Fractured Reservoirs of the Shaikan Anticline, Northern Iraq

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Kahramanmaras
Adıyaman
Batman
Urmia
ارومیه
Maragheh
مراغه
Rasht
رشت
Gaziantep
Urfa
Kızıltepe
Viranşehir
Nusaybin
Mahabad
مهاباد
Zanjān
زنجان
Lāhījān
لاهیجان
Aleppo
حلب
Mosul
الموصل
Arbil
اربیل
Saqqez
سقز
Abhar
ابهر
Qazvin
قزوین
Ar Raqqah
الرقة
Al Hasakah
الحسكة
Kirkuk
كركوك
Deir ez-Zur
دير الزور
Sanandaj
سنندج
Hamah
حماة
Syria
Homs
حمص
Al Bukamal
البوكمال
Hamedan
همدان
Kermanshah
كرمانشاه
Samarra
سامراء
Arak
اراک
Borujerd
بروجرد
Ramadi
الرمادي
Baghdad
بغداد
Kuhdasht
كوهدشت
Khoramabad
خرم آباد
Damascus
دمشق
Irbid
Iraq
Karbala
كربلاء
Kut
الكوت
Dezful
دزفول
Amarah
العمارة
Jerusalem
Jordan
Najaf
النجف الاشرف
Nasiriyah
الناصرية
Ahvaz
اهواز
Arar
عرعر
Basrah
البصرة
Behbahān
بهبهان
Sakaka
سكاكا
Maan
معان
Ābādān
آبادان
Al Khanafah
Wildlife Sanctuary
محمية الطبق
محمية الحنفة
Kuwait City
Kuwait
مدينة الكويت
Tabuk
تبوك
Hafar Al Batin
حفر الباطن
Khafji
الخفجي


Taurus
Zagros
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رشت
Behbahān
بهبهان

29 km x 10 km fold trap

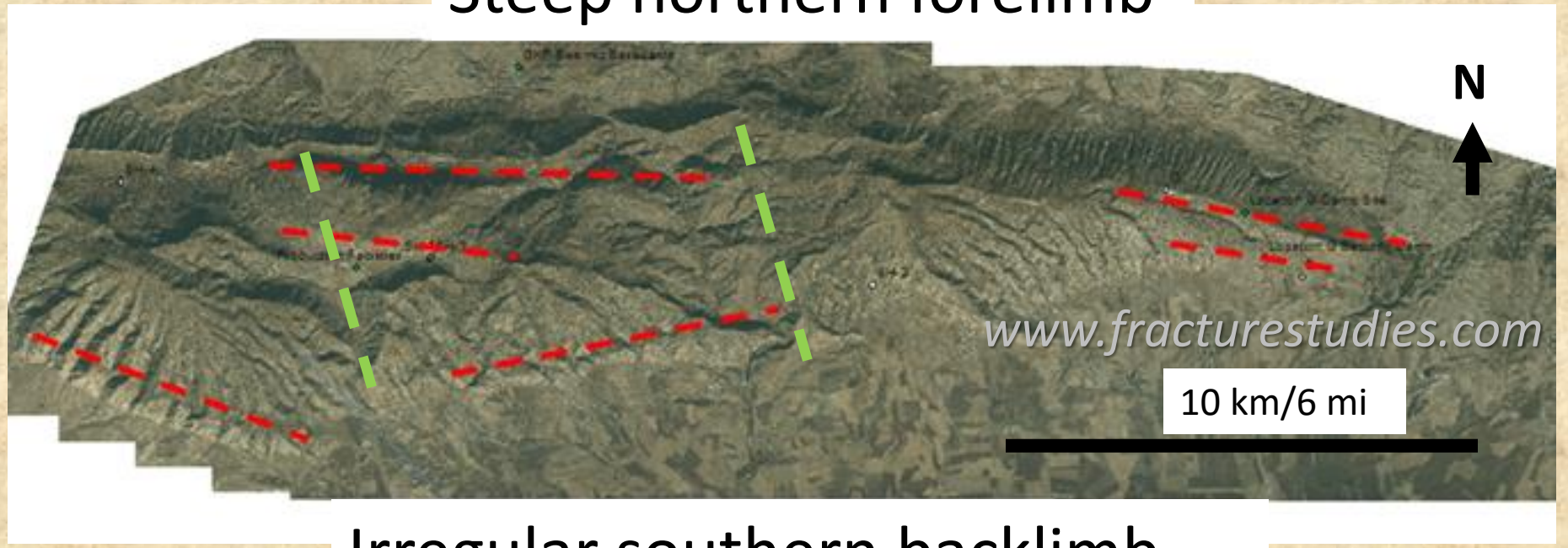
Stacked Mesozoic carbonate reservoirs

-800 m to 3200 m depths

9 billion barrels of oil in place

Internal folds and hinges, transverse faults

Steep northern forelimb

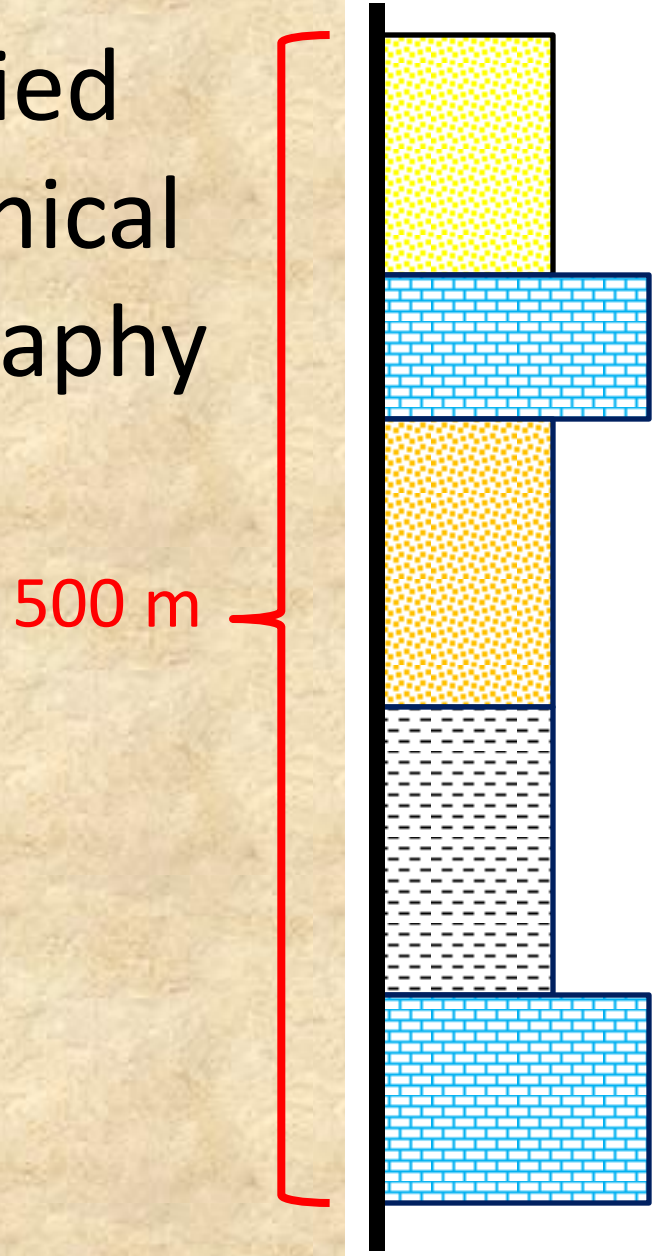


Irregular southern backlimb

Surface Data Set

- 53 outcrop stations, 1500 measured fractures
- 3 basic structural positions
- 5 formations

Simplified mechanical stratigraphy



FARS: Evaporitic clastics

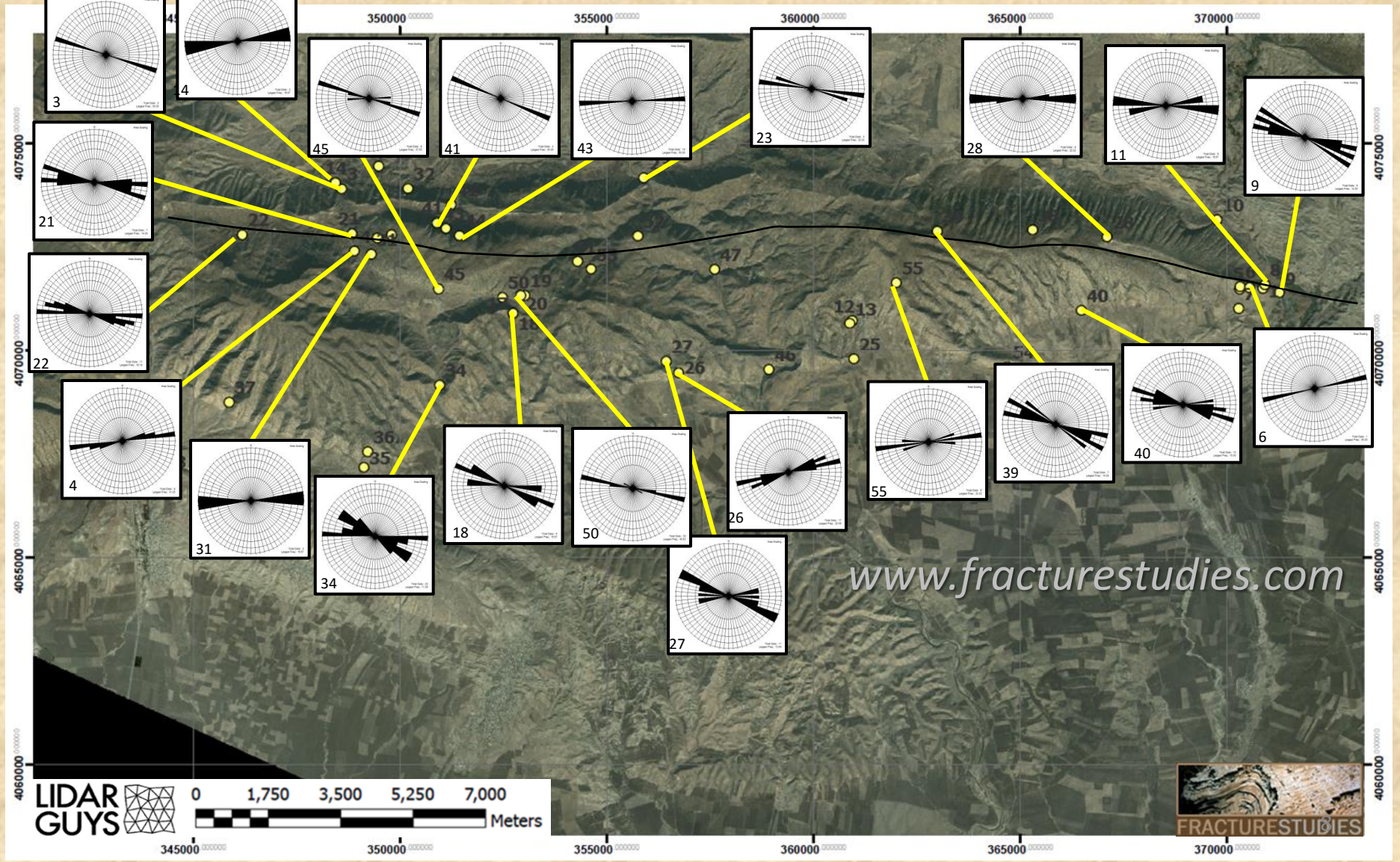
PILA SPI: Limestone

GERCUS: Muddy Clastics

KOLOSH: Shale

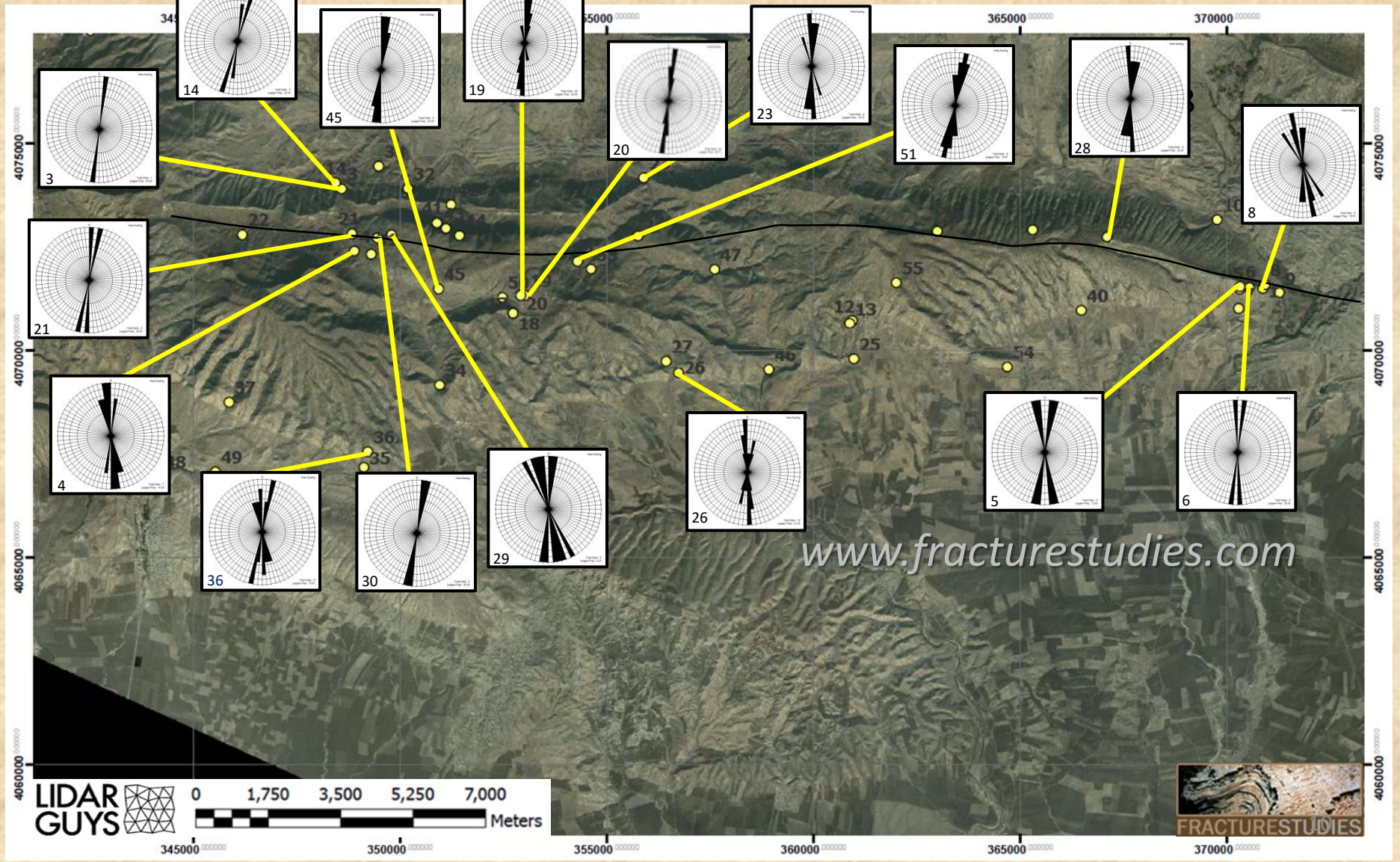
AQRA: Limestone

Extension fractures: E-W, hinge-parallel

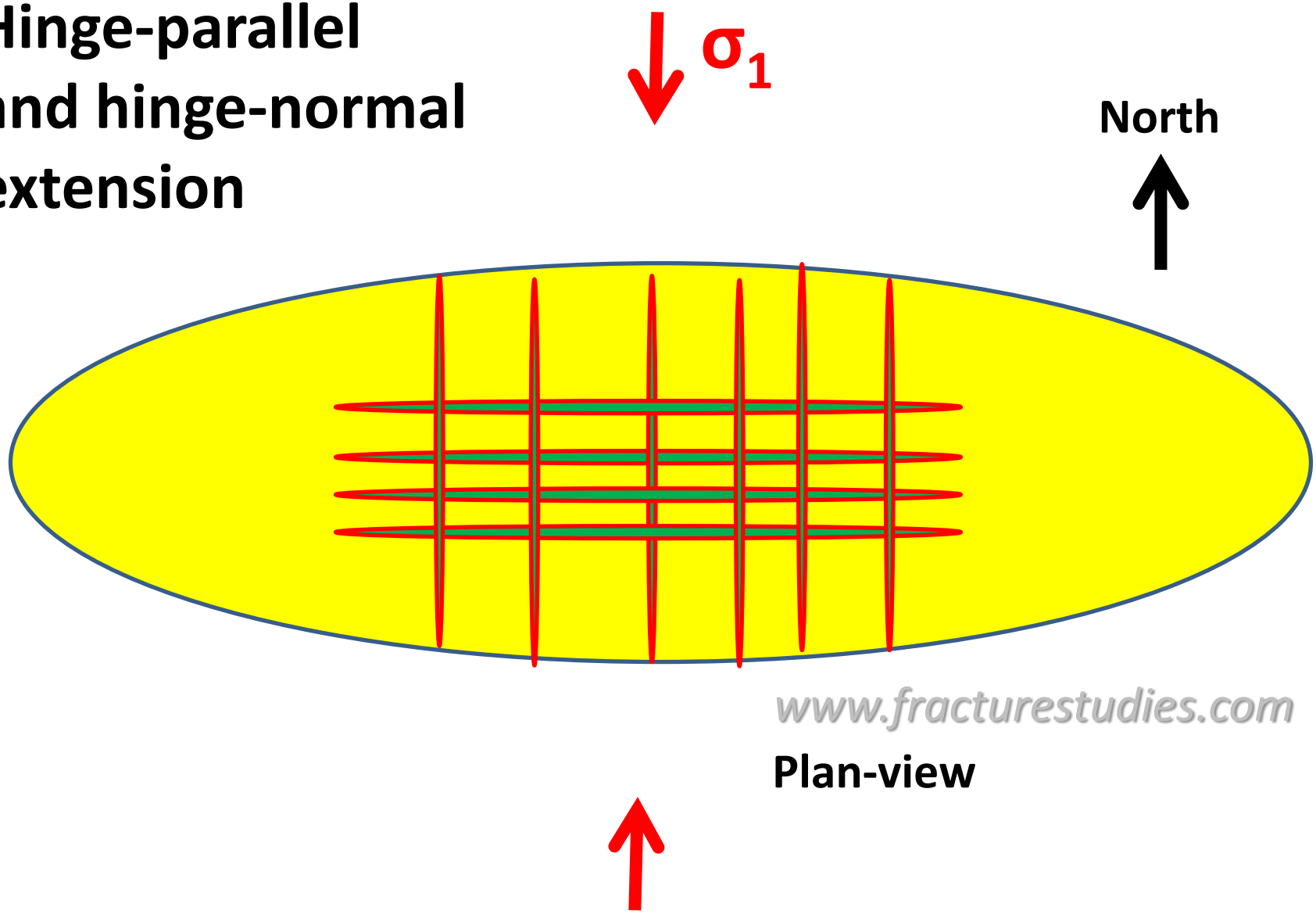


Box-Fold Hinge, South Limb

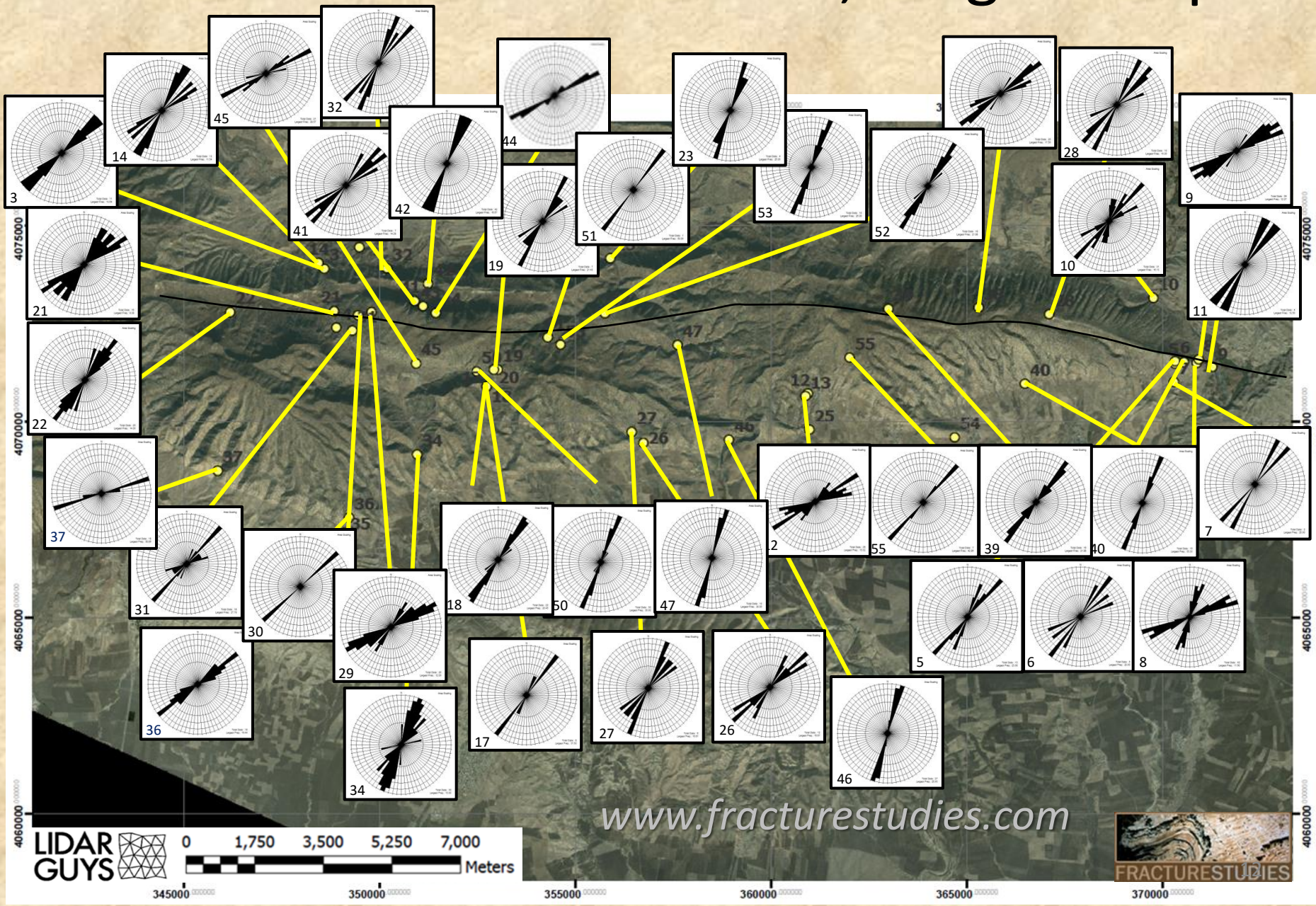
Extension Fractures: N-S, hinge-normal



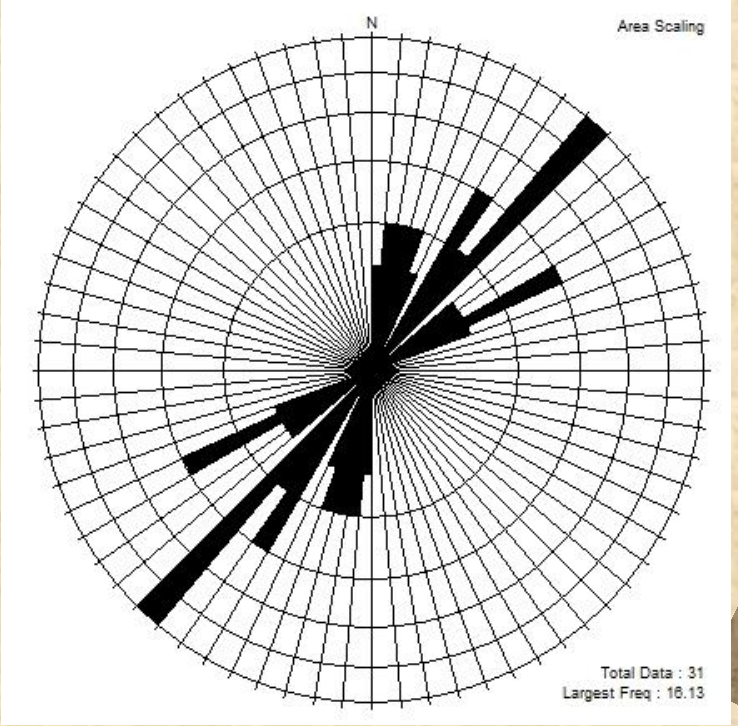
Hinge-parallel and hinge-normal extension

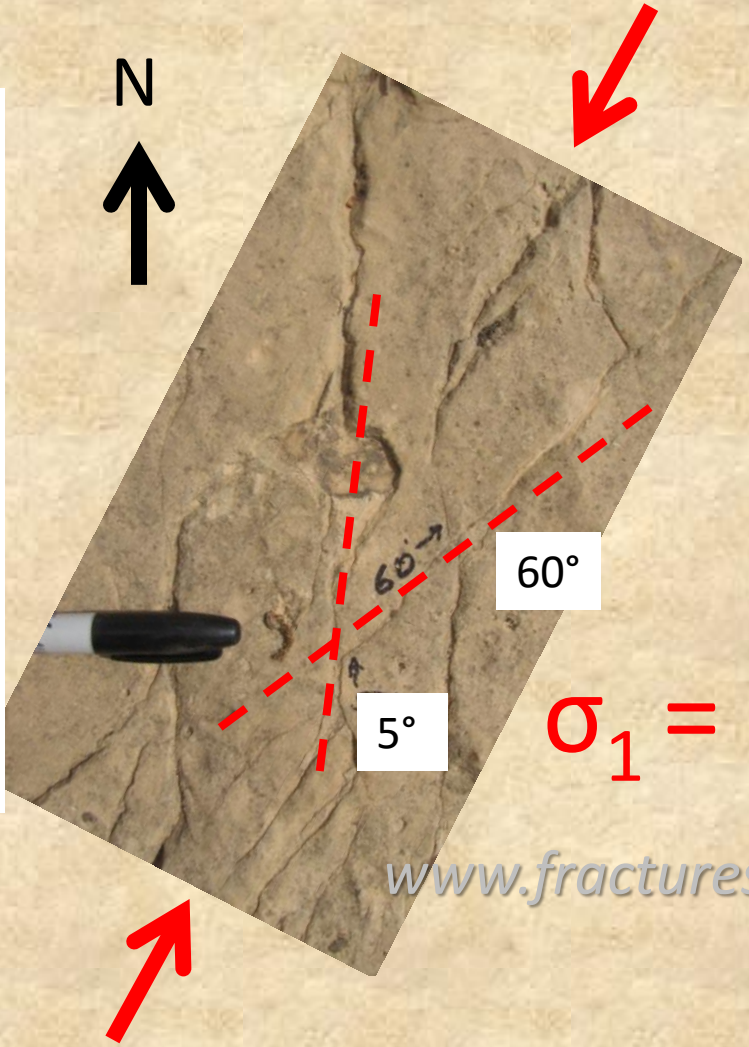


Extension fractures: NE-SW, hinge-oblique



Strike-slip conjugate shears define S_1





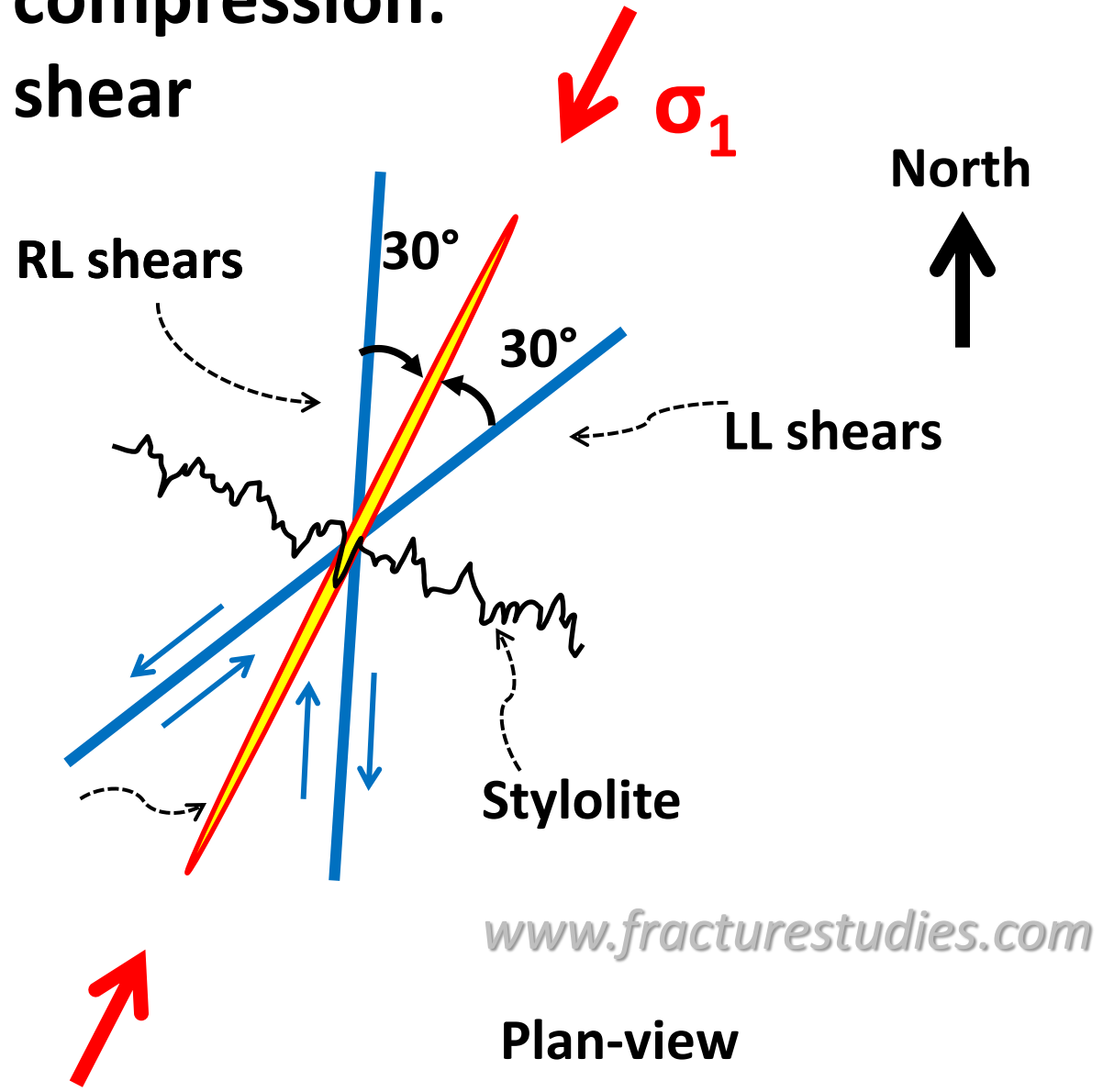
$\sigma_1 = 25\text{-}205°$

Bed-normal stylolites

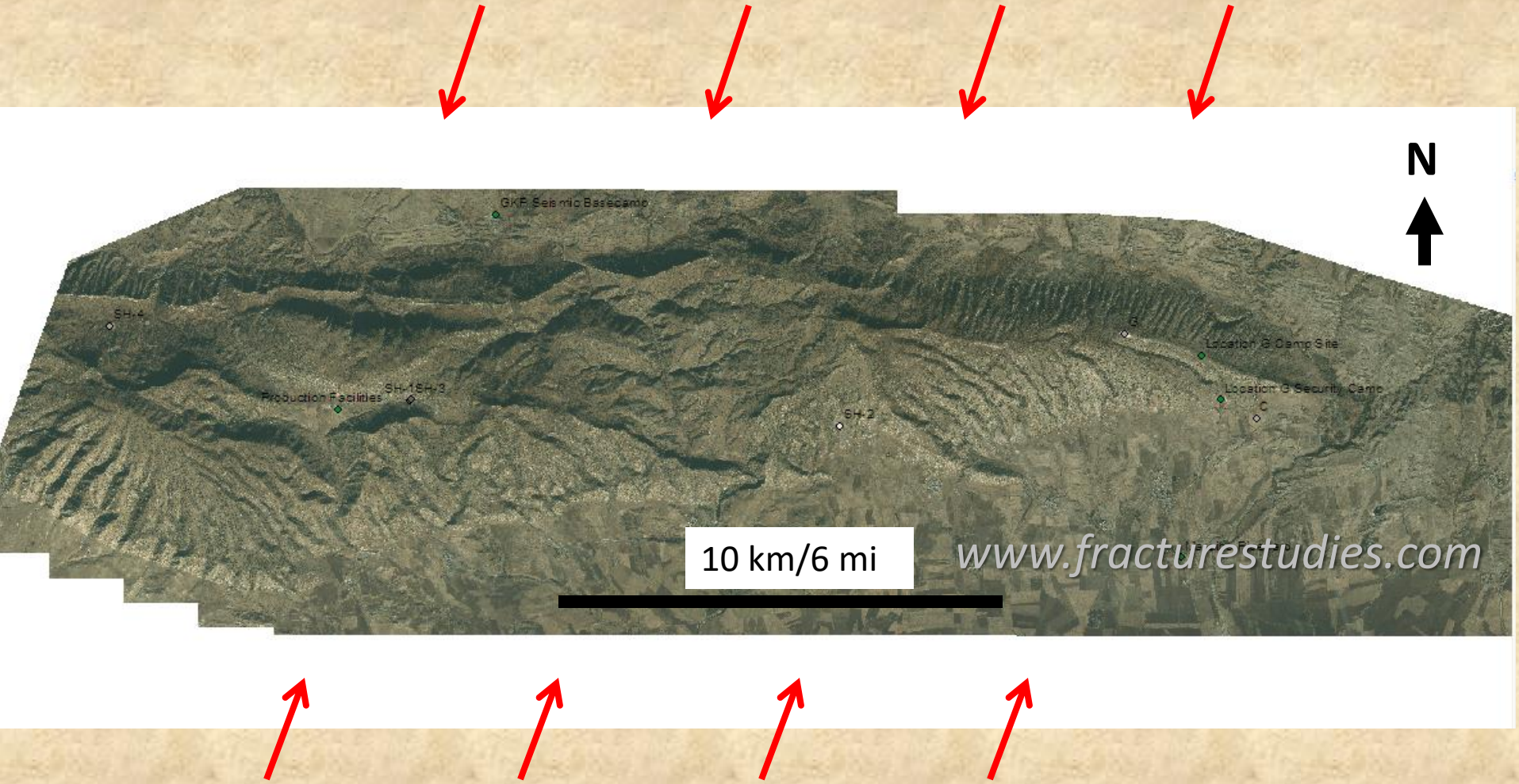
σ_1 = 20-200°

Plan view

Hinge-oblique compression: extension and shear

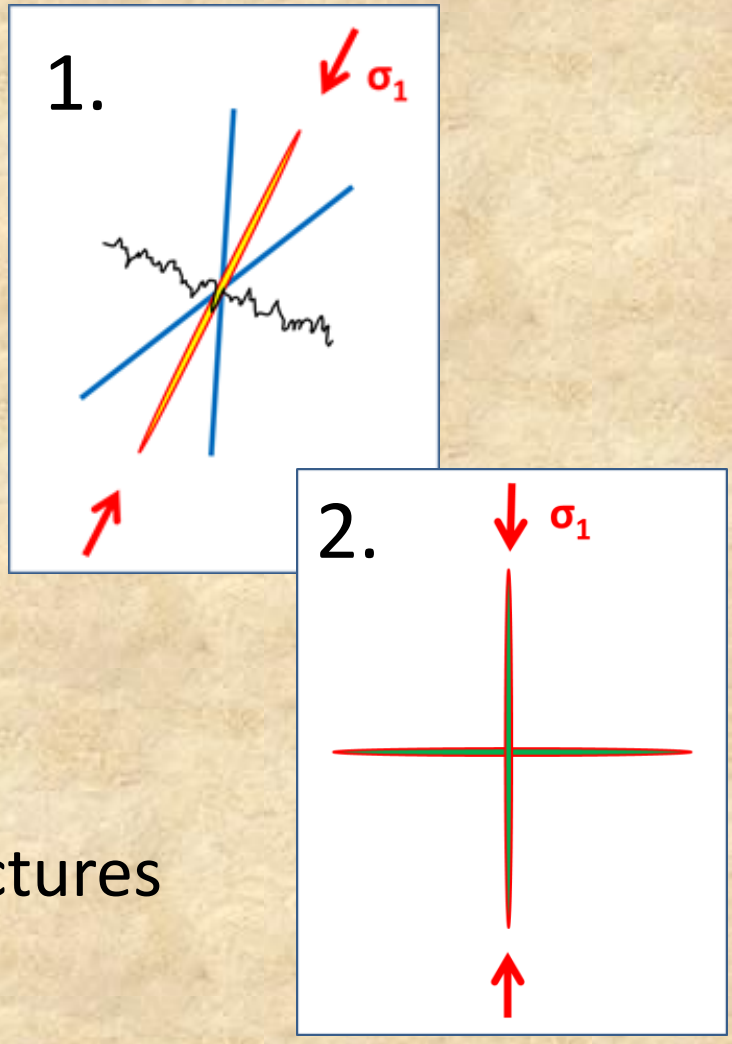


Fractures Record a Pre-Fold NE-SW to NNE-SSW Compression



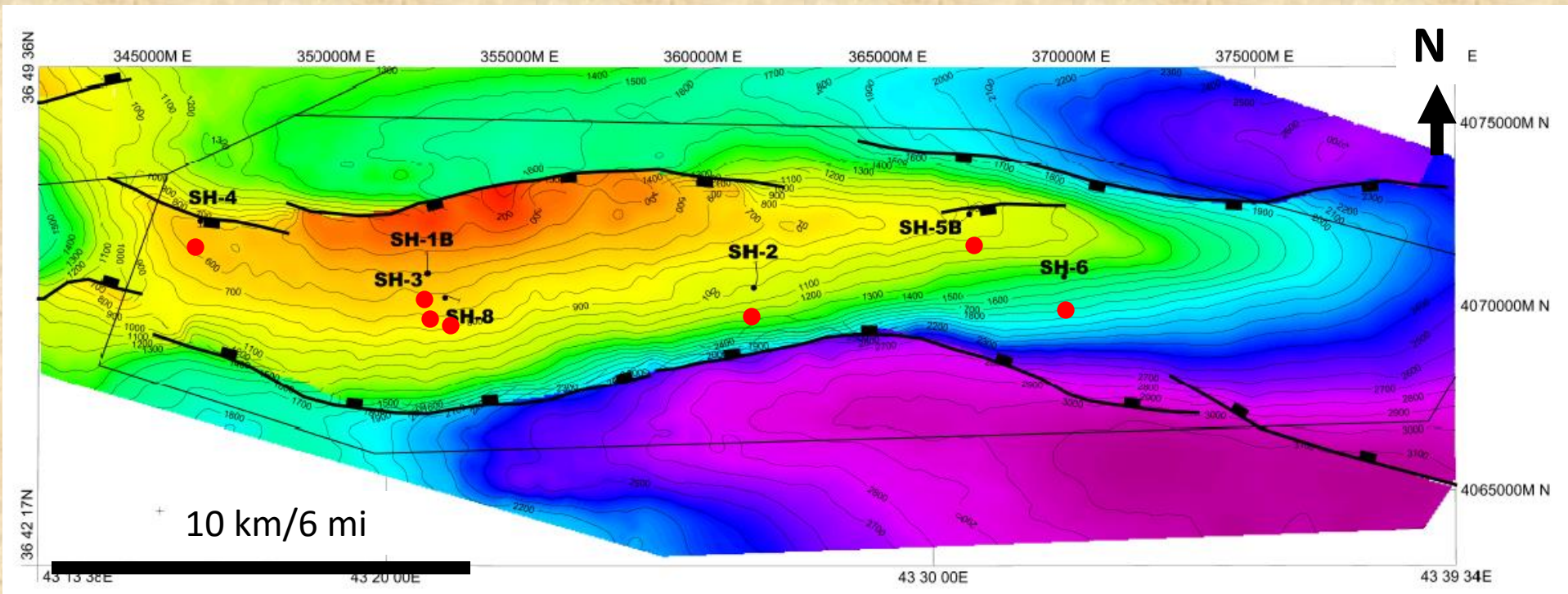
Tectonic model

- 1. Pre-fold
  - NE-SW bed-parallel σ_1
  - Extension and shear fractures
- 2. Folding
  - N-S bed-parallel σ_1
  - Two sets of extension fractures



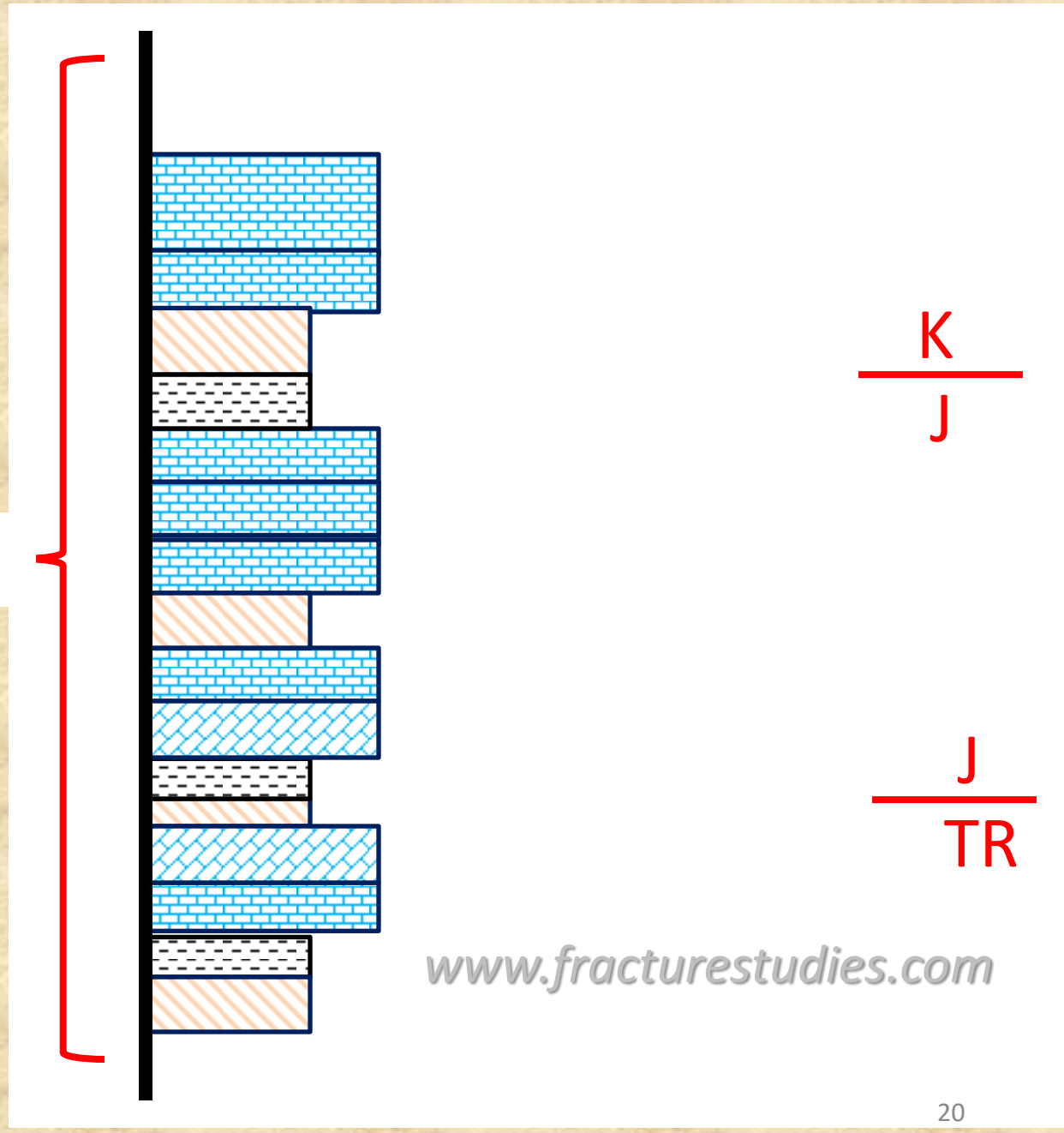
SUBSURFACE DATA SET

- 7 wells
- 11 formations
- 314 meters of core
- 1995 measured fractures

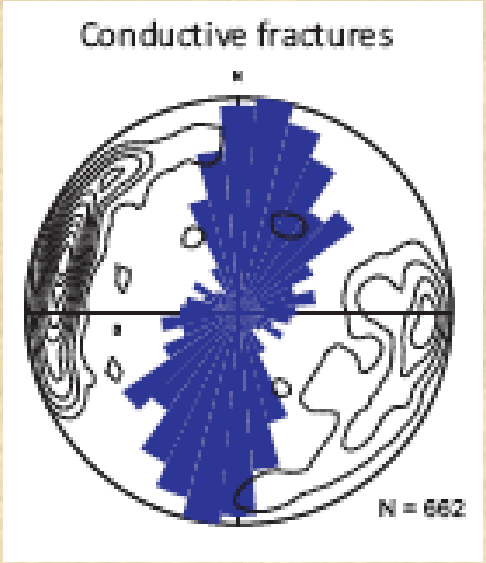


Well#	Structural position: Forelimb	Crest	Backlimb
SH-1A/1B			x
SH-2			x
SH-3			x
SH-4	x		
SH-5B		x	
SH-6			x
SH-8			x

Simplified subsurface mechanical stratigraphy



81% are extension fractures,
Butmah Fm, SH-3



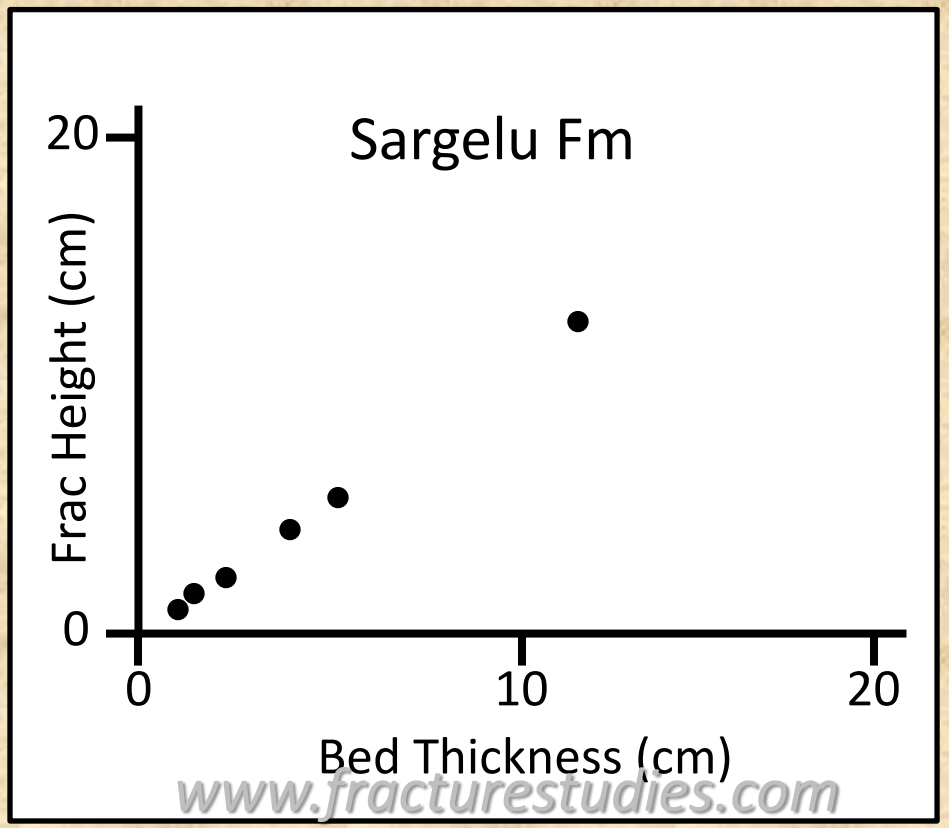
Intersecting extension fractures

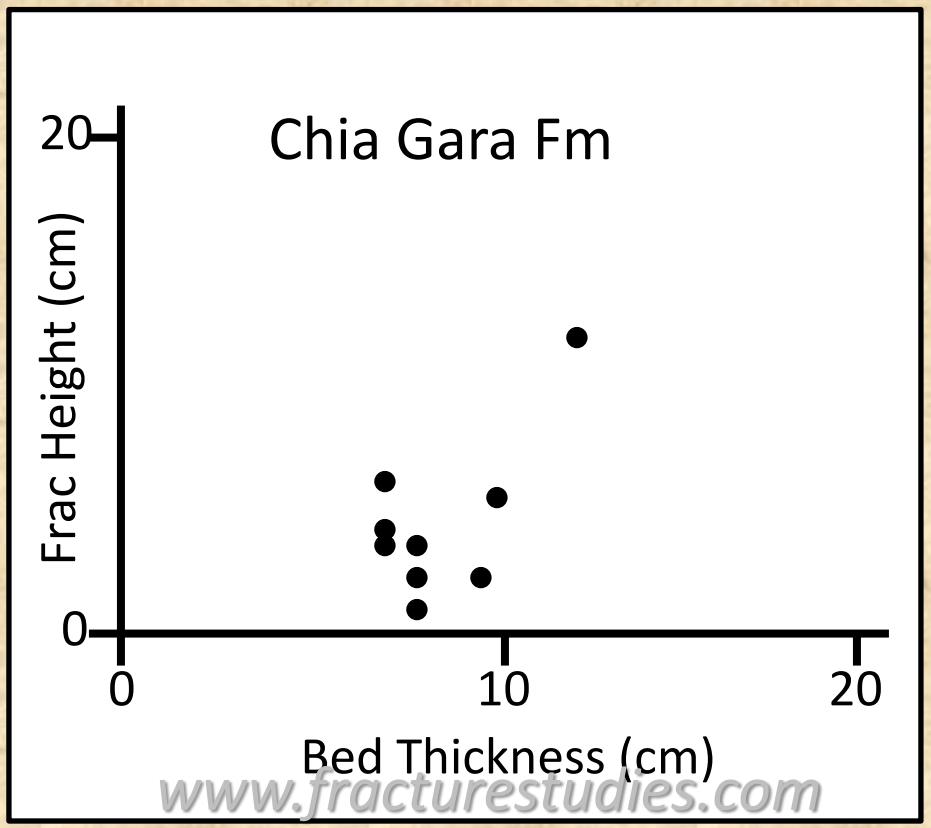
Mus Formation

Alan Formation

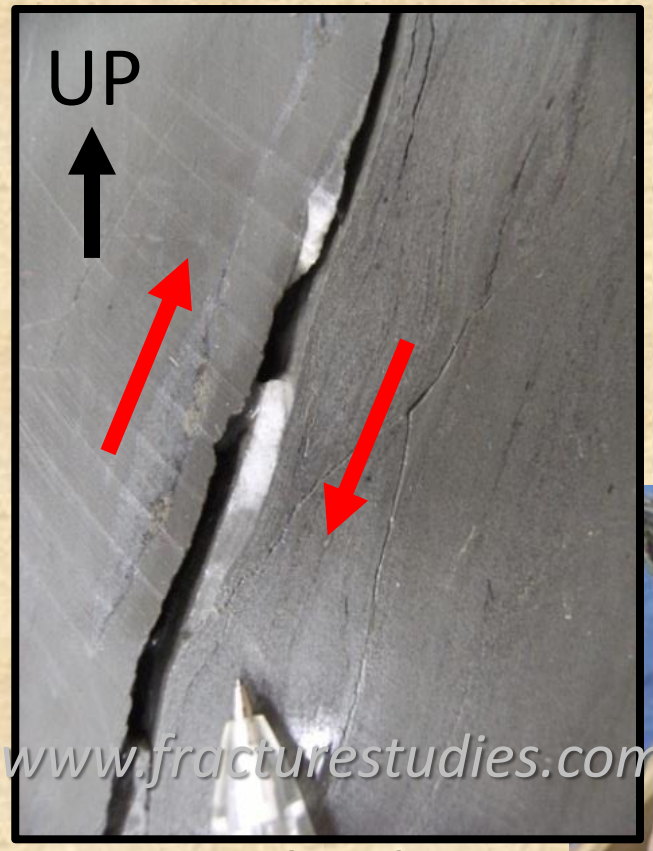
Dissolution slots follow fractures; Sargelu Fm

Strata-bound vs. short fractures in different formations, SH-1B core





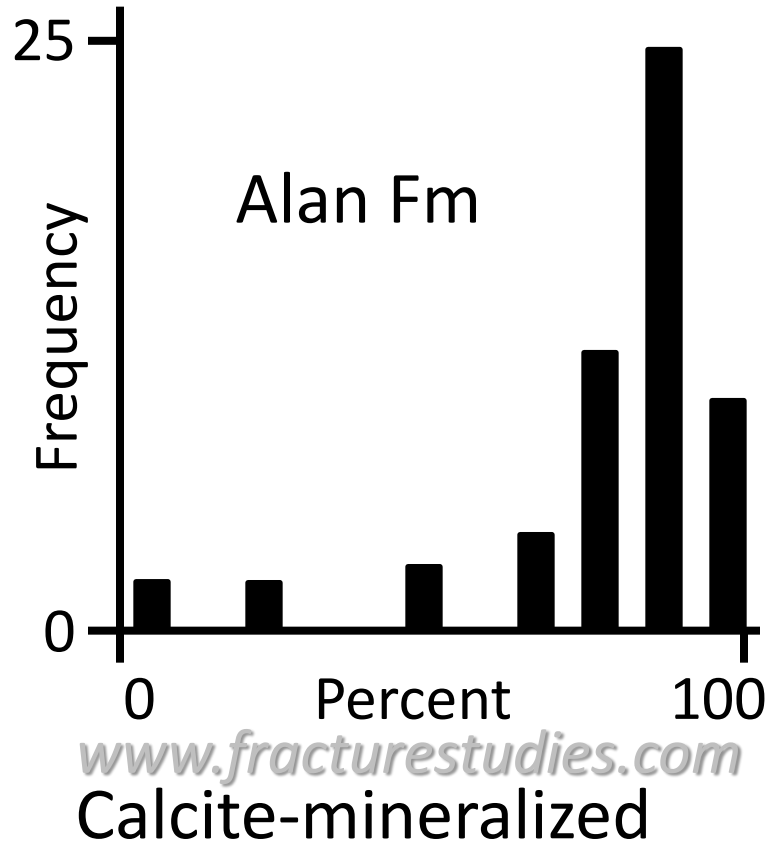
Bed-parallel shear, Alan Fm



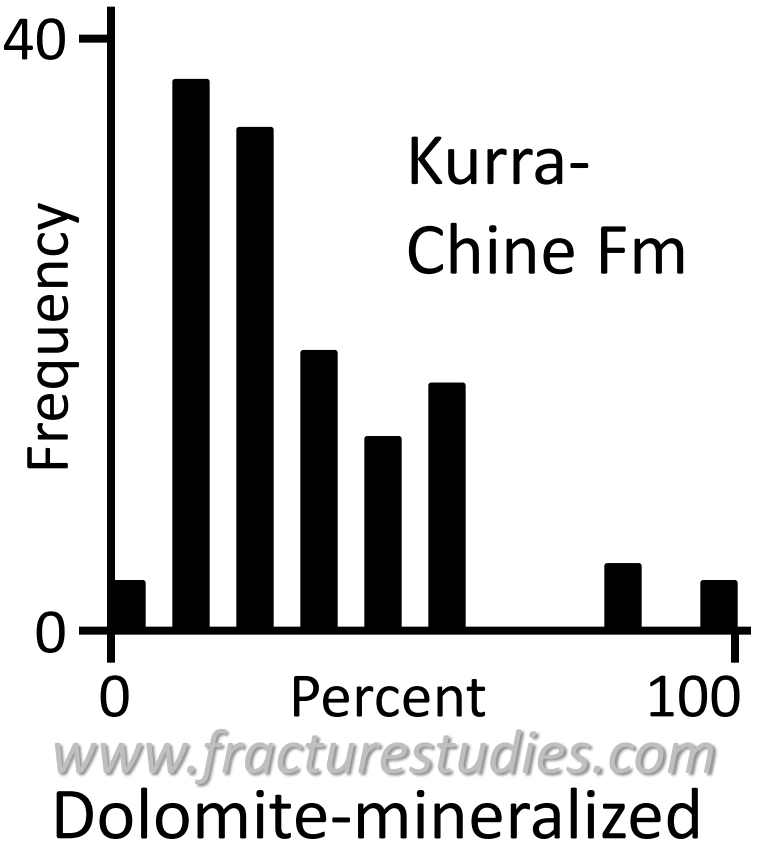
Forelimb

Backlimb

Percent remnant aperture, SH-1B



Calcite-mineralized



Dolomite-mineralized

Fracture intensity varies by structural position *and* by formation

WELL	Ratio fracture height/core height								
	Samord	Garagu	Chia Gara	Sargelu	Alan	Mus	Adaiyah	Butmah	Kurra Chine
SH-1A/1B					0.58				0.36
SH-2					1.44	1.24		0.28	0.43
SH-3	0.29	1.14							
SH-4			0.16	0.46	0.29	0.17		0.45	1.42
SH-5B					2.10				
SH-6			0.02	1.69	0.89	2.74	0.16	0.61	
SH-8							1.58		
Average	0.29	1.14	0.09	1.08	1.06	1.38	0.87	0.45	0.74

Crest

15x

Forelimb

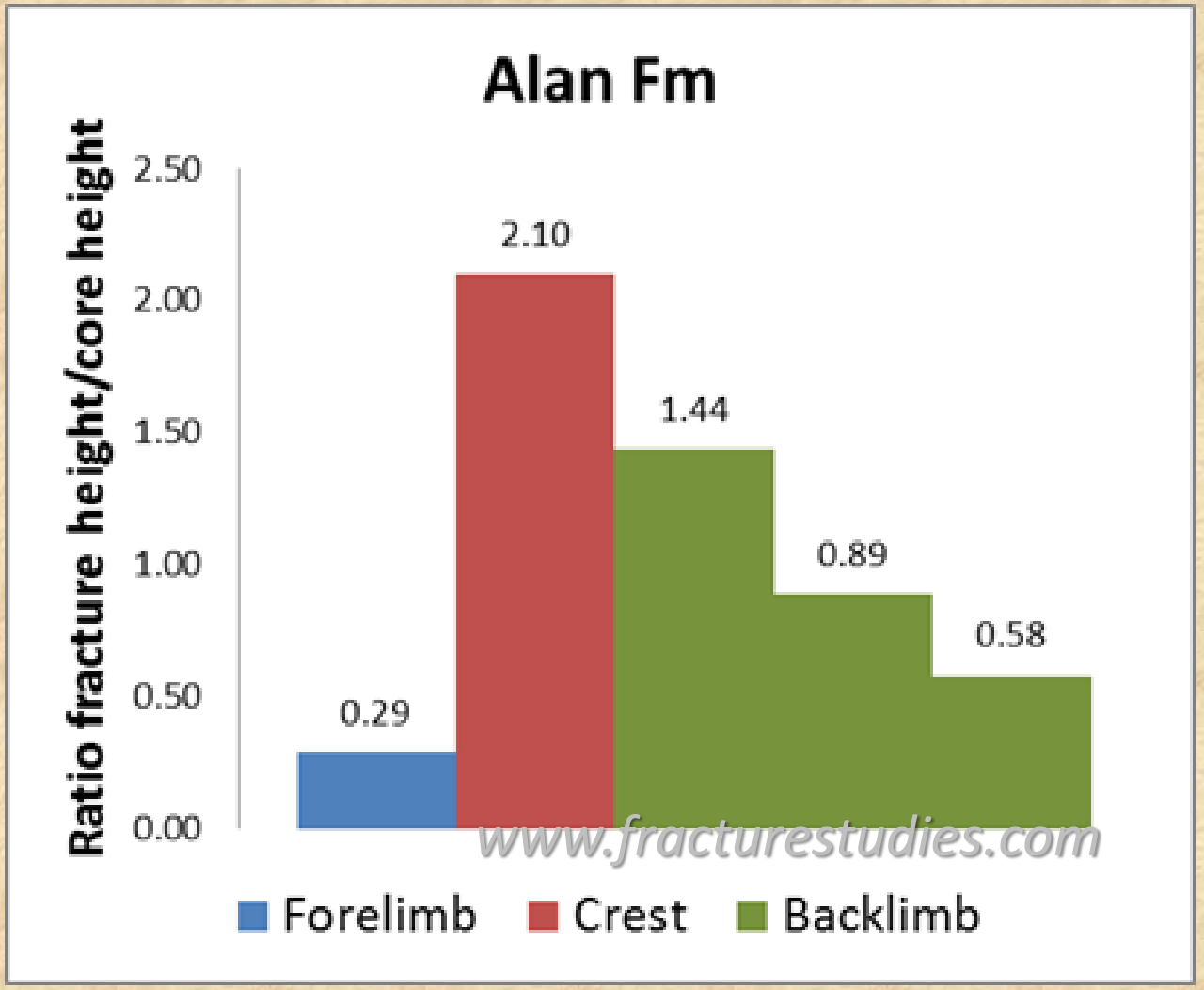
Eliminate one variable: comparisons by structure within one formation

WELL	Ratio fracture height/core height								
	Samord	Garagu	Chia Gara	Sargelu	Alan	Mus	Adaiyah	Butmah	Kurra Chine
SH-1A/1B					0.58				0.36
SH-2					1.44	1.24		0.28	0.43
SH-3	0.29	1.14							
SH-4			0.16	0.46	0.29	0.17		0.45	1.42
SH-5B					2.10				
SH-6			0.02	1.69	0.89	2.74	0.16	0.61	
SH-8							1.58		
Average	0.29	1.14	0.09	1.08	1.06	1.38	0.87	0.45	0.74

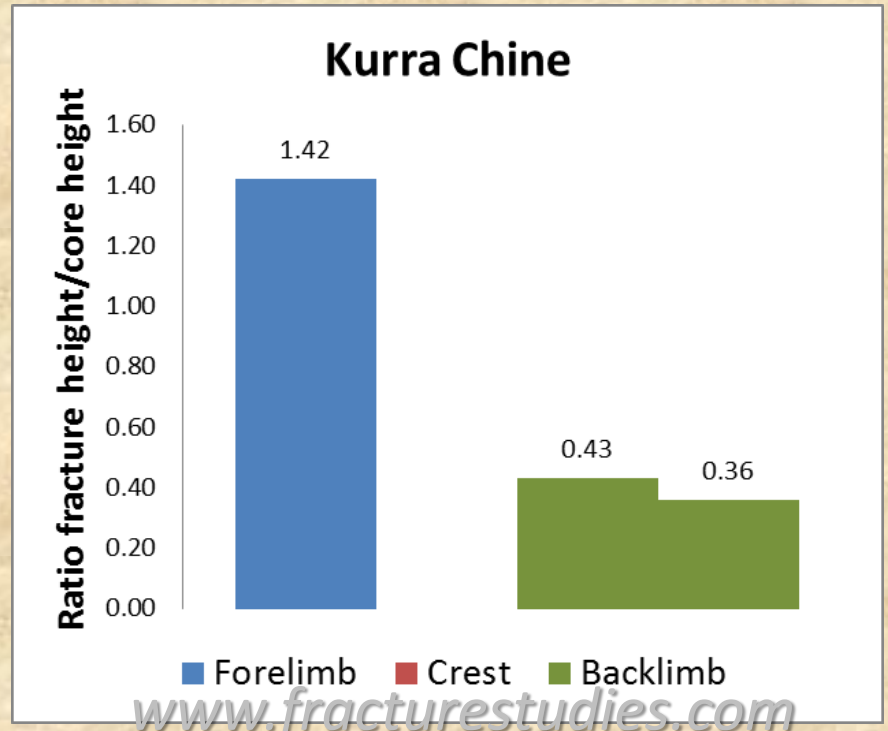
Crest

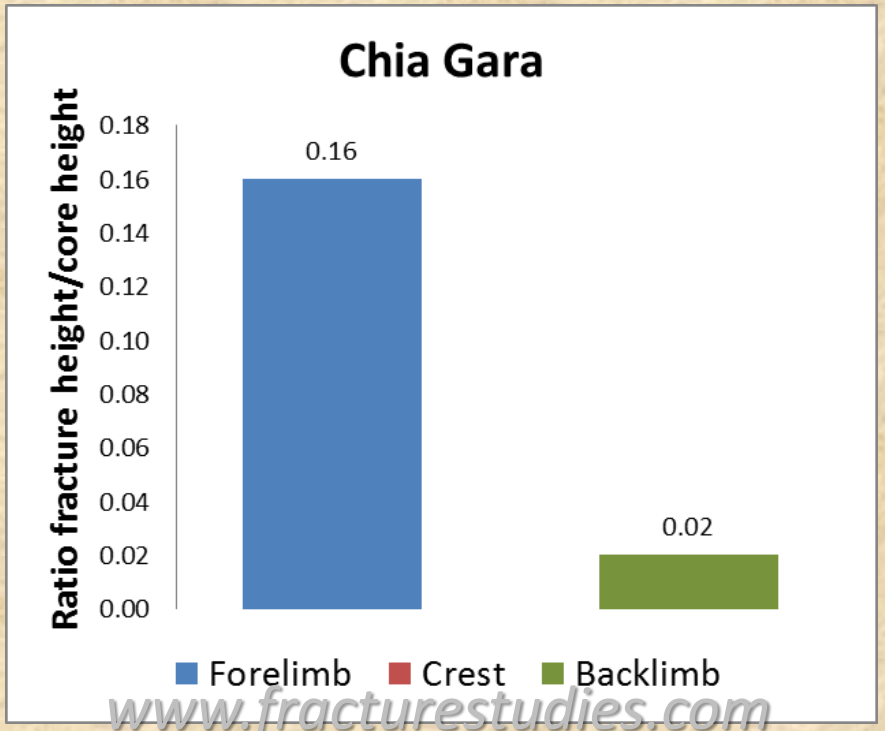
Forelimb

Fracture intensity variation in the Alan Fm by structural position



Fracture intensity increases with degree of folding





Conceptual Model: Fracture-Controlled Permeability at Shaikan

- Fractures are:
  - Abundant, open, and effective
  - Interconnected horizontally
  - Tall where bedding is thick
- Fractures vary with lithology:
  - Dissolution apertures in the Sargelu
  - Intense fracturing in the Alan and Mus
- Fractures vary with structure:
  - Backlimb: low intensity
  - Forelimb: high intensity and shear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