Calibration of Stress Field Models Using Borehole Data

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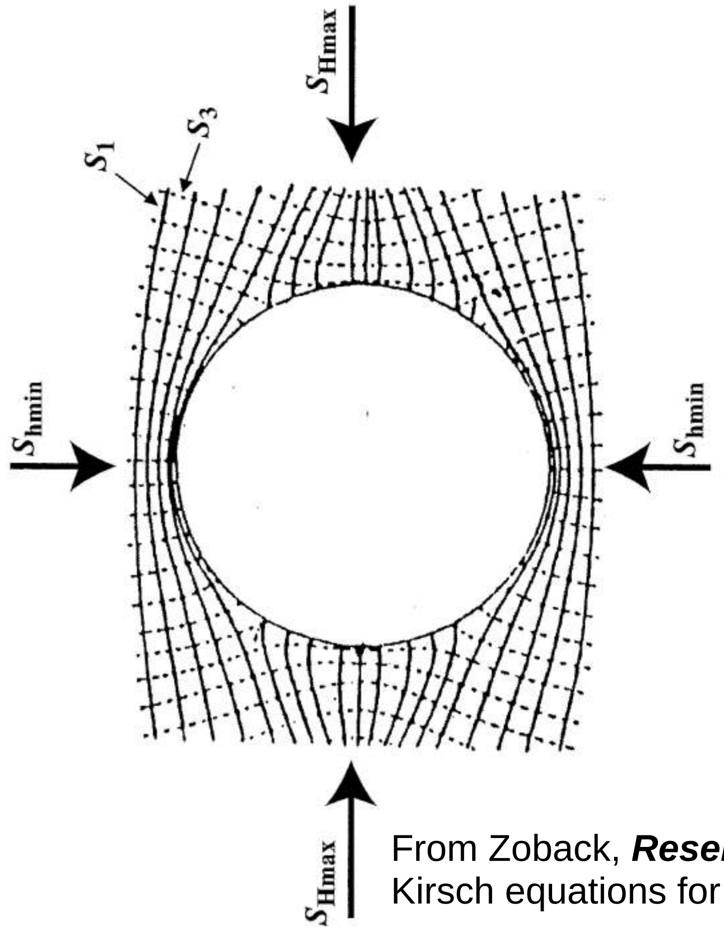
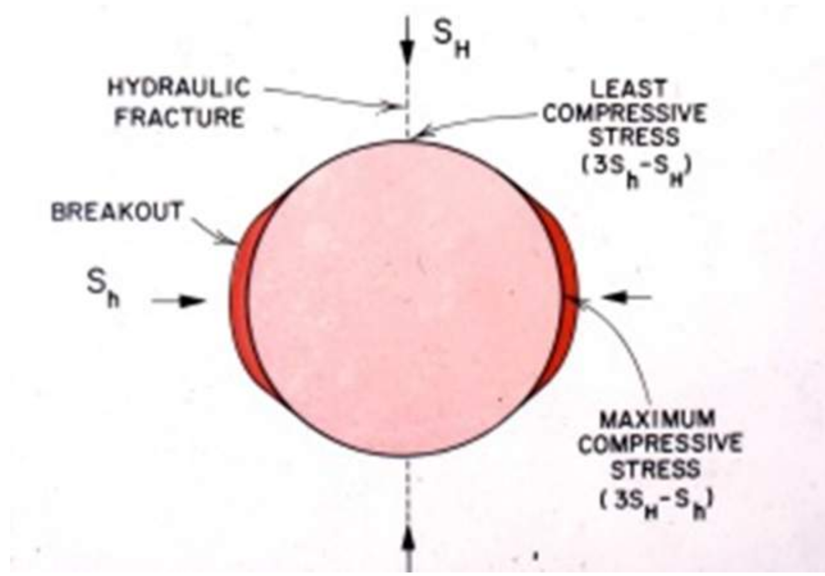
Borehole observations can constrain:

- **Directions** of horizontal principal stress $\boldsymbol{\sigma_h}$ and $\boldsymbol{\sigma_H}$ (from breakouts or drilling induced tensile fractures in a vertical borehole)
- **Directions** and **relative magnitudes** of all three principal stresses, $\boldsymbol{\sigma_1}$ $\boldsymbol{\sigma_2}$ $\boldsymbol{\sigma_3}$, from multiple deviated wells in a small volume
- **Magnitudes** of one or more of the principal stresses, from hydraulic fracturing stress measurements, leakoff test pressures

Far field stress related to features in a fluid- or gas-filled cylindrical hole; NOTE ***breakouts*** and ***hydraulic fractures*** may not be found together





From Zoback, ***Reservoir Geomechanics***,
Kirsch equations for stress around a borehole

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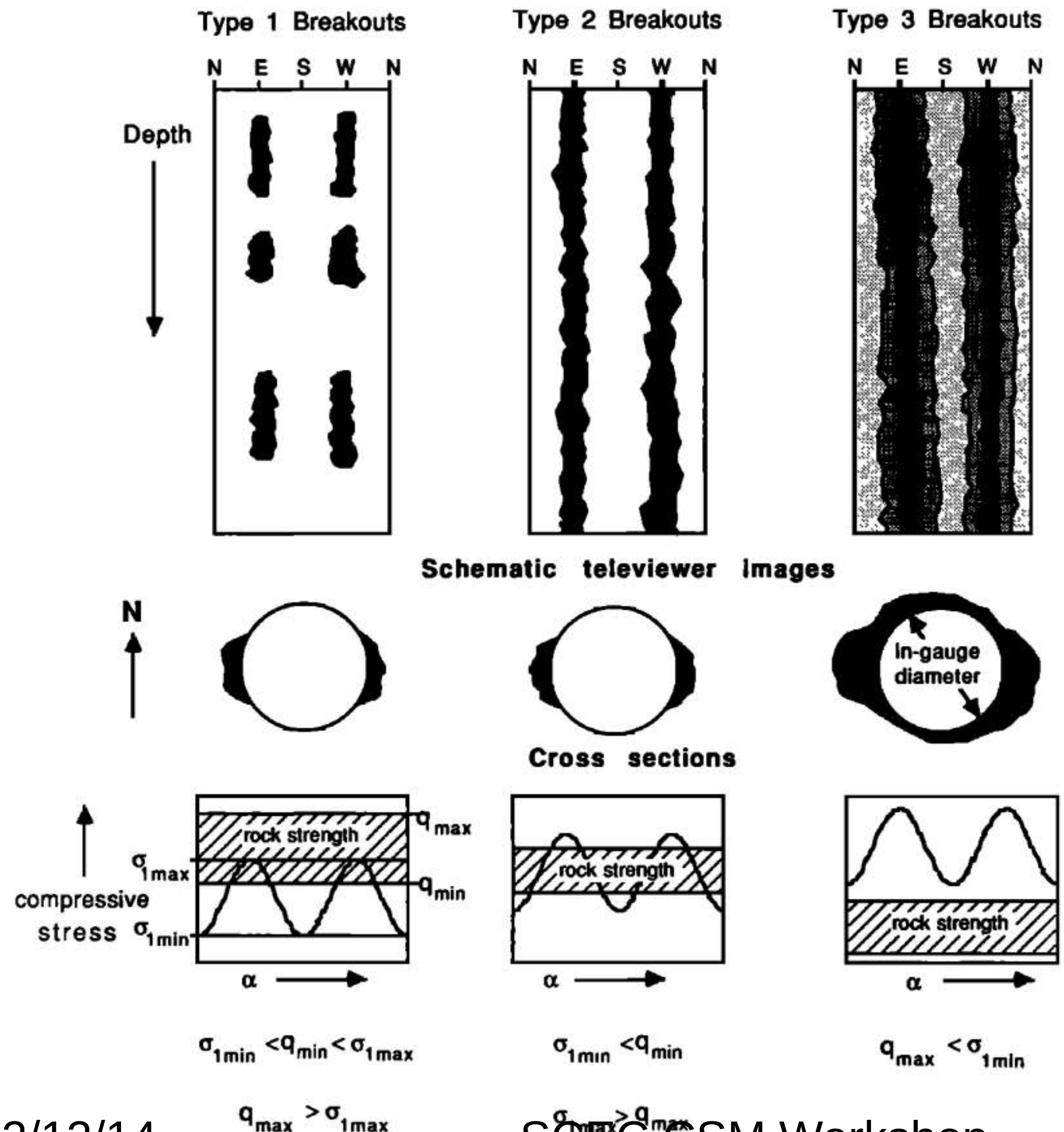
Breakouts depend on stress tensor and rock strength



Mastin,
JGR, 1988

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FIELD OPERATIONS – MEASURING BREAKOUTS

TYPES OF TOOLS:

- Acoustic borehole televiewer
- Oriented 4-arm or 6-arm caliper
- 4-arm to 8-arm electrical imaging log

1. Lower tool (with arms closed) into bottom of section of open hole to be logged
2. Open the arms and winch the tool up the hole at a constant speed.
3. If the hole is cylindrical, the tool will rotate.
4. If the hole is not cylindrical, the long diameter of the tool will tend to stay along the longest axis of the borehole

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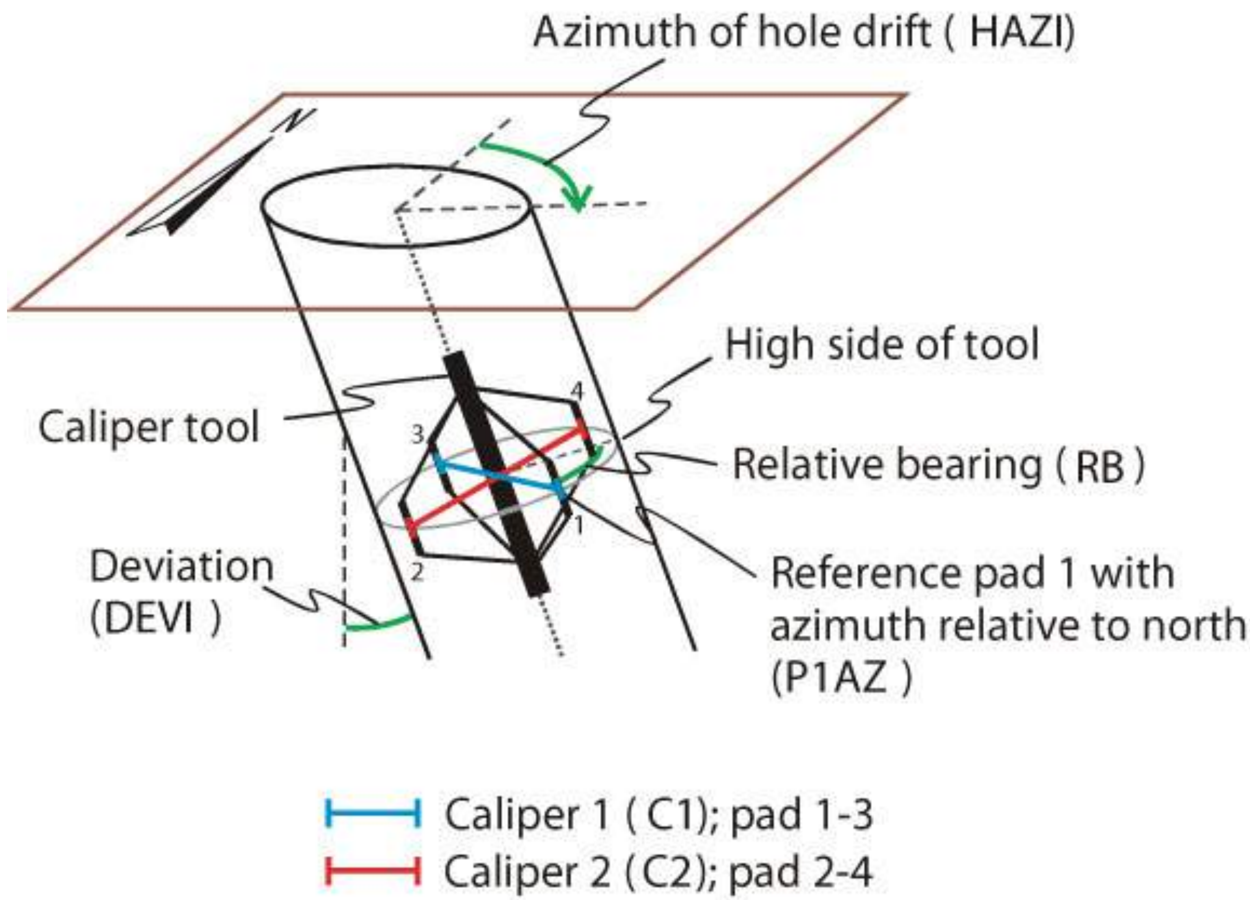
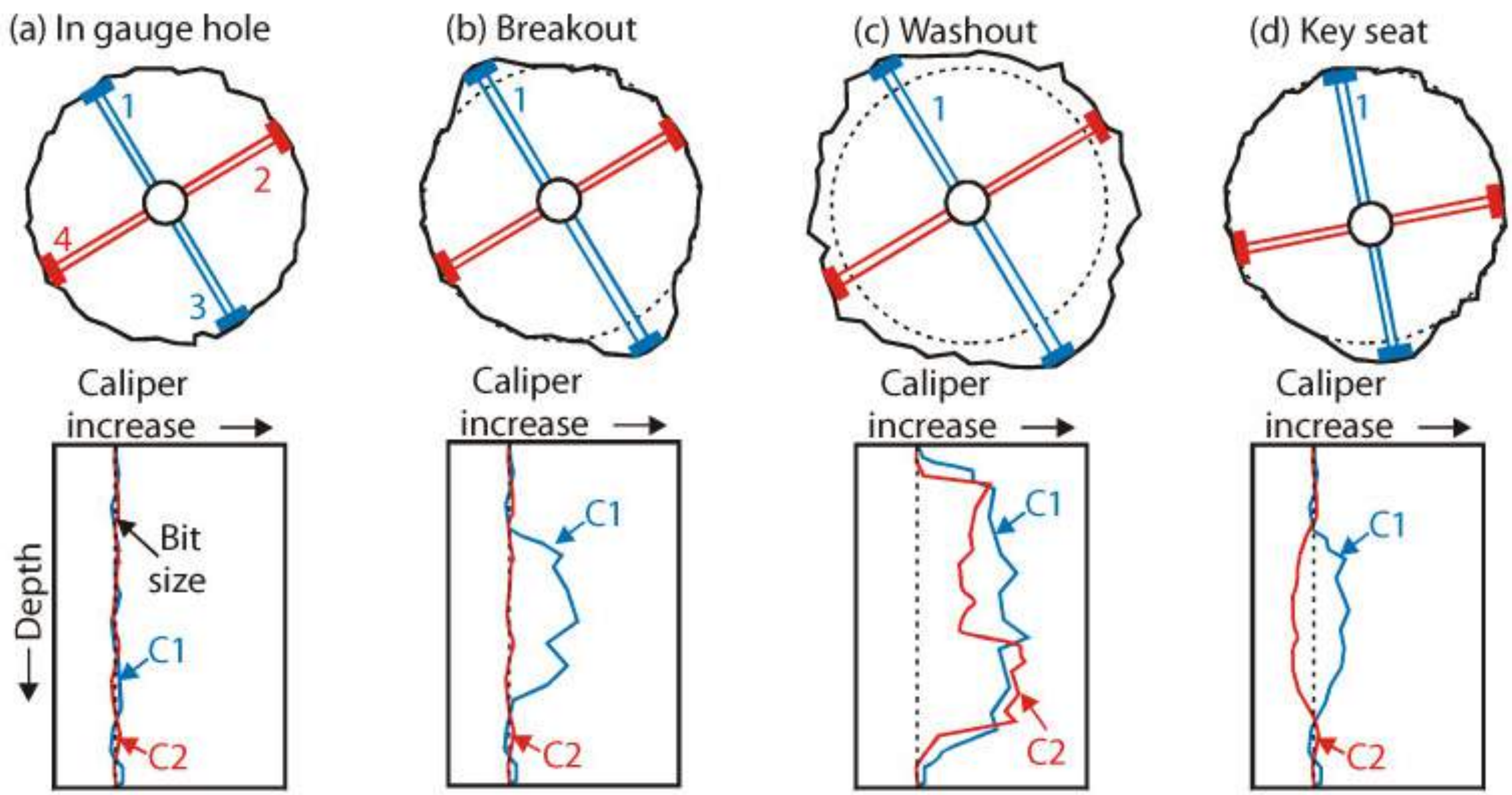


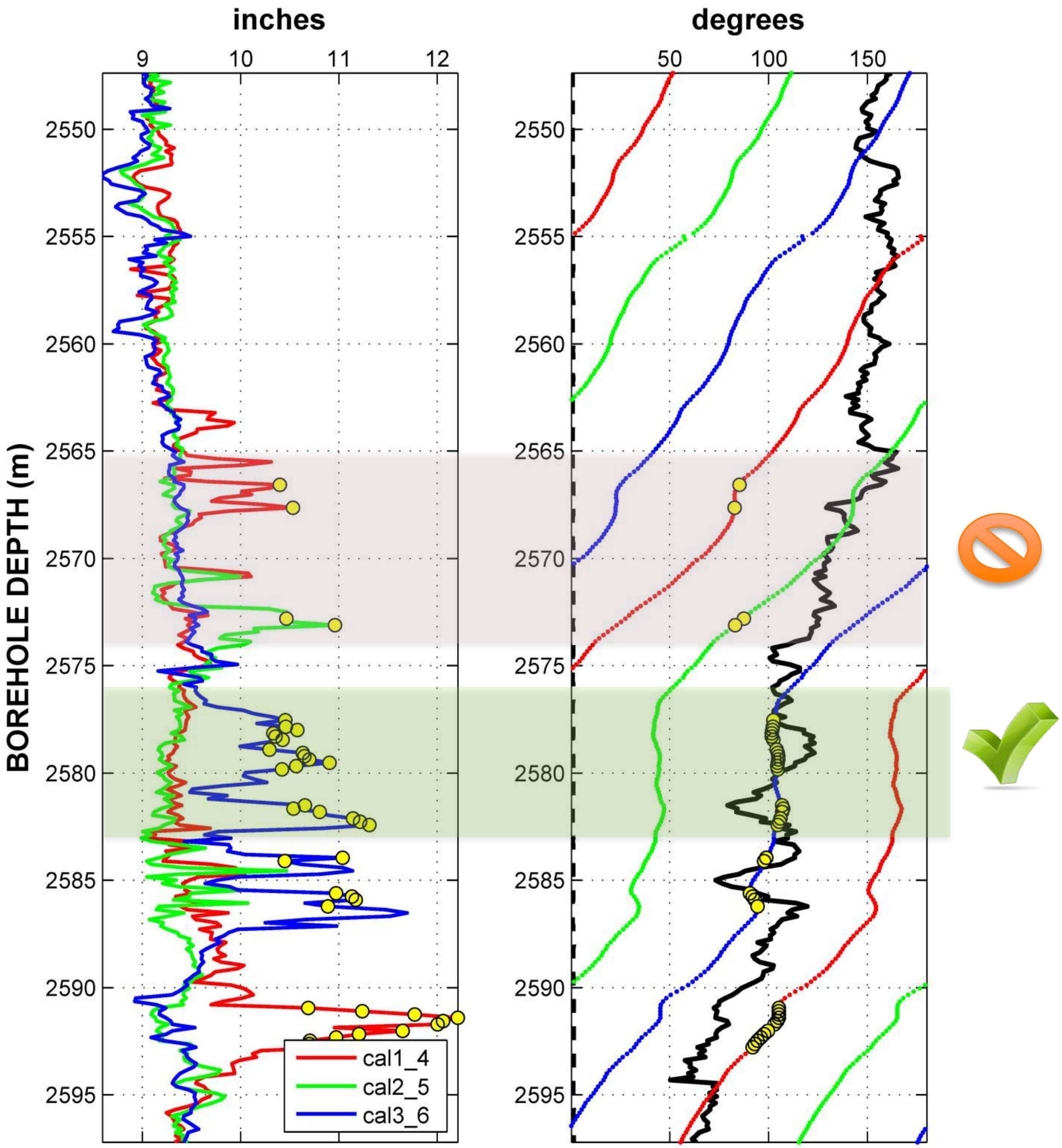
From Reinecker et al., World Stress Map project, after Plumb and Hickman (1985)
4-arm caliper tool

All tools have centralizers above and below (not shown in this diagram)

Identifying breakouts from borehole shape and instrument behavior (tool stops rotating in breakout)



From Reinecker et al., World Stress Map project, after Plumb and Hickman (1985)



Example of breakouts identified from some newly obtained oriented 6-arm caliper data

Criteria:
no tool rotation,
C1 ~ C2
C3 – C2 > 2 cm
Length > 3 m

(criteria modified from Zajac & Stock, JGR, 1997)

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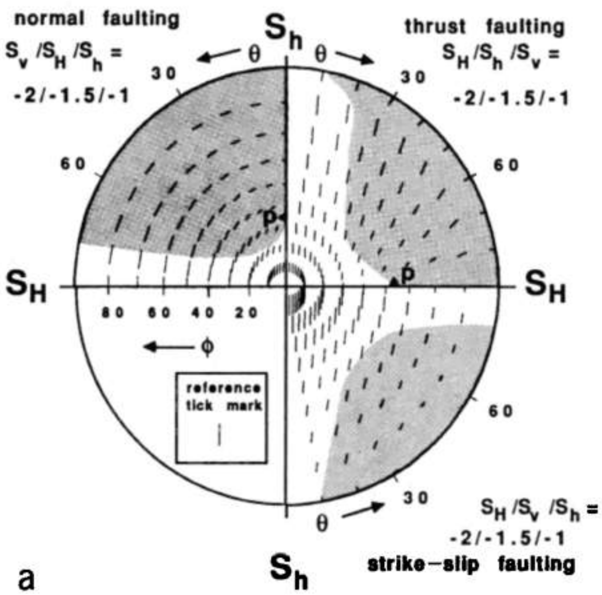
Method for multiple wells with different deviations from a central platform

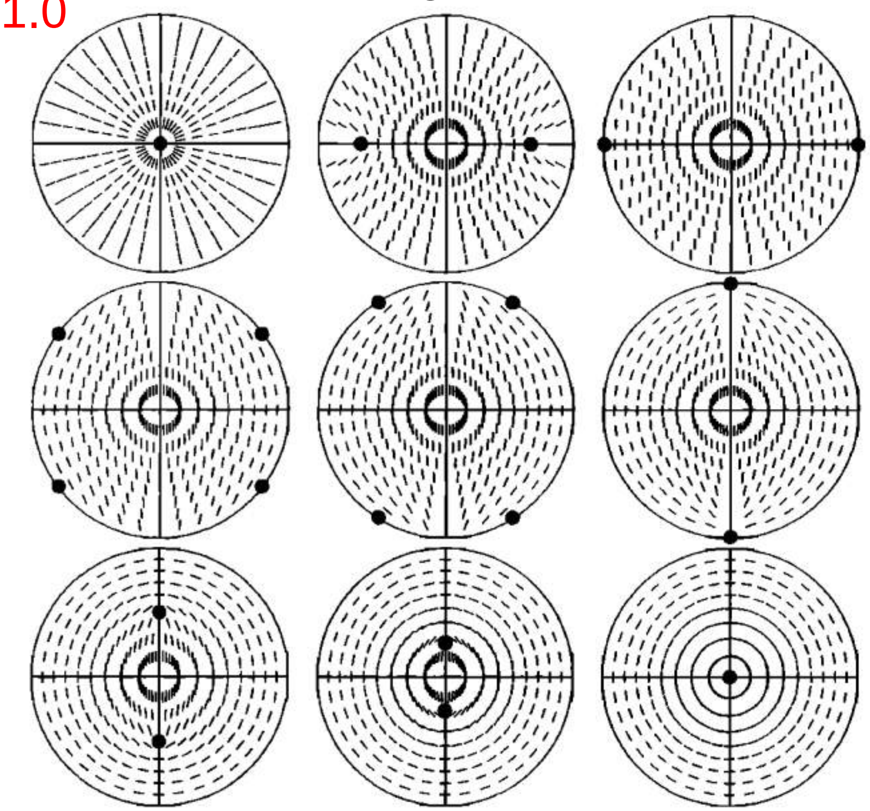
$\phi = S2 - S3 / S1 - S3$



Mastin, JGR, 1988

Thrust faulting

1.0



Strike-slip faulting

0.5

0.2

0.0

Normal faulting

Zajac & Stock, 1997 JGR

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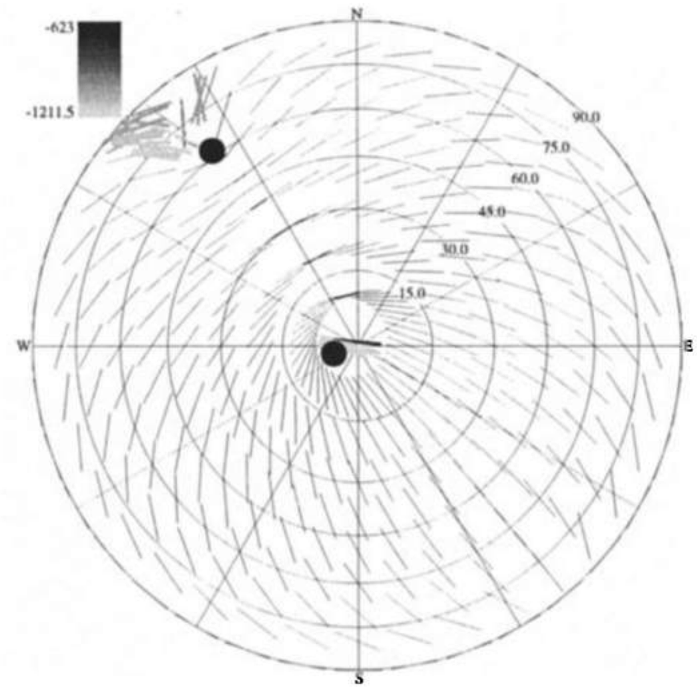
Lower Hemisphere Projections

Breakout observations | **Stress Tensor**



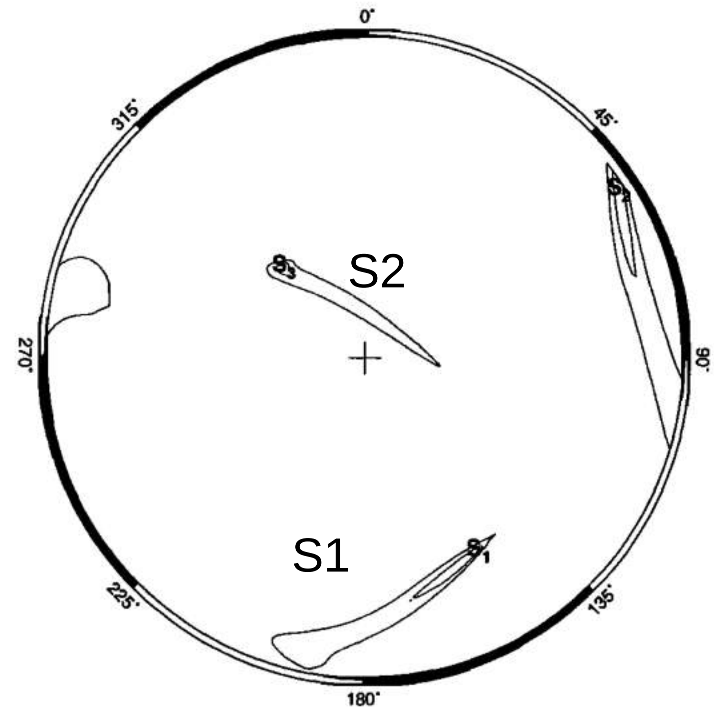


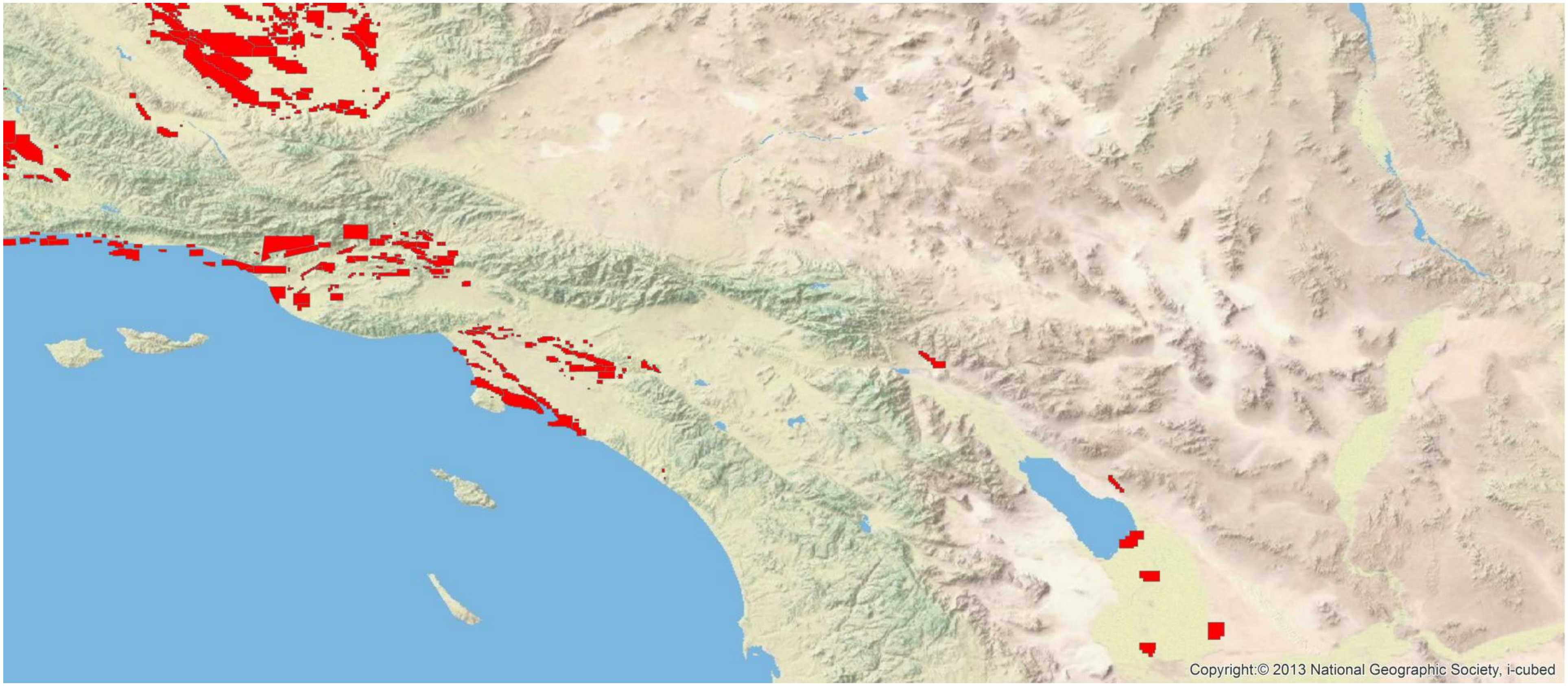
Table 3. Characteristics of the Stress State That Minimized the Weighted One-Norm Misfit of the Point Pedernales Borehole Breakout Data

	S_1	S_2	S_3
Azimuth	N148.5°E	N55.8°E	N318.7°E
Plunge	31.5°	4.4°	58.1°
Value	2	$1.821_{1.584}^{1}$	1

Optimized ϕ, $0.821_{0.584}^{1.000}$; minimum weighted one-norm misfit, 4.84°; 95% confidence level for weighted one-norm misfit, 5.96°.

Stress tensor derived from sparse breakout data, 5 wells in Point Pedernales oil field (Zajac & Stock, 1997 JGR). Nodal points are constrained by breakouts in highly deviated well.

CA DOGGR Administrative Boundaries (Oil, Gas, Geothermal) in Southern CA.



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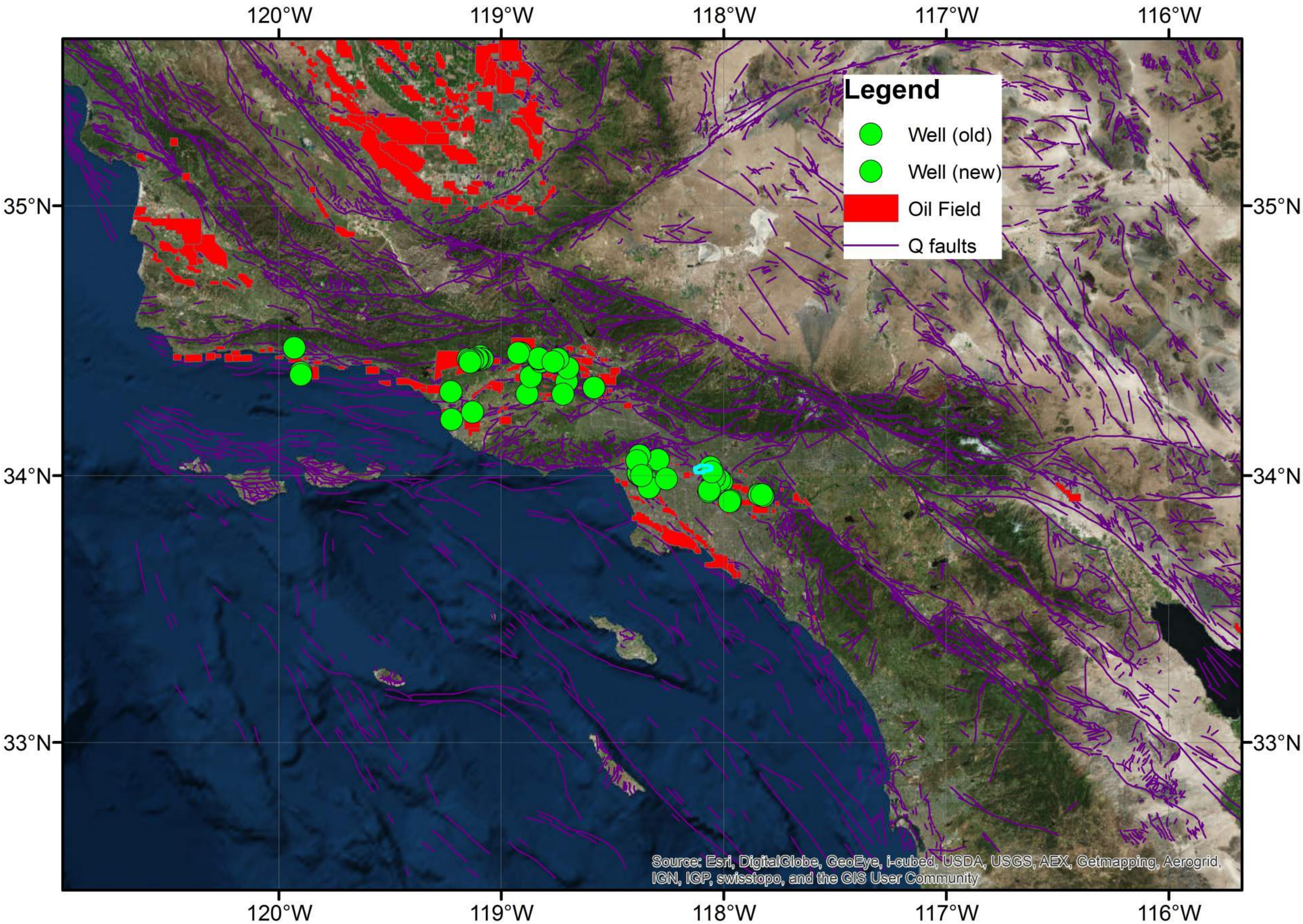
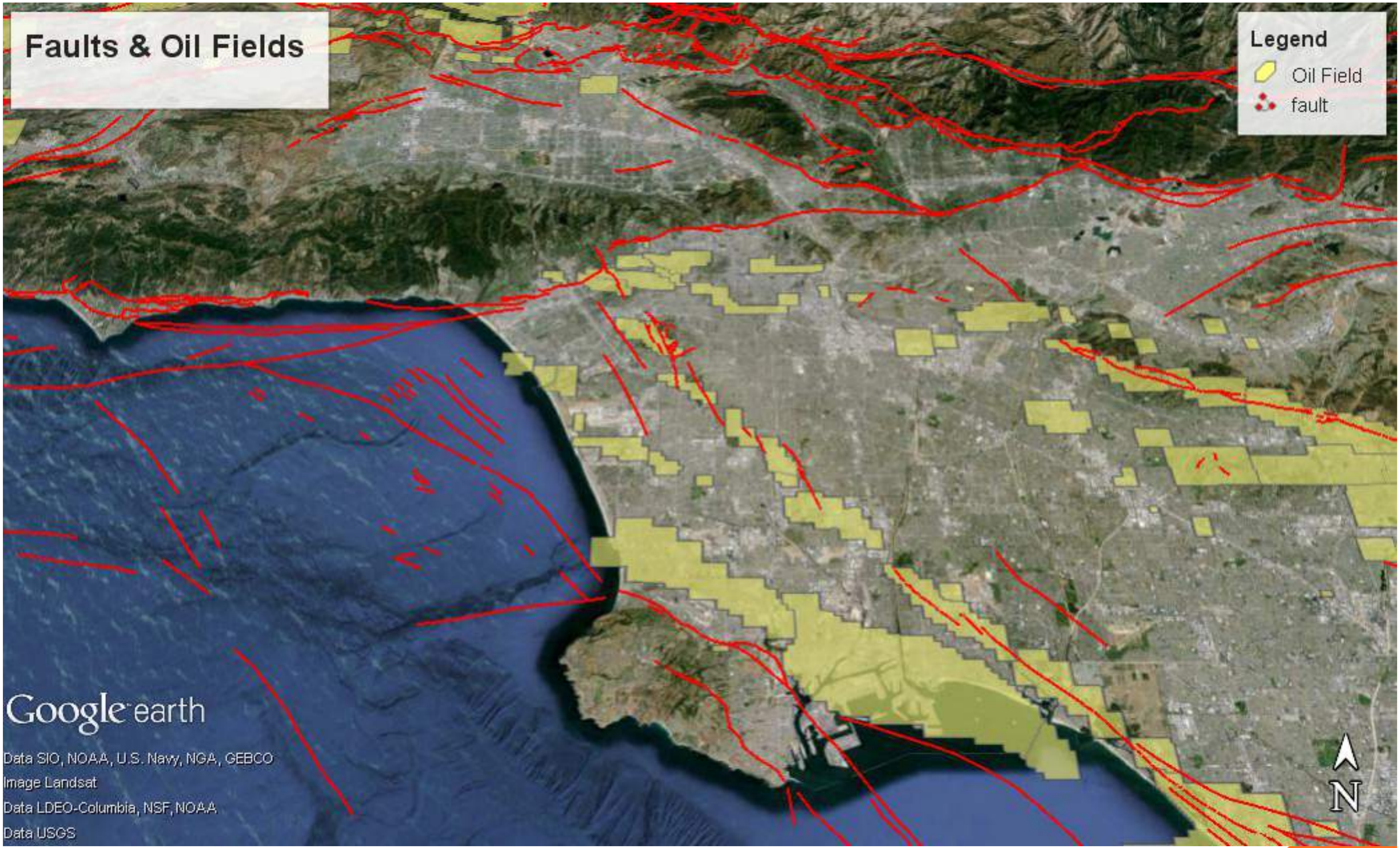

120°W
119°W
118°W
117°W
116°W
35°N
34°N
33°N
Legend
Well (old)
Well (new)
Oil Field
Q faults
Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community


Faults & Oil Fields
Legend
Oil Field
fault
Google earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat
Data LDEO-Columbia, NSF, NOAA
Data USGS
N

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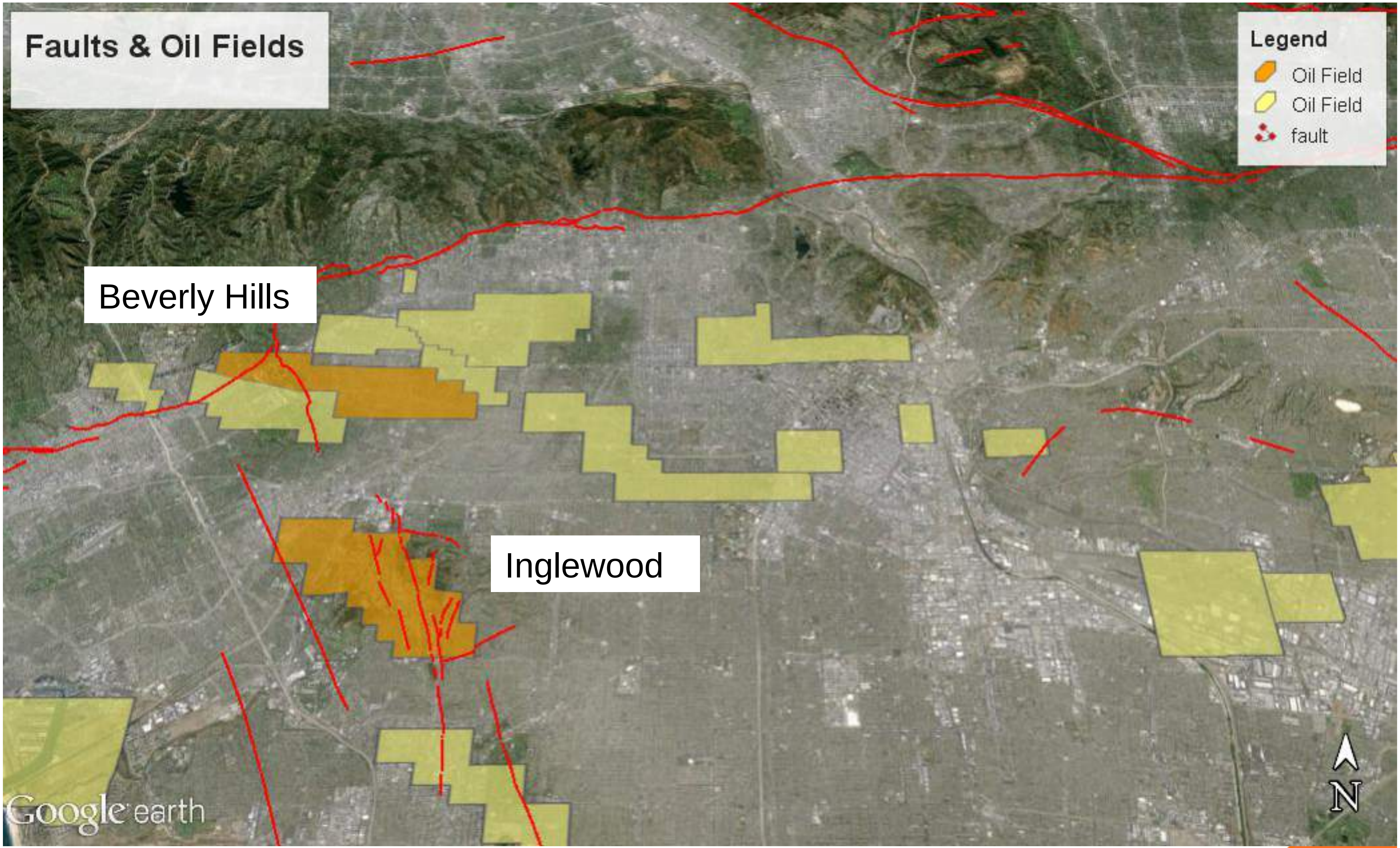
Data sets related to Newport-Inglewood Fault



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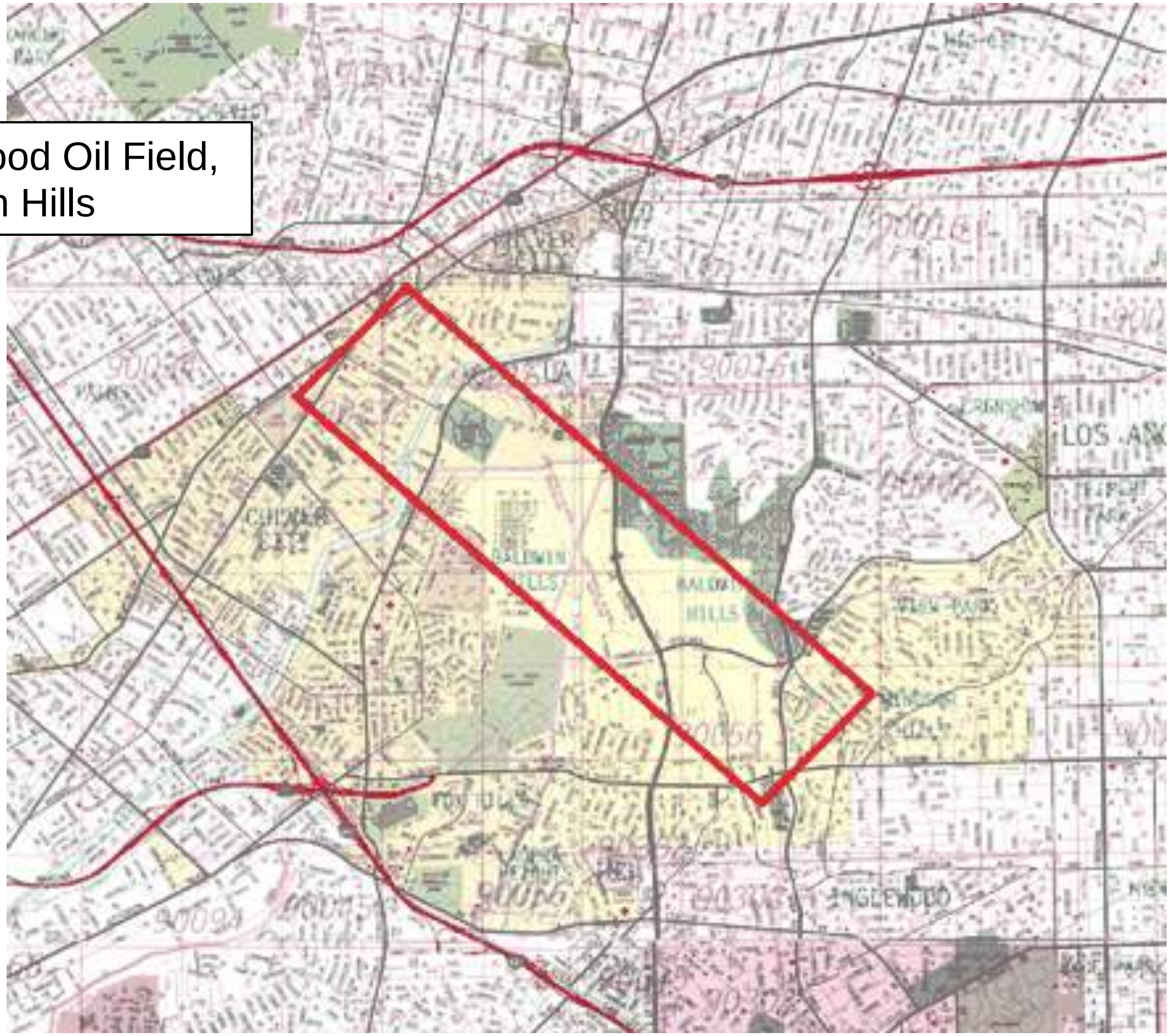
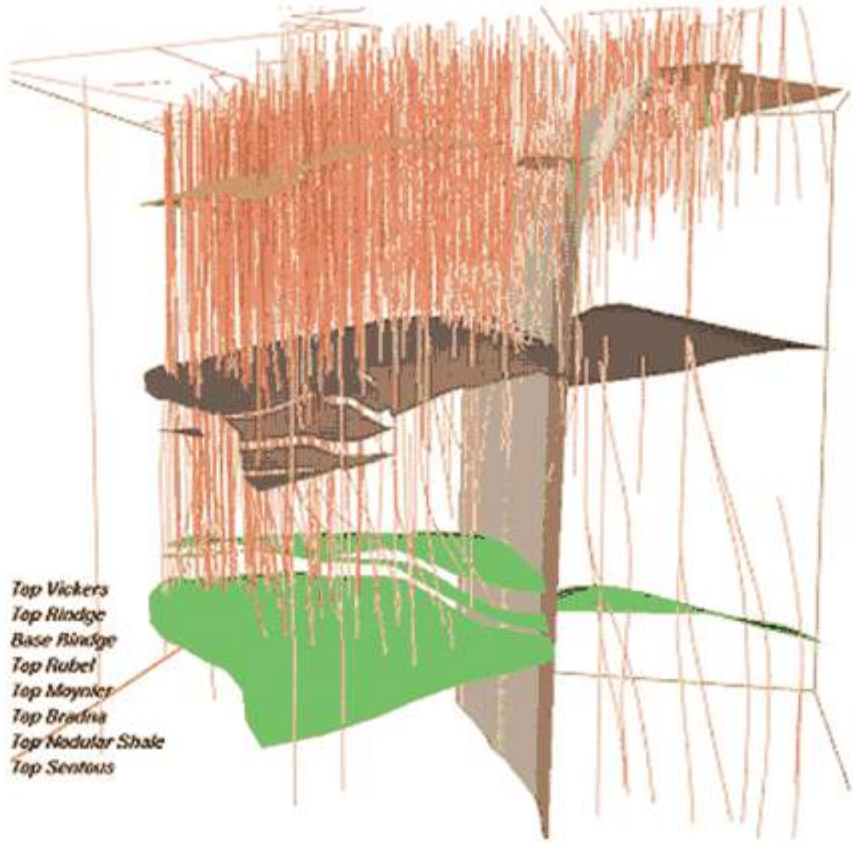
Inglewood Oil Field,
Baldwin Hills



From Lockman, *The Leading Edge October 2005 vol. 24 no. 10 1008-1014*

We have data from 24 of the wells here, mostly on the west side of the Newport-Inglewood fault, 2-3 km depth.

The wells were drilled 8 to 10 years ago.



Our previous study (Wilde & Stock, JGR, 1997) had data from only 1 older well in this field

Well Bores, Inglewood Field, Baldwin Hills

From Lockman, *The Leading Edge October 2005 vol. 24 no. 10 1008-1014*

The Hydraulic Fracturing Method (officially in use since 1957)

USGS Drill Rig

Black Butte, Mojave Desert, CA   1987

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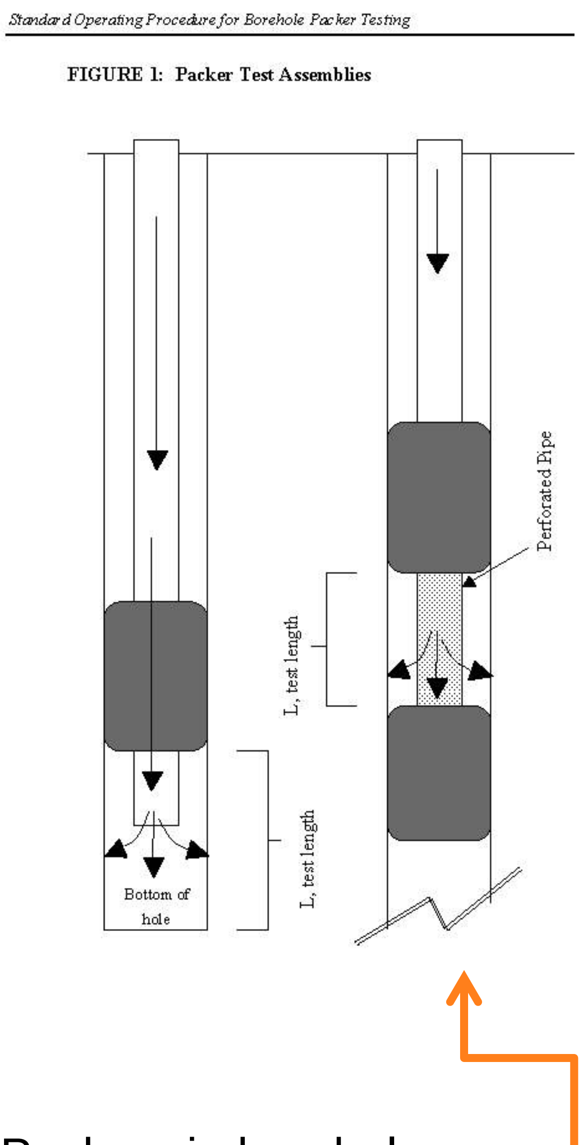
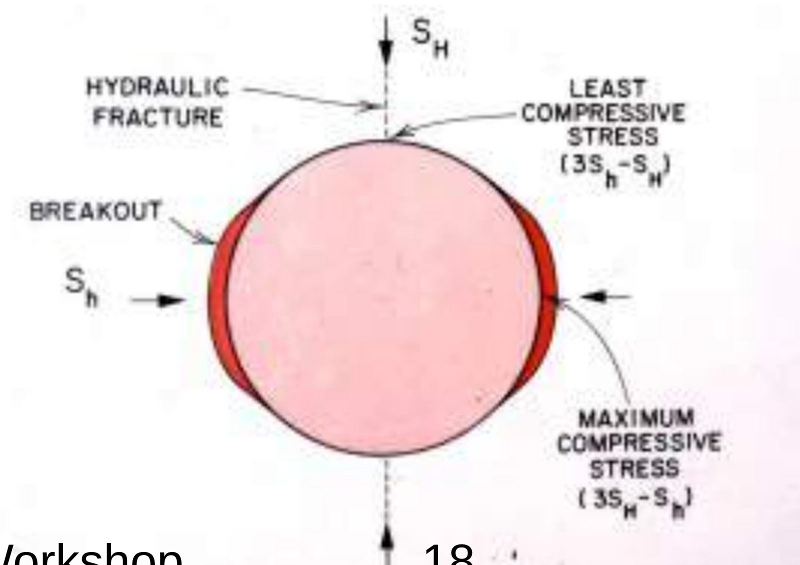


FIELD OPERATIONS – HYDRAULIC FRACTURING

1. Isolate a cylindrical, smooth section of the borehole using a "straddle packer" (two inflatable packers)

2. Inject fluid under high pressure into this section of the borehole

3. When pressure is high enough it will fracture the borehole wall and a fracture will extend out away from the borehole



Packers in borehole

Cross section of borehole

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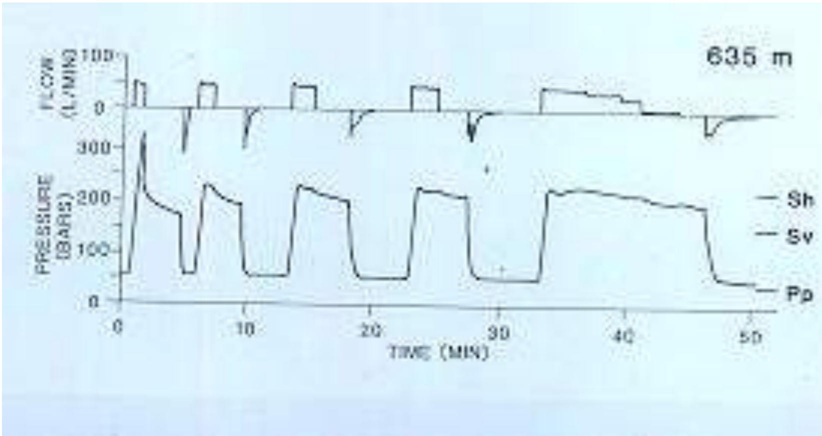
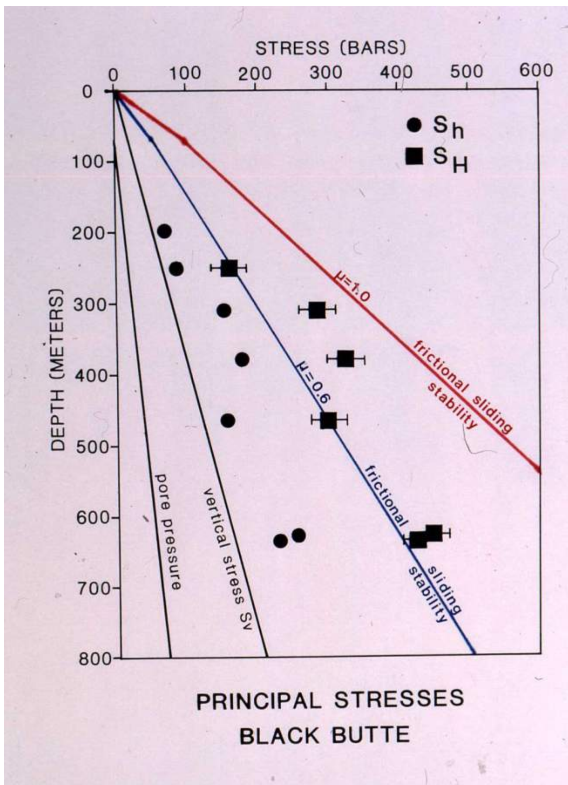




FLOW TESTS

- Measure fluid flow (top curve, left)
- Measure fluid pressure in interval between the packers (bottom curve)

Curves show when fluid is going into fracture and coming out of fracture

Pressure values of curves show the magnitudes of the principal stresses

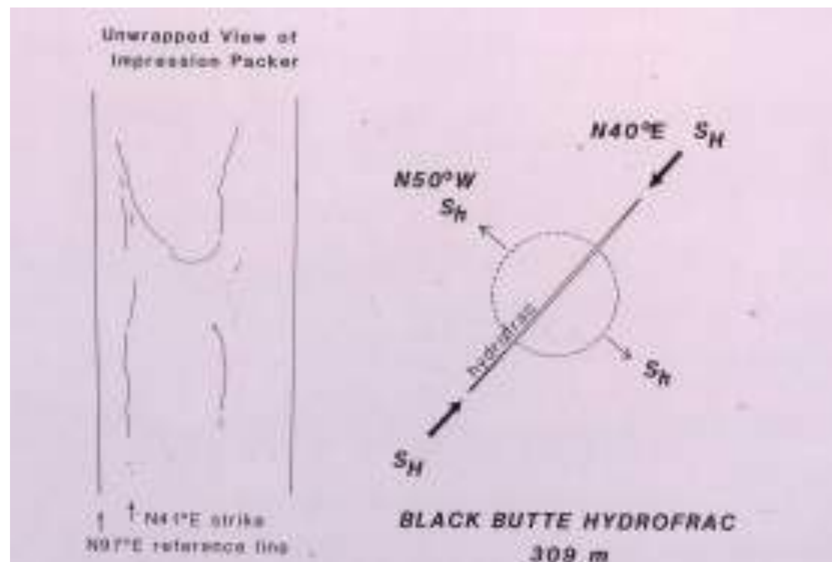
Stress vs. depth plot (left) shows whether faults are close to slipping

Figures from Stock & Healy, 1988, J. Geophys. Res.

ADDITIONAL TEST

4. Remove straddle packer after fluid testing.
5. Run impression packer to get impression of fracture that formed
6. Determine orientation of fracture that formed

Impression Packer



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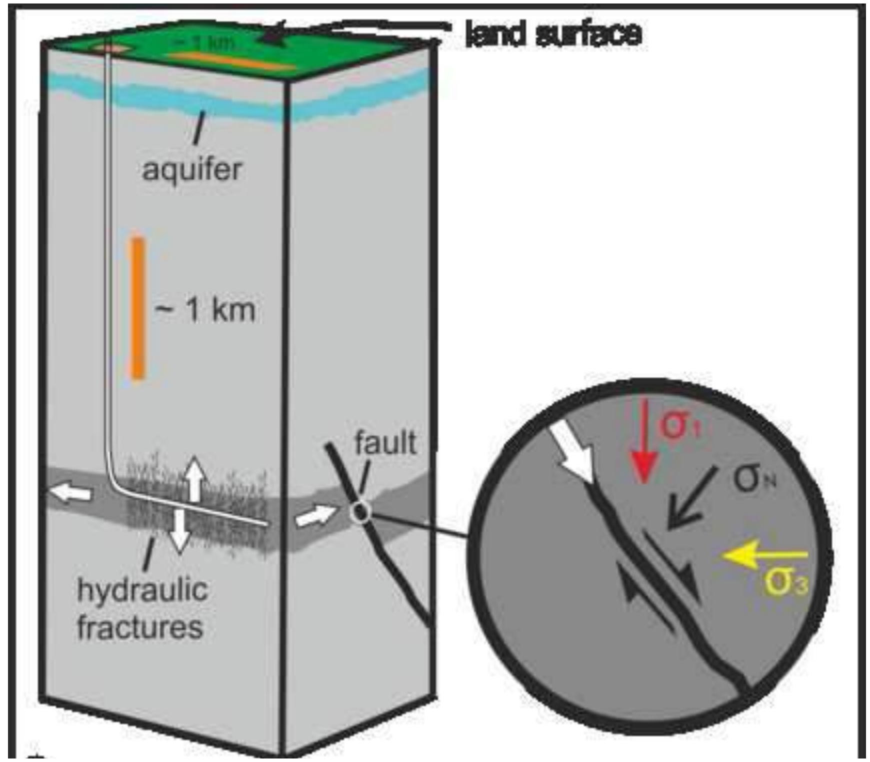
Horizontal drilling and hydraulic fracturing are "unconventional" extraction technologies

- Small volume hydraulic fractures confined to a known stratigraphic layer
- Typically cannot be done in zones of breakouts
- Oil companies usually want to drill horizontal holes in the direction of Sh, and base mud weights on stress tensor for hole stability

Figure from Davies et al., 2013



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Distribution of Monterey Formation and Related Oil Fields

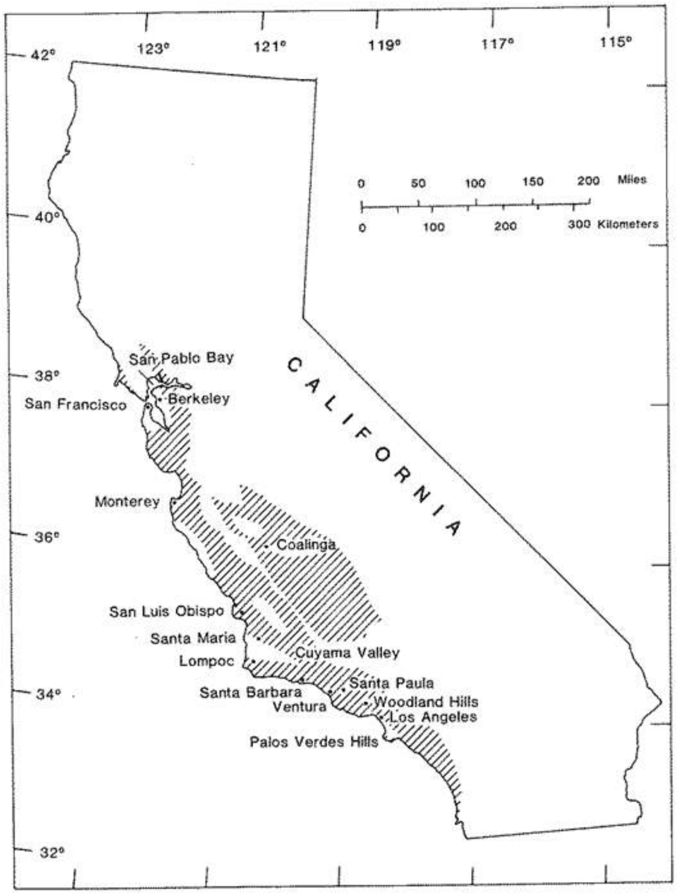


Figure 1. Index map of California showing generalized late Miocene (Mohnian and Delmontian Stages) paleogeography and localities of the Monterey Formation or Monterey Shale discussed in the text.

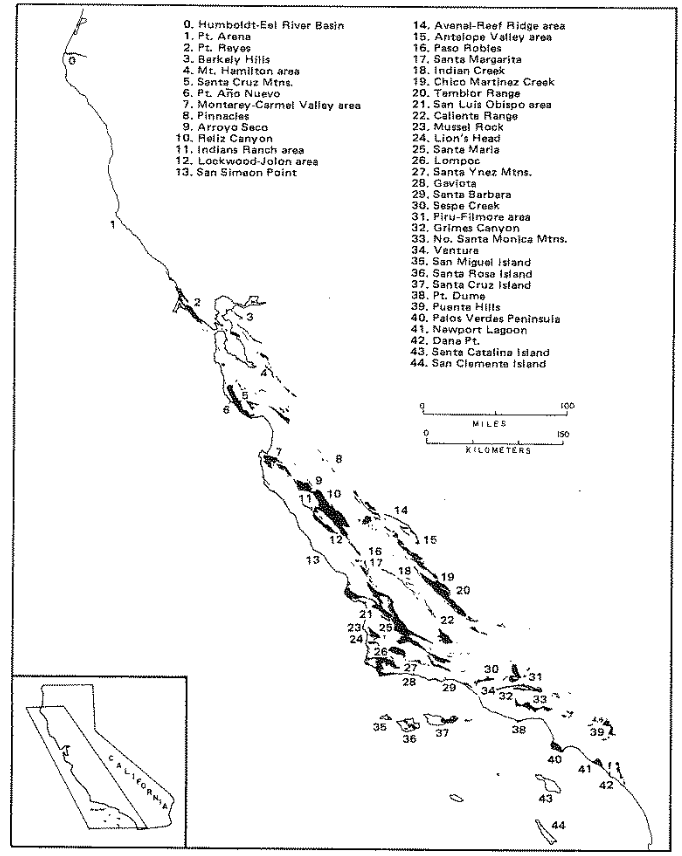
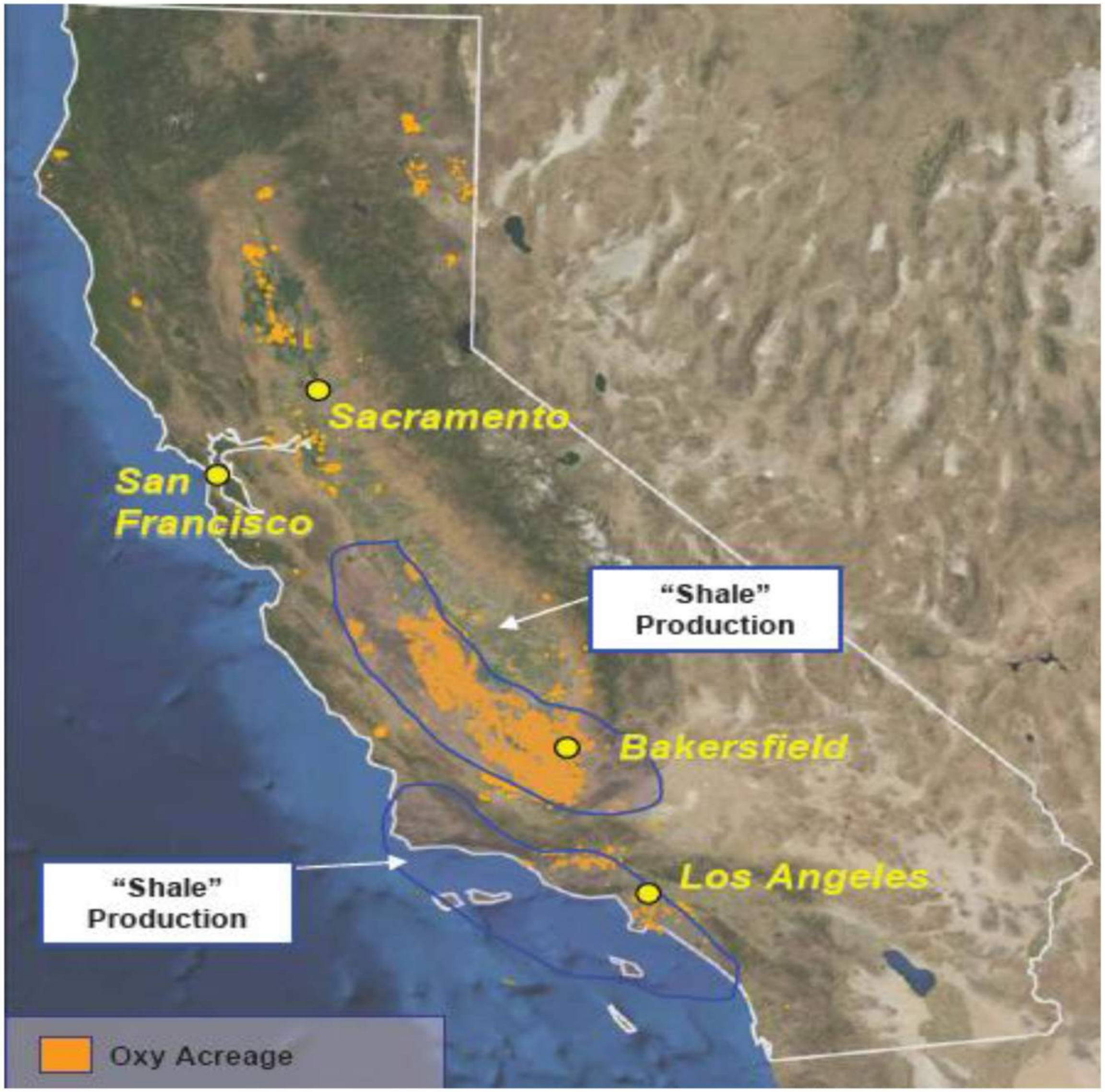


Figure 1. Outcrop distribution of Neogene siliceous rocks in California. Dashed lines are major faults. Numbers refer to localities listed above and referred to in the text. References for base maps and geologic data in Pisciotto (1978).

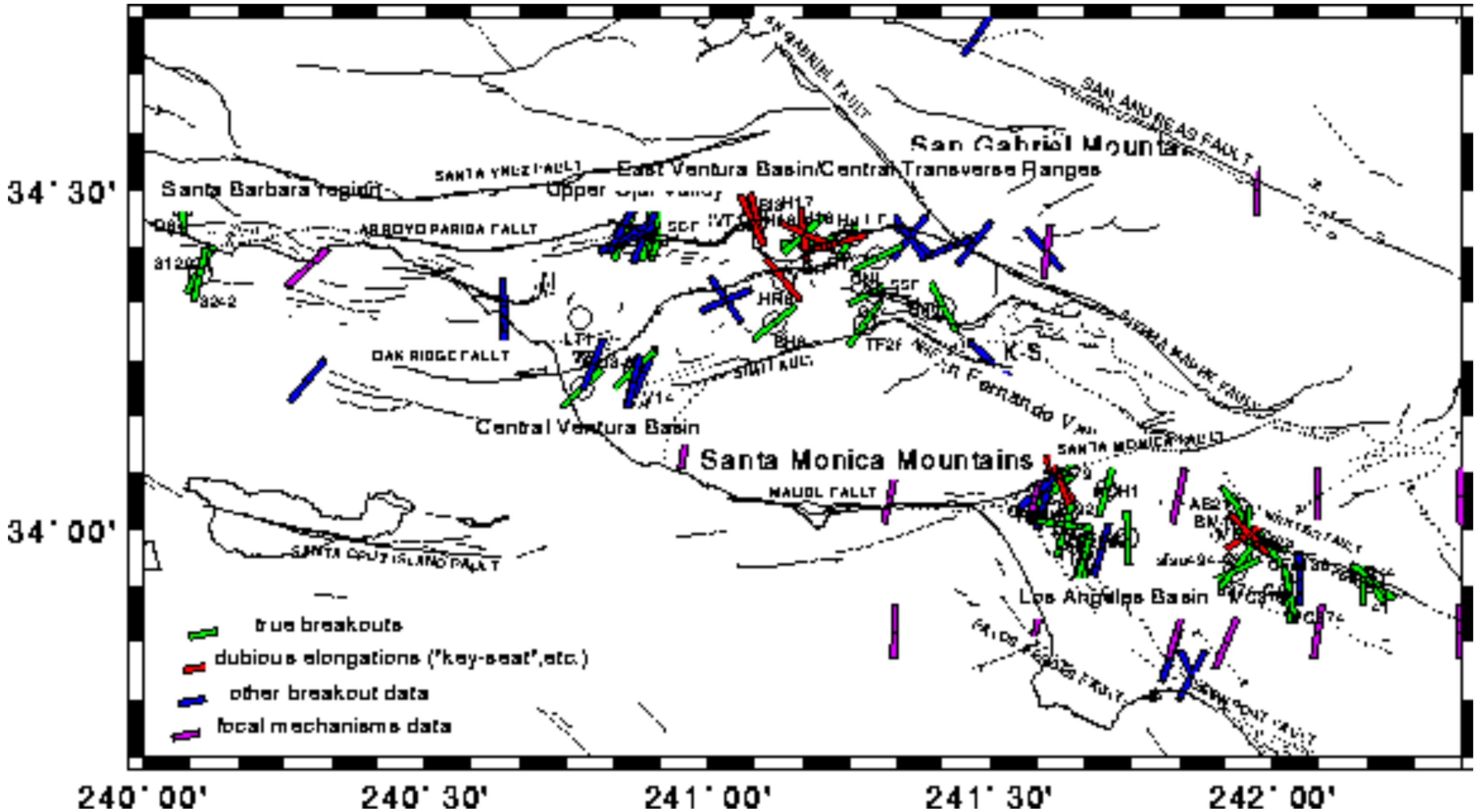
Obradovich & Naeser, 1981; Pisciotto & Garrison, 1981

Figure 32 Monterey/Santos Shale Play



Review of Emerging Resources: U.S. Shale Gas and Shale Oil Plays, 2010

We expect to provide a lot of new constraints in the regions of the oil fields, compared to this map from Wilde & Stock 1997



Summary and Questions

Lots of new drilling in S. California in the last 15 years. However, state public data base (DOGGR) is very backlogged.

We are obtaining well logs elsewhere, with various restrictions on data dissemination (depending on who we get the data from). We are allowed to provide aggregate results on stress information, which will likely mostly be SH and Sh directions vs depth.

- What ***cell size*** or grid size of information is needed by the modeling community?
- Which areas are ***highest priority***?
- How should we integrate our results with the SCEC ***web sites*** so that the results are most useful?

Web site for previous work (1997): http://www.data.scec.org/stress/stress.html

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