

*Application of Natural Fracture and In  
Situ Stress Analyses to  
Production in Geothermal and  
Oil and Gas Reservoirs*

**Colleen Barton, Ph.D.**

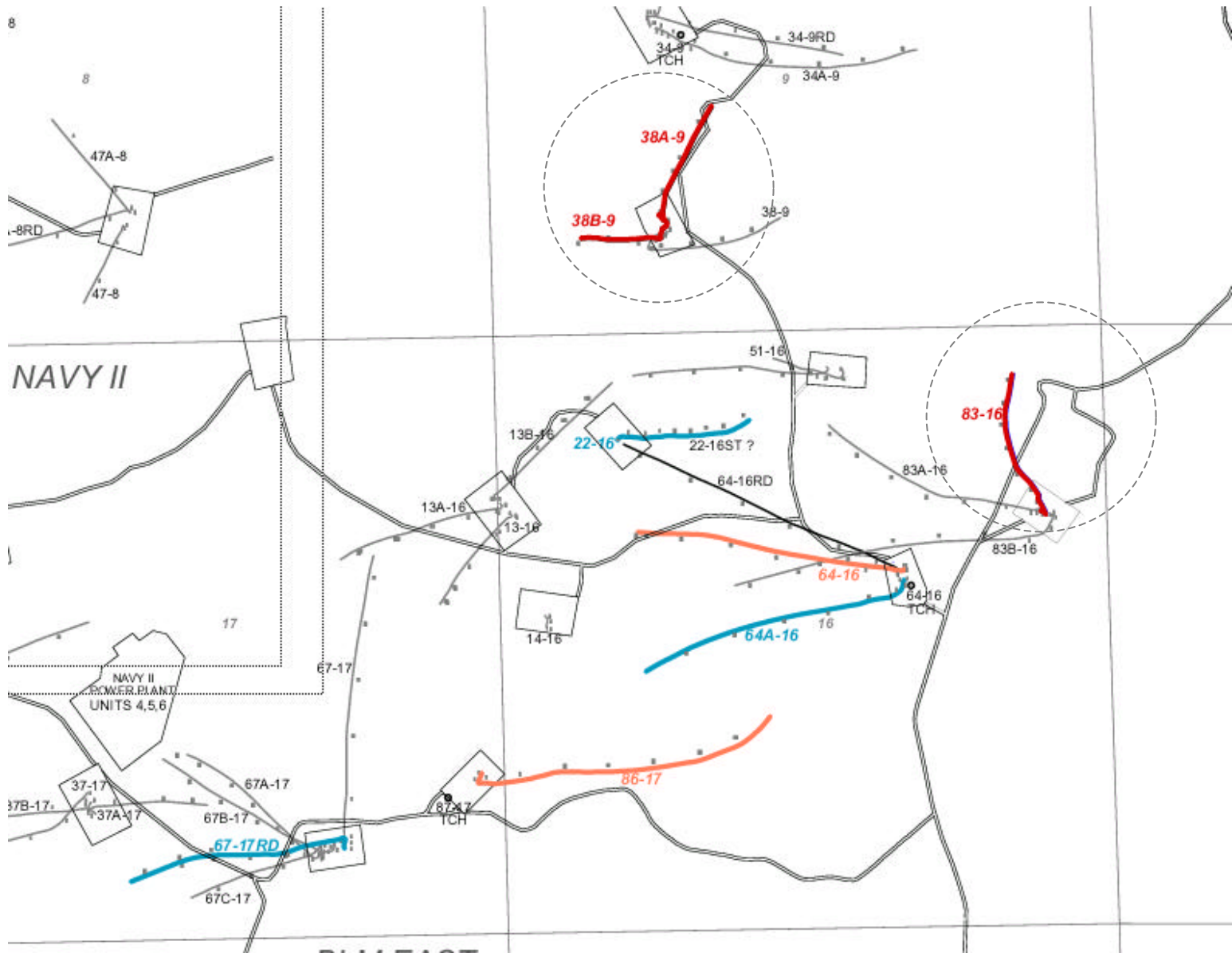
**Amy Day-Lewis, M.S.**

**Judith Sheridan, Ph.D.**

**GeoMechanics International, Inc.**

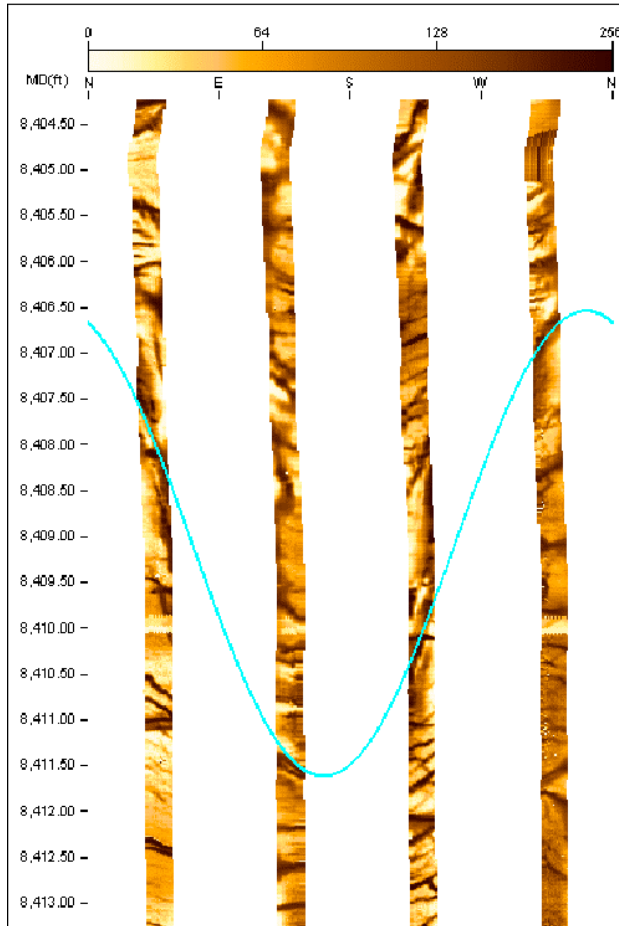
# Coso Geothermal Field

DOE•EGI•CAITHNESS ENERGY

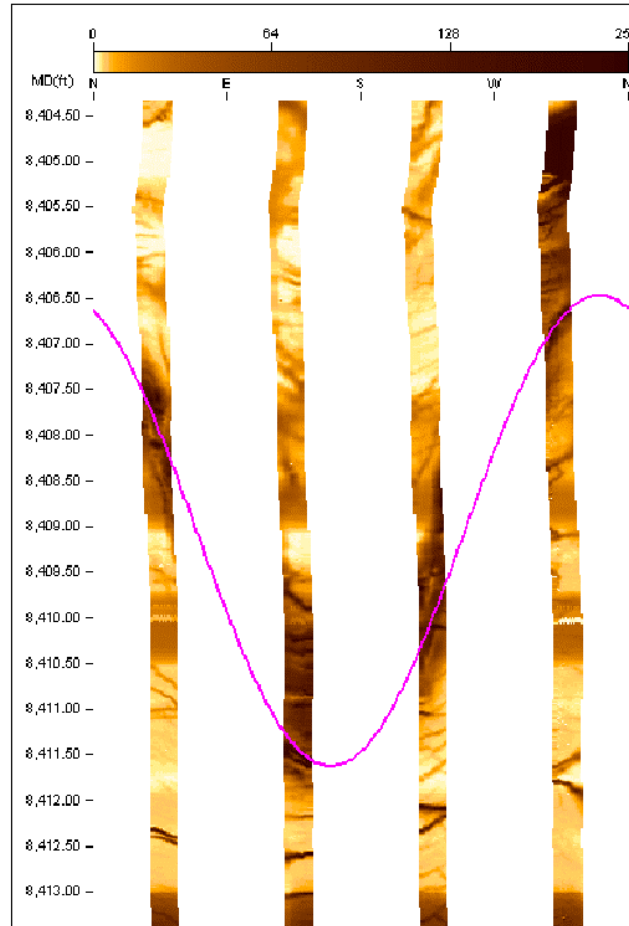


# 83-16 Fractures and Flow Anomaly

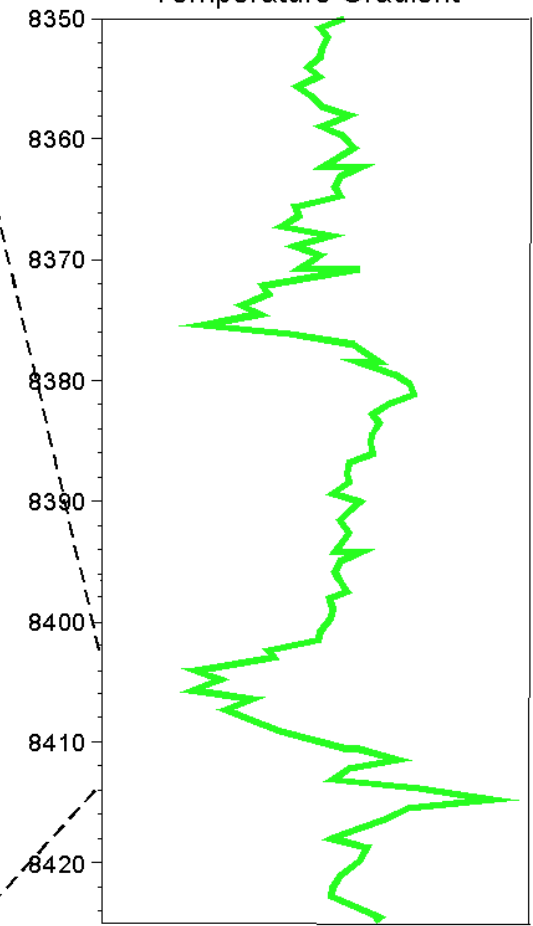
DYNAMIC NORMALIZATION



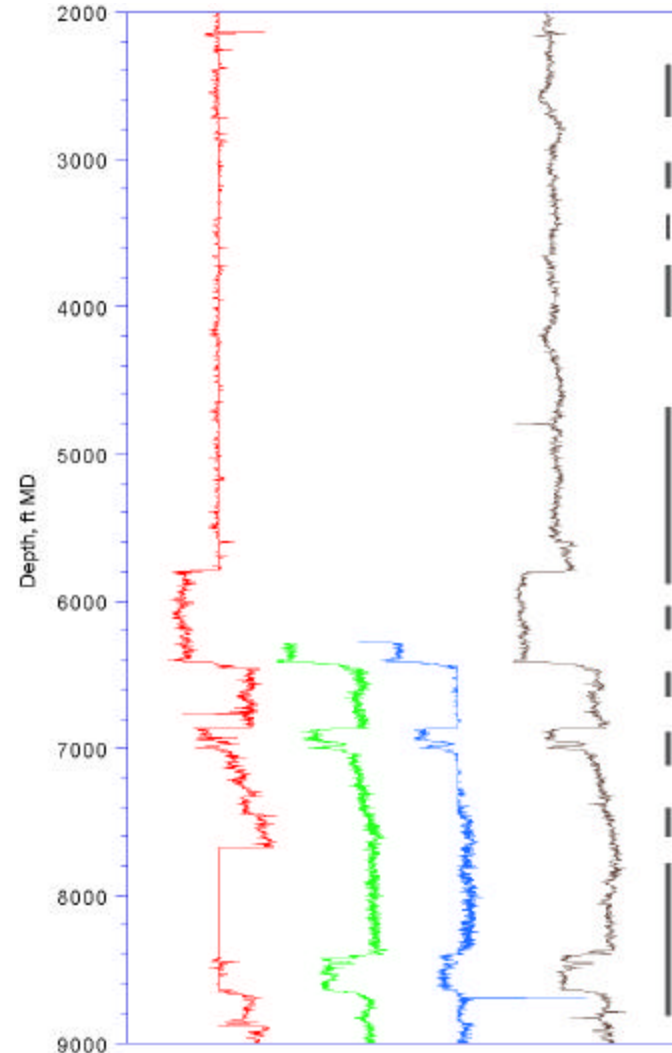
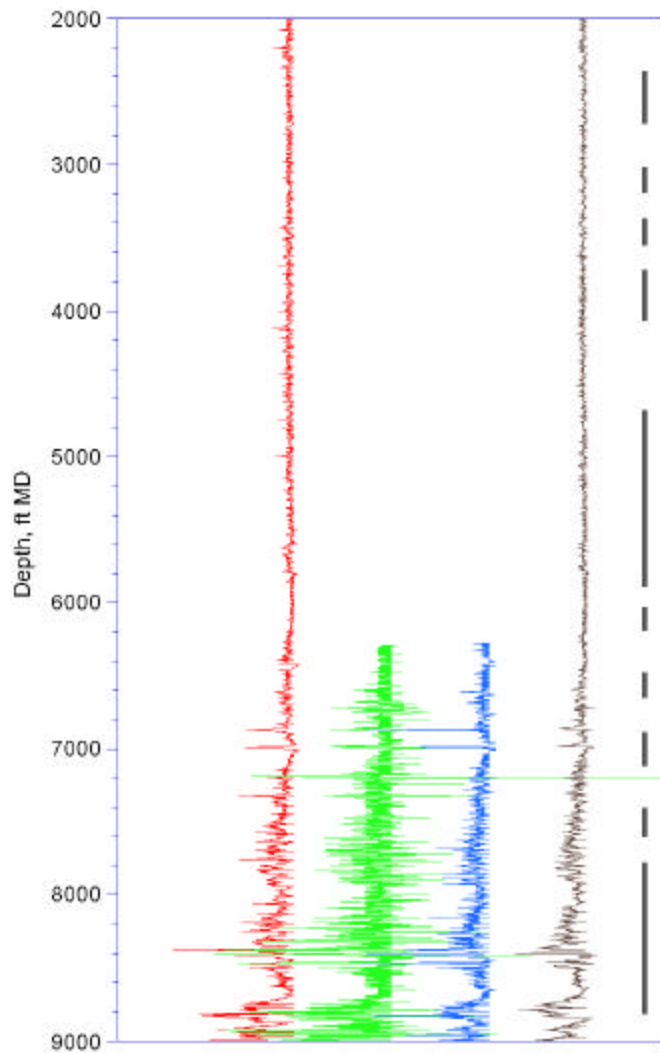
STATIC NORMALIZATION



Temperature Gradient

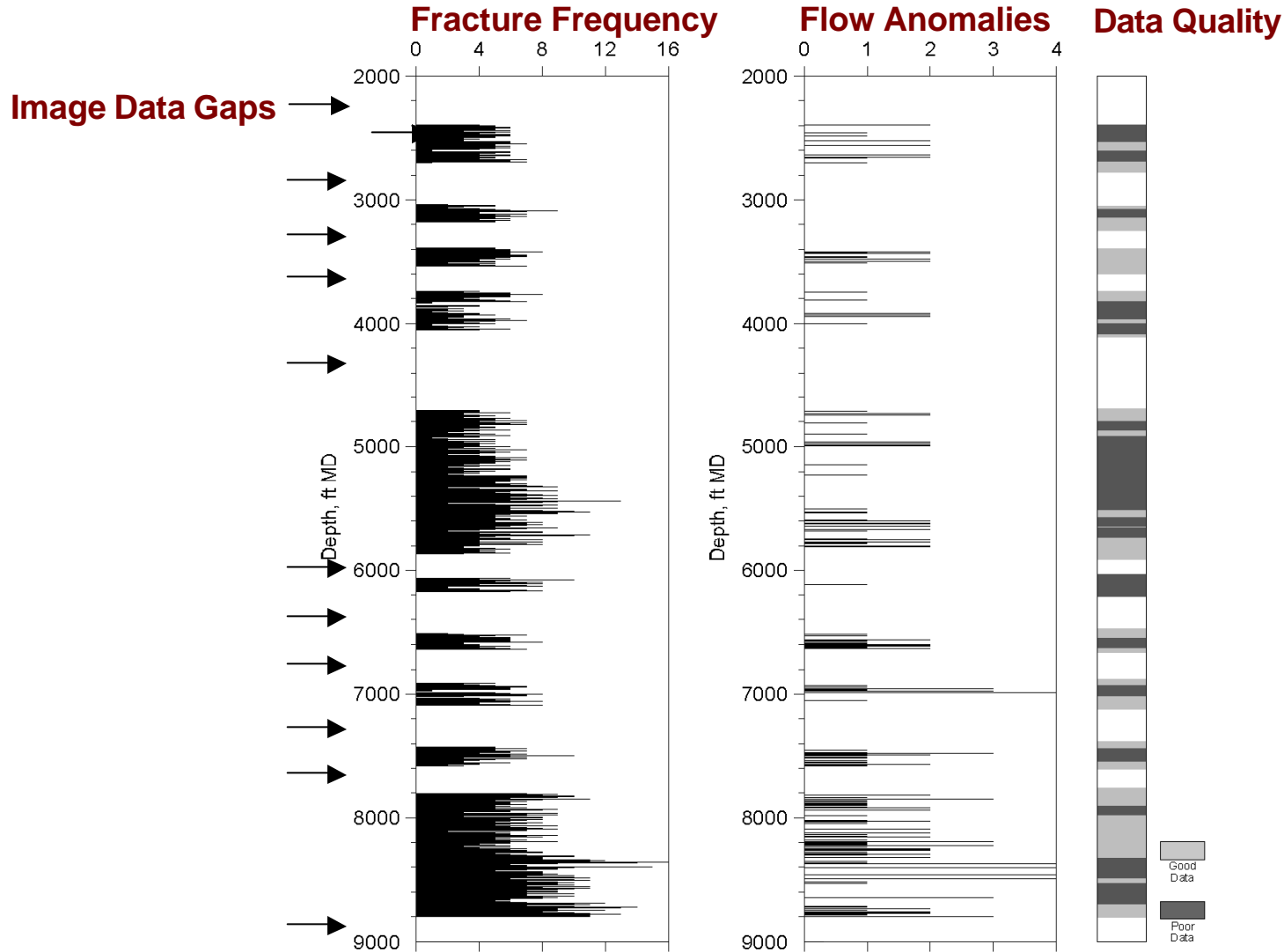


# Fluid Flow Data 83-16



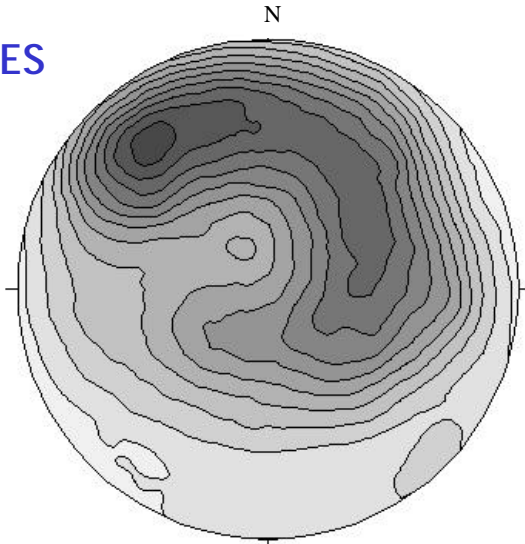
Available image data

# 83-16 Fracture and Flow Analysis

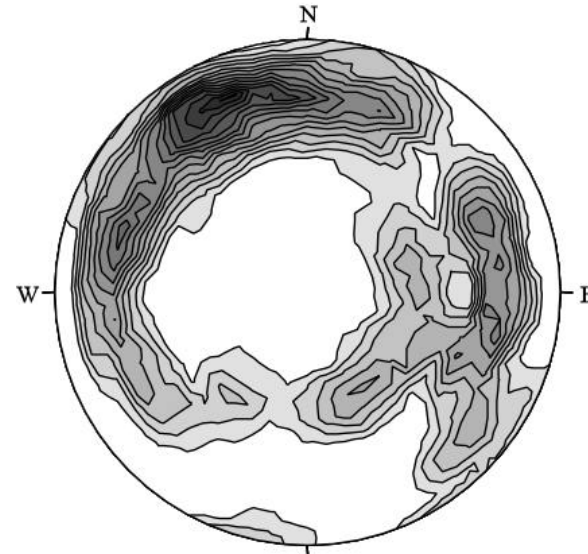


# 83-16 Fracture and Flow Analysis

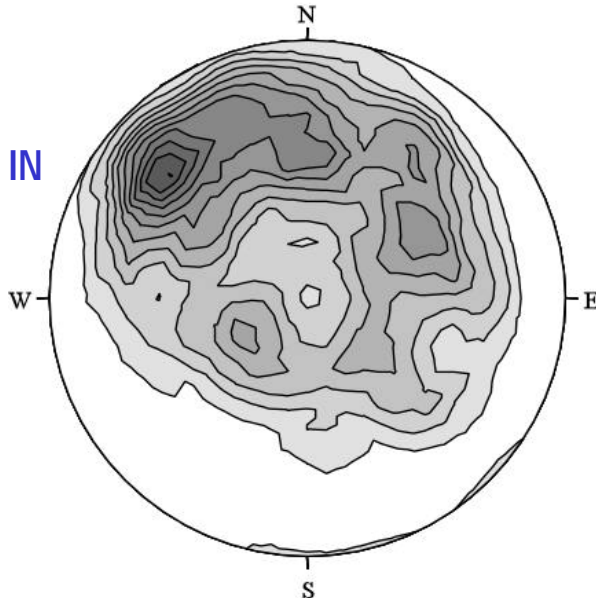
ALL FRACTURES  
N=13552



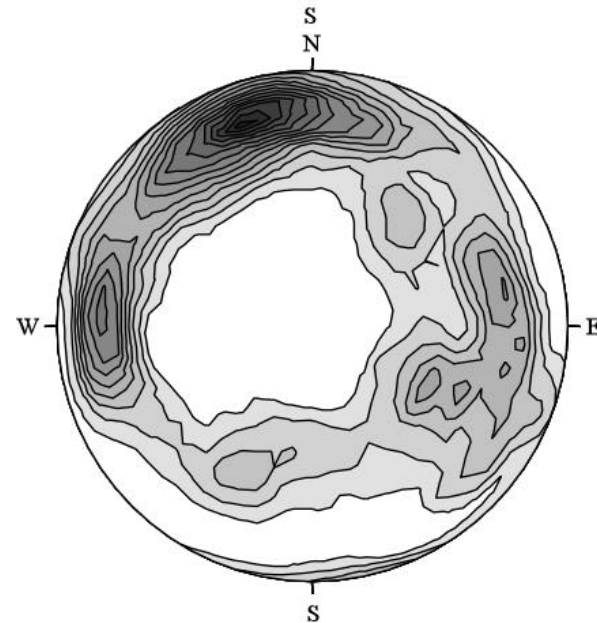
FRACTURES  
CORRELATED  
WITH NON-  
TRANSIENT  
FLOW  
N=214



FRACTURES IN  
NON-FLOW  
INTERVALS  
N=407



FRACTURES  
CORRELATED  
WITH TRANSIENT  
AND NON-  
TRANSIENT FLOW  
N=70

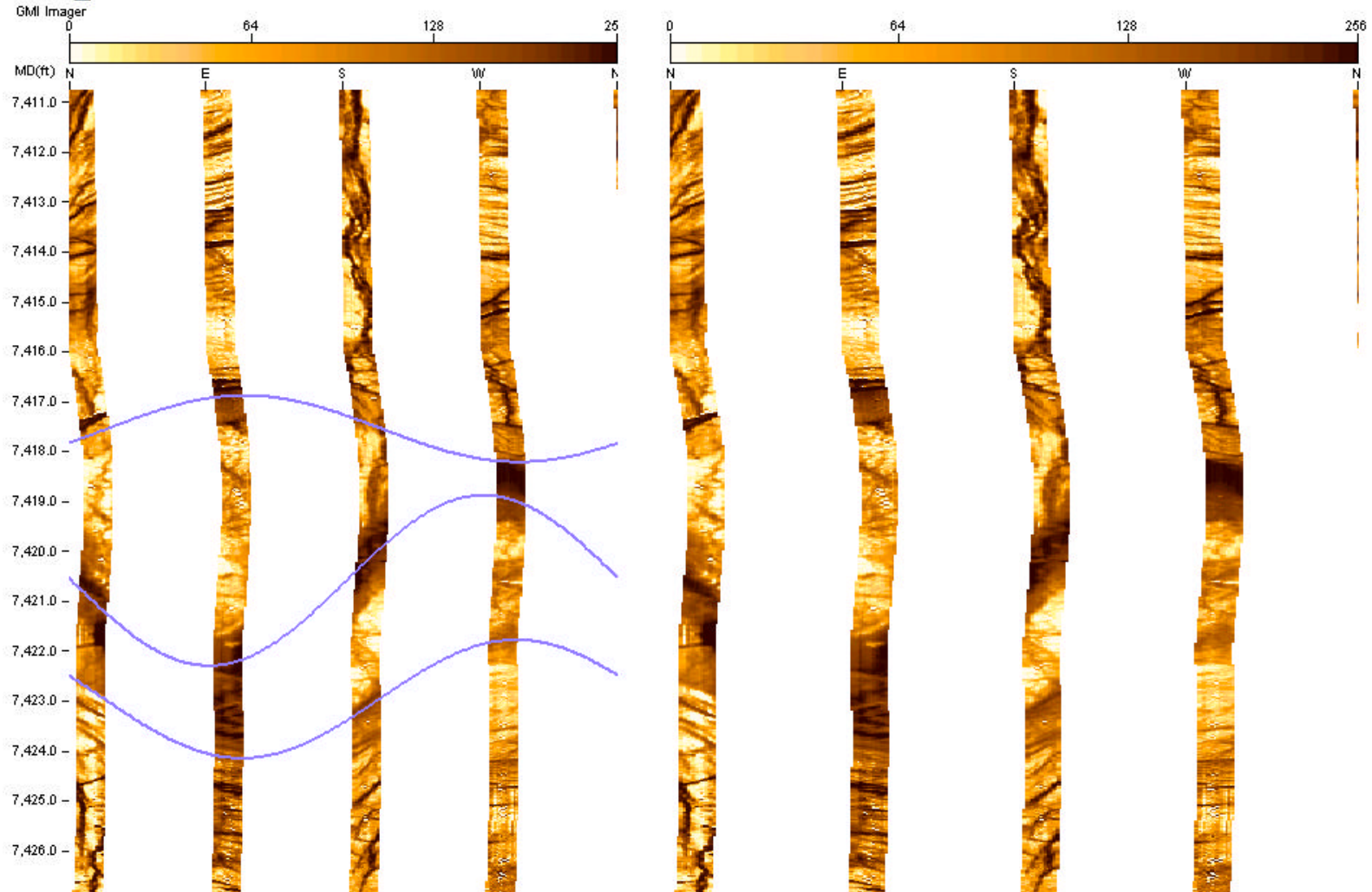




# Potentially Producing Fractures



Well Name: 38A-9 Log Date: 19-MAY-1997  
Well Location: California Depth Range: 7,000.0 - 7,498.0 ft

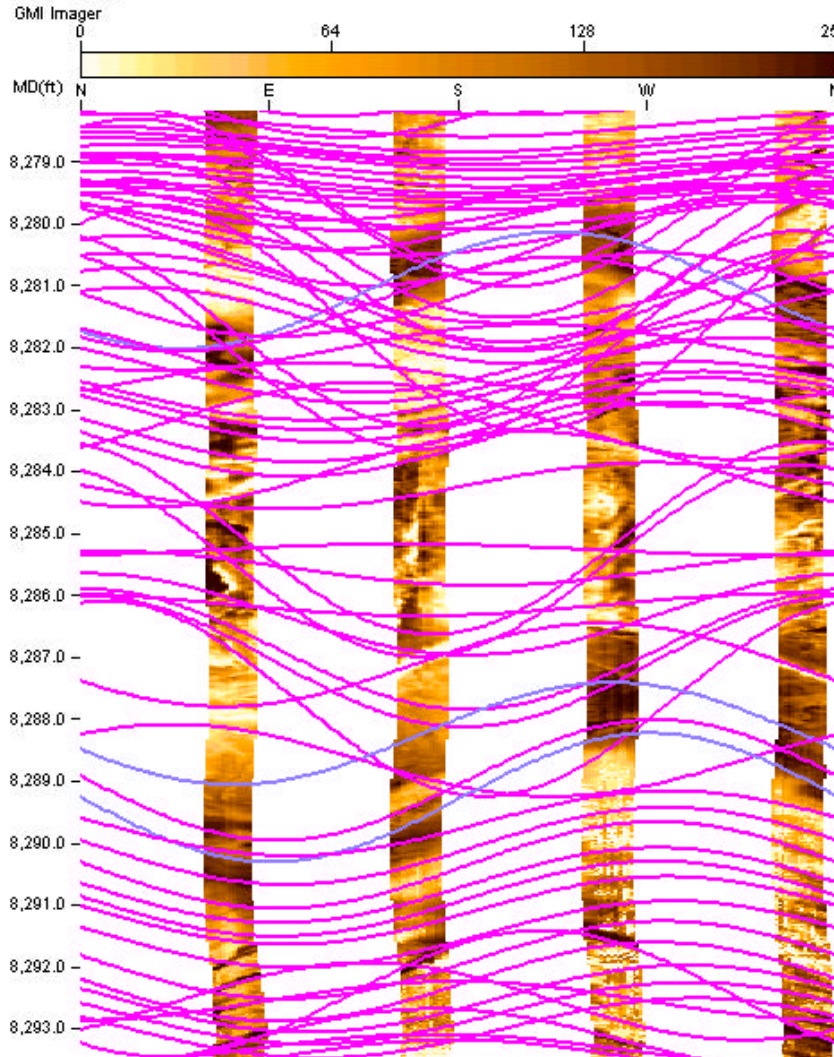


**Well 38A-9**

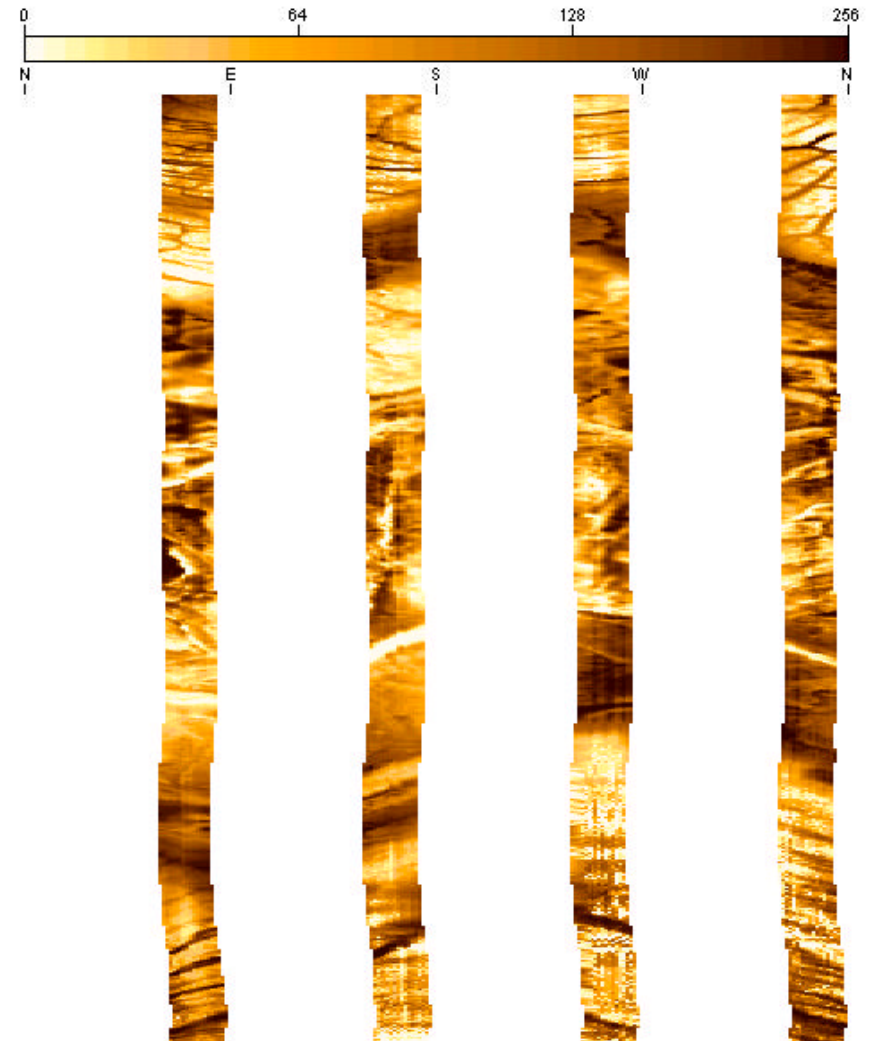
# Potentially Producing Fractures



Well Name: 38B-9 Log Date: 04Jul1998  
Well Location: Coso Depth Range: 8,250.0 - 8,500.0 ft

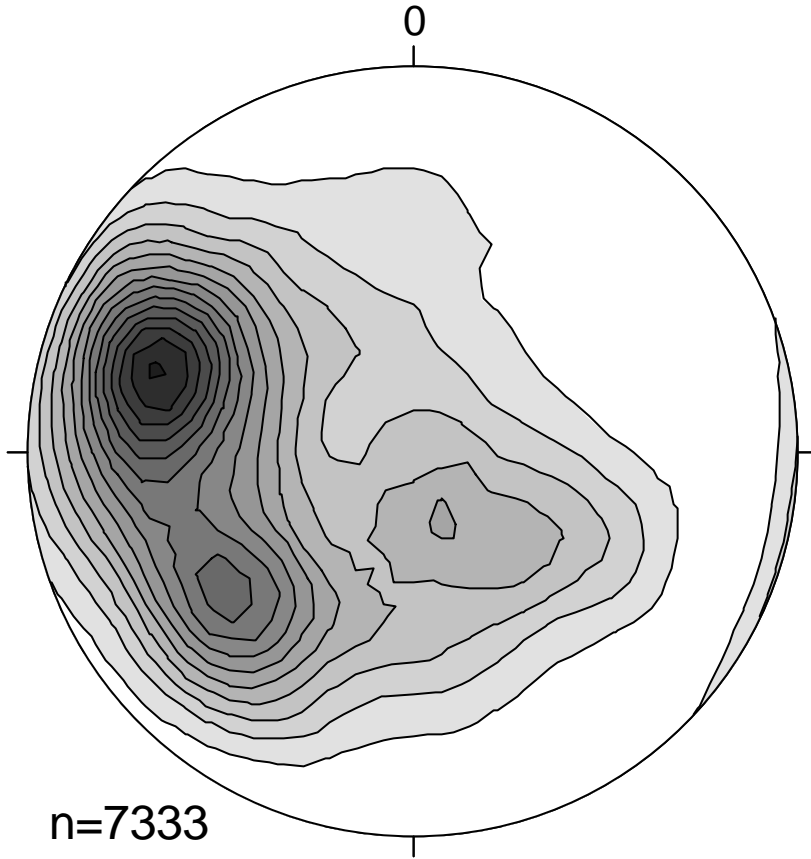


**Well 38B-9**

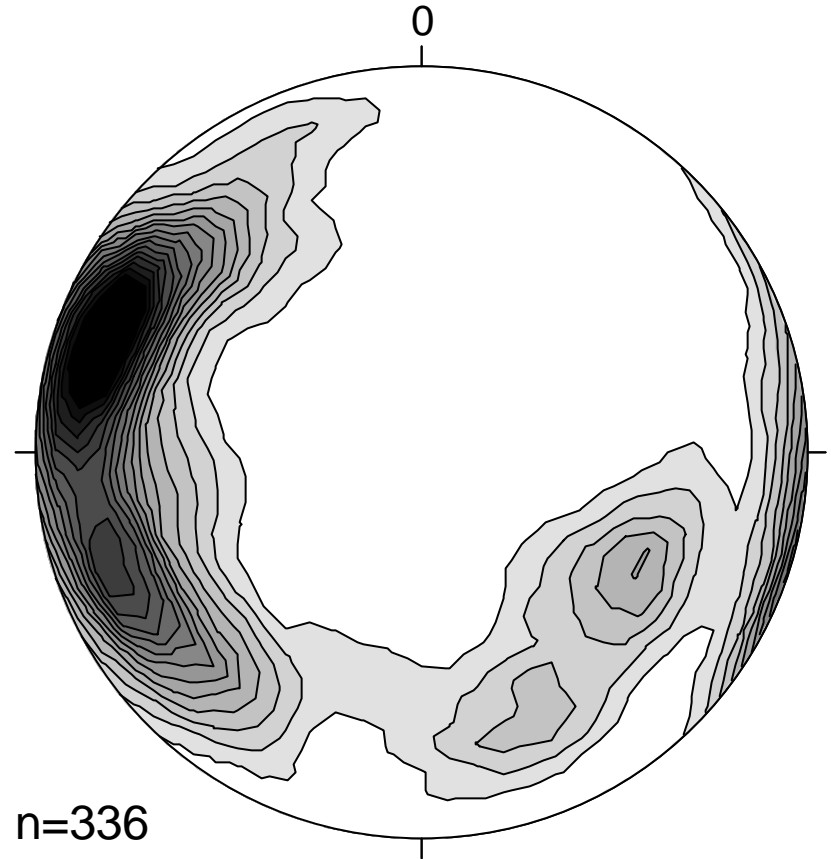




# 38B-9 Fracture Analysis

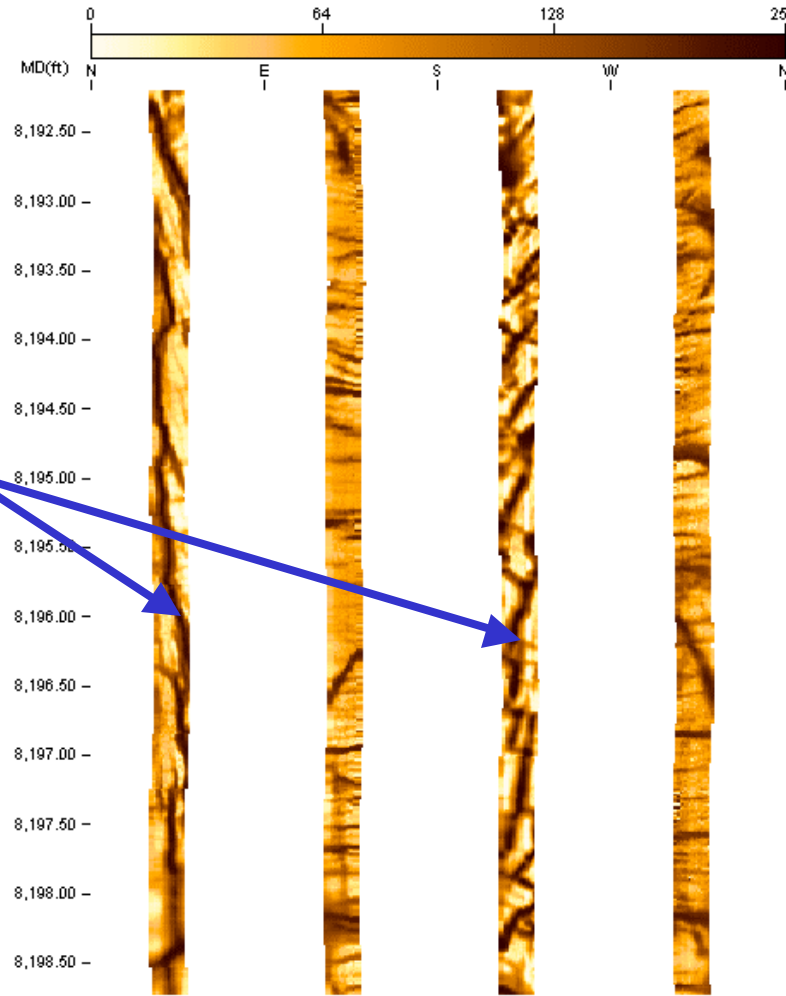


**ALL FRACTURES**

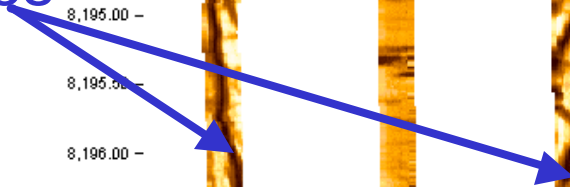


**POTENTIALLY PRODUCING  
FRACTURES**

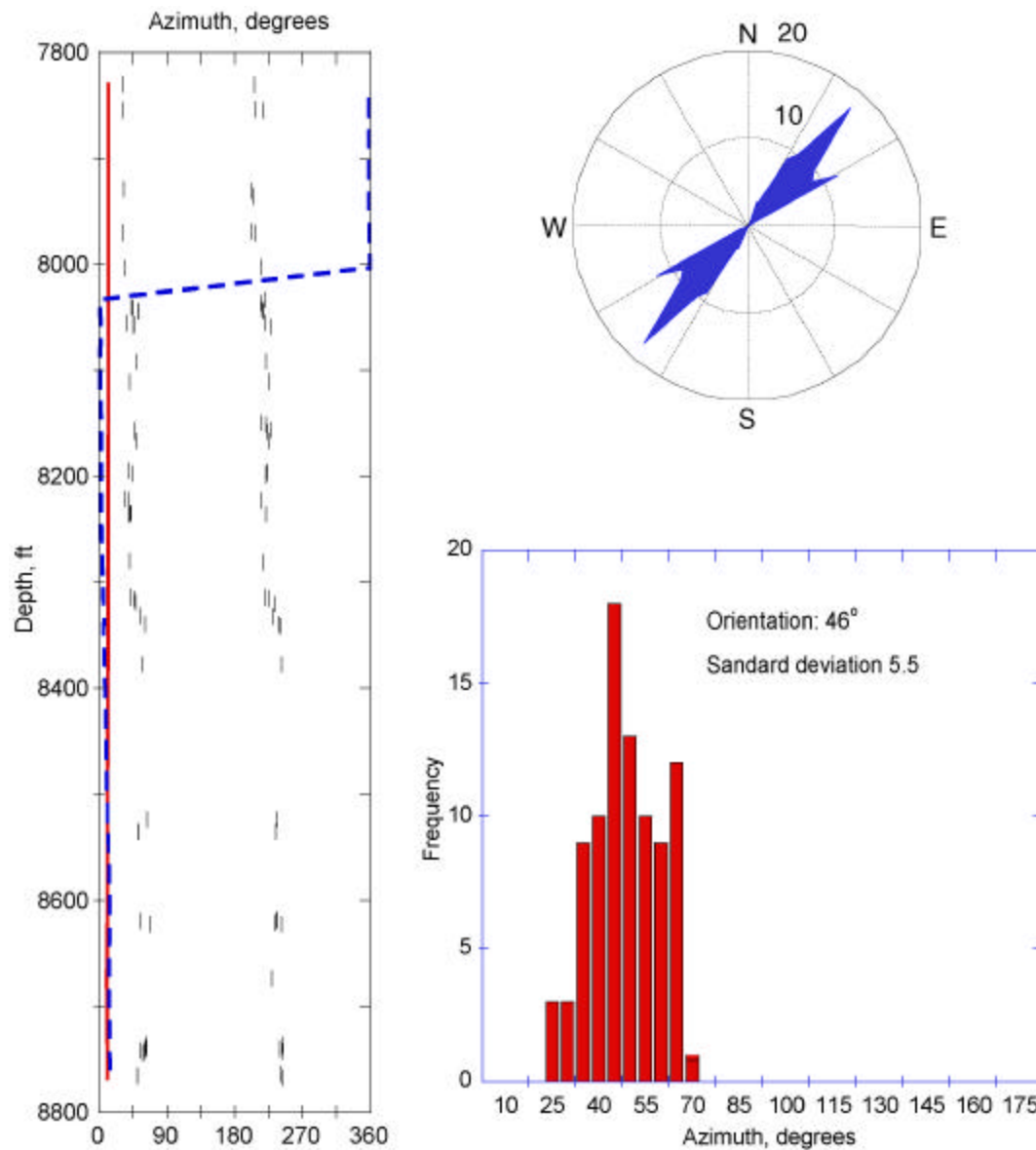
# 83-16 Tensile Wall Fractures



Tensile Wall Fractures

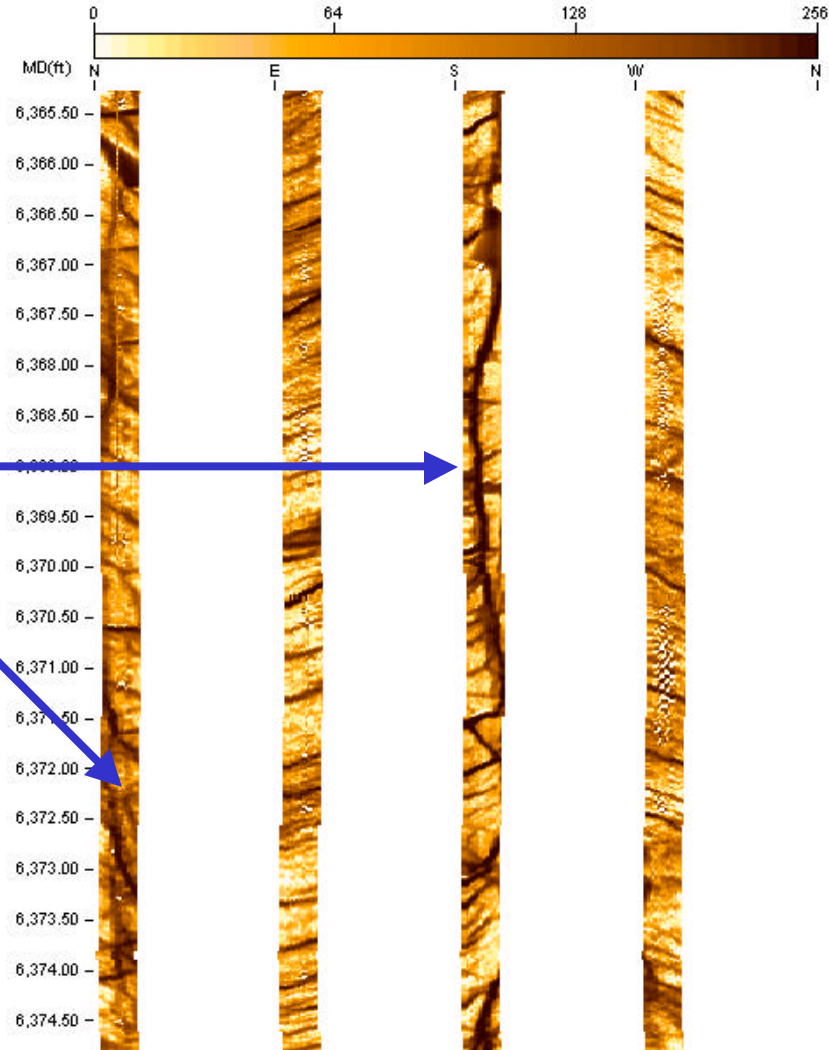


# Tensile Wellbore Failure Analysis 83-16



# 38A-9 Tensile Wall Fractures

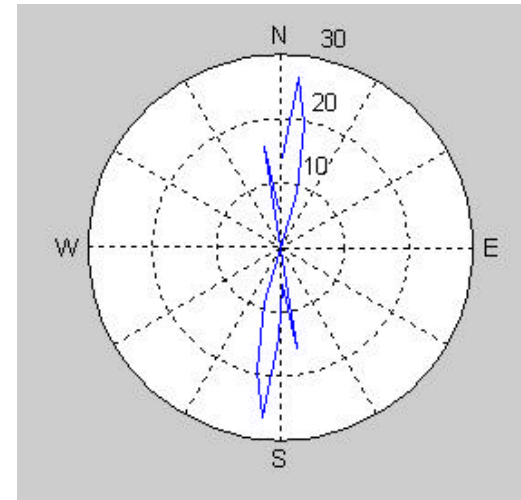
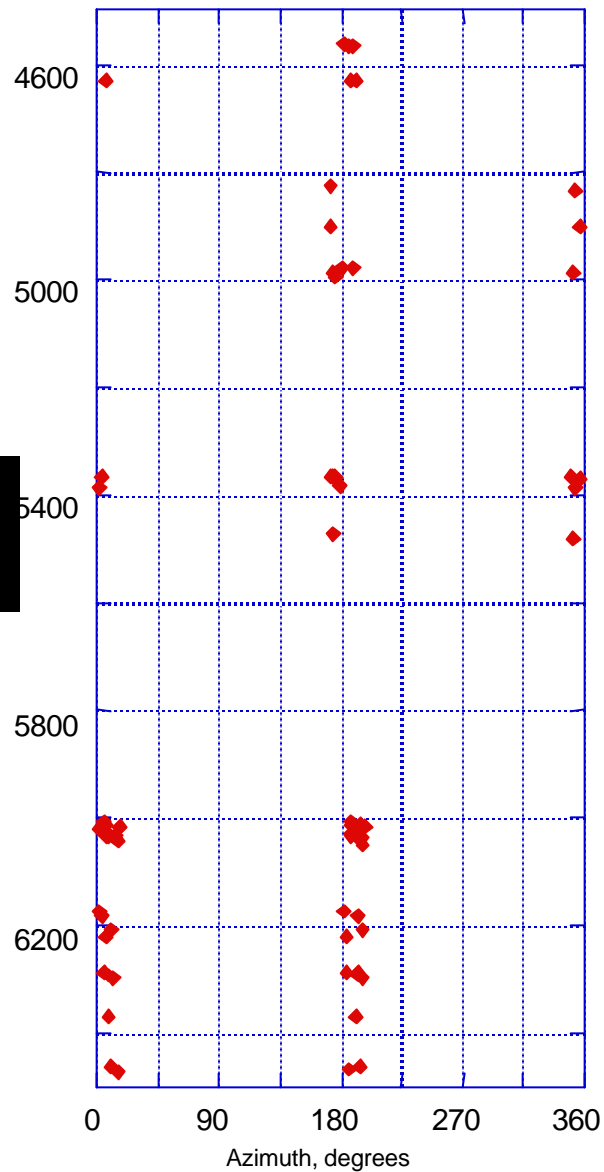
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Well Location: California Depth Range: 6,000.0 - 6,500.0 ft



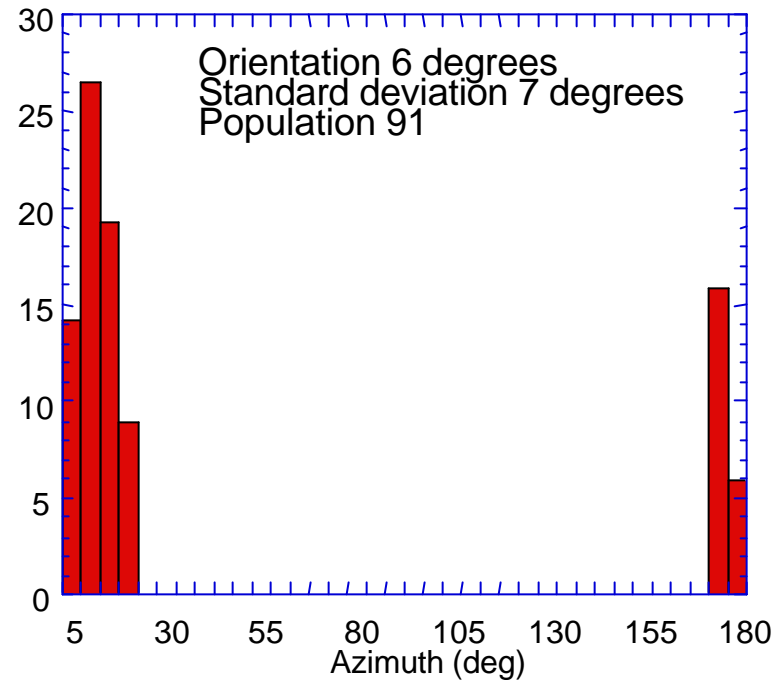
Scale: 1/16 Aspect Ratio: N/A Total Pages: 58

# Tensile Wellbore Failure Analysis 38A-9

## 38A-9 Tensile Fractures



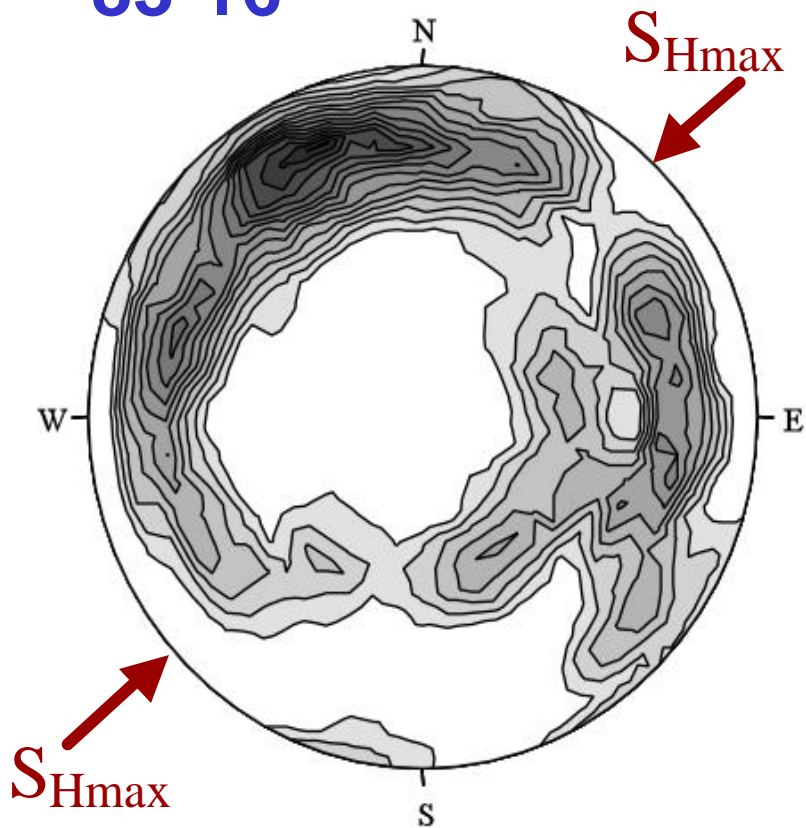
## 38A-9 Tensile Fracture Azimuth



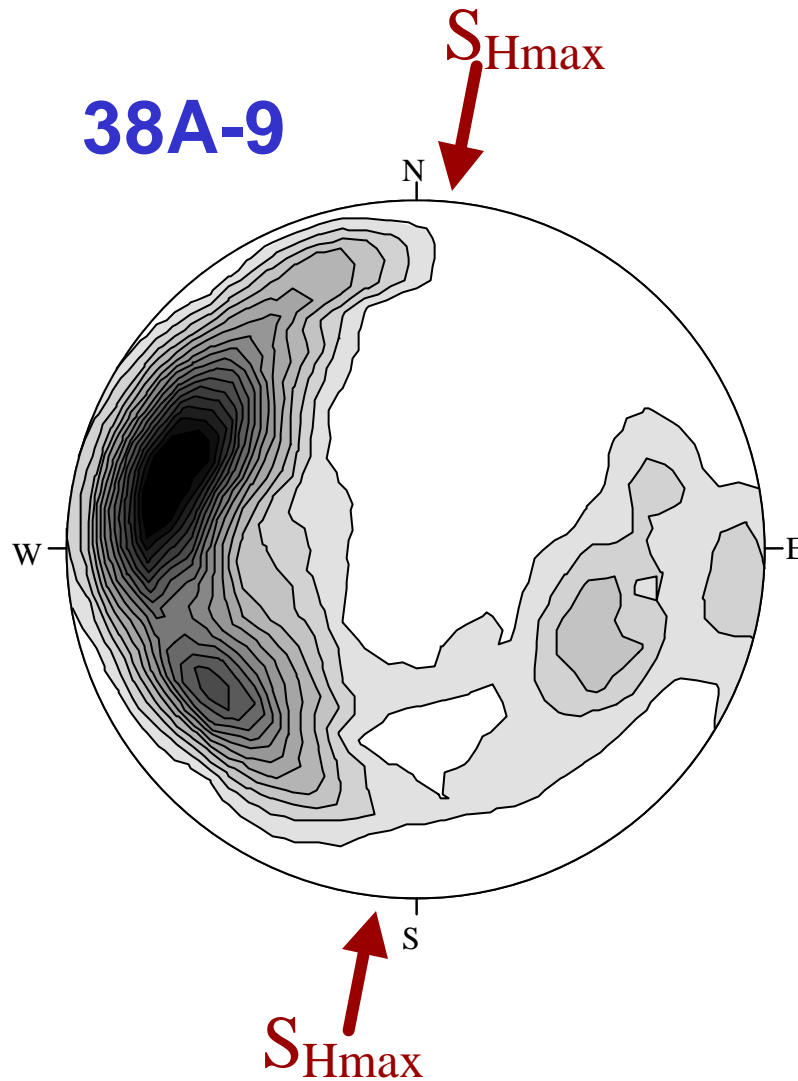


# Permeable Fractures and $S_{Hmax}$

83-16



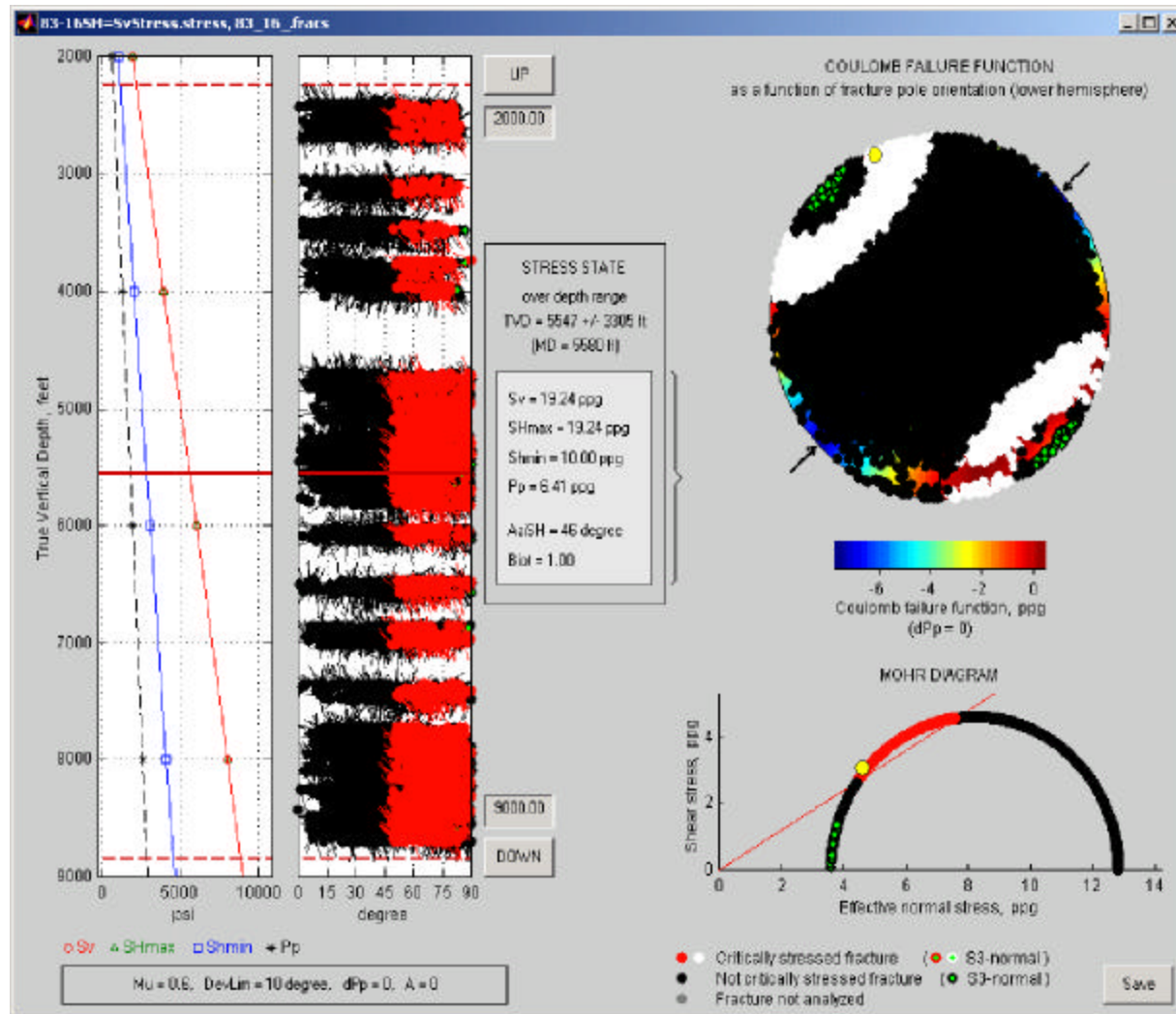
38A-9



# Preliminary In Situ Stress State: Well 83-16

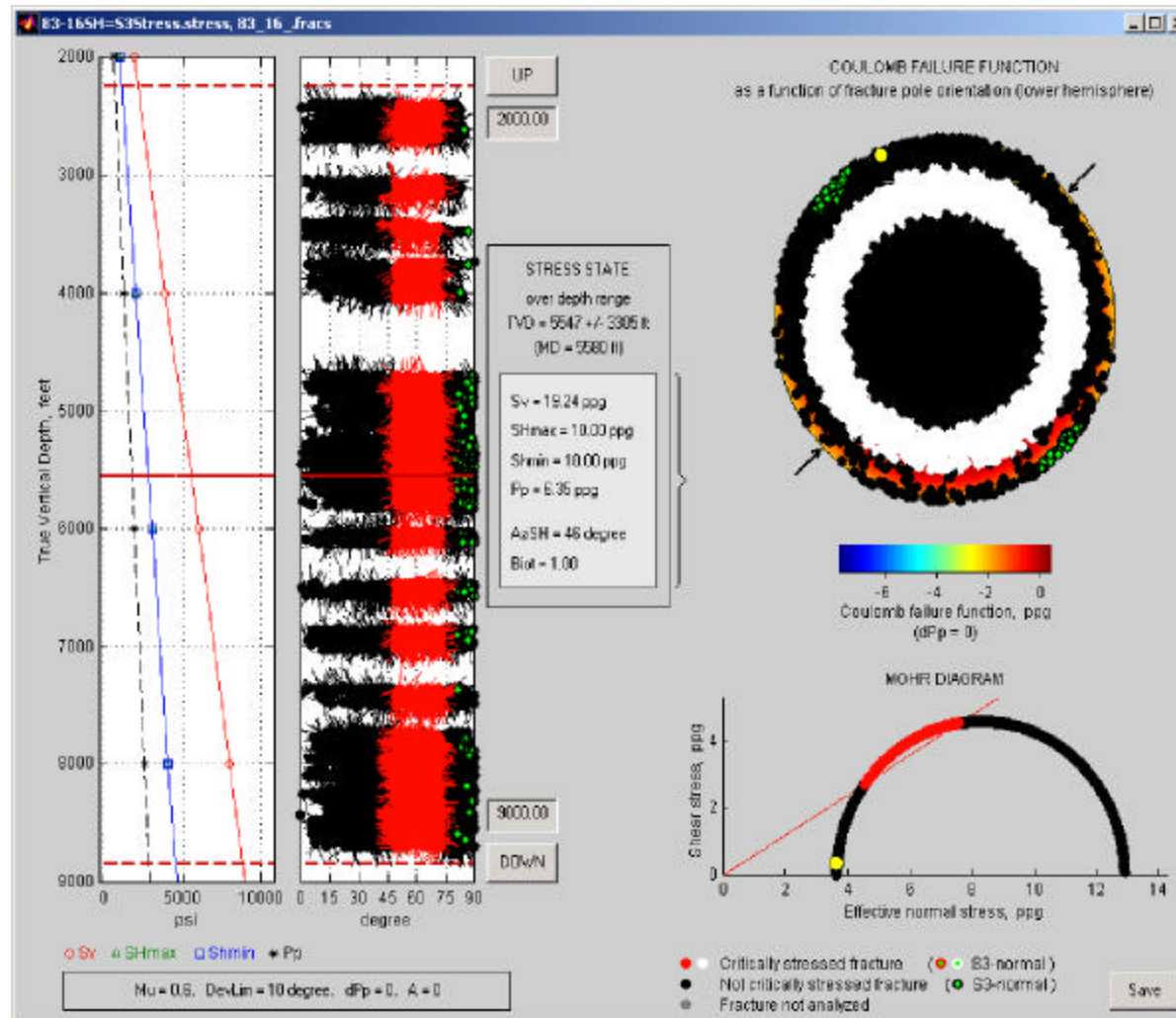
| <b>Faulting case</b> | <b><math>S_v</math></b> | <b><math>S_{Hmax}</math></b> | <b><math>S_{hmin}</math></b> | <b><math>P_p</math></b> | <b>Azi<br/><math>S_{Hmax}</math></b> |
|----------------------|-------------------------|------------------------------|------------------------------|-------------------------|--------------------------------------|
| Normal               | 1<br>psi/ft             | 0.52<br>psi/ft               | 0.52<br>psi/ft               | 0.33<br>psi/ft          | 46°                                  |
| Strike-slip          | 1<br>psi/ft             | 1<br>psi/ft                  | 0.52<br>psi/ft               | 0.33<br>psi/ft          | 46°                                  |

# 83-16 Critically Stressed Fractures



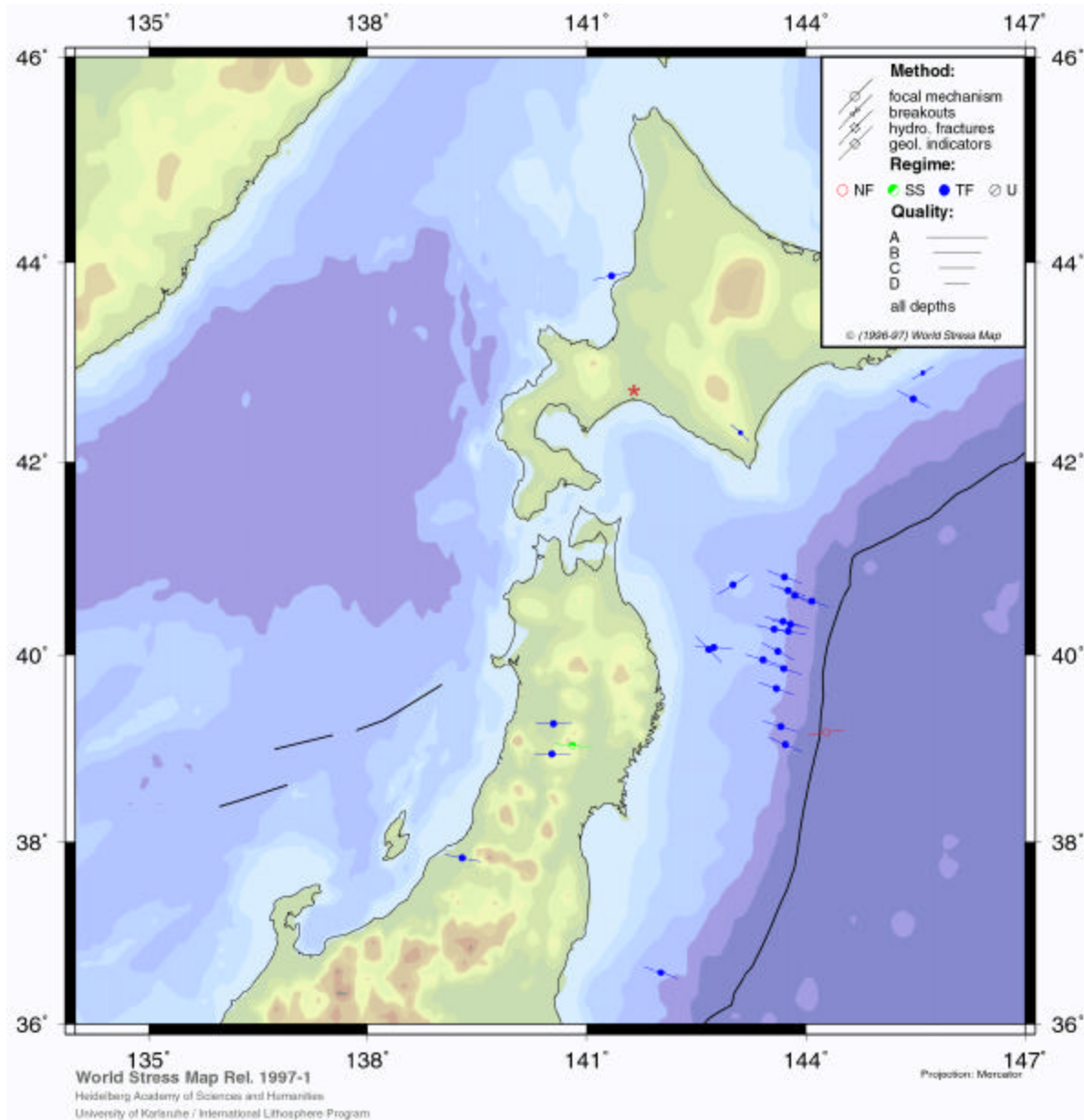
## Strike-Slip Faulting Stress Model

# 83-16 Critically Stressed Fractures



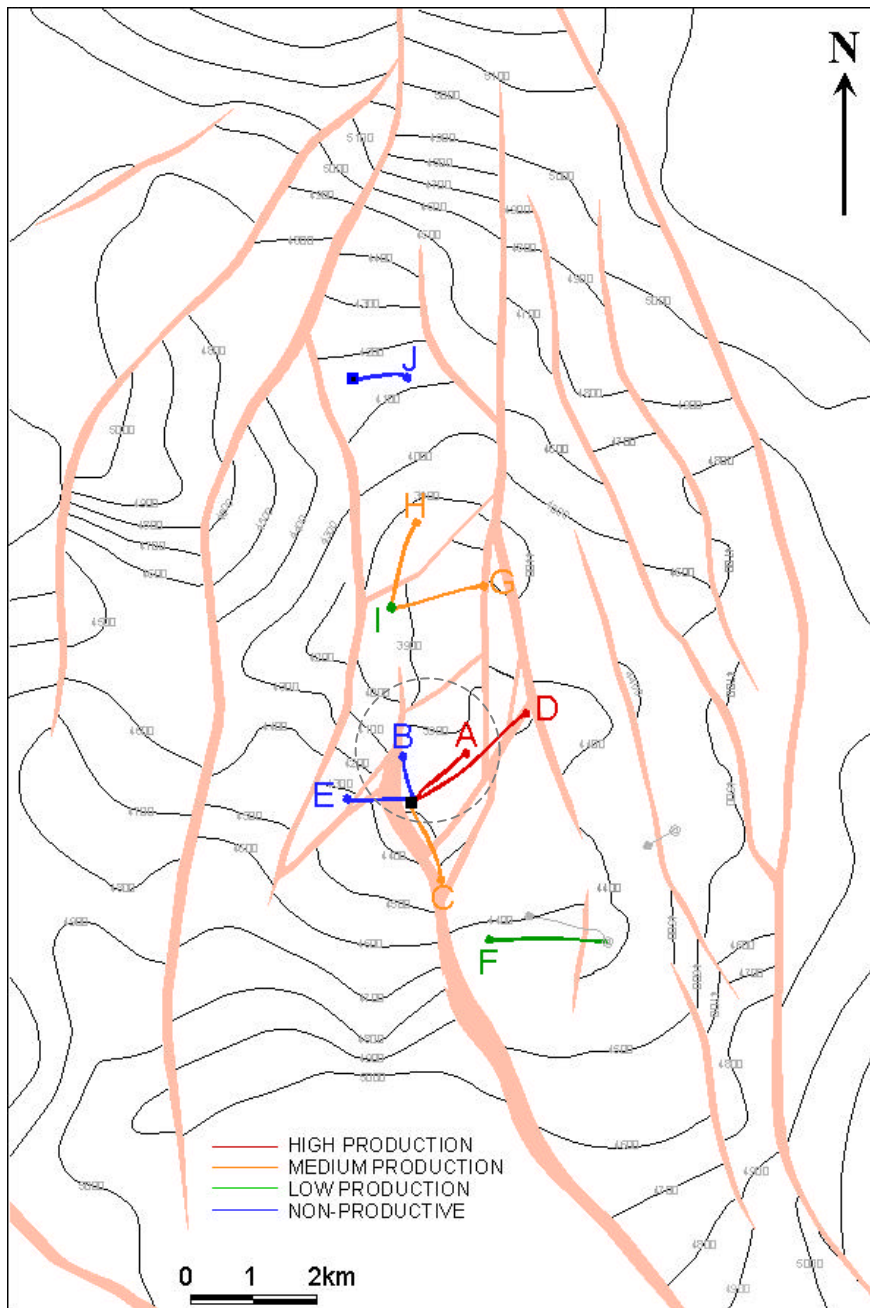
## Normal Faulting Stress Model

# Yufutsu Gas Field, Hokkaido, Japan

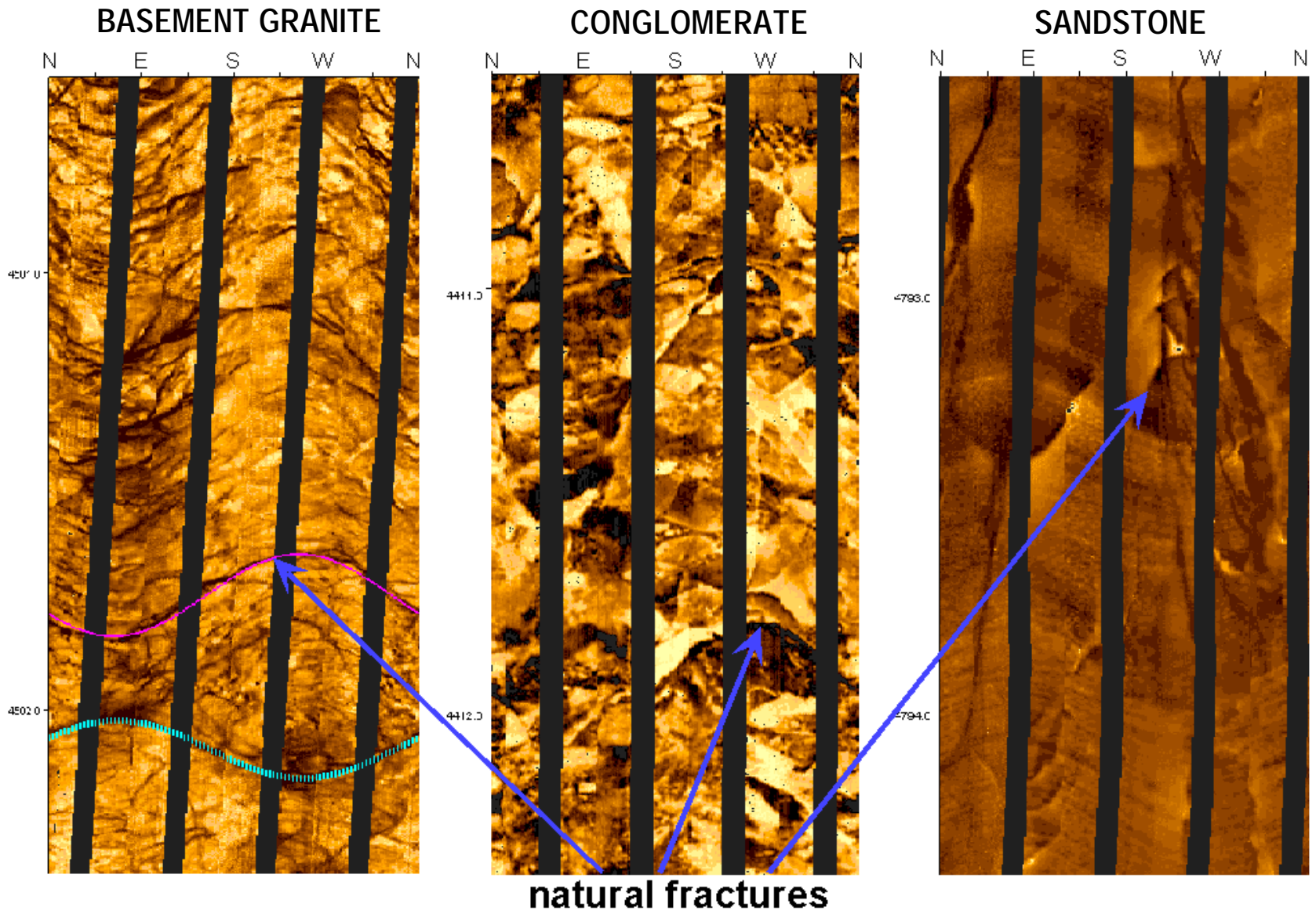




# *Yufutsu Field Well Locations and Production History*



# Yufutsu Natural Fracture Analysis





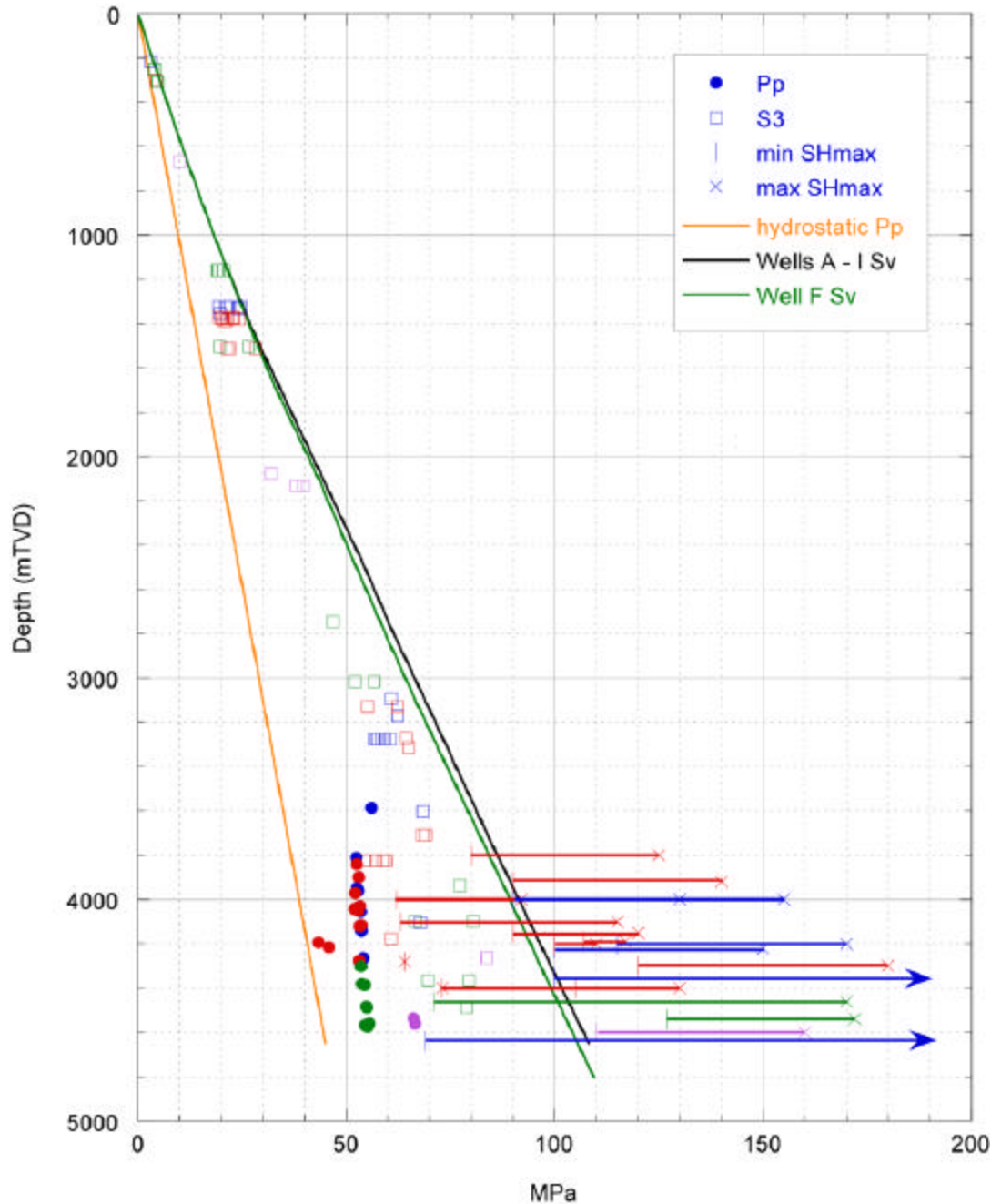
# Yufutsu Field Fracture Populations

| Well Name | Primary Fracture Population | Secondary Fracture Population  | Shallow-dipping Fractures |
|-----------|-----------------------------|--------------------------------|---------------------------|
| <b>J</b>  | SE–NW,<br>Moderate SW dip   | N–S,<br>Moderate SW dip        | Few                       |
| <b>G</b>  | SE–NW,<br>Moderate SW dip   | N–S to NNE–SSW,<br>Steep E dip | Few                       |
| <b>H</b>  | NE–SW,<br>Steep SSE dip     | NNE–SSW,<br>Steep W dip        | Few                       |
| <b>I</b>  | NE–SW,<br>Steep WNW–ESE dip |                                | Few                       |
| <b>A</b>  | NE–SW,<br>Steep SE & NW dip |                                | Moderate                  |
| <b>B</b>  | NE–SW, Steep SE dip         |                                | Abundant                  |
| <b>C</b>  | NE–SW,<br>Steep NW dip      | NE–SW,<br>Shallow SE dip       | Moderate                  |
| <b>D</b>  | NNE–SSW,<br>Steep WNW dip   | SSE–NNW,<br>Steep WSW dip      | Abundant                  |
| <b>E</b>  | SSE–NNW,<br>Moderate W dip  | SE–NW,<br>Steep NE dip         | Abundant                  |
| <b>F</b>  | NE–SW,<br>Moderate NW dip   | E–W, Steep N dip               | Abundant                  |

HIGH PRODUCTION —————  
 MEDIUM PRODUCTION —————  
 LOW PRODUCTION —————  
 NON PRODUCTIVE —————

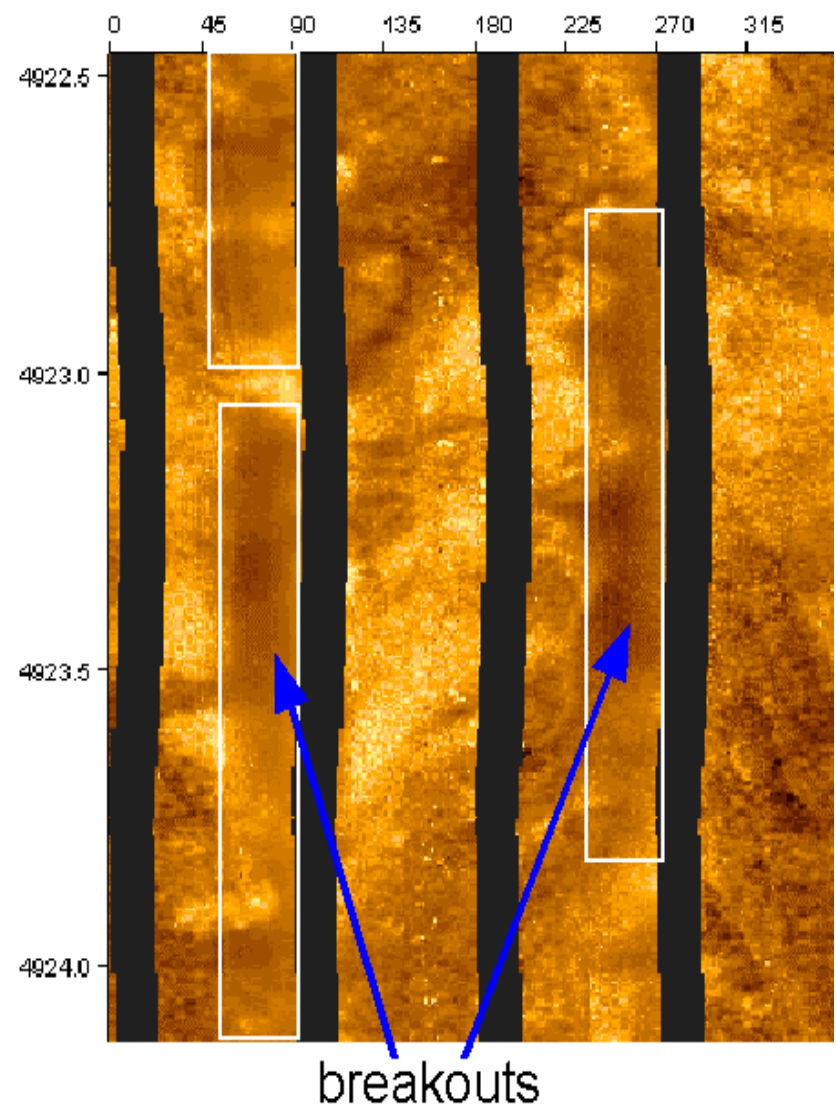
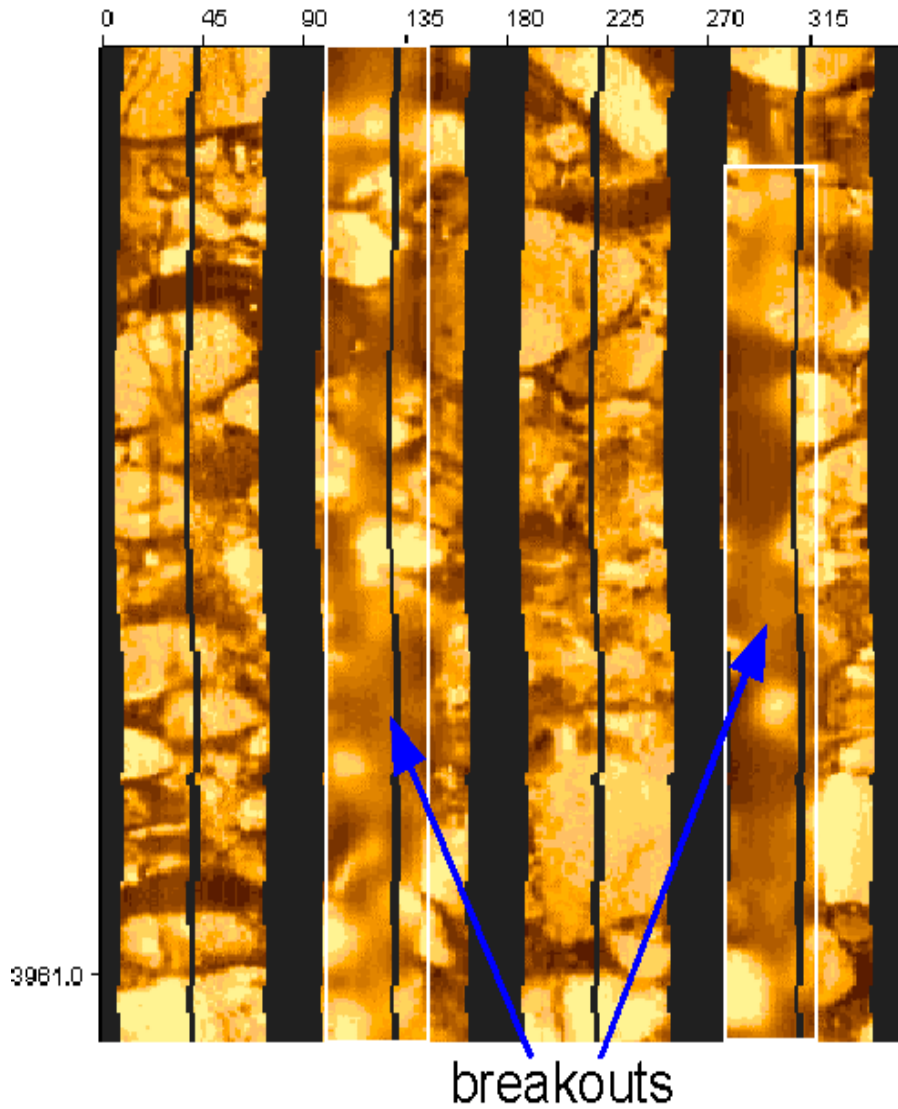


# Yufutsu Field Stress Magnitude Data

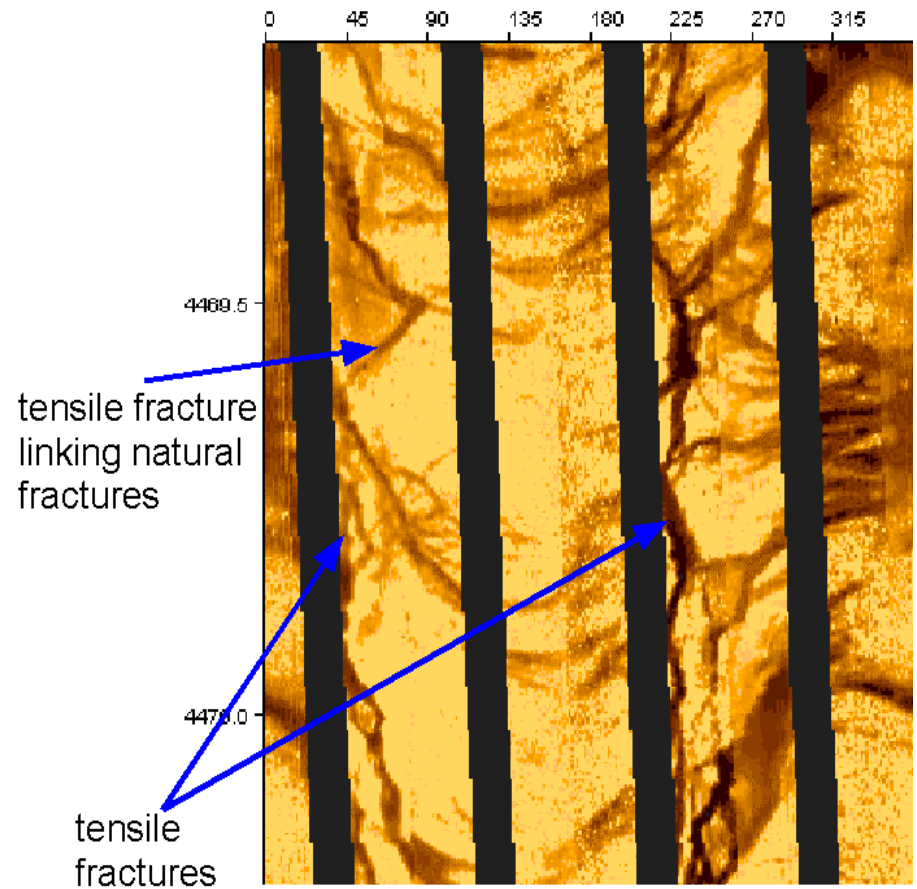
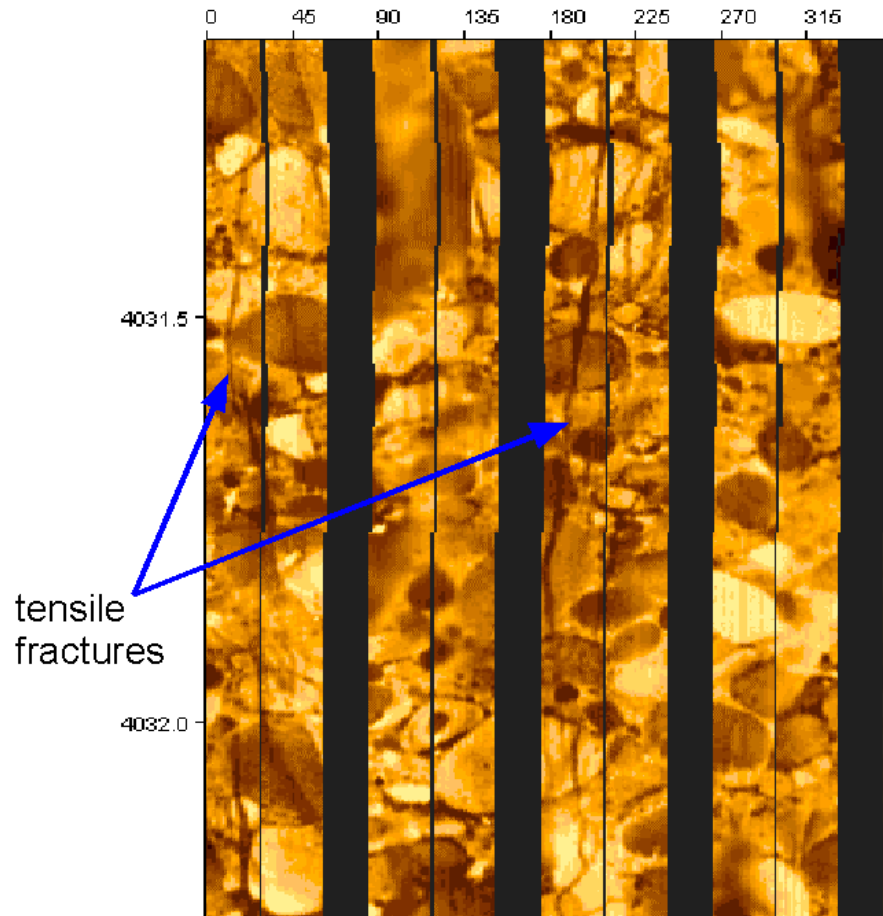




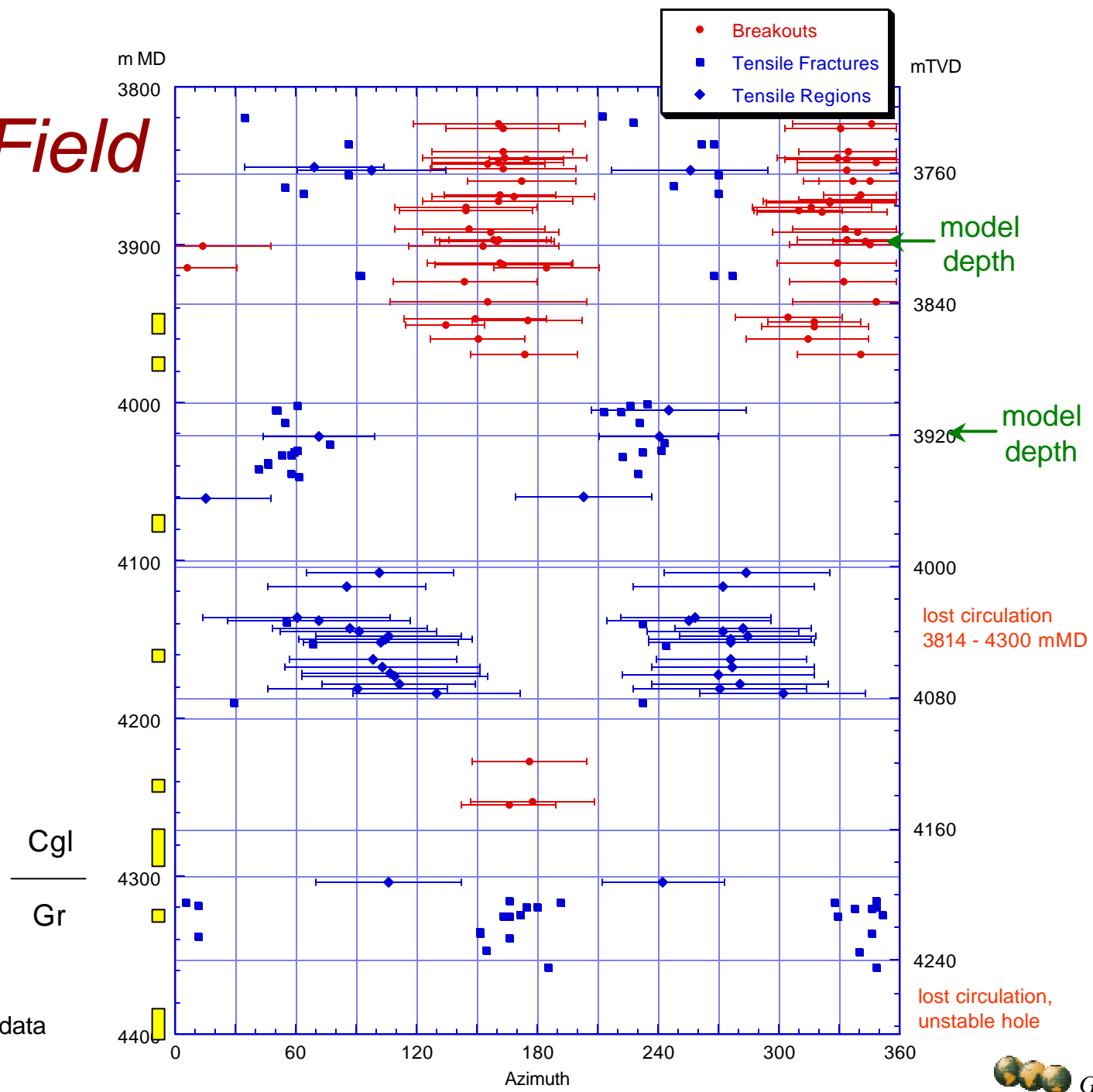
# Yufutsu Wellbore Breakouts



# Yufutsu Tensile Wall Fractures



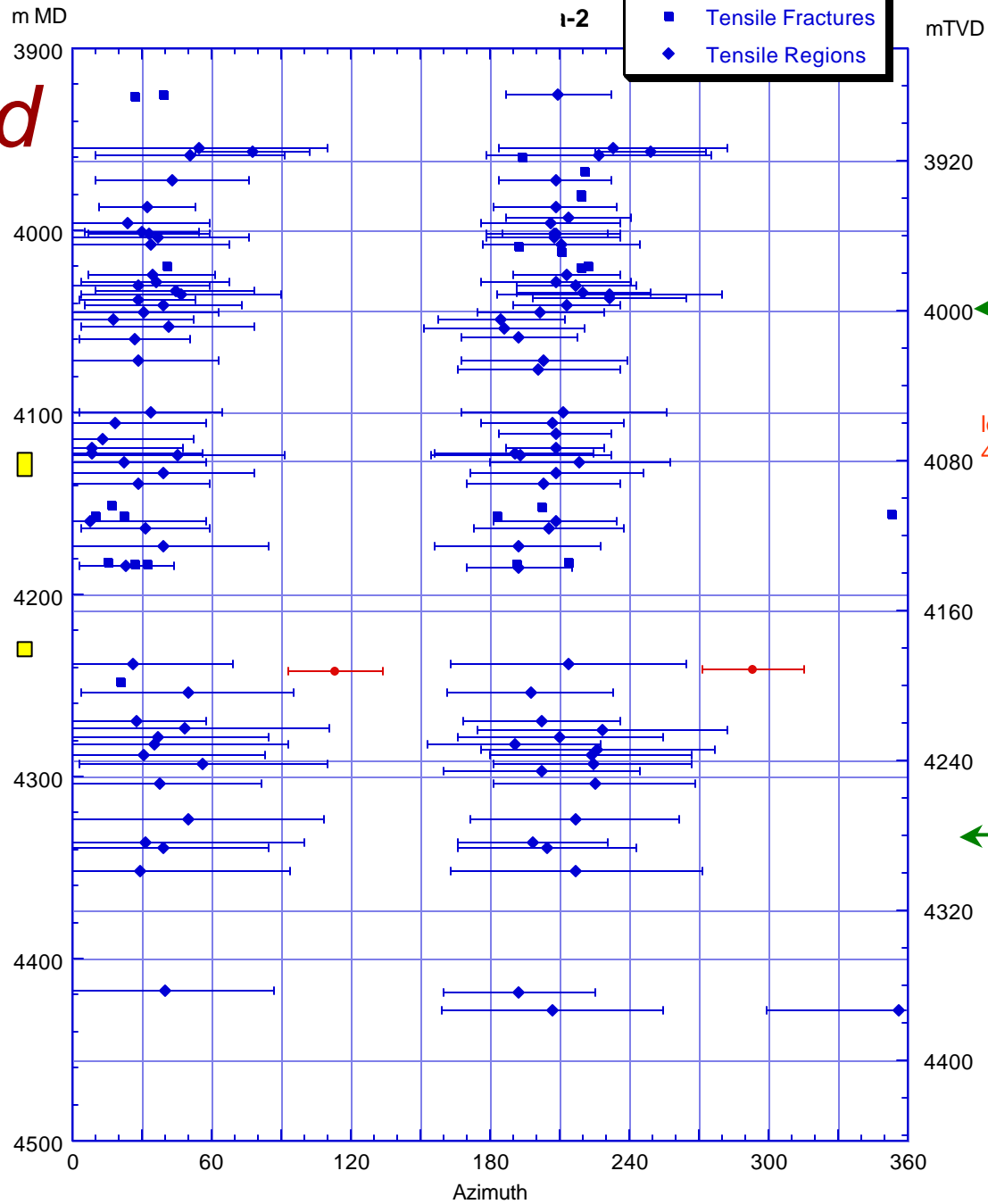
# Yufutsu Field Well A



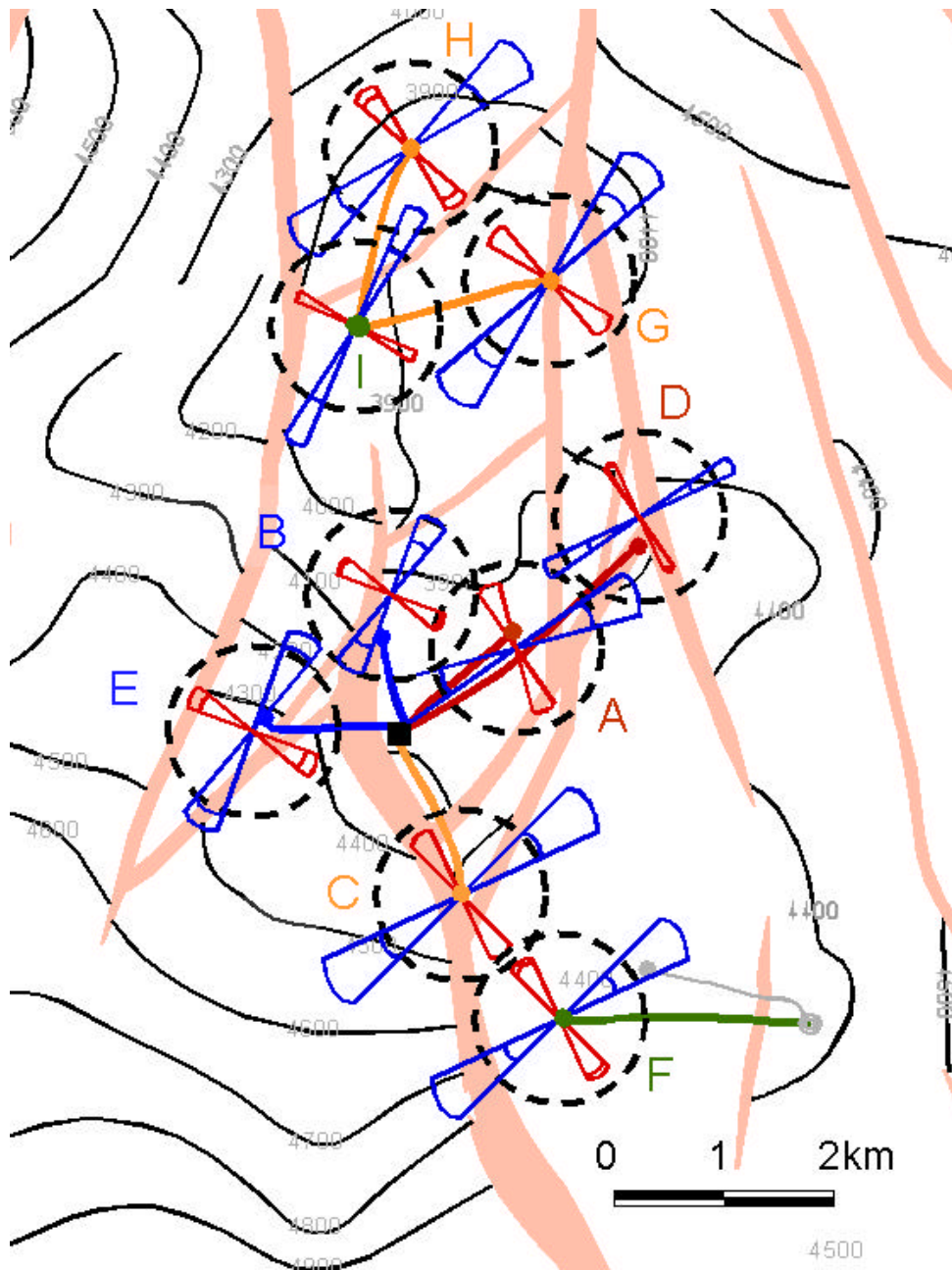
# Yufutsu Field Well B

low quality image data

Cgl  
Gr

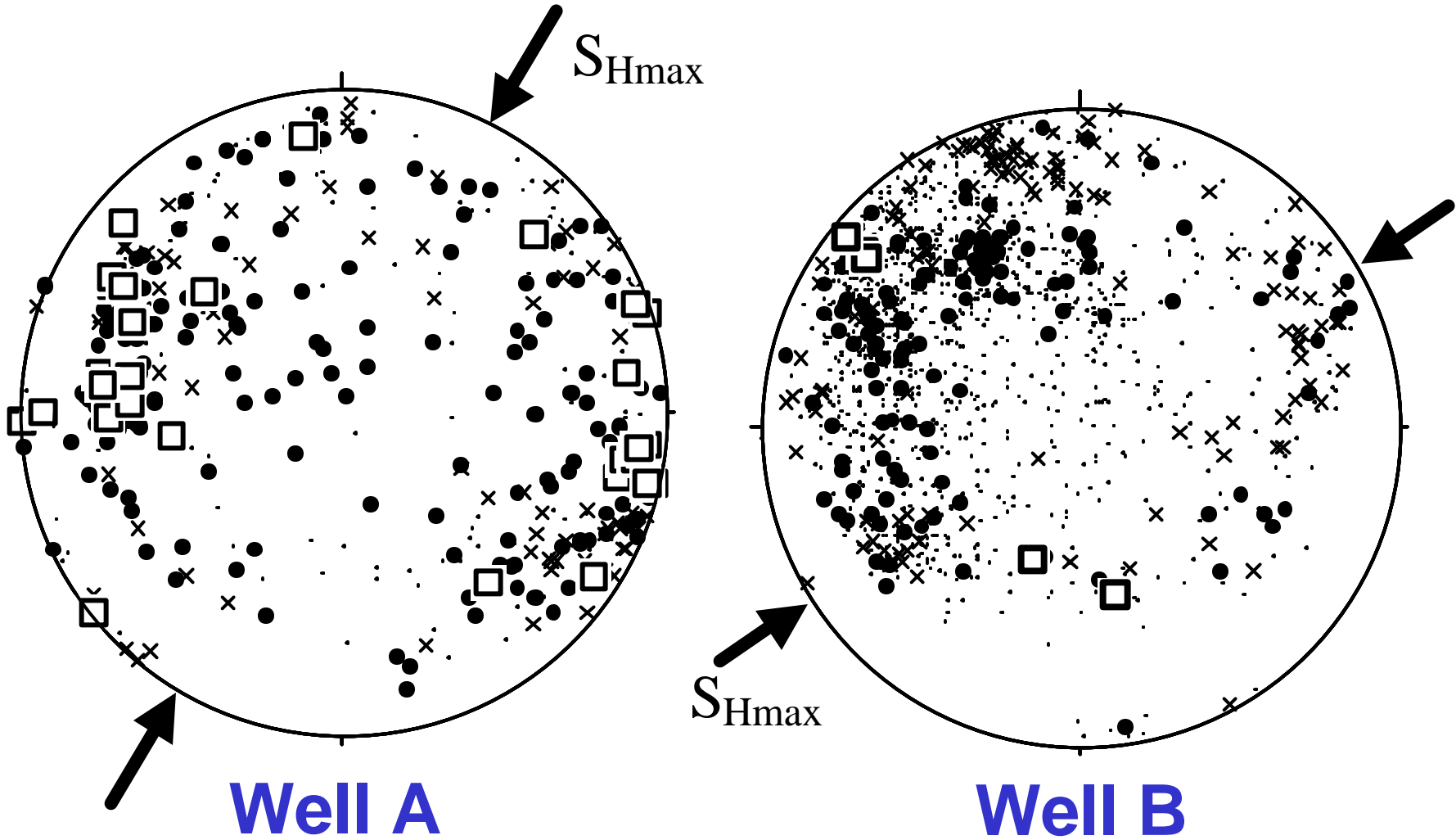


# Yufutsu Field Stress Orientation and Magnitude

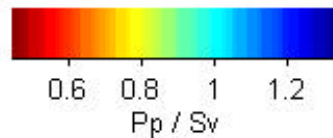
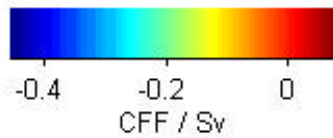
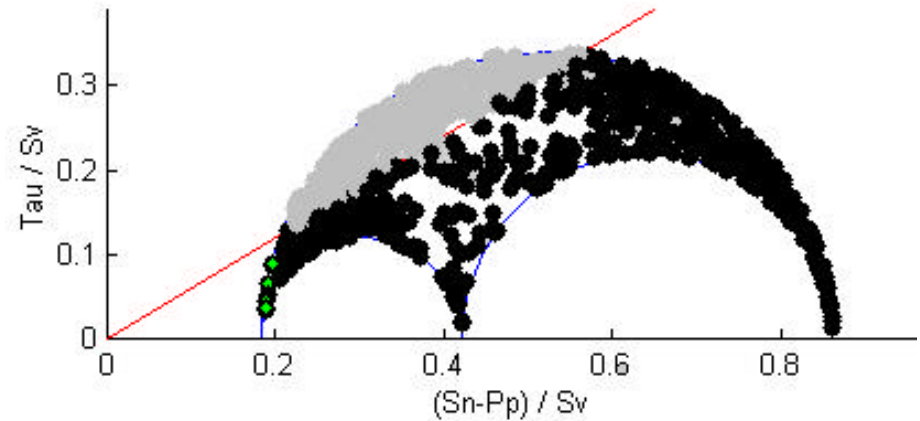
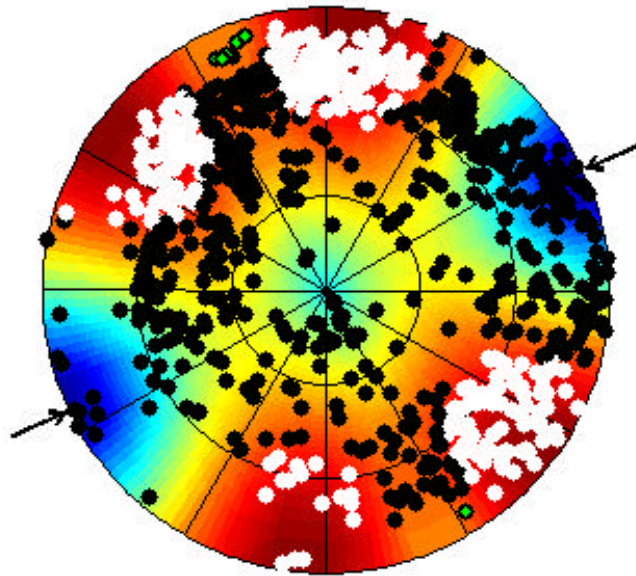




# Natural Fracture Orientations and $S_{Hmax}$



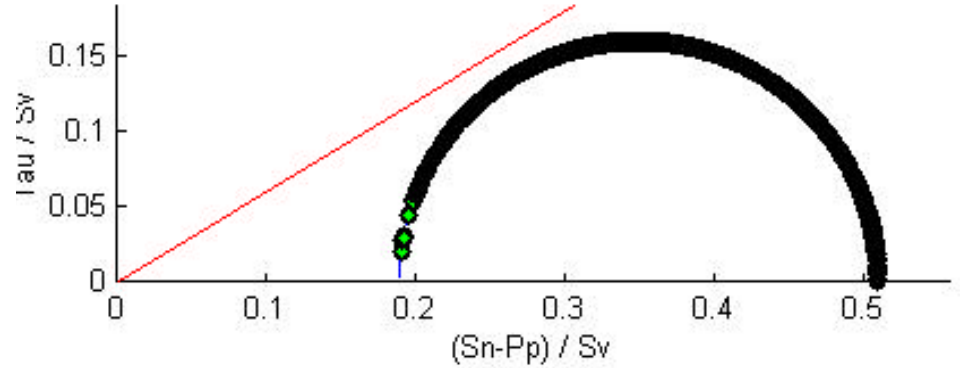
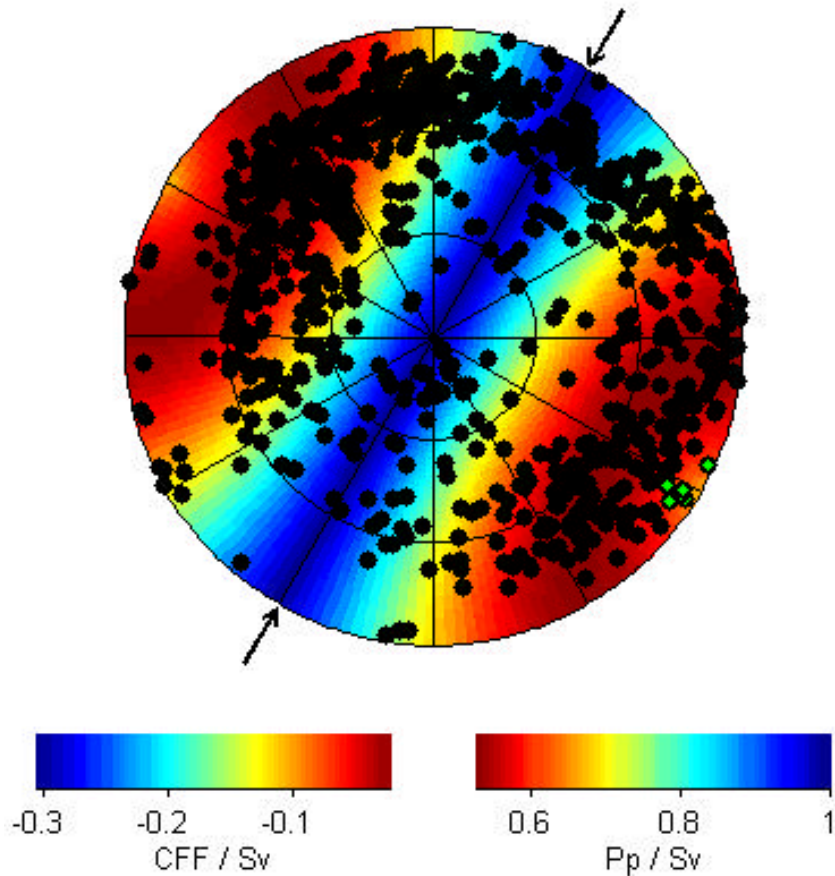
# Yufutsu Field: Well A



**Strike-Slip Faulting**

$$S_{Hmax} > S_v > S_{hmin}$$

# Yufutsu Field: Well B



**Normal Faulting  
Elevated  $S_{hmin}$**

# Central California Oil Field

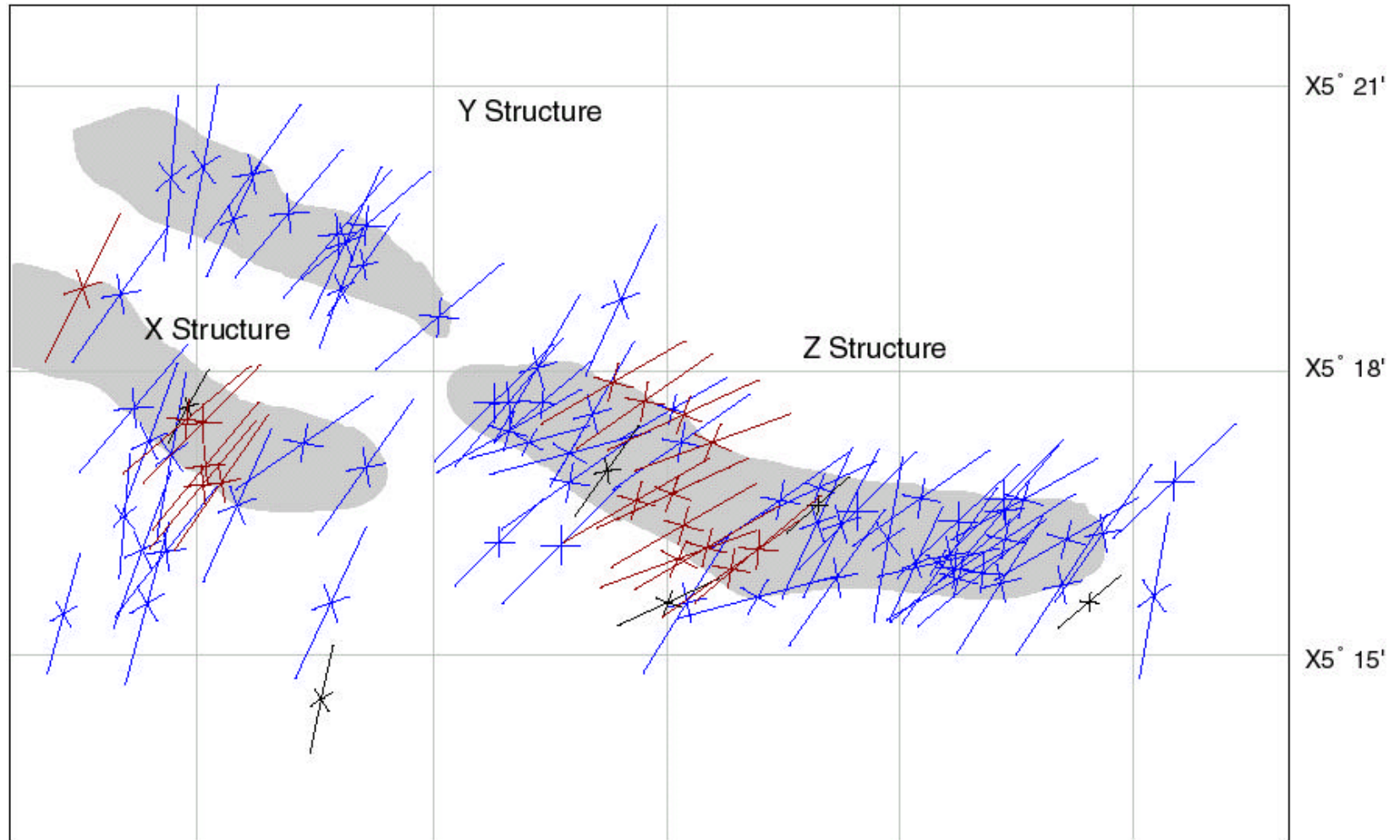
X19° 33'

X19° 30'

X19° 27'

X19° 24'

X19° 21'

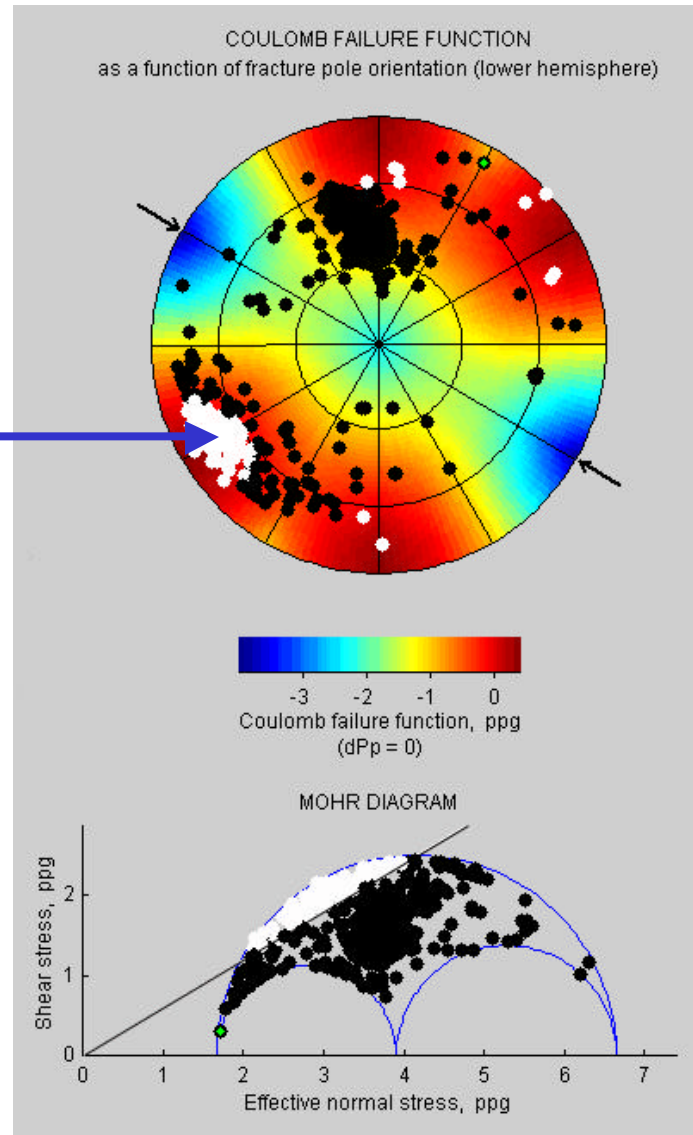


0 5 10 mi

0 5 10km

# Central California Critically Stressed Fractures

High hydrocarbon  
production rate



# Summary

- **The technique to characterize permeable fractures and faults proven at Dixie Valley can extend to other geothermal reservoirs and to oil and gas reservoirs.**
- **Critical data are necessary to assess reservoir permeability enhancement potential:**
  - $S_{hmin}$  measurements (geothermal)
  - High resolution production data (oil and gas)
- **Fractures and faults must be both optimally oriented and critically stressed to enhance production.**