Geomechanical Study of Hydraulic Fracturing in Woodford Shale, Oklahoma*

Xiaodong Ma[1] and Mark D. Zoback[1]

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[1]Department of Geophysics, Stanford University, Stanford, California (xiaodongma.rocks@gmail.com)

Abstract

We conducted a case study to investigate the effectiveness of hydraulic fracturing and formation properties in the Woodford Shale. The analysis involves two parallel horizontal wells, each is about 10,000 feet long with about 15 hydraulic fracture stages. Analysis of Instantaneous Shut-In Pressure (ISIP) of each hydraulic fracture stage yielded values for variations of the minimum horizontal principal stress (*S*hmin) magnitude along the length of the wells. We found significant ISIP variations along the length of both wells. Although there is no direct correlation between the number of micro-earthquakes and *S*hmin magnitude of a given stage, in general, the lower *S*hmin values correlates to further distribution of microseismic events away from the well both vertically and laterally.

We utilized Elemental Capture Spectroscopy (ECS) logs to determine the content of clay and organic matter over the length of the horizontals. We observed that ISIP by stage correlates well with the content of clay and organic matter. By combining the analysis of the ECS log and the well steering data, we found that the wellbore traveled in and out of the target zone and penetrated different facies of the Woodford Shale along its path, resulting variation of mineralogy along the well length. The value of *S*hmin is a measure of the pressure needed for hydraulic fracture. The variation of *S*hmin along the length of the wells appears to correlate with variations of rock composition and mechanical properties of the formation close to the wellbore. Low values of *S*hmin also reflect greater stress anisotropy is this an indicator of relatively, brittle (or less ductile) formations resulting from variations of clay and organic matter.

A plausible explanation is by stress relaxation. According to Sone and Zoback (2014), the viscous creep of ductile materials over geological time is responsible for deviations from expected at certain depth. We plan to quantitatively analyze the connection between mineralogy and stress variation using the viscous stress relaxation model.

References Cited

Alt, R., and Mark D. Zoback, 2016 submitted, In-situ stress and active faulting in Oklahoma: submitted to Bulletin of the Seismological Society of America.

Sone, Hiroki, and Mark D. Zoback, 2014, Viscous relaxation model for predicting least principal stress magnitudes in sedimentary rocks: Journal Petroleum Science and Engineering, v. 124, p. 416-431.

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Xiaodong Ma and Mark Zoback

Stanford University

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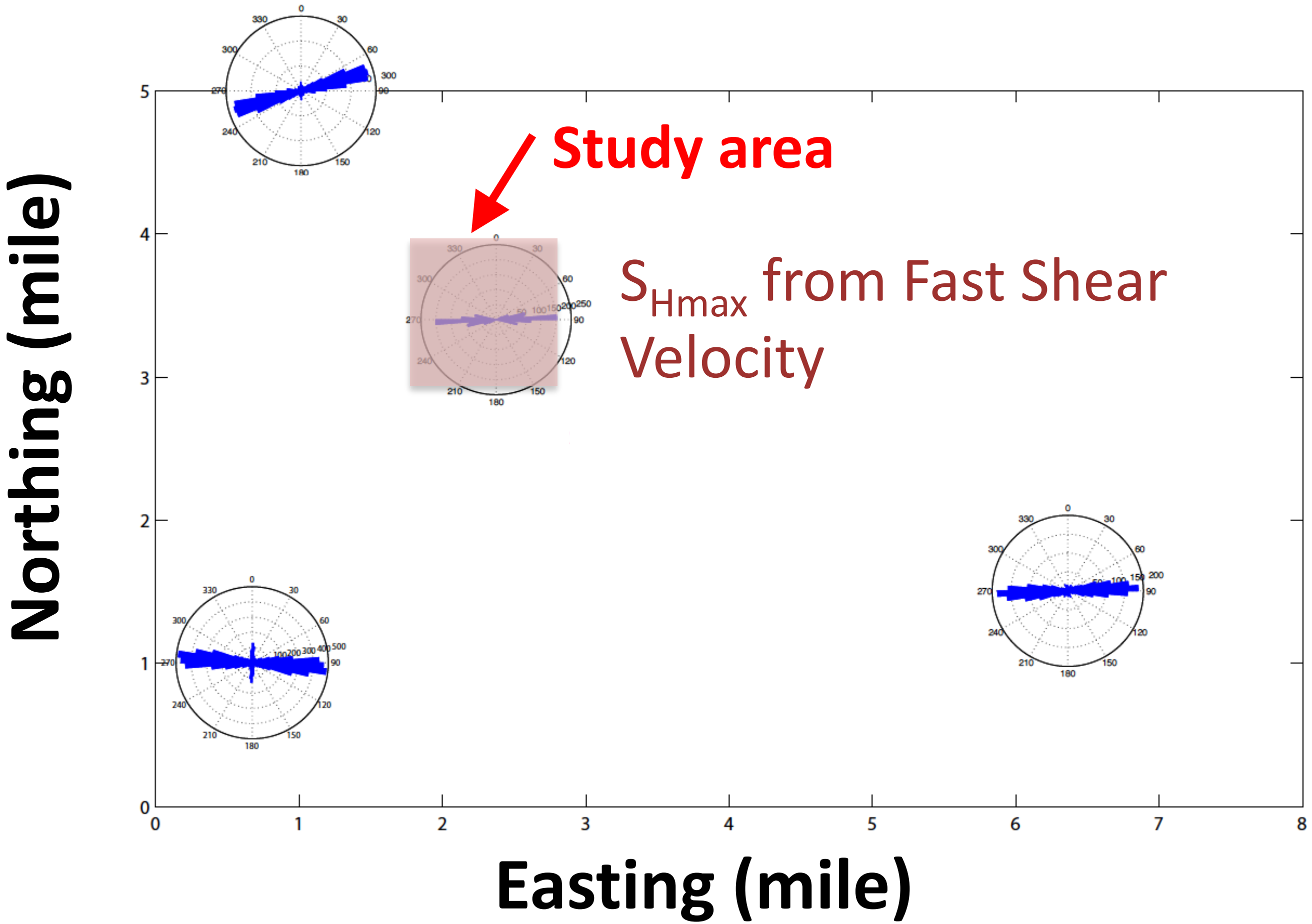
Outline

1. Geomechanical model of the study area
2. Lithology correlation with shut-in pressures
3. Microseismic pattern indicating patchy stimulation
4. Identification of faults based on 3D seismic data

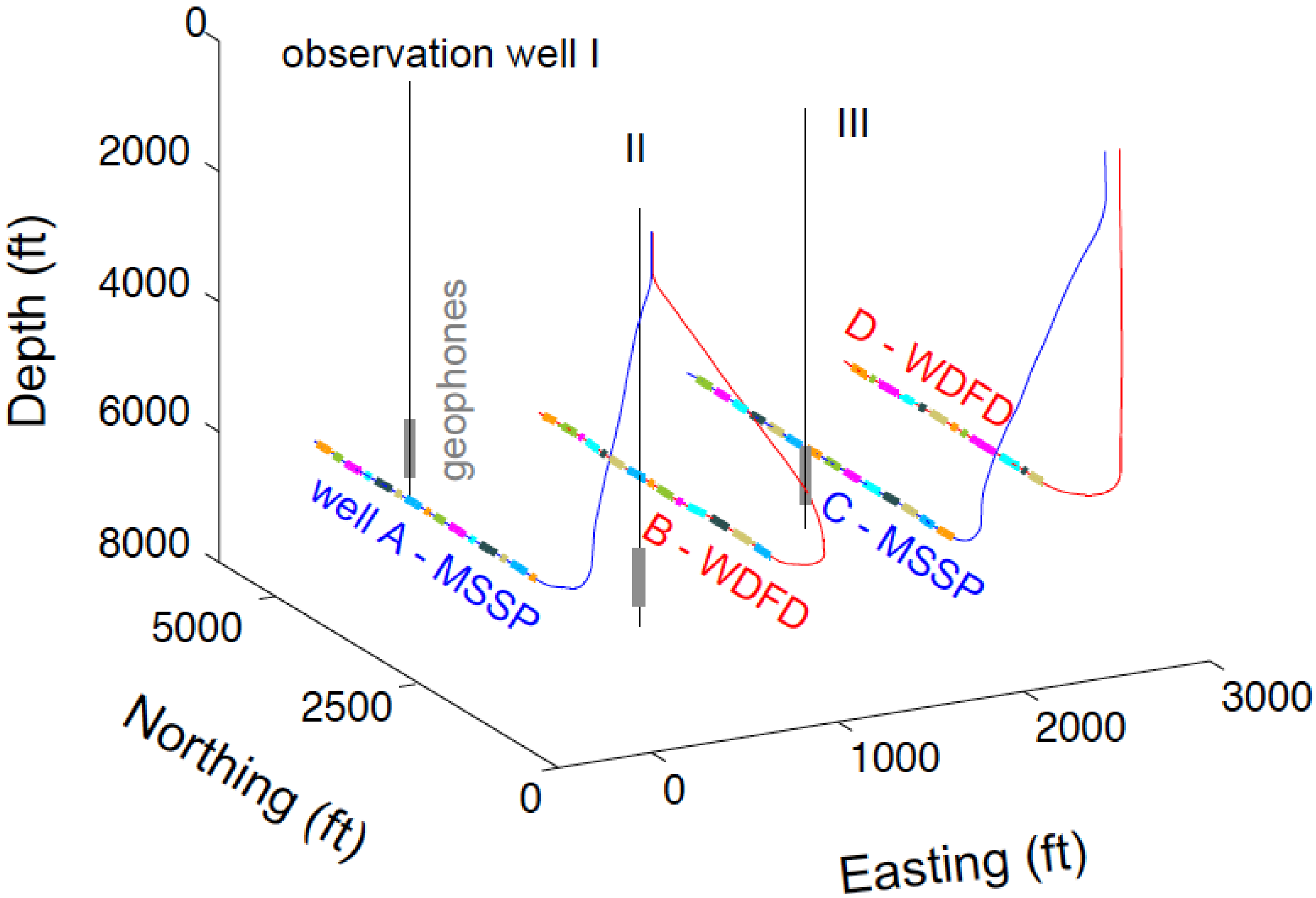
Study Area Overview (MSSP – WDFD play)



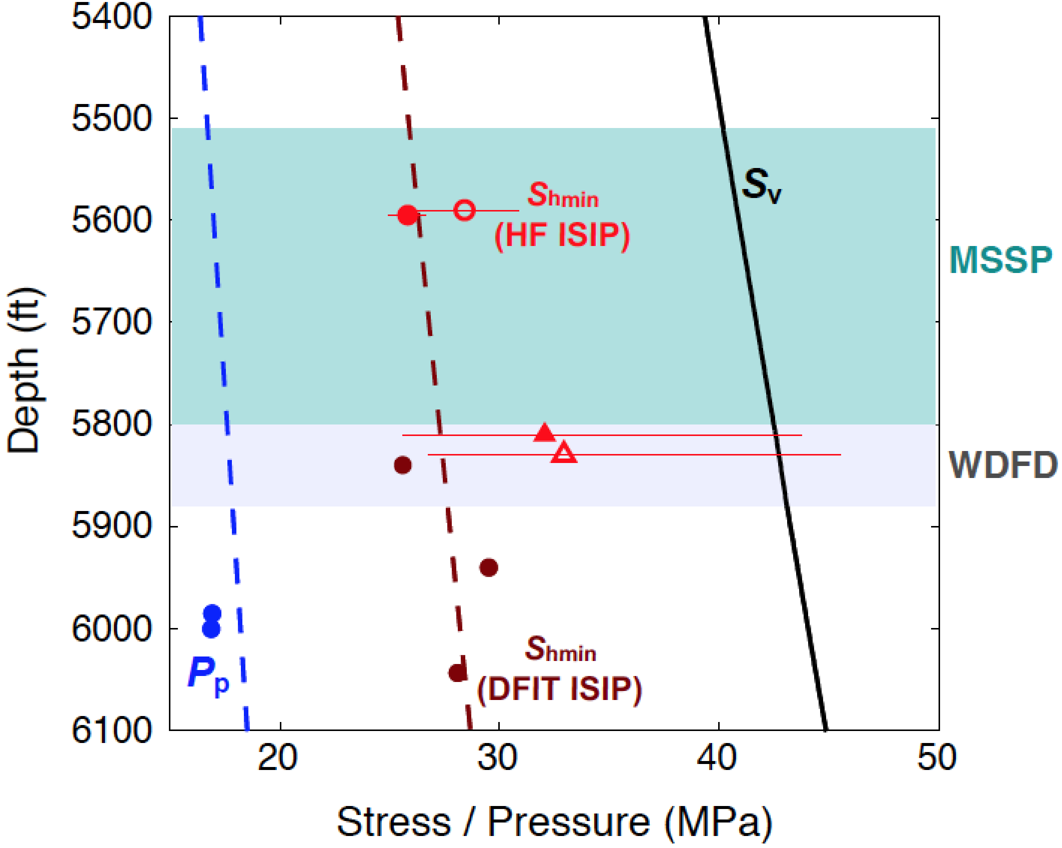
Alt, R and M.D., Zoback, In-situ stress and active faulting in Oklahoma, submitted to *Bulletin of the Seismological Society of America*.

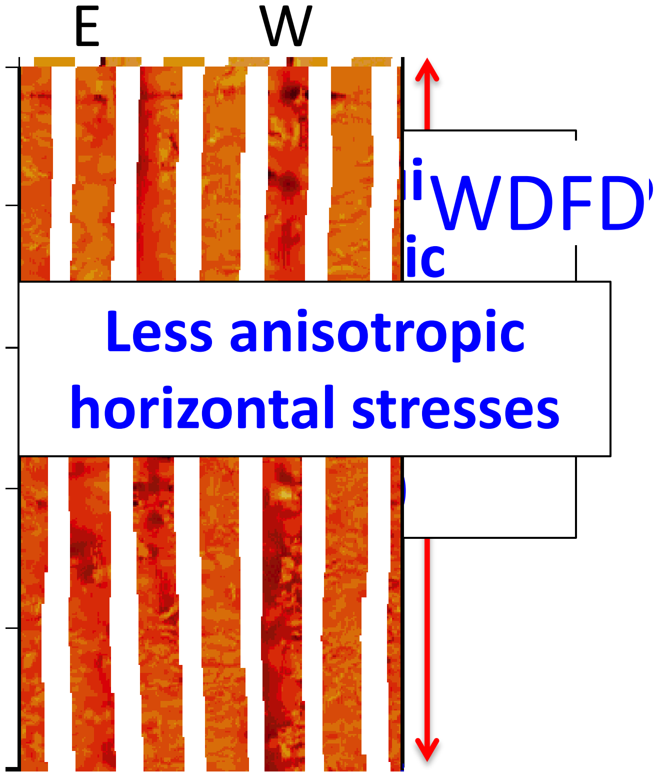
Data based on dipole sonic logs

Well Configurations



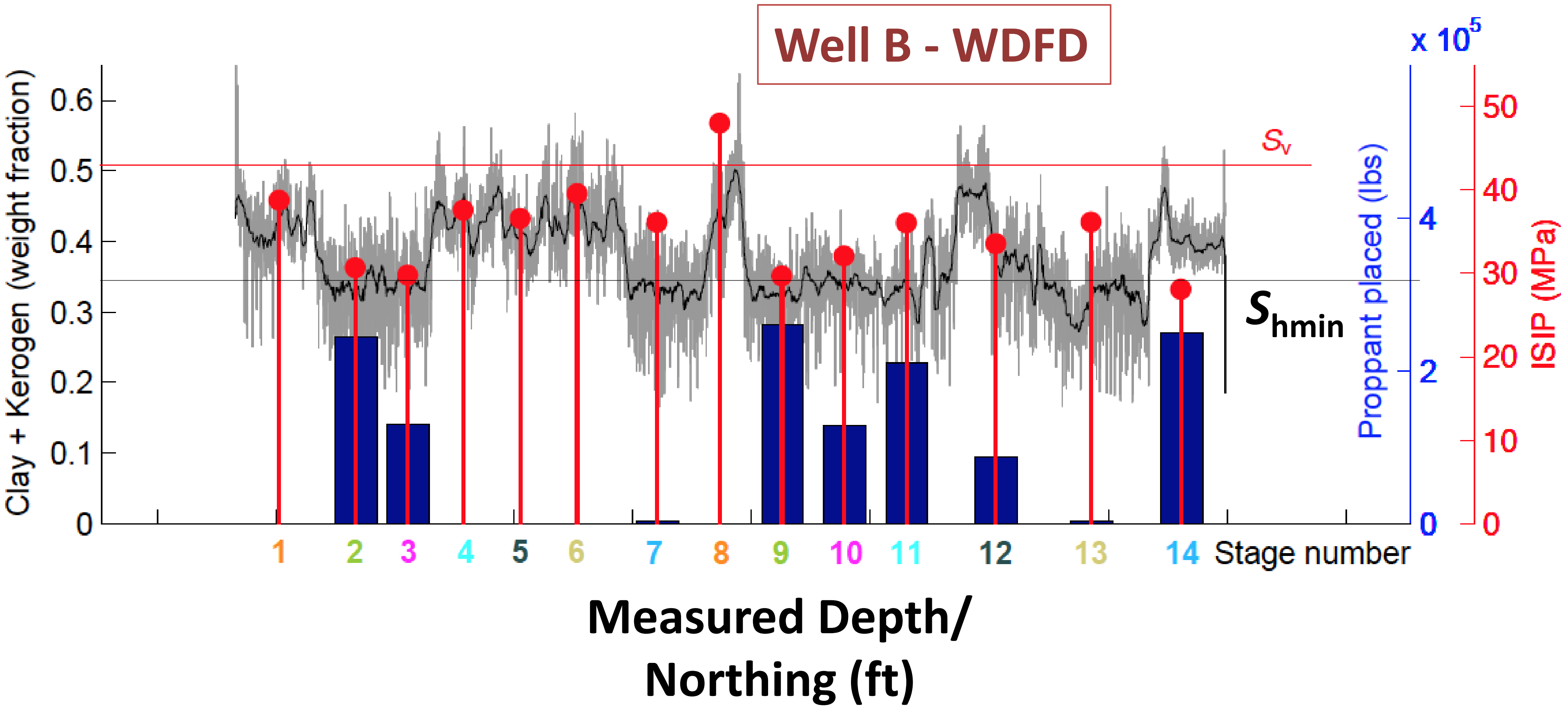
Geomechanical Model



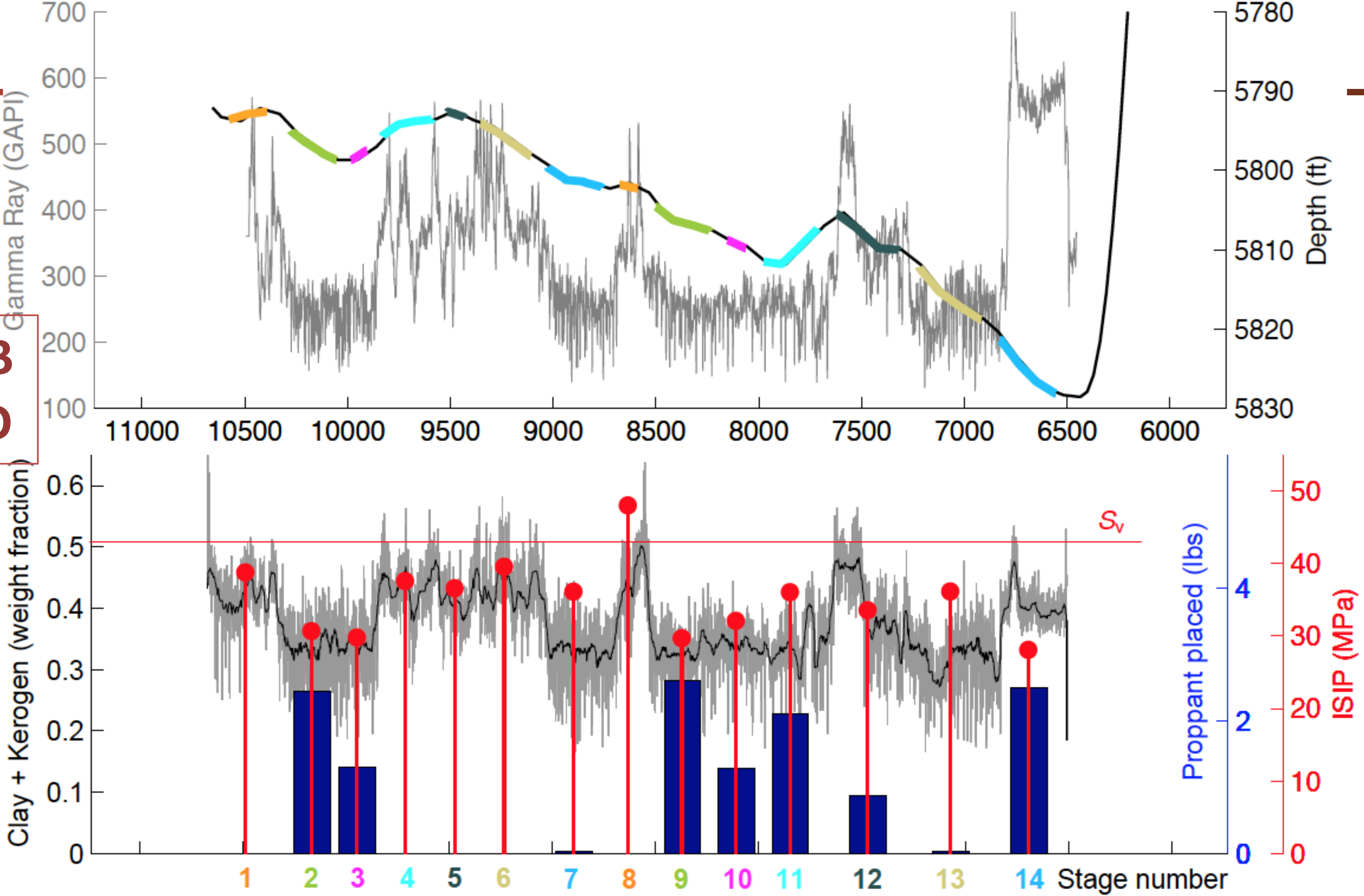


Less anisotropic horizontal stresses

Correlation between ISIP and lithology



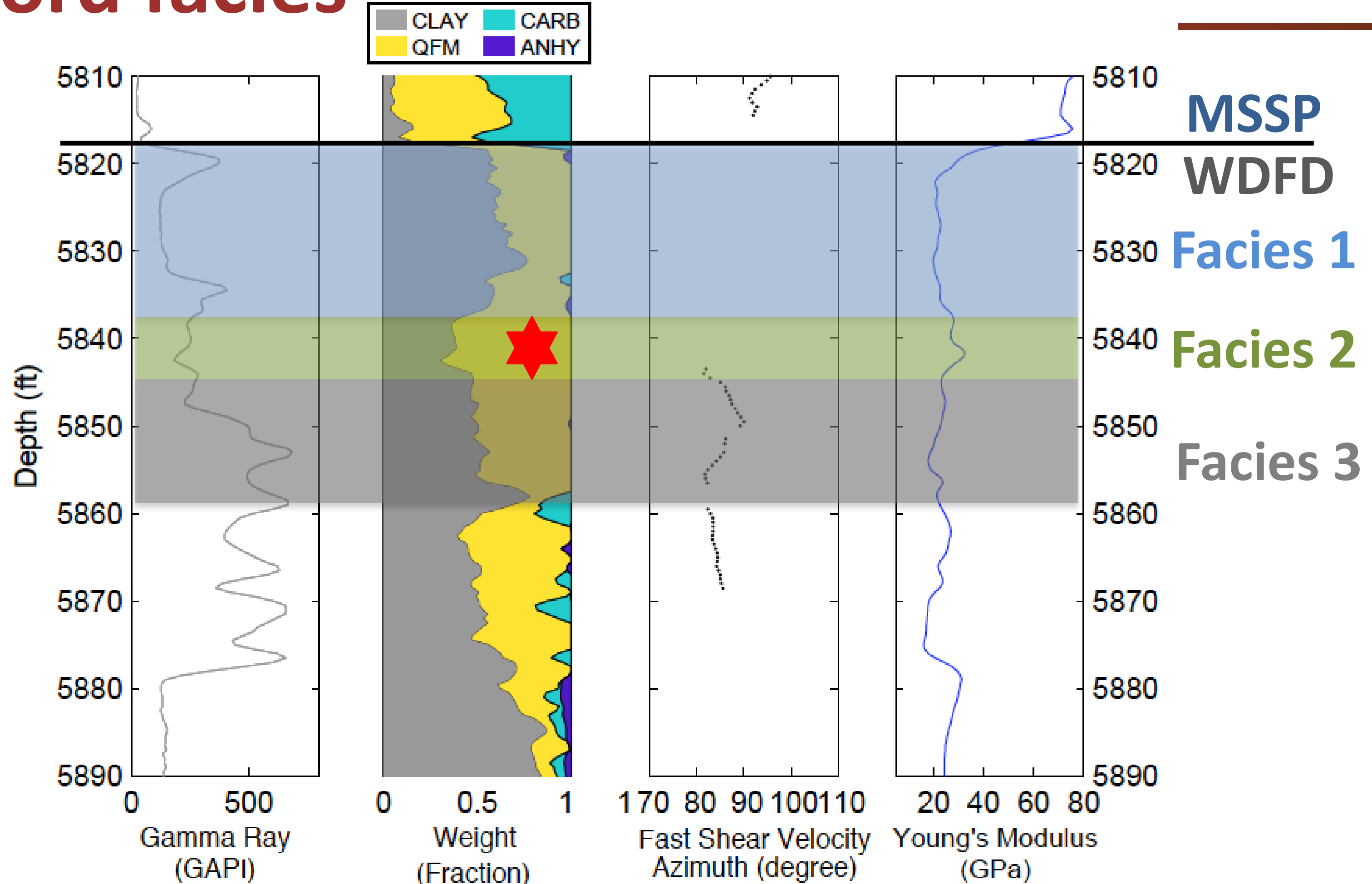
Well B WDFD



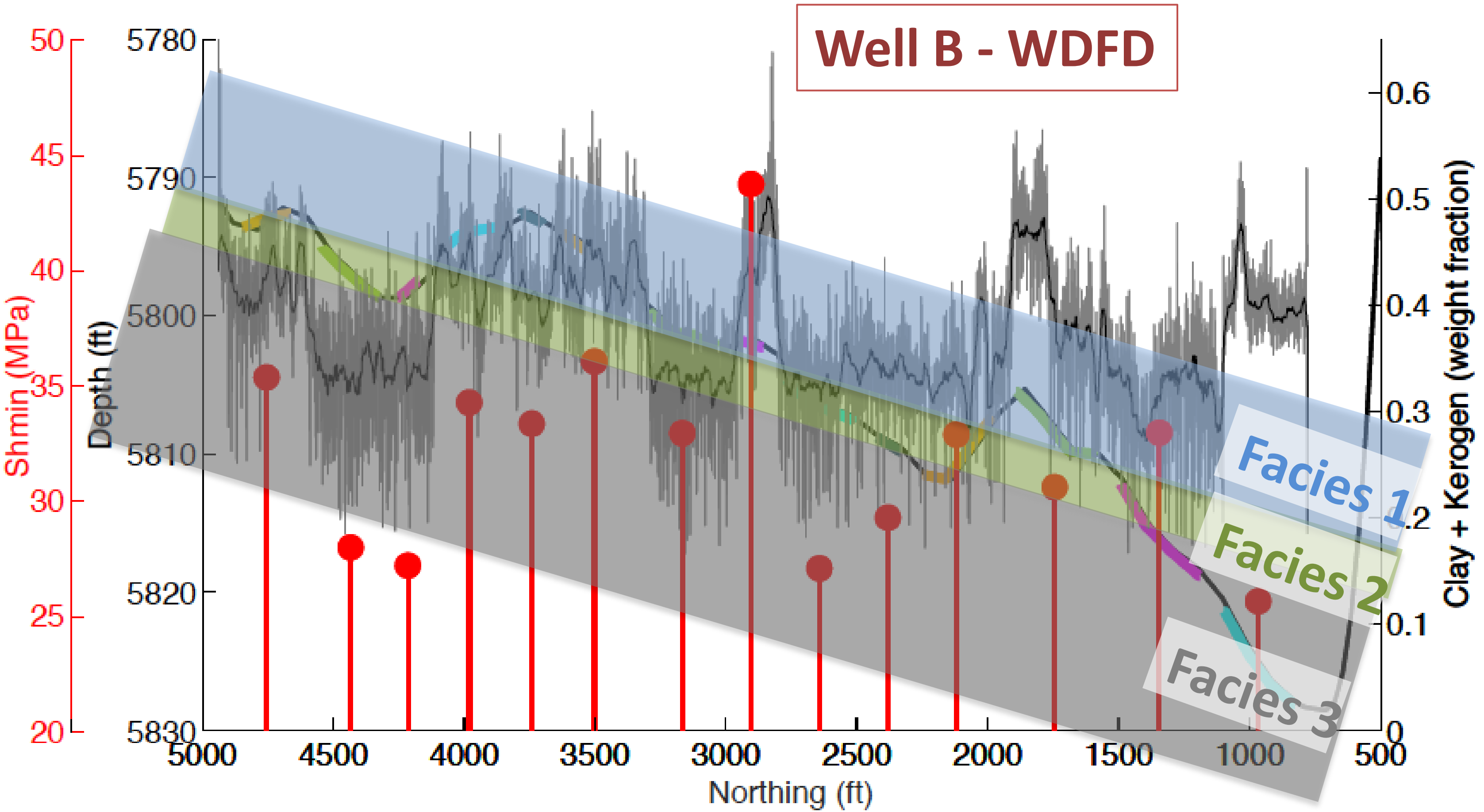
Gamma Ray (GAPI)
700
600
500
400
300
200
100
11000
10500
10000
9500
9000
8500
8000
7500
7000
6500
6000
5780
5790
5800
5810
5820
5830
Depth (ft)
Clay + Kerogen (weight fraction)
0.6
0.5
0.4
0.3
0.2
0.1
0
S_v
Proppant placed (lbs)
4
2
0
ISIP (MPa)
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Stage number

Woodford facies

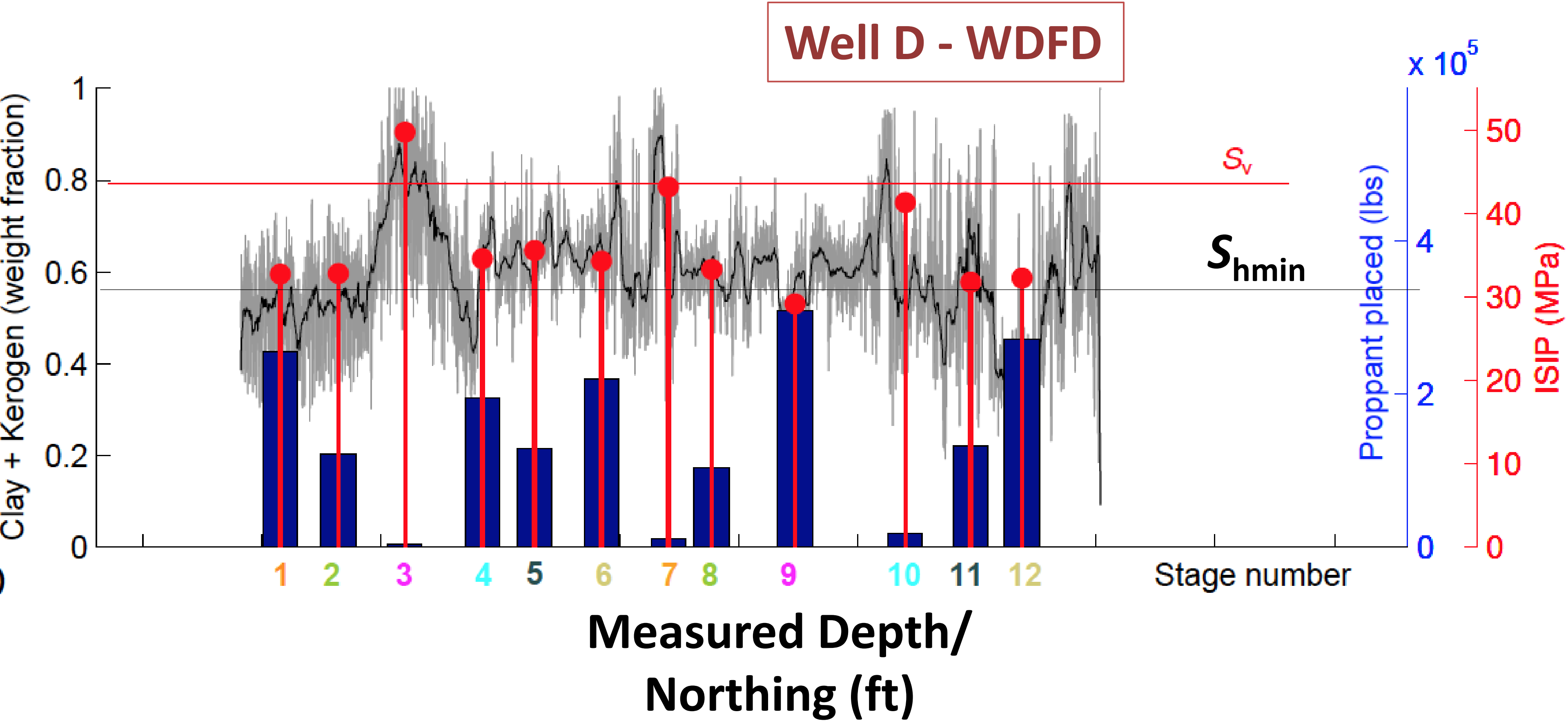
Central Vertical Well



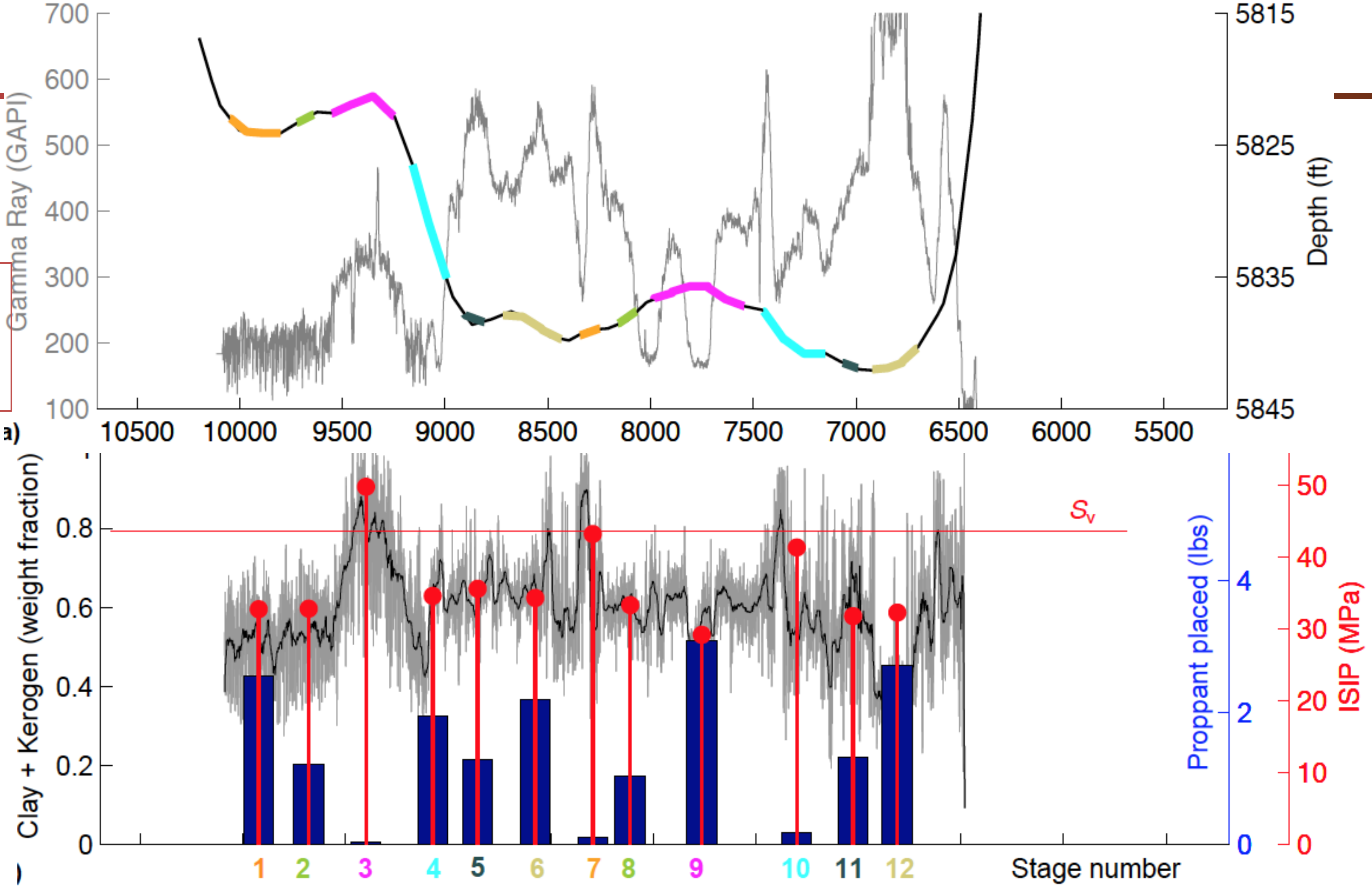
Correlation between ISIP and lithology



Correlation between ISIP and lithology

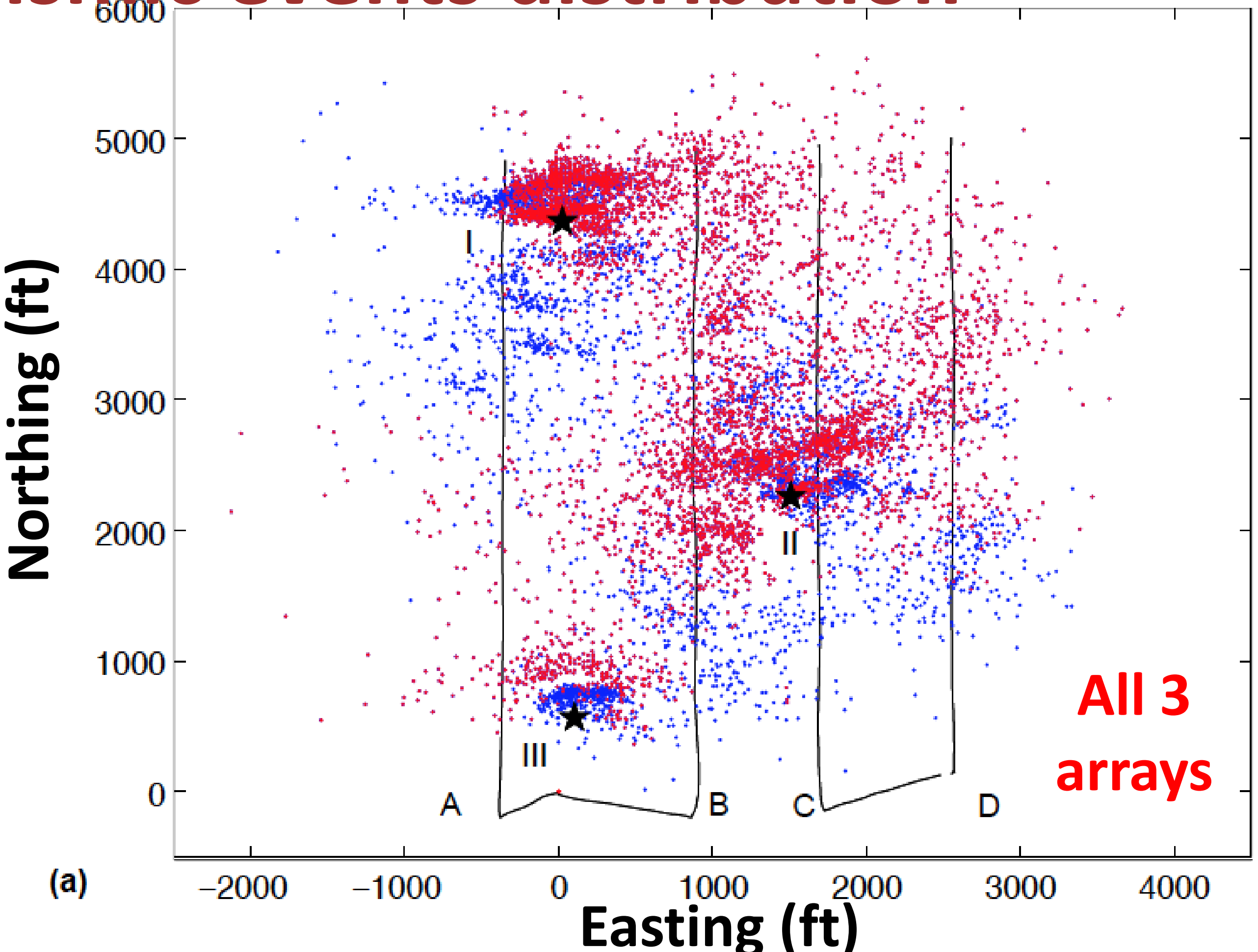


Well D
WDFD

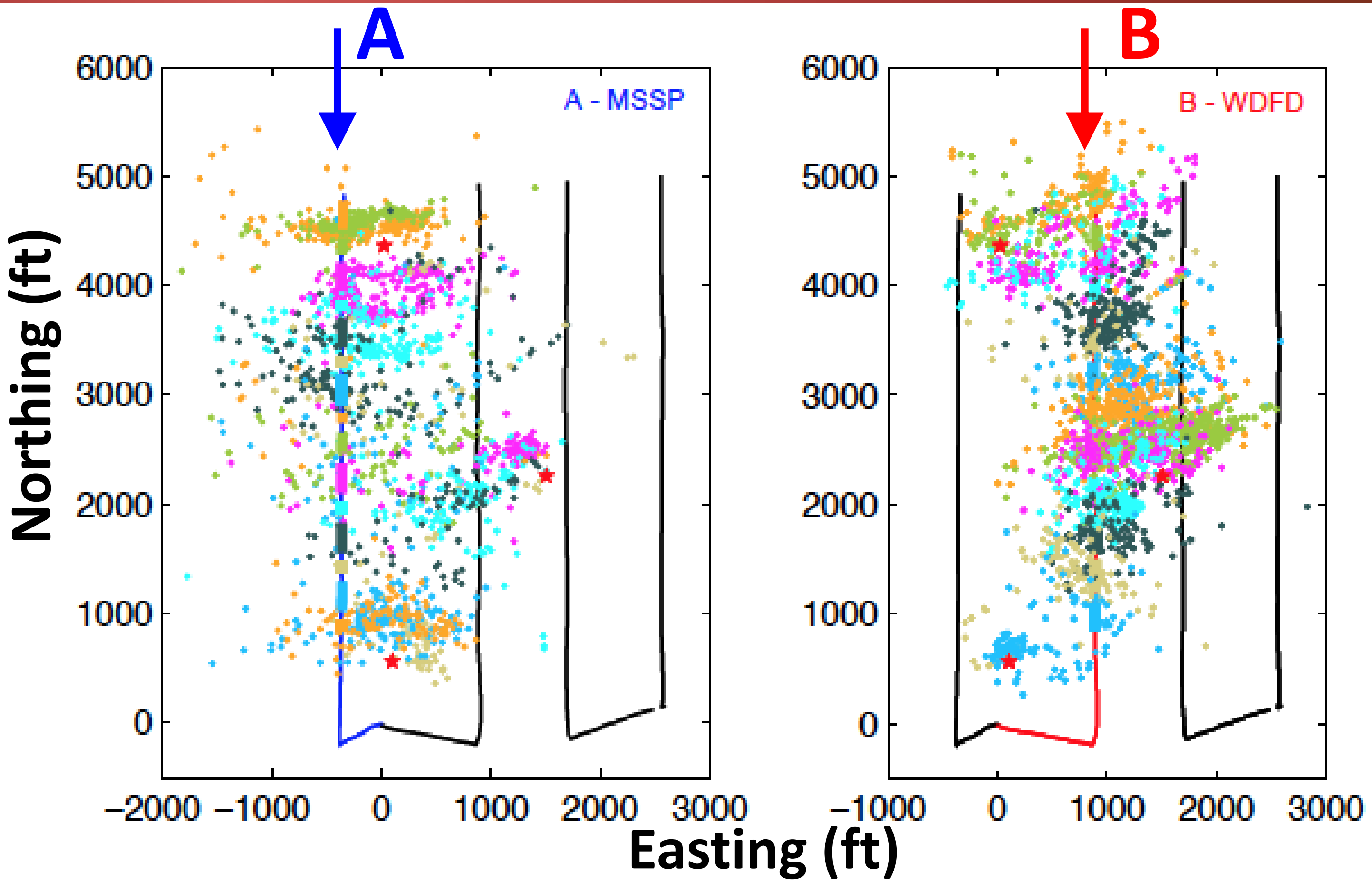


Gamma Ray (GAPI)
700
600
500
400
300
200
100
5815
5825
5835
5845
Depth (ft)
a)
10500
10000
9500
9000
8500
8000
7500
7000
6500
6000
5500
Clay + Kerogen (weight fraction)
0.8
0.6
0.4
0.2
0
S_v
Proppant placed (lbs)
4
2
0
50
40
30
20
10
0
ISIP (MPa)
1
2
3
4
5
6
7
8
9
10
11
12
Stage number

Microseismic events distribution



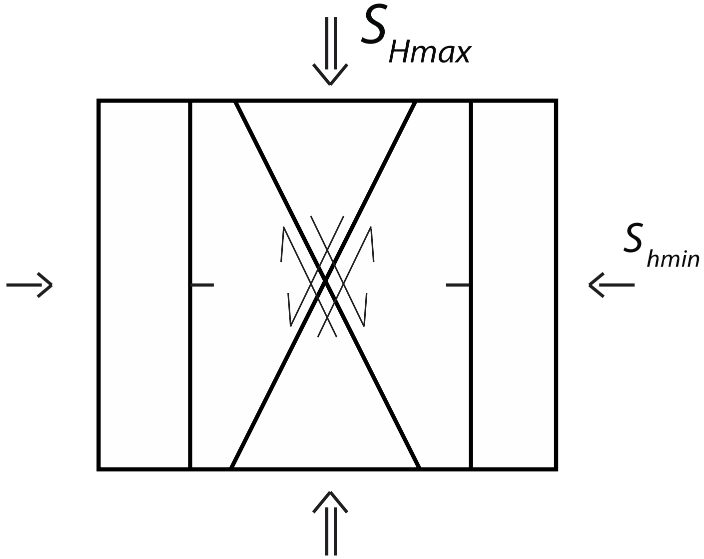
Microseismic events (Wells A and B)

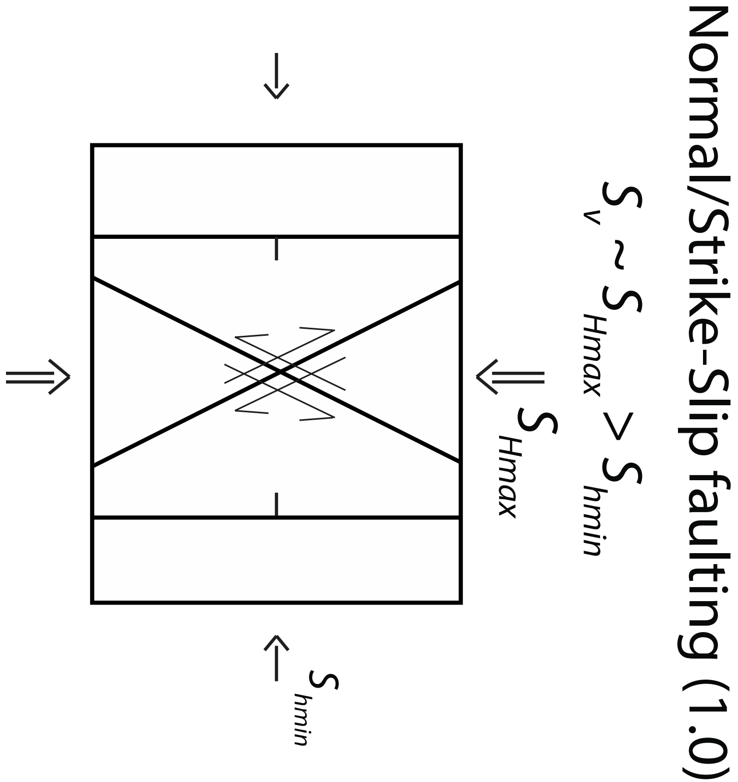


Normal/Strike-Slip Faulting

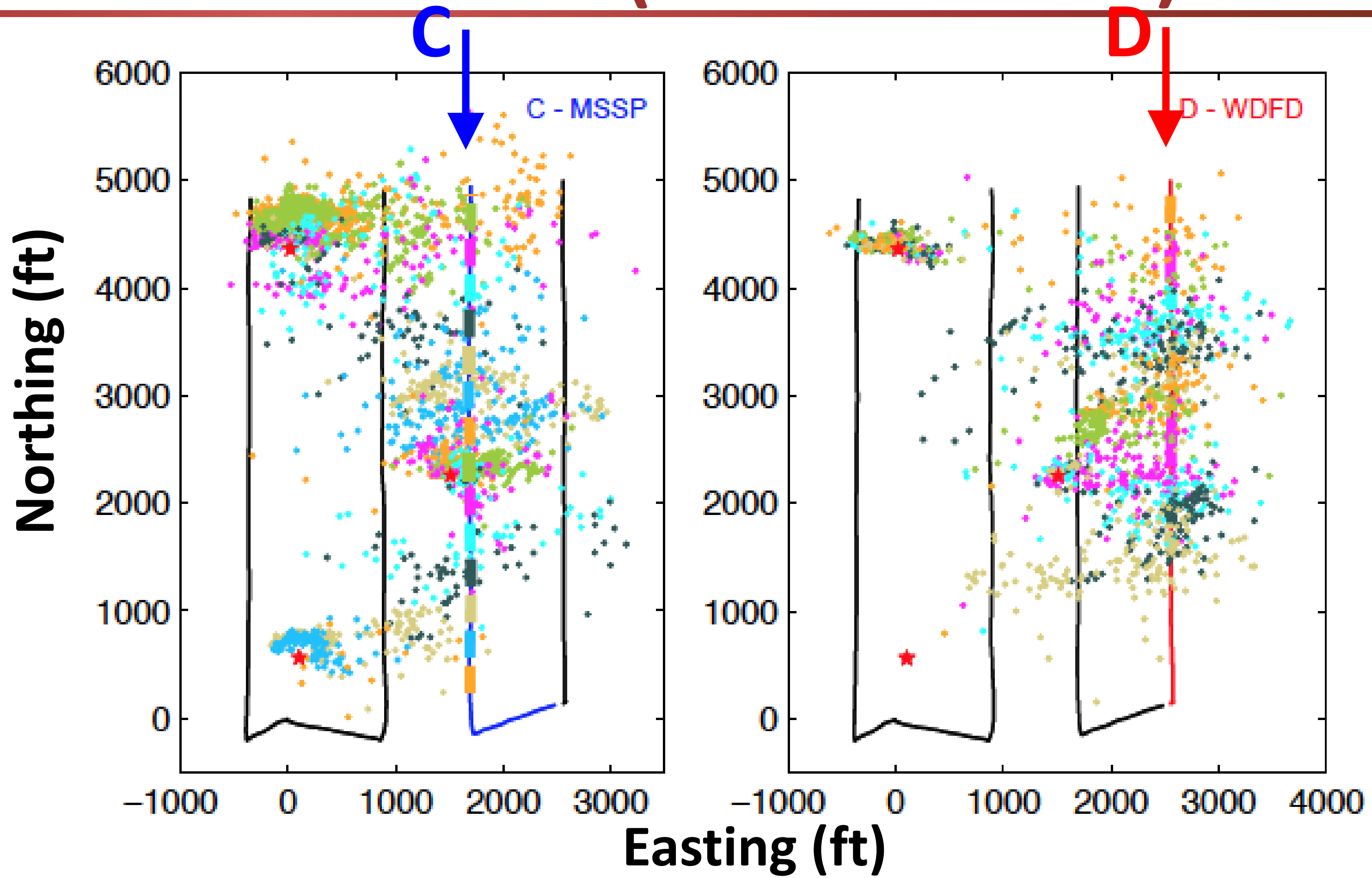
Normal/Strike-Slip faulting (1.0)

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

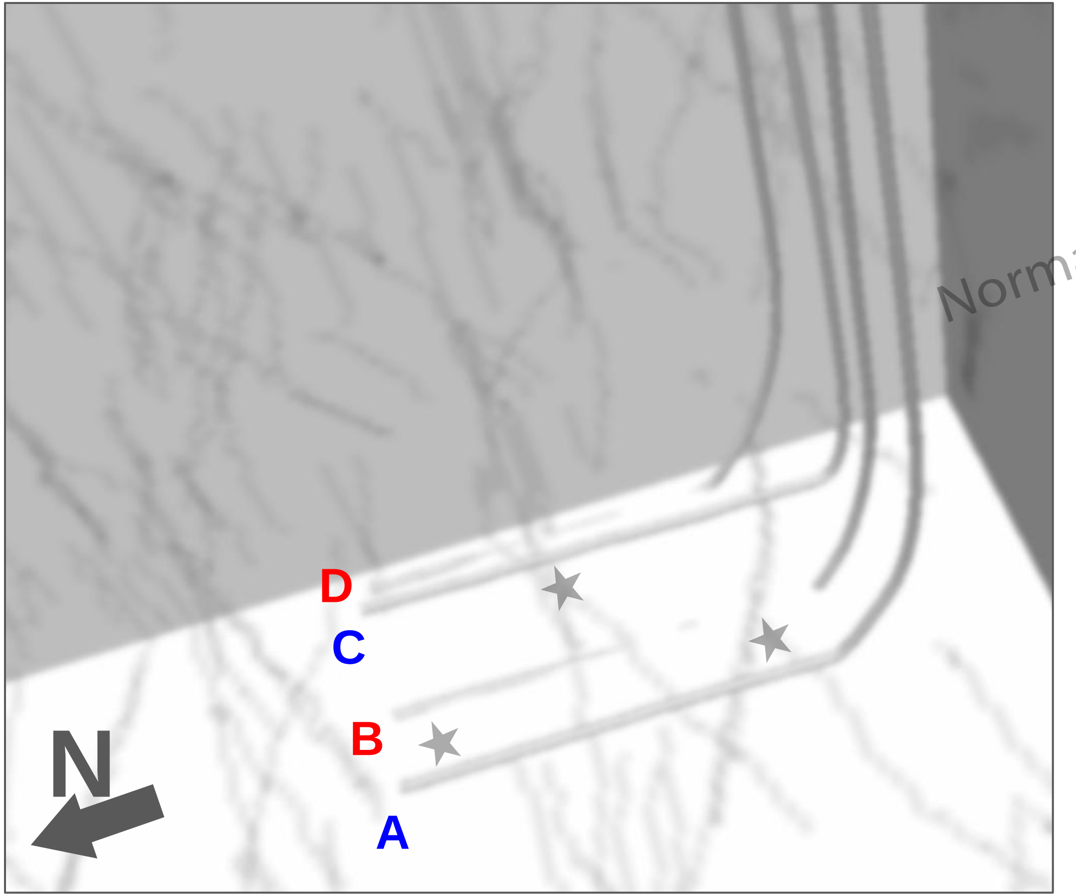


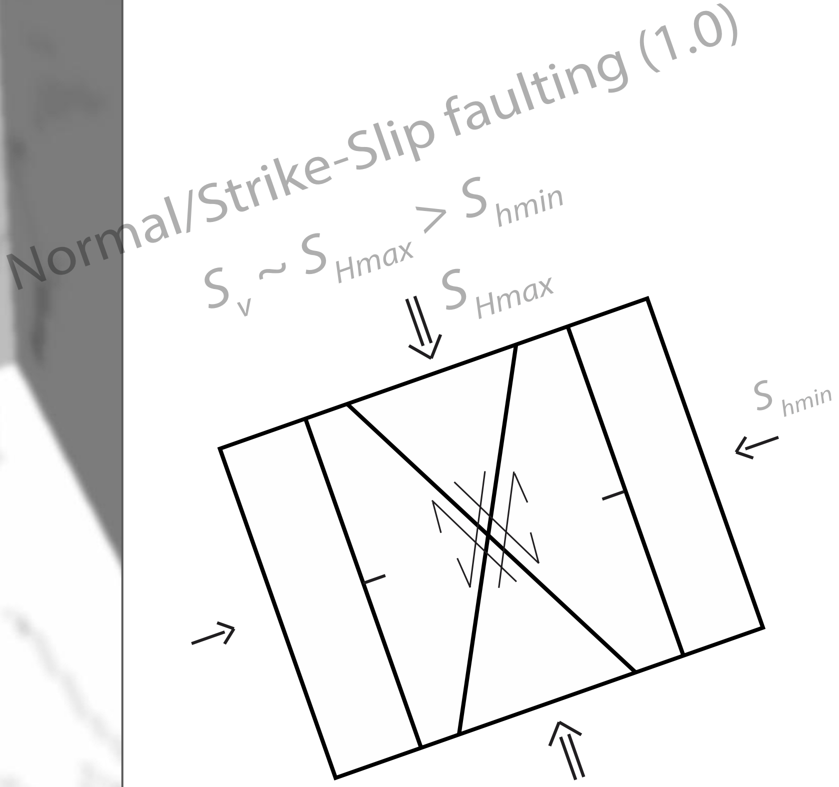


Microseismic events (Wells C and D)



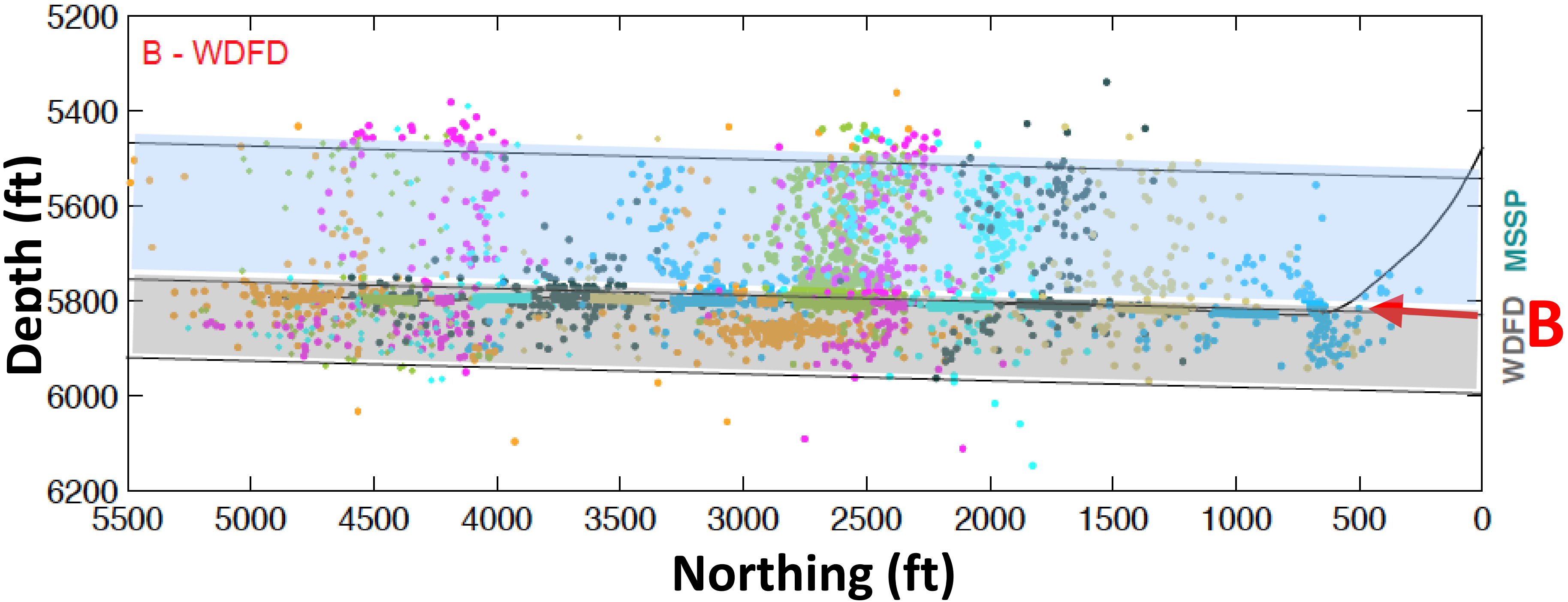
Ant-tracking results





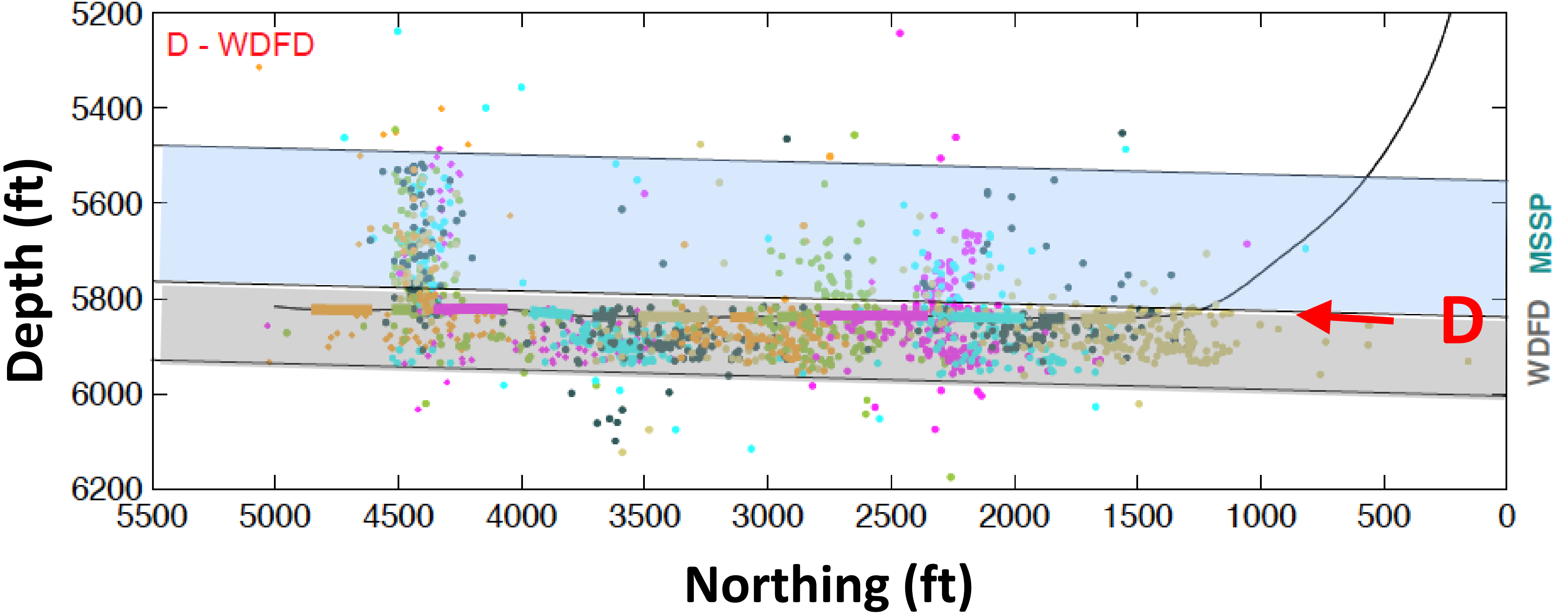
Microseismic events (WDFD Well B)

Vertical lineation and MSSP-WDFD connection



Microseismic events (WDFD Well D)

Vertical lineation and MSSP-WDFD connection



Conclusions

1. Geomechanical model indicates the MSSP formation is strike-slip/normal faulting stress regime, consistent with OK regional stress state.

2. Significant variations of ISIP along WDFD wells correlate with the lithology (clay+kerogen content), which controls the viscous relaxation of stresses.

3. The well trajectory through different lithologies/facies affects frac'ing efficiency.

4. Distribution of microseismic events suggests the control of stress contrast between MSSP and WDFD and pad-size faults.