DP = 10
DP = 5
DP = 2.5
NET Pc = 2000 PSI
NET Pc = 3800 PSI
PERMEABILITY (MICRODARCIES)
.2
.1
0.0
0.000
.005
.010
RECIPROCAL MEAN PORE PRESSURE (1/PSI)

********** WELL NAME: MWX-1, RULISON FIELD, CO. **********

PLUG: 41-01A (6441') Sw=40% PLUG LENGTH: 3.970 CM PLUG AREA: 5.057 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	PERMEABILITY STD. DEV. (%)
05-04	09:37	08:15	2095	100.14	10.65	1.54E-004	94.00	0.01852	0.9992	4.84E-001	(3.2)
05-05	14:54	06:00	2191	200.41	10.58	2.31E-004	94.00	0.01857	0.9987	3.65E-001	(2.7)
05-06	14:00	05:45	2517	499.56	10.82	4.58E-004	94.00	0.01880	0.9982	2.88E-001	(3.1)
05-07	09:30	03:30	3397	1400.44	11.28	1.18E-003	94.00	0.02010	1.0084	2.72E-001	(2.6)
05-07	15:48	05:06	4398	1400.45	10.85	5.07E-004	94.00	0.02010	1.0084	1.21E-001	(9.0)
05-08	00:00	14:03	5407	1400.21	10.56	2.62E-004	94.00	0.02010	1.0084	6.45E-002	(8.1)
05-09	03:15	14:50	5477	1450.73	11.60	2.81E-004	94.00	0.02019	1.0094	6.09E-002	(10.3)
05-10	15:07	05:30	4515	501.45	20.88	2.26E-004	94.00	0.01880	0.9982	7.35E-002	(6.9)
05-11	13:50	22:33	4199	201.31	21.41	1.30E-004	94.00	0.01857	0.9986	1.01E-001	(3.9)
05-14	12:15	20:15	4097	100.57	19.71	8.24E-005	94.00	0.01852	0.9992	1.39E-001	(4.2)
05-15	21:00	17:45	4049	50.51	19.73	6.54E-005	94.00	0.01851	0.9996	2.19E-001	(2.9)

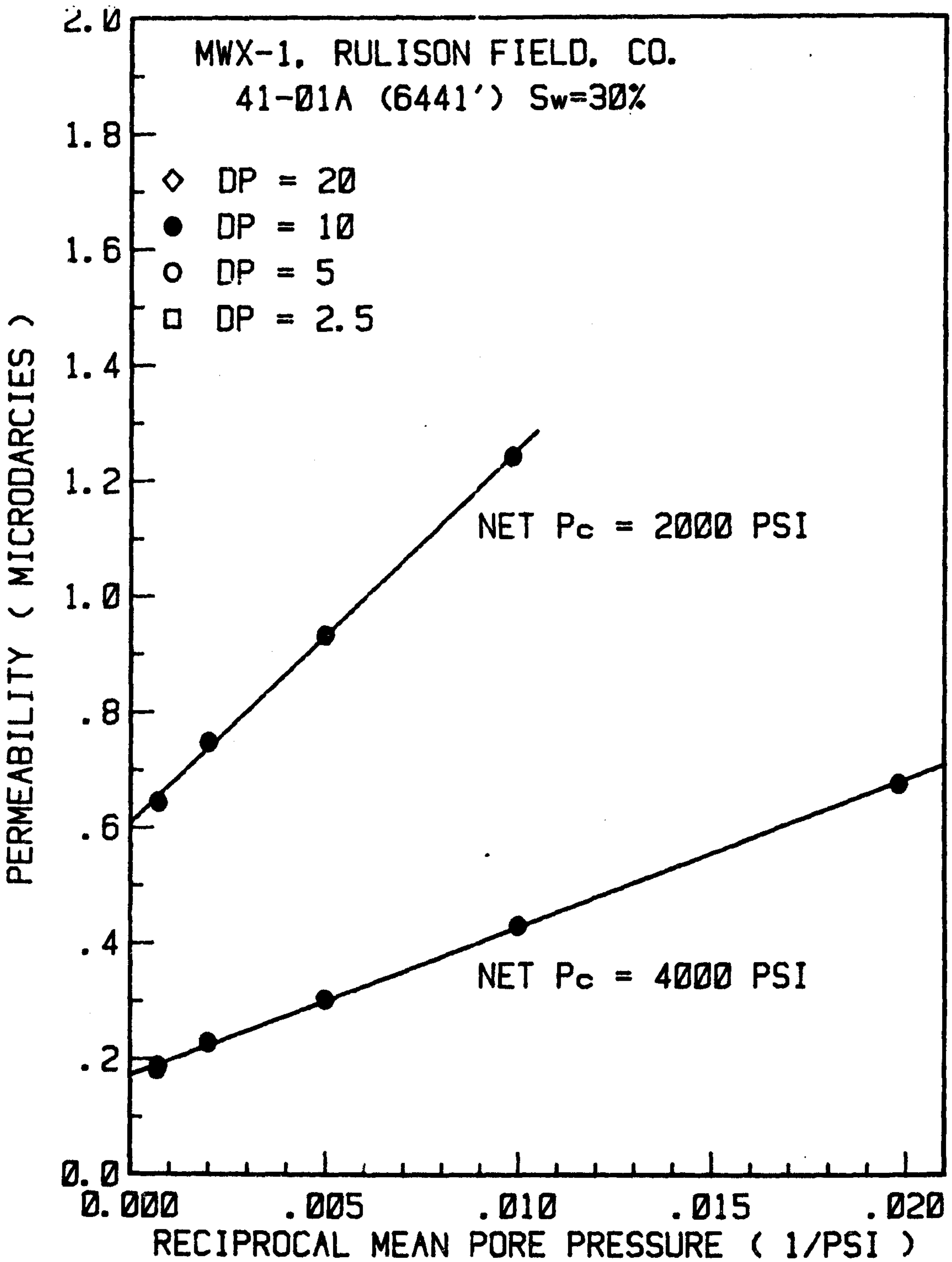


MWX-1, RULISON FIELD, CO.
41-01A (6441') Sw=40%
DP = 20
DP = 10
DP = 5
DP = 2.5
NET Pc = 2000 PSI
NET Pc = 4000 PSI
PERMEABILITY (MICRODARCIES)
RECIPROCAL MEAN PORE PRESSURE (1/PSI)
.8
.6
.4
.2
0.0
0.000
.005
.010
.015
.020

********** WELL NAME: MWX-1, RULISON FIELD, CO. **********

PLUG: 41-01A (6441') Sw=30% PLUG LENGTH: 3.970 CM PLUG AREA: 5.057 CM^2

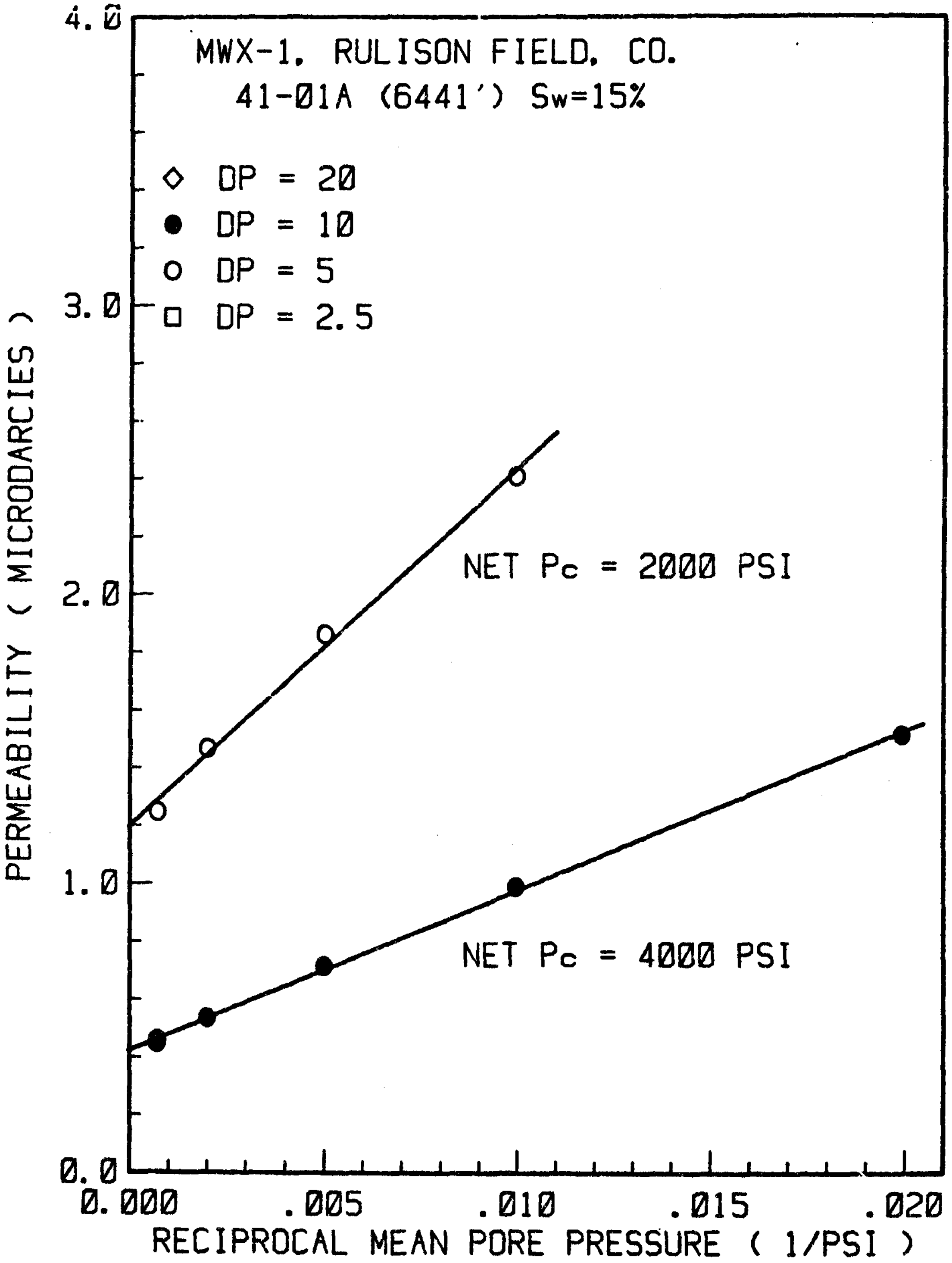
TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	PERMEABILITY STD. DEV. (%)
05-18	08:35	04:35	2095	101.55	10.18	3.84E-004	94.00	0.01852	0.9992	1.24E+000	(1.0)
05-18	15:32	02:32	2199	200.53	10.31	5.74E-004	94.00	0.01857	0.9987	9.32E-001	(1.1)
05-19	13:57	02:21	2500	499.52	10.07	1.11E-003	94.00	0.01880	0.9982	7.48E-001	(.8)
05-21	15:24	03:42	3398	1398.64	9.34	2.32E-003	94.00	0.02009	1.0083	6.44E-001	(1.0)
05-21	20:04	12:19	4398	1399.17	9.26	1.16E-003	94.00	0.02009	1.0083	3.26E-001	(2.3)
05-22	09:30	05:48	5400	1399.62	9.68	6.99E-004	94.00	0.02009	1.0083	1.87E-001	(5.5)
05-23	18:48	13:30	5443	1449.66	9.31	6.70E-004	94.00	0.02019	1.0094	1.81E-001	(5.7)
05-25	10:22	08:38	4497	500.58	9.65	3.25E-004	94.00	0.01880	0.9982	2.29E-001	(9.7)
05-28	13:30	19:10	4197	200.66	9.82	1.78E-004	94.00	0.01857	0.9987	3.03E-001	(2.9)
05-30	17:36	14:12	4091	100.08	9.65	1.24E-004	94.00	0.01852	0.9992	4.30E-001	(2.0)
05-31	18:30	14:01	4053	50.46	9.60	9.77E-005	94.00	0.01851	0.9996	6.75E-001	(1.5)


MWX-1, RULISON FIELD, CO.
41-01A (6441') Sw=30%
DP = 20
DP = 10
DP = 5
DP = 2.5
NET Pc = 2000 PSI
NET Pc = 4000 PSI
PERMEABILITY (MICRODARCIES)
RECIPROCAL MEAN PORE PRESSURE (1/PSI)
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0.0
0.000
.005
.010
.015
.020

********** WELL NAME: MWX-1, RULISON FIELD, CO. **********

PLUG: 41-01A (6441') Sw 15%   PLUG LENGTH: 3.970 CM   PLUG AREA: 5.057 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	STD. DEV. (%)
06-04	10:40	03:25	2097	100.59	5.04	3.65E-004	94.00	0.01852	0.9992	2.41E+000	(1.5)
06-05	09:20	04:40	2199	199.92	5.05	5.60E-004	94.00	0.01857	0.9987	1.86E+000	(.9)
06-06	09:15	03:27	2499	500.40	4.90	1.06E-003	94.00	0.01880	0.9982	1.47E+000	(1.3)
06-07	15:10	02:14	3400	1399.78	4.64	2.23E-003	94.00	0.02009	1.0083	1.25E+000	(2.6)
06-08	09:00	02:48	4400	1400.22	5.20	1.48E-003	94.00	0.02010	1.0084	7.36E-001	(3.0)
06-08	12:54	05:00	5395	1400.11	4.76	8.22E-004	94.00	0.02010	1.0083	4.48E-001	(3.9)
06-09	22:27	03:05	5392	1399.10	10.14	1.80E-003	94.00	0.02009	1.0083	4.60E-001	(3.1)
06-11	09.21	03:51	4499	500.87	9.90	7.79E-004	94.00	0.01880	0.9982	5.33E-001	(1.5)
06-12	09:24	04:14	4199	200.49	9.92	4.23E-004	94.00	0.01857	0.9987	7.12E-001	(1.1)
06-13	09:30	04:25	4100	100.47	9.79	2.90E-004	94.00	0.01852	0.9992	9.87E-001	(1.5)
06-14	09:42	05:00	4050	50.22	10.12	2.30E-004	94.00	0.01851	0.9996	1.51E+000	(2.1)

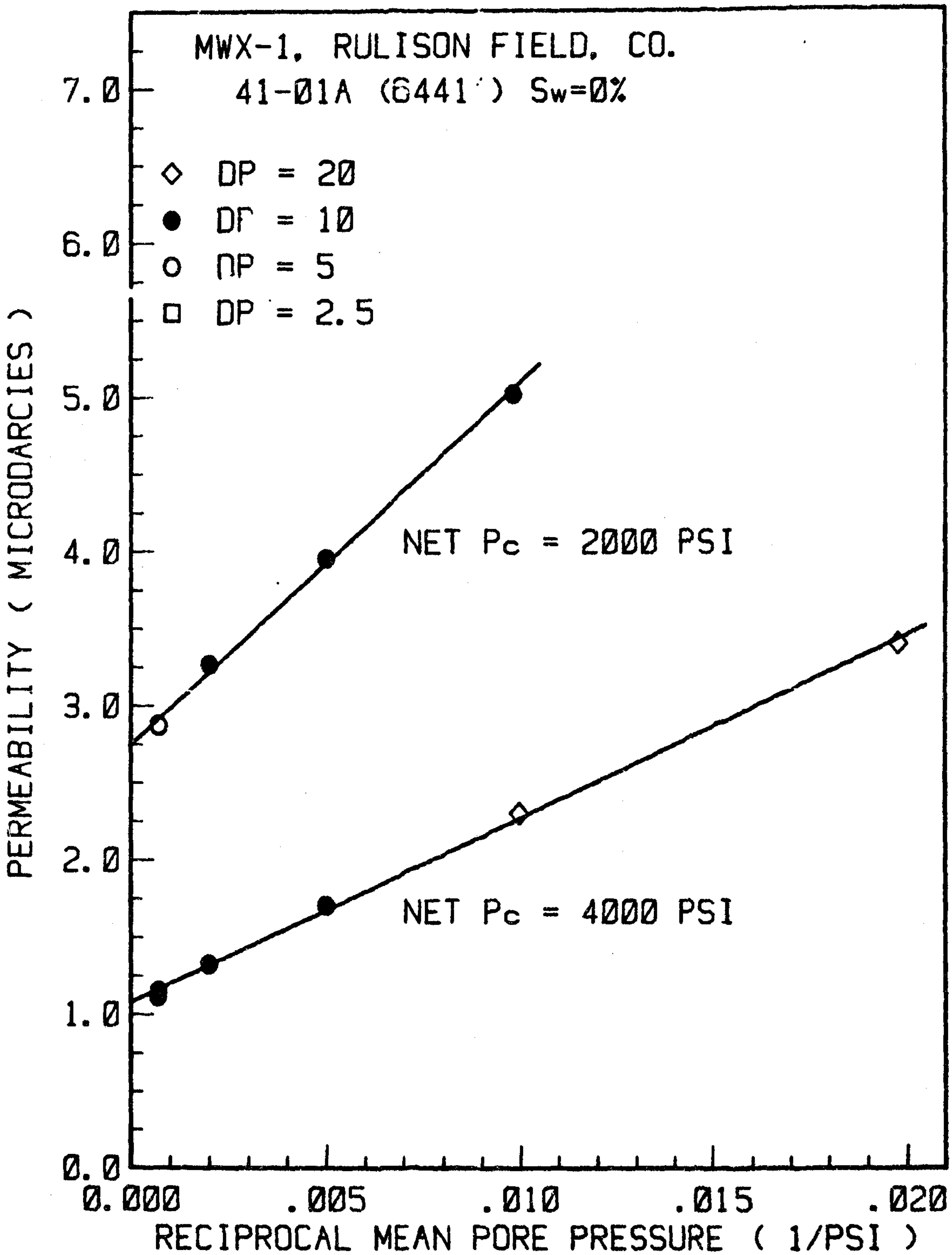


MWX-1, RULISON FIELD, CO.
41-01A (6441') Sw=15%
DP = 20
DP = 10
DP = 5
DP = 2.5
NET Pc = 2000 PSI
NET Pc = 4000 PSI
PERMEABILITY (MICRODARCIES)
0.0
1.0
2.0
3.0
4.0
0.000
.005
.010
.015
.020
RECIPROCAL MEAN PORE PRESSURE (1/PSI)

********** WELL NAME: MWX-1, RULISON FIELD, CO. **********

PLUG: 41-01A (6441') Sw=0% PLUG LENGTH: 3.970 CM PLUG AREA: 5.057 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	PERMEABILITY STD. DEV. (%)
06-19	10:03	01:15	2100	101.94	10.28	1.57E-003	94.00	0.01852	0.9992	5.02E+000	(1.9)
06-19	14:26	01:23	2203	200.40	9.97	2.35E-003	94.00	0.01857	0.9987	3.95E+000	(1.6)
06-20	08:59	01:49	2502	500.06	8.16	3.92E-003	94.00	0.01880	0.9982	3.26E+000	(1.4)
06-20	16:45	01:24	3398	1399.45	4.49	4.96E-003	94.00	0.02009	1.0083	2.87E+000	(1.0)
06-21	09:15	01:21	3402	1399.66	4.82	5.34E-003	94.00	0.02009	1.0083	2.87E+000	(1.4)
06-21	11:04	02:26	4398	1399.87	4.62	3.07E-003	94.00	0.02010	1.0083	1.73E+000	(1.2)
06-21	14:12	02:00	5404	1402.34	8.93	3.97E-003	94.00	0.02010	1.0084	1.15E+000	(.9)
06-22	17:12	01:13	5451	1449.39	9.99	4.41E-003	94.00	0.02019	1.0094	1.11E+000	(1.1)
06-23	10:37	02:37	4500	501.91	10.04	1.96E-003	94.00	0.01880	0.9982	1.32E+000	(1.2)
06-25	09:14	01:42	4202	200.40	10.49	1.07E-003	94.00	0.01857	0.9987	1.70E+000	(1.3)
06-25	15:51	01:04	4101	100.44	19.53	1.34E-003	94.00	0.01852	0.9992	2.29E+000	(1.3)
06-26	09:07	01:28	4049	50.62	19.69	1.01E-003	94.00	0.01851	0.9996	3.39E+000	(1.4)



MWX-1, RULISON FIELD, CO.
41-01A (6441') Sw=0%
DP = 20
DP = 10
DP = 5
DP = 2.5
NET Pc = 2000 PSI
NET Pc = 4000 PSI
PERMEABILITY (MICRODARCIES)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.000
.005
.010
.015
.020
RECIPROCAL MEAN PORE PRESSURE (1/PSI)

IGT MULTIWELL PROJECT : SANDSTONE SCREENING TESTS

SAMPLE INFORMATION: MWX# 1 RUN# 41 C.E.R. CODE 41 - 05

DEPTH: TOP 6453.5 ft BASE 6454.0 ft LENGTH 0.5 ft

LITHOLOGY: MEDIUM COARSE SANDSTONE, THINLY LAMINATED TO THIN BEDDED, CROSS-LAMINATED IN PLACES. COALY LAMINAE, LENSES AND CLASTS OCCUR THROUGHOUT; SOME OF THE COAL IS PYRITIC. ORIENTED.

AS-RECEIVED WATER SATURATION:

DATE	TIME	CHIP WEIGHT (g)	
6-30	16:15	705.5	← Initial weight
7-6	12:00	698.5	
7-8	15:50	698.6	
7-12	15:00	698.2 FINAL	DRY

DRIED AT 50 °C AND 42 % RELATIVE HUMIDITY.

WATER CONTENT OF CHIP: 7.3 g

PORE VOLUME OCCUPIED BY WATER: 36.35%

PLUG INFORMATION: DIAMETER 2.535 cm LENGTH 5.494 cm

DEPTH 6453.7 ft ORIENTATION 90° W OF PRIME N 82° E

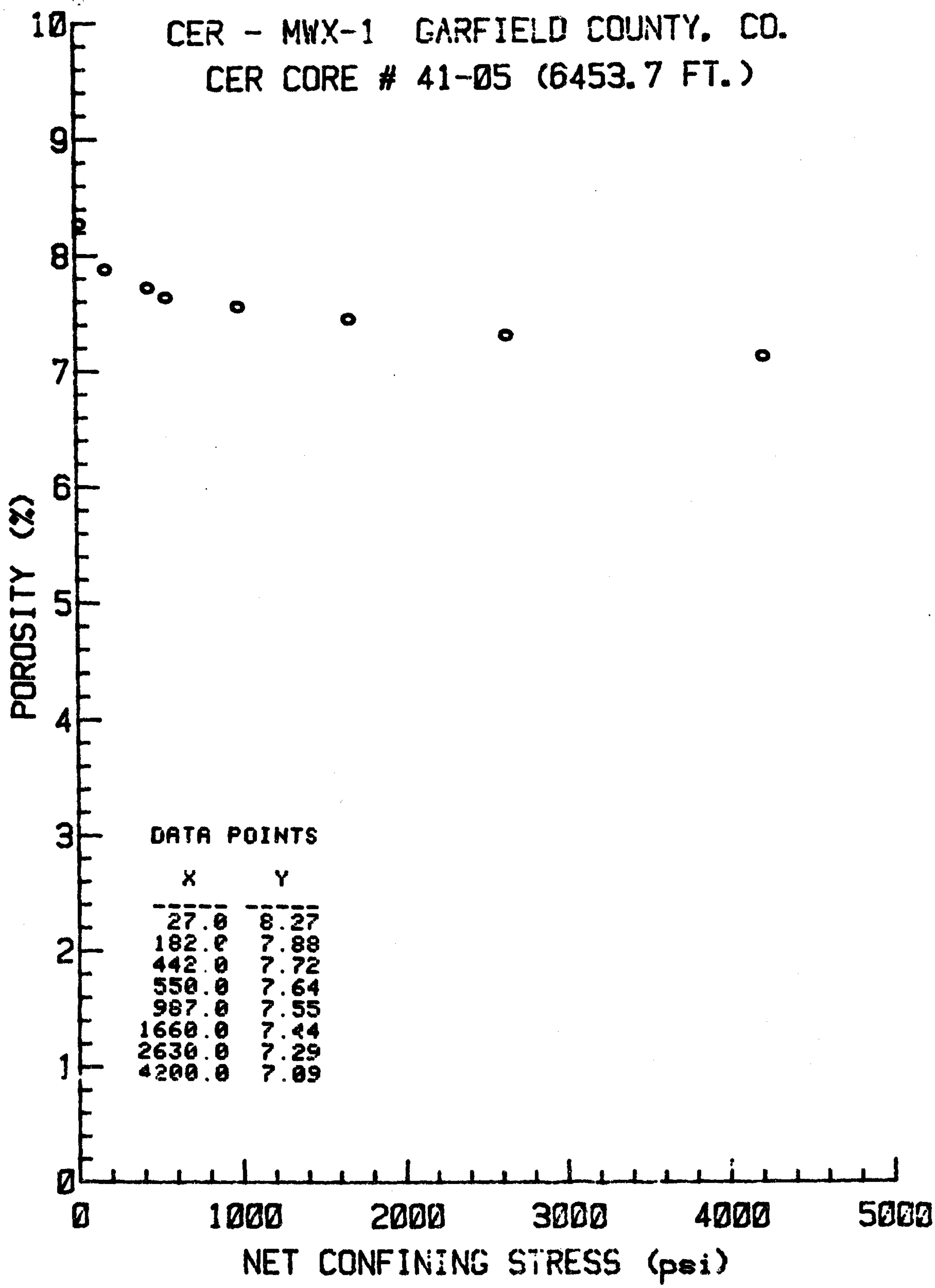
DATE CUT 6-30-82 DRIED AT 60 °C AND 45 % RELATIVE HUMIDITY.

WET WEIGHT 68.373 g DRY WEIGHT 68.357 g VOLUME 27.729 cc

GAS POROSITY UNDER NET CONFINING STRESS 7.09 % TESTING COMPLETE 7-10-82

WEIGHT HISTORY OF PLUG: * WEIGHT AFTER TESTING

	DATE	TIME	WEIGHT	DATE	TIME	WEIGHT
	7-1	18:00	68.373			
	7-2	18:00	68.368			
	7-6	11:00	68.357			
	7-6	18:26	68.344			
*	7-10	00:12	68.378			



DATA POINTS

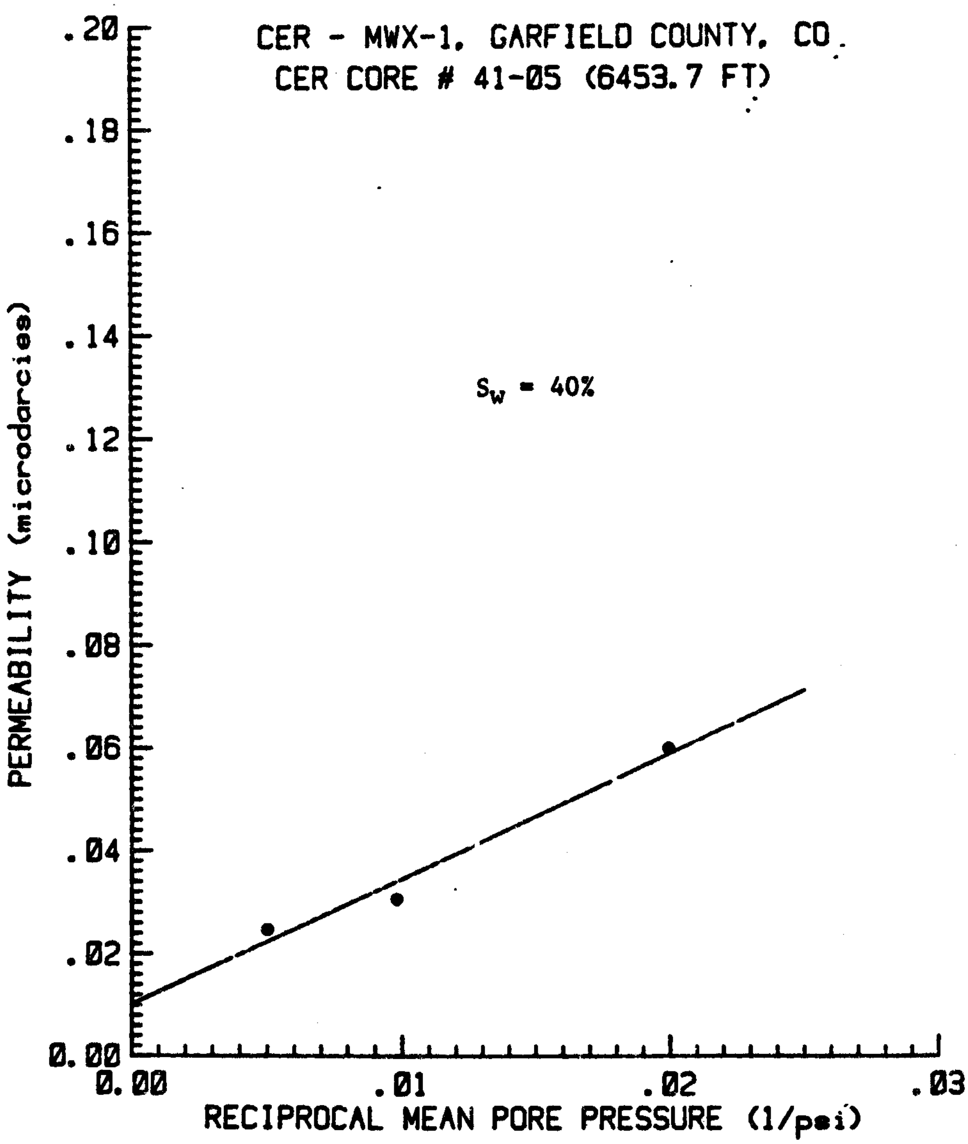
X	Y
27.0	8.27
182.0	7.88
442.0	7.72
550.0	7.64
987.0	7.55
1660.0	7.44
2630.0	7.29
4200.0	7.09

INSTITUTE OF GAS TECHNOLOGY

********** WELL NAME:CER - MWX-1 GARFIELD COUNTY, CO. **********

PLUG: CER CORE # 41-05 (6453.7 FT.) PLUG LENTH: 5.494 CM PLUG AREA: 5.047 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY (STD.DEV.) (MICRODARCY)	NO. OF MEAS
07-08	00:05	09:55	4464	99.91	5.00	2.63E-004	90.00	0.01818	0.9989	2.09 (0.12)	10
07-08	10:22	03:16	4396	50.37	9.59	3.40E-004	90.00	0.01814	0.9994	2.84 (0.08)	20
07-08	13:45	04:15	4365	50.15	4.69	1.71E-004	90.01	0.01814	0.9994	2.92 (0.12)	13
07-08	18:50	01:22	4339	199.83	9.83	8.27E-004	90.00	0.01826	0.9979	1.70 (0.07)	17
07-08	20:38	01:22	4404	199.64	10.14	8.31E-004	90.00	0.01826	0.9979	1.66 (0.08)	14
07-08	22:12	08:56	4514	198.87	5.71	5.16E-004	90.00	0.01826	0.9979	1.85 (0.10)	60
07-09	07:24	04:52	4471	100.30	9.89	5.04E-004	90.01	0.01818	0.9989	2.05 (0.17)	39
07-09	12:32	04:36	4444	100.00	4.96	2.72E-004	90.00	0.01818	0.9989	2.22 (0.11)	20



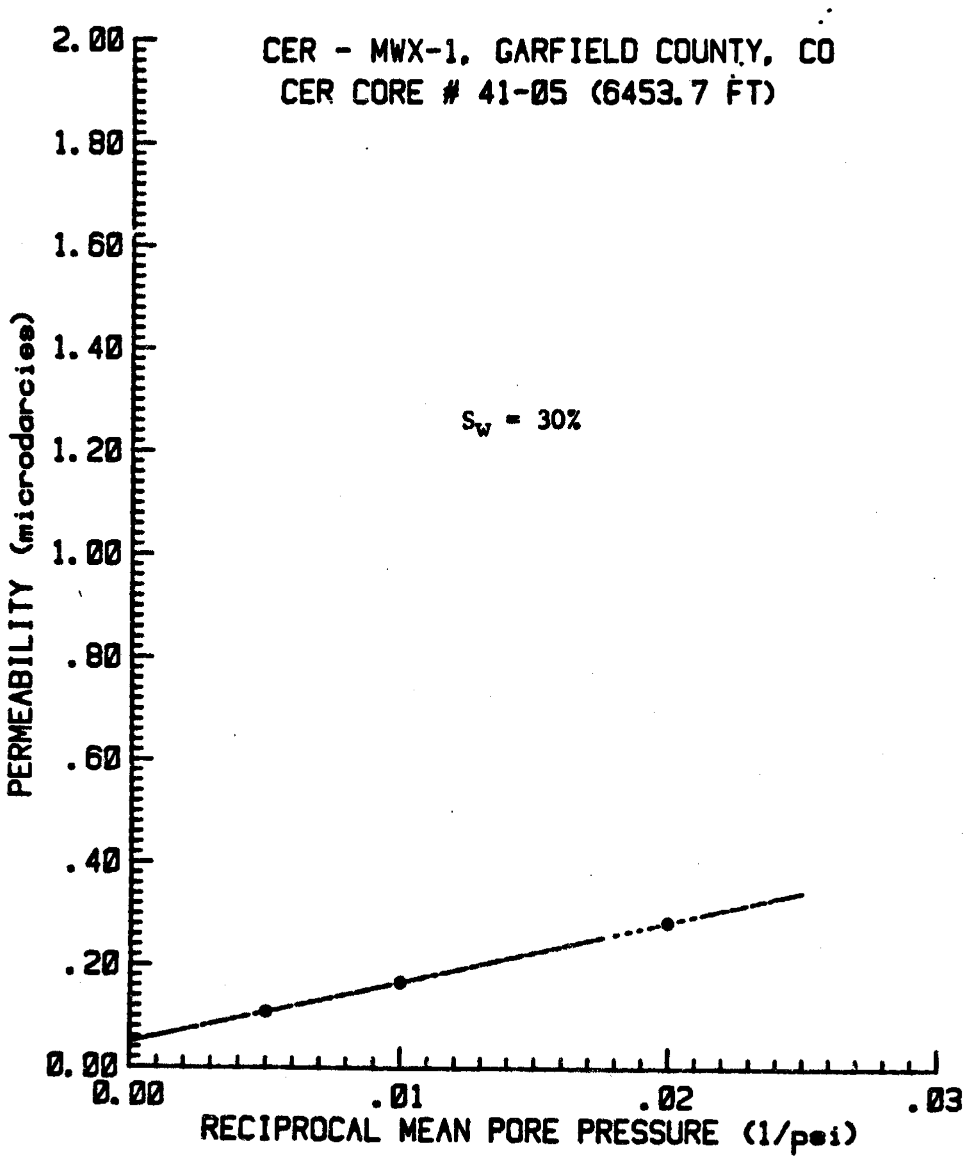
CER - MWX-1, GARFIELD COUNTY, CO
CER CORE # 41-05 (6453.7 FT)
S_w = 40%
PERMEABILITY (microdarcies)
.20
.18
.16
.14
.12
.10
.08
.06
.04
.02
0.00
0.00
.01
.02
.03
RECIPROCAL MEAN PORE PRESSURE (1/psi)

********** WELL NAME: CER - MWX-1, GARFIELD COUNTY, CO. **********

PLUG: CER CORE # 41-05 (6453.7 FT) PLUG LENTH: 5.494 CM PLUG AREA: 5.047 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY [STD.DEV.] (MICRODARCY)	NO. OF MEAS
09-11	09:35	31:05	4347	50.17	9.61	7.14E-006	90.00	0.01814	0.9994	.06 [0.01]	14
09-13	08:40	09:50	4565	199.92	20.01	2.43E-005	89.99	0.01826	0.9979	.02 [0.01]	13
09-14	13:45	22:30	4397	102.17	15.83	1.22E-005	90.00	0.01818	0.9989	.03 [0.00]	7

$S_w = 40\%$



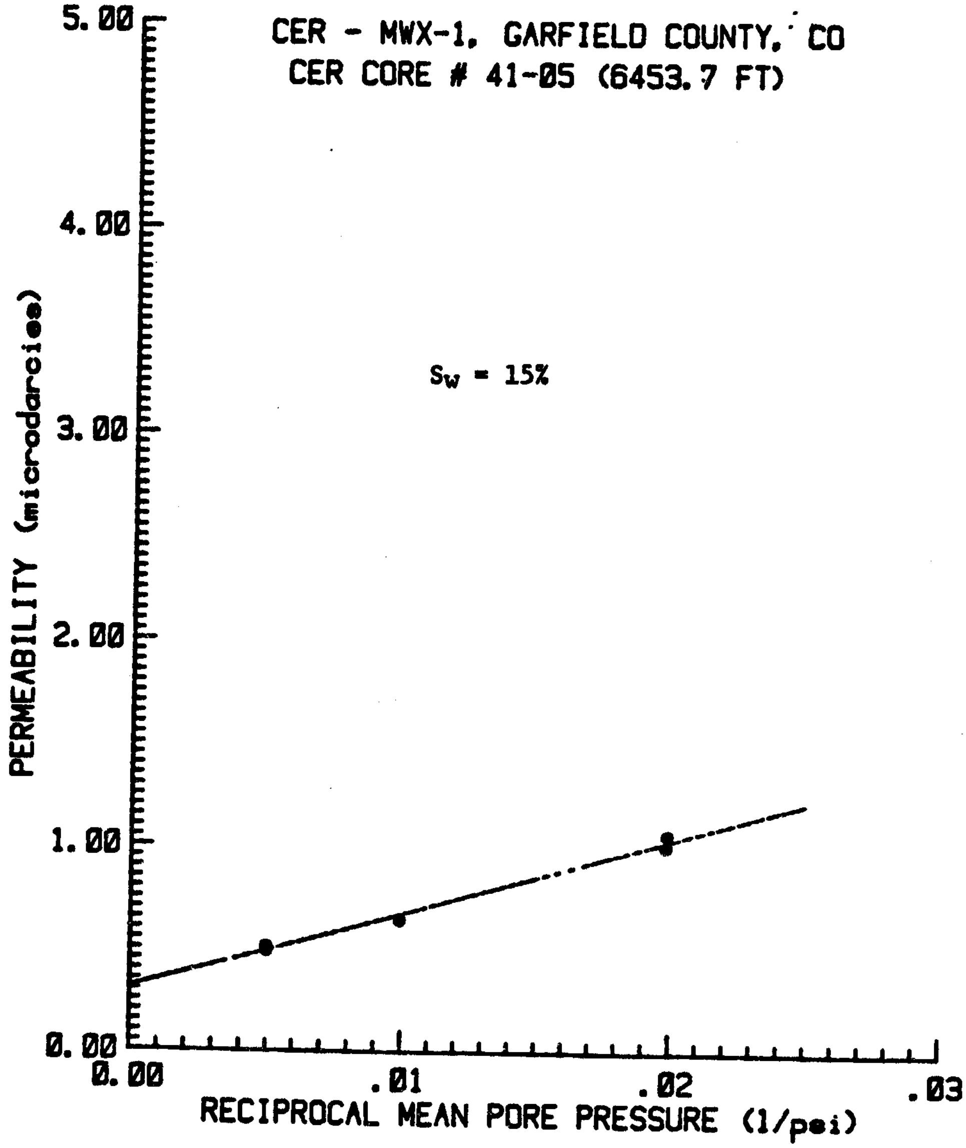
CER - MWX-1, GARFIELD COUNTY, CO
CER CORE # 41-05 (6453.7 FT)
S_w = 30%
PERMEABILITY (microdarcies)
2.00
1.80
1.60
1.40
1.20
1.00
.80
.60
.40
.20
0.00
0.00
.01
.02
.03
RECIPROCAL MEAN PORE PRESSURE (1/psi)

********** WELL NAME: CER - MWX-1, GARFIELD COUNTY, CO. **********

PLUG: CER CORE # 41-05 (6453.7 FT)   PLUG LENTH: 5.194 CM   PLUG AREA: 5.047 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY [STD.DEV.] (MICRODARCY)	NO. OF MEAS
09-17	13:55	23:50	4316	50.11	9.35	3.31E-005	90.00	0.01814	0.9994	.28 [0.02]	17
09-18	22:50	14:30	4436	100.29	9.94	4.11E-005	90.00	0.01818	0.9989	.17 [0.02]	11
09-19	14:50	18:00	4571	200.18	9.67	5.17E-005	90.00	0.01826	0.9979	.11 [0.02]	16

$S_w = 30\%$



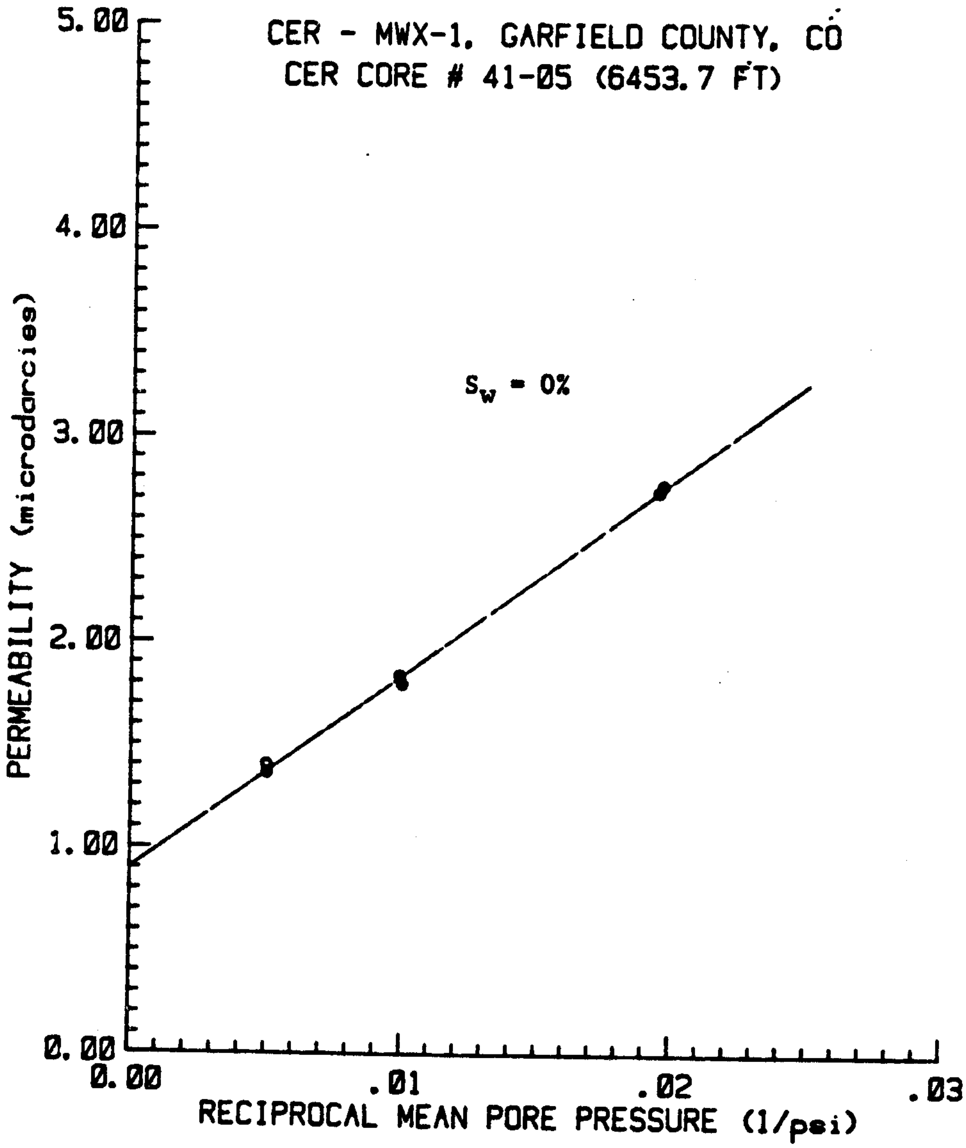
CER - MWX-1, GARFIELD COUNTY, CO
CER CORE # 41-05 (6453.7 FT)
S_W = 15%
PERMEABILITY (microdarcies)
5.00
4.00
3.00
2.00
1.00
0.00
0.00
.01
.02
.03
RECIPROCAL MEAN PORE PRESSURE (1/psi)

********** WELL NAME: CER - MWX-1, GARFIELD COUNTY, CO. **********

PLUG: CER CORE # 41-05 (6453.7 FT) PLUG LENTH: 5.494 CM PLUG AREA: 5.047 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY [STD.DEV.] (MICRODARCY)	NO. OF MEAS
09-21	15:05	16:45	4353	50.38	9.51	1.19E-004	90.00	0.01814	0.9994	1.00 [0.04]	36
09-22	17:24	14:26	4343	100.77	9.31	1.49E-004	90.00	0.01818	0.9909	.64 [0.05]	32
09-23	10:35	02:55	4284	200.61	19.08	4.78E-004	90.00	0.01826	0.9979	.51 [0.03]	20
09-23	13:40	03:10	4268	200.60	18.89	4.58E-004	90.00	0.01826	0.9979	.49 [0.02]	20
09-23	18:37	15:00	4309	50.28	10.01	1.32E-004	90.00	0.01814	0.9994	1.06 [0.04]	38

S_w = 15%



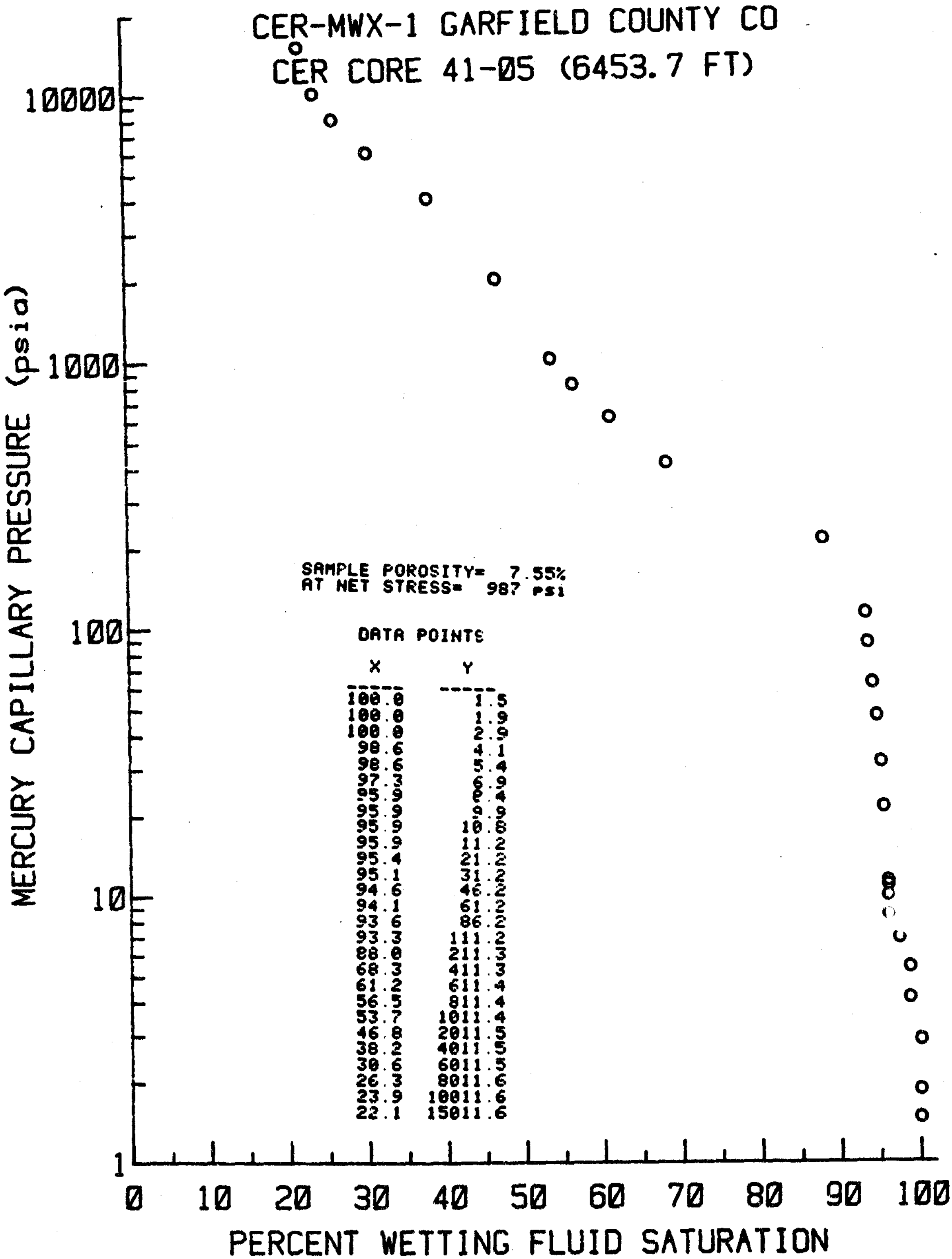
CER - MWX-1, GARFIELD COUNTY, CO
CER CORE # 41-05 (6453.7 FT)
S_w = 0%
PERMEABILITY (microdarcies)
5.00
4.00
3.00
2.00
1.00
0.00
0.00
.01
.02
.03
RECIPROCAL MEAN PORE PRESSURE (1/psi)

********** WELL NAME: CER - MWX-1, GARFIELD COUNTY, CO. **********

PLUG: CER CORE # 41-05 (6453.7 FT) PLUG LENTH: 5.494 CM PLUG AREA: 5.047 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY [STD.DEV.] (MICRODARCY)	NO. OF MEAS
09-27	18:22	14:20	4323	51.37	10.45	3.64E-004	90.00	0.01814	0.9994	2.73 [0.06]	63
09-28	16:35	11:55	4276	101.37	9.08	4.19E-004	90.00	0.01818	0.9989	1.84 [0.06]	69
09-29	10:30	04:25	4301	200.24	20.17	1.40E-003	90.00	0.01826	0.9979	1.40 [0.04]	51
09-29	18:15	13:22	4295	50.95	10.21	3.57E-004	90.00	0.01814	0.9994	2.76 [0.07]	58
09-30	23:05	16:08	4405	100.28	9.76	4.35E-004	90.01	0.01818	0.9989	1.79 [0.06]	50
10-01	08:07	03:58	4527	199.95	9.78	6.57E-004	90.01	0.01826	0.9979	1.36 [0.05]	33

$S_w = 0\%$



X	Y
100.0	1.5
100.0	1.9
100.0	2.9
98.6	4.1
98.6	5.4
97.3	6.9
95.9	8.4
95.9	9.9
95.9	10.8
95.9	11.2
95.4	21.2
95.1	31.2
94.6	46.2
94.1	61.2
93.6	86.2
93.3	111.2
88.0	211.3
68.3	411.3
61.2	611.4
56.5	811.4
53.7	1011.4
46.8	2011.5
38.2	4011.5
30.6	6011.5
26.3	8011.6
23.9	10011.6
22.1	15011.6

IGT MULTIWELL PROJECT : SANDSTONE SCREENING TESTS

SAMPLE INFORMATION: MWX# 1 RUN# 41 C.S.R. CODE 41 - 10

DEPTH: TOP 6501.4 ft BASE 6502.2 ft LENGTH 0.8 ft

LITHOLOGY: FINE SS, THICKLY LAMINATED TO THIN BEDDED. MANY COALY LAMINAE AND CLASTS OCCUR THROUGHOUT; SMALL PYRITE NODULES ARE ASSOC. WITH THE COAL. A FEW SHALY LENSES AND CLASTS ARE ALSO PRESENT. ORIENTED.

AS-RECEIVED WATER SATURATION:

DATE	TIME	CHIP WEIGHT (g)
6-22	18:30	562.1
6-24	14:45	552.1 DRY
6-30	15:40	557.4
7-6	12:00	557.8
7-8	15:30	557.4 FINAL

← Initial weight

DRIED AT 50 °C AND 42 % RELATIVE HUMIDITY.

WATER CONTENT OF CHIP: 10 g

PORE VOLUME OCCUPIED BY WATER: 95.41 %

PLUG INFORMATION: DIAMETER 2.539 cm LENGTH 5.220 cm

DEPTH 6502.0 ft ORIENTATION 90° E OF PRIME N5°E

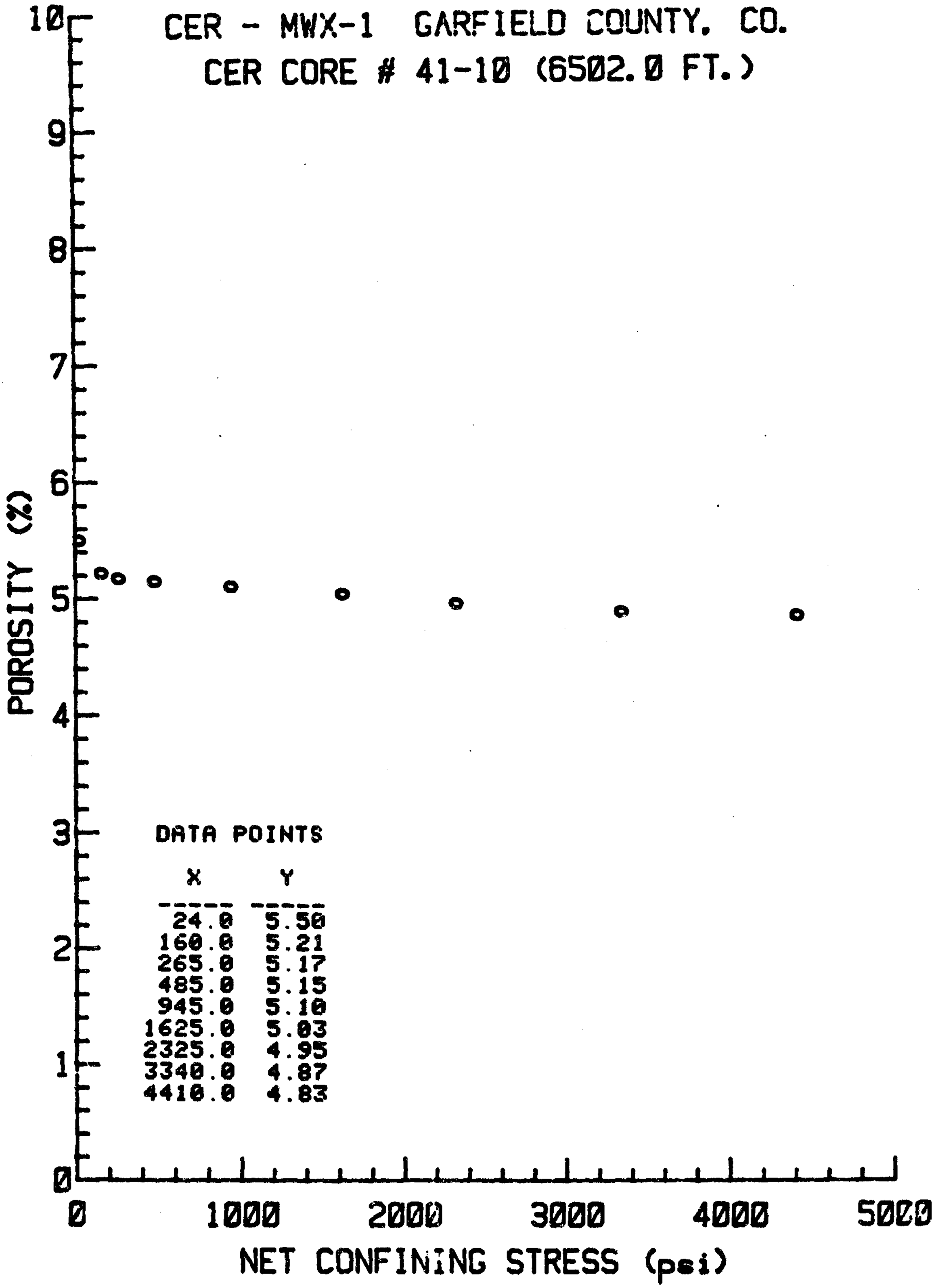
DATE CUT 6-22-82 DRIED AT 60 °C AND 45 % RELATIVE HUMIDITY.

WET WEIGHT 67.910 g DRY WEIGHT 67.267 g VOLUME 26.429 cc

GAS POROSITY UNDER NET CONFINING STRESS 4.832 % TESTING COMPLETE 7-2-82

WEIGHT HISTORY OF PLUG: * WEIGHT AFTER TESTING

DATE	TIME	WEIGHT	DATE	TIME	WEIGHT
6-23	11:30	67.910			
6-24	15:00	67.267			
6-28	19:28	67.270			
* 7-2	23:33	67.352			


CER - MWX-1 GARFIELD COUNTY, CO.
CER CORE # 41-10 (6502.0 FT.)
POROSITY (%)
NET CONFINING STRESS (psi)
0
1
2
3
4
5
6
7
8
9
10
0
1000
2000
3000
4000
5000
DATA POINTS
X Y
24.0 5.50
160.0 5.21
265.0 5.17
485.0 5.15
945.0 5.10
1625.0 5.03
2325.0 4.95
3340.0 4.87
4410.0 4.83

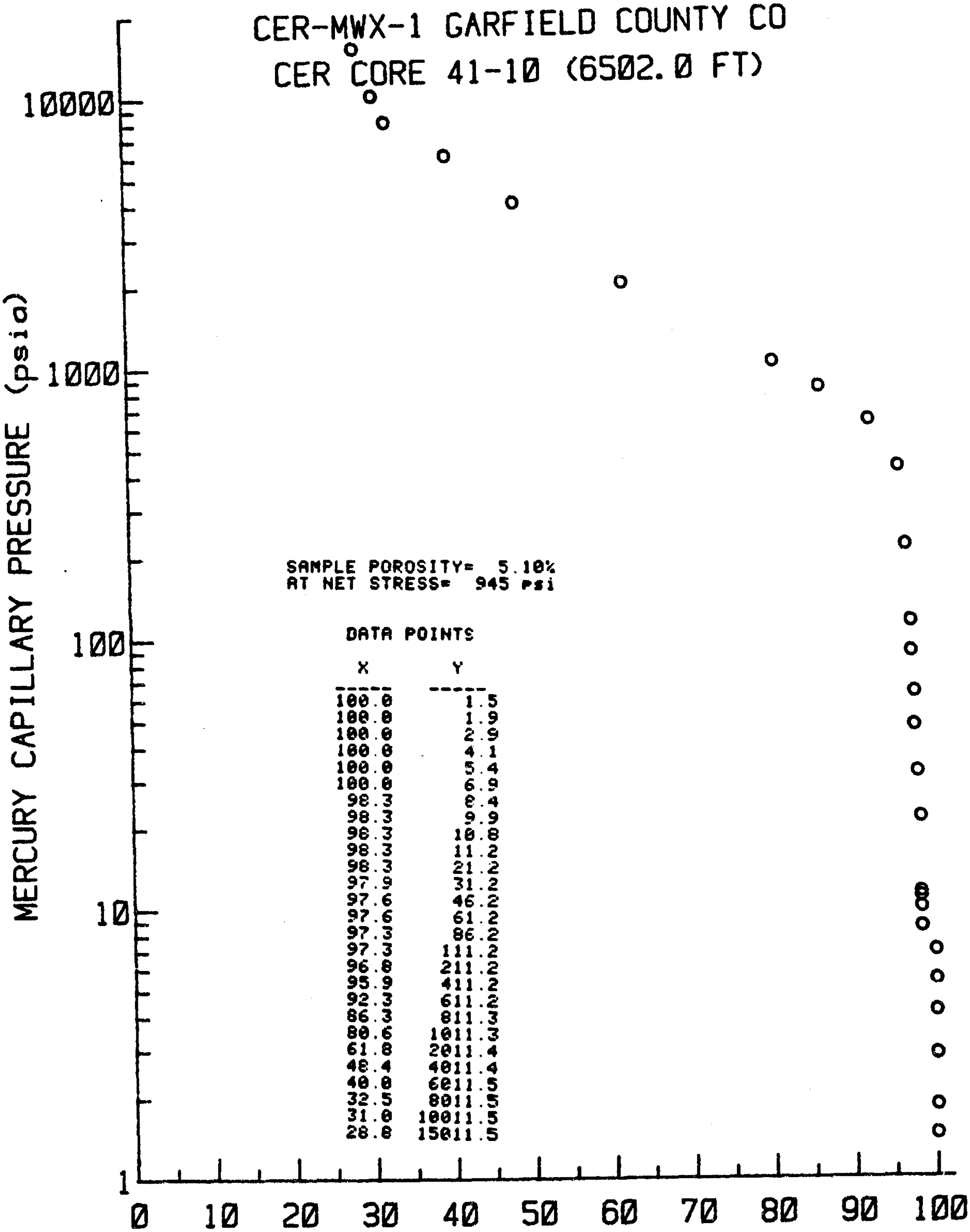
INSTITUTE OF GAS TECHNOLOGY

########## WELL NAME:CER - MWX-1 GARFIELD COUNTY, CO. ##########

PLUG: CER CORE # 41-10 (6502.0 FT.) PLUG LENTH: 5.220 CM PLUG AREA: 5.063 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY [STD.DEV.] (MICRODARCY)	NO. OF MEAS
06-30	07:57	02:09	4281	50.62	19.69	2.82E-004	90.00	0.01814	0.9994	1.08 [0.04]	13
06-30	10:12	04:02	4251	50.32	10.02	1.41E-004	90.01	0.01814	0.9994	1.07 [0.04]	12
06-30	16:40	02:32	4451	100.70	19.84	3.22E-004	90.00	0.01818	0.9989	.62 [0.03]	15
06-30	19:30	02:52	4424	100.45	9.82	1.65E-004	90.01	0.01818	0.9989	.64 [0.03]	9
06-30	22:33	16:00	4374	100.27	4.51	7.06E-005	90.01	0.01818	0.9989	.60 [0.03]	12
07-01	08:30	04:24	4590	200.08	9.34	1.56E-004	90.00	0.01826	0.9979	.32 [0.06]	12
07-01	13:09	02:57	4562	199.83	4.93	5.79E-005	90.01	0.01826	0.9979	.23 [0.03]	3
07-01	17:06	05:03	4414	50.23	9.44	1.43E-004	90.00	0.01814	0.9994	1.15 [0.07]	16
07-01	22:20	09:20	4360	50.07	4.73	7.46E-005	90.00	0.01814	0.9994	1.20 [0.07]	14
07-02	08:25	05:25	4322	25.26	4.60	7.46E-005	90.01	0.01812	0.9996	2.45 [0.10]	10

CER-MWX-1 GARFIELD COUNTY CO
CER CORE 41-10 (6502.0 FT)



SAMPLE POROSITY= 5.10%
AT NET STRESS= 945 psi

DATA POINTS

X	Y
100.0	1.5
100.0	1.9
100.0	2.9
100.0	4.1
100.0	5.4
100.0	6.9
98.3	8.4
98.3	9.9
98.3	10.8
98.3	11.2
98.3	21.2
97.9	31.2
97.6	46.2
97.6	61.2
97.3	86.2
97.3	111.2
96.8	211.2
95.9	411.2
92.3	611.2
86.3	811.3
80.6	1011.3
61.8	2011.4
48.4	4011.4
40.0	6011.5
32.5	8011.5
31.0	10011.5
28.8	15011.5

IGT
EDUCATION · RESEARCH

A. SAMPLE INFORMATION: MWX # 1 RUN # 42 CODE 42 - 11

DEPTH: TOP 6567.3 FT BASE 6567.7 FT

LITHOLOGY BLACK SILTY SHALE, THINLY LAMINATED. COALY PLANT FRAGMENTS AND COALY LAMINAE ARE ABUNDANT. ORIENTED, RUN UPRIGHT.

B. PERMEABILITY TESTS: DATE CORE WAS TRIMMED 5-24-82

TRIMMED CORE DIAMETER: 10.1 cm LENGTH: 8.6 cm

STATION IN MULTIPLE CORE TESTER: 13 BATCH # 1

DATE RUN WAS STARTED: 5-26-82 DURATION OF RUN 316 Hrs.

CONFINING PRESSURE: 1000 PSIG DIFFERENTIAL PRESSURE: 720 PSID

FLOW RATE: $< 10^{-4}$ CC/HR PERMEABILITY TO WATER: 5.55×10^{-5} MD

C. THRESHOLD PRESSURE MEASUREMENT: CONFINING PRESSURE: 1000 PSIG

INITIAL GAS PRESSURE: 775 PSIG STABILIATION TIME: 41 HOURS

STABLE GAS PRESSURE: 760 PSIG = THRESHOLD PRESSURE

D. EFFECTIVE POROSITY: WEIGHT OF GLASS DISH: 31.297g

CHIP DIMENSIONS: THICKNESS: 50.014CM DIAM: 2.526CM VOLUME: 25.125cc

DRIED AT 50 °C AND 42 % RELATIVE HUMIDITY FOR 312 HOURS

CHIP + DISH	CHIP	DATE	TIME
97.074g	*65.777	8-5	15:30
95.855	64.558	8-6	09:00
95.783	64.486	8-9	10:00
95.729	64.432	8-10	11:30
95.825	64.528	8-18	15:30

WATER CONTENT: 1.345 g x 1g/cc =

PORE VOLUME: 1.345 cc

$\frac{\text{PORE VOL.}}{\text{CHIP VOL.}} \times 100 =$ 5.35 % POROSITY

* SATURATED WEIGHT

IGT MULTIWELL PROJECT : SANDSTONE SCREENING TESTS

SAMPLE INFORMATION: MWX# 1 RUN# 42 C.E.R. CODE 42 - 20

DEPTH: TOP 6537.2 ft BASE 6538.3 ft LENGTH 1.10 ft

LITHOLOGY: MEDIUM COARSE SANDSTONE, THICK BEDDED WITH FAINT CROSS-BEDDING. GRAINS ARE POORLY-SORTED AND ANGULAR. ORIENTED.

AS-RECEIVED WATER SATURATION:

DATE	TIME	CHIP WEIGHT (g)
6-22	18:30	294.3 ← Initial weight
6-24	14:45	292.8
6-30	15:40	292.8
7-6	12:00	293.1
7-8	15:30	292.7 FINAL DRY

DRIED AT 50 °C AND 42 % RELATIVE HUMIDITY.

WATER CONTENT OF CHIP: 1.6 g

PORE VOLUME OCCUPIED BY WATER: 22.12 %

PLUG INFORMATION: DIAMETER 2.539 cm LENGTH 5.166 cm

DEPTH 6537.8 ft ORIENTATION 90° W OF PRIME

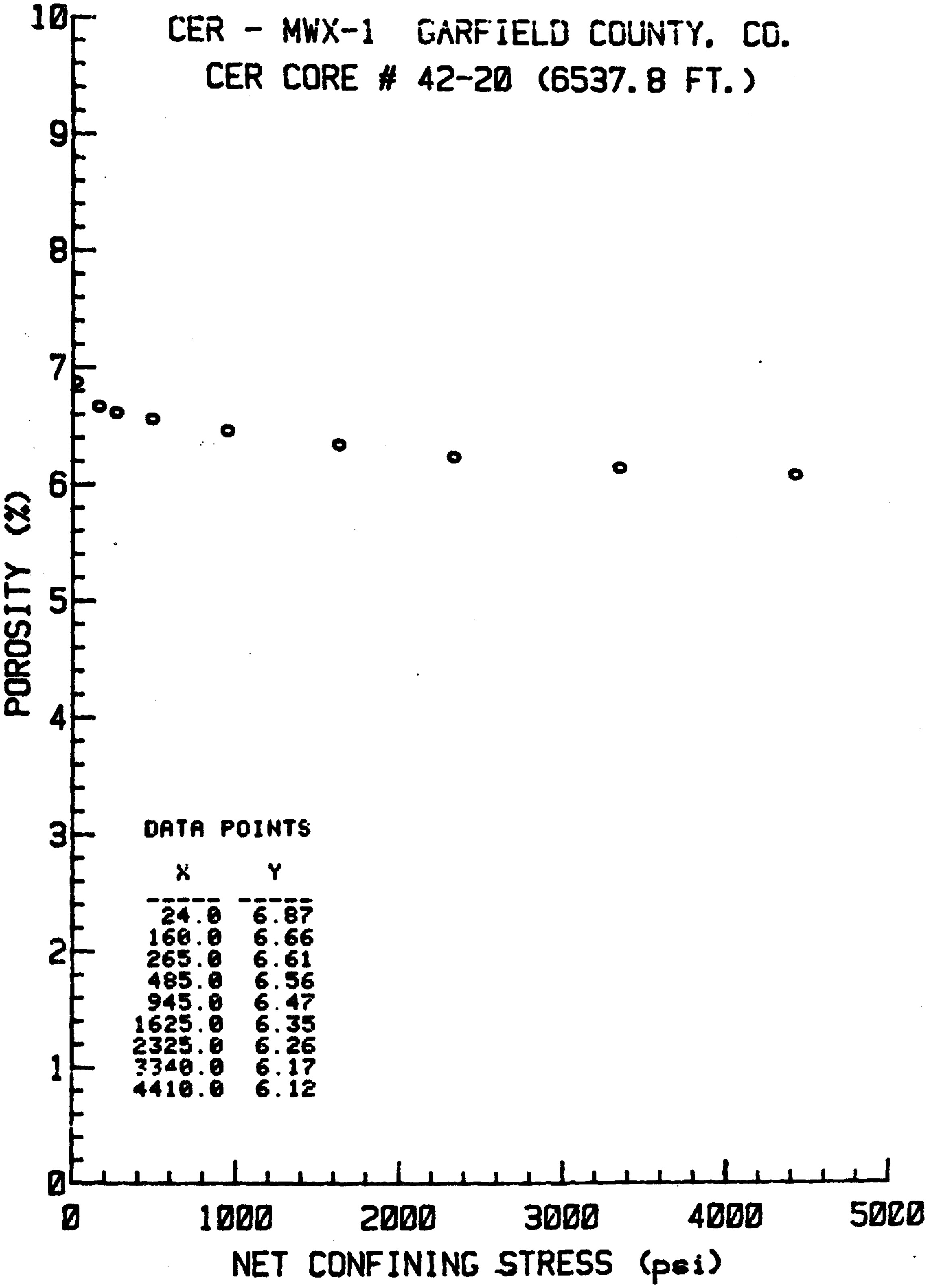
DATE CUT 6-22-82 DRIED AT 60 °C AND 45 % RELATIVE HUMIDITY.

WET WEIGHT 64.980 g DRY WEIGHT 64.784 g VOLUME 26.156 cc

GAS POROSITY UNDER NET CONFINING STRESS 6.121 % TESTING COMPLETE 7-2-82

WEIGHT HISTORY OF PLUG: * WEIGHT AFTER TESTING

DATE	TIME	WEIGHT	DATE	TIME	WEIGHT
6 23	11:30	64.980			
6-24	15:10	64.789			
6-28	19:31	64.784			
* 7-2	23:30	64.932			

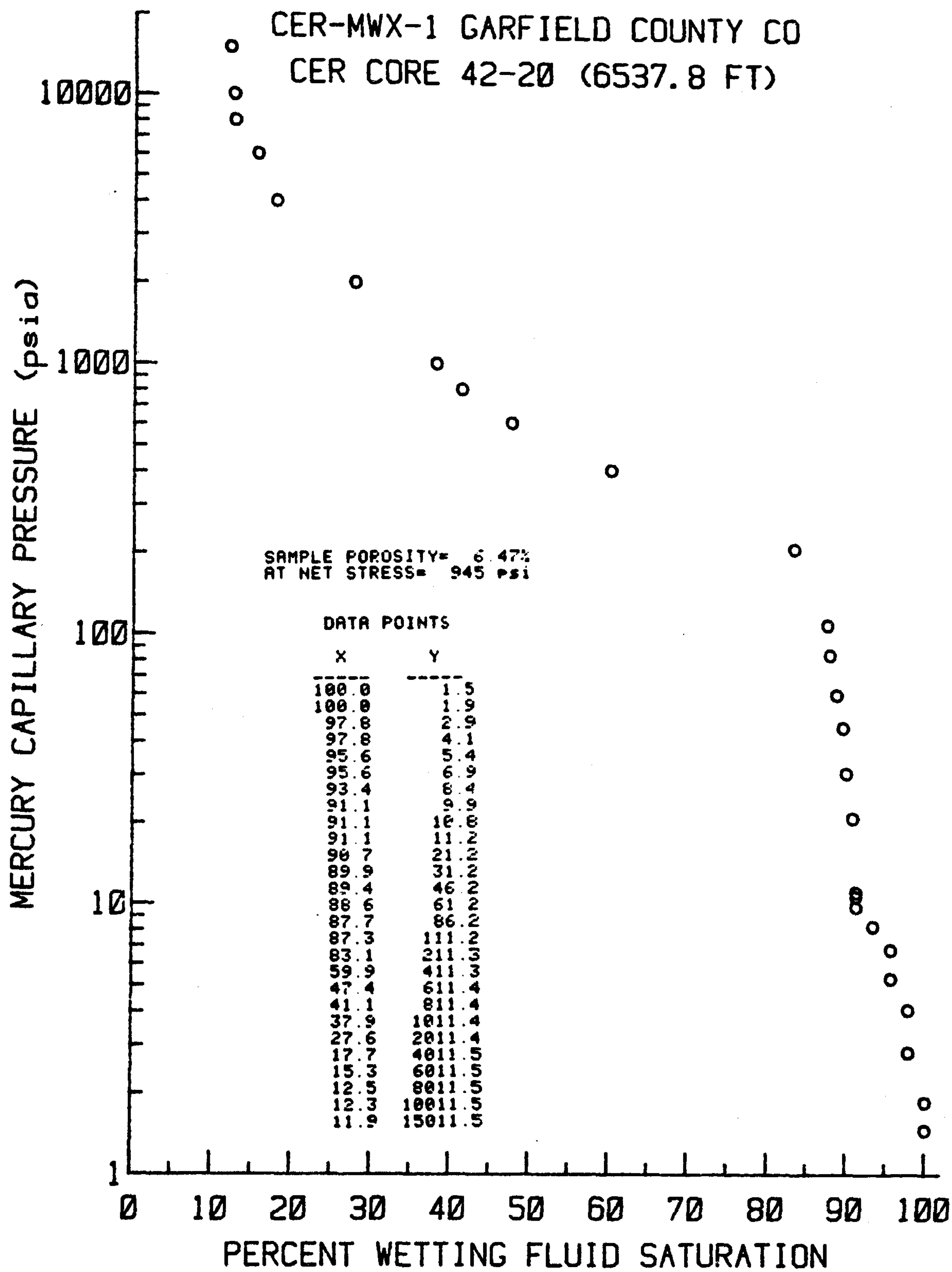

CER - MWX-1 GARFIELD COUNTY, CO.
CER CORE # 42-20 (6537.8 FT.)
POROSITY (%)
0
1
2
3
4
5
6
7
8
9
10
DATA POINTS
X Y
24.0 6.87
160.0 6.66
265.0 6.61
485.0 6.56
945.0 6.47
1625.0 6.35
2325.0 6.26
3340.0 6.17
4410.0 6.12
0
1000
2000
3000
4000
5000
NET CONFINING STRESS (psi)

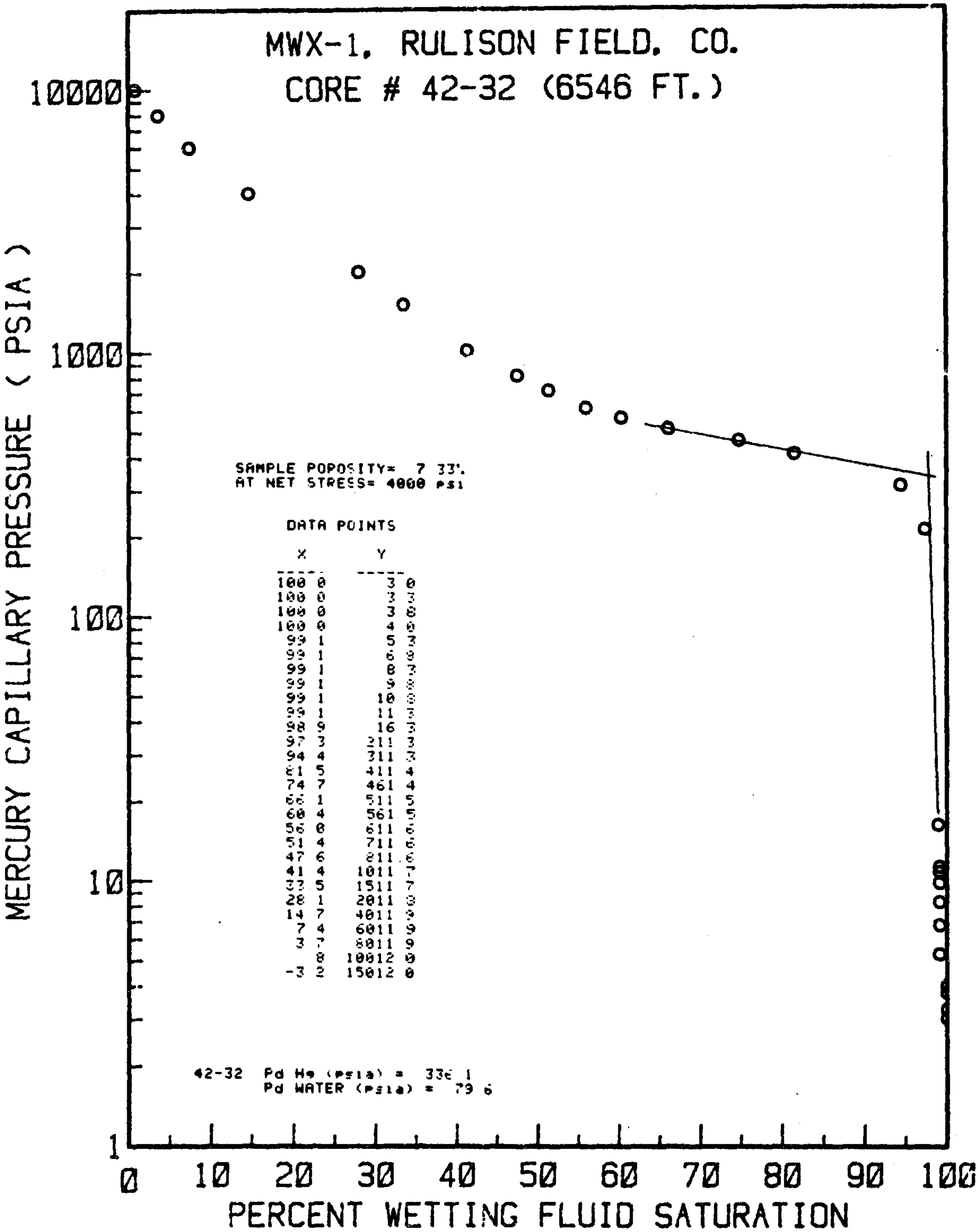
INSTITUTE OF GAS TECHNOLOGY

********** WELL NAME:CER - MWX-1 GARFIELD COUNTY, CO. **********

PLUG: CER CORE # 42-20 (6537.8 FT.) PLUG LENTH: 5.166 CM PLUG AREA: 5.063 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY [STD.DEV.] (MICRODARCY)	NO. OF MEAS
06-30	07:57	02:09	4281	50.65	19.61	8.89E-004	90.01	0.01814	0.9994	3.38 [0.18]	34
06-30	10:12	04:02	4251	50.37	9.93	4.57E-004	90.01	0.01814	0.9994	3.45 [0.08]	33
06-30	16:40	02:32	4451	100.74	19.78	1.26E-003	90.01	0.01818	0.9989	2.38 [0.05]	52
06-30	19:30	02:52	4425	100.43	9.86	6.42E-004	90.00	0.01818	0.9989	2.45 [0.04]	30
06-30	22:33	16:00	4375	100.29	4.48	2.94E-004	90.00	0.01818	0.9989	2.48 [0.10]	39
07-01	08:30	04:24	4591	200.11	9.29	9.26E-004	90.00	0.01826	0.9979	1.89 [0.11]	53
07-01	13:09	02:57	4563	199.94	4.71	4.79E-004	90.01	0.01826	0.9979	1.93 [0.09]	21
07-01	17:06	05:03	4416	50.22	9.47	4.37E-004	90.00	0.01814	0.9994	3.47 [0.09]	35
07-01	22:20	09:20	3930	45.09	4.20	2.50E+498	35.00	0.01814	0.9994.25	[0.00]	40
07-01	22:20	09:20	4366	50.11	4.66	2.21E-004	90.00	0.01814	0.9994	3.58 [0.12]	40


CER-MWX-1 GARFIELD COUNTY CO
CER CORE 42-20 (6537.8 FT)
MERCURY CAPILLARY PRESSURE (psia)
10000
1000
100
10
1
SAMPLE POROSITY= 6.47%
AT NET STRESS= 945 psi
DATA POINTS
X Y
100.0 1.5
100.0 1.9
97.8 2.9
97.8 4.1
95.6 5.4
95.6 6.9
93.4 8.4
91.1 9.9
91.1 10.8
91.1 11.2
90.7 21.2
89.9 31.2
89.4 46.2
88.6 61.2
87.7 86.2
87.3 111.2
83.1 211.3
59.9 411.3
47.4 611.4
41.1 811.4
37.9 1011.4
27.6 2011.4
17.7 4011.5
15.3 6011.5
12.5 8011.5
12.3 10011.5
11.9 15011.5
0 10 20 30 40 50 60 70 80 90 100
PERCENT WETTING FLUID SATURATION

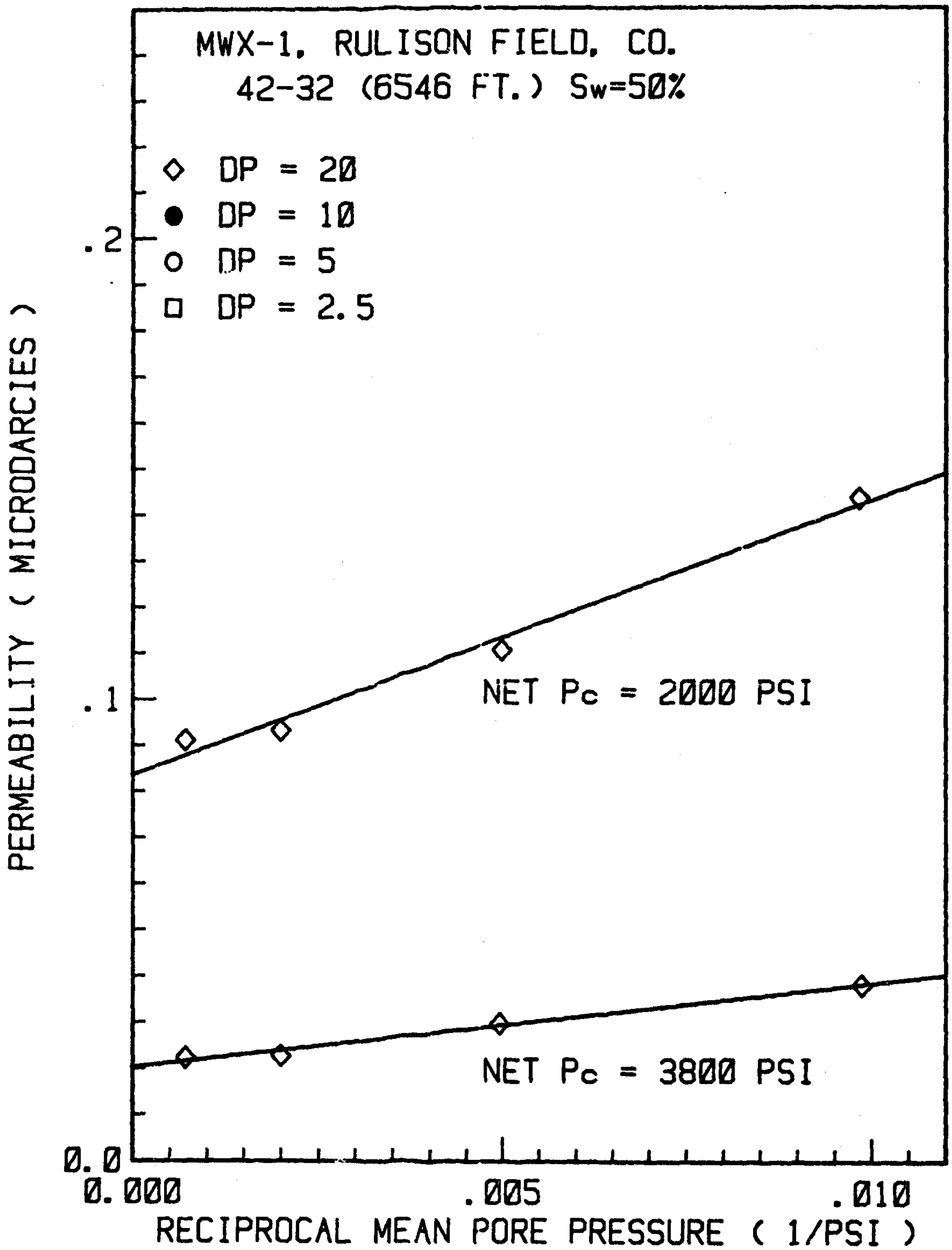


X	Y
100 0	3 0
100 0	3 3
100 0	3 8
100 0	4 0
99 1	5 3
99 1	6 9
99 1	8 3
99 1	9 8
99 1	10 8
99 1	11 3
98 9	16 3
97 3	211 3
94 4	311 3
81 5	411 4
74 7	461 4
66 1	511 5
60 4	561 5
56 0	611 6
51 4	711 6
47 6	811 6
41 4	1011 7
33 5	1511 7
28 1	2011 8
14 7	4011 9
7 4	6011 9
3 7	8011 9
8	10012 0
-3 2	15012 0

********** WELL NAME: MWX-1, RULISON FIELD, CO. **********

PLUG: 42-32 (6546 FT.) Sw-50% PLUG LENGTH: 3.950 CM PLUG AREA: 5.067 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	PERMEABILITY STD. DEV. (%)
04-15	17:15	13:15	2098	101.73	21.20	9.30E-005	94.00	0.01852	0.9992	1.44E-001	(2.0)
04-16	16:48	14:36	2213	200.52	20.62	1.37E-004	94.00	0.01857	0.9987	1.11E-001	(4.6)
04-18	10:20	09:50	2497	500.95	20.73	2.86E-004	94.00	0.01880	0.9982	9.32E-002	(5.1)
04-19	11:22	08:07	3401	1399.95	19.35	6.83E-004	94.00	0.02010	1.0083	9.11E-002	(5.2)
04-19	21:00	16:45	4294	1400.22	19.86	3.35E-004	94.00	0.02010	1.0084	4.35E-002	(11.0)
04-20	17:00	44:00	5208	1399.80	19.72	1.71E-004	94.00	0.02009	1.0083	2.23E-002	(8.5)
04-23	19:20	37:02	4300	500.76	21.03	7.08E-005	94.00	0.01880	0.9982	2.27E-002	(15.4)
04-27	21:30	37:30	4000	201.59	21.38	3.83E-005	94.00	0.01857	0.9986	2.97E-002	(9.0)
05-01	20:40	42:23	3898	101.38	21.87	2.54E-005	94.00	0.01852	0.9992	3.81E-002	(4.8)

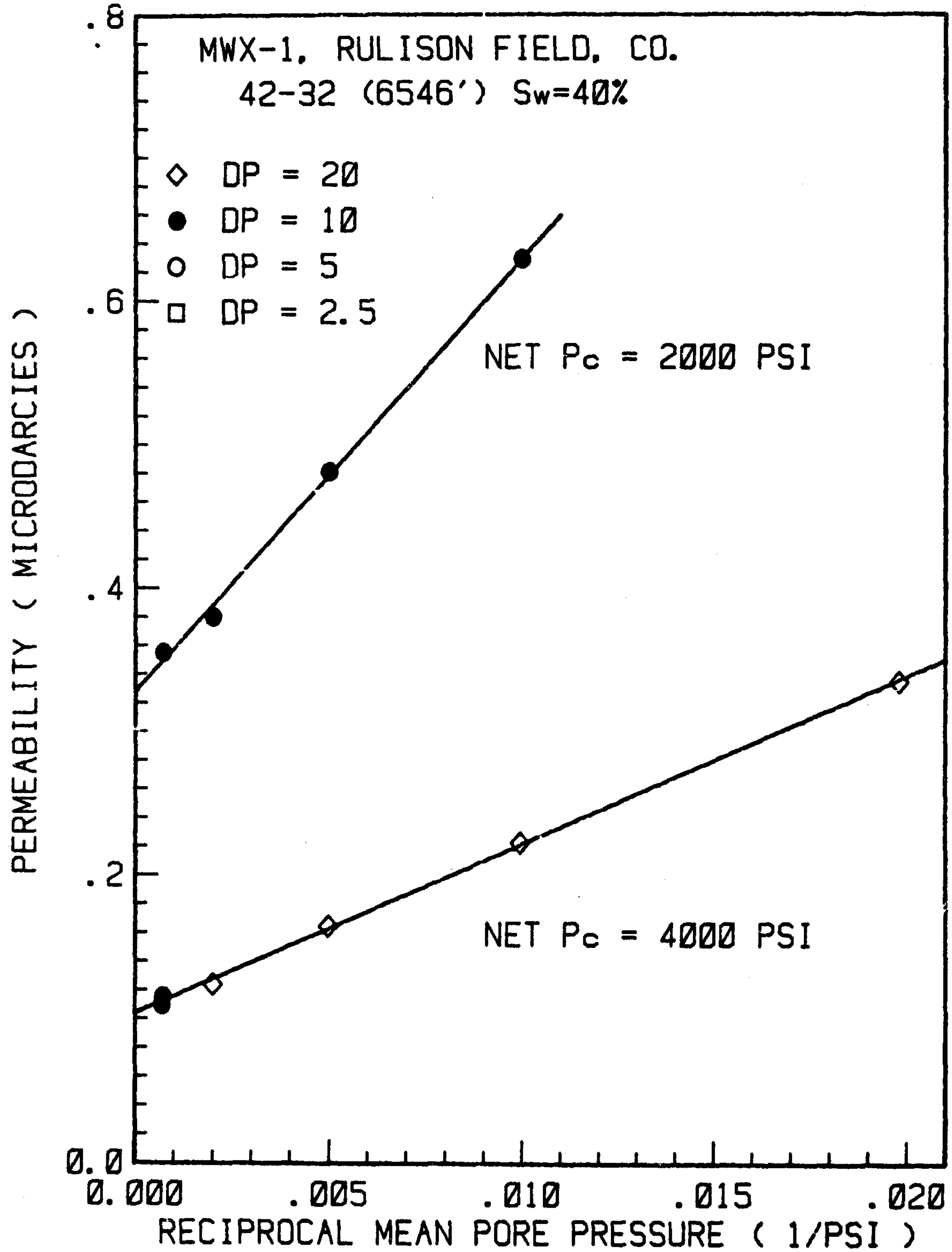


MWX-1, RULISON FIELD, CO.
42-32 (6546 FT.) Sw=50%
DP = 20
DP = 10
DP = 5
DP = 2.5
NET Pc = 2000 PSI
NET Pc = 3800 PSI
PERMEABILITY (MICRODARCIES)
.2
.1
0.0
0.000
.005
.010
RECIPROCAL MEAN PORE PRESSURE (1/PSI)

********** WELL NAME: MWX-1, RULISON FIELD, CO. **********

PLUG: 42-32 (6546') Sw=40% PLUG LENGTH: 3.950 CM PLUG AREA: 5.057 CM^2

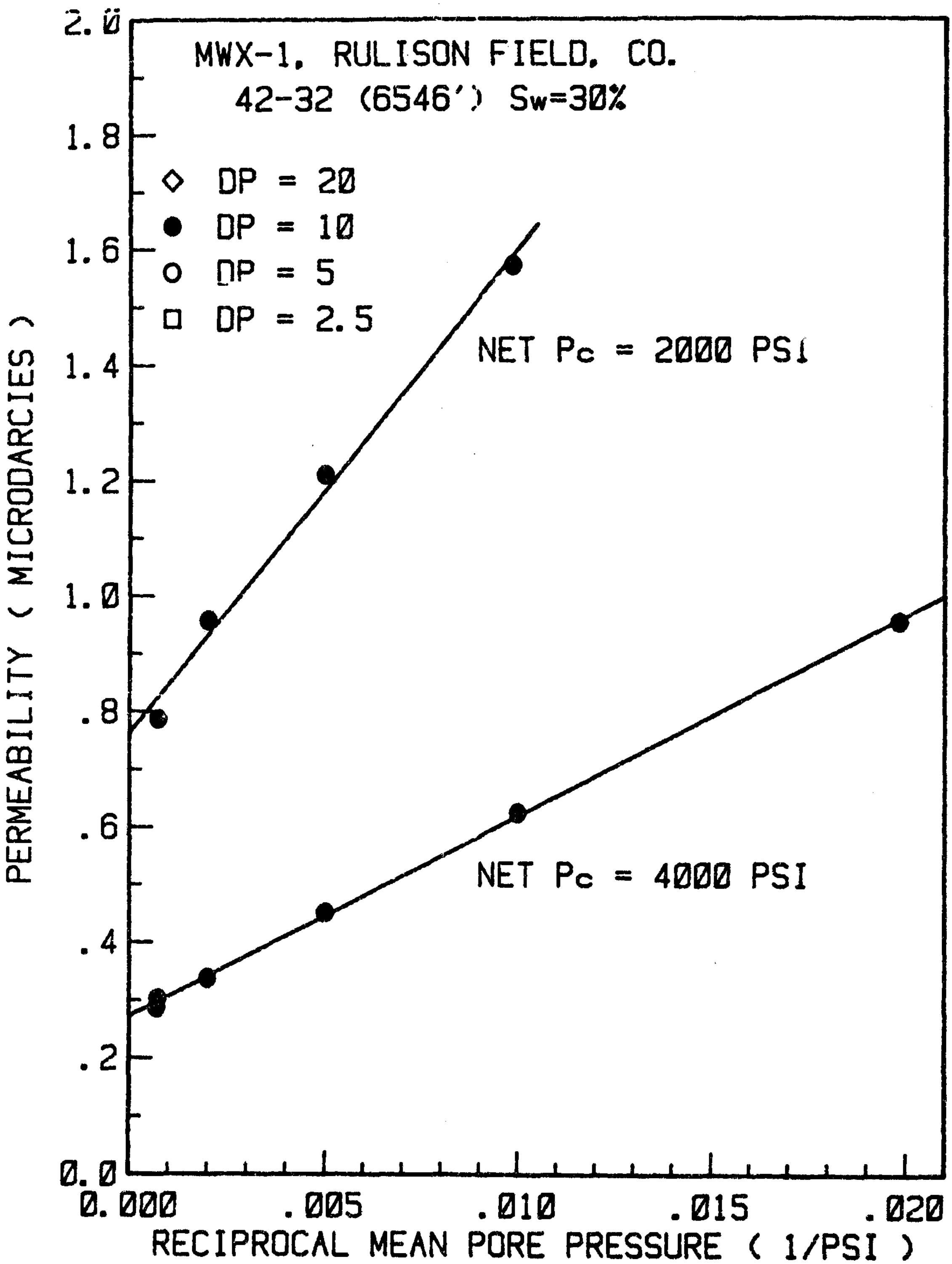
TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	PERMEABILITY STD. DEV. (%)
05-04	10:00	08:01	2094	100.13	10.66	2.01E-004	94.00	0.01852	0.9992	6.29E-001	(3.2)
05-05	14:54	06:12	2191	200.40	10.59	3.06E-004	94.00	0.01857	0.9987	4.81E-001	(2.6)
05-06	14:05	05:40	2517	499.57	10.81	6.07E-004	94.00	0.01880	0.9982	3.80E-001	(1.9)
05-07	09:27	04:03	3396	1400.43	11.26	1.55E-003	94.00	0.02010	1.0084	3.55E-001	(2.0)
05-07	14:39	06:51	4402	1400.44	10.89	7.28E-004	94.00	0.02010	1.0084	1.73E-001	(7.3)
05-07	23:30	14:33	5405	1400.24	10.52	4.71E-004	94.00	0.02010	1.0084	1.16E-001	(8.9)
05-09	01:30	16:35	5482	1450.77	11.58	5.07E-004	94.00	0.02019	1.0094	1.10E-001	(7.3)
05-10	13:30	07:07	4518	501.46	20.86	3.83E-004	94.00	0.01880	0.9982	1.24E-001	(4.4)
05-11	13:40	22:10	4201	201.32	21.39	2.12E-004	94.00	0.01857	0.9986	1.64E-001	(3.1)
05-14	12:00	19:45	4099	100.58	19.70	1.32E-004	94.00	0.01852	0.9992	2.22E-001	(2.4)
05-15	20:30	19:30	4050	50.51	19.72	1.00E-004	94.00	0.01851	0.9996	3.35E-001	(2.4)


MWX-1, RULISON FIELD, CO.
42-32 (6546') Sw=40%
DP = 20
DP = 10
DP = 5
DP = 2.5
NET Pc = 2000 PSI
NET Pc = 4000 PSI
PERMEABILITY (MICRODARCIES)
.8
.6
.4
.2
0.0
0.000
.005
.010
.015
.020
RECIPROCAL MEAN PORE PRESSURE (1/PSI)

********** WELL NAME: MWX-1. RULISON FIELD, CO. **********

PLUG: 42-32 (6546') Sw=30% PLUG LENGTH: 3.950 CM PLUG AREA: 5.057 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	STD. DEV. (%)
05-18	08:35	04:52	2094	101.56	10.16	4.87E-004	94.00	0.01852	0.9992	1.57E+000	(1.4)
05-18	15:28	02:36	2200	200.53	10.31	7.49E-004	94.00	0.01857	0.9987	1.21E+000	(2.5)
05-19	13:55	02:24	2499	499.49	10.11	1.43E-003	94.00	0.01880	0.9982	9.57E-001	(1.0)
05-21	15:22	03:34	3398	1398.64	9.35	2.85E-003	94.00	0.02009	1.0083	7.86E-001	(1.6)
05-21	20:00	12:23	4399	1399.17	9.26	1.62E-003	94.00	0.02009	1.0083	4.52E-001	(1.7)
05-22	09:18	06:12	5403	1399.62	9.68	1.13E-003	94.00	0.02009	1.0083	3.02E-001	(5.5)
05-23	18:36	13:54	5444	1449.67	9.32	1.07E-003	94.00	0.02019	1.0094	2.87E-001	(2.9)
05-25	10:15	08:45	4496	500.58	9.63	4.83E-004	94.00	0.01880	0.9982	3.38E-001	(10.2)
05-28	13:30	19:10	4197	200.67	9.80	2.66E-004	94.00	0.01857	0.9987	4.51E-001	(2.4)
05-30	17:24	14:24	4091	100.08	9.64	1.81E-004	94.00	0.01852	0.9992	6.24E-001	(2.0)
05-31	18:15	14:16	4052	50.46	9.61	1.39E-004	94.00	0.01851	0.9996	9.55E-001	(1.6)

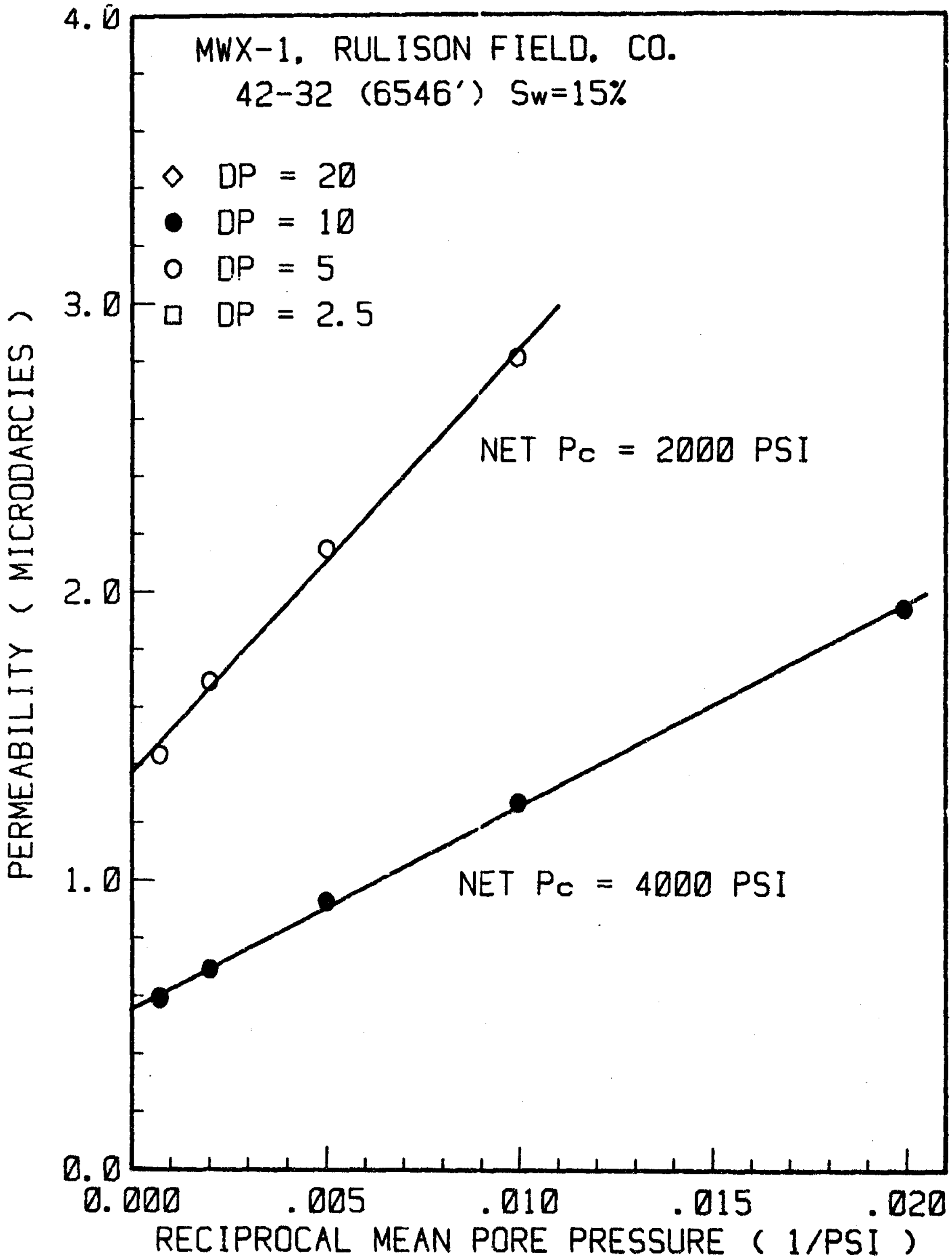


MWX-1, RULISON FIELD, CO.
42-32 (6546') Sw=30%
◇ DP = 20
● DP = 10
○ DP = 5
□ DP = 2.5
NET Pc = 2000 PSI
NET Pc = 4000 PSI
PERMEABILITY (MICRODARCIES)
RECIPROCAL MEAN PORE PRESSURE (1/PSI)
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0.0
0.000
.005
.010
.015
.020

********** WELL NAME: MWX-1, RULISON FIELD, CO. **********

PLUG: 42-32 (6546') Sw=15% PLUG LENGTH: 3.950 CM PLUG AREA: 5.057 CM^2

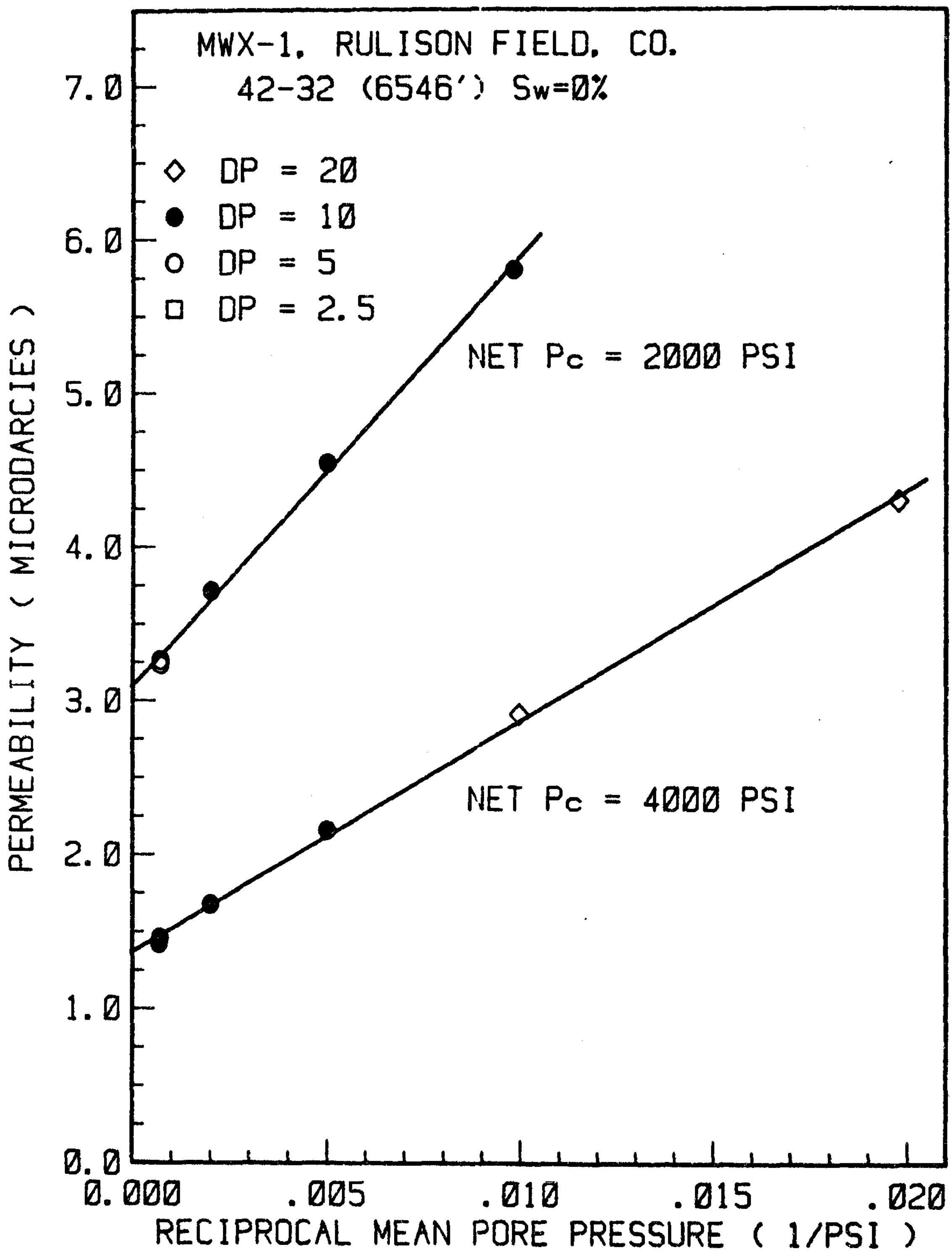
TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	STD. DEV. (%)
06-04	10:40	03:50	2098	100.59	5.04	4.28E-004	94.00	0.01852	0.9992	2.81E+000	(1.7)
06-05	09:20	04:44	2199	199.92	5.05	6.49E-004	94.00	0.01857	0.9987	2.15E+000	(1.5)
06-06	09:15	03:27	2499	500.41	4.88	1.22E-003	94.00	0.01880	0.9982	1.69E+000	(1.6)
06-07	15:07	02:07	3400	1399.78	4.65	2.59E-003	94.00	0.02009	1.0083	1.43E+000	(5.7)
06-08	08:57	03:06	4399	1400.21	5.17	1.77E-003	94.00	0.02010	1.0084	8.81E-001	(2.1)
06-08	12:54	04:54	5395	1400.11	4.78	1.10E-003	94.00	0.02010	1.0083	5.94E-001	(3.4)
06-09	22:27	02:57	5393	1399.11	10.14	2.31E-003	94.00	0.02009	1.0083	5.89E-001	(1.6)
06-11	09:21	04:10	4499	500.88	9.88	1.01E-003	94.00	0.01880	0.9982	6.91E-001	(1.1)
06-12	09:20	04:18	4199	200.49	9.92	5.51E-004	94.00	0.01857	0.9987	9.24E-001	(2.2)
06-13	09:30	04:30	4100	100.49	9.74	3.72E-004	94.00	0.01852	0.9992	1.27E+000	(1.3)
06-14	09:36	05:12	4050	50.23	10.10	2.96E-004	94.00	0.01851	0.9996	1.94E+000	(1.2)


MWX-1, RULISON FIELD, CO.
42-32 (6546') Sw=15%
DP = 20
DP = 10
DP = 5
DP = 2.5
NET Pc = 2000 PSI
NET Pc = 4000 PSI
PERMEABILITY (MICRODARCIES)
4.0
3.0
2.0
1.0
0.0
0.000
.005
.010
.015
.020
RECIPROCAL MEAN PORE PRESSURE (1/PSI)

********** WELL NAME: MWX-1, RULISON FIELD, CO. **********

PLUG: 42-32 (6546') Sw=0% PLUG LENGTH: 3.950 CM PLUG AREA: 5.057 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	STD. DEV. (%)
06-19	10:03	01:15	2108	101.95	10.27	1.82E-003	94.00	0.01852	0.9992	5.80E+000	(1.5)
06-19	14:26	01:23	2203	200.40	9.98	2.72E-003	94.00	0.01857	0.9987	4.54E+000	(1.9)
06-20	08:59	01:49	2501	500.06	8.14	4.47E-003	94.00	0.01880	0.9982	3.71E+000	(1.8)
06-20	16:45	01:24	3398	1399.47	4.46	5.64E-003	94.00	0.02009	1.0083	3.26E+000	(1.5)
06-21	09:15	01:21	3402	1399.67	4.81	6.03E-003	94.00	0.02009	1.0083	3.23E+000	(1.7)
06-21	11:04	02:26	4399	1399.87	4.61	3.67E-003	94.00	0.02010	1.0083	2.06E+000	(1.9)
06-21	14:12	02:00	5403	1402.33	8.93	5.05E-003	94.00	0.02010	1.0084	1.46E+000	(1.7)
06-22	17:12	01:13	5451	1449.40	9.98	5.67E-003	94.00	0.02019	1.0094	1.42E+000	(1.7)
06-23	10:37	02:37	4500	501.92	10.03	2.49E-003	94.00	0.01880	0.9982	1.67E+000	(1.4)
06-25	09:14	01:42	4202	200.40	10.48	1.36E-003	94.00	0.01857	0.9987	2.15E+000	(1.7)
06-25	15:51	01:04	4101	100.43	19.53	1.71E-003	94.00	0.01852	0.9992	2.91E+000	(2.0)
06-26	09:07	01:28	4049	50.61	19.69	1.29E-003	94.00	0.01851	0.9996	4.30E+000	(1.8)



MWX-1, RULISON FIELD, CO.
42-32 (6546') Sw=0%
DP = 20
DP = 10
DP = 5
DP = 2.5
NET Pc = 2000 PSI
NET Pc = 4000 PSI
PERMEABILITY (MICRODARCIES)
RECIPROCAL MEAN PORE PRESSURE (1/PSI)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
0.000
.005
.010
.015
.020

CORAL RUN 34

********* WELL NAME: MWX-1, RULISON FIELD, CO. *********

PLUG: 42-32 (6546') SATN. 0 PLUG LENGTH: 3.950 CM PLUG AREA: 5.057 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	PERMEABILITY STD. DEV. (%)
11-15	14:24	03:02	4184	200.91	7.96	9.89E-004	88.00	0.01857	0.9987	2.04E+000	(1.5)
11-15	17:31	14:51	4171	200.80	2.13	2.64E-004	88.00	0.01857	0.9987	2.04E+000	(2.0)
11-16	11:49	01:28	4538	500.21	9.69	2.19E-003	90.00	0.01880	0.9982	1.51E+000	(2.6)
11-16	15:00	01:42	5039	1004.27	10.53	4.13E-003	90.00	0.01943	1.0017	1.35E+000	(3.5)
11-16	17:40	15:28	5331	1347.44	1.19	5.82E-004	90.00	0.02000	1.0073	1.31E+000	(6.9)
11-17	18:05	12:15	5432	1447.07	4.64	2.40E-003	90.00	0.02018	1.0094	1.28E+000	(2.8)
11-18	11:54	01:10	4519	500.36	18.32	4.08E-003	90.00	0.01880	0.9982	1.49E+000	(4.0)

CORAL RUN 42

********** WELL NAME: MWX-1, RULISON FIELD, CO. **********

PLUG: 42-32 (6546 FT.) SATN. 0 PLUG LENGTH: 3.950 CM PLUG AREA: 5.057 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	PERMEABILITY STD. DEV. (%)
03-20	10:10	03:45	4180	200.34	4.91	5.74E-004	94.00	0.01857	0.9987	1.95E+000	(1.9)
03-20	16:24	02:45	4092	101.04	9.75	7.76E-004	94.00	0.01852	0.9992	2.62E+000	(2.1)
03-21	09:40	03:22	4403	399.79	6.56	1.20E-003	94.00	0.01871	0.9981	1.54E+000	(1.4)
03-21	18:10	01:33	5388	1400.53	9.51	4.58E-003	94.00	0.02010	1.0084	1.24E+000	(1.9)
03-22	20:01	01:09	5449	1451.87	10.08	4.94E-003	94.00	0.02019	1.0095	1.22E+000	(1.6)
03-23	08:58	01:59	4400	400.30	10.69	1.95E-003	94.00	0.01871	0.9981	1.53E+000	(1.6)
03-23	13:24	02:02	4204	200.77	10.46	1.21E-003	94.00	0.01857	0.9987	1.93E+000	(2.3)
03-23	17:40	02:32	4096	101.27	10.77	8.55E-004	94.00	0.01852	0.9992	2.61E+000	(2.3)
03-26	10:05	02:32	4097	101.25	10.94	8.46E-004	94.00	0.01852	0.9992	2.54E+000	(2.2)
03-26	16:00	03:03	4045	50.93	10.66	6.23E-004	94.00	0.01851	0.9996	3.82E+000	(1.6)

IGT MULTIWELL PROJECT : SANDSTONE SCREENING TESTS Pg 29

SAMPLE INFORMATION: MWX# 2 RUN# 50 C.E.R. CODE 50 - 05

DEPTH: TOP 6428.5 ft BASE 6429.3 ft LENGTH 0.8 ft

LITHOLOGY: FINE SANDSTONE, THIN BEDDED. OCCASIONAL THIN COALY LAMINAE OCCUR THROUGHOUT. A COALY LAMINA AT 6428.5' CONTAINS MUD CLASTS AND ROOT STRUCTURES. ORIENTED

AS-RECEIVED WATER SATURATION:

DATE	TIME	CHIP WEIGHT (g)	
8-2	14:10	205.1	← Initial weight
8-5	09:50	203.5	
8-18	15:15	203.5 DRY	FINAL

SAMPLE EXPELLED VISIBLE WATER WHEN FIRST PLACED IN OVEN.

DRIED AT 50° °C AND 42 % RELATIVE HUMIDITY.

WATER CONTENT OF CHIP: 1.6 g

PORE VOLUME OCCUPIED BY WATER: 45.45%

PLUG INFORMATION: DIAMETER 2.537 cm LENGTH 5.456 cm

DEPTH 6429.0 ft ORIENTATION 90° W OF PRIME

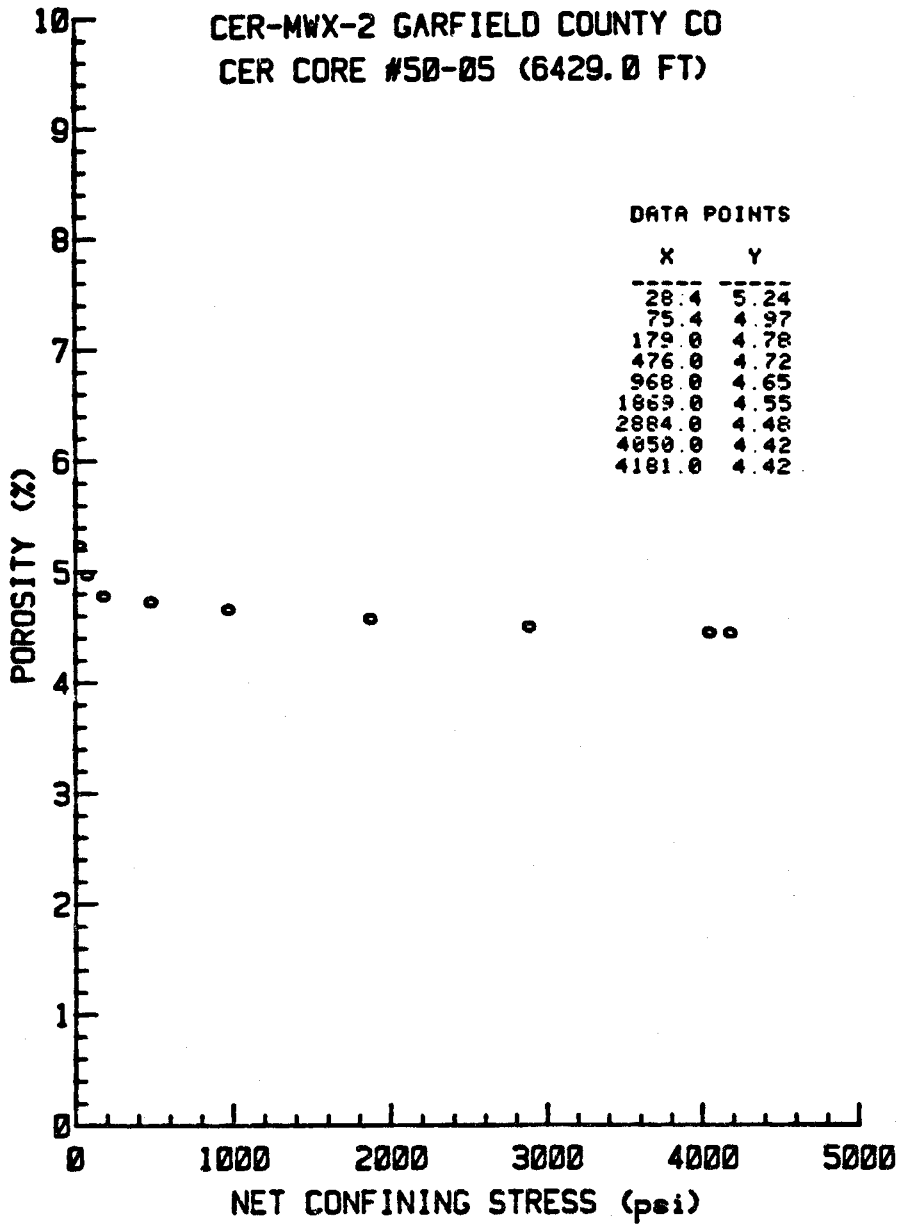
DATE CUT 8-2-82 DRIED AT 60 °C AND 45 % RELATIVE HUMIDITY.

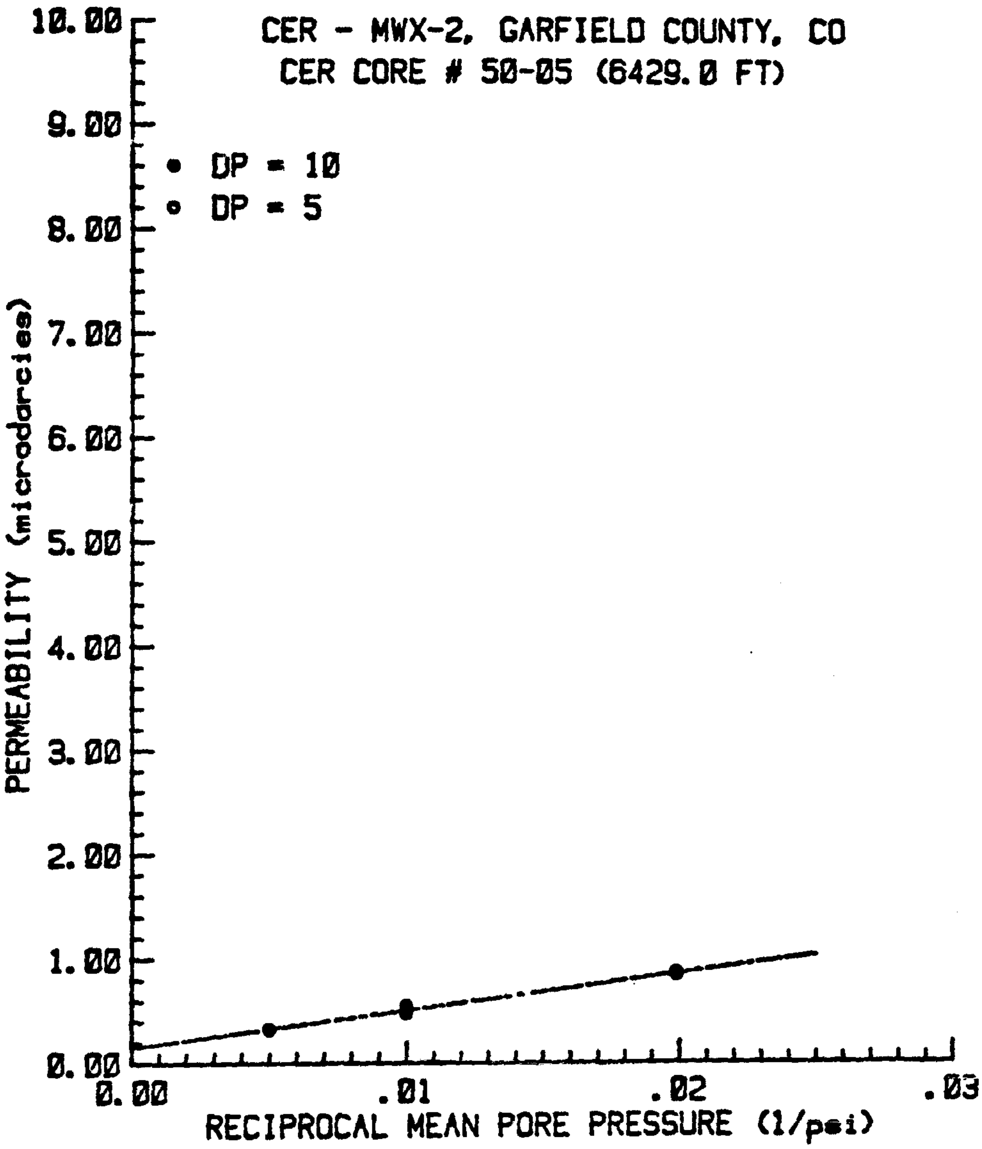
WET WEIGHT ____ g DRY WEIGHT 70.538 g VOLUME 27.581 cc

GAS POROSITY UNDER NET CONFINING STRESS 4.424 % TESTING COMPLETE ____

WEIGHT HISTORY OF PLUG:

DATE	TIME	WEIGHT	DATE	TIME	WEIGHT
8-5	10:20	70.537			
8-17	2009	70.538			


CER-MWX-2 GARFIELD COUNTY CO
CER CORE #50-05 (6429.0 FT)
DATA POINTS
X Y
28.4 5.24
75.4 4.97
179.0 4.78
476.0 4.72
968.0 4.65
1869.0 4.55
2884.0 4.48
4050.0 4.42
4181.0 4.42
POROSITY (%)
NET CONFINING STRESS (psi)
0
1000
2000
3000
4000
5000
1
2
3
4
5
6
7
8
9
10


CER - MWX-2, GARFIELD COUNTY, CO
CER CORE # 50-05 (6429.0 FT)
• DP = 10
∘ DP = 5
PERMEABILITY (microdarcies)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.00
.01
.02
.03
RECIPROCAL MEAN PORE PRESSURE (1/psi)

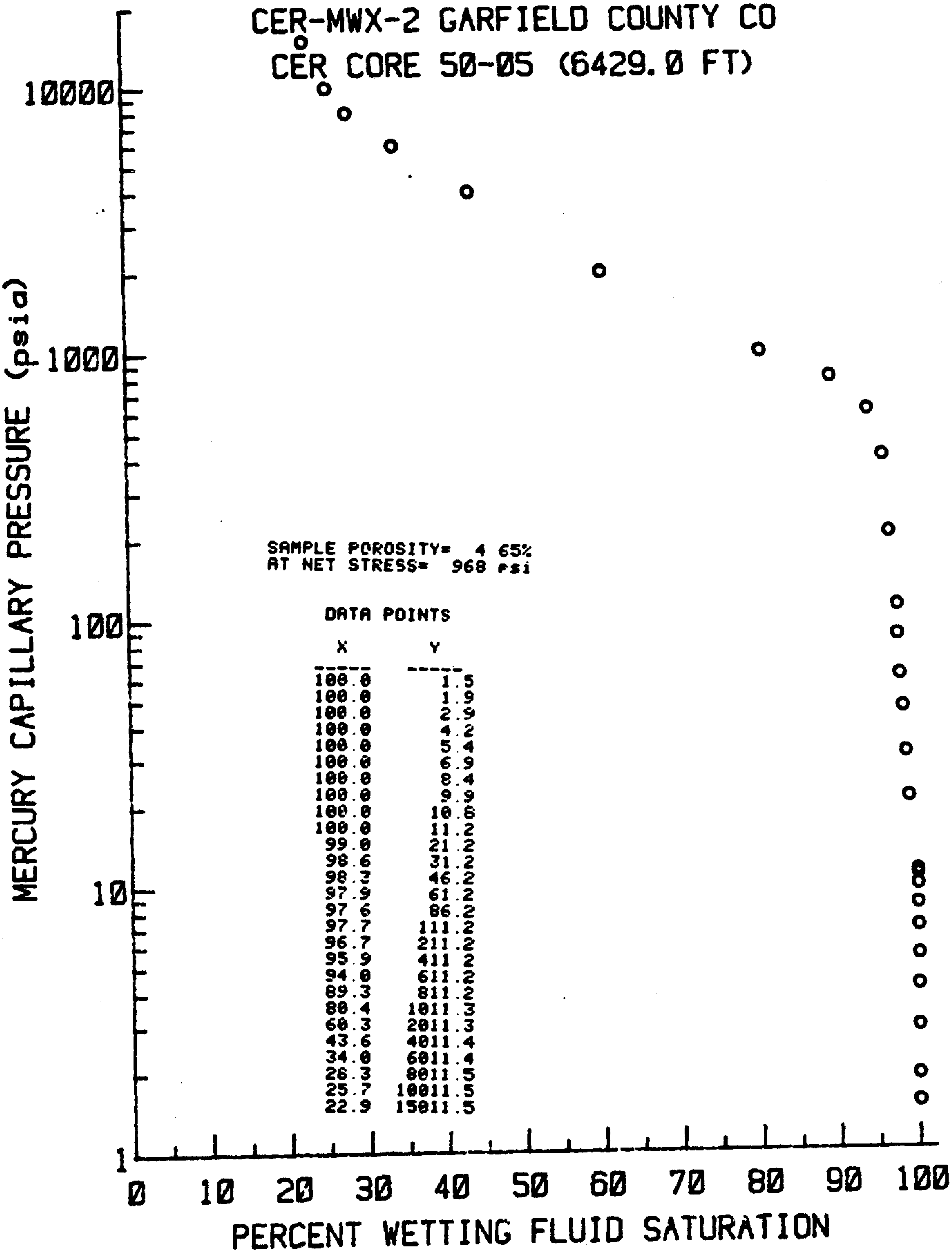
I N S T I T U T E   O F   G A S   T E C H N O L O G Y

########## WELL NAME: CER - MWX-2, GARFIELD COUNTY, CO. ##########

PLUG: CER CORE # 50-05 (6429.0 FT)   PLUG LENTH: 5.456 CM   PLUG AREA: 5.055 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY [STD.DEV.] (MICRODARCY)	NO. OF MEAS
08-18	15:00	03:20	4138	100.16	9.66	1.33E-004	90.00	0.01818	0.9989	.55 [0.03]	8
08-18	19:30	02:20	4275	50.28	9.75	1.06E-004	90.00	0.01814	0.9994	.87 [0.03]	5
08-18	22:30	09:00	4199	50.20	4.58	4.78E-005	90.00	0.01814	0.9994	.83 [0.08]	9
08-19	16:46	02:44	4343	100.05	10.17	1.24E-004	90.00	0.01818	0.9989	.49 [0.07]	8
08-19	22:05	10:20	4258	100.20	4.40	5.17E-005	90.00	0.01818	0.9989	.47 [0.04]	11
08-20	09:06	03:06	4210	200.37	9.84	1.61E-004	90.00	0.01826	0.9979	.33 [0.06]	8
08-20	12:38	03:07	4186	200.10	5.16	8.24E-005	90.01	0.01826	0.9979	.32 [0.02]	5

CER-MWX-2 GARFIELD COUNTY CO
CER CORE 50-05 (6429.0 FT)



SAMPLE POROSITY= 4 65%
AT NET STRESS= 968 psi

DATA POINTS

X	Y
100.0	1.5
100.0	1.9
100.0	2.9
100.0	4.2
100.0	5.4
100.0	6.9
100.0	8.4
100.0	9.9
100.0	10.6
100.0	11.2
99.0	21.2
98.6	31.2
98.3	46.2
97.9	61.2
97 6	86.2
97.7	111.2
96.7	211.2
95.9	411 2
94.0	611.2
89.3	811.2
80.4	1011.3
60.3	2011.3
43.6	4011.4
34.0	6011.4
26.3	8011.5
25.7	10011.5
22.9	15011.5

IGT MULTIWELL PROJECT : SANDSTONE SCREENING TESTS Pg 30

SAMPLE INFORMATION: MWX# 2 RUN# 51 C.E.R. CODE 51 - 09

DEPTH: TOP 6503.1 ft BASE 6504.0 ft LENGTH 0.9 ft

LITHOLOGY: FINE SANDSTONE, THICK BEDDED. SHALY/ COALY CLASTS OCCUR THROUGHOUT. ORIENTED.

AS-RECEIVED WATER SATURATION:

DATE	TIME	CHIP WEIGHT (g)
8-2	14:15	228.4
8-5	09:50	225.7
8-23	10:55	225.7 DRY

CHIP EXPELLED VISIBLE WATER WHEN FIRST PLACED IN OVEN

Initial weight

FINAL

DRIED AT 50 °C AND 42 % RELATIVE HUMIDITY.

WATER CONTENT OF CHIP: 2.7 g

PORE VOLUME OCCUPIED BY WATER: 52.87 %

PLUG INFORMATION: DIAMETER 2.535 cm LENGTH 5.612 cm

DEPTH 6503.9 ft ORIENTATION 90° W OF PRIME

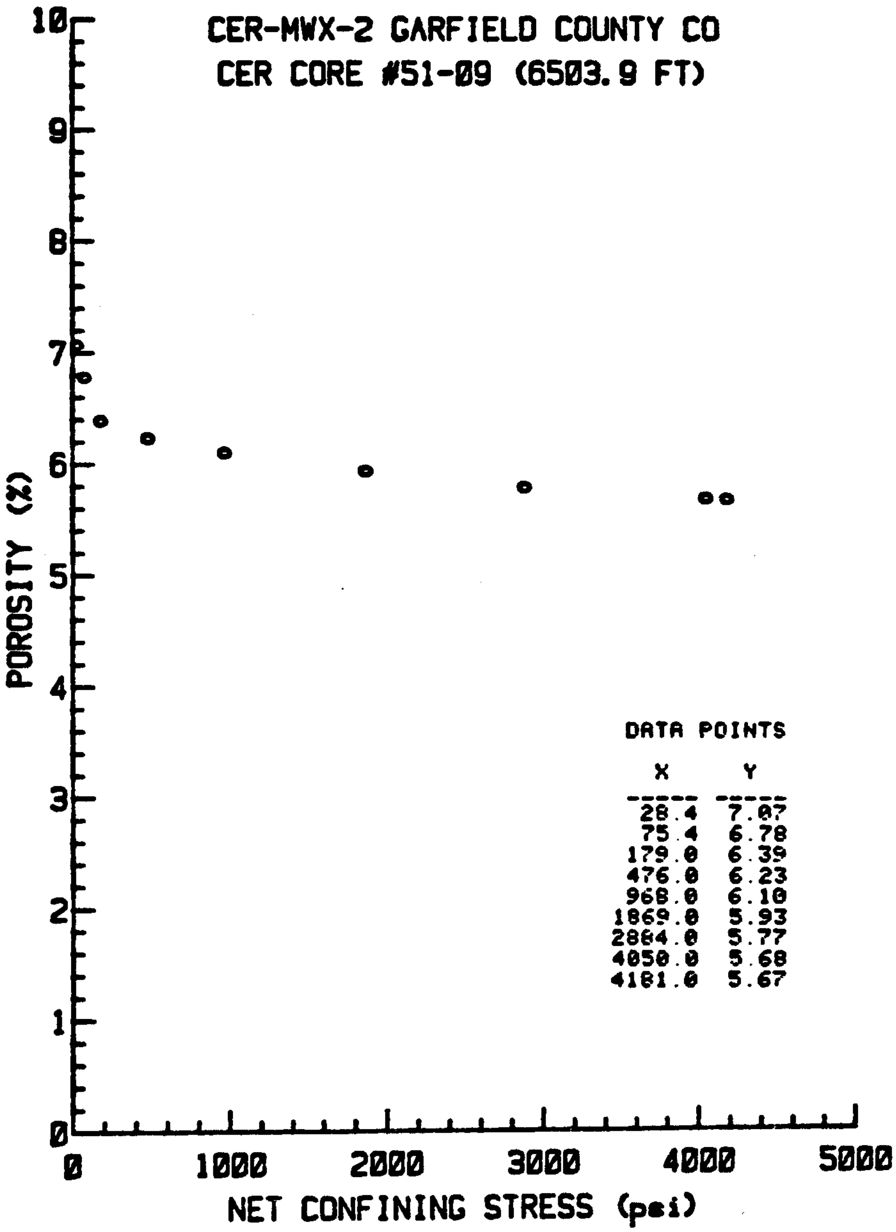
DATE CUT 8-2-82 DRIED AT 60 °C AND 45 % RELATIVE HUMIDITY.

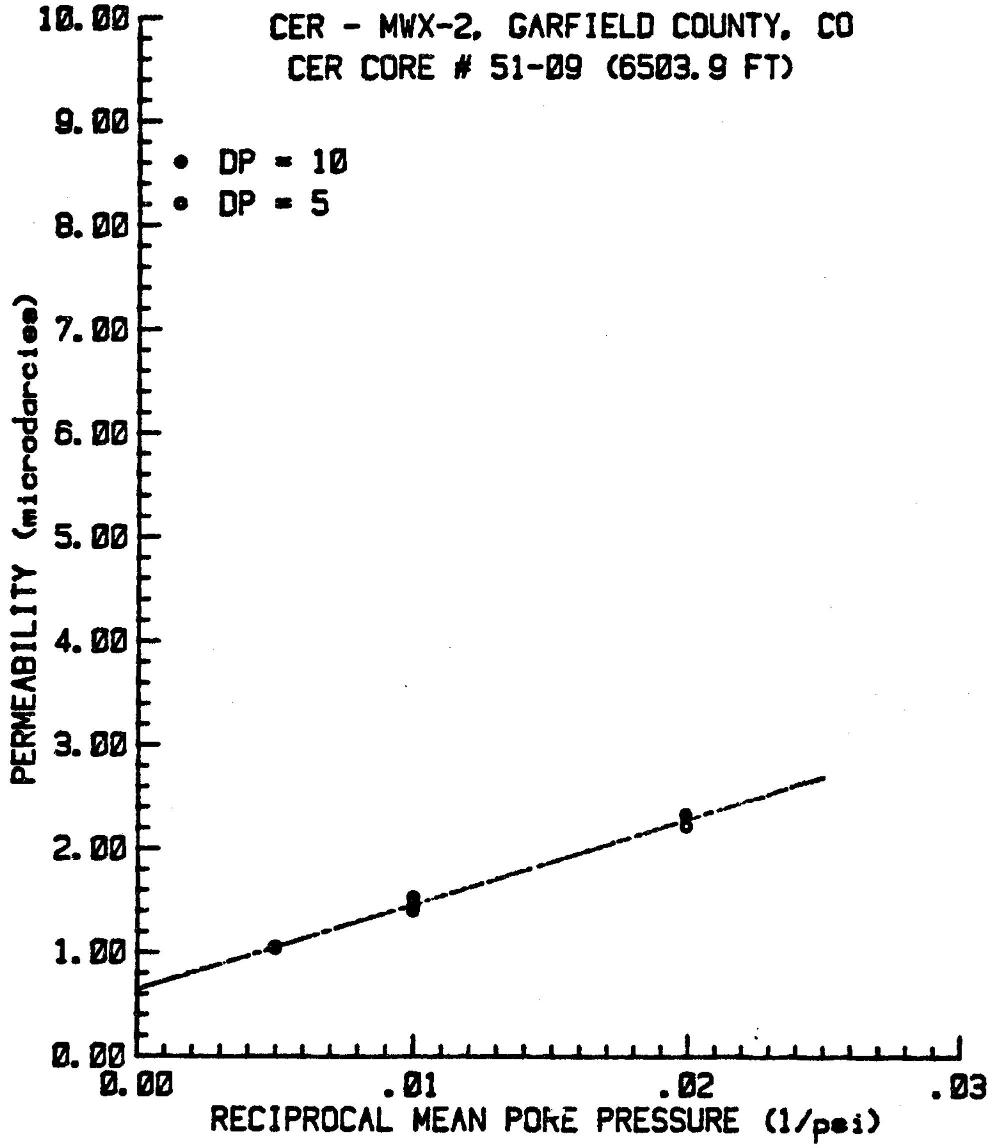
WET WEIGHT 71.092 g DRY WEIGHT 71.084 g VOLUME 28.333 cc

GAS POROSITY UNDER NET CONFINING STRESS 5.677 % TESTING COMPLETE

WEIGHT HISTORY OF PLUG:

DATE	TIME	WEIGHT	DATE	TIME	WEIGHT
8-5	10:25	71.092			
8-17	20:1d	71.084			


CER-MWX-2 GARFIELD COUNTY CO
CER CORE #51-09 (6503.9 FT)
POROSITY (%)
NET CONFINING STRESS (psi)
DATA POINTS
X Y
28.4 7.07
75.4 6.78
179.0 6.39
476.0 6.23
968.0 6.10
1869.0 5.93
2884.0 5.77
4050.0 5.68
4181.0 5.67

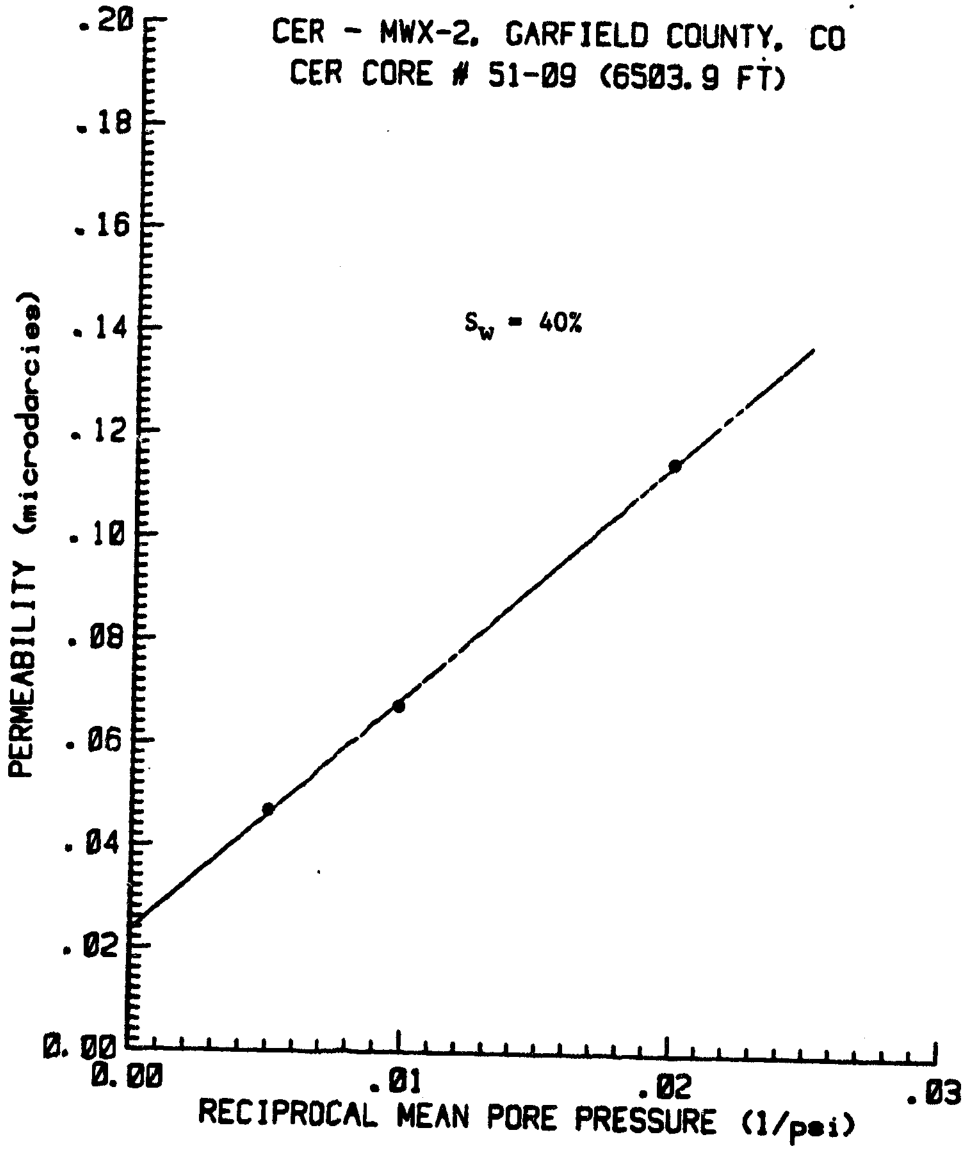

CER - MWX-2, GARFIELD COUNTY, CO
CER CORE # 51-09 (6503.9 FT)
DP = 10
DP = 5
PERMEABILITY (microdarcies)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.00
.01
.02
.03
RECIPROCAL MEAN PORE PRESSURE (1/psi)

INSTITUTE OF GAS TECHNOLOGY

########## WELL NAME: CER - MWX-2, GARFIELD COUNTY, CO. ##########

PLUG: CER CORE # 51-09 (6503.9 FT) PLUG LENTH: 5.612 CM PLUG AREA: 5.047 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY [STD.DEV.] (MICRODARCY)	NO. OF MEAS
08-18	15:00	03:20	4151	100.11	9.75	3.61E-004	90.01	0.01818	0.9989	1.53 [0.05]	21
08-18	18:50	03:00	4279	50.23	9.85	2.79E-004	90.00	0.01814	0.9994	2.32 [0.08]	14
08-18	22:22	09:08	4203	50.18	4.63	1.25E-004	90.00	0.01814	0.9994	2.21 [0.08]	20
08-19	16:46	02:44	4344	100.06	10.16	3.58E-004	90.00	0.01818	0.9989	1.45 [0.08]	18
08-19	22:05	10:20	4264	100.21	4.41	1.50E-004	90.01	0.01818	0.9989	1.40 [0.08]	27
08-20	08:50	03:22	4211	200.40	9.78	4.98E-004	90.01	0.01826	0.9979	1.05 [0.10]	25
08-20	12:30	03:14	4185	200.16	5.02	2.51E-004	90.01	0.01826	0.9979	1.04 [0.09]	13



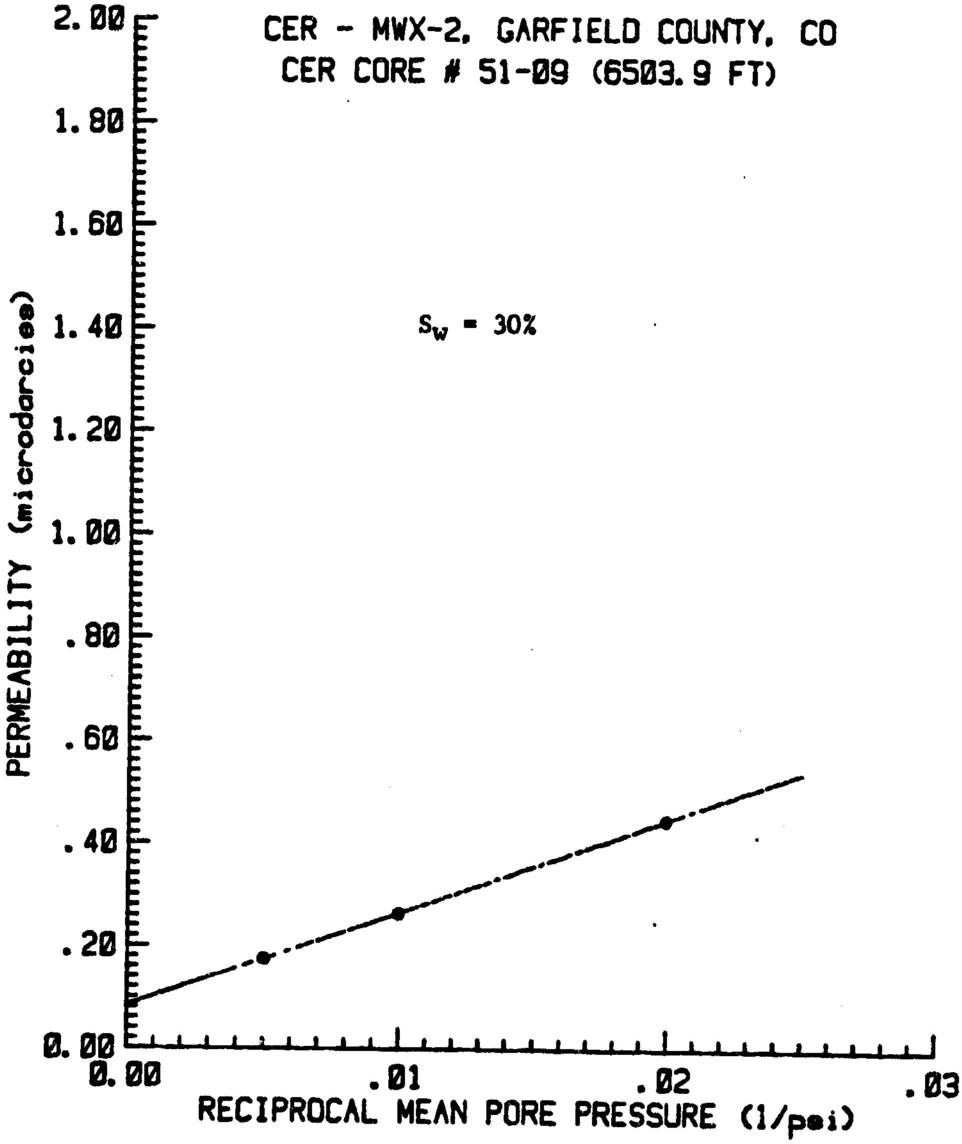
CER - MWX-2, GARFIELD COUNTY, CO
CER CORE # 51-09 (6503.9 FT)
S_w = 40%
PERMEABILITY (microdarcies)
.20
.18
.16
.14
.12
.10
.08
.06
.04
.02
0.00
0.00
.01
.02
.03
RECIPROCAL MEAN PORE PRESSURE (1/psi)

********** WELL NAME: CER - MWX-2, GARFIELD COUNTY, CO. **********

PLUG: CER CORE # 51-09 (6503.9 FT) PLUG LENTH: 5.612 CM PLUG AREA: 5.047 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY [STD.DEV.] (MICRODARCY)	NO. OF MEAS
09-11	09:35	31:11	4078	50.25	9.50	1.32E-005	90.00	0.01814	0.9994	.11 [0.02]	10
09-12	21:30	21:06	4340	200.03	19.70	4.48E-005	90.00	0.01826	0.9979	.05 [0.02]	14
09-14	13:45	22:30	4129	102.16	15.84	2.64E-005	90.00	0.01818	0.9989	.07 [0.01]	11

S_w = 40%

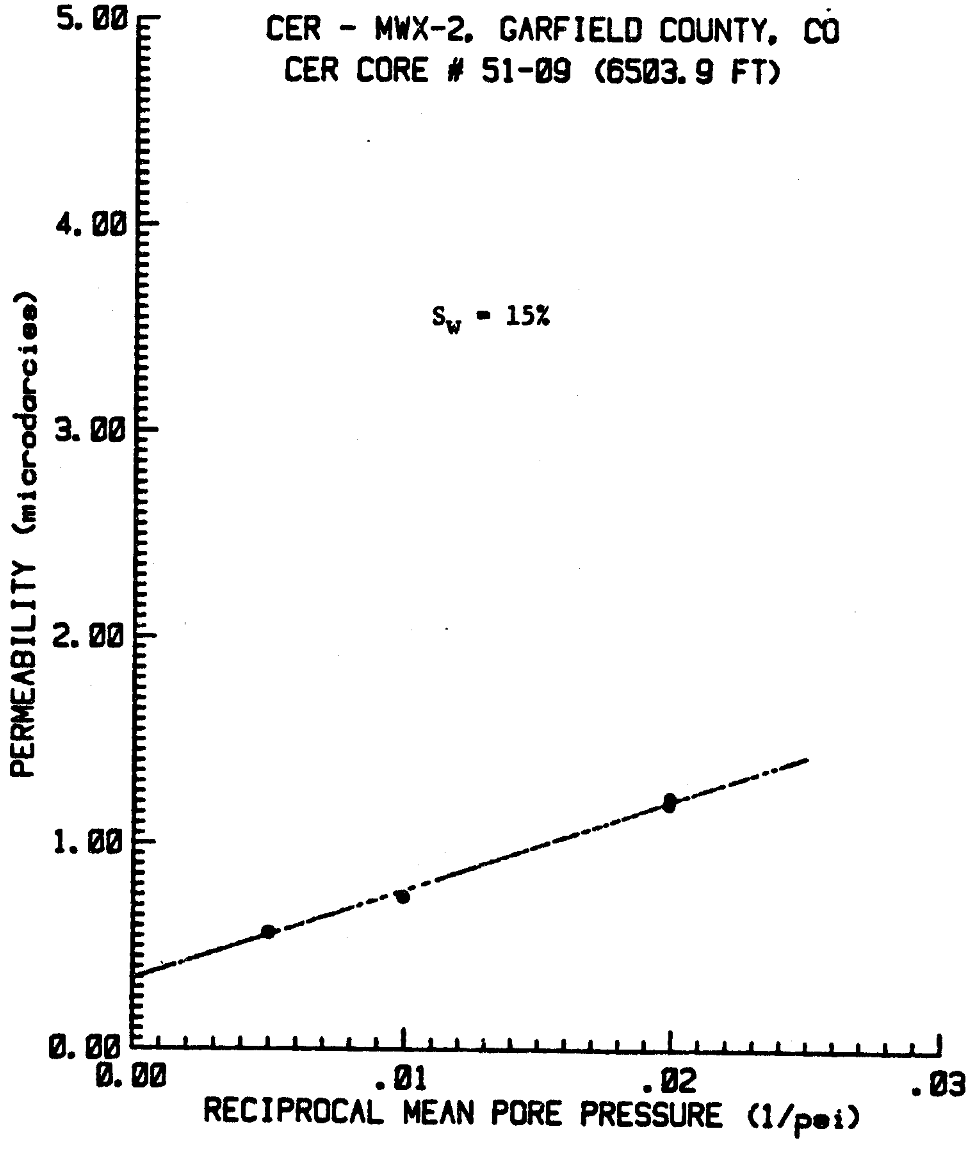

CER - MWX-2, GARFIELD COUNTY, CO
CER CORE # 51-09 (6503.9 FT)
S_w = 30%
PERMEABILITY (microdarcies)
2.00
1.80
1.60
1.40
1.20
1.00
.80
.60
.40
.20
0.00
0.00
.01
.02
.03
RECIPROCAL MEAN PORE PRESSURE (1/psi)

********** WELL NAME: CER - MWX-2, GARFIELD COUNTY, CO. **********

PLUG: CER CORE # 51-09 (6503.9 FT) PLUG LENTH: 5.612 CM PLUG AREA: 5.047 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY [STD.DEV.] (MICRODARCY)	NO. OF MEAS
09-17	11:02	26:43	4100	50.15	9.29	5.05E-005	90.00	0.01814	0.9994	.45 [0.02]	29
09-18	22:50	14:30	4256	100.31	9.89	6.33E-005	90.00	0.01818	0.9989	.26 [0.02]	15
09-19	14:50	18:00	4344	200.20	9.62	8.14E-005	90.00	0.01826	0.9979	.17 [0.02]	21

S_w = 30%

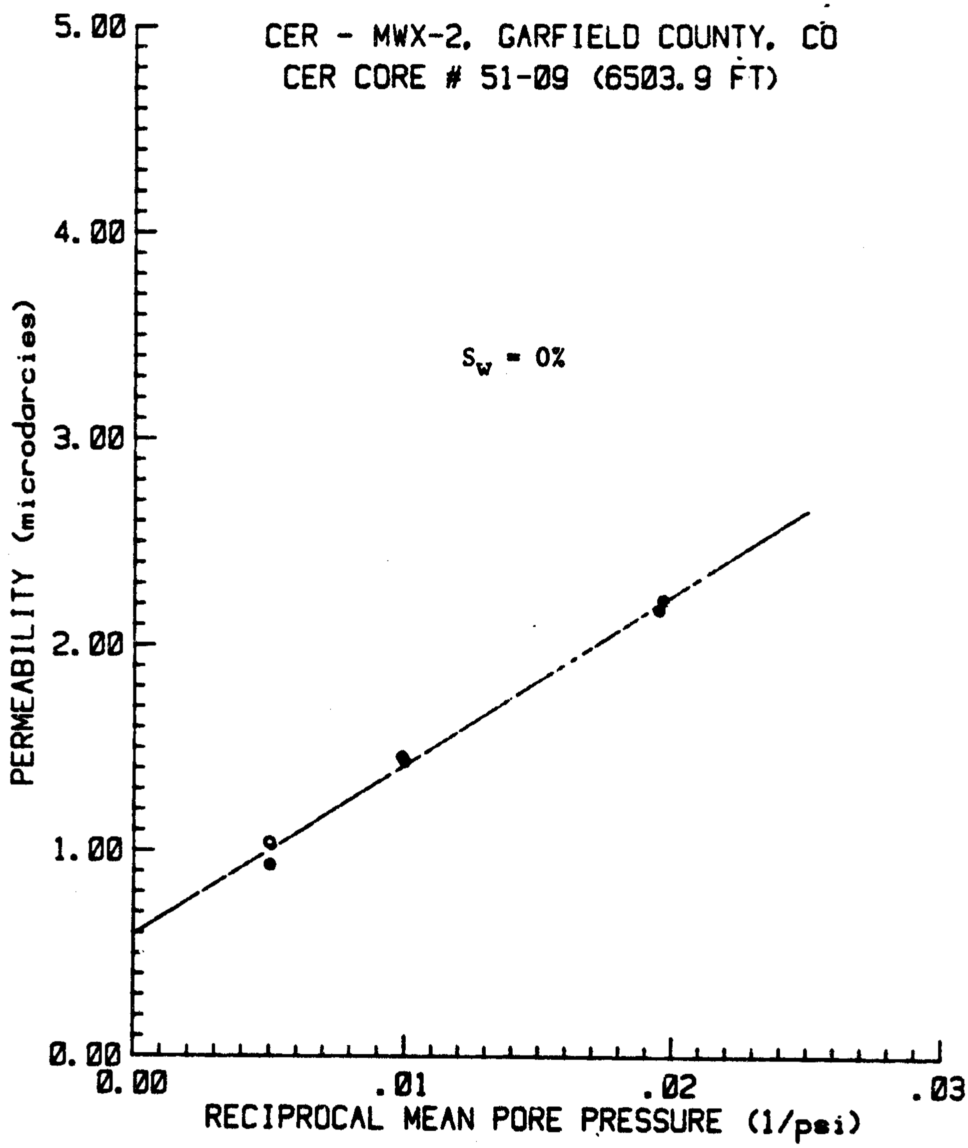

CER - MWX-2, GARFIELD COUNTY, CO
CER CORE # 51-09 (6503.9 FT)
S_w = 15%
PERMEABILITY (microdarcies)
5.00
4.00
3.00
2.00
1.00
0.00
0.00
.01
.02
.03
RECIPROCAL MEAN PORE PRESSURE (1/psi)

********** WELL NAME: CER - MWX-2, GARFIELD COUNTY, CO. **********

PLUG: CER CORE # 51-09 (6503.9 FT) PLUG LENTH: 5.612 CM PLUG AREA: 5.047 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY [STD.DEV.] (MICRODARCY)	NO. OF MEAS
09-21	15:19	16:40	4183	50.36	9.53	1.39E-004	90.00	0.01814	0.9994	1.19 [0.06]	38
09-22	17:24	14:26	4162	100.78	9.29	1.68E-004	90.00	0.01818	0.9989	.74 [0.04]	40
09-23	10:35	02:55	4083	200.60	19.07	5.25E-004	90.01	0.01826	0.9979	.57 [0.02]	23
09-23	13:37	03:13	4064	200.58	18.91	5.19E-004	90.00	0.01826	0.9979	.57 [0.03]	24
09-23	18:37	15:00	4143	50.26	10.02	1.50E-004	90.00	0.01814	0.9994	1.22 [0.06]	40

S_w = 15%


CER - MWX-2, GARFIELD COUNTY, CO
CER CORE # 51-09 (6503.9 FT)
S_w = 0%
PERMEABILITY (microdarcies)
5.00
4.00
3.00
2.00
1.00
0.00
0.00
.01
.02
.03
RECIPROCAL MEAN PORE PRESSURE (1/psi)

********** WELL NAME: CER - MWX-2, GARFIELD COUNTY, CO. **********

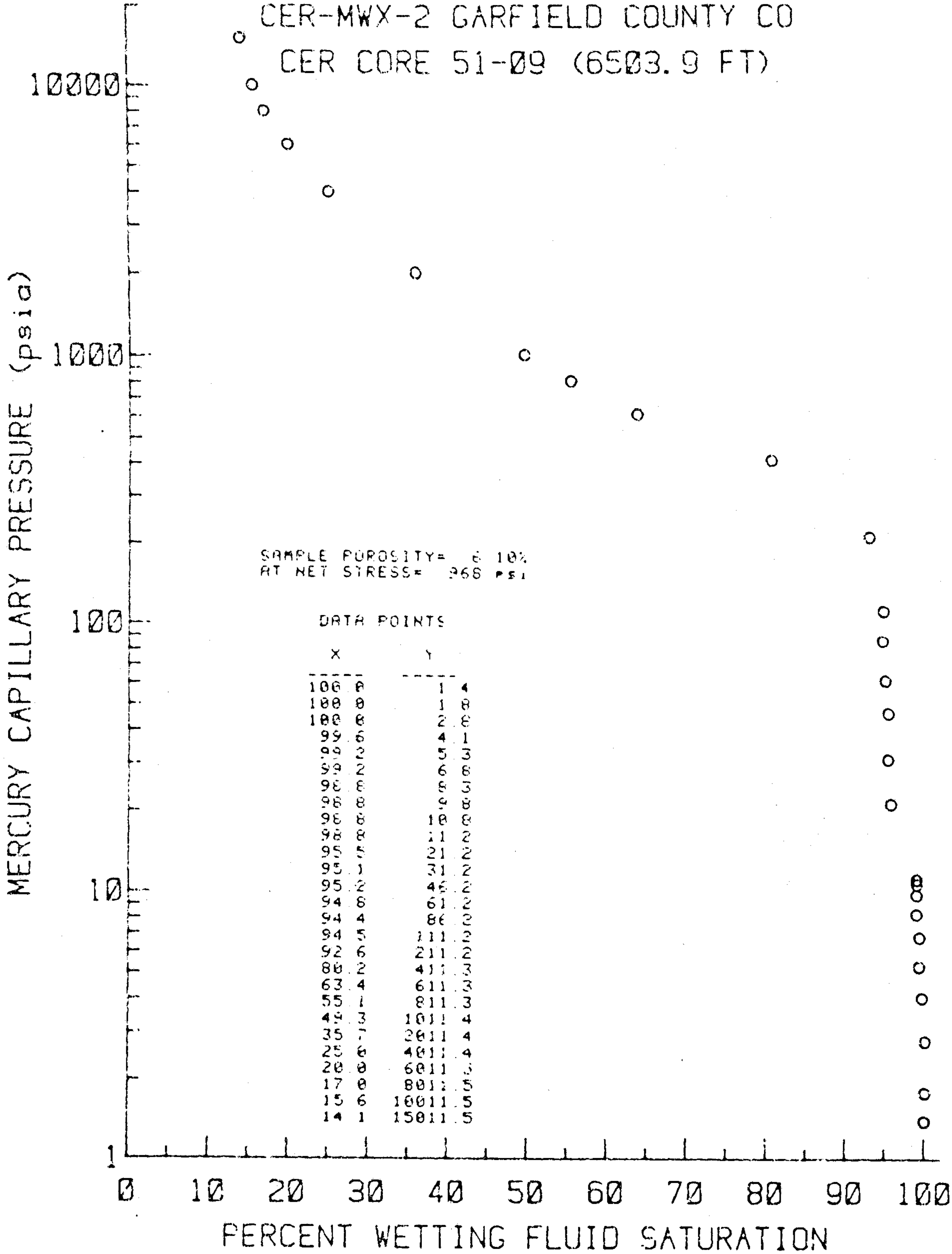
PLUG: CER CORE # 51-09 (6503.9 FT) PLUG LENTH: 5.612 CM PLUG AREA: 5.047 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY [STD.DEV.] (MICRODARCY)	NO. OF MEAS
09-27	18:37	13:53	4202	51.34	10.49	2.84E-004	90.00	0.01814	0.9994	2.17 [0.06]	51
09-28	15:34	17:11	4117	101.35	9.07	3.23E-004	90.00	0.01818	0.9989	1.45 [0.07]	85
09-29	09:55	06:07	4187	200.24	20.14	1.01E-003	90.01	0.01826	0.9979	1.04 [0.03]	70
09-29	16:57	16:33	4185	50.95	10.19	2.79E-004	90.00	0.01814	0.9994	2.22 [0.08]	61
09-30	23:05	16:08	4207	100.28	9.77	3.39E-004	90.00	0.01818	0.9989	1.43 [0.06]	51
10-01	08:07	03:58	4413	199.97	9.74	4.37E-004	90.01	0.01826	0.9979	.93 [0.05]	25

S_w = 0%

CER-MWX-2 GARFIELD COUNTY CO

CER CORE 51-09 (6503.9 FT)



SAMPLE POROSITY= 6.10%
AT NET STRESS= 968 PSI

DATA POINTS

X	Y
100.0	1.4
100.0	1.8
100.0	2.8
99.6	4.1
99.2	5.3
99.2	6.8
98.8	8.3
98.8	9.8
98.8	10.8
98.8	11.2
95.5	21.2
95.1	31.2
95.2	46.2
94.8	61.2
94.4	86.2
94.5	111.2
92.6	211.2
80.2	411.3
63.4	611.3
55.1	811.3
49.3	1011.4
35.7	2011.4
25.6	4011.4
20.0	6011.5
17.0	8011.5
15.6	10011.5
14.1	15011.5

SAMPLE INFORMATION: MWX# 2 RUN# 51 C.R.R. CODE 51 - 20

DEPTH: TOP 6537.8 ft BASE 6538.4 ft LENGTH 0.6 ft

LITHOLOGY: FINE SANDSTONE, THICK BEDDED, UNIFORM IN COLOR AND TEXTURE THROUGHOUT. FINELY-DIVIDED COALY FRAGMENTS ARE SCATTERED THROUGH THE MATRIX OF THE ROCK. ORIENTED.

AS-RECEIVED WATER SATURATION:

DATE	TIME	CHIP WEIGHT (g)
8-2	14:15	177.4
8-5	09:55	175.6
8-23	10:55	175.6 DRY

← Initial weight (8-2 row); FINAL (8-23 row)

DRIED AT 50 °C AND 42 % RELATIVE HUMIDITY.

WATER CONTENT OF CHIP: 1.8 %

PORE VOLUME OCCUPIED BY WATER: 35.47 %

PLUG INFORMATION: DIAMETER 2.536 cm LENGTH 5.455 cm

DEPTH 6538.0 ft ORIENTATION 90° W OF PRIME

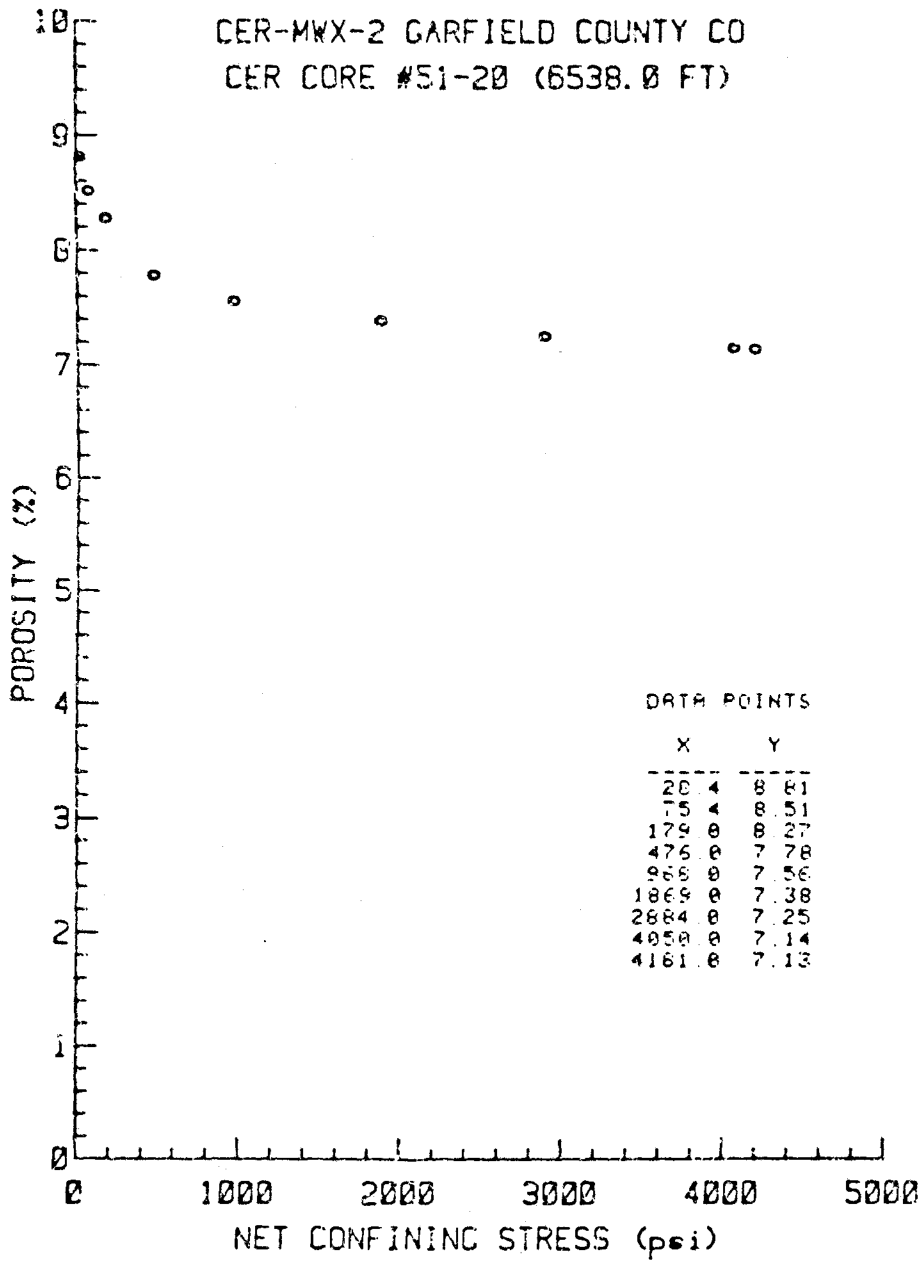
DATE CUT 8-2-82 DRIED AT 60 °C AND 45 % RELATIVE HUMIDITY.

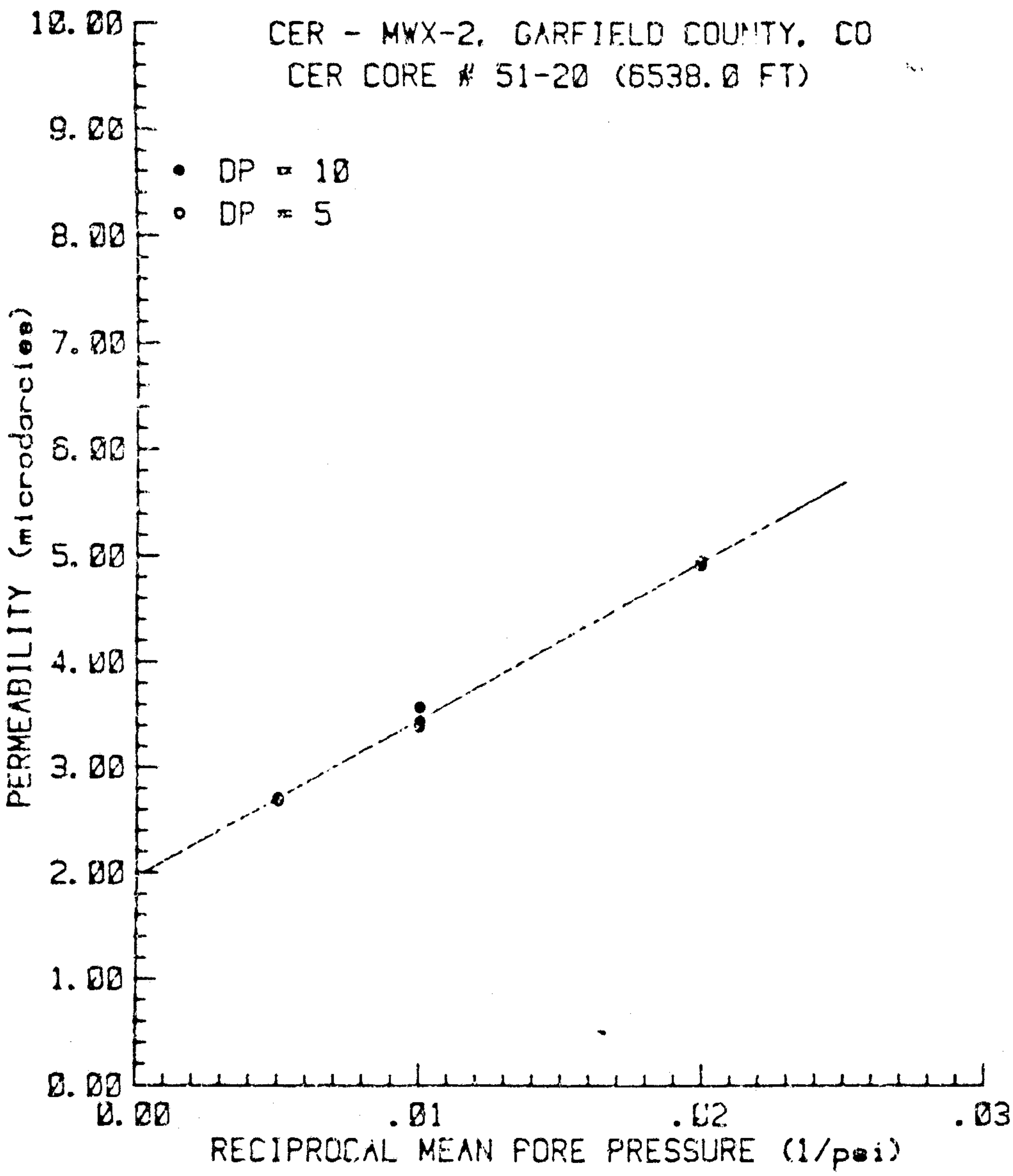
WET WEIGHT ____ g DRY WEIGHT 68.067 g VOLUME 27.547 cc

GAS POROSITY UNDER NET CONFINING STRESS 7.140 % TESTING COMPLETE ____

WEIGHT HISTORY OF PLUG:

DATE	TIME	WEIGHT	DATE	TIME	WEIGHT
8-5	10:25	68.064			
8-17	20:19	68.067			


CER-MWX-2 GARFIELD COUNTY CO
CER CORE #51-20 (6538.0 FT)
POROSITY (%)
NET CONFINING STRESS (psi)
0
1
2
3
4
5
6
7
8
9
10
1000
2000
3000
4000
5000
DATA POINTS
X Y
20.4 8.81
75.4 8.51
179.0 8.27
476.0 7.78
966.0 7.56
1869.0 7.38
2884.0 7.25
4050.0 7.14
4161.0 7.13

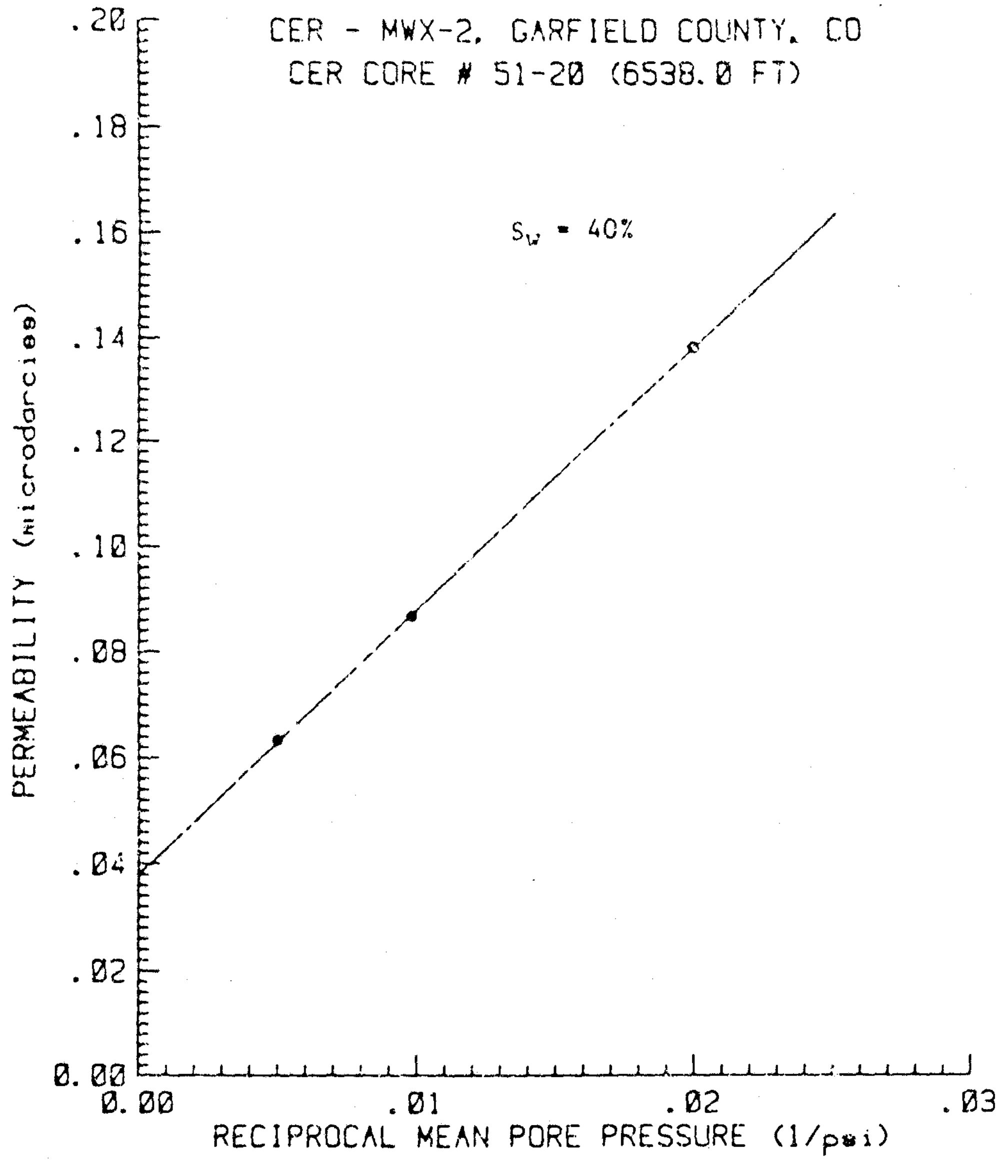

CER - MWX-2, GARFIELD COUNTY, CO
CER CORE # 51-20 (6538.0 FT)
DP = 10
DP = 5
PERMEABILITY (microdarcies)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.00
.01
.02
.03
RECIPROCAL MEAN PORE PRESSURE (1/psi)

INSTITUTE OF GAS TECHNOLOGY

********** WELL NAME: CER - MWX-2, GARFIELD COUNTY, CO. **********

PLUG: CER CORE # 51-20 (6338.0 FT) PLUG LENTH: 5.455 CM PLUG AREA: 5.051 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY [STD.DEV.] (MICRODARCY)	NO. OF MEAS
08-18	15:00	03:20	4150	100.14	9.70	8.65E-004	90.01	0.01818	0.9989	3.56 [0.07]	37
08-18	18:50	03:00	4280	50.23	9.84	6.11E-004	90.00	0.01814	0.9994	4.93 [0.09]	31
08-18	22:30	09:00	4204	50.21	4.57	2.82E-004	90.01	0.01814	0.9994	4.91 [0.06]	32
08-19	16:46	02:44	4343	100.06	10.16	8.71E-004	90.01	0.01818	0.9989	3.43 [0.07]	38
08-19	20:55	11:30	4265	100.22	4.39	3.71E-004	90.01	0.01818	0.9989	3.38 [0.08]	66
08-20	08:50	03:22	4210	200.40	9.75	1.32E-003	90.00	0.01826	0.9979	2.70 [0.07]	49
08-20	12:18	03:26	4185	200.19	4.97	6.63E-004	90.01	0.01826	0.9979	2.68 [0.10]	34

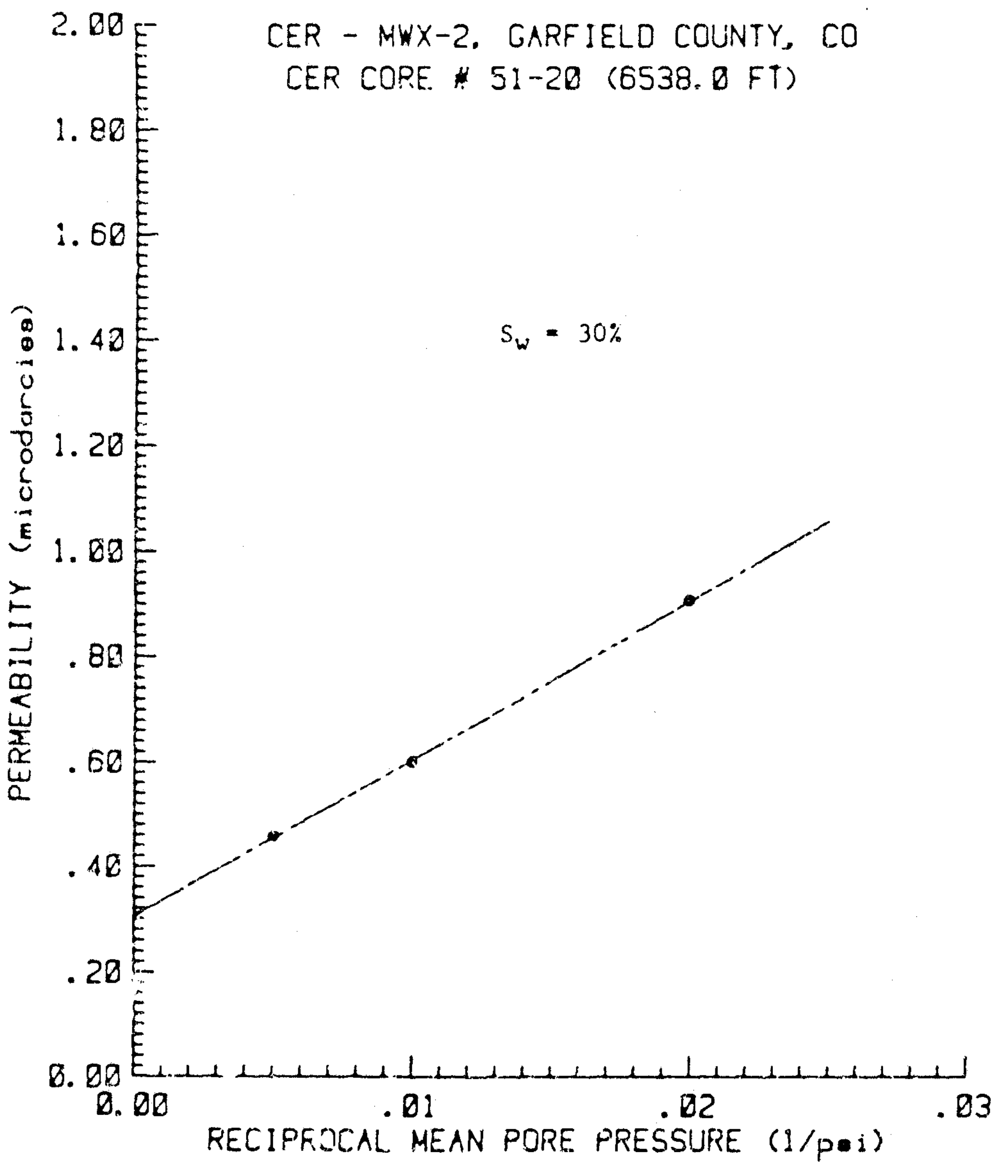

CER - MWX-2, GARFIELD COUNTY, CO
CER CORE # 51-20 (6538.0 FT)
Sw = 40%
PERMEABILITY (microdarcies)
.20
.18
.16
.14
.12
.10
.08
.06
.04
.02
0.00
0.00
.01
.02
.03
RECIPROCAL MEAN PORE PRESSURE (1/psi)

********** WELL NAME: CER - MWX-2, GARFIELD COUNTY, CO. **********

PLUG: CER CORE # 51-20 (6538.0 FT) PLUG LENTH: 5.455 CM PLUG AREA: 5.051 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY [STD.DEV.] (MICRODARCY)	NO. OF MEAS
09-11	11:00	29:40	4067	50.28	9.50	1.65E-005	90.00	0.01814	0.9994	.14 [0.01]	10
09-12	20:10	22:26	4341	200.04	17.75	6.21E-005	90.01	0.01826	0.9979	.06 [0.00]	22
09-14	12:35	23:40	4131	102.19	15.78	3.49E-005	90.00	0.01818	0.9989	.09 [0.01]	15

S_w = 40%

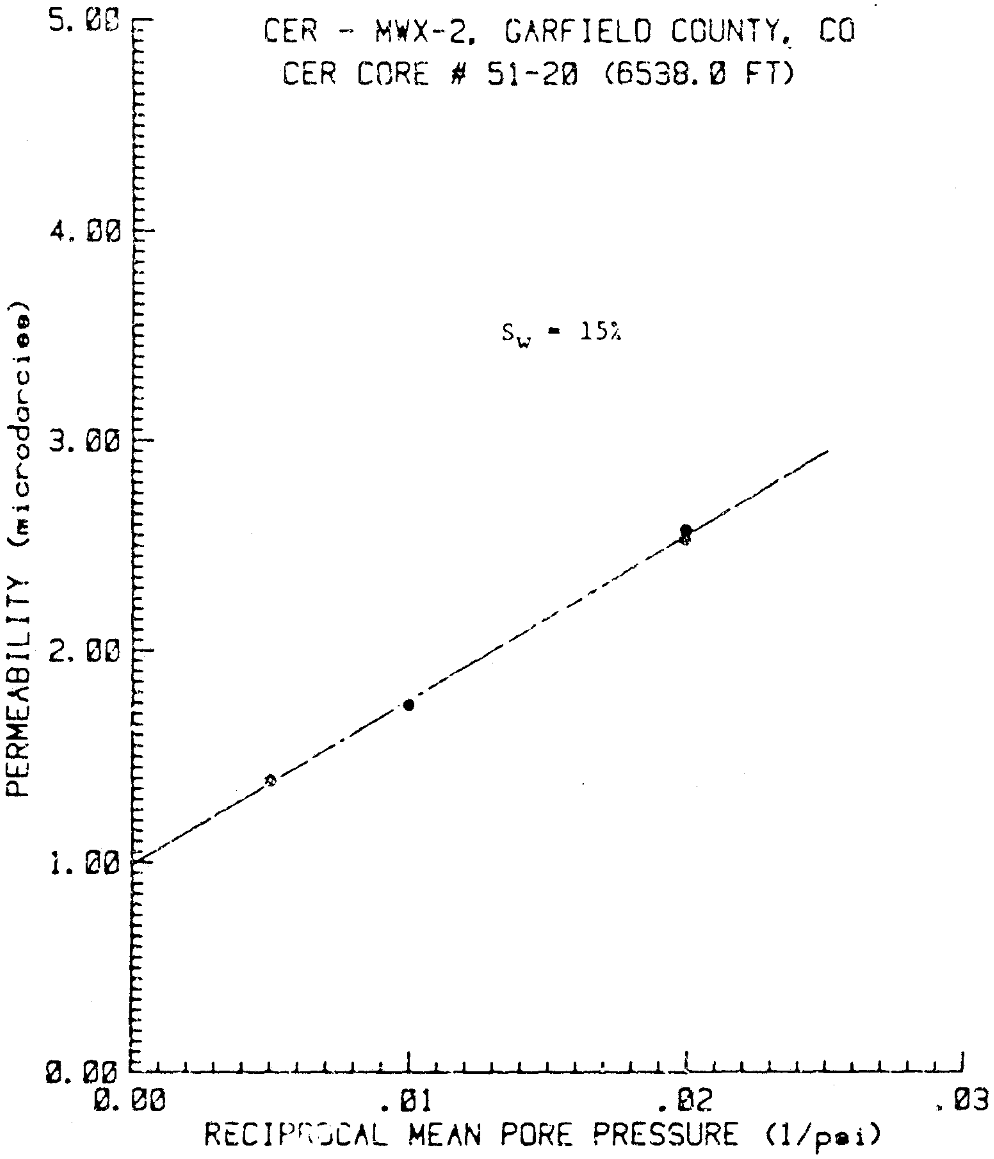

CER - MWX-2, GARFIELD COUNTY, CO
CER CORE # 51-20 (6538.0 FT)
S_w = 30%
PERMEABILITY (microdarcies)
2.00
1.80
1.60
1.40
1.20
1.00
.80
.60
.40
.20
0.00
0.00
.01
.02
.03
RECIPROCAL MEAN PORE PRESSURE (1/psi)

********** WELL NAME: CER - MWX-2, GARFIELD COUNTY, CO. **********

PLUG: CER CORE # 51-20 (6538.0 FT) PLUG LENTH: 5.455 CM PLUG AREA: 5.051 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY (STD.DEV.) (MICRODARCY)	NO. OF MEAS
09-17	11:32	26:43	4100	50.13	9.32	1.06E-004	90.00	0.01814	0.9994	.91 (0.03)	51
09-18	22:50	14:30	4272	100.30	9.92	1.49E-004	90.00	0.01818	0.9989	.60 (0.02)	29
09-19	14:50	18:00	4352	200.21	9.51	2.19E-004	90.00	0.01926	0.9979	.46 (0.02)	52

$S_w = 30\%$

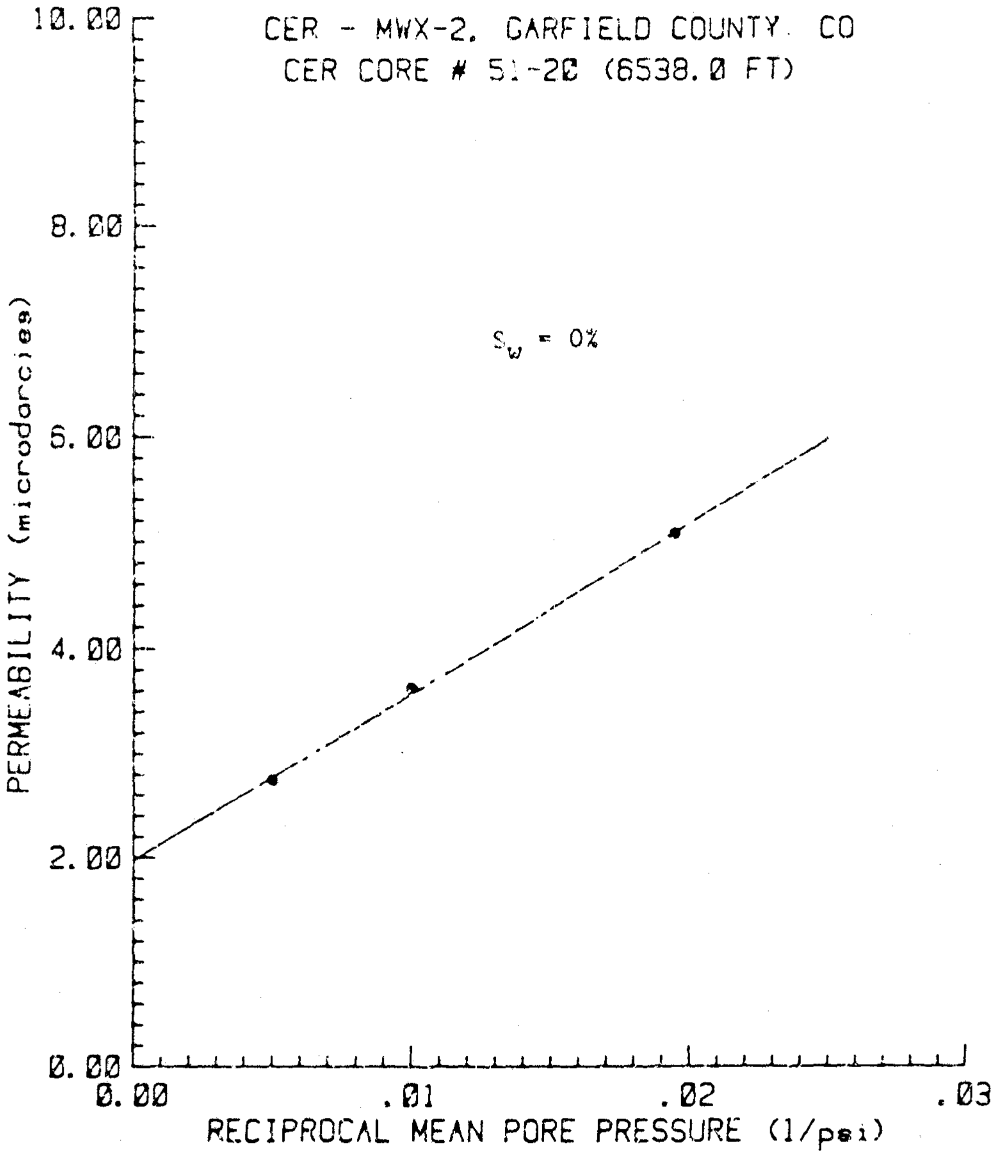

CER - MWX-2, GARFIELD COUNTY, CO
CER CORE # 51-20 (6538.0 FT)
S_w = 15%
PERMEABILITY (microdarcies)
5.00
4.00
3.00
2.00
1.00
0.00
0.00
.01
.02
.03
RECIPROCAL MEAN PORE PRESSURE (1/psi)

********** WELL NAME: CER - MWX-2, GARFIELD COUNTY, CO. **********

PLUG: CER CORE # 51-20 (6538.0 FT) PLUG LENTH: 5.455 CM PLUG AREA: 5.051 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY (STD.DEV.) (MICRODARCY)	NO. OF MEAS
09-21	15:05	15:45	4187	50.39	9.50	3.03E-004	90.01	0.01814	0.9994	2.53 (0.04)	22
09-22	17:24	14:26	4164	100.79	9.28	4.07E-004	90.01	0.01818	0.9989	1.74 (0.04)	71
09-23	10:35	02:40	4085	200.61	19.07	1.32E-003	90.00	0.01826	0.9979	1.39 (0.03)	29
09-23	13:37	03:08	4065	200.60	18.89	1.31E-003	90.00	0.01825	0.9979	1.39 (0.02)	32
09-23	19:00	12:52	4149	50.28	10.03	3.25E-004	90.01	0.01814	0.9994	2.58 (0.03)	44

S_w = 15%



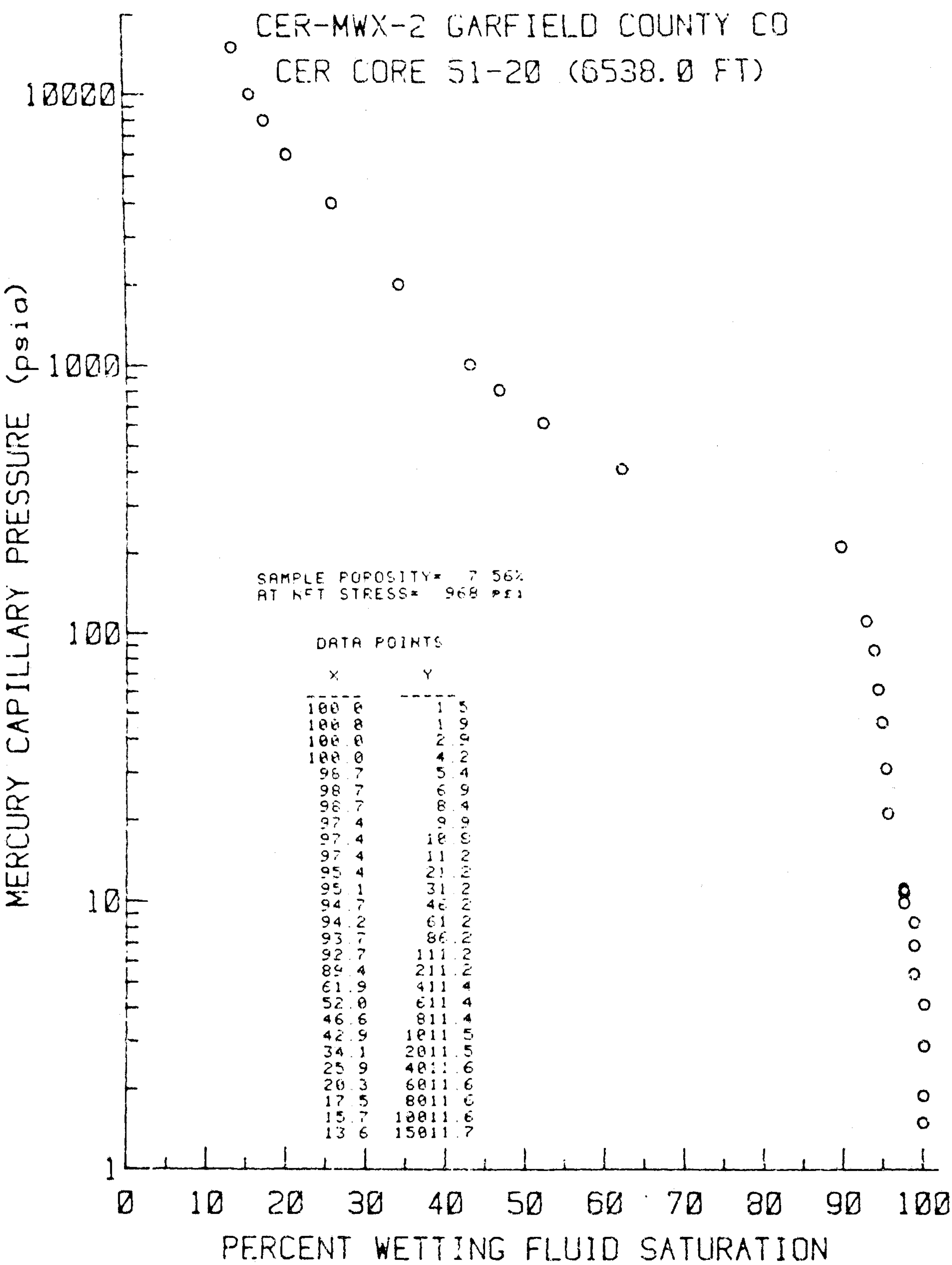
CER - MWX-2, GARFIELD COUNTY, CO
CER CORE # 51-2C (6538.0 FT)
S_w = 0%
PERMEABILITY (microdarcies)
10.00
8.00
6.00
4.00
2.00
0.00
0.00
.01
.02
.03
RECIPROCAL MEAN PORE PRESSURE (1/psi)

********** WELL NAME: CER - MWX-2, GARFIELD COUNTY, CO **********

PLUG: CER CORE # 51-20 (6538.0 FT) PLUG LENGTH: 5.455 CM PLUG AREA: 5.051 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY [STD.DEV.] (MICRODARCY)	NO. OF MEAS
09-27	18:22	13:45	4200	51.35	10.46	6.82E-004	90.01	0.01814	0.9994	5.06 [0.06]	74
09-30	23:05	16:86	4207	100.28	9.74	8.84E-004	90.01	0.01818	0.9989	3.62 [0.05]	80
10-01	08:07	03:58	4415	199.96	9.77	1.33E-003	90.01	0.01826	0.9979	2.74 [0.05]	43

$S_w = 0\%$


CER-MWX-2 GARFIELD COUNTY CO
CER CORE 51-20 (6538.0 FT)
MERCURY CAPILLARY PRESSURE (psia)
10000
1000
100
10
1
SAMPLE POROSITY= 7 56%
AT NET STRESS= 968 psi
DATA POINTS
X Y
100 0 1 5
100 8 1 9
100.0 2.9
100.0 4.2
96.7 5.4
98 7 6 9
96.7 8.4
97 4 9.9
97.4 10.9
97 4 11 2
95 4 21.2
95.1 31.2
94.7 46 2
94.2 61 2
93.7 86.2
92.7 111.2
89.4 211.2
61.9 411 4
52.0 611 4
46.6 811.4
42.9 1011 5
34.1 2011.5
25 9 4011.6
20.3 6011.6
17 5 8011 6
15.7 10011.6
13 6 15011.7
0 10 20 30 40 50 60 70 80 90 100
PERCENT WETTING FLUID SATURATION

IGT MULTIWELL PROJECT : SANDSTONE SCREENING TESTS PR 32

SAMPLE INFORMATION: MWX# 2 RUN# 51 C.E.R. CODE 51 - 26

DEPTH: TOP 6548.5 ft BASE 6548.9 ft LENGTH 0.4 ft

LITHOLOGY: FINE SILTY SANDSTONE, THINLY LAMINATED TO THIN BEDDED. SEVERAL LAMINAE CONTAIN ABUNDANT SHALY/COALY CLASTS. FINELY DIVIDED COALY DEBRIS IS CONCENTRATED ON BEDDING PLANES THROUGHOUT. ORIENTED.

AS-RECEIVED WATER SATURATION:

DATE	TIME	CHIP WEIGHT (g)	
8-2	14:20	574.8	← Initial weight
8-5	09:55	568.0	
8-18	15:15	568.0 DRY	FINAL

DRIED AT 50 °C AND 42 % RELATIVE HUMIDITY.

WATER CONTENT OF CHIP: 6.8 g

PORE VOLUME OCCUPIED BY WATER: 42.55%

PLUG INFORMATION: DIAMETER 2.537 cm LENGTH 5.379 cm

DEPTH 6548.7 ft ORIENTATION 90° W OF PRIME

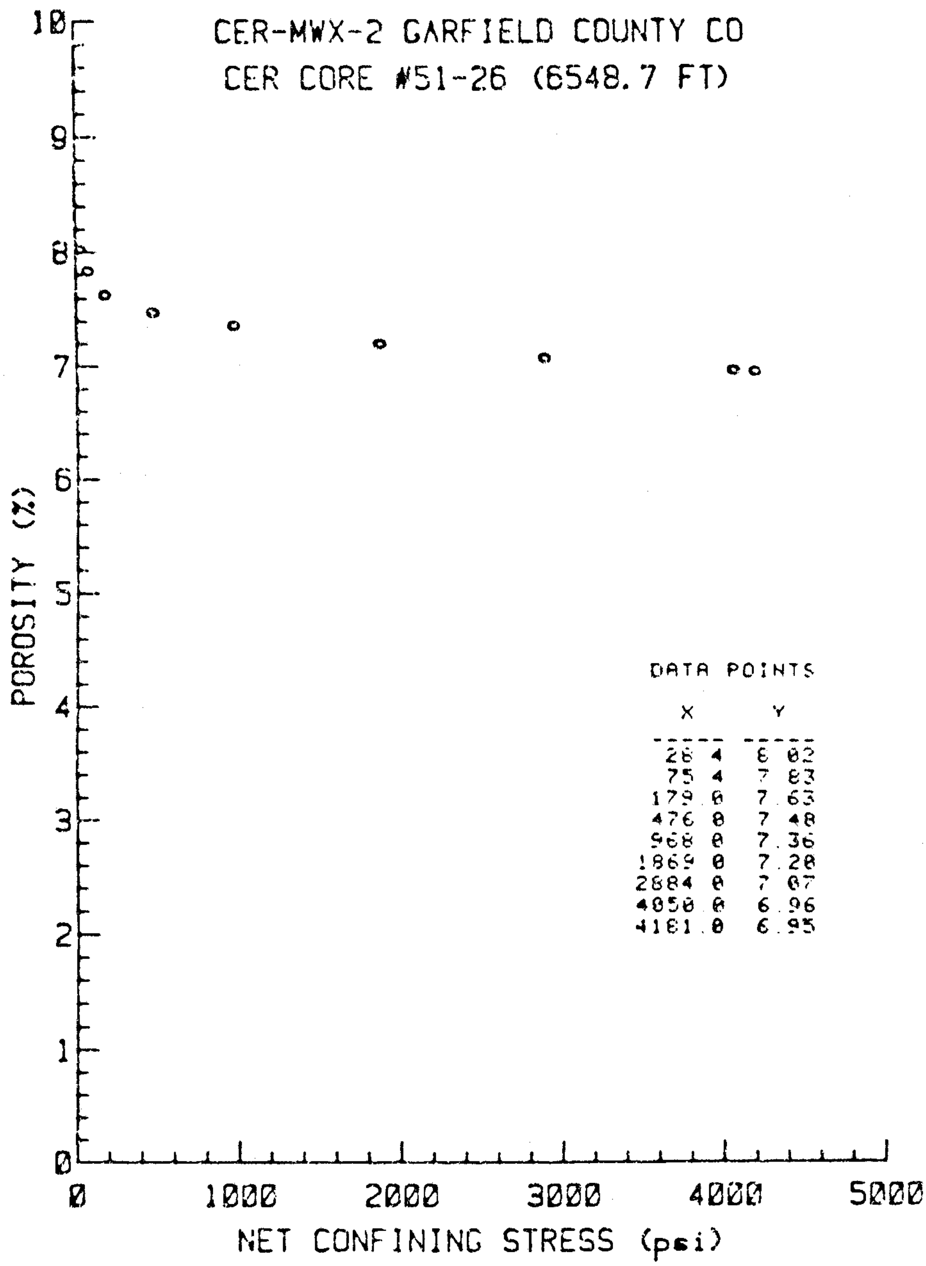
DATE CUT 8-2-82 DRIED AT 60 °C AND 45 % RELATIVE HUMIDITY.

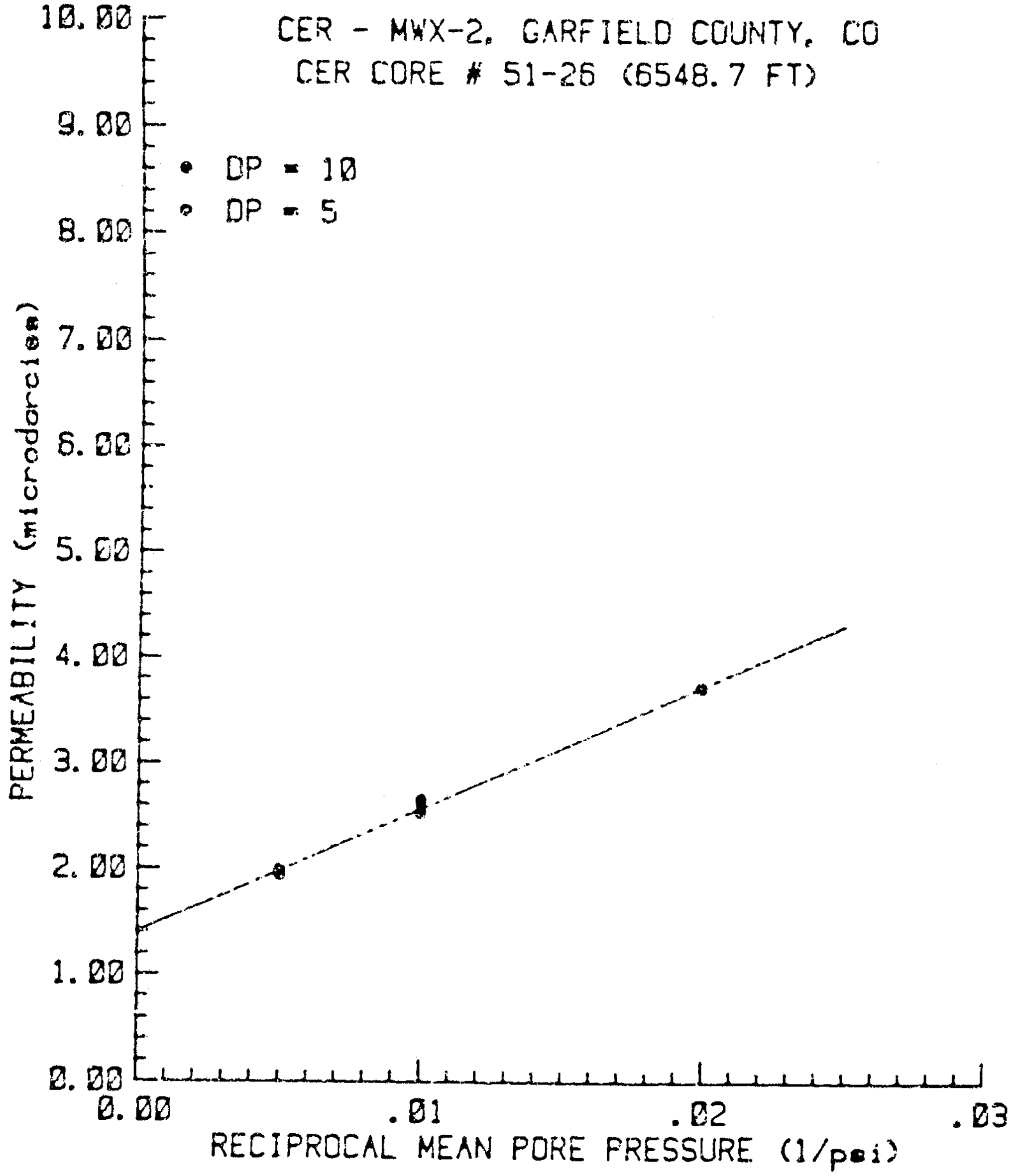
WET WEIGHT _____ g DRY WEIGHT 67.234 g VOLUME 27.183 cc

GAS POROSITY UNDER NET CONFINING STRESS 6.959 % TESTING COMPLETE _____

WEIGHT HISTORY OF PLUG:

DATE	TIME	WEIGHT	DATE	TIME	WEIGHT
8-5	10:25	67.230			
8-17	20:24	67.234			


CER-MWX-2 GARFIELD COUNTY CO
CER CORE #51-26 (6548.7 FT)
POROSITY (%)
NET CONFINING STRESS (psi)
0
1
2
3
4
5
6
7
8
9
10
1000
2000
3000
4000
5000
DATA POINTS
X Y
26.4 8.02
75.4 7.83
179.0 7.63
476.0 7.48
968.0 7.36
1869.0 7.20
2884.0 7.07
4050.0 6.96
4181.0 6.95

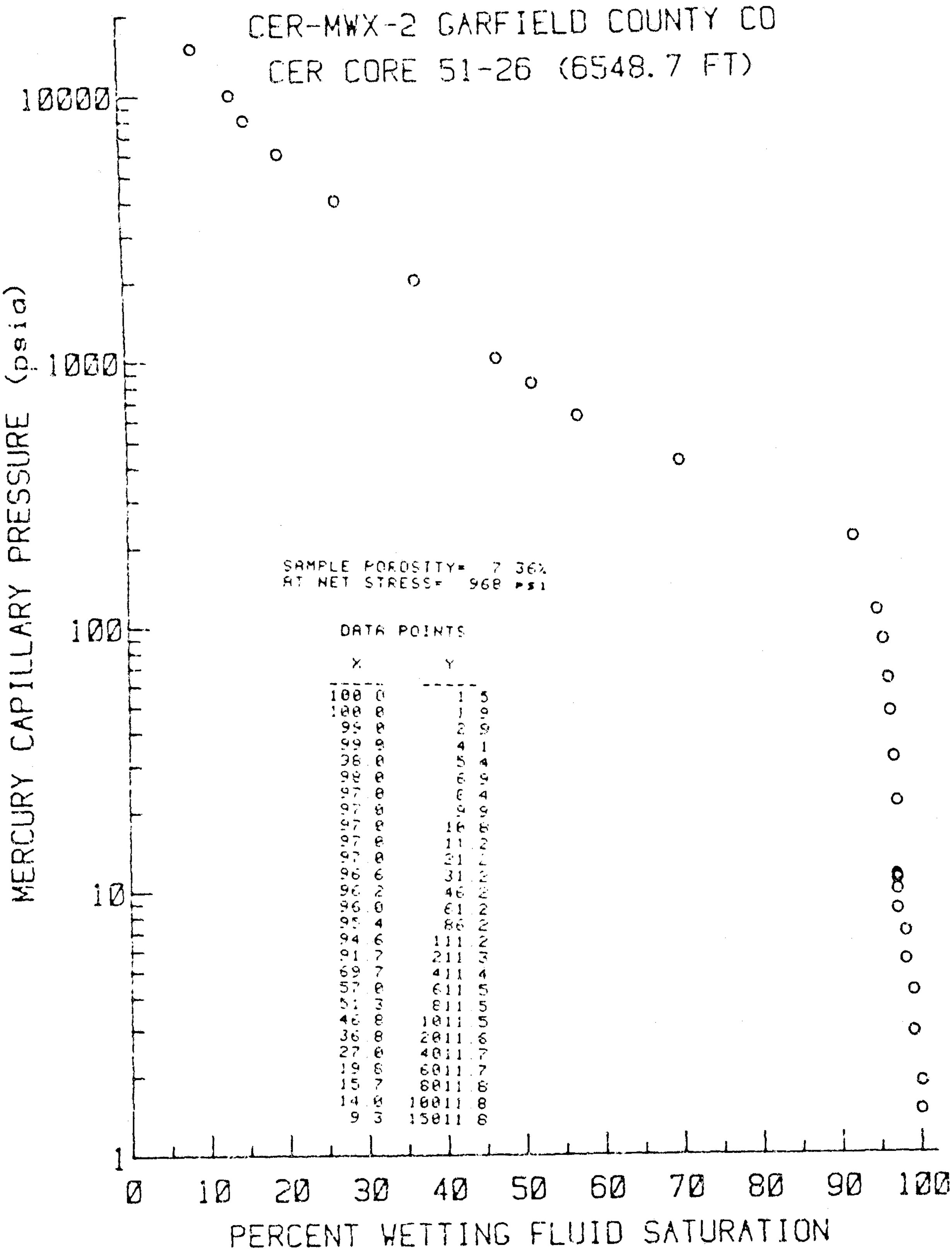

CER - MWX-2, GARFIELD COUNTY, CO
CER CORE # 51-26 (6548.7 FT)
DP = 10
DP = 5
PERMEABILITY (microdarcies)
RECIPROCAL MEAN PORE PRESSURE (1/psi)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.00
.01
.02
.03

INSTITUTE OF GAS TECHNOLOGY

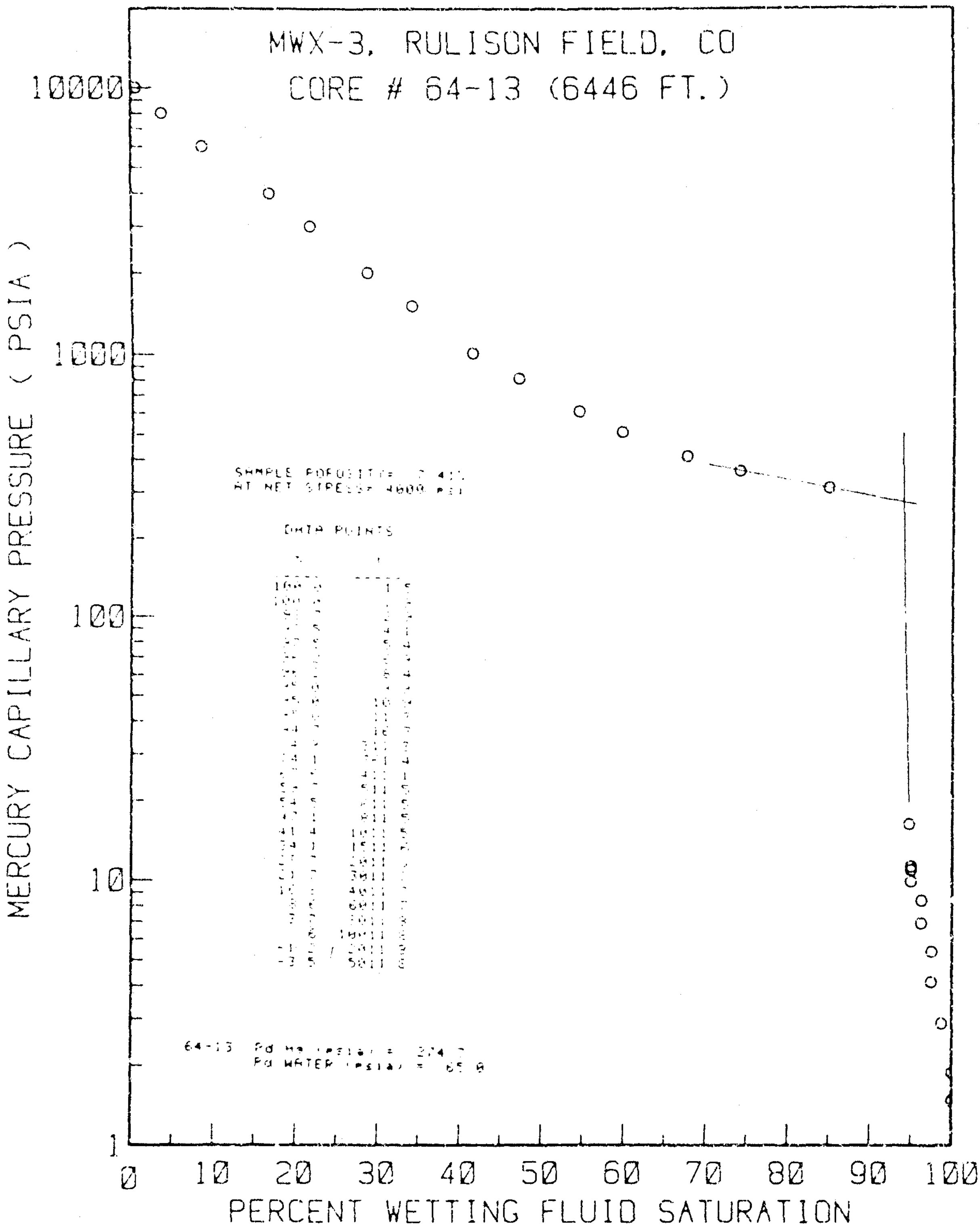
********** WELL NAME: CER - MWX-2, GARFIELD COUNTY, CO. **********

PLUG: CER CORE # 51-26 (6548.7 FT) PLUG LENTH: 5.379 CM PLUG AREA: 5.055 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY (STD.DEV.) (MICRODARCY)	NO. OF MEAS
08-18	15:00	03:20	4150	100.13	9.71	6.53E-004	90.01	0.01818	0.9989	2.65 (0.06)	39
08-18	18:50	03:05	4281	50.20	9.89	4.68E-004	90.01	0.01814	0.9994	3.71 (0.11)	16
08-18	22:30	09:00	4202	50.21	4.57	2.16E-004	90.01	0.01814	0.9994	3.72 (0.07)	33
08-19	16:46	02:44	4343	100.05	10.17	6.61E-004	90.00	0.01819	0.9989	2.56 (0.08)	30
08-19	20:55	11:30	4270	100.21	4.42	2.84E-004	90.00	0.01818	0.9989	2.53 (0.06)	46
08-20	08:50	03:22	4210	200.40	9.76	9.83E-004	90.01	0.01826	0.9979	1.99 (0.35)	49
08-20	12:18	03:26	4185	200.20	4.95	4.87E-004	90.01	0.01826	0.9979	1.94 (0.06)	27



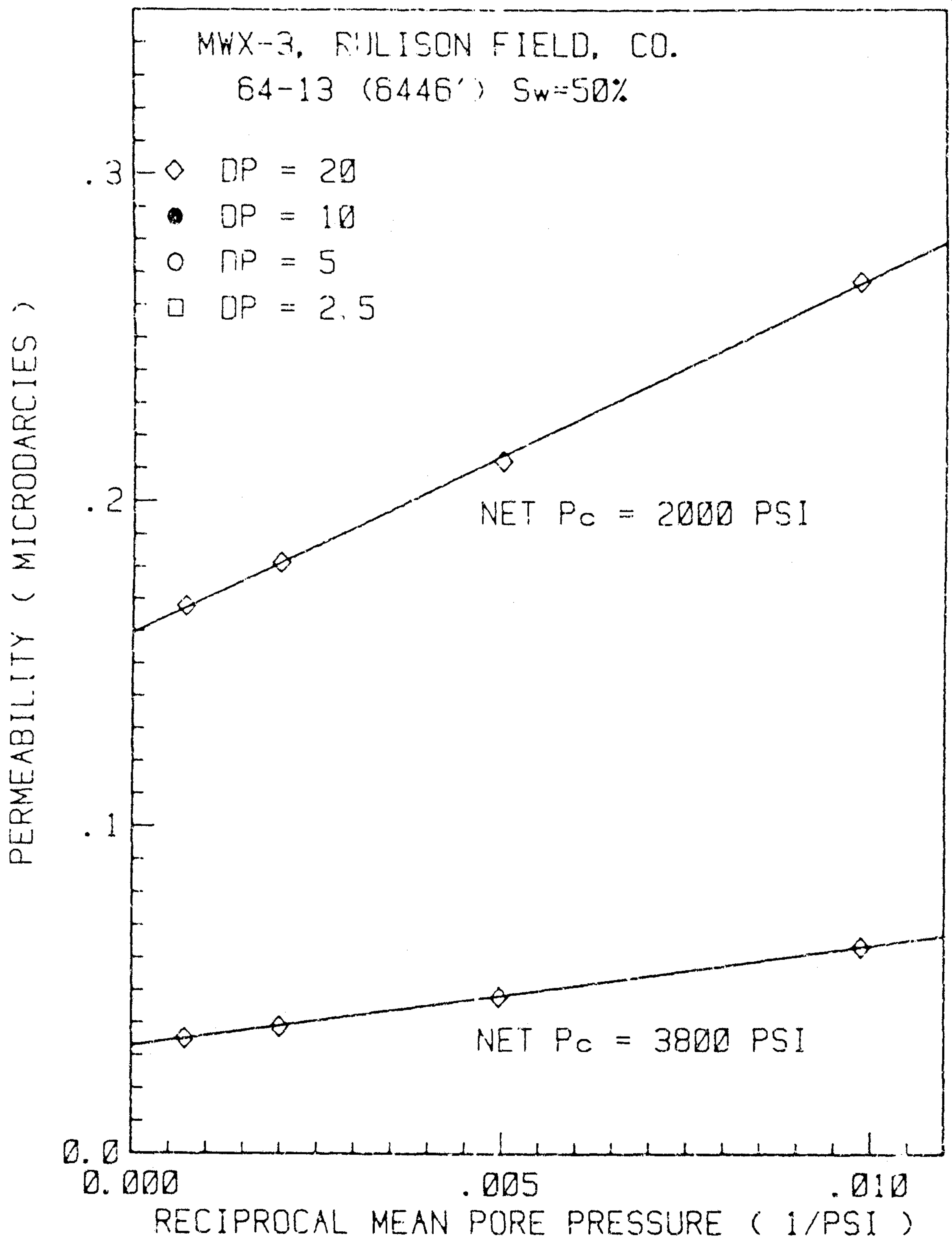
X	Y
100.0	1.5
100.0	1.9
99.8	2.9
99.9	4.1
98.0	5.4
98.0	6.9
97.0	6.4
97.0	9.9
97.0	16.6
97.0	11.2
97.0	21.2
96.6	31.2
96.2	46.2
96.0	61.2
95.4	86.2
94.6	111.2
91.7	211.3
69.7	411.4
57.0	611.5
51.3	811.5
46.8	1011.5
36.8	2011.6
27.0	4011.7
19.6	6011.7
15.7	8011.6
14.0	10011.8
9.3	15011.8


MWX-3, RULISON FIELD, CO
CORE # 64-13 (6446 FT.)
MERCURY CAPILLARY PRESSURE (PSIA)
10000
1000
100
10
1
DATA POINTS
PERCENT WETTING FLUID SATURATION
0
10
20
30
40
50
60
70
80
90
100

********** WELL NAME, MWX-3, RULISON FIELD, CO. **********

PLUG: 64-13 (6446') Sw=50% PLUG LENGTH 3.787 CM PLUG AREA: 5.059 CM^2

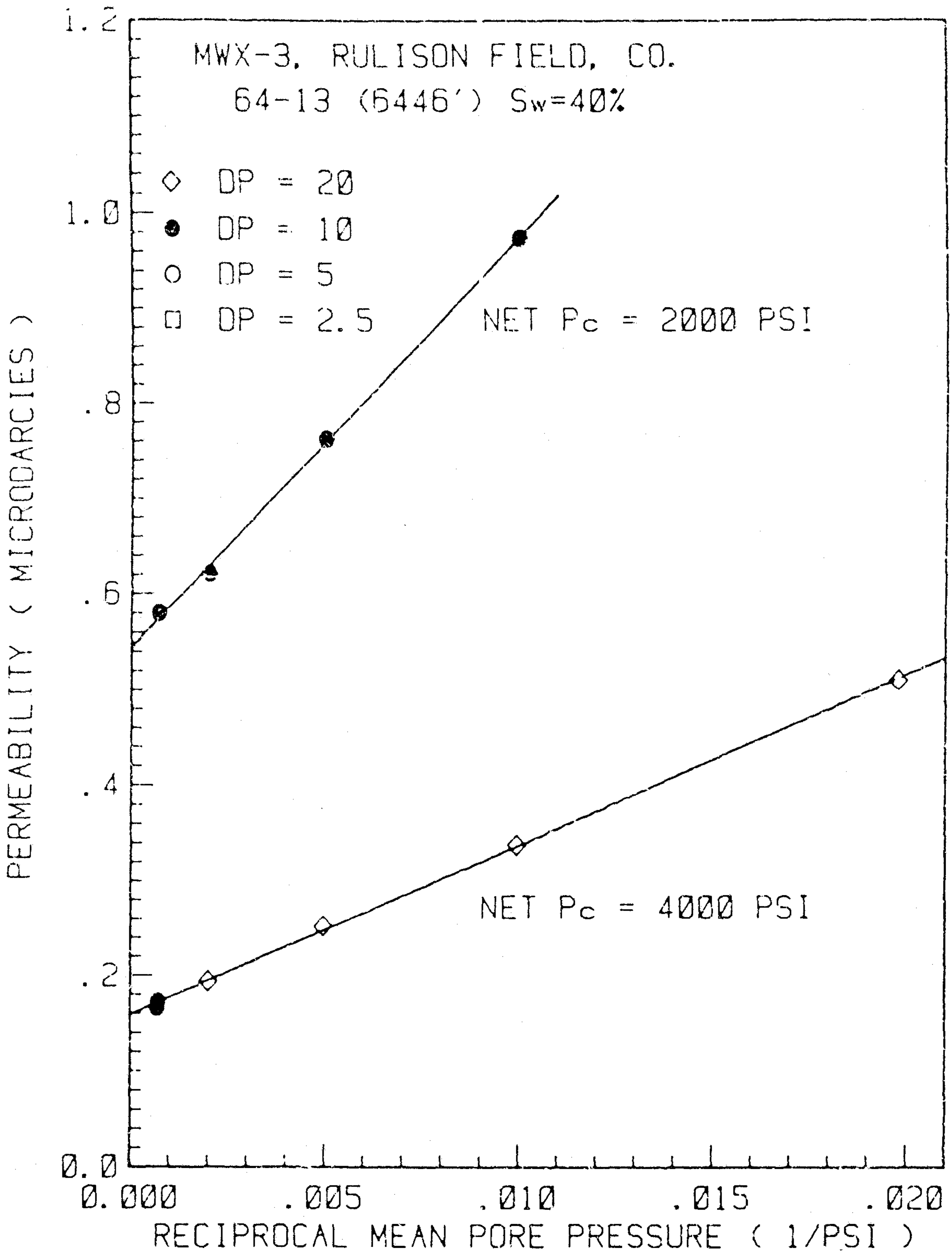
TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	STD DEV (%)
04-15	16:45	14:45	2098	101.74	21.19	1.80E-004	94.00	0.01852	0.9992	2.67E-001	(1.9)
04-16	15:24	16:30	2213	200.54	20.59	2.74E-004	94.00	0.01857	0.9987	2.12E-001	(2.5)
04-18	10:20	09:50	2496	500.96	20.71	5.81E-004	94.00	0.01880	0.9982	1.81E-001	(2.4)
04-19	11:22	08:10	3401	1399.90	19.32	1.31E-003	94.00	0.02010	1.0083	1.68E-001	(2.8)
04-19	20:45	17:00	4296	1400.23	19.85	6.36E-004	94.00	0.02010	1.0084	7.93E-002	(19.6)
04-20	17:00	46:38	5206	1399.78	19.73	2.81E-004	94.00	0.02009	1.0083	3.53E-002	(10.8)
04-23	17:40	35:20	4299	500.77	21.01	1.26E-003	94.00	0.01880	0.9982	3.89E-002	(7.0)
04-27	21:30	38:30	3999	201.60	21.35	6.47E-005	94.00	0.01857	0.9986	4.81E-002	(4.1)
05-01	20:40	42.23	3897	101.38	21.89	4.41E-005	94.00	0.01852	0.9992	6.34E-002	(2.5)


MWX-3, RULISON FIELD, CO.
64-13 (6446') Sw=50%
DP = 20
DP = 10
DP = 5
DP = 2.5
NET Pc = 2000 PSI
NET Pc = 3800 PSI
PERMEABILITY (MICRODARCIES)
.3
.2
.1
0.0
0.000
.005
.010
RECIPROCAL MEAN PORE PRESSURE (1/PSI)

********** WELL NAME: MWX-3, RULISON FIELD, CO. **********

PLUG: 64-13 (6446') Sw=40% PLUG LENGTH: 3.787 CM PLUG AREA: 5.059 CM^2

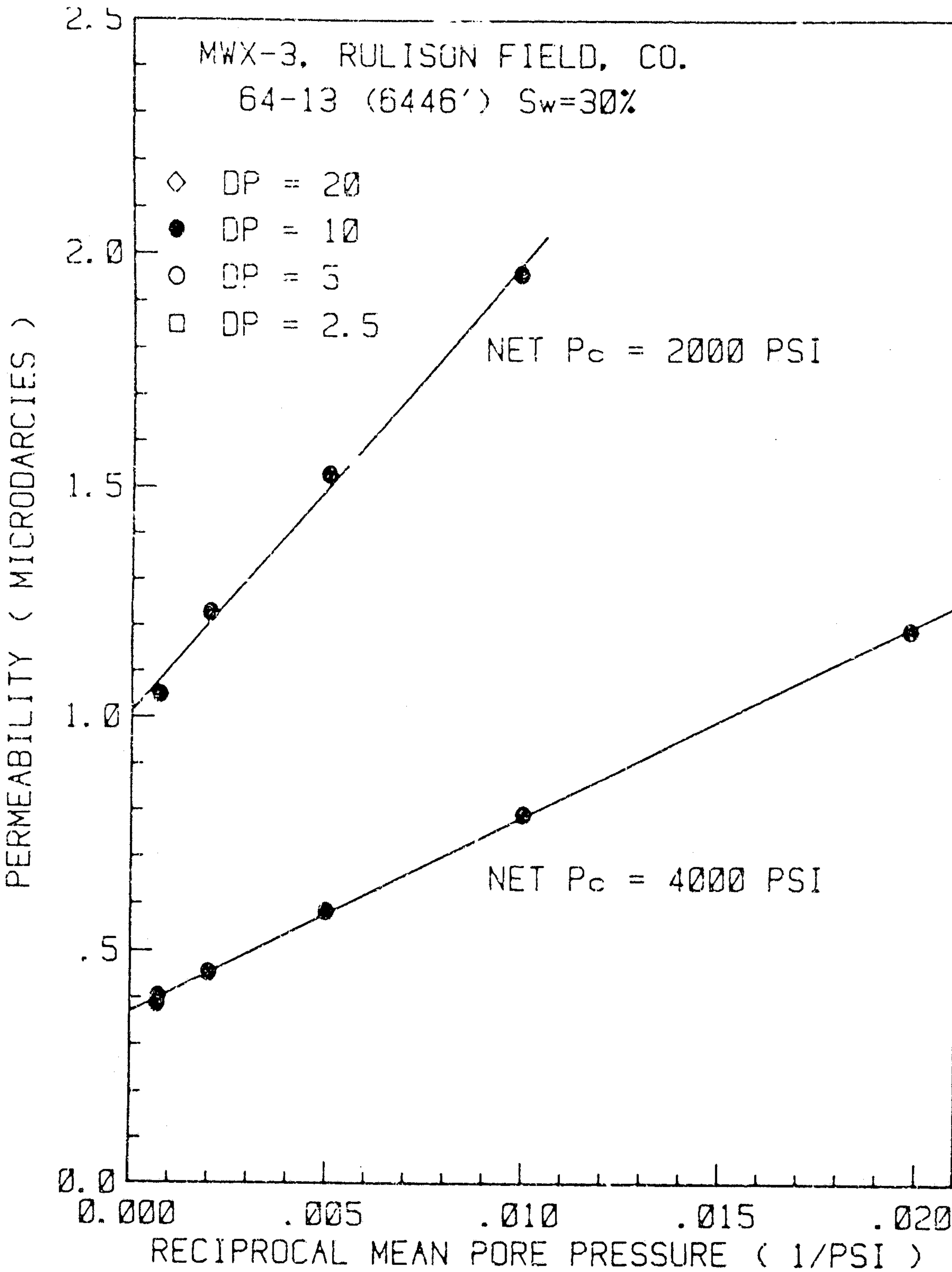
TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	PERMEABILITY STD. DEV. (%)
05-04	09:37	08:07	2094	100.15	10.63	3.25E-004	94.00	0.01852	0.9992	9.75E-001	(1.8)
05-05	14:54	05:54	2191	200.41	10.57	5.05E-004	94.00	0.01857	0.9987	7.63E-001	(1.6)
05-06	14:00	05:45	2518	499.57	10.81	1.04E-003	94.00	0.01880	0.9982	6.21E-001	(1.7)
05-07	09:24	03:39	3397	1400.45	11.26	2.64E-003	94.00	0.02010	1.0084	5.80E-001	(2 0)
05-07	15:30	06:00	4398	1400.46	10.83	1.32E-003	94.00	0.02010	1.0084	3.02E-001	(3.1)
05-07	23:15	13:30	5408	1400.24	10.52	7.35E-004	94.00	0.02010	1.0084	1.73E-001	(5.9)
05-09	01:00	16:30	5482	1450.77	11.58	8.02E-004	94.00	0.02019	1.0094	1.66E-001	(5.7)
05-10	13:52	06:45	4517	501.48	20.83	6.25E-004	94.00	0.01880	0.9982	1.94E-001	(2.6)
05-11	13:30	22:30	4201	201.34	21.35	3.39E-004	94.00	0.01857	0.9986	2.52E-001	(2.3)
05-14	11:45	20:45	4098	100.59	19.69	2.10E-004	94.00	0.01852	0.9992	3.38E-001	(1.8)
05-15	20:15	20:26	4049	50.52	19.71	1.59E-004	94.00	0.01851	0.9996	5.10E-001	(1.6)


MWX-3, RULISON FIELD, CO.
64-13 (6446') Sw=40%
DP = 20
DP = 10
DP = 5
DP = 2.5
NET Pc = 2000 PSI
NET Pc = 4000 PSI
PERMEABILITY (MICRODARCIES)
RECIPROCAL MEAN PORE PRESSURE (1/PSI)
1.2
1.0
.8
.6
.4
.2
0.0
0.000
.005
.010
.015
.020

********** WELL NAME: MWX-3, RULISON FIELD, CO. **********

PLUG: 64-13 (6446') Sw=30%　　PLUG LENGTH: 3.787 CM　　PLUG AREA: 5.059 CM^2

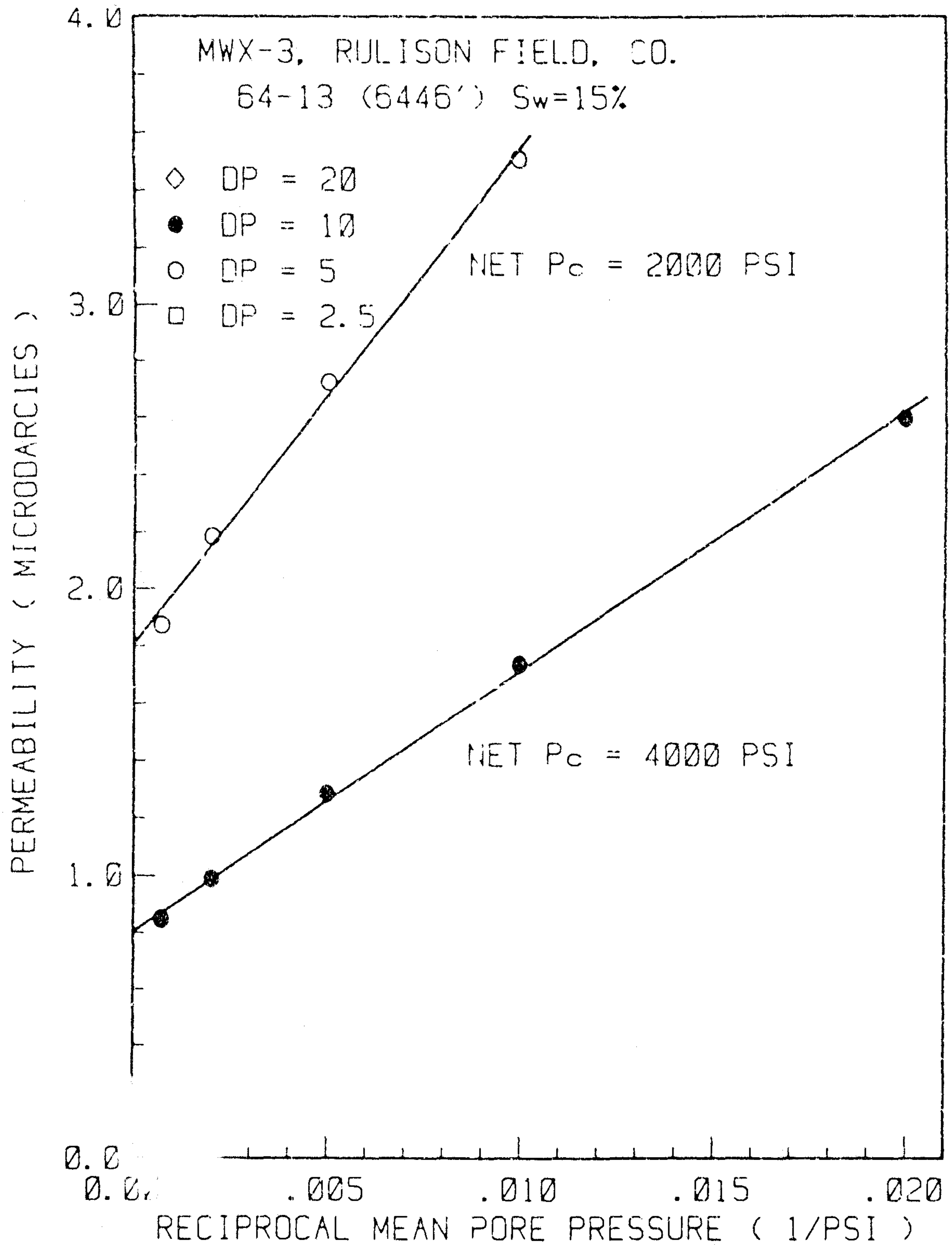
TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	PERMEABILITY STD. DEV. (%)
05-18	08:35	04:52	2093	101.56	10.16	6.33E-004	94.00	0.01852	0.9992	1.96E+000	(1.2)
05-18	15:28	02:36	2200	200.55	10.27	9.84E-004	94.00	0.01857	0.9987	1.53E+000	(1.1)
05-19	13:55	02:24	2499	499.51	10.08	1.91E-003	94.00	0.01880	0.9982	1.23E+000	(1.3)
05-21	15:22	03:44	3398	1398.64	9.36	3.97E-003	94.00	0.02009	1.0093	1.05E+000	(1.8)
05-21	20:00	12:23	4397	1399.18	9.21	2.32E-003	94.00	0.02009	1.0083	6.22E-001	(1.8)
05-22	09:12	06:30	5401	1399.62	9.66	1.57E-003	94.00	0.02009	1.0083	4.03E-001	(2.9)
05-23	18:36	13:54	5443	1449.67	9.30	1.50E-003	94.00	0.02019	1.0094	3.87E-001	(2.3)
05-25	10:15	08:45	4496	500.59	9.61	6.76E-004	94.00	0.01880	0.9982	4.55E-001	(2.4)
05-28	13:30	19:10	4197	200.67	9.80	3.60E-004	94.00	0.01857	0.9987	5.85E-001	(1.8)
05-30	17:24	15:00	4091	100.10	9.62	2.39E-004	94.00	0.01852	0.9992	7.93E-001	(1.5)
05-31	18:15	13:30	4053	50.47	9.59	1.81E-004	94.00	0.01851	0.9996	1.19E+000	(1.6)


MWX-3, RULISON FIELD, CO.
64-13 (6446') Sw=30%
DP = 20
DP = 10
DP = 5
DP = 2.5
NET Pc = 2000 PSI
NET Pc = 4000 PSI
PERMEABILITY (MICRODARCIES)
2.5
2.0
1.5
1.0
.5
0.0
0.000
.005
.010
.015
.020
RECIPROCAL MEAN PORE PRESSURE (1/PSI)

********** WELL NAME: MWX 3, RULISON FIELD, CO. **********

PLUG: 64-13 (6446') Sw=15% PLUG LENGTH: 3.787 CM PLUG AREA: 5.059 CM^2

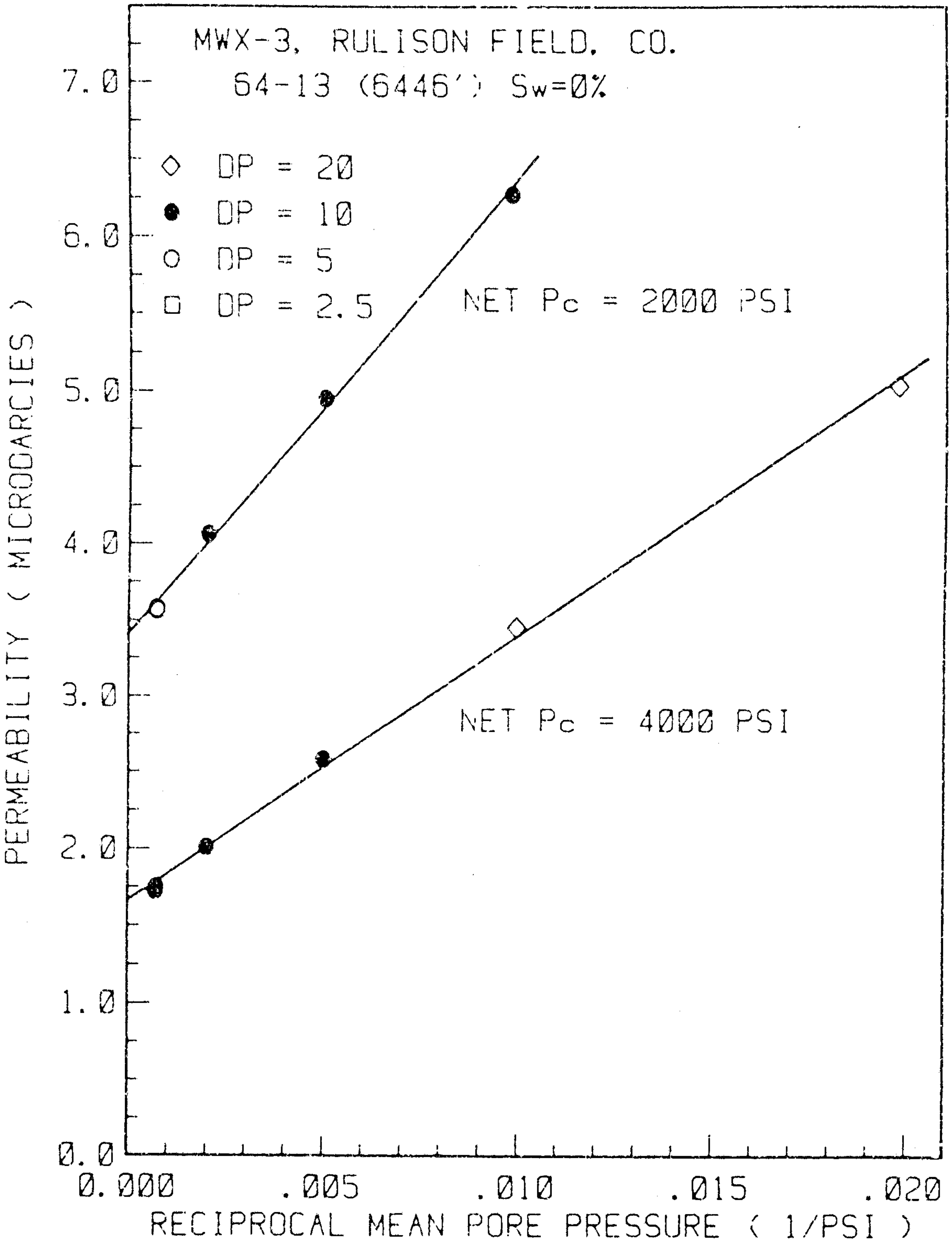
TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	PERMEABILITY STD. DEV. (%)
06-04	10:35	03:55	2097	100.58	5.04	5.50E-004	94.00	0.01852	0.9992	3.51E+000	(1.3)
06-05	09:16	05:00	2199	199.92	5.03	8.57E-004	94.00	0.01857	0.9987	2.72E+000	(1.3)
06-06	09:12	03:30	2499	500.42	4.86	1.64E-003	94.00	0.01880	0.9982	2.18E+000	(1.2)
06-07	15:07	02:16	3400	1399.79	4.63	3.50E-003	94.00	0.02009	1.0083	1.87E+000	(2.6)
06-08	08:57	03:10	4400	1400.22	5.17	2.57E-003	94.00	0.02010	1.0084	1.23E+000	(2.3)
06-08	12:48	05:18	5396	1400.11	4.74	1.62E-003	94.00	0.02010	1.0083	8.45E-001	(2.3)
06-09	22:27	03:05	5392	1399.12	10.12	3.47E-003	94.00	0.02009	1.0083	8.49E-001	(2.0)
06-11	09:18	04:09	4498	500.89	9.85	1.50E-003	94.00	0.01880	0.9982	9.87E-001	(1.1)
06-12	09:16	04:22	4200	200.50	9.91	7.98E-004	94.00	0.01857	0.9987	1.28E+000	(1.2)
06-13	09:25	04:44	4100	100.48	9.76	5.34E-004	94.00	0.01852	0.9992	1.74E+000	(1.0)
06-14	09:36	05:22	4051	50.22	10.12	4.14E-004	94.00	0.01851	0.9996	2.60E+000	(1.1)


MWX-3, RULISON FIELD, CO.
64-13 (6446') Sw=15%
◇ DP = 20
● DP = 10
○ DP = 5
□ DP = 2.5
NET Pc = 2000 PSI
NET Pc = 4000 PSI
PERMEABILITY (MICRODARCIES)
RECIPROCAL MEAN PORE PRESSURE (1/PSI)
4.0
3.0
2.0
1.0
0.0
0.0
.005
.010
.015
.020

********** WELL NAME: MWX-3, RULISON FIELD, CO. **********

PLUG: 64-13 (6446') Sw-0% PLUG LENGTH: 3.787 CM PLUG AREA: 5.057 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	STD. DEV. (%)
06-19	10:03	01:15	2108	101.94	19.28	2.06E-003	94.00	0.01852	0.9992	6.27E+000	(1.6)
06-19	14:26	01:23	2203	200.40	9.98	3.10E-003	94.00	0.01857	0.9987	4.95E+000	(2.1)
06-20	08:59	01:49	2501	500.06	8.14	5.10E-003	94.00	0.01880	0.9982	4.06E+000	(1.6)
06-20	16:45	01:24	3398	1399.47	4.44	6.39E-003	94.00	0.02009	1.0083	3.56E+000	(1.7)
06-21	09:15	01:21	3402	1399.67	4.79	6.93E-003	94.00	0.02009	1.0083	3.57E+000	(1.5)
06-21	11:04	02:26	4398	1399.08	4.60	4.47E-003	94.00	0.02010	1.0083	2.40E+000	(1.7)
06-21	14:12	02:00	5403	1402.34	8.90	6.30E-003	94.00	0.02010	1.0084	1.75E+000	(1.4)
06-22	17:12	01:13	5451	1449.40	9.97	7.14E-003	94.00	0.02019	1.0094	1.72E+000	(1.3)
06-23	10:37	02:37	4500	501.92	10.02	3.12E-003	94.00	0.01880	0.9982	2.01E+000	(1.2)
06-25	09:14	01:42	4202	200.41	10.47	1.69E-003	94.00	0.01857	0.9987	2.58E+000	(1.5)
06-25	15:51	01:04	4101	100.44	19.53	2.13E-003	94.00	0.01852	0.9992	3.46E+000	(.5)
06-26	09:07	01:28	4049	50.62	19.69	1.58E-003	94.00	0.01851	0.9996	5.04E+000	(1.4)


MWX-3, RULISON FIELD, CO.
64-13 (6446') Sw=0%
DP = 20
DP = 10
DP = 5
DP = 2.5
NET Pc = 2000 PSI
NET Pc = 4000 PSI
PERMEABILITY (MICRODARCIES)
RECIPROCAL MEAN PORE PRESSURE (1/PSI)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.000
.005
.010
.015
.020

INSTITUTE OF GAS TECHNOLOGY

CORAL RUN 42

********** WELL NAME: MWX-3, RULISON FIELD, CO. **********

PLUG: 64-13 (6446 FT.) SATN. 0 PLUG LENGTH: 3.707 CM PLUG AREA: 5.059 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	STD. DEV. (%)
03-20	10:35	03:00	4177	200.35	4.90	8.59E-004	94.00	0.01857	0.9987	2.80E+000	(1.2)
03-20	16:21	02:48	4092	101.06	9.73	1.13E-003	94.00	0.01852	0.9992	3.67E+000	(1.5)
03-21	10:04	02:40	4402	399.78	6.55	1.82E-003	94.00	0.01871	0.9981	2.25E+000	(2.4)
03-21	18:17	01:15	5396	1400.53	9.50	6.97E-003	94.00	0.02010	1.0084	1.81E+000	(3.7)
03-22	20:00	01:12	5449	1451.88	10.08	7.51E-003	94.00	0.02019	1.0095	1.78E+000	(3.6)
03-23	09:13	01:24	4400	400.29	10.69	2.94E-003	94.00	0.01871	0.9981	2.21E+000	(2.9)
03-23	13:42	01:44	4203	200.79	10.40	1.77E-003	94.00	0.01857	0.9987	2.72E+000	(2.2)
03-23	18:07	02:10	4096	101.29	10.75	1.24E-003	94.00	0.01852	0.9992	3.62E+000	(2.0)
03-26	10:02	02:13	4098	101.27	10.94	1.24E-003	94.00	0.01852	0.9992	3.56E+000	(1.8)
03-26	15:57	02:45	4046	50.94	10.62	8.08E-004	94.00	0.01851	0.9996	5.23E+000	(1.8)

xxxxxxxxxx WELL NAME: MWX-3, RULISON FIELD, CO. xxxxxxxxxx

PLUG: 64-13 (6446 FT.) N10F, Sw 0 PLUG LENGTH: 3.033 CM PLUG AREA: 5.055 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	PERMEABILITY STD. DEV. (%)
02-20	14:50	01:00	4388	200.25	5.22	1.19E-003	93.00	0.01826	0.9979	2.57E+000	(1.8)
02-20	16:53	01:45	4576	399.03	4.96	1.81E-003	93.00	0.01842	0.9959	2.32E+000	(2.3)
02-20	23:45	08:07	4287	99.57	2.13	3.25E-004	93.00	0.01818	0.9989	3.83E+000	(1.3)
02-21	09:12	01:45	4219	100.36	5.54	8.07E-004	91.00	0.01810	0.9989	3.63E+000	(2.3)
02-21	11:52	01:36	4193	199.13	5.16	1.16E-003	91.00	0.01826	0.9979	2.84E+000	(2.0)
02-21	14:26	01:46	3203	199.14	5.06	1.32E-003	91.00	0.01826	0.9979	3.28E+000	(2.2)
02-21	20:07	11:30	2106	100.92	1.61	3.51E-004	91.00	0.01818	0.9989	5.42E+000	(6.5)
02-22	09:28	01:44	2198	200.22	4.90	1.64E-003	91.00	0.01826	0.9979	4.20E+000	(2.3)
02-22	12:31	00:51	2393	399.16	4.98	2.82E-003	91.00	0.01842	0.9959	3.59E+000	(2.9)
02-22	14:24	02:00	4378	399.16	4.87	1.87E-003	91.00	0.01842	0.9959	2.37E+000	(2.1)
02-23	01:05	06:10	4435	458.89	1.87	7.73E-004	91.00	0.01847	0.9953	2.28E+000	(1.3)
02-23	09:32	02:03	4199	201.16	4.96	1.15E-003	91.00	0.01826	0.9979	2.89E+000	(2.0)
02-23	13:21	01:21	4103	100.62	5.15	8.00E-004	91.00	0.01818	0.9987	3.86E+000	(1.4)

INSTITUTE OF GAS TECHNOLOGY

********** WELL NAME: MWX-3, RULISON FIELD, CO. **********

PLUG: 64-13 (6446 FT.) VERT, Sw 0 PLUG LENGTH: 3.207 CM PLUG AREA: 5.055 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	PERMEABILITY STD DEV. (%)
02-20	14:27	01:23	4412	200.23	5.23	7.56E-004	93.01	0.01826	0.9979	1.92E+000	(1.6)
02-20	16:37	02:03	4599	399.03	4.95	1.12E-003	93.00	0.01842	0.9959	1.52E+000	(2.4)
02-20	22:00	09:22	4310	99.56	2.16	2.07E-004	93.00	0.01818	0.9989	2.54E+000	(1.8)
02-21	08:42	02:12	4239	100.35	5.55	5.16E-004	91.00	0.01818	0.9989	2.45E+000	(3.1)
02-21	12:06	01:08	4215	199.15	5.15	7.28E-004	91.00	0.01826	0.9979	1.88E+000	(1.1)
02-21	14:08	02:12	3219	199.13	5.08	8.25E-004	91.00	0.01826	0.9979	2.16E+000	(2.0)
02-21	19:52	10:53	2119	100.91	1.64	2.22E-004	91.00	0.01818	0.9989	3.52E+000	(2.1)
02-22	08:44	02:18	2210	200.20	4.95	1.02E-003	91.00	0.01826	0.9979	2.24E+000	(1.7)
02-22	12:16	01:00	2406	399.17	4.98	1.69E-003	91.00	0.01842	0.9959	2.28E+000	(1.5)
02-22	14:42	01:34	4399	399.16	4.85	1.11E-003	91.00	0.01842	0.9959	1.53E+000	(2.0)
02-22	22:40	07:35	4460	458.08	1.94	4.37E-004	91.00	0.01847	0.9953	1.31E+000	(4.8)
02-23	09:52	01:50	4220	201.16	4.97	7.15E-004	91.00	0.01826	0.9979	1.96E+000	(1.9)
02-23	13:09	01:42	4125	100.59	5.19	5.20E-004	91.00	0.01818	0.9989	2.63E+000	(1.2)

CORAL RUN 34

********** WELL NAME: MWX-3, RULISON FIELD, CO. **********

PLUG: 64-13 (6446') SATN. 0   PLUG LENGTH: 3.[illegible] CM   PLUG AREA: 5.0[illegible] CM2

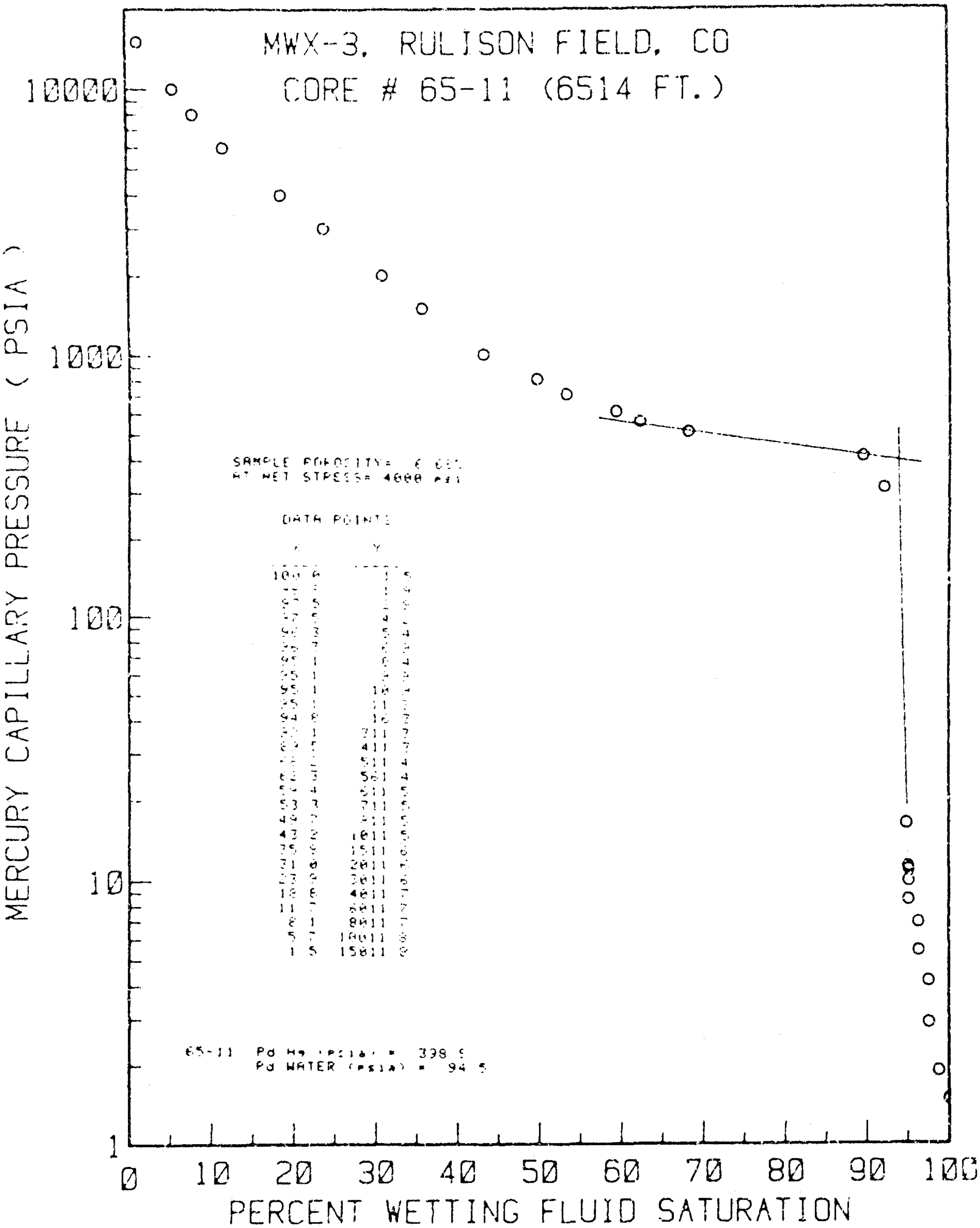
TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	PERMEABILITY STD. DEV (%)
11-15	14:24	03:02	4183	200.91	7.96	1.50E-003	88.00	0.01852	0.9987	2.96E+000	(1.8)
11-15	17:31	14:51	4197	200.77	2.22	4.15E-004	88.00	0.01852	0.9987	2.94E+000	(2.2)
11-16	11:59	01:15	4538	500.19	9.71	3.39E-003	90.00	0.01880	0.9982	2.25E+000	(2.5)
11-16	15:00	01:42	5039	1004.28	10.51	6.31E-003	90.00	0.01943	1.0017	1.99E+000	(2.8)
11-16	20:50	12:18	5317	1347.33	1.05	7.62E-004	90.00	0.02000	1.0573	1.85E+000	(8.4)
11-17	19:15	14:27	5427	1347.08	4.49	3.52E-003	90.00	0.02018	1.0094	1.91E+000	(1.8)
11-18	11:04	02:01	4521	500.36	18.39	6.23E-003	90.00	0.01880	0.9982	2.18E+000	(4.1)

CORAL RUN 42

********** WELL NAME: MWX-3, RULISON FIELD, CO. **********

PLUG: 64-13 (6446 FT.) SATN. 0 PLUG LENGTH: 3.787 CM PLUG AREA: 5.059 CM^2

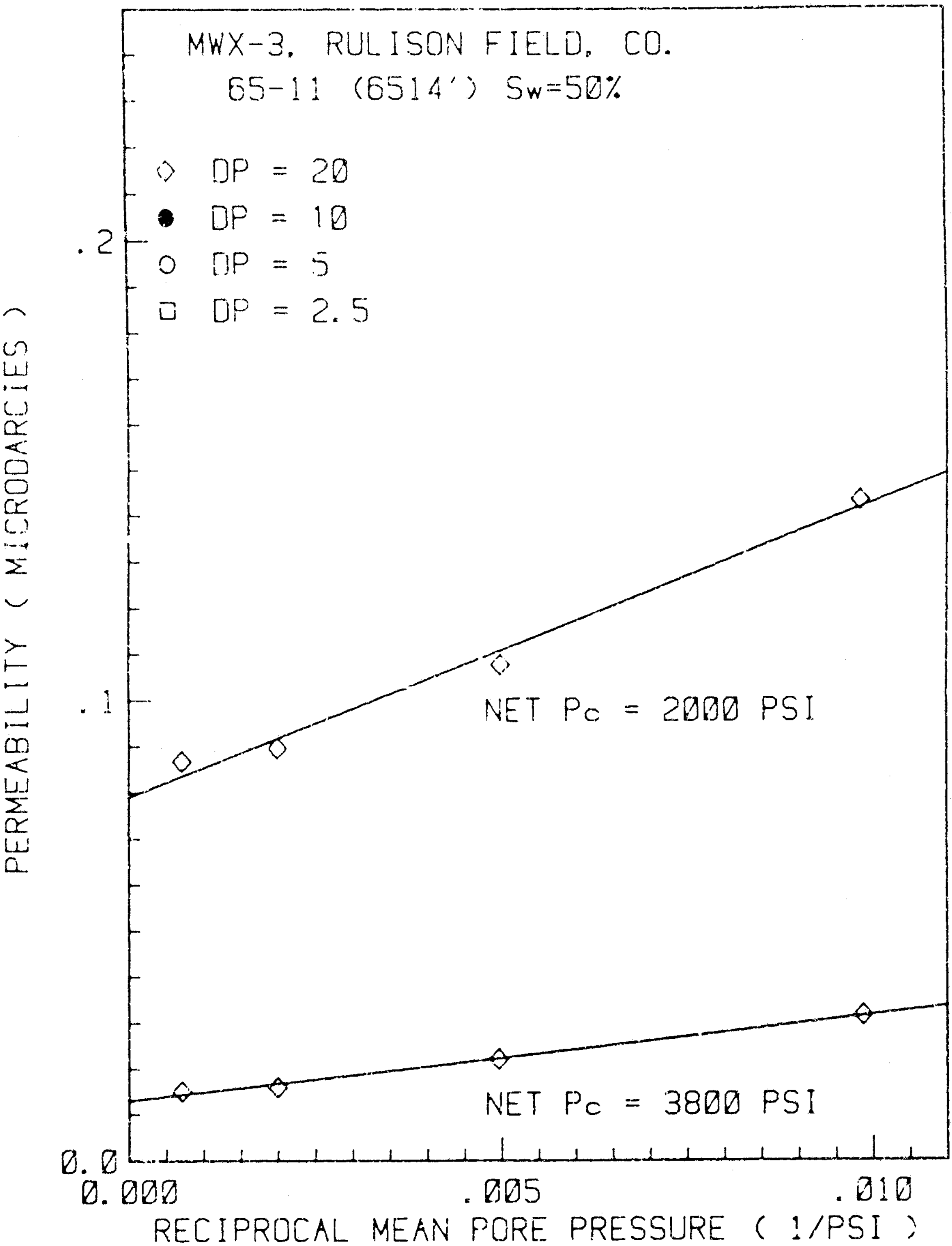
TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	STD. DEV. (%)
03-20	10:35	03:00	4177	200.35	4.90	8.59E-004	94.00	0.01857	0.9987	2.80E+000	(1.2)
03-20	16:21	02:48	4092	101.06	9.73	1.19E-003	94.00	0.01852	0.9992	3.67E+000	(1.5)
03-21	10:04	02:40	4402	399.78	6.55	1.83E-003	94.00	0.01871	0.9981	2.25E+000	(2.4)
03-21	18:17	01:15	5396	1400.53	9.50	6.97E-003	94.00	0.02018	1.0084	1.81E+000	(3.7)
03-22	20:00	01:12	5449	1451.88	10.08	7.51E-003	94.00	0.02019	1.0095	1.78E+000	(3.6)
03-23	09:13	01:24	4400	400.29	10.69	2.94E-003	94.00	0.01871	0.9981	2.21E+000	(2.9)
03-23	13:42	01:44	4203	200.79	10.40	1.77E-003	94.00	0.01857	0.9987	2.72E+000	(2.2)
03-23	18:07	02:10	4096	101.29	10.75	1.24E-003	94.00	0.01852	0.9992	3.62E+000	(2.0)
03-26	10:02	02:13	4098	101.27	10.94	1.24E-003	94.00	0.01852	0.9992	3.56E+000	(1.8)
03-26	15:57	02:45	4046	50.94	10.62	8.08E-004	94.00	0.01851	0.9996	5.23E+000	(1.8)


MWX-3, RULISON FIELD, CO
CORE # 65-11 (6514 FT.)
MERCURY CAPILLARY PRESSURE (PSIA)
PERCENT WETTING FLUID SATURATION
DATA POINTS
65-11
Pd WATER

********** WELL NAME: MWX-3, RULISON FIELD, CO. **********

PLUG: 65-11 (6514') Sw-50% PLUG LENGTH: 4.014 CM PLUG AREA: 5.078 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	PERMEABILITY STD. DEV. (%)
04-15	17:15	14:00	2096	101.73	21.21	9.14E-005	94.00	0.01852	0.9992	1.43E-001	(2.1)
04-16	17:12	14:42	2214	200.51	20.63	1.32E-004	94.00	0.01857	0.9987	1.08E-001	(2.8)
04-18	10:20	09:50	2497	500.95	20.73	2.71E-004	94.00	0.01880	0.9982	8.97E-002	(4.9)
04-19	11:22	08:10	3401	1399.96	19.37	6.42E-004	94.00	0.02010	1.0003	8.69E-002	(4.7)
04-19	21:00	15:30	4297	1400.23	19.80	3.01E-004	94.00	0.02010	1.0004	3.97E-002	(8.4)
04-20	17:00	40:00	5211	1399.86	19.72	1.13E-004	94.00	0.02010	1.0003	1.51E-002	(9.5)
04-23	19:40	36:42	4298	500.76	21.04	4.90E-005	94.00	0.01880	0.9982	1.60E-002	(13.4)
04-27	22:30	31:30	3997	201.60	21.36	2.81E-005	94.00	0.01857	0.9986	2.21E-002	(9.6)
05-01	20:40	42:23	3890	101.30	21.08	2.07E-005	94.00	0.01852	0.9992	3.16E-002	(6.2)

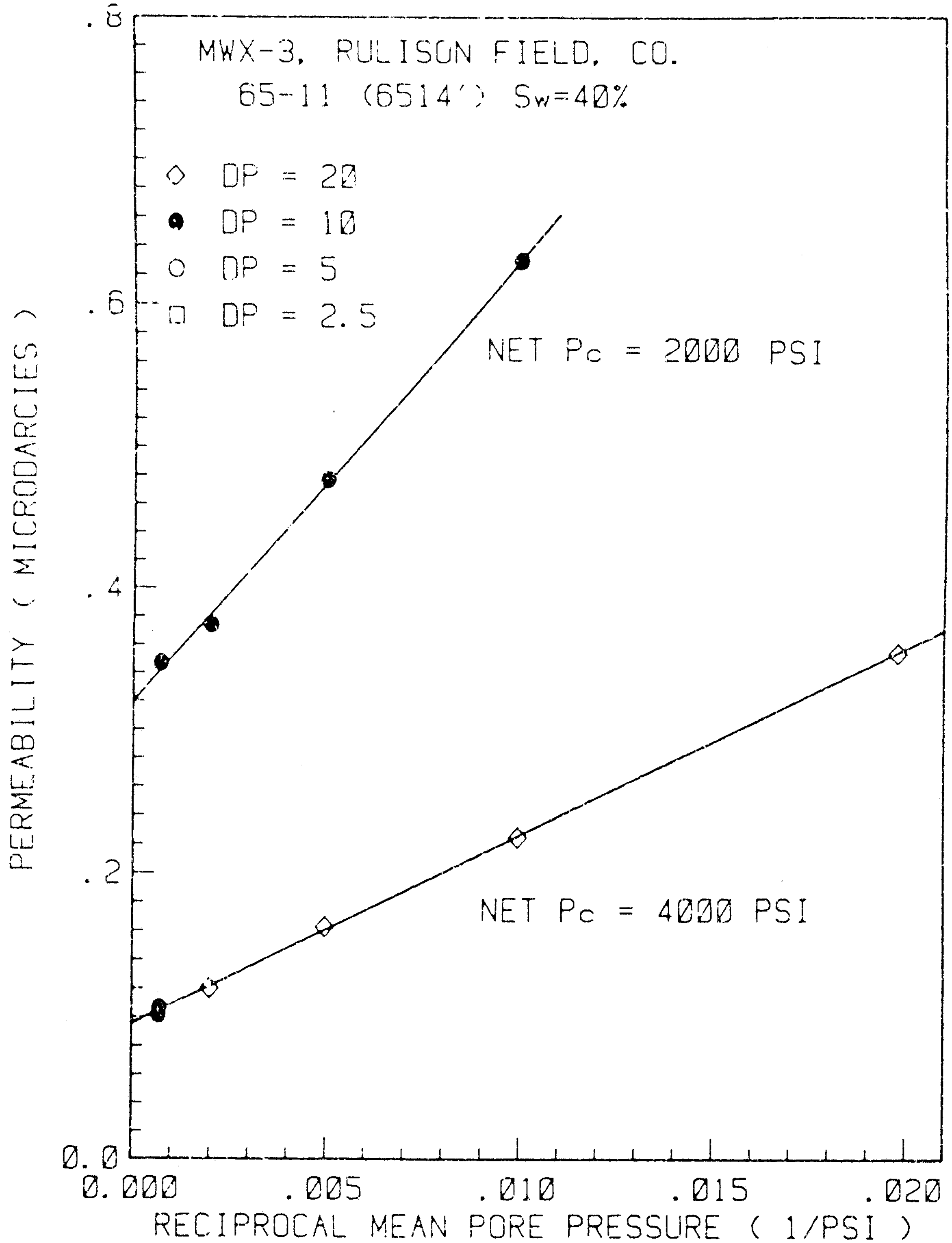


MWX-3, RULISON FIELD, CO.
65-11 (6514') Sw=50%
DP = 20
DP = 10
DP = 5
DP = 2.5
.2
.1
0.0
NET Pc = 2000 PSI
NET Pc = 3800 PSI
0.000
.005
.010
RECIPROCAL MEAN PORE PRESSURE (1/PSI)
PERMEABILITY (MICRODARCIES)

********** WELL NAME: MWX-3, RULISON FIELD, CO. **********

PLUG: 65-11 (6514') Sw=40% PLUG LENGTH: 4.014 CM PLUG AREA: 5.058 CM^2

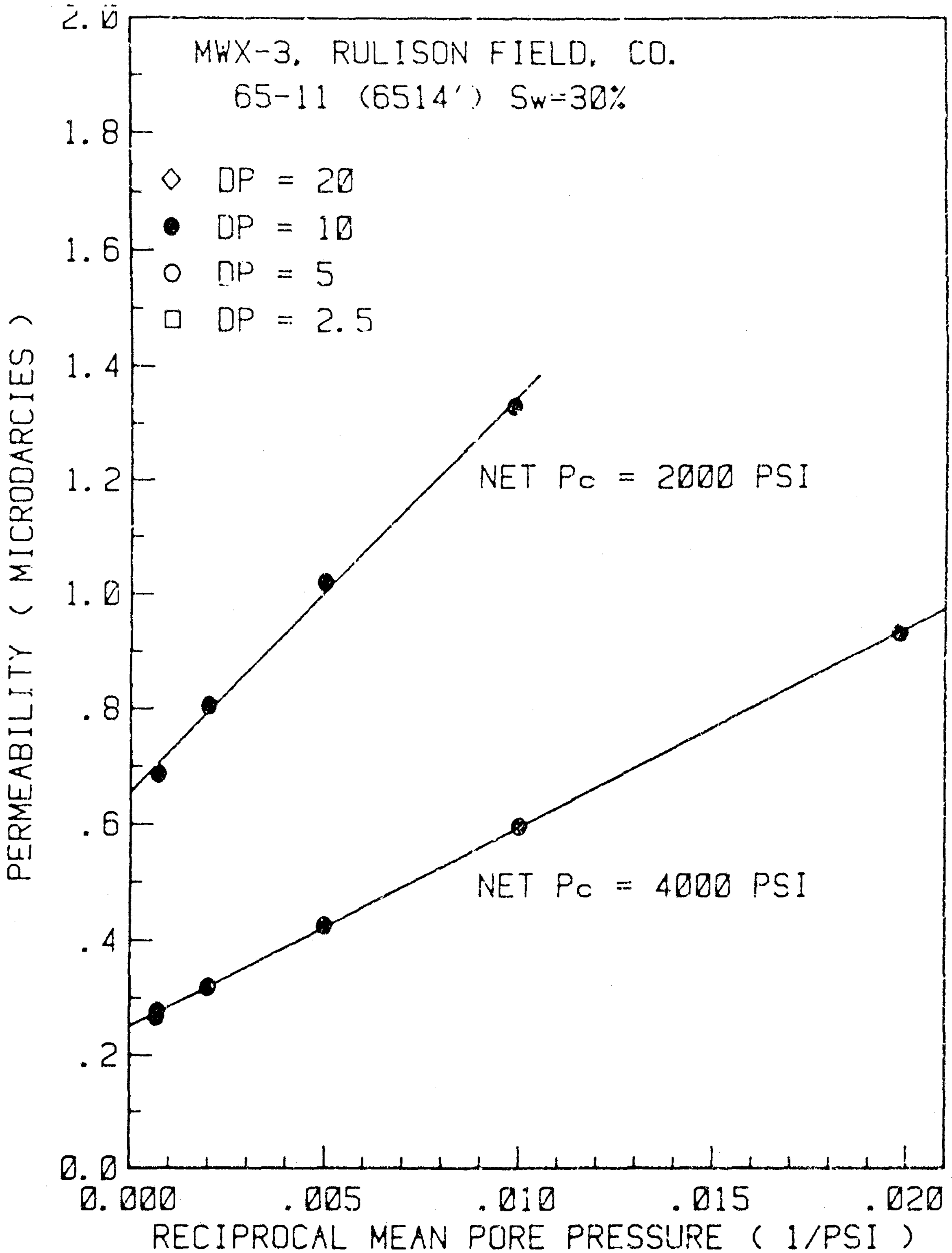
TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	STD. DEV. (%)
05-04	10:07	07:53	2094	100.13	10.66	1.99E-004	94.00	0.01852	0.9992	6.30E-001	(3.0)
05-05	14:54	06:28	2190	200.40	10.60	2.99E-004	94.00	0.01857	0.9987	4.77E-001	(2.1)
05-06	14:10	05:10	2517	499.56	10.81	5.89E-004	94.00	0.01880	0.9982	3.74E-001	(1.7)
05-07	09:27	03:36	3397	1400.44	11.29	1.49E-003	94.00	0.02010	1.0084	3.47E-001	(2.6)
05-07	15:00	06:12	4400	1400.44	10.87	7.36E-004	94.00	0.02010	1.0084	1.78E-001	(6.8)
05-07	23:30	14:15	5404	1400.22	10.52	4.28E-004	94.00	0.02010	1.0084	1.07E-001	(7.3)
05-09	02:15	15:50	5479	1450.76	11.37	4.63E-004	94.00	0.02019	1.0094	1.02E-001	(5.4)
05-10	13:45	06:15	4518	501.47	20.85	3.66E-004	94.00	0.01880	0.9982	1.20E-001	(4.4)
05-11	13:40	21:10	4202	201.32	21.41	2.07E-004	94.00	0.01857	0.9986	1.63E-001	(2.5)
05-14	11:45	20:30	4099	100.58	19.69	1.32E-004	94.00	0.01852	0.9992	2.25E-001	(2.1)
05-15	20:30	19:15	4050	50.51	19.72	1.04E-004	94.00	0.01851	0.9996	3.54E-001	(2.1)


MWX-3, RULISON FIELD, CO.
65-11 (6514') Sw=40%
DP = 20
DP = 10
DP = 5
DP = 2.5
NET Pc = 2000 PSI
NET Pc = 4000 PSI
PERMEABILITY (MICRODARCIES)
RECIPROCAL MEAN PORE PRESSURE (1/PSI)
0.0
.2
.4
.6
.8
0.000
.005
.010
.015
.020

********** WELL NAME: MWX-3, RULISON FIELD, CO. **********

PLUG: 65-11 (6514') Sw=30% PLUG LENGTH: 4.014 CM PLUG AREA: 5.658 CM^2

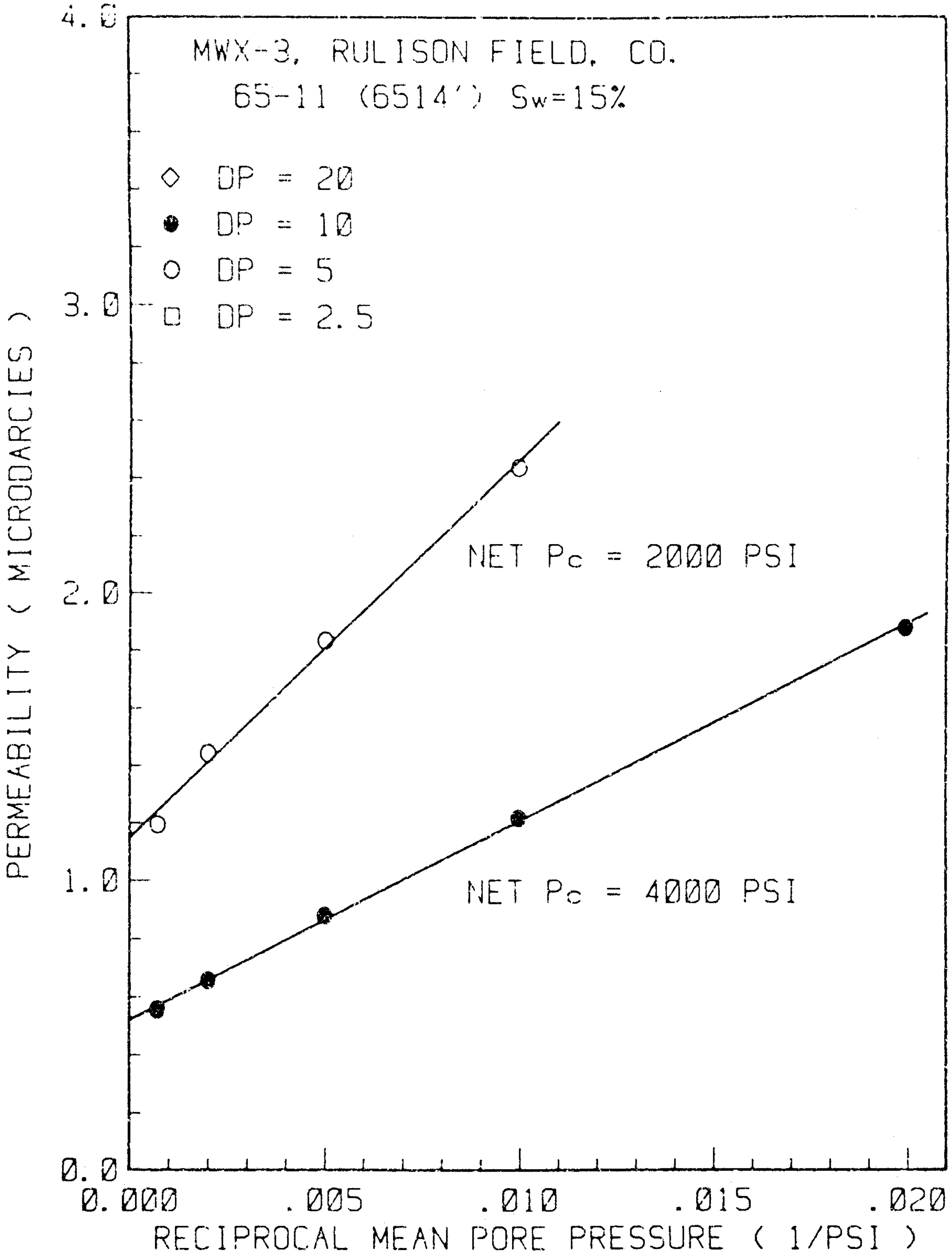
TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	STD. DEV. (%)
05-18	08:35	04:52	2094	101.57	10.15	4.05E-004	94.00	0.01852	0.9992	1.33E+000	(1.1)
05-18	15:32	02:24	2199	200.54	10.28	6.20E-004	94.00	0.01857	0.9947	1.02E+000	(2.1)
05-19	13:57	02:21	2499	499.50	10.09	1.18E-003	94.00	0.01890	0.9982	8.05E-001	(1.1)
05-21	15:24	03:42	3398	1398.63	9.37	2.45E-003	94.00	0.02009	1.0083	6.87E-001	(1.4)
05-21	20:04	12:12	4396	1399.17	9.21	1.47E-003	94.00	0.02009	1.0083	4.18E-001	(2.0)
05-22	09:18	05:54	5402	1399.62	9.70	1.02E-003	94.00	0.02009	1.0083	2.77E-001	(5.4)
05-23	18:42	13:30	5443	1449.67	9.29	9.73E-004	94.00	0.02019	1.0094	2.66E-001	(3.7)
05-25	10:22	08:38	4498	500.58	9.64	4.49E-004	94.00	0.01880	0.9982	3.20E-001	(4.5)
05-28	13:30	19:10	4197	200.67	9.79	2.47E-004	94.00	0.01857	0.9987	4.26E-001	(1.9)
05-30	17:24	15:12	4091	100.08	9.65	1.70E-004	94.00	0.01852	0.9992	5.77E-001	(1.5)
05-31	18:30	13:15	4053	50.47	9.59	1.34E-004	94.00	0.01851	0.9996	9.33E-001	(1.7)


MWX-3, RULISON FIELD, CO.
65-11 (6514') Sw=30%
DP = 20
DP = 10
DP = 5
DP = 2.5
NET Pc = 2000 PSI
NET Pc = 4000 PSI
PERMEABILITY (MICRODARCIES)
RECIPROCAL MEAN PORE PRESSURE (1/PSI)
0.0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
0.000
.005
.010
.015
.020

********** WELL NAME: MWX-3, RULISON FIELD, CO. **********

PLUG: 65-11 (6514') SW=15% PLUG LENGTH: 4.014 CM PLUG AREA: 5.058 CM^2

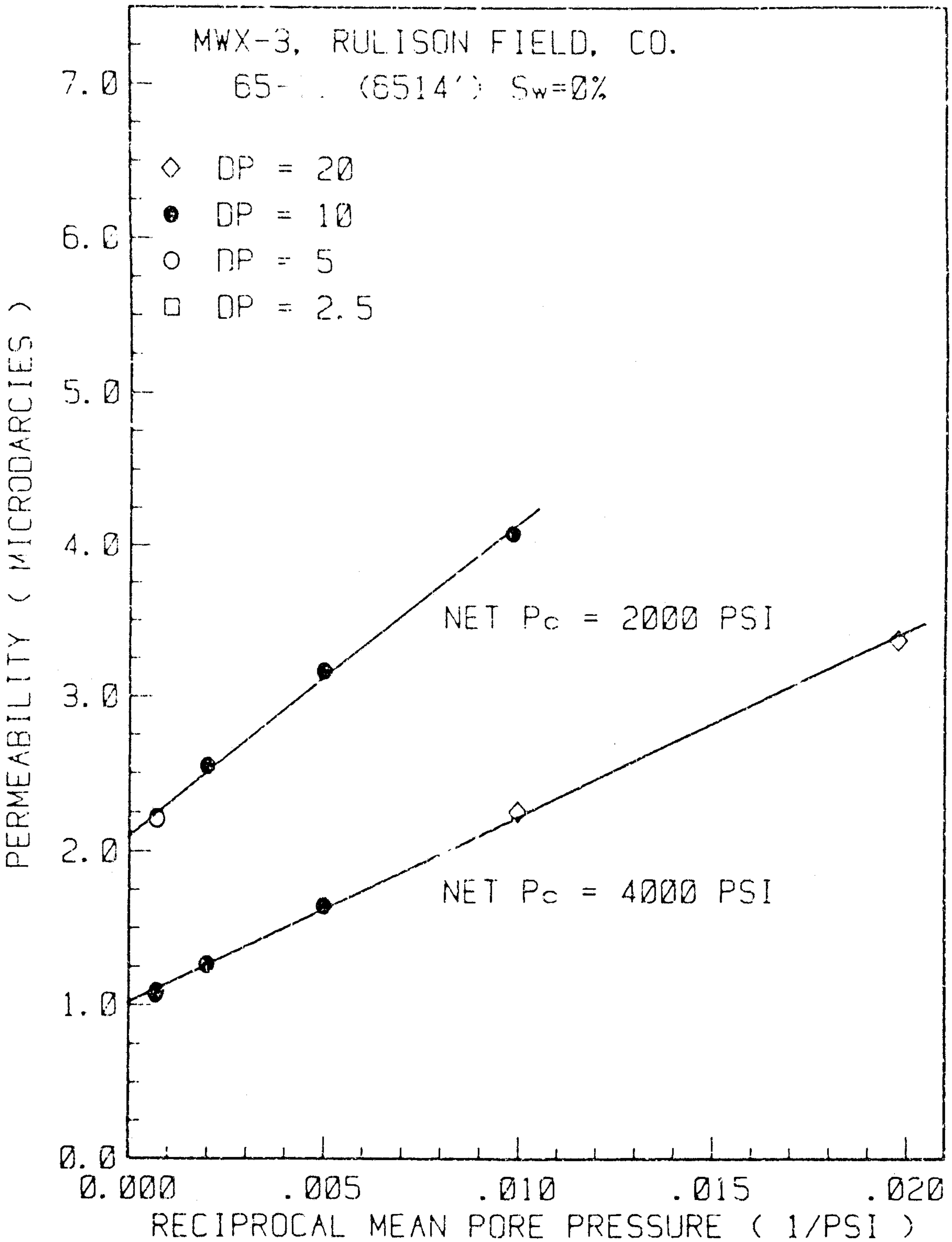
TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	STD. DEV. (%)
06-04	10:40	03:25	2097	100.59	5.04	3.66E-004	94.00	0.01852	0.9992	2.44E+000	(1.5)
06-05	09:20	04:52	2199	199.91	5.06	5.47E-004	94.00	0.01857	0.9987	1.83E+000	(1.4)
06-06	09:15	03:27	2499	500.41	4.38	1.93E-003	94.00	0.01880	0.9982	1.44E+000	(1.1)
06-07	15:10	02:05	3399	1399.79	4.63	2.11E-003	94.00	0.02009	1.0083	1.19E+000	(6.3)
06-08	09:00	03:07	4400	1400.22	5.17	1.61E-003	94.00	0.02010	1.0084	8.18E-001	(2.5)
06-08	12:54	05:15	5398	1400.10	4.77	1.01E-003	94.00	0.02010	1.0083	5.54E-001	(3.0)
06-09	22:27	02:48	5393	1399.09	10.16	2.15E-003	94.00	0.02009	1.0083	5.55E-001	(1.3)
06-11	09:21	04:10	4498	500.08	9.86	9.49E-004	94.00	0.01880	0.9982	6.55E-001	(1.2)
06-12	09:20	04:04	4199	200.50	9.91	5.15E-004	94.00	0.01857	0.9987	9.78E-001	(1.3)
06-13	09:30	04:39	4100	100.47	9.79	3.54E-004	94.00	0.01852	0.9992	1.22E+000	(1.0)
06-14	09:36	05:22	4051	50.21	10.14	2.83E-004	94.00	0.01851	0.9996	1.88E+000	(1.3)


MWX-3, RULISON FIELD, CO.
65-11 (6514') Sw=15%
DP = 20
DP = 10
DP = 5
DP = 2.5
NET Pc = 2000 PSI
NET Pc = 4000 PSI
PERMEABILITY (MICRODARCIES)
4.0
3.0
2.0
1.0
0.0
0.000
.005
.010
.015
.020
RECIPROCAL MEAN PORE PRESSURE (1/PSI)

********** WELL NAME: MWX 3, ROBISON FIELD, CO. **********

PLUG: 65-11 (6514') Sw-0% PLUG LENGTH: 4.014 CM PLUG AREA: 5.058 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	STD. DEV. (%)
06-19	10:03	01:15	2108	101.94	10.28	1.26E-003	94.00	0.01852	0.9992	4.00E+000	(1.7)
06-19	14:26	01:23	2203	200.39	10.00	1.87E-003	94.00	0.01857	0.9987	3.16E+000	(1.9)
06-20	08:59	01:49	2501	500.06	8.15	3.02E-003	94.00	0.01860	0.9982	2.54E+000	(1.3)
06-20	16:45	01:24	3398	1399.46	4.40	3.70E-003	94.00	0.02009	1.0083	2.21E+000	(1.2)
06-21	09:15	01:21	3402	1399.67	4.81	4.04E-003	94.00	0.02009	1.0083	2.20E+000	(1.6)
06-21	11:04	02:26	4398	1399.86	4.62	2.64E-003	94.00	0.02010	1.0083	1.50E+000	(1.4)
06-21	14:12	02:00	5404	1402.33	8.94	3.71E-003	94.00	0.02010	1.0084	1.09E+000	(1.2)
06-22	17:12	01:13	5451	1449.39	10.00	4.20E-003	94.00	0.02019	1.0094	1.07E+000	(1.1)
06-23	10:37	02:37	4500	501.90	10.05	1.85E-003	94.00	0.01880	0.9982	1.26E+000	(1.3)
06-25	09:14	01:42	4202	200.41	10.47	1.0[illegible]E-003	94.00	0.01857	0.9987	1.64E+000	(1.8)
06-25	15:51	01:04	4101	100.44	19.52	1.31E-003	94.00	0.01852	0.9992	2.25E+000	(1.5)
06-26	09:07	01:28	4049	50.61	19.70	9.95E-004	94.00	0.01851	0.9996	3.37E+000	(1.4)



MWX-3, RULISON FIELD, CO.
65- . (6514') Sw=0%
◇ DP = 20
● DP = 10
○ DP = 5
□ DP = 2.5
NET Pc = 2000 PSI
NET Pc = 4000 PSI
PERMEABILITY (MICRODARCIES)
RECIPROCAL MEAN PORE PRESSURE (1/PSI)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
0.000
.005
.010
.015
.020

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CORAL RUN 42

********** WELL NAME: MWX-3, RULISON FIELD, CO. **********

PLUG: 65-11 (6514 FT.) SATN.= 0 PLUG LENGTH: 1.014 CM PLUG AREA: 5.058 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	PERMEABILITY STD. DEV. (%)
03-20	10:10	03:45	4177	200.34	4.91	4.37E-004	94.00	0.01857	0.9987	1.50E+000	(1.3)
03-20	16:24	02:51	4092	101.03	9.75	6.06E-004	94.00	0.01852	0.9992	2.08E+000	(1.5)
03-21	09:42	03:08	4404	399.77	6.58	9.08E-004	94.00	0.01871	0.9981	1.17E+000	(2.4)
03-21	17:57	01:45	5391	1400.52	9.52	3.35E-003	94.00	0.02010	1.0084	9.23E-001	(2.9)
03-22	20:02	01:15	5449	1451.85	10.07	3.62E-003	94.00	0.02019	1.0095	9.11E-001	(1.9)
03-23	09:00	01:55	4400	400.28	10.70	1.47E-003	94.00	0.01871	0.9981	1.17E+000	(1.3)
03-23	13:26	02:00	4203	200.79	10.43	9.29E-004	94.00	0.01857	0.9987	1.50E+000	(1.7)
03-23	17:42	02:35	4096	101.26	10.76	6.72E-004	94.00	0.01852	0.9992	2.09E+000	(1.8)
03-26	10:07	02:30	4097	101.26	10.93	6.56E-004	94.00	0.01852	0.9992	2.03E+000	(1.6)
03-26	16:00	03:03	4045	50.94	10.64	4.92E-004	94.00	0.01851	0.9996	3.07E+000	(1.8)

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A-27

********** WELL NAME: MWX-3, RULISON FIELD, CO. **********

PLUG: 65-11 (6515 T.) NIDE, Sw 0 PLUG LENGTH: 3.325 CM PLUG AREA: 5.057 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	STD. DEV. (%)
03-05	18:50	02:20	4190	199.81	5.46	2.70E-004	91.00	0.01826	0.9929	1.94E+000	(1.0)
03-06	09:15	02:25	4188	199.83	5.40	2.66E-004	91.00	0.01826	0.9929	1.9[illegible]E+000	(1.2)
03-06	14:24	02:18	4084	100.32	10.34	9.90E-004	91.00	0.01818	0.9989	2.63E+000	(1.3)
03-07	08:52	02:40	4389	399.92	5.16	1.17E-003	91.00	0.01842	0.9959	1.52E+000	(1.5)
03-07	16:32	02:44	4443	463.64	5.15	1.26E-003	91.00	0.01842	0.9953	1.47E+000	(1.5)
03-08	07:10	04:00	4190	199.77	5.07	2.16E-004	91.00	0.01826	0.9929	1.93E+000	(1.1)
03-08	14:10	02:45	3201	199.7[illegible]	5.0[illegible]	7.90E-00[illegible]	91.00	0.01826	0.9929	2.18E+000	(1.2)
03-08	18:19	00:48	2200	199.79	4.92	9.85E-004	91.00	0.01826	0.9929	2.24E+000	(1.3)
03-09	13:52	01:50	2395	400.26	4.91	1.50E-003	91.00	0.01842	0.9959	2.37E+000	(1.9)
03-09	17:48	02:00	2093	100.02	5.22	7.54E-004	91.00	0.01818	0.9989	3.92E+000	(1.4)
03-10	14:03	02:03	2189	200.27	5.51	1.16E-003	91.00	0.01826	0.9929	2.89E+000	(1.6)

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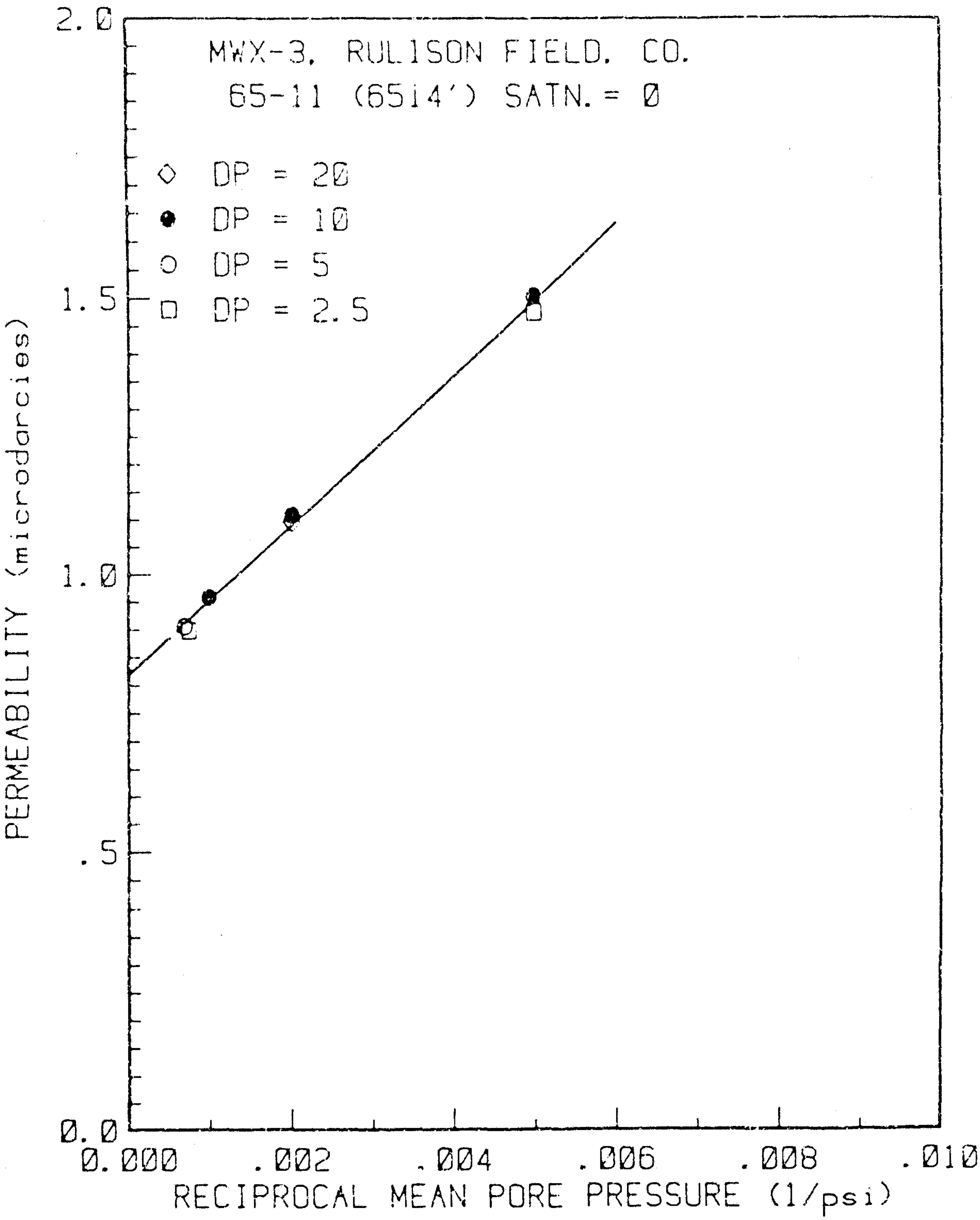
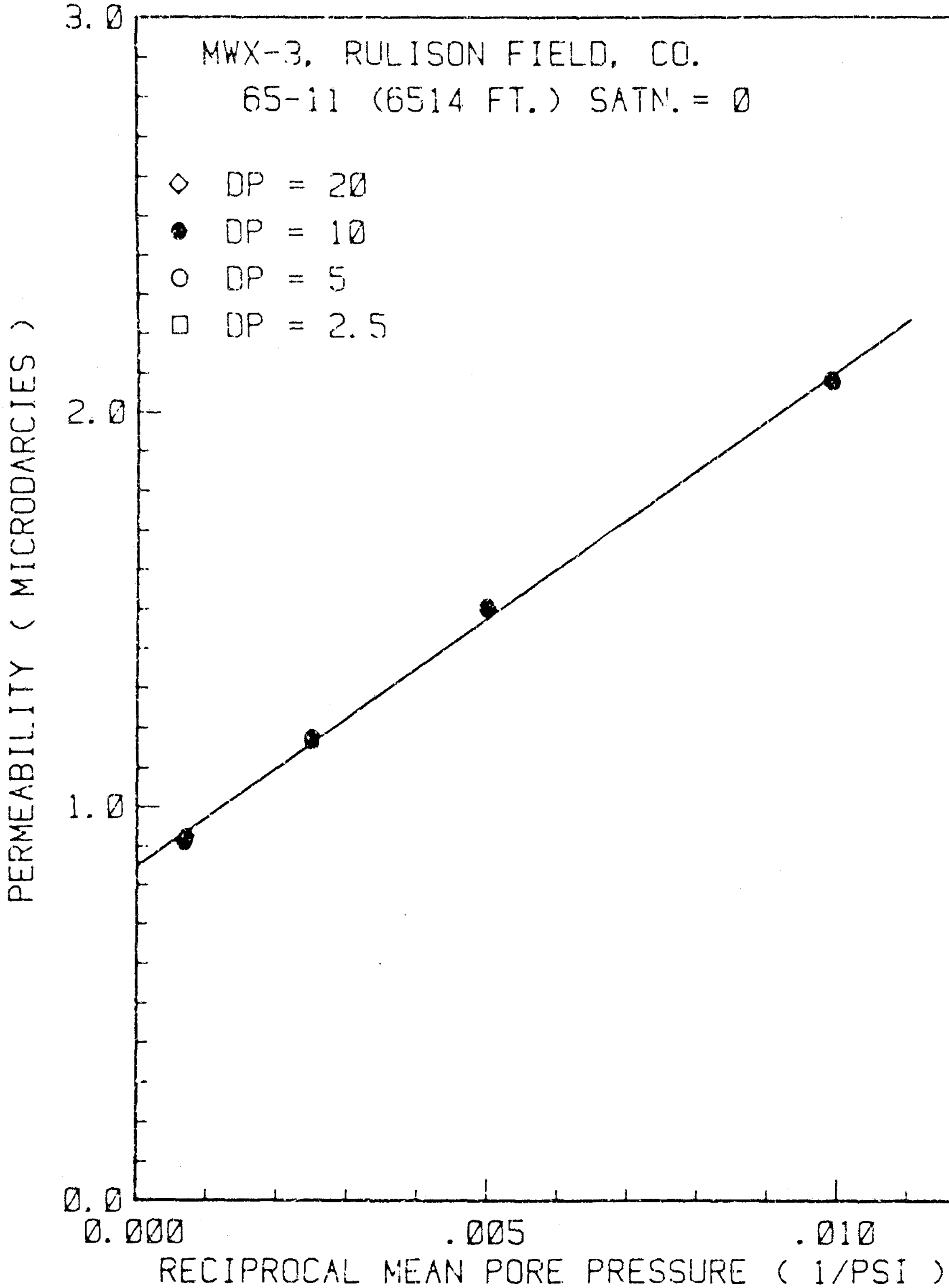
********* WELL NAME: MWX 3, RULISON FIELD, CO. *********

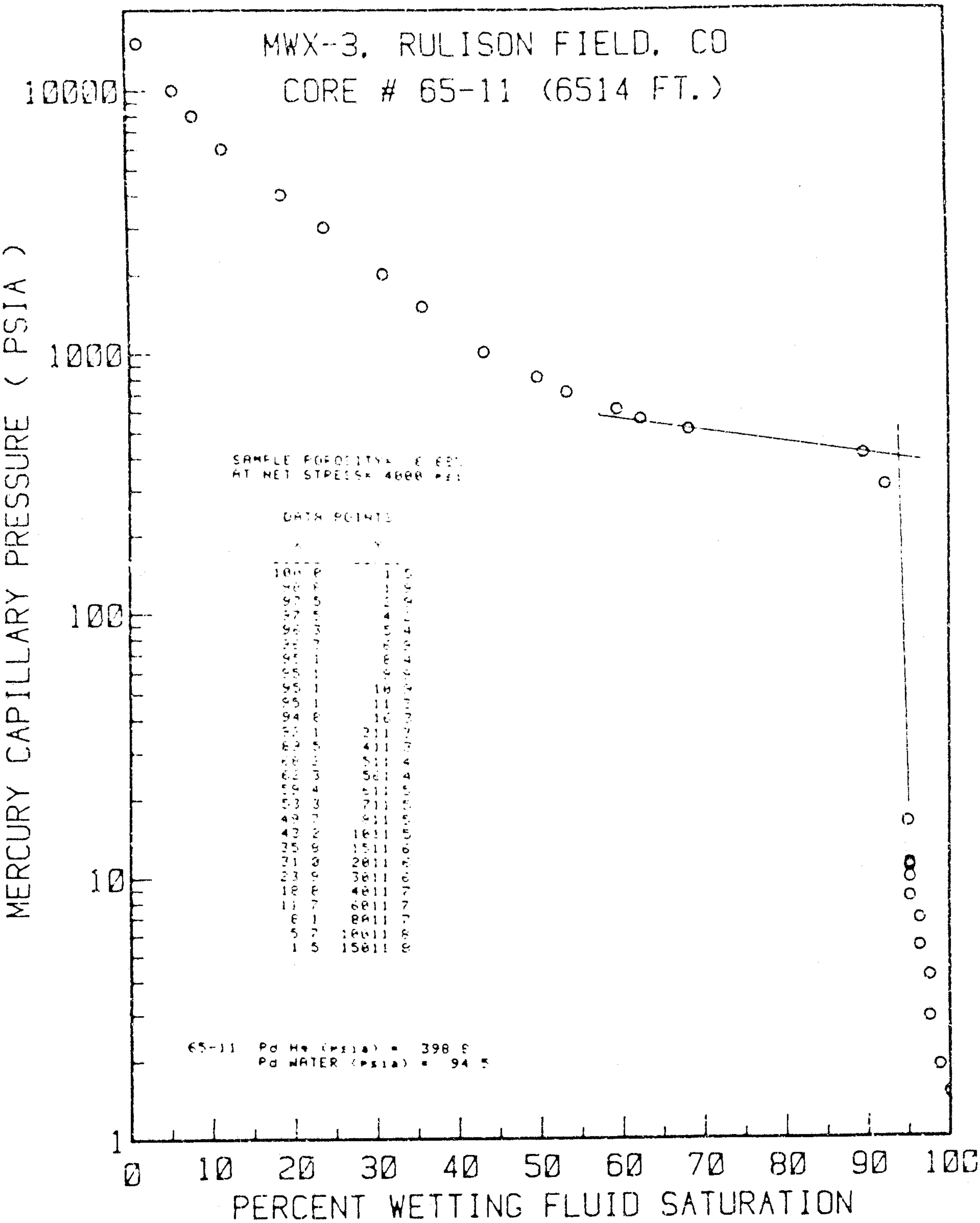
PLUG: 65-11 (6515 FT.) VERT, Sw 0 PLUG LENGTH: 3.240 IN PLUG AREA: 5.062 CM^2

TEST DATE (M-D)	BEGIN TIME (H:M)	DUR-ATION (H:M)	CONFINING PRESSURE (PSIA)	MEAN PORE P (PSIA)	DIFFERENTIAL PRESSURE (PSI)	FLOW RATE (SCC/S)	TEMPERATURE (DEG. F)	VISCOSITY (C POISE)	COMPRES-SIBILITY (Z)	PERMEABILITY VALUE (MICRODARCY)	STD. DEV. (%)
03-05	19:15	02:10	4211	199.80	5.47	5.31E-004	91.00	0.01826	0.9929	1.30E+000	(1.8)
03-06	08:35	03:20	4211	199.82	5.43	5.26E-004	91.00	0.01826	0.9929	1.30E+000	(1.8)
03-06	14:09	02:42	4107	100.31	10.36	7.13E-004	91.00	0.01818	0.9989	1.83E+000	(1.8)
03-07	09:00	02:44	4413	399.76	5.10	7.83E-004	91.00	0.01842	0.9959	1.02E+000	(3.0)
03-07	16:52	02:08	4467	463.62	5.18	8.53E-004	91.00	0.01842	0.9953	9.68E-001	(2.7)
03-08	09:35	03:35	4214	199.78	5.10	4.91E-004	91.00	0.01826	0.9929	1.29E+000	(1.7)
03-08	14:35	02:20	3220	199.78	5.02	5.46E-004	91.00	0.01826	0.9929	1.46E+000	(1.6)
03-08	17:18	01:54	2215	199.75	4.99	6.06E-004	91.00	0.01826	0.9929	1.84E+000	(1.8)
03-09	14:02	01:35	2409	400.23	4.96	1.14E-003	91.00	0.01842	0.9959	1.55E+000	(2.2)
03-09	17:20	02:52	2107	100.00	5.23	5.25E-004	91.00	0.01818	0.9989	2.67E+000	(2.1)
03-10	14:18	01:39	2203	200.27	5.52	7.94E-004	91.00	0.01826	0.9929	1.92E+000	(1.9)


MWX-3, RULISON FIELD, CO.
65-11 (6514') SATN. = 0
◇ DP = 20
● DP = 10
○ DP = 5
□ DP = 2.5
PERMEABILITY (microdarcies)
2.0
1.5
1.0
.5
0.0
0.000
.002
.004
.006
.008
.010
RECIPROCAL MEAN PORE PRESSURE (1/psi)

CORAL RUN 42


MWX-3, RULISON FIELD, CO.
65-11 (6514 FT.) SATN. = Ø
DP = 20
DP = 10
DP = 5
DP = 2.5
3.Ø
2.Ø
1.Ø
Ø.Ø
PERMEABILITY (MICRODARCIES)
Ø.ØØØ
.ØØ5
.Ø1Ø
RECIPROCAL MEAN PORE PRESSURE (1/PSI)


MWX-3, RULISON FIELD, CO
CORE # 65-11 (6514 FT.)
MERCURY CAPILLARY PRESSURE (PSIA)
PERCENT WETTING FLUID SATURATION
AT NET STRESS= 4000 psi
65-11 Pd He (psia) = 398.8
Pd WATER (psia) = 94.5
10000
1000
100
10
1
0
10
20
30
40
50
60
70
80
90
100

APPENDIX 11.6

RE/SPEC DATA

APPENDIX 11.6

RE/SPEC, INC. CORE DATA

RE/SPEC, Inc. performed most of the rock property measurements on the MWX core. As part of their sample preparation, RE/SPEC plugged all core vertically (parallel to the axis of the core). Test plugs ranged from 1-1/2 inches to 2 inches in diameter and from 1 inch to 4 inches in length. Bedding planes and laminations may have affected some of the property measurements.

This appendix includes all RE/SPEC's stress-strain curves for coastal samples as well as plots of tangent modulus and incremental strain ratio as a function of axial stress difference. The curves and plots in this appendix are presented by well. The specific MWX Data File references are as follows:

MWX-1	1.2.25.009
MWX-2	1.2.25.010
MWX-3	1.2.25.012

MWX-1

Mwx-1

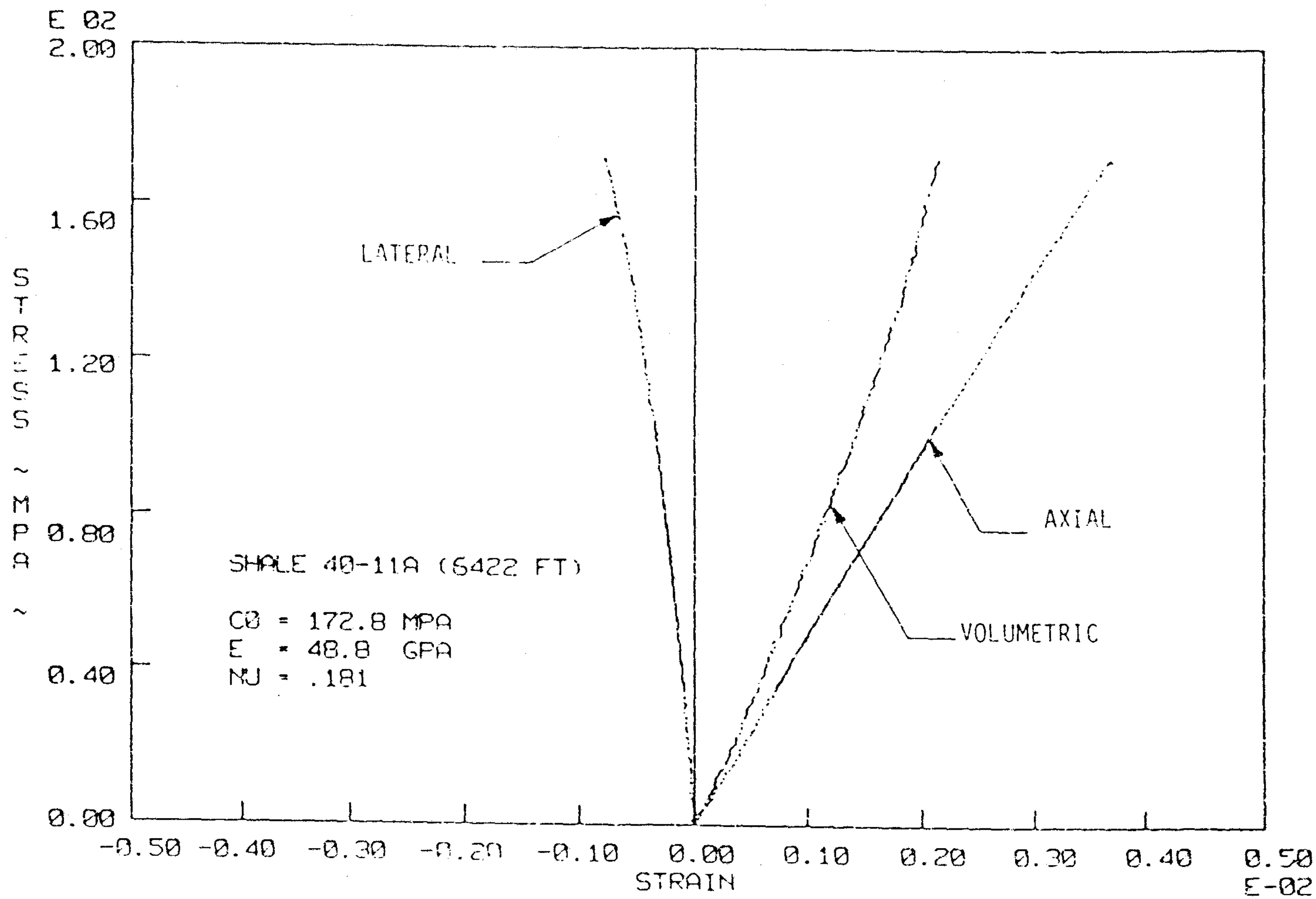
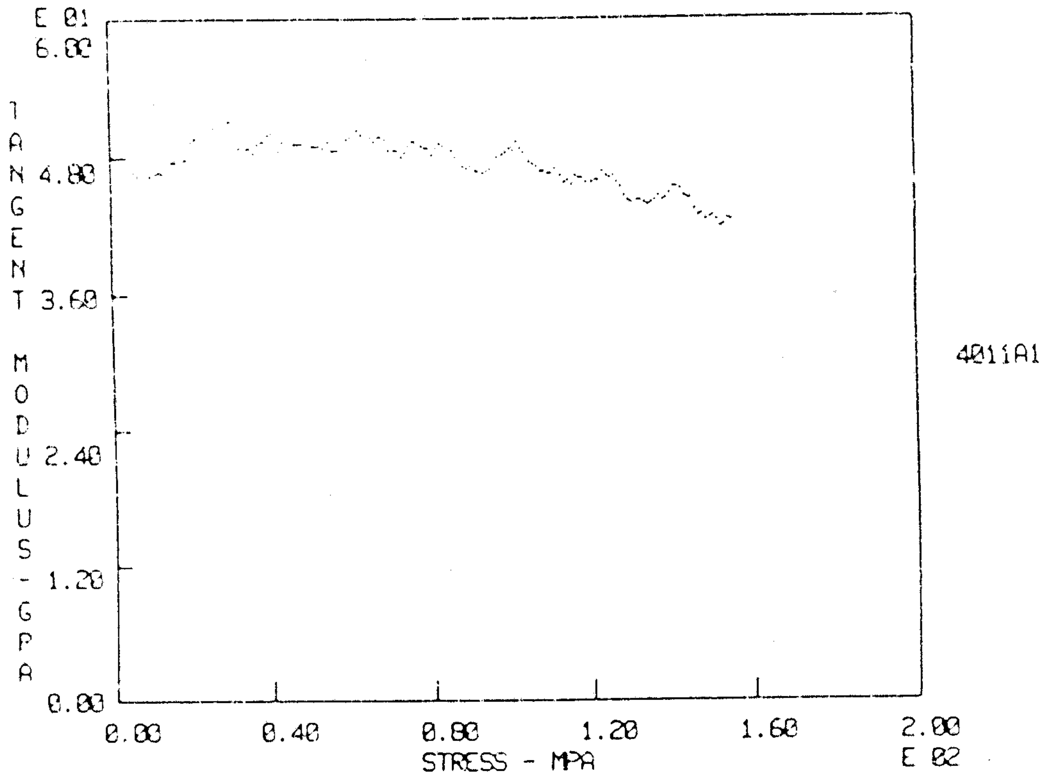


Figure 37. Axial Stress Difference Versus Axial, Lateral and Volumetric Strain for Unconfined Compression of Shale 40-11A.

RSI DWG C46-82-04

RSI DWG 046-83-182



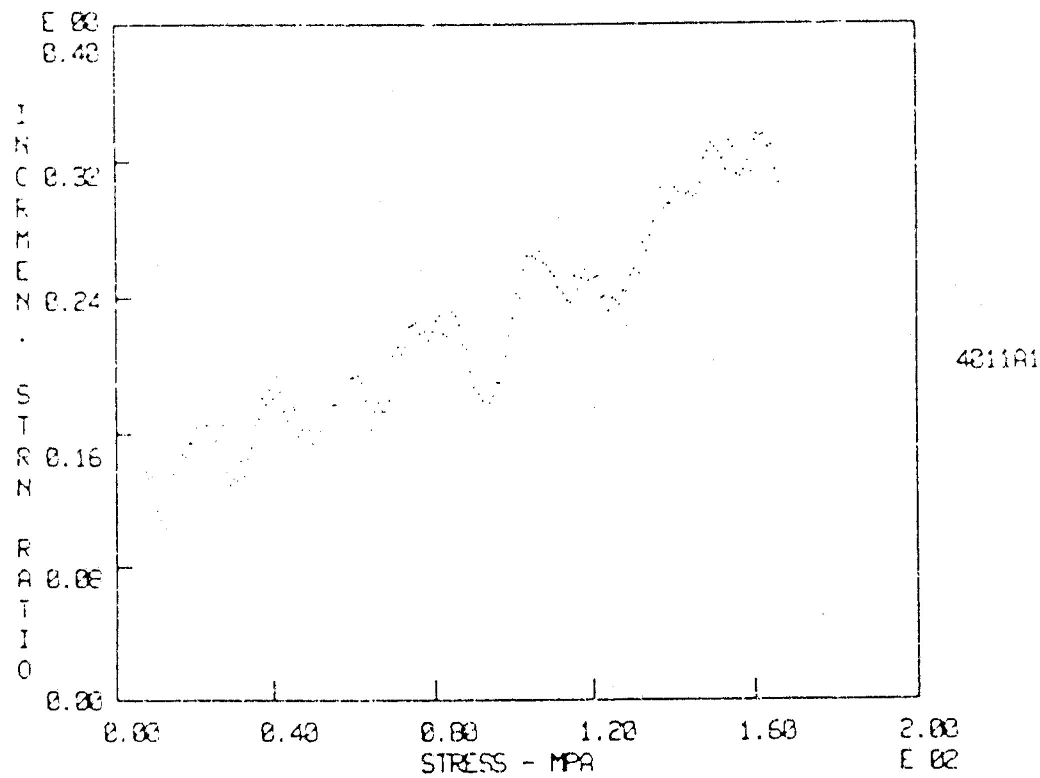


Figure 88. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Shale 40-11A (6422 Feet). P = 0 MPa.

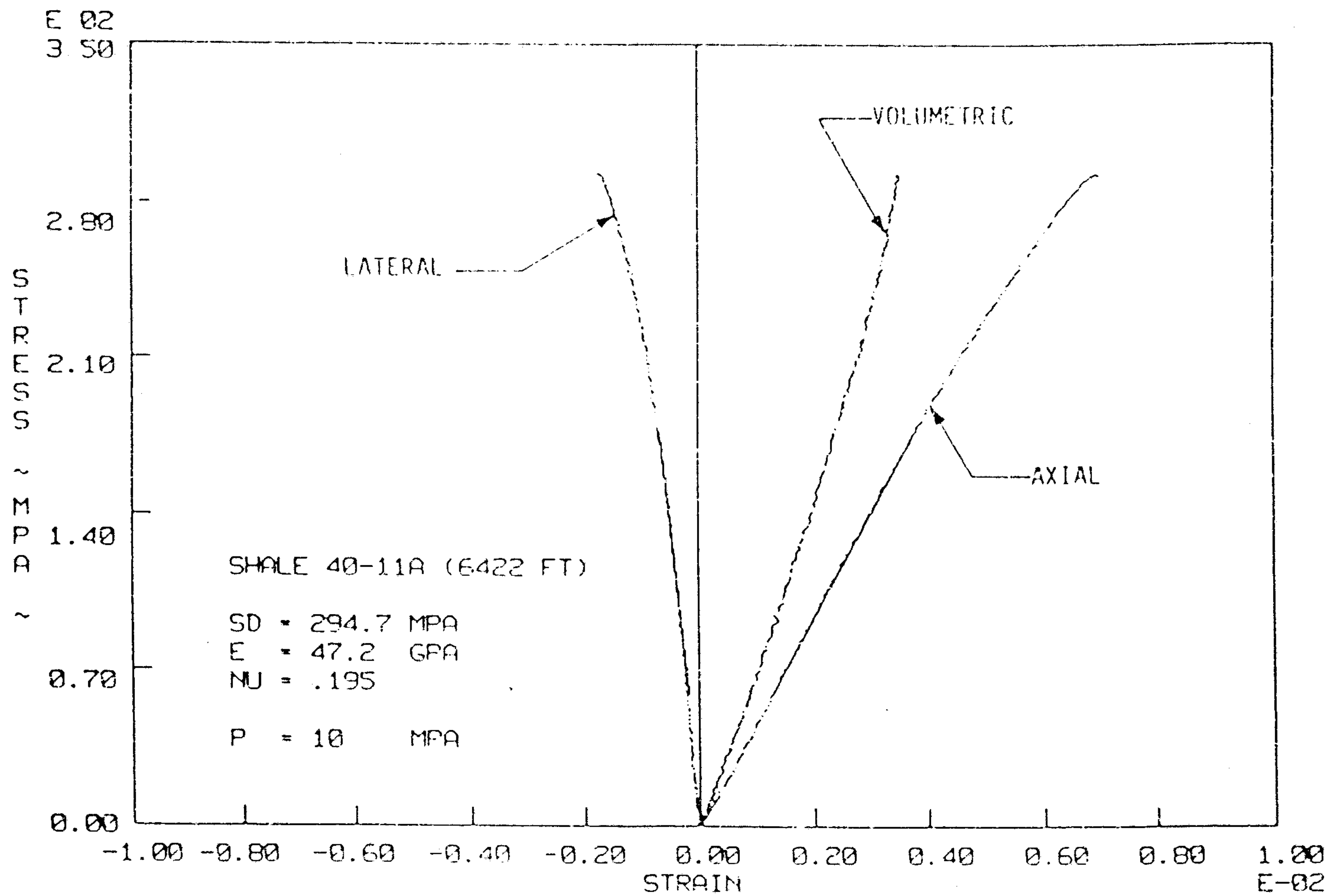
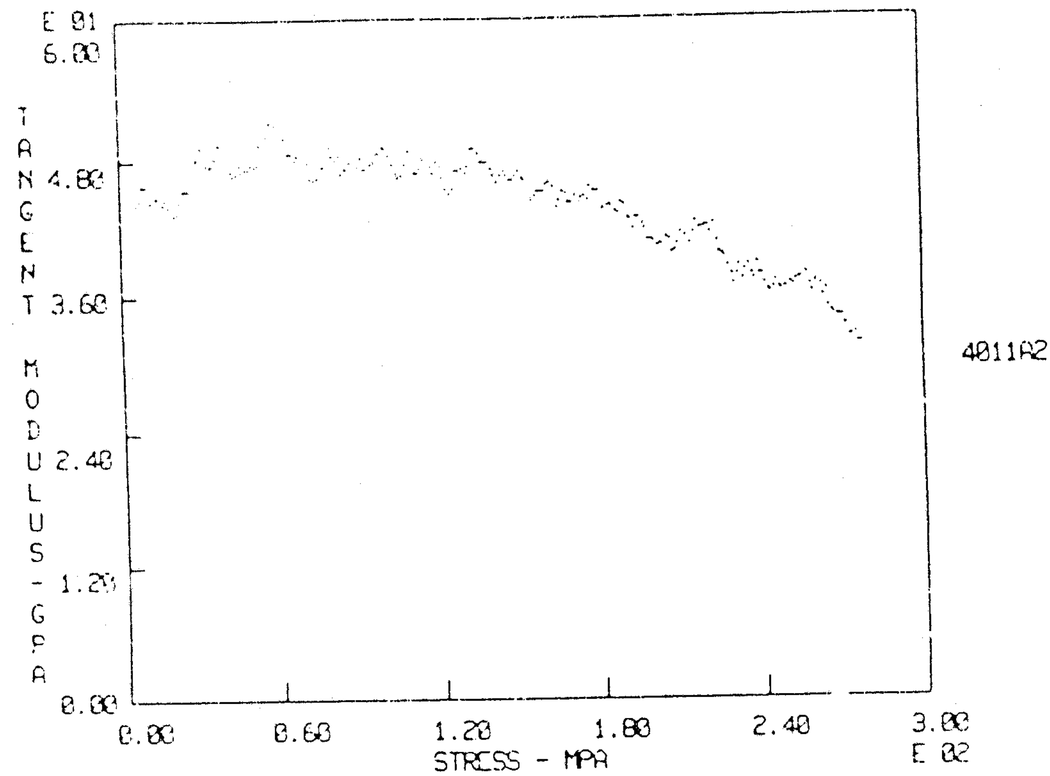


Figure 89. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Shale 40-11A. P = 10 MPa.

RSI DWG 046-82-23

RSI DWG 046-83-183



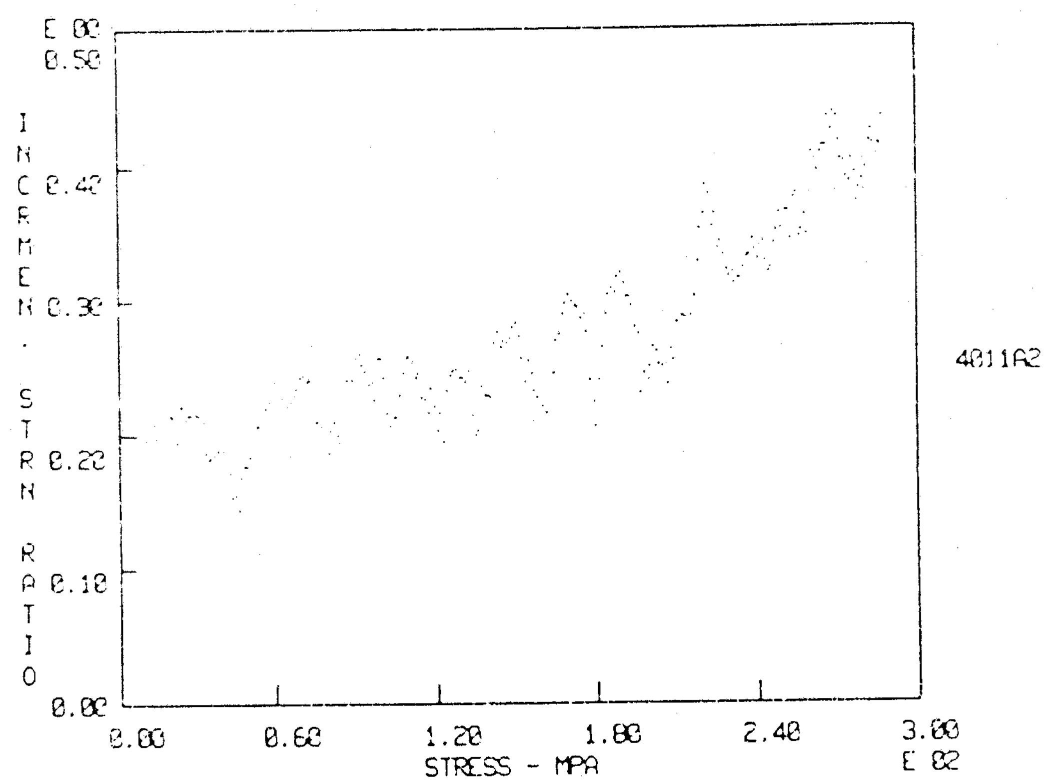


Figure 90. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Shale 40-11A (6422 Feet). P = 10 MPa.

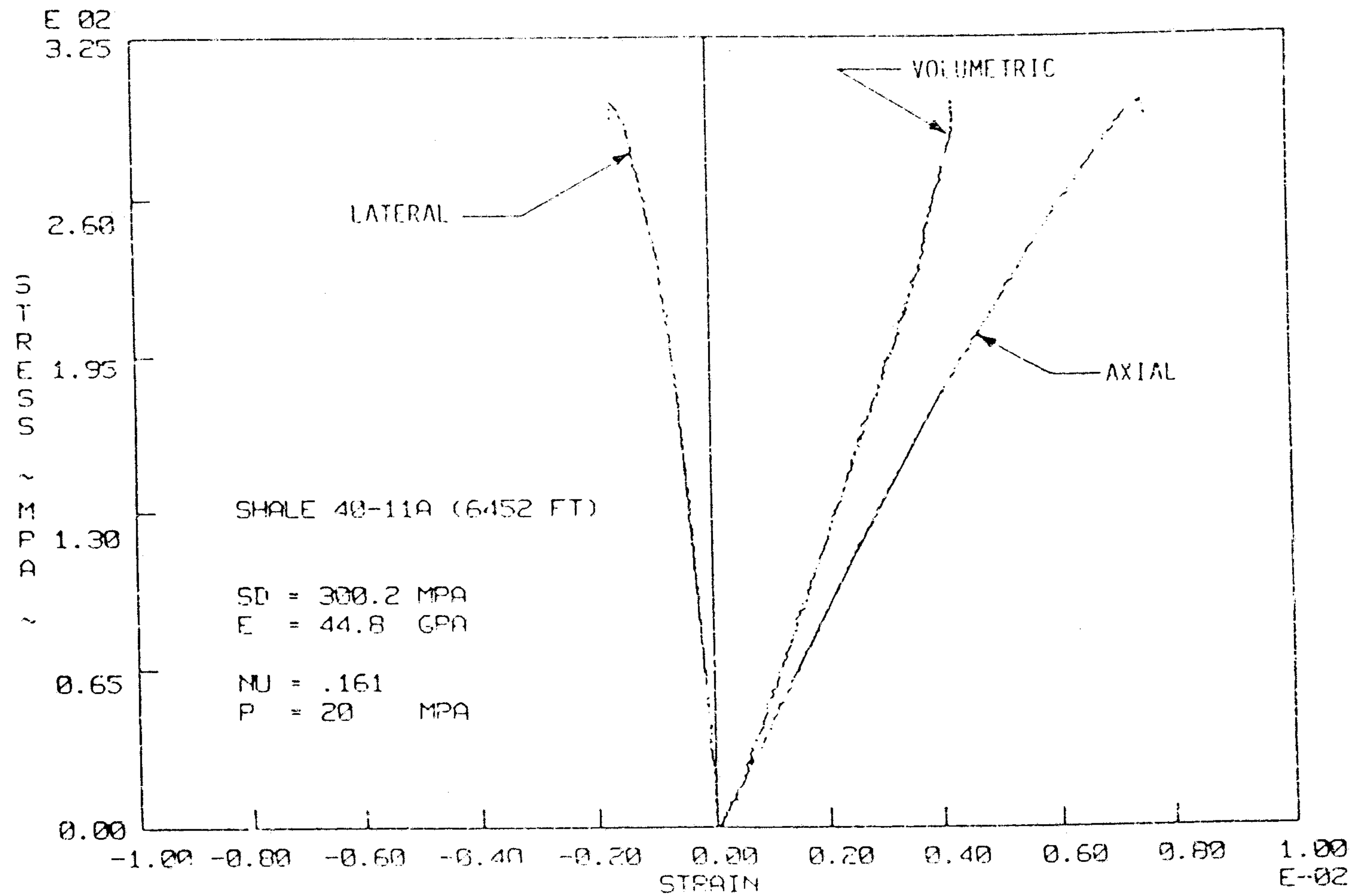
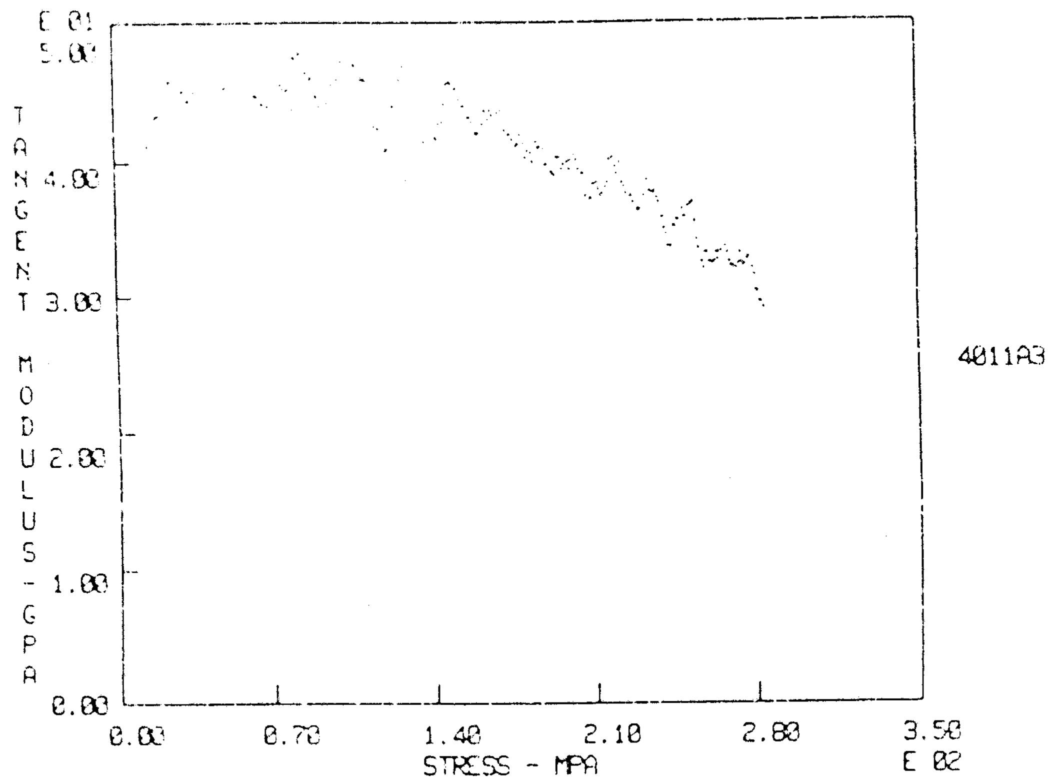


Figure 91. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Shale 40-11A. P = 20 MPa.

RSI DWG 046-82-24

RSI DWG 046-83-184



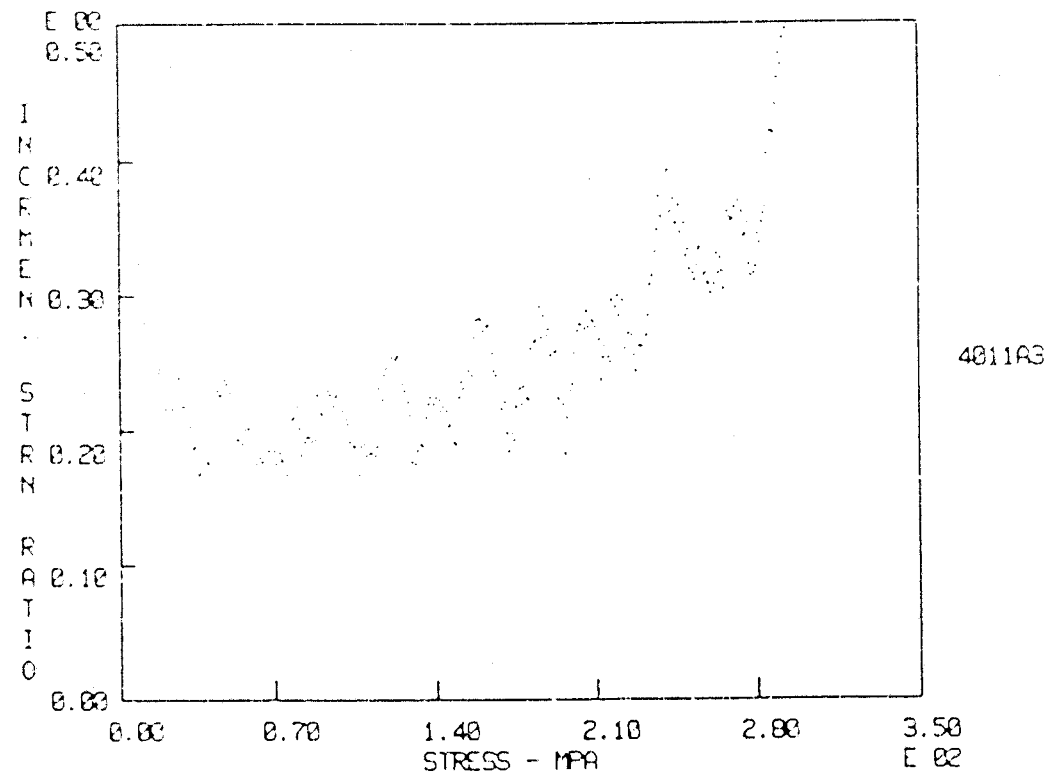


Figure 92. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Shale 40-11A (2 Feet). P = 20 MPa.

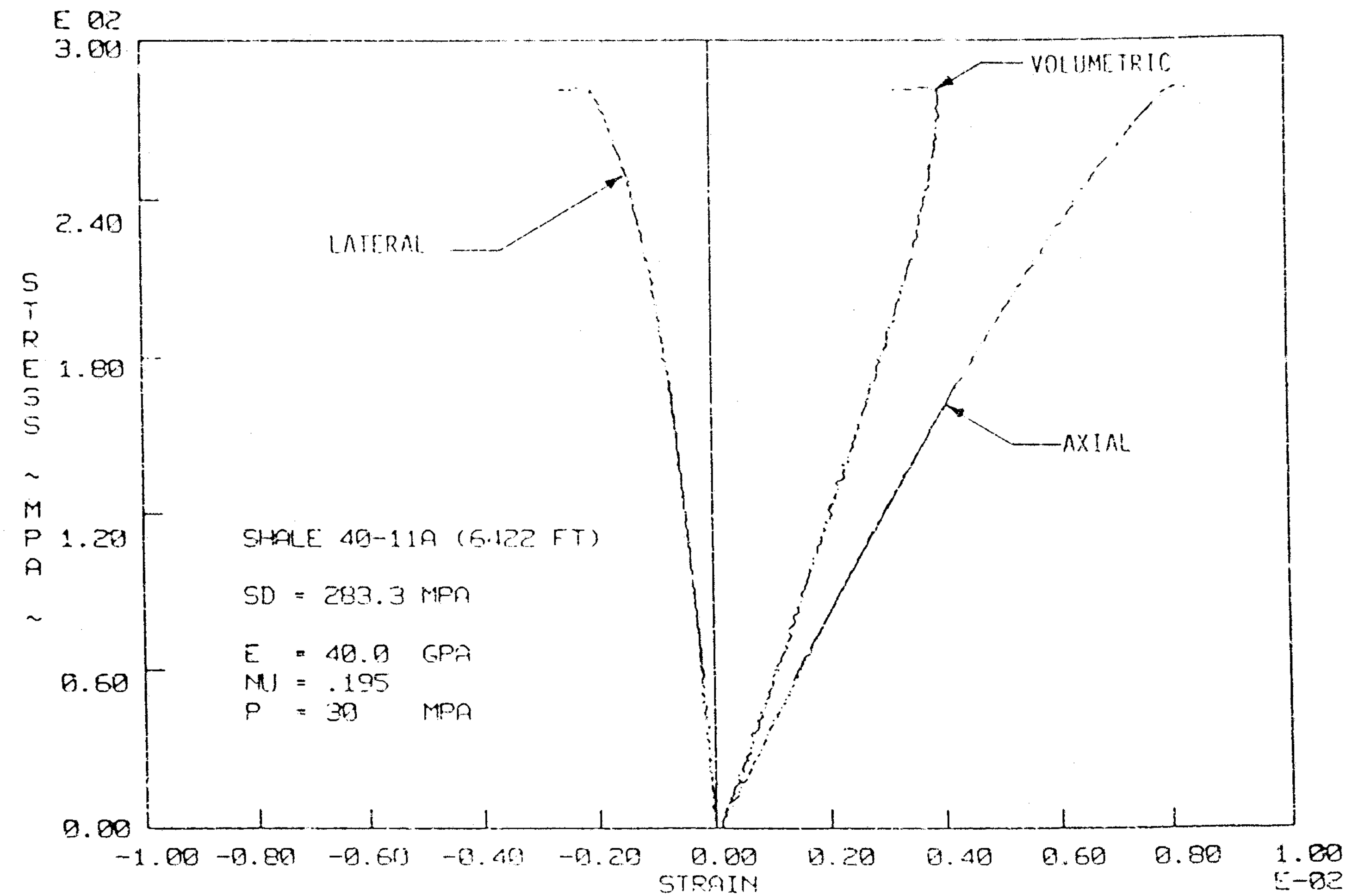
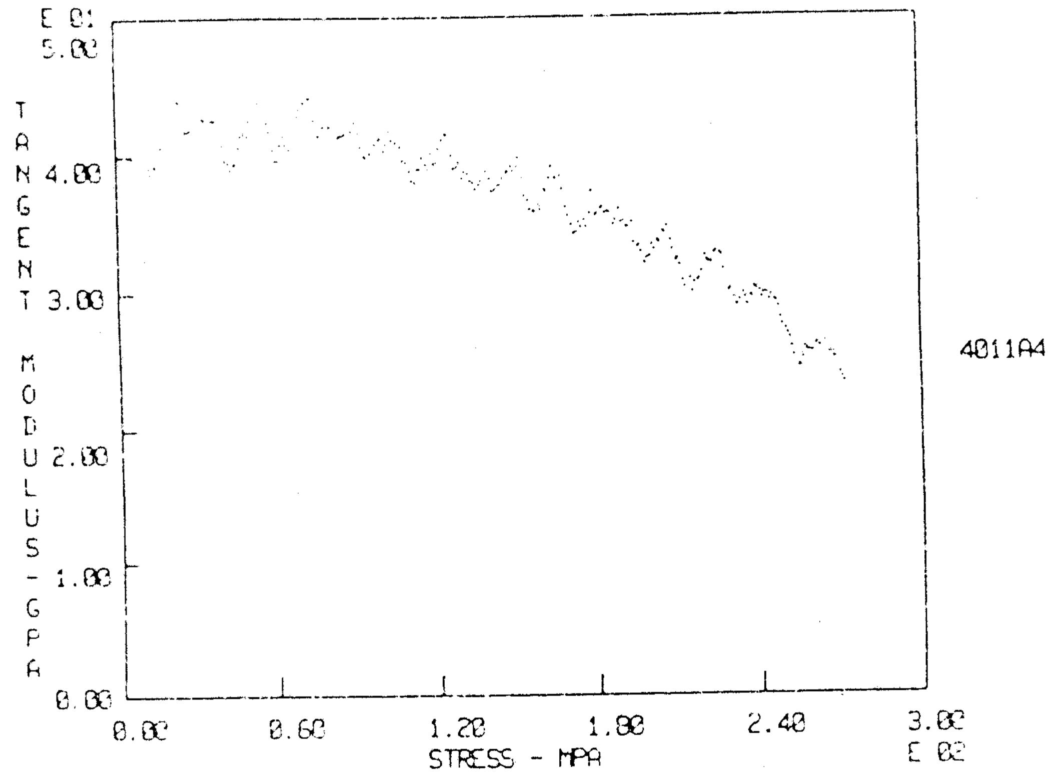


Figure 93. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Shale 40-11A. P = 30 MPa.

RSI DWG 046-82-25

RSI DWG 046-83-185



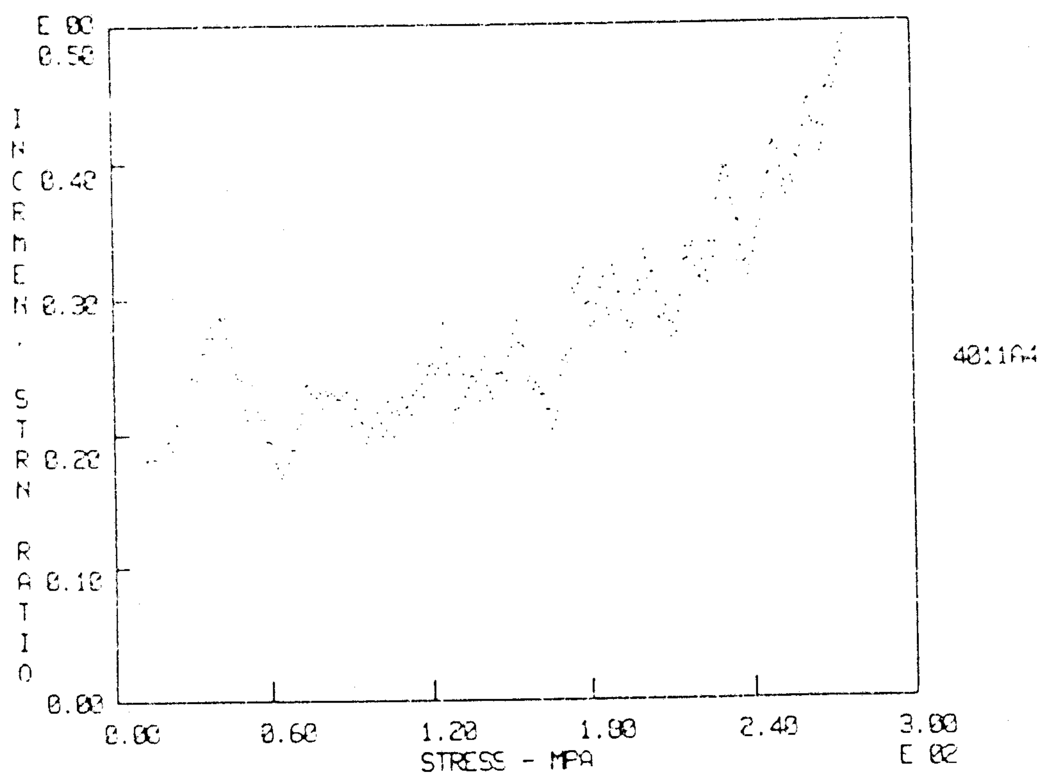


Figure 94. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Shale 40-11A (6422 Feet). P = 30 MPa.

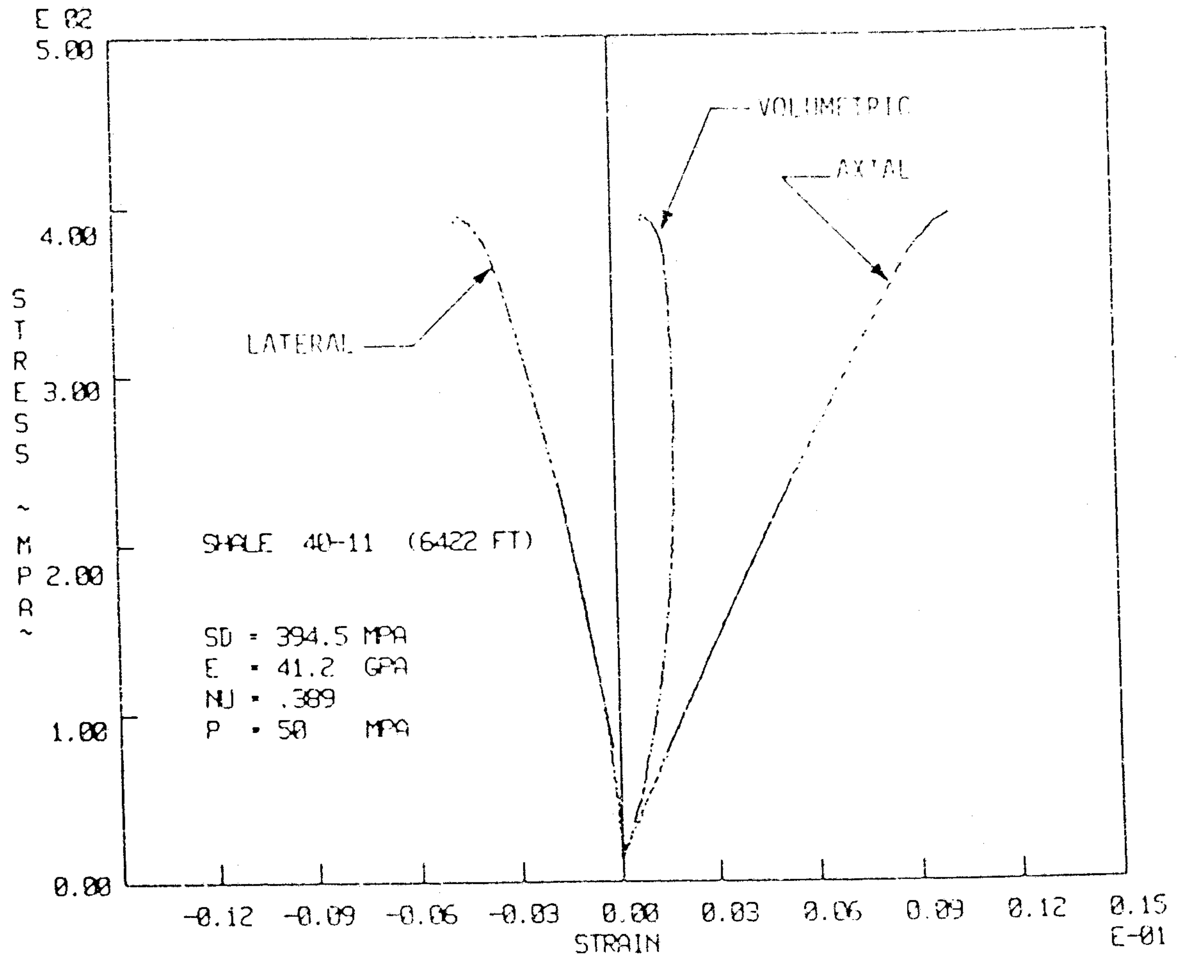


Figure 95. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Shale 40-11. P = 50 MPa.

RSI DWG 046-83-186

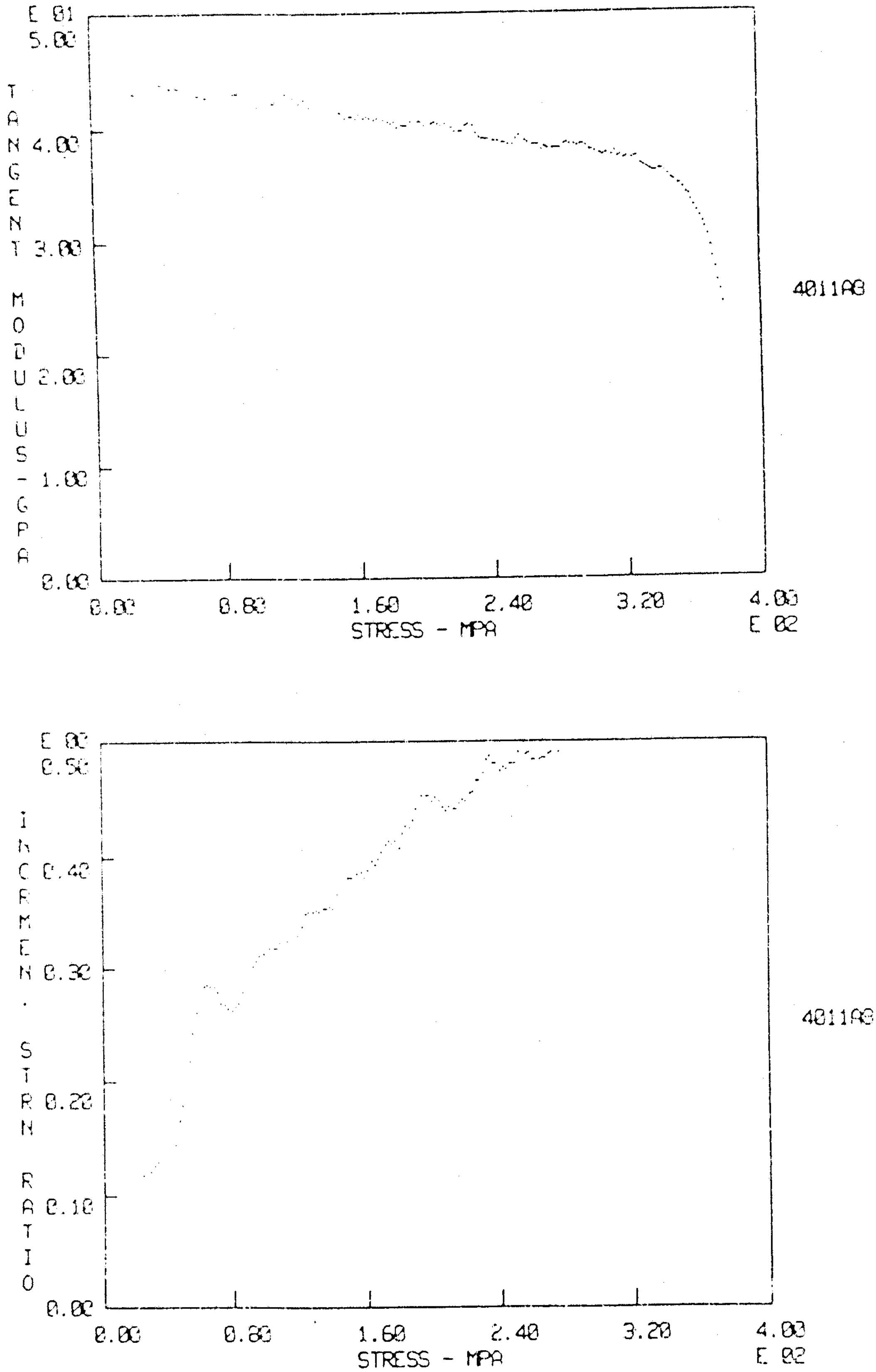


Figure 96. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Shale 40-11A (6422 Feet). P = 50 MPa.

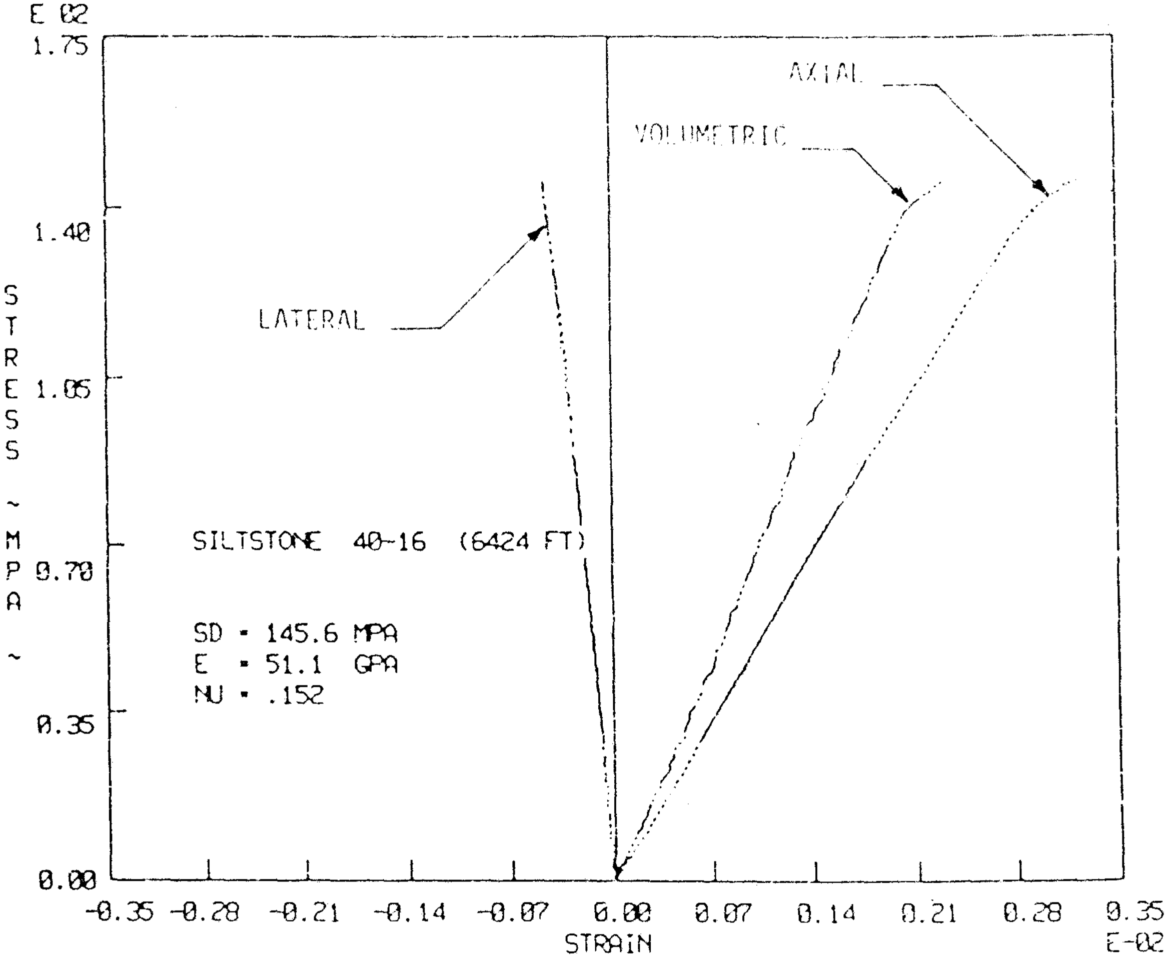
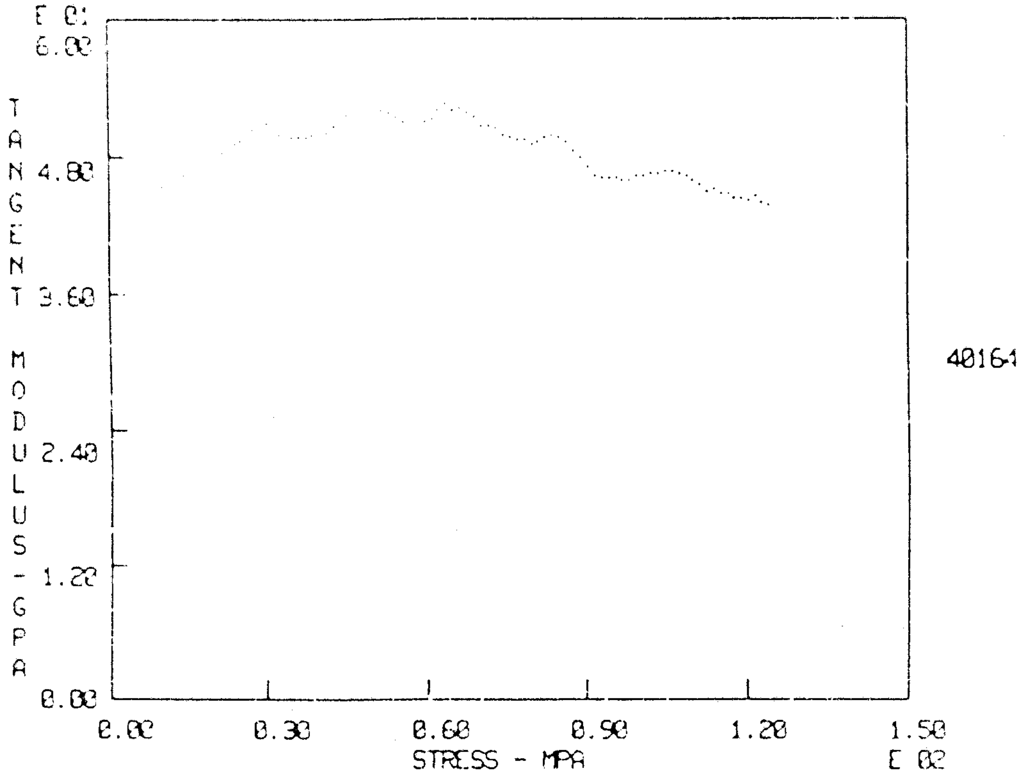


Figure 97. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Unconfined Compression of Siltstone 40-16.

RSI DWG 046-83-63

RSI DWG 046-83-197



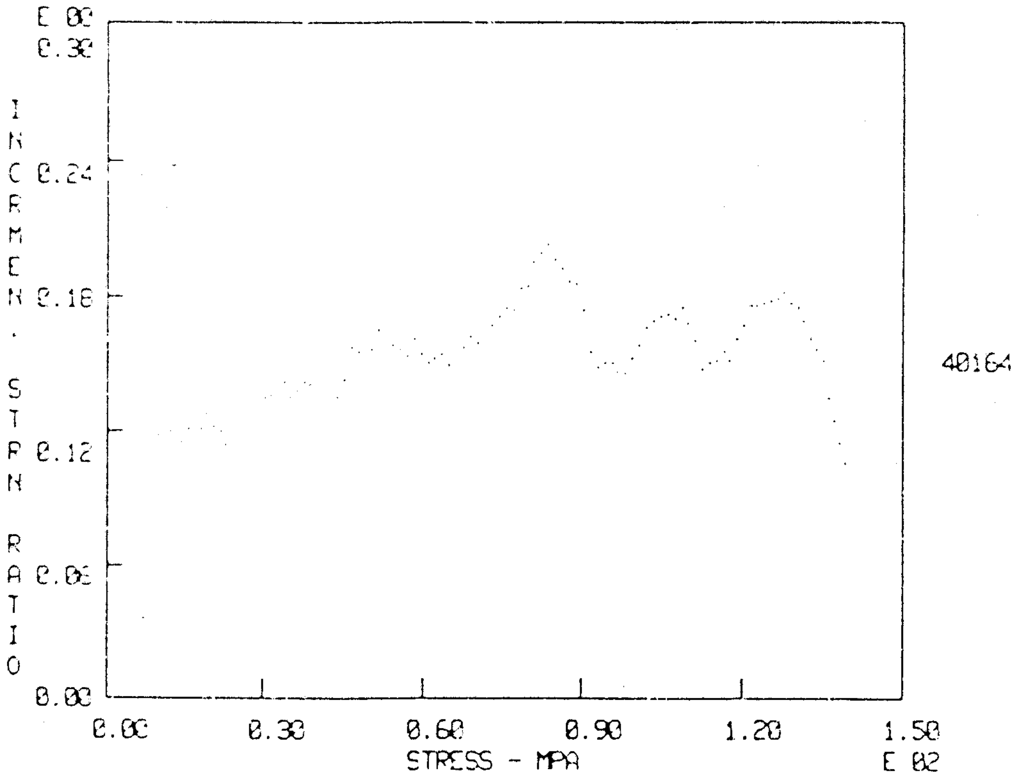


Figure 98. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Siltstone 40-16 (6424 Feet). P = 0 MPa.

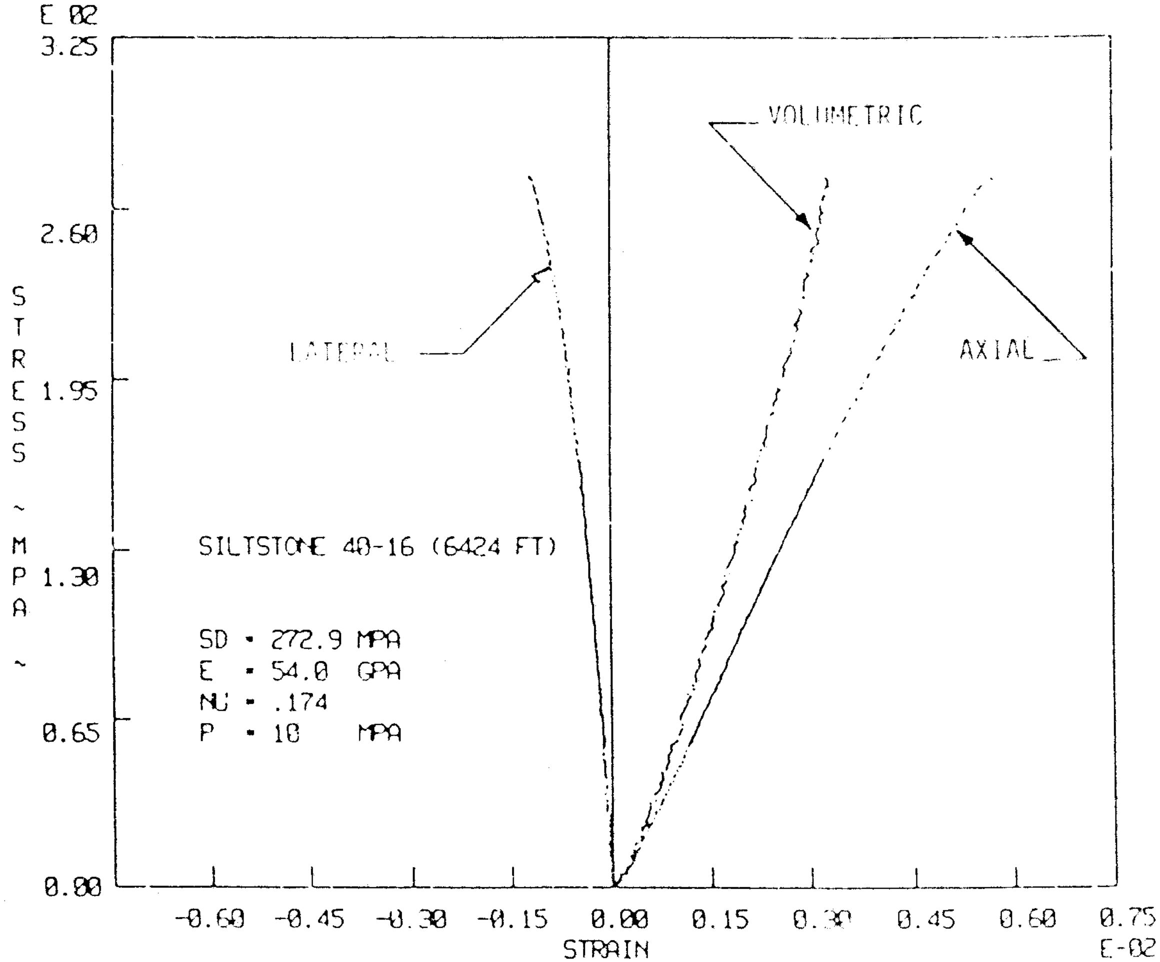
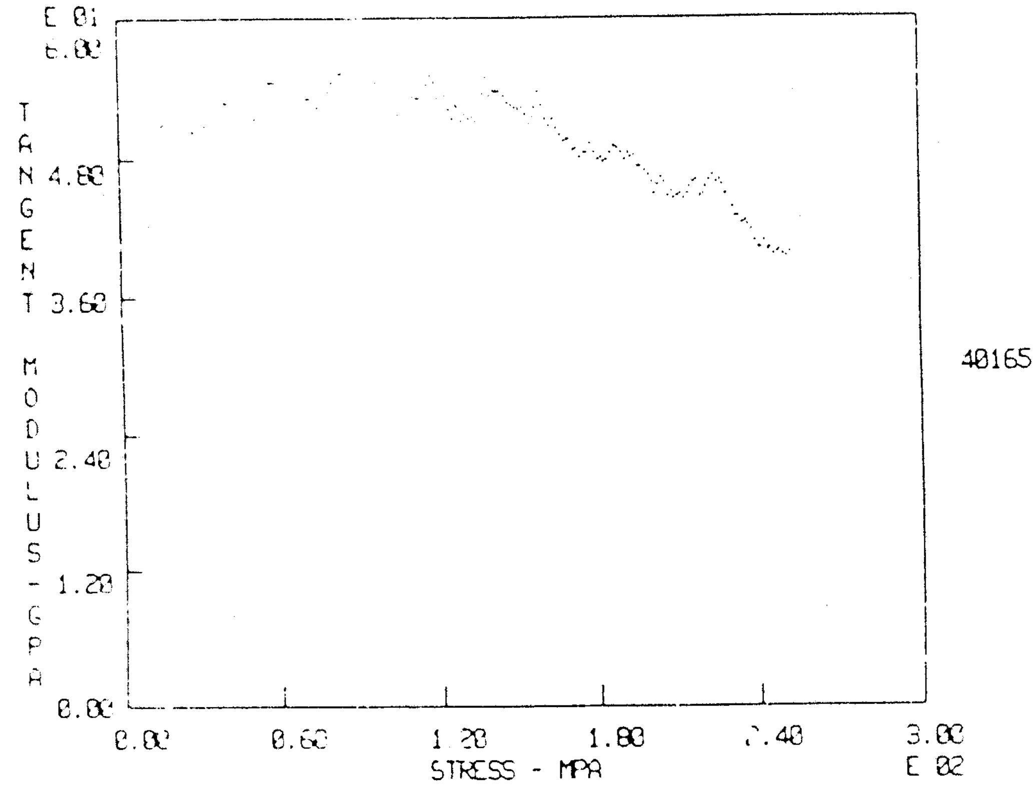


Figure 99. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Siltstone 40-16. P = 10 MPa.

RSI DWG 046-83-06

RSI DWG 046-83-185



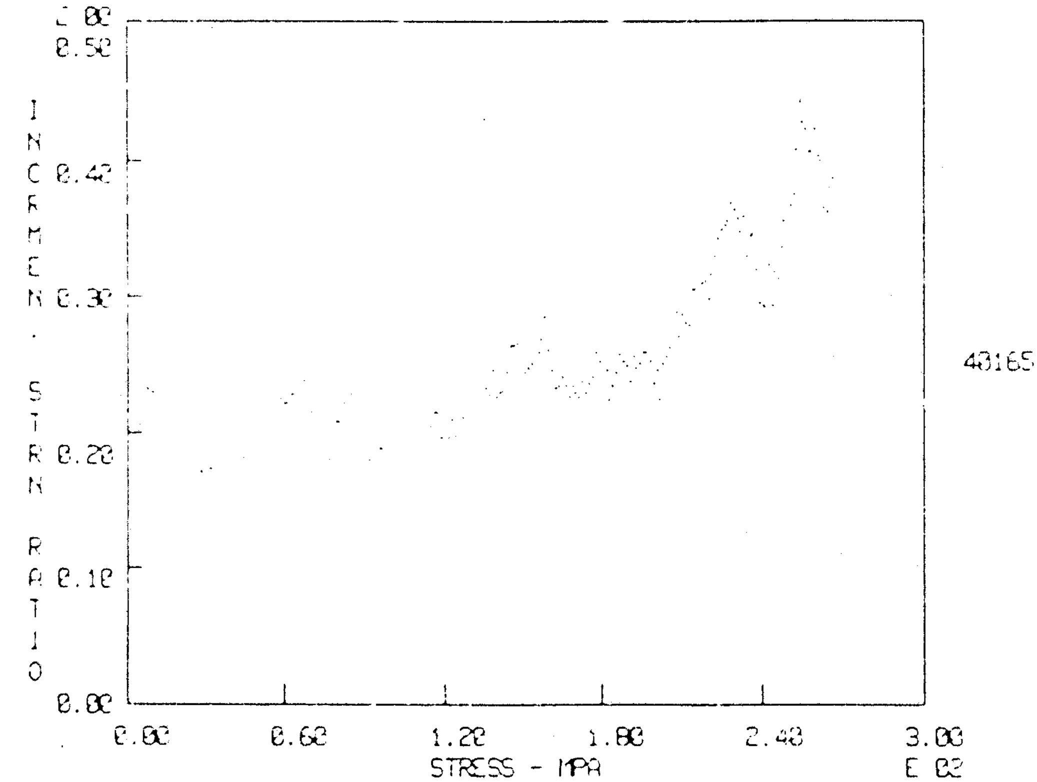


Figure 100. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Siltstone 40-16 (6424 Feet). P = 10 MPa.

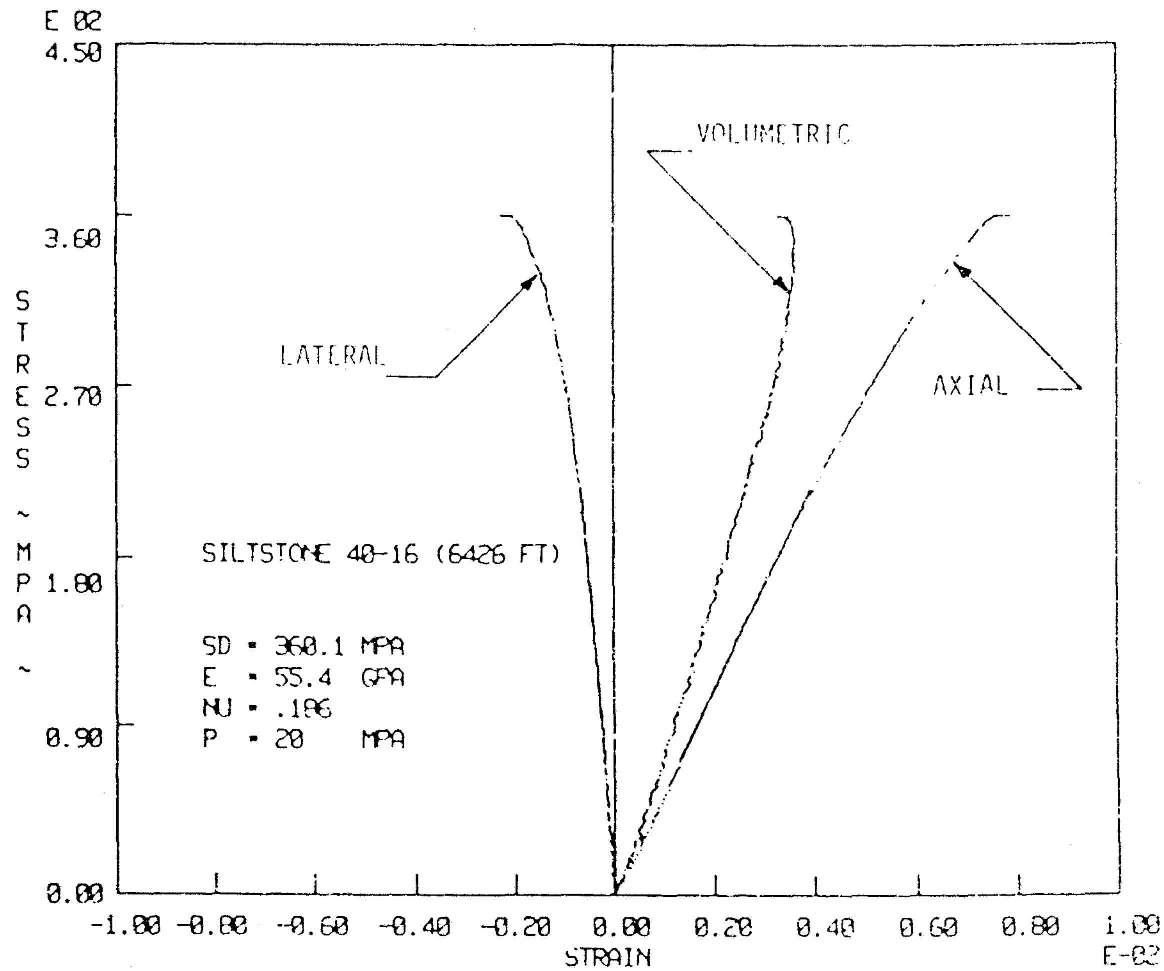
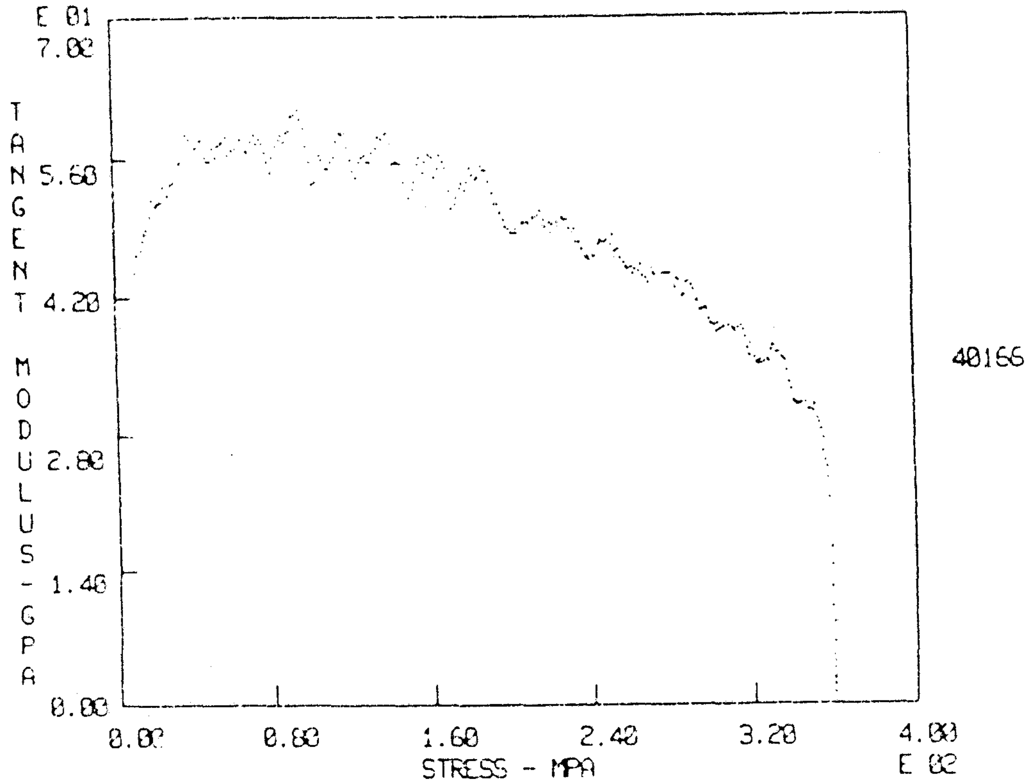


Figure 101. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Siltstone 40-16. P = 20 MPa.

RSI DWG 046-83-09

RSI DWG 046-83-189



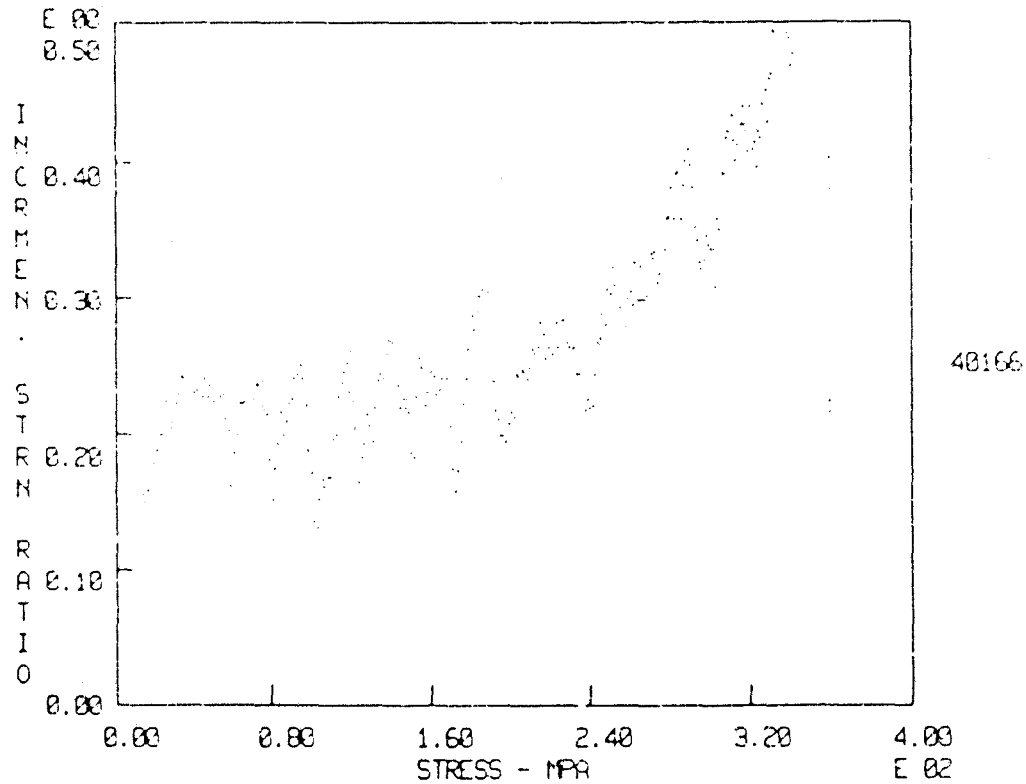


Figure 102. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Siltstone 40-16 (6424 Feet). P = 20 MPa.

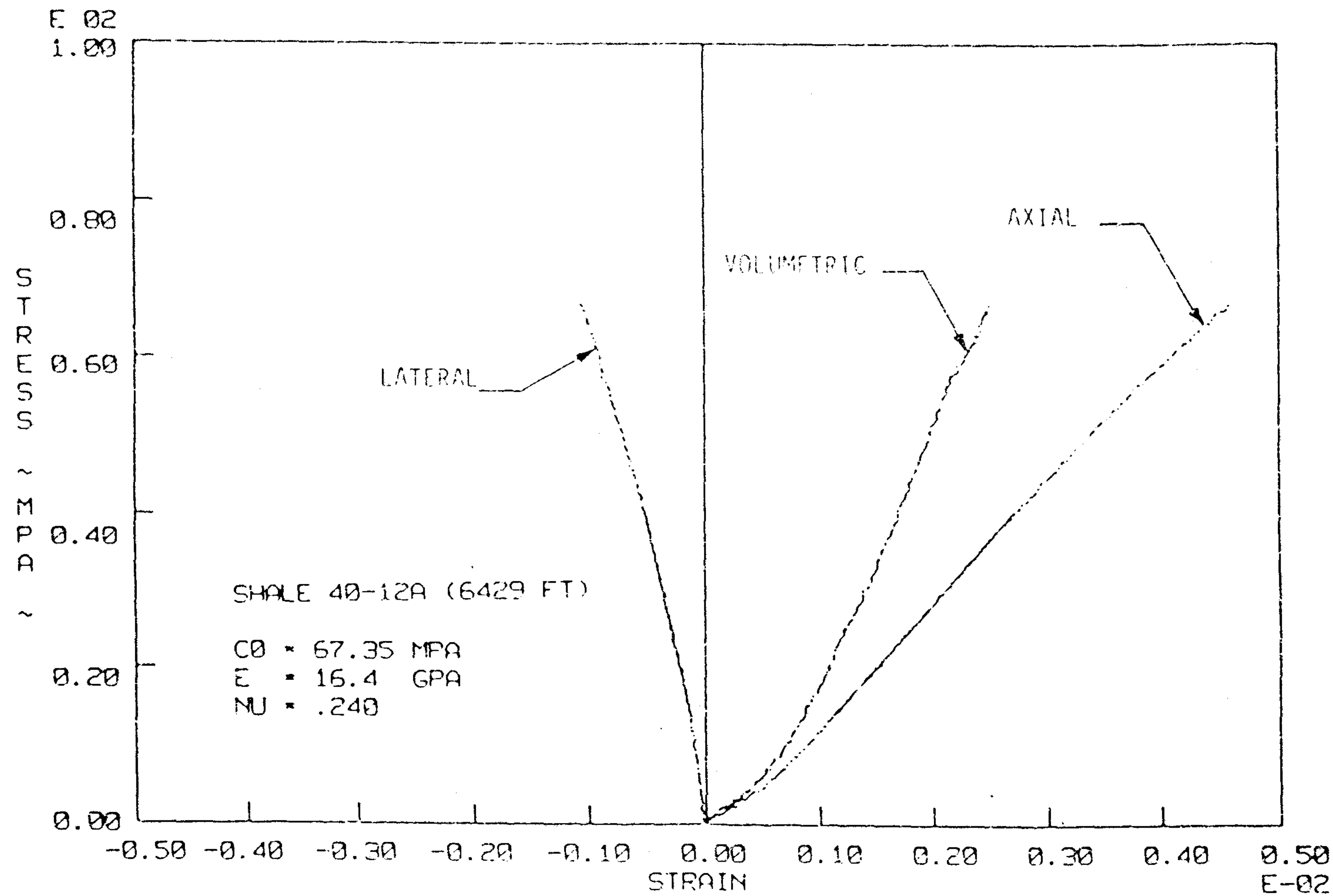
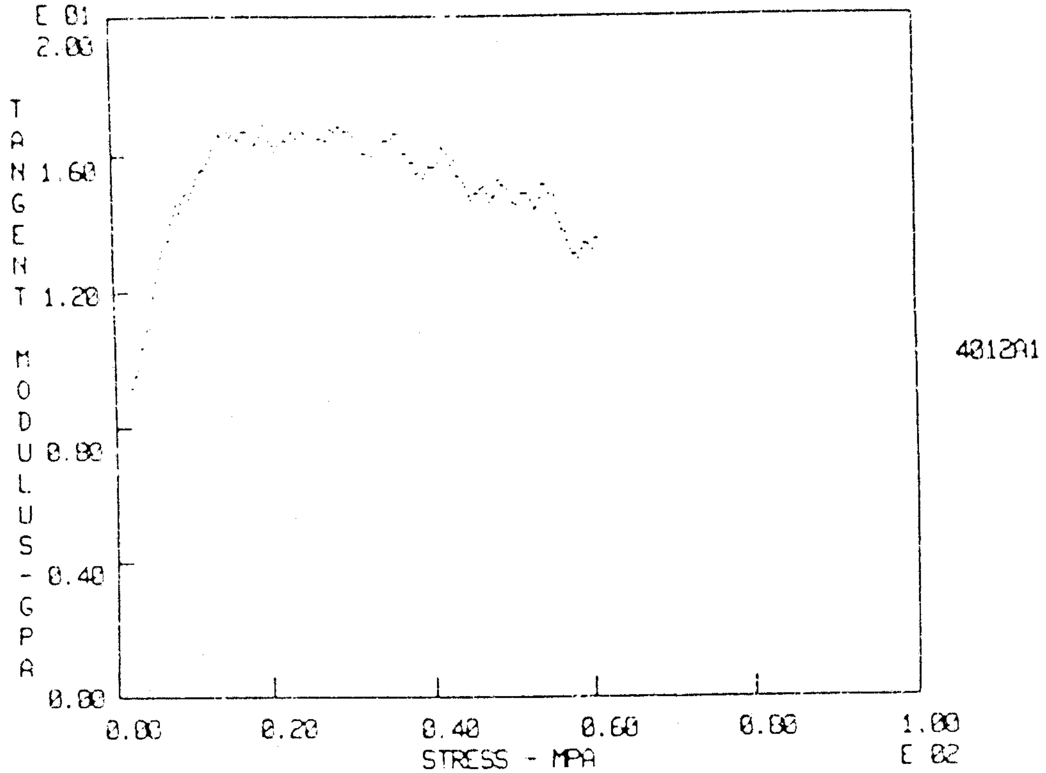


Figure 103. Axial Stress Difference Versus Axial, Lateral and Volumetric Strain for Unconfined Compression of Shale 40-12A.

RSI DWG 046-82-01

RSI DWG 046-83-190



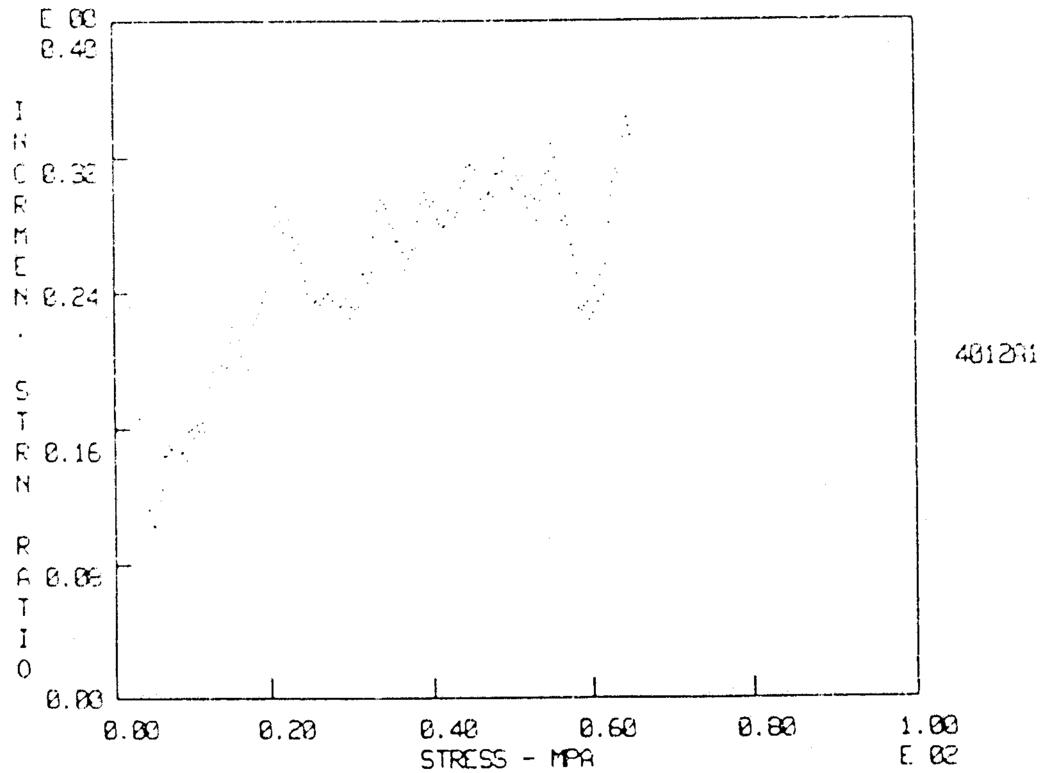


Figure 104. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Shale 40-12A (6429 Feet). P = 0 MPa.

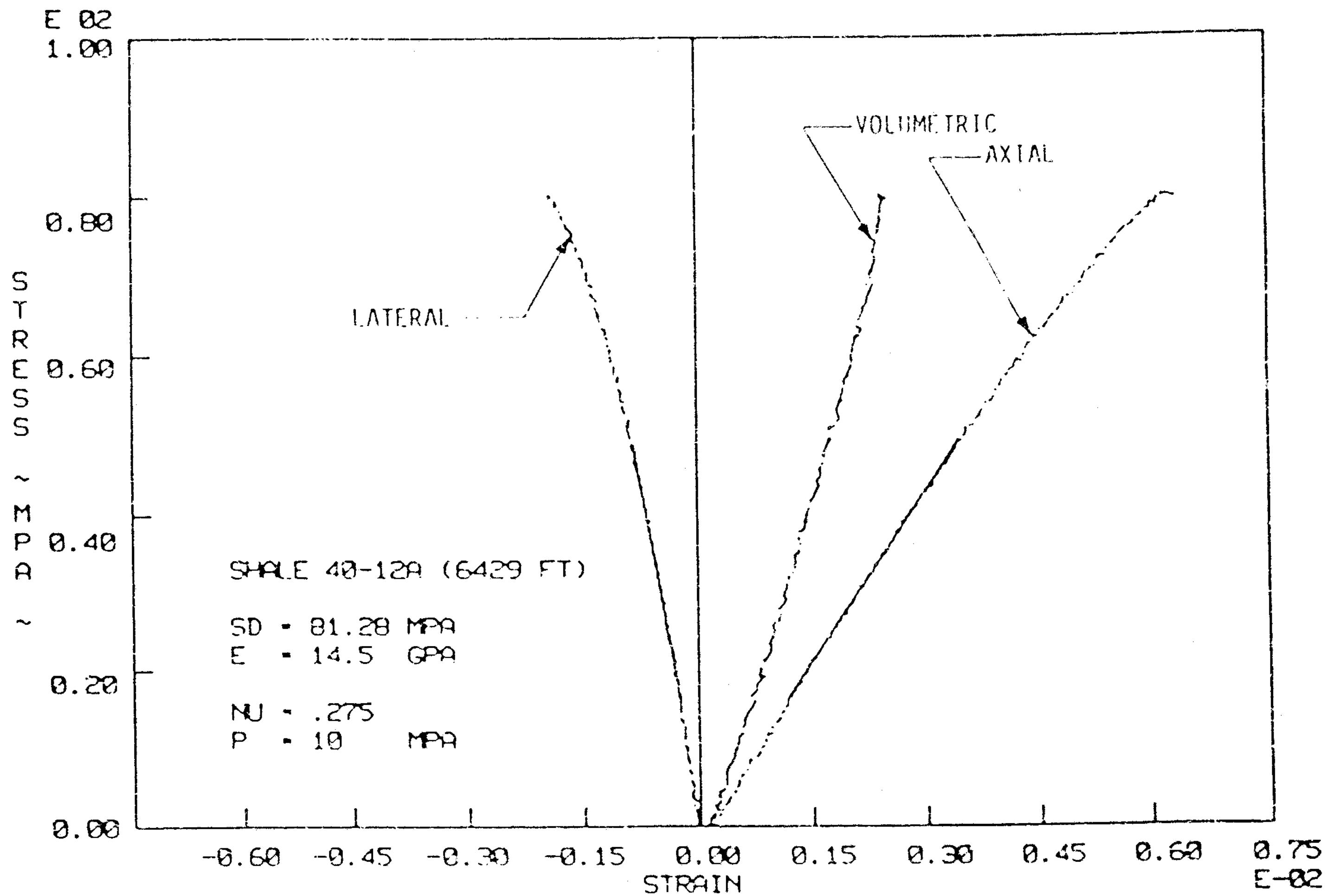
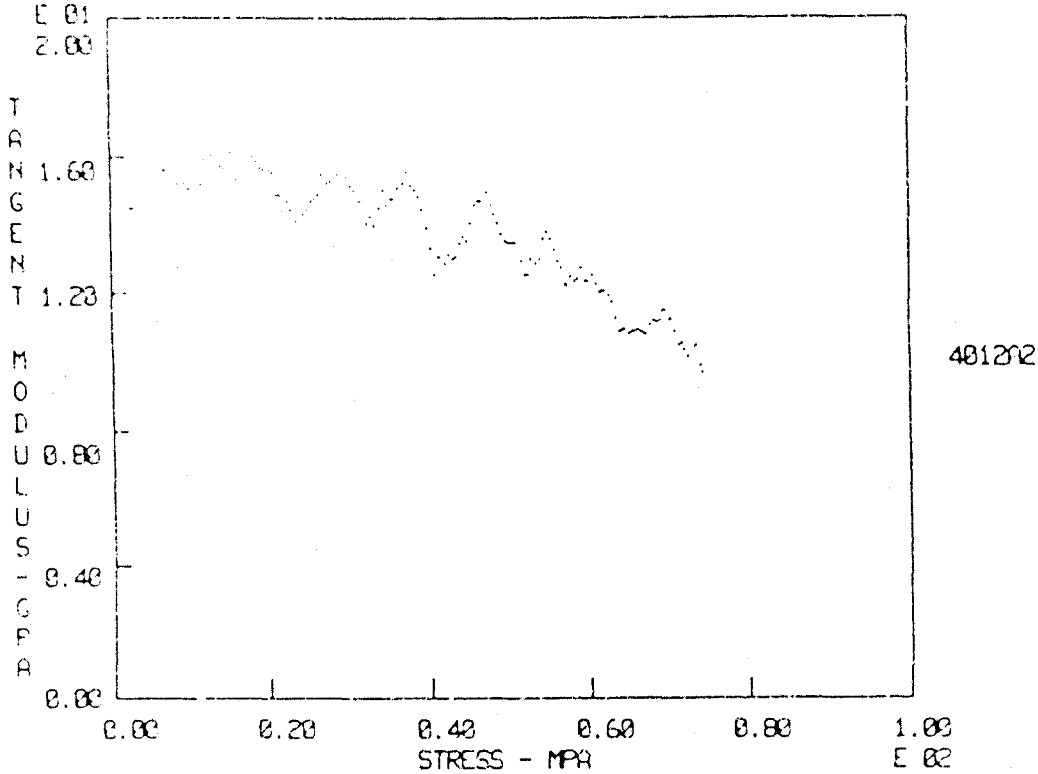


Figure 105. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Shale 40-12A. P = 10 MPa.

RSI DWG 046-82-11

RSI DWG 046-83-191



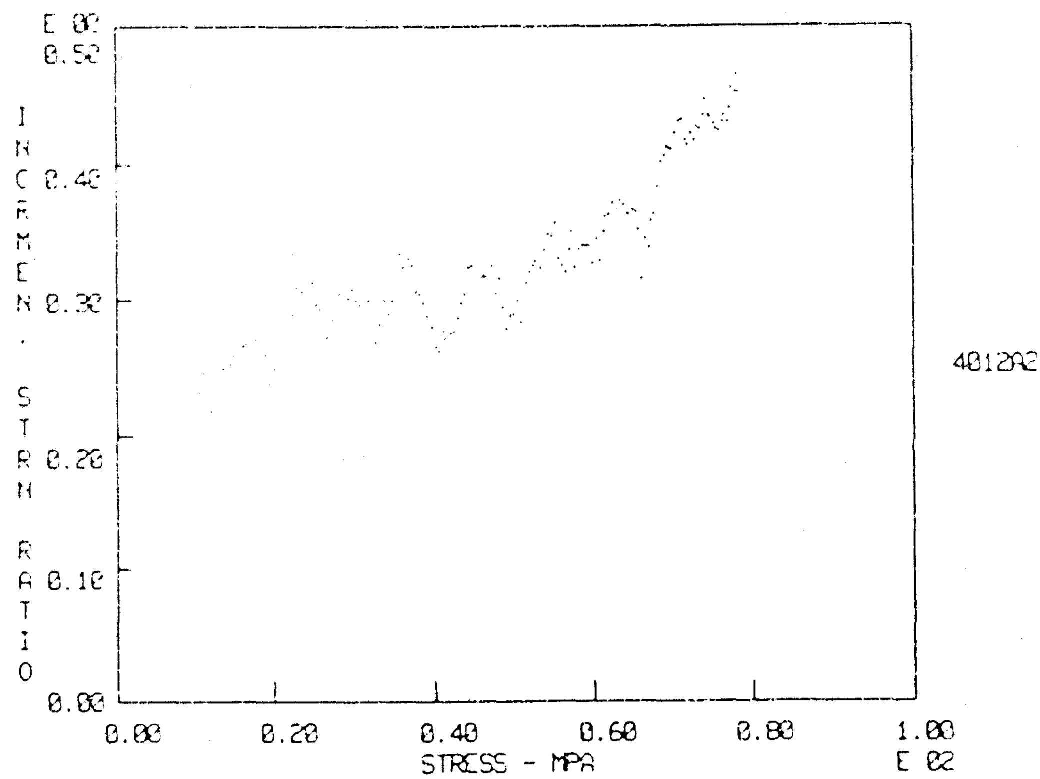


Figure 106. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Shale 40-12A (6429 Feet). P = 10 MPa.

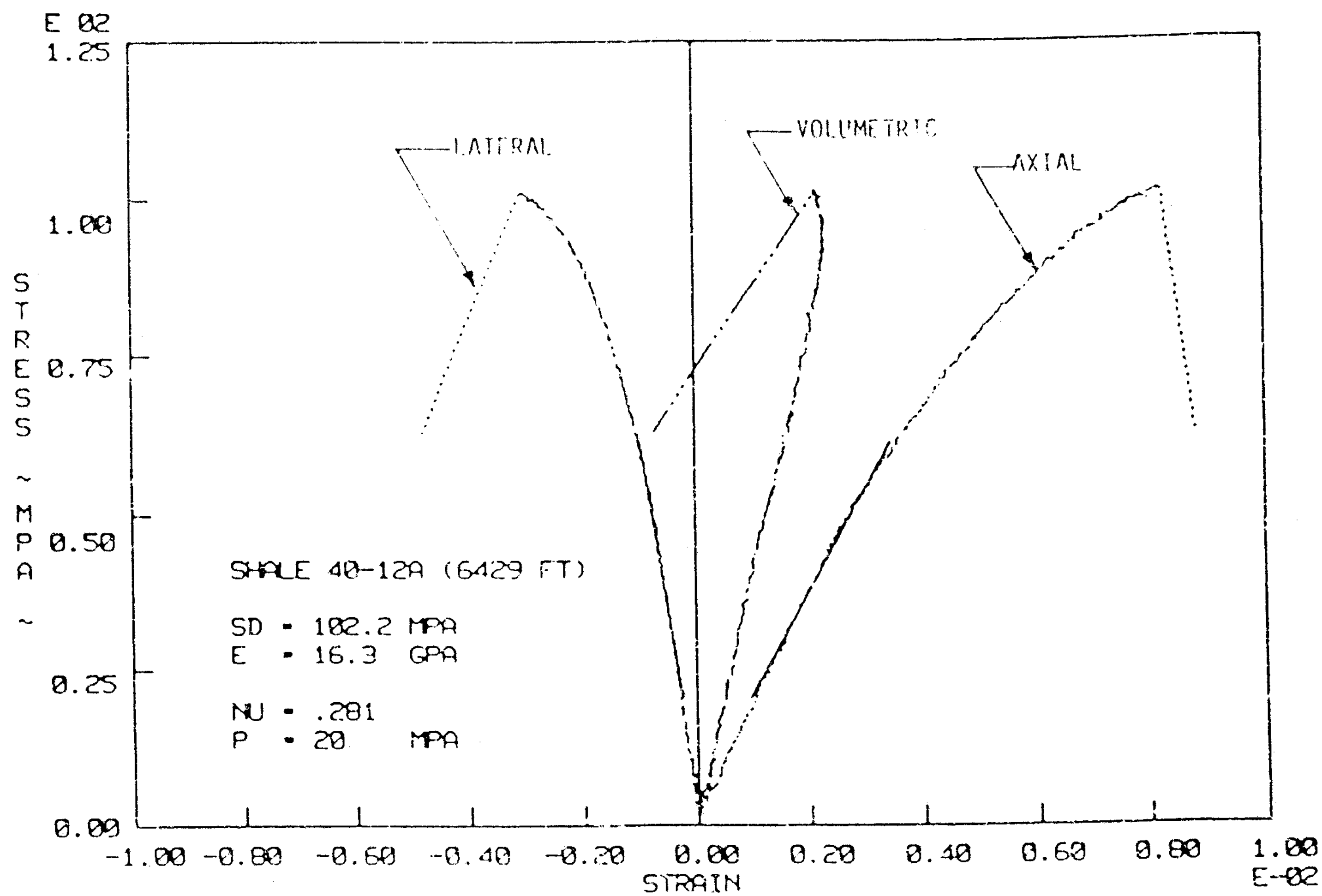
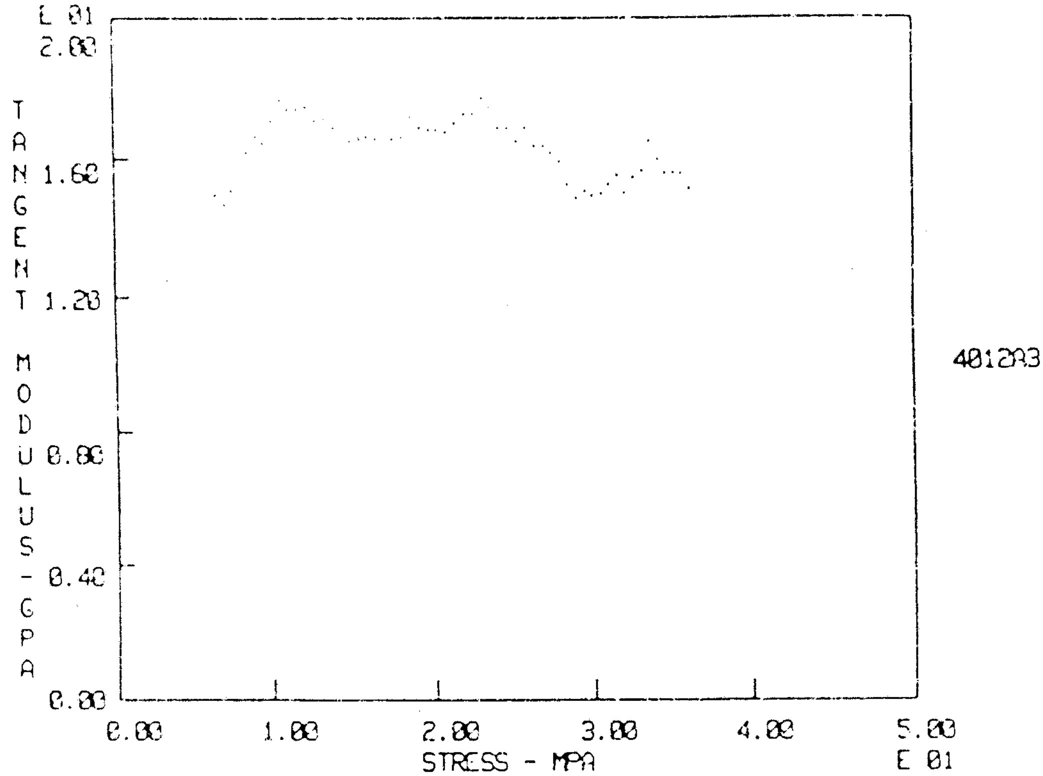


Figure 107. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Shale 40-12A. P = 20 MPa.

RSI DWG 046-82-12

RSI DWG 046-83-192



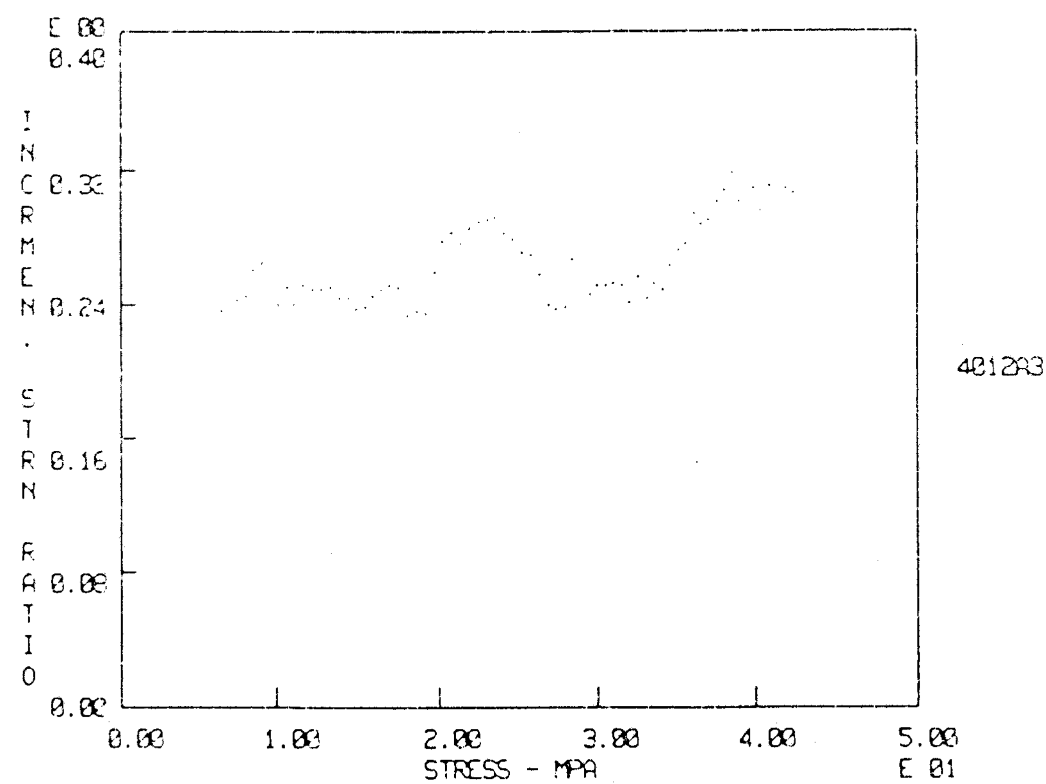


Figure 102. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Shale 40-12A (6429 Feet). P = 20 MPa.

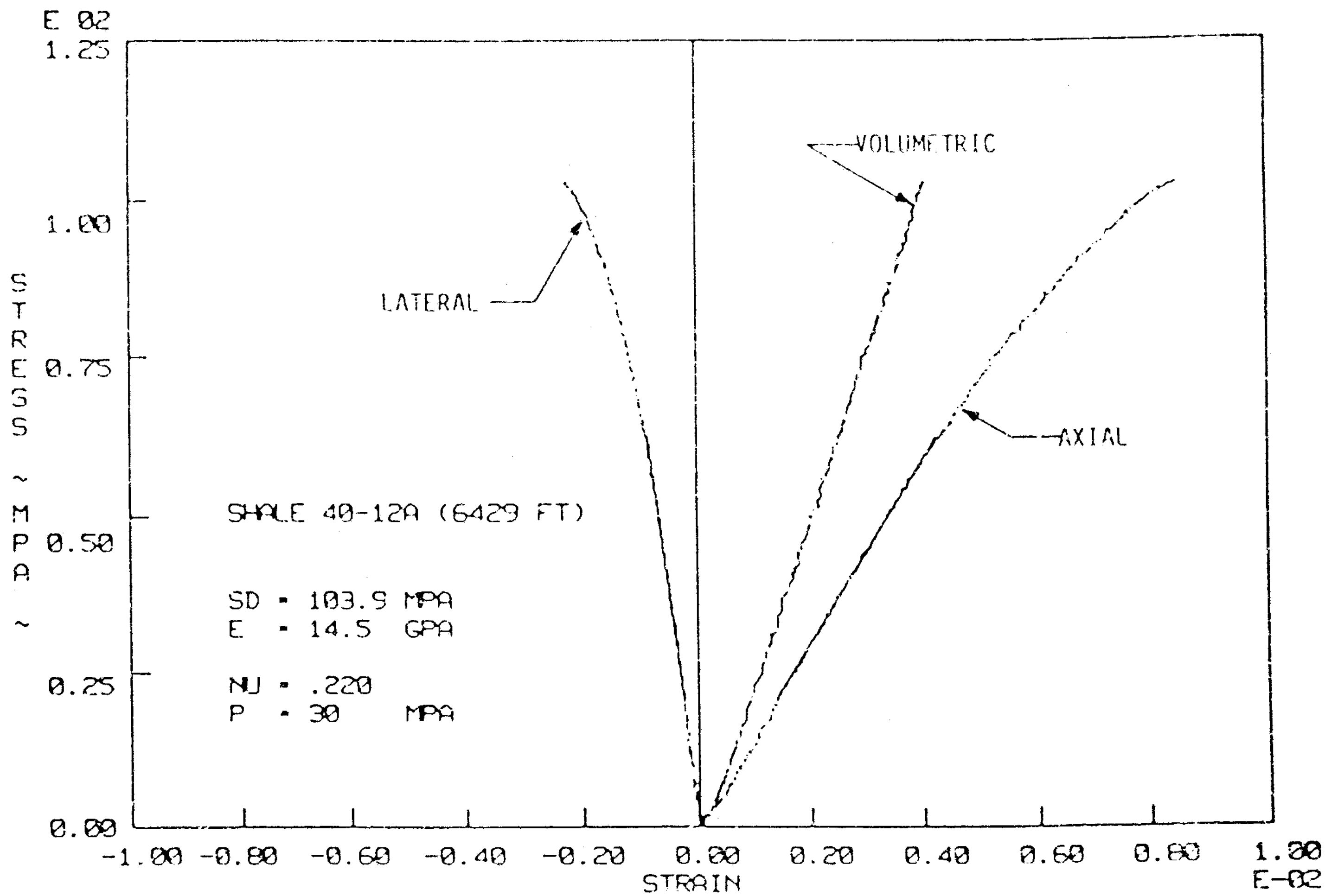
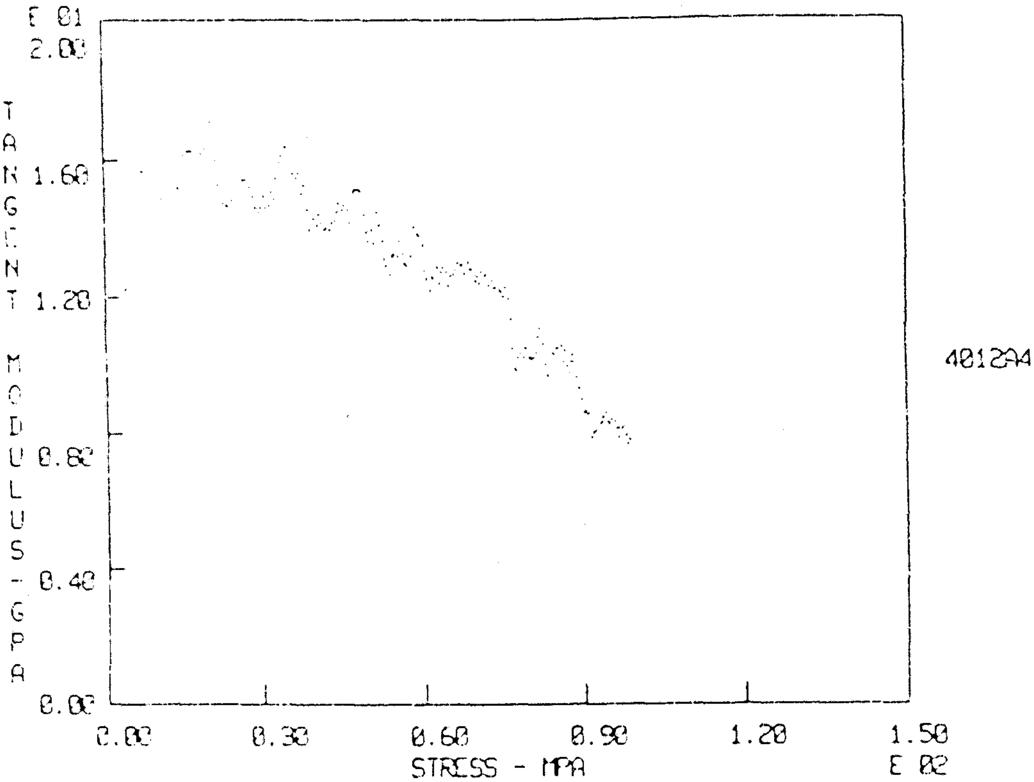


Figure 109. Axial Stress Difference Versus, Axial, Lateral, and Volumetric Strain for Triaxial Compression of Shale 40-12A. P = 30 MPa.

RSI DWG 046-82-13

RSI DWG 046-83-193



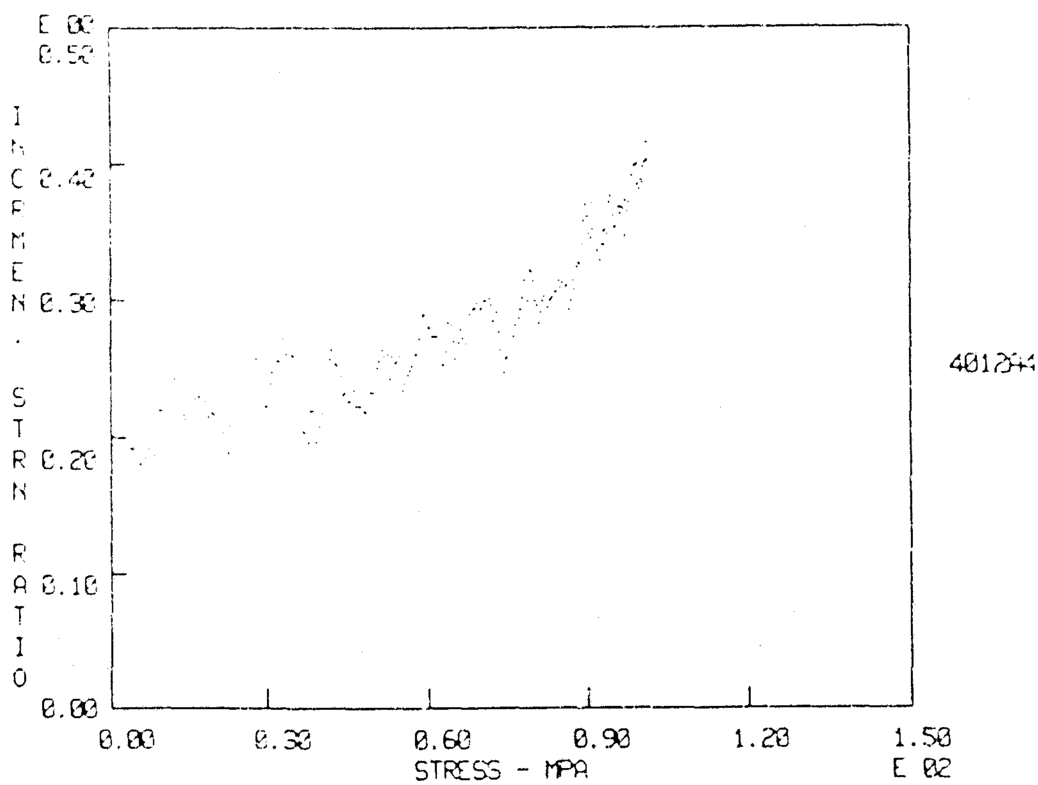


Figure 110. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Shale 40-12A (6429 Feet). P = 30 MPa.

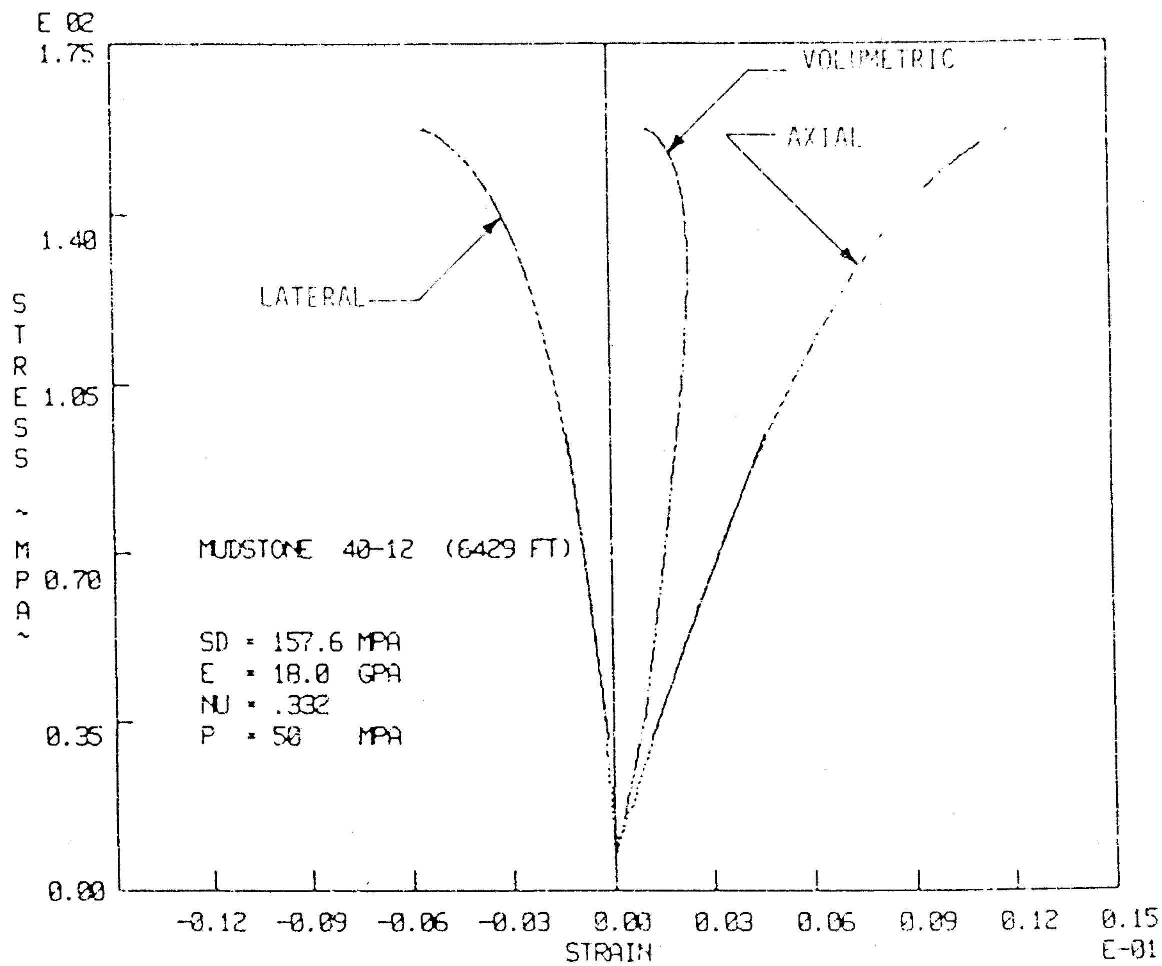
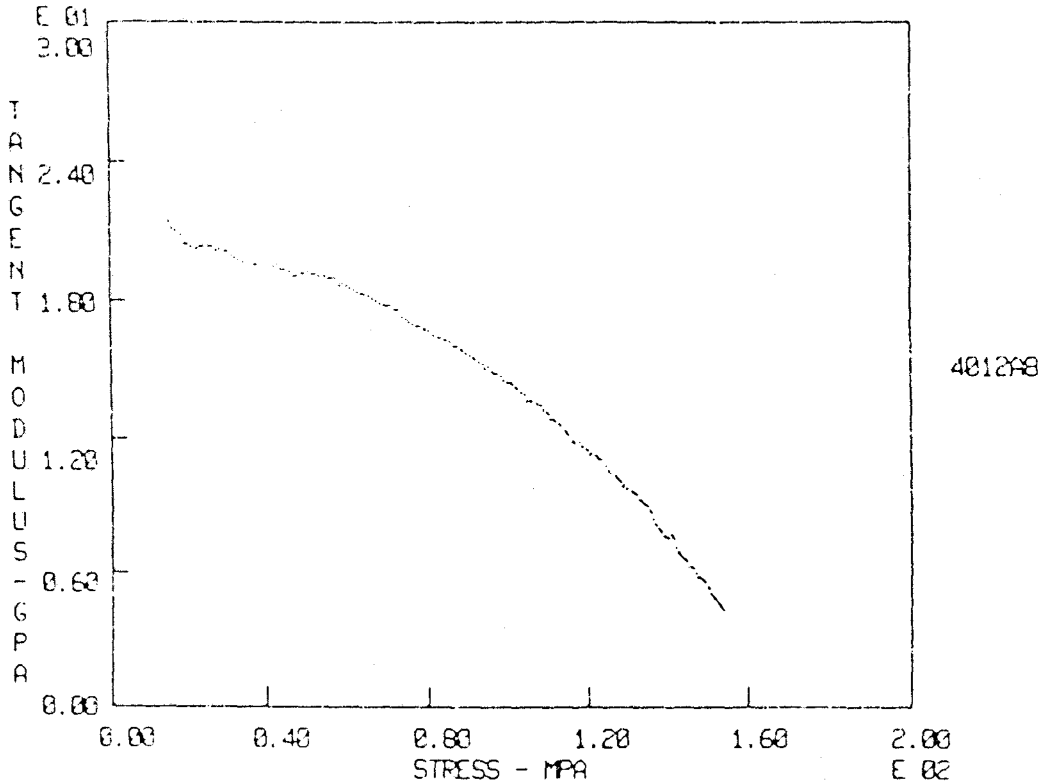


Figure 111. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Mudstone 40-12. P = 50 MPa.

RSI DWG 046-83-91

RSI DWG 046-83-194



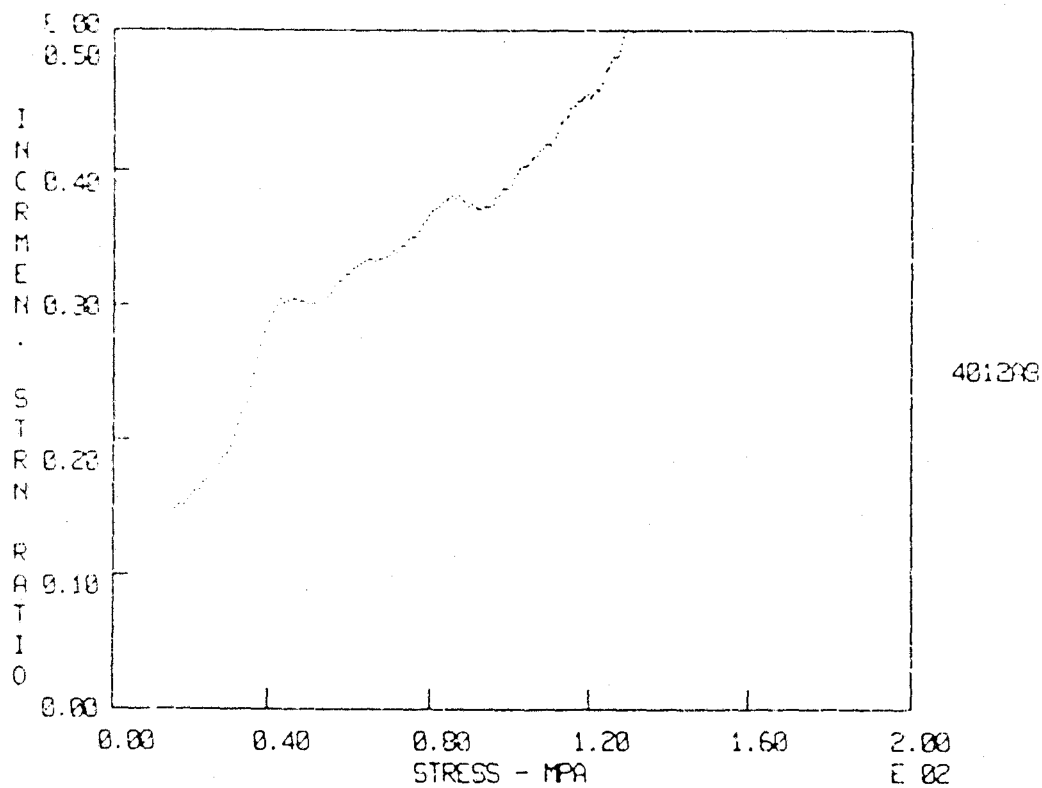


Figure 112. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Mudstone 40-12 (6429 Feet). P = 50 MPa.

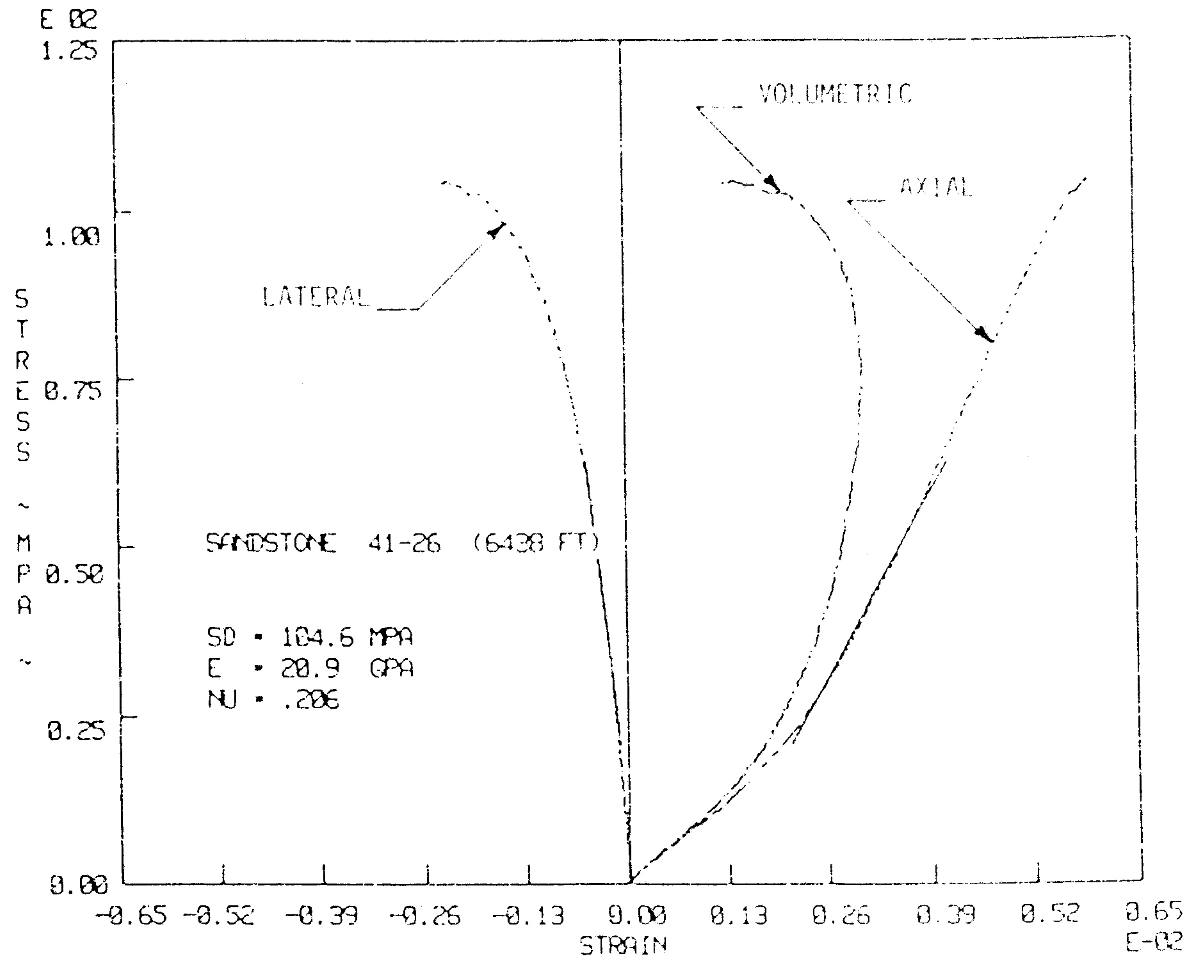


Figure 113. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Unconfined Compression of Sandstone 41-26.

RSI DWG 046-83-62

RSI DWG 046-83-155

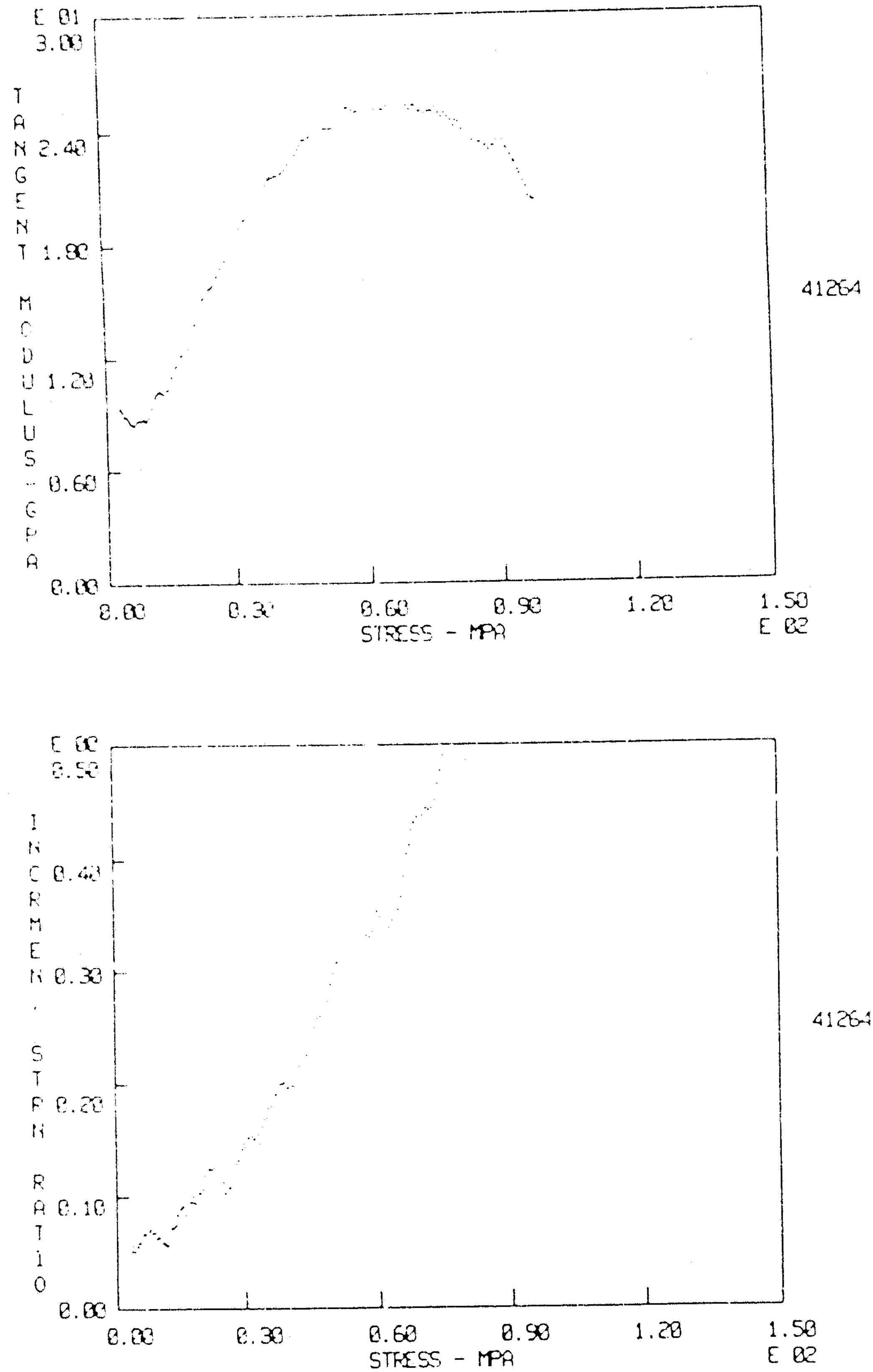


Figure 114. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 41-26 (6438 Feet). P = 0 MPa.

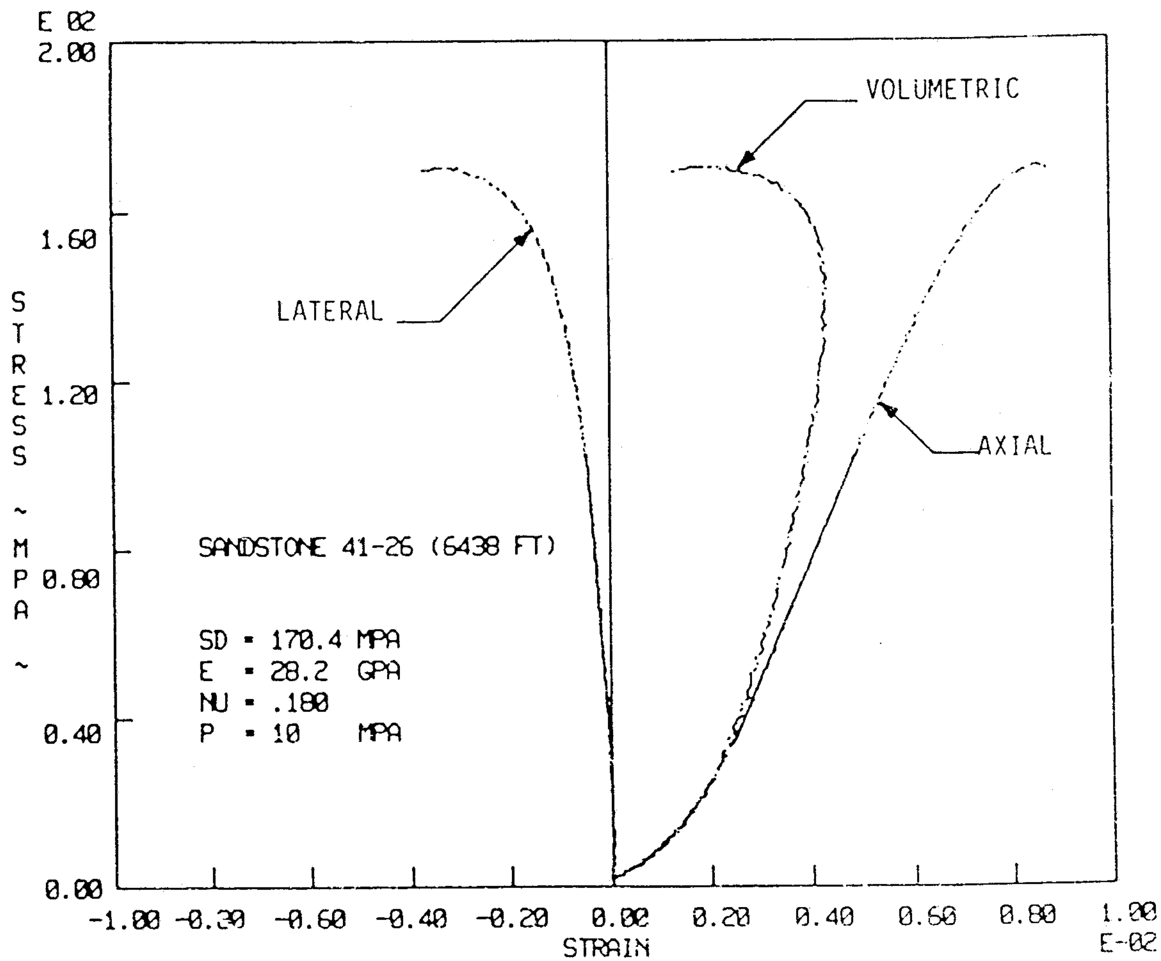
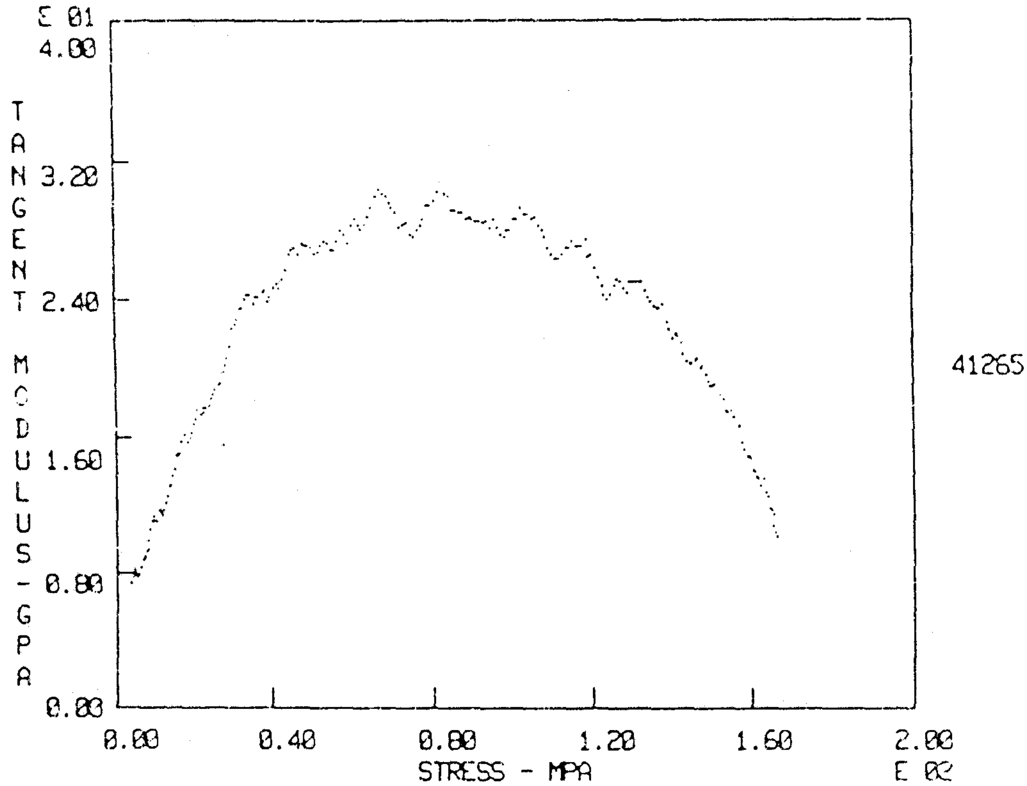


Figure 115. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 41-26. P = 10 MPa.

RSI DWG 046-83-10

RSI DWG 046-83-196



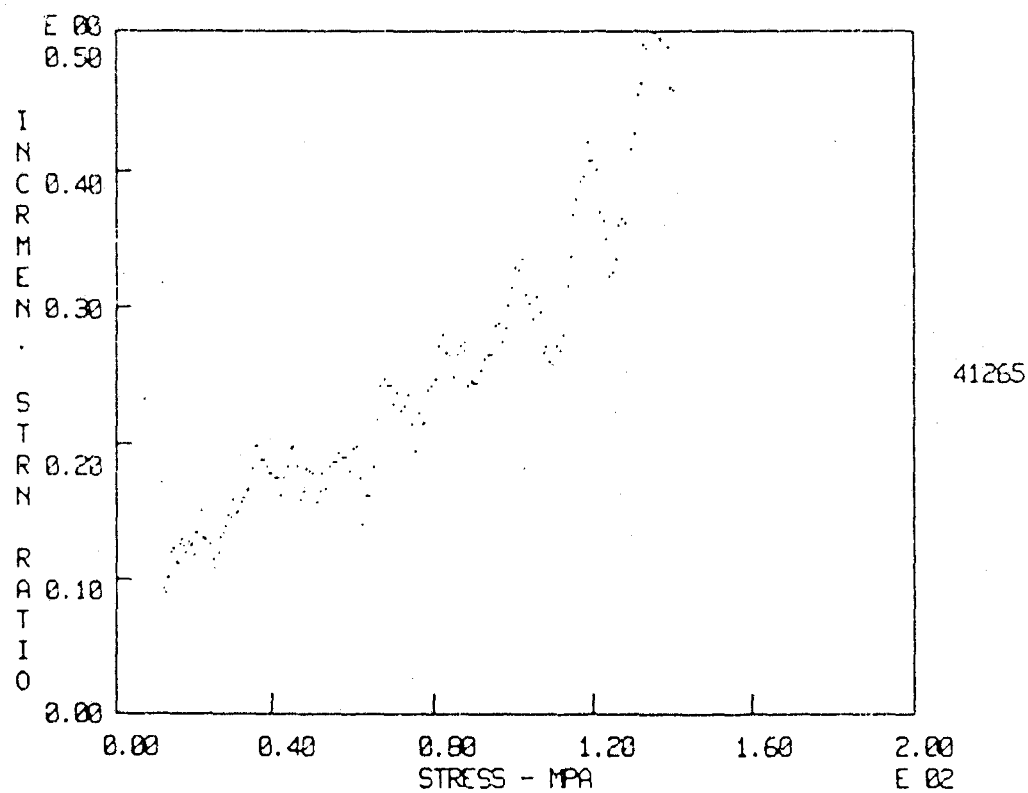


Figure 116. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 41-26 (6438 Feet). P = 10 MPa.

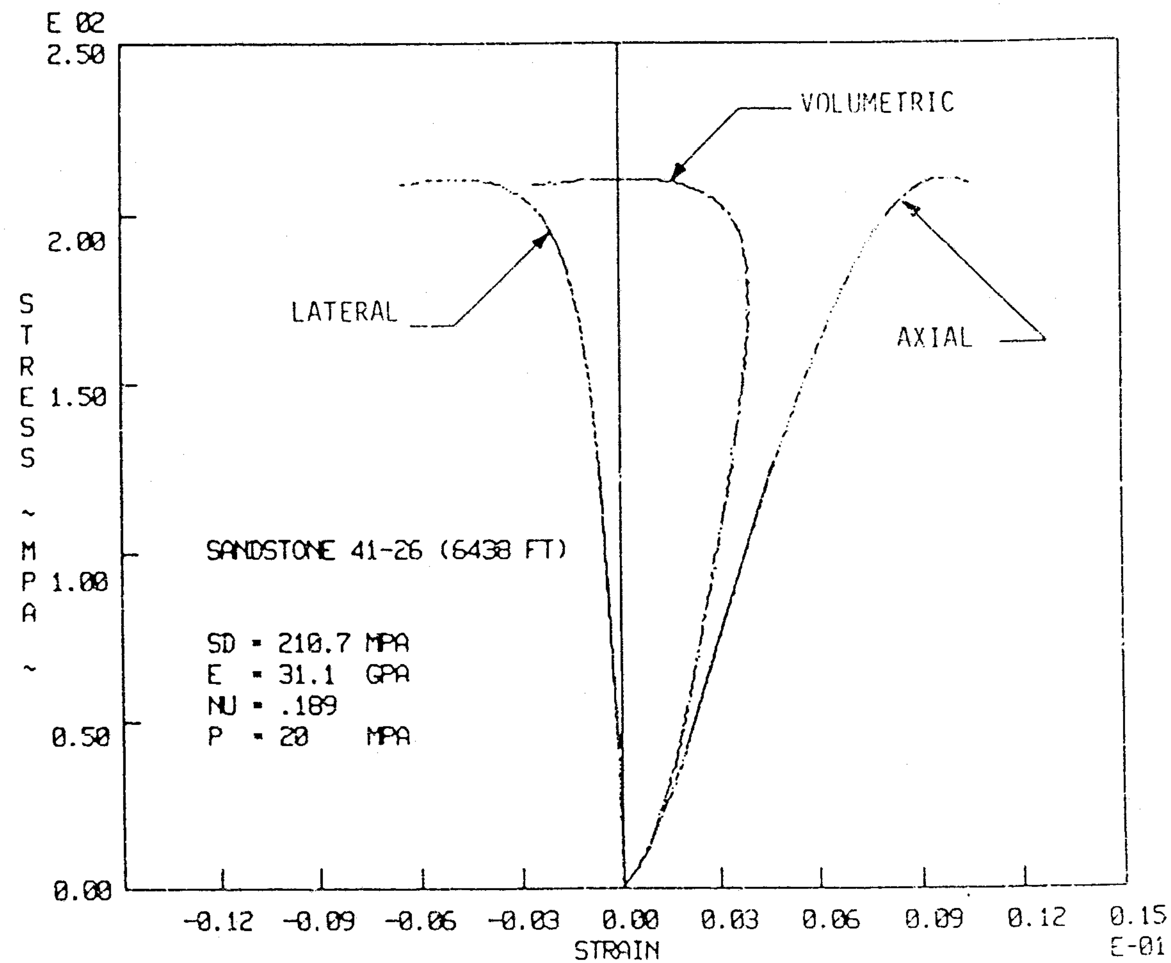
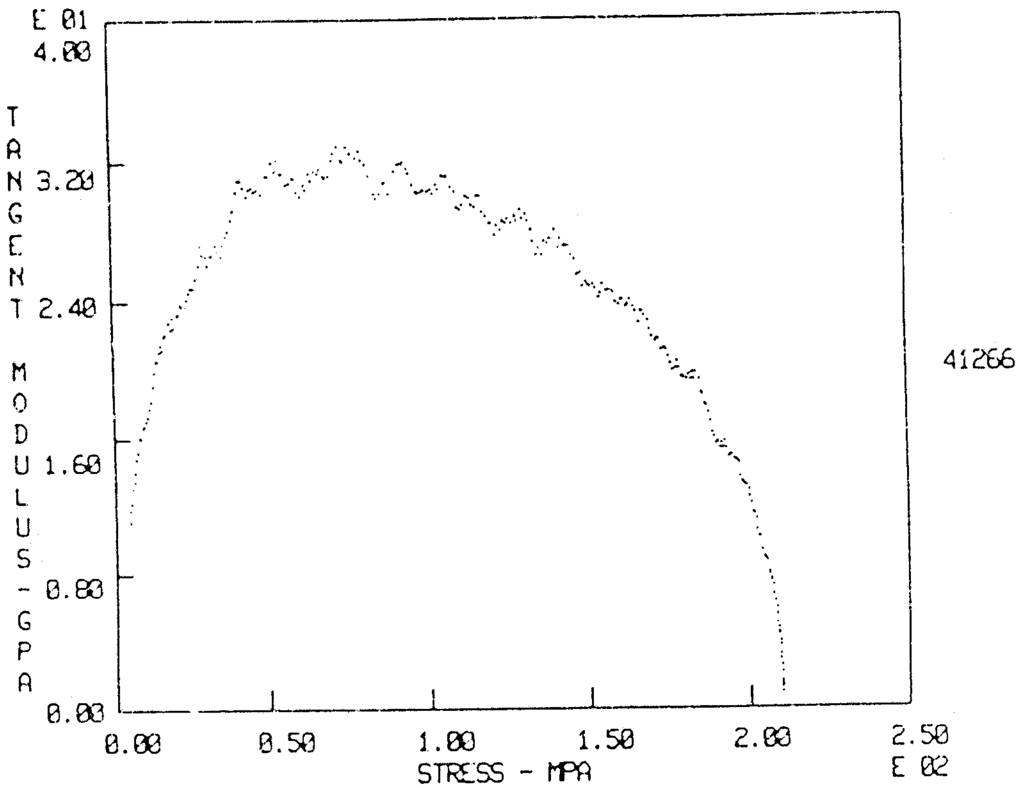


Figure 117. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 41-26. P = 20 MPa.

RSI DWG 046-83-11

RSI DWG 046-83-197



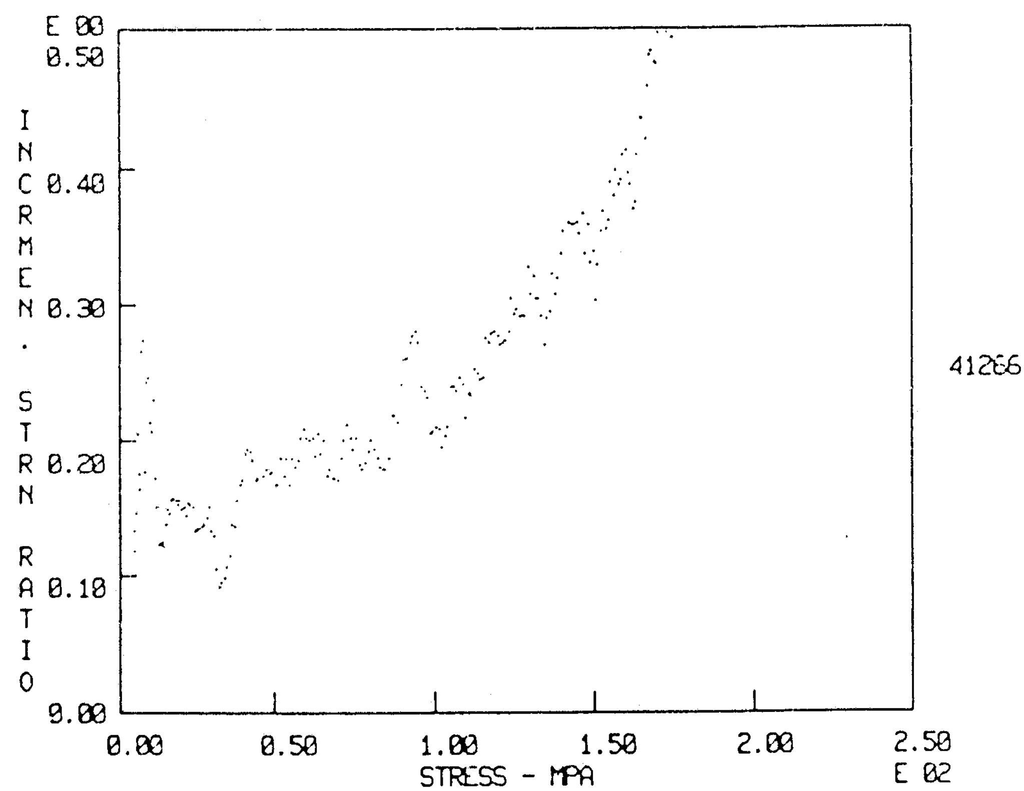


Figure 118. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 41-26 (6438 Feet). P = 20 MPa.

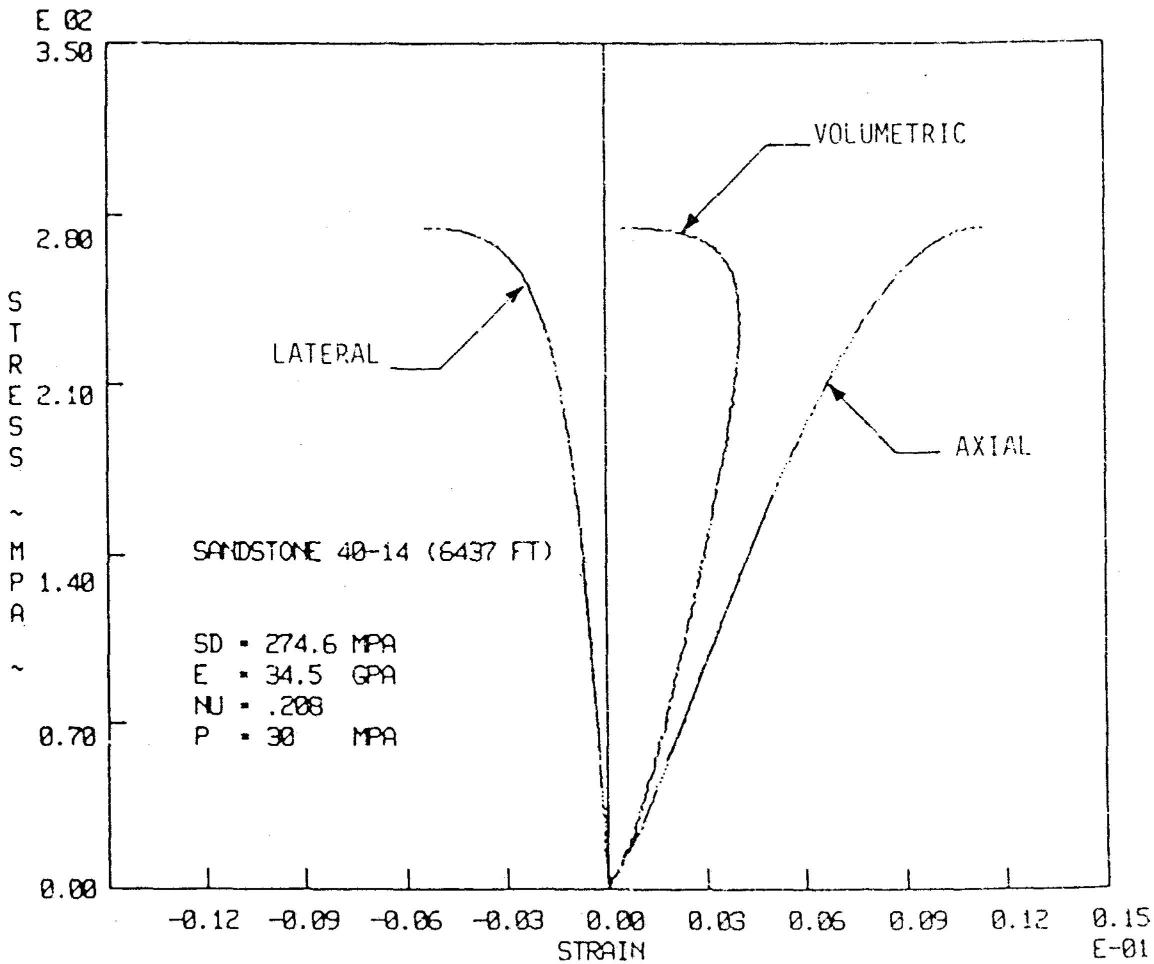
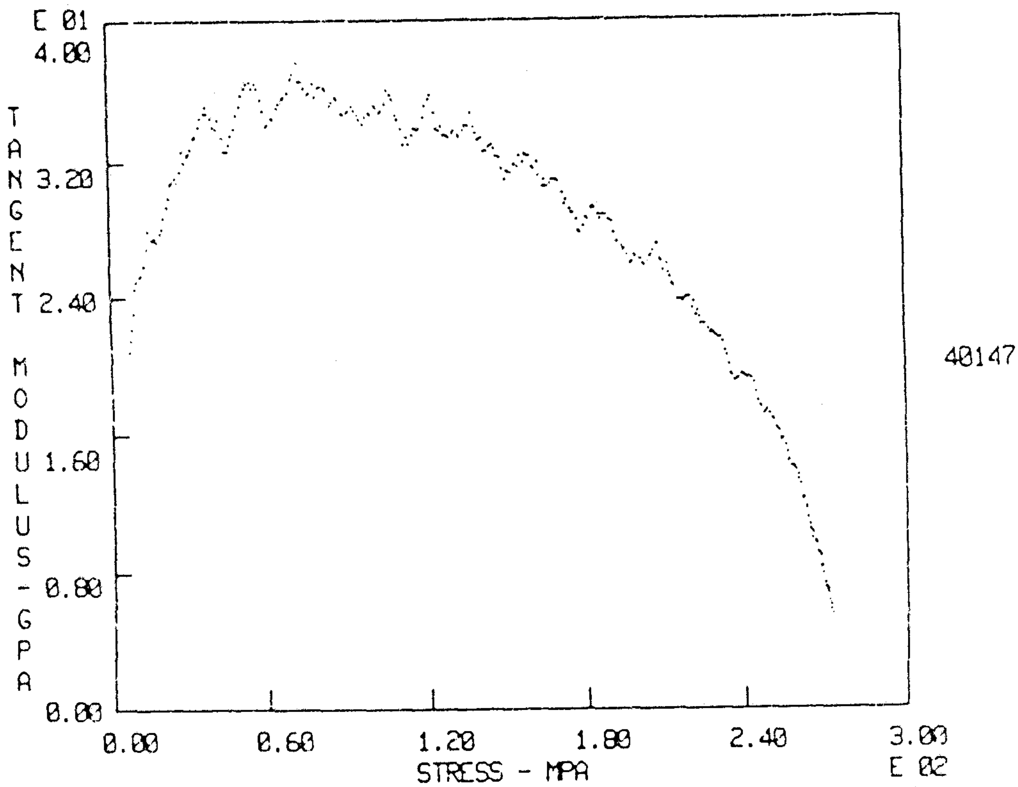


Figure 119. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 40-14. P = 30 MPa.

RSI DWG 046-83-198



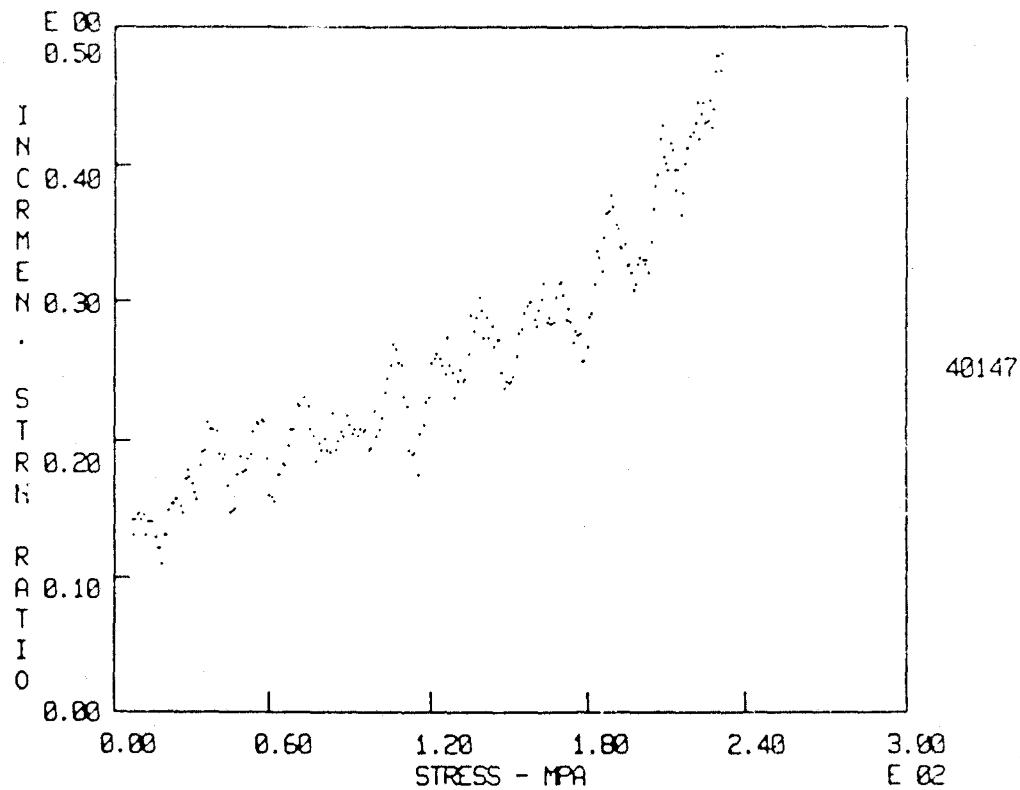


Figure 120. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 41-14 (6437 Feet). P = 30 MPa.

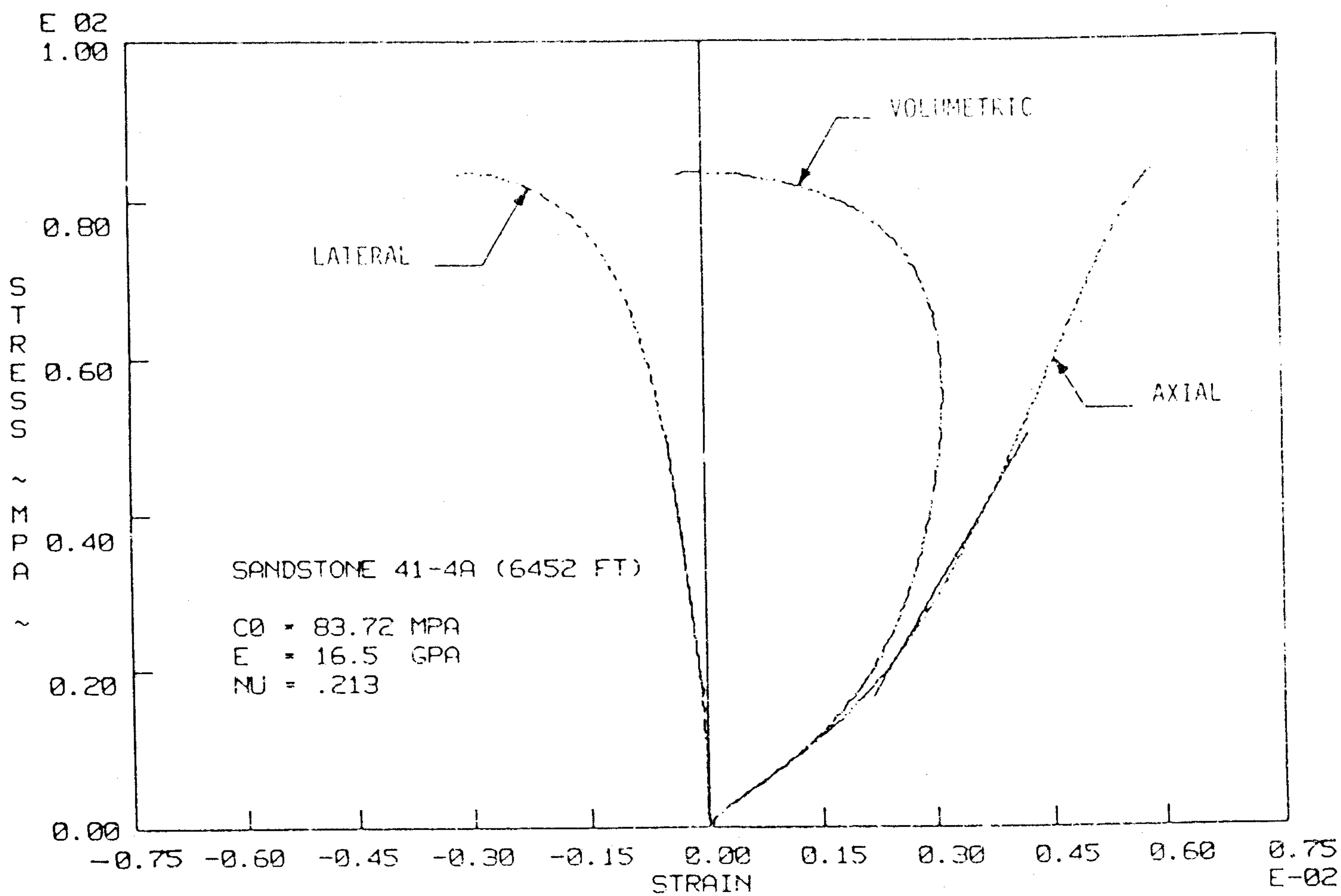


Figure 121. Axial Stress Difference Versus Axial, Lateral and Volumetric Strain for Unconfined Compression of Sandstone 41-4A.

RSI DWG 046-83-199

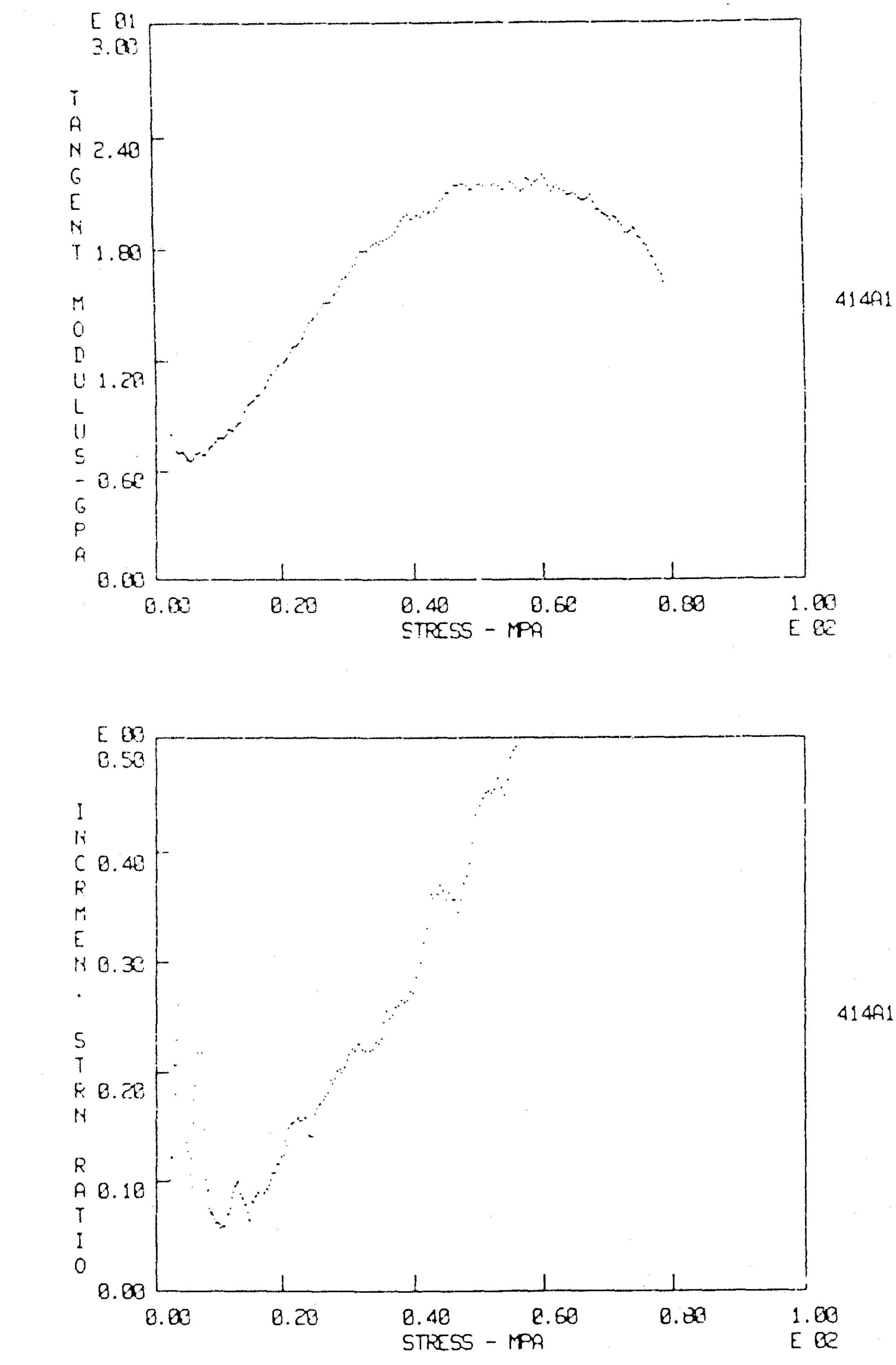


Figure 122. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 41-4A (6452 Feet). P = 0 MPa.

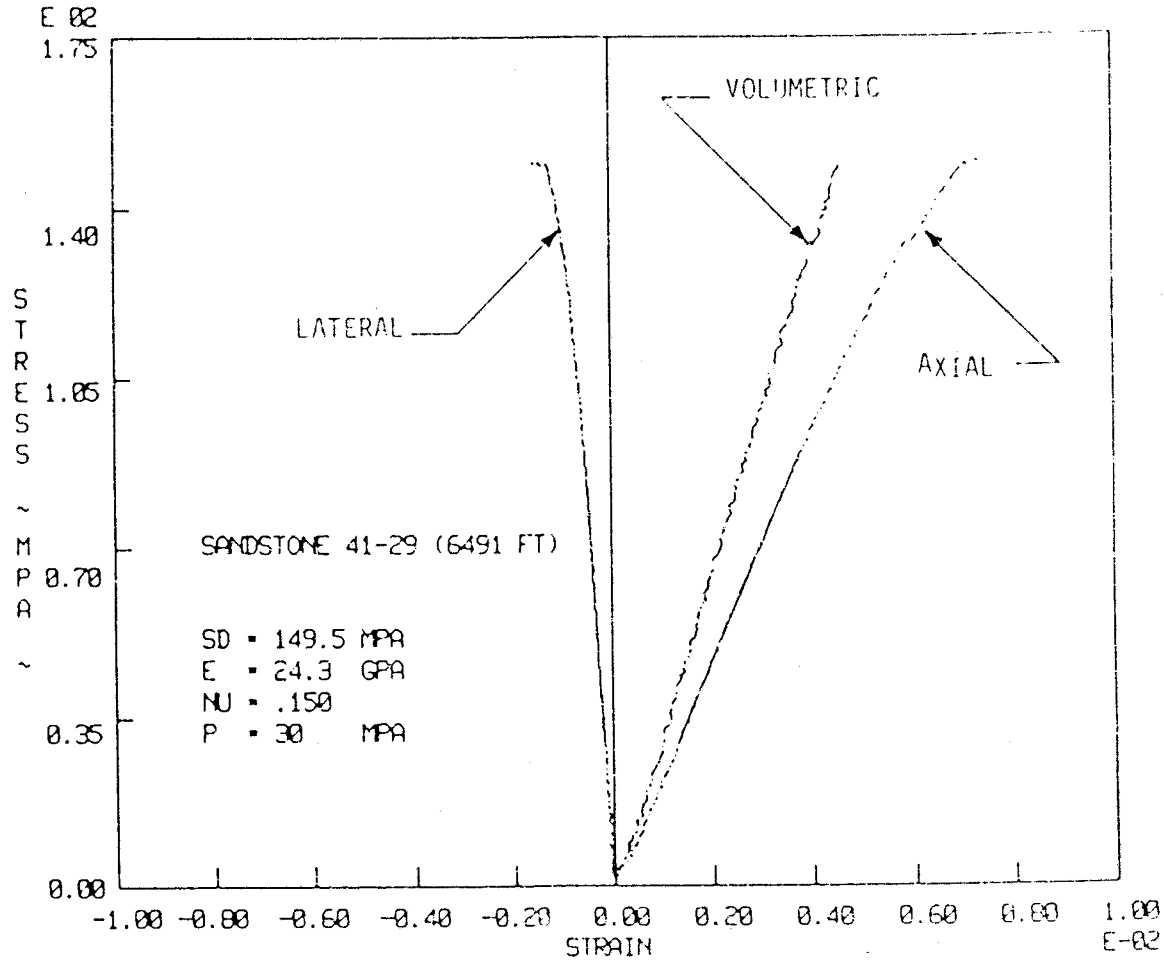
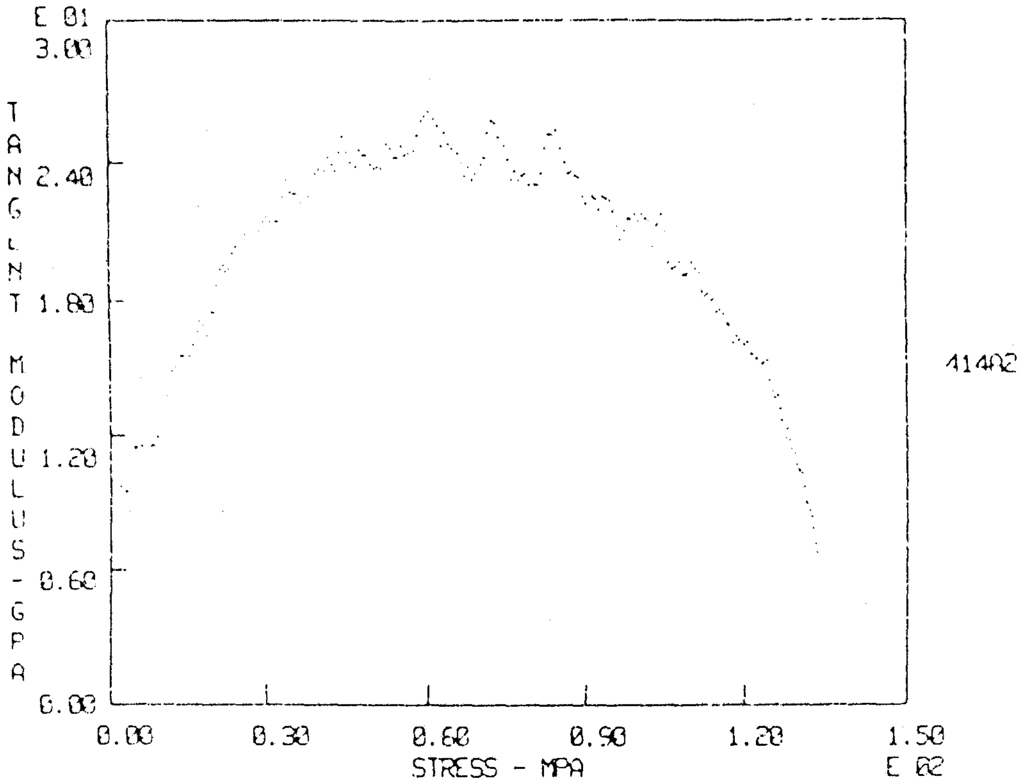


Figure 123. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 41-29. P = 30 MPa.

RSI DWG 046-83-200



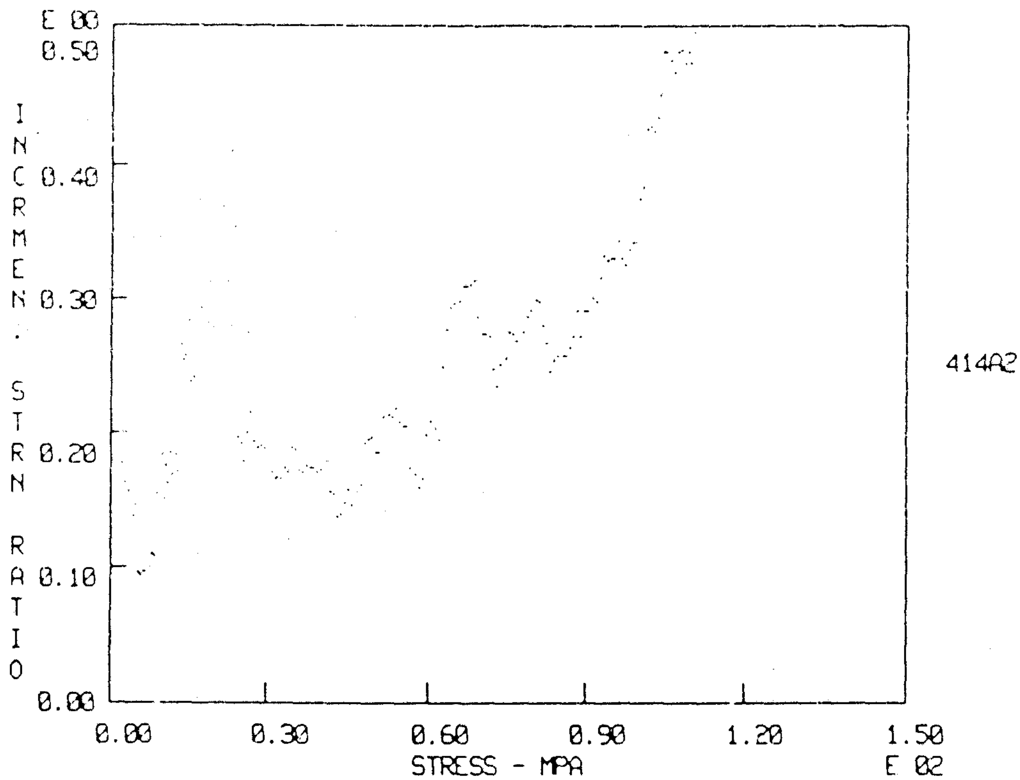


Figure 124. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 41-4A (6452 Feet). P = 10 MPa.

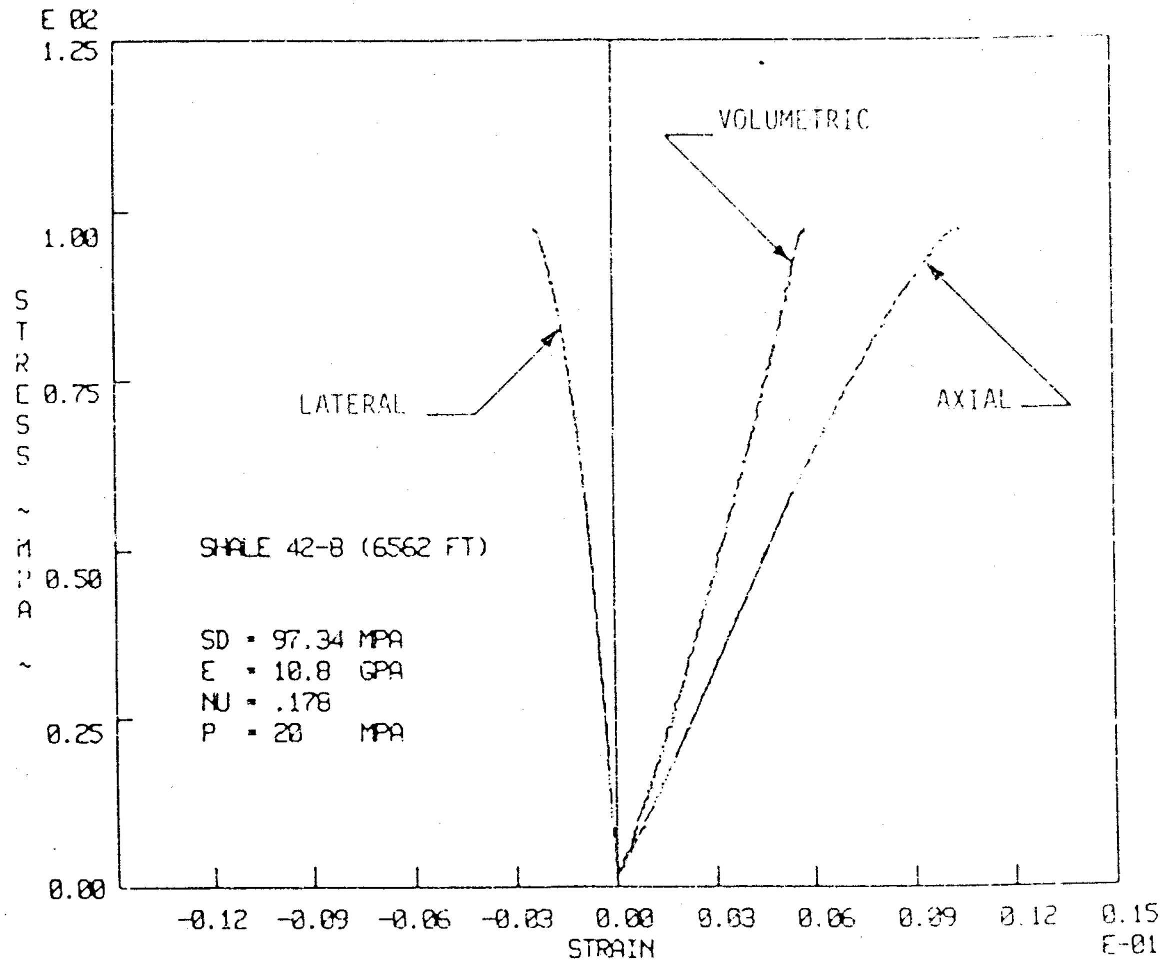
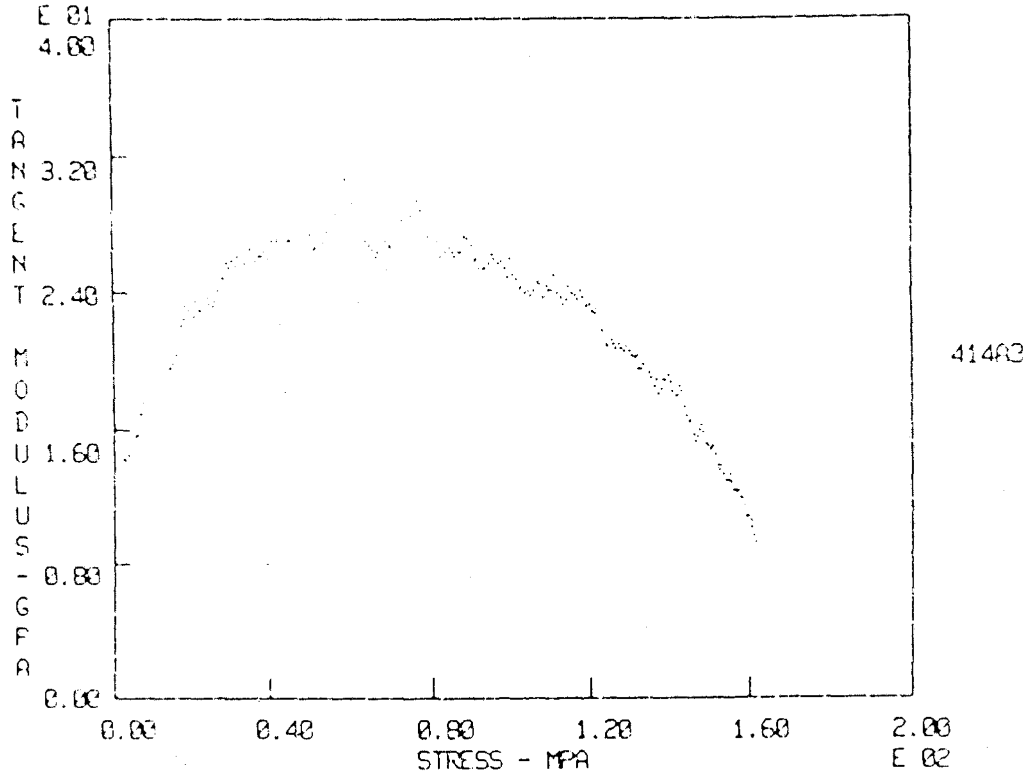


Figure 125. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Shale 42-8. P = 20 MPa.

RSI DWG 046-83-15

RSI DWG 046-83-201



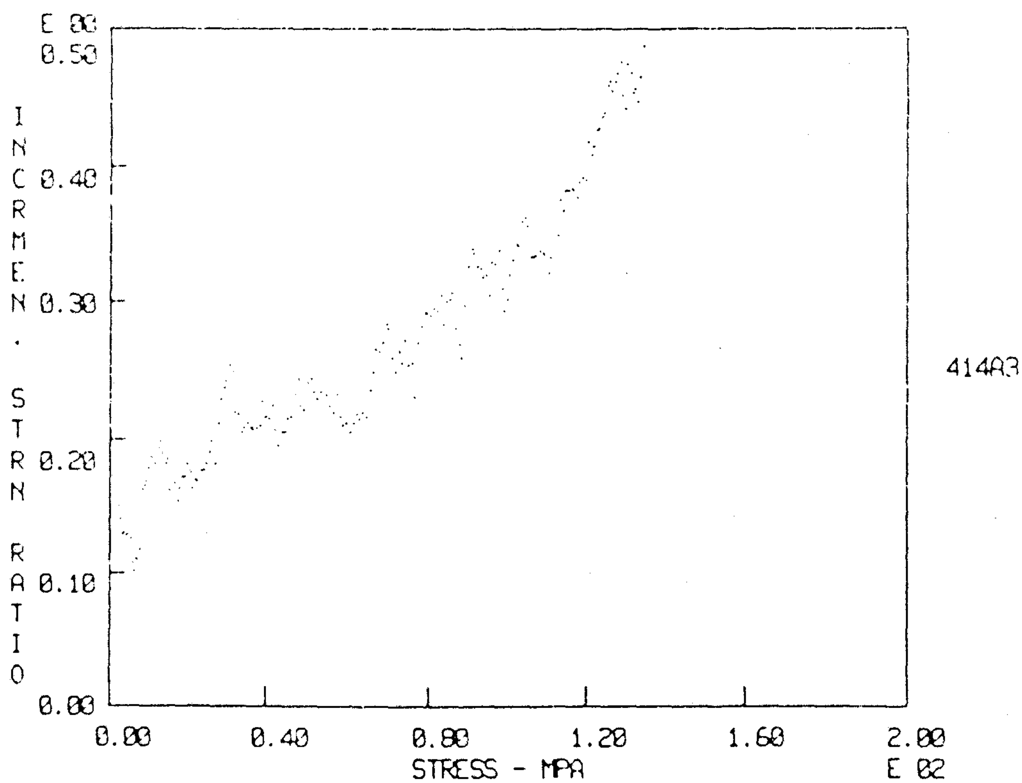


Figure 126. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 41-4A (6452 Feet). P = 20 MPa.

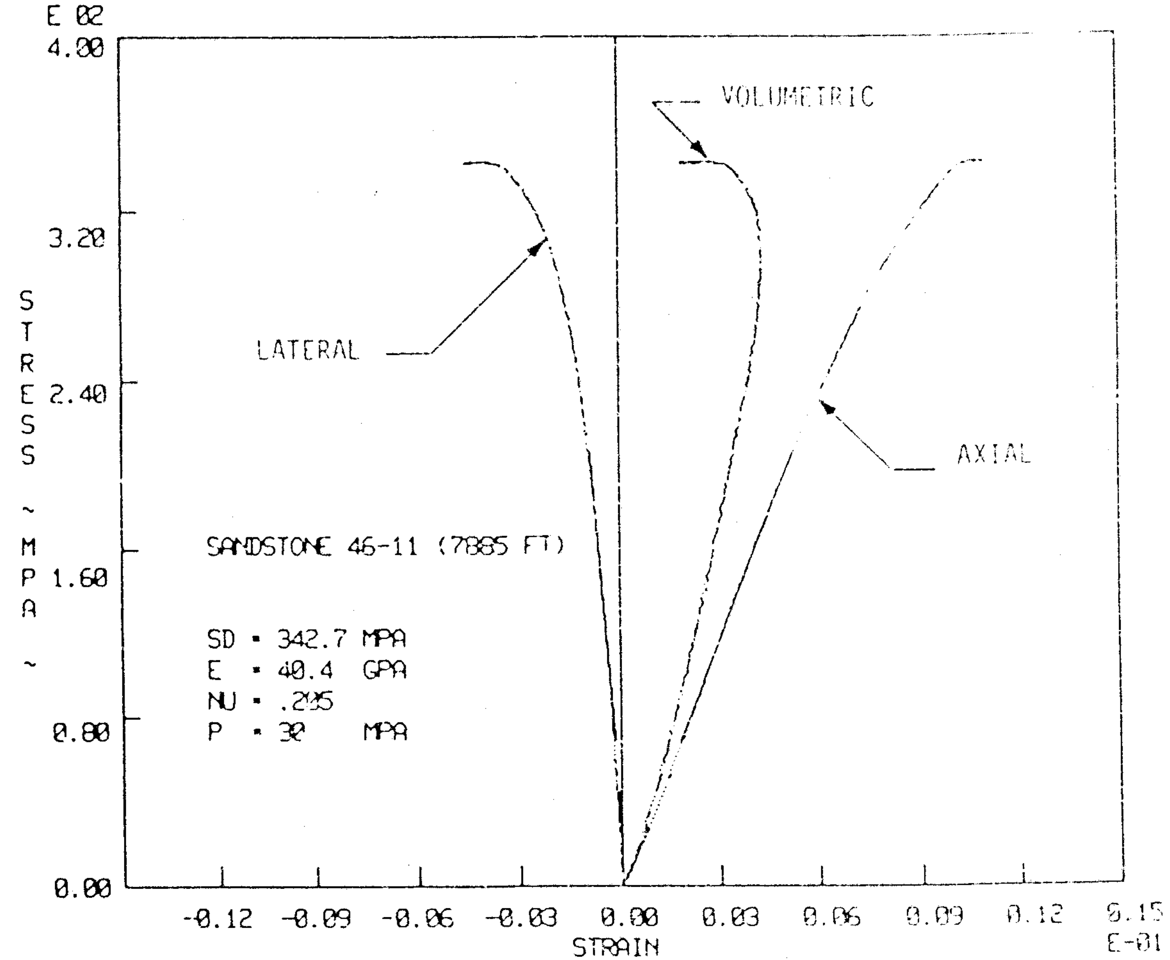
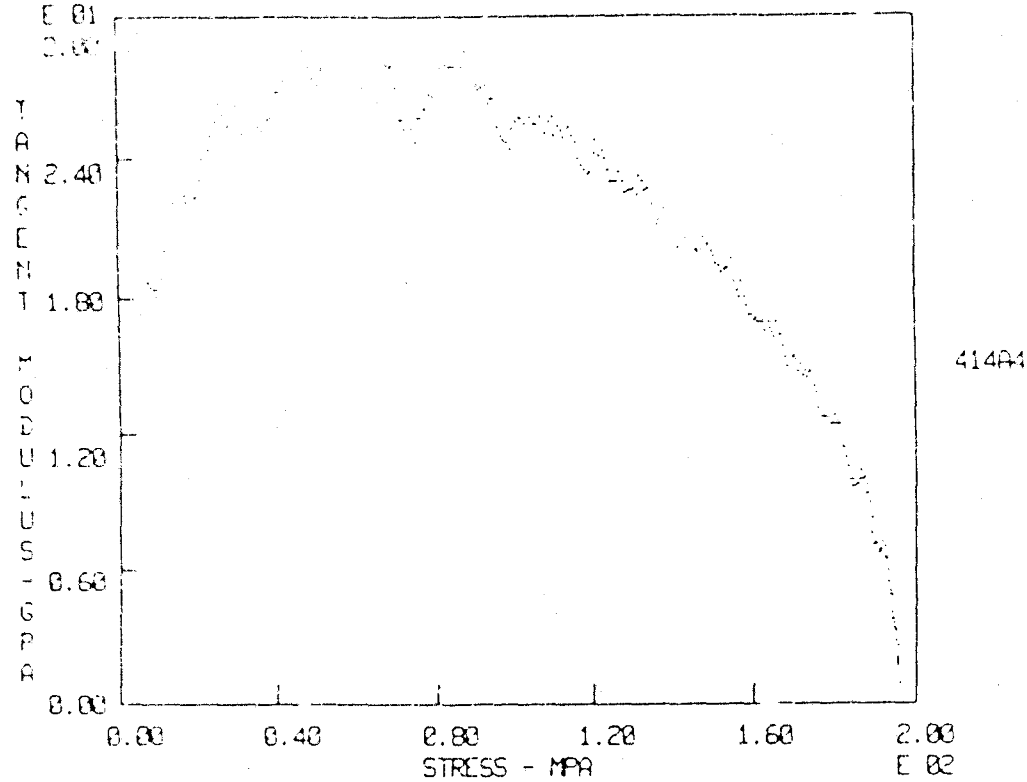


Figure 127. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 46-11. P = 30 MPa.

RSI DWG 046-86-202



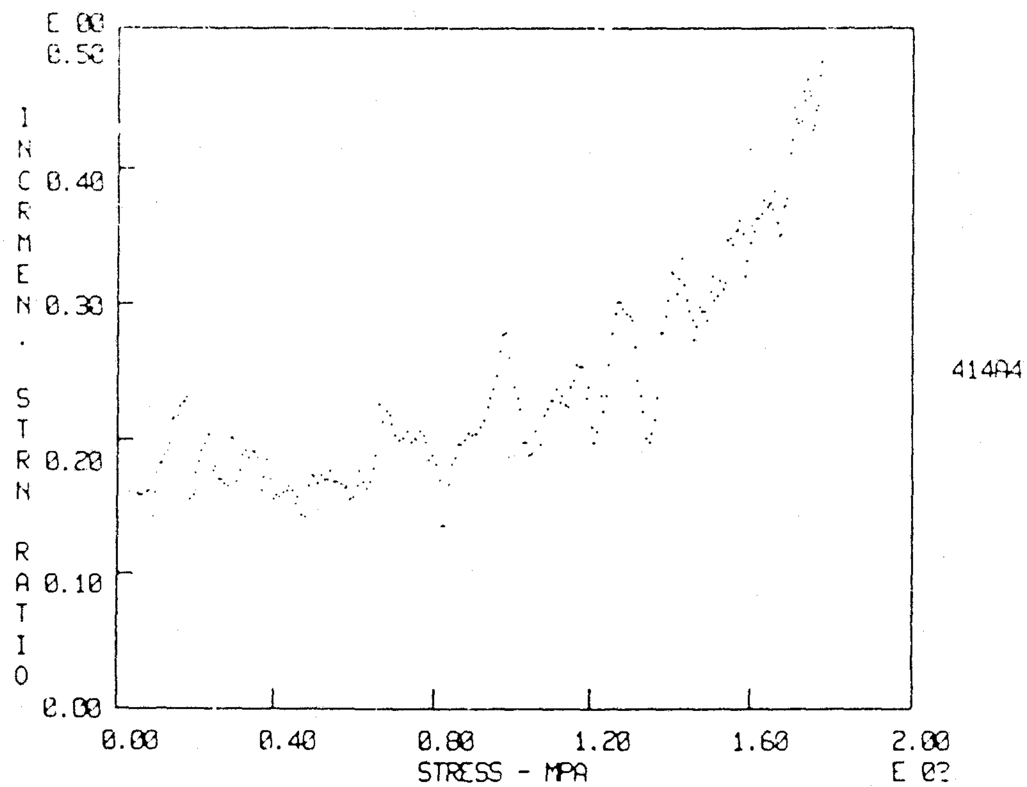


Figure 128. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 41-4A (6452 Feet). P = 30 MPa.

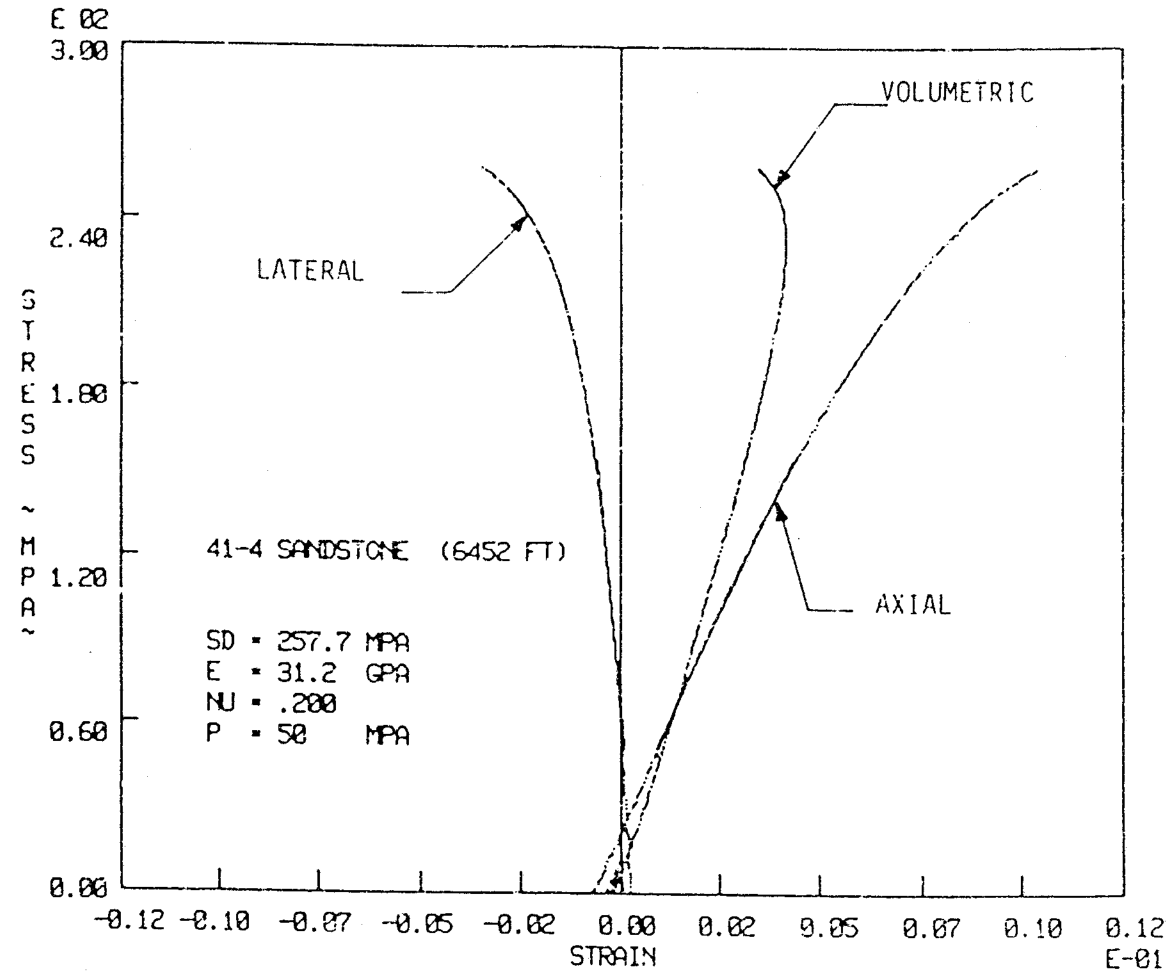


Figure 129. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 41-4. P = 50 MPa.

RSI DWG 046-83-110

RSI DWG 046-83-203

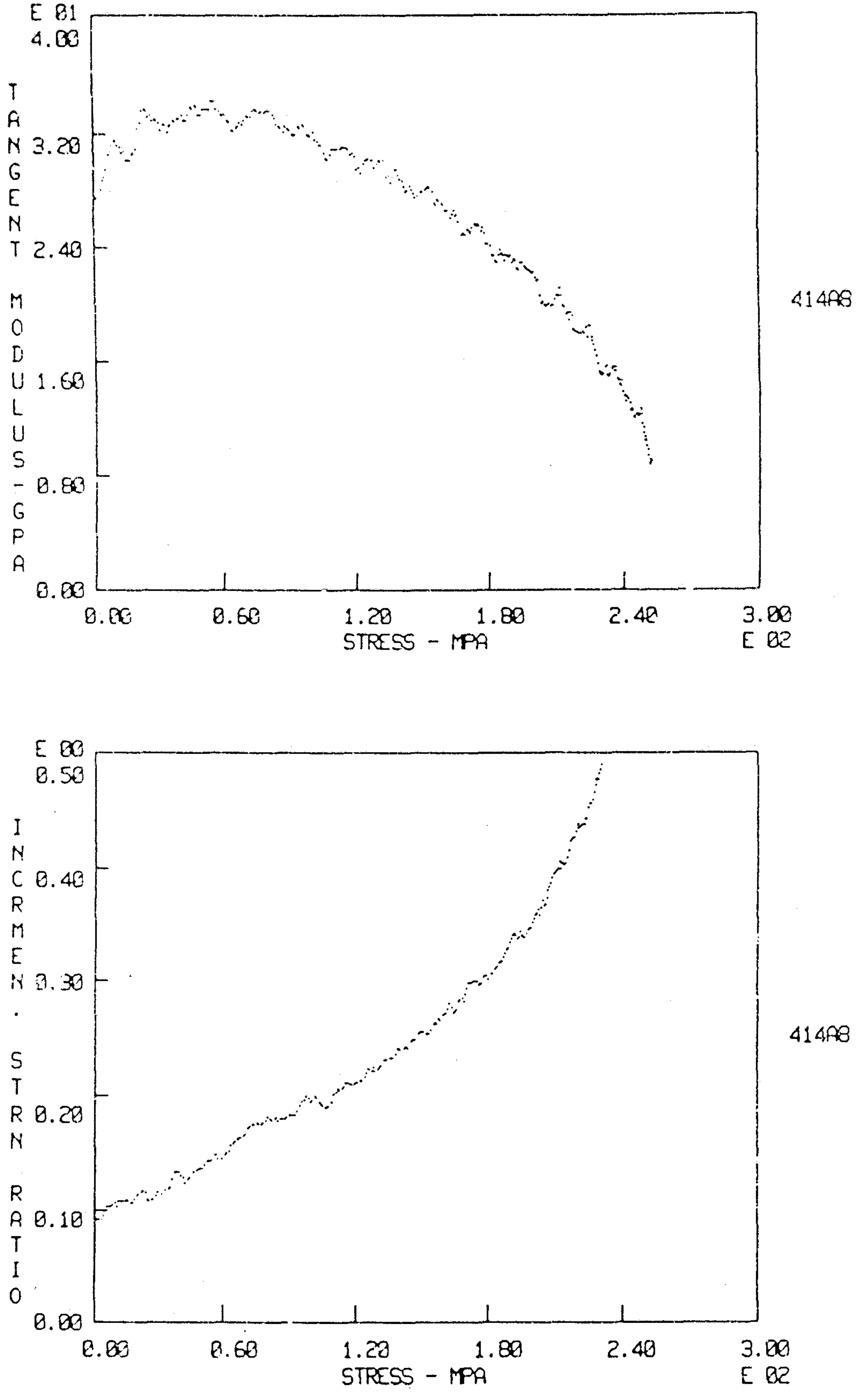


Figure 130. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 41-4 (6452 Feet). P = 50 MPa.

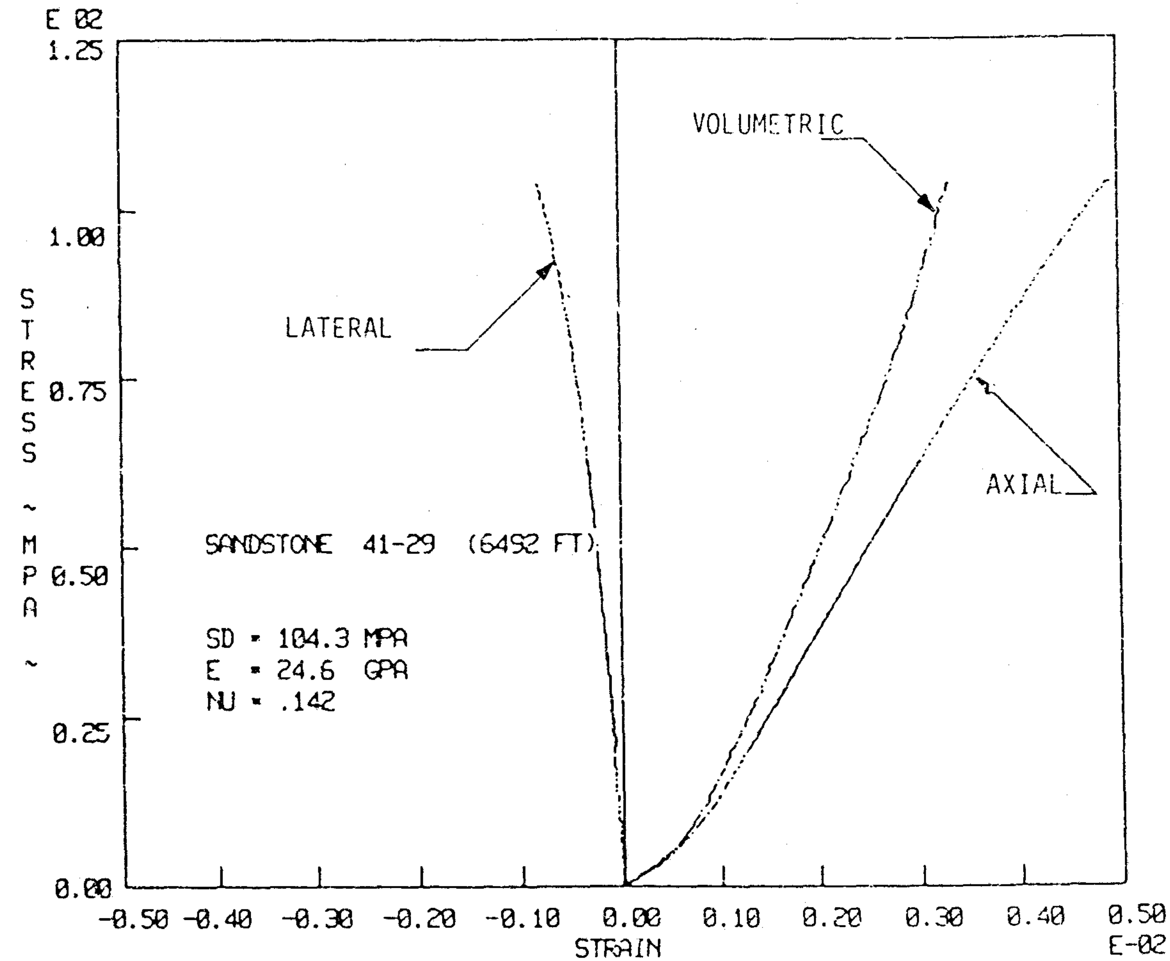


Figure 131. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Unconfined Compression of Sandstone 41-29.

RSI DWG 046-83-61

RSI DWG 046-83-204

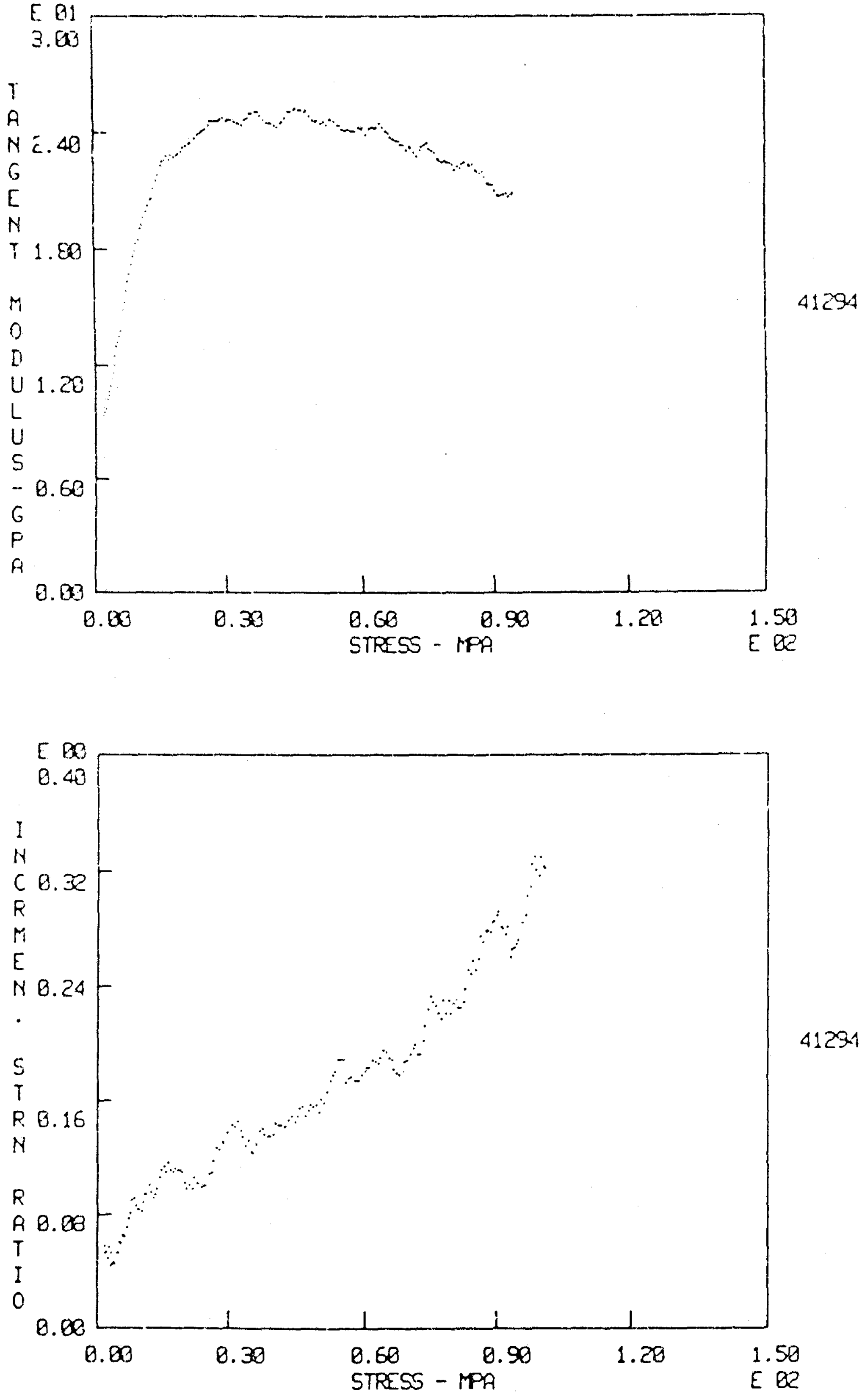


Figure 132. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 41-29 (6492 Feet). P = 0 MPa.

RSI DWG 046-83-12

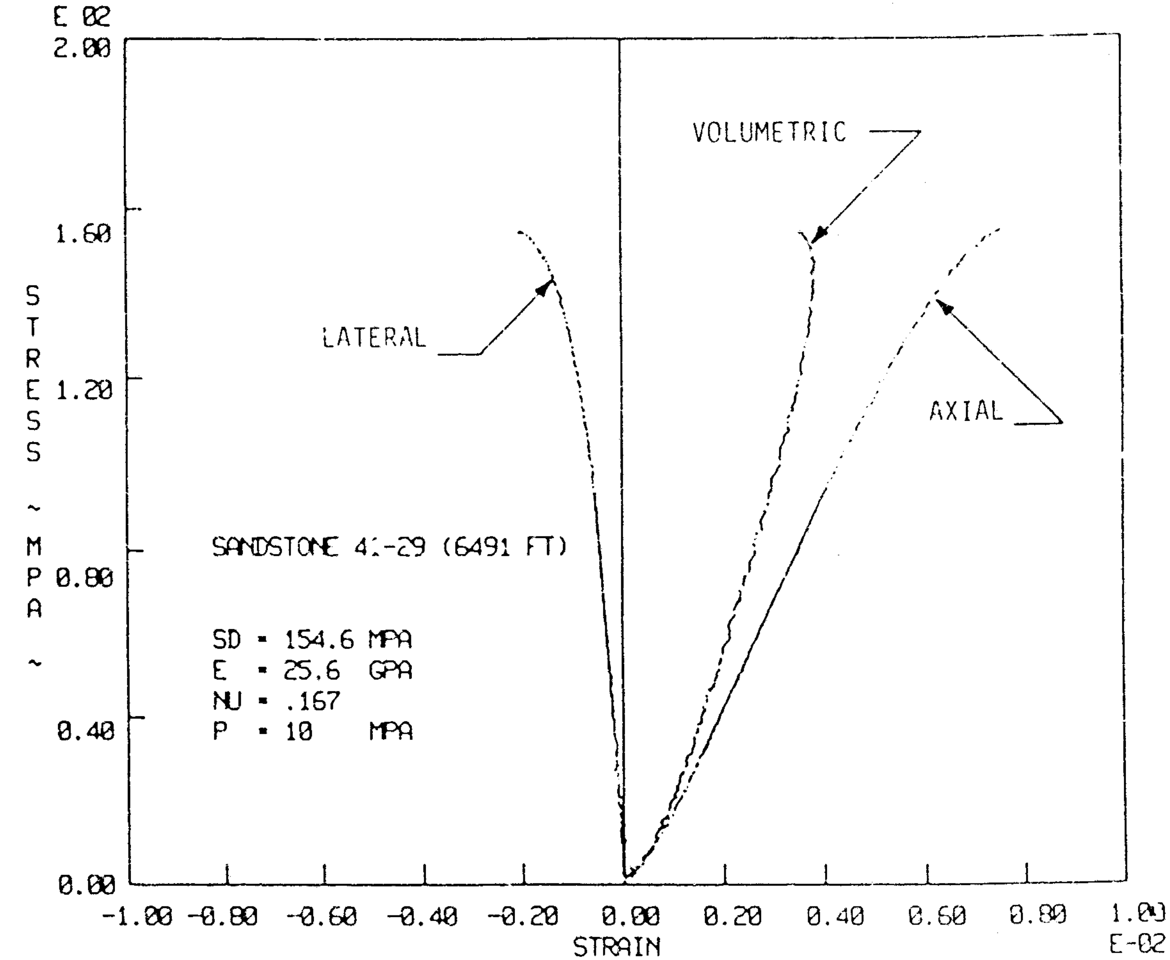


Figure 133. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 41-29. P = 10 MPa.

RSI DWG 046-83-205

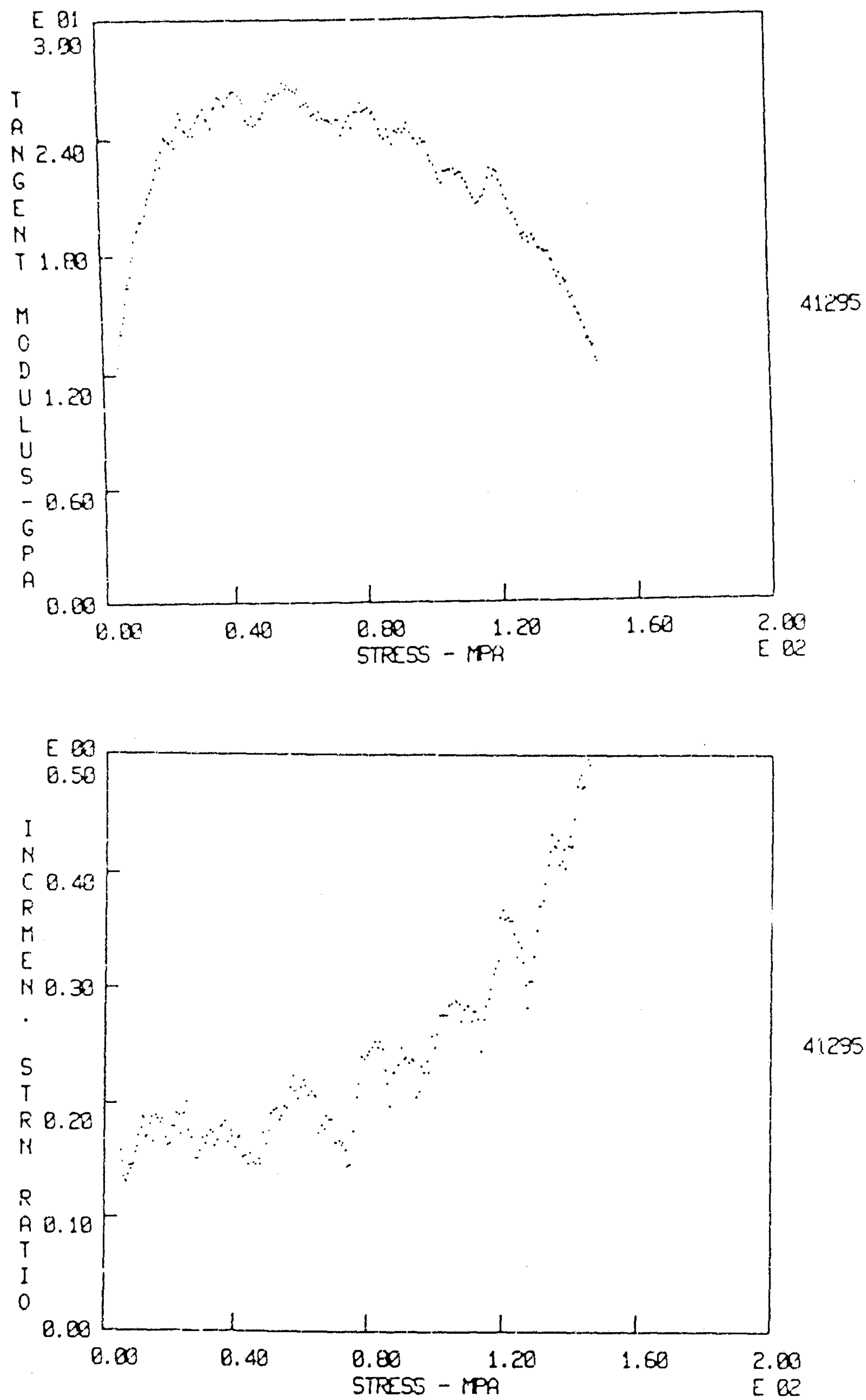


Figure 134. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 41-29 (6491 Feet). P = 10 MPa.

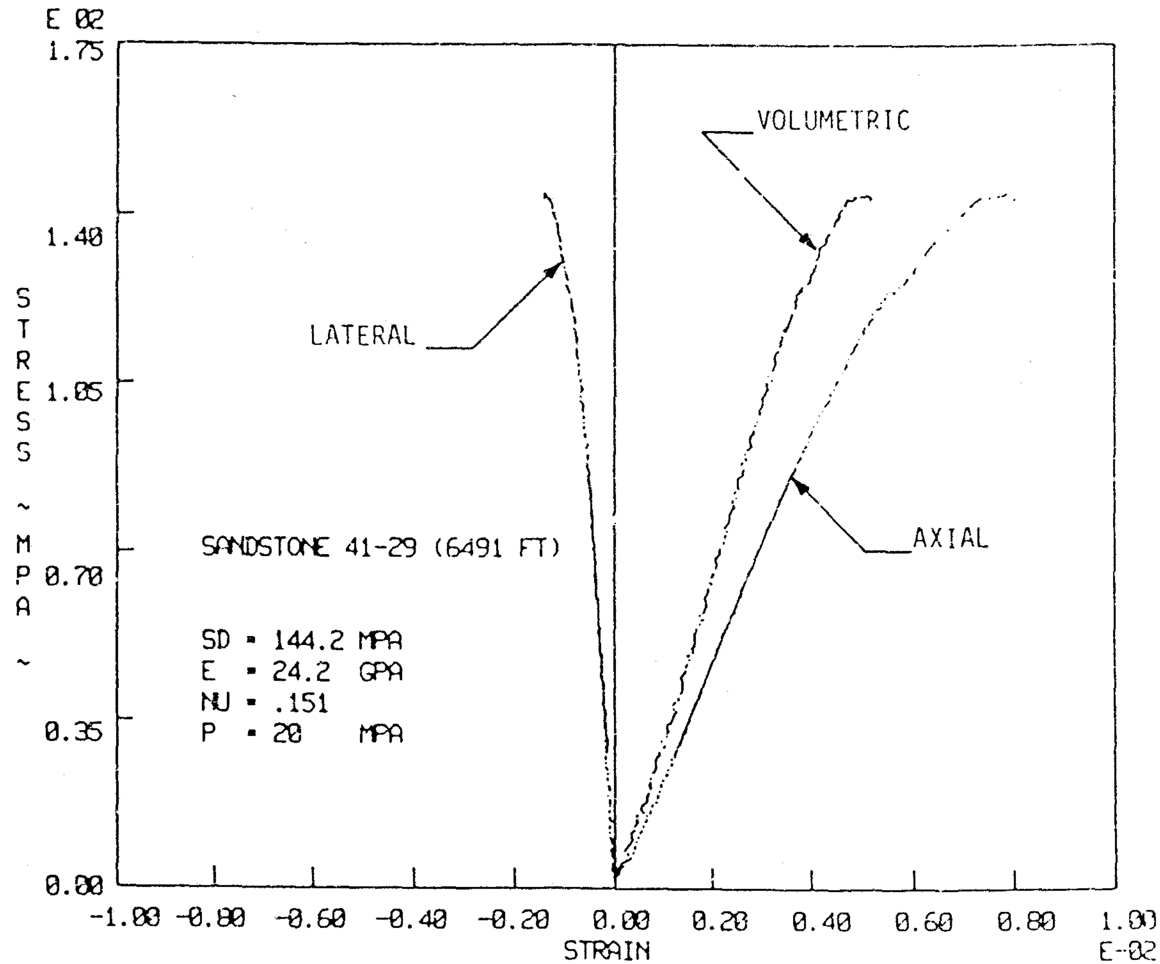
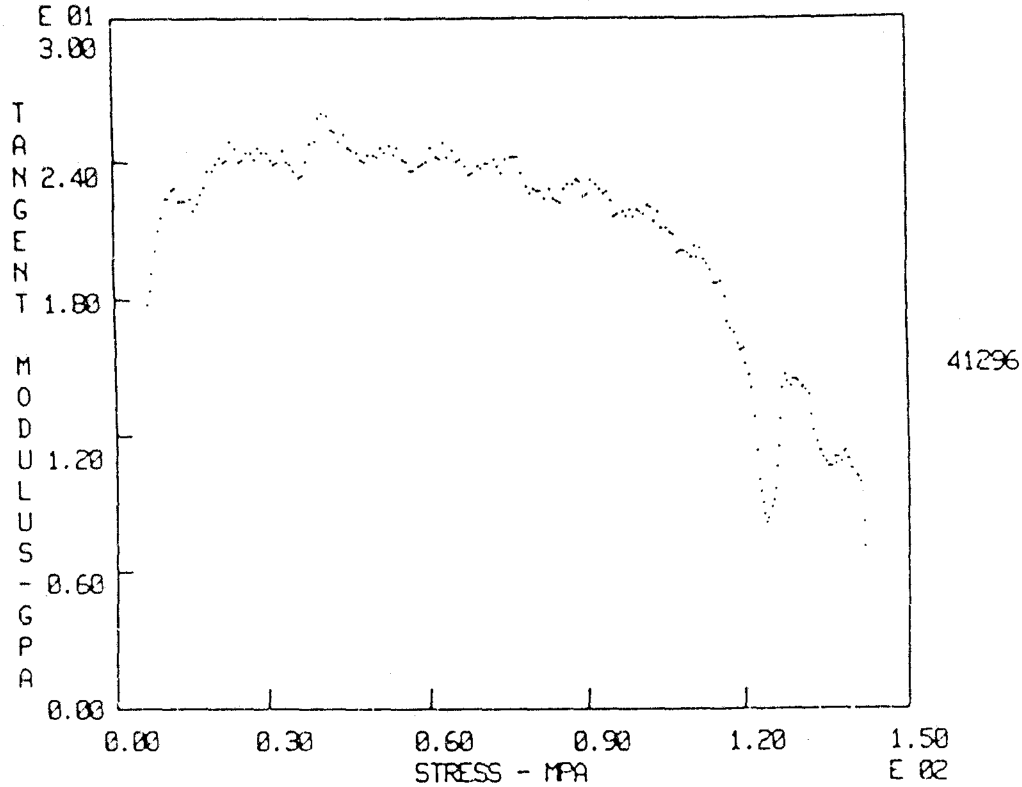


Figure 135. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 41-29. P = 20 MPa.

RSI DWG 046-83-13

RSI DWG 046-83-206



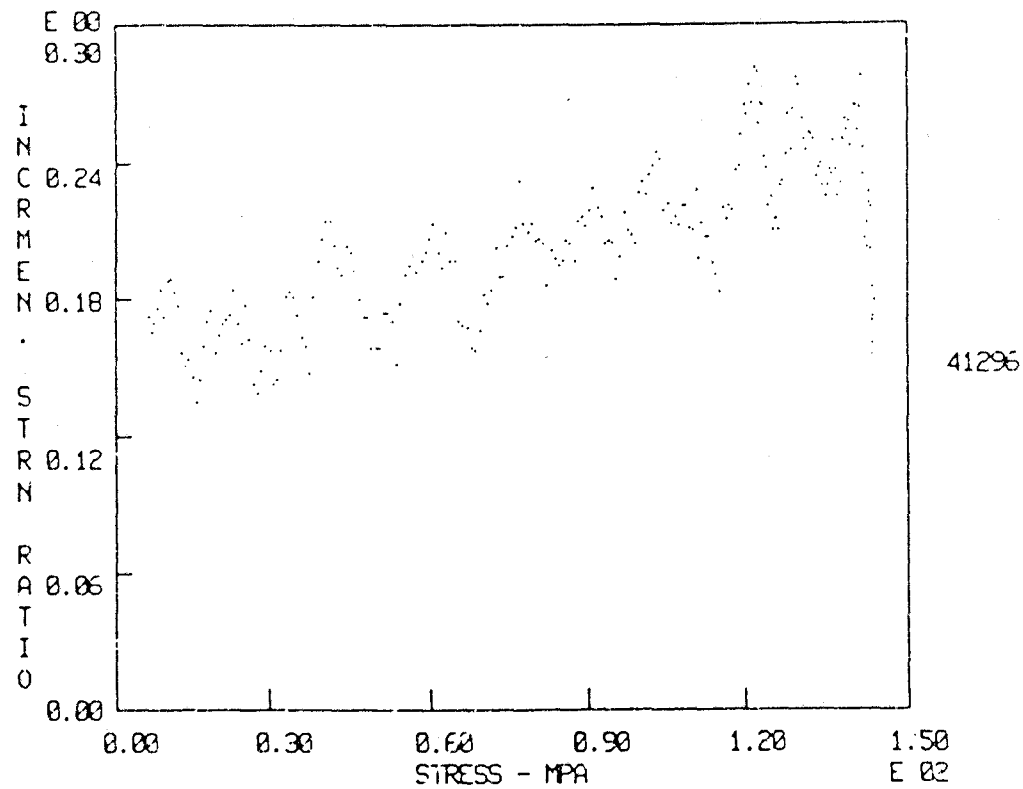


Figure 136. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 41-29 (6491 Feet). P = 20 MPa.

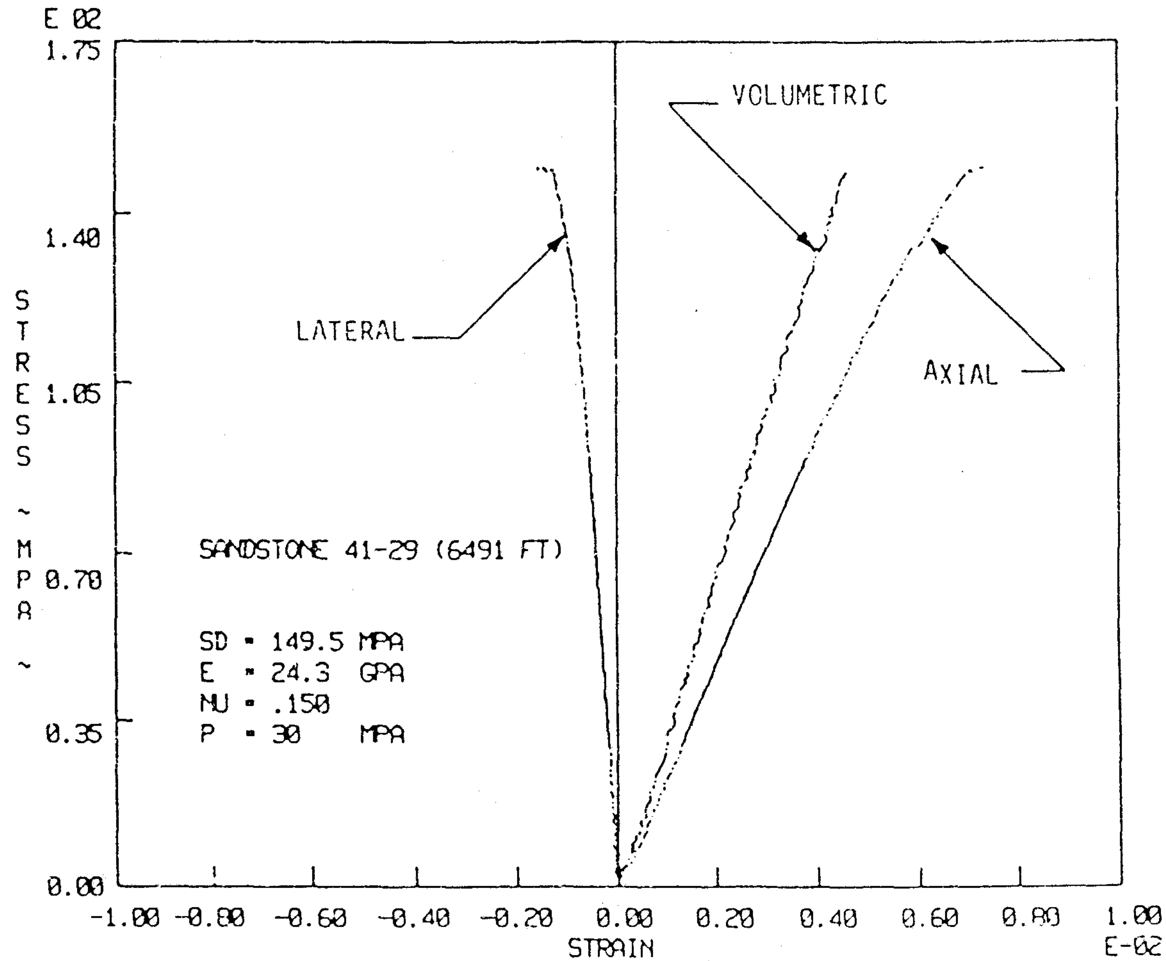
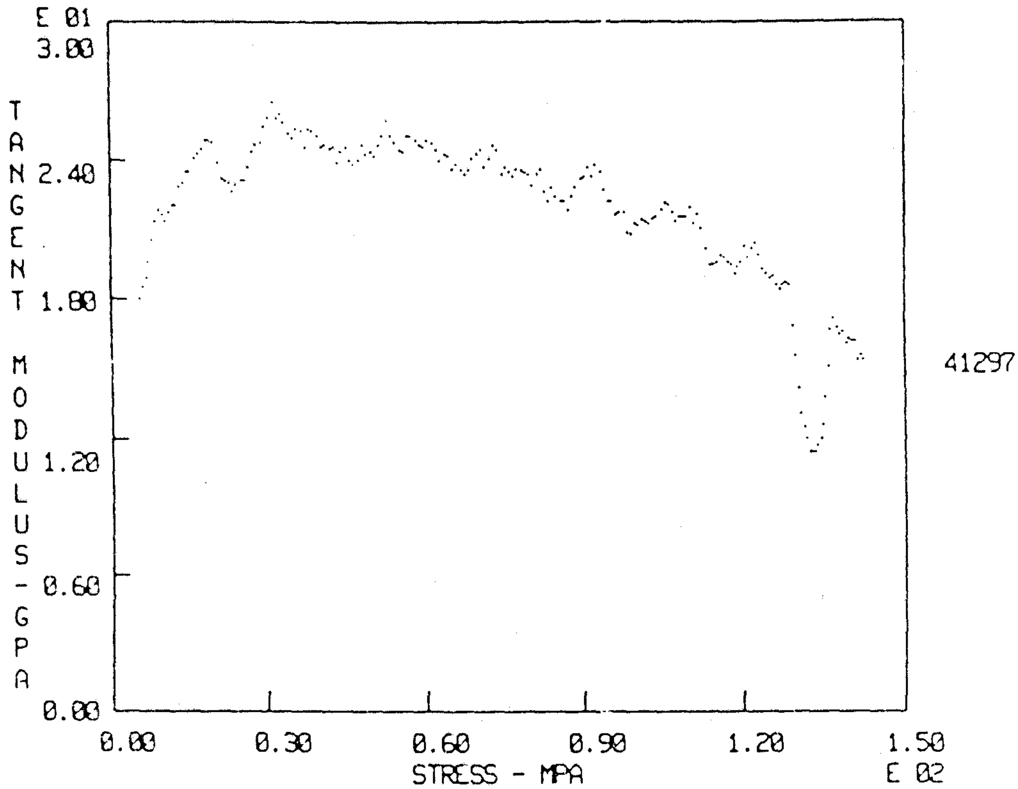


Figure 137. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 41-29. P = 30 MPa.

RSI DWG 046-83-14

RSI DWG 046-83-207



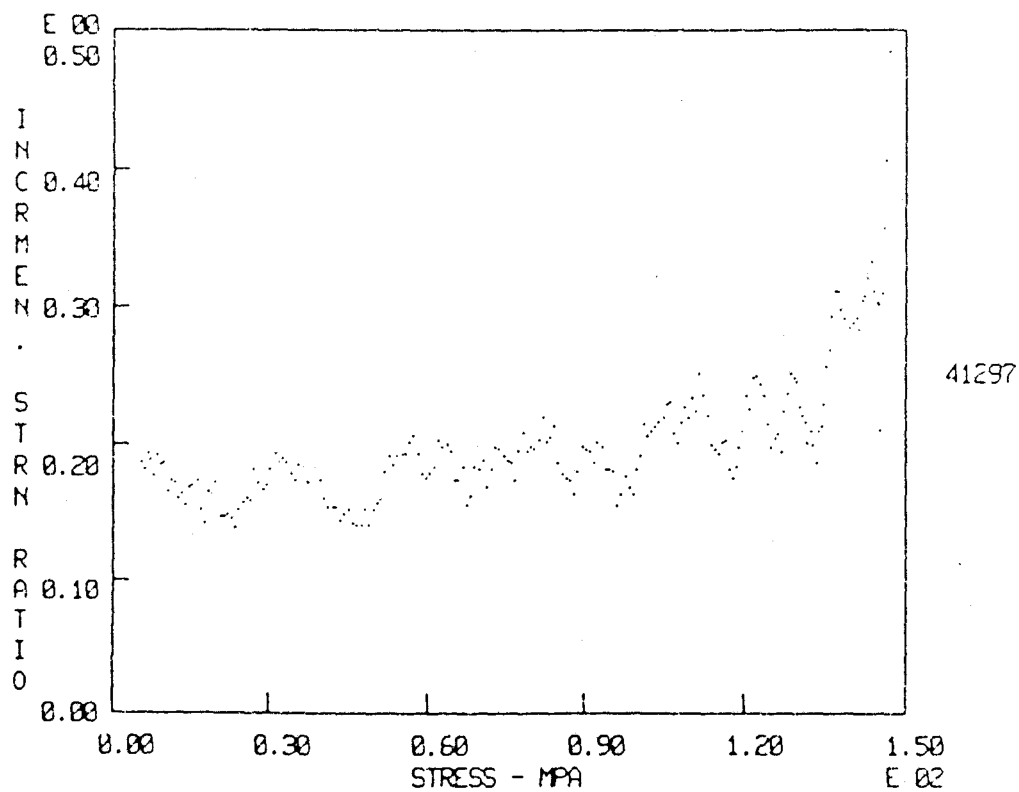


Figure 138. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 41-29 (6491 Feet). P = 30 MPa.

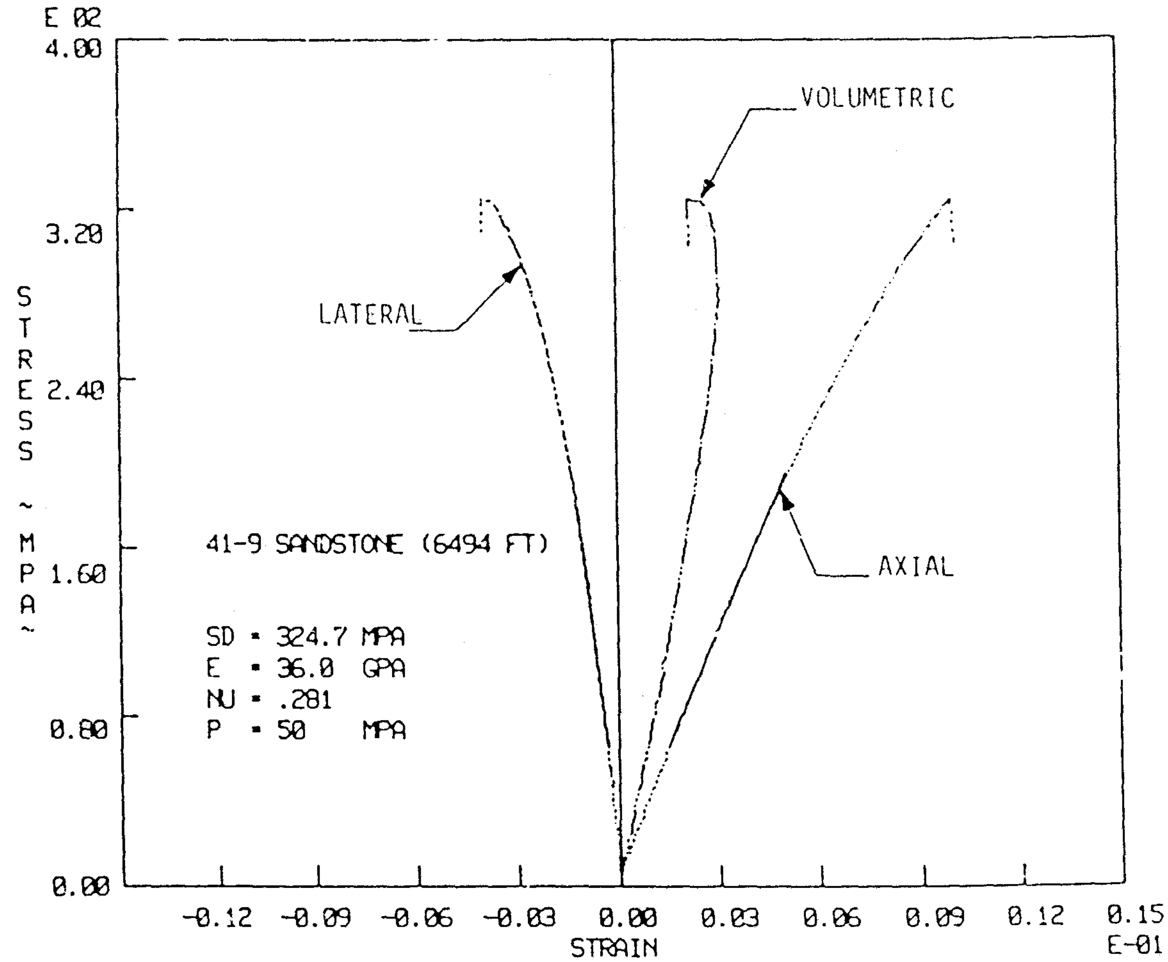
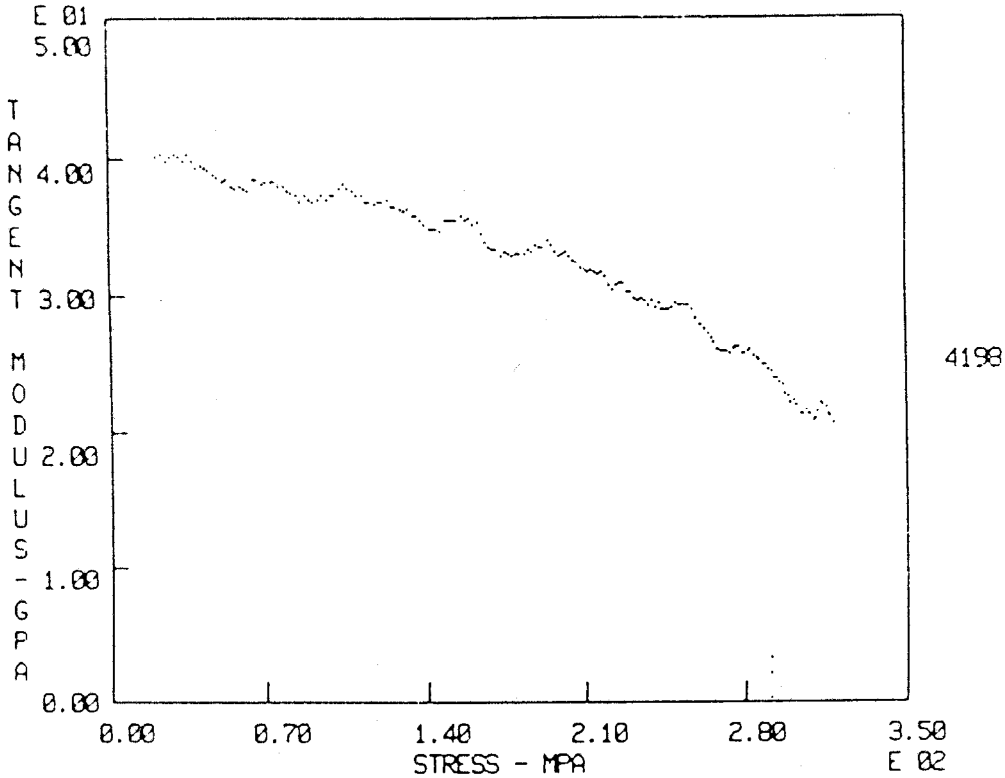


Figure 139. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 41-9. P = 50 MPa.

RSI DWG 046-83-111

RSI DWG 046-83-208



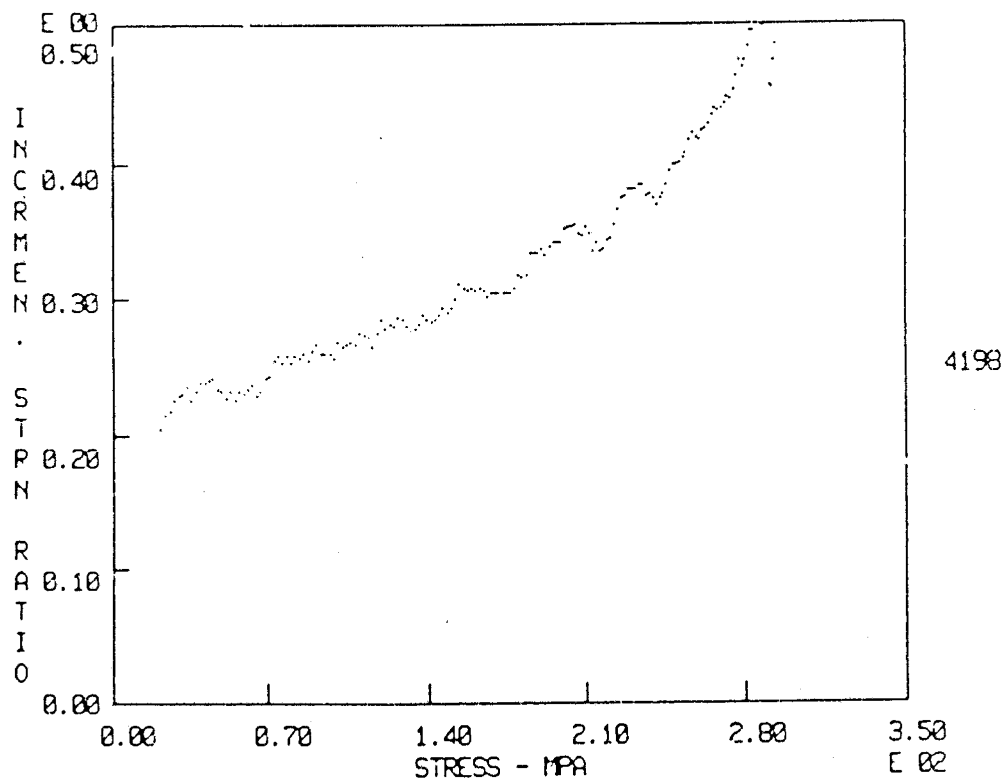


Figure 140. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 41-9 (6494 Feet). P = 50 MPa.

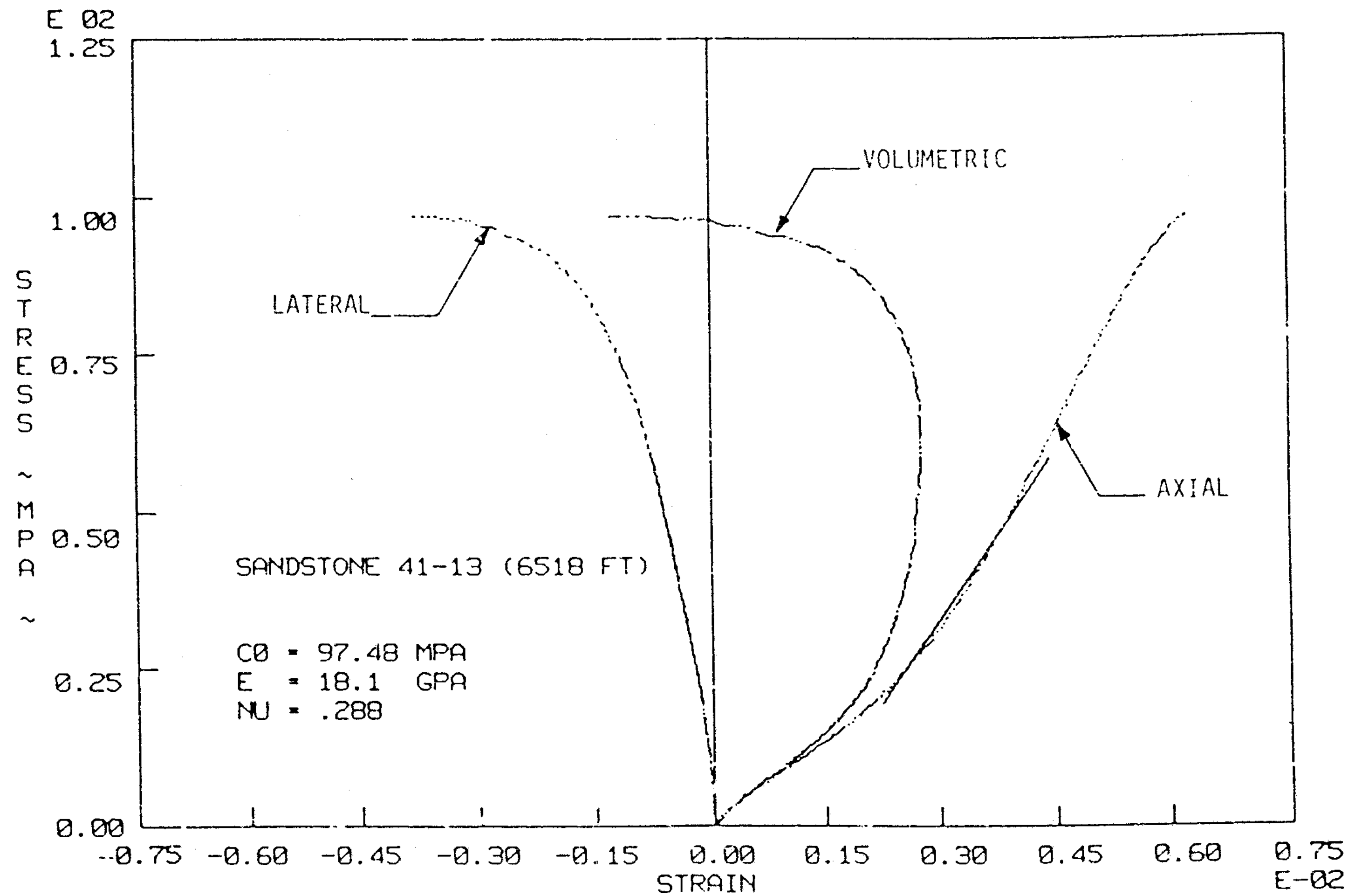
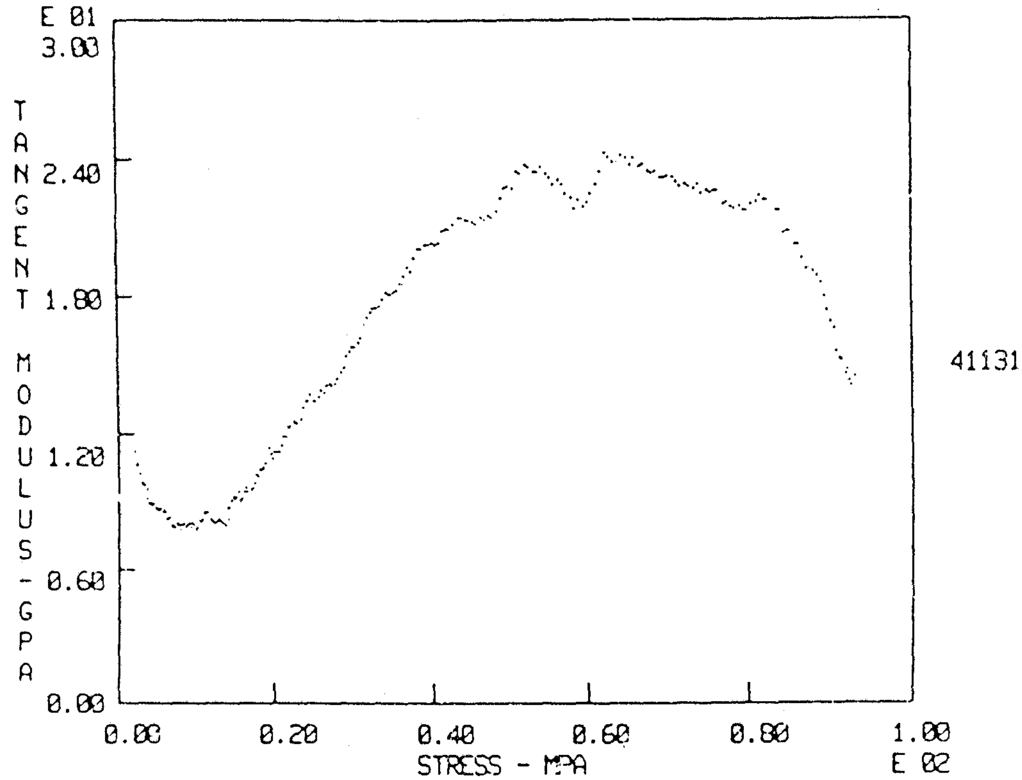


Figure 141. Axial stress Difference Versus Axial, Lateral and Volumetric Strain for Unconfined Compression of Sandstone 41-13.

RSI DWG 046-82-03

RSI DWG 046-83-?09



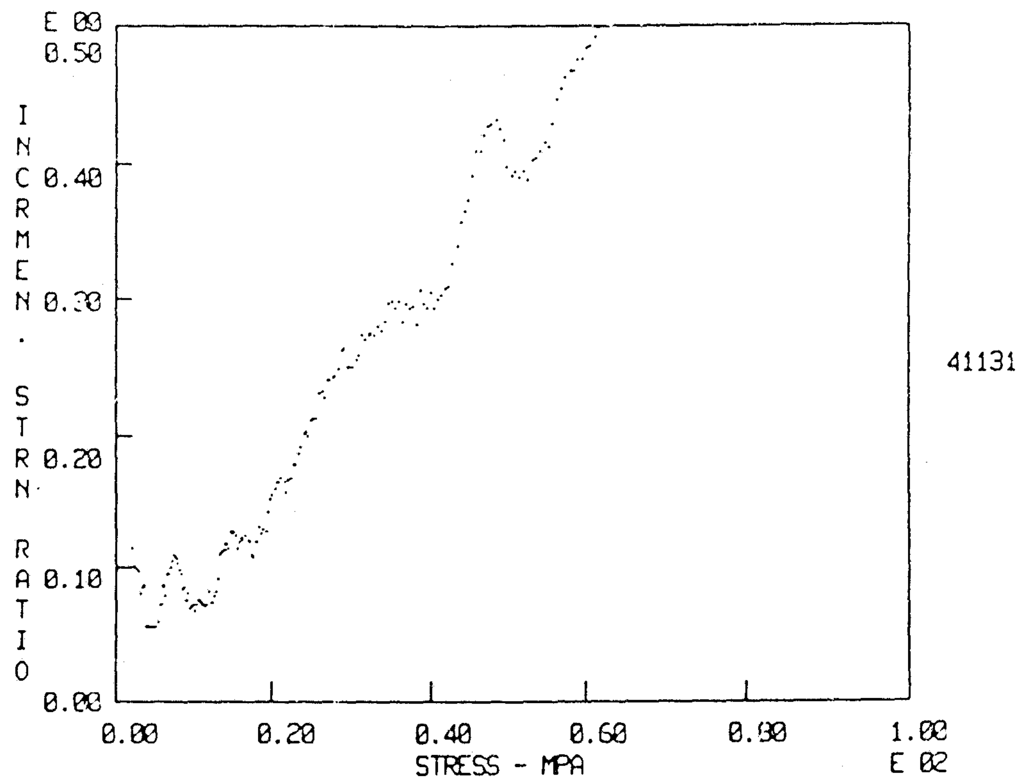


Figure 142. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 41-13 (6518 Feet). P = 0 MPa.

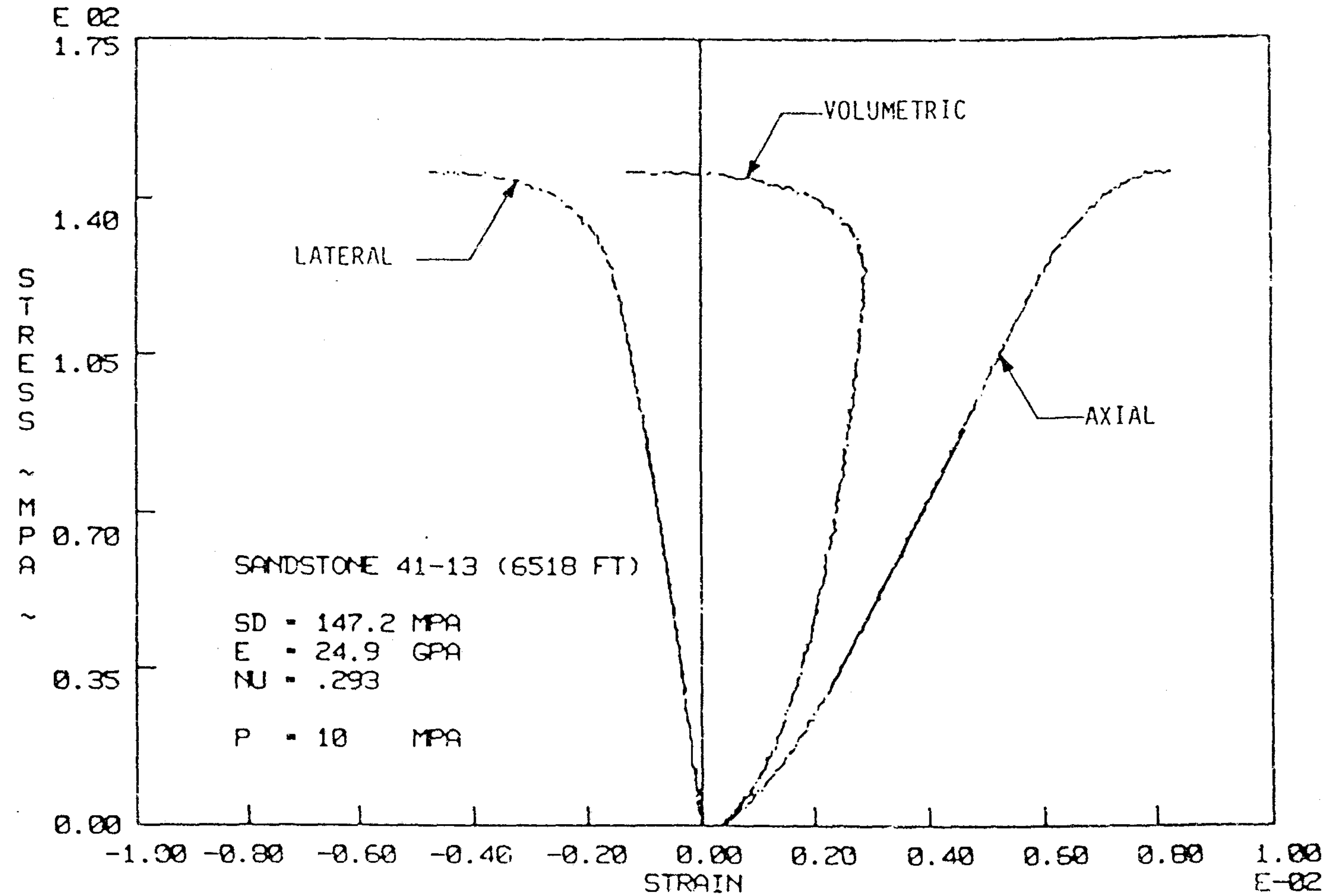
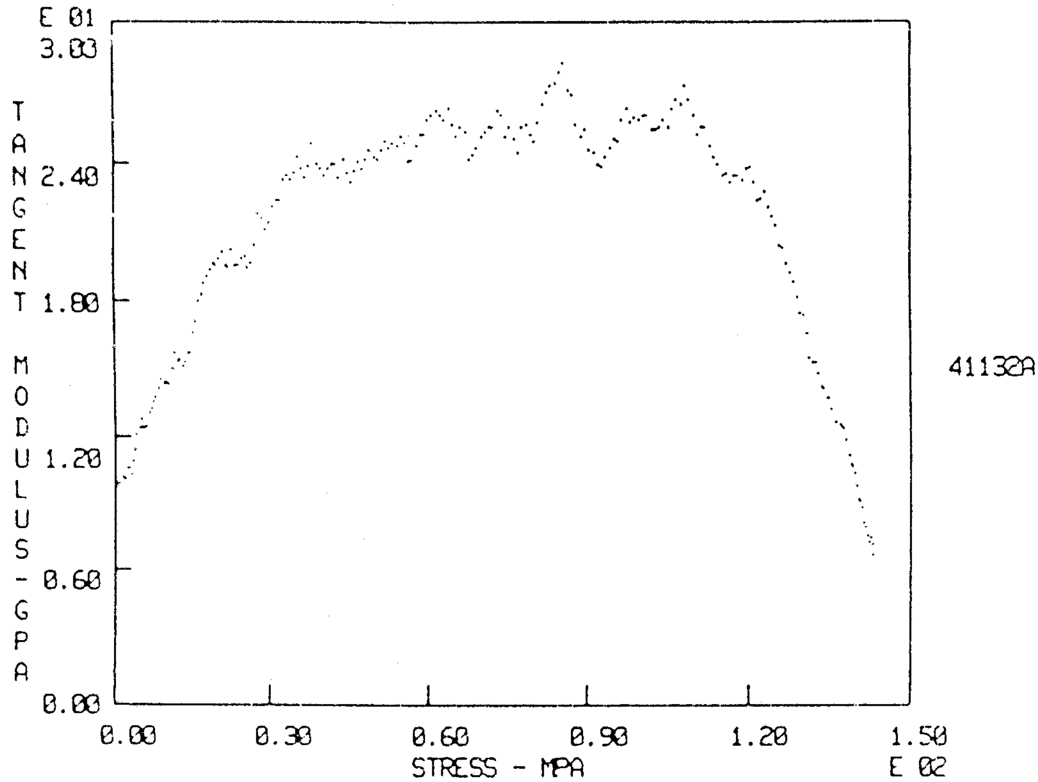


Figure 143. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 41-13. P = 10 MPa.

RSI DWG 046-82-17

RSI DWG 046-83-210



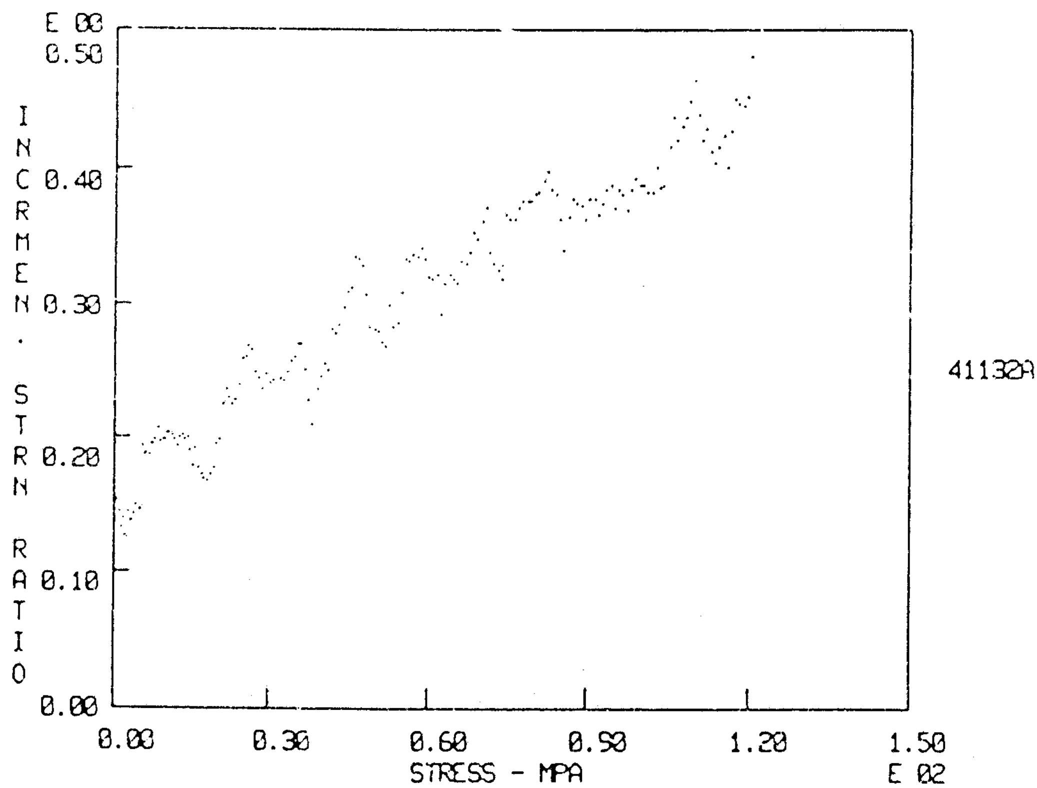


Figure 144. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 41-13 (6518 Feet). P = 10 MPa.

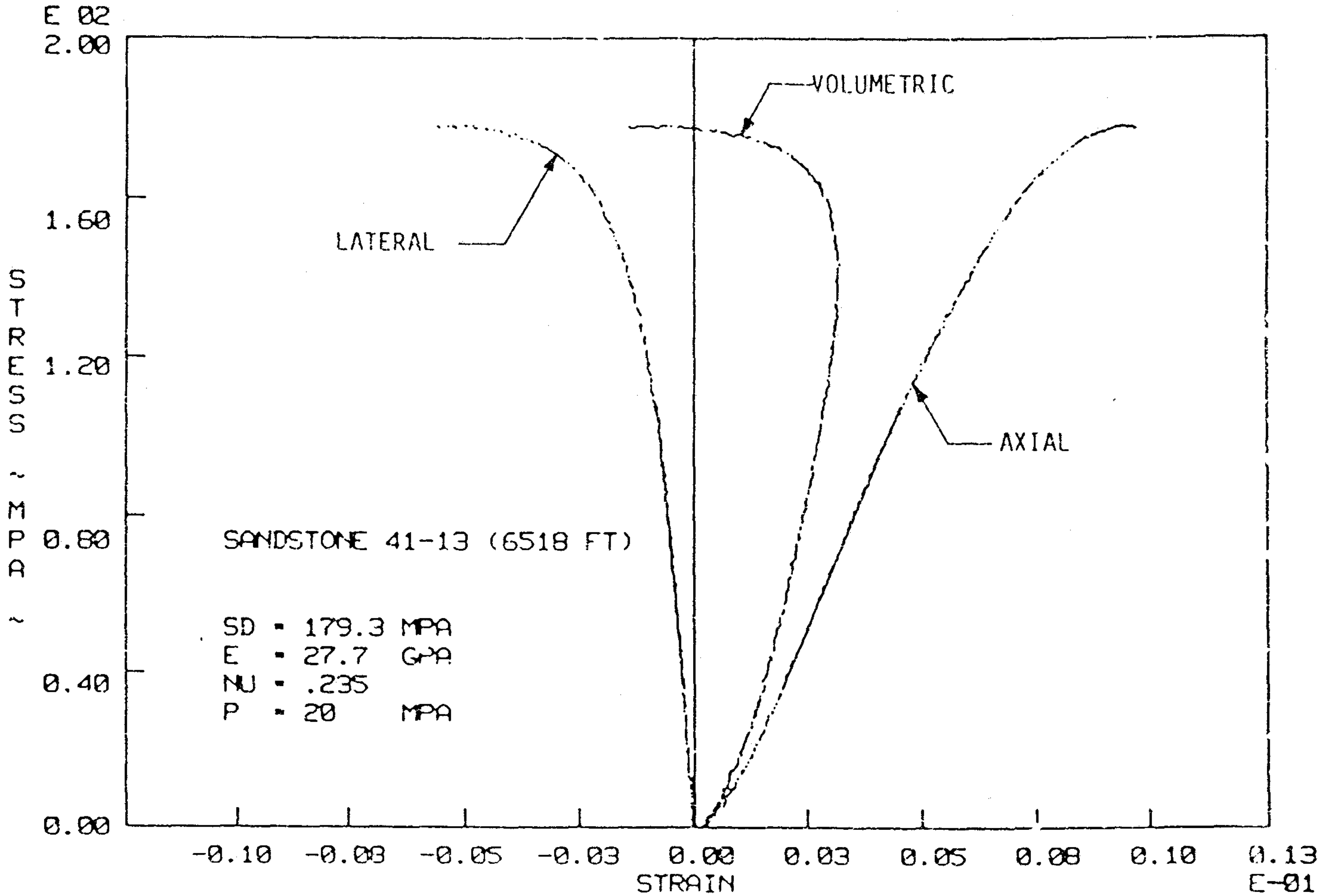
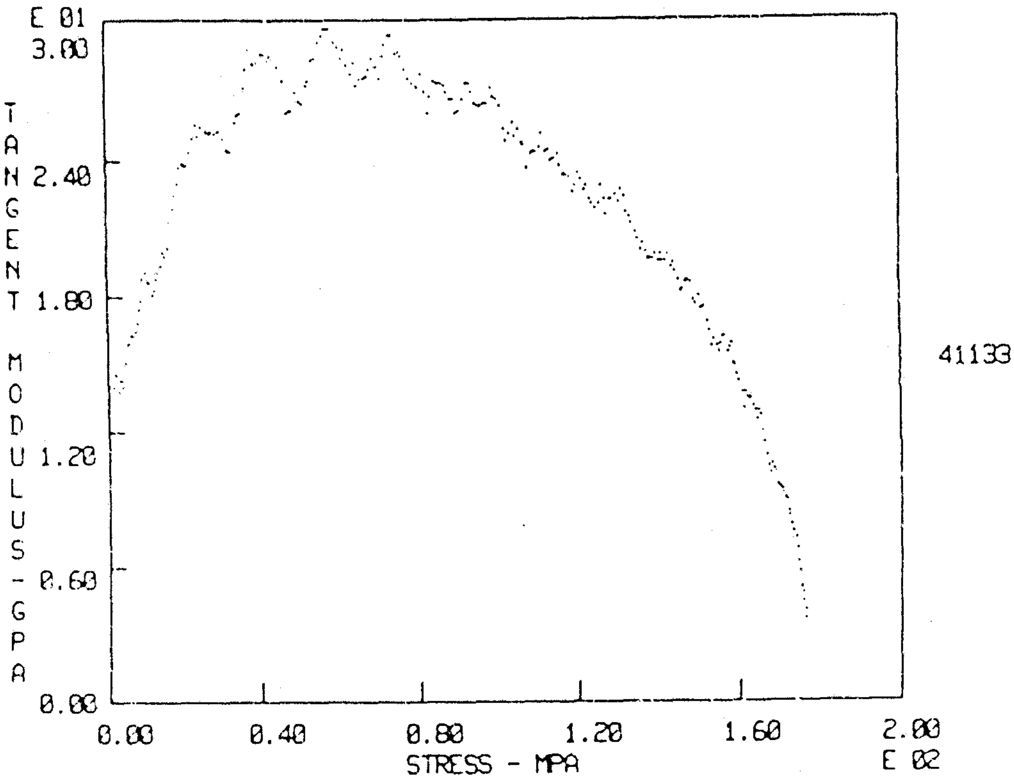


Figure 145. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 41-13. P = 20 MPa.

RSI DWG 046-82-18

RSI DWG 046-83-211



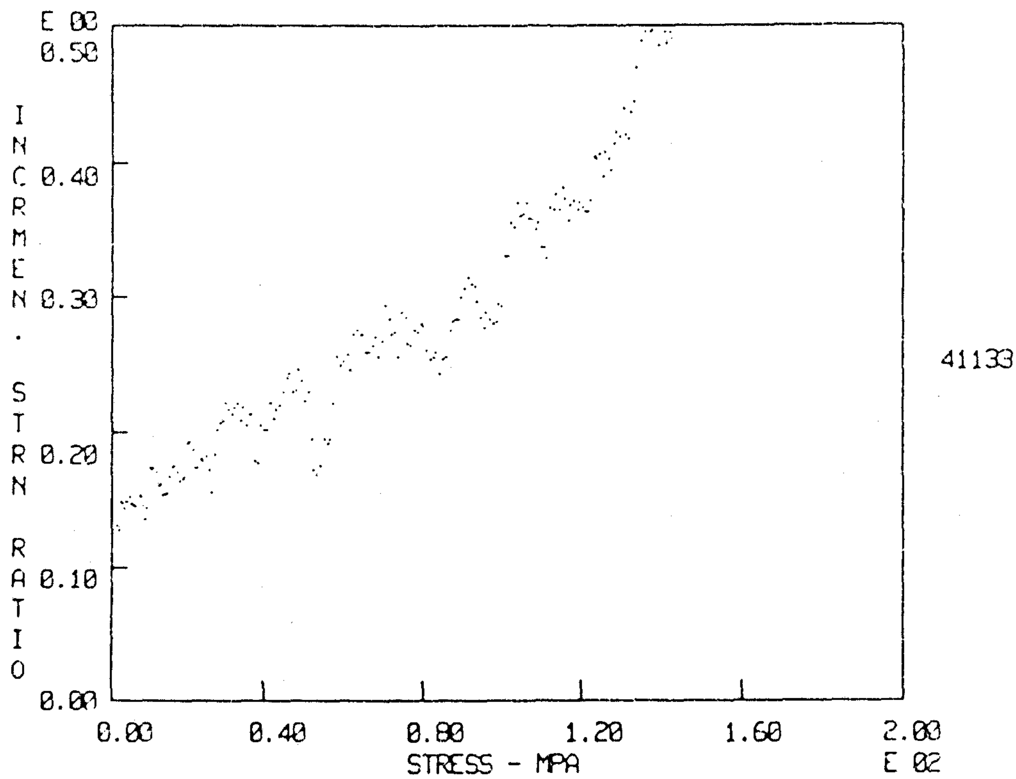


Figure 146. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 41-13 (6518 Feet). P = 20 MPa.

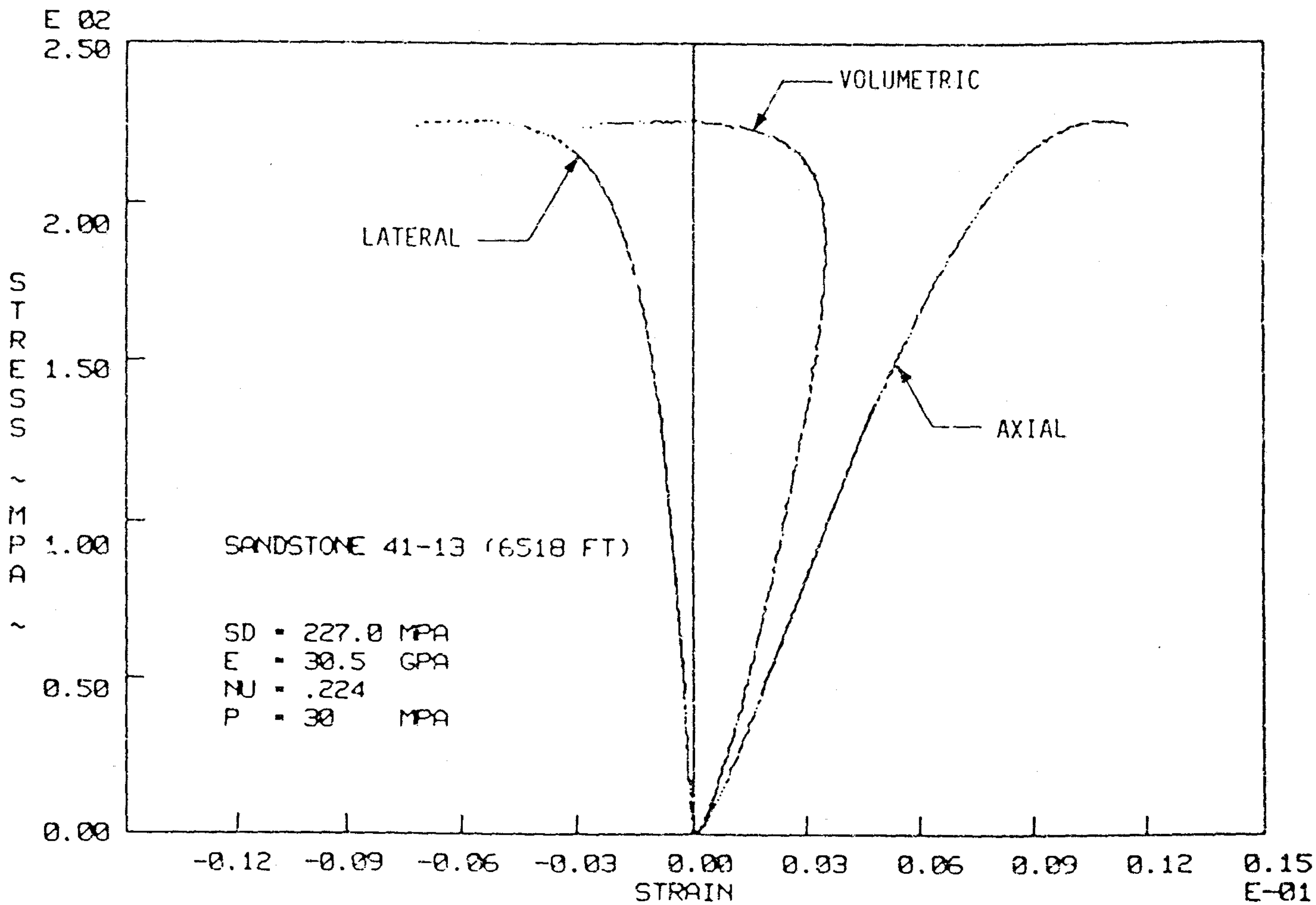
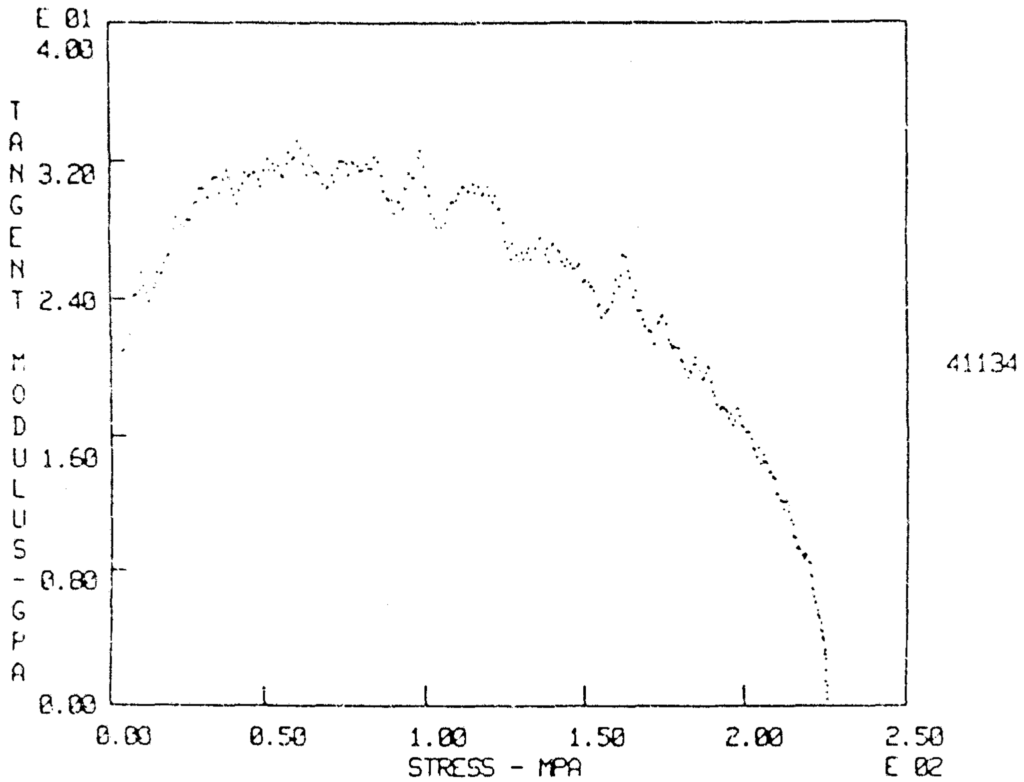


Figure 147. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 41-13. P = 30 MPa.

RSI DWG 046-82-19

RSI DWG 046-83-212



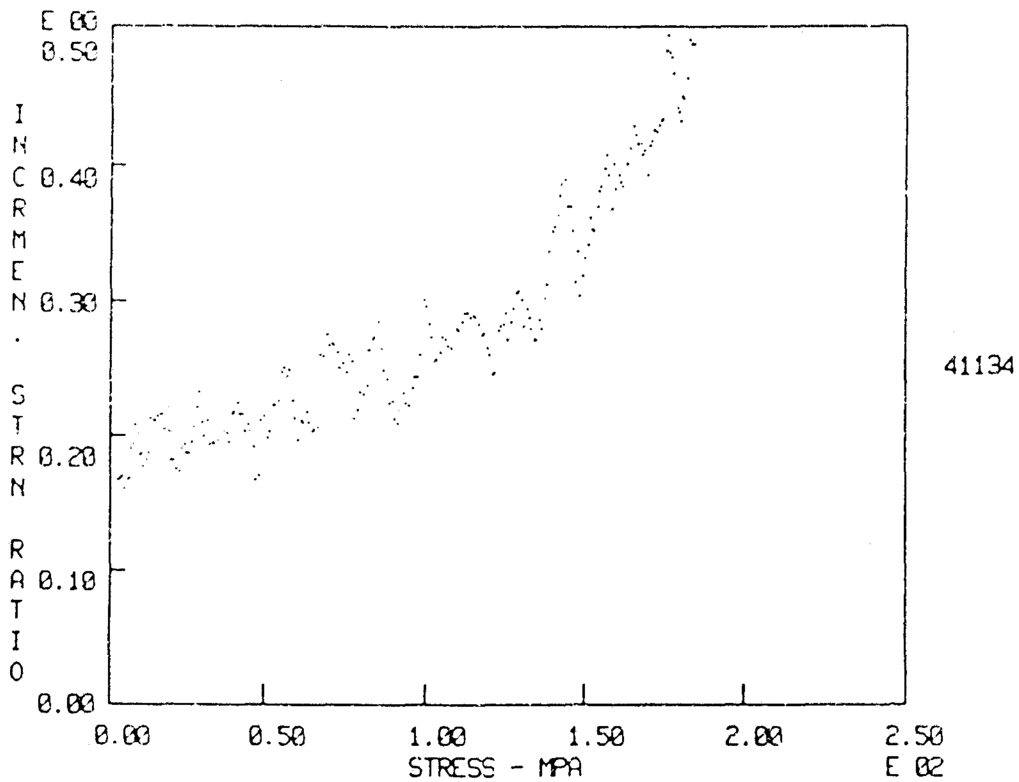


Figure 148. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 41-13 (6518 Feet). P = 30 MPa.

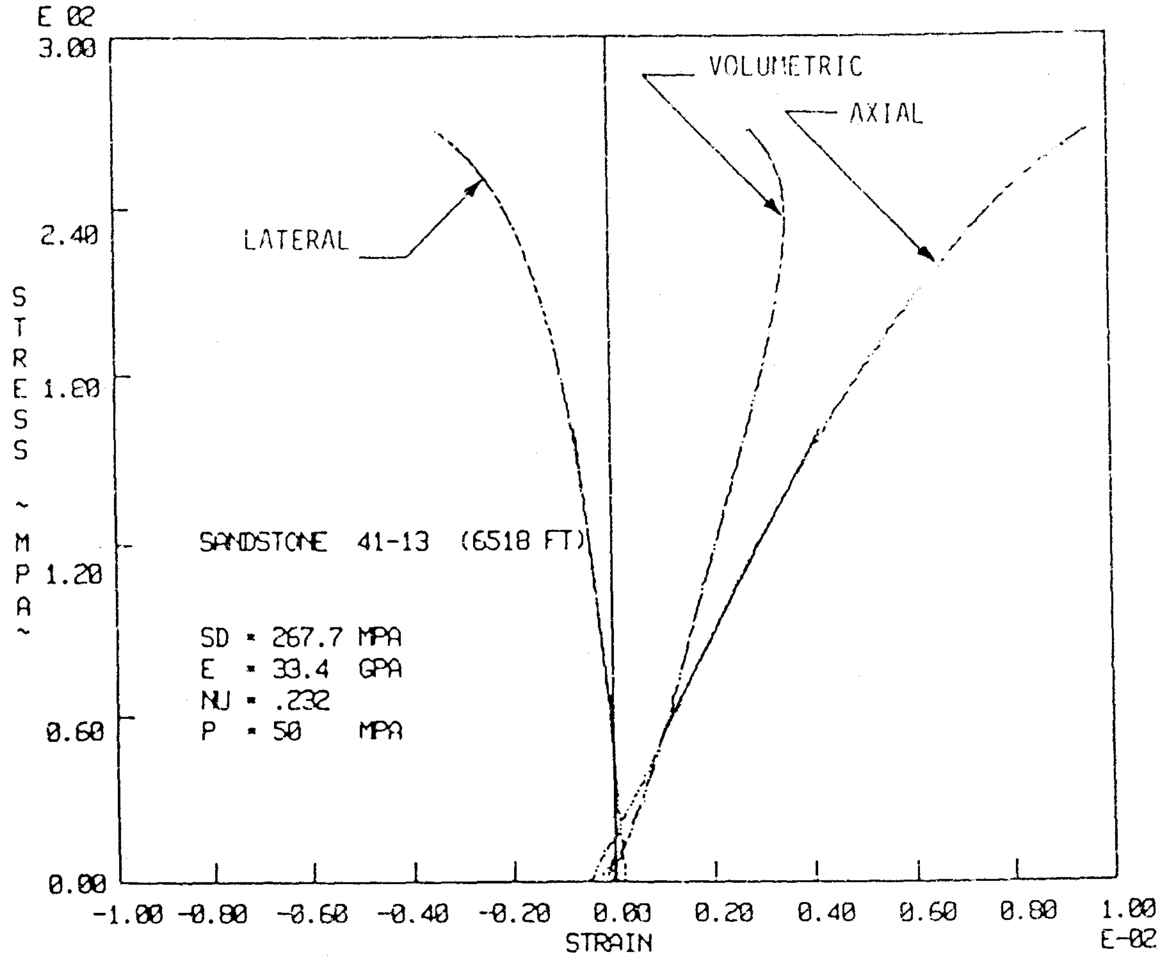
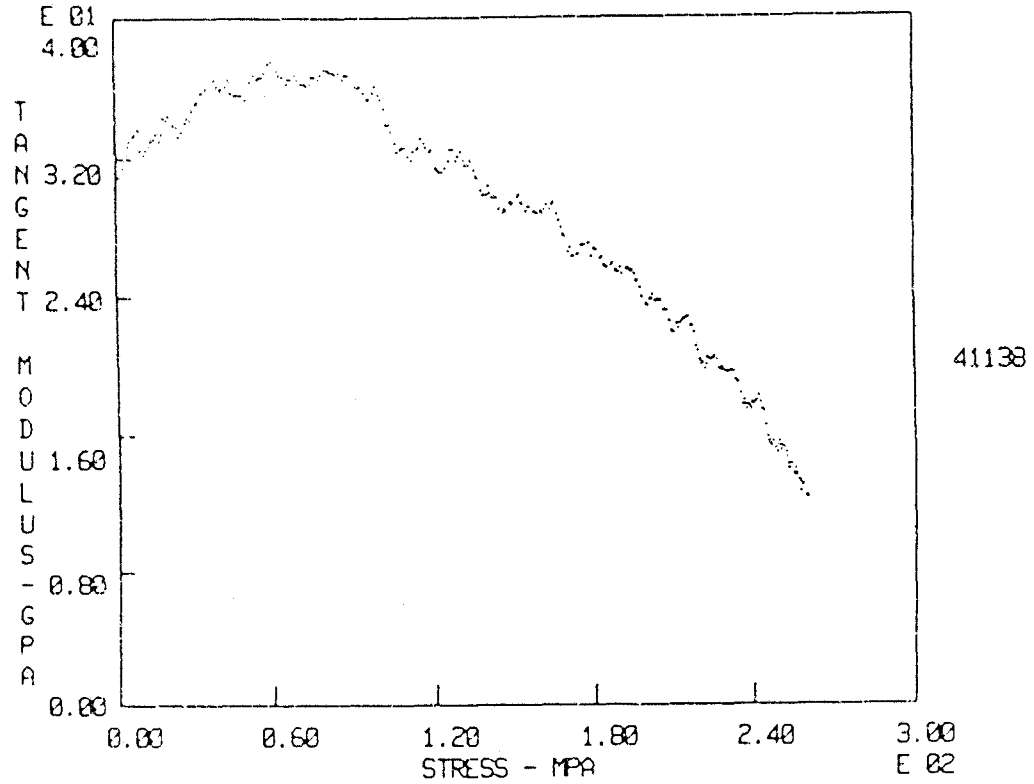


Figure 149. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 41-13. P = 50 MPa.

RSI DWG 046-83-213



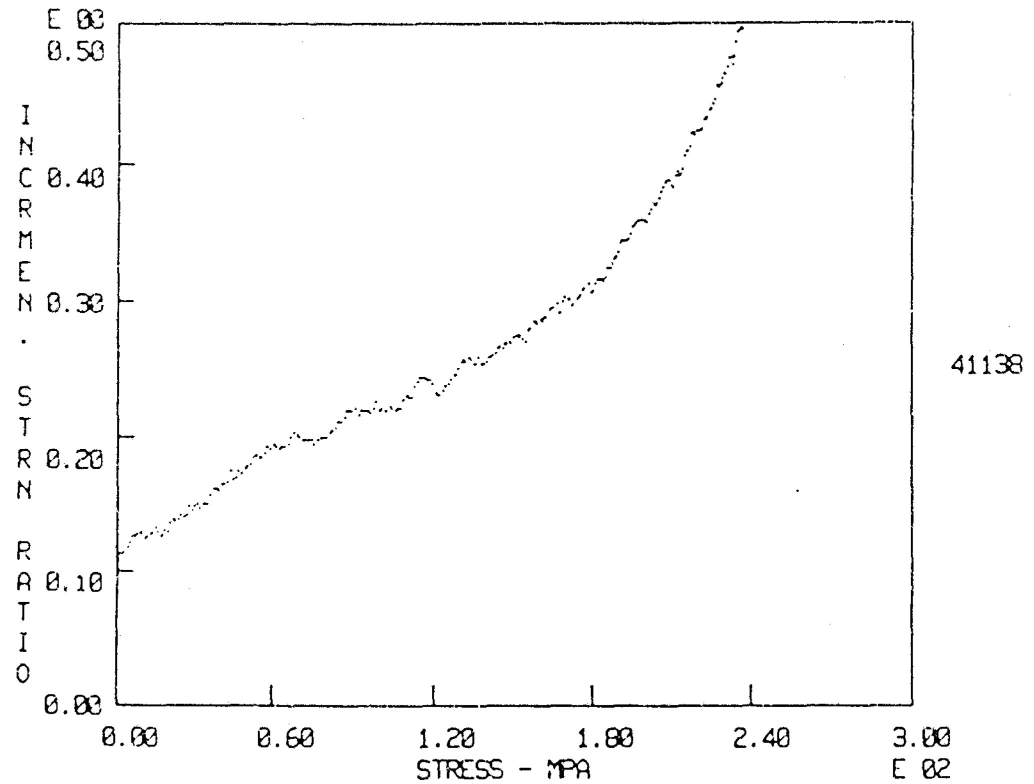
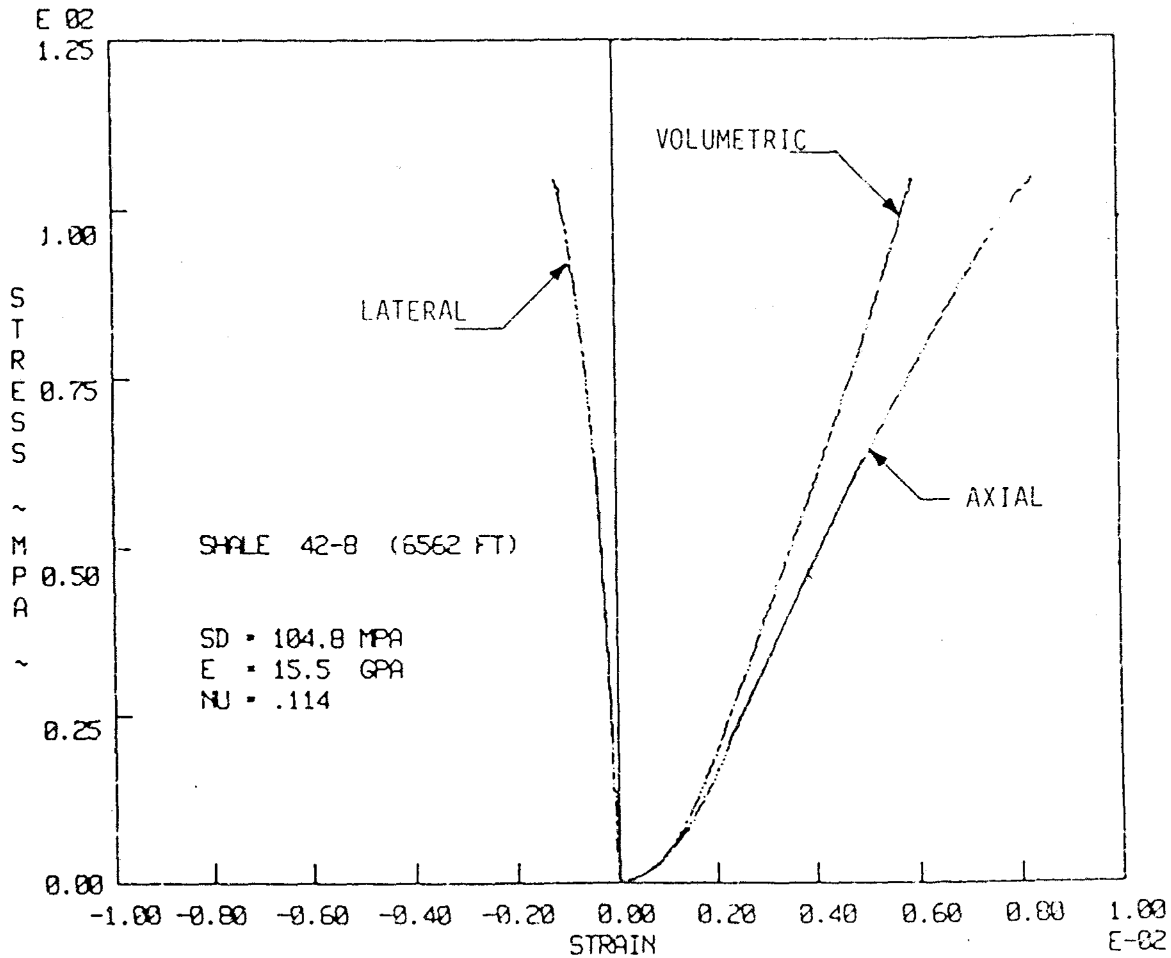


Figure 150. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 41-13 (6518 Feet). P = 50 MPa.



RSI DWG 046-83-60

Figure 151. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Unconfined Compression of Shale 42-8.

RSI DWG 046-83-214

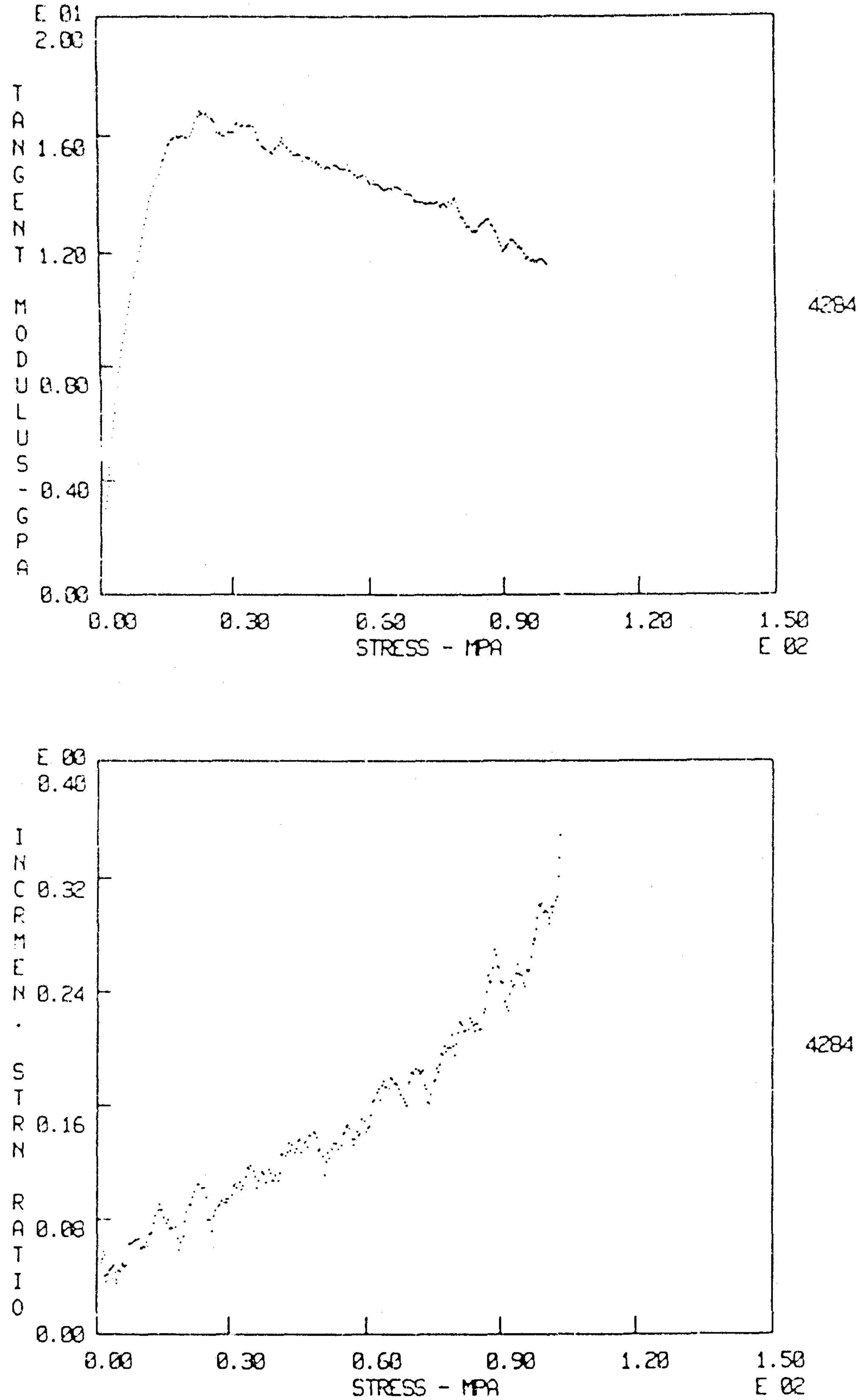


Figure 152. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Shale 42-8 (6562 Feet). P = 0 MPa.

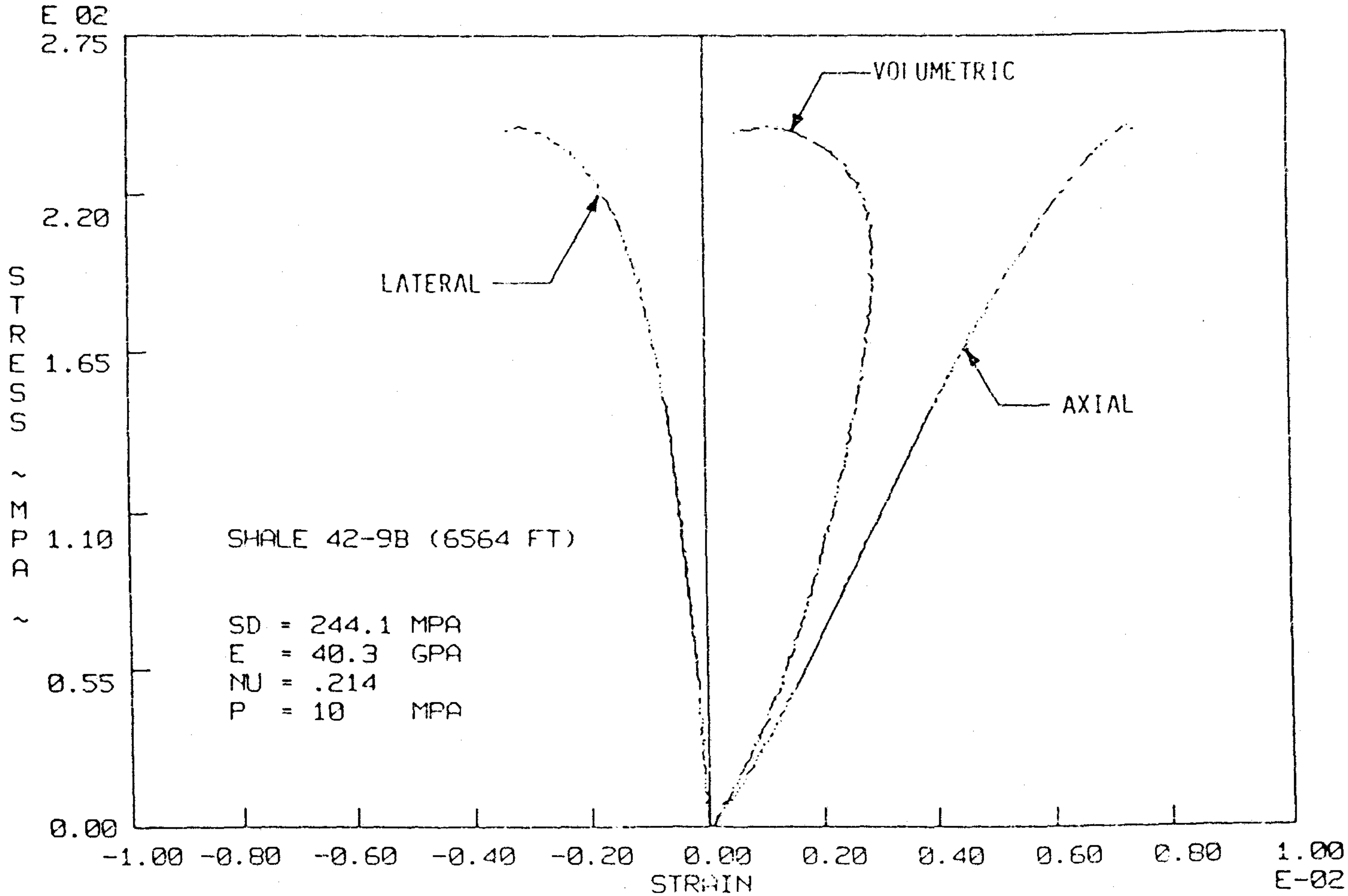
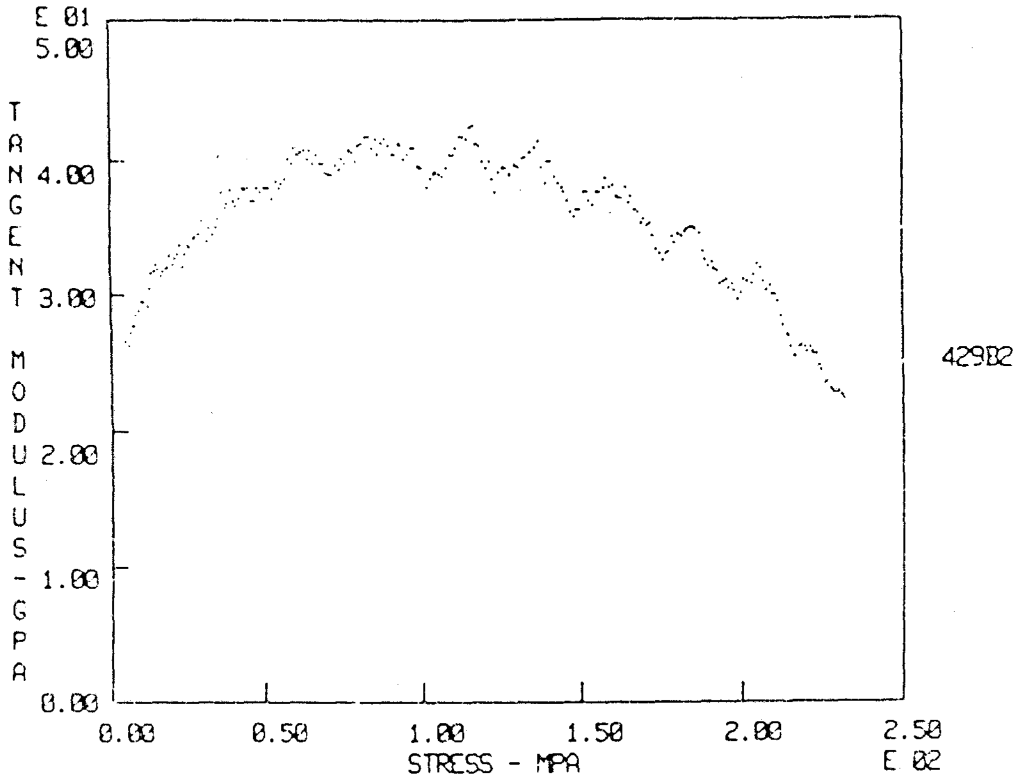


Figure 153. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Shale 42-9B. P = 10 MPa.

RSI DWG 046-83-215



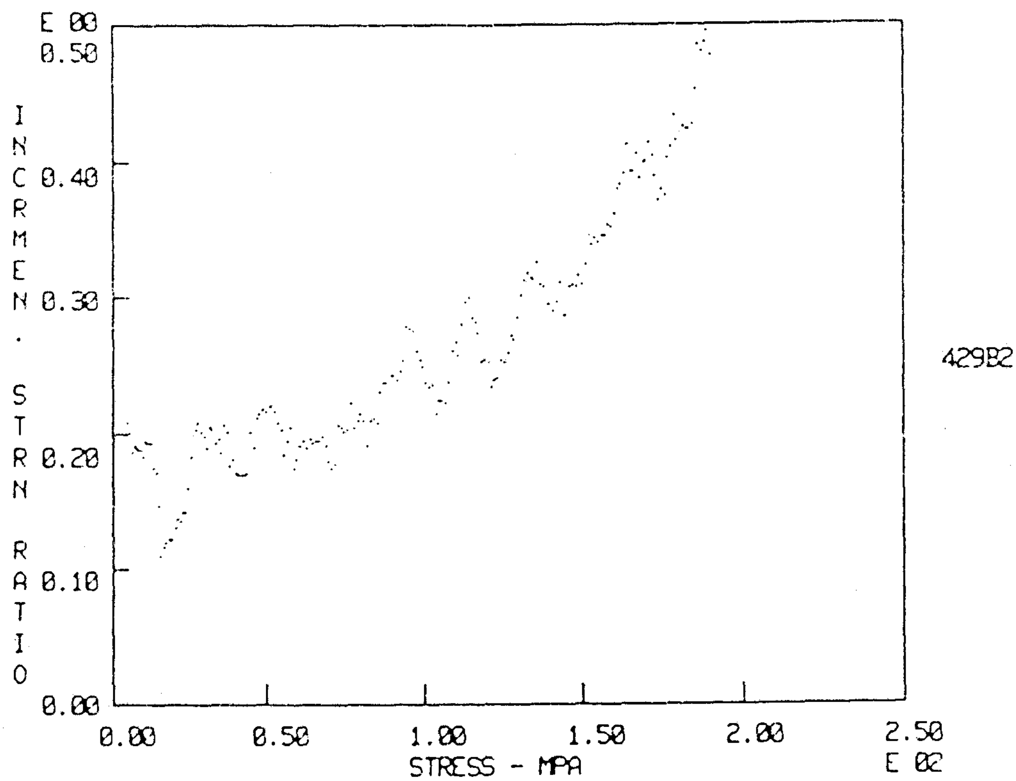


Figure 154. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Shale 42-9B (6564 Feet). P = 10 MPa.

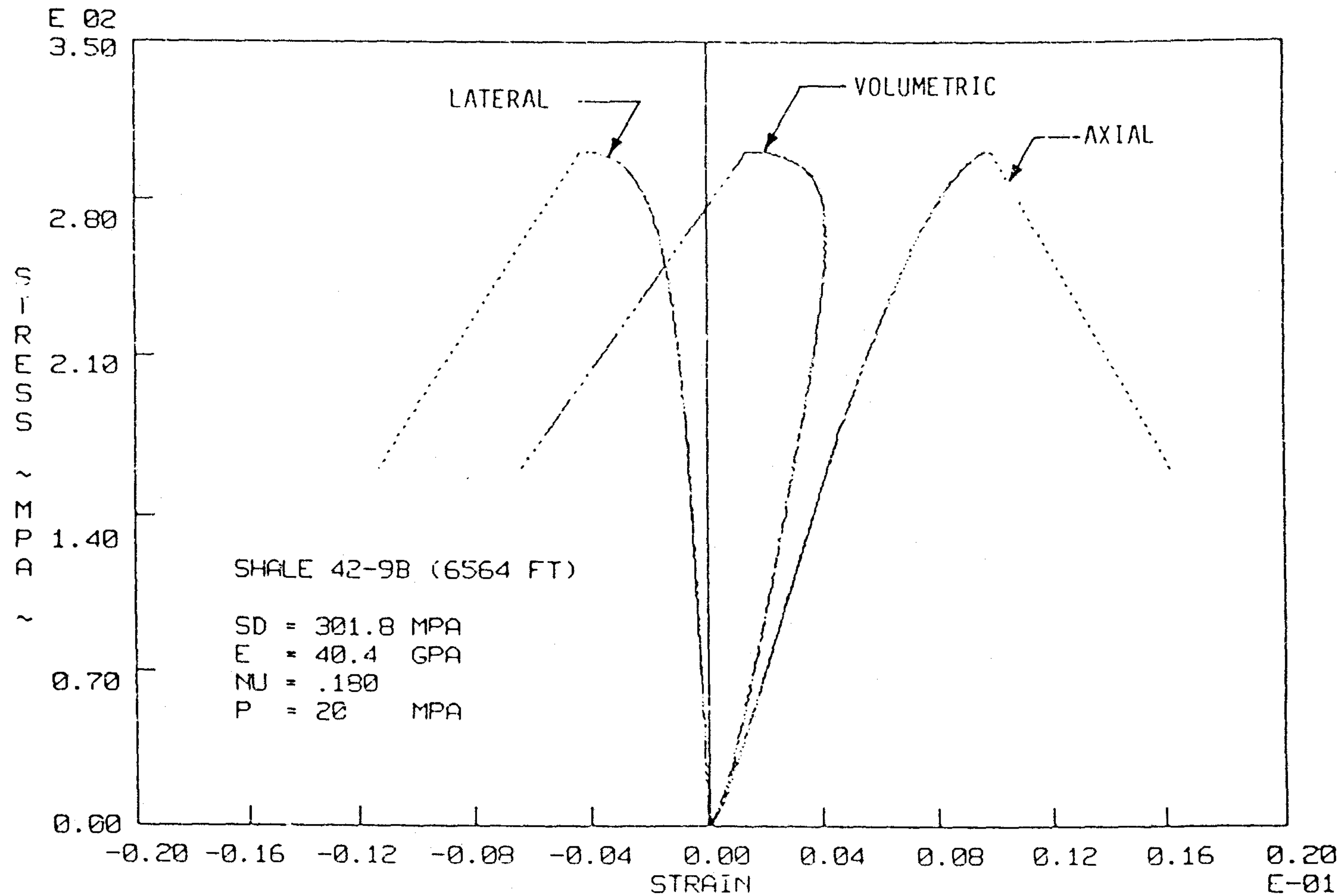
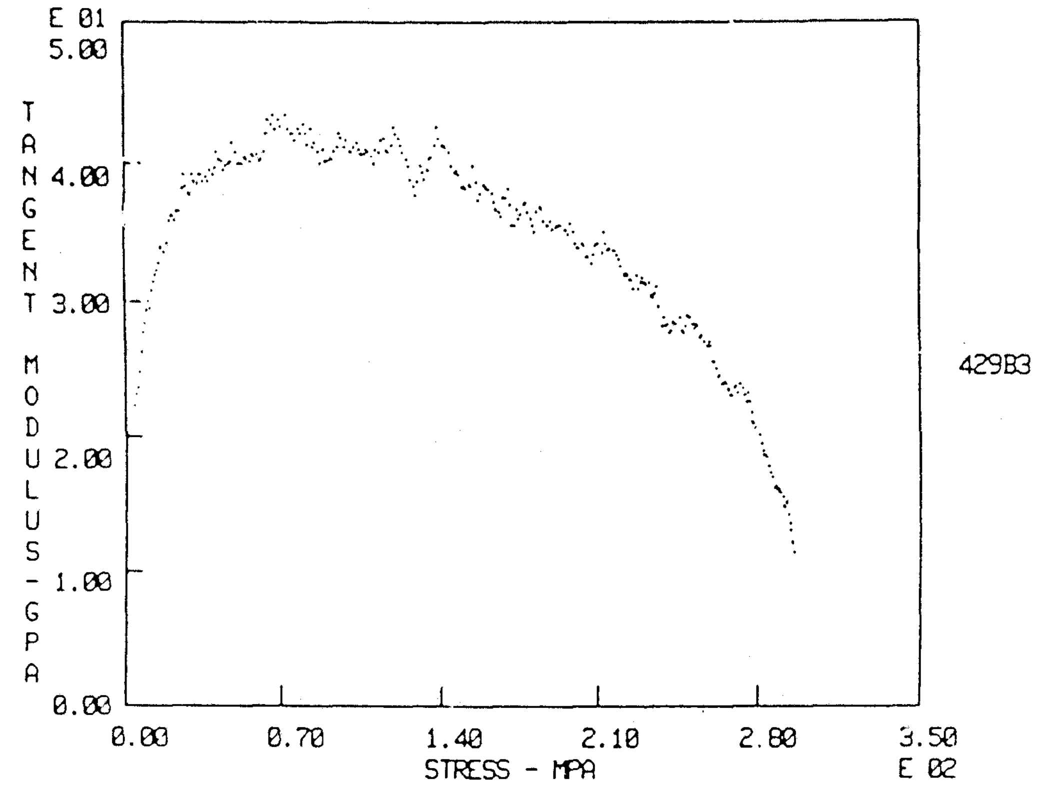


Figure 155. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Shale 42-9B. P = 20 MPa.

RSI DWG 046-82-21

RSI DWG 046-83-216



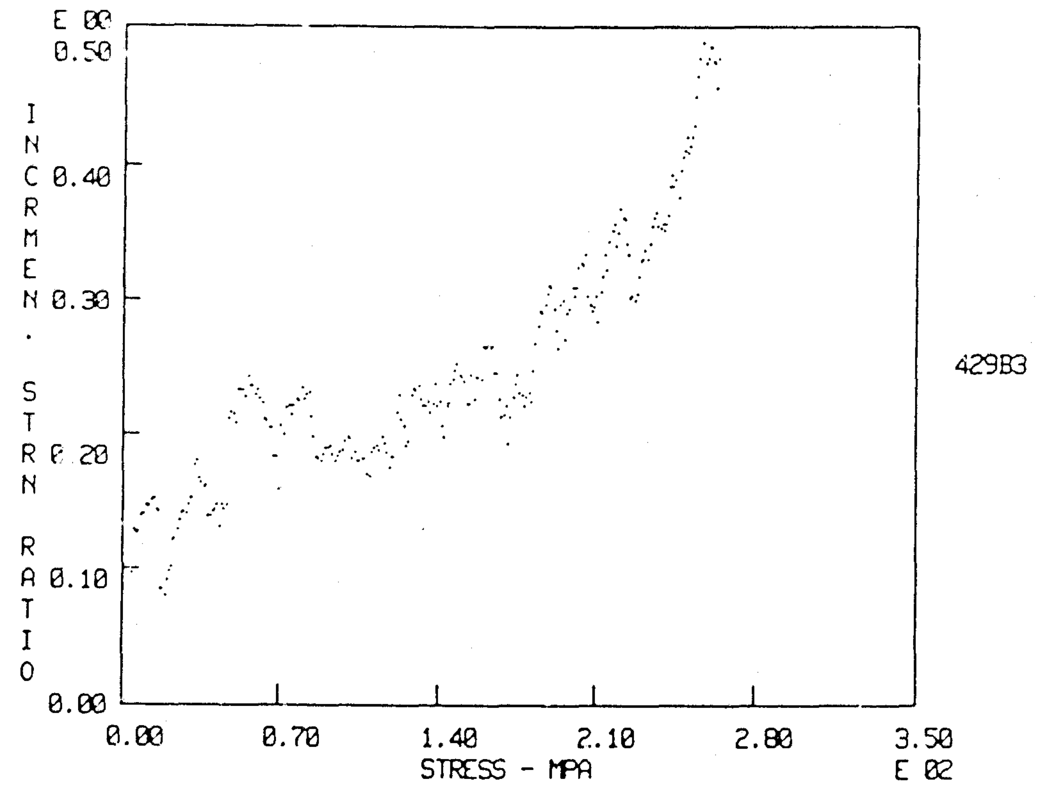


Figure 156. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Shale 42-9B (6564 Feet). P = 20 MPa.

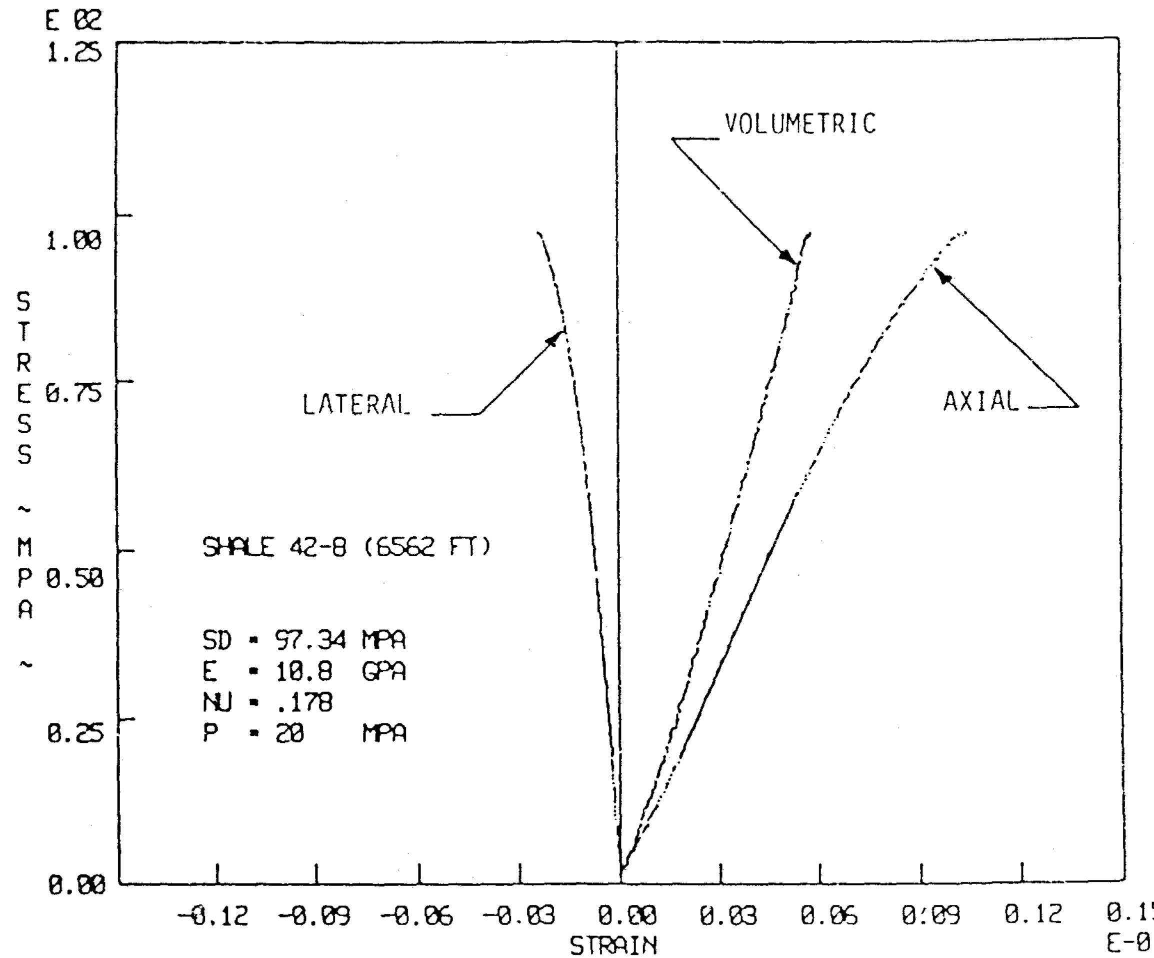
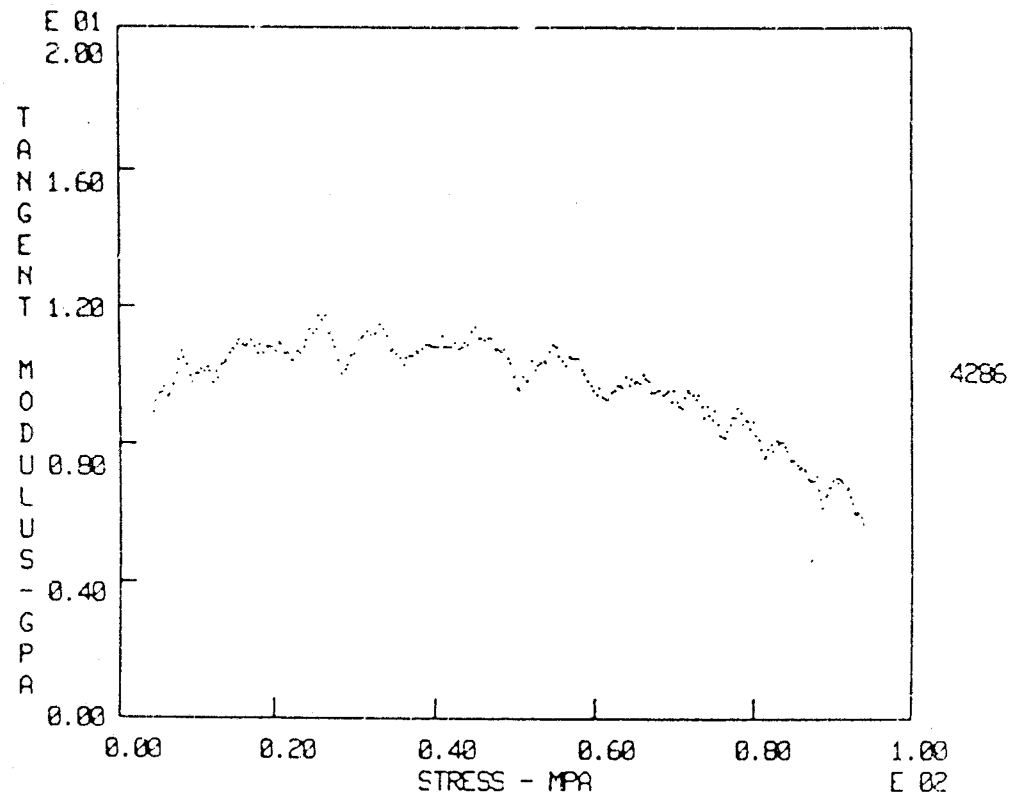


Figure 157. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Shale 42-8. P = 20 MPa.

RSI DWG 046-83-15

RSI DWG 046-83-217



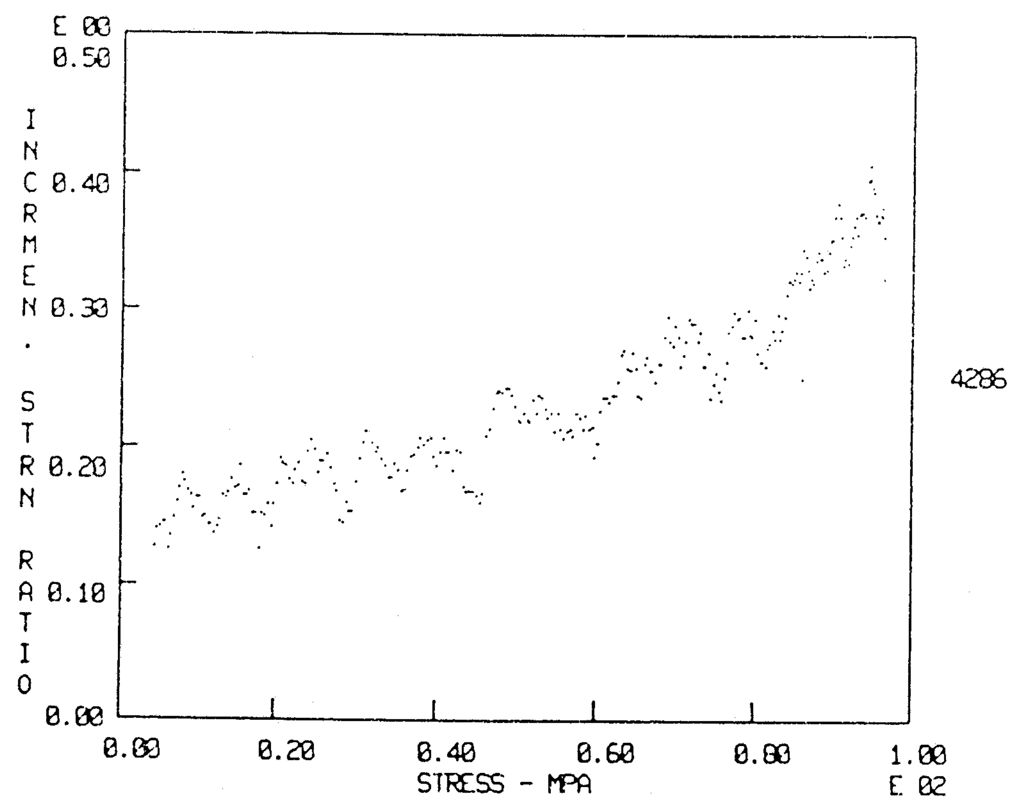


Figure 158. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Shale 42-8 (6562 Feet). P = 20 MPa.

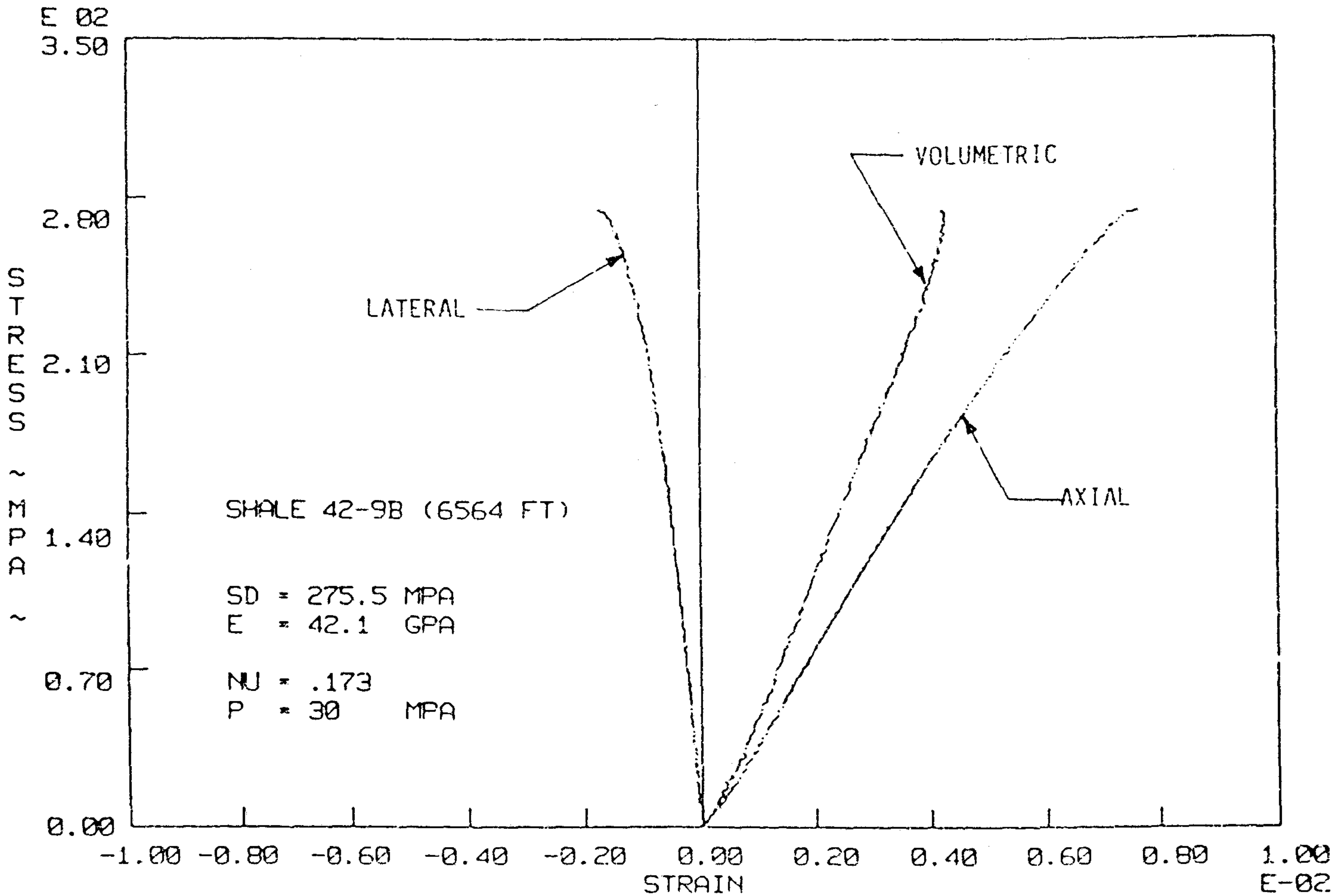
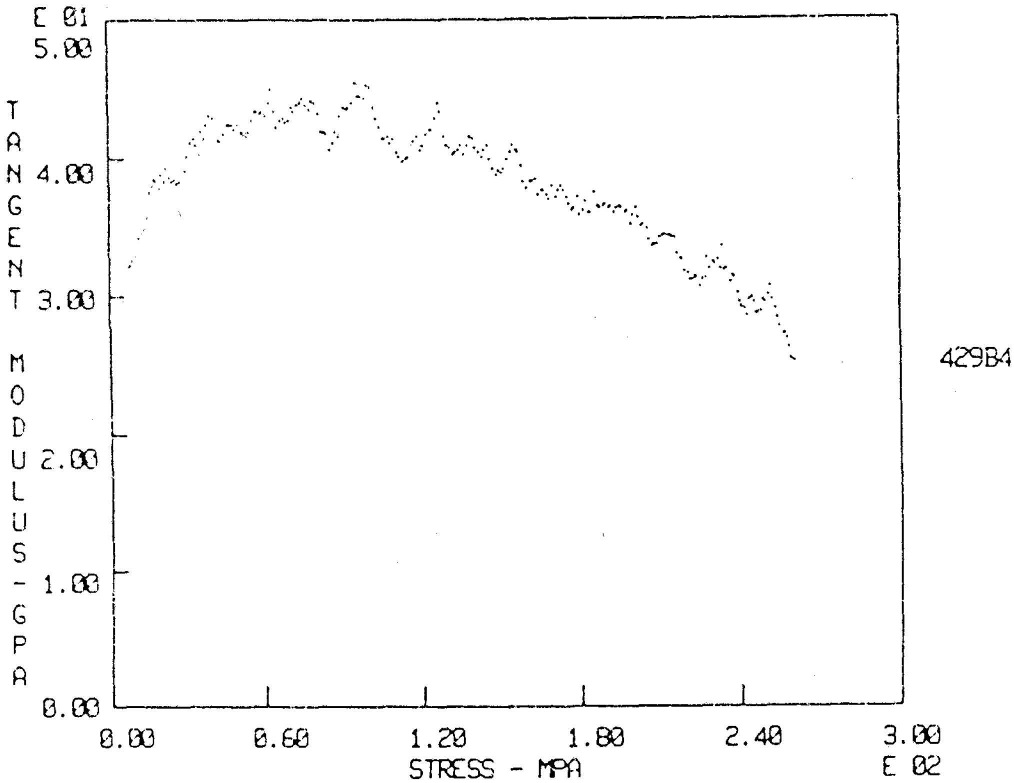


Figure 159. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Shale 42-9B. P = 30 MPa.

RSI DWG 046-82-22

RSI DWG 046-83-218



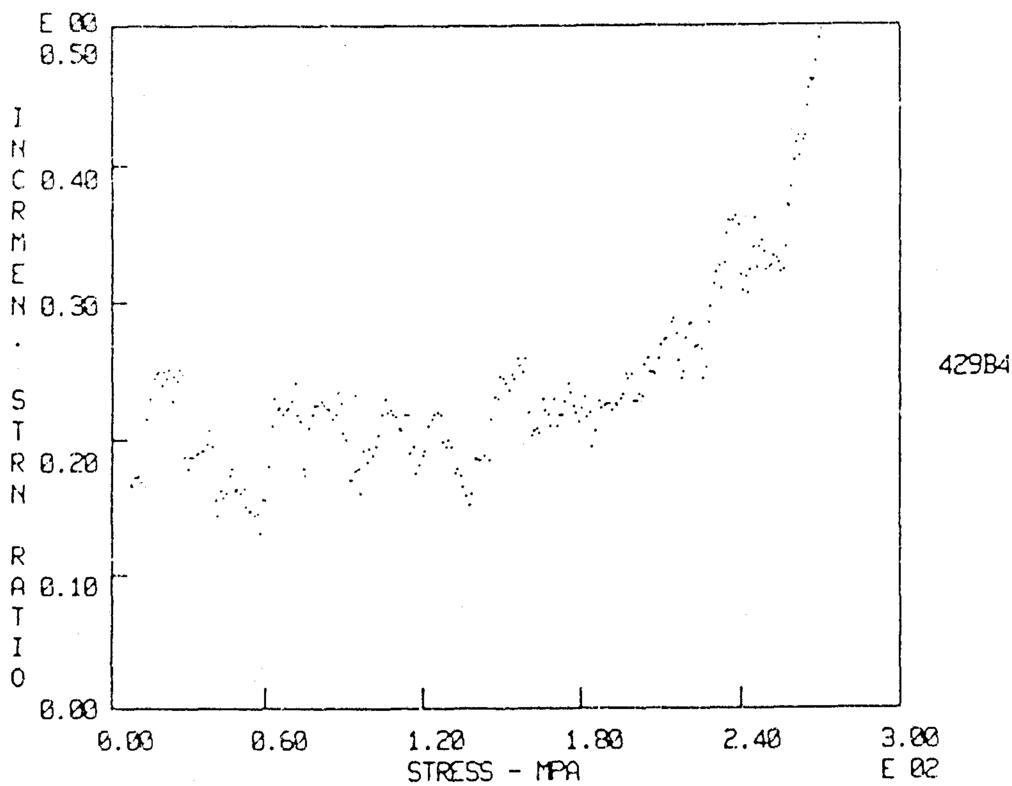


Figure 160. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Shale 42-9B (6564 Feet). P = 30 MPa.

MWX-2

MWX-2

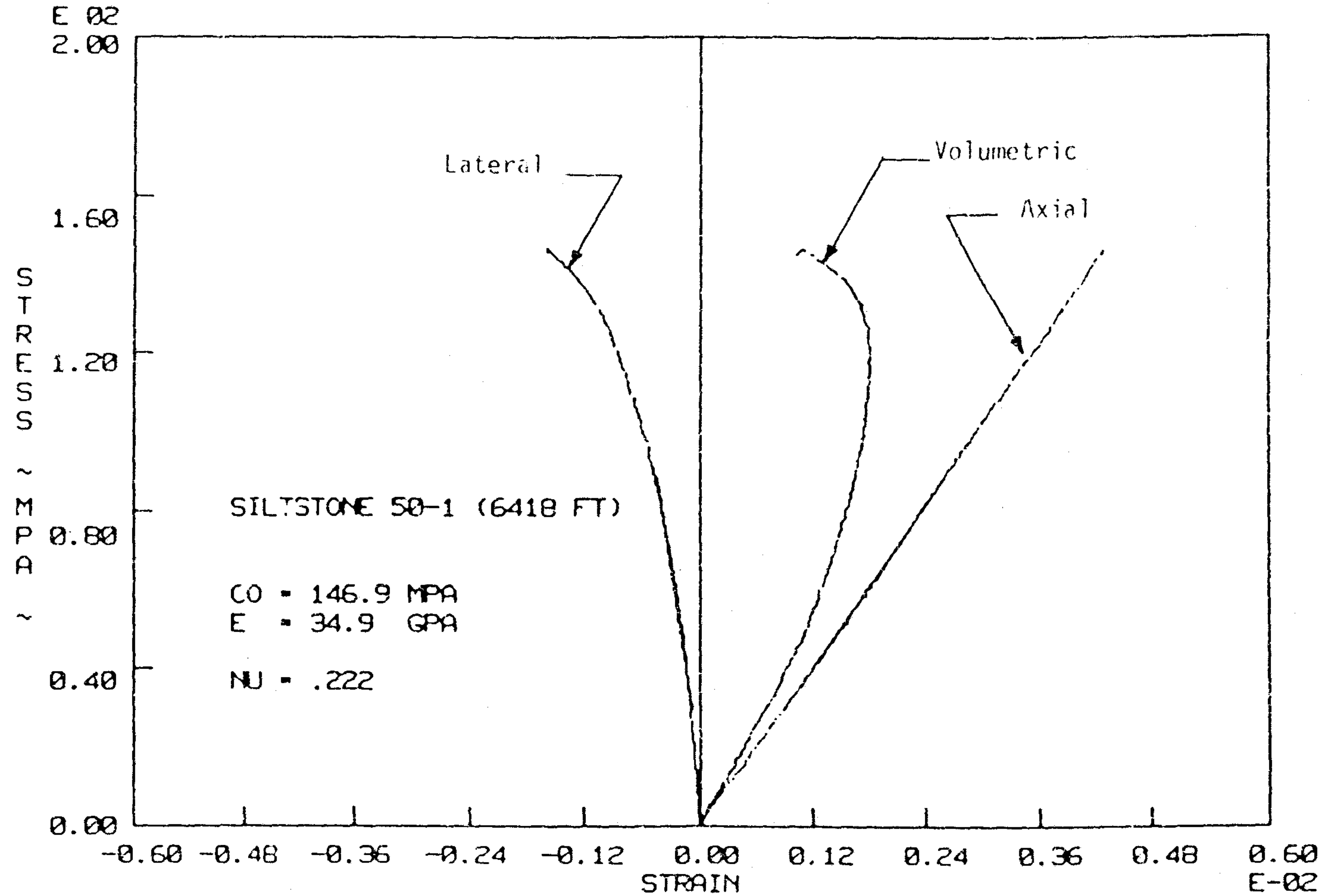


Figure 93. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Unconfined Compression of Siltstone 50-1.

RSI DWG 046-82-054

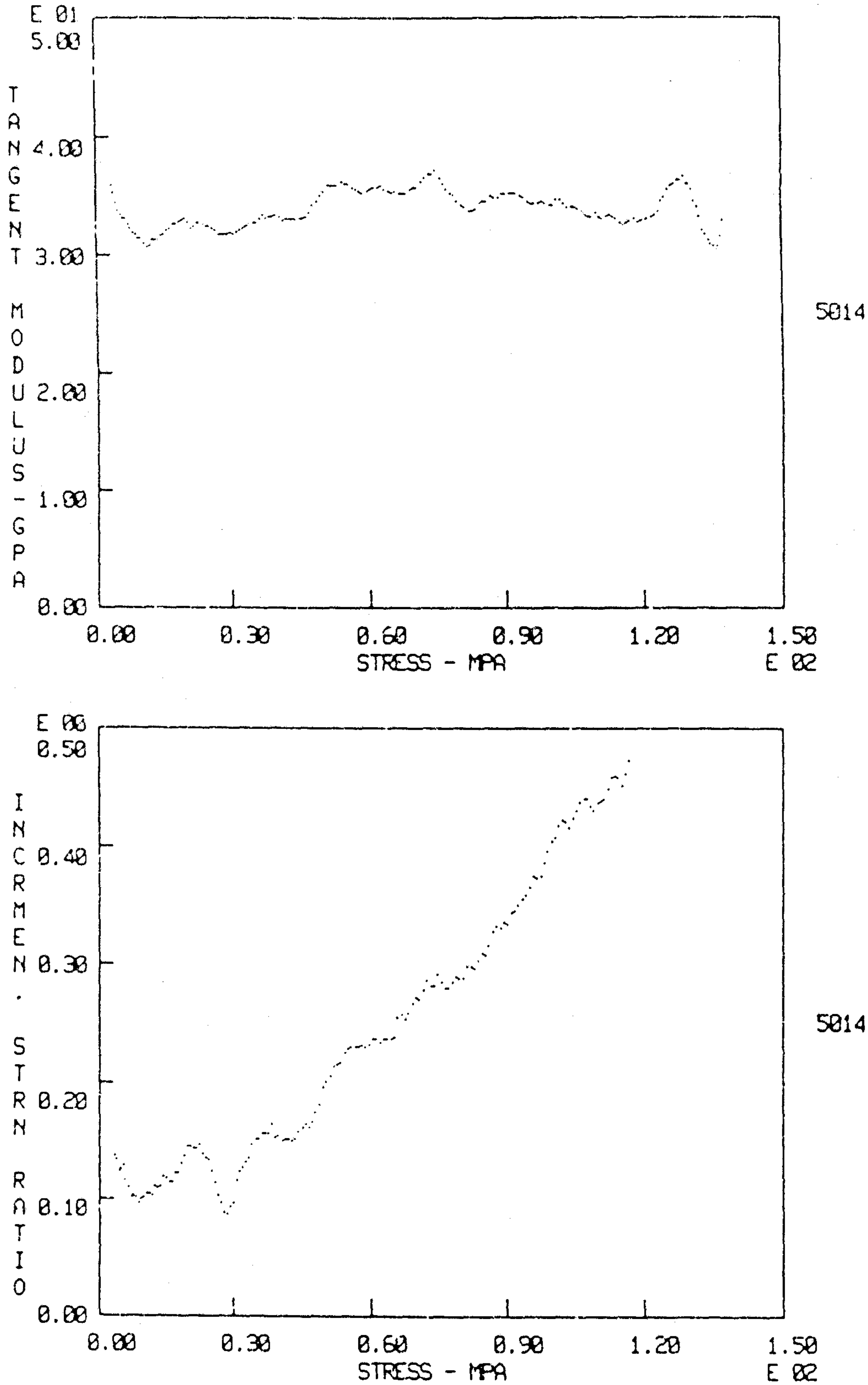


Figure 94. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Siltstone 50-1 (6418 Feet). P = 0 Mpa.

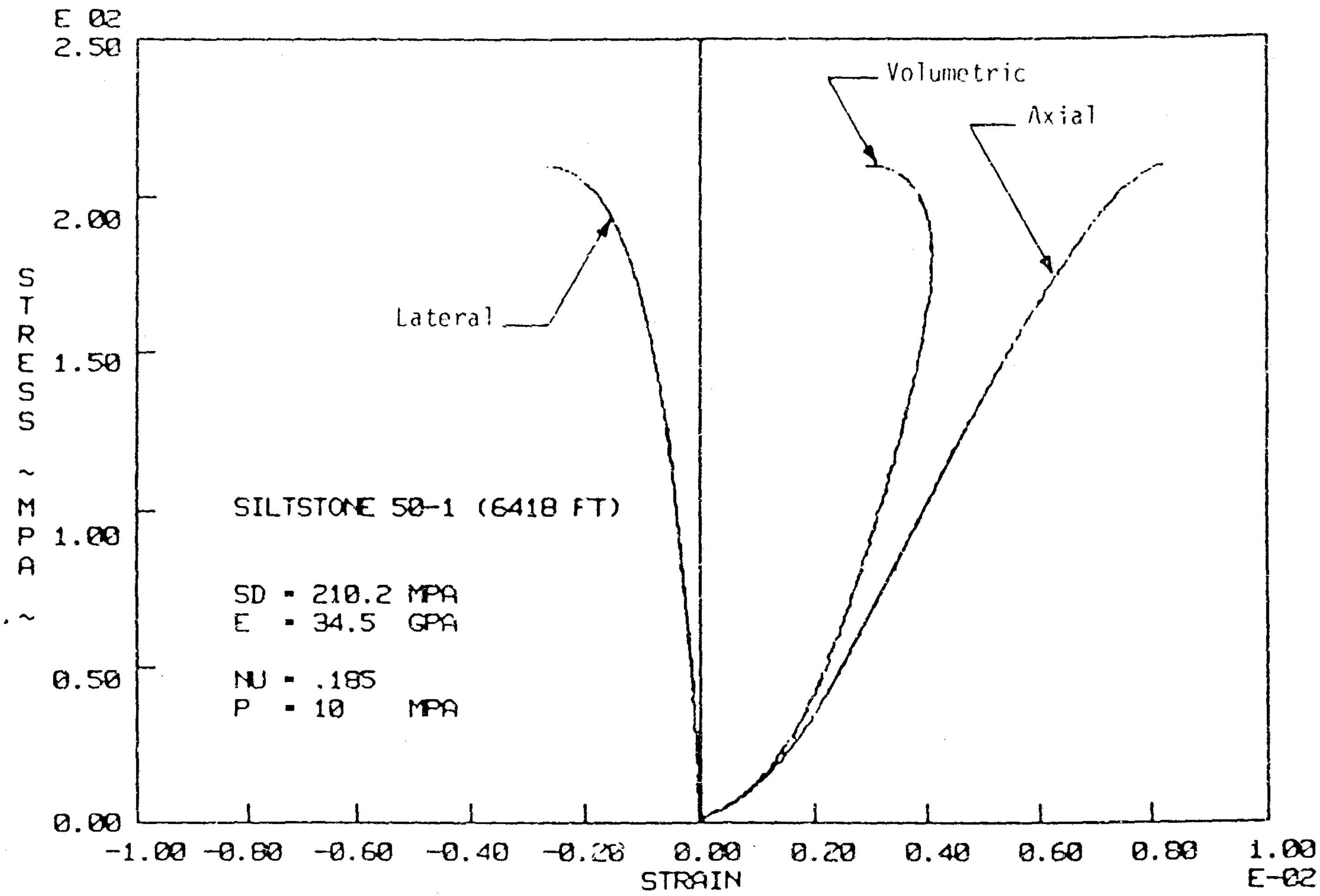
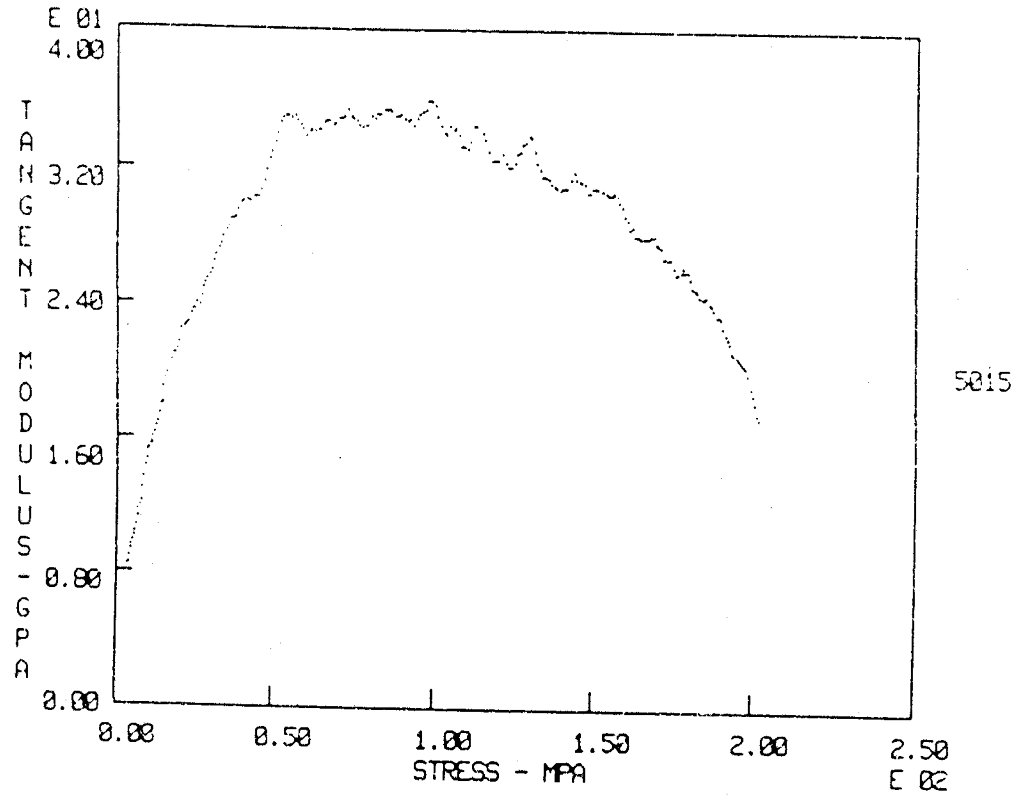


Figure 95. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Siltstone 50-1. P = 10 MPa.

RSI DWG 046-82-055



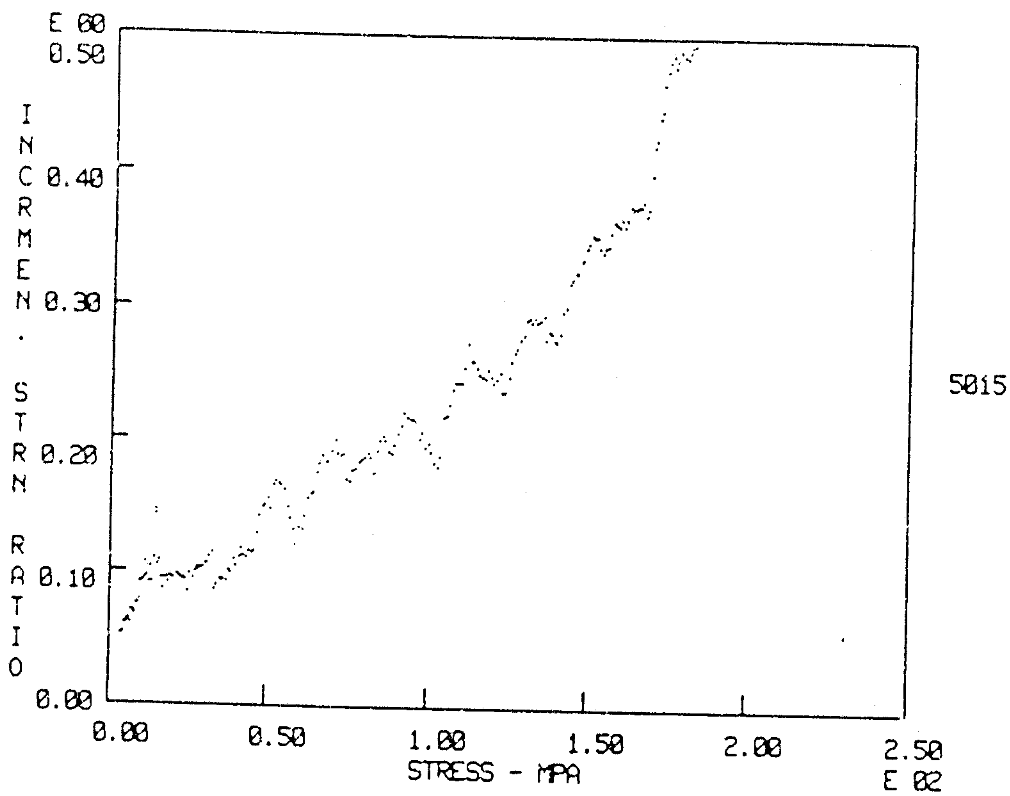


Figure 96. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Siltstone 50-1 (6418 Feet). P = 10 MPa.

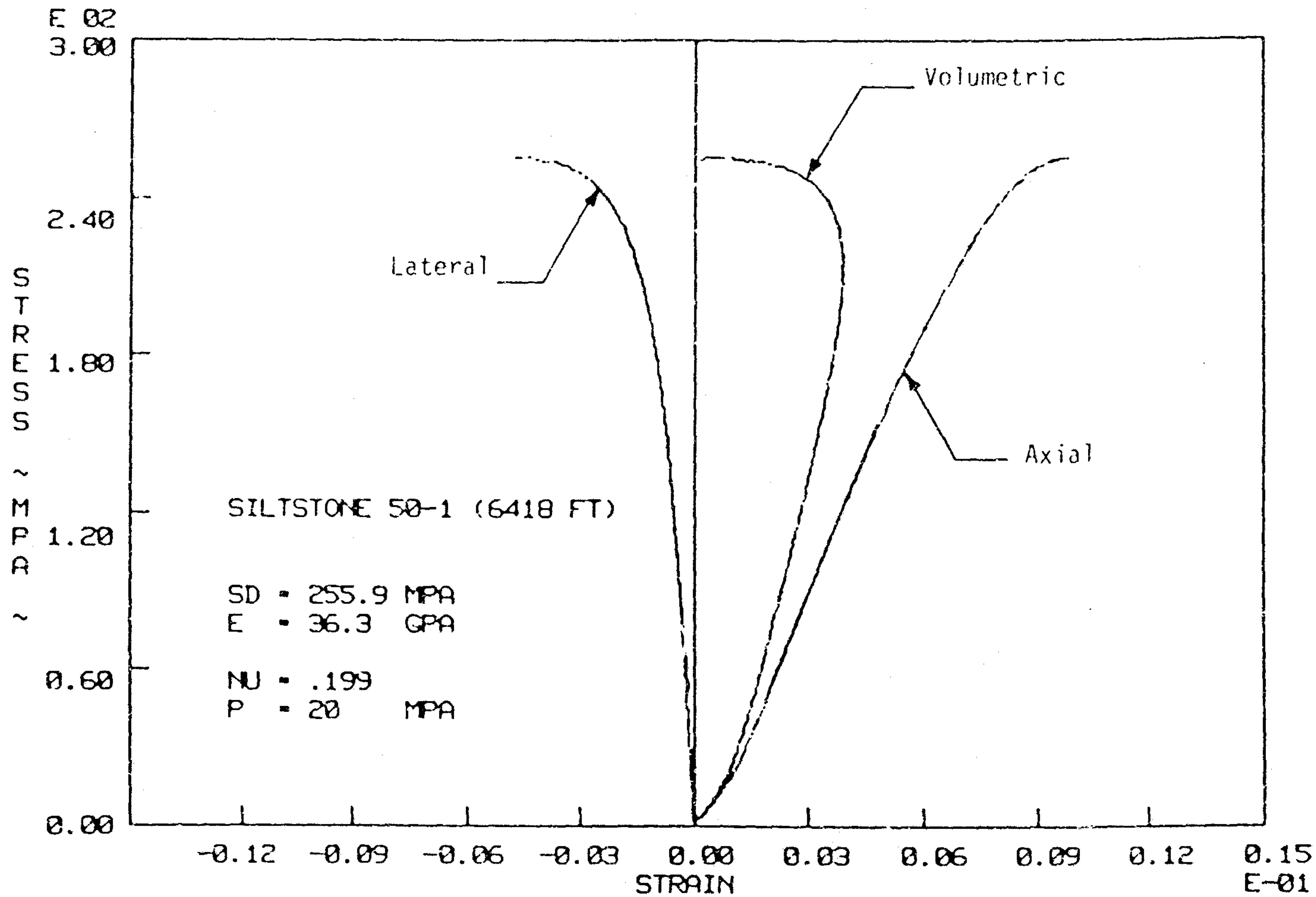
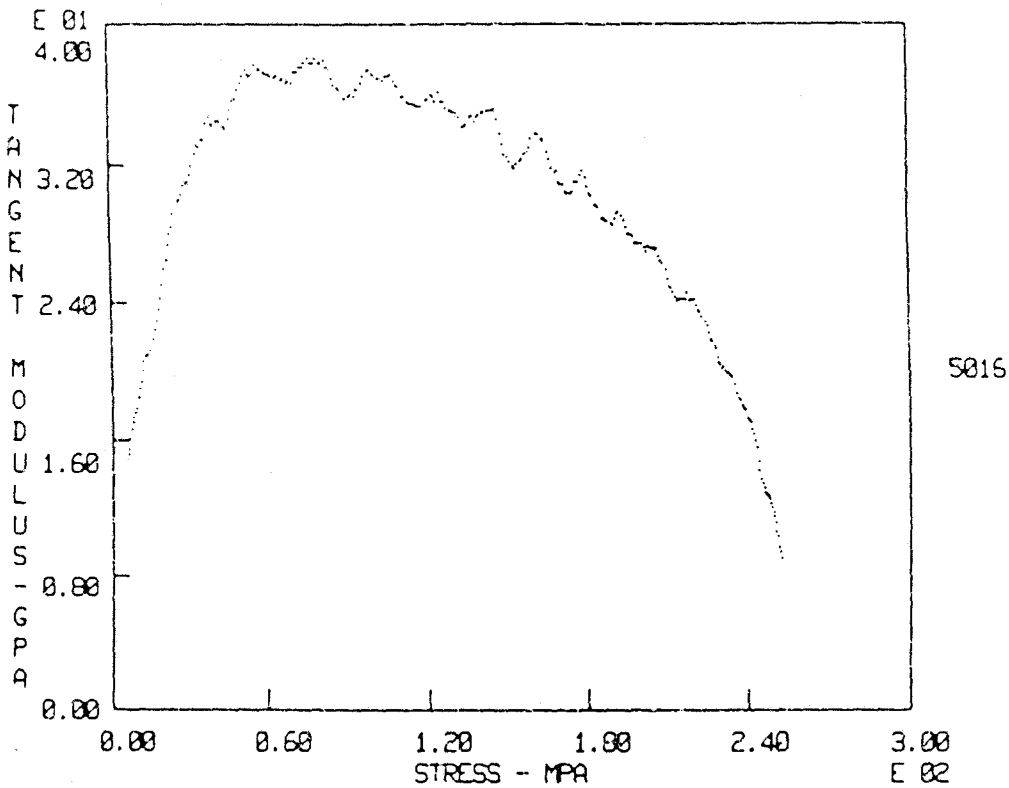


Figure 97. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Siltstone 50-1. P = 20 MPa.

RSI DWG 046-82-056



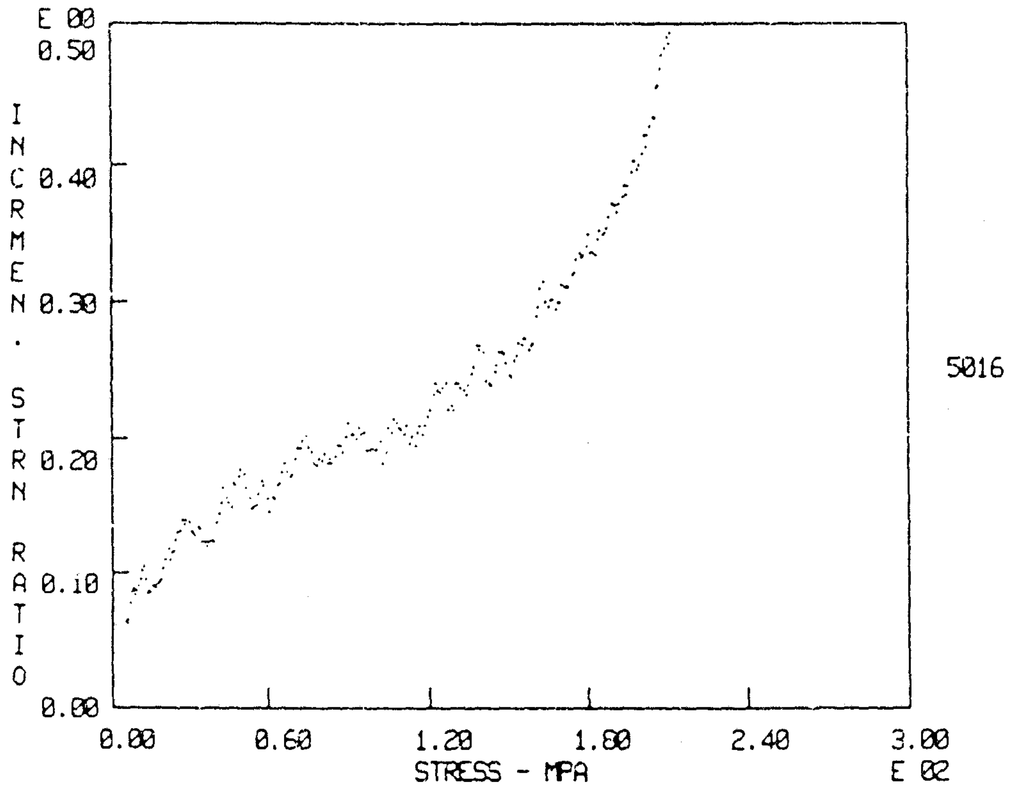


Figure 98. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Siltstone 50-1 (6418 Feet). P = 20 Mpa.

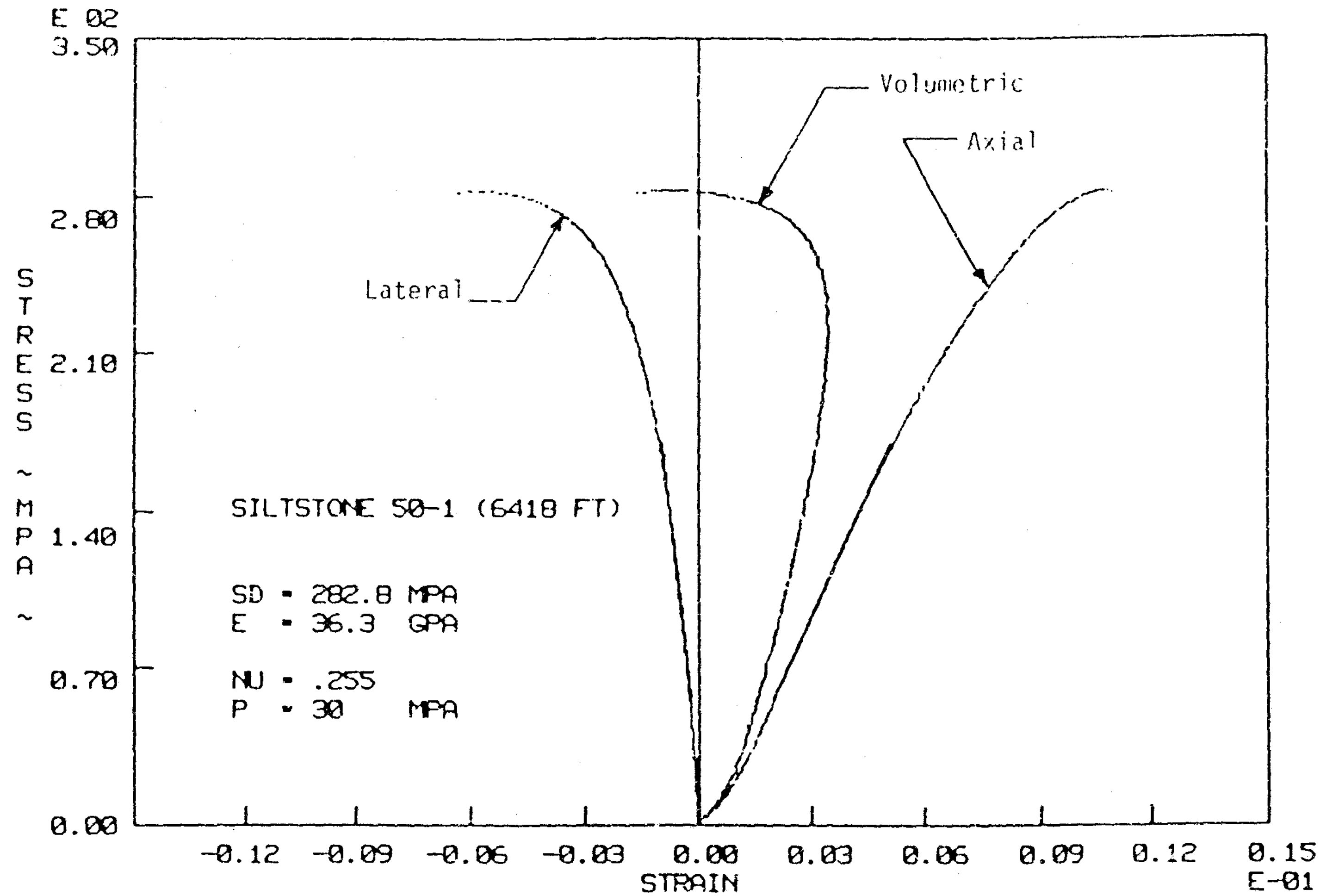
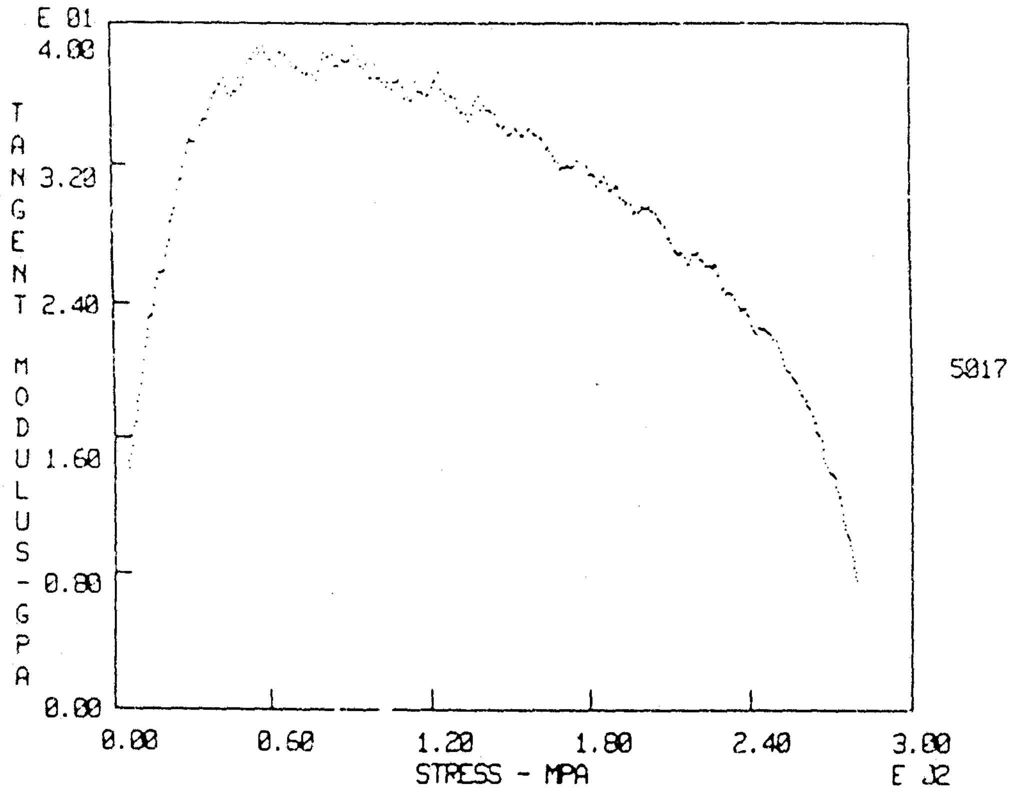


Figure 99. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Siltstone 50-1. P = 30 MPa.

RSI DWG 046-82-057



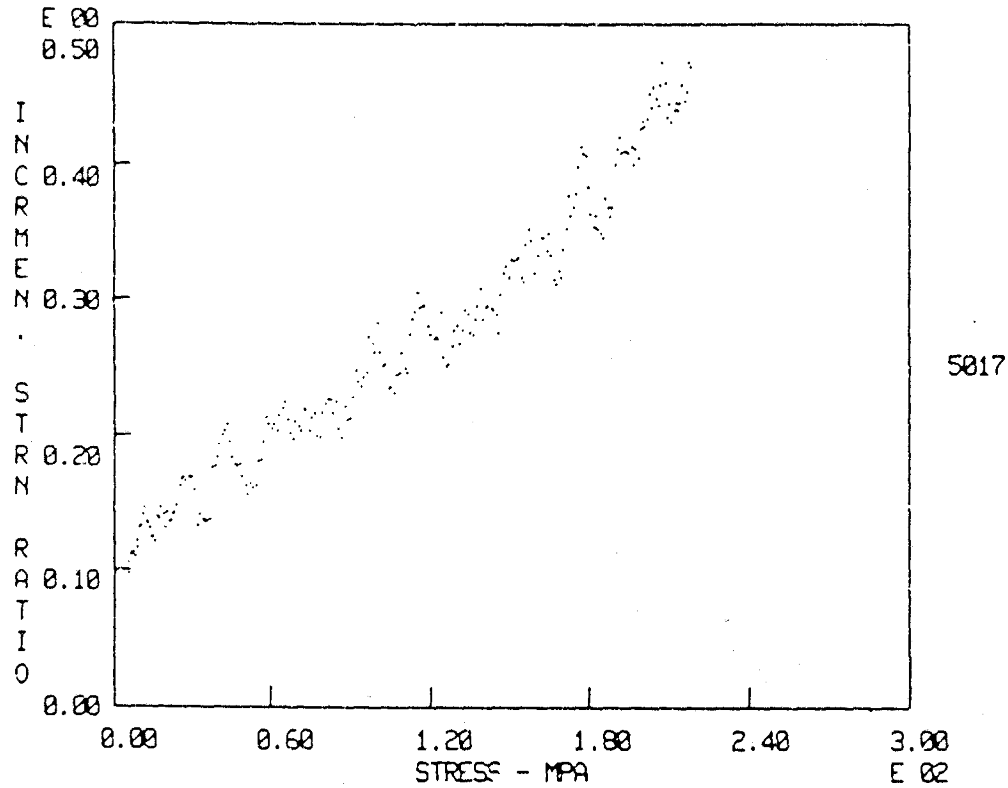


Figure 100. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Siltstone 50-1 (6418 Feet). P = 30 MPa.

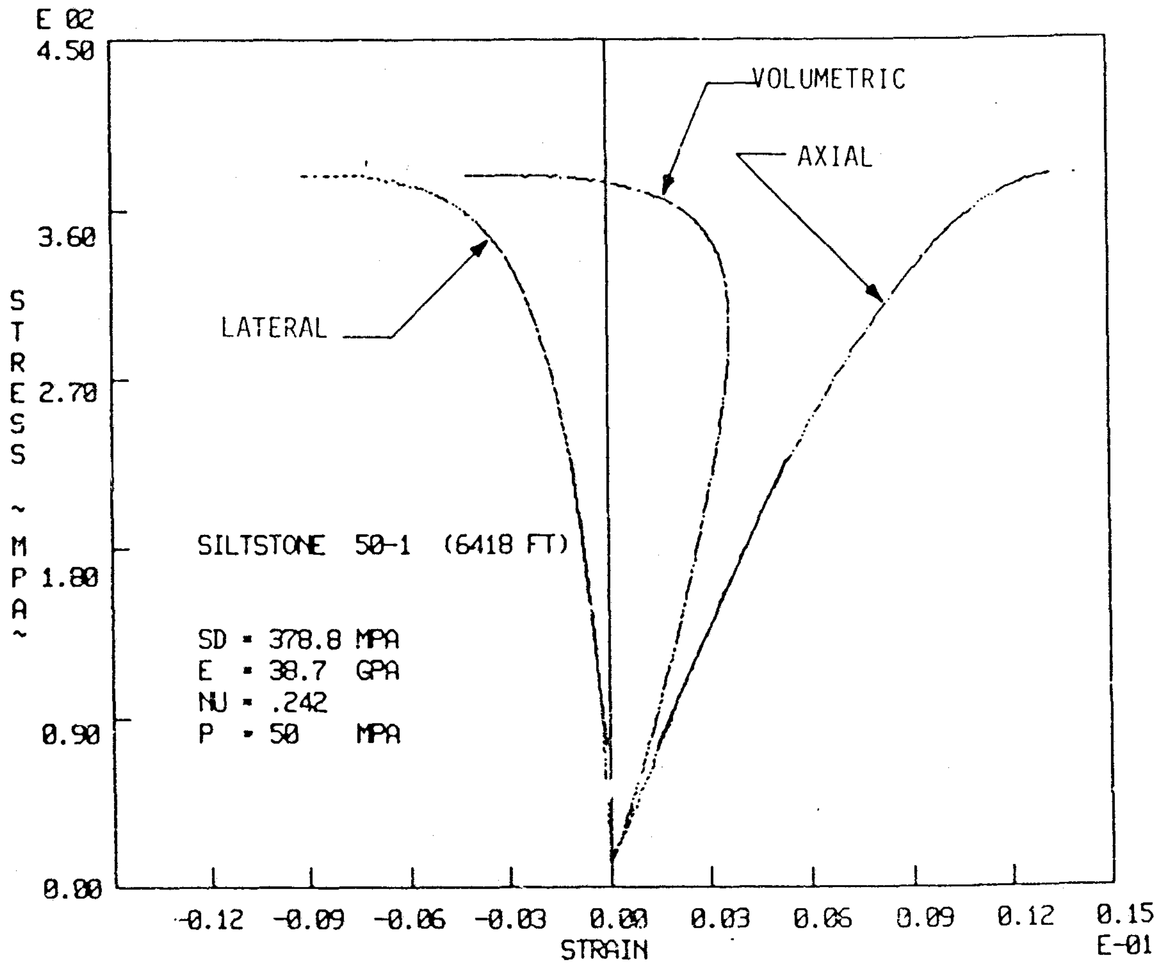
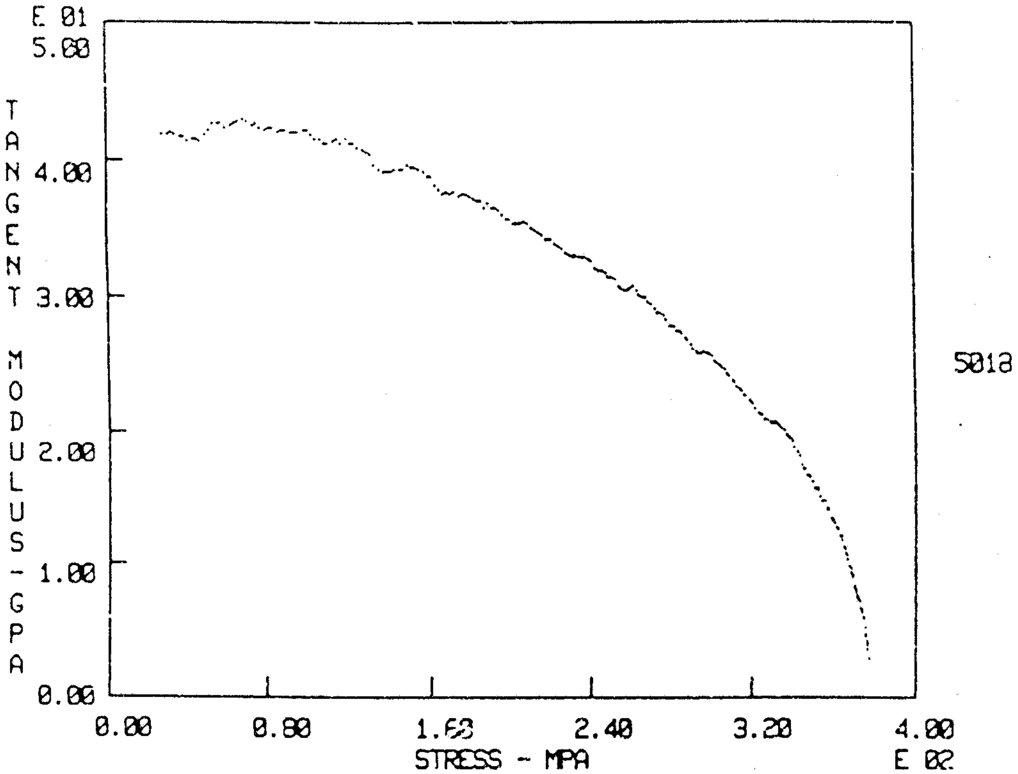


Figure 101. Axial Stress Difference Verus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Siltstone 50-1. P = 50 MPa.

RSI DWG 046-83-96



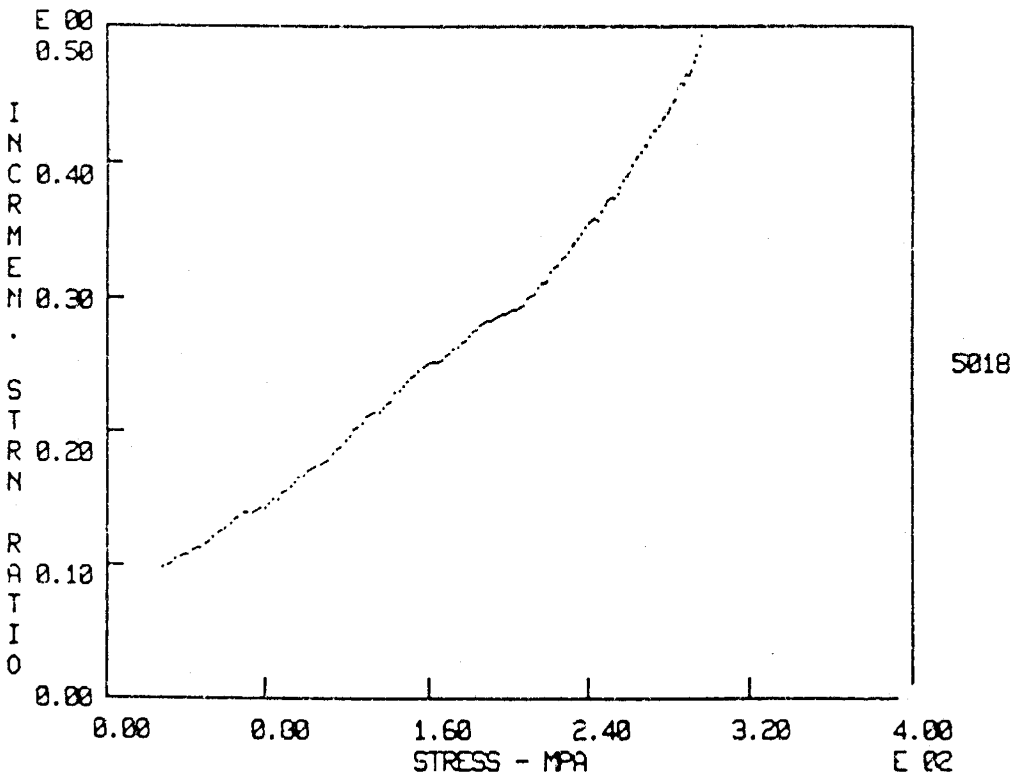


Figure 102. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Siltstone 50-1 (6418 Feet). P = 50 MPa.

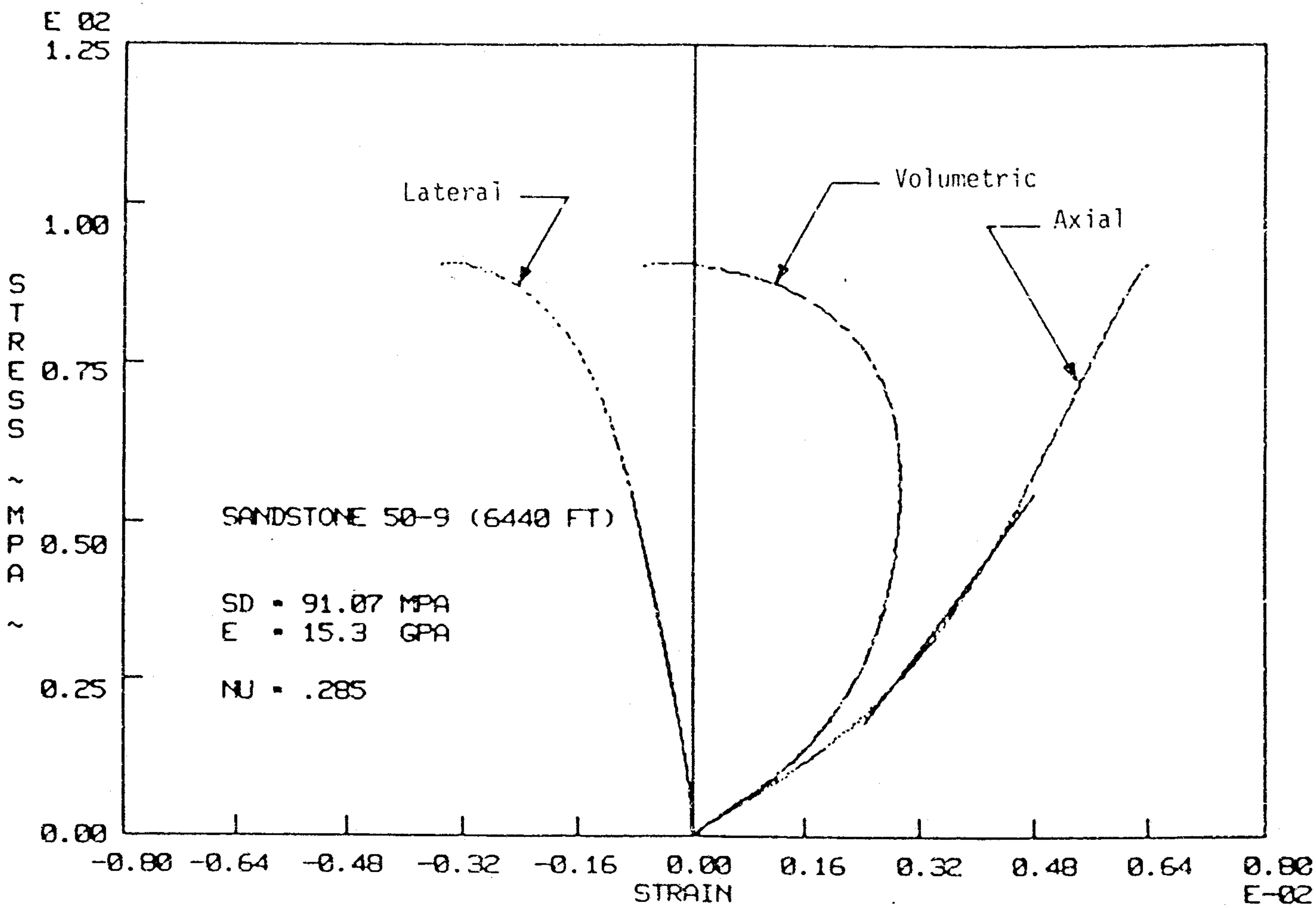


Figure 103. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Unconfined Compression of Sandstone 50-9.

RSI DWG 046-82-058

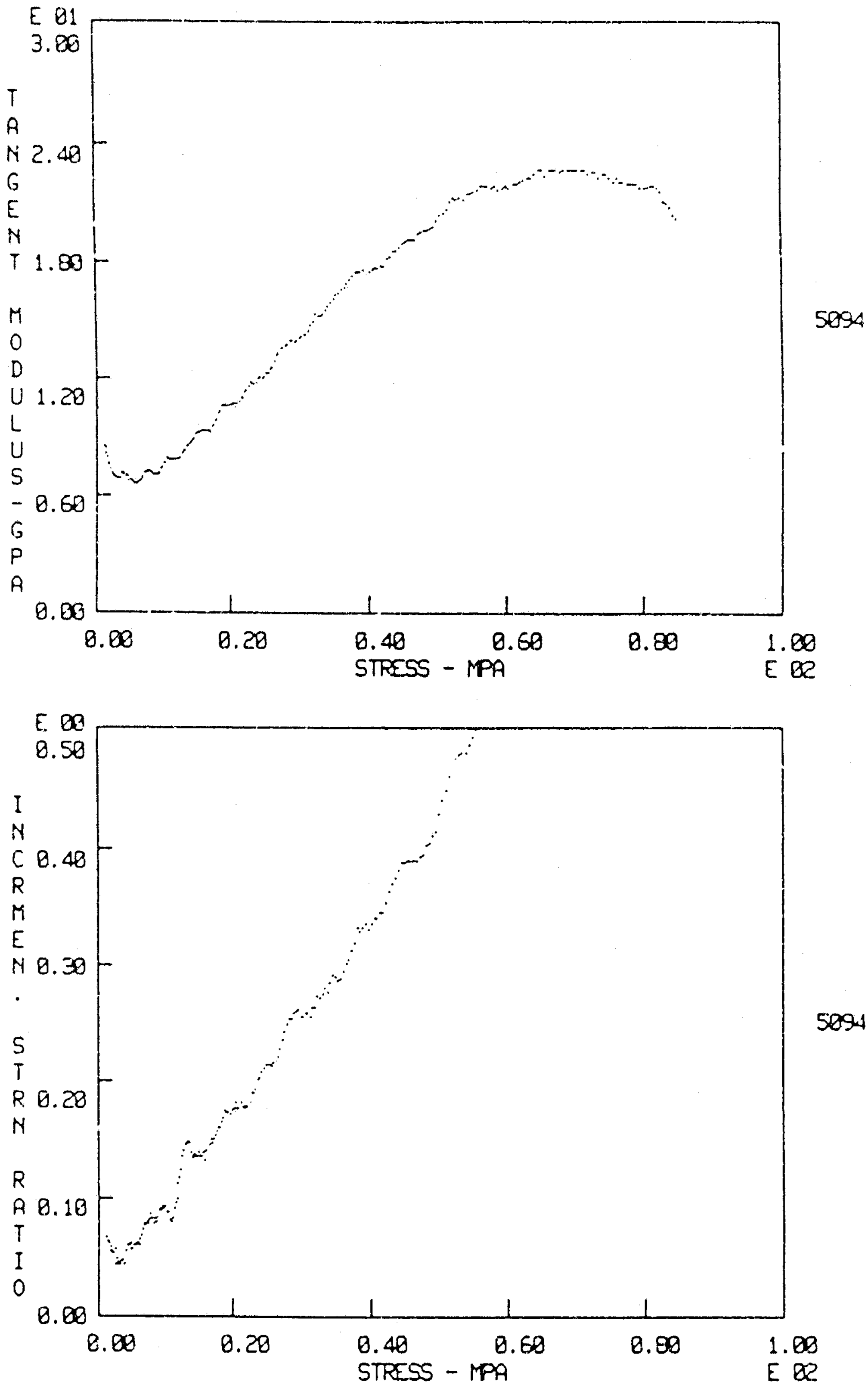


Figure 104. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 50-9 (6440 Feet). P = 0 MPa.

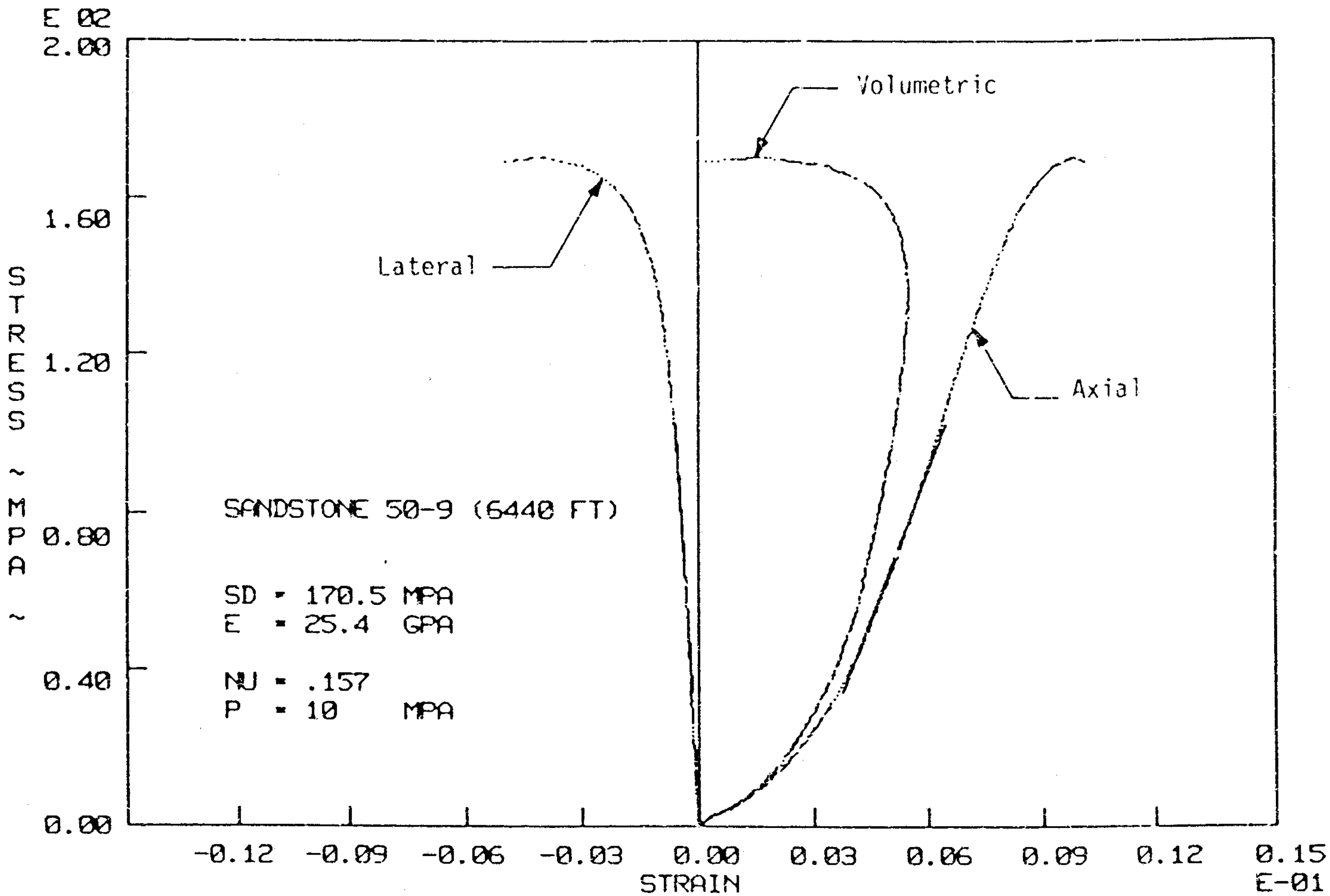


Figure 105. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 50-9. P = 10 MPa.

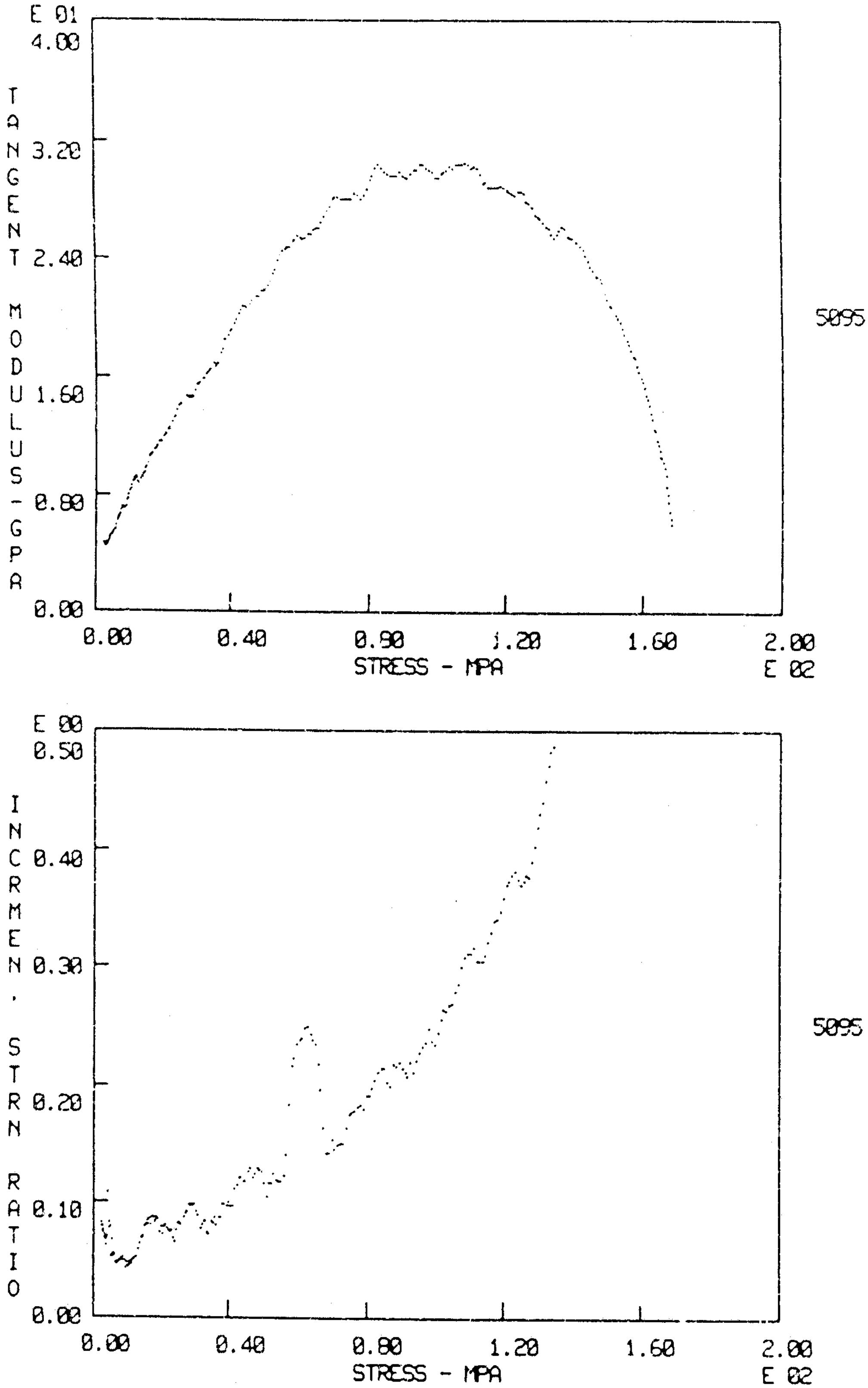


Figure 106. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 50-9 (6440 Feet). P = 10 MPa.

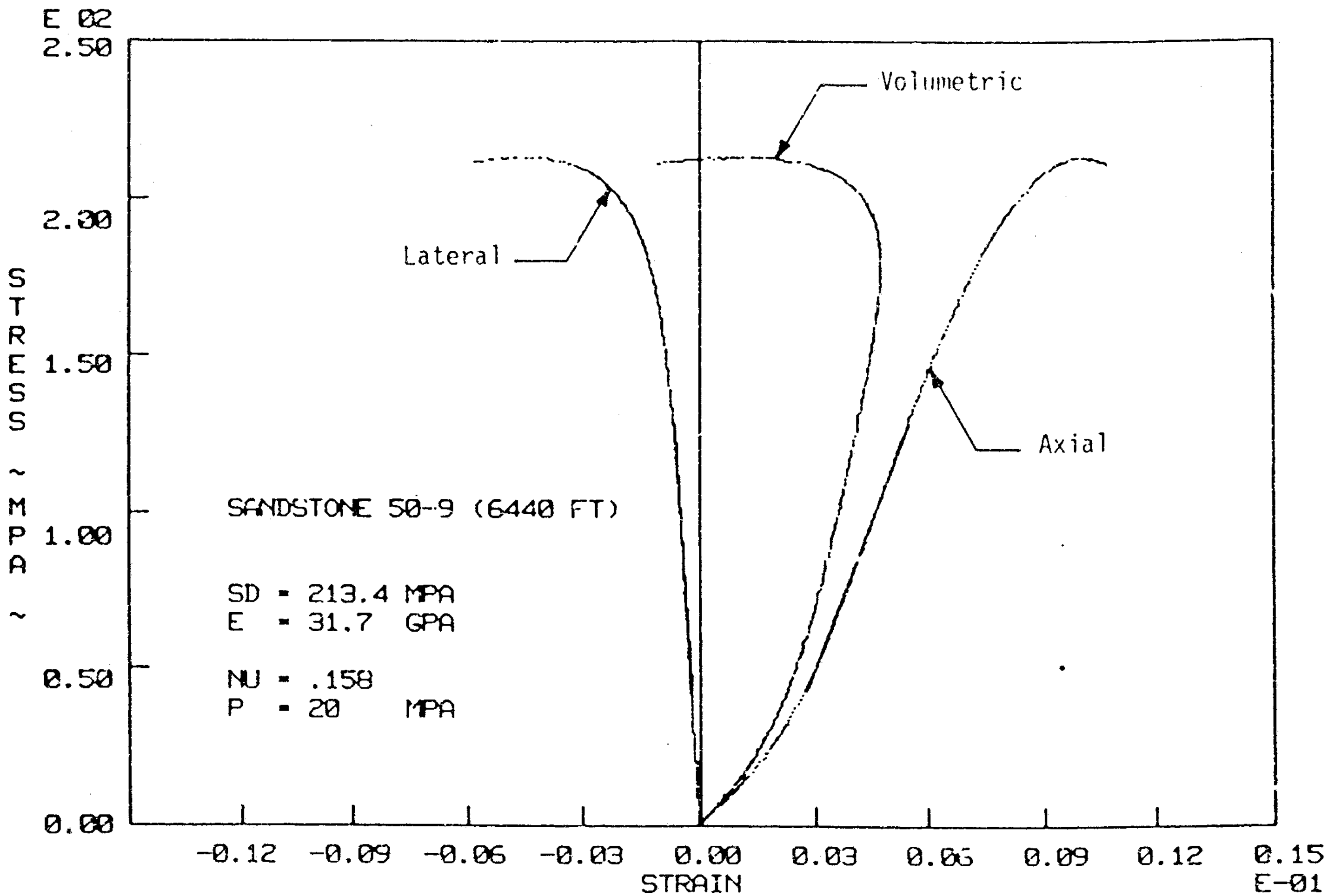
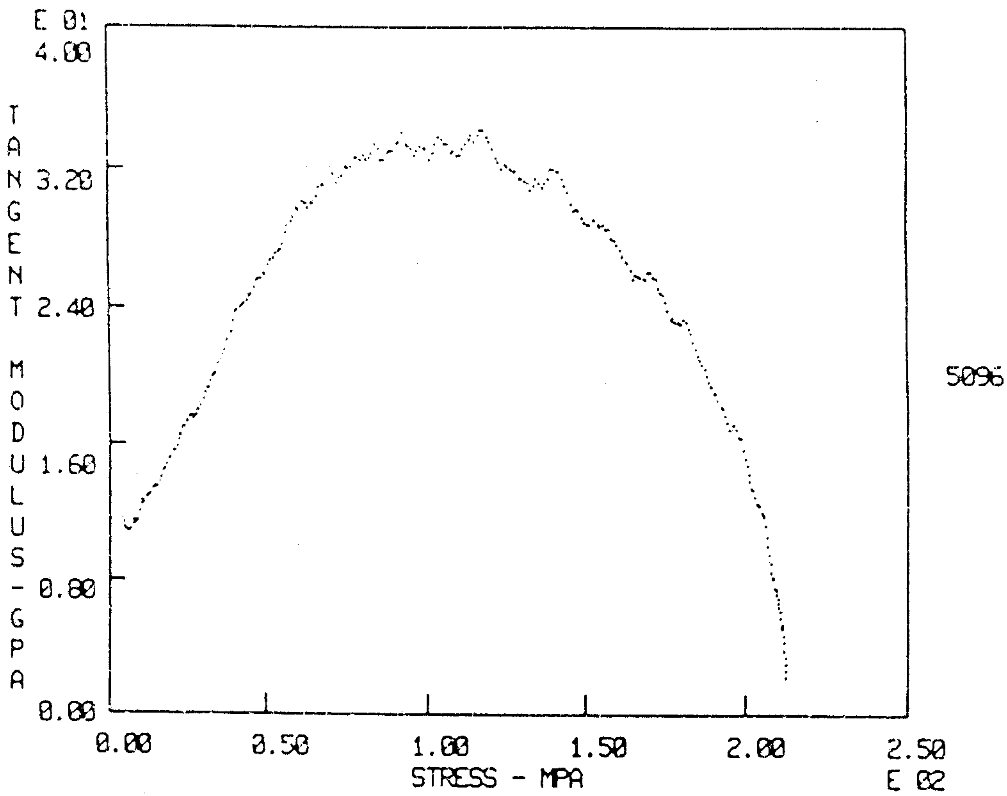


Figure 107. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 50-9. P = 20 MPa.

RSI DWG 046-82-060



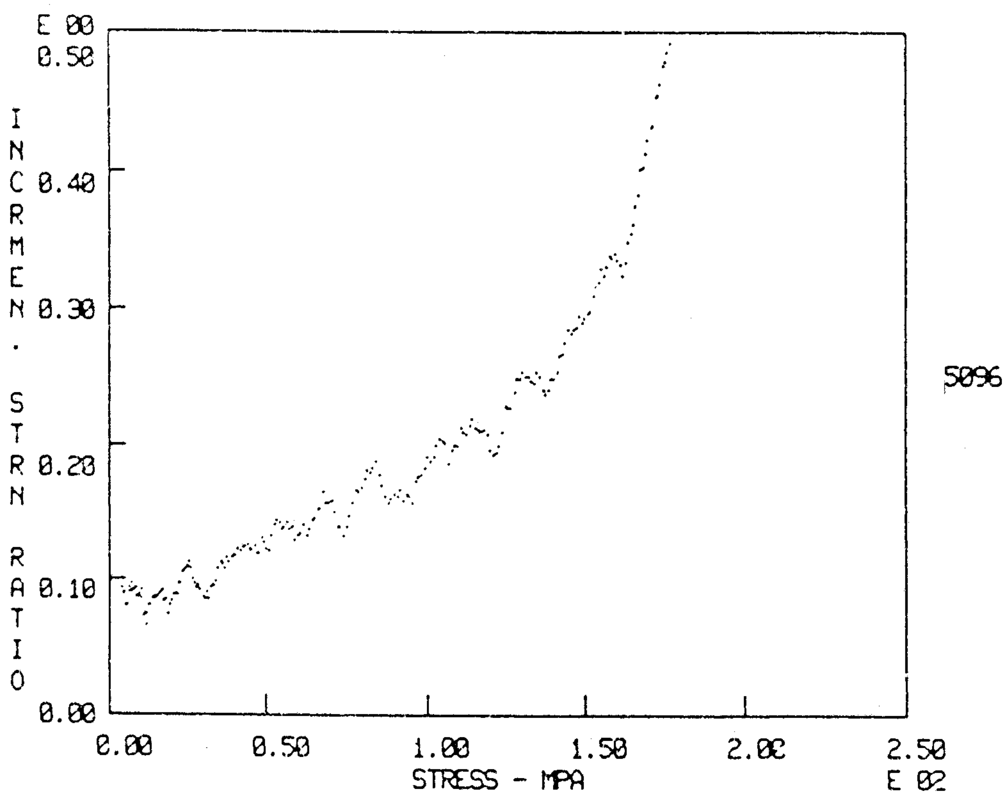


Figure 108. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 50-9 (6440 Feet). P = 20 MPa.

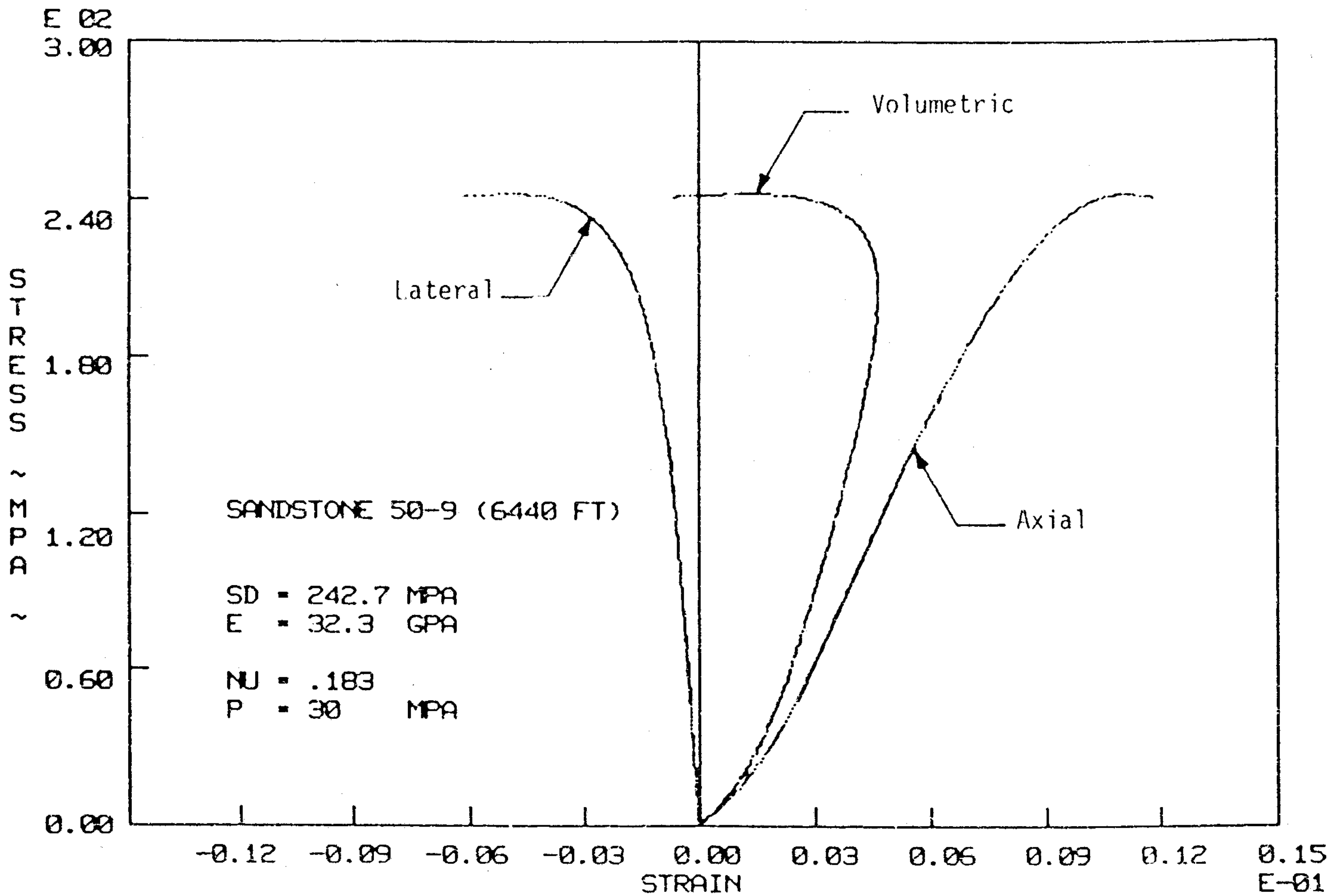
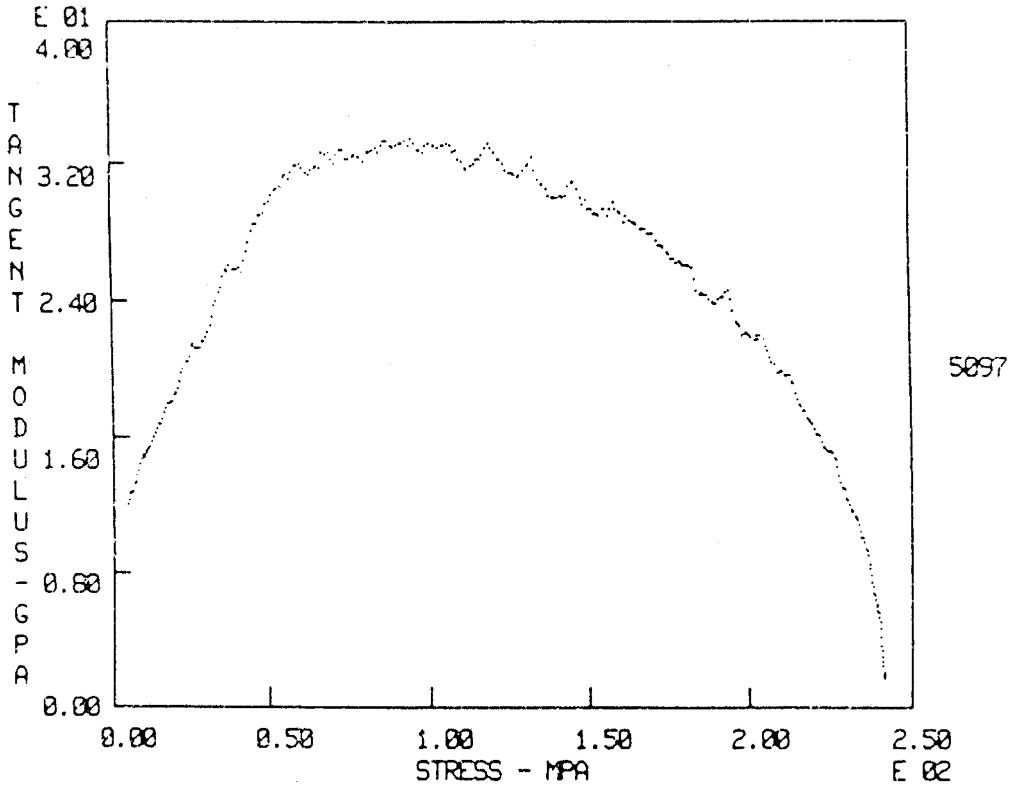


Figure 109. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 50-9. P = 30 MPa.

RSI DWG 046-82-061



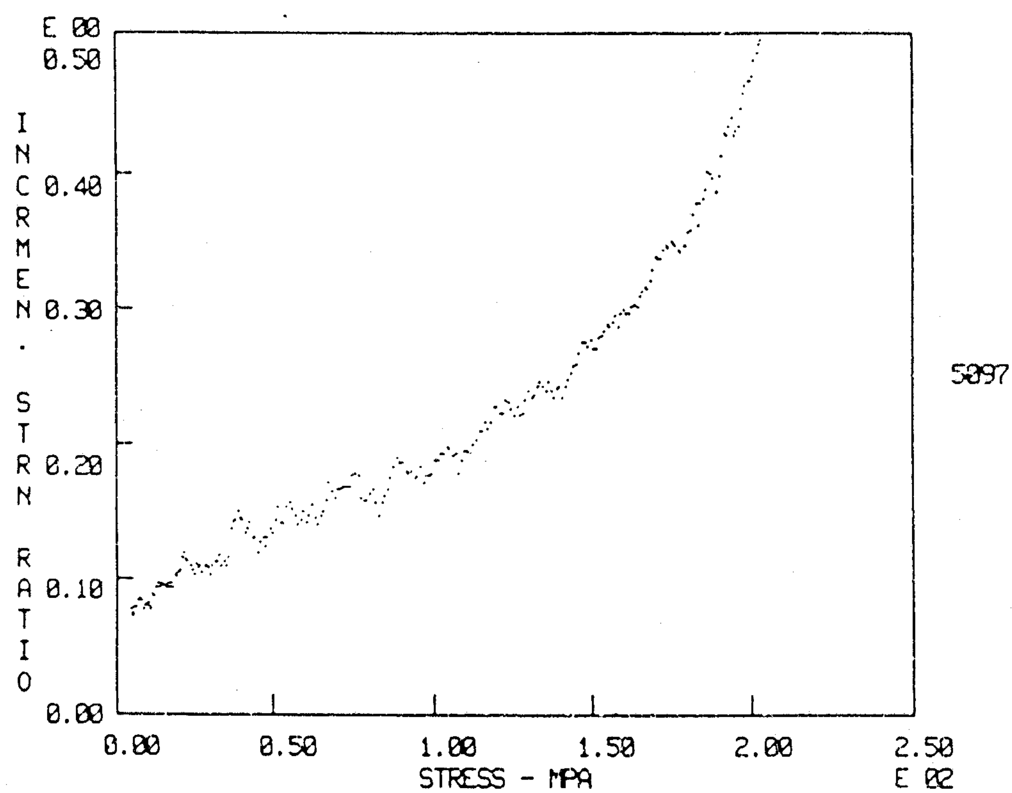


Figure 110. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 50-9 (6440 Feet). P = 30 MPa.

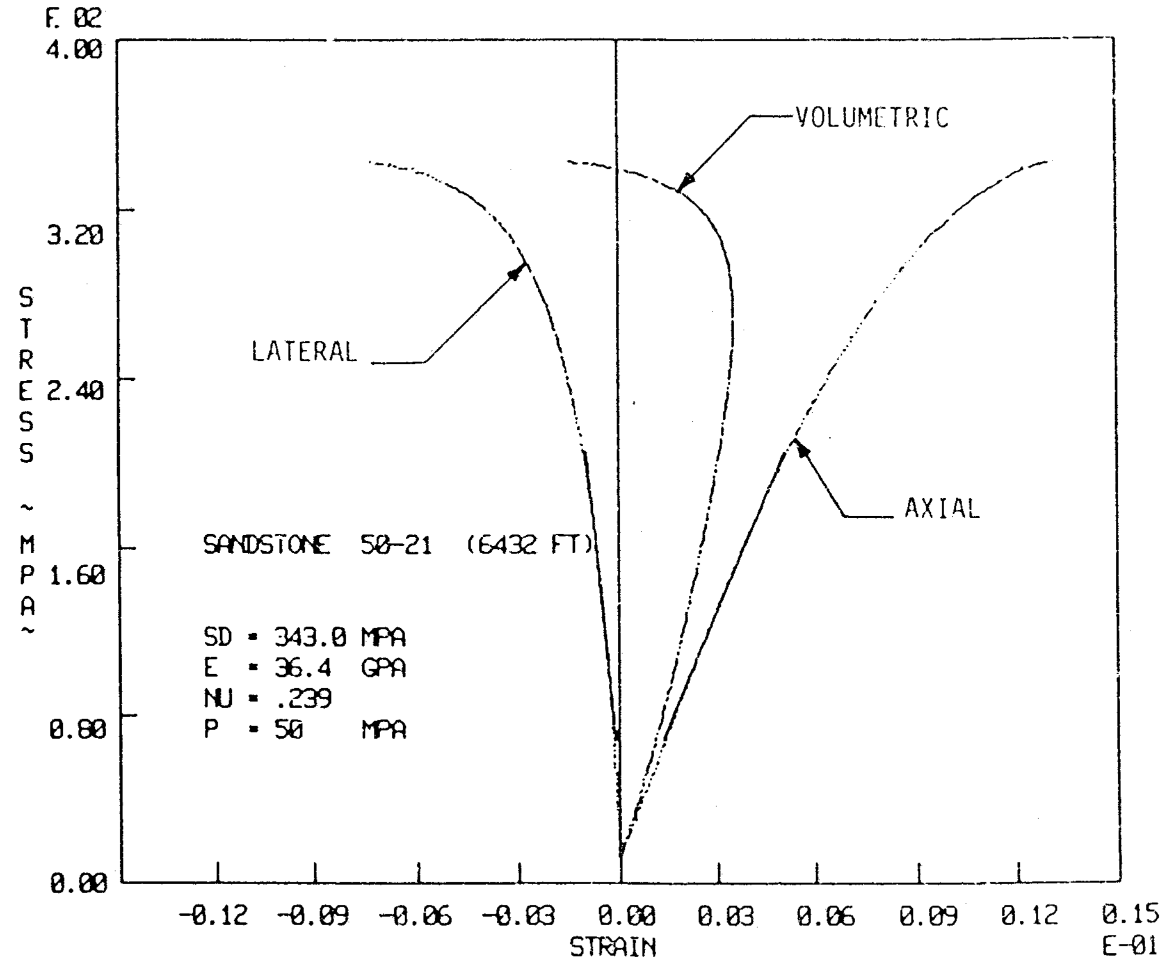
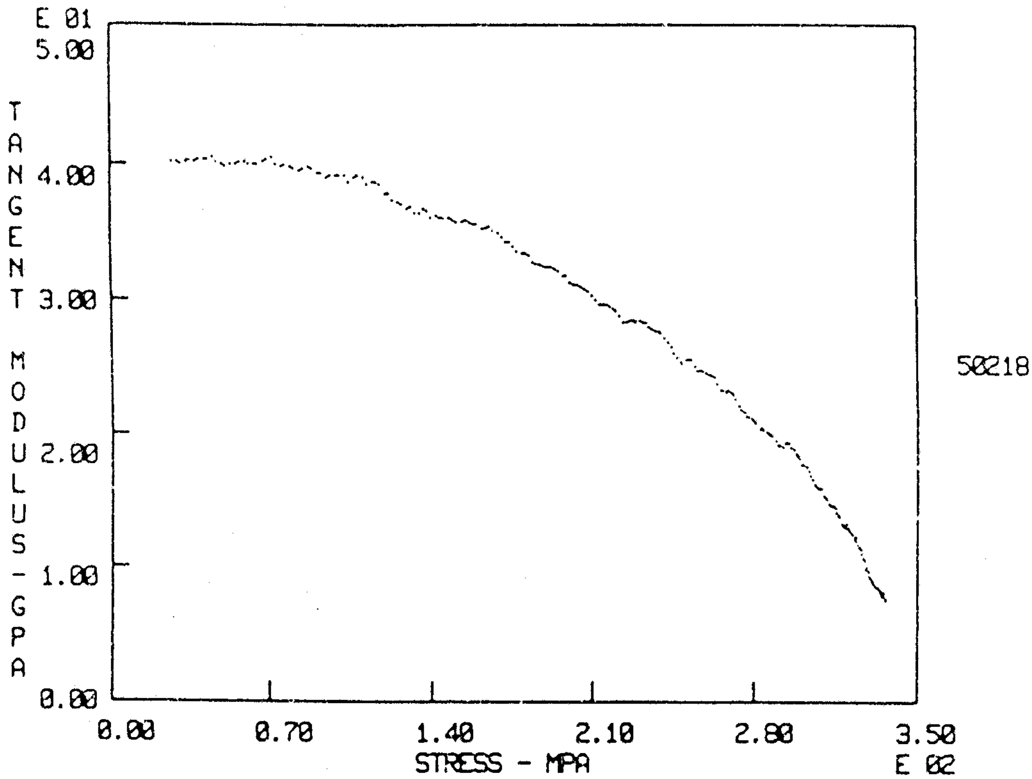


Figure 111. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 50-21. P = 50 MPa.



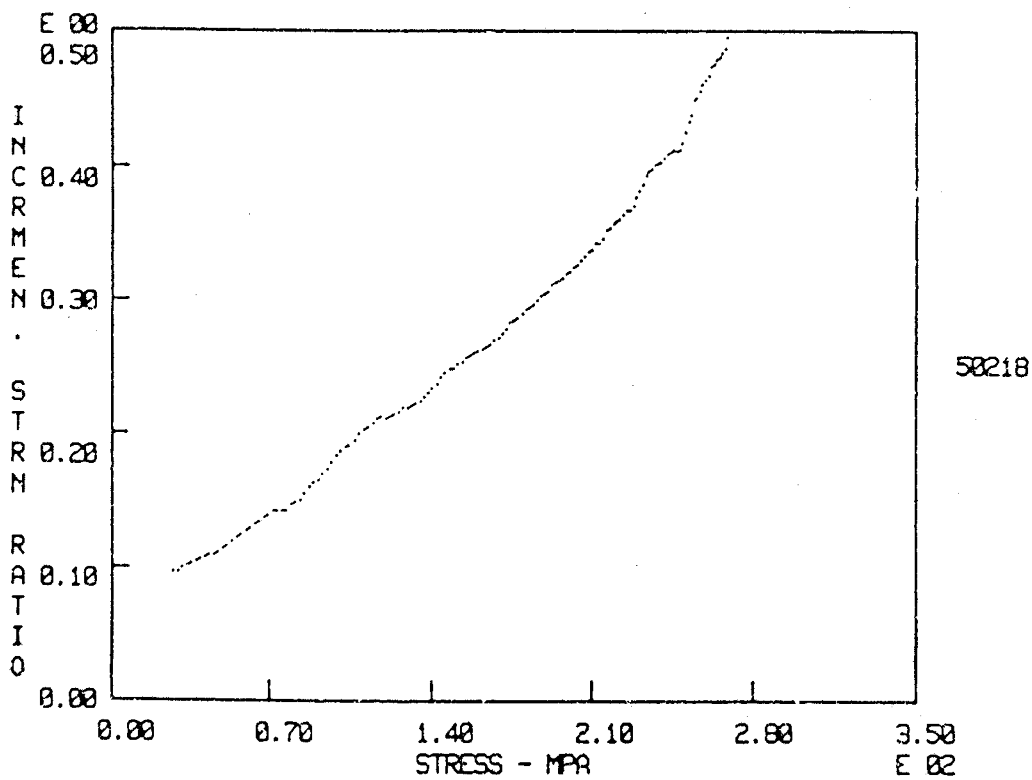


Figure 112. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 50-21 (6432 Feet). P = 50 MPa.

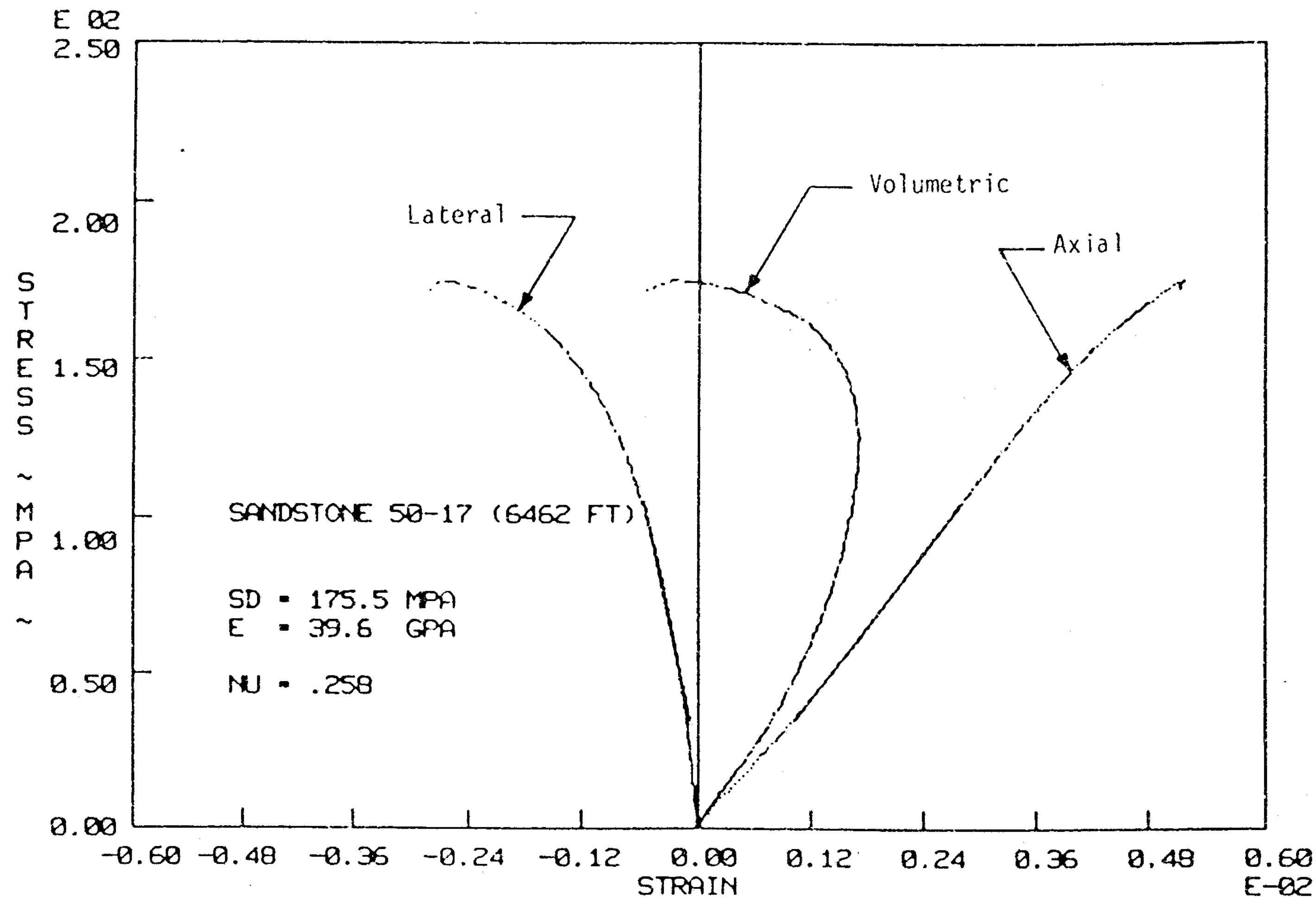
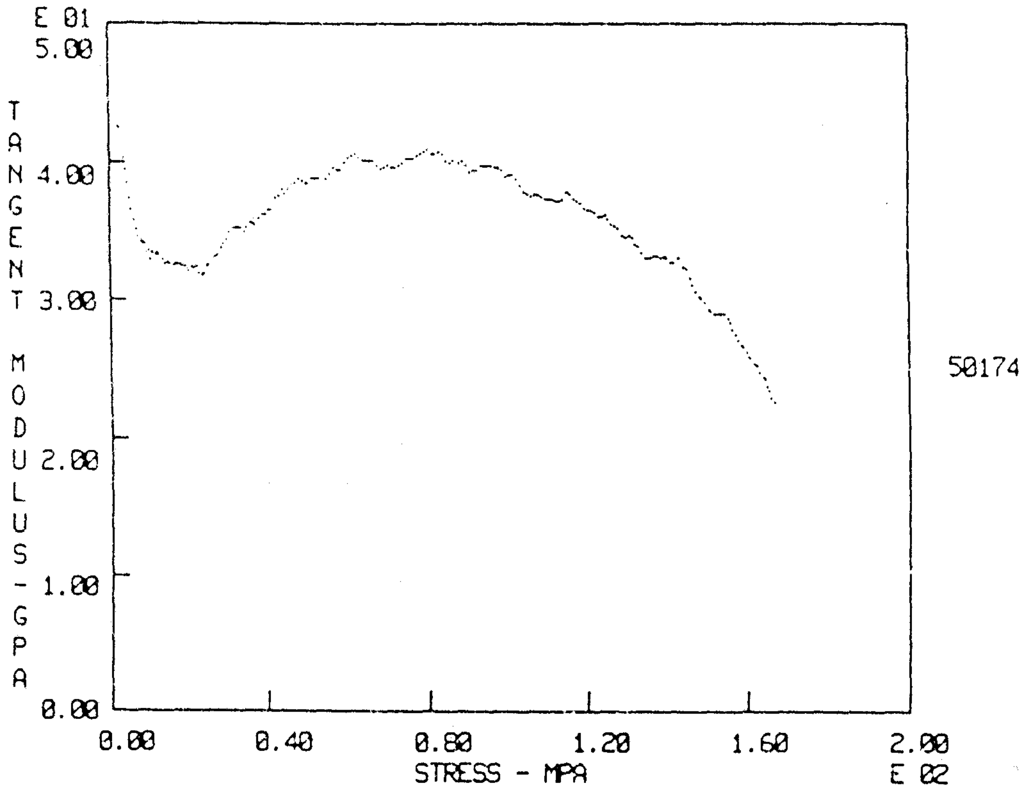


Figure 113. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Unconfined Compression of Sandstone 50-17.

RSI DWG 046-82-062



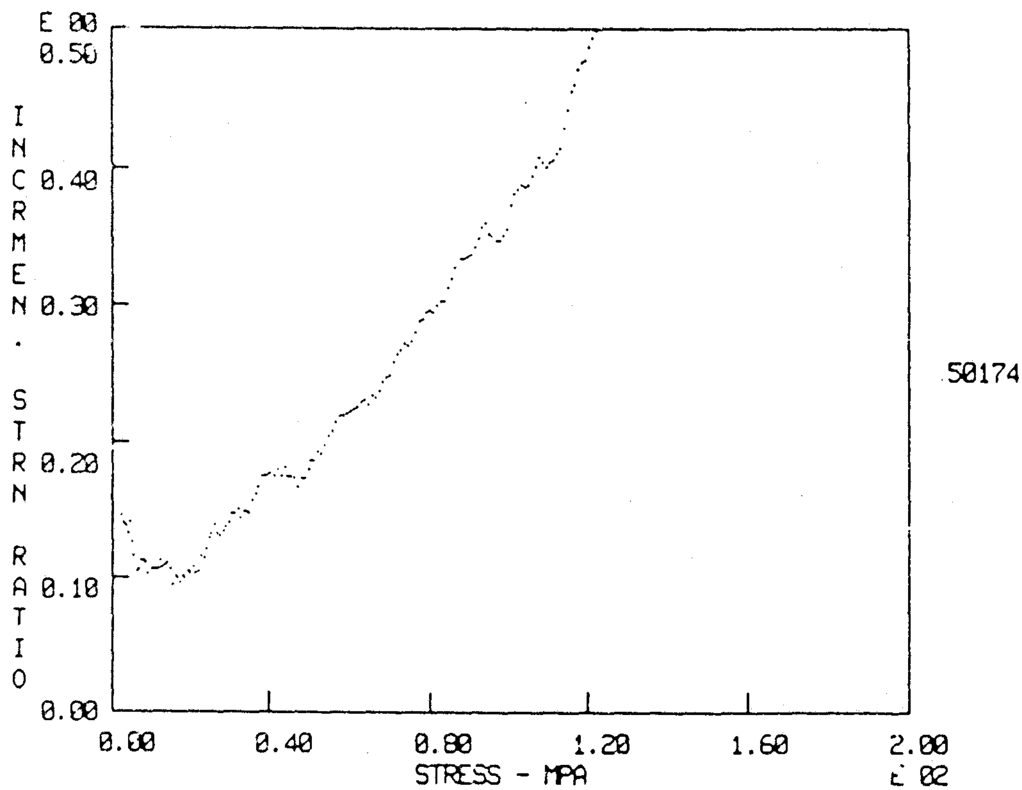


Figure 1.14. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 50-17 (6462 Feet). P = 0 MPa.

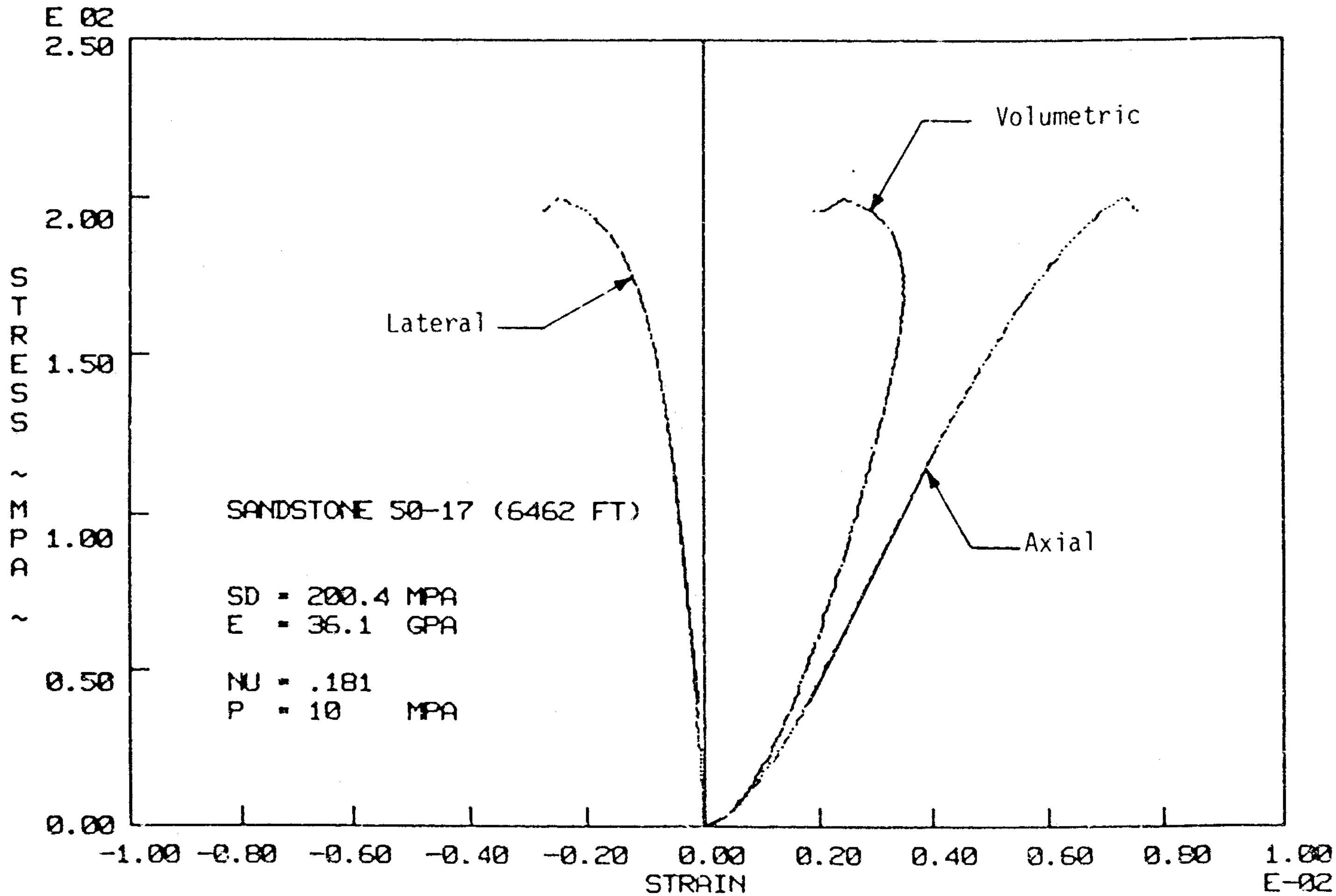
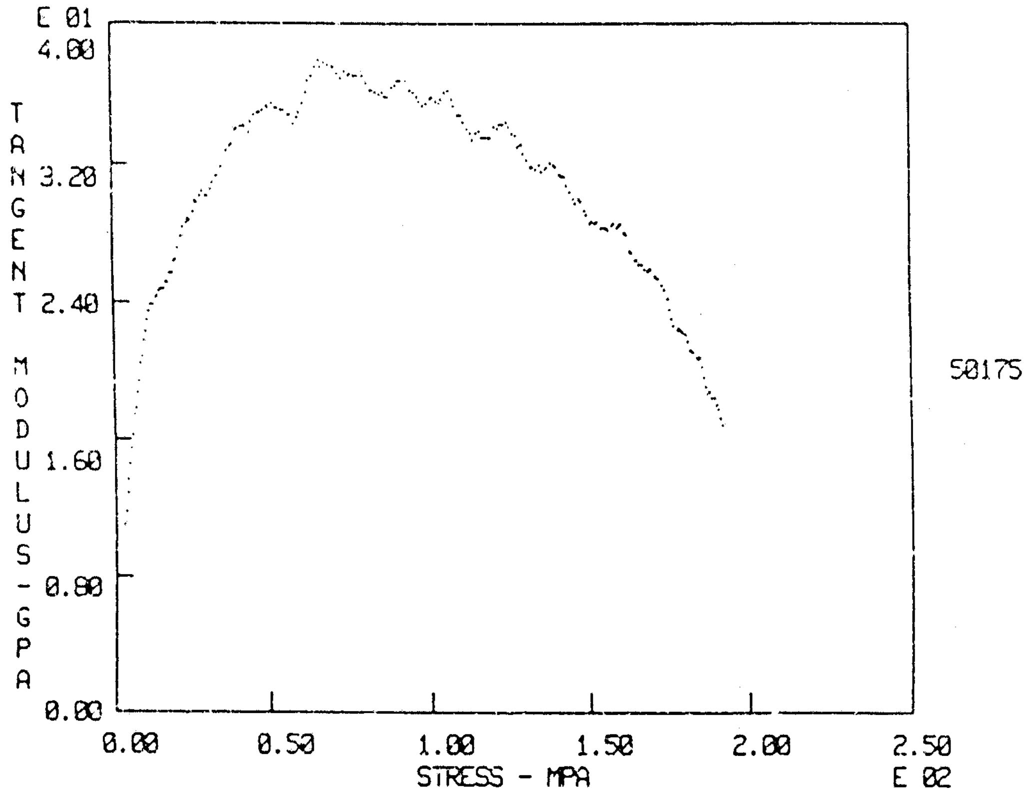


Figure 115. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 50-17. P = 10 MPa.



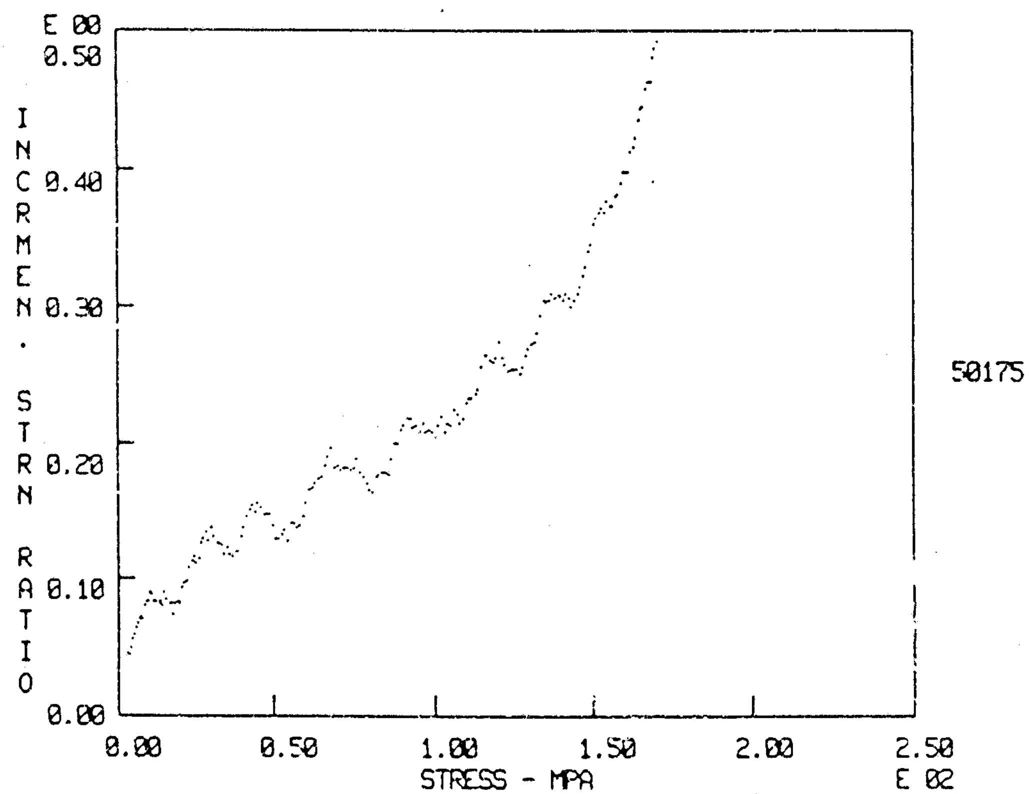


Figure 116. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 50-17 (6462 Feet). P = 10 MPa.

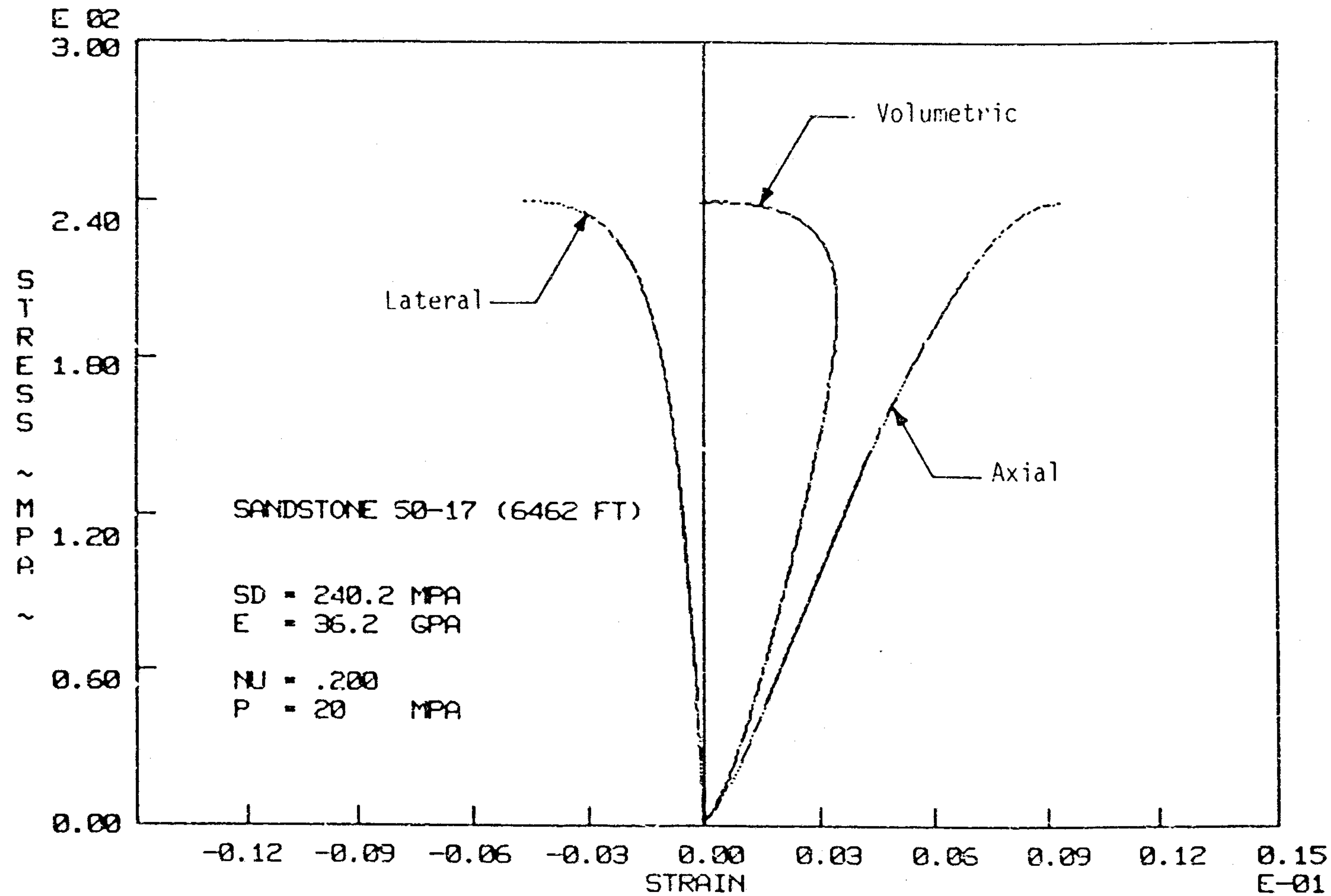
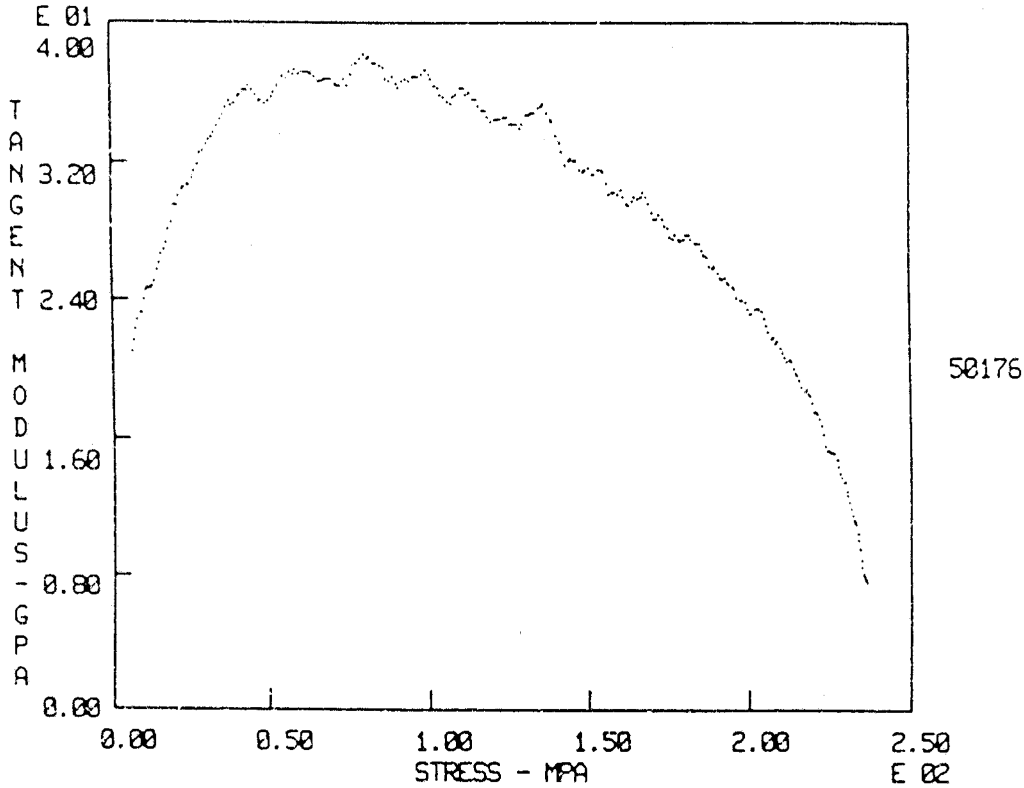


Figure 117. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 50-17. P = 20 MPa.

RSI DWG 046-82-064



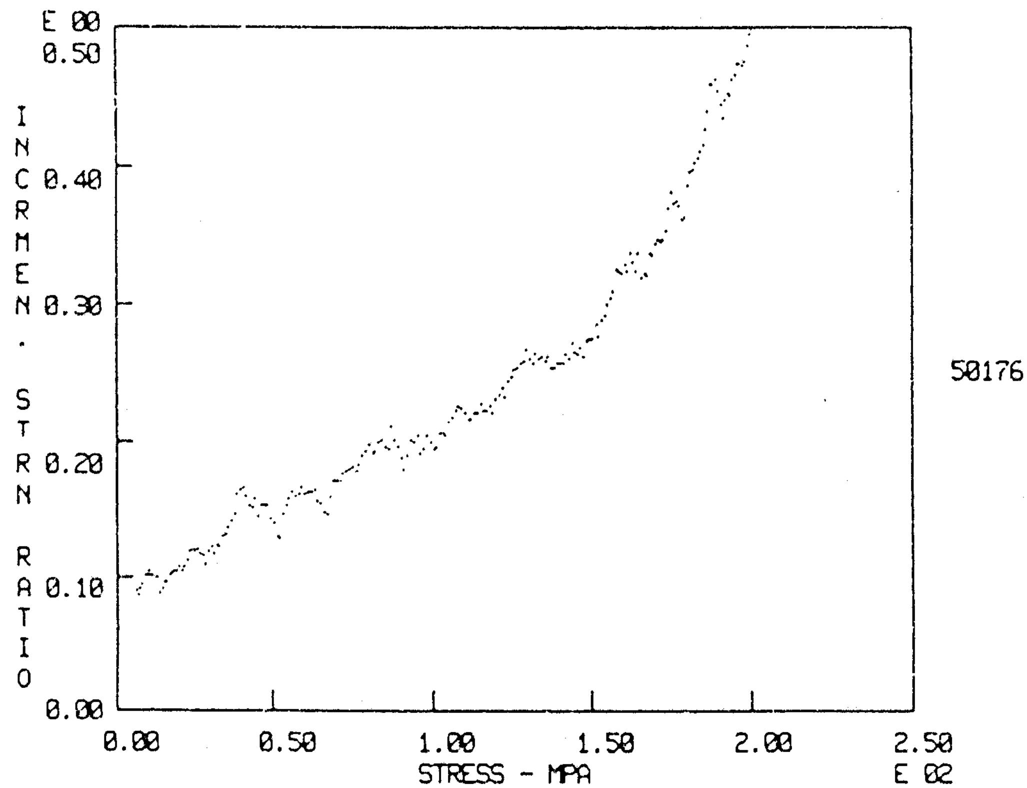


Figure 118. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 50-17 (6462 Feet). P = 20 MPa.

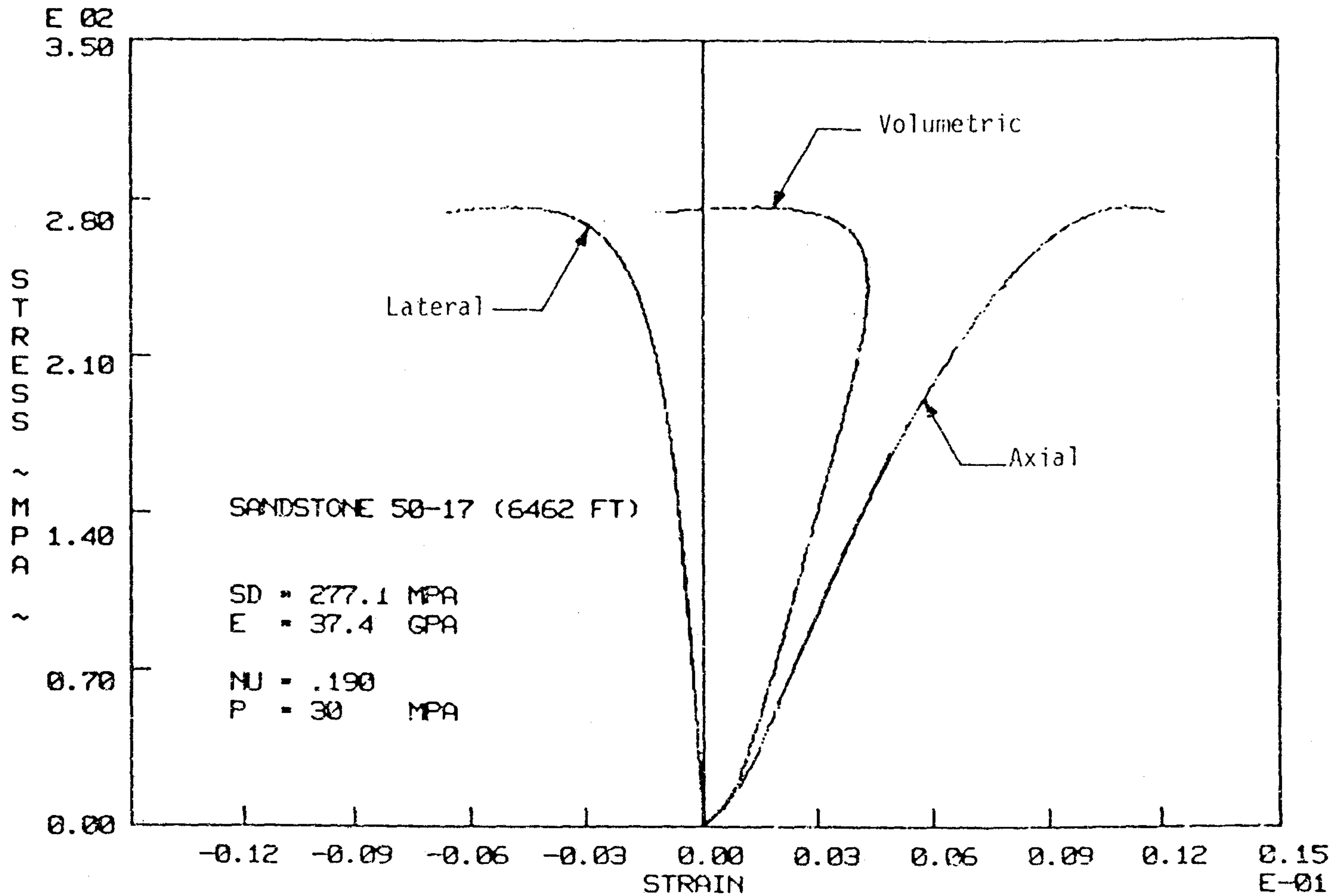
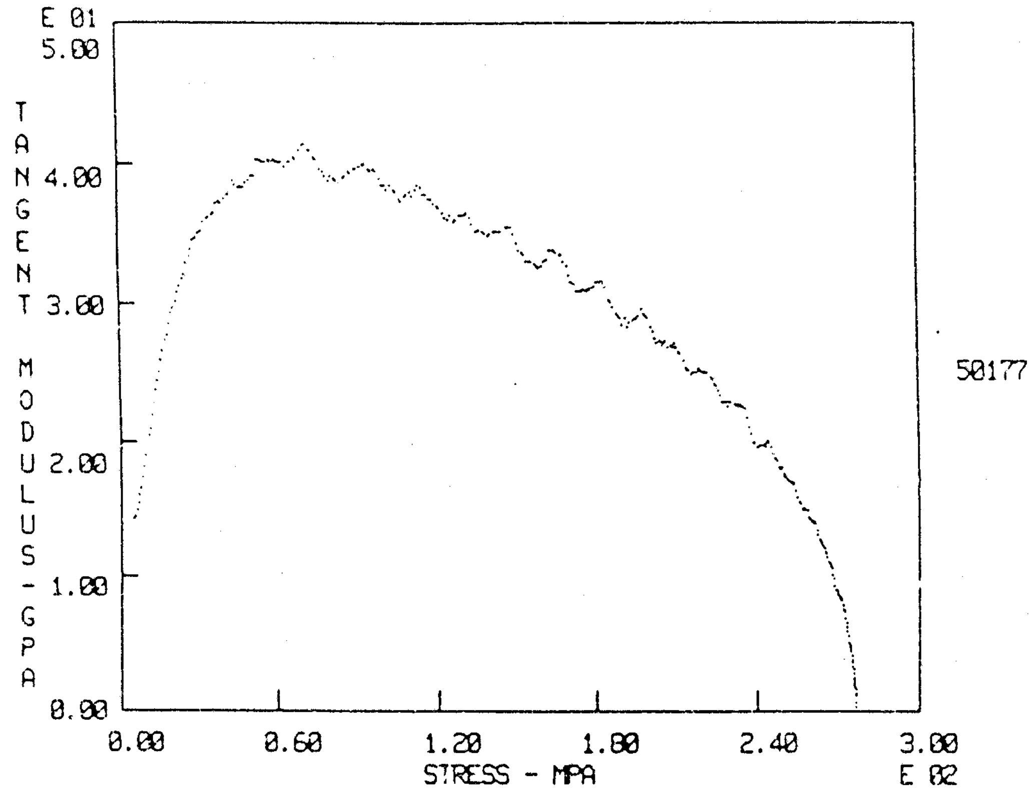


Figure 119. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 50-17. P = 30 MPa.

RSI DWG 046-82-065



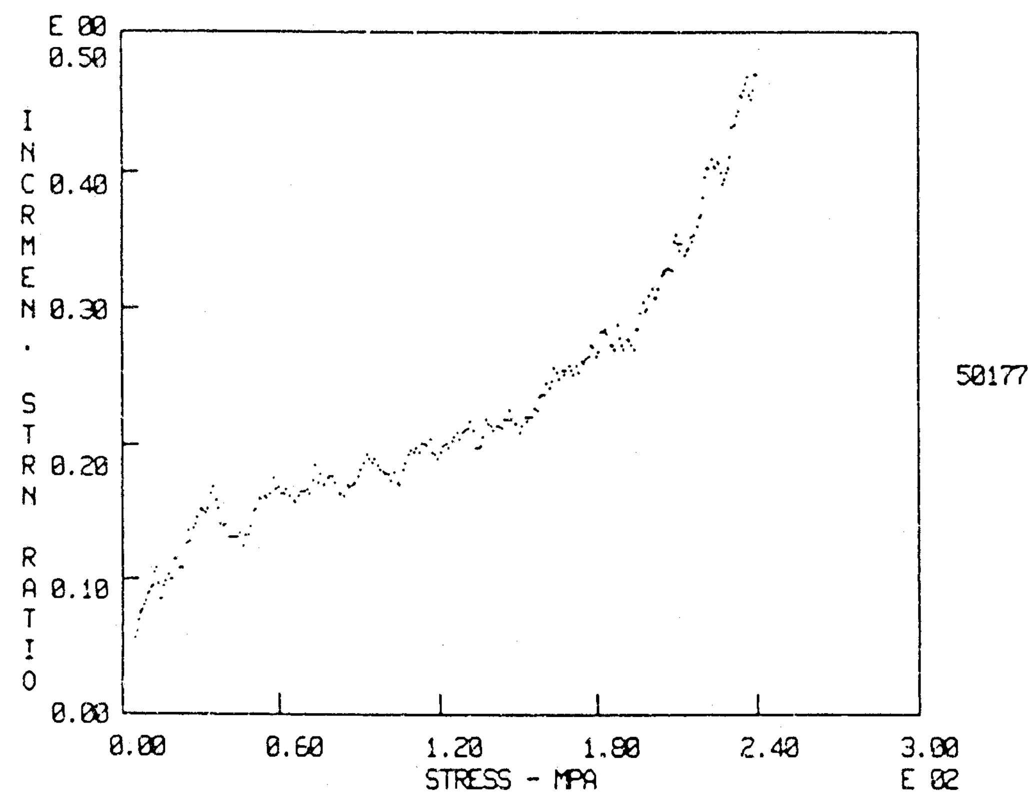


Figure 120. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 50-17 (6462 Feet). P = 30 MPa.

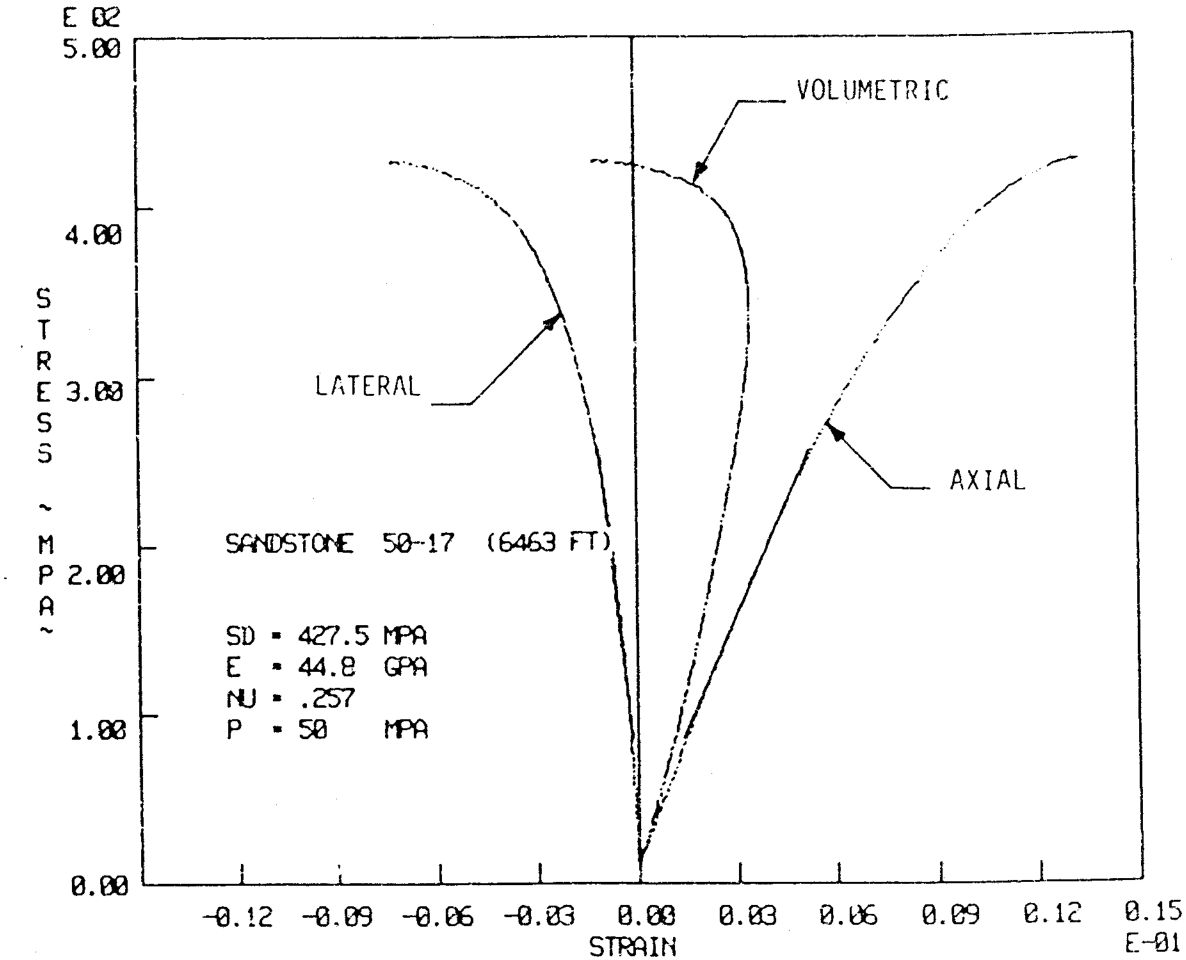
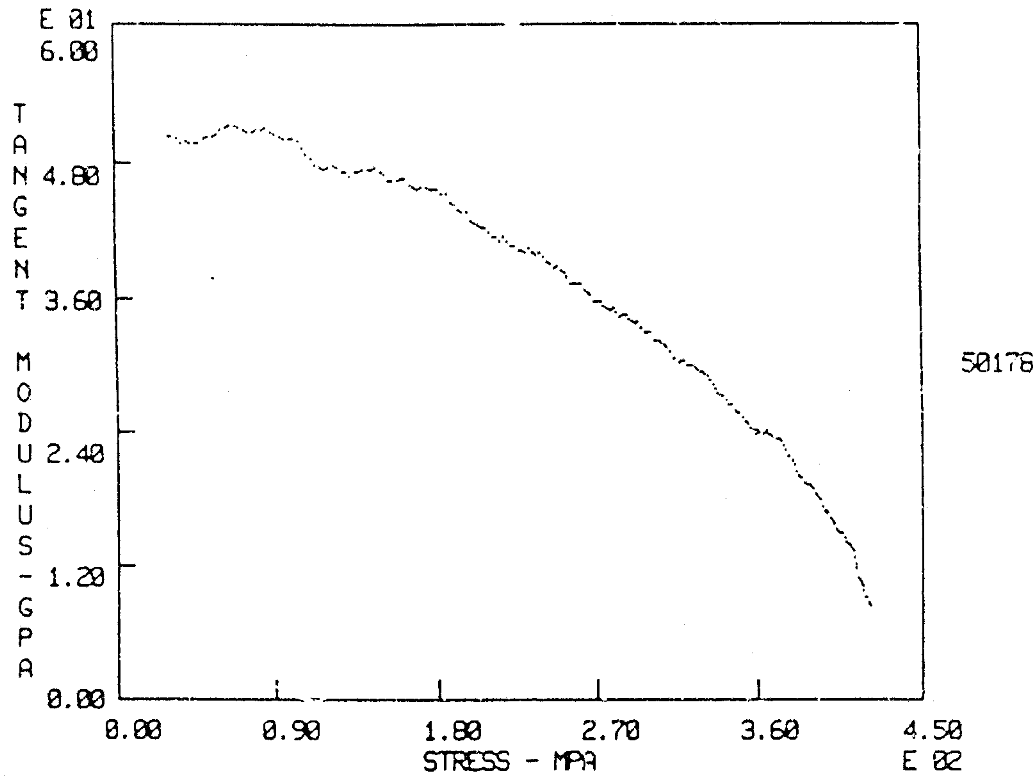


Figure 121. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 50-17. P = 50 MPa.

RSI DWG 046-83-97



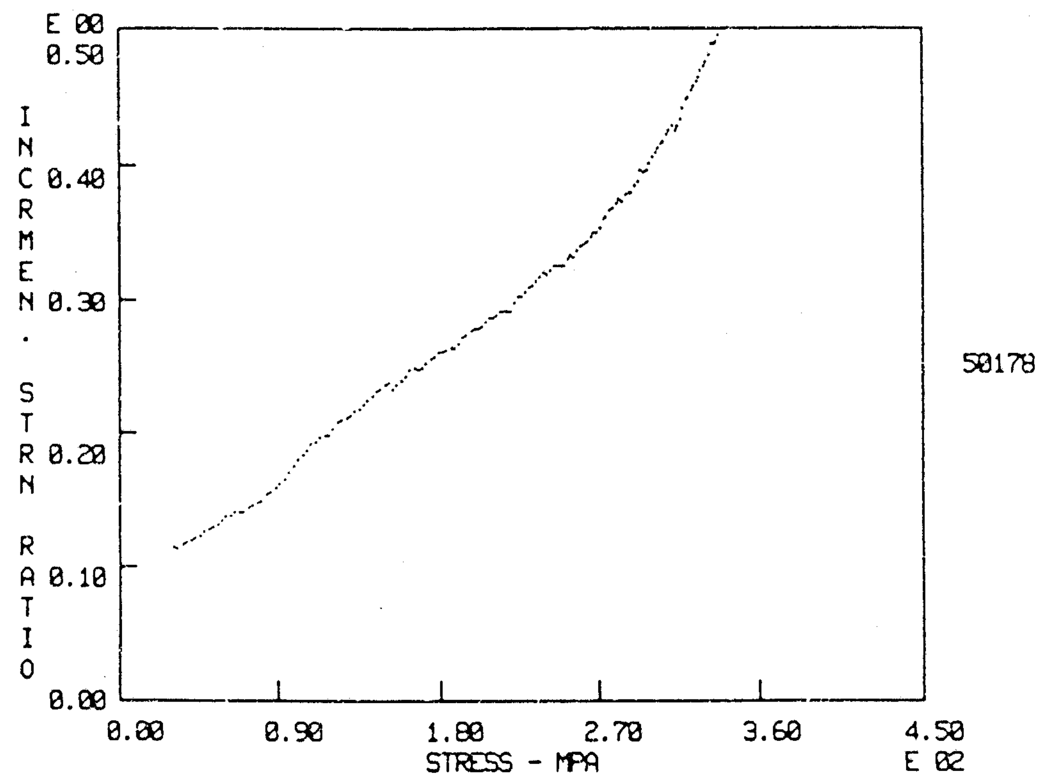


Figure 122. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 50-17 (6462 Feet). P = 50 MPa.

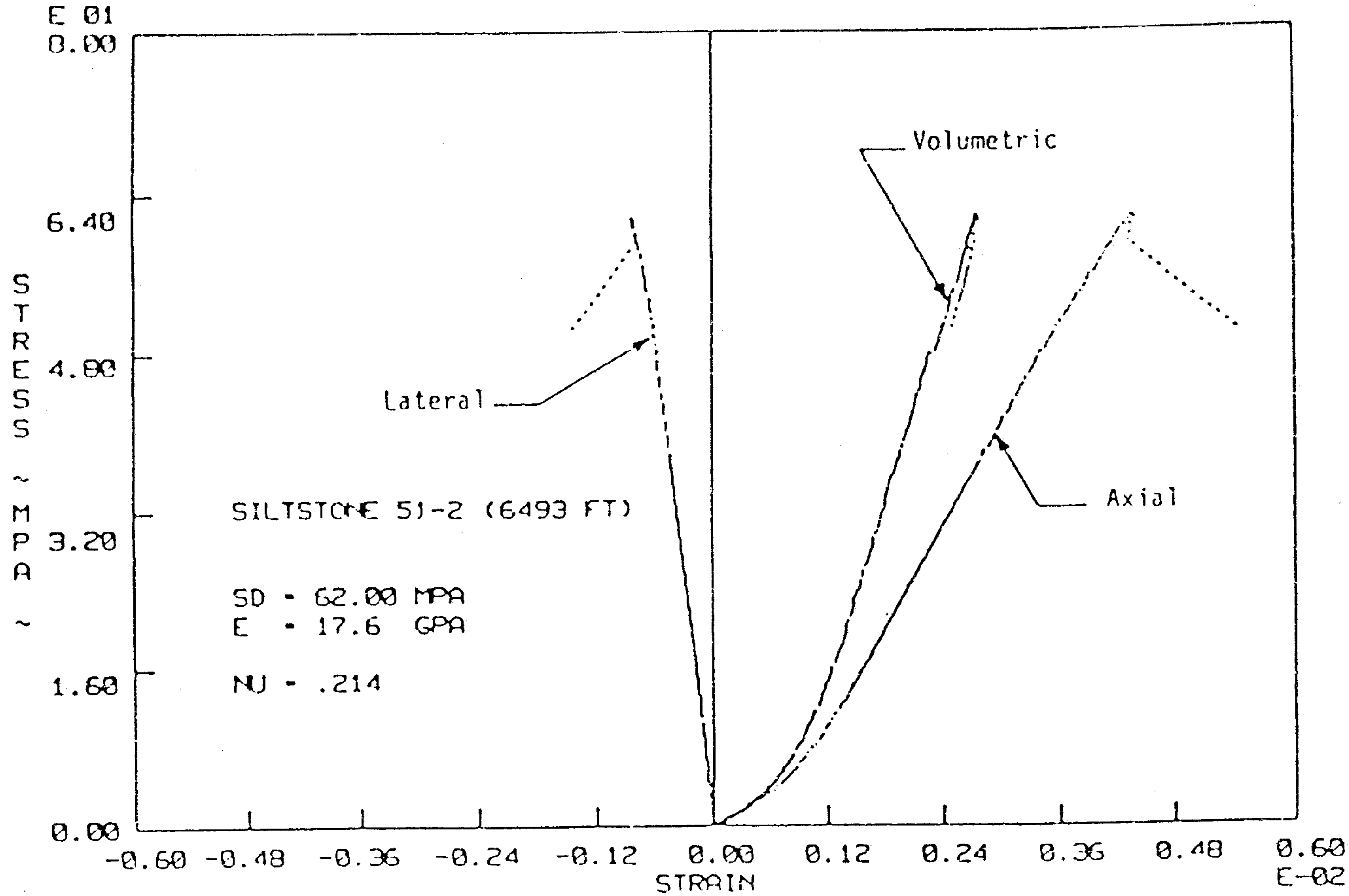
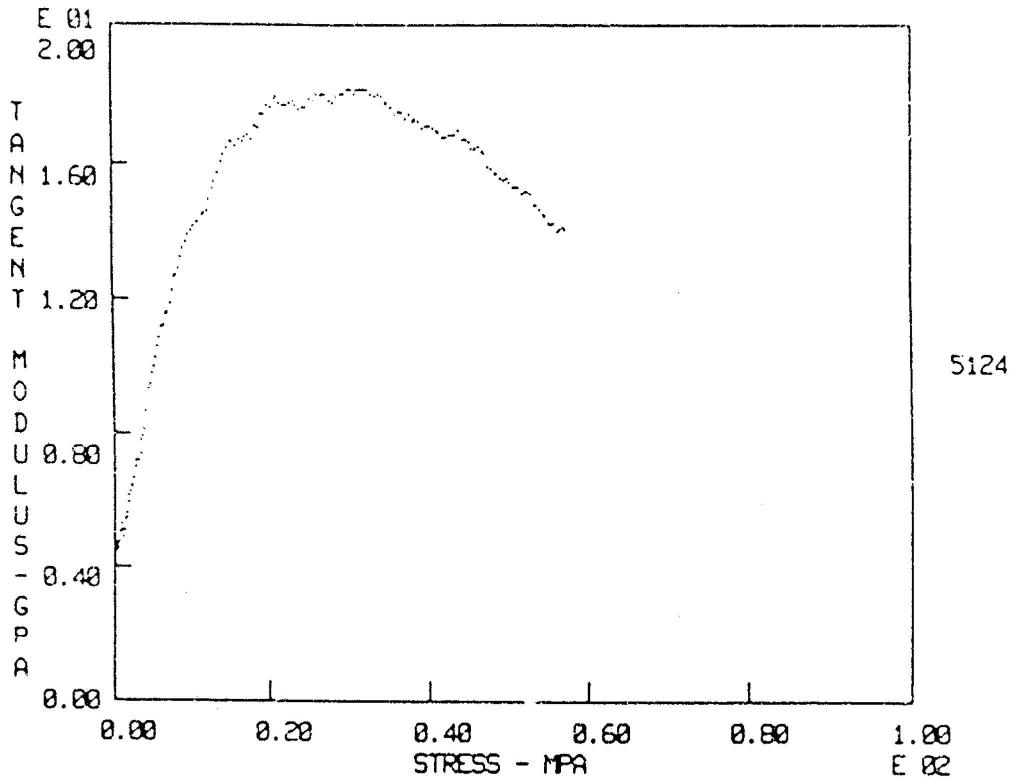


Figure 123. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Unconfined Compression of Siltstone 51-2.

RSI DWG 046-82-055



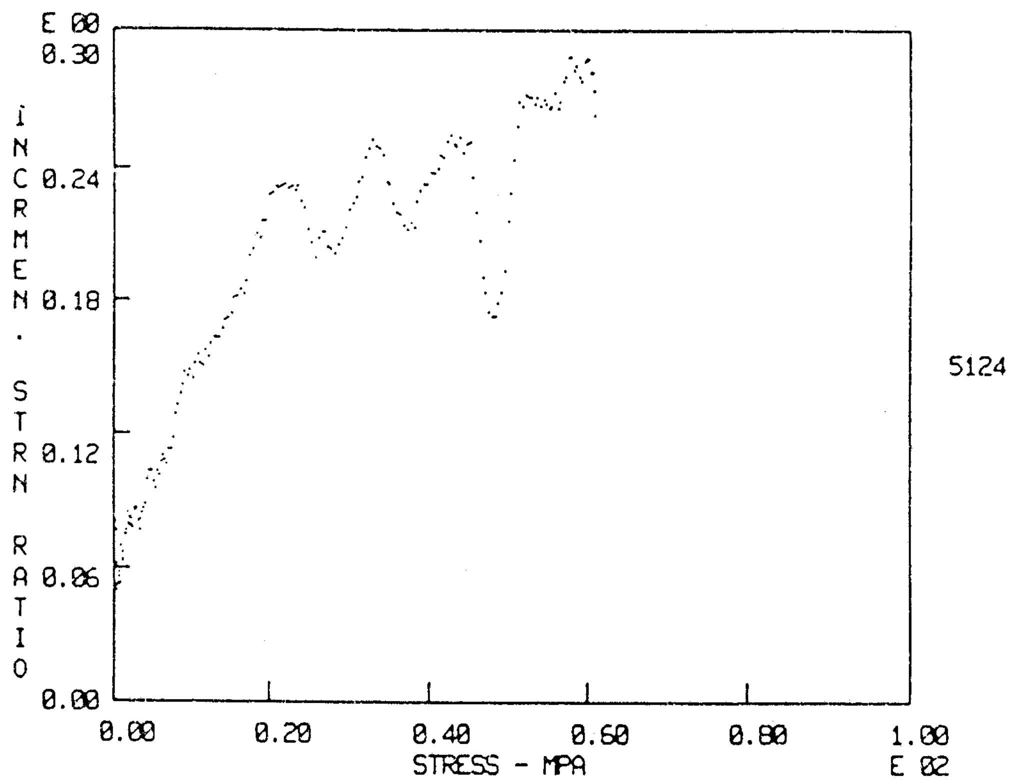


Figure 124. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Siltstone 51-2 (6493 Feet). P = 0 MPa.

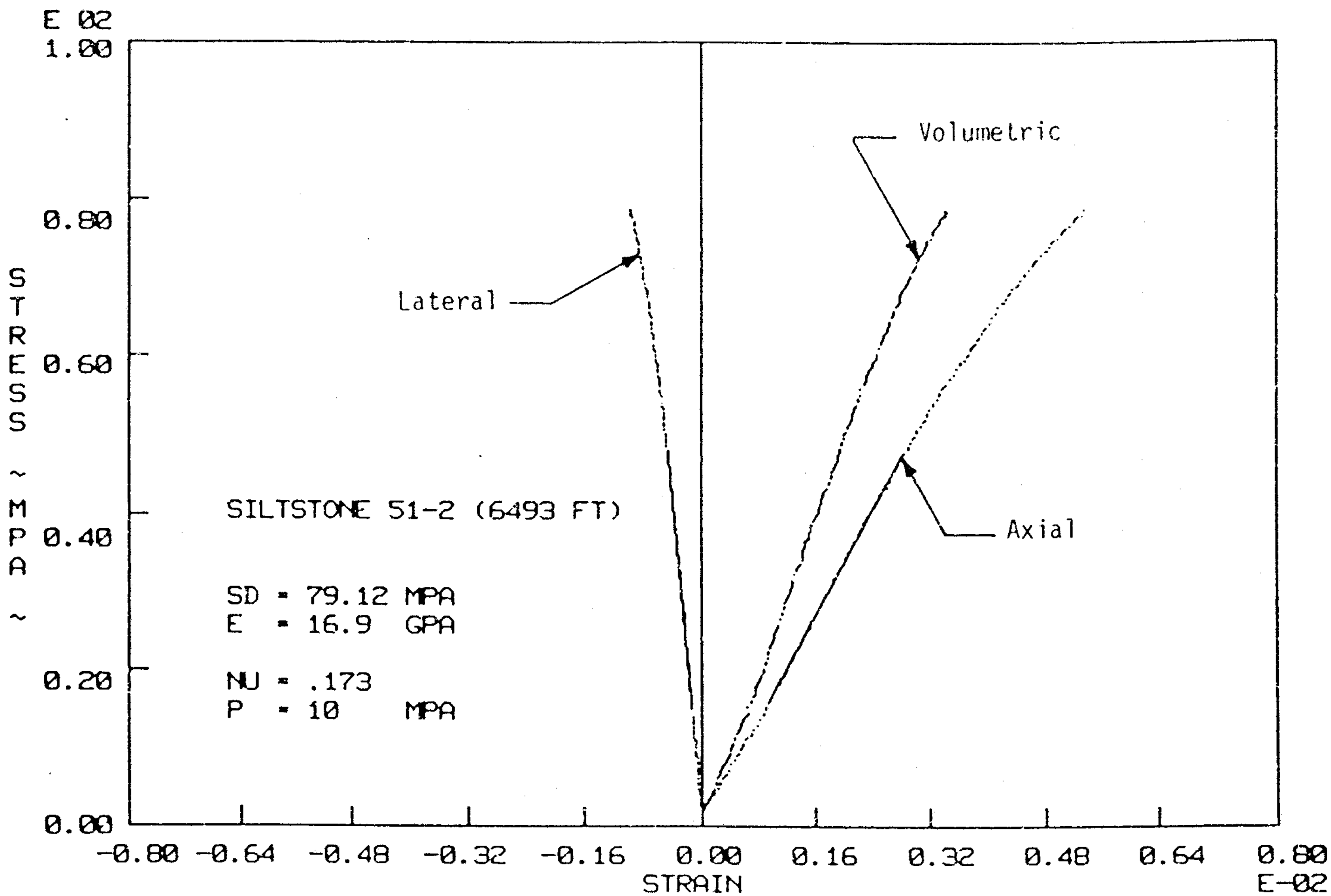
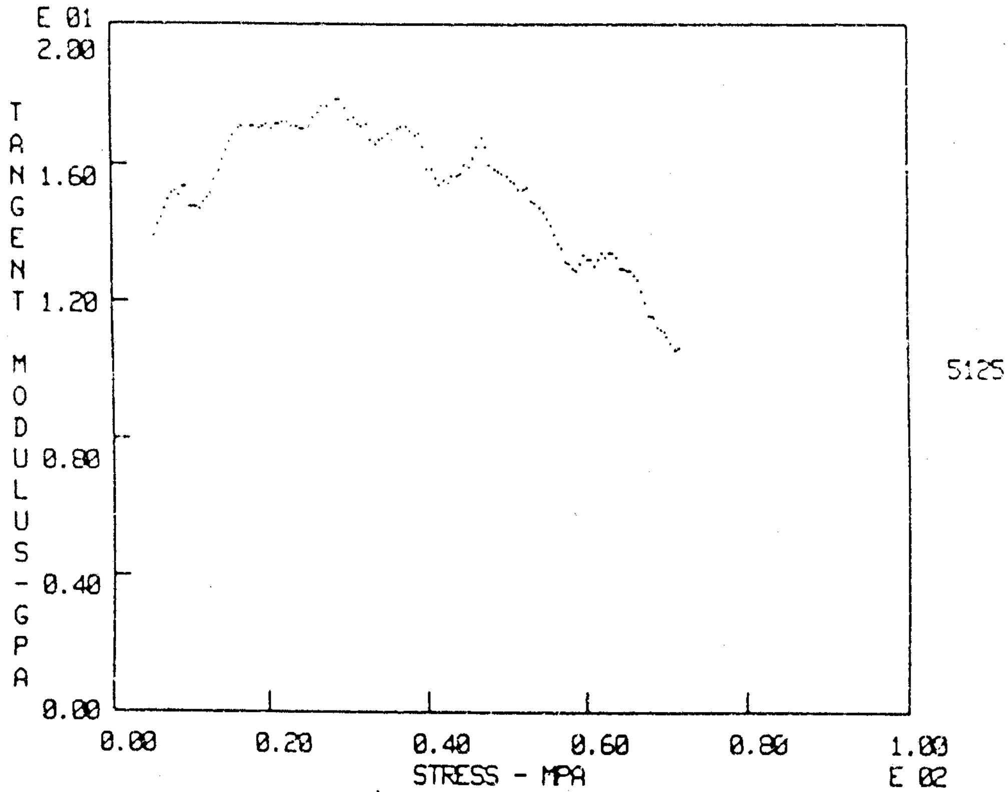


Figure 125. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Siltstone 51-2. P = 10 MPa.

RSI DWG 046-82-067



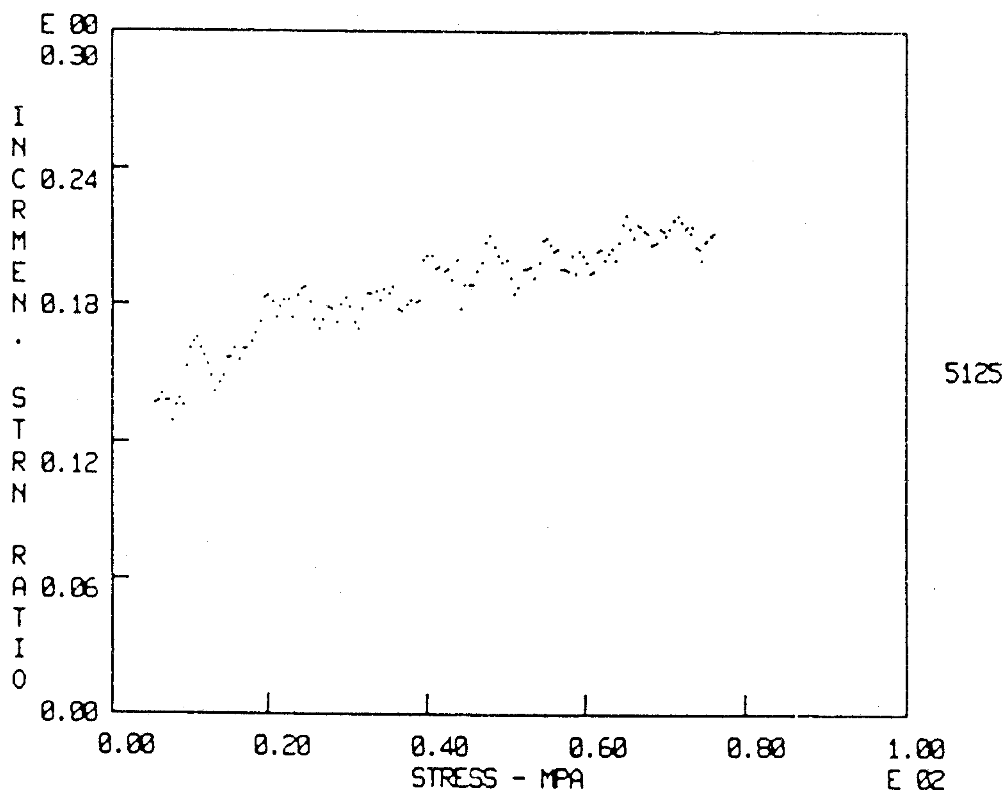


Figure 126. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Siltstone 51-2 (6493 Feet). P = 10 MPa.

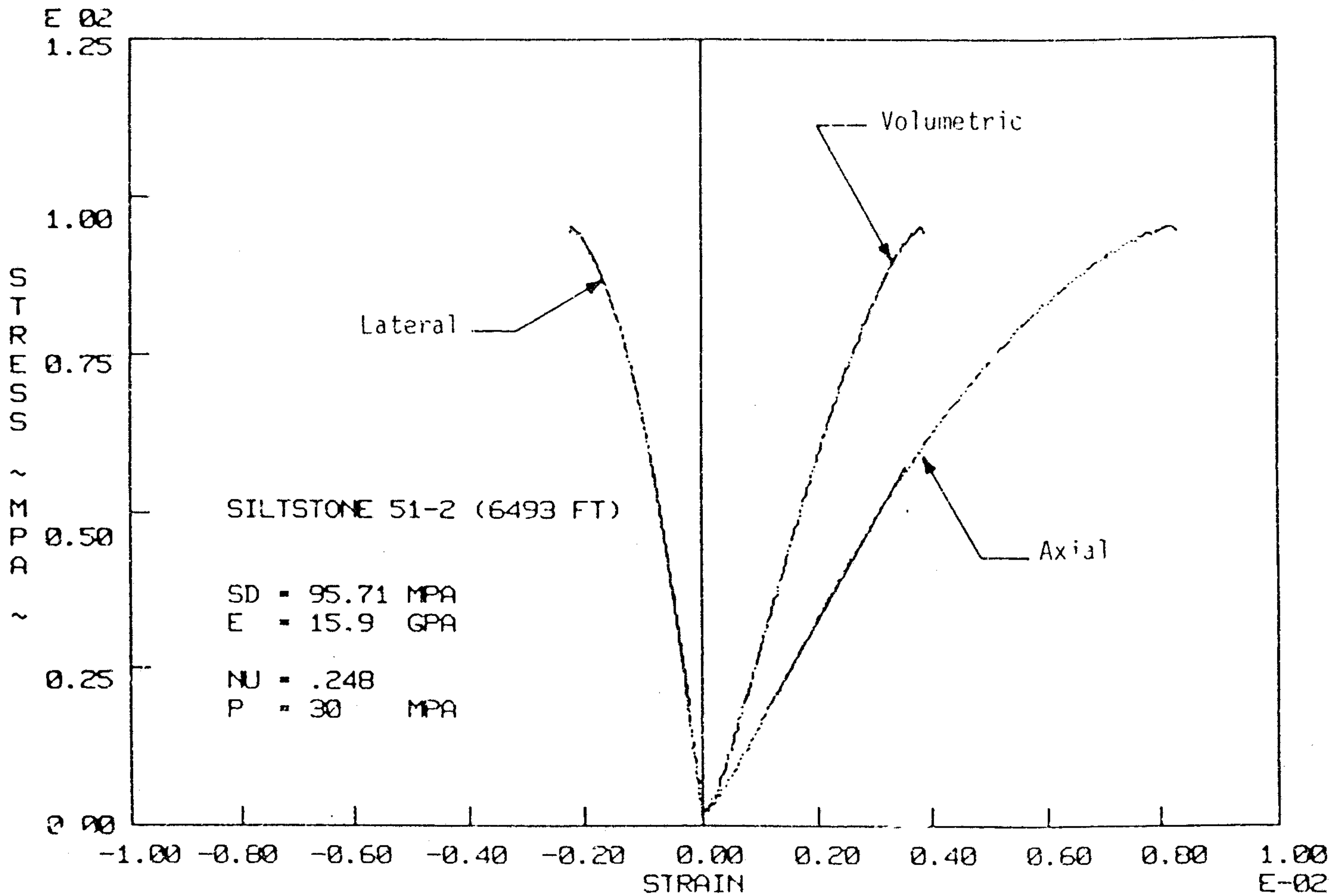
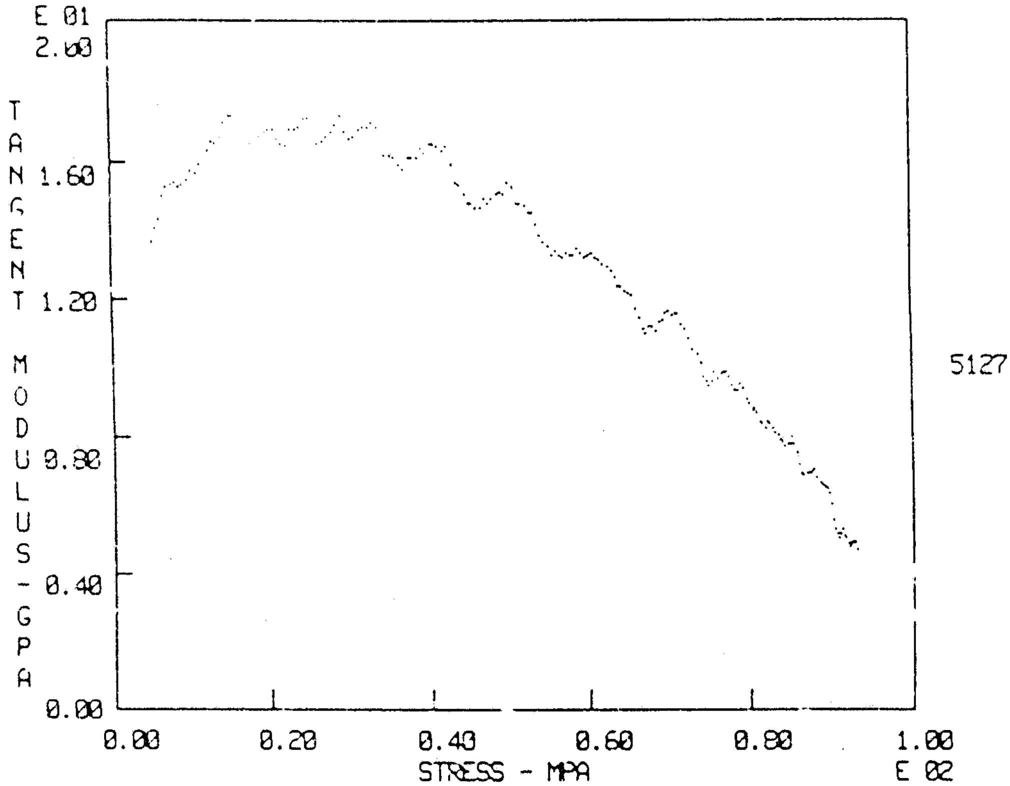


Figure 127. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Siltstone 51-2. P = 30 MPa.

RSI DWG 046-82-068



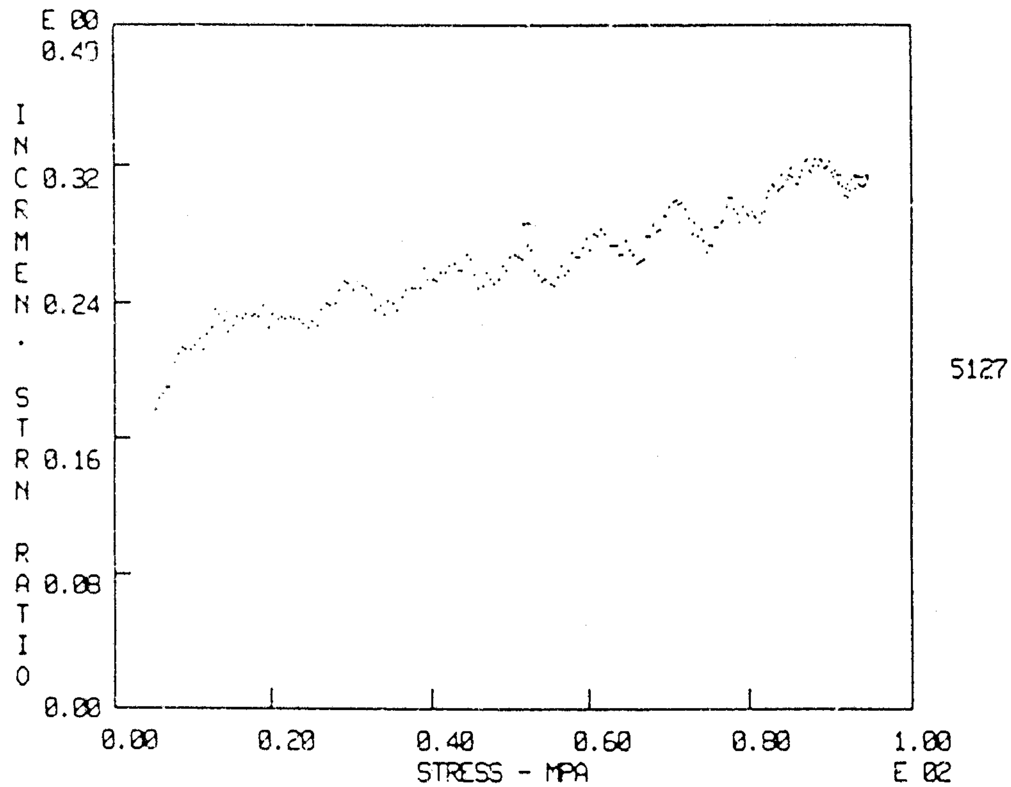


Figure 128. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Siltstone 51-2 (6493 Feet). P = 30 MPa.

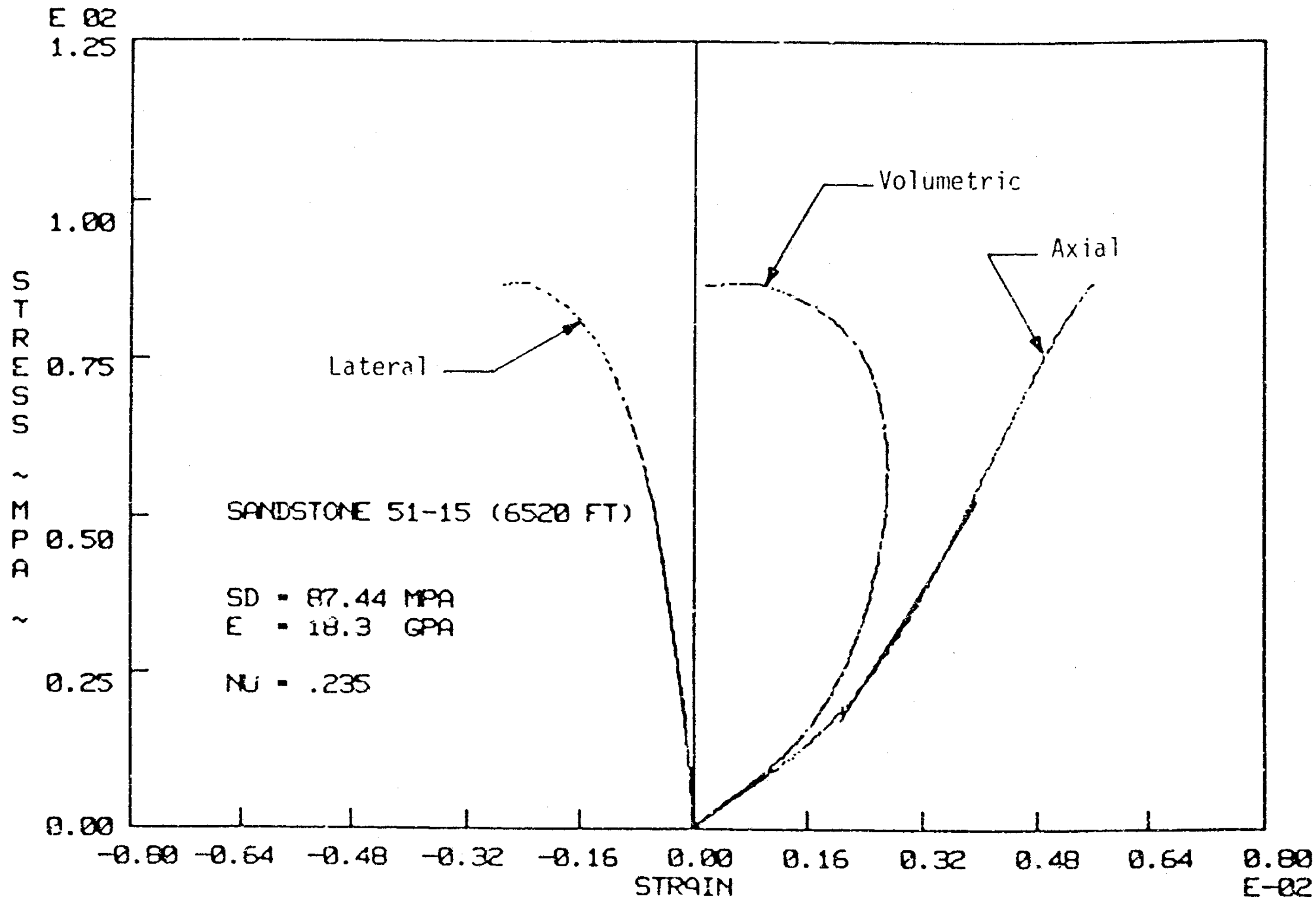


Figure 129. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Unconfined Compression of Sandstone 51-15.

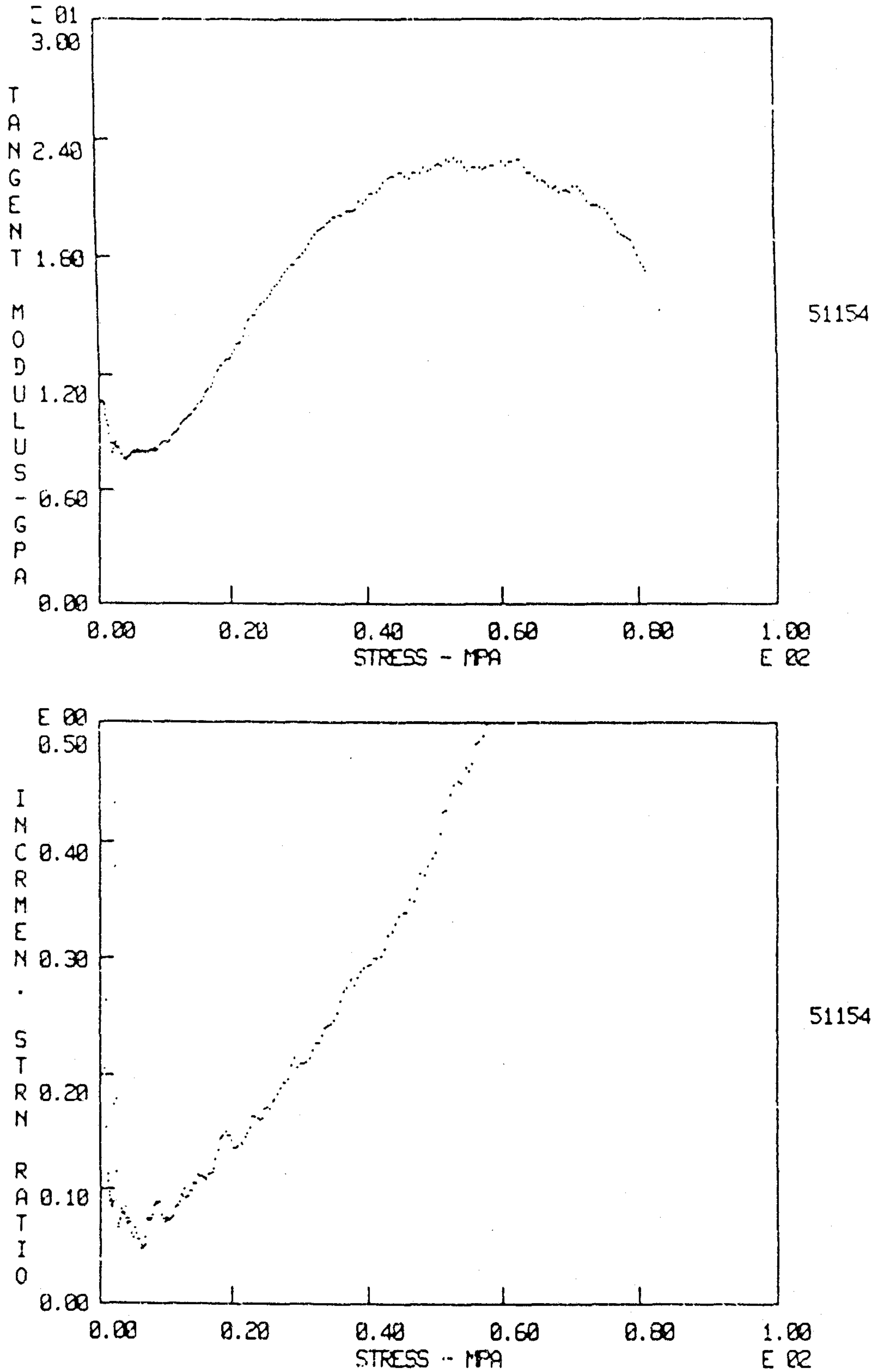


Figure 130. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 51-15 (6520 Feet). P = 0 MPa.

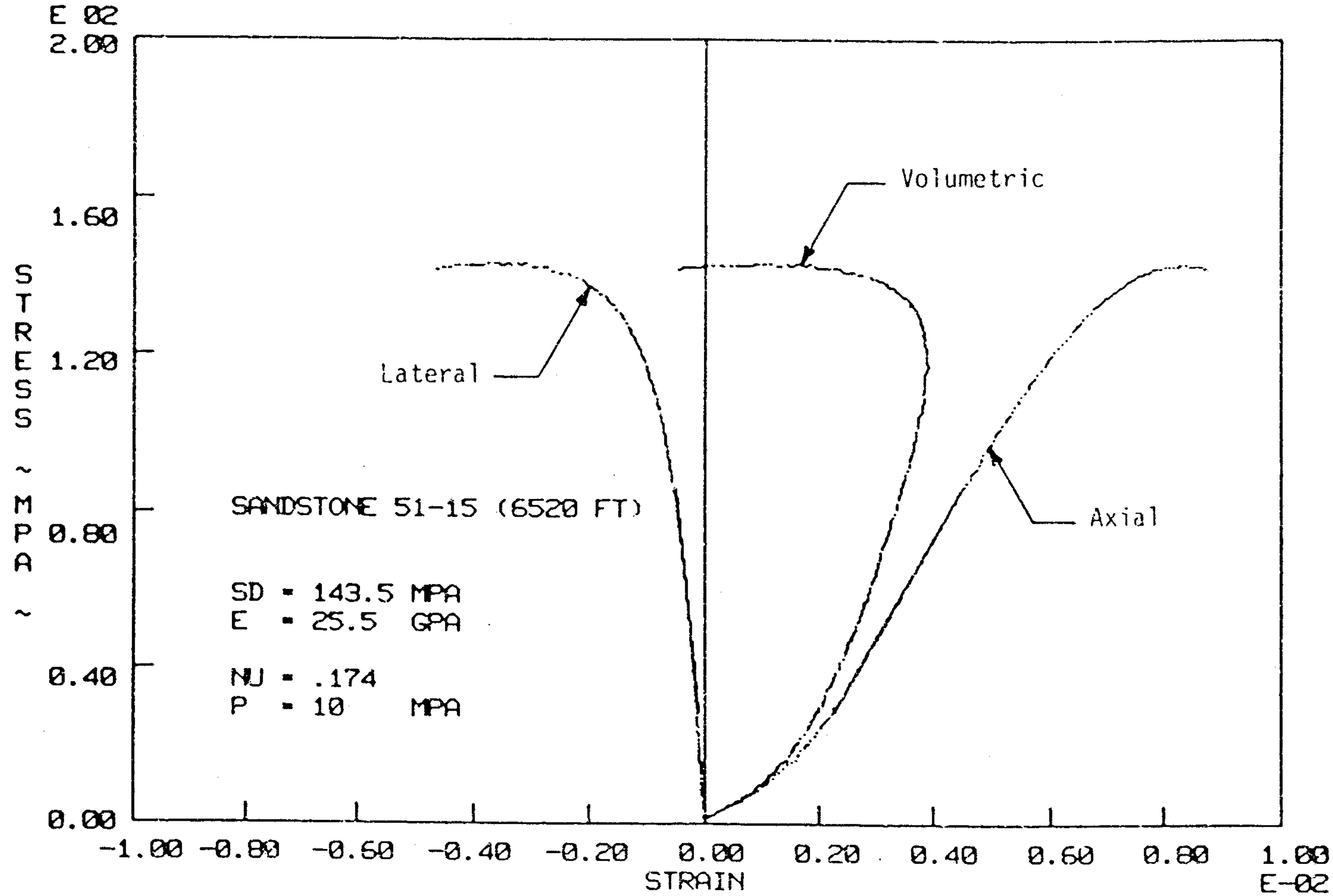
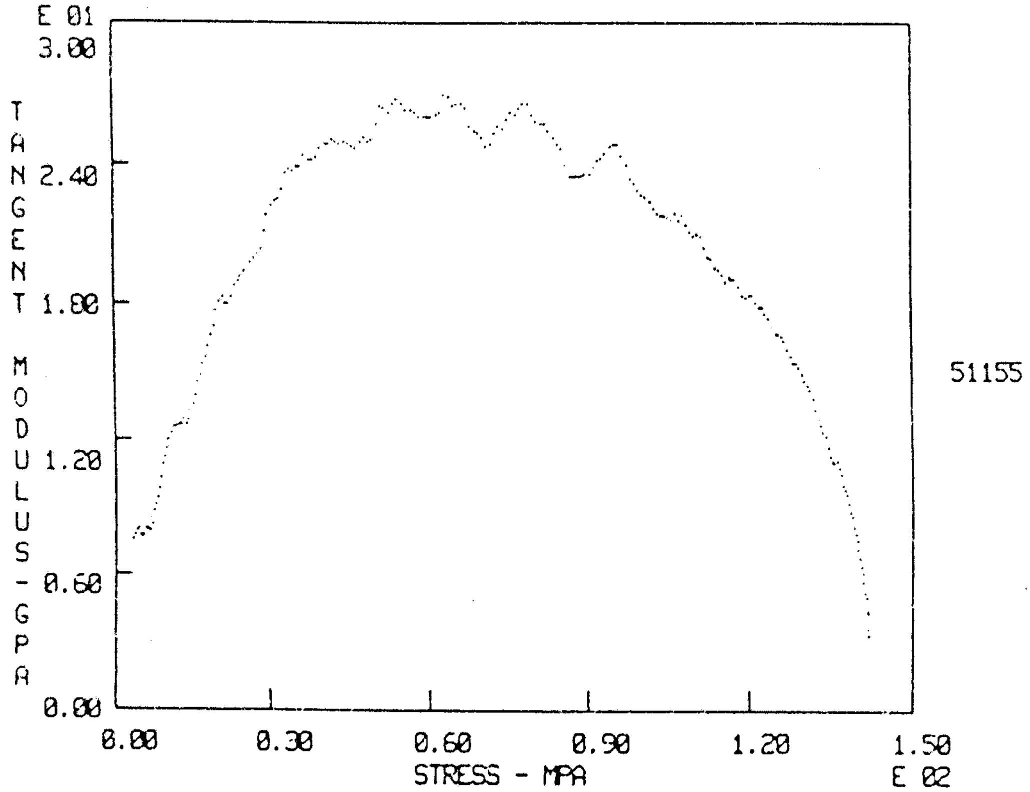


Figure 131. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 51-15. P = 10 MPa.

RSI DWG 046-82-070



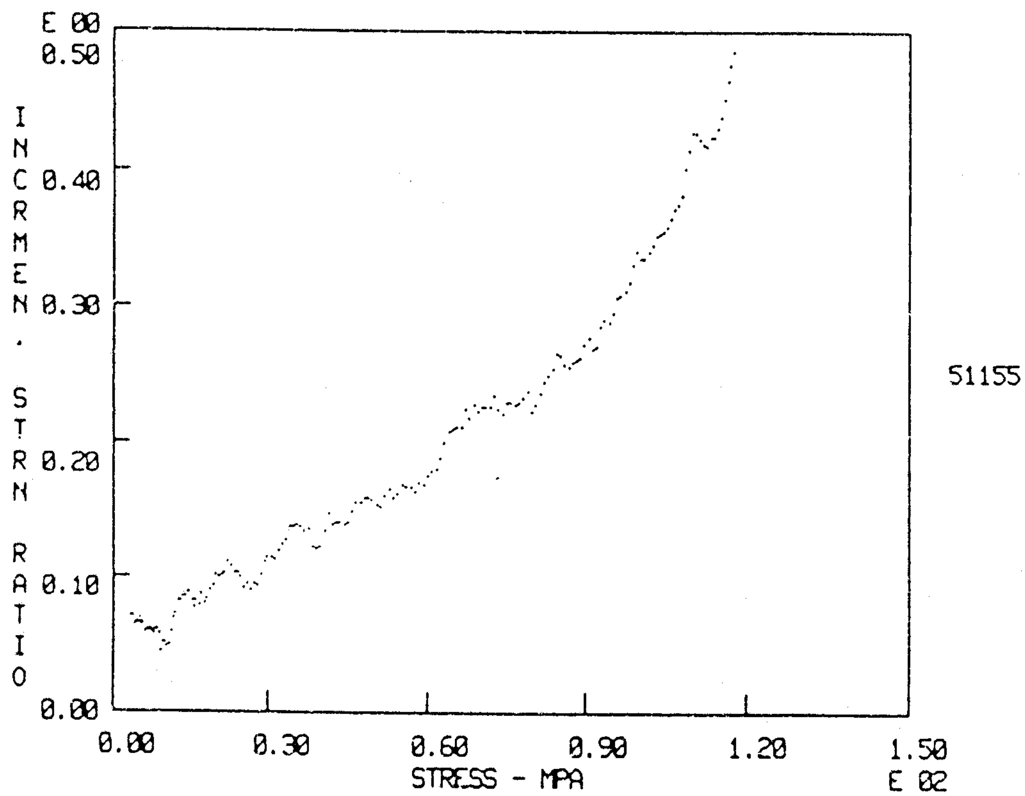


Figure 132. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 51-15 (6520 Feet). P = 10 MPa.

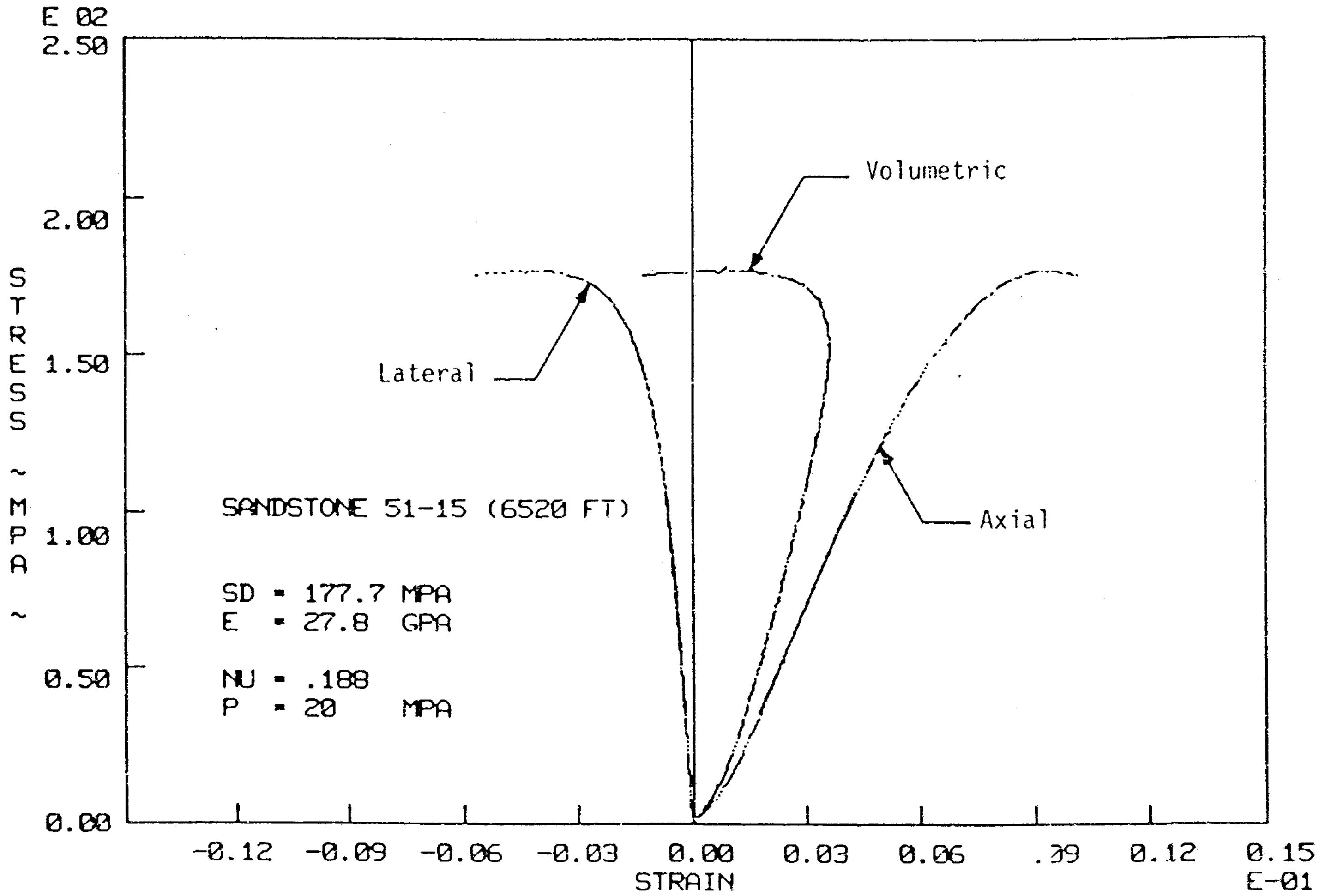
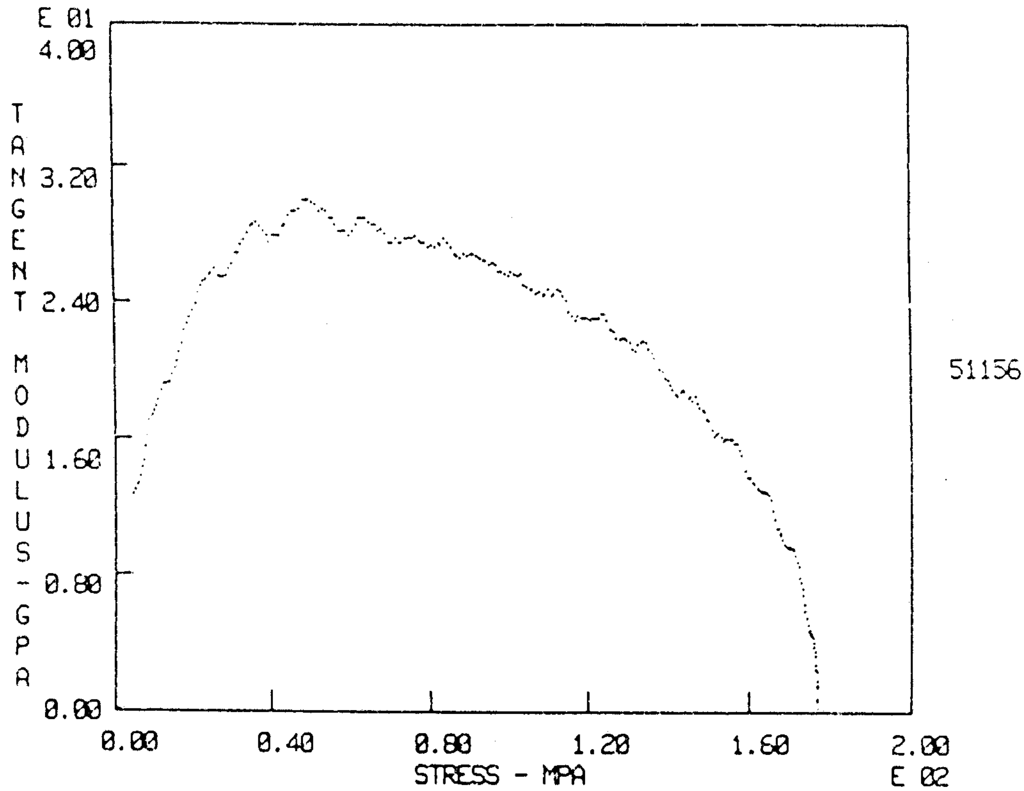


Figure 133. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 51-15. P = 20 MPa.



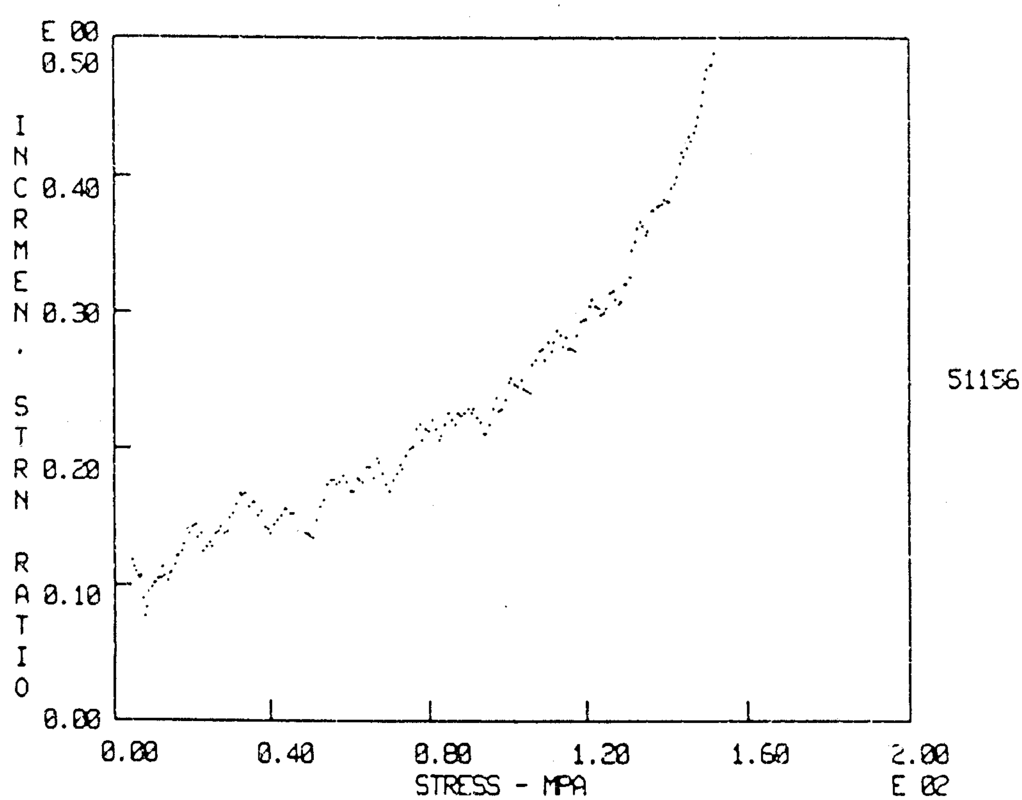


Figure 134. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 51-15 (6520 Feet). P = 20 MPa.

RSI DWG 046-82-072

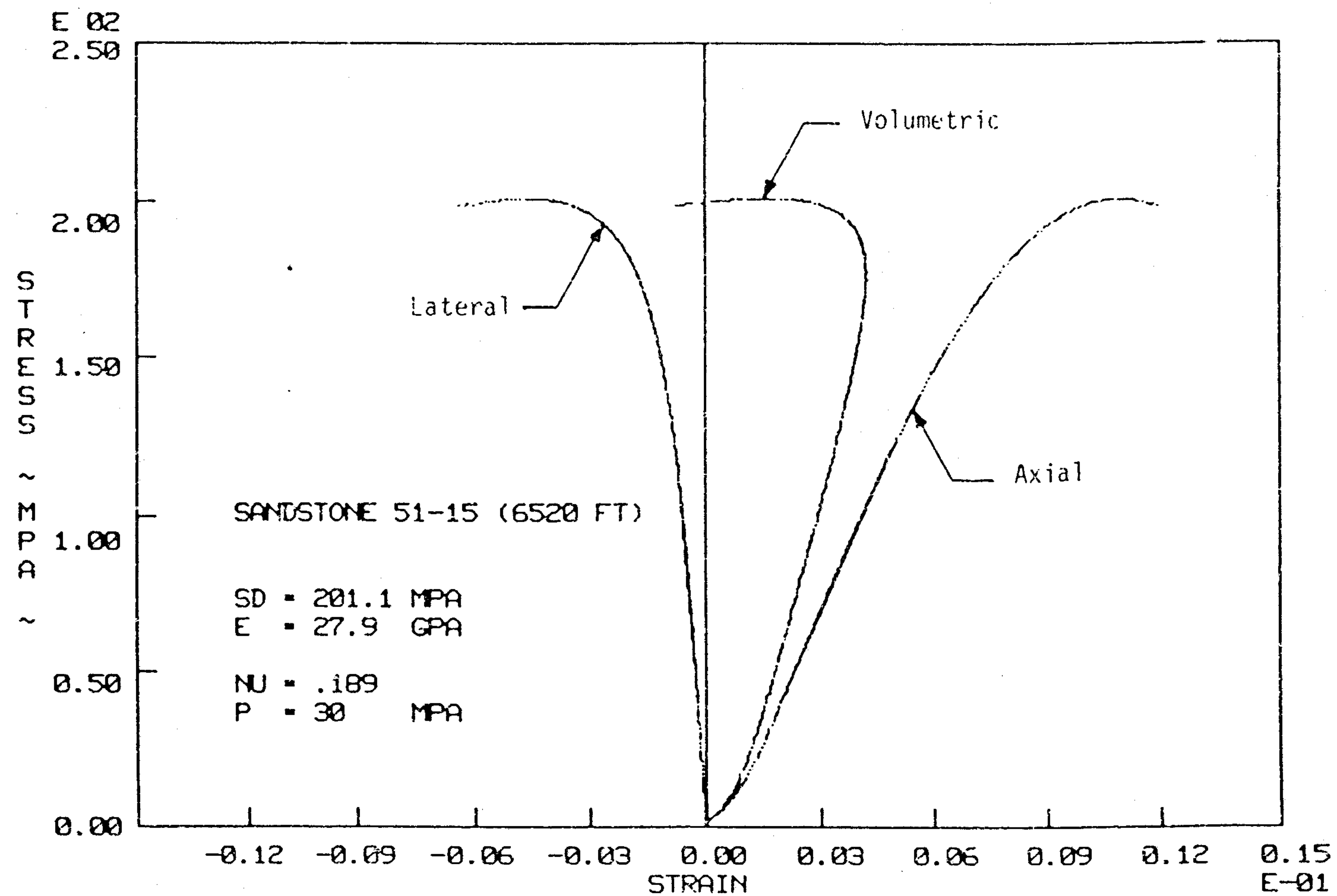


Figure 135. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 51-15. P = 30 MPa.

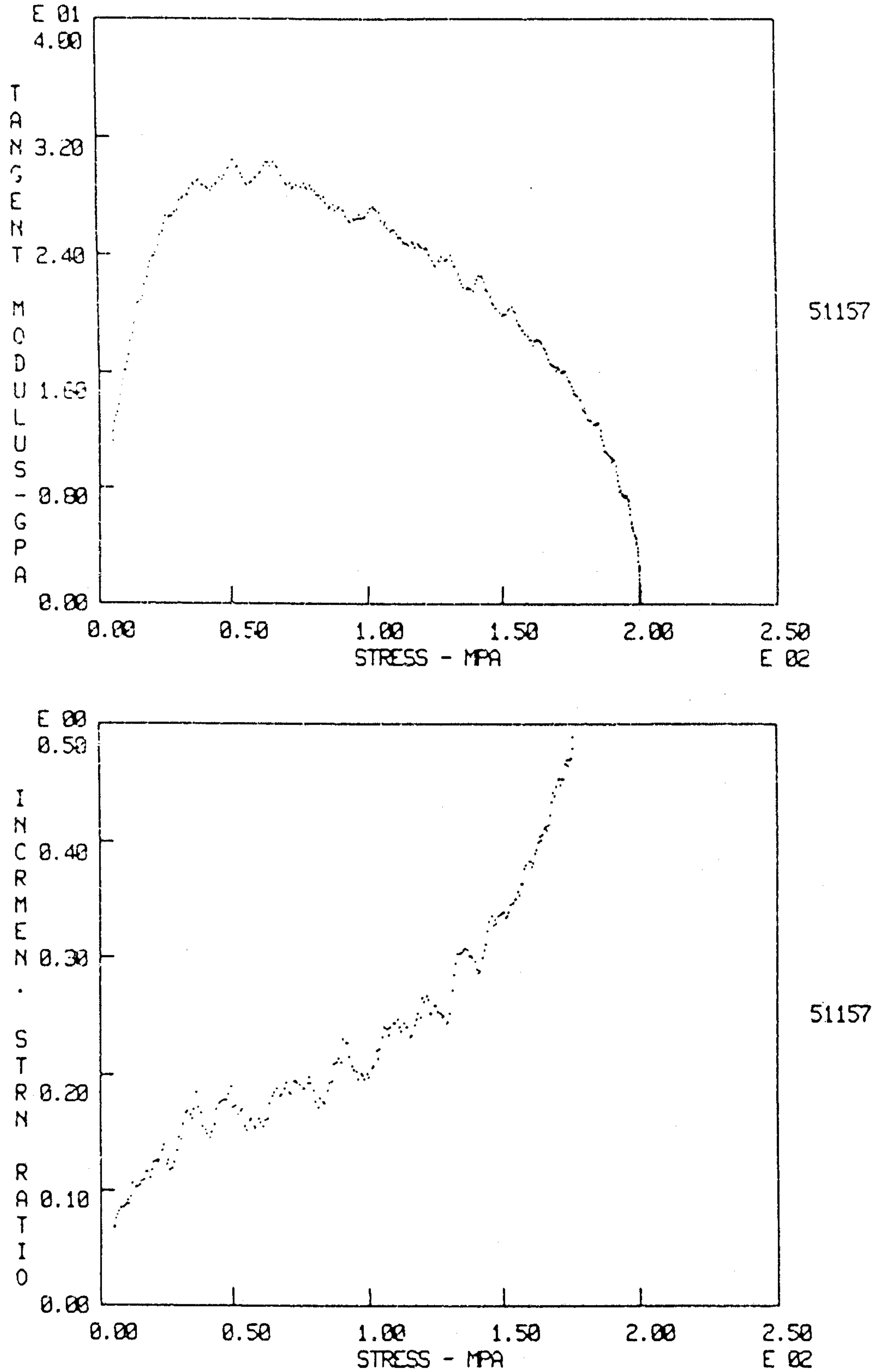


Figure 136. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 51-15 (6520 Feet). P = 30 MPa.

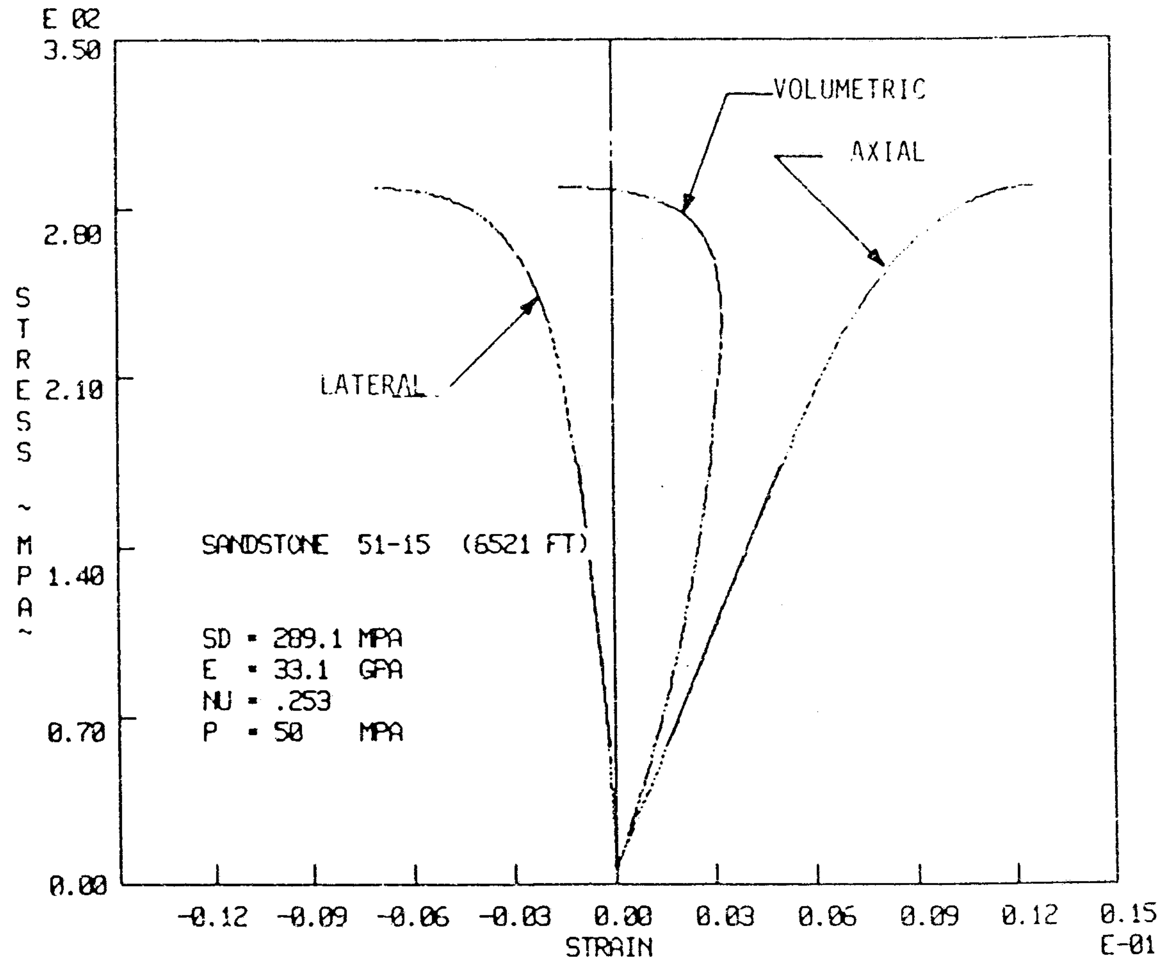
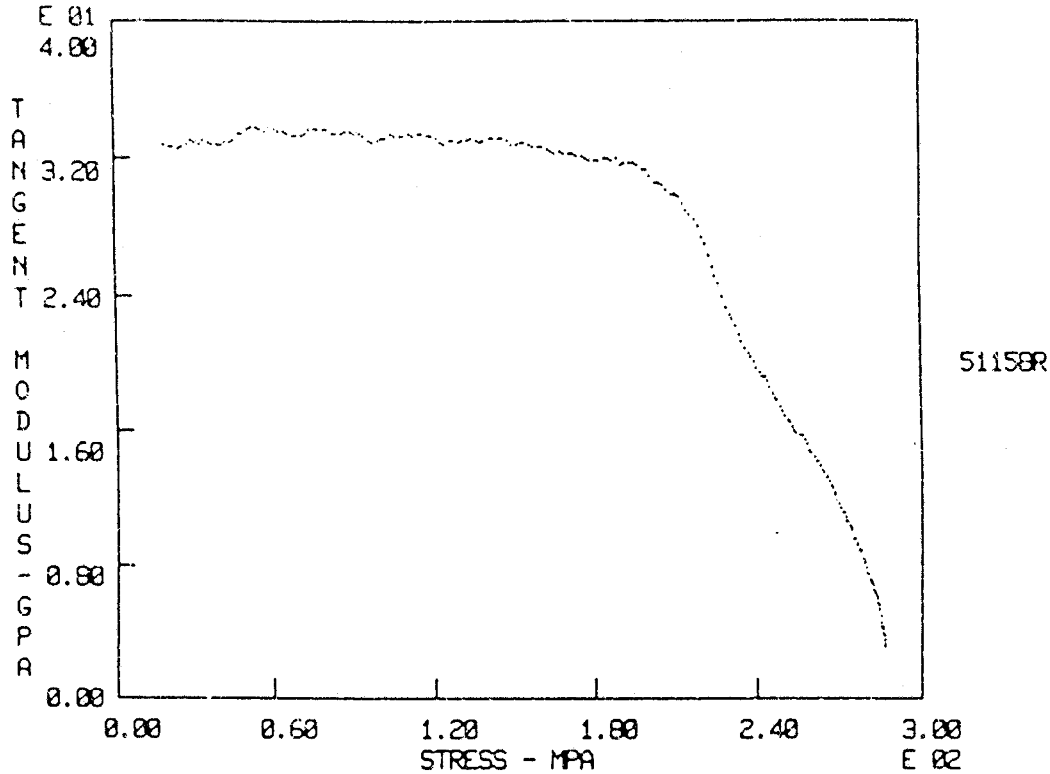


Figure 137. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 51-15. P = 50 MPa.



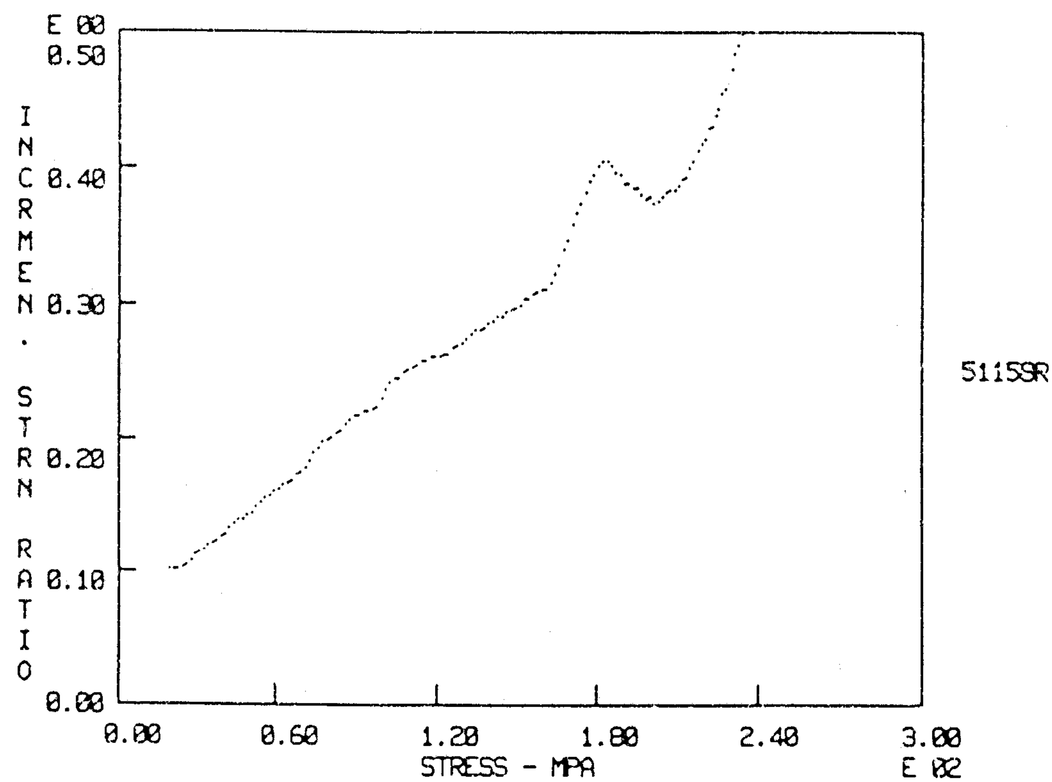


Figure 138. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 51-15 (6520 Feet). P = 50 MPa.

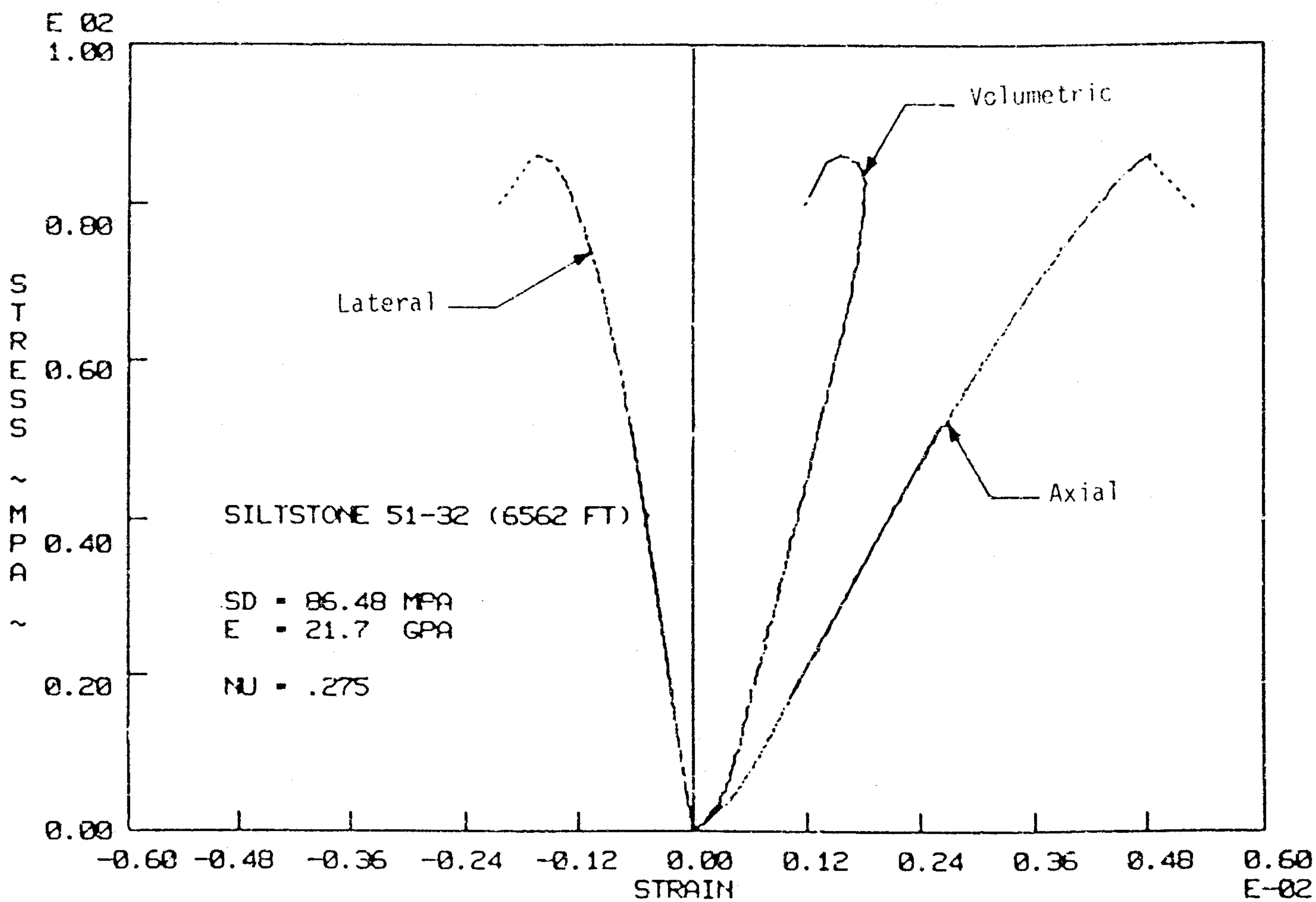


Figure 139. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Unconfined Compression of Siltstone 51-32.

RSI DWG 046-82-073

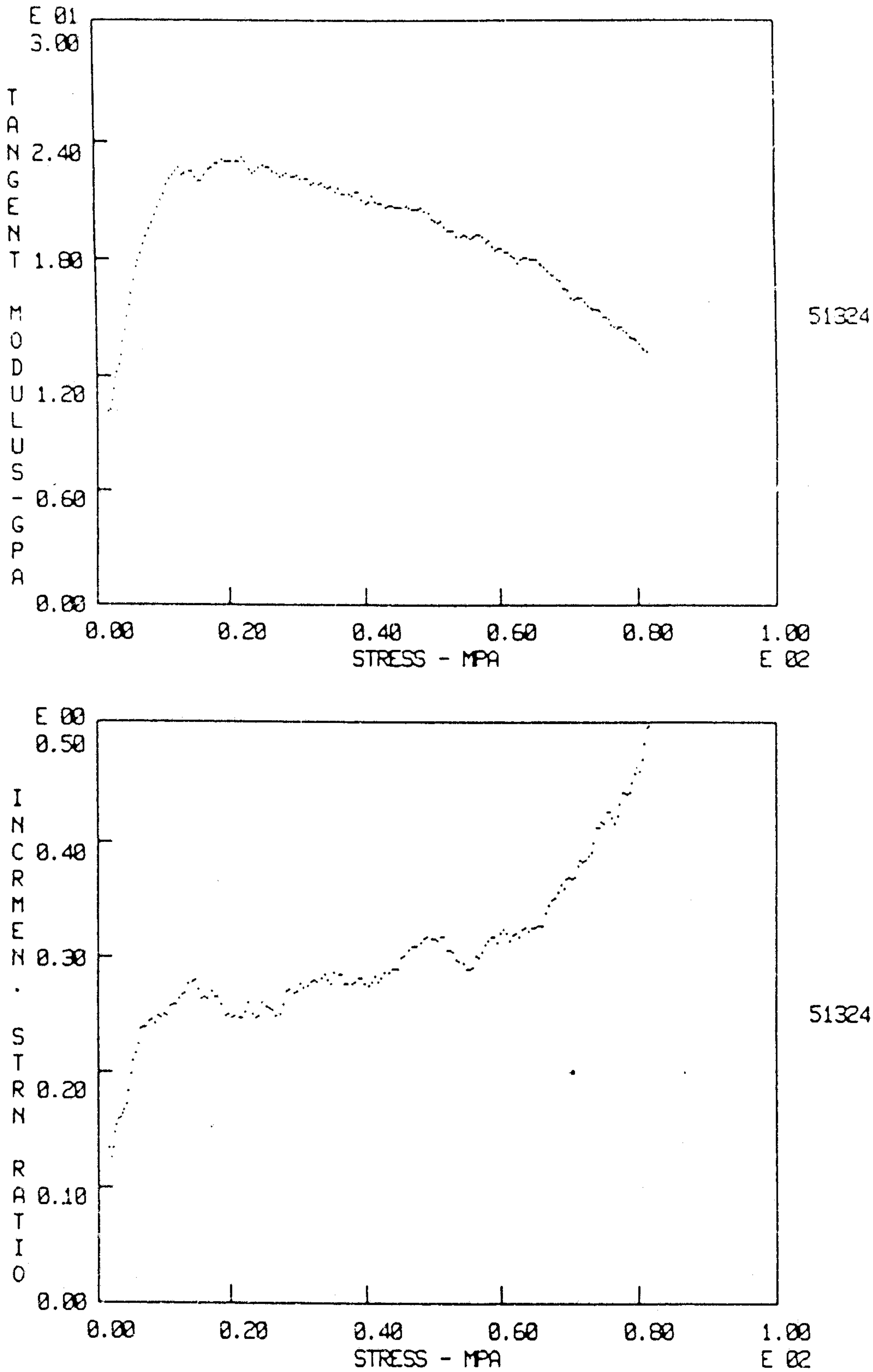


Figure 140. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Siltstone 51-32 (6562 Feet). P = 0 MPa.

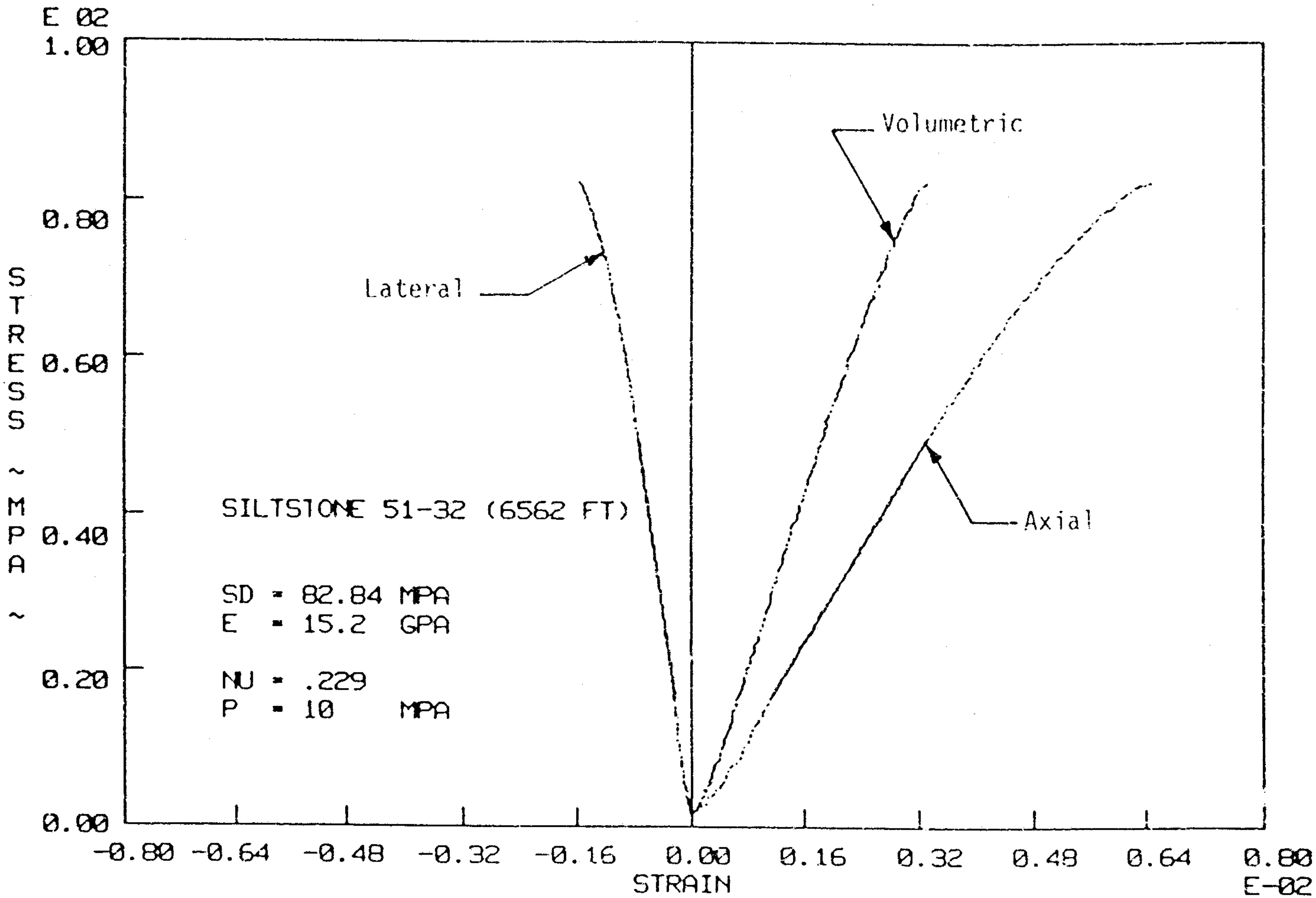
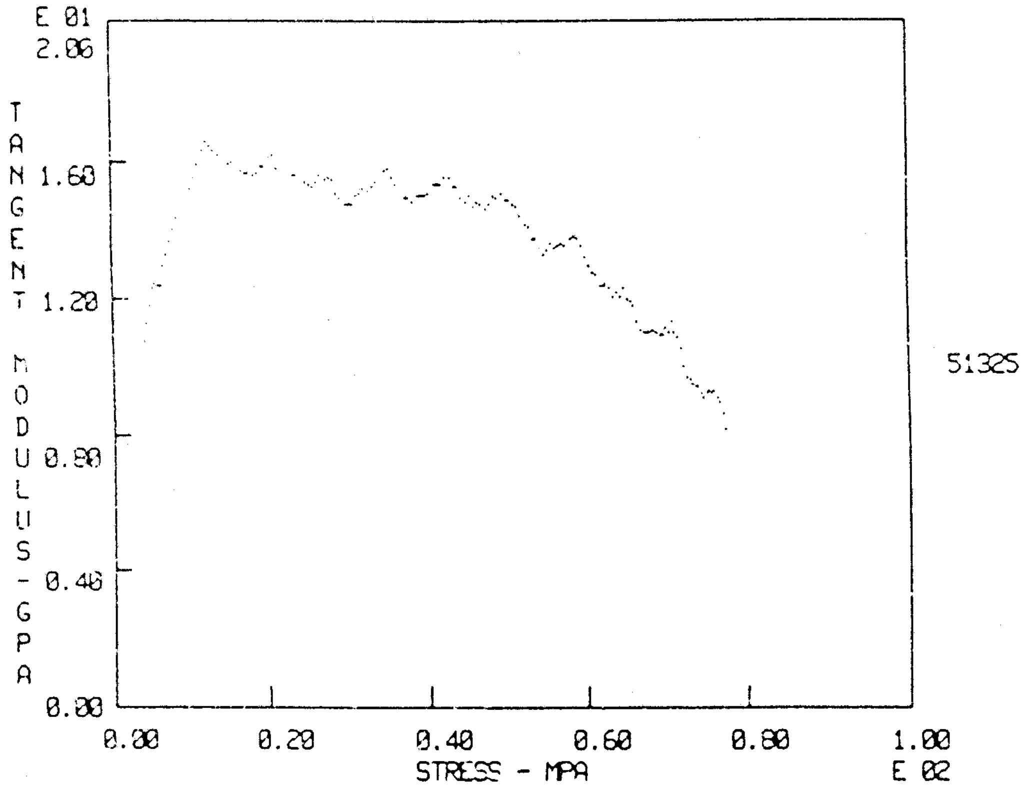


Figure 141. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Siltstone 51-32. P = 10 MPa.

RSI DWG 046-82-074



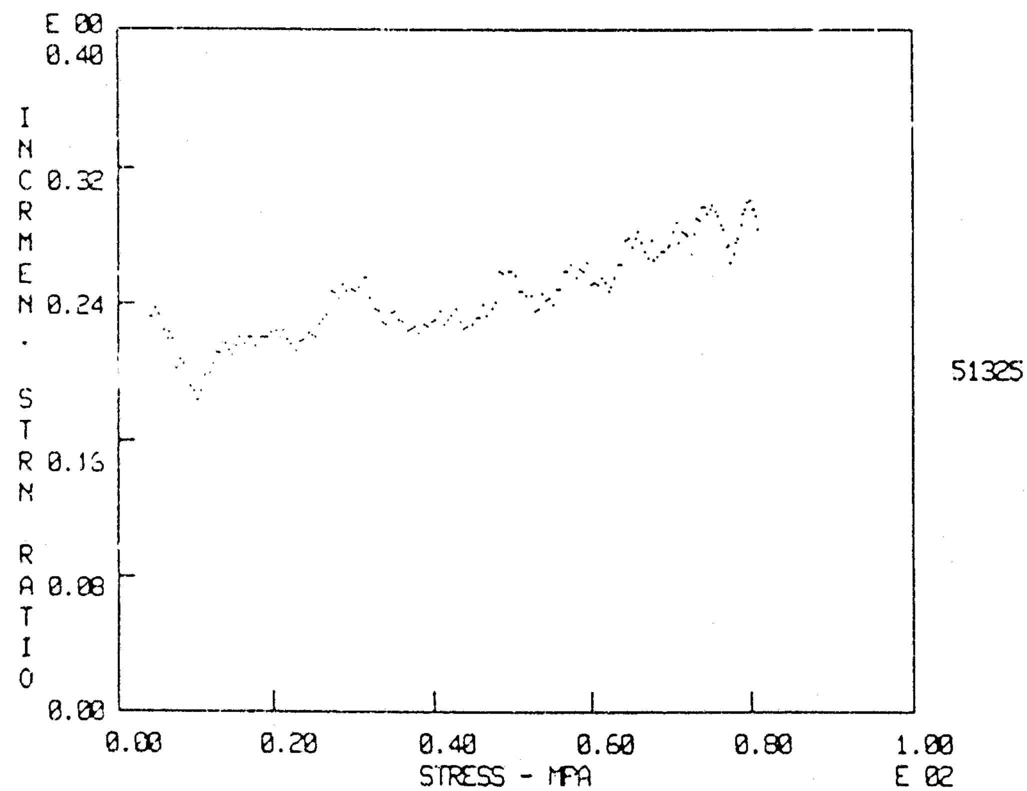


Figure 142. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Siltstone 51-32 (6562 Feet). P = 10 MPa.

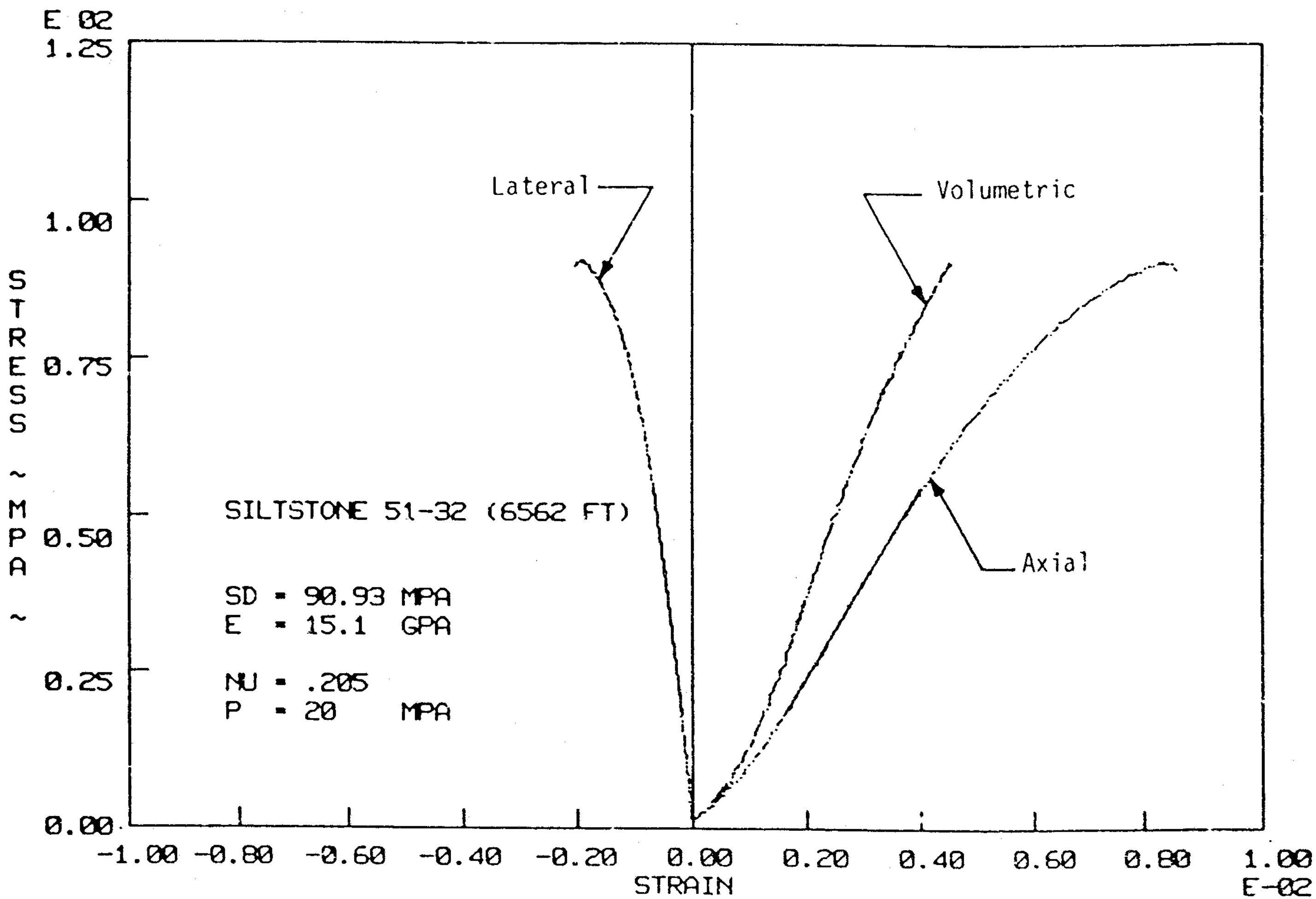
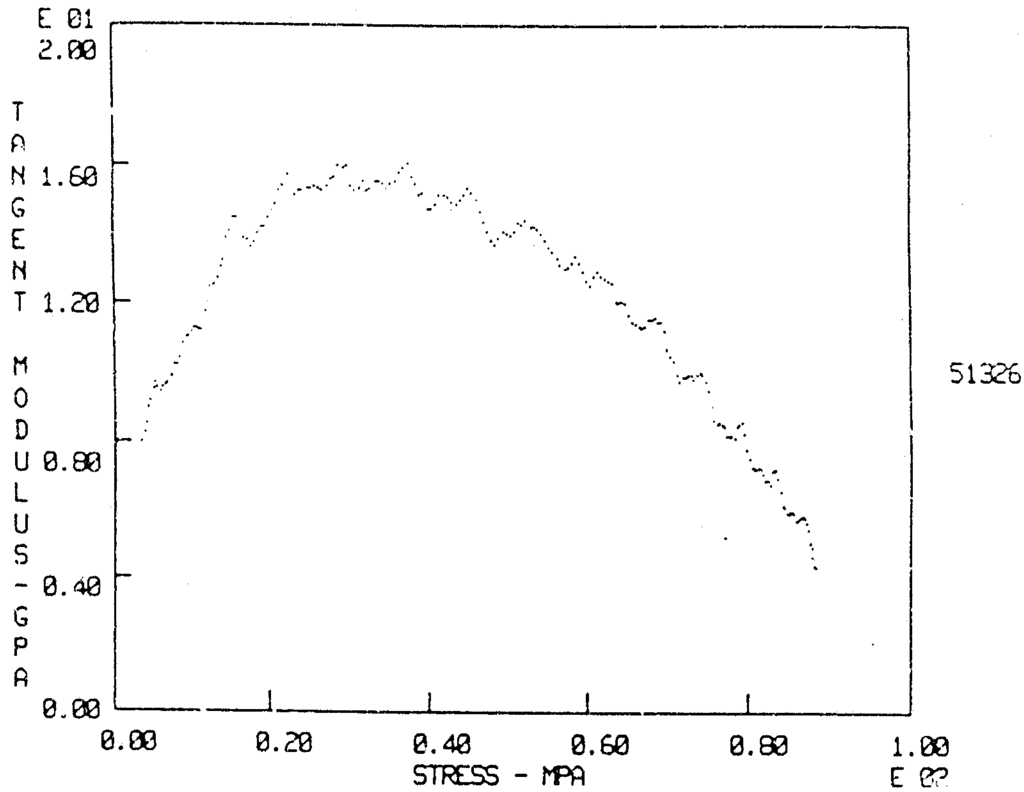


Figure 143. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Siltstone 51-32. P = 20 MPa.

RSI DWG 046-82-075



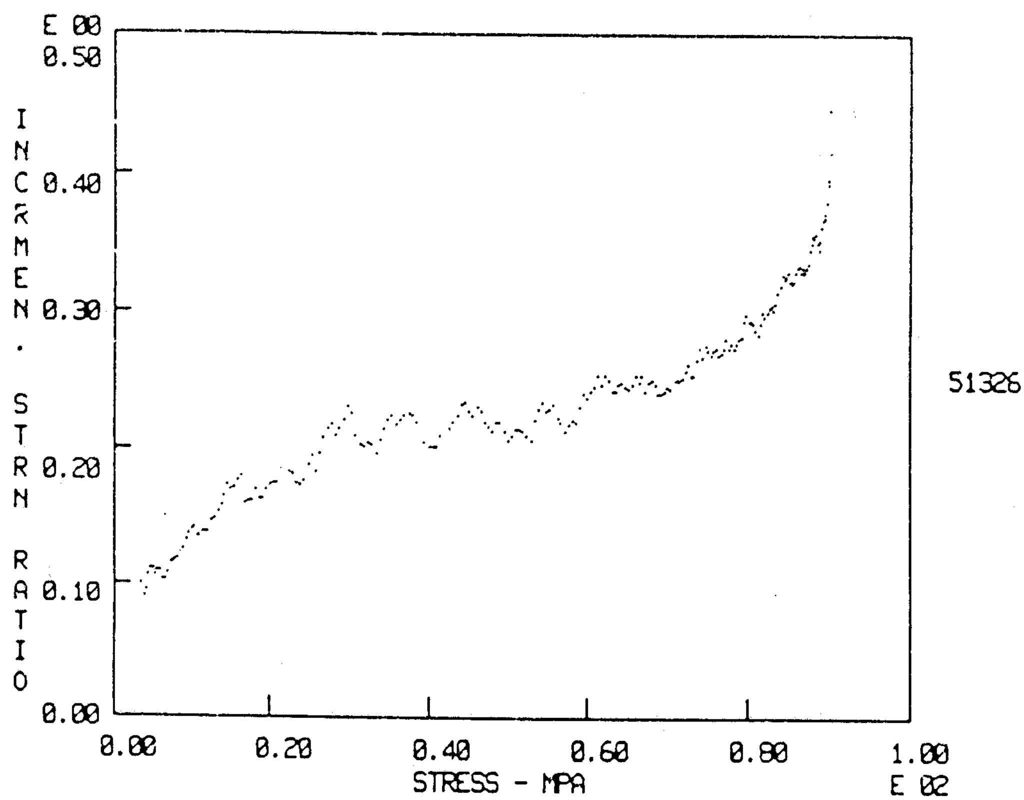


Figure 144. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Siltstone 51-32 (6562 Feet). P = 20 MPa.

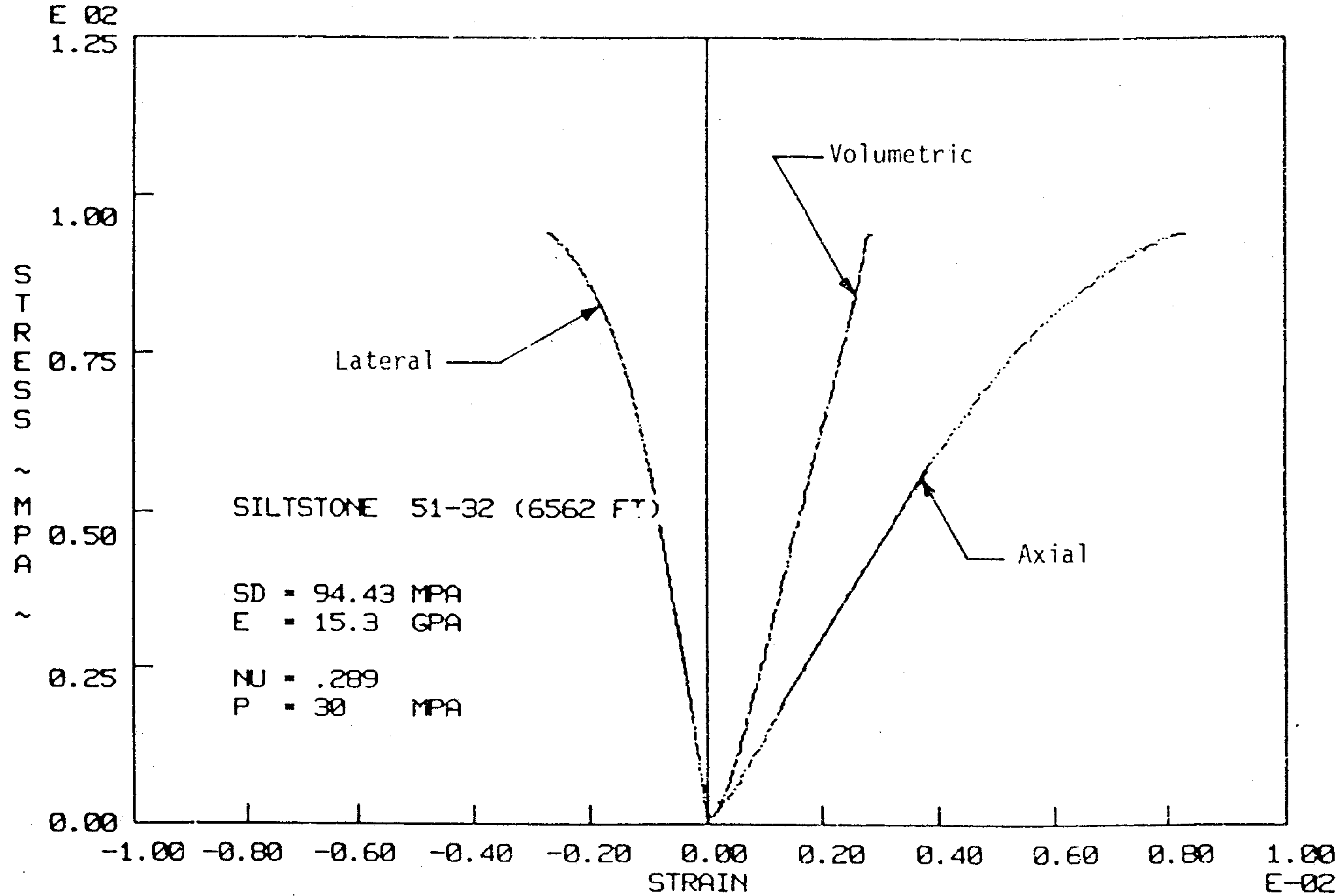


Figure 145. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Siltstone 51-32. P = 30 MPa.

RSI DWG 046-82-076

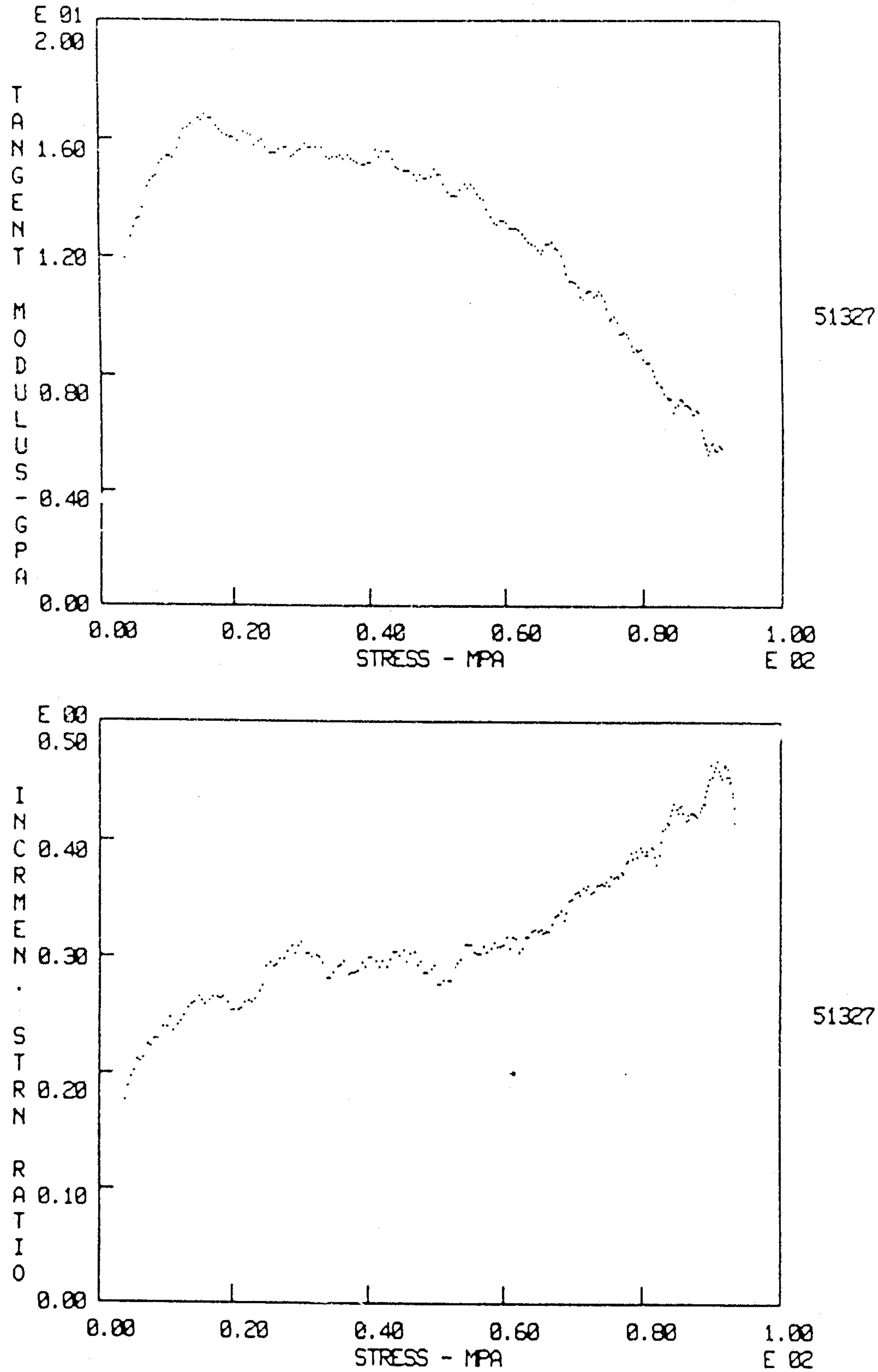


Figure 146. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Siltstone 51-32 (6562 Feet). P = 30 MPa.

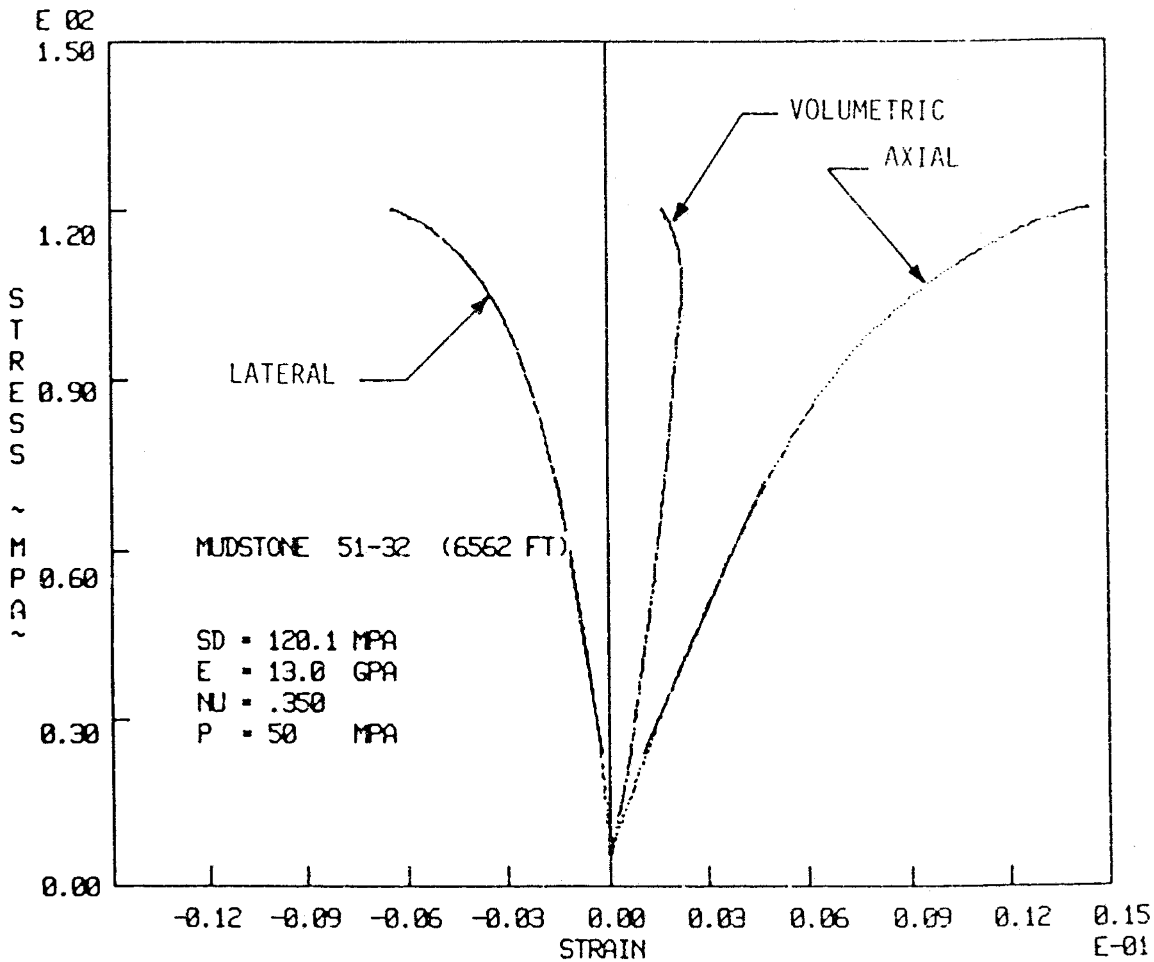
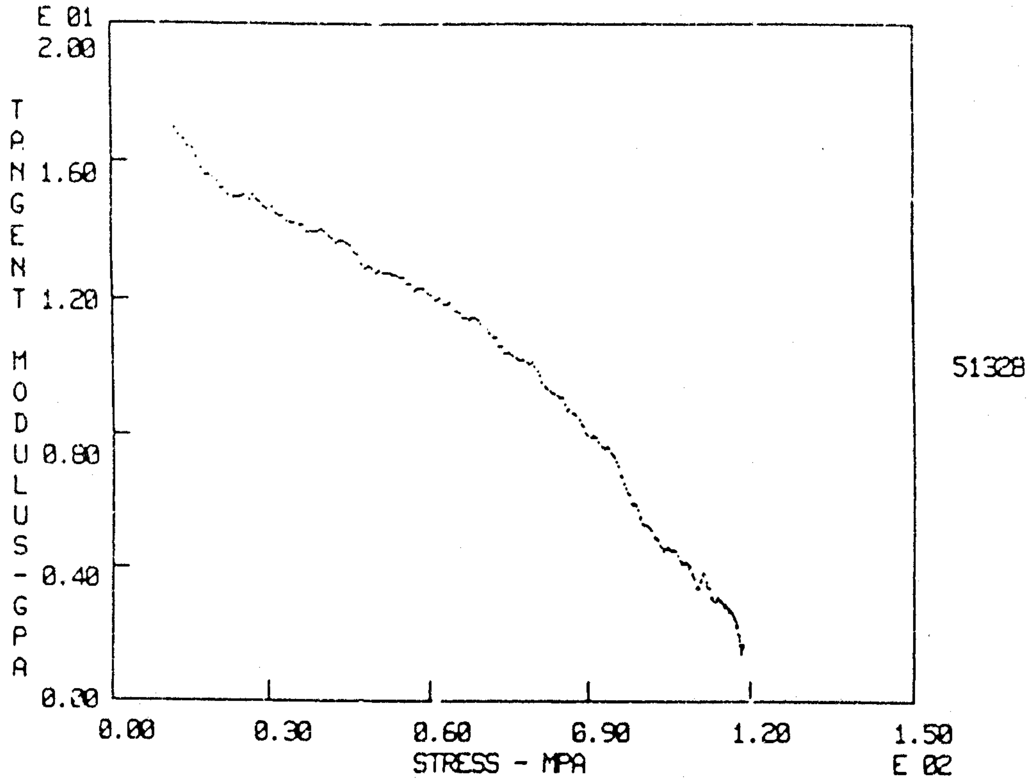


Figure 147. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Mudstone 51-32. P = 50 MPa.

RSI DWG 046-83-99



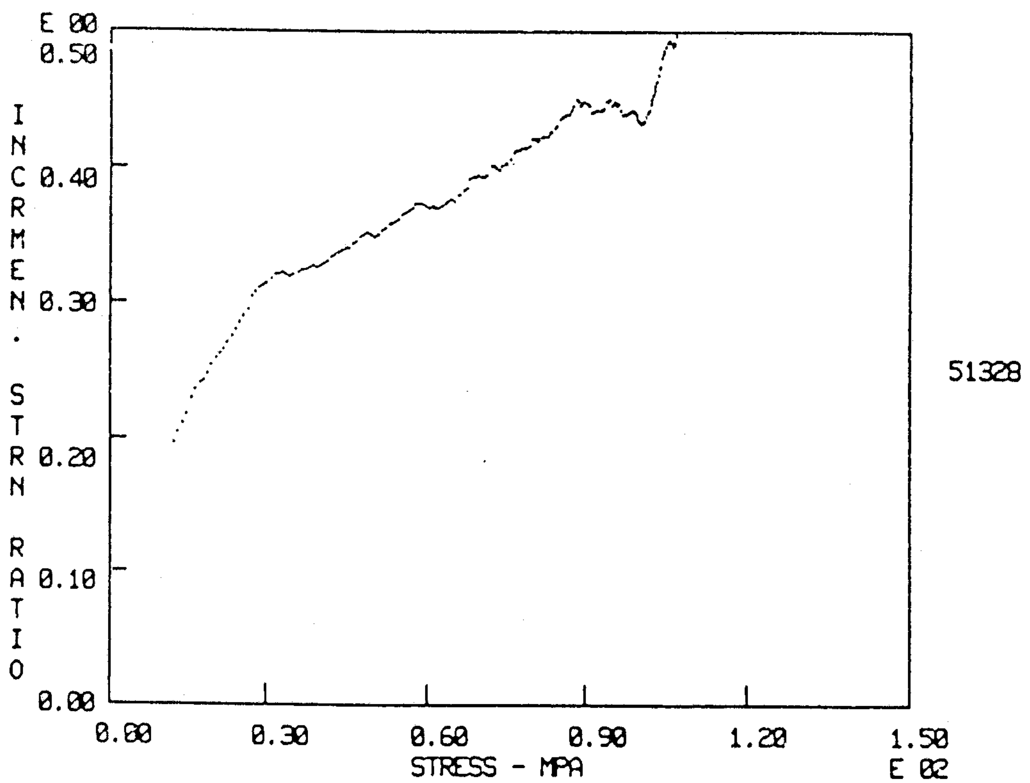


Figure 148. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Mudstone 51-32 (6562 Feet). P = 50 MPa.

MWX-3

MWX-3

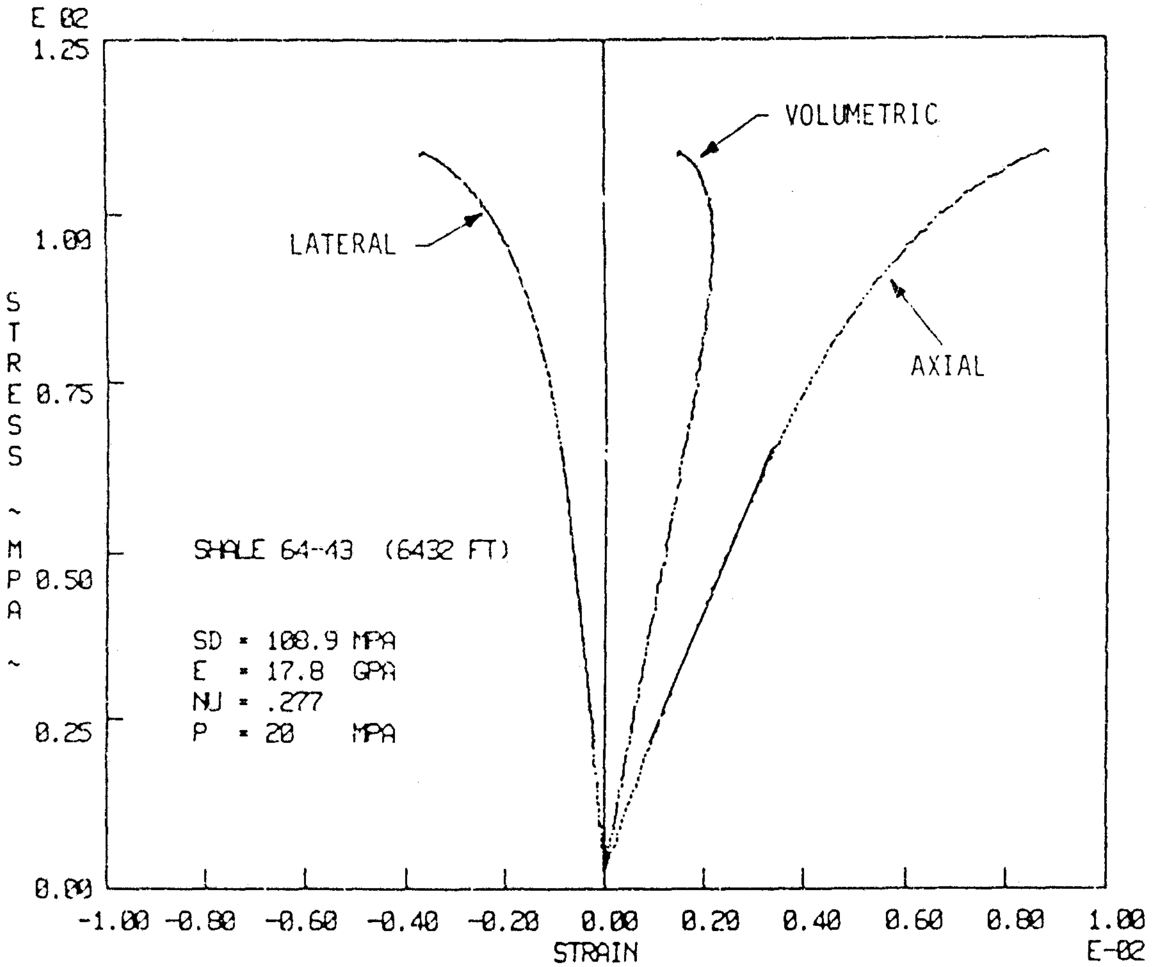
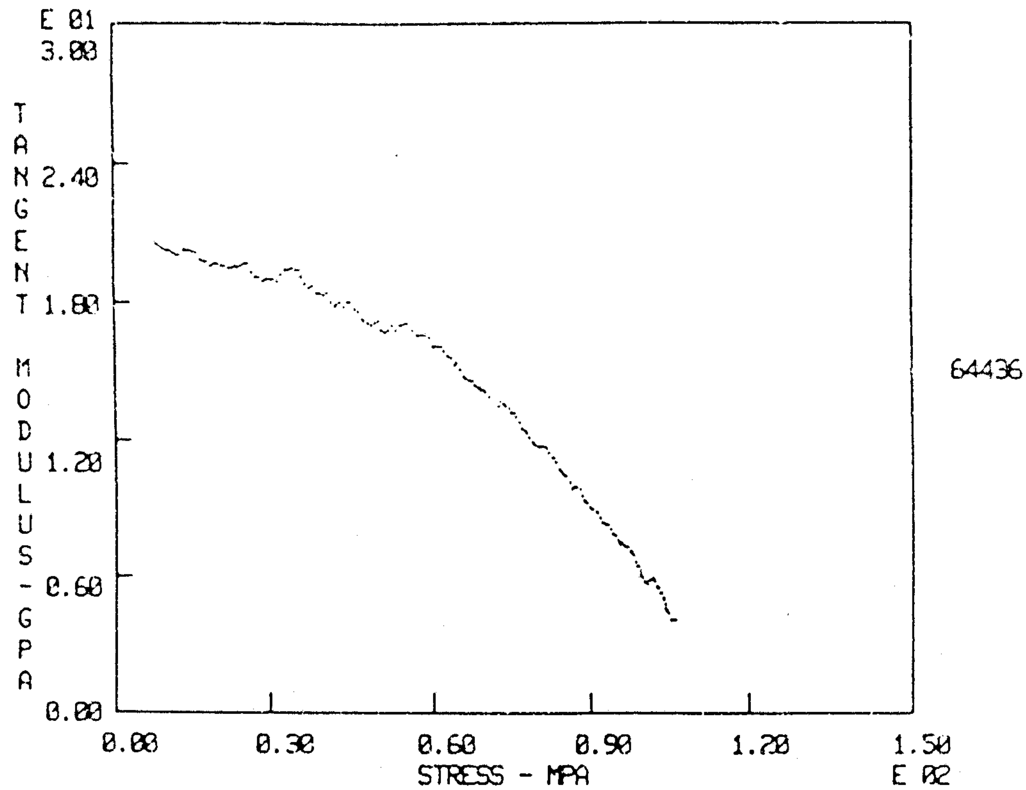


Figure 1. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Shale 64-43. P = 20 MPa.



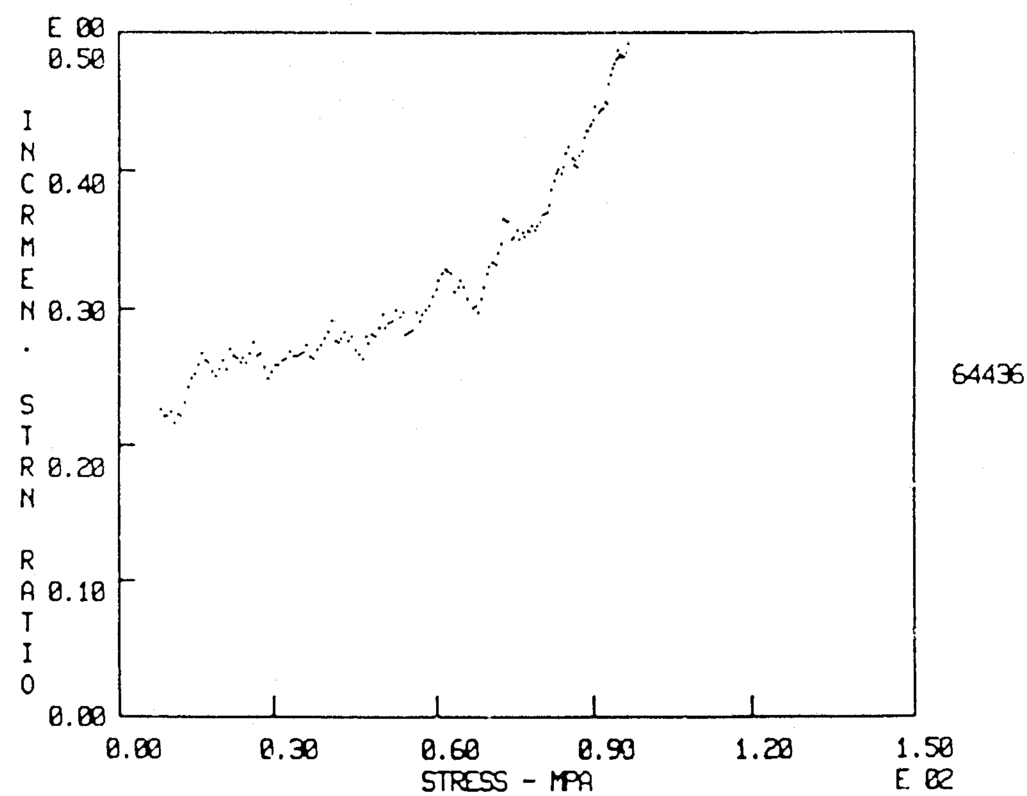


Figure 2. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Shale 64-43 (6432 Feet). P = 20 MPa.

RSI DWG 046-83-382

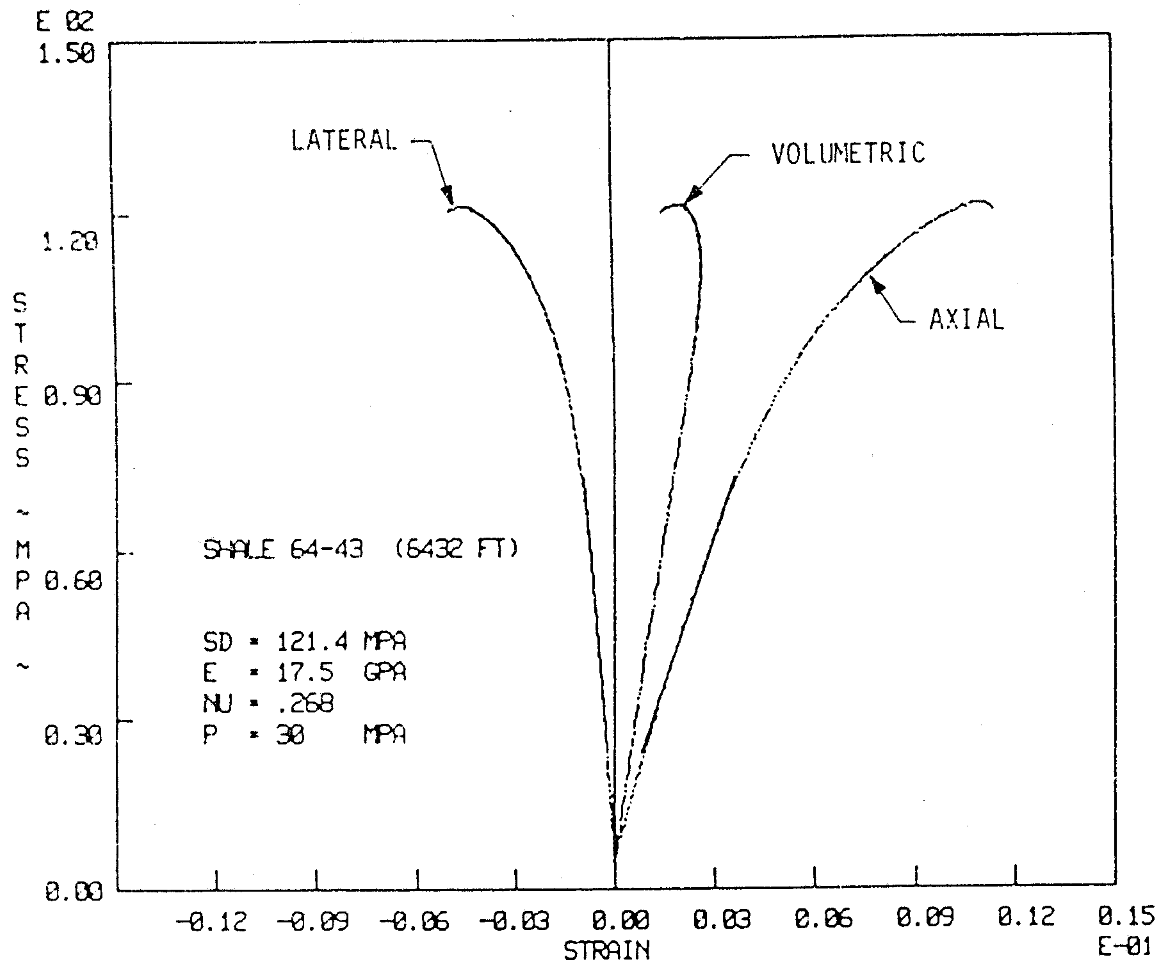
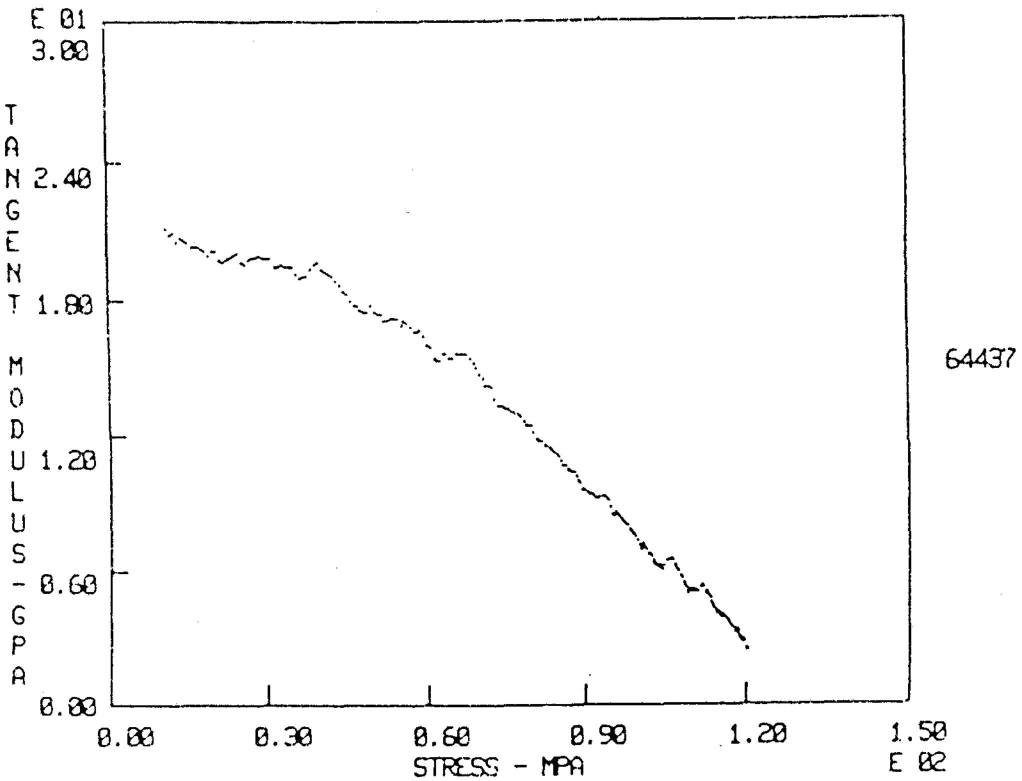


Figure 3. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Shale 64-43. P = 30 MPa.



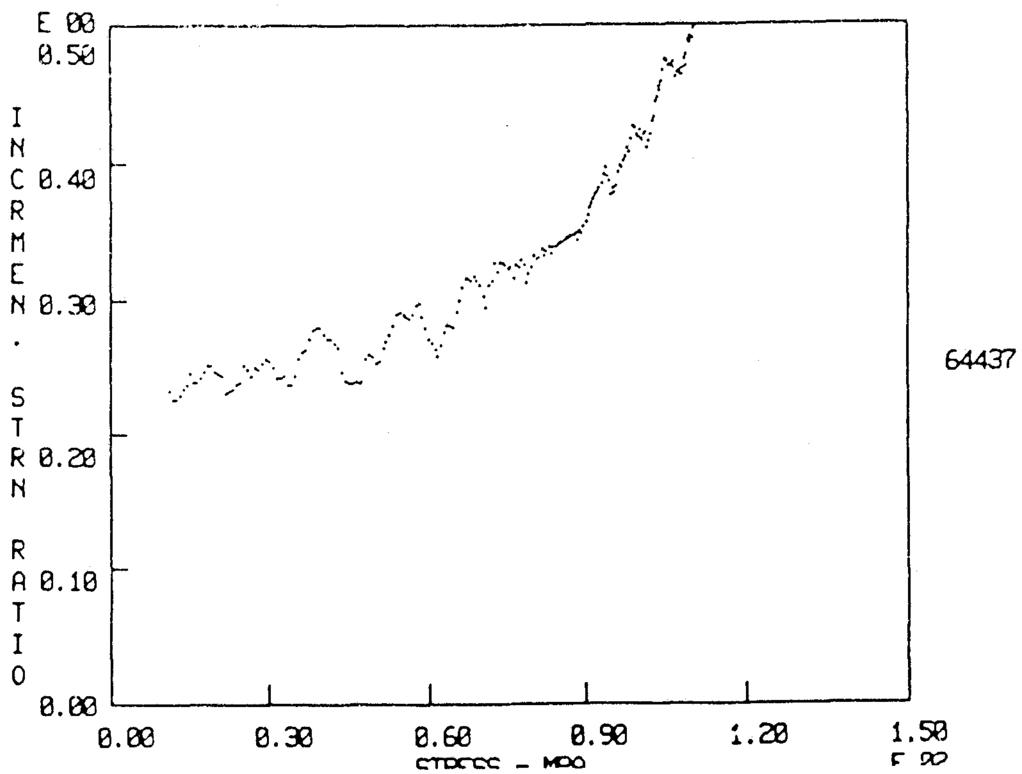


Figure 4. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Shale 64-43 (6432 Feet). P = 30 MPa.

RSI DWG 046-83-384

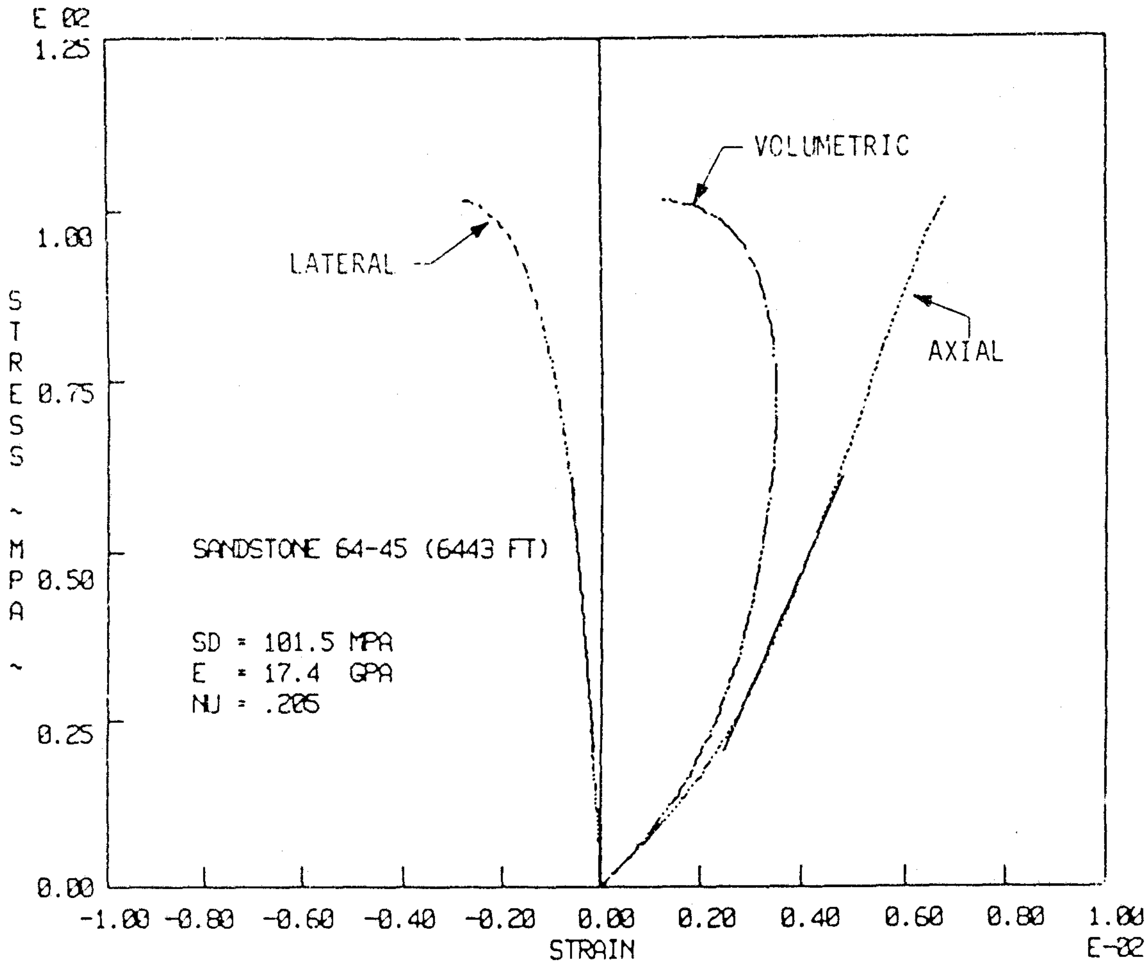
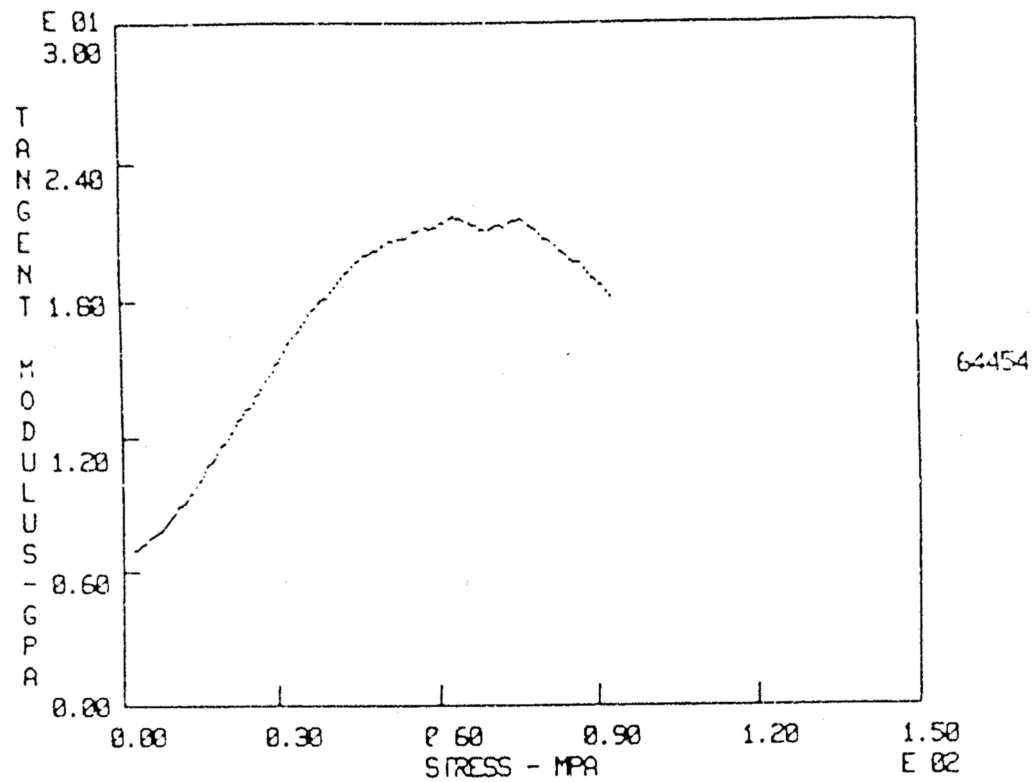


Figure 5. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 64-45. P = 0 MPa.



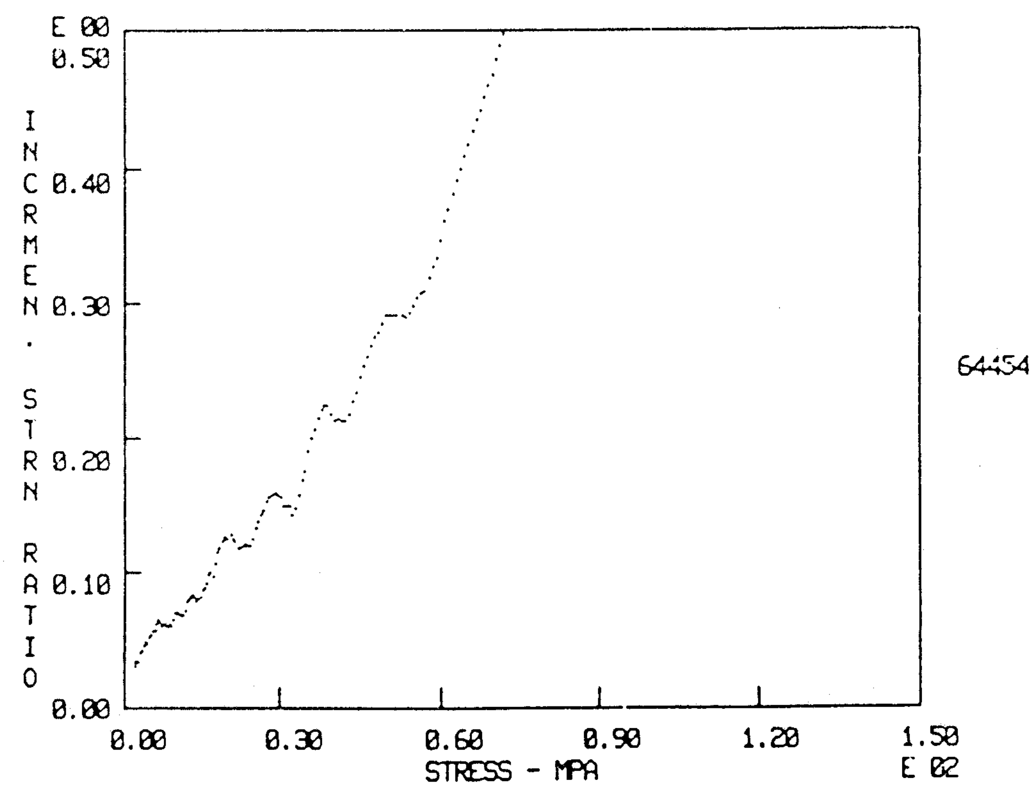


Figure 6. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 64-45 (6443 Feet). P = 0 MPa.

RSI DWG 046-83-?86

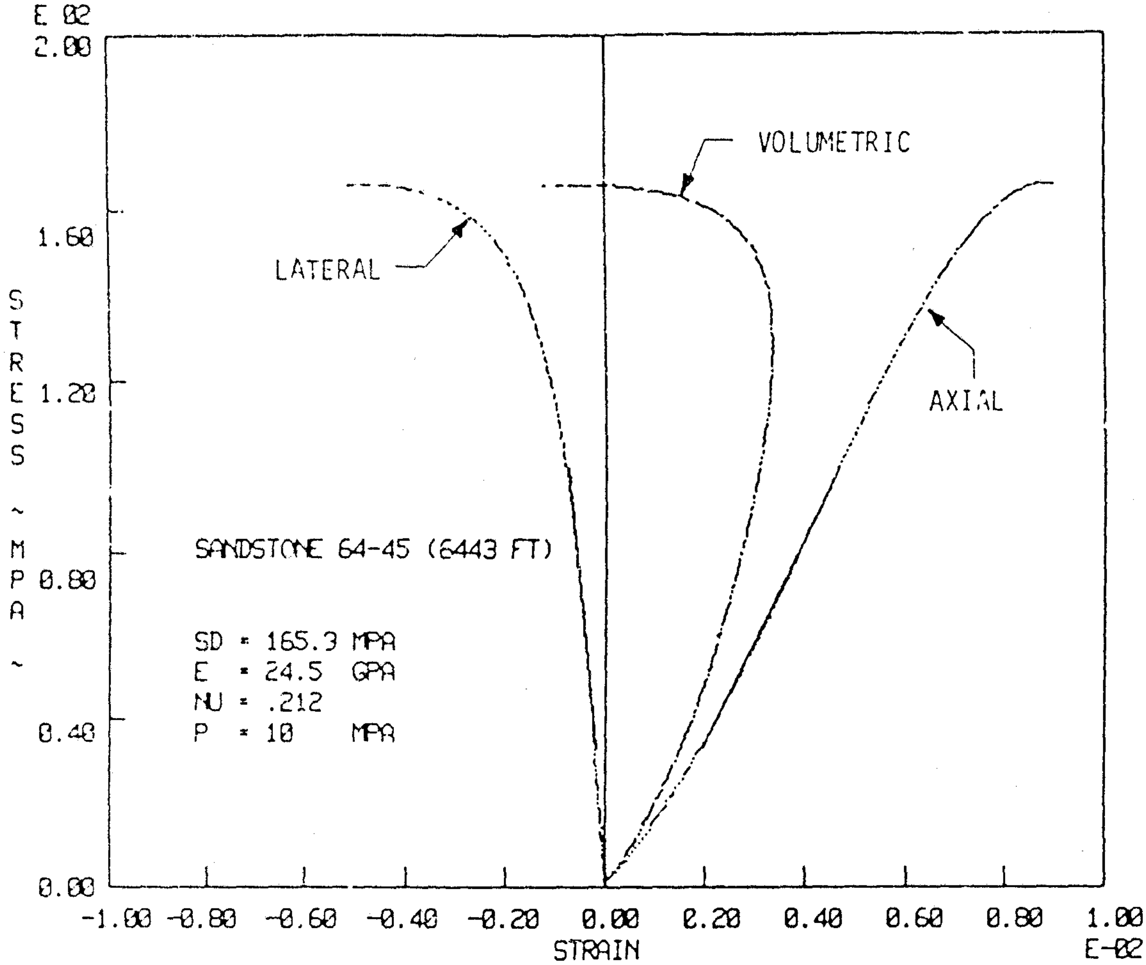
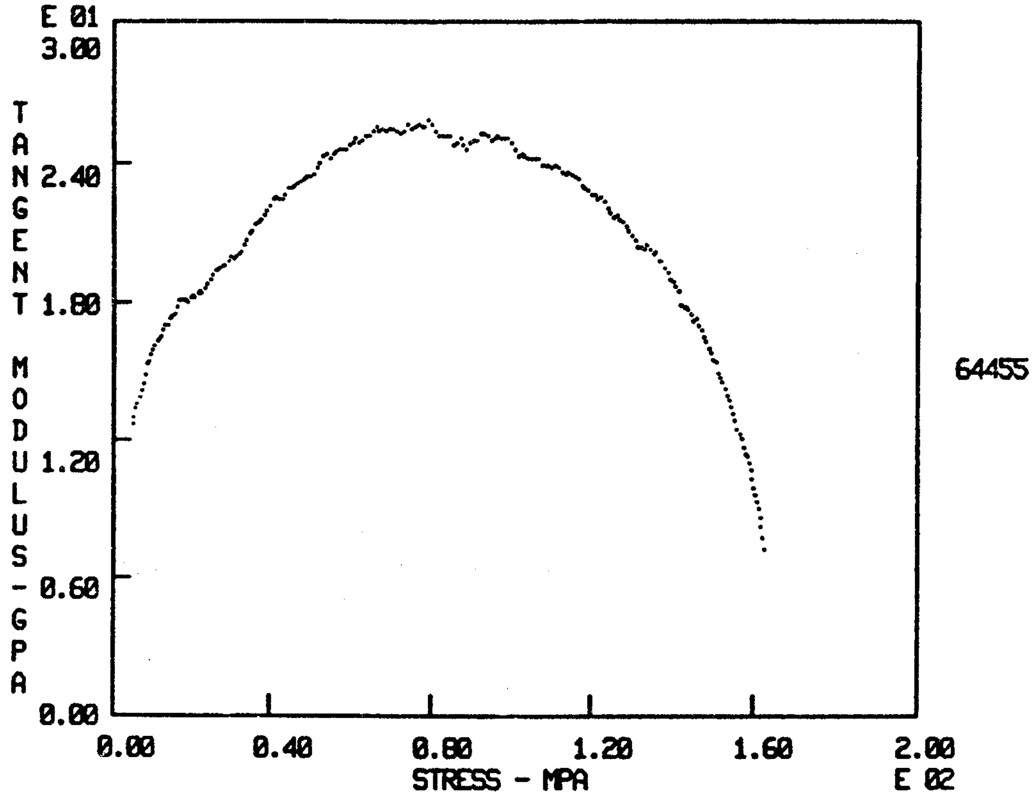


Figure 7. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 64-45. P = 10 MPa.

RSI DWG 046-83-387



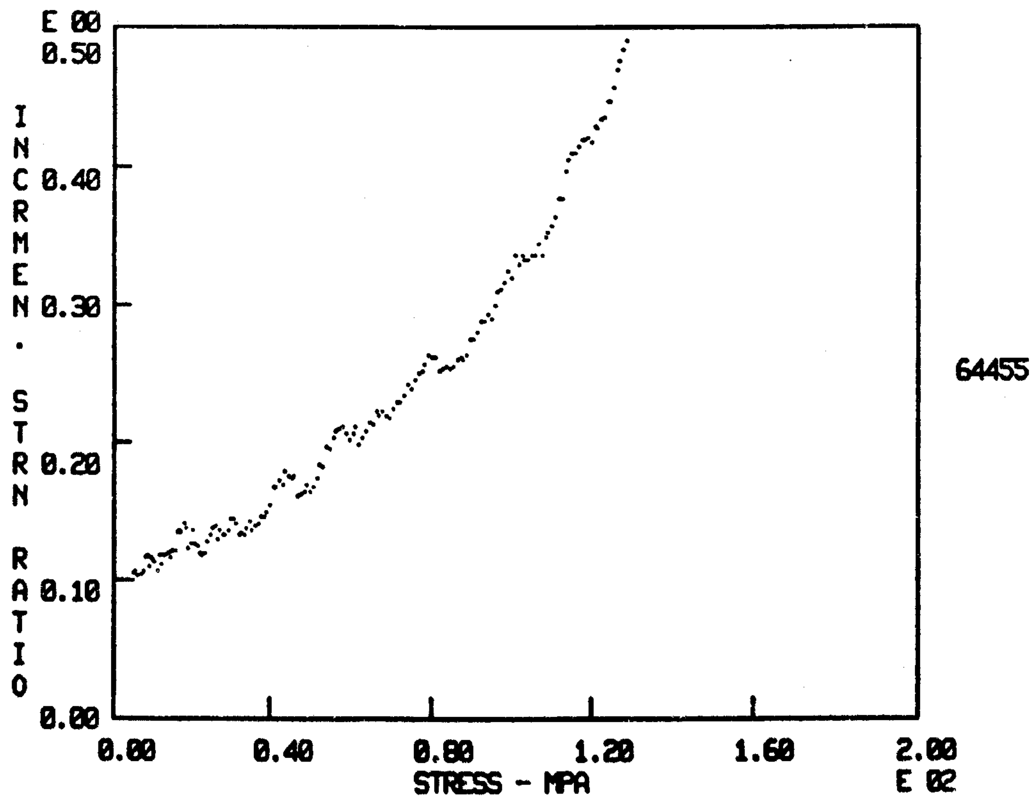


Figure 8. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 64-45 (6443 Feet). P = 10 MPa.

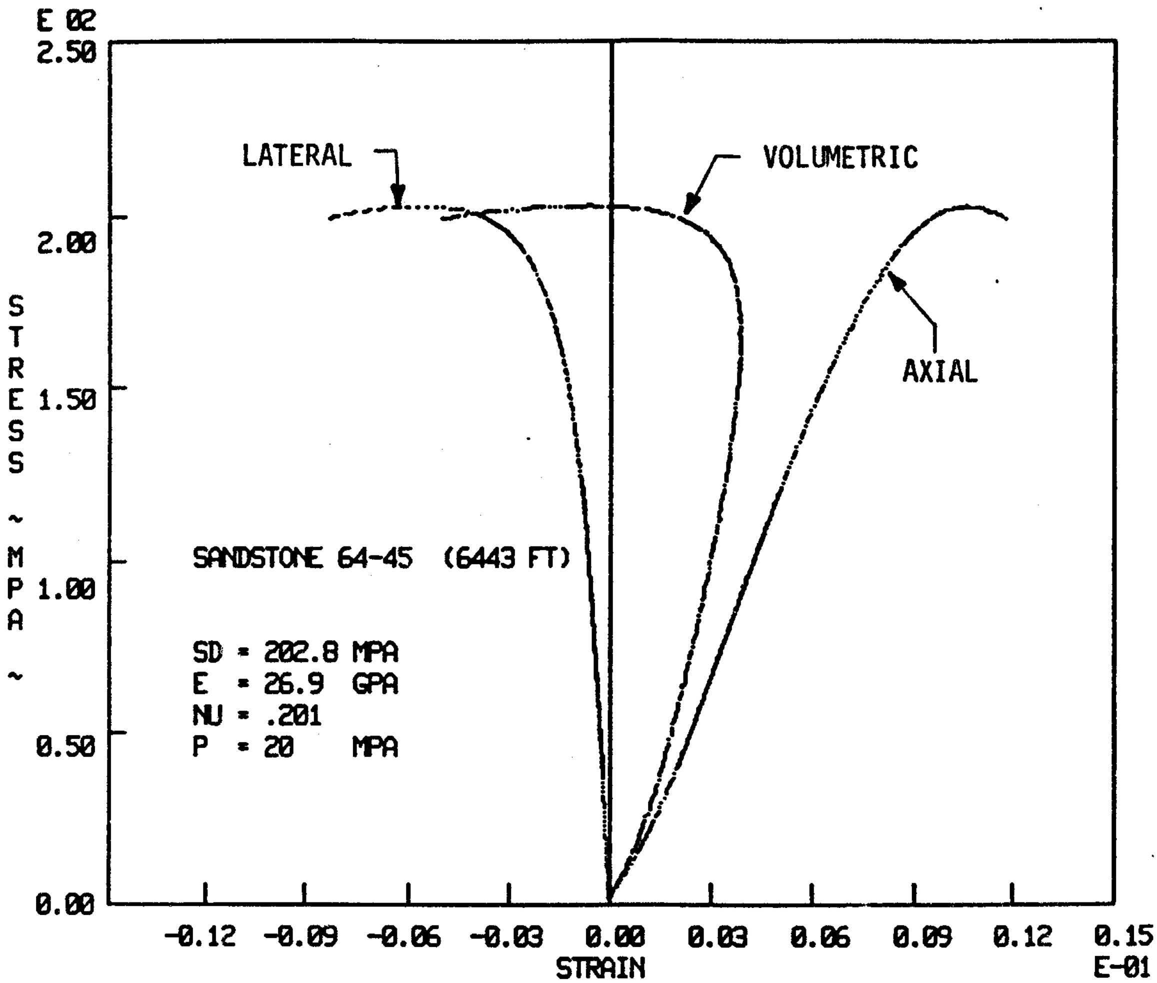
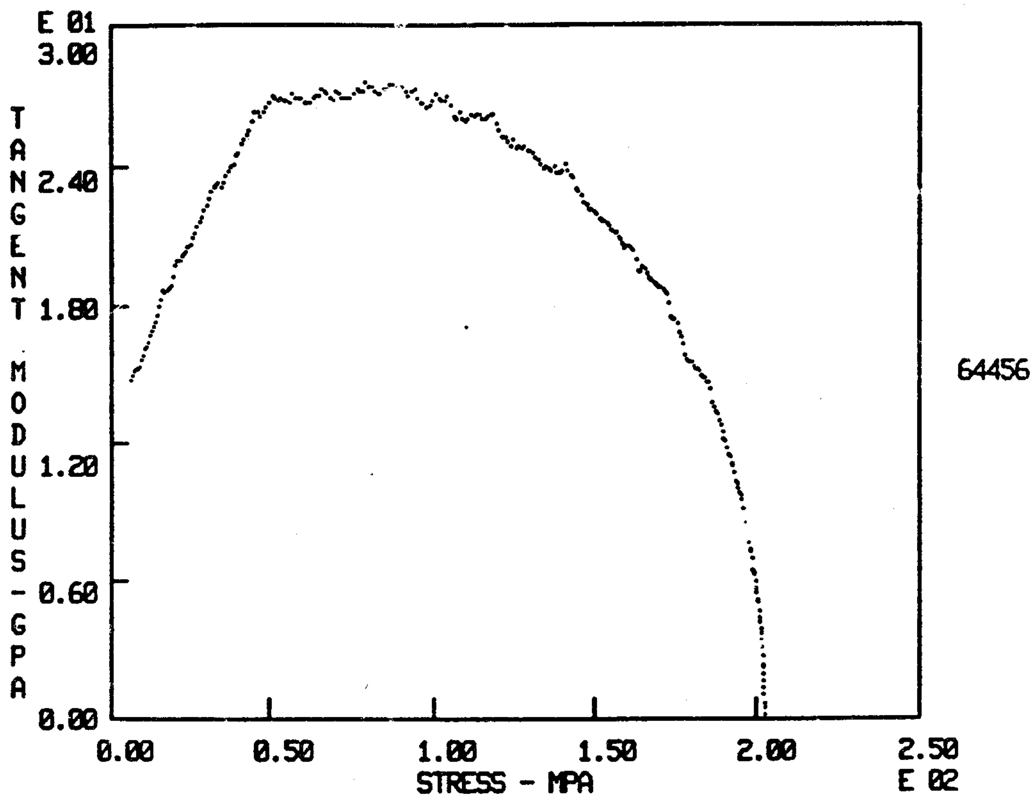


Figure 9. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 64-45. P = 20 MPa.

RSI DWG 046-83-389



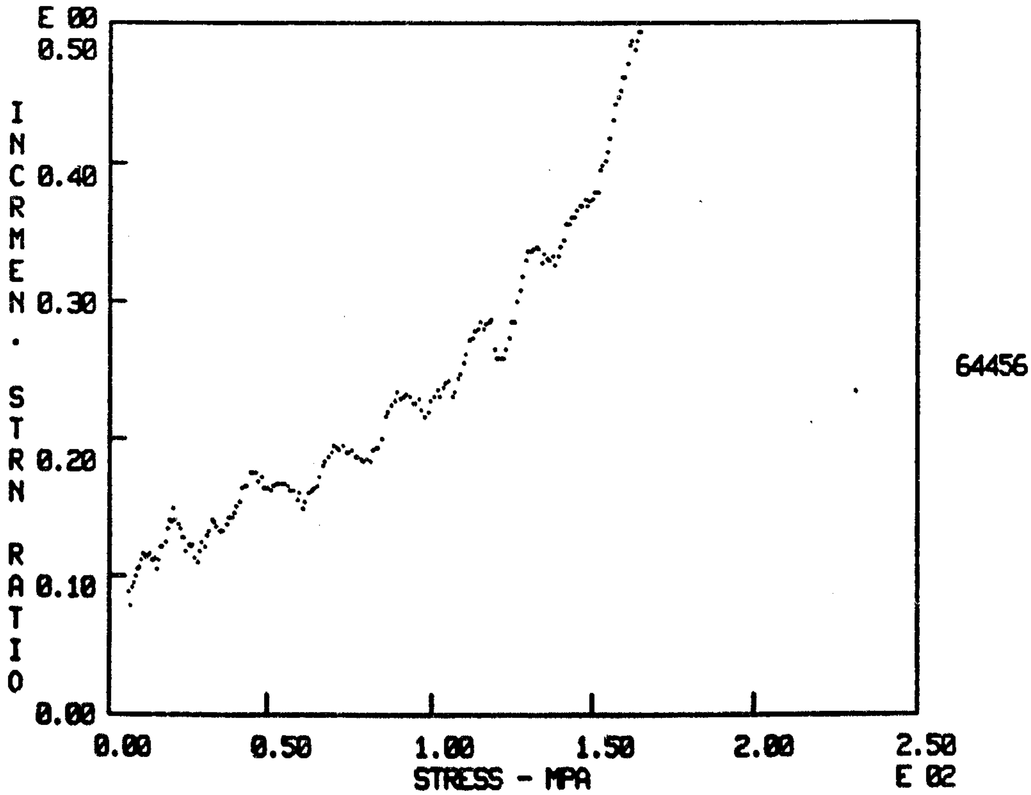


Figure 10. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone (6443 Feet). P = 20 MPa.

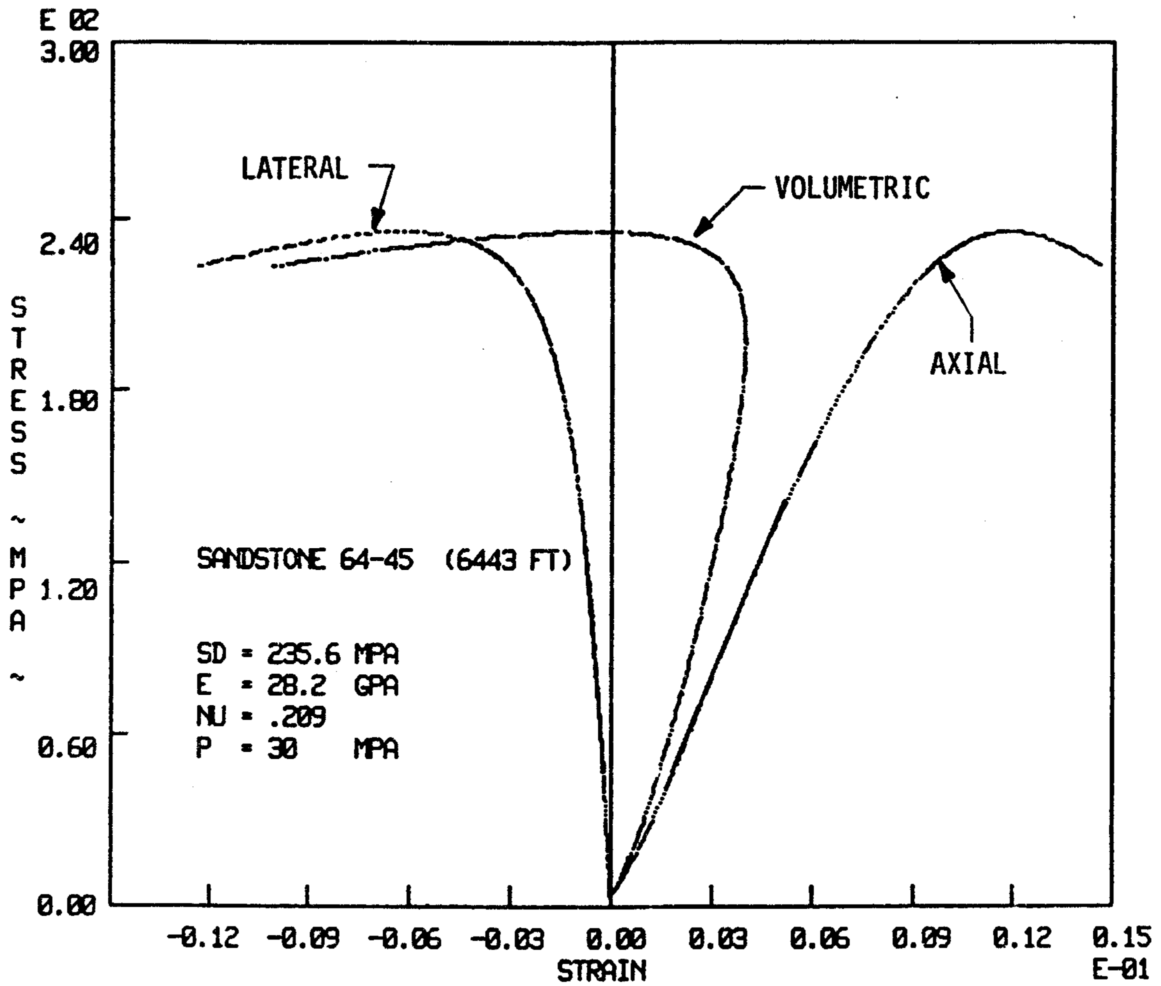
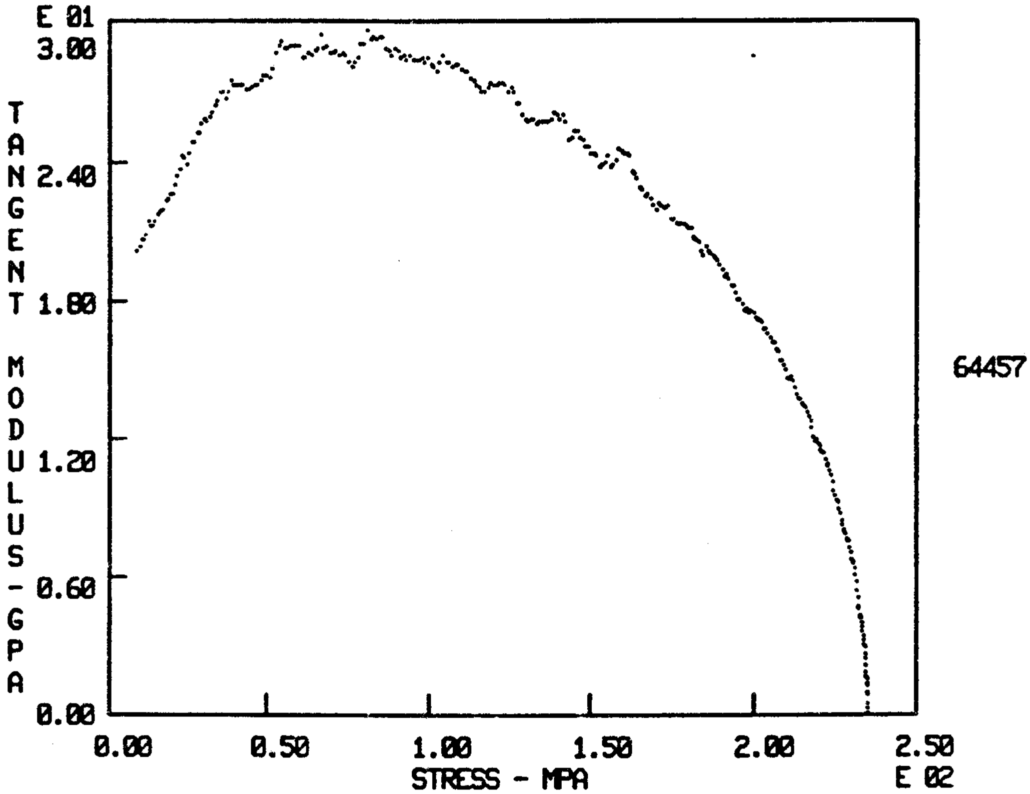


Figure 11. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 64-45. P = 30 MPa.

RSI DWG 046-83-391



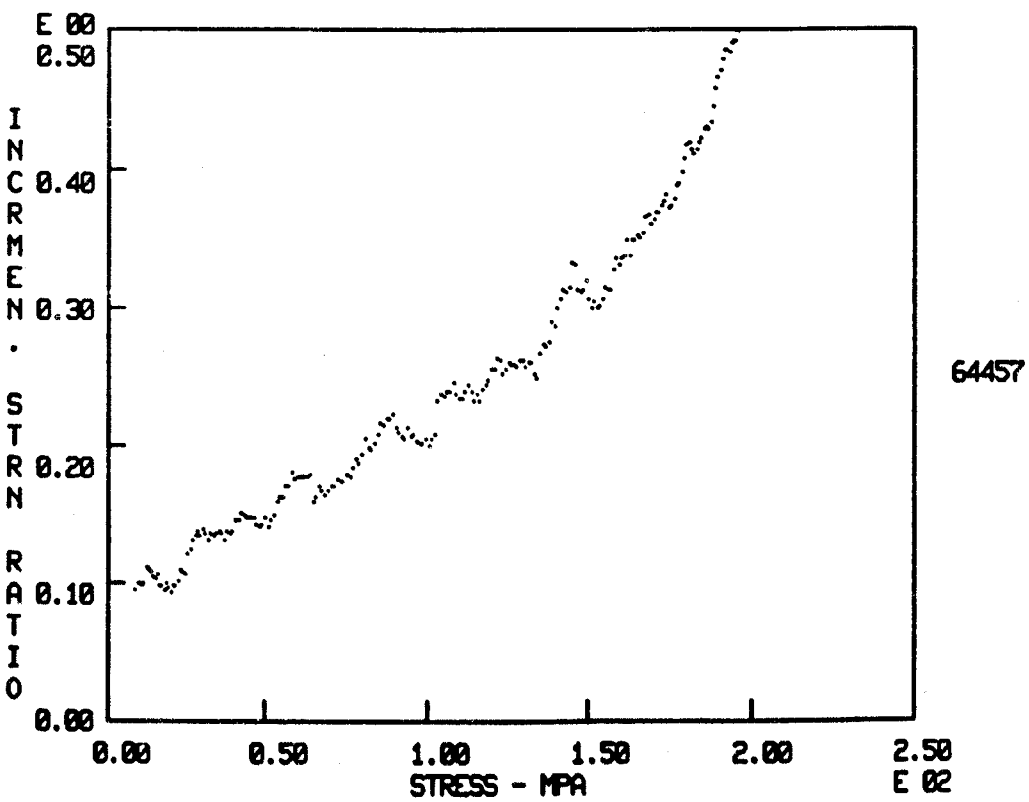


Figure 12. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 64-45 (6443 Feet). P = 30 MPa.

RSI DWG 046-83-392

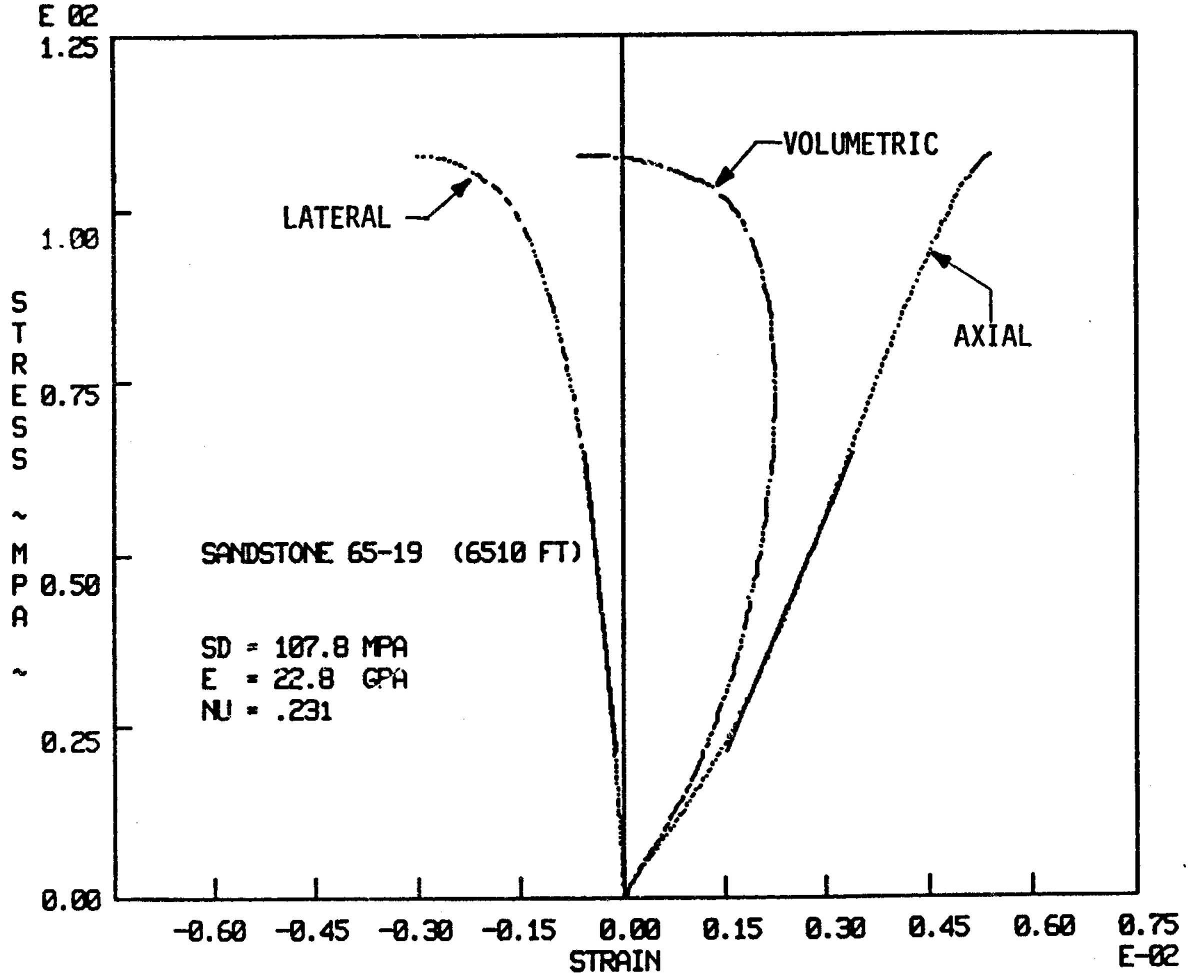
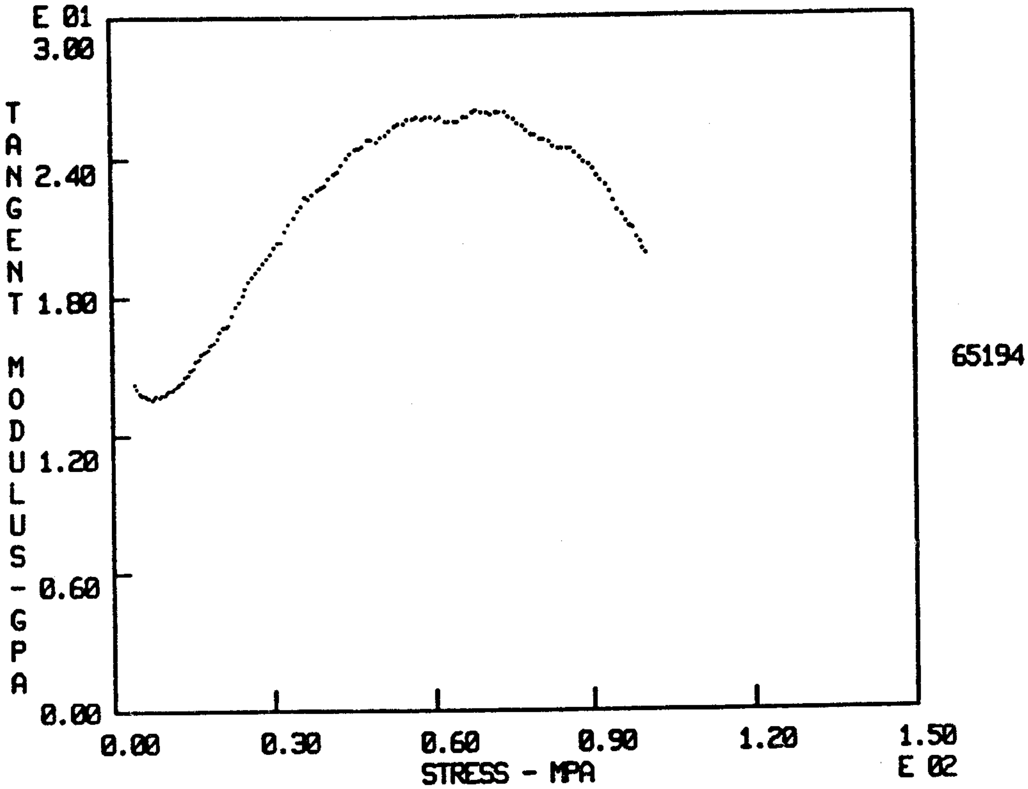


Figure 13. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 65-19. P = 0 MPa.

RSI DWG 046-83-393



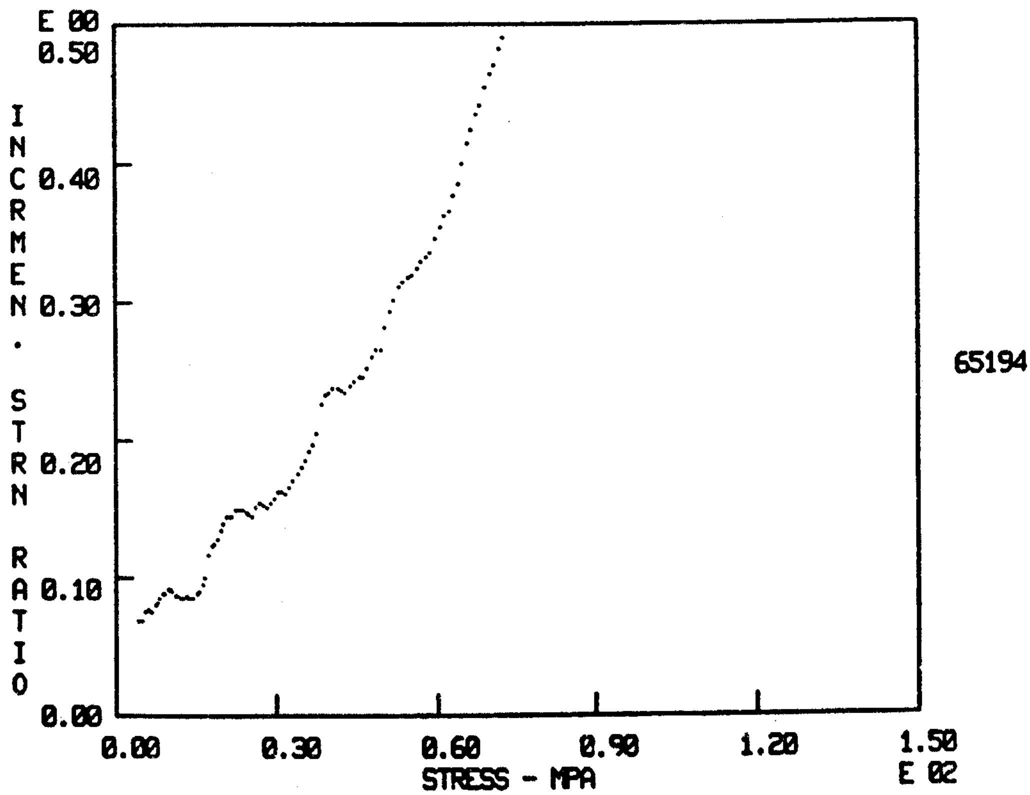


Figure 14. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 65-19 (6510 Feet). P = 0 MPa.

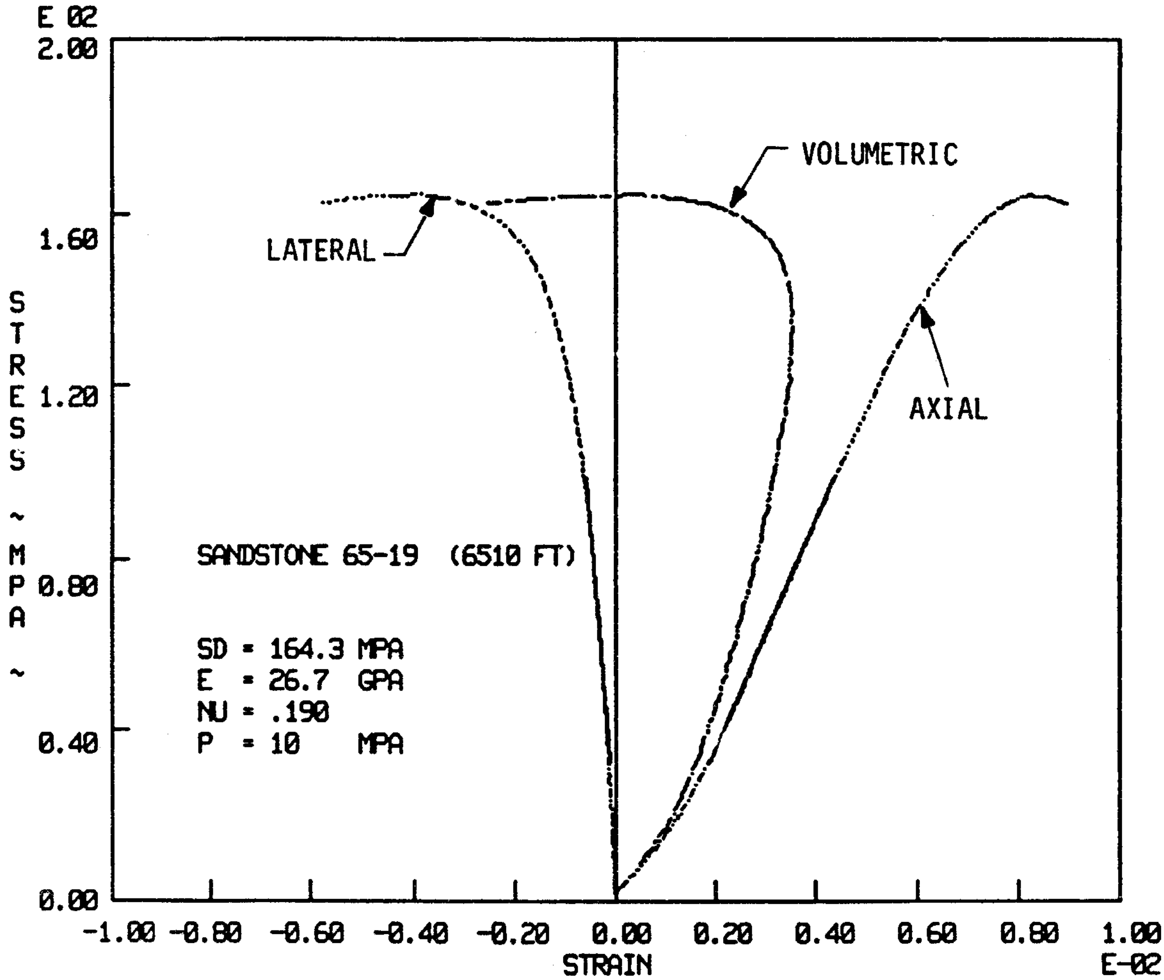
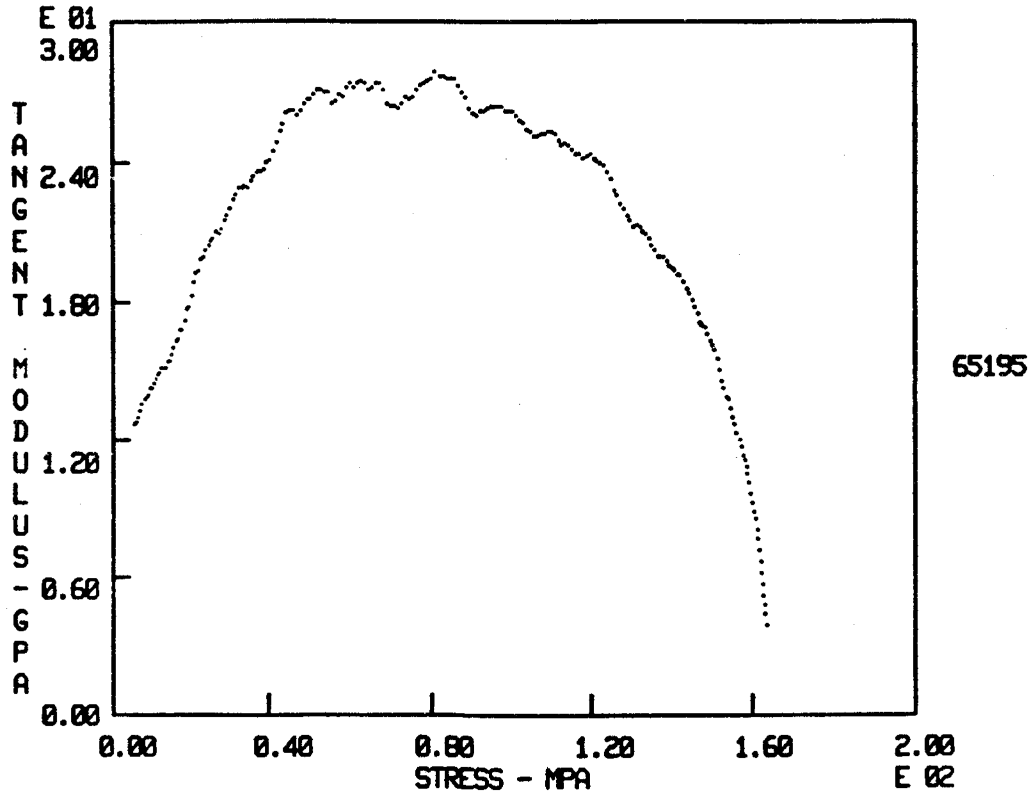


Figure 15. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 65-19. P = 10 MPa.

RSI DWG 046-83-395



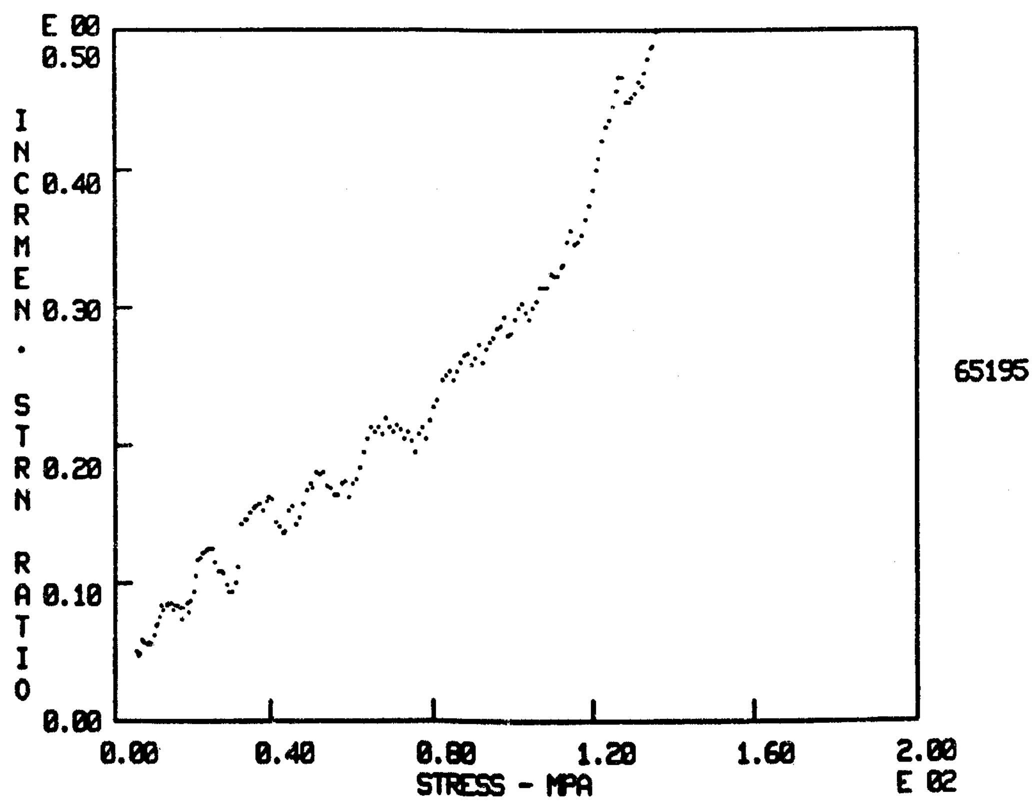


Figure 16. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 65-19 (6510 Feet). P = 10 MPa.

RSI DWG 046-83-396

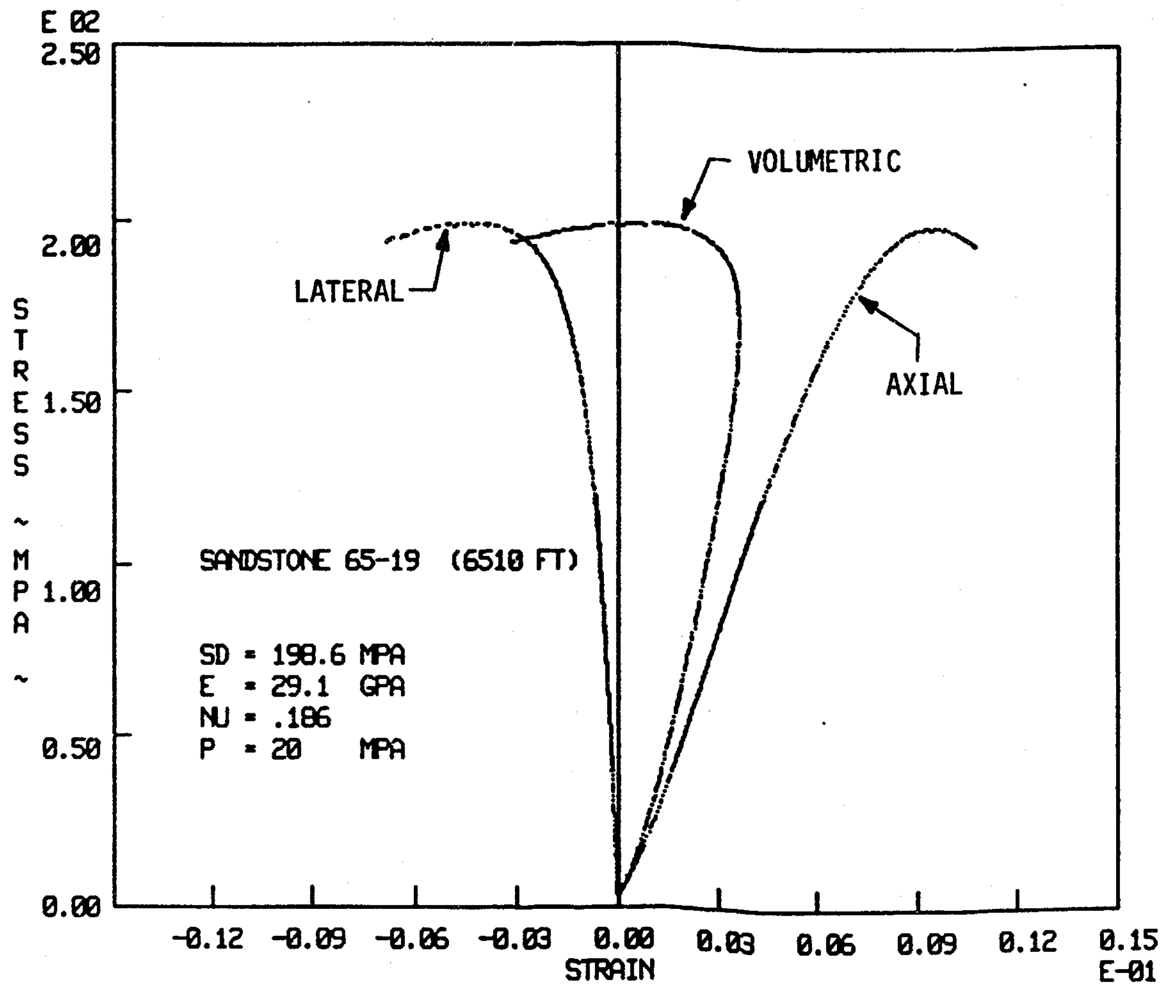
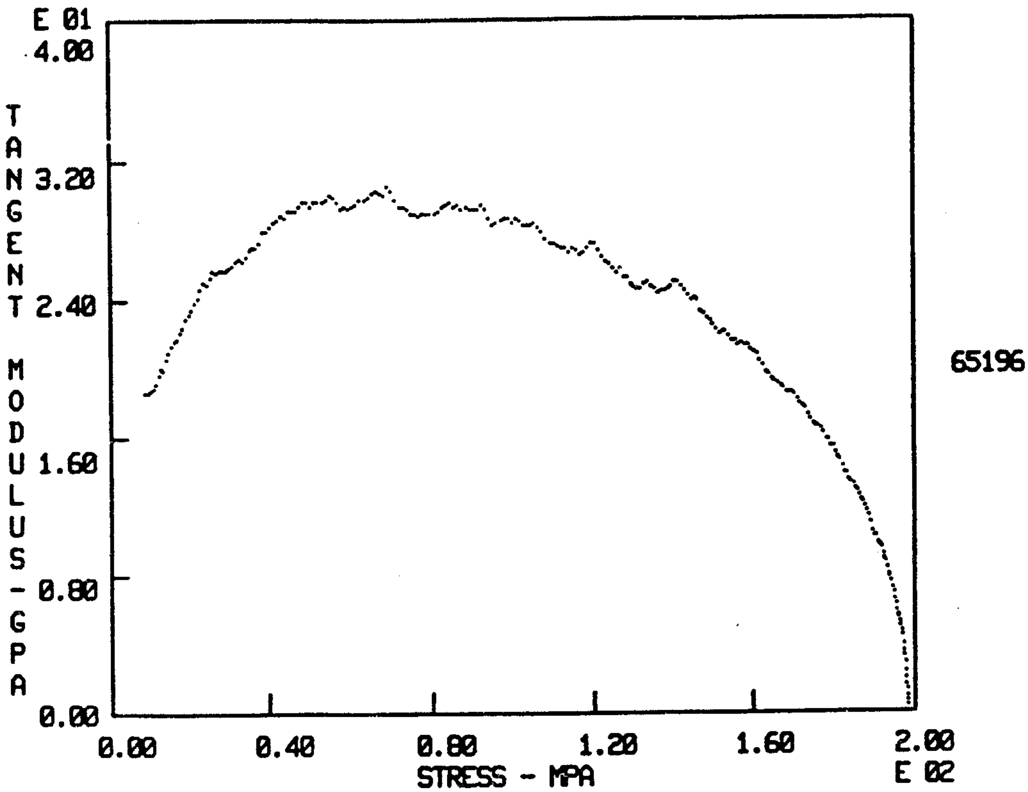


Figure 17. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 65-19. P = 20 MPa.

RSI DWG 046-83-397



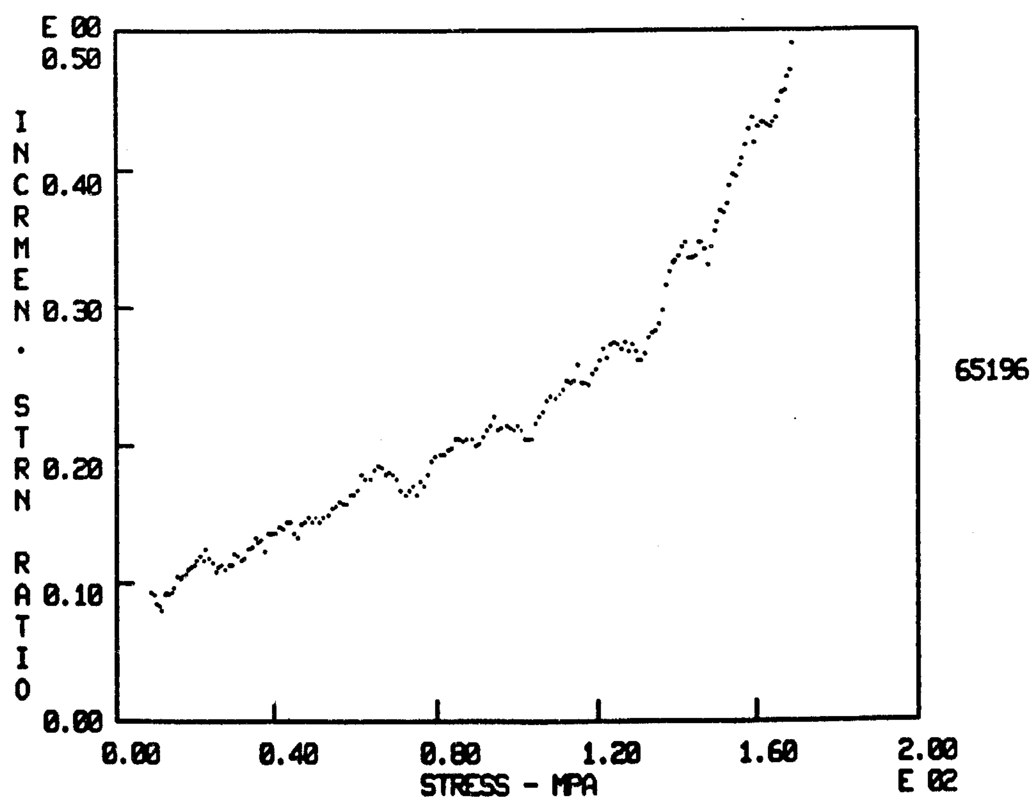


Figure 18. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Sandstone 65-19 (6510 Feet). P = 20 MPa.

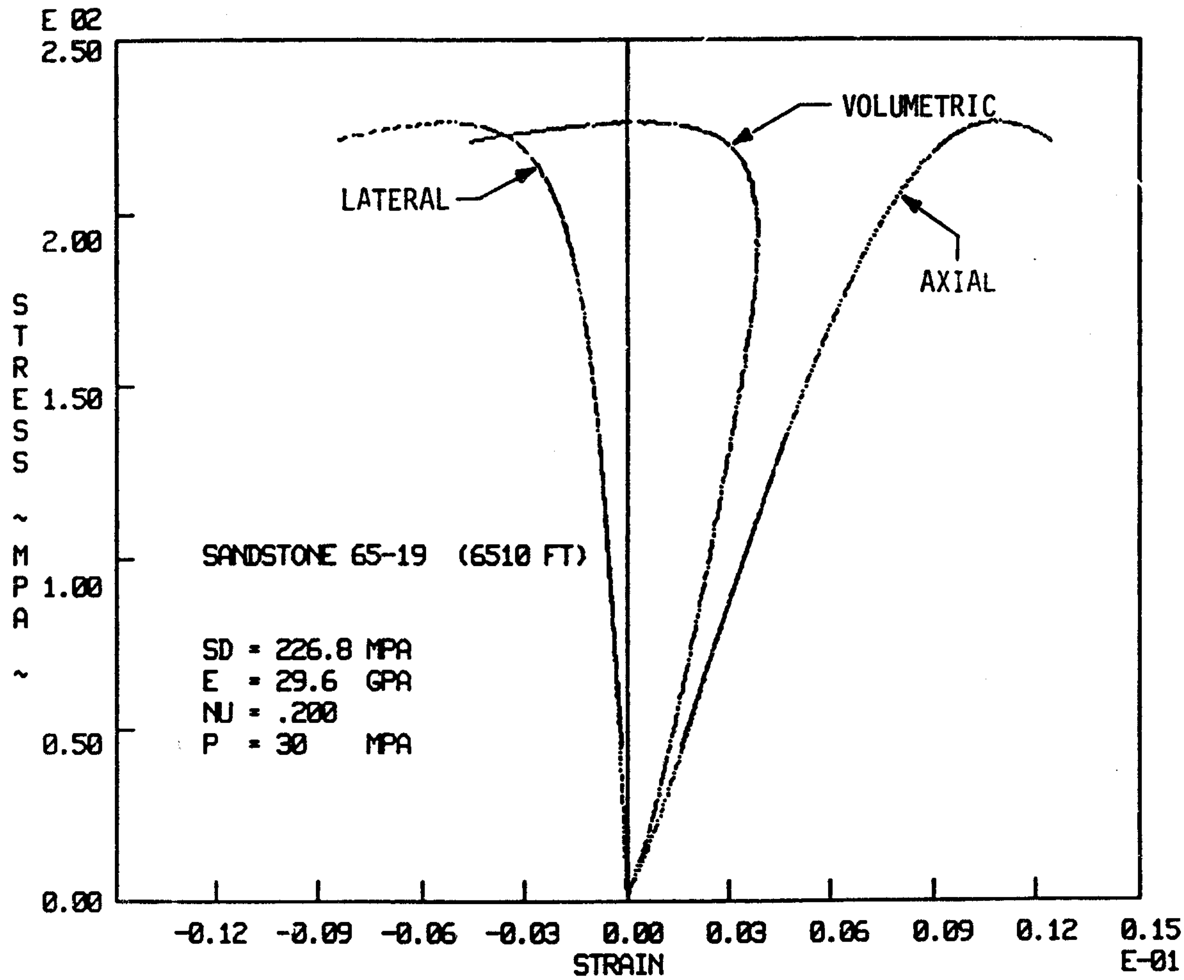
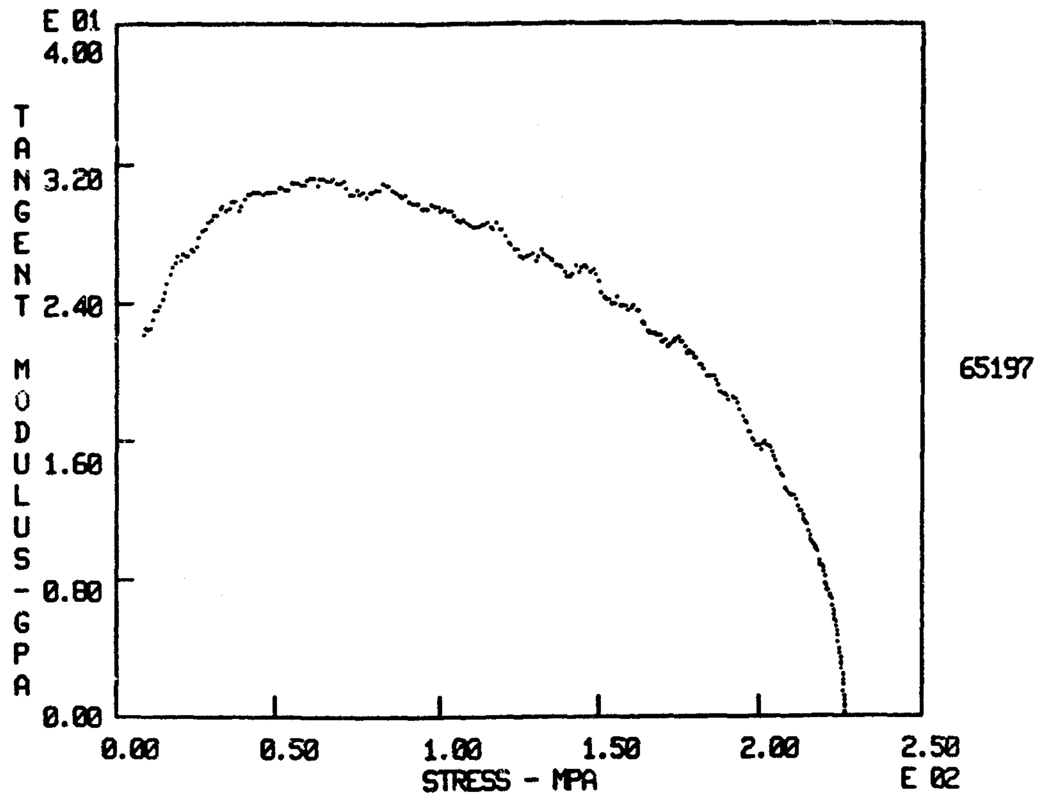


Figure 19. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Sandstone 65-19. P = 30 MPa.

RSI DWG 046-83-399



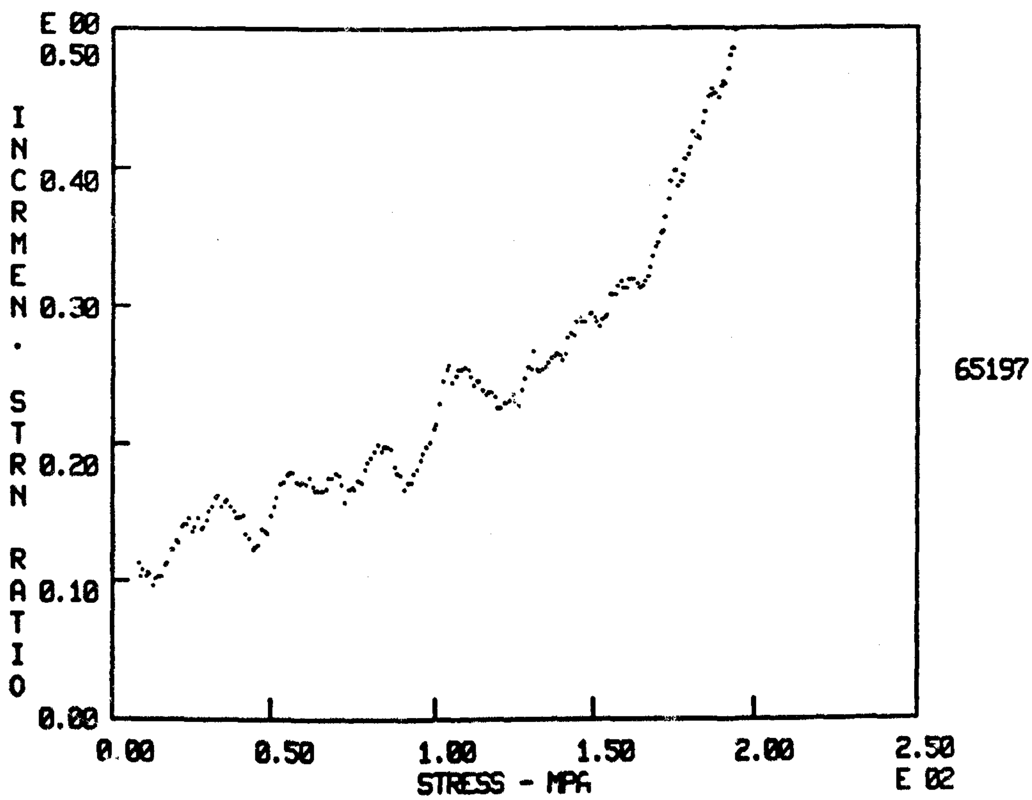


Figure 20. Tangent Modulus and Incremental Strain Ratic Versus Axial Stress Difference for Triaxial Compression of Sandstone 65-19 (6510 Feet). P = 30 MPa.

RSI DWG 046-83-400

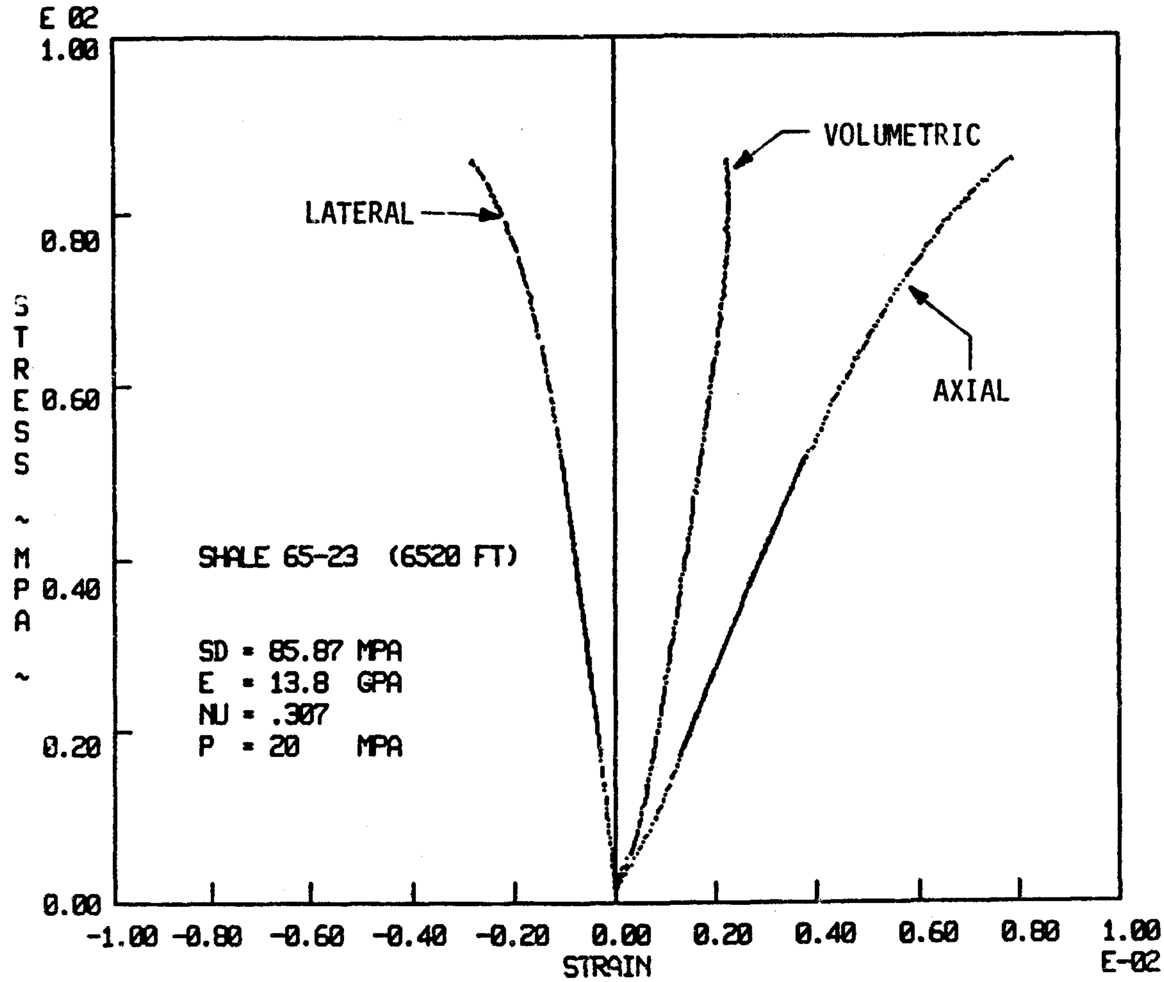
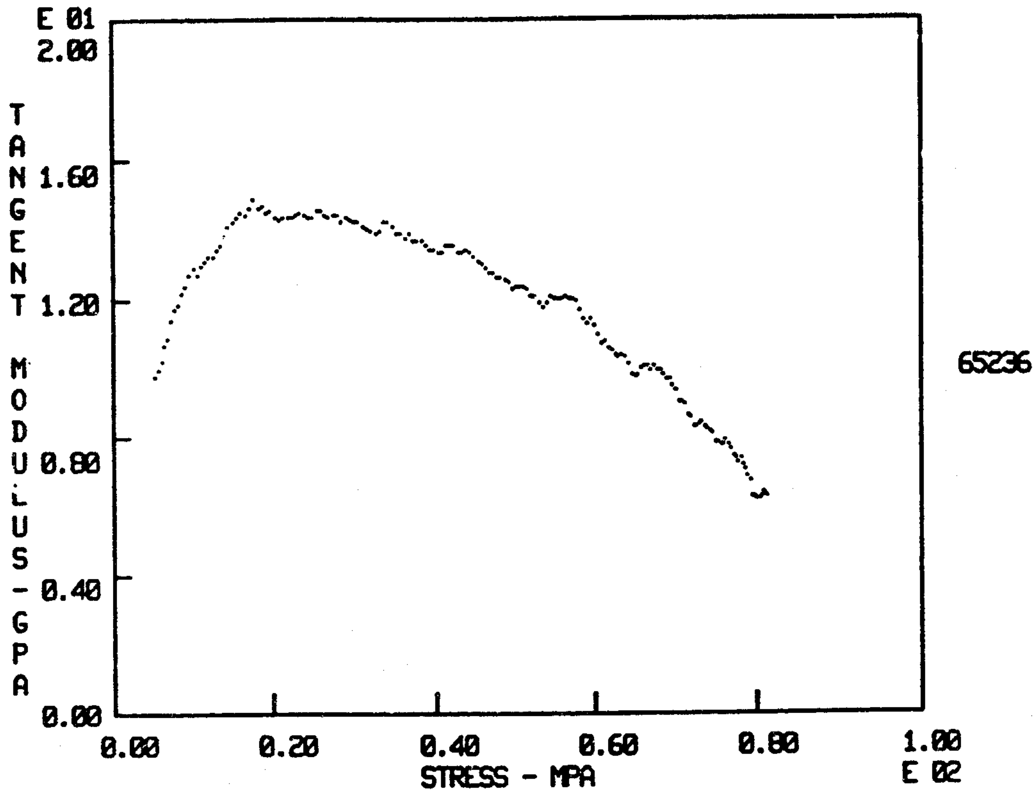


Figure 21. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Shale 65-23. P = 20 MPa.

RSI DWG 046-83-401



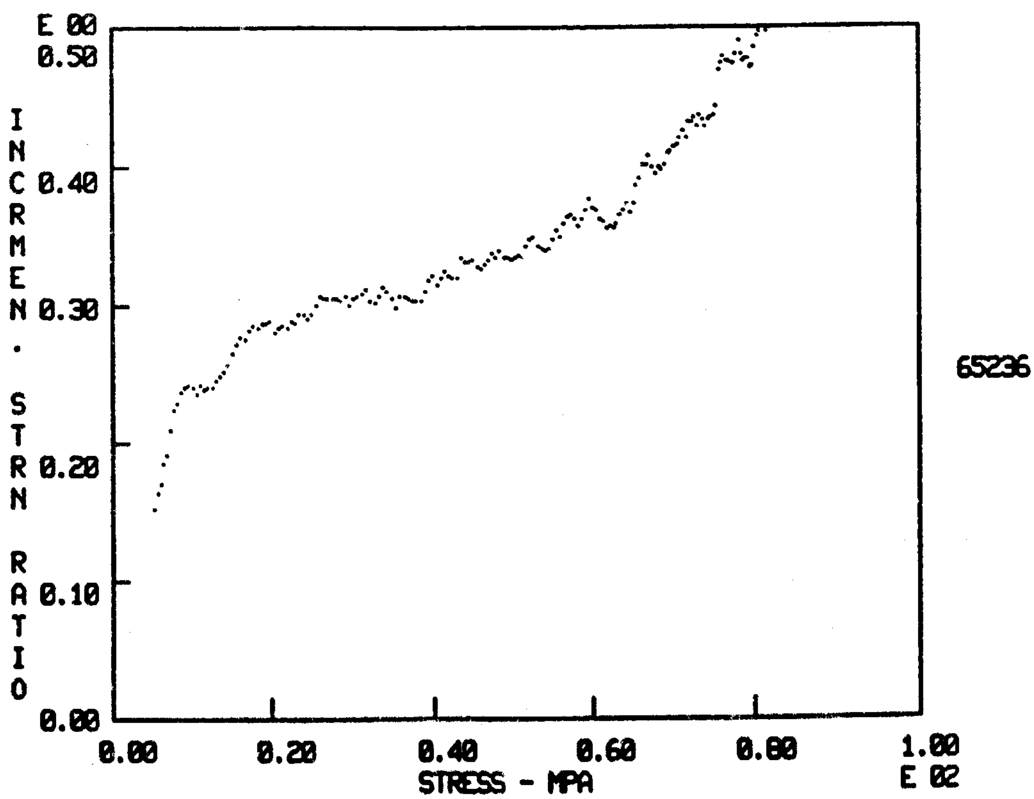


Figure 22. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Shale 65-23 (6520 Feet). P = 20 MPa.

RSI DWG 046-83-402

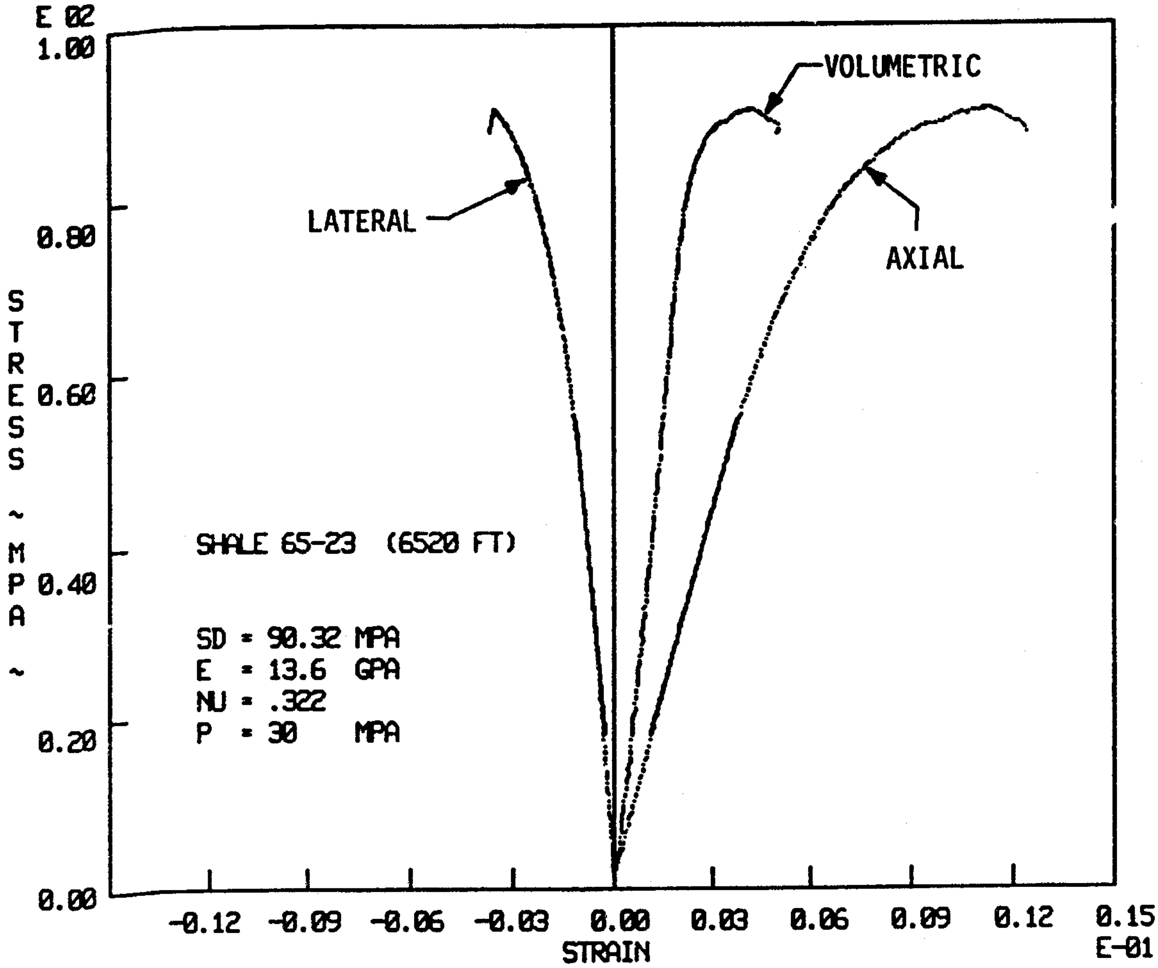
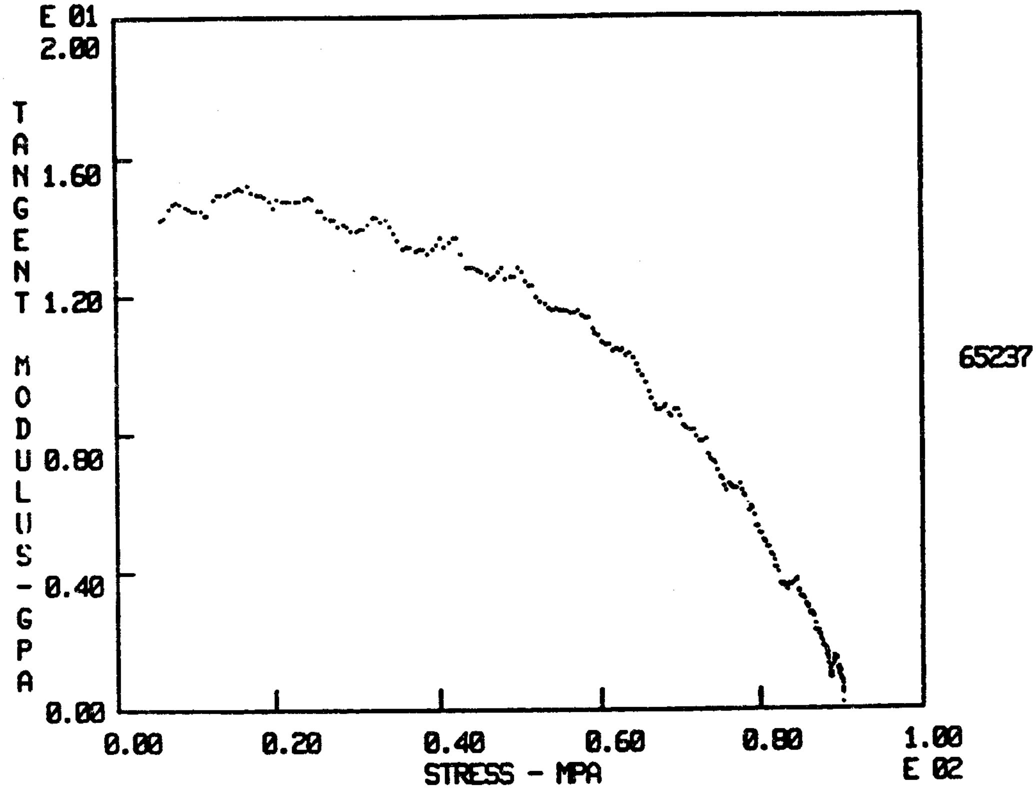


Figure 23. Axial Stress Difference Versus Axial, Lateral, and Volumetric Strain for Triaxial Compression of Shale 65-23. P = 30 MPa.

RSI DWG 046-83-403



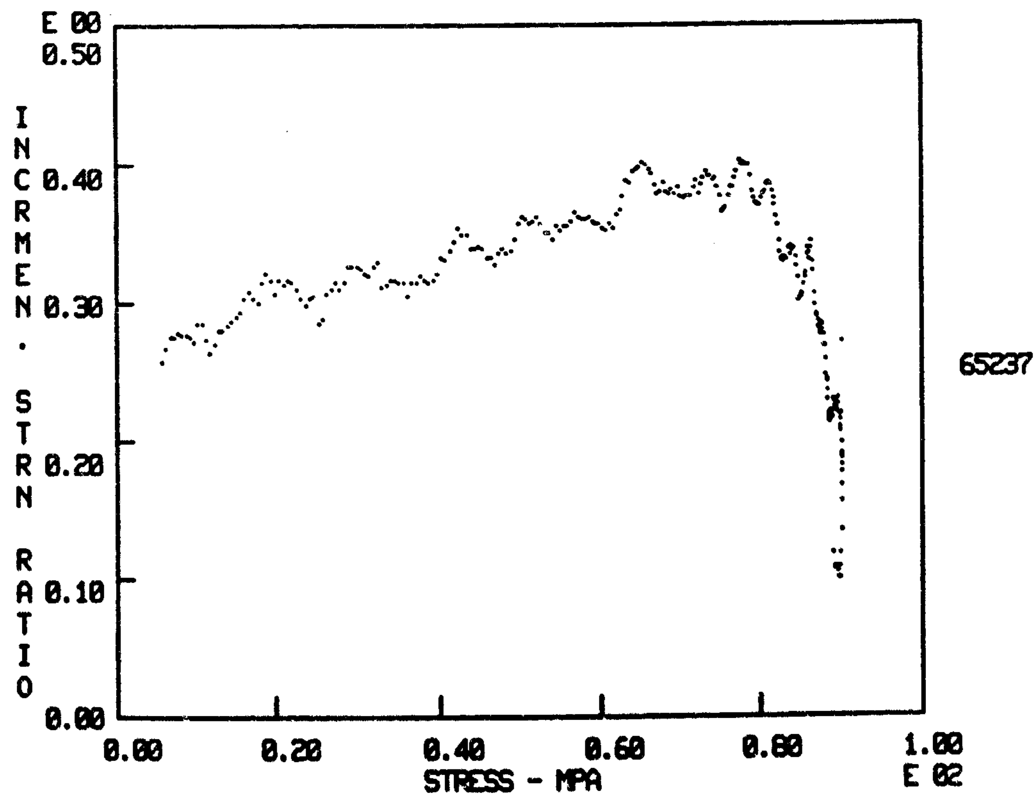


Figure 24. Tangent Modulus and Incremental Strain Ratio Versus Axial Stress Difference for Triaxial Compression of Shale 65-23 (6520 Feet). P = 30 MPa.

APPENDIX 11.7

PRE-FRACTURE WELL TEST DATA FROM RED SANDSTONES

CER Corporation

* MWX #1, 2 & 3 COASTAL RED ZONE SEPTEMBER TO NOVEMBER 1984

* ELAPSED TIME (HOURS)	MWX #1 B.H. PRESS. (PSI)	MWX #2 B.H. PRESS. (PSI)	MWX #3 B.H. PRESS. (PSI)	MWX #1 FLOW RATE (MCFD)
315.04001	3706.47	N/A	N/A	0.00
317.79001	3854.68	N/A	N/A	0.00
320.54001	3959.53	N/A	N/A	0.00
323.29001	4038.27	N/A	N/A	0.00
326.04001	4082.62	N/A	N/A	0.00
329.00000	4108.70	N/A	N/A	0.00
331.75000	4128.31	N/A	N/A	0.00
334.50000	4141.80	N/A	N/A	0.00
338.70999	4158.29	N/A	N/A	0.00
344.25000	4177.02	N/A	N/A	0.00
347.70999	4182.88	N/A	N/A	0.00
350.45999	4187.90	N/A	N/A	0.00
353.25000	4192.40	N/A	N/A	0.00
356.00000	4196.54	N/A	N/A	0.00
358.75000	4200.11	N/A	N/A	0.00
360.62000	3985.41	N/A	N/A	98.89
361.53000	3768.32	N/A	N/A	92.52
363.06000	3483.46	N/A	N/A	115.86
363.98001	3297.13	N/A	N/A	109.07
364.89999	3151.28	N/A	N/A	103.47
365.97000	3015.66	N/A	N/A	97.96
367.32999	2835.26	N/A	N/A	103.27
370.23001	2519.19	N/A	N/A	109.05
372.63000	2241.63	N/A	N/A	103.26
375.29999	1974.22	N/A	N/A	96.46
377.47000	1755.05	N/A	N/A	99.07
379.50000	1543.29	N/A	N/A	94.64
382.64001	1200.23	N/A	N/A	101.09
385.97000	924.45	N/A	N/A	90.07
388.17999	790.38	N/A	N/A	59.27
390.57999	803.17	N/A	N/A	64.90
392.73001	955.42	N/A	N/A	67.90
395.23001	[illegible]19.88	N/A	N/A	65.18
397.20999	791.04	N/A	N/A	74.30
399.60999	739.38	N/A	N/A	64.54
402.07999	698.85	N/A	N/A	63.95
404.04999	681.36	N/A	N/A	60.89
406.03000	683.36	N/A	N/A	60.09
408.41000	712.36	N/A	N/A	56.37
410.87000	720.32	N/A	N/A	60.01
413.42001	284.81	N/A	N/A	56.73
416.09000	460.02	N/A	N/A	0.00
418.04999	808.30	N/A	N/A	60.41
420.64999	1066.52	N/A	N/A	0.00
422.87000	1054.40	N/A	N/A	53.81
426.79999	1117.00	N/A	N/A	51.75
428.95999	1154.00	N/A	N/A	55.17
430.92001	1180.19	N/A	N/A	55.77
433.51999	1172.69	N/A	N/A	55.93
435.51001	1178.53	N/A	N/A	56.86
437.57999	1180.84	N/A	N/A	56.72
439.81000	1183.19	N/A	N/A	56.52
441.95001	1184.53	N/A	N/A	55.71
443.95001	1186.00	N/A	N/A	55.51
445.95001	1189.36	N/A	N/A	55.16

448.17999	1191.91	N/A	N/A	54.78
450.20999	1195.06	N/A	N/A	54.80
452.29001	1196.39	N/A	N/A	54.38
454.45001	1199.15	N/A	N/A	54.67
456.79001	1202.11	N/A	N/A	54.73
458.76999	1221.20	N/A	N/A	55.25
461.01999	1209.51	N/A	N/A	55.29
463.22000	1215.61	N/A	N/A	55.55
465.34000	1218.25	N/A	N/A	55.17
467.75000	1217.95	N/A	N/A	55.22
469.72000	1212.66	N/A	N/A	54.78
471.84000	1206.67	N/A	N/A	54.31
481.23001	1192.34	N/A	4203.87	54.75
483.20999	1185.03	N/A	4212.62	54.38
485.63000	1183.79	N/A	4221.92	54.06
487.59000	1501.64	N/A	N/A	0.00
489.60001	1859.09	N/A	4235.04	0.00
491.76001	2202.30	N/A	4241.07	0.00
493.69000	2485.30	N/A	4245.94	0.00
495.60001	2721.91	N/A	4250.44	0.00
497.92001	2997.13	N/A	4255.44	0.00
500.04001	3246.50	N/A	4259.51	0.00
501.95999	3439.48	N/A	N/A	0.00
504.51999	3632.35	N/A	4267.00	0.00
506.60001	3714.53	N/A	4270.29	0.00
508.70001	3790.71	N/A	4263.73	0.00
510.64001	3838.67	N/A	4250.83	0.00
512.58002	3871.97	N/A	4240.03	0.00
514.78003	3899.88	N/A	4232.23	0.00
517.21997	3918.75	N/A	4227.51	0.00
519.13000	3932.09	N/A	4225.42	0.00
521.03998	3940.66	N/A	4224.11	0.00
523.21997	3951.03	N/A	4223.32	0.00
525.27002	3957.71	N/A	4222.95	0.00
527.73999	3967.02	N/A	4222.75	0.00
529.94000	3976.55	4197.74	4223.67	0.00
532.07001	3981.57	4200.21	4225.01	0.00
534.71997	3986.70	4203.15	4227.06	0.00
536.98999	3989.69	4205.58	4229.15	0.00
538.92999	3991.44	4207.47	4230.97	0.00
541.28998	3995.34	4209.80	4233.29	0.00
543.50000	4000.95	4211.92	4235.45	0.00
545.63000	4003.99	4213.98	4237.54	0.00
547.56000	4007.58	4215.76	4239.36	0.00
549.48999	4009.73	4217.48	4241.21	0.00
552.08002	4014.02	4219.68	4243.60	0.00
553.23999	3888.34	4220.62	4244.67	98.57
553.83002	3763.45	4221.08	4245.20	71.13
554.41998	3648.18	4221.60	4245.80	77.87
555.08002	3557.57	N/A	4246.31	74.81
555.65997	3465.84	N/A	N/A	72.99
556.25000	3401.17	4223.00	4247.29	70.43
556.98999	3327.40	N/A	4247.94	70.92
557.84003	3256.43	4224.22	4248.67	68.45
558.44000	3205.73	4224.66	4249.20	86.87
559.02002	3136.68	4225.12	4249.73	83.71
559.60999	3076.65	4225.57	N/A	81.02
560.28998	3015.41	4226.07	4250.81	78.66
561.03003	2957.19	4226.63	4251.45	76.22
561.71997	2910.18	4227.16	4252.05	74.41

562.39001	2867.88	4227.65	4252.64	72.19
562.97998	2833.93	4228.08	4253.17	70.59
563.57001	2805.32	4228.53	4253.68	69.50
564.15002	2777.74	4228.92	4254.17	68.25
564.72998	2748.67	4229.35	4254.67	74.02
565.31000	2715.40	4229.76	N/A	72.70
566.06000	2674.07	4230.30	N/A	71.01
566.83002	2639.00	4230.82	4256.42	69.41
567.40997	2613.08	4231.22	4256.90	68.24
568.00000	2618.10	N/A	1956.70	67.05
568.58002	2566.28	4231.97	4257.86	66.04
569.23999	2544.85	4232.45	4258.43	65.04
569.83002	2513.59	4232.84	4258.94	72.39
570.46997	2479.46	4233.29	4259.45	71.02
571.06000	2451.28	4233.68	4259.95	69.68
571.64001	2425.28	4234.07	4260.42	68.28
572.29999	2398.65	4234.51	4260.96	67.22
572.88000	2377.18	4234.88	4261.43	66.08
573.53998	2354.15	4235.35	4261.98	64.64
574.12000	2330.17	4235.72	4262.45	71.22
574.78998	2298.72	4236.16	4263.00	69.73
576.48999	2231.63	4237.28	4264.44	66.14
577.65997	2195.99	4237.98	4265.27	64.99
579.17999	2158.03	N/A	N/A	62.97
579.37000	2154.38	N/A	N/A	62.70
581.02002	2123.37	4240.03	4267.85	61.20
582.03003	2094.00	4240.60	4268.56	68.29
583.01001	2059.76	4241.19	4269.31	66.32
584.14001	2026.68	4241.86	4270.13	64.23
585.32001	1996.67	4242.56	4271.02	62.59
586.37000	1976.87	4243.15	4271.81	61.09
587.34003	1944.11	4243.69	4272.49	52.71
588.40997	1936.91	4244.31	4273.26	66.82
589.39001	1910.13	4244.83	4273.98	65.30
590.35999	1885.81	4245.38	4274.63	65.25
591.33002	1860.67	4245.91	4275.31	64.47
592.35999	1823.38	4246.48	4276.09	75.55
593.33002	1790.94	4246.98	N/A	61.94
594.29999	1769.06	4247.48	4277.35	60.35
595.20001	1750.45	4248.04	4278.03	59.19
596.39001	1735.50	4248.59	4278.75	58.26
597.37000	1722.75	4249.09	4279.41	57.28
598.34998	1711.43	4249.59	4280.07	56.87
599.78003	1699.40	4250.30	4281.00	56.24
600.73999	1690.91	4250.78	4281.66	55.63
601.71002	1684.17	4251.25	4282.22	55.08
602.66998	1678.54	4251.74	4282.85	54.65
603.64001	1672.42	4252.21	4283.53	54.73
604.59998	1669.09	4252.65	4284.07	54.23
605.57001	1664.02	4253.12	4284.68	53.80
606.53998	1660.41	4253.57	4285.28	53.54
607.60999	1656.34	4254.08	4285.96	53.25
608.72998	1654.09	4254.59	4286.63	52.66
609.71997	1653.72	4255.02	4287.22	51.66
610.78998	1660.08	4255.54	4287.91	50.32
611.90002	1666.95	4256.04	N/A	49.33
613.07001	1679.67	4256.55	4289.21	48.32
614.03998	1689.20	4256.96	4289.81	48.79
615.01001	1696.03	4257.39	4290.33	53.73
615.97998	1690.30	4257.80	N/A	53.20

617.16998	1684.14	4258.31	4291.55	52.67
618.14001	1681.68	4258.73	4292.09	52.53
619.09998	1680.66	4259.15	4292.60	52.37
620.09003	1678.79	4259.54	4293.16	51.70
621.22998	1675.72	4260.03	4293.78	51.67
622.21997	1675.27	4260.47	4294.35	51.74
623.87000	1675.81	4261.14	4295.16	51.48
624.83002	1676.88	4261.54	4295.67	51.38
625.79999	1679.50	4261.93	4296.14	51.69
626.77002	1681.45	4262.31	4296.59	51.93
627.72998	1699.82	N/A	4297.12	52.36
628.70001	1685.58	4263.10	4297.56	52.32
629.66998	1686.98	4263.50	4298.00	52.31
630.63000	1687.88	4263.90	4298.48	52.24
631.71997	1688.29	4264.33	4299.01	52.07
633.03003	1688.68	4264.85	4299.66	51.60
634.00000	1686.51	4265.21	4300.11	51.65
634.96997	1687.19	4265.61	4300.58	51.33
635.94000	1687.59	4266.01	4301.02	51.27
637.02002	1689.67	4266.41	4301.57	50.71
638.25000	1691.22	4266.87	4302.14	50.74
639.22998	1691.75	4267.28	N/A	50.45
640.35999	1693.77	4267.68	4303.12	50.79
641.33002	1694.50	4268.06	4303.54	50.27
642.40997	1695.63	4268.46	4304.10	50.15
643.50000	1695.82	4268.84	4304.53	49.99
644.66998	1697.34	4269.33	4305.12	49.68
645.64001	1699.07	4269.69	4305.51	49.87
646.65997	1701.61	4270.04	4305.96	49.49
651.28003	1628.29	4271.73	4307.97	53.83
653.21002	1609.90	4272.39	4308.79	52.58
655.16998	1601.29	4273.10	4309.62	51.52
657.12000	1597.32	4273.77	4310.46	50.89
659.15002	1598.26	4274.46	4311.31	50.40
661.16998	1597.91	4275.14	4312.13	50.23
663.34998	1624.04	4275.89	4313.00	45.89
665.41998	1646.87	4276.55	4313.83	47.19
667.35999	1658.96	4277.23	N/A	47.77
669.82001	1669.01	4278.04	N/A	48.14
672.28003	1674.80	4278.81	4316.52	48.33
674.42999	1679.04	4279.53	4317.30	48.79
676.53003	1681.02	4280.21	4318.10	48.60
678.90997	1684.52	4280.97	4318.91	48.50
680.85999	1685.69	4281.54	4319.57	48.58
682.79999	1688.20	4282.12	4320.20	48.62
684.75000	1689.47	4282.73	4321.06	48.02
686.69000	1692.67	4283.32	4321.67	48.17
688.76001	1694.78	4283.88	4322.39	47.94
690.71002	1698.15	4284.43	4323.01	47.89
693.40002	1703.83	4285.18	4323.92	48.02
695.78003	1706.62	4285.81	4324.61	47.89
697.16998	1846.73	N/A	N/A	0.00
698.26001	2048.39	N/A	N/A	0.00
703.77002	2917.38	4287.99	4327.17	0.00
705.70001	3157.85	4288.54	4327.83	0.00
707.90997	3357.92	4289.14	4328.38	0.00
710.03003	3517.19	4289.74	4329.02	0.00
711.98999	3617.01	4290.25	4329.73	0.00
713.95001	3682.31	4290.78	4330.27	0.00
716.03003	3729.39	4291.28	4330.95	0.00

717.98999	3761.65	4291.76	4331.47	0.00
720.71997	3809.30	N/A	4332.23	0.00
722.94000	3812.32	4292.98	4332.81	0.00
724.90002	3823.85	4293.47	4333.41	0.00
726.84998	3834.44	4293.94	4333.98	0.00
729.01001	3843.00	4294.38	4334.57	0.00
731.03003	3851.33	4294.90	4335.04	0.00
732.98999	3858.36	4295.36	4335.60	0.00
734.94000	3863.70	4295.83	4336.21	0.00
737.07001	3870.24	4296.28	4336.73	0.00
739.09998	3873.68	4296.73	4337.26	0.00
741.27002	3879.83	4297.25	4337.81	0.00
743.70001	3883.78	4297.80	4338.42	0.00
745.70001	3889.87	4298.23	4338.82	0.00
747.64001	3893.25	4298.66	4339.33	0.00
749.59003	3896.39	4299.10	4339.84	0.00
751.53003	3899.21	4299.53	4340.37	0.00
754.04999	3466.83	4300.10	4341.02	60.35
756.08002	3282.84	4300.50	4341.41	55.44
758.03998	3174.68	4300.90	4341.96	51.44
760.16998	3099.61	4301.36	N/A	52.83
762.34003	3029.20	4301.81	4342.96	50.52
764.39001	2997.54	N/A	4343.34	48.98
766.59003	2926.43	4302.67	4343.92	51.25
768.85999	2866.90	4303.11	4344.44	62.26
770.83002	2765.95	4303.50	4344.89	58.37
772.96002	2690.48	4303.98	4345.37	55.37
775.09003	2635.73	4304.38	4345.76	53.21
777.35999	2593.03	4304.84	4346.31	51.45
779.50000	2572.40	4305.23	4346.83	49.52
781.69000	2559.13	4305.70	4347.30	49.67
783.65002	2539.09	4306.02	4347.68	70.58
786.25000	2432.37	4306.54	4348.22	52.58
788.19000	2416.82	4306.90	4348.66	50.15
790.28003	2410.27	4307.28	4349.01	49.34
792.50000	2375.74	4307.67	4349.52	60.78
794.64001	2304.67	4308.06	4349.99	56.51
796.75000	2264.00	4308.43	4350.44	54.28
798.91998	2230.75	4308.84	4350.83	52.90
801.25000	2207.43	4309.24	N/A	51.08
803.19000	2189.19	4309.61	4351.64	50.88
805.21002	2098.76	4309.95	4352.09	55.38
807.15002	2054.76	4310.27	4352.38	53.65
809.23999	2018.15	4310.64	4352.83	52.04
811.39001	1990.21	4311.05	4353.19	49.98
813.45001	1941.16	4311.42	4353.67	52.15
816.95001	1893.77	4311.99	4354.36	48.24
819.53003	1892.23	4312.42	4354.78	46.23
821.46002	1901.43	4312.73	4355.09	45.63
823.39001	1910.47	4313.05	4355.49	45.59
825.84998	1923.48	4313.48	4355.90	45.13
827.78998	1930.00	4313.82	4356.27	47.73
829.90002	1927.80	4314.11	4356.60	48.67
831.84998	1923.37	4314.40	4356.97	48.81
833.95001	1912.55	4314.67	4357.32	48.42
835.89001	1899.15	4315.03	4357.64	47.32
837.84998	1888.60	4315.33	4357.96	46.68
840.84003	1844.02	4315.82	4358.44	47.58
843.27002	1839.33	4316.65	4358.85	45.56
845.47998	1871.75	N/A	4359.21	44.67

847.66998	1821.62	N/A	4359.64	61.89
849.66998	1758.50	N/A	4359.91	56.57
851.79999	1727.13	N/A	4360.22	52.94
854.08002	1711.09	N/A	4360.56	50.26
856.17999	1708.88	N/A	4360.98	49.04
858.19000	1705.20	N/A	4361.26	47.49
860.19000	1707.00	N/A	4361.52	47.73
862.19000	1719.10	N/A	4361.88	48.32
864.45001	1743.54	N/A	4361.67	42.87
866.40997	1773.30	N/A	N/A	45.20
868.41998	1788.41	N/A	N/A	46.56
870.60999	1799.14	N/A	N/A	47.65
872.44000	1800.32	N/A	N/A	48.28
874.28003	1791.75	N/A	N/A	47.05
876.10999	1801.45	N/A	N/A	47.37
878.29999	1802.43	N/A	N/A	46.59
880.16998	1800.25	N/A	N/A	47.18
882.00000	1798.82	N/A	N/A	42.43
883.83002	1789.43	N/A	N/A	43.57
885.66998	1784.98	N/A	N/A	45.26
887.82001	1806.79	N/A	N/A	40.19
889.65997	1814.4[illegible]	N/A	N/A	47.07
891.50000	1804.36	N/A	N/A	46.01
893.33002	1803.56	N/A	N/A	46.17
895.16998	1815.21	N/A	N/A	42.69
897.09003	1832.10	N/A	N/A	43.44
898.92999	1839.62	N/A	N/A	43.14
900.76001	1838.81	N/A	N/A	44.28
902.59998	1837.25	N/A	N/A	43.77
904.50000	1832.11	N/A	N/A	52.35
906.34003	1814.03	N/A	N/A	46.83
908.16998	1805.68	N/A	N/A	47.40
910.00000	1803.38	N/A	N/A	43.32
922.31000	1885.99	N/A	N/A	42.47
922.53998	2893.89	N/A	N/A	0.00
922.73999	3291.60	N/A	N/A	0.00
922.94000	3465.50	N/A	N/A	0.00
923.14001	3554.56	N/A	N/A	0.00
923.46997	3631.11	N/A	N/A	0.00
924.46002	3723.24	N/A	N/A	0.00
925.42999	3758.69	N/A	N/A	0.00
926.70001	3786.14	N/A	N/A	0.00
927.78003	3799.77	N/A	N/A	0.00
928.79999	3817.09	N/A	N/A	0.00
929.84998	3828.45	N/A	N/A	0.00
930.82001	3837.35	N/A	N/A	0.00
932.00000	3846.59	N/A	N/A	0.00
932.97998	3853.48	N/A	N/A	0.00
934.09003	3861.00	N/A	N/A	0.00
935.26001	3868.00	N/A	N/A	0.00
936.35999	3873.84	N/A	N/A	0.00
937.46997	3879.37	N/A	N/A	0.00
938.46002	3884.08	N/A	N/A	0.00
939.44000	3888.25	N/A	N/A	0.00
940.73999	3893.84	N/A	N/A	0.00
941.78998	3897.83	N/A	N/A	0.00
942.78998	3901.42	N/A	N/A	0.00
943.78998	3904.52	N/A	N/A	0.00
946.53003	3912.49	N/A	N/A	0.00
947.58002	3915.44	N/A	N/A	0.00

948.65002	3918.30	N/A	N/A	0.00
949.62000	3920.82	N/A	N/A	0.00
950.75000	3923.72	N/A	N/A	0.00
951.71997	3926.06	N/A	N/A	0.00
952.71002	3928.43	N/A	N/A	0.00
953.71002	3930.78	N/A	N/A	0.00
954.84998	3933.27	N/A	N/A	0.00
955.82001	3935.32	N/A	N/A	0.00
956.78998	3937.34	N/A	N/A	0.00
957.81000	3939.44	N/A	N/A	0.00
966.82001	3954.93	N/A	N/A	0.00
968.69000	3958.30	N/A	N/A	0.00
970.52002	3960.75	N/A	N/A	0.00
972.35999	3963.41	N/A	N/A	0.00
974.19000	3964.48	N/A	N/A	0.00
975.65002	3967.86	N/A	N/A	0.00
977.16998	3970.06	N/A	N/A	0.00
979.00000	3971.66	N/A	N/A	0.00
980.83002	3973.92	N/A	N/A	0.00
983.34003	3976.95	N/A	N/A	0.00
985.16998	3980.00	N/A	N/A	0.00
987.00000	3980.93	N/A	N/A	0.00
988.84003	3982.37	N/A	N/A	0.00
990.66998	3985.11	N/A	N/A	0.00
1007.09003	4000.93	N/A	N/A	0.00
1007.46997	4000.22	N/A	N/A	0.00
1007.50000	4000.27	N/A	N/A	0.00
1007.66998	4001.35	N/A	N/A	0.00
1010.89001	4003.09	N/A	N/A	0.00
1013.34998	4004.99	N/A	N/A	0.00
1015.59998	4006.77	N/A	N/A	0.00
1019.63000	4009.98	N/A	N/A	0.00
1021.59003	4011.08	N/A	N/A	0.00
1023.50000	4013.19	N/A	N/A	0.00
1025.42004	4013.82	N/A	N/A	0.00
1027.25000	4015.16	N/A	N/A	0.00
1029.16003	4016.61	N/A	N/A	0.00
1031.82996	4018.27	N/A	N/A	0.00
1033.95996	4019.72	N/A	N/A	0.00
1035.80005	4020.83	N/A	N/A	0.00
1037.63000	4022.09	N/A	N/A	0.00
1039.46997	4024.18	N/A	N/A	0.00
1041.30005	4024.45	N/A	N/A	0.00
1043.14001	4026.67	N/A	N/A	0.00
1044.96997	4026.76	N/A	N/A	0.00
1046.80005	4028.36	N/A	N/A	0.00
1048.67004	4029.32	N/A	N/A	0.00
1050.50000	4030.23	N/A	N/A	0.00
1052.32996	4031.73	N/A	N/A	0.00
1054.23999	4032.20	N/A	N/A	0.00
1056.35999	4049.39	N/A	N/A	0.00
1058.18994	4035.55	N/A	N/A	0.00
1060.03003	4036.02	N/A	N/A	0.00
1061.85999	4036.87	N/A	N/A	0.00
1063.69995	4037.89	N/A	N/A	0.00
1065.53003	4038.44	N/A	N/A	0.00
1067.37000	4039.51	N/A	N/A	0.00
1069.19995	4040.99	N/A	N/A	0.00
1071.17004	4041.87	N/A	N/A	0.00
1073.00000	4043.46	N/A	N/A	0.00

1074.82996	4044.07	N/A	N/A	0.00
1077.00000	4039.86	N/A	N/A	0.00
1079.32996	4044.97	N/A	N/A	0.00
1081.16003	4045.34	N/A	N/A	0.00
1083.29004	4047.35	N/A	N/A	0.00
1085.13000	4064.12	N/A	N/A	0.00
1087.43994	4049.15	N/A	N/A	0.00
1089.27002	4051.07	N/A	N/A	0.00
1091.09998	4052.08	N/A	N/A	0.00
1092.93994	4051.91	N/A	N/A	0.00
1094.77002	4053.74	N/A	N/A	0.00
1096.67004	4054.68	N/A	N/A	0.00
1098.50000	4055.62	N/A	N/A	0.00
1100.32996	4056.00	N/A	N/A	0.00
1102.43005	4057.21	N/A	N/A	0.00
1104.40002	4057.31	N/A	N/A	0.00
1106.23999	4058.21	N/A	N/A	0.00
1108.06995	4059.09	N/A	N/A	0.00
1110.34998	4061.01	N/A	N/A	0.00
1112.18994	4061.09	N/A	N/A	0.00
1114.02002	4062.24	N/A	N/A	0.00
1115.85999	4062.74	N/A	N/A	0.00
1117.68994	4063.55	N/A	N/A	0.00
1119.67004	4065.13	N/A	N/A	0.00
1121.50000	4065.73	N/A	N/A	0.00
1123.32996	4066.26	N/A	N/A	0.00
1125.17004	4067.16	N/A	N/A	0.00
1127.34998	4068.22	N/A	N/A	0.00
1129.18005	4069.09	N/A	N/A	0.00
1131.02002	4068.92	N/A	N/A	0.00
1133.12000	4069.96	N/A	N/A	0.00
1134.94995	4070.90	N/A	N/A	0.00
1136.79004	4071.76	N/A	N/A	0.00
1138.62000	4072.72	N/A	N/A	0.00
1140.45996	4072.69	N/A	N/A	0.00
1142.29004	4073.57	N/A	N/A	0.00
1144.17004	4074.29	N/A	N/A	0.00
1146.00000	4075.10	N/A	N/A	0.00
1147.82996	4075.73	N/A	N/A	0.00
1149.67004	4076.53	N/A	N/A	0.00
1152.19995	4077.88	N/A	N/A	0.00
1154.03003	4077.90	N/A	N/A	0.00

APPENDIX 11.8

PRE-FRACTURE WELL TEST DATA FROM YELLOW SANDSTONES

CER Corporation

* MWX #1, 2 & 3 COASTAL YELLOW ZONE NOVEMBER 1984

* ELAPSED TIME (HOURS)	MWX #1 B.H. PRESS. (PSI)	MWX #2 B.H. PRESS. (PSI)	MWX #3 B.H. PRESS. (PSI)	MWX #1 FLOW RATE (MCFD)
146.68639	1270.65	N/A	N/A	0.00
148.51971	2290.70	N/A	N/A	0.00
151.43253	2795.67	N/A	948.88	0.00
154.34280	3324.65	N/A	1671.62	0.00
157.24667	3650.33	N/A	2253.35	0.00
160.26222	3752.04	N/A	2772.93	0.00
163.16083	3799.73	N/A	3216.67	0.00
166.05861	3826.75	N/A	3568.02	0.00
169.37083	3846.73	N/A	3780.00	0.00
172.32639	3858.85	N/A	3852.10	0.00
175.12029	3546.24	N/A	3884.19	52.68
177.04381	3419.81	N/A	N/A	50.09
178.97501	3353.29	N/A	N/A	48.53
180.91125	3311.09	N/A	3921.53	49.23
182.87334	3189.65	N/A	N/A	70.60
184.87582	3061.42	N/A	N/A	75.53
186.80750	2976.83	N/A	N/A	72.91
188.73750	2921.04	N/A	3951.30	71.09
190.67694	2879.54	N/A	N/A	71.45
192.79750	2723.76	N/A	N/A	101.08
194.71130	2590.77	N/A	N/A	80.05
197.23164	2430.71	N/A	4083.34	97.51
199.36057	2332.95	N/A	4095.60	96.57
201.50461	2230.25	N/A	4103.38	103.00
204.01639	2132.59	N/A	4109.82	95.19
206.58945	2067.57	N/A	4115.40	105.70
208.70500	1977.96	N/A	4119.22	100.55
210.65202	1929.38	N/A	4122.17	96.10
212.59833	1882.73	N/A	4124.99	97.16
214.54361	1825.39	N/A	4127.60	102.89
216.89468	1772.08	N/A	4130.35	97.48
218.84138	1824.27	N/A	4132.52	76.55
220.95250	1907.16	N/A	4134.78	81.17
222.89796	1964.07	N/A	4136.71	80.86
224.98703	2020.81	N/A	4138.20	82.66
227.02728	2051.42	N/A	4139.96	84.78
228.97166	2066.87	N/A	4141.77	85.28
230.92111	2071.32	4101.08	4143.63	84.94
232.88194	2060.70	4104.21	4145.34	84.91
234.83031	2056.33	4107.25	4147.32	84.22
236.78194	2051.25	4110.17	4149.24	84.09
238.85062	2028.96	4113.24	N/A	82.56
240.90833	2043.87	4116.16	4153.63	82.83
242.86000	2043.87	4118.89	4155.43	82.48
244.79372	2044.10	4121.52	4157.22	81.86
246.79723	2047.08	4124.19	4159.18	81.57
248.91139	2044.28	4126.91	4161.11	79.91
250.86722	2031.46	4129.33	4162.65	78.45
252.82195	1985.38	4131.75	4164.35	93.40
254.75539	1902.24	4134.02	4166.06	92.37
256.70444	1843.92	4136.21	4167.70	87.36
258.62988	1813.75	4138.42	4169.23	83.95
260.56445	1756.64	4140.59	4170.85	90.21
262.49451	1695.31	N/A	4172.27	95.94
264.74179	1630.66	4145.15	4174.18	89.02

266.67166	1612.20	4147.18	4175.58	87.08
268.78220	1594.79	4149.33	4177.19	88.78
270.72141	1565.63	4151.30	4178.71	90.55
272.65073	1545.19	4153.20	4179.54	86.06
274.87726	1510.99	4155.37	4181.69	92.01
276.81805	1480.59	4157.14	4182.91	86.41
278.76450	1455.55	4158.96	4184.27	88.85
280.88333	1433.06	4159.93	4185.71	85.44
282.80972	1425.48	4161.60	4186.91	84.04
284.73972	1507.88	4163.21	4188.17	58.71
286.89667	1602.73	4165.03	4189.51	74.96
289.14389	1578.35	4166.96	4190.89	87.91
291.07562	1523.24	4168.64	4192.12	90.52
293.00632	1503.56	4170.21	4193.19	86.88
294.93533	1499.61	4171.85	4194.35	84.63
297.01889	1446.96	4173.55	4195.52	104.78
299.47693	1298.61	4175.55	4196.94	100.78
301.50665	1272.18	4177.15	4198.09	77.80
303.46027	1302.17	4178.73	4199.21	81.44
305.41806	1315.66	4180.19	4200.29	81.53
307.35971	1323.85	4181.64	4201.25	82.06
309.30557	1330.86	4183.00	4202.33	81.81
311.54416	1337.71	4184.53	4203.53	81.56
313.88666	1347.27	4186.09	4204.75	82.82
315.94595	1356.32	4187.50	4205.82	82.87
317.88223	1366.59	4188.75	4206.85	83.59
319.81473	1374.40	4188.27	4207.49	83.06
321.93250	1381.08	4181.70	4208.81	82.18
323.87943	1386.77	4179.62	4209.76	81.50
325.92282	1394.94	4178.69	4210.75	81.22
327.86584	1401.56	4179.19	4211.61	81.35
329.94199	1407.72	4180.28	4212.62	81.49
331.88943	1410.44	4181.85	4213.56	80.98
333.82971	1412.03	4182.96	4214.42	80.96
336.26633	1428.29	N/A	4215.61	77.06
338.53528	1437.45	4190.99	4216.58	84.13
340.49741	1436.32	N/A	4217.49	83.05
342.45721	1435.40	N/A	4218.36	83.27
344.81250	1423.89	4197.11	4219.25	82.85
346.78171	1414.72	4198.79	4220.27	81.76
348.73840	1409.58	4200.14	4221.12	77.85
350.70746	1408.99	4201.41	4222.18	79.69
352.89362	1411.65	4202.77	4223.14	78.92
355.03201	1418.50	4203.95	4224.01	72.71
356.98749	1433.90	4205.07	4224.85	73.63
359.02487	1443.10	4206.17	4225.69	74.19
362.44473	1436.41	4208.03	4227.17	73.91
364.47916	1449.74	4208.98	4227.98	76.55
366.42249	1456.85	4209.94	4228.67	76.33
368.37292	1459.70	4210.87	4229.57	74.72
370.57446	1465.05	4211.78	4230.71	74.46
372.51443	1469.99	4212.53	4232.59	73.95
374.46722	1472.29	4213.34	4233.31	73.41
376.53836	1489.04	4214.21	4234.21	69.84
378.48669	1503.01	4214.95	4235.06	71.27
380.43777	1514.00	4215.78	4235.83	71.44
382.44885	1523.60	4216.55	4236.66	71.50
384.86191	1534.15	4217.44	4237.57	72.21
387.00974	1543.12	4218.21	4238.22	72.39
388.96222	1554.51	4218.84	4238.89	73.32

392.12845	1582.71	4219.87	4240.02	74.07
394.06638	1563.66	4220.47	N/A	75.97
395.99695	1598.25	4221.10	4240.98	78.12
398.21527	1597.07	4221.81	4241.53	76.42
400.17725	1581.63	N/A	N/A	76.85
402.62979	1607.65	4223.16	4242.72	77.56
404.55612	1600.76	4223.77	4243.16	75.25
406.48184	1597.57	4224.40	4243.66	74.00
408.75449	1605.63	4225.08	4244.32	75.98
410.73337	1603.51	4225.67	4244.77	75.71
412.71890	1605.77	4226.31	4245.25	74.78
416.15359	1591.90	4227.35	4246.15	69.61
418.42917	1616.56	4228.00	4246.62	71.80
420.36139	1627.20	4228.63	4247.04	72.71
422.29285	1634.86	4229.16	4247.58	72.05
424.35168	1612.11	N/A	N/A	70.57
426.28082	1743.34	4230.32	4248.42	60.88
428.20914	1780.41	4230.94	4248.85	64.31
430.13223	1842.00	4231.46	4249.43	76.03
432.66968	1828.78	4232.24	4249.95	75.41
434.59616	1837.65	4232.77	4250.30	66.56
436.52487	1860.71	4233.37	4250.61	66.48
438.44943	1812.44	4233.88	4251.24	112.99
440.02560	1761.74	4234.36	4251.58	0.00
440.98724	2061.92	4234.65	4251.75	0.00
441.94528	2293.76	N/A	N/A	0.00
443.04471	2519.54	N/A	4252.10	0.00
444.01166	2681.62	4235.52	4252.31	0.00
444.97250	2809.84	N/A	4252.45	0.00
446.10727	2959.68	4236.05	4252.60	0.00
448.17456	3144.84	4236.65	4253.08	0.00
450.10751	3272.20	4237.16	N/A	0.00
452.02985	3367.27	4237.69	4253.99	0.00
453.95697	3439.60	4238.19	4254.33	0.00
456.37418	3505.72	4238.88	4254.76	0.00
458.32446	3544.04	4239.44	4255.08	0.00
459.40588	3560.86	N/A	N/A	0.00
459.41068	3560.85	N/A	N/A	0.00
459.41409	3561.17	N/A	N/A	0.00
459.54028	3563.34	N/A	N/A	0.00
459.73682	2326.19	N/A	N/A	0.00
459.93219	1604.17	N/A	N/A	0.00
460.12869	1225.11	N/A	N/A	0.00
460.32193	973.15	N/A	N/A	0.00
460.51804	1052.45	N/A	N/A	70.75
460.71057	1115.17	N/A	N/A	17.64
460.90393	1159.87	N/A	N/A	0.00
461.09918	1191.26	N/A	N/A	0.00
461.29056	1221.68	N/A	N/A	0.00
461.48389	1250.70	N/A	N/A	0.00
461.67776	1280.06	N/A	N/A	0.00
461.87222	1308.25	N/A	N/A	0.00
462.06305	1337.43	N/A	N/A	0.00
462.25360	1350.11	N/A	N/A	37.96
462.44617	1360.47	N/A	N/A	0.00
462.64389	1293.19	N/A	N/A	146.26
462.83807	1270.82	N/A	N/A	146.99
463.03241	1243.03	N/A	N/A	131.95
464.34445	1249.83	4241.02	N/A	46.21
466.31592	1282.29	4241.58	4256.83	0.00

468.26749	1443.81	4241.99	4257.12	31.73
470.57361	1558.61	4242.59	4257.52	39.09
472.53000	1627.53	4243.11	4258.10	39.34
474.46368	1619.19	4243.55	4258.50	59.87
476.40302	1570.12	4244.02	4258.78	55.10
478.33496	1614.66	4244.51	4259.12	37.21
480.56833	1584.24	4244.98	4259.43	56.30
482.56082	1566.34	4245.47	4259.77	54.15
484.54028	1679.80	4246.00	4260.14	43.03
486.51556	1640.22	4246.49	4260.59	64.32
488.49860	1613.71	4247.02	4261.20	53.86
490.72452	1532.20	4247.49	4261.52	64.57
492.66083	1515.01	4247.96	N/A	43.74
494.59833	1613.83	4248.38	4262.17	50.74
496.70502	1625.61	4248.81	4262.50	53.58
498.63611	1645.81	4249.24	4262.82	53.65
500.56693	1641.34	4249.63	4263.10	51.31
502.48917	1641.88	4249.98	4263.58	53.04
504.70279	1633.56	4250.36	4264.15	55.50
506.68307	1606.33	4250.72	4264.42	51.77
508.67224	1613.64	4251.08	4264.78	51.88
510.65610	1615.33	4251.45	N/A	51.90
513.71332	1612.15	4251.91	4265.58	54.33
516.27087	1603.50	4252.15	4265.91	52.80
518.25543	1604.67	4252.46	4266.16	52.28
520.35889	1579.47	N/A	N/A	51.35
522.33862	1595.46	4252.97	4267.12	50.19
524.31445	1601.03	4253.17	N/A	50.30
526.29779	1607.05	N/A	4267.80	51.42
528.44397	1610.89	4253.58	4268.07	51.84
530.43475	1608.96	4253.66	N/A	51.49
532.43219	1613.42	4253.71	N/A	52.01
534.40472	1630.53	N/A	4268.66	53.85
536.37219	1633.49	N/A	4268.76	53.96
538.64276	1620.46	4253.66	N/A	53.08
540.78192	1631.37	N/A	4269.23	52.67
542.71777	1640.05	4253.56	4269.65	53.13
544.70636	1649.89	N/A	4269.92	54.06
546.63275	1654.33	4253.52	4270.15	54.22
548.55859	1659.00	4253.49	N/A	54.36
550.71832	1649.70	N/A	N/A	53.54
552.72113	1651.00	4253.49	N/A	53.97
554.78900	1657.96	N/A	4271.01	54.32
556.08362	1681.56	4253.56	4271.12	0.00
556.65997	1830.33	N/A	4271.22	0.00
557.23761	1960.40	N/A	4271.27	0.00
557.81219	2079.64	4253.61	4271.32	0.00
558.56897	2222.83	4253.60	N/A	0.00
559.14471	2328.48	4253.61	N/A	0.00
559.72058	2428.10	4253.62	N/A	0.00
560.54999	2559.15	4253.61	4271.63	0.00
561.16278	2649.05	N/A	4271.68	0.00
561.77509	2731.21	N/A	4271.76	0.00
562.38452	2805.52	4253.55	N/A	0.00
562.97418	2870.24	N/A	4271.90	0.00
563.71368	2943.27	N/A	4271.94	0.00
564.29321	2993.17	4253.41	N/A	0.00
564.87390	3037.05	N/A	4272.05	0.00
565.44940	3075.65	N/A	4272.16	0.00
565.96057	3104.97	N/A	N/A	0.00

566.15222	3114.93	N/A	N/A	0.00
566.34479	3123.86	N/A	N/A	0.00
566.53918	3133.15	N/A	N/A	0.00
566.73389	3140.98	N/A	N/A	0.00
566.92609	3149.01	N/A	N/A	0.00
567.11969	3157.44	N/A	N/A	0.00
567.31445	3163.64	N/A	N/A	0.00
567.50531	3171.61	N/A	N/A	0.00
567.69928	3178.43	N/A	N/A	0.00
567.89221	3184.34	N/A	N/A	0.00
568.08691	3190.66	N/A	N/A	0.00
568.27838	3196.68	N/A	N/A	0.00
568.46997	3172.31	N/A	N/A	0.00
568.66278	1529.42	N/A	N/A	0.00
568.85748	1407.24	N/A	N/A	0.00
569.04785	1471.23	4252.95	4272.88	0.00
569.24084	1523.10	N/A	N/A	0.00
569.43359	1581.32	N/A	N/A	0.00
569.62665	1644.38	N/A	N/A	0.00
569.81860	1704.81	N/A	N/A	0.00
570.00946	1759.84	N/A	N/A	0.00
570.20117	1812.17	N/A	N/A	0.00
570.39368	1862.79	N/A	N/A	0.00
570.58832	1912.52	N/A	N/A	0.00
570.78058	1959.53	N/A	N/A	0.00
570.97058	2003.94	4252.76	4273.16	0.00
571.16394	2048.98	N/A	N/A	0.00
571.35626	2093.37	N/A	N/A	0.00
571.54858	2135.17	N/A	N/A	0.00
571.74170	2176.48	N/A	N/A	0.00
571.93695	2217.60	N/A	N/A	0.00
572.13031	2257.55	N/A	N/A	0.00
572.32306	2296.48	N/A	N/A	0.00
572.51672	2333.43	N/A	N/A	0.00
572.70905	2371.55	N/A	N/A	0.00
572.90161	2407.27	4252.55	4273.34	0.00
573.09332	2443.74	N/A	N/A	0.00
573.28668	2478.50	N/A	N/A	0.00
573.48010	2513.04	N/A	N/A	0.00
573.67212	2546.06	N/A	N/A	0.00
573.86169	2578.19	N/A	N/A	0.00
574.05389	2611.39	N/A	N/A	0.00
574.24335	2641.48	N/A	N/A	0.00
574.43469	2672.03	N/A	N/A	0.00
574.68616	2711.27	N/A	N/A	0.00
574.92279	2746.94	N/A	N/A	0.00
577.09332	3020.70	N/A	N/A	0.00
579.01971	3177.00	N/A	N/A	0.00
580.94312	3286.32	N/A	N/A	0.00
583.15698	3378.46	N/A	N/A	0.00
585.10309	3438.57	4251.76	4274.88	0.00
587.05396	3482.15	4251.67	4275.05	0.00
588.97888	3515.68	N/A	4275.29	0.00
590.89862	3541.80	N/A	4275.52	0.00
592.87195	3560.87	4251.57	4275.88	0.00
594.79553	3576.09	N/A	4276.27	0.00
596.72284	3571.50	4251.52	N/A	0.00
598.72986	3587.92	4251.53	N/A	0.00
600.77527	3612.67	N/A	4277.04	0.00
602.69391	3623.48	N/A	4277.30	0.00

604.63641	3347.61	N/A	4277.53	62.70
606.56555	3107.73	N/A	4277.78	50.35
608.99121	2861.42	N/A	N/A	54.73
610.93286	2592.61	N/A	4278.27	70.79
612.86530	2370.07	N/A	4278.49	69.86
615.06140	2152.09	N/A	N/A	67.57
617.04858	2055.86	N/A	4278.95	48.85
618.98322	2002.02	4251.84	4279.33	52.04
620.90948	1963.77	N/A	4279.66	50.00
623.05280	1886.36	N/A	4279.92	55.59
624.99249	1839.28	4252.03	N/A	52.18
626.92639	1813.57	N/A	4280.31	49.83
628.86200	1772.23	N/A	N/A	58.76
630.98254	1714.42	4252.21	4280.52	53.85
633.09613	1683.69	4252.26	N/A	51.76
635.02661	1672.19	4252.30	4280.86	50.63
637.17554	1640.34	4252.36	4281.02	54.61
639.15442	1610.93	4252.40	4281.20	51.58
641.25775	1597.10	4252.46	4281.37	50.43
643.23010	1592.83	N/A	4281.53	50.17
645.20752	1600.13	4252.56	4281.73	50.64
647.55389	1620.57	N/A	4282.03	50.89
649.50775	1624.14	N/A	4282.32	51.17
651.46112	1628.83	4252.82	4282.64	51.19
653.60388	1631.98	N/A	4282.84	50.97
655.55750	1634.79	4253.01	4283.07	50.50
657.73950	1641.01	4253.10	N/A	51.17
659.86139	1643.03	N/A	4283.46	50.78
661.83112	1645.90	N/A	4283.64	51.28
663.80042	1649.21	4253.30	4283.85	50.86
665.79059	1648.67	4253.39	4284.03	50.87
667.75580	1645.98	4253.47	4284.25	50.87
669.72119	1651.68	4253.56	4284.42	51.06
671.90332	1659.60	4253.66	4284.63	51.65
673.89087	1660.61	4253.76	4284.17	50.82
676.19604	1669.07	4253.90	4284.63	51.18
678.30859	1672.20	N/A	4285.02	51.11
680.26056	1680.35	4254.12	4285.36	50.95
681.14886	1806.52	N/A	N/A	0.00
681.34113	2136.38	N/A	N/A	0.00
681.53418	2673.80	N/A	N/A	0.00
681.73914	3048.69	N/A	N/A	0.00
681.94427	3241.97	N/A	N/A	0.00
683.08759	3504.75	N/A	N/A	0.00
684.05585	3553.94	4254.30	N/A	0.00
685.11444	3585.75	N/A	4286.31	0.00
686.24915	3610.99	4254.39	4286.46	0.00
688.35333	3643.64	4254.48	4286.72	0.00
690.46112	3665.94	N/A	4287.02	0.00
692.38531	3681.18	4254.67	4287.23	0.00
694.31305	3693.04	N/A	N/A	0.00
697.24011	3708.89	4254.89	4287.77	0.00
699.17529	3717.01	4255.00	4287.98	0.00
701.11707	3724.42	N/A	4288.22	0.00
703.05707	3731.19	N/A	4288.44	0.00
705.26807	3738.70	4255.33	4288.67	0.00
707.24359	3744.27	N/A	4288.88	0.00
709.21362	3749.24	4255.44	4289.05	0.00
711.26526	3758.90	N/A	4289.23	0.00
713.23749	3763.65	N/A	4289.43	0.00

715.17645	3767.68	4255.64	4289.61	0.00
717.29248	3772.53	4255.73	4289.84	0.00
719.41443	3776.86	4255.88	N/A	0.00
721.58612	3781.70	N/A	4290.43	0.00
723.57056	3787.60	4256.14	4290.67	0.00
725.63086	3790.72	4256.29	N/A	0.00
728.04755	3795.94	4256.39	4291.17	0.00
730.11322	3798.66	N/A	3317.67	0.00
732.35364	3801.68	4256.48	2931.79	0.00
734.41138	3804.50	4256.56	3046.59	0.00
736.92859	3807.91	4256.62	3066.90	0.00
738.98846	3811.27	N/A	3068.25	0.00
741.04749	3813.04	4256.83	3072.70	0.00
743.55249	3816.06	4257.01	2137.13	0.00
745.79779	3818.84	4257.14	2637.01	0.00
747.84479	3820.33	4257.25	N/A	0.00
750.01581	3822.86	4257.38	N/A	0.00
752.03754	3824.30	4257.50	N/A	0.00
754.13196	3824.46	4257.61	N/A	0.00
756.09583	3825.24	4257.76	N/A	0.00
758.07904	3824.36	4257.88	N/A	0.00
760.18085	3822.18	N/A	N/A	0.00
762.16193	3821.68	N/A	N/A	0.00
764.13409	3819.34	4258.31	N/A	0.00
766.10706	3818.39	4258.45	N/A	0.00
768.22137	3816.75	4258.60	N/A	0.00
770.13696	3815.24	N/A	N/A	0.00
771.39471	3815.22	N/A	N/A	0.00
771.58527	3814.66	N/A	N/A	0.00
771.77417	3814.61	N/A	N/A	0.00
771.96667	3814.59	N/A	N/A	0.00
772.15637	3814.96	N/A	N/A	0.00
772.34955	3814.53	N/A	N/A	0.00
772.53973	3814.18	N/A	N/A	0.00
772.73383	3814.10	N/A	N/A	0.00
772.92047	3814.01	N/A	N/A	0.00
773.11029	3813.83	N/A	N/A	0.00
773.45776	3813.85	N/A	N/A	0.00
774.53748	3813.80	4259.03	N/A	0.00
775.53857	3812.87	N/A	N/A	0.00
776.53143	3812.65	4259.18	N/A	0.00
777.52692	3812.28	N/A	N/A	0.00
778.51447	3812.37	4259.31	N/A	0.00
779.51361	3811.53	N/A	N/A	0.00
780.50513	3812.16	4259.42	N/A	0.00
781.49872	3810.86	N/A	N/A	0.00
782.48889	3810.63	4259.56	N/A	0.00
783.48401	3810.96	N/A	N/A	0.00
784.53534	3809.65	4259.72	N/A	0.00
785.53308	3809.37	N/A	N/A	0.00
786.53333	3809.51	4259.86	N/A	0.00
787.78192	3807.61	4259.95	N/A	0.00
788.75110	3808.43	N/A	N/A	0.00
789.72156	3807.70	4260.07	N/A	0.00
790.90112	3805.58	N/A	N/A	0.00
791.86108	3805.26	4260.23	N/A	0.00
792.82642	3804.75	N/A	N/A	0.00
793.78497	3803.94	4260.38	N/A	0.00
794.74225	3804.03	N/A	N/A	0.00
795.22083	3804.01	N/A	N/A	0.00

795.42108	3803.92	N/A	N/A	0.00
795.63776	3803.80	N/A	N/A	0.00
795.82111	3803.71	N/A	N/A	0.00
801.15942	3800.99	4261.04	N/A	0.00
803.37476	3800.41	4261.26	N/A	0.00
805.70587	3800.16	4261.56	N/A	0.00
807.63458	3800.18	4261.76	N/A	0.00
810.98834	3800.31	4262.19	N/A	0.00
813.25726	3800.67	4262.40	N/A	0.00
815.51306	3801.02	4262.63	N/A	0.00
817.86890	3801.52	4262.83	N/A	0.00
820.02472	3801.94	4263.03	N/A	0.00
822.16724	3802.43	N/A	N/A	0.00
824.35278	3803.02	4263.42	N/A	0.00
826.18610	3803.46	4263.57	N/A	0.00
828.18610	3803.96	N/A	N/A	0.00
830.16888	3804.40	4263.91	N/A	0.00
832.33331	3804.91	4264.08	N/A	0.00
834.50000	3805.43	4264.25	N/A	0.00
836.33331	3805.92	4264.41	N/A	0.00
838.16669	3806.39	4264.56	N/A	0.00
840.24719	3807.02	4264.74	N/A	0.00
842.08057	3807.58	4264.89	N/A	0.00
843.91388	3808.19	4265.00	N/A	0.00
845.91388	3808.93	4265.17	N/A	0.00
847.89081	3809.60	4265.33	N/A	0.00
850.14056	3810.44	4265.50	N/A	0.00
851.97388	3811.21	4265.65	N/A	0.00
853.80719	3811.86	4265.77	N/A	0.00
855.64056	3812.50	4265.90	N/A	0.00
857.83331	3813.44	N/A	N/A	0.00
859.66669	3814.26	4266.20	N/A	0.00
861.50000	3815.14	4266.33	N/A	0.00
863.70001	3816.13	4266.52	N/A	0.00
865.83057	3817.04	4266.66	N/A	0.00
868.07697	3818.14	4266.78	N/A	0.00
870.14862	3819.13	4266.96	N/A	0.00
872.14862	3820.11	4267.16	N/A	0.00
874.05109	3821.07	N/A	N/A	0.00
876.23834	3822.18	N/A	N/A	0.00
878.49805	3823.28	N/A	N/A	0.00
880.72418	3824.48	N/A	N/A	0.00
882.72668	3825.52	N/A	N/A	0.00
884.72998	3826.58	N/A	N/A	0.00
886.97363	3827.75	N/A	N/A	0.00
888.92706	3828.83	N/A	N/A	0.00
890.89691	3829.92	N/A	N/A	0.00
892.87665	3831.06	N/A	N/A	0.00
895.01447	3832.18	N/A	N/A	0.00
897.14502	3833.32	N/A	N/A	0.00
899.10083	3834.43	N/A	N/A	0.00
901.04553	3835.53	N/A	N/A	0.00
903.37469	3836.83	N/A	N/A	0.00
905.62341	3838.04	N/A	N/A	0.00
907.76886	3839.22	N/A	N/A	0.00
909.89642	3840.43	N/A	N/A	0.00
912.15833	3841.66	N/A	N/A	0.00
914.30713	3842.84	N/A	N/A	0.00

APPENDIX 11.9

GAS CHROMATOGRAPHY SYSTEMS FOR NITROGEN TESTS

CER Corporation

APPENDIX 11.9

GAS CHROMATOGRAPHY SYSTEMS FOR NITROGEN TESTS
CER Corporation

In order to establish the presence of the N_2 tracer at remote locations in the Red and Yellow sandstones that would originate from the injection well, MWX-2, gas chromatography (GC) was performed on the gas flowing from the observation wells, MWX-1 and 3.

Figure 1 illustrates a GC system, assembled and tested at Sandia, which was connected through a manifold to either of the MWX observation wells. The Produced gases flowed through a high pressure regulator where the pressure was reduced to approximately 40 psi, in order to accommodate the low pressure filters and GC specifications. Once the pressure was reduced to acceptable pressure levels, the gas flowed through a desiccant filter designed to eliminate liquids, then through a 7 μm particular trap, and finally through a flow meter which was used to adjust and maintain constant flow rate. The gas sample passed through the filter system, was injected into the Carle SX Gas Chromatograph and analyzed in 10 minutes. Output consisted of printed reports and an auxiliary output data port that supplied data directly to the main VAX computer system. This system was almost totally automated and remotely switched solenoid valves, purged flow lines, performed calibrations, printed results and vented the system. Software modifications to accommodate specific field requirements were easily performed.

In addition to the on-line GC system, gas samples from both observation wells, MWX-1 and MWX-3, were taken in 0.3 liter plastic bags for on-site and future analysis.

A second field GC system, Figure 2, was scheduled to provide quasi real-time analysis of the gas bag samples. Syringe sampling ports were installed on the tubing of the wellhead of MWX-1 and MWX-3. These sampling ports consisted of 0.25-in. swagelock tubing, two valves and a hypodermic needle. With this configuration, valves could be opened, allowing gas to continually flow through the lines, purging them of stagnant gas or contaminants and assuring that the sample was indicative of gas flowing in the high pressure tubing.

Gas sample bags (0.3 liter Tedlar) with rubber septums were used for sampling containers to transport gas from the wellhead to the GC system. Initially each gas bag was filled with helium and then purged using a hand held vacuum pump. This procedure was designed to minimize gas contaminants, particularly air. Once evacuated, the bag was placed over the hypo needle on the sample port and the exhaust line on the sample port was plugged allowing gas to flow and fill the sample bag. Each bag was labeled with the date, time, sample number, catalogued and either had its contents analyzed in the GC or stored for future analysis.

The analysis consisted of using a 10 cc syringe to pull a sample from the gas bag (the syringe was purged two times with sample before injection), and then injected into the sample loop on the front panel of the Carle Series III gas chromatograph. The GC was then advanced to the first valve switch, thus allowing the sample to enter the GC. The cycle run time was 32 minutes with the chromatogram (TCD detection) being traced out on a strip chart recorder. The chromatogram was then analyzed fro area and percent volume. These reports were then logged and entered into a database file.

The field GC system had an analytic cycle time of 32 minutes and supplied output in the form of strip chart recorder data. Unfortunately, this system remained operational for only a few hours into the test; one of the flow loops became contaminated, causing the unit to fail and therefore providing little usable data. Subsequently, Bendix Corporation of Grand Junction, Colorado, was utilized to perform laboratory GC analysis from a selective group of gas samples taken from MWX-1 and MWX-3 wellheads.

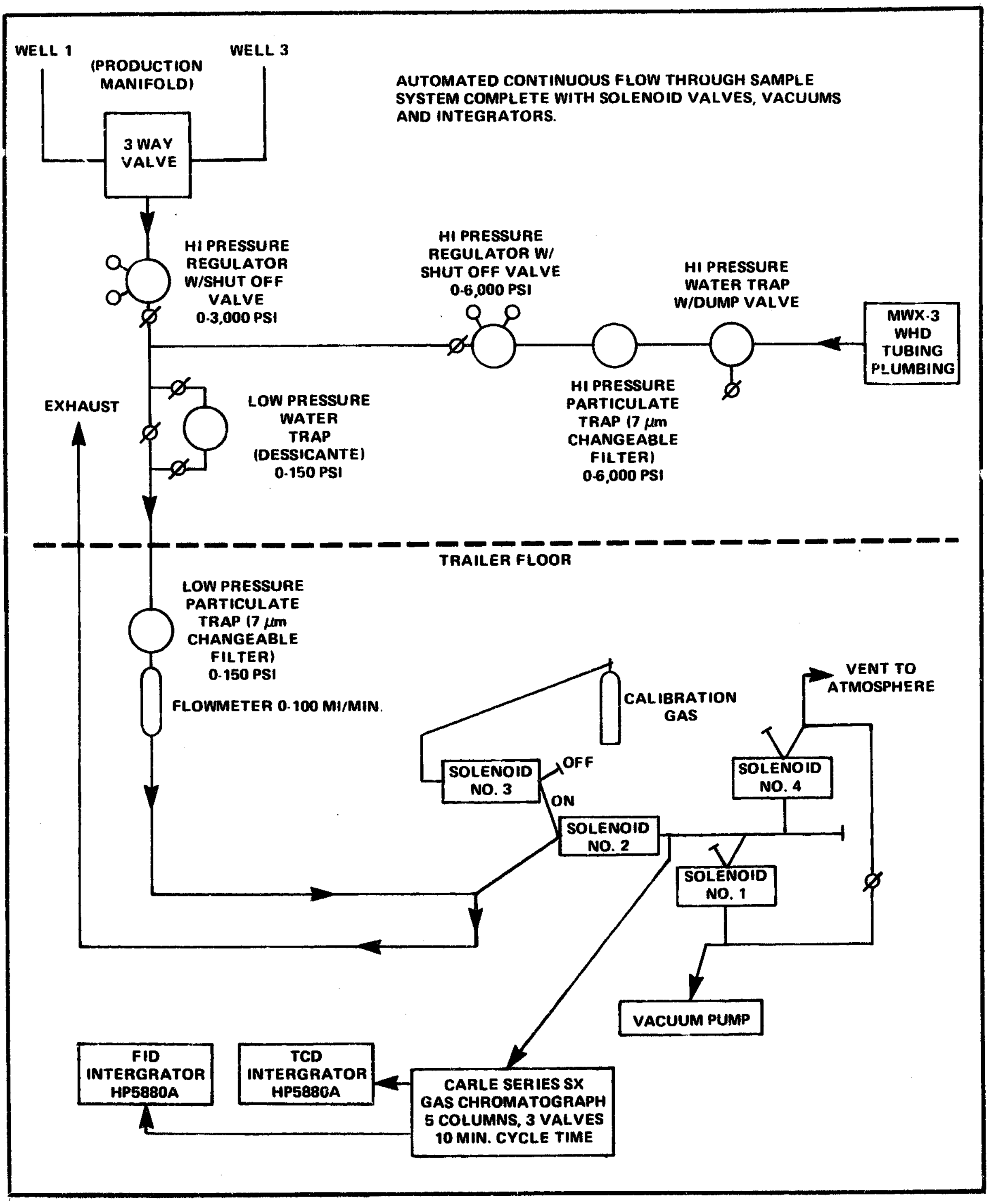


Figure 1 Sandia's Semi-Automatic Gas Chromatograph System

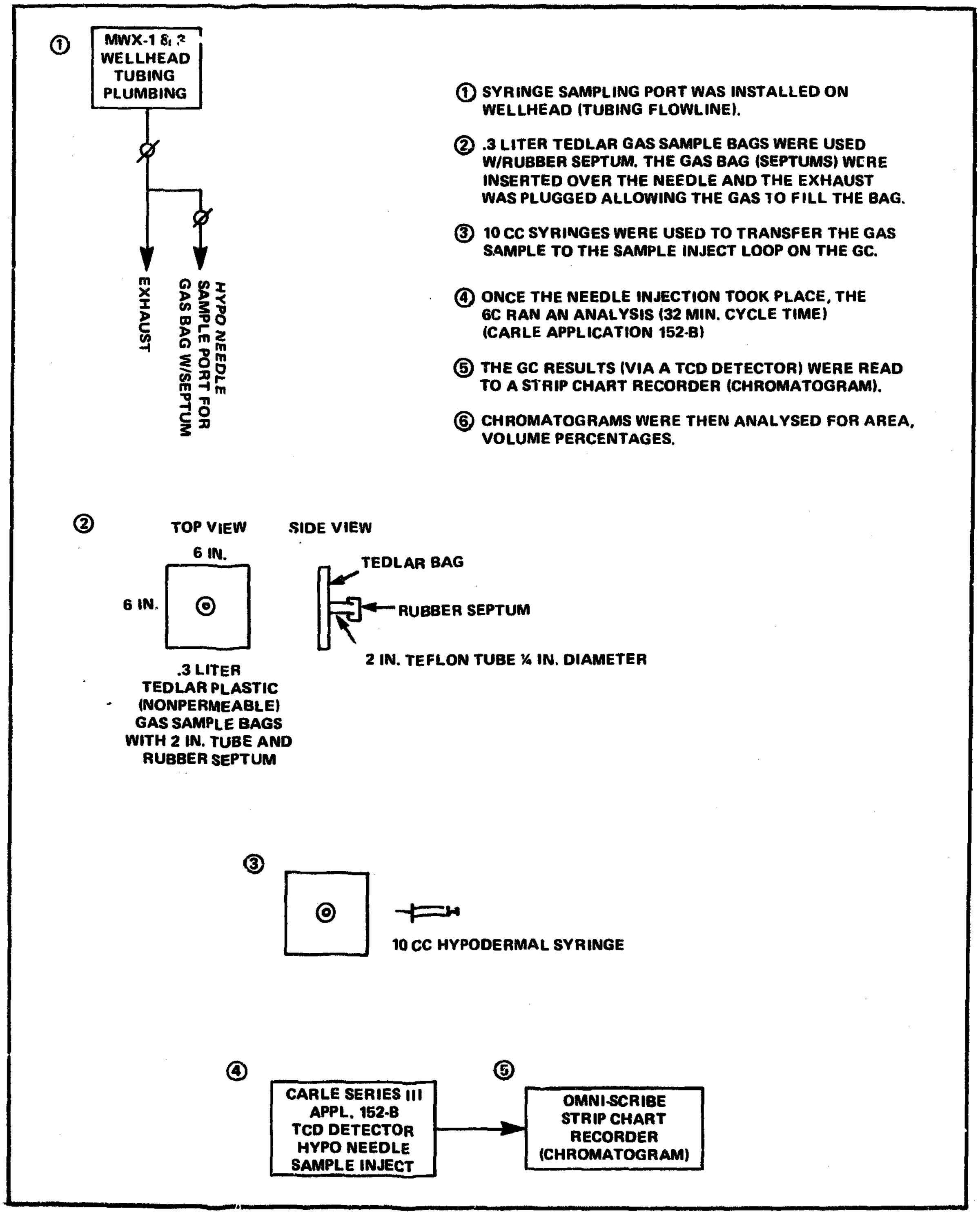


Figure 2 Field Gas Chromatograph System

APPENDIX 11.10

WELL TEST DATA FOR THE NITROGEN INJECTION TEST

CER Corporation

* MWX #2 COASTAL RED-YELLOW N2 INJECTION APRIL 1985

* ELAPSED TIME (HOURS)	MWX #2 B.H. PRESS. (PSI)	MWX #2 SURFACE PRESS. (PSI)
93.33258	N/A	542.52
93.41653	N/A	780.56
93.46653	N/A	1709.65
93.51653	N/A	2958.66
93.56653	N/A	3282.50
93.61653	N/A	3258.49
93.66653	N/A	3078.53
93.71653	N/A	2747.10
93.79469	N/A	2735.14
93.84458	N/A	2747.10
93.89458	N/A	2743.12
93.94653	N/A	2735.14
93.99819	N/A	2735.14
94.04819	N/A	3174.49
94.09819	N/A	3687.22
94.14819	N/A	4149.46
94.19819	N/A	4379.24
94.24819	N/A	4500.38
94.29819	N/A	4472.10
94.34819	N/A	4407.49
94.39819	N/A	4350.99
94.44819	N/A	4306.62
94.49819	N/A	4270.33
94.54819	N/A	4230.02
94.59847	N/A	4201.82
94.64847	N/A	4181.68
94.69847	N/A	4153.48
94.74847	N/A	4129.32
94.80236	N/A	4109.19
94.85322	N/A	4089.07
94.91958	N/A	4060.90
94.97236	N/A	4044.80
95.02464	N/A	4028.71
95.07514	N/A	4016.64
95.12514	N/A	4322.75
95.17625	N/A	4346.96
95.22764	N/A	4310.65
95.27858	N/A	4278.39
95.32958	N/A	4254.21
95.38347	N/A	4230.02
95.43347	N/A	4209.88
95.48347	N/A	4189.73
95.53678	N/A	4177.65
95.58903	N/A	4149.46
95.63903	N/A	4129.32
95.68903	N/A	4113.22
95.74264	N/A	4097.12
95.79319	N/A	4081.02
95.84494	N/A	4060.90
95.89567	N/A	4044.80
95.94569	N/A	4028.71
95.99678	N/A	4008.60
96.04681	N/A	3996.53
96.09708	N/A	4217.94
96.14708	N/A	4371.17

96.19708	N/A	4298.55
96.24736	N/A	4254.21
96.30042	N/A	4209.88
96.35294	N/A	4165.56
96.40375	N/A	4137.38
96.45375	N/A	4093.09
96.50375	N/A	4076.99
96.55375	N/A	4048.82
96.60375	N/A	4024.69
96.65375	N/A	4004.57
96.70375	N/A	3984.47
96.75375	N/A	3960.34
96.80375	N/A	3940.24
96.85375	N/A	3920.14
96.90375	N/A	46.87
96.95375	N/A	73.82
97.00375	N/A	150.93
97.05375	N/A	143.21
97.10375	N/A	135.50
97.15375	N/A	127.78
97.20375	N/A	116.21
97.25375	N/A	123.93
97.30375	N/A	112.36
97.39800	N/A	1923.61
97.45181	N/A	1927.58
97.50181	N/A	1931.55
97.55181	N/A	1935.51
97.60178	N/A	1935.51
97.65181	N/A	1935.51
97.70433	N/A	1931.55
97.75772	N/A	1931.55
97.81097	N/A	N/A
97.86289	N/A	N/A
97.91514	N/A	N/A
97.96514	N/A	N/A
98.01514	N/A	N/A
98.06514	N/A	N/A
98.11511	N/A	N/A
98.16514	N/A	N/A
98.21514	N/A	N/A
98.26514	N/A	N/A
98.31514	N/A	N/A
98.36514	N/A	N/A
98.41514	N/A	N/A
98.46514	N/A	N/A
98.51514	N/A	N/A
98.56514	N/A	N/A
98.61514	N/A	N/A
98.66514	N/A	N/A
98.71514	N/A	1967.25
98.76514	N/A	1959.31
98.81514	N/A	1963.28
98.86514	N/A	1959.31
98.91514	N/A	1963.28
98.96514	N/A	1959.31
99.01514	N/A	1955.35
99.06514	N/A	1955.35
99.11514	2025.38	1939.48
99.16514	2055.23	1927.58
99.21542	2081.60	1769.04

99.26542	2093.91	1828.47
99.31542	2107.65	1844.32
99.36653	2109.74	1856.21
99.41653	2115.64	1840.36
99.46653	2130.07	1876.03
99.51653	2127.07	1860.17
99.56681	2116.94	1848.28
99.61681	2123.76	1864.14
99.66708	2153.49	1868.10
99.71708	2207.26	1876.03
99.76708	2266.86	1876.03
99.81708	2338.97	690.68
99.88486	2355.02	1927.58
99.93486	2418.39	1927.58
99.98486	2447.43	1919.65
100.03486	2541.49	2038.69
100.08486	2899.14	2356.65
100.13486	3455.04	2838.88
100.18514	4069.36	3346.55
100.23514	4722.57	3916.12
100.28511	5345.79	4411.53
100.33514	5440.89	4395.38
100.38514	5274.50	4262.27
100.43514	5169.68	4278.39
100.48514	5088.32	4205.85
100.53542	5142.48	4355.02
100.58542	5474.77	4597.41
100.63542	5511.46	4540.80
100.68542	5347.81	4411.53
100.73542	5240.42	4334.85
100.78542	5155.41	4254.21
100.83542	5085.46	4254.21
100.88542	5432.71	4532.71
100.93542	5468.42	4540.80
100.98542	5405.69	4492.30
101.03542	5379.94	4468.06
101.08542	5363.99	4451.90
101.13542	5354.43	4407.49
101.18542	5349.02	4447.87
101.23653	5339.83	4443.83
101.28792	5267.21	4367.13
101.34256	5187.80	4294.52
101.39681	5113.48	4230.02
101.45042	5059.39	4181.68
101.50294	5004.17	4153.48
101.55653	4961.81	4105.17
101.60986	4923.48	4076.99
101.66319	4882.97	4040.78
101.71319	4851.69	4008.60
101.76358	4822.80	3972.40
101.81625	4795.99	3956.32
101.86622	5065.78	4254.21
101.91625	5450.30	4556.97
101.96625	5462.68	4552.93
102.01625	5471.68	4500.38
102.06625	5327.46	4395.38
102.11625	5234.73	4322.75
102.16625	5162.24	4258.24
102.21622	5101.71	4213.91
102.26625	5049.87	4169.59

102.31625	5004.76	4125.30
102.36625	4965.05	4085.04
102.41625	4929.83	4056.87
102.46625	4897.87	4024.69
102.51625	4868.82	3996.53
102.56625	4842.00	3956.32
102.61625	4817.38	3924.16
102.66625	4794.23	3912.10
102.71625	4772.80	3883.97
102.76625	4752.49	3871.92
102.81625	4733.27	3855.84
102.86625	4715.21	3839.78
102.91625	4698.36	3823.71
102.96625	4682.05	3811.66
103.01625	4666.93	3795.60
103.06625	4652.38	3787.57
103.11625	4638.58	3771.51
103.16625	4625.54	3791.58
103.21625	4613.11	3759.46
103.26625	4601.24	3751.43
103.31625	4590.41	3747.42
103.36625	4931.35	4068.94
103.41625	5218.67	4310.65
103.46625	5369.01	4435.75
103.51625	5421.78	4488.26
103.56625	5447.69	4500.38
103.61625	5462.22	4512.50
103.66625	5469.46	4516.55
103.71625	5472.63	4520.59
103.76622	5479.10	4520.59
103.81625	5481.81	4520.59
103.91722	N/A	4330.82
104.16708	5045.79	4149.46
104.42233	4892.10	4032.73
104.67236	4793.27	3956.32
104.92236	4720.53	3892.01
105.17236	4663.95	3835.76
105.42236	4618.64	3811.66
105.67236	4581.32	3783.55
105.92236	4549.60	3759.46
106.17233	4521.83	3731.36
106.42236	4496.97	3711.30
106.67236	4474.52	3691.23
106.92236	4454.52	3675.18
107.17236	4436.82	3655.12
107.42236	4420.74	3635.07
107.67236	4406.04	3631.05
107.92236	4392.69	3619.02
108.17236	4380.37	3602.98
108.42236	4368.85	3586.94
108.67236	4357.80	3582.93
108.92236	4346.88	3534.82
109.17236	4336.43	3542.84
109.42236	4326.38	3550.86
109.67236	4316.91	3534.82
109.92236	4307.75	3530.81
110.17236	4298.86	3522.80
110.42236	4289.77	3518.79
110.69236	4279.09	3502.76
110.94242	4268.91	3494.75

111.19569	4259.23	3486.73
111.44569	4250.25	3478.72
111.69569	4241.90	3482.72
111.94569	4233.46	3486.73
112.19792	4225.70	3474.71
112.45875	4218.11	3474.71
112.66236	4212.70	3458.68
112.91236	4209.71	3474.71
113.16792	4199.64	3446.67
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113.46514	4224.90	3450.67
113.49150	4224.03	3450.67
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113.54514	4225.75	3450.67
113.57014	4220.70	3446.67
113.59514	4221.52	3458.68
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113.84708	5523.96	4605.50
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113.89931	5536.02	4629.78
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116.06242	N/A	3695.24
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117.12886	N/A	3659.13
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119.89597	4316.17	3570.90
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141.54036	2000
141.66486	2000
141.66536	1800
142.14225	1800
142.14275	0.0

APPENDIX 11.11

TREATMENT DATA FOR COASTAL NITROGEN FOAM FRACTURE

Sandia National Laboratories

A	01-AUG-85	05:18:32:0	21.30889	4095.233	10.722	3331.481	179.400
A	01-AUG-85	05:18:42:0	21.31167	3974.671	5.150	3327.527	79.400
A	01-AUG-85	05:18:52:0	21.31444	3973.958	10.722	3327.527	79.400
A	01-AUG-85	05:19:02:0	21.31722	3974.205	10.722	3331.481	79.400
A	01-AUG-85	05:19:12:0	21.32000	3973.766	10.722	3327.527	79.400
A	01-AUG-85	05:19:22:0	21.32278	3973.556	16.291	3331.481	79.400
A	01-AUG-85	05:19:32:0	21.32556	3973.120	16.291	3327.527	79.400
A	01-AUG-85	05:19:42:0	21.32833	4093.878	10.722	3331.481	179.400
A	01-AUG-85	05:19:52:0	21.33111	4094.278	10.722	3327.527	179.400
A	01-AUG-85	05:20:02:0	21.33389	4094.081	10.722	3327.527	179.400
A	01-AUG-85	05:20:12:0	21.33667	4093.270	10.722	3327.527	179.400
A	01-AUG-85	05:20:22:0	21.33944	4093.081	10.722	3327.527	179.400
A	01-AUG-85	05:20:32:0	21.34222	4093.300	21.858	3331.481	179.400
A	01-AUG-85	05:20:42:0	21.34500	4093.292	16.291	3323.573	179.500
A	01-AUG-85	05:20:52:0	21.34778	4092.771	5.150	3327.527	179.500
A	01-AUG-85	05:21:02:0	21.35056	4092.564	5.150	3323.573	179.500
A	01-AUG-85	05:21:12:0	21.35333	4092.741	10.722	3323.573	179.500
A	01-AUG-85	05:21:22:0	21.35611	4092.485	5.150	3323.573	179.500
A	01-AUG-85	05:21:32:0	21.35889	4092.306	5.150	3327.527	179.500
A	01-AUG-85	05:21:42:0	21.36167	4092.111	5.150	3323.573	179.500
A	01-AUG-85	05:21:52:0	21.36444	4091.798	10.722	3323.573	179.500
A	01-AUG-85	05:22:02:0	21.36722	4091.438	5.150	3323.573	179.500
A	01-AUG-85	05:22:12:0	21.37000	4091.156	5.150	3327.527	179.500
A	01-AUG-85	05:22:22:0	21.37278	4091.247	10.722	3323.573	179.500
A	01-AUG-85	05:22:32:0	21.37556	4090.366	10.722	3323.573	179.500
A	01-AUG-85	05:22:42:0	21.37833	4090.904	5.150	3323.573	179.500
A	01-AUG-85	05:22:52:0	21.38111	4090.284	3398.005	3327.527	179.500
A	01-AUG-85	05:23:02:0	21.38389	4086.893	3407.585	3331.481	179.500
A	01-AUG-85	05:23:12:0	21.38667	4088.830	3388.424	3327.527	179.500
A	01-AUG-85	05:23:22:0	21.38944	4089.406	3374.050	3327.527	179.500
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A	01-AUG-85	05:23:42:0	21.39500	4089.145	3364.465	3331.481	179.500
A	01-AUG-85	05:23:52:0	21.39778	4086.794	3359.673	3331.481	179.500
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A	01-AUG-85	05:24:22:0	21.40611	4087.707	3350.086	3331.481	179.500
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A	01-AUG-85	05:24:52:0	21.41444	4156.225	3421.953	3386.841	179.600
A	01-AUG-85	05:25:01:9	21.41719	4195.488	3455.468	3422.434	179.600
A	01-AUG-85	05:25:12:0	21.42000	4234.917	3479.398	3458.030	179.600
A	01-AUG-85	05:25:22:0	21.42278	4273.527	3527.238	3489.675	179.600
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A	01-AUG-85	05:25:42:0	21.42833	4350.984	3584.613	3560.885	179.900
A	01-AUG-85	05:25:52:0	21.43111	4389.011	3637.176	3588.581	179.900
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A	01-AUG-85	05:26:22:0	21.43944	4503.761	3727.905	3695.433	179.900
A	01-AUG-85	05:26:32:0	21.44222	4541.311	3756.541	3727.099	179.900
A	01-AUG-85	05:26:42:0	21.44500	4581.464	3785.171	3762.727	180.300
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A	01-AUG-85	05:27:12:0	21.45333	4694.839	3880.563	3861.716	180.300
A	01-AUG-85	05:27:22:0	21.45611	4732.571	3913.937	3889.439	180.300
A	01-AUG-85	05:27:32:0	21.45889	4770.348	3952.070	3925.086	180.300
A	01-AUG-85	05:27:42:0	21.46167	4808.032	3980.665	3956.776	180.800
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A	01-AUG-85	05:29:22:0	21.48944	5186.216	4295.020	4289.757	181.700

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A	01-AUG-85	05:29:42:0	21.49500	5261.916	4366.439	4345.301	182.800
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A	01-AUG-85	05:34:32:0	21.57556	6048.862	5004.838	5037.132	186.800
A	01-AUG-85	05:34:42:0	21.57833	6068.232	5057.316	5053.076	187.500
A	01-AUG-85	05:34:52:0	21.58111	6083.291	5066.859	5065.036	187.500
A	01-AUG-85	05:35:02:0	21.58389	6097.923	5052.544	5076.998	187.500
A	01-AUG-85	05:35:12:0	21.58667	6110.967	5076.402	5088.960	187.500
A	01-AUG-85	05:35:21:9	21.58942	6122.457	5085.946	5096.936	187.500
A	01-AUG-85	05:35:32:0	21.59222	6135.292	5085.946	5108.900	187.500
A	01-AUG-85	05:35:42:0	21.59500	6145.860	5105.036	5120.866	187.800
A	01-AUG-85	05:35:52:0	21.59778	6157.126	5119.355	5132.833	187.800
A	01-AUG-85	05:36:02:0	21.60056	6167.603	5114.582	5140.812	187.800
A	01-AUG-85	05:36:12:0	21.60333	6177.981	5100.264	5148.791	187.800
A	01-AUG-85	05:36:22:0	21.60611	6187.823	5124.128	5160.762	187.800
A	01-AUG-85	05:36:32:0	21.60889	6196.328	5128.902	5168.743	187.800
A	01-AUG-85	05:36:42:0	21.61167	6208.187	5138.449	5176.724	188.000
A	01-AUG-85	05:36:52:0	21.61444	6215.715	5152.771	5192.689	188.000
A	01-AUG-85	05:37:02:0	21.61722	6224.480	5162.319	5192.689	188.000
A	01-AUG-85	05:37:12:0	21.62000	6231.804	5147.997	5192.689	188.000
A	01-AUG-85	05:37:22:0	21.62278	6238.794	5143.223	5208.656	188.000
A	01-AUG-85	05:37:32:0	21.62556	6246.180	5147.997	5208.656	188.000
A	01-AUG-85	05:37:42:0	21.62833	6253.205	5152.771	5216.641	188.100
A	01-AUG-85	05:37:52:0	21.63111	6258.382	5133.675	5224.626	188.100
A	01-AUG-85	05:38:02:0	21.63389	6263.286	5195.744	5224.626	188.100
A	01-AUG-85	05:38:12:0	21.63667	6268.213	5162.319	5232.612	188.100
A	01-AUG-85	05:38:22:0	21.63944	6271.857	5167.094	5240.598	188.100
A	01-AUG-85	05:38:32:0	21.64222	6275.773	5171.869	5244.591	188.100
A	01-AUG-85	05:38:42:0	21.64500	6277.133	5152.771	5240.598	187.900
A	01-AUG-85	05:38:52:0	21.64778	6280.077	5205.295	5248.585	187.900
A	01-AUG-85	05:39:02:0	21.65056	6283.177	5167.094	5248.585	187.900
A	01-AUG-85	05:39:12:0	21.65333	6285.327	5181.418	5248.585	187.900
A	01-AUG-85	05:39:22:0	21.65611	6287.376	5176.643	5248.585	187.900
A	01-AUG-85	05:39:32:0	21.65889	6289.563	5167.094	5256.573	187.900
A	01-AUG-85	05:39:42:0	21.66167	6291.880	5167.094	5256.573	187.800
A	01-AUG-85	05:39:52:0	21.66444	6293.052	5181.418	5256.573	187.800
A	01-AUG-85	05:40:02:0	21.66722	6294.686	5190.969	5256.573	187.800
A	01-AUG-85	05:40:12:0	21.67000	6296.568	5162.319	5260.567	187.800
A	01-AUG-85	05:40:21:9	21.67275	6298.029	5190.969	5260.567	187.800

A	01-AUG-85	05:40:32:0	21.67556	6298.987	5200.520	5260.567	187.800
A	01-AUG-85	05:40:42:0	21.67833	6301.020	5176.643	5260.567	187.600
A	01-AUG-85	05:40:52:0	21.68111	6302.216	5186.193	5268.555	187.600
A	01-AUG-85	05:41:02:0	21.68389	6307.189	5200.520	5276.545	187.600
A	01-AUG-85	05:41:12:0	21.68667	6313.701	5152.771	5276.545	187.600
A	01-AUG-85	05:41:22:0	21.68944	6318.568	5205.295	5280.540	187.600
A	01-AUG-85	05:41:32:0	21.69222	6322.584	5224.400	5284.535	187.600
A	01-AUG-85	05:41:42:0	21.69500	6325.100	5167.094	5284.535	187.300
A	01-AUG-85	05:41:52:0	21.69778	6328.260	5224.400	5288.530	187.300
A	01-AUG-85	05:42:02:0	21.70056	6331.111	5133.675	5288.530	187.300
A	01-AUG-85	05:42:12:0	21.70333	6334.301	5190.969	5292.525	187.300
A	01-AUG-85	05:42:22:0	21.70611	6336.233	5133.675	5292.525	187.300
A	01-AUG-85	05:42:32:0	21.70889	6338.190	5186.193	5292.525	187.300
A	01-AUG-85	05:42:42:0	21.71167	6336.877	5200.520	5300.517	186.900
A	01-AUG-85	05:42:52:0	21.71444	6337.982	5176.643	5300.517	186.900
A	01-AUG-85	05:43:02:0	21.71722	6340.037	5114.582	5300.517	186.900
A	01-AUG-85	05:43:12:0	21.72000	6341.266	5147.997	5308.508	186.900
A	01-AUG-85	05:43:22:0	21.72278	6342.646	5138.449	5300.517	186.900
A	01-AUG-85	05:43:32:0	21.72556	6343.940	5095.491	5300.517	186.900
A	01-AUG-85	05:43:42:0	21.72833	6344.243	5133.675	5308.508	186.500
A	01-AUG-85	05:43:52:0	21.73111	6344.817	5057.316	5300.517	186.500
A	01-AUG-85	05:44:02:0	21.73389	6345.068	5124.128	5300.517	186.500
A	01-AUG-85	05:44:12:0	21.73667	6344.318	5047.773	5308.508	186.500
A	01-AUG-85	05:44:22:0	21.73944	6344.060	5109.809	5304.512	186.500
A	01-AUG-85	05:44:32:0	21.74222	6344.685	5114.582	5304.512	186.500
A	01-AUG-85	05:44:42:0	21.74500	6343.197	5090.719	5304.512	186.100
A	01-AUG-85	05:44:52:0	21.74778	6343.625	5085.946	5304.512	186.100
A	01-AUG-85	05:45:02:0	21.75056	6342.919	5081.174	5300.517	186.100
A	01-AUG-85	05:45:12:0	21.75333	6343.917	5071.630	5300.517	186.100
A	01-AUG-85	05:45:22:0	21.75611	6344.922	5057.316	5304.512	186.100
A	01-AUG-85	05:45:32:0	21.75889	6345.164	5052.544	5296.521	186.100
A	01-AUG-85	05:45:42:0	21.76167	6342.030	4990.529	5300.517	185.600
A	01-AUG-85	05:45:52:0	21.76444	6342.087	5071.630	5300.517	185.600
A	01-AUG-85	05:46:02:0	21.76722	6342.121	5004.838	5300.517	185.600
A	01-AUG-85	05:46:12:0	21.77000	6342.220	5014.378	5304.512	185.600
A	01-AUG-85	05:46:22:0	21.77278	6344.345	4971.451	5300.517	185.600
A	01-AUG-85	05:46:32:0	21.77556	6344.290	4985.759	5300.517	185.600
A	01-AUG-85	05:46:42:0	21.77833	6344.504	4914.230	5300.517	185.000
A	01-AUG-85	05:46:52:0	21.78111	6343.683	4928.534	5300.517	185.000
A	01-AUG-85	05:47:02:0	21.78389	6344.494	4957.144	5300.517	185.000
A	01-AUG-85	05:47:12:0	21.78667	6343.570	4961.913	5304.512	185.000
A	01-AUG-85	05:47:22:0	21.78944	6344.819	4966.682	5300.517	185.000
A	01-AUG-85	05:47:32:0	21.79222	6344.664	4942.839	5304.512	185.000
A	01-AUG-85	05:47:42:7	21.79519	6342.526	4885.625	5300.517	184.400
A	01-AUG-85	05:47:53:0	21.79806	6342.376	4861.791	5300.517	184.400
A	01-AUG-85	05:48:03:0	21.80083	6341.438	4890.392	5300.517	184.400
A	01-AUG-85	05:48:13:0	21.80361	6343.361	4880.858	5304.512	184.400
A	01-AUG-85	05:48:23:0	21.80639	6337.614	4823.661	5300.517	184.400
A	01-AUG-85	05:48:33:0	21.80917	6334.401	4833.193	5296.521	184.400
A	01-AUG-85	05:48:43:0	21.81194	6329.175	4785.538	5288.530	183.900
A	01-AUG-85	05:48:53:0	21.81472	6327.155	4809.364	5292.525	183.900
A	01-AUG-85	05:49:03:0	21.81750	6325.456	4809.364	5288.530	183.900
A	01-AUG-85	05:49:13:1	21.82031	6325.047	4771.243	5292.525	183.900
A	01-AUG-85	05:49:23:0	21.82306	6323.761	4785.538	5284.535	183.900
A	01-AUG-85	05:49:38:0	21.82722	6321.976	4809.364	5284.535	183.200
A	01-AUG-85	05:49:53:0	21.83139	6320.606	4780.773	5284.535	183.200
A	01-AUG-85	05:50:08:0	21.83556	6319.525	4780.773	5276.545	183.200
A	01-AUG-85	05:50:23:0	21.83972	6318.462	4790.303	5276.545	183.200
A	01-AUG-85	05:50:38:0	21.84389	6314.688	4766.478	5272.550	182.600
A	01-AUG-85	05:50:53:0	21.84806	6313.521	4771.243	5280.540	182.600
A	01-AUG-85	05:51:08:0	21.85222	6312.688	4776.008	5268.555	182.600
A	01-AUG-85	05:51:22:9	21.85636	6312.206	4785.538	5276.545	182.600
A	01-AUG-85	05:51:38:0	21.86056	6310.927	4785.538	5272.550	181.900
A	01-AUG-85	05:51:53:0	21.86472	6309.656	4766.478	5272.550	181.900
A	01-AUG-85	05:52:08:0	21.86889	6310.281	4761.713	5268.555	181.900
A	01-AUG-85	05:52:23:0	21.87306	6308.097	4776.008	5268.555	181.900

A	01-AUG-85	05:52:38:0	21.87722	6309.267	4766.478	5268.555	181.300
A	01-AUG-85	05:52:53:0	21.88139	6310.878	4756.949	5272.550	181.300
A	01-AUG-85	05:53:08:0	21.88556	6316.203	4780.773	5272.550	181.300
A	01-AUG-85	05:53:23:0	21.88972	6326.698	4785.538	5280.540	181.300
A	01-AUG-85	05:53:38:0	21.89389	6340.843	4795.068	5296.521	180.500
A	01-AUG-85	05:53:52:9	21.89803	6357.865	4799.833	5308.508	180.500
A	01-AUG-85	05:54:08:0	21.90222	6370.909	4795.068	5320.498	180.500
A	01-AUG-85	05:54:23:0	21.90639	6390.398	4814.130	5332.488	180.500
A	01-AUG-85	05:54:38:0	21.91056	6401.497	4828.427	5344.480	179.700
A	01-AUG-85	05:54:53:0	21.91472	6412.531	4847.492	5352.476	179.700
A	01-AUG-85	05:55:08:0	21.91889	6421.257	4861.791	5368.469	179.700
A	01-AUG-85	05:55:23:0	21.92306	6431.446	4866.558	5372.468	179.700
A	01-AUG-85	05:55:38:0	21.92722	6435.125	4885.625	5376.467	177.800
A	01-AUG-85	05:55:53:0	21.93139	6445.316	4904.695	5392.465	177.800
A	01-AUG-85	05:56:08:0	21.93556	6453.974	4890.392	5400.464	177.800
A	01-AUG-85	05:56:23:0	21.93972	6462.638	4904.695	5408.465	177.800
A	01-AUG-85	05:56:38:0	21.94389	6463.481	4895.160	5412.465	175.100
A	01-AUG-85	05:56:52:9	21.94803	6470.526	4904.695	5416.466	175.100
A	01-AUG-85	05:57:08:0	21.95222	6478.157	4904.695	5420.467	175.100
A	01-AUG-85	05:57:23:0	21.95639	6485.810	4909.462	5432.471	175.100
A	01-AUG-85	05:57:38:0	21.96056	6485.439	4923.766	5436.472	172.000
A	01-AUG-85	05:57:53:0	21.96472	6492.915	4942.839	5440.474	172.000
A	01-AUG-85	05:58:08:0	21.96889	6498.945	4971.451	5456.483	172.000
A	01-AUG-85	05:58:23:0	21.97306	6504.639	4942.839	5452.481	172.000
A	01-AUG-85	05:58:38:0	21.97722	6502.025	4928.534	5452.481	169.000
A	01-AUG-85	05:58:53:0	21.98139	6507.838	4947.607	5456.483	169.000
A	01-AUG-85	05:59:08:0	21.98556	6512.823	4947.607	5460.486	169.000
A	01-AUG-85	05:59:23:0	21.98972	6516.921	4957.144	5464.489	169.000
A	01-AUG-85	05:59:38:0	21.99389	6514.810	4990.529	5464.489	166.200
A	01-AUG-85	05:59:53:0	21.99806	6518.353	4985.759	5472.495	166.200
A	01-AUG-85	06:00:08:0	22.00222	6523.369	4980.990	5472.495	166.200
A	01-AUG-85	06:00:23:0	22.00639	6526.855	5014.378	5480.502	166.200
A	01-AUG-85	06:00:38:0	22.01056	6523.889	4985.759	5480.502	163.600
A	01-AUG-85	06:00:53:0	22.01472	6528.057	4985.759	5476.499	163.600
A	01-AUG-85	06:01:08:0	22.01889	6530.795	5019.149	5488.510	163.600
A	01-AUG-85	06:01:23:0	22.02306	6533.603	5019.149	5480.502	163.600
A	01-AUG-85	06:01:38:0	22.02722	6532.061	5028.690	5488.510	161.100
A	01-AUG-85	06:01:53:0	22.03139	6535.270	5038.231	5488.510	161.100
A	01-AUG-85	06:02:08:0	22.03556	6538.746	5038.231	5488.510	161.100
A	01-AUG-85	06:02:23:0	22.03972	6542.708	5038.231	5492.514	161.100
A	01-AUG-85	06:02:38:0	22.04389	6541.363	5071.630	5496.519	158.800
A	01-AUG-85	06:02:53:0	22.04806	6546.037	5090.719	5504.528	158.800
A	01-AUG-85	06:03:08:0	22.05222	6552.302	5105.036	5504.528	158.800
A	01-AUG-85	06:03:23:0	22.05639	6560.590	5109.809	5508.533	158.800
A	01-AUG-85	06:03:38:0	22.06056	6562.901	5109.809	5512.538	156.700
A	01-AUG-85	06:03:53:0	22.06472	6571.168	5114.582	5524.555	156.700
A	01-AUG-85	06:04:08:0	22.06889	6581.266	5128.902	5528.561	156.700
A	01-AUG-85	06:04:23:0	22.07306	6592.441	5152.771	5536.573	156.700
A	01-AUG-85	06:04:38:0	22.07722	6602.409	5181.418	5548.594	154.800
A	01-AUG-85	06:04:53:0	22.08139	6619.557	5190.969	5556.608	154.800
A	01-AUG-85	06:05:08:0	22.08556	6638.625	5238.730	5576.648	154.800
A	01-AUG-85	06:05:23:0	22.08972	6653.427	5257.838	5584.665	154.800
A	01-AUG-85	06:05:38:0	22.09389	6669.331	5267.394	5600.702	153.100
A	01-AUG-85	06:05:53:0	22.09806	6689.368	5233.953	5616.742	153.100
A	01-AUG-85	06:06:08:0	22.10222	6671.495	5133.675	5616.742	153.100
A	01-AUG-85	06:06:23:0	22.10639	6641.893	5076.402	5588.674	153.100
A	01-AUG-85	06:06:38:0	22.11056	6617.329	5066.859	5564.623	151.300
A	01-AUG-85	06:06:53:0	22.11472	6600.869	5038.231	5552.601	151.300
A	01-AUG-85	06:07:08:0	22.11889	6587.773	5023.919	5540.580	151.300
A	01-AUG-85	06:07:23:0	22.12306	6576.122	5009.608	5528.561	151.300
A	01-AUG-85	06:07:38:0	22.12722	6559.753	5004.838	5520.549	149.500
A	01-AUG-85	06:07:53:0	22.13139	6551.291	4990.529	5512.538	149.500
A	01-AUG-85	06:08:08:0	22.13556	6542.840	4980.990	5508.533	149.500
A	01-AUG-85	06:08:23:0	22.13972	6536.972	4971.451	5504.528	149.500
A	01-AUG-85	06:08:38:0	22.14389	6527.232	4971.451	5492.514	148.200
A	01-AUG-85	06:08:53:0	22.14806	6521.572	4961.913	5492.514	148.200

A	01-AUG-85	06:09:08:0	22.15222	6515.825	4957.144	5484.506	148.200
A	01-AUG-85	06:09:22:9	22.15636	6509.138	4957.144	5480.502	148.200
A	01-AUG-85	06:09:38:0	22.16056	6501.574	4952.376	5468.492	147.100
A	01-AUG-85	06:09:53:0	22.16472	6495.741	4942.839	5464.489	147.100
A	01-AUG-85	06:10:08:0	22.16889	6490.707	4933.302	5468.492	147.100
A	01-AUG-85	06:10:23:0	22.17306	6485.160	4933.302	5460.486	147.100
A	01-AUG-85	06:10:38:0	22.17722	6478.422	4923.766	5456.483	146.000
A	01-AUG-85	06:10:53:0	22.18139	6473.707	4918.998	5448.478	146.000
A	01-AUG-85	06:11:08:0	22.18556	6467.878	4928.534	5440.474	146.000
A	01-AUG-85	06:11:23:0	22.18972	6463.671	4909.462	5440.474	146.000
A	01-AUG-85	06:11:38:0	22.19389	6457.242	4918.998	5432.471	145.200
A	01-AUG-85	06:11:53:0	22.19806	6453.769	4914.230	5432.471	145.200
A	01-AUG-85	06:12:08:0	22.20222	6449.637	4904.695	5432.471	145.200
A	01-AUG-85	06:12:23:0	22.20639	6446.025	4904.695	5424.468	145.200
A	01-AUG-85	06:12:38:0	22.21056	6440.029	4904.695	5420.467	144.500
A	01-AUG-85	06:12:53:0	22.21472	6436.079	4895.160	5424.468	144.500
A	01-AUG-85	06:13:08:0	22.21889	6431.920	4890.392	5416.466	144.500
A	01-AUG-85	06:13:23:0	22.22306	6427.938	4885.625	5412.465	144.500
A	01-AUG-85	06:13:38:0	22.22722	6422.357	4895.160	5408.465	143.800
A	01-AUG-85	06:13:53:0	22.23139	6418.132	4885.625	5408.465	143.800
A	01-AUG-85	06:14:08:0	22.23556	6413.679	4876.091	5400.464	143.800
A	01-AUG-85	06:14:23:0	22.23972	6408.871	4871.324	5400.464	143.800
A	01-AUG-85	06:14:37:9	22.24386	6405.413	4880.858	5396.464	143.100
A	01-AUG-85	06:14:53:0	22.24806	6401.175	4871.324	5388.465	143.100
A	01-AUG-85	06:15:08:0	22.25222	6397.740	4866.558	5388.465	143.100
A	01-AUG-85	06:15:23:0	22.25639	6393.923	4871.324	5384.465	143.100
A	01-AUG-85	06:15:38:0	22.26056	6389.208	4866.558	5380.466	142.600
A	01-AUG-85	06:15:53:0	22.26472	6381.103	4861.791	5376.467	142.600
A	01-AUG-85	06:16:08:0	22.26889	6377.844	4857.024	5372.468	142.600
A	01-AUG-85	06:16:23:0	22.27306	6373.694	4852.258	5368.469	142.600
A	01-AUG-85	06:16:38:0	22.27722	6370.188	4857.024	5364.471	142.100
A	01-AUG-85	06:16:53:0	22.28139	6365.937	4842.725	5364.471	142.100
A	01-AUG-85	06:17:08:0	22.28556	6359.955	4837.959	5360.472	142.100
A	01-AUG-85	06:17:23:0	22.28972	6355.095	4837.959	5348.478	142.100
A	01-AUG-85	06:17:38:0	22.29389	6348.925	4833.193	5348.478	141.700
A	01-AUG-85	06:17:53:0	22.29806	6348.532	4828.427	5344.480	141.700
A	01-AUG-85	06:18:08:0	22.30222	6345.162	4828.427	5344.480	141.700
A	01-AUG-85	06:18:23:0	22.30639	6342.197	4823.661	5344.480	141.700
A	01-AUG-85	06:18:38:0	22.31056	6339.463	4823.661	5340.483	141.300
A	01-AUG-85	06:18:53:0	22.31472	6336.168	4823.661	5344.480	141.300
A	01-AUG-85	06:19:08:0	22.31889	6333.799	4818.896	5336.485	141.300
A	01-AUG-85	06:19:23:0	22.32306	6330.994	4818.896	5336.485	141.300
A	01-AUG-85	06:19:38:0	22.32722	6328.544	4809.364	5328.491	141.100
A	01-AUG-85	06:19:53:0	22.33139	6326.188	4809.364	5332.488	141.100
A	01-AUG-85	06:20:08:0	22.33556	6322.868	4809.364	5324.494	141.100
A	01-AUG-85	06:20:23:0	22.33972	6320.704	4804.599	5328.491	141.100
A	01-AUG-85	06:20:38:0	22.34389	6316.465	4809.364	5324.494	140.900
A	01-AUG-85	06:20:53:0	22.34806	6313.482	4804.599	5320.498	140.900
A	01-AUG-85	06:21:08:0	22.35222	6309.458	4799.833	5320.498	140.900
A	01-AUG-85	06:21:23:0	22.35639	6307.810	4799.833	5316.501	140.900
A	01-AUG-85	06:21:38:0	22.36056	6305.122	4804.599	5312.505	140.600
A	01-AUG-85	06:21:53:0	22.36472	6300.915	4795.068	5308.508	140.600
A	01-AUG-85	06:22:08:0	22.36889	6298.370	4790.303	5308.508	140.600
A	01-AUG-85	06:22:23:0	22.37306	6297.297	4795.068	5304.512	140.600
A	01-AUG-85	06:22:38:0	22.37722	6294.538	4799.833	5304.512	140.500
A	01-AUG-85	06:22:53:0	22.38139	6292.897	4795.068	5300.517	140.500
A	01-AUG-85	06:23:08:0	22.38556	6290.576	4790.303	5300.517	140.500
A	01-AUG-85	06:23:23:0	22.38972	6288.336	4780.773	5296.521	140.500
A	01-AUG-85	06:23:38:0	22.39389	6285.260	4785.538	5300.517	140.400
A	01-AUG-85	06:23:53:0	22.39806	6282.872	4780.773	5296.521	140.400
A	01-AUG-85	06:24:08:0	22.40222	6280.828	4776.008	5288.530	140.400
A	01-AUG-85	06:24:23:0	22.40639	6277.716	4780.773	5288.530	140.400
A	01-AUG-85	06:24:38:0	22.41056	6275.524	4780.773	5288.530	140.200
A	01-AUG-85	06:24:53:0	22.41472	6272.924	4771.243	5284.535	140.200
A	01-AUG-85	06:25:08:0	22.41889	6270.253	4771.243	5280.540	140.200
A	01-AUG-85	06:25:23:0	22.42306	6267.658	4780.773	5280.540	140.200

A	01-AUG-85	06:25:38:0	22.42722	6264.433	4761.713	5280.540	140.000
A	01-AUG-85	06:25:53:0	22.43139	6262.204	4761.713	5280.540	140.000
A	01-AUG-85	06:26:08:0	22.43556	6258.744	4756.949	5272.550	140.000
A	01-AUG-85	06:26:23:0	22.43972	6257.771	4761.713	5272.550	140.000
A	01-AUG-85	06:26:38:0	22.44389	6252.419	4756.949	5272.5[illegible]	139.900
A	01-AUG-85	06:26:53:0	22.44806	6250.067	4752.184	5264.561	139.900
A	01-AUG-85	06:27:08:0	22.45222	6247.040	4747.420	5272.550	139.900
A	01-AUG-85	06:27:23:0	22.45639	6244.566	4747.420	5260.567	139.900
A	01-AUG-85	06:27:38:0	22.46056	6241.432	4742.655	5256.573	139.700
A	01-AUG-85	06:27:53:0	22.46472	6239.228	4742.655	5256.573	139.700
A	01-AUG-85	06:28:08:0	22.46889	6235.810	4737.891	5256.573	139.700
A	01-AUG-85	06:28:23:0	22.47306	6234.658	4737.891	5256.573	139.700
A	01-AUG-85	06:28:38:0	22.47722	6231.715	4737.891	5252.579	139.600
A	01-AUG-85	06:28:53:0	22.48139	6230.280	4733.127	5248.585	139.600
A	01-AUG-85	06:29:08:0	22.48556	6227.883	4733.127	5252.579	139.600
A	01-AUG-85	06:29:23:0	22.48972	6225.122	4733.127	5248.585	139.600
A	01-AUG-85	06:29:38:0	22.49389	6222.536	4733.127	5248.585	139.400
A	01-AUG-85	06:29:53:0	22.49806	6220.313	4723.598	5240.598	139.400
A	01-AUG-85	06:30:08:0	22.50222	6216.407	4718.834	5236.605	139.400
A	01-AUG-85	06:30:23:0	22.50639	6213.265	4714.070	5244.591	139.400
A	01-AUG-85	06:30:38:0	22.51056	6212.252	4718.834	5236.605	139.300
A	01-AUG-85	06:30:53:0	22.51472	6210.227	4723.598	5236.605	139.300
A	01-AUG-85	06:31:08:0	22.51889	6208.526	4718.834	5232.612	139.300
A	01-AUG-85	06:31:22:9	22.52303	6207.268	4718.834	5232.612	139.300
A	01-AUG-85	06:31:38:0	22.52722	6205.016	4714.070	5228.61[illegible]	139.200
A	01-AUG-85	06:31:53:0	22.53139	6201.924	4709.307	5228.619	139.200
A	01-AUG-85	06:32:08:0	22.53556	6200.930	4704.543	5228.619	139.200
A	01-AUG-85	06:32:23:0	22.53972	6198.340	4704.543	5224.626	139.200
A	01-AUG-85	06:32:38:0	22.54389	6196.841	4704.543	5220.633	139.100
A	01-AUG-85	06:32:53:0	22.54806	6195.621	4704.543	5224.626	139.100
A	01-AUG-85	06:33:08:0	22.55222	6194.149	4699.779	5220.633	139.100
A	01-AUG-85	06:33:23:0	22.55639	6193.027	4704.543	5220.633	139.100
A	01-AUG-85	06:33:38:0	22.56056	6192.080	4699.779	5220.633	139.000
A	01-AUG-85	06:33:52:9	22.56469	6190.412	4709.307	5220.633	139.000
A	01-AUG-85	06:34:08:0	22.56889	6190.002	4690.252	5216.641	139.000
A	01-AUG-85	06:34:23:0	22.57306	6188.291	4695.016	5216.641	139.000
A	01-AUG-85	06:34:38:0	22.57722	6187.692	4695.016	5212.648	139.100
A	01-AUG-85	06:34:53:0	22.58139	6186.256	4690.252	5216.641	139.100
A	01-AUG-85	06:35:08:0	22.58556	6185.124	4690.252	5216.641	139.100
A	01-AUG-85	06:35:22:9	22.58969	6183.731	4690.252	5212.648	139.100
A	01-AUG-85	06:35:37:9	22.59386	6183.058	4690.252	5216.641	139.300
A	01-AUG-85	06:35:53:0	22.59806	6181.151	4685.488	5216.641	139.300
A	01-AUG-85	06:36:08:0	22.60222	6180.967	4685.488	5212.648	139.300
A	01-AUG-85	06:36:23:0	22.60639	6179.281	4680.725	5208.656	139.300
A	01-AUG-85	06:36:38:0	22.61056	6178.597	4675.962	5212.648	139.600
A	01-AUG-85	06:36:53:0	22.61472	6177.748	4680.725	5212.648	139.600
A	01-AUG-85	06:37:08:0	22.61889	6177.355	4685.488	5212.648	139.600
A	01-AUG-85	06:37:23:0	22.62306	6176.034	4685.488	5208.656	139.600
A	01-AUG-85	06:37:38:0	22.62722	6175.070	4685.488	5208.656	139.900
A	01-AUG-85	06:37:53:0	22.63139	6173.661	4675.962	5208.656	139.900
A	01-AUG-85	06:38:08:0	22.63556	6172.936	4675.962	5208.656	139.900
A	01-AUG-85	06:38:23:0	22.63972	6172.334	4675.962	5204.664	139.900
A	01-AUG-85	06:38:38:0	22.64389	6173.189	4675.962	5200.672	140.200
A	01-AUG-85	06:38:53:0	22.64806	6172.180	4671.198	5204.664	140.200
A	01-AUG-85	06:39:08:0	22.65222	6171.813	4671.198	5204.664	140.200
A	01-AUG-85	06:39:23:0	22.65639	6170.811	4671.198	5200.672	140.200
A	01-AUG-85	06:39:38:0	22.66056	6170.023	4671.198	5200.672	140.600
A	01-AUG-85	06:39:53:0	22.66472	6169.172	4671.198	5196.680	140.600
A	01-AUG-85	06:40:08:0	22.66889	6167.986	4666.435	5200.672	140.600
A	01-AUG-85	06:40:23:0	22.67306	6167.479	4666.435	5196.680	140.600
A	01-AUG-85	06:40:38:0	22.67722	6168.755	4671.198	5200.672	141.000
A	01-AUG-85	06:40:53:0	22.68139	6167.319	4661.672	5196.680	141.000
A	01-AUG-85	06:41:08:0	22.68556	6166.766	4666.435	5196.680	141.000
A	01-AUG-85	06:41:23:0	22.68972	6166.225	4666.435	5196.680	141.000
A	01-AUG-85	06:41:38:0	22.69389	6165.362	4661.672	5192.689	141.500
A	01-AUG-85	06:41:53:0	22.69806	6164.564	4671.198	5196.680	141.500

A	01-AUG-85	06:42:08:0	22.70222	6163.915	4656.909	5192.689	141.500
A	01-AUG-85	06:42:23:0	22.70639	6163.506	4661.672	5196.680	141.500
A	01-AUG-85	06:42:38:0	22.71056	6162.157	4666.435	5192.689	141.900
A	01-AUG-85	06:42:53:0	22.71472	6162.251	4656.909	5192.689	141.900
A	01-AUG-85	06:43:08:0	22.71889	6162.026	4656.909	5192.689	141.900
A	01-AUG-85	06:43:23:0	22.72306	6160.826	4666.435	5184.706	141.900
A	01-AUG-85	06:43:38:0	22.72722	6162.148	4656.909	5196.680	142.300
A	01-AUG-85	06:43:53:0	22.73139	6160.628	4661.672	5192.689	142.300
A	01-AUG-85	06:44:08:0	22.73556	6160.016	4652.146	5188.697	142.300
A	01-AUG-85	06:44:23:0	22.73972	6159.698	4652.146	5188.697	142.300
A	01-AUG-85	06:44:37:9	22.74386	6159.444	4656.909	5188.697	142.800
A	01-AUG-85	06:44:53:0	22.74806	6158.852	4647.383	5188.697	142.800
A	01-AUG-85	06:45:08:0	22.75222	6157.545	4647.383	5188.697	142.800
A	01-AUG-85	06:45:23:0	22.75639	6156.679	4647.383	5184.706	142.800
A	01-AUG-85	06:45:38:0	22.76056	6158.725	4656.909	5184.706	143.200
A	01-AUG-85	06:45:53:0	22.76472	6158.215	4652.146	5184.706	143.200
A	01-AUG-85	06:46:08:0	22.76889	6156.700	4647.383	5184.706	143.200
A	01-AUG-85	06:46:23:0	22.77306	6156.077	4652.146	5188.697	143.200
A	01-AUG-85	06:46:38:0	22.77722	6155.509	4656.909	5180.715	143.600
A	01-AUG-85	06:46:53:0	22.78139	6154.913	4661.672	5184.706	143.600
A	01-AUG-85	06:47:08:0	22.78556	6154.649	4656.909	5188.697	143.600
A	01-AUG-85	06:47:23:0	22.78972	6154.003	4652.146	5184.706	143.600
A	01-AUG-85	06:47:38:0	22.79389	6154.579	4652.146	5184.706	144.100
A	01-AUG-85	06:47:53:0	22.79806	6154.764	4647.383	5180.715	144.100
A	01-AUG-85	06:48:08:0	22.80222	6154.049	4647.383	5180.715	144.100
A	01-AUG-85	06:48:23:0	22.80639	6153.526	4652.146	5180.715	144.100
A	01-AUG-85	06:48:38:0	22.81056	6152.885	4647.383	5180.715	144.600
A	01-AUG-85	06:48:53:0	22.81472	6152.113	4652.146	5180.715	144.600
A	01-AUG-85	06:49:08:0	22.81889	6151.486	4647.383	5180.715	144.600
A	01-AUG-85	06:49:23:0	22.82306	6151.243	4652.146	5180.715	144.600
A	01-AUG-85	06:49:38:0	22.82722	6151.625	4656.909	5180.715	145.000
A	01-AUG-85	06:49:53:0	22.83139	6151.026	4652.146	5176.724	145.000
A	01-AUG-85	06:50:08:0	22.83556	6151.125	4647.383	5176.724	145.000
A	01-AUG-85	06:50:23:0	22.83972	6150.648	4656.909	5176.724	145.000
A	01-AUG-85	06:50:38:0	22.84389	6149.345	4647.383	5176.724	145.500
A	01-AUG-85	06:50:53:0	22.84806	6149.761	4647.383	5176.724	145.500
A	01-AUG-85	06:51:08:0	22.85222	6148.769	4647.383	5176.724	145.500
A	01-AUG-85	06:51:23:0	22.85639	6148.354	4647.383	5180.715	145.500
A	01-AUG-85	06:51:38:0	22.86056	6147.269	4647.383	5172.733	145.900
A	01-AUG-85	06:51:53:0	22.86472	6147.230	4647.383	5176.724	145.900
A	01-AUG-85	06:52:08:0	22.86889	6146.916	4647.383	5172.733	145.900
A	01-AUG-85	06:52:23:0	22.87306	6146.150	4647.383	5172.733	145.900
A	01-AUG-85	06:52:38:0	22.87722	6147.113	4647.383	5168.743	146.400
A	01-AUG-85	06:52:53:0	22.88139	6146.320	4642.620	5176.724	146.400
A	01-AUG-85	06:53:08:0	22.88556	6146.634	4642.620	5172.733	146.400
A	01-AUG-85	06:53:23:0	22.88972	6145.807	4637.857	5172.733	146.400
A	01-AUG-85	06:53:37:9	22.89386	6145.445	4647.383	5168.743	146.800
A	01-AUG-85	06:53:53:0	22.89806	6144.680	4642.620	5172.733	146.800
A	01-AUG-85	06:54:08:0	22.90222	6143.845	4642.620	5172.733	146.800
A	01-AUG-85	06:54:23:0	22.90639	6143.107	4652.146	5168.743	146.800
A	01-AUG-85	06:54:38:0	22.91056	6145.234	4647.383	5168.743	147.200
A	01-AUG-85	06:54:53:0	22.91472	6144.704	4647.383	5164.752	147.200
A	01-AUG-85	06:55:08:0	22.91889	6143.836	4642.620	5168.743	147.200
A	01-AUG-85	06:55:22:9	22.92303	6143.576	4647.383	5160.762	147.200
A	01-AUG-85	06:55:38:0	22.92722	6142.641	4656.909	5160.762	147.700
A	01-AUG-85	06:55:53:0	22.93139	6141.983	4652.146	5164.752	147.700
A	01-AUG-85	06:56:08:0	22.93556	6142.038	4642.620	5164.752	147.700
A	01-AUG-85	06:56:23:0	22.93972	6141.736	4647.383	5164.752	147.700
A	01-AUG-85	06:56:38:0	22.94389	6142.604	4647.383	5164.752	148.000
A	01-AUG-85	06:56:53:0	22.94806	6142.449	4647.383	5164.752	148.000
A	01-AUG-85	06:57:08:0	22.95222	6142.161	4637.857	5164.752	148.000
A	01-AUG-85	06:57:23:0	22.95639	6141.379	4647.383	5160.762	148.000
A	01-AUG-85	06:57:38:0	22.96056	6140.959	4642.620	5168.743	148.500
A	01-AUG-85	06:57:53:0	22.96472	6140.587	4637.857	5160.762	148.500
A	01-AUG-85	06:58:08:0	22.96889	6140.280	4637.857	5160.762	148.500
A	01-AUG-85	06:58:23:0	22.97306	6139.626	4642.620	5164.752	148.500

A	01-AUG-85	06:58:38:0	22.97722	6139.378	4633.094	5164.752	148.900
A	01-AUG-85	06:58:53:0	22.98139	6139.148	4637.857	5160.762	148.900
A	01-AUG-85	06:59:08:0	22.98556	6138.082	4642.620	5160.762	148.900
A	01-AUG-85	06:59:23:0	22.98972	6138.215	4647.383	5164.752	148.900
A	01-AUG-85	06:59:38:0	22.99389	6138.834	4637.857	5164.752	149.300
A	01-AUG-85	06:59:53:0	22.99806	6138.693	4637.857	5164.752	149.300
A	01-AUG-85	07:00:08:0	23.00222	6138.309	4637.857	5160.762	149.300
A	01-AUG-85	07:00:23:0	23.00639	6137.629	4637.857	5160.762	149.300
A	01-AUG-85	07:00:38:0	23.01056	6137.880	4642.620	5160.762	149.700
A	01-AUG-85	07:00:53:0	23.01472	6136.797	4633.094	5156.771	149.700
A	01-AUG-85	07:01:08:0	23.01889	6136.597	4633.094	5152.781	149.700
A	01-AUG-85	07:01:23:0	23.02306	6135.892	4633.094	5160.762	149.700
A	01-AUG-85	07:01:38:0	23.02722	6137.763	4637.857	5156.771	150.000
A	01-AUG-85	07:01:53:0	23.03139	6137.497	4642.620	5156.771	150.000
A	01-AUG-85	07:02:08:0	23.03556	6136.743	4633.094	5156.771	150.000
A	01-AUG-85	07:02:23:0	23.03972	6136.205	4637.857	5152.781	150.000
A	01-AUG-85	07:02:38:0	23.04389	6135.401	4633.094	5156.771	150.400
A	01-AUG-85	07:02:52:9	23.04803	6135.302	4637.857	5152.781	150.400
A	01-AUG-85	07:03:08:0	23.05222	6134.273	4623.569	5156.771	150.400
A	01-AUG-85	07:03:23:0	23.05639	6134.249	4642.620	5152.781	150.400
A	01-AUG-85	07:03:38:0	23.06056	6133.954	4628.331	5152.781	150.800
A	01-AUG-85	07:03:53:0	23.06472	6133.676	4637.857	5156.771	150.800
A	01-AUG-85	07:04:08:0	23.06889	6133.118	4633.094	5152.781	150.800
A	01-AUG-85	07:04:23:0	23.07306	6132.788	4637.857	5152.781	150.800
A	01-AUG-85	07:04:38:0	23.07722	6133.863	4633.094	5144.802	151.200
A	01-AUG-85	07:04:53:0	23.08139	6134.163	4637.857	5152.781	151.200
A	01-AUG-85	07:05:08:0	23.08556	6133.403	4628.331	5152.781	151.200
A	01-AUG-85	07:05:23:0	23.08972	6132.778	4633.094	5152.781	151.200
A	01-AUG-85	07:05:38:0	23.09389	6131.995	4628.331	5152.781	151.600
A	01-AUG-85	07:05:53:0	23.09806	6131.662	4628.331	5148.791	151.600
A	01-AUG-85	07:06:08:0	23.10222	6131.944	4628.331	5148.791	151.600
A	01-AUG-85	07:06:23:0	23.10639	6130.813	4628.331	5148.791	151.600
A	01-AUG-85	07:06:38:0	23.11056	6130.413	4628.331	5148.791	151.900
A	01-AUG-85	07:06:53:0	23.11472	6130.394	4628.331	5144.802	151.900
A	01-AUG-85	07:07:08:0	23.11889	6130.260	4623.569	5144.802	151.900
A	01-AUG-85	07:07:23:0	23.12306	6129.964	4623.569	5152.781	151.900
A	01-AUG-85	07:07:37:9	23.12719	6131.081	4633.094	5144.802	152.400
A	01-AUG-85	07:07:53:0	23.13139	6130.136	4628.331	5148.791	152.400
A	01-AUG-85	07:08:08:0	23.13556	6129.702	4628.331	5156.771	152.400
A	01-AUG-85	07:08:23:0	23.13972	6130.034	4628.331	5144.802	152.400
A	01-AUG-85	07:08:38:0	23.14389	6128.882	4628.331	5144.802	152.700
A	01-AUG-85	07:08:53:0	23.14806	6129.129	4628.331	5144.802	152.700
A	01-AUG-85	07:09:08:0	23.15222	6128.632	4623.569	5144.802	152.700
A	01-AUG-85	07:09:22:9	23.15636	6128.175	4628.331	5144.802	152.700
A	01-AUG-85	07:09:38:0	23.16056	6129.746	4628.331	5144.802	153.100
A	01-AUG-85	07:09:53:0	23.16472	6129.827	4628.331	5144.802	153.100
A	01-AUG-85	07:10:08:0	23.16889	6129.242	4623.569	5144.802	153.100
A	01-AUG-85	07:10:23:0	23.17306	6128.638	4623.569	5140.812	153.100
A	01-AUG-85	07:10:38:0	23.17722	6128.214	4618.806	5140.812	153.500
A	01-AUG-85	07:10:53:0	23.18139	6127.947	4623.569	5148.791	153.500
A	01-AUG-85	07:11:08:0	23.18556	6127.047	4633.094	5144.802	153.500
A	01-AUG-85	07:11:23:0	23.18972	6126.454	4623.569	5144.802	153.500
A	01-AUG-85	07:11:38:0	23.19389	6126.562	4623.569	5140.812	153.900
A	01-AUG-85	07:11:53:0	23.19806	6126.136	4623.569	5144.802	153.900
A	01-AUG-85	07:12:08:0	23.20222	6125.005	4618.806	5140.812	153.900
A	01-AUG-85	07:12:23:0	23.20639	6125.300	4623.569	5144.802	153.900
A	01-AUG-85	07:12:38:0	23.21056	6126.200	4623.569	5140.812	154.200
A	01-AUG-85	07:12:53:0	23.21472	6126.083	4628.331	5140.812	154.200
A	01-AUG-85	07:13:08:0	23.21889	6126.151	4628.331	5140.812	154.200
A	01-AUG-85	07:13:23:0	23.22306	6125.342	4623.569	5140.812	154.200
A	01-AUG-85	07:13:38:0	23.22722	6125.331	4618.806	5140.812	154.700
A	01-AUG-85	07:13:53:0	23.23139	6124.523	4609.281	5140.812	154.700
A	01-AUG-85	07:14:08:0	23.23556	6124.695	4599.756	5140.812	154.700
A	01-AUG-85	07:14:23:0	23.23972	6124.178	4580.707	5140.812	154.700
A	01-AUG-85	07:14:38:0	23.24389	6125.850	2815.553	5128.844	155.000
A	01-AUG-85	07:14:53:0	23.24806	6125.410	1079.278	5128.844	155.000

A	01-AUG-85	07:15:08:0	23.25222	6124.776	0.000	5128.844	155.000
A	01-AUG-85	07:15:23:0	23.25639	6124.838	0.000	5124.855	155.000
A	01-AUG-85	07:15:38:0	23.26056	6124.129	165.815	5128.844	155.400
A	01-AUG-85	07:15:53:0	23.26472	6124.292	0.000	5124.855	155.400
A	01-AUG-85	07:16:08:0	23.26889	6122.908	0.000	5124.855	155.400
A	01-AUG-85	07:16:23:0	23.27306	6123.304	0.000	5124.855	155.400
A	01-AUG-85	07:16:38:0	23.27722	6123.253	0.000	5120.866	155.700
A	01-AUG-85	07:16:53:0	23.28139	6122.525	0.000	5124.855	155.700
A	01-AUG-85	07:17:08:0	23.28556	6122.293	0.000	5128.844	155.700
A	01-AUG-85	07:17:23:0	23.28972	6121.368	0.000	5124.855	155.700
A	01-AUG-85	07:17:38:0	23.29389	6123.574	0.000	5124.855	156.000
A	01-AUG-85	07:17:53:0	23.29806	6123.228	0.000	5128.844	156.000
A	01-AUG-85	07:18:08:0	23.30222	6122.387	0.000	5124.855	156.000
A	01-AUG-85	07:18:23:0	23.30639	6122.343	0.000	5120.866	156.000
A	01-AUG-85	07:18:38:0	23.31056	6121.526	0.000	5120.866	156.300
A	01-AUG-85	07:18:53:0	23.31472	6121.551	0.000	5120.866	156.300
A	01-AUG-85	07:19:08:0	23.31889	6120.598	0.000	5120.866	156.300
A	01-AUG-85	07:19:23:0	23.32306	6120.981	0.000	5124.855	156.300
A	01-AUG-85	07:19:37:9	23.32719	6120.391	0.000	5120.866	156.600
A	01-AUG-85	07:19:53:0	23.33139	6120.265	0.000	5116.877	156.600
A	01-AUG-85	07:20:08:0	23.33556	6119.548	0.000	5120.866	156.600
A	01-AUG-85	07:20:23:0	23.33972	6119.176	0.000	5120.866	156.600
A	01-AUG-85	07:20:38:0	23.34389	6117.292	0.000	5116.877	156.900
A	01-AUG-85	07:20:53:0	23.34806	6116.826	0.000	5116.877	156.900
A	01-AUG-85	07:21:08:0	23.35222	6117.179	0.000	5116.877	156.900
A	01-AUG-85	07:21:23:0	23.35639	6116.277	0.000	5120.866	156.900
A	01-AUG-85	07:21:38:0	23.36056	6117.580	0.000	5116.877	157.200

APPENDIX 11.12

POST-FRACTURE WELL TEST DATA FROM YELLOW SANDSTONES

CER Corporation

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* MWX #1,  COASTAL YELLOW POST N2 FOAM FRAC AUGUST 1985
* ELAPSED     MWX #1      MWX #1
*  TIME        B.H.        FLOW
* (HOURS)     PRESS.      RATE
*             (PSI)       (MCFD)
 178.86722     170.34       0.00
 180.70056     568.54       0.00
 182.53389     891.94       0.00
 184.50000    1184.62       0.00
 186.33333    1425.58       0.00
 188.16722    1637.94       0.00
 190.00056    1825.43       0.00
 192.41528    2045.54       0.00
 194.24861    2178.23       0.00
 194.73250    2185.18      67.70
 194.91582    2141.02     143.30
 195.09917    2108.40     134.10
 195.28250    2077.92     160.90
 195.46584    2044.55     153.90
 195.64917    2013.80     154.80
 195.83250    1985.03     152.90
 196.01582    1957.58     152.50
 196.19917    1931.54     152.50
 196.38251    1907.04     148.00
 196.56583    1879.00     154.60
 196.74918    1856.11     146.50
 198.72610    1640.39     148.30
 200.79611    1442.39     142.10
 202.62971    1271.43     140.00
 204.46306    1093.54     139.10
 206.29639     938.86     144.40
 208.16667     810.23     153.30
 210.00000    1206.15      23.10
 211.83333    1438.58     157.10
 213.66667    1251.67      28.40
 216.06332     931.15     153.90
 218.36501     796.45     116.10
 220.19833     802.24      99.00
 222.03168     804.10      98.40
 223.99055     804.07      96.50
 225.82668     804.21      97.00
 227.66000     803.62      97.40
 229.49333     800.57      96.40
 231.59084     796.76      95.10
 233.50000     791.63      94.70
 235.33333     787.59      93.40
 237.16669     783.75      93.20
 248.28694     770.78     100.60
 250.12029     759.77      98.70
 251.95361    1064.03       0.00
 253.78694    1355.94       0.00
 255.62029    1582.14       0.00
 257.50000    1773.72       0.00
 259.33334    1932.29       0.00
 261.16666    2075.53       0.00
 262.99997    2195.27       0.00
 264.83362    2293.72       0.00
 266.66693    2373.06       0.00
 268.50024    2440.98       0.00
 270.47610    2504.95       0.00
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272.44888	2556.86	0.00
274.28223	2597.77	0.00
276.11557	2633.04	0.00
280.50000	2703.64	0.00
282.33334	2729.15	0.00
284.16666	2752.35	0.00
286.00000	2773.95	0.00
287.83362	2794.73	0.00
290.09000	2782.85	0.00
291.92334	2469.98	197.30
293.75693	2250.35	179.70
295.59027	1956.70	238.30
297.52246	1613.34	282.60
299.74112	1317.51	121.80
302.51721	1029.65	193.80
304.50000	836.39	202.30
306.33334	638.25	199.10
308.16666	433.47	200.90
310.00000	207.75	216.60
311.16666	25.02	0.00
346.04971	250.18	0.00
350.08112	996.64	0.00
353.00000	1366.61	0.00
355.75000	1645.64	0.00
358.50000	1947.94	0.00
362.58499	2195.55	0.00
363.59500	2243.49	0.00
363.77832	2251.31	0.00
363.96194	2259.64	0.00
364.22083	2270.80	0.00
367.32056	2383.69	0.00
370.07056	2458.73	0.00
372.82056	2520.33	0.00
385.69443	2719.17	0.00
386.24445	2725.60	0.00
386.94360	2711.29	0.00
387.49359	2568.44	116.80
388.17776	2517.76	119.10
389.09500	2417.10	143.30
390.19144	2320.96	143.80
391.14639	2269.53	122.40
392.40640	2123.98	206.30
393.32443	2094.03	107.30
394.32443	2025.26	85.00
395.32443	1997.17	162.00
396.24112	1953.25	157.90
397.15778	1902.70	148.90
398.40778	1857.66	110.50
399.32443	1845.05	131.10
400.33334	1814.09	145.80
401.58334	1725.33	153.00
402.50000	1697.85	132.70
403.41666	1674.67	129.40
404.33334	1611.74	116.40
405.25000	1549.57	160.50
406.16666	1499.57	158.60
407.41693	1409.31	179.70
409.27695	1489.94	148.30
410.44693	1333.69	133.00
411.86890	1313.63	126.30

412.78555	1299.53	125.20
413.70557	1282.98	125.60
414.62222	1263.92	125.90
415.54056	1244.52	124.90
416.46857	1224.22	124.60
417.38528	1205.66	125.40
418.30194	1187.68	123.40
419.32611	1168.08	119.60
420.24277	1151.43	118.20
421.15945	1135.54	116.90
422.07611	1120.24	115.50
422.99277	1076.12	143.30
423.90945	1022.39	138.20
424.83331	979.33	132.70
425.75000	930.32	134.30
426.66666	893.47	128.90
427.58334	849.09	143.30
428.50000	802.11	119.10
429.41666	787.71	116.00
430.33334	766.51	118.30
431.35556	750.93	110.90
432.27222	732.36	114.00
434.10556	711.08	109.30
435.52222	703.46	108.60
437.15778	698.40	106.00
438.77417	695.61	105.40
441.11221	695.95	103.90
445.40305	698.14	100.40
447.68610	713.14	100.50
449.66666	695.79	99.10
451.50000	693.54	99.70
453.33334	691.11	99.40
456.14639	686.23	98.20
458.11139	684.68	98.50
459.94470	684.26	101.70
461.78168	678.59	103.50
463.62695	668.67	103.70
465.65195	657.43	102.70
467.48529	648.56	101.70
469.37305	639.80	99.60
471.20639	632.22	98.60
473.16666	624.93	98.20
475.00000	619.56	97.20
477.04361	612.95	95.80
478.87695	608.07	95.60
481.37833	607.02	94.60
483.21167	612.71	96.30
485.04501	618.27	97.70
486.89249	623.80	96.70
488.87833	630.13	99.10
490.88251	634.67	100.60
492.71582	637.10	98.90
494.54916	639.11	99.10
496.50000	641.67	99.80
498.33334	643.30	97.90
500.16663	644.43	97.90
502.00000	645.42	96.50
504.31445	645.94	98.40
506.22806	646.62	98.70
508.30807	646.85	97.50

510.14139	646.28	97.00
511.98807	645.47	96.20
513.82141	645.39	98.30
515.65466	644.84	96.60
517.65222	643.43	95.60
519.48553	643.15	95.40
521.33331	642.84	95.50
523.37000	641.33	95.20
525.20331	640.32	95.20
527.90027	639.01	94.60
529.96808	638.09	95.30
531.80359	638.34	94.20
533.63696	637.83	96.30
535.47028	636.98	94.90
537.30359	636.41	95.10
539.13696	635.63	94.50
540.97028	634.80	93.50
542.80359	633.19	92.80
544.66669	632.86	93.30
546.50000	632.19	92.80
548.33331	631.28	92.10
550.73975	629.31	91.20
552.57416	628.53	90.70
554.40747	627.23	91.40
556.24084	627.76	90.60
558.07416	629.08	91.10
559.90747	630.42	92.80
561.90747	626.71	89.70
563.74084	607.54	86.90
565.82391	516.87	96.80
575.29114	622.86	87.10
578.14941	637.46	93.00
578.33276	588.88	0.00
578.51611	664.49	0.00
579.08276	673.13	0.00
579.26611	703.20	0.00
579.44946	745.62	0.00
579.60614	942.55	0.00
579.63947	960.27	0.00
579.66998	953.62	0.00
579.70056	1087.89	0.00
579.73114	1128.85	0.00
579.76166	1134.46	0.00
579.79224	1146.80	0.00
579.82275	1160.89	0.00
579.85333	1175.90	0.00
579.88391	1190.83	0.00
579.91443	1205.82	0.00
580.03778	1262.41	0.00
580.22113	1333.63	0.00
580.40442	1392.11	0.00
580.55914	1434.52	0.00
580.56256	1435.55	0.00
580.56555	1435.83	0.00
580.56860	1436.69	0.00
580.57166	1437.53	0.00
580.57471	1438.25	0.00
580.57776	1439.13	0.00
580.58081	1440.01	0.00
580.58386	1440.31	0.00

580.58691	1441.19	0.00
580.59003	1441.90	0.00
580.59308	1442.81	0.00
580.59613	1443.56	0.00
580.59918	1444.58	0.00
580.60223	1445.14	0.00
580.60529	1445.90	0.00
580.60834	1446.89	0.00
580.61139	1447.66	0.00
580.61444	1448.22	0.00
580.61749	1449.22	0.00
580.62054	1449.89	0.00
580.62360	1450.68	0.00
580.62665	1451.36	0.00
580.63000	1451.78	0.00
580.63306	1452.90	0.00
580.63611	1453.74	0.00
580.63916	1453.91	0.00
580.64221	1454.88	0.00
580.72748	1474.52	0.00
580.91083	1514.60	0.00
582.58136	1746.37	0.00
584.41473	1903.38	0.00
587.10059	2052.14	0.00
588.93384	2123.85	0.00
590.76721	2181.18	0.00
592.66669	2230.73	0.00
594.50000	2272.30	0.00
596.33331	2309.83	0.00
598.16669	2342.76	0.00
600.18890	2402.85	0.00
602.16138	2406.23	0.00
603.99469	2431.22	0.00
605.82806	2455.42	0.00
607.66138	2477.47	0.00
609.49469	2497.91	0.00
611.32806	2518.04	0.00
613.16138	2536.30	0.00
614.99469	2554.29	0.00
616.83331	2571.53	0.00
618.89557	2589.64	0.00
620.72888	2604.96	0.00
623.25140	2624.95	0.00
625.41528	2641.05	0.00
627.24860	2654.06	0.00
629.08197	2667.23	0.00
630.91528	2679.61	0.00
632.74860	2691.19	0.00
634.58197	2702.77	0.00
636.41528	2713.71	0.00
638.24860	2724.92	0.00
640.16669	2735.33	0.00
642.00000	2745.53	0.00
643.83331	2755.21	0.00
645.66669	2764.72	0.00
647.77191	2775.55	0.00
649.60529	2784.36	0.00
651.43860	2792.80	0.00
653.27191	2801.68	0.00
655.10529	2809.57	0.00

656.93860	2818.02	0.00
658.77191	2825.52	0.00
660.60693	2833.25	0.00
662.70551	2841.44	0.00
664.66669	2849.70	0.00
666.56000	2856.95	0.00
668.39331	2863.42	0.00
670.71582	2872.35	0.00
672.54919	2879.09	0.00
674.38251	2885.74	0.00
676.29193	2892.38	0.00
678.12531	2898.55	0.00
680.09558	2920.73	0.00
682.12640	2911.51	0.00
683.95972	2917.68	0.00
685.79303	2923.03	0.00
687.62640	2928.64	0.00
689.50000	2934.64	0.00
691.33331	2940.12	0.00
693.16669	2944.88	0.00
695.34332	2951.84	0.00
697.18085	2956.51	0.00
699.01416	2961.87	0.00
700.84747	2966.61	0.00
702.79279	2972.15	0.00
704.67694	2976.87	0.00
707.08026	2983.38	0.00
709.09637	2988.44	0.00
710.92975	2992.67	0.00
712.83331	2997.34	0.00
714.66669	3001.96	0.00
716.50000	3006.16	0.00
718.33331	3011.12	0.00
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728.64307	3034.10	0.00
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831.53558	3213.45	0.00
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855.40332	3240.35	0.00
861.00000	3245.94	0.00
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885.00000	3269.89	0.00
891.18109	3276.15	0.00
896.68359	3269.58	0.00
902.18359	3275.34	0.00
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1080.50000	3367.53	0.00
1086.00000	3365.65	0.00
1091.50000	3366.67	0.00
1097.50000	3366.14	0.00
1103.00000	3366.70	0.00
1108.50000	3365.93	0.00
1114.00000	3365.61	0.00
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1125.50000	3365.33	0.00
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1170.50000	3365.38	0.00
1176.00000	3365.81	0.00

APPENDIX 11.13

BOREHOLE SEISMIC SYSTEM EVALUATION

Sandia National Laboratories

APPENDIX 11.13

BOREHOLE SEISMIC SYSTEM EVALUATION

H. E. Morris
Sandia National Laboratories

BOREHOLE SEISMIC SYSTEM CALIBRATION

System calibration must be accomplished to facilitate a meaningful analysis of BSS data. A comprehensive component-by-component check is necessary prior to the analysis of each field test data set to insure that each element of the system is functioning as expected. Figure 1 depicts the specific components that are involved in the system check-outs that must be made. This system calibration should be completed prior to fielding the BSS. However, schedules for the coastal stimulation precluded completion of this task prior to fielding. The downhole packages themselves had been satisfactorily calibrated prior to the experiment, and any remaining problems were limited to the surface hardware, somewhere between the analog record of the stimulation and the computer. Gathering the data in analog form enables calibrations of the surface system to be made after the stimulation experiment and prior to data processing.

A plan of investigation and calibration was outlined. First, the digitized data set was evaluated by thoroughly calibrating the system, subsystem by subsystem, including downhole equipment and software to identify problems that would require redigitization. If redigitization was necessary, preparations would be made to redigitize by (1) insuring that accurate analog playback is possible; (2) calibrating the surface equipment in a playback mode; and (3) generating known signals to simulate seismic events and play them through the entire system to verify system performance.

New hardware was developed to provide a fast, accurate means of simulating events and nulling the system. A synthetic event generator

(SEG) was developed to generate three-component sinusoidal signals of specified amplitude, frequency and phase. A null system was developed to look for possible disparities between channels. System evaluation at this stage assumed that the longitudinal and shear waveforms were monofrequency and in the 200 to 500 Hz range.

(1) DC Offset

The first problem identified in the digitized data set was a DC offset. Using the SEG as the input and the existing horizontal and vertical polarization plotting algorithms as a monitor, a simulated event was input at the computer interface. An amplitude offset was being introduced in the sample-and-hold component in one of the MWX-2 signal paths. This faulty component introduced a DC offset of up to 0.2 volts and the offset varied as a function of temperature. This problem alone was enough to require redigitization.

(2) Phase Parity

All subsystems were tested for phase parity. Varying degrees of phase error did exist in several subassemblies and the phase errors of the various entities were additive. Each subassembly was checked separately in order to better understand where corrections could be made. The SEG was used as the input and the null system was used to monitor the output. The phase parity calibration results are summarized in Figure 2. Maximum observed errors are given for each subassembly. Large phase errors can make the polarization direction of the P-wave time series appear random and can also affect the P- and S-wave times of arrival.

(3) Analog Playback

Since the playback capabilities and their potential for error contribution had not been examined, known signals from the SEG were input to the recorder and played back. Both recording and playback were found to be satisfactory for the redigitization task. Gain disparity between channels resulting from record and playback was less than one percent and phase disparity was less than one degree between channels. Background noise increased from approximately 6 millivolts to 17 millivolts, but this level is negligible compared to the approximately 40 millivolt background noise level in the coastal data set.

REDIGITIZATION

Before redigitization, the faulty sample-and-hold was replaced, and a recheck of the system showed no DC offsets. The band edge voltage settings on the discriminators were adjusted so that gain parity could be achieved and maintained at less than one percent. The phase error for the surface system could be maintained at less than two degrees, but to accomplish this, the low pass filter corner (F2) had to be 1000 Hz for the required 200 to 500 Hz bandwidth. Aliasing distortion would occur at this F2 setting with the 2.15 kHz sample frequency possible with the 8 channel software. Since the MWX-3 data was too weak for analysis and the 45° geophone was not being used, 3-channel software was written and tests showed that a digitization rate of 4.76 kHz per channel was possible. This new software allowed the low pass corner of the bandpass filters to be set at 1000 Hz without danger of aliasing. The resultant system phase shift contribution to the polarization plot of an ideal 400 Hz input was shown to be negligible.

The MWX-2 orientation data were redigitized. Because of the increased sampling rate, the first break was more distinct. Figure 3 shows the clarity of the first arrival of the MWX-2 orientation data. The first arrival had been overlooked previously because of the limited number of samples acquired using the 2.15 kHz digitization rate. The second arrival was the waveform that had been used for previous orientation computations. The previously assumed S-wave arrival appeared shortly thereafter. The presence of multiple waveforms explains the complexity of the Figure 3 time series. The difference in the times of arrival between the first and third arrival provided a velocity coefficient of 20 ft/ms. The time between arrivals two and four was approximately equal to the time between arrivals one and three. The direct waveform may have been reflected or refracted from some inhomogeneity near MWX-2 creating second P- and S-waves. The events appeared to have frequency content above the 200 to 500 Hz band to which we thought the data were limited. This higher frequency content was likely a contributor to the increased signal level, and hence the improved first break signal-to-noise ratio.

The pre-test tubing shots from MWX-2 to MWX-3 were redigitized. Figure 4 shows the superimposed horizontal time series for one of the detected events. Notice that the waveforms from the two channels are almost identically in phase for several cycles, the signal-to-noise ratio is good, and the S-wave arrival is very distinct where the two in phase waveforms go out of phase. All of the pre-test data are in a textbook example form. The horizontal polarization direction is very tight and the orthogonal shear break-out is clear from the hodograms. As with the MWX-2 orientation data, there was event-related higher frequency content. Post-flow microseisms were redigitized. They all exhibited the multi-wave characteristics of the MWX-2 orientation data. Horizontal polarizations were tighter, but there was still no distinct inclination.

Two conclusions were drawn from this test series. First, there is a difference in the signal signature between the pre-test waveforms received in MWX-3 and that from both orientation shot and fracture-induced data received in MWX-2. There are apparently four distinctly polarized waveforms present in the MWX-2 data and two in the MWX-3 data. Secondly, all signals appear to contain more than the monofrequency P- and S-wave content that had been assumed. The inclusion of the higher frequency content appears to increase the signal-to-noise ratio, make wave arrivals more distinct, and tighten the polarization ellipsoids.

CALIBRATION FOR 100 TO 1000 HZ BANDPASS

The waveform characterization exercise revealed that it is desirable to include the higher frequency content of the waveforms. However, the entire borehole seismic system had been designed for the much narrower 100 to 500 Hz bandpass. The geophone and tool specifications were not written for the higher frequency bandpass. Responses of the geophones were unknown above the specification frequencies, and the response of the bandpass filters to a multi-frequencied waveform was uncertain. Either a nonlinear geophone response or the inability of the filters to maintain gain and phase parity between channels could introduce considerable error into the data. A complete re-evaluation of the system was required to insure that gain and phase parity could be maintained both between channels and within a channel for the new bandpass.

(1) Parity Between Channels

Quantitative measurements were made at frequencies of 300, 700, and 1200 Hz. The null system was then used to monitor system balance while a sinusoidal signal was input from a frequency sweep generator to the borehole seismic unit/geophone interface. Gain parity between channels could be maintained across the spectrum at less than one percent. Phase parity between channels could be maintained at less than one degree from 300 to approximately 800 Hz. Above or below that bandwidth, however, a gradual increase in phase error is encountered. The largest measured phase error was five degrees at 1200 Hz.

(2) Parity Within a Channel

Gain parity within a channel for varying frequencies was evaluated using the scheme for parity checks between channels by referencing the output to the input. Phase relationships within a channel were evaluated by measuring delay through the system at different frequencies, and impulse response distortion was discovered in the filtering system. This distortion was characterized by greatly attenuated first few cycles when an impulse of sinusoidal signal was applied to the filter. The amount of distortion increased as the applied frequency neared either of the bandpass limits and made accurate time delay measurements impossible. The test setup shown in Figure 5 was used to measure the phase relationships within a channel.

(3) Impulse Distortion

It was important to evaluate the effect of impulse distortion on the coastal data set since the detected events are impulses of sinusoidal-like input to the filters. The 400 Hz sinusoid of known amplitude shown in Figure 6(a) was input to the filters, bandpassing from 100 to 500 Hz. The resultant output of the filters is shown in Figure 6(b). Note the complete loss of the first half cycle and the continued distortion into the next few half cycles.

Next, actual coastal event data were examined for impulse response distortion. Figure 7 illustrates both the need for filtering and the increased distortion as the high pass setting is increased from 0 to 50 Hz. The undesired low frequency noise is evident in Figure 7(a). Note the first cycle on the event in Figure 7(a) and its reduction in amplitude as the high pass filter setting moves to 50 Hz in Figure 7(b). Using a high pass setting of 100 Hz essentially eliminates the first half cycle, and thus the true first arrival.

(4) Geophone Calibration

The calibration data for the three geophones used in the H1 component of the MWX-2 tool during the coastal experiment are shown in Figure 8. All geophones had less than three percent deviation from 100 to 500 Hz, but the deviation increased rapidly above 400 Hz. The data for the geophones used in MWX-2 did not include information beyond 700 Hz. When the data at 700 Hz were correlated, a net deviation of approximately 9 percent in each triaxial channel was calculated.

(5) Bandpass Calibration Conclusions

(1) Gain and phase parity between channels can be maintained at reasonable levels.

(2) The gain variance between frequencies within a channel is undesirable because of the loss of signal strength at the higher frequencies, but is acceptable because gain parity between channels can be maintained.

(3) Phase error between frequencies within a given channel and impulse response distortion are being introduced by the high pass filters.

(4) With the filter mode set to flat delay, a 1000 Hz low pass setting created little phase error and only slight impulse response distortion at 600 Hz, but the amplitude was approximately 60 percent of the amplitude at 400 Hz. With the filter mode set to flat amplitude, no gain error and only slight impulse response distortion was noted, but up to 5° of phase error was observed. It was concluded that 1000 Hz flat delay should be the low pass setting.

(5) The frequency response of the geophones implies that there was not equal amplitude response over the 100 to 1000 Hz range. Thus, a 1000 Hz low pass is probably not acceptable.

CONCLUSIONS

Phase and amplitude parity are critical to use of the polarization method. Techniques were found and new hardware was built to balance the system and minimize these errors. The new 8-channel software developed for the redesigned tools was not able to operate above a 2.15 kHz sample rate. Since it was necessary to set the low pass filter a 1 kHz, this sample rate would have resulted in aliasing. Three-channel data acquisition was prepared and the event detection scheme was streamlined as much as possible to obtain a 4.76 kHz digitization rate.

The in-depth investigations into the system and coastal data set provided a wealth of new information about the system and microseismic data that is relevant to any data set. The newly discovered system and data characteristics are crucial to the future development of any BSS. The major implications of this study on future data sets may be summarized as follows:

(1) The background noise level is significantly increased during periods of flow prohibiting data analysis.

(2) Gain parity between channels can be maintained, but periodic checks are necessary.

(3) Phase parity can also be maintained between channels if the system is balanced periodically. The low pass settings must be balanced so that phase and gain parity between channels are maintained.

(4) The digitization rate is critical to BSS data analysis. Not only can aliasing distortion prevent data analysis, but a slow digitization rate can result in overlooking the true properties of the data set.

(5) All data had frequency content above the 100 to 500 Hz band for which the BSS was designed. Distinct first arrivals were not possible in the MWX-2 data without the higher frequency content. The higher frequency content also reduced variation in the polarization direction.

(6) The response of the geophones used is nonlinear above 400 Hz, distorting the higher frequency content of the data.

(7) Use of filters, particularly in the high pass mode, creates impulse distortion in the waveforms. The first half cycle of the MWX-2 data was virtually eliminated and the second half cycle greatly attenuated as a result of bandpass filtering.

(8) Gain parity between frequencies within a channel cannot be maintained when using bandpass filters. This implies that when balanced, the higher frequency content will be attenuated more than the lower frequency content. The lack of gain parity between frequencies does not, however, affect the polarization direction if the high frequency attenuation is equivalent on all three channels.

(9) Severe phase disparity between frequencies within a channel is introduced by flat amplitude high pass filtering. This phenomenon does distort the polarization ellipsoid.

(10) With the current instrumentation design, high pass filtering is essential. The downhole seismic noise level is intolerable and must be filtered out of the data.

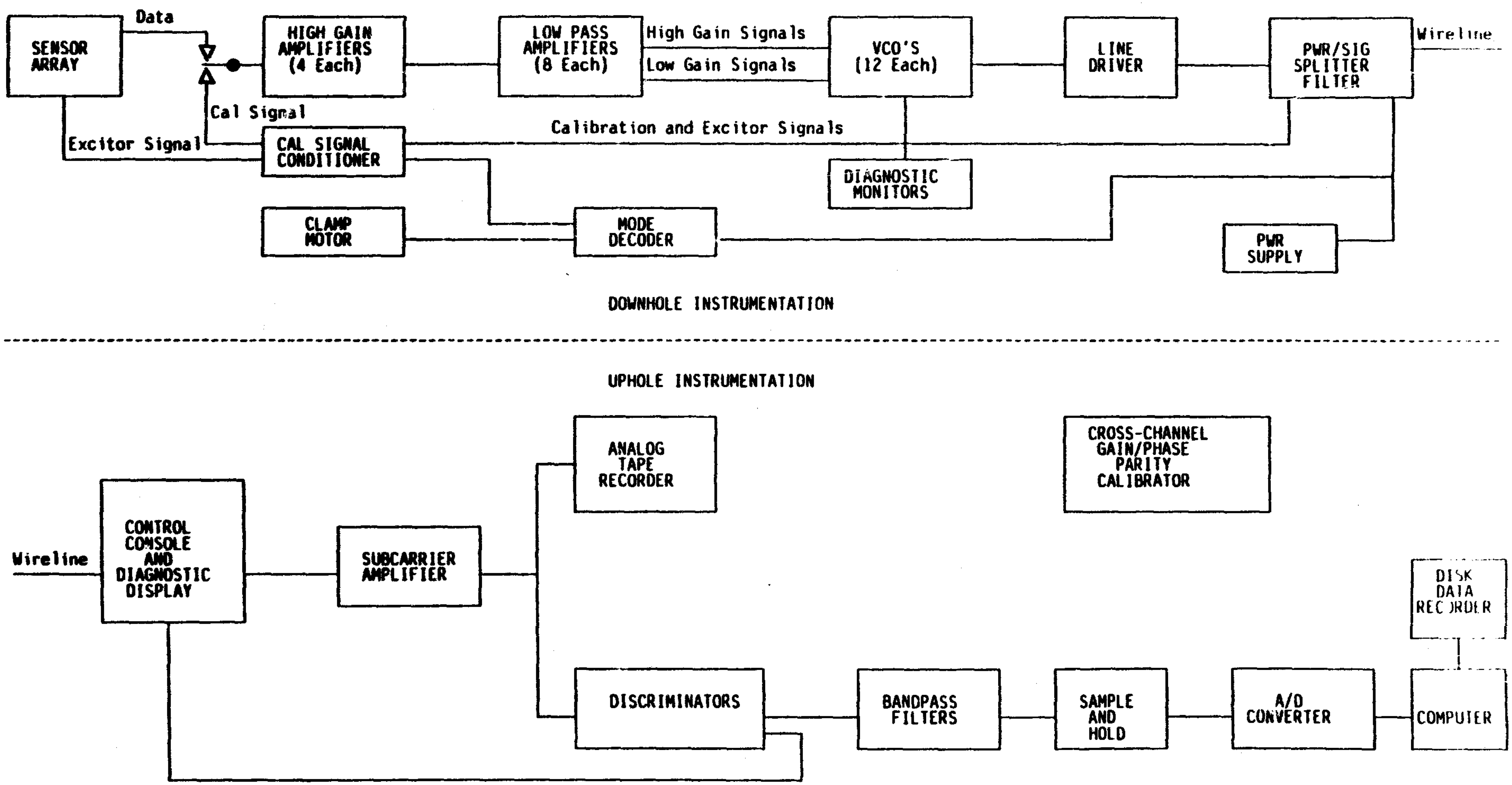


Figure 1. Borehole Seismic System Block Diagram

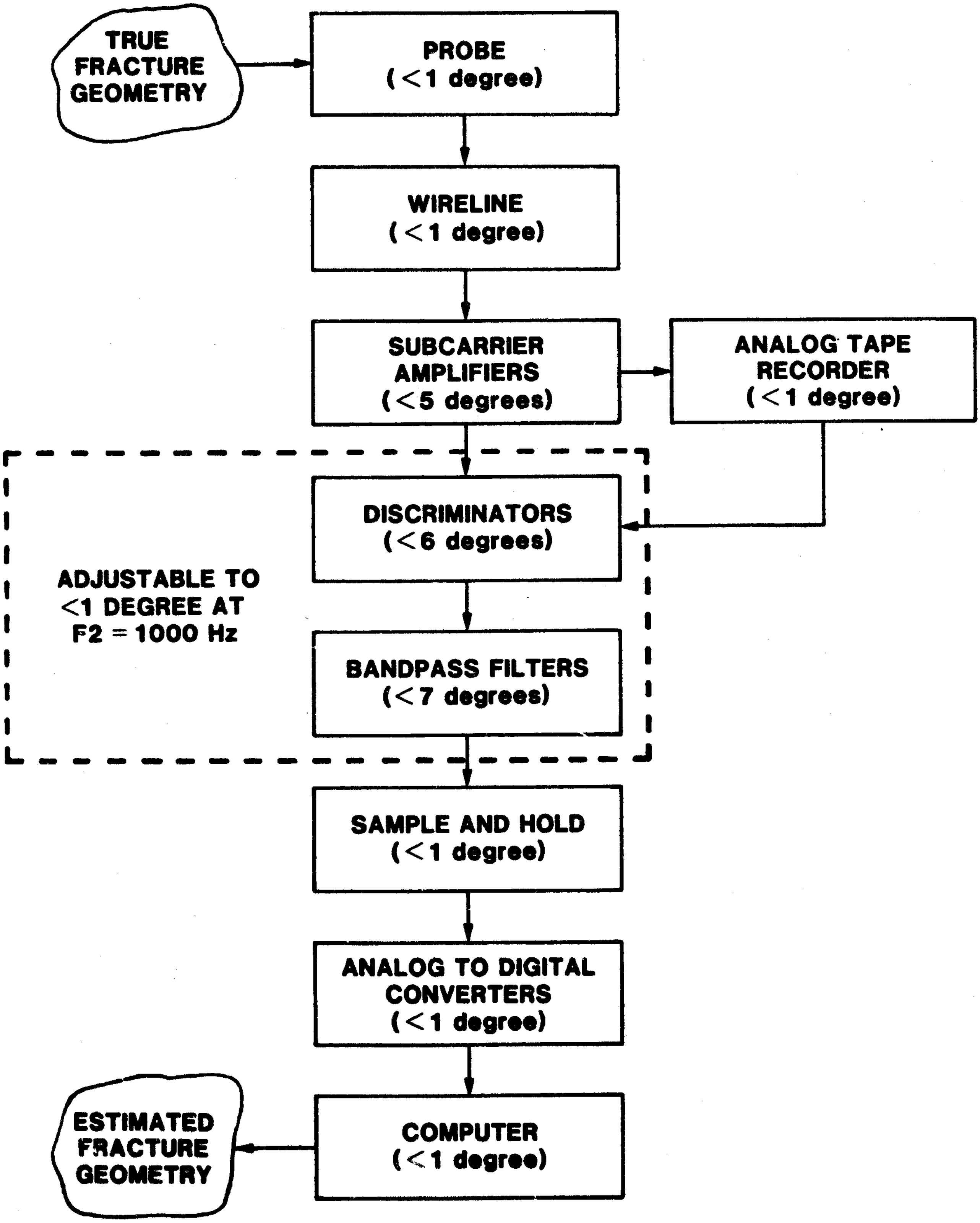


Figure 2. Borehole Seismic System Subassembly Phase Errors

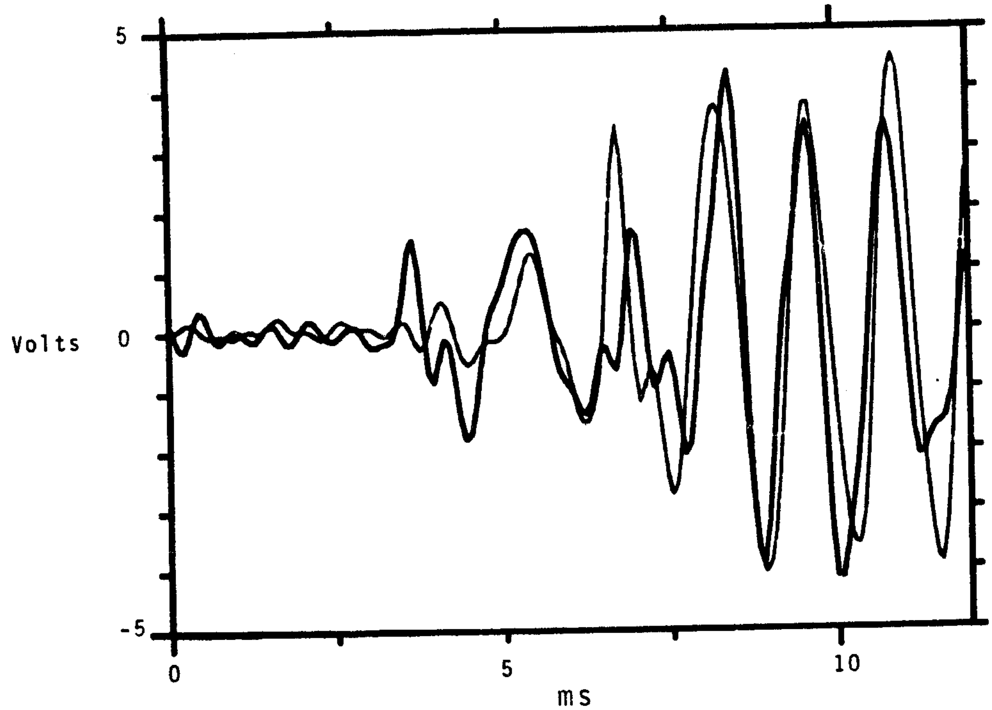


Figure 3. Orientation Shot Superimposed Horizontal Time Series.

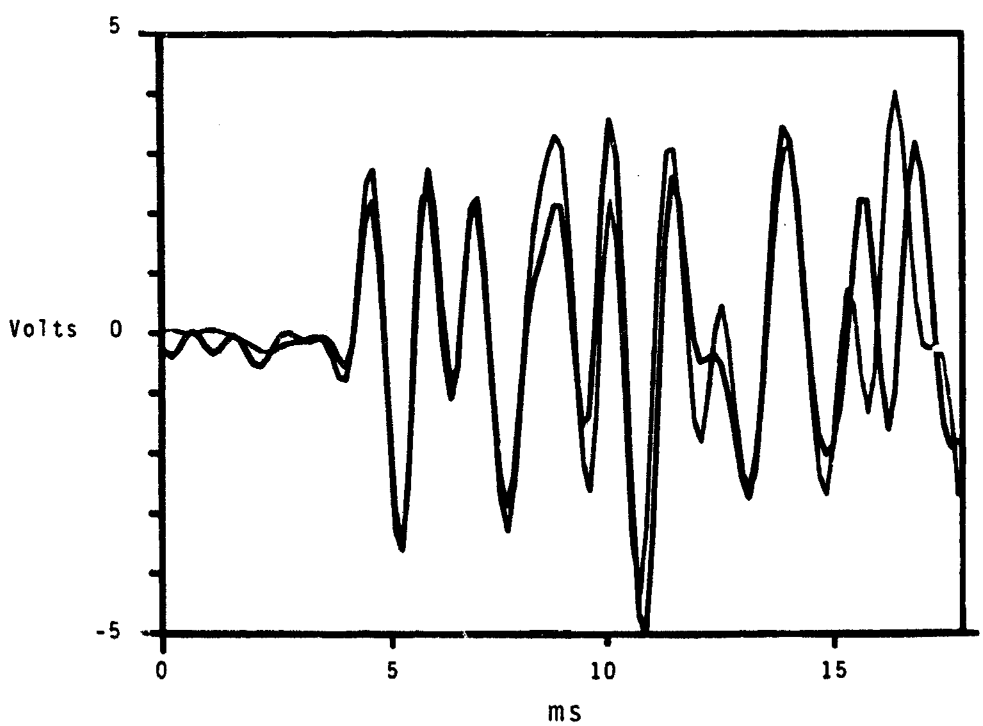


Figure 4. Pre-test Tubing Shot Superimposed Horizontal Time Series.

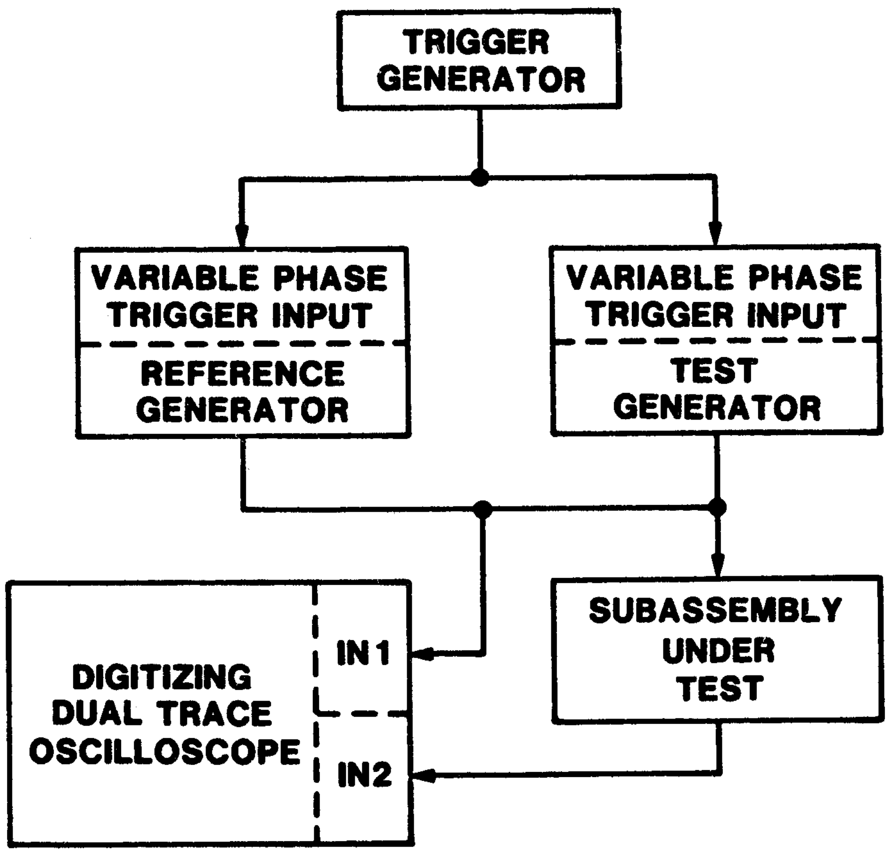


Figure 5. Test Setup to Check Phase Parity Within a Channel

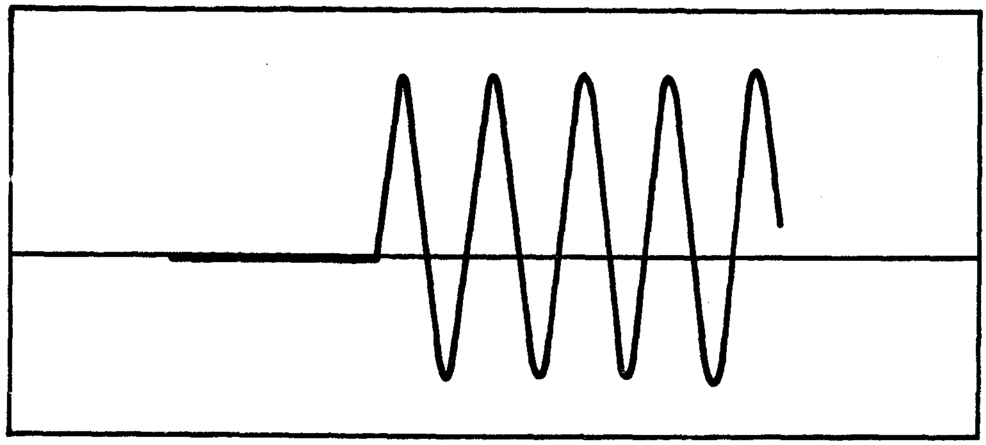


Figure 6(a). Test Signal Filter Input.

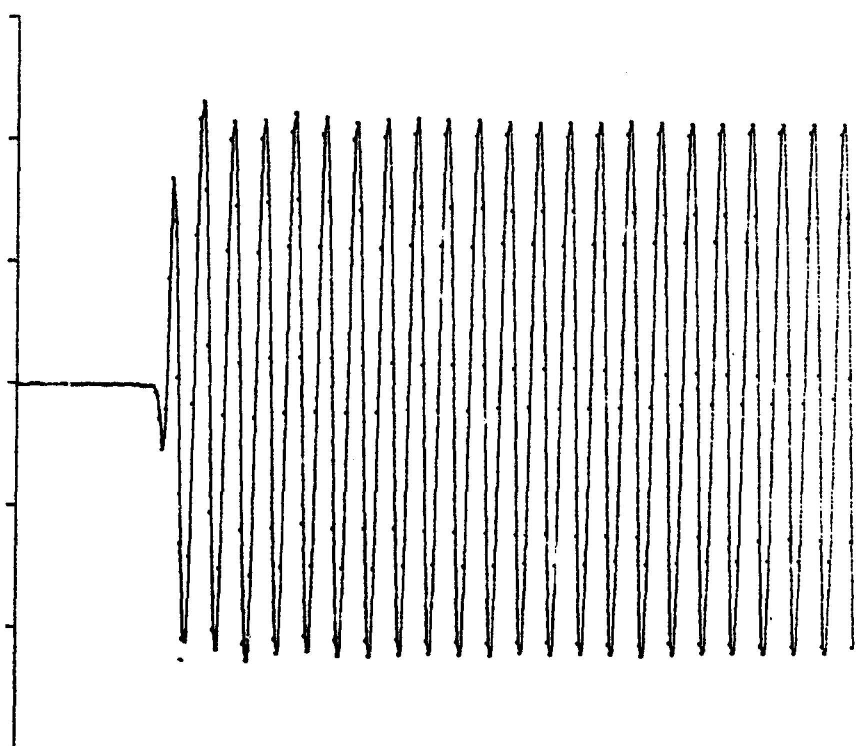


Figure 6(b). Test Signal Filter Output.

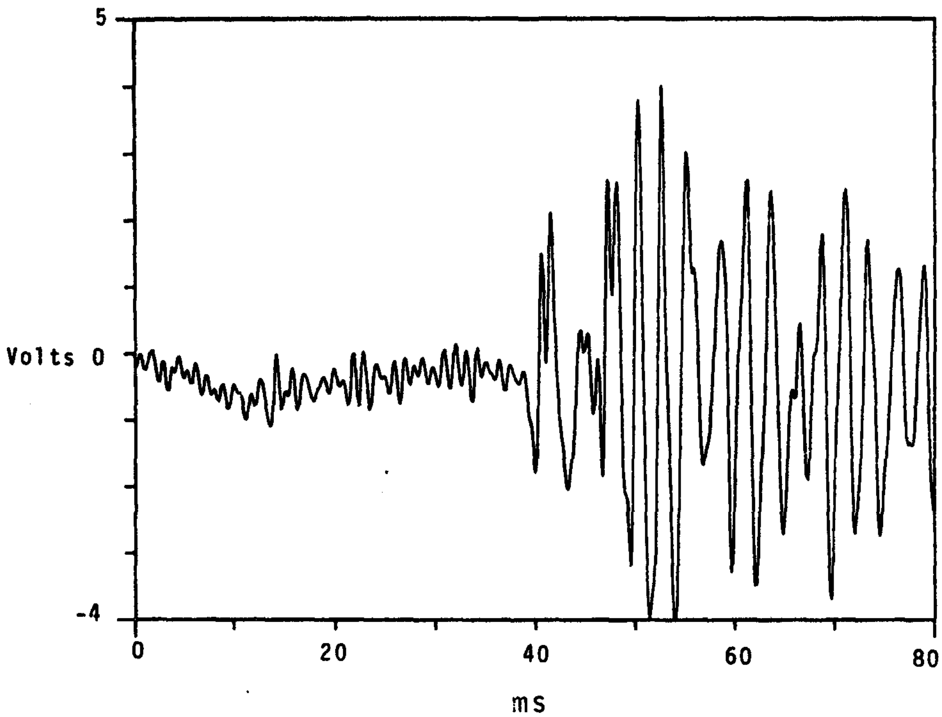


Figure 7(a). Reference Event.

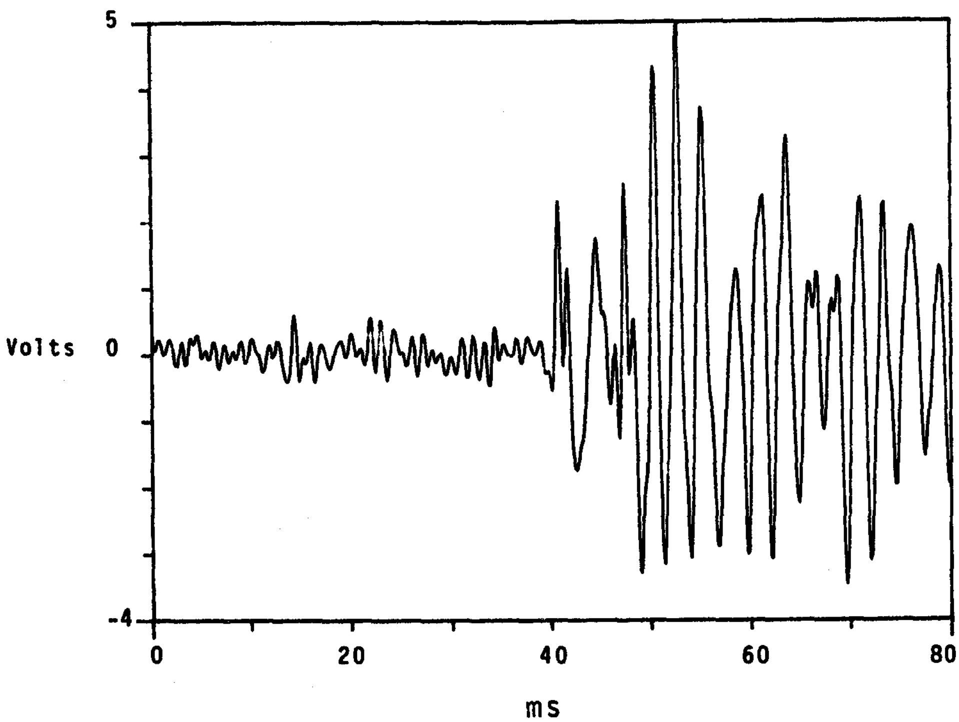
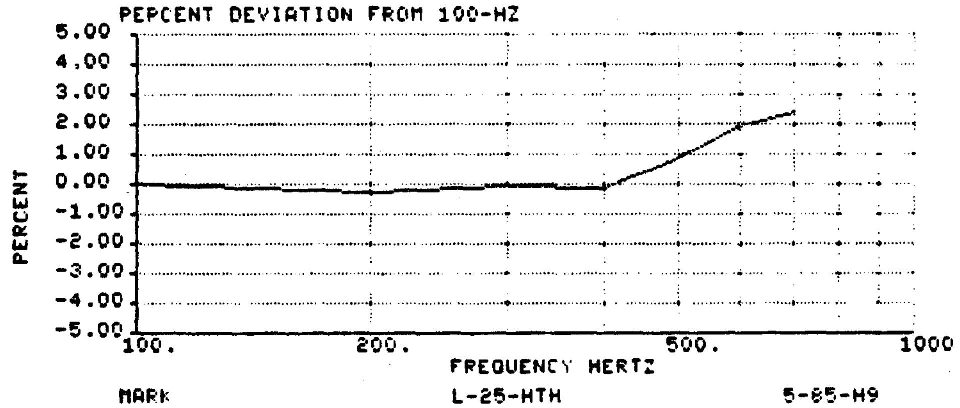
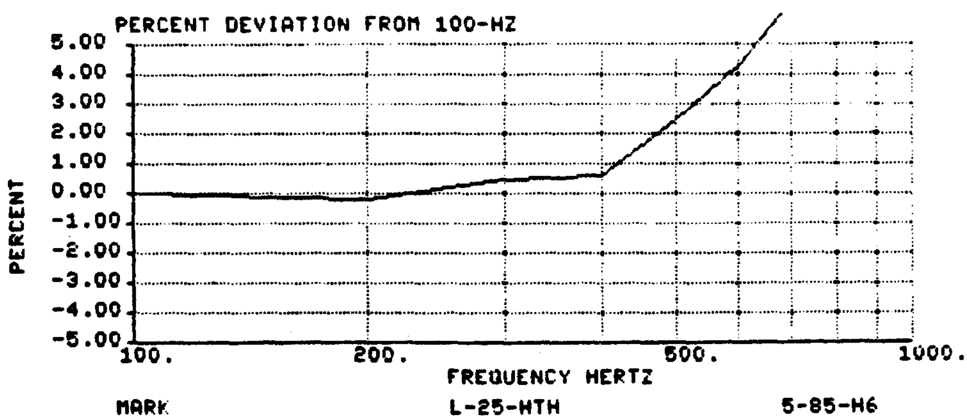


Figure 7(b). Effect of 50 Hz High Pass Filter on Reference Event.





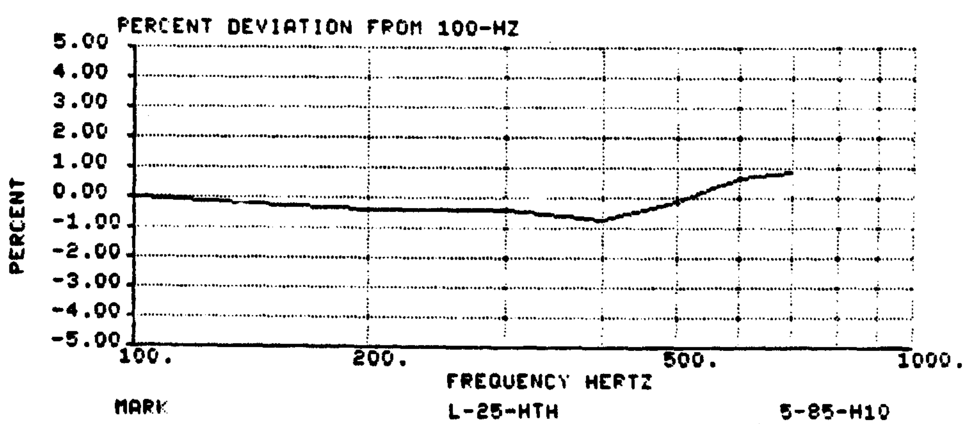


Figure 8. Geophone Calibration Data.

APPENDIX 11.14

COASTAL MWX DATA FILE ENTRIES

Sandia National Laboratories

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ACCES NUM   N00741
REPORT NUM 1.0.4.009
AUTHOR   BRANAGAN,P
TITLE   COMPARISON OF MEASURED RESERVOIR PRESSURES WITH DRILLING MUD
            WEIGHT DATA AT MWX
CORP AUTH   CER
DATE   870110
KEYWORD   MWX WELLS
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE
KEYWORD   RESERVOIR ANALYSIS
KEYWORD   PRESSURE
KEYWORD   RESERVOIR PRESSURE
KEYWORD   MUD REPORT
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ACCES NUM   N00550
REPORT NUM 1.1.15.008
TITLE   CONTINUOUS FLOW SURVEY
CORP AUTH   GH
DATE   850606
KEYWORD   MWX1
KEYWORD   LOGS
KEYWORD   COASTAL
KEYWORD   WELL TESTING
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ACCES NUM   N00549
REPORT NUM 1.1.15.009
TITLE   FLUID DENSITY LOG
CORP AUTH   GH
DATE   850606
KEYWORD   MWX1
KEYWORD   LOGS
KEYWORD   COASTAL
KEYWORD   WELL TESTING
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ACCES NUM   N00548
REPORT NUM 1.1.15.010
TITLE   COMPOSITE PRODUCTION LOG
CORP AUTH   GH
DATE   850606
KEYWORD   MWX1
KEYWORD   LOGS
KEYWORD   COASTAL
KEYWORD   WELL TESTING
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ACCES NUM   N00610
REPORT NUM 1.1.15.013
TITLE   MWX-1 DIFFERENTIAL TEMPERATURE SURVEY
CORP AUTH   GH
DATE   850607
KEYWORD   MWX1
KEYWORD   LOGS
KEYWORD   COASTAL
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ACCES NUM   N00450
REPORT NUM 1.1.36.003
AUTHOR   BLACKWELL,DD
TITLE   TEMPERATURE DEPTH LOGS
CORP AUTH   SMU
DATE   831109
KEYWORD   MWX3
KEYWORD   TEMPERATURE LOG
KEYWORD   COASTAL

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ACCES NUM N00497
REPORT NUM 1.1.4.009
AUTHOR KUKAL,GC
AUTHOR SIMONS,KE
TITLE MWX COASTAL INTERVAL LOG ANALYSIS INTERIM REPORT, RED AND YELLOW SANDS
CORP AUTH CER
DATE 850122
KEYWORD LOG ANALYSIS
KEYWORD COASTAL
KEYWORD TITEGAS
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ACCES NUM N00573
REPORT NUM 1.1.4.010
AUTHOR KUKAL,GC
TITLE IMPROVE APPLICATION OF CONVENTIONAL LOGS TO TIGHT SANDS
CORP AUTH CER
DATE 840626
KEYWORD LOGGING
KEYWORD TIGHT GAS SANDS
KEYWORD LOG ANALYSIS
KEYWORD CORCORAN
KEYWORD COZZETTE
KEYWORD MARINE
KEYWORD PALUDAL
KEYWORD COASTAL
KEYWORD FLUVIAL
KEYWORD MWX WELLS
KEYWORD LOG INTERPRETATION
NOTES PRESENTED AT UNCONVENTIONAL GAS RECOVERY, MWX, PEER REVIEW SESSION
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ACCES NUM N00574
REPORT NUM 1.1.4.011
AUTHOR KUKAL,GC
AUTHOR SIMONS,KE
TITLE LOG ANALYSIS TECHNIQUES FOR QUANTIFYING THE PERMEABILITY OF SUB-MILLIDARCY SANDSTONE RESERVOIRS
CORP AUTH CER
DATE 850500
ALT NUMBER SPEDOE13880
KEYWORD LOG ANALYSIS
KEYWORD PERMEABILITY
KEYWORD MESAVERDE
KEYWORD MARINE
KEYWORD PALUDAL
KEYWORD COASTAL
KEYWORD FLUVIAL
KEYWORD FORMAL
NOTES PRESENTED AT THE SPE/DOE 1985 LOW PERMEABILITY GAS RESERVOIR SYMPOSIUM DENVER, COLORADO, MAY 19-22 1985.
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ACCES NUM N00575
REPORT NUM 1.1.4.012
AUTHOR KUKAL,GC
TITLE A SYSTEMATIC APPROACH FOR THE EFFECTIVE LOG ANALYSIS OF TIGHT GAS SANDS
CORP AUTH CER
DATE 840500
ALT NUMBER SPEDOE12851
KEYWORD FORMAL
KEYWORD TITEGAS
KEYWORD LOG ANALYSIS
KEYWORD LOG INTERPRETATION
KEYWORD CORCORAN

KEYWORD   COZZETTE
KEYWORD   MARINE
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KEYWORD   COASTAL
NOTES   PRESENTED AT SPE/DOE/GRI UNCONVENTIONAL GAS RECOVERY SYMPOSIUM, MAY 13-15, 1984, PITTSBURGH PA
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ACCES NUM N00578
REPORT NUM 1.1.4.015
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CORP AUTH CER
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KEYWORD   LOG ANALYSIS
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KEYWORD   MARINE
KEYWORD   COZZETTE
KEYWORD   CORCORAN
NOTES   PRESENTED AT 3RD ANNUAL WGSP REVIEW, MORGANTOWN,WV NOV. 7-8,1984
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ACCES NUM N00621
REPORT NUM 1.1.4.018
AUTHOR   KUKAL,GC
AUTHOR   SIMONS,KE
TITLE   MULTI-WELL EXPERIMENT, WELL LOG ANALYSIS OF COASTAL INTERVAL, MWX-1, MWX-2, AND MWX-3
CORP AUTH CER
DATE   860214
KEYWORD   LOG ANALYSIS
KEYWORD   COASTAL
KEYWORD   MWX WELLS
KEYWORD   NATURAL FRACTURES
KEYWORD   TITEGAS
KEYWORD   CLAYPLOT
KEYWORD   FINAL REPORT
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REPORT NUM 1.2.11.001
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KEYWORD   KLINKENBERG PERMEABILITY
KEYWORD   CEC ANALYSIS
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DATE   820914

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REPORT NUM 1.2.11.013
TITLE SPECIAL CORE ANALYSIS STUDY , MWX1 AND MWX2
CORP AUTH CL
DATE 830128
ALT NUMBER 203-820088
KEYWORD MWX2
KEYWORD MWX1
KEYWORD CORE ANALYSIS
KEYWORD CEC ANALYSIS
KEYWORD GRAIN DENSITY
KEYWORD POROSITY
KEYWORD SHALE
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD MARINE
KEYWORD COZZETTE
****
ACCES NUM N00015
REPORT NUM 1.2.11.014
TITLE SPECIAL CORE ANALYSIS STUDY, MWX1 AND MWX2
CORP AUTH CL
DATE 830209
ALT NUMBER SCAL 203-820075
KEYWORD MWX1
KEYWORD MWX2
KEYWORD CORE ANALYSIS
KEYWORD CAPILLARY PRESSURE
KEYWORD COASTAL
KEYWORD KLINKENBERG PERMEABILITY
KEYWORD MARINE
KEYWORD COZZETTE
KEYWORD RESISTIVITY MEASUREMENTS
KEYWORD CEC ANALYSIS
KEYWORD POROSITY
KEYWORD CORCORAN
****
ACCES NUM N00018
REPORT NUM 1.2.11.017
TITLE SPECIAL CORE ANALYSIS STUDY, MWX1 AND MWX2
CORP AUTH CL
DATE 830624
ALT NUMBER SCAL 203-830019
KEYWORD MWX1
KEYWORD MWX2
KEYWORD CORE ANALYSIS
KEYWORD POROSITY
KEYWORD CEC ANALYSIS
KEYWORD KLINKENBERG PERMEABILITY
KEYWORD PARALIC
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD MARINE
****

ACCES NUM N00019
REPORT NUM 1.2.11.018
TITLE CORE ANALYSIS REPORT, MWX3
CORP AUTH CL
DATE 830718
ALT NUMBER 3806-7199
KEYWORD MWX3
KEYWORD CORE ANALYSIS
KEYWORD BOYLES' LAW POROSITY
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL

****

ACCES NUM N00021
REPORT NUM 1.2.11.020
TITLE SPECIAL CORE ANALYSIS STUDY, MWX1 AND MWX3
CORP AUTH CL
DATE 831116
ALT NUMBER SCAL 203-830070
KEYWORD MWX1
KEYWORD MWX3
KEYWORD CORE ANALYSIS
KEYWORD KLINKENBERG PERMEABILITY
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL

****

ACCES NUM N00022
REPORT NUM 1.2.11.021
TITLE SPECIAL CORE ANALYSIS STUDY, MWX1 AND MWX2
CORP AUTH CL
DATE 840315
ALT NUMBER SCAL 203-830024
KEYWORD MWX1
KEYWORD MWX2
KEYWORD CORE ANALYSIS
KEYWORD POROSITY
KEYWORD PERMEABILITY
KEYWORD KLINKENBERG PERMEABILITY
KEYWORD CAPILLARY PRESSURE
KEYWORD RELATIVE PERMEABILITY
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE
KEYWORD COZZETTE

****

ACCES NUM N00023
REPORT NUM 1.2.11.022
TITLE SPECIAL CORE ANALYSIS STUDY, MWX2 AND MWX3
CORP AUTH CL
DATE 840327
ALT NUMBER SCAL 203-830055
KEYWORD MWX2
KEYWORD MWX3
KEYWORD CORE ANALYSIS
KEYWORD CEC ANALYSIS
KEYWORD CAPROCK ANALYSIS
KEYWORD KLINKENBERG PERMEABILITY
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE
KEYWORD ROLLINS

****

ACCES NUM N00399

REPORT NUM 1.2.11.023
TITLE SPECIAL CORE ANALYSIS
CORP AUTH CL
DATE 840508
ALT NUMBER SCAL 203-840016
KEYWORD MWX1
KEYWORD MWX2
KEYWORD CEC ANALYSIS
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE
****
ACCES NUM N00408
REPORT NUM 1.2.11.025
TITLE SPECIAL CORE ANALYSIS STUDY
CORP AUTH CL
DATE 840820
ALT NUMBER SCAL 203-840026
KEYWORD KLINKENBERG PERMEABILITY
KEYWORD FORMATION RESISTIVITY
KEYWORD RESISTIVITY INDEX
KEYWORD MWX WELLS
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
****
ACCES NUM N00409
REPORT NUM 1.2.11.026
TITLE SPECIAL CORE ANALYSIS STUDY
CORP AUTH CL
DATE 841114
ALT NUMBER 203-840077
KEYWORD MWX1
KEYWORD KLINKENBERG PERMEABILITY
KEYWORD OVERBURDEN
KEYWORD FLUVIAL
KEYWORD COASTAL
****
ACCES NUM N00598
REPORT NUM 1.2.11.027
TITLE FILTRATE INVASION ANALYSIS, MWX3
CORP AUTH CL
DATE 840126
ALT NUMBER P83012
KEYWORD MWX3
KEYWORD CORE ANALYSIS
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE
****
ACCES NUM N00612
REPORT NUM 1.2.11.029
TITLE SPECIAL CORE ANALYSIS STUDY, MWX1 AND MWX2
CORP AUTH CL
DATE 851218
ALT NUMBER SCAL 203-850062
KEYWORD NATURAL FRACTURES
KEYWORD MWX1
KEYWORD MWX2
KEYWORD PERMEABILITY
KEYWORD POROSITY
KEYWORD COASTAL
KEYWORD FLUVIAL
KEYWORD KLINKENBERG PERMEABILITY

NOTES REPORT ON FRACTURE PERMEABILITY
****
ACCES NUM N00659
REPORT NUM 1.2.11.030
TITLE SPECIAL CORE ANALYSIS STUDY, MWX-1 AND MWX-2
CORP AUTH CL
DATE 860501
KEYWORD MWX1
KEYWORD MWX2
KEYWORD FLUVIAL
KEYWORD PARALIC
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE
KEYWORD COZZETTE
KEYWORD CORCORAN
KEYWORD POROSITY
KEYWORD WATER SATURATION
KEYWORD KLINKENBERG PERMEABILITY
KEYWORD CORRELATION
****
ACCES NUM N00755
REPORT NUM 1.2.11.033
TITLE SPECIAL CORE ANALYSIS
CORP AUTH CL
DATE 870424
ALT NUMBER SCAL203-87005
KEYWORD MWX WELLS
KEYWORD KLINKENBERG PERMEABILITY
KEYWORD PERMEABILITY
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD NATURAL FRACTURES
****
ACCES NUM N00803
REPORT NUM 1.2.11.034
TITLE SPECIAL CORE ANALYSIS
CORP AUTH CL
DATE 871112
ALT NUMBER SCAL 203-87050
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD CORE ANALYSIS
KEYWORD CLAYS
KEYWORD RESISTIVITY MEASUREMENTS
KEYWORD CEC ANALYSIS
****
ACCES NUM N00850
REPORT NUM 1.2.11.036
TITLE SPECIAL CORE ANALYSIS STUDY
CORP AUTH CL
DATE 880908
ALT NUMBER SCAL 203-88026
KEYWORD NATURAL FRACTURES
KEYWORD MWX1
KEYWORD COASTAL
KEYWORD KLINKENBERG PERMEABILITY
KEYWORD FRACTURE FILLING
NOTES PERMEABILITY OF DICKITE MINERALIZED FRACTURES MEASURED
****
ACCES NUM N00024
REPORT NUM 1.2.12.001
TITLE CAPROCK TEST MEASUREMENTS
CORP AUTH IGT

DATE   820621
KEYWORD   CAPROCK ANALYSIS
KEYWORD   MWX1
KEYWORD   MWX2
KEYWORD   CORE ANALYSIS
KEYWORD   FLUVIAL
KEYWORD   MARINE
KEYWORD   CORCORAN
KEYWORD   COZZETTE
KEYWORD   COASTAL
KEYWORD   PALUDAL

****

ACCES NUM   N00025
REPORT NUM 1.2.12.002
TITLE   SANDSTONE POROSITY AND PERMEABILITY MEASUREMENTS
CORP AUTH   IGT
DATE   820722
KEYWORD   SANDSTONES
KEYWORD   POROSITY
KEYWORD   PERMEABILITY
KEYWORD   KLINKENBERG PERMEABILITY
KEYWORD   MWX1
KEYWORD   MWX2
KEYWORD   DRY CORE ANALYSIS
KEYWORD   GAS PRESSURE
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE
KEYWORD   COZZETTE
KEYWORD   CORCORAN

****

ACCES NUM   N00026
REPORT NUM 1.2.12.003
TITLE   SANDSTONE POROSITY AND PERMEABILITY MEASUREMENTS
CORP AUTH   IGT
DATE   820825
KEYWORD   SANDSTONES
KEYWORD   MWX1
KEYWORD   MWX2
KEYWORD   POROSITY
KEYWORD   PERMEABILITY
KEYWORD   DRY CORE ANALYSIS
KEYWORD   KLINKENBERG PERMEABILITY
KEYWORD   GAS PRESSURE
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE
KEYWORD   COZZETTE
KEYWORD   CORCORAN

****

ACCES NUM   N00027
REPORT NUM 1.2.12.004
TITLE   CAPROCK TEST MEASUREMENTS
CORP AUTH   IGT
DATE   820902
KEYWORD   CAPROCK ANALYSIS
KEYWORD   MWX1
KEYWORD   MWX2
KEYWORD   POROSITY
KEYWORD   PERMEABILITY
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE

KEYWORD   COZZETTE
KEYWORD   CORCORAN
****
ACCES NUM   N00028
REPORT NUM 1.2.12.005
TITLE   SANDSTONE POROSITY AND PERMEABILITY MEASUREMENTS
CORP AUTH   IGT
DATE   821013
KEYWORD   SANDSTONES
KEYWORD   MWX1
KEYWORD   MWX2
KEYWORD   POROSITY
KEYWORD   PERMEABILITY
KEYWORD   DRY CORE ANALYSIS
KEYWORD   KLINKENBERG PERMEABILITY
KEYWORD   GAS PRESSURE
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE
KEYWORD   COZZETTE
KEYWORD   CORCORAN
****
ACCES NUM   N00029
REPORT NUM 1.2.12.006
TITLE   SANDSTONE POROSITY AND PERMEABILITY MEASUREMENTS
CORP AUTH   IGT
DATE   821013
KEYWORD   SANDSTONES
KEYWORD   POROSITY
KEYWORD   PERMEABILITY
KEYWORD   KLINKENBERG PERMEABILITY
KEYWORD   MWX1
KEYWORD   MWX2
KEYWORD   DRY CORE ANALYSIS
KEYWORD   GAS PRESSURE
KEYWORD   COASTAL
KEYWORD   MARINE
KEYWORD   COZZETTE
****
ACCES NUM   N00031
REPORT NUM 1.2.12.008
TITLE   ROCK MATRIX ANALYSIS OF EASTERN GAS SHALE AND WESTERN TIGHT GAS
            SANDS
CORP AUTH   IGT
DATE   840100
ALT NUMBER DOEMC204321
KEYWORD   CORE ANALYSIS
KEYWORD   GAS SHALE
KEYWORD   PERMEABILITY
KEYWORD   TIGHT GAS SANDS
KEYWORD   CAPROCK ANALYSIS
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
NOTES   QUARTERLY REPORT
****
ACCES NUM   N00032
REPORT NUM 1.2.12.009
TITLE   ROCK MATRIX ANALYSIS OF EASTERN GAS SHALE AND WESTERN TIGHT GAS
            SANDS
CORP AUTH   IGT
DATE   840400
ALT NUMBER DOEMC204323
KEYWORD   CORE ANALYSIS
KEYWORD   PERMEABILITY

KEYWORD   CAPROCK ANALYSIS
KEYWORD   GAS SHALE
KEYWORD   TIGHT GAS SANDS
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE
KEYWORD   COZZETTE
KEYWORD   CORCORAN
NOTES   QUARTERLY REPORT
****
ACCES NUM N00033
REPORT NUM 1.2.12.010
AUTHOR   SOEDER,DJ
TITLE   ANALYSIS OF STRATIGRAPHIC BARRIERS (CAPROCK) BETWEEN SANDS IN
           THE CRETACEOUS MESAVERDE FORMATION, U.S. DOE MULTIWELL
           EXPERIMENT, GARFIELD COUNTY, COLORADO
CORP AUTH IGT
DATE   840600
ALT NUMBER DOEMC203422
KEYWORD   MWX WELLS
KEYWORD   MESAVERDE
KEYWORD   CAPROCK ANALYSIS
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE
KEYWORD   COZZETTE
KEYWORD   CORCORAN
****
ACCES NUM N00411
REPORT NUM 1.2.12.011
TITLE   SPECIAL DRY CORE ANALYSIS OF THE MESAVERDE FORMATION
CORP AUTH IGT
DATE   840600
ALT NUMBER DOEMC20342-6
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE
KEYWORD   CORAL
KEYWORD   KLINKENBERG PERMEABILITY
KEYWORD   POROSITY
****
ACCES NUM N00410
REPORT NUM 1.2.12.013
TITLE   DIRECTIONAL CORE ANALYSIS OF THE MESAVERDE FORMATION
CORP AUTH IGT
DATE   840900
ALT NUMBER DOEMC20342-4
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   DIRECTIONAL DEPENDENCE
KEYWORD   RESERVOIR PROPERTIES
KEYWORD   MWX3
****
ACCES NUM N00443
REPORT NUM 1.2.12.018
AUTHOR   SOEDER,DJ
TITLE   MEASUREMENT AND ANALYSIS OF TWO PHASE FLOW THROUGH LOW
           PERMEABILITY MEDIA
CORP AUTH IGT
DATE   840800
KEYWORD   MWX WELLS
KEYWORD   GRI REPORT

KEYWORD   QUARTERLY
KEYWORD   CAPILLARY PRESSURE
KEYWORD   PORE SIZE DISTRIBUTIONS
KEYWORD   RELATIVE PERMEABILITY
KEYWORD   RESERVOIR PARAMETERS
KEYWORD   BLANKET SANDSTONES
KEYWORD   MARINE
KEYWORD   COZZETTE
KEYWORD   COASTAL
KEYWORD   FLUVIAL
KEYWORD   PALUDAL
****
ACCES NUM   N00496
REPORT NUM 1.2.12.019
AUTHOR   RANDOLPH,PL
AUTHOR   SOEDER,DJ
AUTHOR   CHOWDIAH,P
TITLE   EFFECTS OF WATER AND STRESS UPON PERMEABILITY TO GAS OF PALUDAL
            AND COASTAL SANDS, U.S. DOE MULTIWELL EXPERIMENT
CORP AUTH   IGT
DATE   850200
ALT NUMBER DOE/MC/20342-1838
KEYWORD   PERMEABILITY
KEYWORD   FORMAL
KEYWORD   CORAL
KEYWORD   PALUDAL
KEYWORD   COASTAL
KEYWORD   WATER SATURATION
KEYWORD   STRESS NET
KEYWORD   KLINKENBERG PERMEABILITY
****
ACCES NUM   N00300
REPORT NUM 1.2.12.020
AUTHOR   RANDOLPH,PL
TITLE   POROSITY AND PERMEABILITY OF MESAVERDE SANDSTONE CORE FROM THE
            U.S. DOE MULTIWELL EXPERIMENT, GARFIELD COUNTRY, COLORADO
CORP AUTH   IGT
DATE   830300
ALT NUMBER SPEDOE11765
KEYWORD   POROSITY
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE
KEYWORD   RESERVOIR PROPERTIES
KEYWORD   FORMAL
KEYWORD   PERMEABILITY
KEYWORD   KLINKENBERG PERMEABILITY
KEYWORD   CORE ANALYSIS
NOTES   THIS PAPER WAS PRESENTED AT THE 1983 SPE/DOE SYMPOSIUM ON LOW
            PERMEABILITY HELD IN DENVER, COLORADO, MARCH 14-16, 1983
****
ACCES NUM   N00326
REPORT NUM 1.2.12.021
AUTHOR   RANDOLPH,PL
AUTHOR   SOEDER,DJ
AUTHOR   CHOWDIAH,P
TITLE   POROSITY AND PERMEABILITY OF TIGHT SANDS
CORP AUTH   IGT
DATE   840513
ALT NUMBER SPEDOEGRI12836
KEYWORD   POROSITY
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE

KEYWORD   KLINKENBERG PERMEABILITY
KEYWORD   TIGHT GAS SANDS
KEYWORD   CORE ANALYSIS
KEYWORD   FORMAL
NOTES   PRESENTED AT THE 1984 SPE/DOE/GRI UNCONVENTIONAL GAS RECOVERY
            SYMPOSIUM, PITTSBURGH, PENNSYLVANIA, MAY 13-15, 1984
****
ACCES NUM   N00329
REPORT NUM 1.2.12.022
AUTHOR   SOEDER,DJ
AUTHOR   RANDOLPH,PL
TITLE   POROSITY, PERMEABILITY AND PORE STRUCTURE OF THE TIGHT MESA
            VERDE SANDSTONE, PICEANCE BASIN, COLORADO
CORP AUTH   IGT
DATE   840916
ALT NUMBER SPE13134
KEYWORD   FORMAL
KEYWORD   TIGHT GAS SANDS
KEYWORD   POROSITY
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE
KEYWORD   PERMEABILITY
KEYWORD   RESERVOIR PROPERTIES
KEYWORD   MESAVERDE
KEYWORD   CORE ANALYSIS
KEYWORD   PETROGRAPHIC ANALYSIS
NOTES   PRESENTED AT THE 59TH ANNUAL TECHNICAL CONFERENCE AND EXHIBITION
            HELD IN HOUSTON, TEXAS, SEPTEMBER 16-19, 1984
****
ACCES NUM   N00708
REPORT NUM 1.2.12.023
AUTHOR   RANDOLPH,PL
AUTHOR   SOEDER,DJ
TITLE   ROCK MATRIX ANALYSIS OF EASTERN GAS SHALE AND WESTERN TIGHT GAS
            SANDS, FINAL REPORT OCT./1983-DEC./1984
CORP AUTH   IGT
DATE   860800
ALT NUMBER DOE/MC 20342-2135
KEYWORD   POROSITY
KEYWORD   WATER SATURATION
KEYWORD   GAS PERMEABILITY
KEYWORD   CAPILLARY PRESSURE
KEYWORD   NET STRESS
KEYWORD   PORE PRESSURE
KEYWORD   CAPROCK ANALYSIS
KEYWORD   MWX WELLS
KEYWORD   CORE ANALYSIS
KEYWORD   CORAL
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE
NOTES   PRELIMINARY DRAFT 20342-9 IN FILE ALSO
****
ACCES NUM   N00037
REPORT NUM 1.2.21.002
AUTHOR   SMITH,MB
TITLE   STRESS-STRAIN CURVES
CORP AUTH   AMOCO
DATE   830610
KEYWORD   MWX1
KEYWORD   CORE ANALYSIS
KEYWORD   STRESS-STRAIN ANALYSIS
KEYWORD   ROCK PROPERTY DATA

KEYWORD   YOUNG'S MODULUS
KEYWORD   POISSON'S RATIO
KEYWORD   COASTAL
****
ACCES NUM   N00038
REPORT NUM 1.2.22.001
TITLE   MULTIWELL EXPERIMENT: DIFFERENTIAL STRAIN CURVE ANALYSIS ON MWX-1
            CORES
CORP AUTH   DOWELL
DATE   820800
KEYWORD   MWX1
KEYWORD   CORE ANALYSIS
KEYWORD   STRESS-STRAIN ANALYSIS
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   MARINE
KEYWORD   COZZETTE
****
ACCES NUM   N00039
REPORT NUM 1.2.23.001
AUTHOR   ANDERSON,GD
TITLE   MECHANICAL PROPERTIES IN COASTAL SAMPLE
CORP AUTH   LLNL
DATE   821025
KEYWORD   MWX1
KEYWORD   CORE ANALYSIS
KEYWORD   COASTAL
KEYWORD   STRESS-STRAIN ANALYSIS
KEYWORD   MECHANICAL PROPERTIES
****
ACCES NUM   N00040
REPORT NUM 1.2.23.002
AUTHOR   LIN,W
TITLE   MECHANICAL PROPERTIES OF MULTIWELL SILTSTONE AT 1994-M DEPTH
CORP AUTH   LLNL
DATE   821100
KEYWORD   MWX1
KEYWORD   CORE ANALYSIS
KEYWORD   MECHANICAL PROPERTIES
KEYWORD   SILTSTONE
KEYWORD   COASTAL
****
ACCES NUM   N00042
REPORT NUM 1.2.23.004
AUTHOR   LIN,W
TITLE   MECHANICAL PROPERTIES OF MULTIWELL MWX-1 SANDSTONE AND SILTSTONE
            AT HIGH PRESSURES
CORP AUTH   LLNL
DATE   840400
KEYWORD   MECHANICAL PROPERTIES
KEYWORD   SANDSTONES
KEYWORD   SILTSTONE
KEYWORD   MWX1
KEYWORD   PRESSURE
KEYWORD   COASTAL
KEYWORD   PALUDAL
****
ACCES NUM   N00043
REPORT NUM 1.2.24.001
TITLE   VERIFICATION TEST OF PROBABLE FRACTURE ORIENTATION VIA
            DIRECTIONAL
CORP AUTH   MTU
DATE   811216
KEYWORD   MWX1
KEYWORD   TIGHT GAS SANDS
KEYWORD   FRACTURES

KEYWORD VELOCITY
KEYWORD FLUVIAL
KEYWORD COASTAL
****
ACCES NUM N00044
REPORT NUM 1.2.25.001
TITLE PROGRESS REPORT FOR SANDIA NATIONAL LABORATORIES CONTRACT NO. 61-5742 COVERING THE PERIOD MAY 1, 1982 TO MAY 31, 1982
CORP AUTH RSI
DATE 820604
KEYWORD CORE ANALYSIS
KEYWORD MWX1
KEYWORD MWX2
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE
KEYWORD COZZETTE
KEYWORD CORCORAN
KEYWORD ROCK PROPERTIES
****
ACCES NUM N00045
REPORT NUM 1.2.25.002
TITLE PROGRESS REPORT FOR SANDIA NATIONAL LABORATORIES CONTRACT NO. 61-5742 COVERING THE PERIOD JUNE 1, 1982 TO JUNE 30, 1982
CORP AUTH RSI
DATE 820714
KEYWORD MWX1
KEYWORD CORE ANALYSIS
KEYWORD BRAZILIAN TESTS
KEYWORD COMPRESSION TESTS
KEYWORD STRESS-STRAIN ANALYSIS
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD MARINE
KEYWORD COZZETTE
KEYWORD ROCK PROPERTIES
****
ACCES NUM N00046
REPORT NUM 1.2.25.003
TITLE PROGRESS REPORT FOR SANDIA NATIONAL LABORATORIES CONTRACT NO. 61-5742 COVERING THE PERIOD JULY 1, 1982 TO JULY 31, 1982
CORP AUTH RSI
DATE 820810
KEYWORD MWX1
KEYWORD CORE ANALYSIS
KEYWORD TRIAXIAL TESTS
KEYWORD STRESS-STRAIN ANALYSIS
KEYWORD COASTAL
KEYWORD MARINE
KEYWORD COZZETTE
KEYWORD FLUVIAL
KEYWORD PARALIC
KEYWORD ROCK PROPERTIES
****
ACCES NUM N00047
REPORT NUM 1.2.25.004
TITLE PROGRESS REPORT FOR SANDIA NATIONAL LABORATORIES CONTRACT NO. 61-5742 COVERING THE PERIOD OCTOBER 1, 1982 TO OCTOBER 31, 1982
CORP AUTH RSI
DATE 821109
KEYWORD MWX2
KEYWORD CORE ANALYSIS
KEYWORD BRAZILIAN TESTS
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE

KEYWORD   COZZETTE
KEYWORD   CORCORAN
KEYWORD   ROCK PROPERTIES
****
ACCES NUM N00048
REPORT NUM 1.2.25.005
TITLE   PROGRESS REPORT FOR SANDIA NATIONAL LABORATORIES CONTRACT NO.
           61-5742 COVERING THE PERIOD NOVEMBER 1, 1982 TO NOVEMBER 30, 1982
CORP AUTH RSI
DATE   821210
KEYWORD   BRAZILIAN TESTS
KEYWORD   TRIAXIAL TESTS
KEYWORD   MWX2
KEYWORD   COASTAL
KEYWORD   MARINE
KEYWORD   COZZETTE
KEYWORD   CORCORAN
KEYWORD   ROCK PROPERTIES
****
ACCES NUM N00049
REPORT NUM 1.2.25.006
TITLE   PROGRESS REPORT FOR SANDIA NATIONAL LABORATORIES CONTRACT NO.
           61-5742 COVERING THE PERIOD DECEMBER 1, 1982 TO DECEMBER 31, 1982
CORP AUTH RSI
DATE   830105
KEYWORD   MWX1
KEYWORD   MWX2
KEYWORD   BRAZILIAN TESTS
KEYWORD   TRIAXIAL TESTS
KEYWORD   PARALIC
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE
KEYWORD   COZZETTE
KEYWORD   FLUVIAL
KEYWORD   CORCORAN
KEYWORD   ROCK PROPERTIES
****
ACCES NUM N00050
REPORT NUM 1.2.25.007
TITLE   PROGRESS REPORT FOR SANDIA NATIONAL LABORATORIES CONTRACT NO.
           61-5742 COVERING THE PERIOD JANUARY 1, 1983 TO JANUARY 31, 1983
CORP AUTH RSI
DATE   830204
KEYWORD   MWX1
KEYWORD   MWX2
KEYWORD   BRAZILIAN TESTS
KEYWORD   TRIAXIAL TESTS
KEYWORD   PARALIC
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE
KEYWORD   COZZETTE
KEYWORD   CORCORAN
KEYWORD   ROCK PROPERTIES
****
ACCES NUM N00051
REPORT NUM 1.2.25.008
TITLE   PROGRESS REPORT FOR SANDIA NATIONAL LABORATORIES CONTRACT NO.
           61-5742 COVERING THE PERIOD FEBRUARY 1, 1983 TO FEBRUARY 28, 1983
CORP AUTH RSI
DATE   830309
KEYWORD   TRIAXIAL TESTS
KEYWORD   MWX1
KEYWORD   MWX2

KEYWORD   BRAZILIAN TESTS
KEYWORD   PARALIC
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE
KEYWORD   COZZETTE
KEYWORD   CORCORAN
KEYWORD   ROCK PROPERTIES
****
ACCES NUM   N00052
REPORT NUM 1.2.25.009
AUTHOR   SENSENY,PE
TITLE   TRIAXIAL COMPRESSION AND BRAZILIAN TEST RESULTS FOR SAMPLES FROM
            MWX-1
CORP AUTH   RSI
DATE   830900
ALT NUMBER RSI-0226
KEYWORD   MWX1
KEYWORD   BRAZILIAN TESTS
KEYWORD   COMPRESSION TESTS
KEYWORD   TRIAXIAL TESTS
KEYWORD   STRESS-STRAIN ANALYSIS
KEYWORD   PARALIC
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   MARINE
KEYWORD   COZZETTE
KEYWORD   ROCK PROPERTIES
****
ACCES NUM   N00053
REPORT NUM 1.2.25.010
AUTHOR   SENSENY,PE
TITLE   TRIAXIAL COMPRESSION AND BRAZILIAN TEST RESULTS FOR SAMPLES FROM
            MWX-2
CORP AUTH   RSI
DATE   831000
ALT NUMBER RSI-0234
KEYWORD   MWX2
KEYWORD   BRAZILIAN TESTS
KEYWORD   COMPRESSION TESTS
KEYWORD   TRIAXIAL TESTS
KEYWORD   STRESS-STRAIN ANALYSIS
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE
KEYWORD   COZZETTE
KEYWORD   CORCORAN
KEYWORD   ROCK PROPERTIES
****
ACCES NUM   N00054
REPORT NUM 1.2.25.011
AUTHOR   SENSENY,PE
TITLE   PROGRESS REPORT FOR SANDIA NATIONAL LABORATORIES, CONTRACT NO.
            61-5742 COVERING THE PERIOD JUNE 1, 1984, TO JUNE 30, 1984
CORP AUTH   RSI
DATE   840703
KEYWORD   BRAZILIAN TESTS
KEYWORD   TRIAXIAL TESTS
KEYWORD   FRACTURE TOUGHNESS
KEYWORD   MWX3
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE

KEYWORD   ROLLINS
KEYWORD   ROCK PROPERTIES
****
ACCES NUM   N00453
REPORT NUM 1.2.25.012
AUTHOR   SENSENY,PE
TITLE   TRIAXIAL COMPRESSION AND BRAZIALIAN TEST RESULTS FOR SAMPLES FROM MWX-3
CORP AUTH   RSI
DATE   831100
ALT NUMBER RSI-0238
KEYWORD   MWX3
KEYWORD   ROLLINS
KEYWORD   MARINE
KEYWORD   PALUDAL
KEYWORD   COASTAL
KEYWORD   FLUVIAL
KEYWORD   ROCK PROPERTIES
KEYWORD   BRAZILIAN TESTS
KEYWORD   TRIAXIAL COMPRESSION
KEYWORD   YOUNG'S MODULUS
KEYWORD   POISSON'S RATIO
****
ACCES NUM   N00452
REPORT NUM 1.2.25.013
AUTHOR   SENSENY,PE
TITLE   PROGRESS REPORT (JANUARY 1,1984 TO JANUARY 31,1984)
CORP AUTH   RSI
DATE   840207
KEYWORD   MWX WELLS
KEYWORD   FRACTURE TOUGHNESS
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   MARINE
KEYWORD   COZZETTE
KEYWORD   PALUDAL
KEYWORD   CORCORAN
KEYWORD   YOUNG'S MODULUS
KEYWORD   ROCK PROPERTIES
KEYWORD   TENSILE STRENGTH
KEYWORD   COMPRESSIVE STRENGTH
****
ACCES NUM   N00451
REPORT NUM 1.2.25.014
AUTHOR   SENSENY,PE
AUTHOR   PFEIFLE,TW
TITLE   MEASURED FRACTURE TOUGHNESS OF SANDSTONES AND SHALES
CORP AUTH   RSI
DATE   840224
KEYWORD   ROCK PROPERTIES
KEYWORD   FRACTURE TOUGHNESS
KEYWORD   MWX WELLS
KEYWORD   MASSIVE HYDRAULIC FRACTURE
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   MARINE
KEYWORD   COZZETTE
KEYWORD   PALUDAL
****
ACCES NUM   N00606
REPORT NUM 1.2.25.017
AUTHOR   FINLEY,SJ
TITLE   LITHOLOGY DESCRIPTIONS OF RESPEC MWX CORE SAMPLES
CORP AUTH   SAND
DATE   851218
KEYWORD   PARALIC

```
KEYWORD     FLUVIAL
KEYWORD     COASTAL
KEYWORD     PALUDAL
KEYWORD     MARINE
KEYWORD     ROLLINS
KEYWORD     COZZETTE
KEYWORD     CORCORAN
KEYWORD     CORE ANALYSIS
KEYWORD     LITHOLOGY
KEYWORD     ROCK PROPERTY DATA
KEYWORD     ROCK PROPERTIES
****************************************************************************
ACCES NUM   N00302
REPORT NUM  1.2.25.018
AUTHOR      SENSENY,PE
TITLE       LABORATORY MEASUREMENTS OF MECHANICAL PROPERTIES OF SANDSTONES
            AND SHALES
CORP AUTH   RSI
DATE        830314
ALT NUMBER  SPEDOE11762
KEYWORD     MECHANICAL PROPERTIES
KEYWORD     FORMAL
KEYWORD     FLUVIAL
KEYWORD     COASTAL
KEYWORD     PALUDAL
KEYWORD     CORE ANALYSIS
KEYWORD     ROCK PROPERTIES
NOTES       THIS PAPER WAS PRESENTED AT THE 1983 SPE/DOE SYMPOSIUM ON LOW
            PERMEABILITY HELD IN DENVER, COLORADO, MARCH 14-16, 1983
****************************************************************************
ACCES NUM   N00056
REPORT NUM  1.2.26.002
AUTHOR      TEUFEL,LW
TITLE       DETERMINATION OF HORIZONTAL IN-SITU STRESS DIRECTIONS AT MWX SITE
             BASED ON ANELASTIC STRAIN RECOVERY MEASUREMENTS OF ORIENTED CORE
CORP AUTH   SAND
DATE        820723
KEYWORD     MWX1
KEYWORD     ANELASTIC STRAIN RECOVERY
KEYWORD     CORE RELAXATION
KEYWORD     CORE ANALYSIS
KEYWORD     FRACTURES
KEYWORD     NATURAL FRACTURES
KEYWORD     MWX2
KEYWORD     FRACTURE AZIMUTH
KEYWORD     FLUVIAL
KEYWORD     COASTAL
KEYWORD     MARINE
KEYWORD     COZZETTE
KEYWORD     CORCORAN
****************************************************************************
ACCES NUM   N00635
REPORT NUM  1.2.26.003
AUTHOR      LORENZ,JC
TITLE       RESULTS OF INQUIRY ON NONDESTRUCTIVE TESTING OF MWX CORE
CORP AUTH   SAND
DATE        860313
KEYWORD     NATURAL FRACTURES
KEYWORD     CALCITE FILLING
KEYWORD     CORE ANALYSIS
KEYWORD     CORE RELAXATION
KEYWORD     MWX1
KEYWORD     MWX3
KEYWORD     COASTAL
****************************************************************************
ACCES NUM   N00688
```

REPORT NUM 1.2.27.001
TITLE PERMEABILITY MEASUREMENTS TO TEST NET STRESS HYPOTHESIS IN TIGHT SANDS
CORP AUTH PETSER
DATE 860527
KEYWORD POROSITY
KEYWORD PERMEABILITY
KEYWORD GRAIN DENSITY
KEYWORD PORE PRESSURE
KEYWORD NET STRESS
KEYWORD MWX1
KEYWORD MWX2
KEYWORD CORE ANALYSIS
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD MARINE
****
ACCES NUM N00698
REPORT NUM 1.2.27.002
TITLE GAS PERMEABILITY OF SANDSTONE SAMPLES CONTRACT NO. 04-4594
CORP AUTH PETSER
DATE 860700
KEYWORD GAS PERMEABILITY
KEYWORD POROSITY
KEYWORD GRAIN DENSITY
KEYWORD MWX1
KEYWORD MWX2
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD MARINE
KEYWORD PORE PRESSURE
KEYWORD NET STRESS
KEYWORD CORE ANALYSIS
****
ACCES NUM N00783
REPORT NUM 1.2.27.004
AUTHOR WALLS,J
TITLE GAS PERMEABILITY OF FRACTURED WHOLE CORE AND MATRIX PLUGS WITH VARIABLE WATER SATURATION AND PORE PRESSURE
CORP AUTH CL
DATE 870700
ALT NUMBER 308-87069
KEYWORD GAS PERMEABILITY
KEYWORD PORE PRESSURE
KEYWORD WATER SATURATION
KEYWORD MARINE
KEYWORD CORCORAN
KEYWORD COASTAL
****
ACCES NUM N00836
REPORT NUM 1.2.27.006
TITLE SPECIAL CORE ANALYSIS
CORP AUTH CL
DATE 880224
ALT NUMBER SCAL 308-87192
KEYWORD CORE ANALYSIS
KEYWORD CAPILLARY PRESSURE
KEYWORD COASTAL
KEYWORD MARINE
KEYWORD PERMEABILITY
KEYWORD POROSITY
NOTES FORMERLY PETROPHYSICAL SERVICES
****
ACCES NUM N00058
REPORT NUM 1.2.31.001
AUTHOR HEMLER,T

TITLE MWX 1, MWX 2 CORES VITRINITE REFLECTANCE DATA
CORP AUTH AMOCO(COLO)
DATE 821119
KEYWORD MWX1
KEYWORD MWX2
KEYWORD CORE ANALYSIS
KEYWORD VITRINITE REFLECTANCE
KEYWORD PARALIC
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE
KEYWORD CORCORAN
KEYWORD COZZETTE
****
ACCES NUM N00059
REPORT NUM 1.2.31.002
AUTHOR JONES,RE
TITLE PALYNOLOGY REPORT: PALEOENVIRONMENTAL STUDY OF SELECTED SAMPLES
CORP AUTH AMOCO(COLO)
DATE 830217
KEYWORD MWX1
KEYWORD MWX2
KEYWORD CORE ANALYSIS
KEYWORD PALYNOLOGY
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE
KEYWORD CORCORAN
****
ACCES NUM N00060
REPORT NUM 1.2.32.001
AUTHOR TREMAIN,C
TITLE DESCRIPTIONS OF CORE SAMPLES FOR MWX1
CORP AUTH CGS
DATE 820104
KEYWORD COAL
KEYWORD MWX1
KEYWORD LITHOLOGY
KEYWORD PARALIC
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
****
ACCES NUM N00062
REPORT NUM 1.2.32.003
TITLE VITRINITE REFLECTANCE DATA, PROJECT JOHNSON PICEANCE CREEK
CORP AUTH CGS
DATE 000000
KEYWORD VITRINITE REFLECTANCE
KEYWORD PICEANCE BASIN
KEYWORD COAL
KEYWORD PALUDAL
KEYWORD PARALIC
KEYWORD COASTAL
KEYWORD MARINE
KEYWORD COZZETTE
****
ACCES NUM N00063
REPORT NUM 1.2.32.004
AUTHOR TREMAIN,C
TITLE ULTIMATE, PROXIMATE AND PETROGRAPHIC SUMMARY OF MWX1 COALS
CORP AUTH CGS
DATE 821108
KEYWORD MWX1
KEYWORD COAL

```
KEYWORD     ULTIMATE ANALYSIS
KEYWORD     PROXIMATE ANALYSIS
KEYWORD     PETROGRAPHIC ANALYSIS
KEYWORD     FLUVIAL
KEYWORD     COASTAL
KEYWORD     PALUDAL
KEYWORD     MARINE
KEYWORD     COZZETTE
*****************************************************************************
ACCES NUM   N00064
REPORT NUM  1.2.32.005
TITLE       SUMMARY OF MWX1, MWX2 COAL DATA
CORP AUTH   CGS
DATE        830200
KEYWORD     COAL
KEYWORD     CORE ANALYSIS
KEYWORD     MWX1
KEYWORD     MWX2
KEYWORD     DESORPTION
KEYWORD     FLUVIAL
KEYWORD     COASTAL
KEYWORD     PALUDAL
KEYWORD     MARINE
KEYWORD     COZZETTE
*****************************************************************************
ACCES NUM   N00624
REPORT NUM  1.2.35.003
TITLE       TOTAL ORGANIC CARBON ROCK EVAL PYROLYSIS AND C1-C5 GAS ANALYSIS,
            MWX3
CORP AUTH   CL
DATE        840306
ALT NUMBER  84012
KEYWORD     PALUDAL
KEYWORD     COASTAL
KEYWORD     FLUVIAL
KEYWORD     CORE ANALYSIS
KEYWORD     GAS ANALYSIS
KEYWORD     GEOCHEMISTRY
KEYWORD     MWX3
*****************************************************************************
ACCES NUM   N00626
REPORT NUM  1.2.35.005
TITLE       TOTAL ORGANIC CARBON ROCK EVAL PYROLYSIS AND C1-C5 GAS ANALYSIS,
            MWX1 AND MWX2
CORP AUTH   CL
DATE        840810
ALT NUMBER  84137
KEYWORD     CORE ANALYSIS
KEYWORD     MWX1
KEYWORD     MWX2
KEYWORD     GAS ANALYSIS
KEYWORD     GEOCHEMISTRY
KEYWORD     FLUVIAL
KEYWORD     COASTAL
KEYWORD     PALUDAL
KEYWORD     MARINE
*****************************************************************************
ACCES NUM   N00563
REPORT NUM  1.2.35.010
TITLE       COMPOSITIONAL ANALYSIS (MWX-1, COASTAL YELLOW SAND)
CORP AUTH   CL
DATE        850822
ALT NUMBER  ARFL-850129
KEYWORD     NITROGEN FOAM FRAC
KEYWORD     COASTAL
KEYWORD     MWX1
```

KEYWORD   RESERVOIR FLUID ANALYSIS
KEYWORD   STIMULATION
KEYWORD   HYDROCARBONS
****
ACCES NUM N00716
REPORT NUM 1.2.35.011
TITLE   HYDROCARBON ANALYSIS OF A METER RUN GAS SAMPLE (COASTAL RED AND YELLOW)
CORP AUTH CL
DATE   860600
ALT NUMBER ARFL-860115
KEYWORD   COASTAL
KEYWORD   HYDROCARBONS
KEYWORD   GAS ANALYSIS
KEYWORD   WELL TESTING
****
ACCES NUM N00074
REPORT NUM 1.2.41.001
AUTHOR   EATOUGH,MO
AUTHOR   DIXON,ML
TITLE   PRELIMINARY RESULTS OF MINERALOGY AND PETROLOGY OF THE COASTAL INTERVAL (DEPTH 5345-6582 FT) DRILL CORE MWX-1
CORP AUTH BENDIX
DATE   820702
KEYWORD   MWX1
KEYWORD   COASTAL
KEYWORD   MINERALOGY
KEYWORD   PETROLOGY
KEYWORD   CORE ANALYSIS
****
ACCES NUM N00079
REPORT NUM 1.2.41.006
AUTHOR   EATOUGH,MO
TITLE   PRELIMINARY RESULTS OF MINERALOGY AND PETROLOGY OF THE COASTAL INTERVAL (DEPTH 6400-6580 FT) DRILL CORE MWX-2
CORP AUTH BENDIX
DATE   830128
KEYWORD   MWX2
KEYWORD   COASTAL
KEYWORD   MINERALOGY
KEYWORD   PETROLOGY
KEYWORD   CORE ANALYSIS
****
ACCES NUM N00517
REPORT NUM 1.2.41.022
AUTHOR   FUKUI,LM
AUTHOR   HOPPING,RB
TITLE   X-RAY DIFFRACTION ANALYSES OF SELECTED SAMPLES COASTAL INTERVAL AND ROLLINS MEMBER, DRILL CORE MWX-3
CORP AUTH BENDIX
DATE   840130
KEYWORD   COASTAL
KEYWORD   MARINE
KEYWORD   ROLLINS
KEYWORD   X-RAY DIFFRACTION
****
ACCES NUM N00558
REPORT NUM 1.2.41.023
AUTHOR   FINLEY,SJ
TITLE   SUMMARY OF MWX BENDIX REPORTS
CORP AUTH SAND
DATE   850812
KEYWORD   MWX PROGRAM
KEYWORD   CORCORAN
KEYWORD   COZZETTE
KEYWORD   ROLLINS

KEYWORD   MARINE
KEYWORD   PALUDAL
KEYWORD   COASTAL
KEYWORD   FLUVIAL
KEYWORD   PARALIC
KEYWORD   MINERALOGY
KEYWORD   PETROLOGY
****
ACCES NUM N00634
REPORT NUM 1.2.41.024
AUTHOR   EATOUGH,MJ
TITLE   PRELIMINARY RESULTS OF MINERALOGY AND PETROLOGY OF THE COASTAL
           INTERVAL (DEPTH 6432-6515), DRILL CORE MWX-3
CORP AUTH SAND
CORP AUTH BENDIX
DATE   840322
KEYWORD   COASTAL
KEYWORD   MWX3
KEYWORD   PETROGRAPHIC ANALYSIS
KEYWORD   MINERALOGY
KEYWORD   PETROLOGY
KEYWORD   CORE ANALYSIS
KEYWORD   X-RAY DIFFRACTION
KEYWORD   CLAYS
****
ACCES NUM N00093
REPORT NUM 1.2.42.001
AUTHOR   SPENCER,CW
AUTHOR   PITMAN,JK
TITLE   USGS REVIEW OF MESAVERDE COASTAL INTERVAL
CORP AUTH USGS
DATE   820915
KEYWORD   MESAVERDE
KEYWORD   MWX1
KEYWORD   MINERALOGY
KEYWORD   COASTAL
KEYWORD   POROSITY
KEYWORD   RESISTIVITY MEASUREMENTS
KEYWORD   CORE ANALYSIS
KEYWORD   SEM
****
ACCES NUM N00100
REPORT NUM 1.2.51.001
AUTHOR   SPENCER,CW
TITLE   ISOTOPE ANALYSIS FOR MWX-2
CORP AUTH USGS
DATE   820915
KEYWORD   MWX2
KEYWORD   ISOTOPIC ANALYSIS
KEYWORD   VITRINITE REFLECTANCE
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
****
ACCES NUM N00101
REPORT NUM 1.2.51.002
AUTHOR   SPENCER,CW
AUTHOR   PITMAN,JK
TITLE   CARBON AND OXYGEN ISOTOPE ANALYSES OF MWX FRACTURE FILLING CALCITE
CORP AUTH USGS
DATE   830131
KEYWORD   MWX1
KEYWORD   ISOTOPIC ANALYSIS
KEYWORD   CALCITE FILLING
KEYWORD   NATURAL FRACTURES
KEYWORD   MWX2

KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE
KEYWORD   CORCORAN
****
ACCES NUM   N00095
REPORT NUM 1.2.52.001
AUTHOR   SPRUNT,ES
TITLE   ISOTOPE DATA FROM MWX1 AND MWX2
CORP AUTH   MOBIL
DATE   820806
KEYWORD   MWX1
KEYWORD   MWX2
KEYWORD   ISOTOPIC ANALYSIS
KEYWORD   CORE ANALYSIS
KEYWORD   MARINE
KEYWORD   CORCORAN
KEYWORD   COASTAL
****
ACCES NUM   N00096
REPORT NUM 1.2.52.002
AUTHOR   SPRUNT,ES
TITLE   ISOTOPIC COMPOSITION OF SELECTED CARBONATES FROM THE MESA VERDE
            FORMATION CORE SAMPLES FROM GOVERNMENT WELL # MWX-1
CORP AUTH   MOBIL
DATE   820915
KEYWORD   MESAVERDE
KEYWORD   MWX1
KEYWORD   CORE ANALYSIS
KEYWORD   CALCITE FILLING
KEYWORD   NATURAL FRACTURES
KEYWORD   ISOTOPIC ANALYSIS
KEYWORD   COASTAL
****
ACCES NUM   N00098
REPORT NUM 1.2.53.002
AUTHOR   VAN ALSTINE,DR
AUTHOR   GILLETT,SL
TITLE   PALEOMAGNETIC CORE ORIENTING FOR THE MULTIWELL EXPERIMENT
CORP AUTH   SG
DATE   820700
KEYWORD   MWX1
KEYWORD   PALEOMAGNETISM
KEYWORD   CORE ANALYSIS
KEYWORD   MWX2
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   MARINE
KEYWORD   COZZETTE
****
ACCES NUM   N00104
REPORT NUM 1.2.55.001
AUTHOR   MORROW,NR
TITLE   RELATIONSHIP OF PORE STRUCTURE TO FLUID BEHAVIOR IN LOW
            PERMEABILITY GAS SANDS, FIRST ANNUAL REPORT
CORP AUTH   NMPRRC
DATE   831000
ALT NUMBER DOEBC10216-13
KEYWORD   CORE ANALYSIS
KEYWORD   PARALIC
KEYWORD   MWX WELLS
KEYWORD   MARINE
KEYWORD   PALUDAL
KEYWORD   FLUVIAL
KEYWORD   COASTAL

KEYWORD   WATER SATURATION
KEYWORD   GRAIN SIZE
KEYWORD   KLINKENBERG PERMEABILITY
KEYWORD   NATURAL FRACTURES
KEYWORD   CALCITE FILLING
KEYWORD   GAS PERMEABILITY
KEYWORD   CAPILLARY PRESSURE
KEYWORD   FORMAL

****

ACCES NUM N00444
REPORT NUM 1.2.55.003
AUTHOR   WARD,J
AUTHOR   MORROW,NR
TITLE   MULTIWELL SPECIAL CORE ANALYSIS
CORP AUTH NMPRRC
DATE   841001
ALT NUMBER PRRC 84-25
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   PARALIC
KEYWORD   AIR PERMEABILITY
KEYWORD   CAPILLARY PRESSURE
KEYWORD   WATER SATURATION
KEYWORD   MWX WELLS
KEYWORD   FORMAL

****

ACCES NUM N00447
REPORT NUM 1.2.55.004
AUTHOR   MORROW,NR
AUTHOR   BROWER,KR
AUTHOR   KILMER,NH
TITLE   RELATIONSHIP OF PORE STRUCTURE TO FLUID BEHAVIOR IN LOW
           PERMEABILITY GAS SANDS
CORP AUTH NMPRRC
DATE   820000
ALT NUMBER DOE BC 10216-14
KEYWORD   PERMEABILITY
KEYWORD   OVERBURDEN PRESSURE
KEYWORD   CORCORAN
KEYWORD   COZZETTE
KEYWORD   MARINE
KEYWORD   PALUDAL
KEYWORD   COASTAL
KEYWORD   FLUVIAL
KEYWORD   MWX2
KEYWORD   MWX1
KEYWORD   GRAIN SIZE
KEYWORD   PETROGRAPHIC ANALYSIS
KEYWORD   WATER SATURATION
KEYWORD   POROSITY
KEYWORD   SEM ANALYSIS
KEYWORD   RESIN PORE CASTS
KEYWORD   X-RAY DIFFRACTION
KEYWORD   TEMPERATURE
KEYWORD   FORMAL

****

ACCES NUM N00328
REPORT NUM 1.2.55.005
AUTHOR   MORROW,NR
TITLE   RELATIONSHIP OF PORE STRUCTURE TO FLUID BEHAVIOR IN LOW
           PERMEABILITY GAS SANDS
CORP AUTH NMPRRC
DATE   840500
ALT NUMBER NMERDI2703303
KEYWORD   TIGHT GAS SANDS
KEYWORD   PERMEABILITY

KEYWORD CORE ANALYSIS
KEYWORD FORMAL
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE
KEYWORD RESERVOIR PROPERTIES
KEYWORD POROSITY
****
ACCES NUM N00647
REPORT NUM 1.2.55.006
AUTHOR WARD,J
AUTHOR MORROW,NR
TITLE CAPILLARY PRESSURES AND GAS RELATIVE PERMEABILITIES OF LOW PERMEABILITY SANDSTONE
CORP AUTH NMPRRC
DATE 850519
ALT NUMBER SPEDOE13882
KEYWORD CAPILLARY PRESSURE
KEYWORD GAS PERMEABILITY
KEYWORD CORE ANALYSIS
KEYWORD PERMEABILITY
KEYWORD MWX WELLS
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD PARALIC
KEYWORD FORMAL
NOTES PRESENTED AT THE SPEDOE 1985 LOW PERMEABILITY RESERVOIRS MEETING IN DENVER CO, MAY 19-22,1985
****
ACCES NUM N00668
REPORT NUM 1.2.55.008
AUTHOR MORROW,NR
AUTHOR WARD,J
AUTHOR BROWER,KR
TITLE ROCK MATRIX AND FRACTURE ANALYSIS OF FLOW IN WESTERN TIGHT GAS SANDS
CORP AUTH NMPRRC
DATE 860300
ALT NUMBER NMERDI 2-73-4313
KEYWORD CORE ANALYSIS
KEYWORD NATURAL FRACTURES
KEYWORD GAS PERMEABILITY
KEYWORD POROSITY
KEYWORD KLINKENBERG PERMEABILITY
KEYWORD PETROGRAPHIC ANALYSIS
KEYWORD WATER SATURATION
KEYWORD OVERBURDEN PRESSURE
KEYWORD CAPILLARY PRESSURE
KEYWORD MWX WELLS
KEYWORD PARALIC
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE
KEYWORD X-RAY DIFFRACTION
KEYWORD COZZETTE
KEYWORD CORCORAN
****
ACCES NUM N00669
REPORT NUM 1.2.55.009
AUTHOR MORROW,NR
AUTHOR WARD,J
AUTHOR BROWER,KR
TITLE ROCK MATRIX AND FRACTURE ANALYSIS OF FLOW IN WESTERN TIGHT GAS SANDS, 1985 ANNUAL REPORT

CORP AUTH NMPRRC
DATE 860200
ALT NUMBER DOEMC21179-2032
KEYWORD FORMAL
KEYWORD CORE ANALYSIS
KEYWORD NATURAL FRACTURES
KEYWORD GAS PERMEABILITY
KEYWORD POROSITY
KEYWORD KLINKENBERG PERMEABILITY
KEYWORD PETROGRAPHIC ANALYSIS
KEYWORD WATER SATURATION
KEYWORD OVERBURDEN PRESSURE
KEYWORD CAPILLARY PRESSURE
KEYWORD MWX WELLS
KEYWORD PARALIC
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD COZZETTE
KEYWORD CORCORAN
KEYWORD MARINE
KEYWORD X-RAY DIFFRACTION
****
ACCES NUM N00703
REPORT NUM 1.2.55.010
AUTHOR WEI,KK
AUTHOR MORROW,NR
AUTHOR BROWER,KR
TITLE THE EFFECT OF FLUID, CONFINING PRESSURE, AND TEMPERATURE ON ABSOLUTE PERMEABILITIES OF LOW PERMEABILITY SANDSTONES
CORP AUTH NMPRRC
DATE 840916
ALT NUMBER SPE 13093
KEYWORD FORMAL
KEYWORD GAS PERMEABILITY
KEYWORD MWX1
KEYWORD MWX2
KEYWORD KLINKENBERG PERMEABILITY
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD CORE ANALYSIS
NOTES PRESENTED AT THE 59TH ANNUAL TECHNICAL CONFERENCE AND EXHIBITION HELD IN HOUSTON, TEXAS SEPT 16-19,1984
****
ACCES NUM N00704
REPORT NUM 1.2.55.011
AUTHOR MORROW,NR
AUTHOR BROWER,KR
AUTHOR KILMER,NH
TITLE RELATIONSHIP OF PORE STRUCTURE TO FLUID BEHAVIOR IN LOW PERMEABILITY GAS SANDS, 1984 FINAL REPORT
CORP AUTH NMPRRC
DATE 840900
ALT NUMBER DOEBC10216-13
KEYWORD FORMAL
KEYWORD CORE ANALYSIS
KEYWORD GAS PERMEABILITY
KEYWORD PORE SIZE DISTRIBUTIONS
KEYWORD CALCITE FILLING
KEYWORD NATURAL FRACTURES
KEYWORD KLINKENBERG PERMEABILITY
KEYWORD MWX WELLS
KEYWORD PARALIC
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL

KEYWORD   MARINE
KEYWORD   MATHEMATICAL MODELS
****
ACCES NUM   N00705
REPORT NUM 1.2.55.012
AUTHOR   MORROW,NR
TITLE   RELATIONSHIP OF PORE STRUCTURE TO FLUID BEHAVIOR IN LOW PERMEABILITY GAS SANDS: YEAR THREE
CORP AUTH   NMPRRC
DATE   850200
ALT NUMBER NMERDI 2-72-4309
KEYWORD   PERMEABILITY
KEYWORD   FORMAL
KEYWORD   KLINKENBERG PERMEABILITY
KEYWORD   OVERBURDEN PRESSURE
KEYWORD   MATHEMATICAL MODELS
KEYWORD   NATURAL FRACTURES
KEYWORD   CALCITE FILLING
KEYWORD   CORE ANALYSIS
KEYWORD   MWX WELLS
KEYWORD   PARALIC
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE
****
ACCES NUM   N00727
REPORT NUM 1.2.55.013
AUTHOR   MORROW,NR
AUTHOR   WARD,J
AUTHOR   BROWER,KR
AUTHOR   CATHER,SM
TITLE   ROCK MATRIX AND FRACTURE ANALYSIS OF FLOW IN WESTERN TIGHT GAS SANDS
CORP AUTH   NMPRRC
DATE   860900
ALT NUMBER PRRC 86-16
KEYWORD   QUARTERLY REPORT
KEYWORD   CORE ANALYSIS
KEYWORD   PETROGRAPHIC ANALYSIS
KEYWORD   KLINKENBERG PERMEABILITY
KEYWORD   WATER SATURATION
KEYWORD   NATURAL FRACTURES
KEYWORD   CALCITE FILLING
KEYWORD   FLUID ANALYSIS
KEYWORD   POROSITY
KEYWORD   CAPILLARY PRESSURE
KEYWORD   FLUVIAL
KEYWORD   PALUDAL
KEYWORD   COASTAL
NOTES   QUARTERLY TECHNICAL PROGRESS REPORT JULY-SEPT. 1986
****
ACCES NUM   N00820
REPORT NUM 1.2.55.014
AUTHOR   MORROW,NR
AUTHOR   BROWER,KR
AUTHOR   KILMER,NH
AUTHOR   WARD,J
TITLE   ROCK MATRIX AND FRACTURE ANALYSIS OF FLOW IN WESTERN TIGHT GAS SANDS
CORP AUTH   NMPRRC
DATE   850000
ALT NUMBER PRRC 84-29
KEYWORD   QUARTERLY REPORT
KEYWORD   CORE ANALYSIS
KEYWORD   NATURAL FRACTURES

KEYWORD FRACTURE FILLING
KEYWORD PERMEABILITY
KEYWORD PALUDAL
KEYWORD COASTAL
KEYWORD PARALIC
NOTES QUARTERLY TECHNICAL PROGRESS REPORT, SEPTEMBER-DECEMBER,1984
****
ACCES NUM N00821
REPORT NUM 1.2.55.015
AUTHOR MORROW,NR
AUTHOR BUCKLEY,JS
AUTHOR CATHER,SM
AUTHOR BROWER,KR
TITLE ROCK MATRIX AND FRACTURE ANALYSIS OF FLOW IN WESTERN TIGHT GAS SANDS- PHASE 3
CORP AUTH NMPRRC
DATE 880100
ALT NUMBER PRRC 87-10
KEYWORD QUARTERLY REPORT
KEYWORD CORE ANALYSIS
KEYWORD NATURAL FRACTURES
KEYWORD PERMEABILITY
KEYWORD WATER SATURATION
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
NOTES QUARTERLY TECHNICAL PROGRESS REPORT, JULY-SEPTEMBER,1987
****
ACCES NUM N00822
REPORT NUM 1.2.55.016
AUTHOR MORROW,NR
AUTHOR WARD,J
AUTHOR BROWER,KR
TITLE ROCK MATRIX AND FRACTURE ANALYSIS OF FLOW IN WESTERN TIGHT GAS SANDS
CORP AUTH NMPRRC
DATE 860100
ALT NUMBER PRRC86-2
KEYWORD PERMEABILITY
KEYWORD CORE ANALYSIS
KEYWORD PETROGRAPHIC ANALYSIS
KEYWORD NATURAL FRACTURES
KEYWORD WATER SATURATION
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE
KEYWORD QUARTERLY REPORT
NOTES QUARTERLY TECHNICAL
****
ACCES NUM N00823
REPORT NUM 1.2.55.017
AUTHOR MORROW,NR
AUTHOR BUCKLEY,JS
AUTHOR CATHER,SM
AUTHOR BROWER,KR
TITLE ROCK MATRIX AND FRACTURE ANALYSIS OF FLOW IN WESTERN TIGHT GAS SANDS, 1986 ANNUAL REPORT
CORP AUTH NMPRRC
DATE 870200
ALT NUMBER PRRC 87-3
KEYWORD CORE ANALYSIS
KEYWORD NATURAL FRACTURES
KEYWORD GAS PERMEABILITY
KEYWORD WATER SATURATION
KEYWORD PETROGRAPHIC ANALYSIS

KEYWORD   OVERBURDEN PRESSURE
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
****
ACCES NUM   N00824
REPORT NUM 1.2.55.018
AUTHOR   MORROW,NR
AUTHOR   BUCKLEY,JS
AUTHOR   CATHER,SM
AUTHOR   BROWER,KR
TITLE   ROCK MATRIX AND FRACTURE ANALYSIS OF FLOW IN WESTERN TIGHT GAS
            SANDS
CORP AUTH   NMPRRC
DATE   871200
ALT NUMBER PRRC 87-12
KEYWORD   CORE ANALYSIS
KEYWORD   CLAYS
KEYWORD   X-RAY DIFFRACTION
KEYWORD   NATURAL FRACTURES
KEYWORD   PERMEABILITY
KEYWORD   CHEMICAL ANALYSIS
KEYWORD   WATER SATURATION
KEYWORD   RESISTIVITY MEASUREMENTS
KEYWORD   FLUVIAL
KEYWORD   COASTAL
NOTES   QUARTERLY TECHNICAL PROGRESS REPORT,OCT-DEC,1987
****
ACCES NUM   N00825
REPORT NUM 1.2.55.019
AUTHOR   MORROW,NR
AUTHOR   BUCKLEY,JS
AUTHOR   CATHER,SM
AUTHOR   BROWER,KR
TITLE   ROCK MATRIX AND FRACTURE ANALYSIS OF FLOW IN WESTERN TIGHT GAS
            SANDS, PHASE 3-1987 ANNUAL REPORT
CORP AUTH   NMPRRC
DATE   871200
ALT NUMBER PRRC 87-11
KEYWORD   CORE ANALYSIS
KEYWORD   NATURAL FRACTURES
KEYWORD   PERMEABILITY
KEYWORD   CHEMICAL ANALYSIS
KEYWORD   CLAYS
KEYWORD   RESISTIVITY MEASUREMENTS
KEYWORD   WATER SATURATION
KEYWORD   PARALIC
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE
****
ACCES NUM   N00565
REPORT NUM 1.2.62.001
TITLE   MULTIWELL EXPERIMENT CORE ANALYSIS OF MWX-1,MWX-2,AND MWX-3 - AN
            INTERIM REPORT
CORP AUTH   DOWELL
DATE   850800
KEYWORD   CORE ANALYSIS
KEYWORD   PERMEABILITY
KEYWORD   FLUID ANALYSIS
KEYWORD   MECHANICAL PROPERTIES
KEYWORD   PROPPANT
KEYWORD   COASTAL
KEYWORD   MWX WELLS
****

ACCES NUM   N00556
REPORT NUM 1.2.62.002
AUTHOR   SATTLER,AR
TITLE   LABORATORY WORK SUPPORTING THE FRACTURE DESIGN FOR THE COASTAL YELLOW SAND
CORP AUTH   SAND
DATE   850708
KEYWORD   COASTAL
KEYWORD   FRACTURE DESIGN
KEYWORD   STIMULATION
****
ACCES NUM   N00583
REPORT NUM 1.2.62.003
AUTHOR   SATTLER,AR
TITLE   LABORATORY WORK SUPPORTING THE FRACTURE DESIGN FOR THE COASTAL YELLOW SAND, NUMBER 2.
CORP AUTH   SAND
DATE   851004
KEYWORD   COASTAL
KEYWORD   FRACTURE DESIGN
KEYWORD   STIMULATION
KEYWORD   ROCK PROPERTIES
KEYWORD   PETROGRAPHIC ANALYSIS
KEYWORD   PROPPANT EMBEDMENT
KEYWORD   FRACTURE CONDUCTIVITY
KEYWORD   GAS PERMEABILITIES
****
ACCES NUM   N00587
REPORT NUM 1.2.62.005
AUTHOR   RAIBLE,CJ
TITLE   FRACTURE CONDUCTIVITY STUDIES - PROJECT RESEARCH SUMMARY
CORP AUTH   NIPER
DATE   850100
KEYWORD   COASTAL
KEYWORD   CORE ANALYSIS
KEYWORD   FRACTURE CONDUCTIVITY
KEYWORD   PROPPANT EMBEDMENT
NOTES   MONTHLY REPORT FOR JANUARY
****
ACCES NUM   N00589
REPORT NUM 1.2.62.007
AUTHOR   RAIBLE,CJ
TITLE   FLUID LOSS AND FORMATION DAMAGE DUE TO HYDRAULIC FRACTURING FLUID
CORP AUTH   NIPER
DATE   831001
KEYWORD   COASTAL
KEYWORD   FLUID ANALYSIS
KEYWORD   GAS PERMEABILITY
KEYWORD   CORE ANALYSIS
KEYWORD   FRACTURING FLUID
****
ACCES NUM   N00590
REPORT NUM 1.2.62.008
AUTHOR   RAIBLE,CJ
AUTHOR   MALONEY,D
TITLE   MWX COASTAL ZONE FRACTURE FLOW CAPACITY PREDICTIONS
CORP AUTH   NIPER
DATE   850719
KEYWORD   COASTAL
KEYWORD   FRACTURE CONDUCTIVITY
KEYWORD   FRACTURE WIDTH
KEYWORD   PROPPANT
KEYWORD   CORE ANALYSIS
KEYWORD   PROPPANT EMBEDMENT
NOTES   DRAFT
****

ACCES NUM   N00591
REPORT NUM 1.2.62.009
AUTHOR   RAIBLE,CJ
TITLE   LABORATORY STUDIES OF THE FRACTURING FLUID BASE GEL USED IN THE MWX STIMULATION OF THE YELLOW SANDS
CORP AUTH   NIPER
DATE   850830
KEYWORD   COASTAL
KEYWORD   CORE ANALYSIS
KEYWORD   FORMATION DAMAGE
KEYWORD   FLUID ANALYSIS
KEYWORD   FRACTURING FLUID
KEYWORD   NITROGEN FOAM FRAC
****
ACCES NUM   N00592
REPORT NUM 1.2.62.010
AUTHOR   GALL,BL
TITLE   MWX COASTAL CORE EVALUATION: GAS PERMEABILITY AND CLEANUP TIME AS A FUNCTION OF LIQUID SATURATION
CORP AUTH   NIPER
DATE   850614
KEYWORD   COASTAL
KEYWORD   CORE ANALYSIS
KEYWORD   GAS PERMEABILITY
KEYWORD   CLEAN UP
KEYWORD   WATER SATURATION
****
ACCES NUM   N00595
REPORT NUM 1.2.62.013
AUTHOR   MALONEY,D
TITLE   FRACTURE CONDUCTIVITY STUDIES
CORP AUTH   NIPER
DATE   850000
KEYWORD   COASTAL
KEYWORD   PROPPANT EMBEDMENT
KEYWORD   CORE ANALYSIS
KEYWORD   FRACTURE WIDTH
****
ACCES NUM   N00596
REPORT NUM 1.2.62.014
TITLE   API WATER ANALYSIS REPORT
CORP AUTH   CL
DATE   850414
KEYWORD   COASTAL
KEYWORD   WATER ANALYSIS
KEYWORD   FLUID ANALYSIS
KEYWORD   FRACTURING FLUID
****
ACCES NUM   N00597
REPORT NUM 1.2.62.015
TITLE   API WATER ANALYSIS REPORT
CORP AUTH   CL
DATE   850830
KEYWORD   COASTAL
KEYWORD   WATER ANALYSIS
KEYWORD   NITROGEN FOAM FRAC
KEYWORD   FLUID ANALYSIS
KEYWORD   FRACTURING FLUID
****
ACCES NUM   N00638
REPORT NUM 1.2.62.016
AUTHOR   SATTLER,AR
TITLE   COASTAL CORE DATA SUMMARY
CORP AUTH   SAND
DATE   840131
KEYWORD   COASTAL

KEYWORD   CORE ANALYSIS
KEYWORD   RESERVOIR PROPERTIES
KEYWORD   ROCK PROPERTIES
KEYWORD   MINERALOGY
KEYWORD   PETROLOGY
KEYWORD   KLINKENBERG PERMEABILITY
KEYWORD   POROSITY
KEYWORD   WATER SATURATION
KEYWORD   YOUNG'S MODULUS
KEYWORD   POISSON'S RATIO
KEYWORD   FRACTURE TOUGHNESS
KEYWORD   TENSILE STRENGTH
KEYWORD   BRAZILIAN TESTS
KEYWORD   COMPRESSION TESTS
****
ACCES NUM   N00672
REPORT NUM 1.2.62.017
AUTHOR   SATTLER,AR
AUTHOR   HUDSON,PJ
AUTHOR   RAIBLE,CJ
AUTHOR   GALL,BL
AUTHOR   MALONEY,D
TITLE   LABORATORY STUDIES FOR THE DESIGN AND ANALYSIS OF HYDRAULIC
            FRACTURED STIMULATIONS IN LENTICULAR, TIGHT GAS RESERVOIRS
CORP AUTH   SAND
CORP AUTH   DOWELL
CORP AUTH   NIPER
DATE   860518
ALT NUMBER SPE 15245
KEYWORD   FORMAL
KEYWORD   CORE ANALYSIS
KEYWORD   STIMULATION
KEYWORD   PALUDAL
KEYWORD   FRACTURING FLUID
KEYWORD   COASTAL
KEYWORD   FORMATION DAMAGE
KEYWORD   PERMEABILITY
KEYWORD   LEAKOFF
KEYWORD   NATURAL FRACTURES
KEYWORD   WATER ANALYSIS
KEYWORD   PROPPANT EMBEDMENT
KEYWORD   FRACTURE CONDUCTIVITY
KEYWORD   FRACTURE WIDTH
KEYWORD   MWX1
KEYWORD   MINERALOGY
NOTES   THIS PAPER WAS PRESENTED AT THE UNCONVENTIONAL GAS TECHNOLOGY
            SYMPOSIUM OF THE SOCIETY OF PETROLEUM ENGINEERS HELD IN
            LOUISVILLE, KENTUCKY, MAY 1
****
ACCES NUM   N00691
REPORT NUM 1.2.62.018
AUTHOR   SATTLER,AR
TITLE   LABORATORY WORK SUPPORTING THE COASTAL AND FLUVIAL ZONE
            STIMULATION OPERATIONS
CORP AUTH   SAND
CORP AUTH   NIPER
CORP AUTH   DOWELL
DATE   860627
KEYWORD   COASTAL
KEYWORD   FLUVIAL
KEYWORD   PALUDAL
KEYWORD   STIMULATION
KEYWORD   CORE ANALYSIS
KEYWORD   PROPPANT
KEYWORD   FRACTURING FLUID
KEYWORD   WATER ANALYSIS

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KEYWORD    MWX WELLS
KEYWORD    MINERALOGY
KEYWORD    PETROLOGY
KEYWORD    NATURAL FRACTURES
KEYWORD    GAS PERMEABILITY
KEYWORD    STRESS-STRAIN ANALYSIS
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ACCES NUM  N00706
REPORT NUM 1.2.63.003
AUTHOR     RAIBLE,CJ
AUTHOR     GALL,BL
AUTHOR     MALONEY,D
TITLE      LABORATORY RESEARCH OF FRACTURING MATERIALS FOR THE DOE/MWX,
           QUARTERLY REPORT FOR APR-JUN,1986
CORP AUTH  NIPER
DATE       860700
ALT NUMBER CONTRACT# 85-68B
KEYWORD    QUARTERLY REPORT
KEYWORD    FRACTURING FLUID
KEYWORD    FLUID ANALYSIS
KEYWORD    FLUVIAL
KEYWORD    COASTAL
KEYWORD    PALUDAL
KEYWORD    CORE ANALYSIS
KEYWORD    PROPPANT EMBEDMENT
KEYWORD    GAS PERMEABILITY
KEYWORD    FORMATION DAMAGE
KEYWORD    NATURAL FRACTURES
KEYWORD    FRACTURE CONDUCTIVITY
********************************************************************************
ACCES NUM  N00782
REPORT NUM 1.2.63.023
AUTHOR     RAIBLE,CJ
AUTHOR     CARROLL,HB
TITLE      FORMATION DAMAGE TESTS USING BIOPOLYMER BASED FRACTURING FLUIDS
CORP AUTH  NIPER
DATE       870804
KEYWORD    FRACTURING FLUID
KEYWORD    CORE ANALYSIS
KEYWORD    FLUID ANALYSIS
KEYWORD    FLUVIAL
KEYWORD    GAS PERMEABILITY
KEYWORD    COASTAL
KEYWORD    PROPPANT
KEYWORD    FORMATION DAMAGE
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ACCES NUM  N00665
REPORT NUM 1.2.65.003
AUTHOR     MALONEY,D
TITLE      FRACTURE CONDUCTIVITY STUDIES - FINAL REPORT
CORP AUTH  NIPER
DATE       851100
ALT NUMBER NIPER-121
KEYWORD    HYDRAULIC FRACTURING
KEYWORD    STIMULATION
KEYWORD    FRACTURE CONDUCTIVITY
KEYWORD    PROPPANT
KEYWORD    FRACTURE WIDTH
KEYWORD    PROPPANT EMBEDMENT
KEYWORD    HYDRAULIC FRACTURE
KEYWORD    FRACTURING FLUID
KEYWORD    CORE ANALYSIS
KEYWORD    COASTAL
KEYWORD    PALUDAL
KEYWORD    MARINE
********************************************************************************
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ACCES NUM N00738
REPORT NUM 1.2.65.005
AUTHOR RAIBLE,CJ
AUTHOR GALL,BL
AUTHOR MALONEY,D
TITLE LABORATORY RESEARCH OF FRACTURING MATERIALS FOR THE DOE/MWX
CORP AUTH NIPER
DATE 860700
KEYWORD QUARTERLY REPORT
KEYWORD STIMULATION
KEYWORD CORE ANALYSIS
KEYWORD FLUID ANALYSIS
KEYWORD WATER ANALYSIS
KEYWORD FRACTURING FLUID
KEYWORD DAMAGE
KEYWORD PROPPANT
KEYWORD PROPPANT EMBEDMENT
KEYWORD FRACTURE CONDUCTIVITY
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
NOTES QUARTERLY REPORT FOR THE PERIOD APRIL-JUNE,1986
****
ACCES NUM N00843
REPORT NUM 1.2.65.008
AUTHOR GALL,BL
AUTHOR MALONEY,D
AUTHOR RAIBLE,CJ
TITLE PERMEABILITY DAMAGE TO ARTIFICIALLY FRACTURED CORES
CORP AUTH NIPER
DATE 880500
ALT NUMBER 95-4340
KEYWORD FINAL REPORT
KEYWORD FORMATION DAMAGE
KEYWORD GAS PERMEABILITY
KEYWORD CORE ANALYSIS
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD FRACTURING FLUID
KEYWORD FLUID ANALYSIS
KEYWORD NATURAL FRACTURES
****
ACCES NUM N00370
REPORT NUM 1.3.001
TITLE MWX-1 LOG-CORE DEPTH CORRELATIONS
CORP AUTH CL
CORP AUTH CER
DATE 811103
KEYWORD LOGS
KEYWORD PARALIC
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE
KEYWORD CORRELATION
KEYWORD DRILL CORE
KEYWORD MWX1
****
ACCES NUM N00372
REPORT NUM 1.3.003
TITLE MWX-2 LOG-CORE DEPTH CORRELATIONS
CORP AUTH CL
CORP AUTH CER
DATE 820301
KEYWORD MWX2

KEYWORD   LOGS
KEYWORD   CORRELATION
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE
KEYWORD   DRILL CORE
****
ACCES NUM   N00374
REPORT NUM 1.3.005
AUTHOR   SATTLER,AR
TITLE   COMPARISON OF PROPERTIES BETWEEN LENTICULAR AND BLANKET SANDS
CORP AUTH   SAND
DATE   821129
KEYWORD   LENTICULAR SANDS
KEYWORD   CORRELATION
KEYWORD   COASTAL
KEYWORD   MARINE
KEYWORD   COZZETTE
KEYWORD   LOGS
KEYWORD   DRILL CORE
KEYWORD   MWX1
KEYWORD   MWX2
****
ACCES NUM   N00495
REPORT NUM 1.3.008
AUTHOR   SATTLER,AR
TITLE   RESISTIVITY OF COASTAL ZONE CORE AT IN SITU CONDITIONS VS. THAT
            OF KCL BRINE
CORP AUTH   SAND
DATE   850131
KEYWORD   RESISTIVITY
KEYWORD   RESISTIVITY INDEX
KEYWORD   COASTAL
****
ACCES NUM   N00692
REPORT NUM 1.3.011
AUTHOR   FINLEY,SJ
TITLE   LOG/CORE DEPTH CORRELATIONS
CORP AUTH   SAND
DATE   860410
KEYWORD   CORRELATION
KEYWORD   PARALIC
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE
KEYWORD   LOG ANALYSIS
KEYWORD   DRILL CORE
KEYWORD   MWX WELLS
****
ACCES NUM   N00154
REPORT NUM 1.4.2.009
AUTHOR   HEINZE,DM
TITLE   OVERVIEW OF MINERALOGY/PETROLOGY OF MWX COASTAL (RED, YELLOW, AND
            GREEN (C&D)) ZONES
CORP AUTH   SAND
DATE   840125
KEYWORD   MWX1
KEYWORD   MWX2
KEYWORD   COASTAL
KEYWORD   MINERALOGY
KEYWORD   PETROLOGY
KEYWORD   ANALYSES
****
ACCES NUM   N00301

REPORT NUM 1.4.2.012
AUTHOR EATOUGH,MO
TITLE MINERALOGIC AND PETROLOGIC OVERVIEW OF CORE SAMPLES FROM THE DEPT. OF ENERGY'S WESTERN GAS SANDS PROJECT MULTIWELL EXPERIMENT, PICEANCE BASIN, COLORADO
CORP AUTH BENDIX
DATE 830300
ALT NUMBER SPEDOE11764
KEYWORD MINERALOGY
KEYWORD PETROLOGY
KEYWORD FORMAL
KEYWORD CORE ANALYSIS
KEYWORD POROSITY
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE
KEYWORD MESAVERDE
NOTES THIS PAPER WAS PRESENTED AT THE 1983 SPE/DOE SYMPOSIUM ON LOW PERMEABILITY HELD IN DENVER, COLORADO, MARCH 14-16, 1983
****
ACCES NUM N00308
REPORT NUM 1.4.2.013
AUTHOR HEINZE,DM
TITLE MINERALOGY AND PETROLOGY ASPECTS OF THE MESAVERDE FORMATION AT RIFLE GAP, COLORADO, SPECIFIC TO THE SEDIMENTOLOGY AND GAS-BEARING INTERVALS IN THE SUBSURFACE
DATE 830300
ALT NUMBER SAND830287
KEYWORD OUTCROP DATA
KEYWORD PARALIC
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE
KEYWORD MINERALOGY
KEYWORD MESAVERDE
KEYWORD PETROLOGY
KEYWORD SEDIMENTOLOGY
KEYWORD CORE ANALYSIS
KEYWORD FORMAL
****
ACCES NUM N00848
REPORT NUM 1.4.2.014
TITLE X-RAY DIFFRACTION ANALYSIS, MWX-1 AND MWX-2
CORP AUTH CL
DATE 840425
ALT NUMBER PS-84054
KEYWORD MWX1
KEYWORD MWX2
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE
KEYWORD CLAYS
KEYWORD X-RAY DIFFRACTION
****
ACCES NUM N00118
REPORT NUM 1.4.3.016
AUTHOR LORENZ,JC
TITLE RESERVOIR SEDIMENTOLOGY IN MESAVERDE ROCKS AT THE MWX SITE
CORP AUTH SAND
DATE 830131
KEYWORD MESAVERDE
KEYWORD MWX1
KEYWORD MWX2

KEYWORD   SANDSTONES
KEYWORD   SEDIMENTOLOGY
KEYWORD   RESERVOIR
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   ROLLINS
KEYWORD   COZZETTE
KEYWORD   CORCORAN
KEYWORD   MARINE
****
ACCES NUM N00119
REPORT NUM 1.4.3.017
AUTHOR   LORENZ,JC
TITLE   CROSSBEDS AND LENS ORIENTATIONS IN THE COASTAL AND PALUDAL
           INTERVALS OF THE MWX WELLS
CORP AUTH SAND
DATE   830209
KEYWORD   CROSSBEDS
KEYWORD   PALUDAL
KEYWORD   COASTAL
KEYWORD   MWX1
KEYWORD   MWX2
****
ACCES NUM N00470
REPORT NUM 1.4.3.026
AUTHOR   PETERSON,RE
TITLE   GEOLOGICAL AND PRODUCTION CHARACTERISTICS OF THE NON-MARINE PART
           OF THE MESAVERDE GROUP, RULISON FIELD AREA,PICEANCE BASIN,
           COLORADO
CORP AUTH CER
DATE   840514
ALT NUMBER SPE 12835
KEYWORD   PALUDAL
KEYWORD   COASTAL
KEYWORD   FLUVIAL
KEYWORD   PARALIC
KEYWORD   SEDIMENTOLOGY
KEYWORD   OHIO CREEK
KEYWORD   PRODUCTION
KEYWORD   STRUCTURE
KEYWORD   FORMAL
NOTES   PRESENTED AT THE SPE/DOE/GRI UNCONVENTIONAL GAS RECOVERY
           SYMPOSIUM IN PITTSBURGH PA, MAY 13-15,1984.
****
ACCES NUM N00493
REPORT NUM 1.4.3.028
AUTHOR   LORENZ,JC
TITLE   REFINED GEOLOGIC INTERPRETATIONS FOR THE COASTAL ZONE
CORP AUTH SAND
DATE   850225
KEYWORD   SEDIMENTOLOGY
KEYWORD   COASTAL
KEYWORD   LENS MORPHOLOGY
****
ACCES NUM N00511
REPORT NUM 1.4.3.030
AUTHOR   LORENZ,JC
TITLE   PREDICTIONS OF SIZE AND ORIENTATIONS OF LENTICULAR RESERVOIRS IN
           THE MESAVERDE GROUP, NORTHWESTERN COLORADO
CORP AUTH SAND
DATE   850519
ALT NUMBER SPEDOE13851
KEYWORD   OUTCROP DATA
KEYWORD   COASTAL
KEYWORD   PALUDAL

KEYWORD   LENTICULAR SANDS
KEYWORD   FORMAL
NOTES   PRESENTED AT THE SPE/DOE 1985 LOW PERMEABILITY GAS RESERVOIRS
            SYMPOSIUM, DENVER,CO, MAY 19-22 1985
****
ACCES NUM   N00601
REPORT NUM 1.4.3.031
AUTHOR   WRIGHT,R
AUTHOR   NORTH,RW
TITLE   SEDIMENT TEXTURAL CHARACTERISTICS OF FLUVIAL SANDSTONE IN
            MESAVERDE STRATA AT THE MULTI-WELL EXPERIMENT(MWX) SITE,
            NORTHWESTERN COLORADO
CORP AUTH   UNM
DATE   851105
ALT NUMBER 21-0245
KEYWORD   SEDIMENTOLOGY
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   GRAIN SIZE
KEYWORD   CORE ANALYSIS
KEYWORD   CORE LITHOLOGY
NOTES   CONTRACT REPORT, SANDIA-UNIVERSITY RESEARCH PROGRAM AWARD #21-0245
****
ACCES NUM   N00294
REPORT NUM 1.4.3.033
AUTHOR   LORENZ,JC
TITLE   SEDIMENTOLOGY OF THE MESAVERDE FORMATION AT RIFLE GAP, COLORADO
            AND IMPLICATIONS FOR GAS-BEARING INTERVALS IN THE SUBSURFACE
DATE   820300
ALT NUMBER SAND820604
KEYWORD   MESAVERDE
KEYWORD   OUTCROP DATA
KEYWORD   MARINE
KEYWORD   PALUDAL
KEYWORD   COASTAL
KEYWORD   FLUVIAL
KEYWORD   PARALIC
KEYWORD   SEDIMENTOLOGY
KEYWORD   GEOLOGY
KEYWORD   LENS MORPHOLOGY
KEYWORD   FORMAL
****
ACCES NUM   N00295
REPORT NUM 1.4.3.034
AUTHOR   PETERSON,RE
TITLE   WESTERN GAS SANDS PROJECT: AN APPROXIMATION OF CONTINUITY OF
            LENTICULAR MESAVERDE SANDSTONE LENSES, UTILIZING CLOSE WELL
            CORRELATIONS, PICEANCE BASIN, NORTHWEST COLORADO
CORP AUTH   CER
DATE   821100
ALT NUMBER DOENV102493
KEYWORD   MESAVERDE
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   LENS MORPHOLOGY
KEYWORD   FORMAL
KEYWORD   GEOLOGY
****
ACCES NUM   N00305
REPORT NUM 1.4.3.035
AUTHOR   PETERSON,RE
AUTHOR   KOHOUT,J
TITLE   AN APPROXIMATION OF CONTINIUITY OF LENTICULAR MESAVERDE SANDSTONE
            LENSES UTILIZING CLOSE-WELL CORRELATIONS, PICEANCE BASIN,

NORTHWESTERN COLORADO
CORP AUTH CER
DATE 830300
ALT NUMBER SPEDOE11610
KEYWORD MESAVERDE
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD LENS MORPHOLOGY
KEYWORD GEOLOGY
KEYWORD FORMAL
NOTES THIS PAPER WAS PRESENTED AT THE 1983 SPE/DOE SYMPOSIUM ON LOW PERMEABILITY HELD IN DENVER, COLORADO, MARCH 14-16, 1983

****

ACCES NUM N00309
REPORT NUM 1.4.3.037
AUTHOR LORENZ,JC
TITLE RESERVOIR SEDIMENTOLOGY IN MESAVERDE ROCKS AT THE MULTI-WELL EXPERIMENT SITE
DATE 830600
ALT NUMBER SAND83-1078
KEYWORD LENS MORPHOLOGY
KEYWORD SEDIMENTOLOGY
KEYWORD MESAVERDE
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE
KEYWORD GEOLOGY
KEYWORD FORMAL

****

ACCES NUM N00748
REPORT NUM 1.4.3.039
AUTHOR LORENZ,JC
TITLE RESERVOIR SEDIMENTOLOGY OF MESAVERDE ROCKS AT THE MULTIWELL EXPERIMENT SITE AND EAST CENTRAL PICEANCE CREEK BASIN
CORP AUTH SAND
DATE 870100
ALT NUMBER SAND87-0040UC-92A
KEYWORD SEDIMENTOLOGY
KEYWORD MWX WELLS
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE
KEYWORD COZZETTE
KEYWORD CORCORAN
KEYWORD CORE ANALYSIS
KEYWORD RESERVOIR ANALYSIS

****

ACCES NUM N00780
REPORT NUM 1.4.3.040
AUTHOR LORENZ,JC
AUTHOR RUTLEDGE,AK
TITLE LATE CRETACEOUS MESAVERDE GROUP OUTCROPS AT RIFLE GAP, PICEANCE CREEK BASIN, NORTHWESTERN COLORADO
CORP AUTH SAND
DATE 870000
ALT NUMBER 68
KEYWORD FORMAL
KEYWORD OUTCROP DATA
KEYWORD MESAVERDE
KEYWORD MARINE
KEYWORD PALUDAL
KEYWORD COASTAL
KEYWORD FLUVIAL

KEYWORD   PARALIC
KEYWORD   OHIO CREEK
NOTES   GEOLOGICAL SOCIETY OF AMERICA CENTENNIAL FIELD GUIDE - ROCKY
            MOUNTAIN SECTION, 1987
****
ACCES NUM   N00143
REPORT NUM 1.4.4.015
AUTHOR   LORENZ,JC
TITLE   PICEANCE CREEK BASIN STRESS/TECTONIC HISTORY
CORP AUTH   SAND
DATE   840524
KEYWORD   NATURAL FRACTURES
KEYWORD   PICEANCE BASIN
KEYWORD   MESAVERDE
KEYWORD   STRESS HISTORY
KEYWORD   TECTONICS
KEYWORD   STRUCTURE
KEYWORD   PORE PRESSURE
KEYWORD   OVERBURDEN PRESSURE
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   ROLLINS
KEYWORD   MARINE
****
ACCES NUM   N00622
REPORT NUM 1.4.4.026
AUTHOR   FINLEY,SJ
TITLE   PRELIMINARY SUMMARY OF FRACTURE DATA FOR THE COASTAL RED AND
            YELLOW ZONES IN MWX WELLS
CORP AUTH   SAND
DATE   851113
KEYWORD   NATURAL FRACTURES
KEYWORD   CORE ANALYSIS
KEYWORD   MWX WELLS
KEYWORD   FRAC DATA
KEYWORD   CALCITE FILLING
KEYWORD   COASTAL
KEYWORD   FRACTURE DISTRIBUTION
KEYWORD   FRACTURE ORIENTATION
KEYWORD   FRACTURE HEIGHT
KEYWORD   FRACTURE WIDTH
****
ACCES NUM   N00623
REPORT NUM 1.4.4.027
AUTHOR   FINLEY,SJ
TITLE   PRELIMINARY MEMO ON THE DISTRIBUTION OF WIDER MINERALIZED
            FRACTURES IN THE MWX CORE
CORP AUTH   SAND
DATE   860310
KEYWORD   NATURAL FRACTURES
KEYWORD   CORE ANALYSIS
KEYWORD   FRACTURE WIDTH
KEYWORD   FRACTURE DISTRIBUTION
KEYWORD   CALCITE FILLING
KEYWORD   MWX1
KEYWORD   MWX2
KEYWORD   FRAC DATA
KEYWORD   COASTAL
KEYWORD   FLUVIAL
KEYWORD   PALUDAL
KEYWORD   MARINE
KEYWORD   FRACTURE HEIGHT
KEYWORD   FRACTURE ORIENTATION
****
ACCES NUM   N00633

REPORT NUM 1.4.4.028
AUTHOR   LORENZ,JC
TITLE   FRACTURE PERMEABILITY IN PLUGS
CORP AUTH   SAND
DATE   860324
KEYWORD   NATURAL FRACTURES
KEYWORD   COASTAL
KEYWORD   FLUVIAL
KEYWORD   CORCORAN
KEYWORD   CORE ANALYSIS
KEYWORD   PARALIC
KEYWORD   PERMEABILITY
KEYWORD   KLINKENBERG PERMEABILITY
KEYWORD   CALCITE FILLING
****
ACCES NUM   N00057
REPORT NUM 1.4.4.030
TITLE   MACROFRACTURE DEVELOPMENT IN MWX CORE
CORP AUTH   SAND
DATE   000000
KEYWORD   MWX1
KEYWORD   NATURAL FRACTURES
KEYWORD   CORE ANALYSIS
KEYWORD   MWX2
KEYWORD   PARALIC
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE
KEYWORD   COZZETTE
****
ACCES NUM   N00687
REPORT NUM 1.4.4.031
AUTHOR   FINLEY,SJ
TITLE   CORE FRACTURE FREQUENCY AND WIDTH DISTRIBUTION WITH RESPECT TO DEPTH IN MWX-1
CORP AUTH   SAND
DATE   851100
KEYWORD   MWX1
KEYWORD   NATURAL FRACTURES
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   CORE ANALYSIS
NOTES   CHART SHOWING MINERALIZED FRACTURE DISTRIBUTION IN MWX-1 CORE. (5000' TO 6600')
****
ACCES NUM   N00745
REPORT NUM 1.4.4.038
AUTHOR   FINLEY,SJ
TITLE   NATURAL FRACTURES IN DESIGNATED RESERVOIRS IN MWX-1 AND -2 CORE
CORP AUTH   SAND
DATE   870304
KEYWORD   CORE ANALYSIS
KEYWORD   NATURAL FRACTURES
KEYWORD   RESERVOIR ANALYSIS
KEYWORD   MWX1
KEYWORD   MWX2
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE
****
ACCES NUM   N00758
REPORT NUM 1.4.4.039
AUTHOR   FINLEY,SJ
TITLE   ORIENTED NATURAL FRACTURES IN MWX CORE

CORP AUTH SAND
DATE 870520
KEYWORD CORE ANALYSIS
KEYWORD NATURAL FRACTURES
KEYWORD FRACTURE ORIENTATION
KEYWORD ORIENTED CORE
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE

****

ACCES NUM N00793
REPORT NUM 1.4.4.041
AUTHOR LORENZ,JC
AUTHOR FINLEY,SJ
TITLE DIFFERENCES IN FRACTURE CHARACTERISTICS AND RELATED PRODUCTION OF NATURAL GAS IN DIFFERENT ZONES OF THE MESAVERDE FORMATION, NORTHWESTERN, COLORADO
CORP AUTH SAND
DATE 870927
ALT NUMBER SPE16809
KEYWORD FORMAL
KEYWORD NATURAL FRACTURES
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE
KEYWORD FRACTURE ORIENTATION
KEYWORD FRACTURE FILLING
KEYWORD FRACTURE DISTRIBUTION
KEYWORD WELL TESTING
KEYWORD GAS PRODUCTION
NOTES PRESENTED AT THE ANNUAL SPE CONFERENCE IN DALLAS,TX SEPT. 27-30,1987

****

ACCES NUM N00806
REPORT NUM 1.4.4.042
AUTHOR NORMAN,DI
TITLE REPORT ON INCLUSION VOLATILE ANALYSES ON SAMPLES FROM THE PICEANCE CREEK BASIN
CORP AUTH NMTECH
DATE 870831
ALT NUMBER 33-6617
KEYWORD NATURAL FRACTURES
KEYWORD FRACTURE FILLING
KEYWORD GEOCHEMISTRY
KEYWORD GAS ANALYSIS
KEYWORD TEMPERATURE ANALYSIS
KEYWORD FLUID INCLUSION ANALYSIS
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE

****

ACCES NUM N00807
REPORT NUM 1.4.4.043
AUTHOR NORMAN,DI
TITLE REPORT ON FLUID INCLUSION STUDY OF FRACTURE MINERALS FROM THE PICEANCE BASIN, COLORADO
CORP AUTH NMTECH
DATE 870831
ALT NUMBER 33-6617
KEYWORD NATURAL FRACTURES
KEYWORD FRACTURE FILLING
KEYWORD GEOCHEMISTRY
KEYWORD GAS ANALYSIS

KEYWORD   TEMPERATURE ANALYSIS
KEYWORD   FLUID INCLUSION ANALYSIS
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE
****
ACCES NUM   N00842
REPORT NUM 1.4.4.046
AUTHOR   GARRETT,CH
TITLE   FLUORESCENCE MICROSCOPY STUDY, MWX-3 6457'
CORP AUTH   CL
DATE   880317
KEYWORD   NATURAL FRACTURES
KEYWORD   PETROGRAPHIC ANALYSIS
KEYWORD   COASTAL
****
ACCES NUM   N00474
REPORT NUM 1.4.5.003
AUTHOR   SPENCER,CW
AUTHOR   KEIGHIN,CW
TITLE   GEOLOGIC STUDIES IN SUPPORT OF THE U.S. DOE'S MULTI-WELL EXPERIMENT,GARFIELD COUNTY, COLORADO.
CORP AUTH   USGS
DATE   841100
ALT NUMBER OFR 84757
KEYWORD   PARALIC
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   ROLLINS
KEYWORD   CORCORAN
KEYWORD   COZZETTE
KEYWORD   MARINE
KEYWORD   GEOLOGY
KEYWORD   GEOPHYSICS
KEYWORD   NATURAL FRACTURES
KEYWORD   MESAVERDE
KEYWORD   SEDIMENTOLOGY
KEYWORD   MINERALOGY
KEYWORD   PETROLOGY
KEYWORD   ORGANIC MATURATION
KEYWORD   FORMAL
NOTES   SUMMARY OF USGS WORK ON MWX
****
ACCES NUM   N00570
REPORT NUM 1.4.5.005
AUTHOR   BOSTICK,NH
AUTHOR   FREEMAN,VL
TITLE   VITRINITE REFLECTANCE AND PALEOTEMPERATURE MODELS TESTED AT DOE'S MULTIWELL EXPERIMENT SITE IN THE PICEANCE BASIN, COLORADO
CORP AUTH   USGS
DATE   840100
KEYWORD   COAL
KEYWORD   MESAVERDE
KEYWORD   VITRINITE REFLECTANCE
KEYWORD   MARINE
KEYWORD   PALUDAL
KEYWORD   COASTAL
KEYWORD   FLUVIAL
KEYWORD   MWX2
KEYWORD   MWX1
KEYWORD   CORE ANALYSIS
KEYWORD   PALEOTEMPERATURE
****
ACCES NUM   N00671

REPORT NUM 1.4.5.013
AUTHOR LORENZ,JC
AUTHOR BRANAGAN,P
AUTHOR WARPINSKI,NR
AUTHOR SATTLER,AR
TITLE FRACTURE CHARACTERISTICS AND RESERVOIR BEHAVIOR OF STRESS-SENSITIVE FRACTURE SYSTEMS IN FLAT-LYING LENTICULAR FORMATIONS
CORP AUTH SAND
CORP AUTH CER
DATE 860518
ALT NUMBER SPE 15244
KEYWORD FORMAL
KEYWORD NATURAL FRACTURES
KEYWORD HYDRAULIC FRACTURE
KEYWORD PERMEABILITY
KEYWORD RESERVOIR MODELING
KEYWORD PORE PRESSURE
KEYWORD WELL TESTING
KEYWORD OUTCROP DATA
KEYWORD CORE ANALYSIS
KEYWORD LENTICULAR SANDS
KEYWORD STIMULATION
KEYWORD PALUDAL
KEYWORD COASTAL
KEYWORD MINIFRACS
KEYWORD FORMATION DAMAGE
KEYWORD COZZETTE
KEYWORD CORCORAN
KEYWORD MARINE
NOTES PRESENTED AT THE UNCONVENTIONAL GAS TECHNOLOGY SYMPOSIUM OF THE SOCIETY OF PETROLEUM ENGINEERS, LOUISVILLE, KY, MAY 18-21,1986
****
ACCES NUM N00707
REPORT NUM 1.4.5.014
AUTHOR LAW,BE
TITLE FY1985 USGS ANNUAL REPORT
CORP AUTH USGS
DATE 860500
ALT NUMBER DOE/MX/20422-2044
KEYWORD PETROLOGY
KEYWORD MINERALOGY
KEYWORD ISOTOPIC ANALYSIS
KEYWORD PETROGRAPHIC ANALYSIS
KEYWORD X-RAY DIFFRACTION
KEYWORD CALCITE FILLING
KEYWORD NATURAL FRACTURES
KEYWORD VITRINITE REFLECTANCE
KEYWORD PARALIC
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE
****
ACCES NUM N00845
REPORT NUM 1.4.5.016
AUTHOR LORENZ,JC
AUTHOR FINLEY,SJ
TITLE SIGNIFICANCE OF DRILLING- AND CORING-INDUCED FRACTURES IN MESAVERDE CORE, NORTHWESTERN COLORADO
CORP AUTH SAND
DATE 880600
ALT NUMBER SAND88-1623
KEYWORD CORE ANALYSIS
KEYWORD DRILLING-INDUCED FRACTURES
KEYWORD SEM ANALYSIS

KEYWORD MWX WELLS
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD FORMAL
KEYWORD MARINE
****
ACCES NUM N00160
REPORT NUM 1.6.2.002
AUTHOR LEE,MW
TITLE VERTICAL SEISMIC PROFILES AT MULTI-WELL EXPERIMENT SITE, GARFIELD COUNTY, COLORADO
CORP AUTH USGS
DATE 831100
ALT NUMBER USGS OPEN FILE REPORT 84-168
KEYWORD COLORADO
KEYWORD FORMAL
KEYWORD MWX1
KEYWORD MWX2
KEYWORD PARALIC
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE
KEYWORD VSP
KEYWORD GEOPHYSICS
KEYWORD SEISMIC SURVEYS
****
ACCES NUM N00161
REPORT NUM 1.6.2.003
AUTHOR LEE,MW
TITLE DELINEATION OF LENTICULAR-TYPE SAND BODIES BY VERTICAL SEISMIC PROFILING METHOD
CORP AUTH USGS
DATE 831100
ALT NUMBER USGS OPEN FILE REPORT 84-265
KEYWORD VSP
KEYWORD FORMAL
KEYWORD GEOPHYSICS
KEYWORD SEISMIC SURVEYS
KEYWORD LENTICULAR SANDS
KEYWORD MESAVERDE
KEYWORD COASTAL
KEYWORD PALUDAL
****
ACCES NUM N00500
REPORT NUM 1.6.2.004
AUTHOR LEE,MW
AUTHOR MILLER,JJ
TITLE ACQUISITION AND PROCESSING OF AZIMUTHAL VERTICAL SEISMIC PROFILES AT MULTIWELL EXPERIMENT SITE, GARFIELD COUNTY, COLORADO
CORP AUTH USGS
DATE 850400
ALT NUMBER 85-427
KEYWORD FORMAL
KEYWORD VSP
KEYWORD GEOPHYSICS
KEYWORD MWX WELLS
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE
KEYWORD LENTICULAR SANDS
NOTES OPEN FILE REPORT
****
ACCES NUM N00501

REPORT NUM 1.6.2.005
AUTHOR LEE,MW
TITLE INTERPRETATION OF AZIMUTHAL VERTICAL SEISMIC PROFILE SURVEY AT MULTI-WELL EXPERIMENT SITE, GARFIELD COUNTY, COLORADO
CORP AUTH USGS
DATE 850400
ALT NUMBER 85-428
KEYWORD FORMAL
KEYWORD VSP
KEYWORD SEISMIC SURVEYS
KEYWORD GEOPHYSICS
KEYWORD COASTAL
KEYWORD LENTICULAR SANDS
NOTES OPEN FILE REPORT
****
ACCES NUM N00162
REPORT NUM 1.6.3.001
AUTHOR ALBRIGHT,JN
TITLE LOS ALAMOS MWX CROSSWELL ACOUSTIC MEASUREMENTS
CORP AUTH LANL
DATE 830207
KEYWORD GEOPHYSICS
KEYWORD MWX1
KEYWORD MWX2
KEYWORD LENTICULAR SANDS
KEYWORD COLORADO
KEYWORD CROSSWELL MEASUREMENTS
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE
****
ACCES NUM N00164
REPORT NUM 1.6.3.003
AUTHOR ALBRIGHT,JN
TITLE CROSSWELL ACOUSTIC IMAGING PROJECT - MONTHLY REPORT
CORP AUTH LANL
DATE 840113
KEYWORD GEOPHYSICS
KEYWORD MONTHLY REPORTS
KEYWORD CROSSWELL MEASUREMENTS
KEYWORD TOMOGRAPHY
KEYWORD COASTAL
KEYWORD MWX2
KEYWORD COMPUTER CODES
****
ACCES NUM N00165
REPORT NUM 1.6.3.004
AUTHOR ALBRIGHT,JN
TITLE LOS ALAMOS CROSSWELL ACOUSTIC SURVEY
CORP AUTH LANL
DATE 840201
KEYWORD CROSSWELL MEASUREMENTS
KEYWORD GEOPHYSICS
KEYWORD MWX2
KEYWORD COASTAL
****
ACCES NUM N00166
REPORT NUM 1.6.3.005
AUTHOR ALBRIGHT,JN
TITLE CROSSWELL ACOUSTIC IMAGING PROJECT - MONTHLY REPORT
CORP AUTH LANL
DATE 840216
KEYWORD GEOPHYSICS
KEYWORD MONTHLY REPORTS
KEYWORD CROSSWELL MEASUREMENTS

KEYWORD TOMOGRAPHY
KEYWORD MWX WELLS
KEYWORD COASTAL
KEYWORD COMPUTER CODES
****
ACCES NUM N00167
REPORT NUM 1.6.3.006
AUTHOR ALBRIGHT,JN
TITLE CROSSWELL ACOUSTIC IMAGING PROJECT - MONTHLY REPORT
CORP AUTH LANL
DATE 840314
KEYWORD GEOPHYSICS
KEYWORD MONTHLY REPORTS
KEYWORD CROSSWELL MEASUREMENTS
KEYWORD TOMOGRAPHY
KEYWORD COASTAL
KEYWORD COMPUTER CODES
****
ACCES NUM N00168
REPORT NUM 1.6.3.007
AUTHOR ALBRIGHT,JN
TITLE CROSSWELL ACOUSTIC IMAGING - MONTHLY REPORT
CORP AUTH LANL
DATE 840416
KEYWORD GEOPHYSICS
KEYWORD MONTHLY REPORTS
KEYWORD CROSSWELL MEASUREMENTS
KEYWORD TOMOGRAPHY
KEYWORD MWX1
KEYWORD MWX2
KEYWORD COASTAL
KEYWORD COMPUTER CODES
****
ACCES NUM N00170
REPORT NUM 1.6.3.008
AUTHOR ALBRIGHT,JN
TITLE CROSSWELL ACOUSTIC IMAGING - MONTHLY REPORT
CORP AUTH LANL
DATE 840618
KEYWORD GEOPHYSICS
KEYWORD MONTHLY REPORTS
KEYWORD CROSSWELL MEASUREMENTS
KEYWORD MWX1
KEYWORD MWX2
KEYWORD COASTAL
****
ACCES NUM N00169
REPORT NUM 1.6.3.009
AUTHOR ALBRIGHT,JN
AUTHOR TERRY,DA
TITLE CROSSWELL ACOUSTIC IMAGING PROJECT, JUNE 1984 REVIEW
CORP AUTH LANL
DATE 840600
ALT NUMBER LAUR841928
KEYWORD CROSSWELL MEASUREMENTS
KEYWORD GEOPHYSICS
KEYWORD COASTAL
KEYWORD MWX WELLS
NOTES PEER REVIEW OF UNCONVENTIONAL GAS RECOVERY RESEARCH JUNE 26-28, 1984 IN ROSSLYN, VIRGINIA
****
ACCES NUM N00639
REPORT NUM 1.6.3.010
AUTHOR JOHNSON,PA
AUTHOR ALBRIGHT,JN
TITLE IN SITU PHYSICAL PROPERTIES MEASUREMENTS USING CROSSWELL

ACOUSTIC DATA
CORP AUTH LANL
DATE 850500
ALT NUMBER SPE13881
KEYWORD COASTAL
KEYWORD FORMAL
KEYWORD CROSSWELL MEASUREMENTS
KEYWORD POROSITY
KEYWORD YOUNG'S MODULUS
KEYWORD POISSON'S RATIO
KEYWORD GEOPHYSICS
KEYWORD VELOCITY
NOTES PRESENTED AT 1985 SPE/DOE SYMPOSIUM ON LOW PERMEABILITY RESERVOIRS

****

ACCES NUM N00640
REPORT NUM 1.6.3.011
AUTHOR ALBRIGHT,JN
AUTHOR TERRY,DA
AUTHOR BRADLEY,CR
TITLE PATTERN RECOGNITION AND TOMOGRAPHY USING CROSSWELL ACOUSTIC DATA
CORP AUTH LANL
DATE 850500
ALT NUMBER SPE13854
KEYWORD CROSSWELL MEASUREMENTS
KEYWORD GEOPHYSICS
KEYWORD COASTAL
KEYWORD VELOCITY
KEYWORD TOMOGRAPHY
KEYWORD FORMAL
NOTES PRESENTED AT 1985 SPE/DOE SYMPOSIUM ON LOW PERMEABILITY RESERVOIRS, MAY 19-22,1985, DENVER,CO.

****

ACCES NUM N00641
REPORT NUM 1.6.3.012
AUTHOR ALBRIGHT,JN
AUTHOR JOHNSON,PA
TITLE CROSSWELL ACOUSTIC SURVEYING OF GAS SANDS: TRAVEL-TIME PATTERN RECOGNITION, SEISMIC Q, AND CHANNEL WAVES
CORP AUTH LANL
DATE 850619
KEYWORD FORMAL
KEYWORD CROSSWELL MEASUREMENTS
KEYWORD COASTAL
KEYWORD GEOPHYSICS
NOTES PRESENTED AT ANNUAL MEETING OF THE SOCIETY OF PROFESSIONAL WELL LOG ANALYSTS (SPWLA) JUNE 19,1985 DALLAS, TEXAS.

****

ACCES NUM N00642
REPORT NUM 1.6.3.013
AUTHOR ALBRIGHT,JN
AUTHOR JOHNSON,PA
AUTHOR PHILLIPS,WS
TITLE CROSSWELL ACOUSTIC IMAGING-MONTHLY REPORTS, JANUARY-NOVEMBER,1985
CORP AUTH LANL
DATE 850000
KEYWORD COASTAL
KEYWORD GEOPHYSICS
KEYWORD CROSSWELL MEASUREMENTS
KEYWORD MONTHLY REPORTS
KEYWORD TOMOGRAPHY
KEYWORD VSP
KEYWORD VELOCITY

****

ACCES NUM N00572
REPORT NUM 1.6.4.002

AUTHOR   SEARLS,CA
TITLE   THE MULTIWELL EXPERIMENT GEOPHYSICS PROGRAM FINAL REPORT
CORP AUTH   SAND
DATE   850900
ALT NUMBER SAND 85-1013
KEYWORD   FORMAL
KEYWORD   FINAL REPORT
KEYWORD   VSP
KEYWORD   3D SEISMIC
KEYWORD   SEISMIC SURVEYS
KEYWORD   SEISMOGRAM
KEYWORD   PALUDAL
KEYWORD   COASTAL
KEYWORD   FLUVIAL
KEYWORD   MWX WELLS
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE
KEYWORD   MWX PROGRAM
KEYWORD   GEOPHYSICS
****
ACCES NUM   N00297
REPORT NUM 1.6.4.003
AUTHOR   SEARLS,CA
AUTHOR   LEE,MW
AUTHOR   MILLER,JJ
AUTHOR   ALBRIGHT,JN
AUTHOR   FRIED,J
AUTHOR   APPLEGATE,JK
TITLE   A COORDINATED SEISMIC STUDY OF THE MULTI-WELL EXPERIMENT SITE
CORP AUTH   SAND
CORP AUTH   USGS
CORP AUTH   LANL
CORP AUTH   CSM
DATE   830300
ALT NUMBER SPEDOE11613
KEYWORD   FORMAL
KEYWORD   SEISMIC SURVEYS
KEYWORD   VSP
KEYWORD   3D SEISMIC
KEYWORD   FLUVIAL
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   MARINE
KEYWORD   CROSSWELL
NOTES   THIS PAPER WAS PRESENTED AT THE 1983 SPE/DOE SYMPOSIUM ON LOW
            PERMEABILITY HELD IN DENVER, COLORADO, MARCH 14-16, 1983
****
ACCES NUM   N00376
REPORT NUM 1.7.2.001
AUTHOR   WARPINSKI,NR
TITLE   INITIAL STRESS TEST RESULTS IN COASTAL INTERVAL
CORP AUTH   SAND
DATE   841008
KEYWORD   MINIFRACS
KEYWORD   IN SITU STRESS
KEYWORD   STRESS TESTS
KEYWORD   HYDRAULIC FRACTURE
KEYWORD   MWX3
KEYWORD   COASTAL
KEYWORD   LENTICULAR SANDS
****
ACCES NUM   N00670
REPORT NUM 1.7.3.001
AUTHOR   WARPINSKI,NR

TITLE INITIAL STRESS TESTS IN FLUVIAL ZONE
CORP AUTH SAND
DATE 860523
KEYWORD FLUVIAL
KEYWORD STRESS TESTS
KEYWORD MWX2
KEYWORD COZZETTE
KEYWORD CORCORAN
KEYWORD MARINE
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD PERFORATIONS
KEYWORD FRACTURE HEIGHT
KEYWORD FRACTURE WIDTH
KEYWORD CONTAINMENT
KEYWORD FRACTURE DESIGN
KEYWORD IN SITU STRESS
****
ACCES NUM N00759
REPORT NUM 1.7.5.002
AUTHOR WARPINSKI,NR
AUTHOR TEUFEL,LW
TITLE IN SITU STRESSES IN LOW PERMEABILITY, NONMARINE ROCKS
CORP AUTH SAND
DATE 870518
ALT NUMBER SPEDOE 16402
KEYWORD FORMAL
KEYWORD IN SITU STRESS
KEYWORD LENTICULAR SANDS
KEYWORD CORE ANALYSIS
KEYWORD ANELASTIC STRAIN RECOVERY
KEYWORD HYDRAULIC FRACTURE
KEYWORD MINIFRACS
KEYWORD RESERVOIR MODELING
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
NOTES PRESENTED AT THE 1987 SPEDOE JOINT SYMPOSIUM ON LOW PERMEABILITY RESERVOIRS, MAY18--19,1987, DENVER,CO.
****
ACCES NUM N00829
REPORT NUM 1.7.5.003
AUTHOR WARPINSKI,NR
TITLE NET CONFINING STRESSES IN MWX INTERVALS
CORP AUTH SAND
DATE 880217
KEYWORD MARINE
KEYWORD PALUDAL
KEYWORD COASTAL
KEYWORD FLUVIAL
KEYWORD IN SITU STRESS
KEYWORD STRESS TESTS
KEYWORD NET STRESS
****
ACCES NUM N00770
REPORT NUM 1.8.2.001
AUTHOR BRANAGAN,P
AUTHOR CIPOLLA,C
AUTHOR LEE,SJ
AUTHOR WILMER,R
TITLE PRELIMINARY RESERVOIR BASELINE ESTIMATES: COASTAL RED AND YELLOW SANDS
CORP AUTH CER
DATE 850321
KEYWORD WELL TESTING
KEYWORD RESERVOIR ANALYSIS

KEYWORD   COASTAL
****
ACCES NUM N00492
REPORT NUM 1.8.2.002
AUTHOR   BRANAGAN,P
AUTHOR   PALMER,S
TITLE   FLUID AND GAS SAMPLES FROM MWX-1 COASTAL RED AND YELLOW ZONES
CORP AUTH CER
DATE   850319
KEYWORD   COASTAL
KEYWORD   FLUID ANALYSIS
KEYWORD   GAS ANALYSIS
****
ACCES NUM N00503
REPORT NUM 1.8.2.003
AUTHOR   BRANAGAN,P
TITLE   PERF/BREAKDOWN IN MWX-1 AND PERF IN MWX-2
CORP AUTH CER
DATE   840921
KEYWORD   COASTAL
KEYWORD   WELL TESTING
****
ACCES NUM N00505
REPORT NUM 1.8.2.004
AUTHOR   BRANAGAN,P
TITLE   POST FRACTURE PRODUCTION PREDICTIONS FOR COASTAL RED ZONE
CORP AUTH CER
DATE   850320
KEYWORD   COASTAL
KEYWORD   RESERVOIR ANALYSIS
KEYWORD   PRODUCTION
****
ACCES NUM N00506
REPORT NUM 1.8.2.005
AUTHOR   BRANAGAN,P
TITLE   JANUARY LIQUID CLEAN-UP; COASTAL RED AND YELLOW ZONES
CORP AUTH CER
DATE   850115
KEYWORD   PRODUCTION
KEYWORD   COASTAL
KEYWORD   CLEAN-UP
****
ACCES NUM N00547
REPORT NUM 1.8.2.006
AUTHOR   BRANAGAN,P
TITLE   PRE-STIMULATION NITROGEN INJECTION TESTING OF THE RED AND YELLOW
           SANDSTONES
CORP AUTH CER
DATE   850603
KEYWORD   COASTAL
KEYWORD   NITROGEN INJECTION
KEYWORD   MWX2
KEYWORD   RESERVOIR ANALYSIS
KEYWORD   WELL TESTING
NOTES   DRAFT COPY ONLY
****
ACCES NUM N00557
REPORT NUM 1.8.2.007
AUTHOR   BRANAGAN,P
AUTHOR   LEE,SJ
AUTHOR   WILMER,R
AUTHOR   PALMER,S
TITLE   DATA AND TESTING OVERVIEW OF THE NITROGEN INJECTION EXPERIMENT
           PERFORMED IN THE RED AND YELLOW SANDSTONES
CORP AUTH CER
DATE   850724

KEYWORD   COASTAL
KEYWORD   NITROGEN INJECTION
KEYWORD   OVERVIEW
KEYWORD   WELL TESTING
****
ACCES NUM   N00632
REPORT NUM 1.8.2.008
AUTHOR   ELKINS,LF
TITLE   NITROGEN INJECTION TESTS, COASTAL YELLOW ZONE
DATE   860324
KEYWORD   COASTAL
KEYWORD   WELL TESTING
KEYWORD   STIMULATION
KEYWORD   RESERVOIR MODELING
KEYWORD   RESERVOIR ANALYSIS
KEYWORD   NITROGEN INJECTION
KEYWORD   NITROGEN FRAC
KEYWORD   NITROGEN FOAM FRAC
NOTES   LETTER TO DAVE NORTHROP FROM LINCOLN F. ELKINS, PETROLEUM
            CONSULTANT
****
ACCES NUM   N00699
REPORT NUM 1.9.1.024
AUTHOR   SATTLER,AR
AUTHOR   NORTHROP,DA
TITLE   MWX FRAC GRADIENTS AND TREATING PRESSURES
CORP AUTH   SAND
DATE   841120
KEYWORD   PALUDAL
KEYWORD   COASTAL
KEYWORD   STIMULATION
KEYWORD   HYDRAULIC FRACTURING
KEYWORD   MWX1
KEYWORD   1XM9
NOTES   SPE 12108 "ABNORMAL TREATING PRESSURES IN MHF TREATMENTS" IS
            ATTACHED AS A REFERENCE
****
ACCES NUM   N00508
REPORT NUM 1.9.2.001
AUTHOR   WARPINSKI,NR
TITLE   NITROGEN FRAC
CORP AUTH   SAND
DATE   850513
KEYWORD   COASTAL
KEYWORD   HYDRAULIC FRACTURING
KEYWORD   STIMULATION
KEYWORD   NITROGEN
****
ACCES NUM   N00546
REPORT NUM 1.9.2.002
AUTHOR   BRANAGAN,P
TITLE   PRELIMINARY RESULTS OF THE N2 FRACTURING EXPERIMENT IN THE YELLOW
            SANDSTONE
CORP AUTH   CER
DATE   850619
KEYWORD   STIMULATION
KEYWORD   COASTAL
KEYWORD   NITROGEN FRAC
NOTES   INCLUDES C. CIPOLLA'S MEMO ON SAME SUBJECT
****
ACCES NUM   N00560
REPORT NUM 1.9.2.003
AUTHOR   BRANAGAN,P
AUTHOR   WILMER,R
AUTHOR   PALMER,S
TITLE   COASTAL YELLOW SANDSTONE NITROGEN FOAM FRAC GAMMA RAY TRACER

SURVEYS
CORP AUTH CER
DATE 850815
KEYWORD FRACTURE HEIGHT
KEYWORD FRACTURE ZONE
KEYWORD COASTAL
KEYWORD MWX1
KEYWORD CONTAINMENT
KEYWORD NITROGEN FOAM FRAC
KEYWORD RADIOACTIVE TRACER

****

ACCES NUM N00561
REPORT NUM 1.9.2.004
AUTHOR CIPOLLA,C
TITLE COASTAL FOAM FRAC OPERATIONS
CORP AUTH CER
DATE 850806
KEYWORD MWX1
KEYWORD STIMULATION
KEYWORD COASTAL
KEYWORD OPERATIONS
KEYWORD NITROGEN FOAM FRAC
NOTES A QUALITY CONTROL ASSESSMENT AND REPORT

****

ACCES NUM N00562
REPORT NUM 1.9.2.005
AUTHOR BRANAGAN,P
TITLE N2 FOAM FRAC RESERVOIR DATA
CORP AUTH CER
DATE 850819
KEYWORD STIMULATION
KEYWORD NITROGEN FOAM FRAC
KEYWORD COASTAL
KEYWORD MWX1

****

ACCES NUM N00585
REPORT NUM 1.9.2.006
AUTHOR WARPINSKI,NR
TITLE SPECULATIONS ON PERMEABILITY REDUCTION OF NATURAL FRACTURES DUE TO
CORP AUTH SAND
DATE 851016
KEYWORD COASTAL
KEYWORD ASPERITY SHEARING
KEYWORD NATURAL FRACTURES
KEYWORD HYDRAULIC FRACTURE
KEYWORD PERMEABILITY

****

ACCES NUM N00603
REPORT NUM 1.9.2.007
AUTHOR WARPINSKI,NR
TITLE ASPERITY SHEARING MECHANISM FOR DAMAGING NATURAL FRACTURES DURING HYDRAULIC FRACTURING
CORP AUTH SAND
DATE 851127
KEYWORD NATURAL FRACTURES
KEYWORD ASPERITY SHEARING
KEYWORD HYDRAULIC FRACTURING
KEYWORD STIMULATION
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD FORMATION DAMAGE

****

ACCES NUM N00605
REPORT NUM 1.9.2.008
AUTHOR WARPINSKI,NR

TITLE ANALYSIS OF MWX YELLOW COASTAL ZONE NITROGEN FRAC
CORP AUTH SAND
DATE 850702
KEYWORD NITROGEN FRAC
KEYWORD COASTAL
KEYWORD RESERVOIR MODELING
KEYWORD INTERFERENCE TEST
KEYWORD MWX1

****

ACCES NUM N00695
REPORT NUM 1.9.2.009
AUTHOR WARPINSKI,NR
TITLE ANALYSES OF AUGUST,1985 COASTAL FOAM FRAC
CORP AUTH SAND
DATE 860725
KEYWORD COASTAL
KEYWORD STIMULATION
KEYWORD NITROGEN INJECTION
KEYWORD INTERFERENCE TEST
KEYWORD NITROGEN FOAM FRAC
KEYWORD CORE ANALYSIS
KEYWORD RESERVOIR PROPERTIES
KEYWORD ROCK PROPERTIES
KEYWORD STRESS TESTS
KEYWORD FRACTURE DESIGN
KEYWORD FRACTURE DIAGNOSTICS
KEYWORD BOREHOLE SEISMIC
KEYWORD FRAC DATA
KEYWORD LEAKOFF
KEYWORD NATURAL FRACTURES
KEYWORD FRACTURE HEIGHT
KEYWORD PROPPANT

****

ACCES NUM N00797
REPORT NUM 1.9.2.010
AUTHOR HART,CM
AUTHOR NEWELL,RA
AUTHOR MORRIS,HE
TITLE BOREHOLE SEISMIC SYSTEM ANALYSIS FOR A COMPLEX DATA SET: CHRONOLOGY
CORP AUTH SAND
DATE 860400
ALT NUMBER DRAFT OF SAND86-0705
KEYWORD COASTAL
KEYWORD FRACTURE DIAGNOSTICS
KEYWORD BOREHOLE SEISMIC
KEYWORD STIMULATION

****

ACCES NUM N00776
REPORT NUM 1.9.3.013
AUTHOR WARPINSKI,NR
TITLE ANALYSIS OF THE FLUVIAL "B" FRACTURE EXPERIMENT
CORP AUTH SAND
DATE 870616
KEYWORD STIMULATION
KEYWORD FLUVIAL
KEYWORD HYDRAULIC FRACTURING
KEYWORD DAMAGE
KEYWORD NATURAL FRACTURES
KEYWORD FRACTURING FLUID
KEYWORD NITROGEN FRAC
KEYWORD NITROGEN FOAM FRAC
KEYWORD COASTAL
KEYWORD MECHANICAL PROPERTIES
KEYWORD STRESS TESTS
NOTES B SAND

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ACCES NUM   N00513
REPORT NUM 1.9.5.004
AUTHOR   TEUFEL,LW
AUTHOR   HART,CM
AUTHOR   SATTLER,AR
AUTHOR   CLARK,JA
TITLE   DETERMINATION OF HYDRAULIC FRACTURE AZIMUTH BY GEOPHYSICAL,
            GEOLOGICAL, AND ORIENTED CORE METHODS AT THE MULTI-WELL
            EXPERIMENT SITE, RIFLE, CO.
CORP AUTH   SAND
DATE   840916
ALT NUMBER SPE 13226
KEYWORD   ANELASTIC STRAIN RECOVERY
KEYWORD   HYDRAULIC FRACTURE
KEYWORD   CORE RELAXATION
KEYWORD   GEOLOGY
KEYWORD   GEOPHYSICS
KEYWORD   FORMAL
KEYWORD   ORIENTED CORE
KEYWORD   FRACTURE AZIMUTH
KEYWORD   COASTAL
KEYWORD   FRACTURE DIAGNOSTICS
KEYWORD   TELEVIEWER LOGS
KEYWORD   MARINE
KEYWORD   PALUDAL
KEYWORD   FLUVIAL
KEYWORD   MWX WELLS
NOTES   PRESENTED AT THE 59TH ANNUAL SPE MEETING HOUSTON TX,
            SEPTEMBER,1984
****
ACCES NUM   N00614
REPORT NUM 1.9.5.006
AUTHOR   WARPINSKI,NR
TITLE   COMPARISON OF MWX FRACTURING EXPERIMENTS WITH OTHER EXHAUSTIVE
            FRACTURING TESTS
CORP AUTH   SAND
DATE   860108
KEYWORD   PALUDAL
KEYWORD   COASTAL
KEYWORD   STIMULATION
KEYWORD   NATURAL FRACTURES
KEYWORD   WELL TESTING
KEYWORD   FORMATION DAMAGE
KEYWORD   OVERVIEW
****
ACCES NUM   00398
REPORT NUM 3.1.003
AUTHOR   FROHNE,KH
TITLE   THIRD ANNUAL WESTERN GAS SANDS PROGRAM REVIEW
CORP AUTH   METC
DATE   841100
ALT NUMBER DOEMETC 85-7
KEYWORD   SEDIMENTOLOGY
KEYWORD   GEOLOGY
KEYWORD   MARINE
KEYWORD   COZZETTE
KEYWORD   COASTAL
KEYWORD   PALUDAL
KEYWORD   FLUVIAL
KEYWORD   PARALIC
KEYWORD   NATURAL FRACTURES
KEYWORD   MWX PROGRAM
KEYWORD   REVIEW
****
ACCES NUM   N00630

REPORT NUM 3.1.004
AUTHOR KOMAR,CA
TITLE PROCEEDINGS OF THE UNCONVENTIONAL GAS RECOVERY CONTRACTORS MEETING
CORP AUTH DOE
DATE 851100
ALT NUMBER DOE/METC-86/6034
KEYWORD TIGHT GAS SANDS
KEYWORD PICEANCE BASIN
KEYWORD MWX PROGRAM
KEYWORD GEOLOGY
KEYWORD GEOPHYSICS
KEYWORD CORE ANALYSIS
KEYWORD REVIEW
KEYWORD FORMAL
KEYWORD RESERVOIR MODELING
KEYWORD STIMULATION
KEYWORD PALUDAL
KEYWORD COASTAL
****
ACCES NUM N00854
REPORT NUM 3.1.018
AUTHOR WARPINSKI,NR
TITLE GAS IN PLACE AT MULTIWELL EXPERIMENT SITE
CORP AUTH SAND
DATE 880929
KEYWORD GAS PRODUCTION
KEYWORD RESERVOIR ANALYSIS
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE
****
ACCES NUM N00847
REPORT NUM 3.1.021
AUTHOR LORENZ,JC
AUTHOR WARPINSKI,NR
AUTHOR TEUFEL,LW
AUTHOR BRANAGAN,P
AUTHOR SATTLER,AR
AUTHOR NORTHROP,DA
TITLE RESULTS OF THE MULTIWELL EXPERIMENT, IN SITU STRESSES, NATURAL FRACTURES, AND OTHER GEOLOGICAL CONTROLS ON RESERVOIRS
CORP AUTH SAND
CORP AUTH CER
DATE 880830
KEYWORD FORMAL
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD MARINE
KEYWORD MWX WELLS
KEYWORD IN SITU STRESS
KEYWORD NATURAL FRACTURES
KEYWORD STIMULATION
NOTES EOS VOL 69, NO 35 P817,825-826
****
ACCES NUM N00613
REPORT NUM 3.5.009
AUTHOR SATTLER,AR
AUTHOR LORENZ,JC
AUTHOR WARPINSKI,NR
TITLE MULTIWELL EXPERIMENT TOPICAL MEETING ON FEBRUARY 26 AND 27,1986
CORP AUTH SAND
DATE 860103
KEYWORD TOPICAL MEETINGS
KEYWORD WELL TESTING

KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD PALUDAL
KEYWORD NATURAL FRACTURES
KEYWORD CORE ANALYSIS
KEYWORD OUTCROP DATA
KEYWORD RESERVOIR MODELING
KEYWORD ASPERITY SHEARING
KEYWORD STIMULATION
NOTES TOPICAL MEETING FEBRUARY 26 AND 27,1986 -ALBUQUERQUE
****
ACCES NUM N00519
REPORT NUM 5.3.1.001
TITLE SPECIAL CORE ANALYSIS STUDY - 1XM9
CORP AUTH CL
DATE 850225
KEYWORD NOSR
KEYWORD 1XM9
KEYWORD WASATCH
KEYWORD FLUVIAL
KEYWORD COASTAL
KEYWORD KLINKENBERG PERMEABILITY
KEYWORD POROSITY