# Mechanical Stratigraphy of the Monterey Formation and Relationship with Sedimentary Cycles, Montaña de Oro, California*

**Heather Strickland[1], Michael Gross[2], and Richard J. Behl[1]**

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[1]California State University at Long Beach, Long Beach, CA (hstrick06@gmail.com)
[2]Shell E & P, Houston, TX

## Abstract

The Monterey-equivalent Miguelito Member of the Pismo Formation at Montaña de Oro State Park displays four orders of fracture length that can be related to stratigraphic position in primary sedimentary cycles of bed-thickness and composition. Characterization of fractures such as these is crucial to understanding reservoir behavior in low-permeability, fine-grained rocks that require natural or induced fractures for economic hydrocarbon production. We define the fracture network and mechanical stratigraphy – the subdivision of a rock section into discrete units defined by mechanical layer boundaries – at scales from cm's to 10's of m.

A ~200-m-thick interval of the upper Miocene Miguelito Member consists principally of rhythmically interbedded porcelanite, mudstone and dolostone; sedimentary cycles in porcelanite:mudstone ratio, bedding thickness and dolostone occurrence are quantitatively defined by spectral gamma ray and ground-based three-dimensional LiDAR (light detection and ranging). We hypothesize that primary sedimentary cyclicity influences subsequent fracture and fault development (and the resulting mechanical stratigraphy) in the Miguelito Member and likely other thin-bedded siliceous successions and therefore may be used as a predictive tool for fracture frequency and length in conjunction with other geologic information such as tectonic strain and structural position. We are mapping the dimensions of fractures and faults and calculating their frequencies in relation to the overall stratal stacking pattern and variations due to sedimentary cyclicity. As fracture type and frequency are known to be directly related to lithology in the Monterey Formation on a single-bed scale, intervals where strata are thinner-bedded and have a higher silica:mudstone ratio are predicted to develop a higher number of both bed-confined fractures and multilayer features than intervals that are thickly-bedded and have a lower silica to mudstone ratio. Mechanical layer boundaries also occur at a number of thickness scales and terminate different size structural features, but predominantly occur at distinct changes in stratal stacking pattern. We have also found that thick-bedded dolomite horizons and thin volcanic tuff can be effective mechanical layer boundaries.

## Selected References

Gross, M.R., and Y. Eyal, 2007, Throughgoing fractures in layered carbonate rocks: GSA Bulletin, v. 119/11-12, p. 1387-1404.

Hardebeck, J.L., 2010, Seismotectonics and fault structure of the California Central Coast: Bulletin of the Seismological Society of America, v. 100, p. 1031-1050.

# Mechanical Stratigraphy of the Monterey Formation and Relationship with Sedimentary Cycles, Montaña de Oro, California

By: Heather Strickland

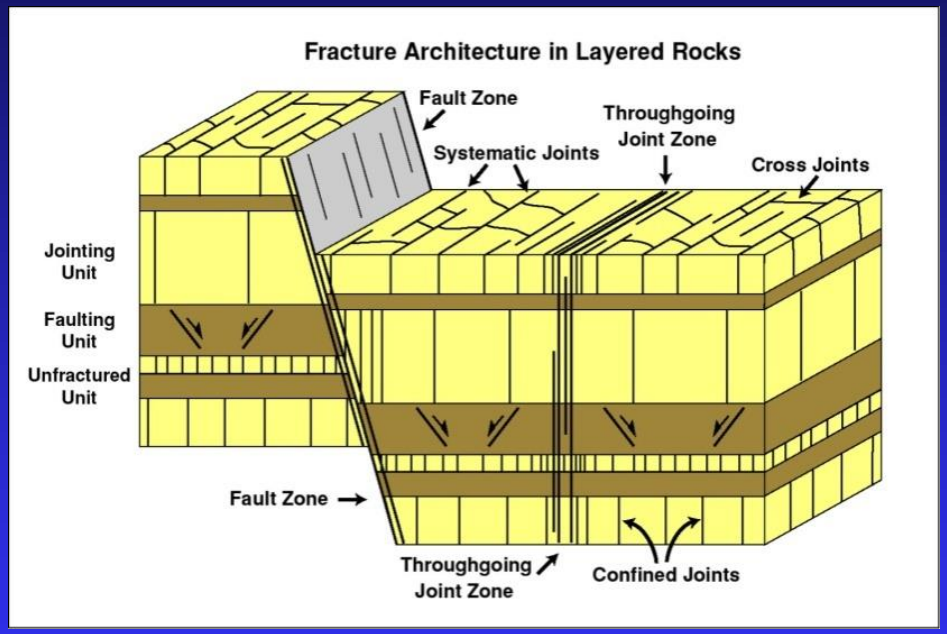
Co-Authors:

Michael Gross, Shell E & P

Prof. Richard J. Behl, CSULB

# Mechanical Stratigraphy

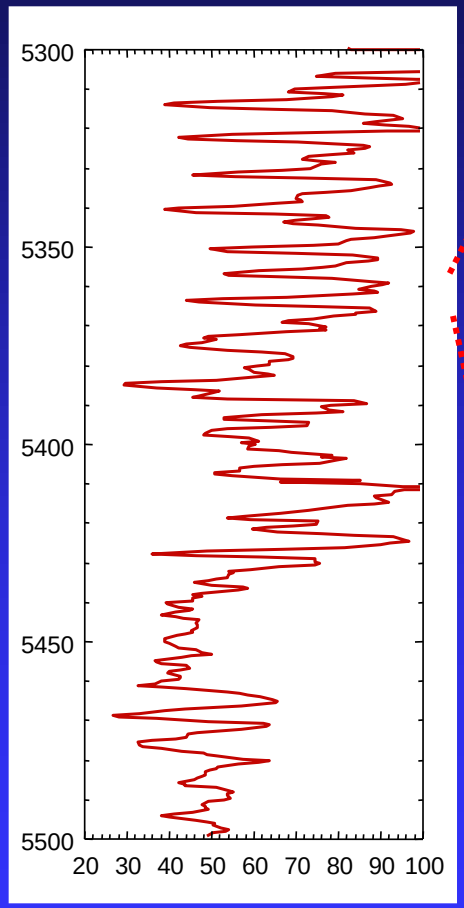
- Subdivision of rock section into discrete units
  - Defined by structures, deformational style or mechanical properties
- Each unit is defined by mechanical layer boundaries
  - Can be defined at different scales
  - Structural or stratigraphic



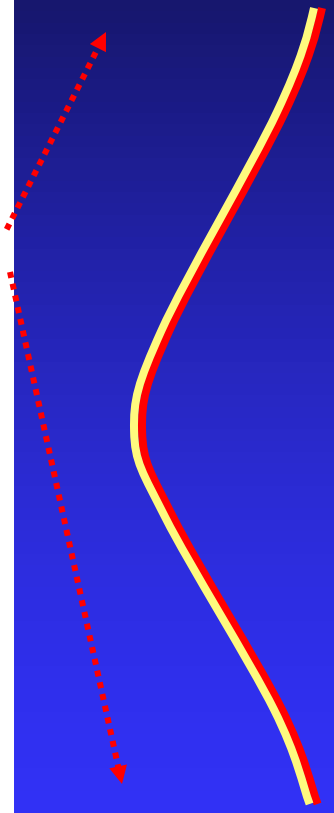

Gross & Eyal (2007)

# Stacking Patterns for Silica-Clay cycle

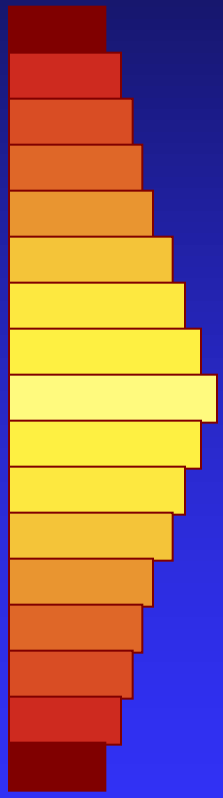
Gamma-ray log



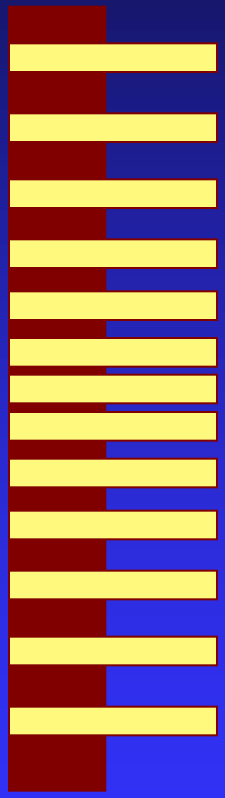

Gamma-ray cycle



Varied bed composition



Varied shale thickness



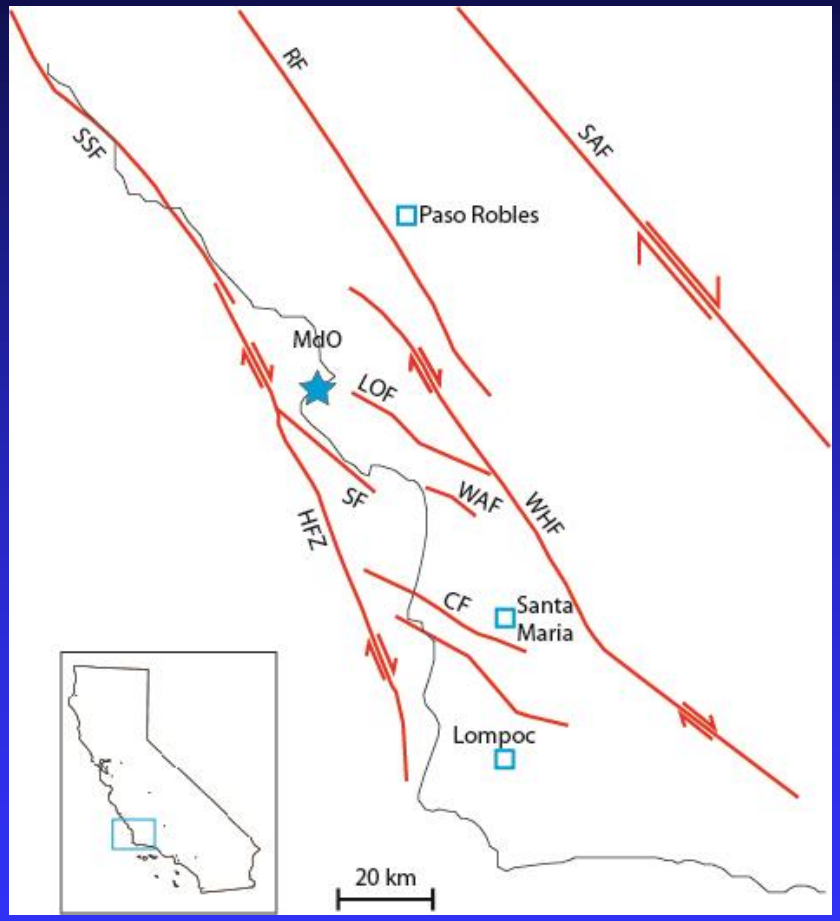
Courtesy Rick Behl

# Objectives

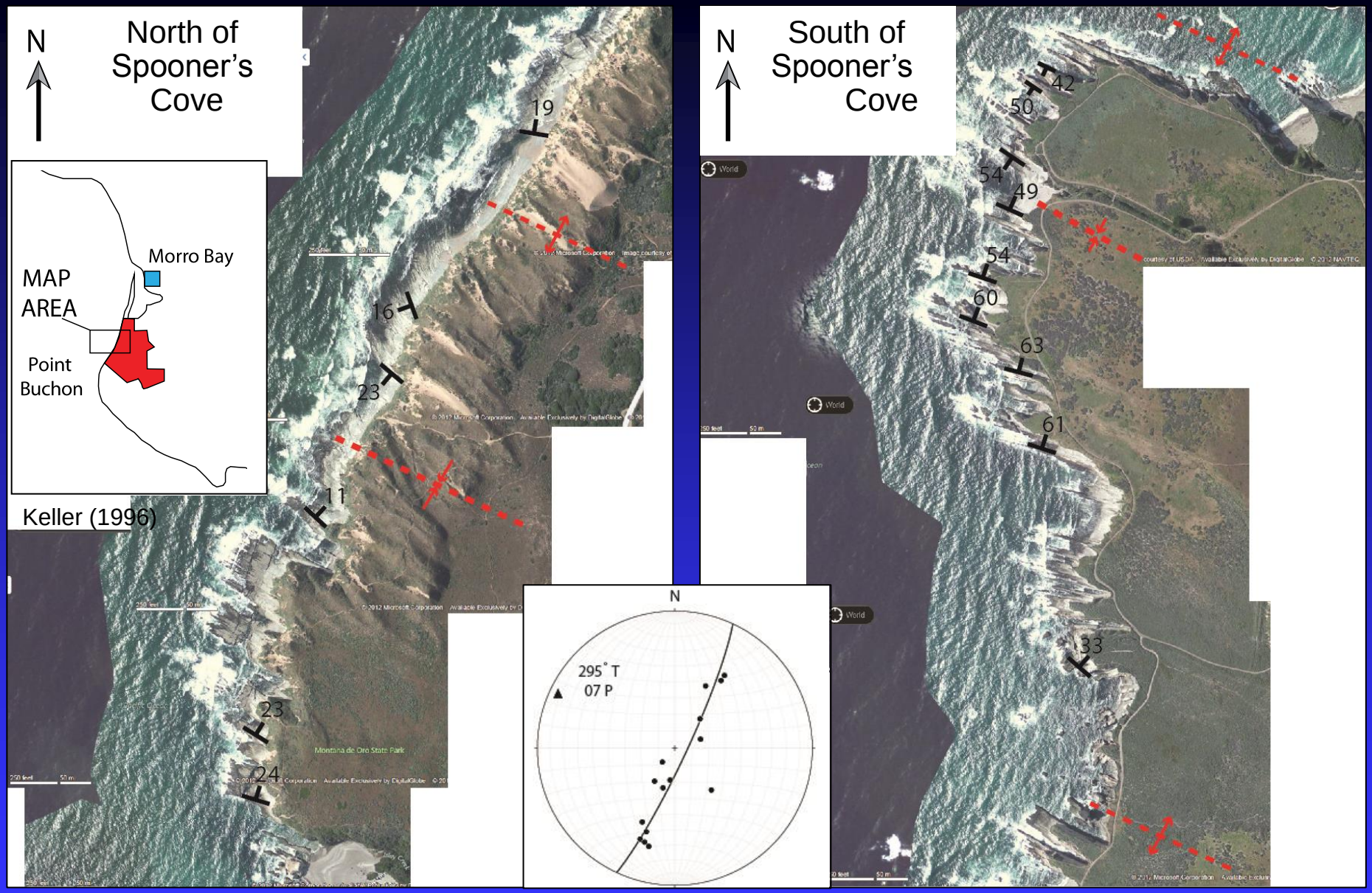
- Map and define mechanical units at different scales
- Create fracture maps to define the fracture architecture within the field area
- Quantify cyclic and secular variation in lithologic composition
- Correlate variation in stratigraphic architecture and position in sedimentary cycles to fracture populations

# Geologic Setting

- Study area between to major right-lateral strike-slip faults
  - San Andreas fault
  - Hosgri fault
- Outcrops include Monterey and Pismo Formations




Modified from Hardebeck, 2010

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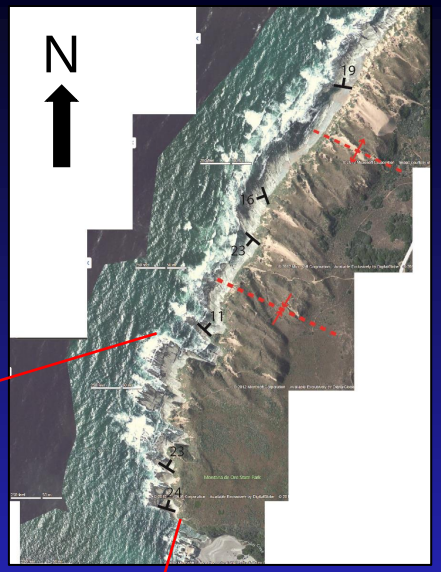
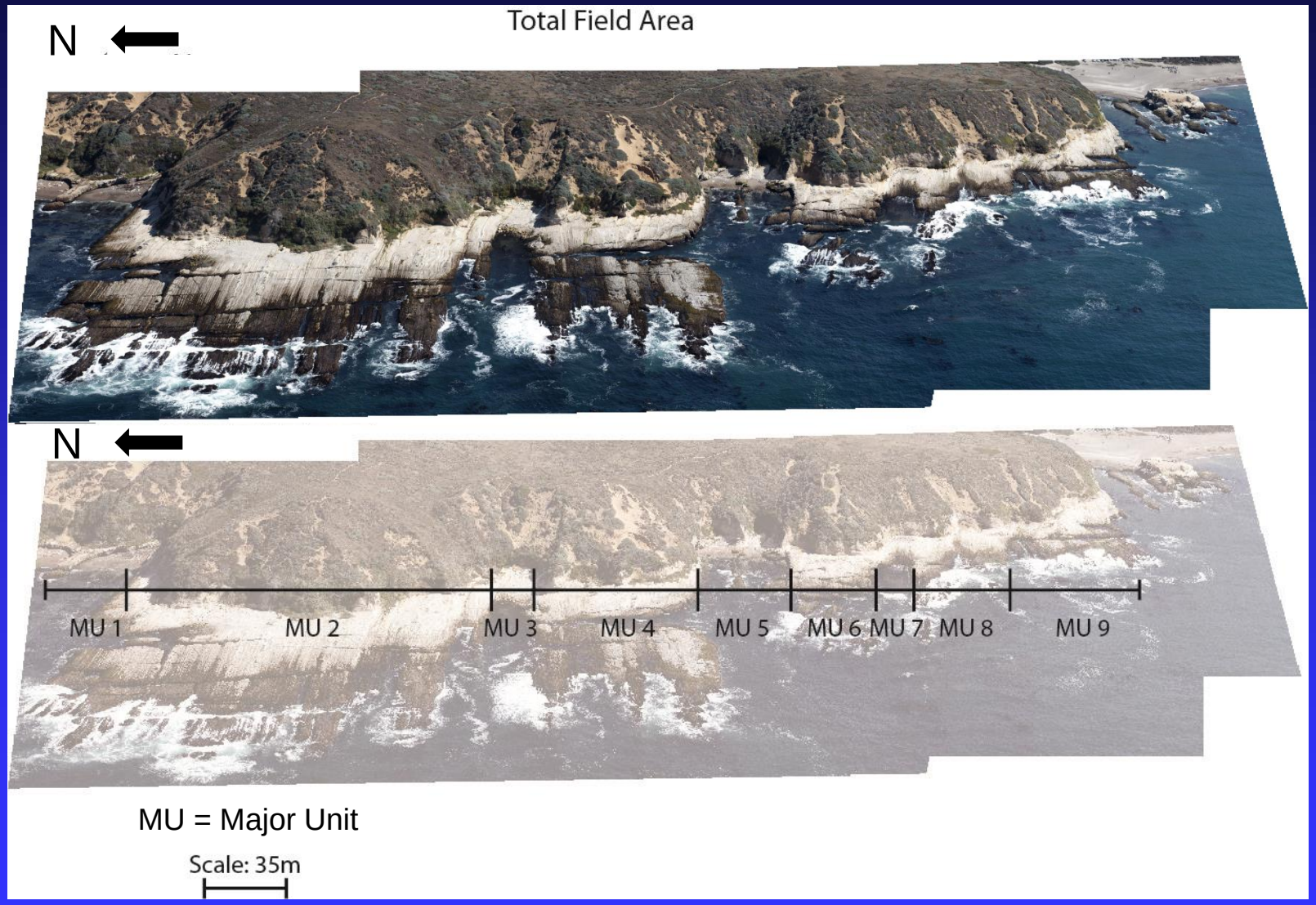
# Field Area

- Study area is ~400m in length and ~200m of stratigraphic section
  - Opal-CT porcelanite, dolomite, mudstone
  - Homoclinal dip north 25-30 degrees




# Major Lithostratigraphic Units

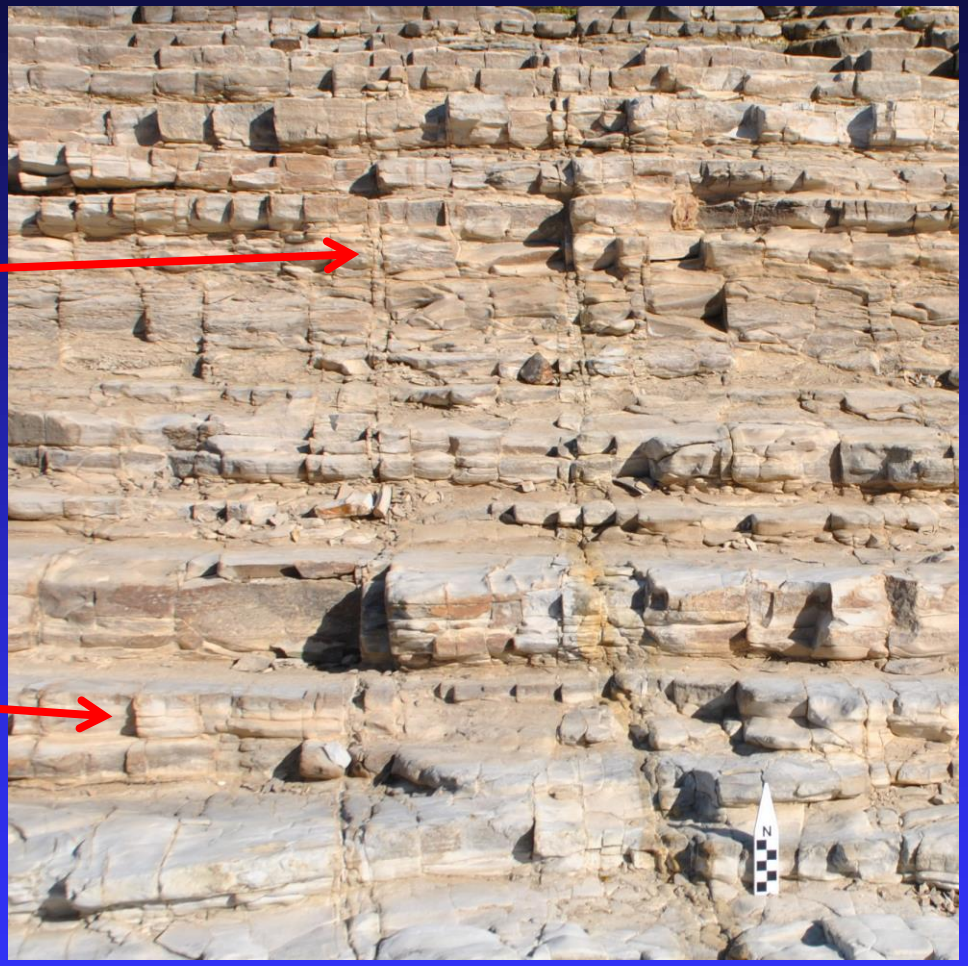


# Fracture Classification

# Fracture Classification

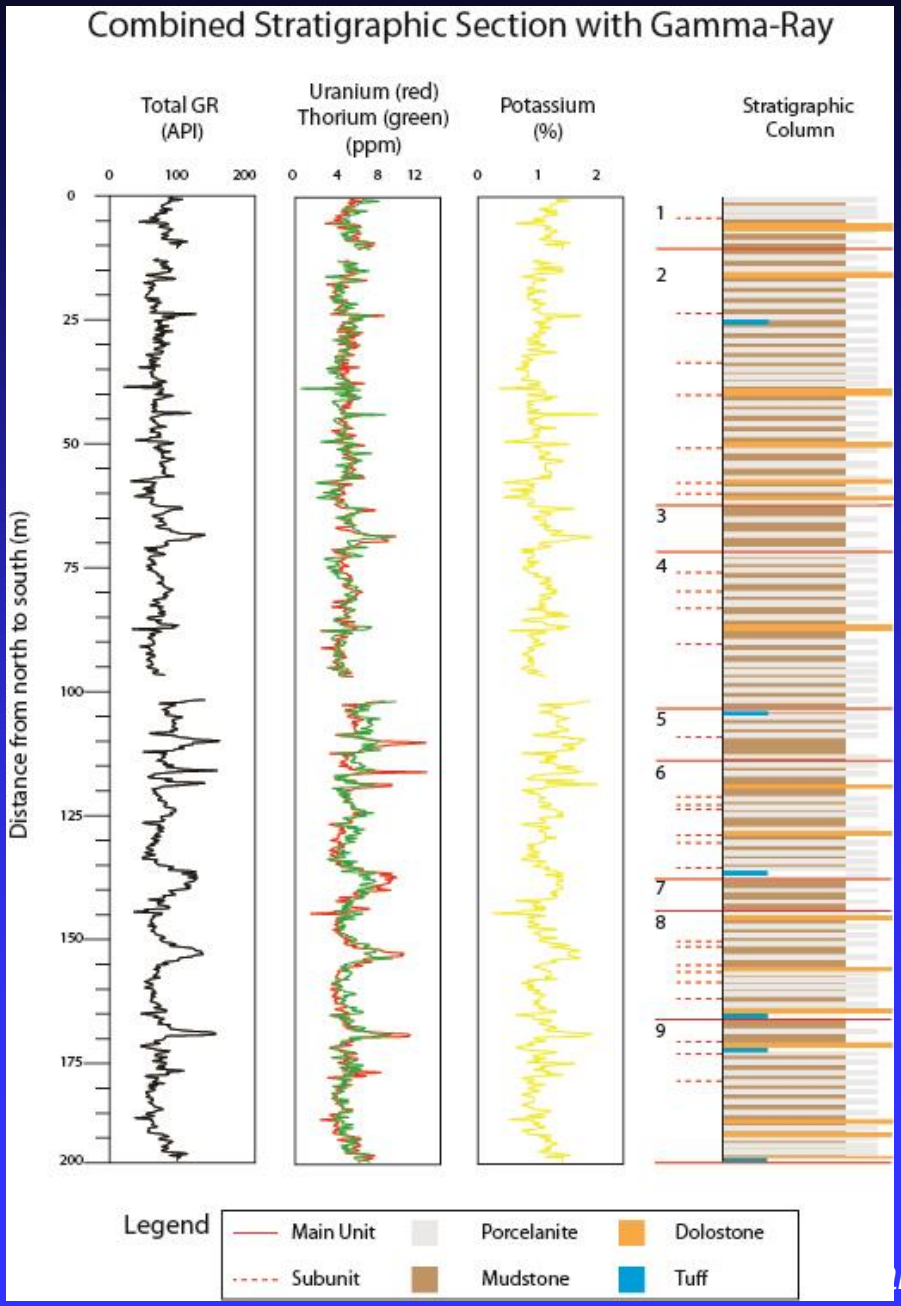
3rd order

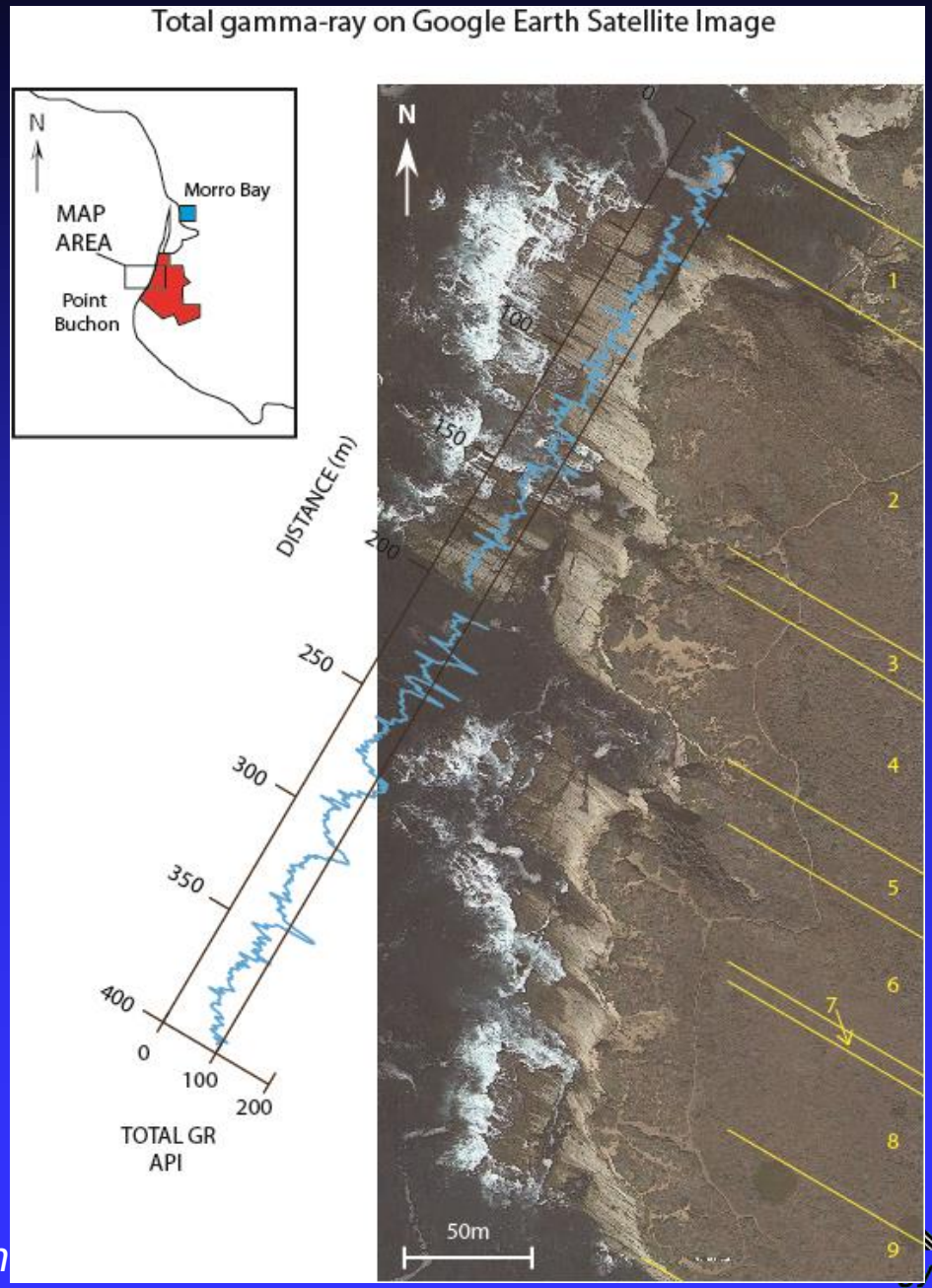
4th order

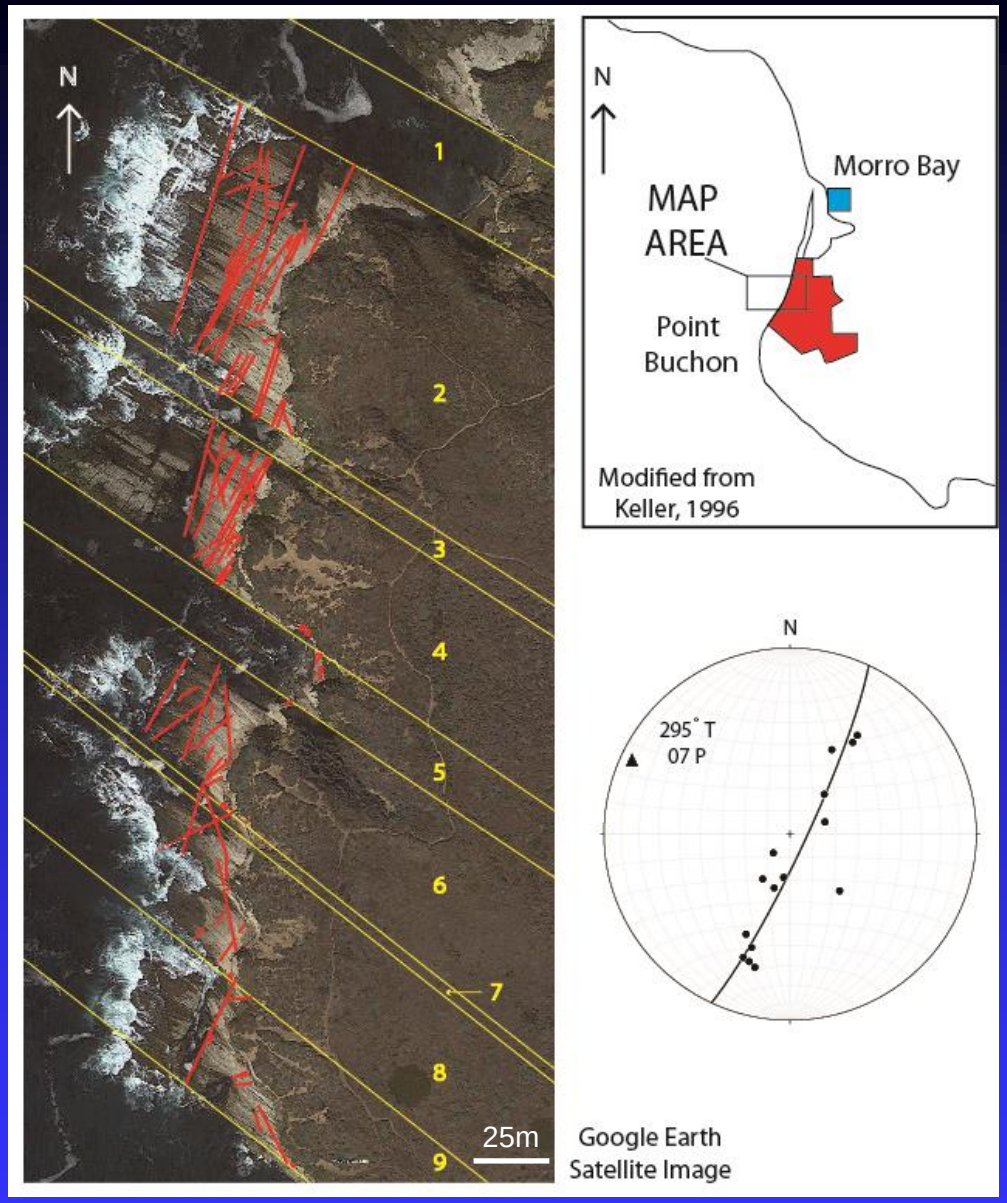


# Data Collection

- Spectral gamma-ray survey at a 25 cm resolution
- Scan lines parallel to strike targeting all fracture orders
  - Spacing
  - Orientation
  - Fracture order
- Delineation of major and minor lithostratigraphic units
  - Major units defined by coastal erosional patterns
  - Subunits defined by stratal stacking and porcelanite to mudstone ratio


Combined Stratigraphic Section with Gamma-Ray
Total GR (API)
Uranium (red) Thorium (green) (ppm)
Potassium (%)
Stratigraphic Column
Distance from north to south (m)
Legend
Main Unit
Subunit
Porcelanite
Mudstone
Dolostone
Tuff


Total gamma-ray on Google Earth Satellite Image
N
MAP AREA
Morro Bay
Point Buchon
DISTANCE (m)
TOTAL GR API
50m

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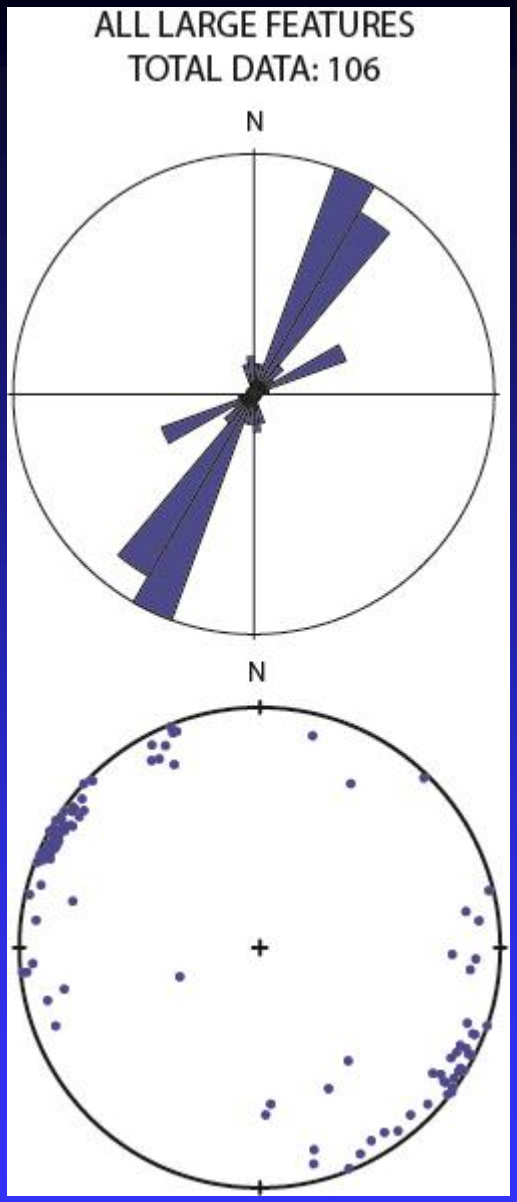


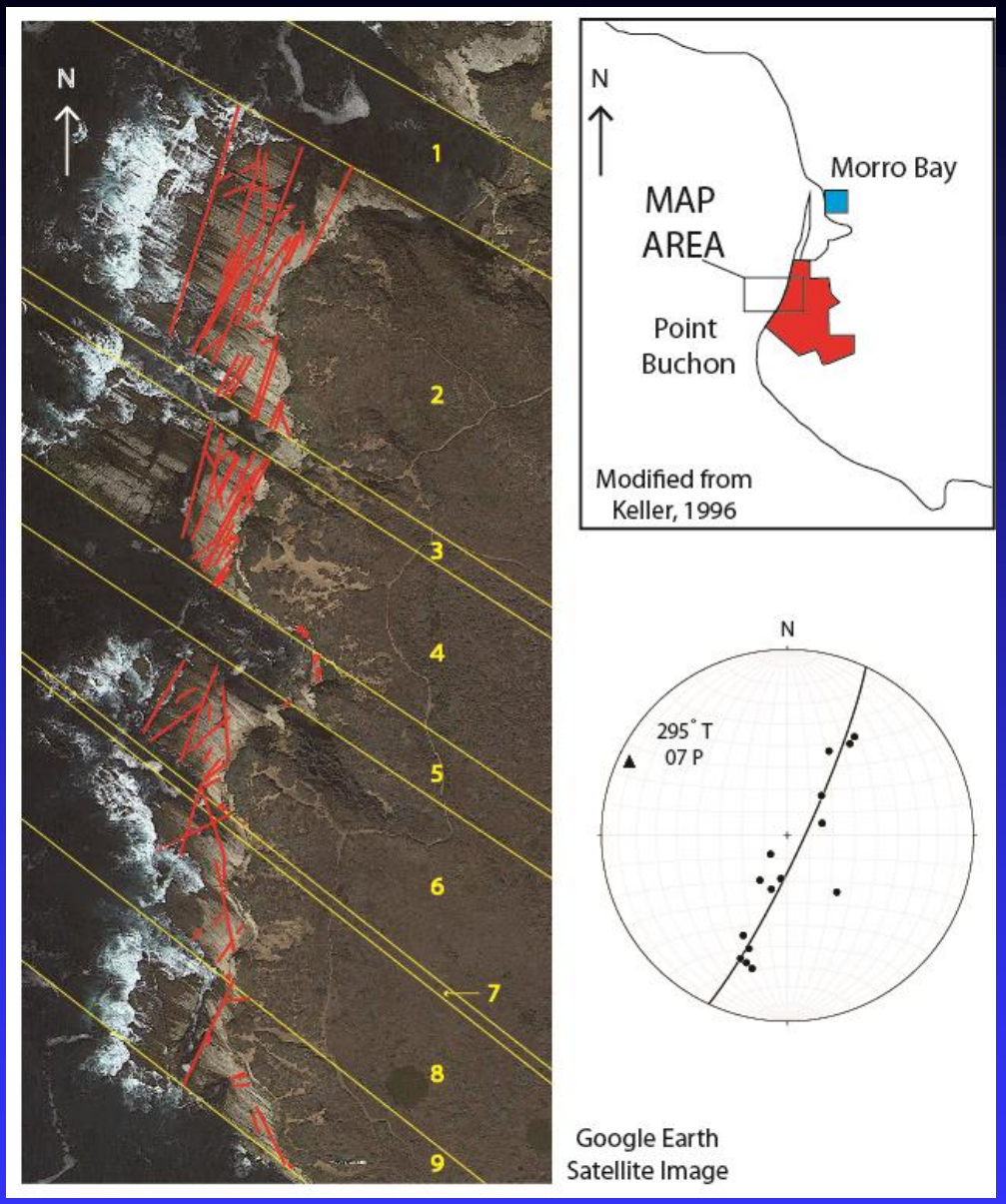


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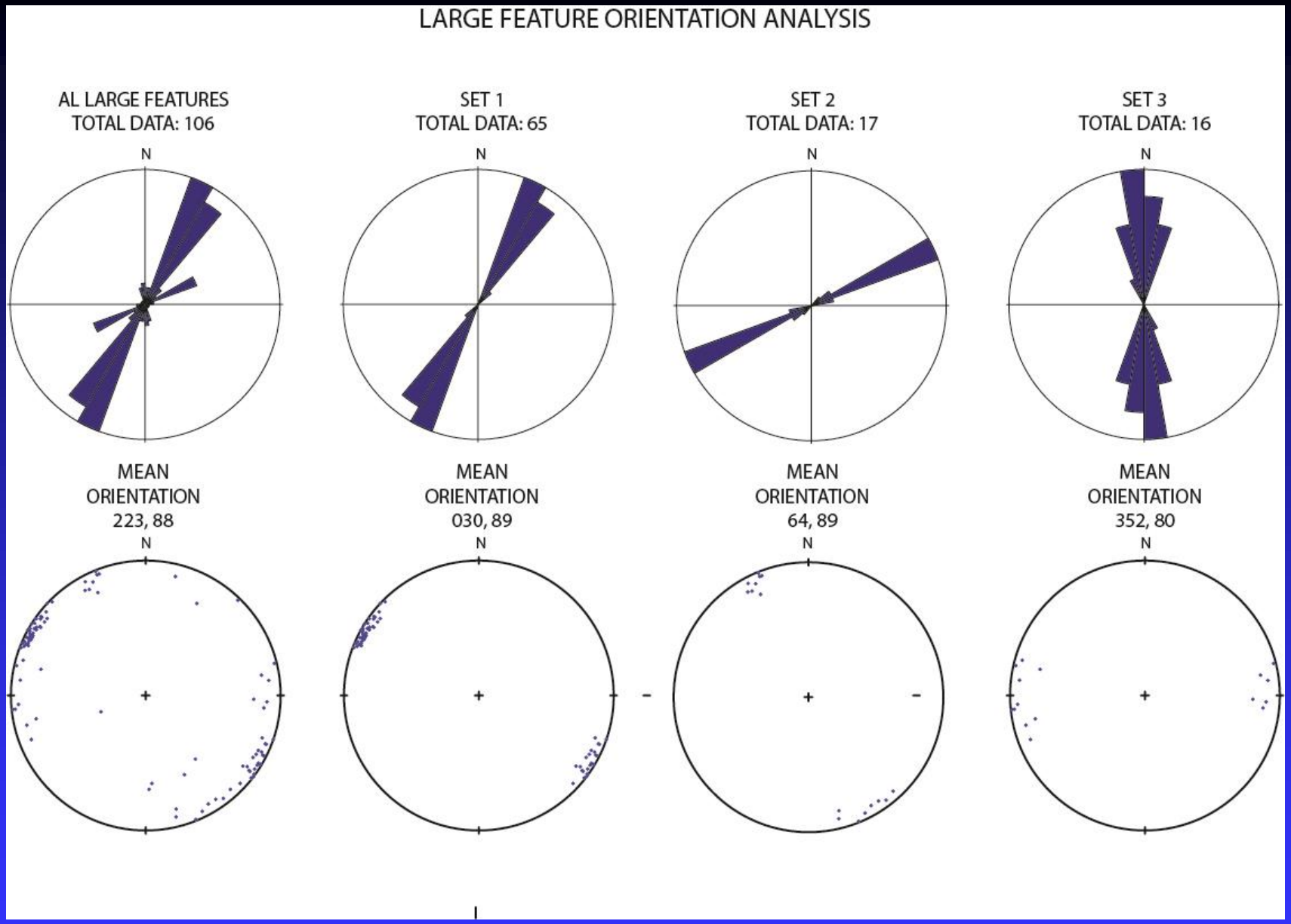
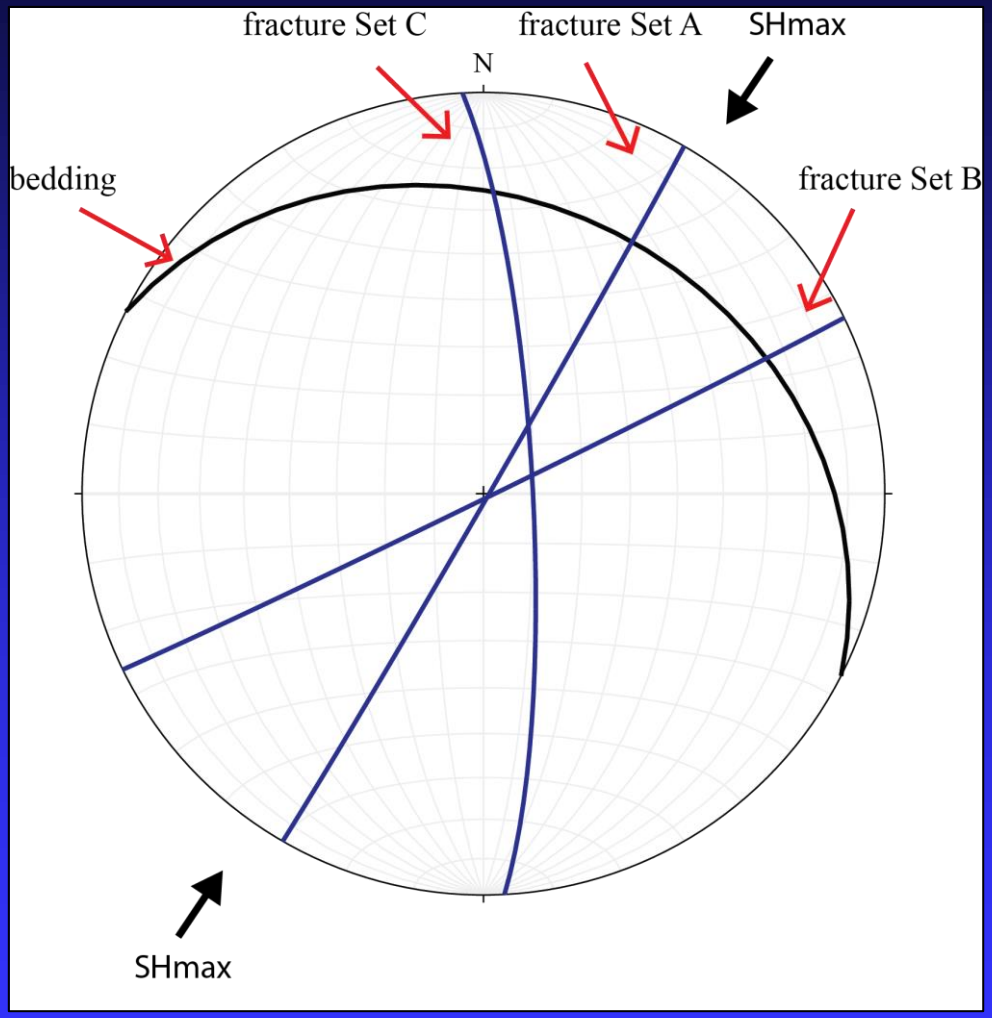
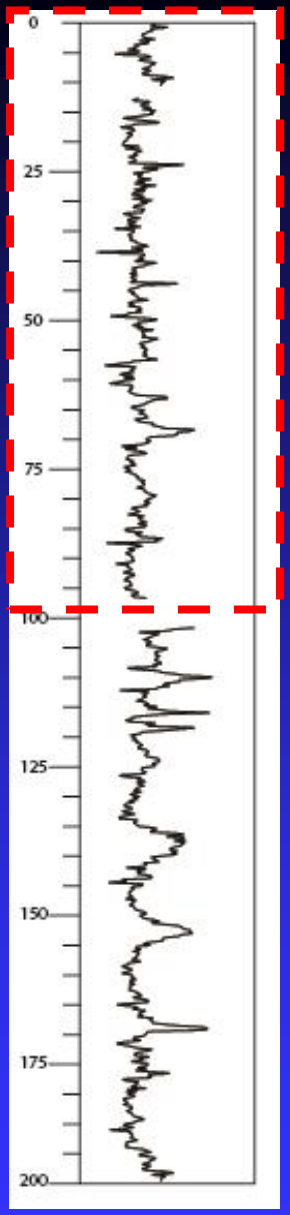
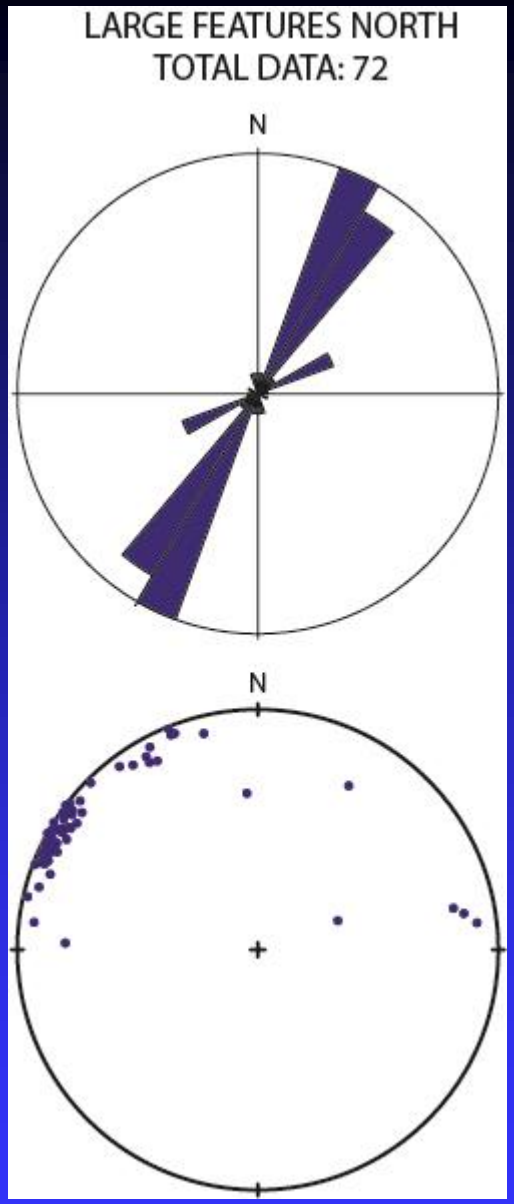
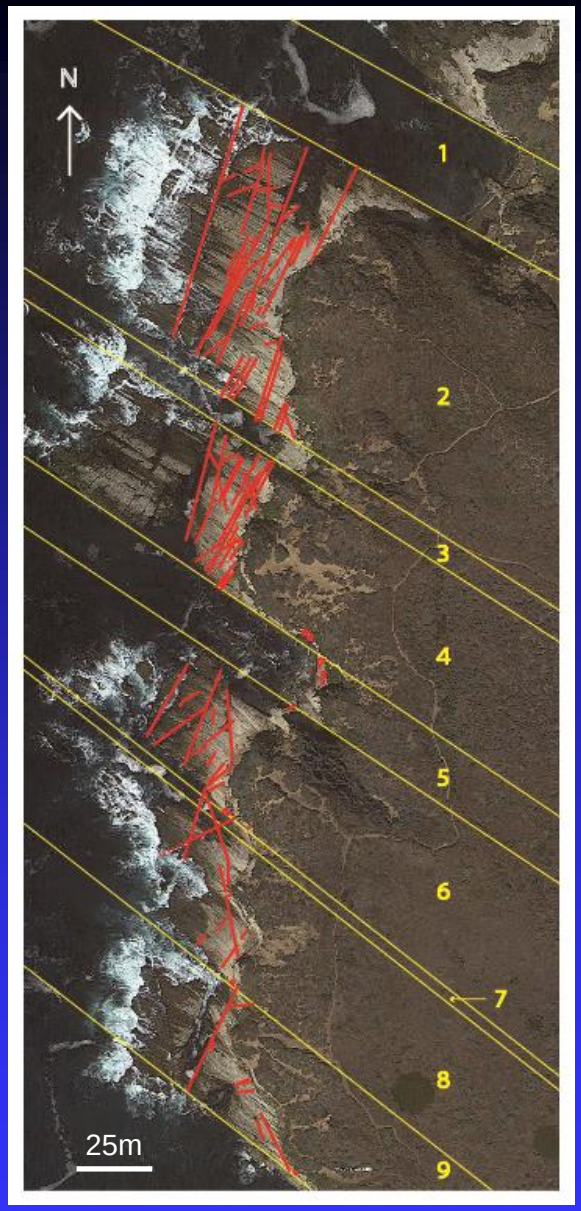

LARGE FEATURE ORIENTATION ANALYSIS
AL LARGE FEATURES
TOTAL DATA: 106
SET 1
TOTAL DATA: 65
SET 2
TOTAL DATA: 17
SET 3
TOTAL DATA: 16
N
MEAN
ORIENTATION
223, 88
MEAN
ORIENTATION
030, 89
MEAN
ORIENTATION
64, 89
MEAN
ORIENTATION
352, 80

# Fracture Sets (Orders 1-3)



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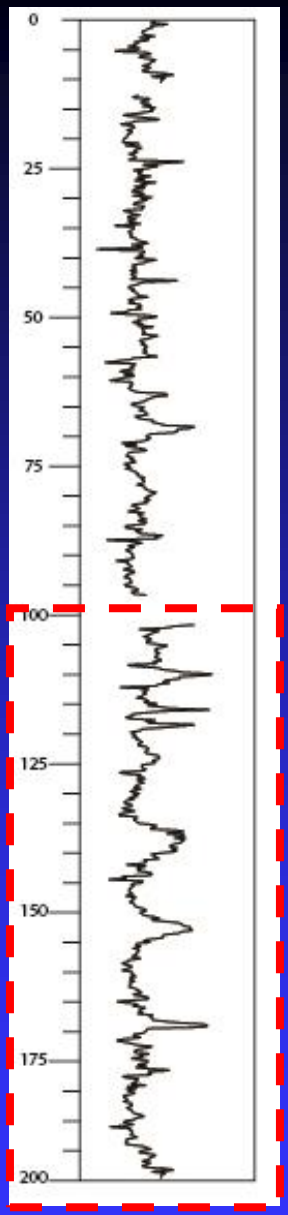


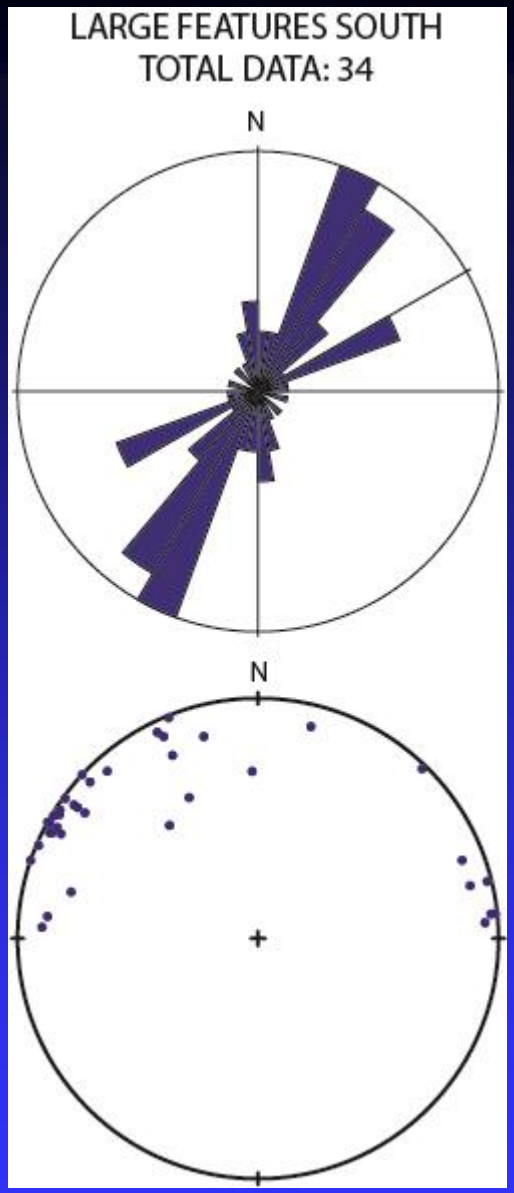


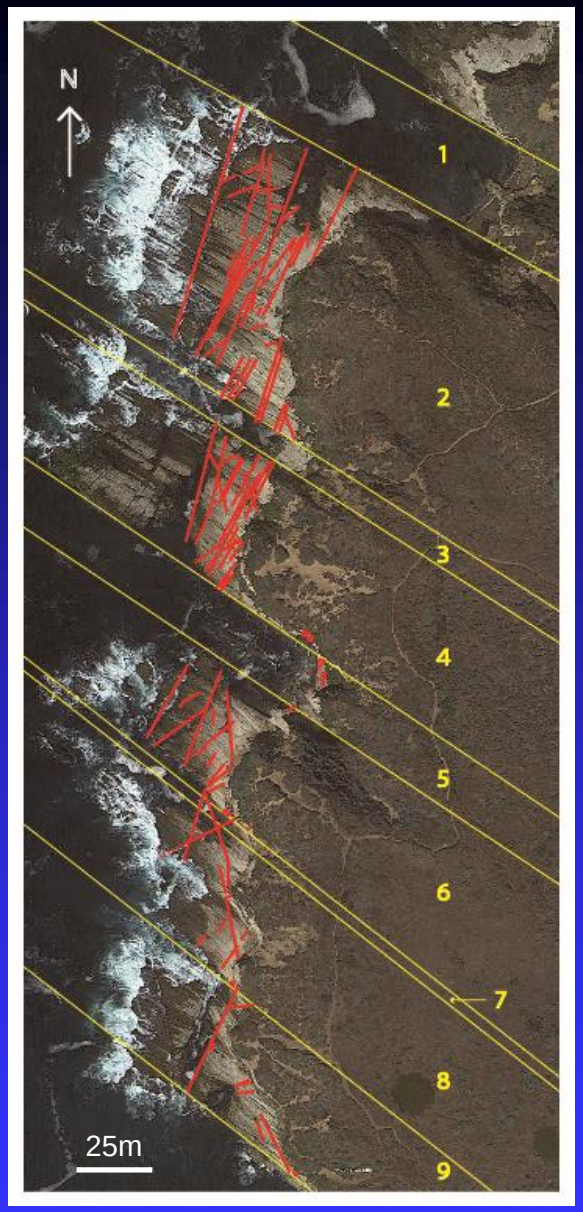


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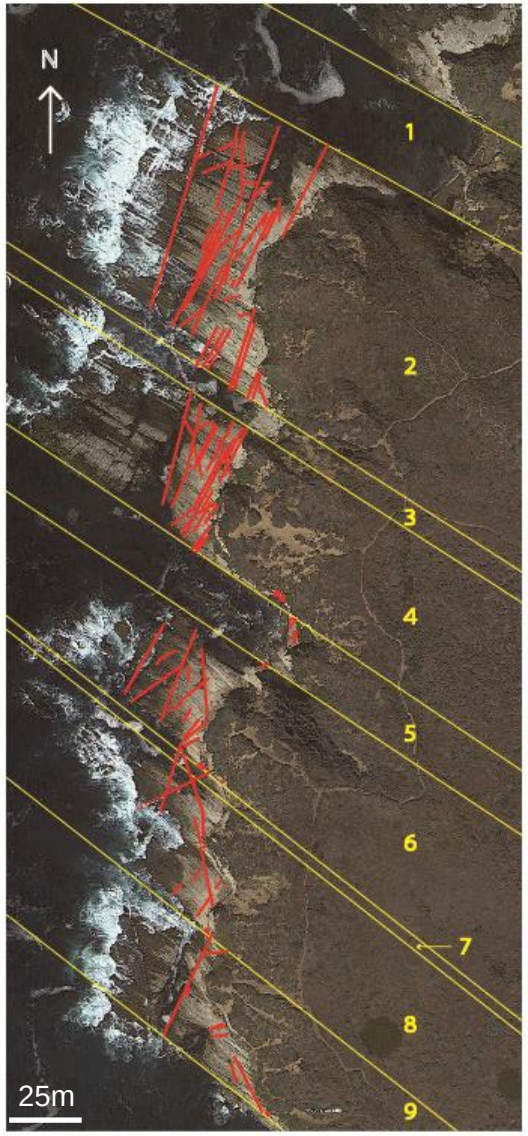
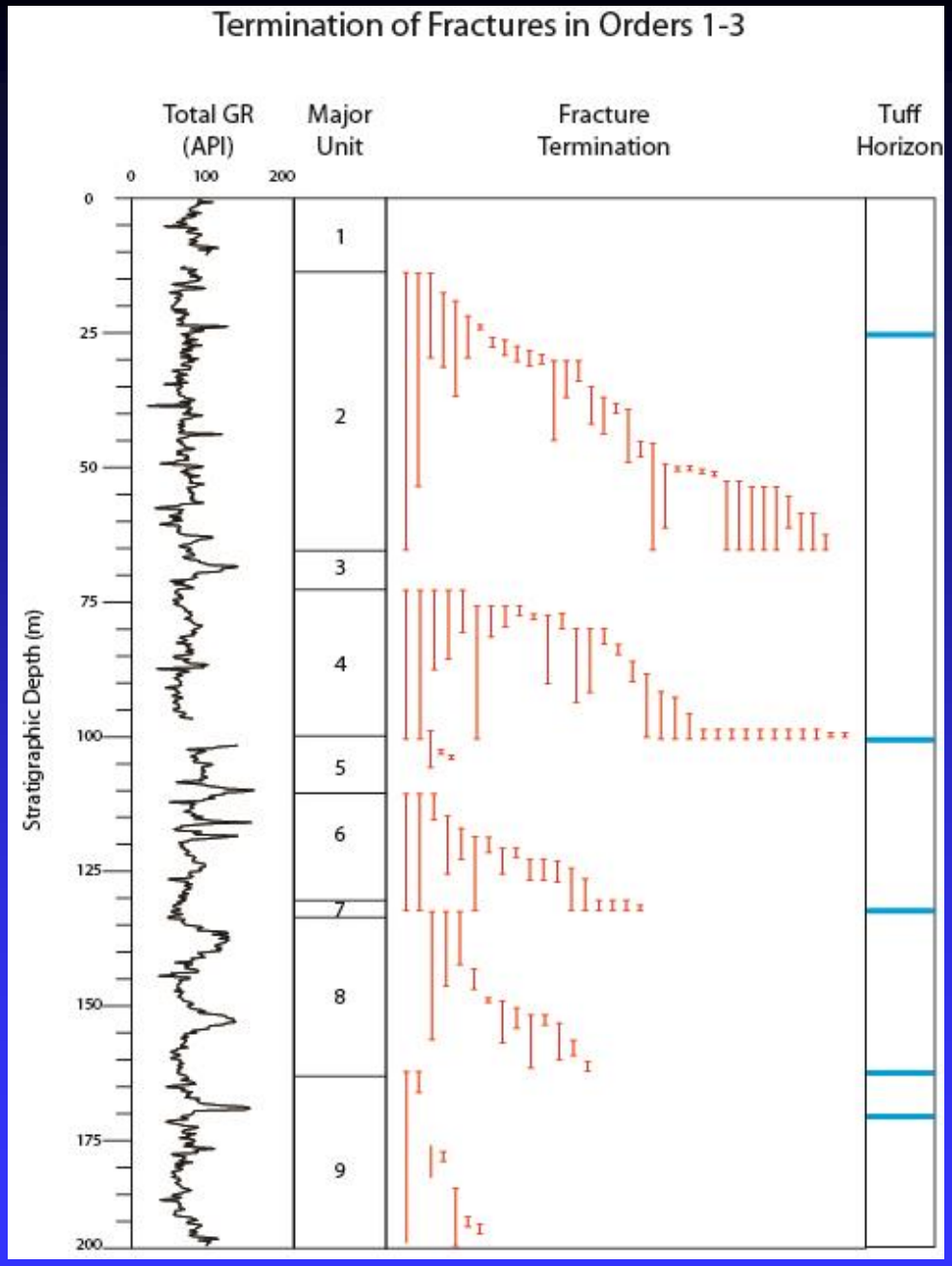
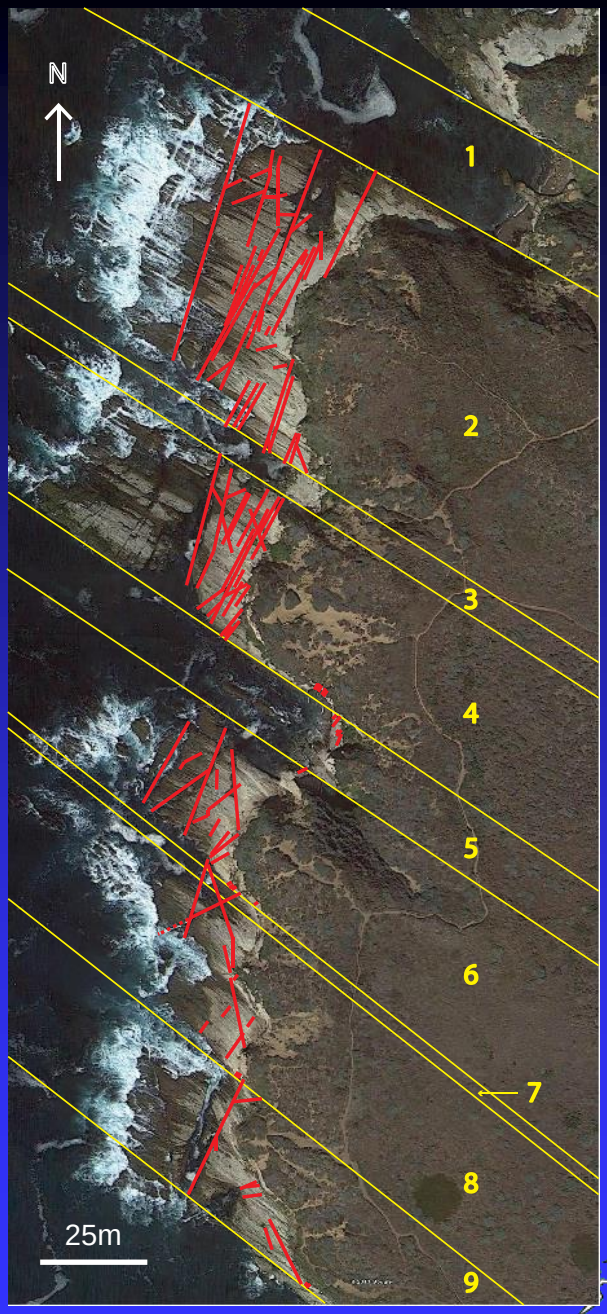
# Summary of Fracture Orders 1-3

| | 0 – 100m | 100-200m |
|---|---|---|
| Major Units | 1 - 4 | 5 - 9 |
| # Set 1 | 49 | 19 |
| # Set 2 | 11 | 5 |
| # Set 3 | 5 | 9 |
| Ratio Set 1 : 2&3 | 3.06 | 1.35 |



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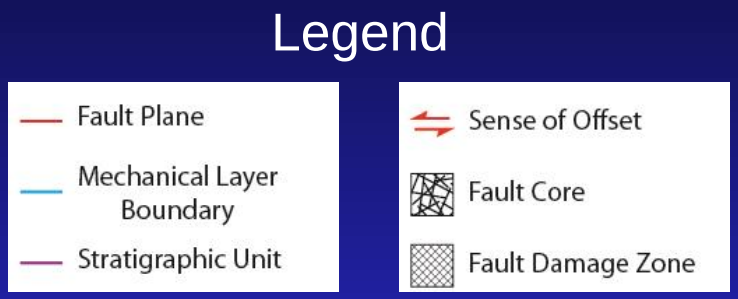
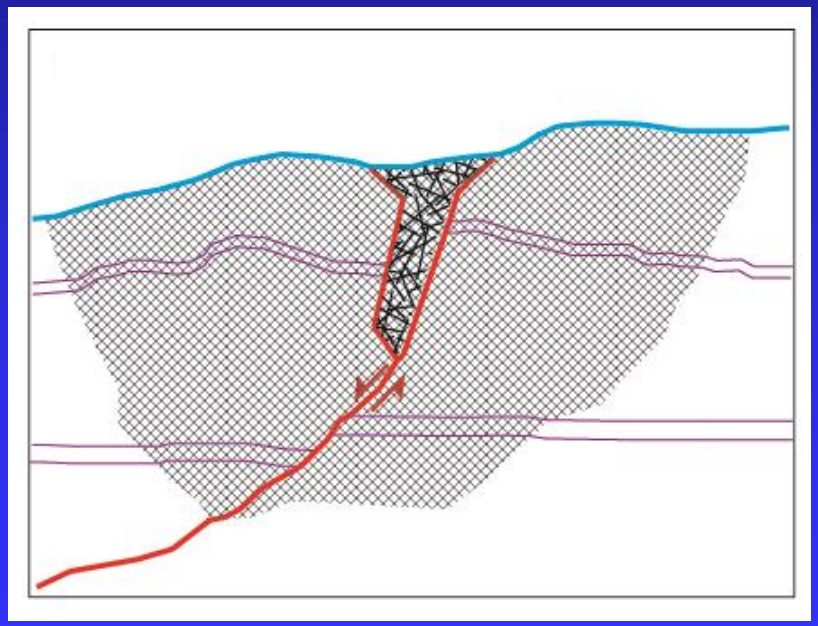
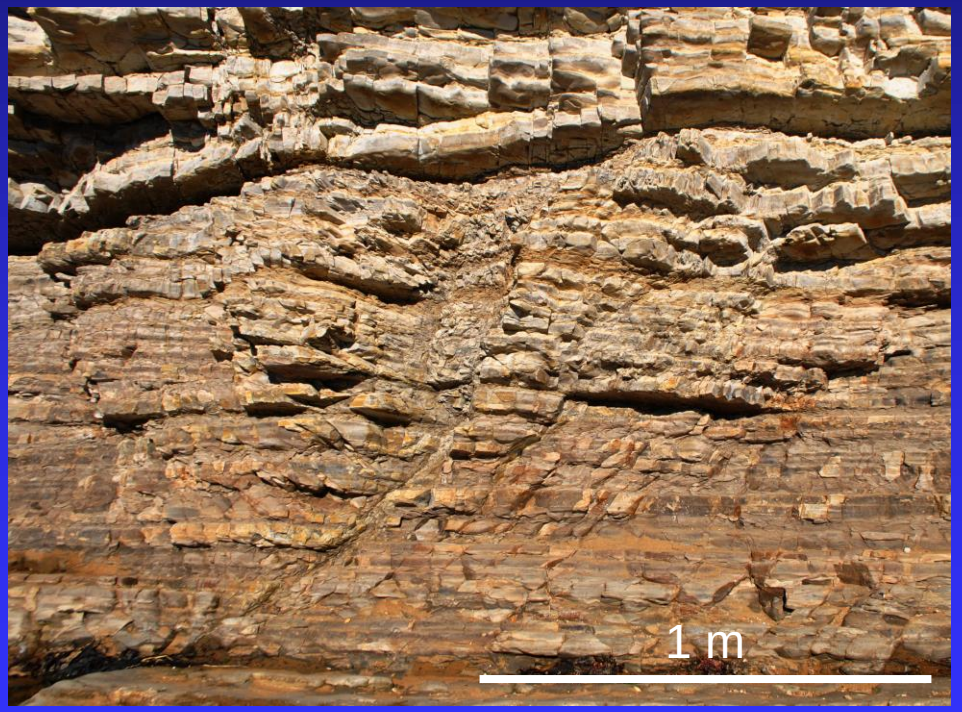
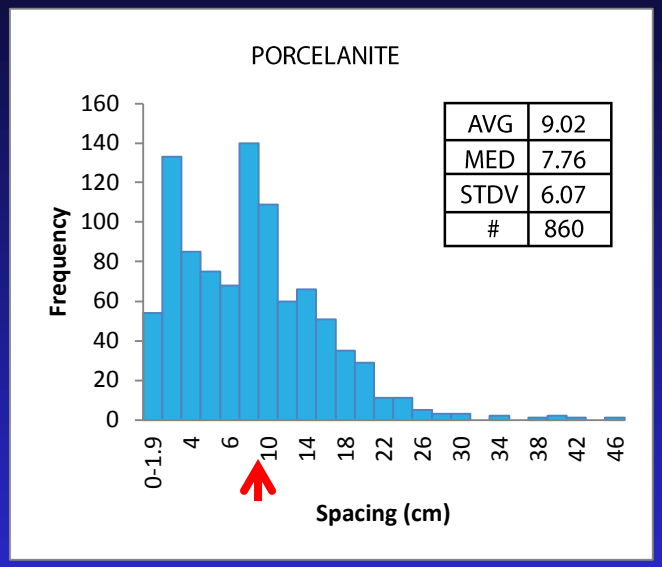
# Tuff as Mechanical Layer Boundary

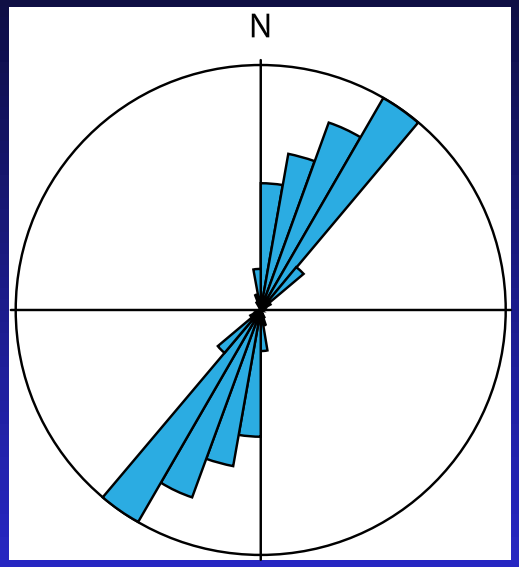


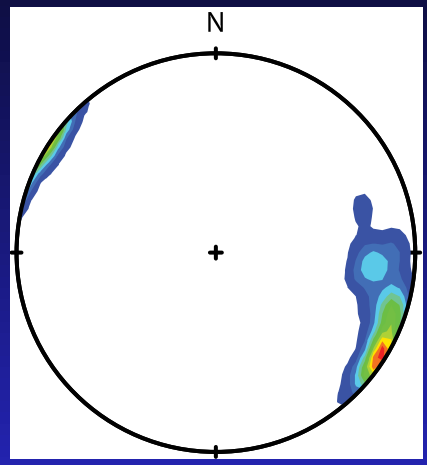



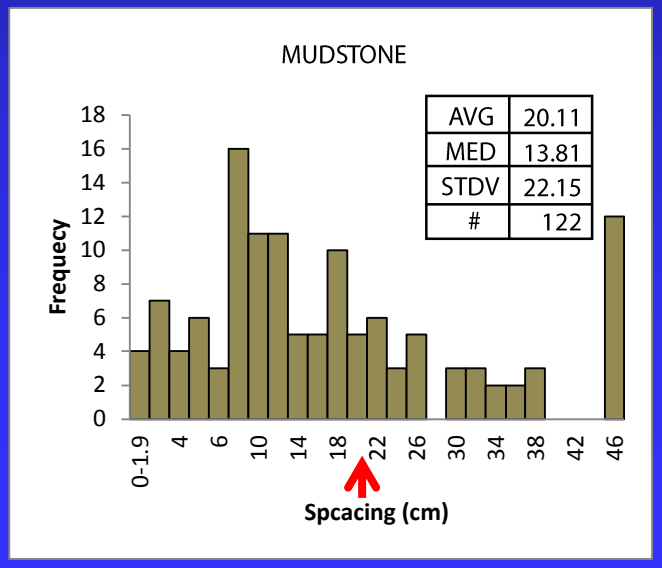


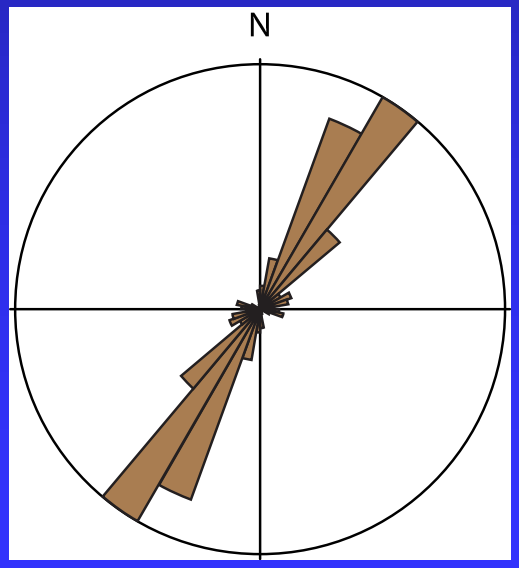
# Effect of Lithology – 4th Order Fractures

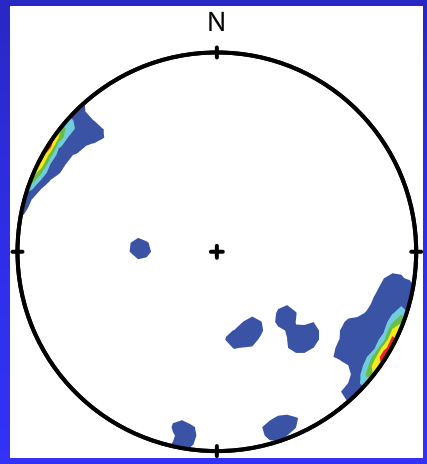
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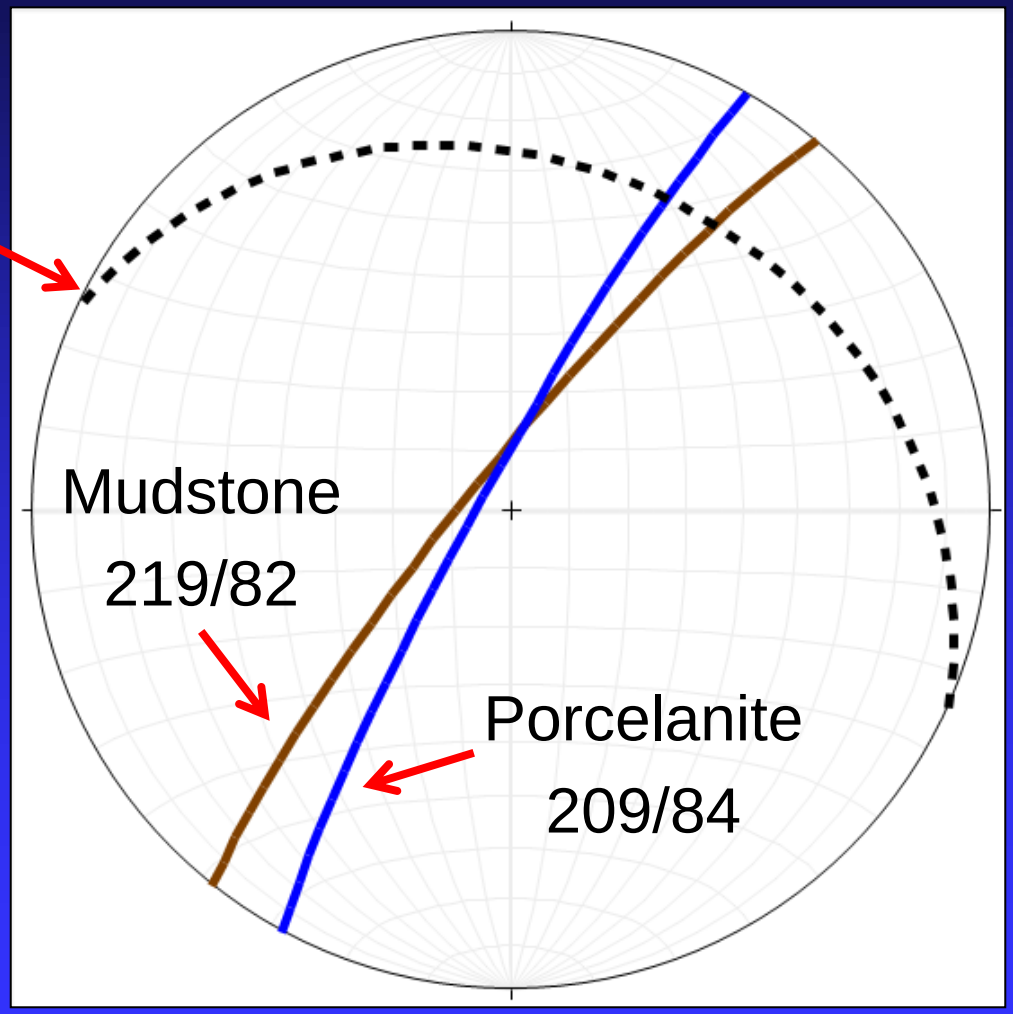
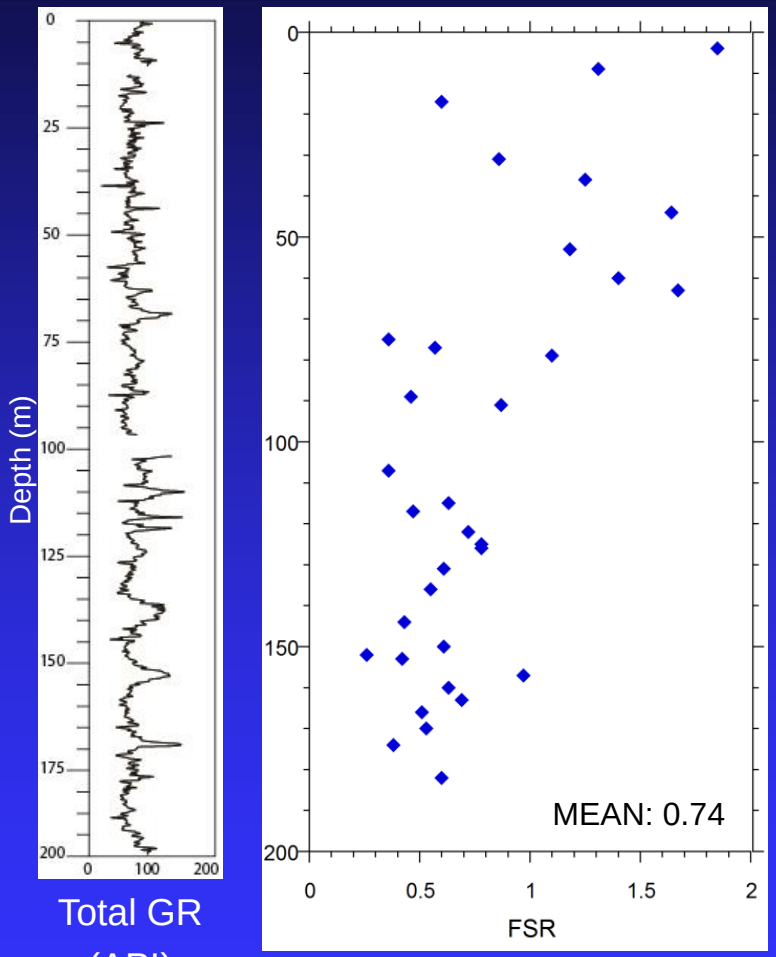
# 4th-Order Fractures



# Fracture Spacing Ratio – 4th Order

Porcelanite




FSR =
Mechanical layer thickness
÷
median facture spacing

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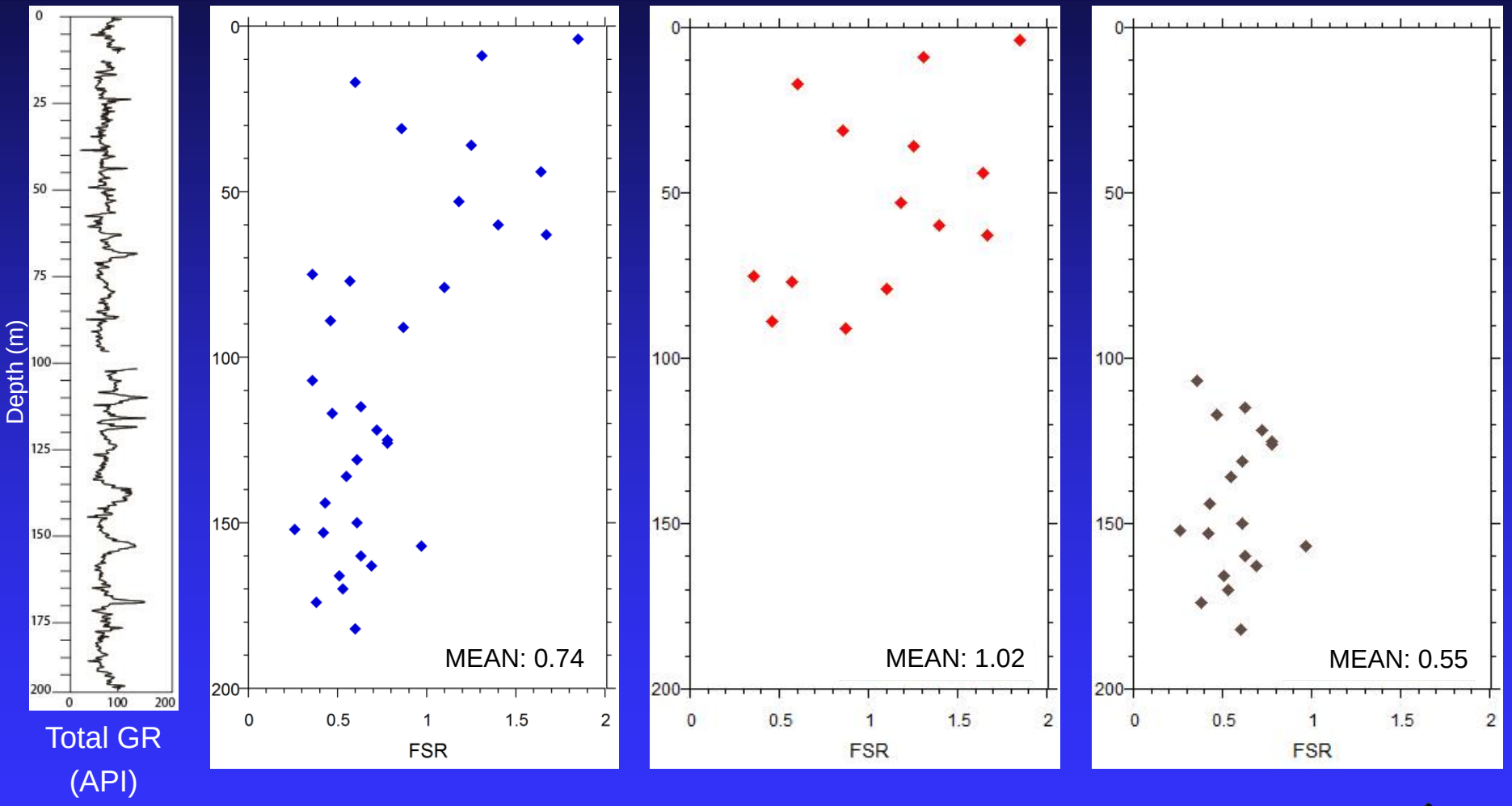
# Fracture Spacing Ratio

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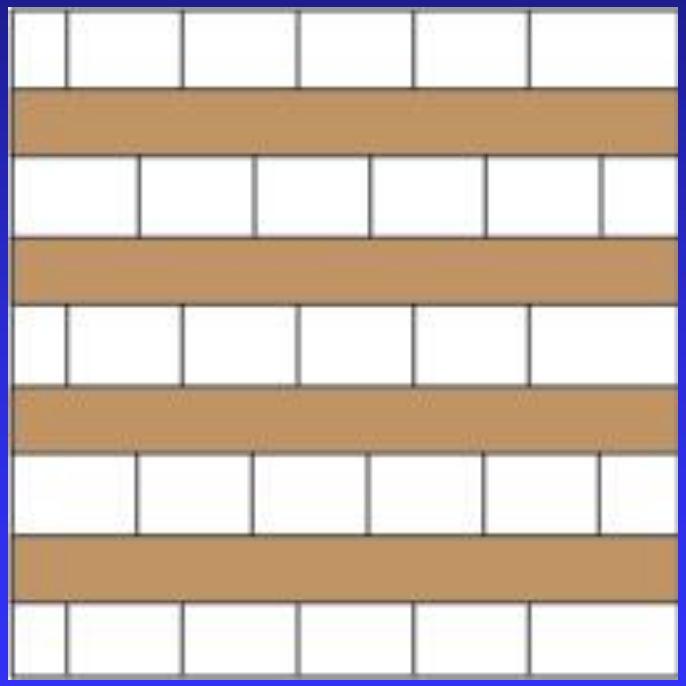
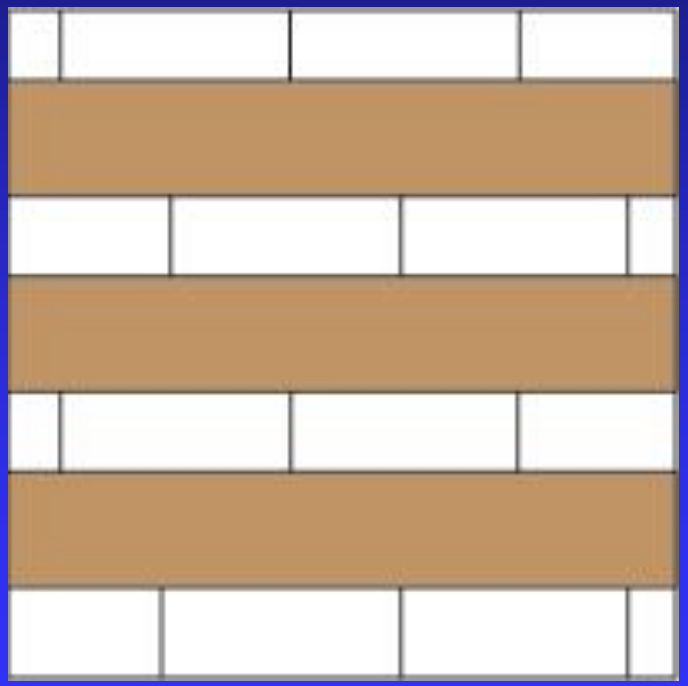
# Fracture Relationships

FSR = 1.02



0-100m

FSR = 0.55



100-200m

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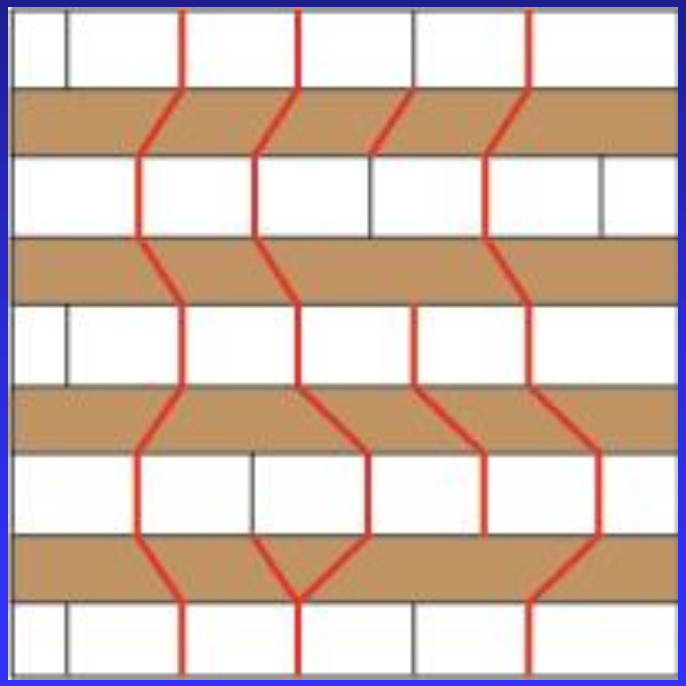
# Fracture Relationships

Set 1 : 2+3 = 3.06

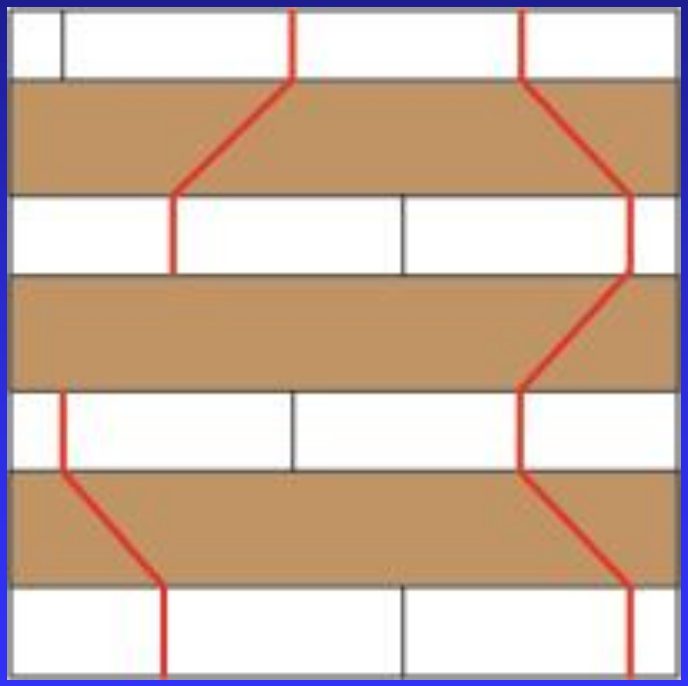
FSR = 1.02



0-100m

Set 1 : 2+3 = 1.35

FSR = 0.55



100-200m

# Summary

- Stratal stacking influences bed-confined fracturing and can affect the propagation of larger fractures
- Gamma-ray signatures can be used to characterize lithostratigraphic units that may act as mechanical units at various scales
- Tuff horizons are most effective lithologic mechanical layer boundary for all 4 orders of fractures
- Fracture set 1 is a structural mechanical layer boundary to fracture sets 2 and 3, indicating that set 1 formed prior to set 2 and 3

# Thank You