Using Borehole Image Logs to Characterize a Major Fault in the Ventura Avenue Field*

Jon Schwalbach[1], Thomas Hauge[2], Michael Glascock[1], Plamen Ganev[1], Jaron Lucero[1], and Ralph Coldewey[1]

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[1]Aera Energy LLC, Bakersfield, CA, USA (jrschwalbach@aeraenergy.com)
[2]Hauge Geoscience, Seattle, WA, USA

Abstract

An updated 3D model of the complexly faulted Ventura Avenue Field reveals the geometric relations of the major north and south verging thrust faults that compartmentalize the reservoir. Wells penetrate these thrust faults in a variety of ramp and flat positions. Borehole image logs were obtained for a number of these wells, enabling us to characterize the fault zones in the subsurface.

The focus of this study is the Taylor 73 Fault (named for the well where the fault was originally identified). This major south verging thrust acts as an effective seal, separating most of the productive reservoir intervals from shallower zones above. The reservoir facies are turbidite sandstones that include thickly bedded amalgamated units, thinner inter-bedded sandstone and mudstone units, and intervals that are predominantly mudstone. The facies act as contrasting mechanical units that can affect the character of the fault zone. The position along the fault plane is also a primary factor. Not surprisingly, it is often difficult to identify specific fault planes in the flat-on-flat fault position. Identifying the fault zone in ramp positions is much more obvious, although the character and fault expression are highly variable. Fault cores and damage zones range in thickness from tens to hundreds of feet, and can consist of sheared and fractured intervals, intact rotated blocks, and cemented intervals. Our ongoing work investigates position along the fault plane, fault separation, and mechanical stratigraphy as factors that affect fault expression. Refining fault interpretations with image logs constrains the overall subsurface interpretation. We can more confidently distinguish structural from stratigraphic deformation, and identify potentially isolated compartments and barriers in the reservoir.

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Aera Energy LLC

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Hauge Geoscience

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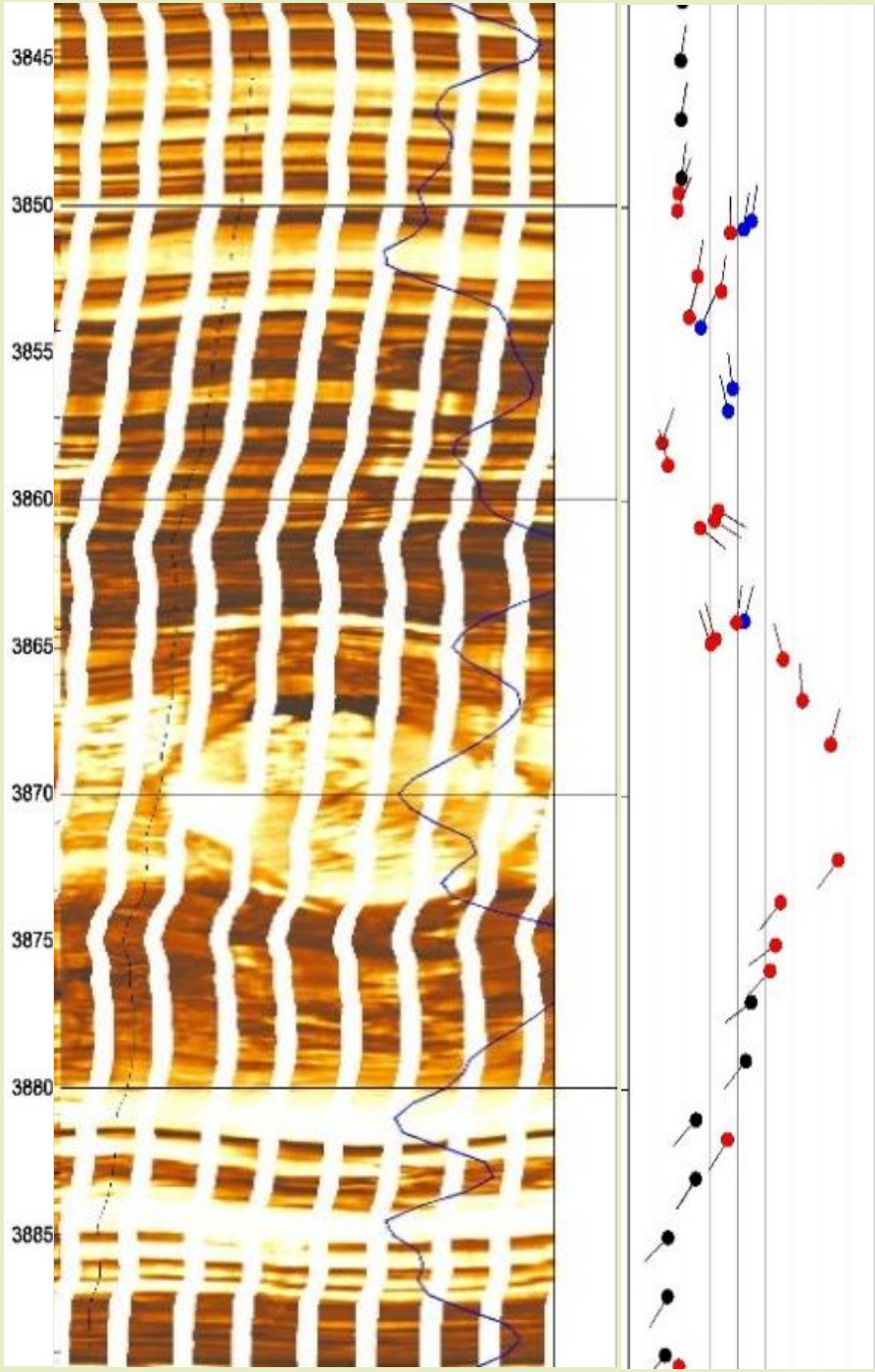
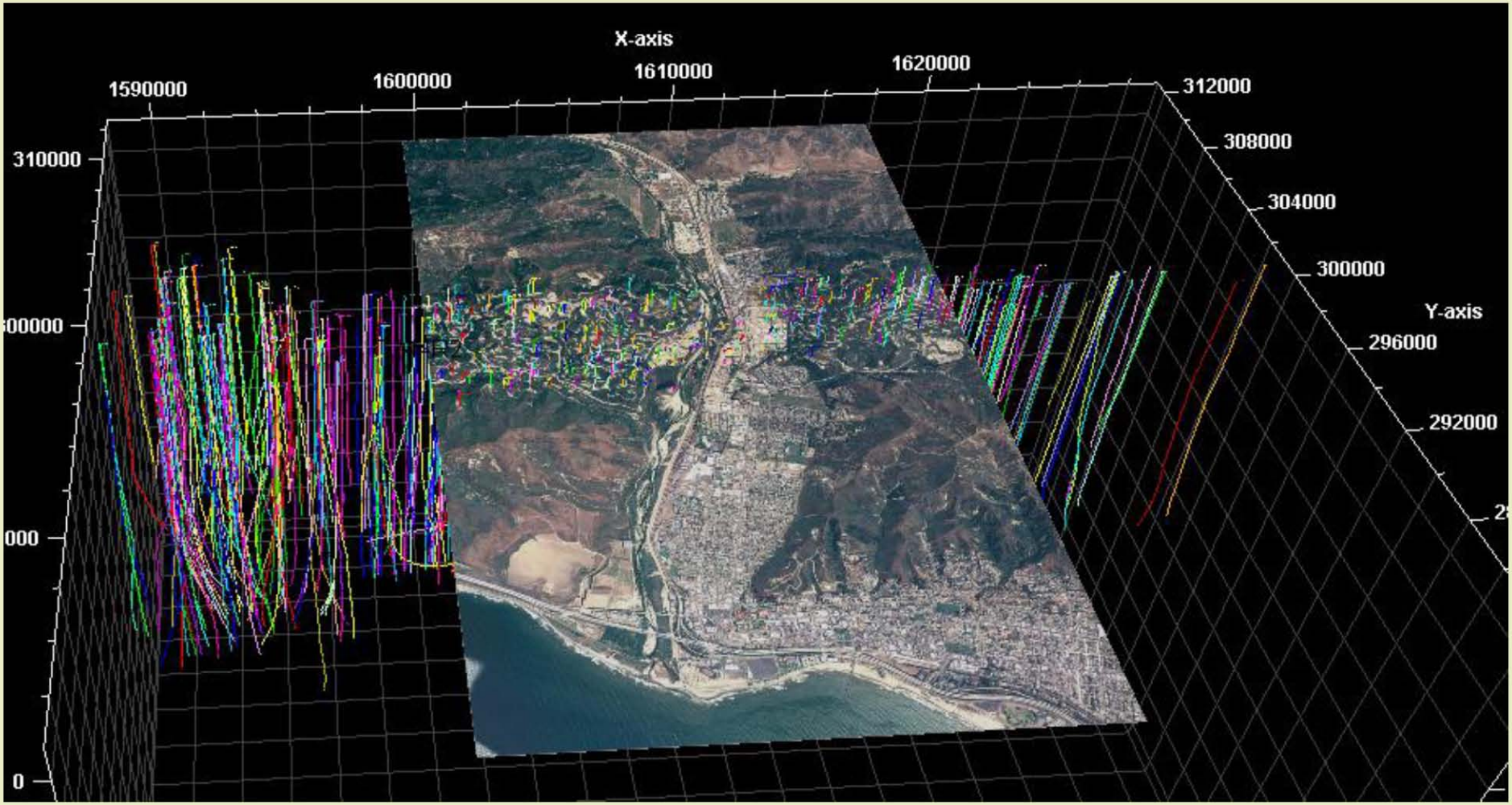


Main Takeaways

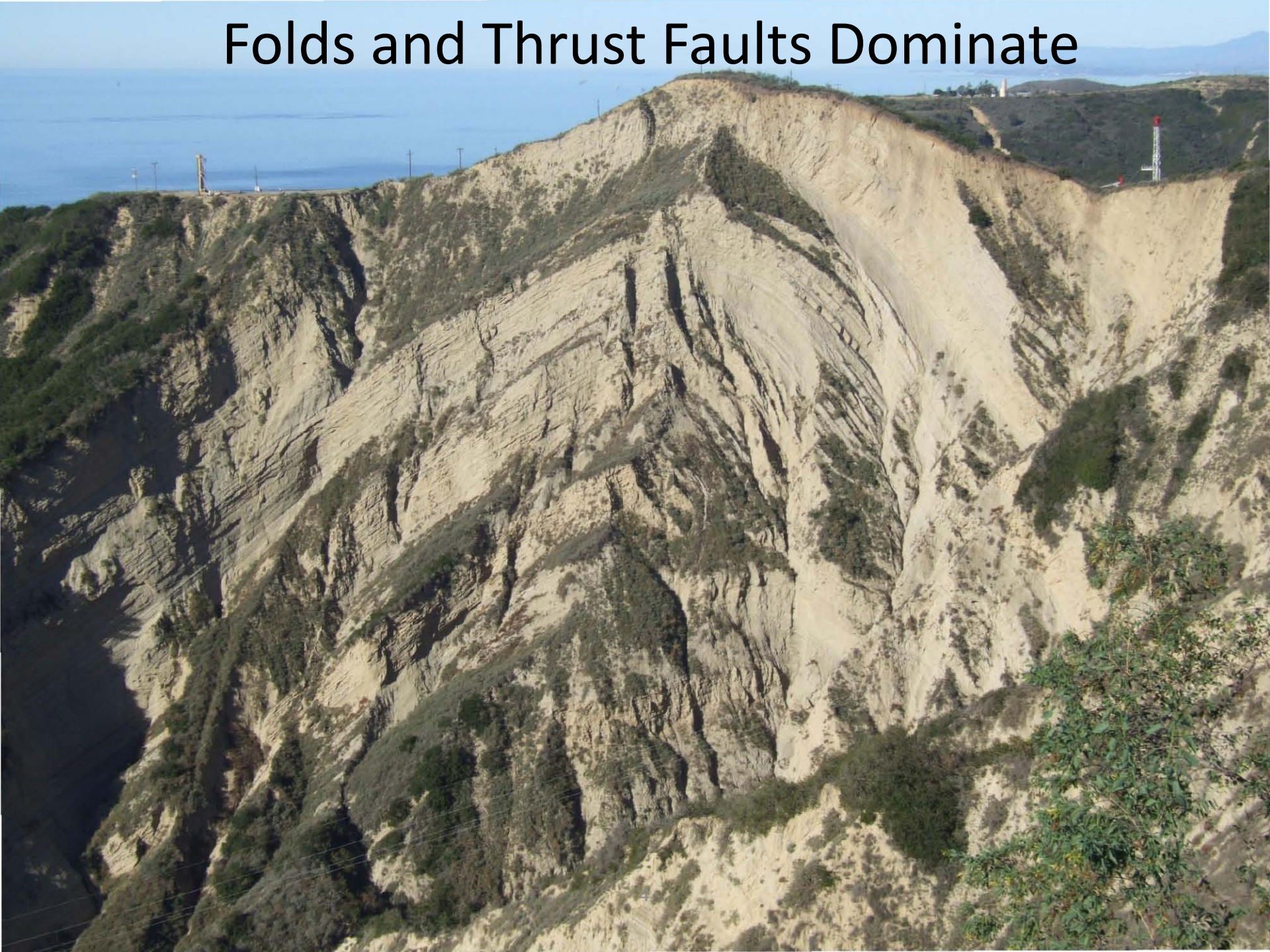
- *Fault character varies significantly over short distances*

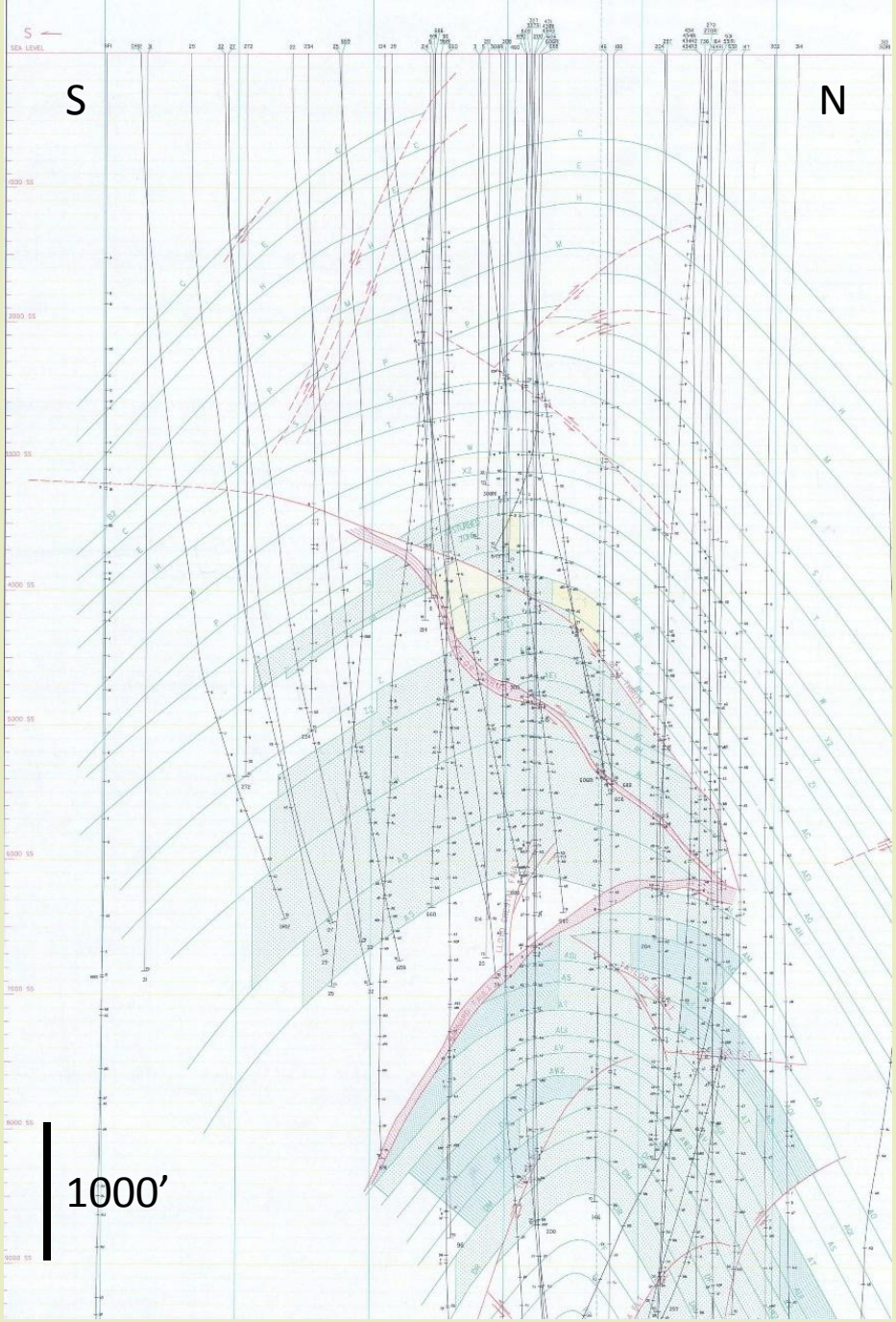
- *Fault zone characteristics can be related to specific structural domains in the fault-bend fold, flat-ramp-flat environment*

Ventura Field View From South



Folds and Thrust Faults Dominate





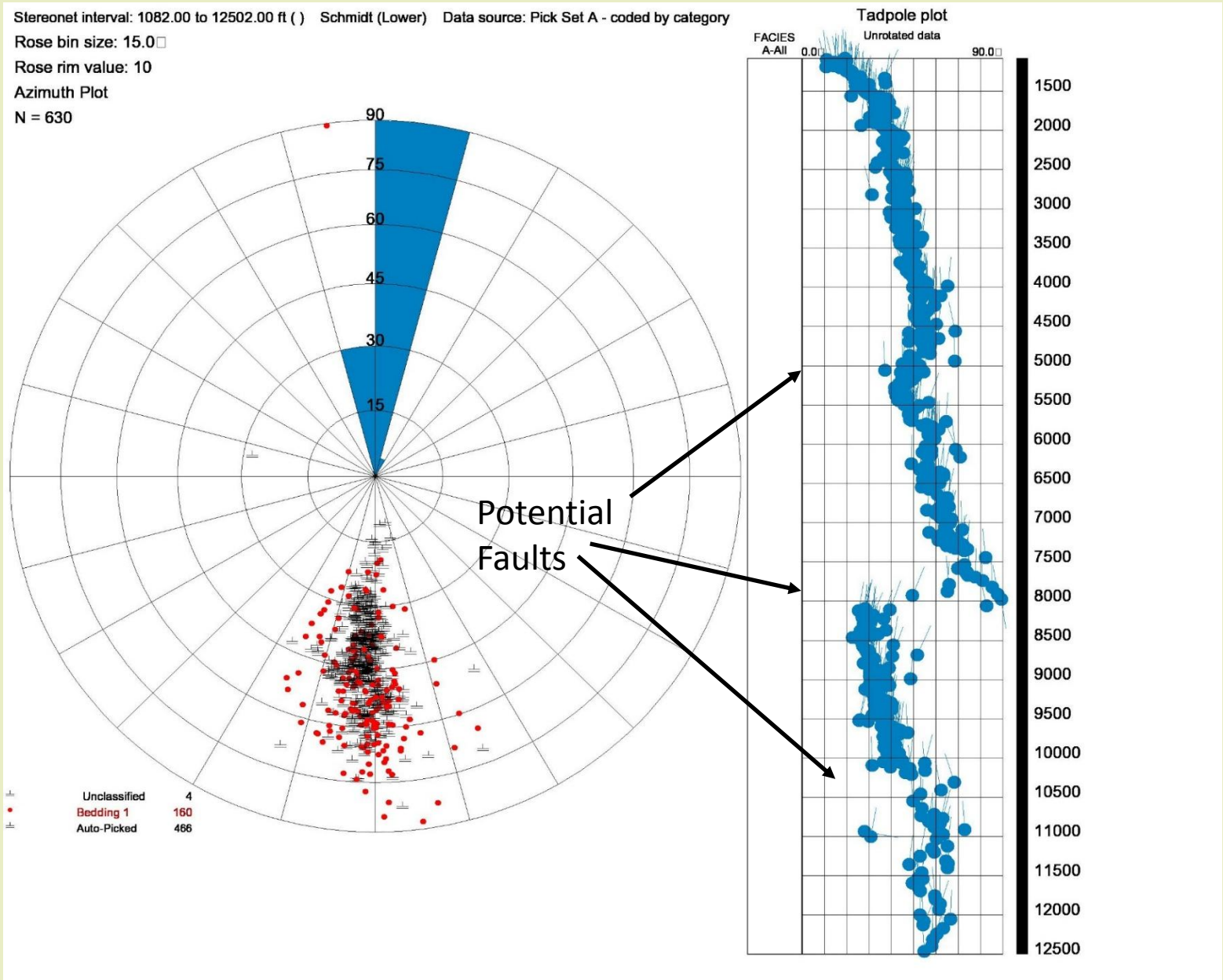
Cross Section (no vertical exaggeration)

Ventura Field Structure

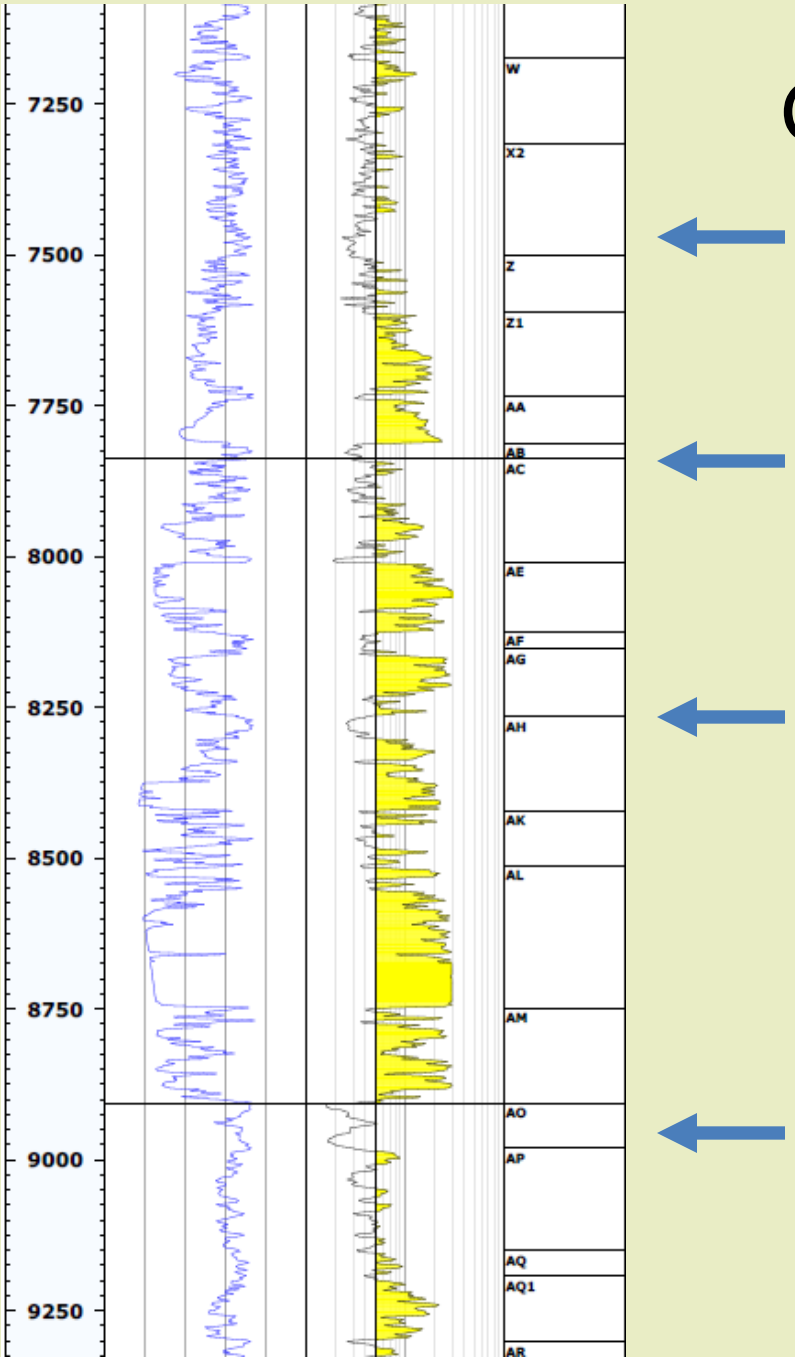
- Interpretation based on over 2500 well penetrations
- Series of N-S cross sections spaced 500’-1000’ apart, built along with field development from 1950’s through 1990’s
- Steep bed dips and complex fault network, mostly ramps identified
- No seismic because of steep dips and surface topography

- Focus on Taylor 73 Fault
  - Fault separation approx. 1400’ along length
  - Most hydrocarbons occur below this fault

40 Wells with Image Logs for Bed Dips

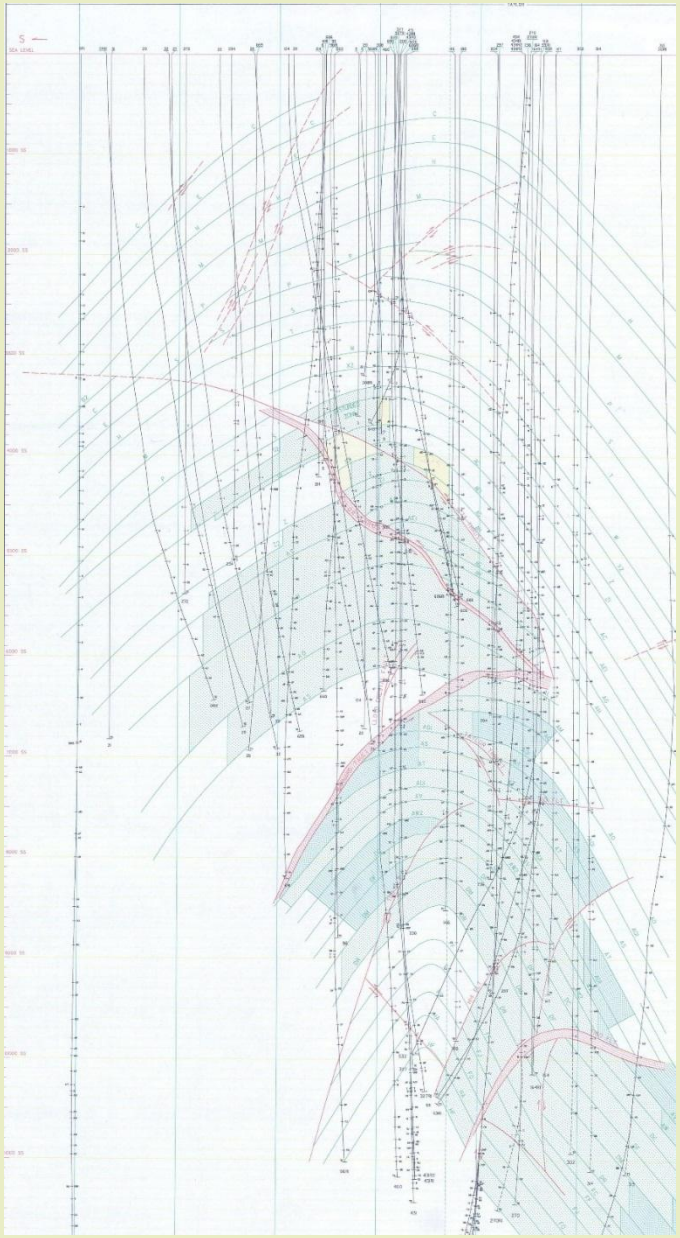


Ventura Field
Generalized Stratigraphy



- Over 10,000’ of stacked turbidites
- Contrasting mechanical properties of interbedded sandstones and mudstones
- **Numerous possible detachment horizons**

Faults Revised in Cross Section



Original

-1000’

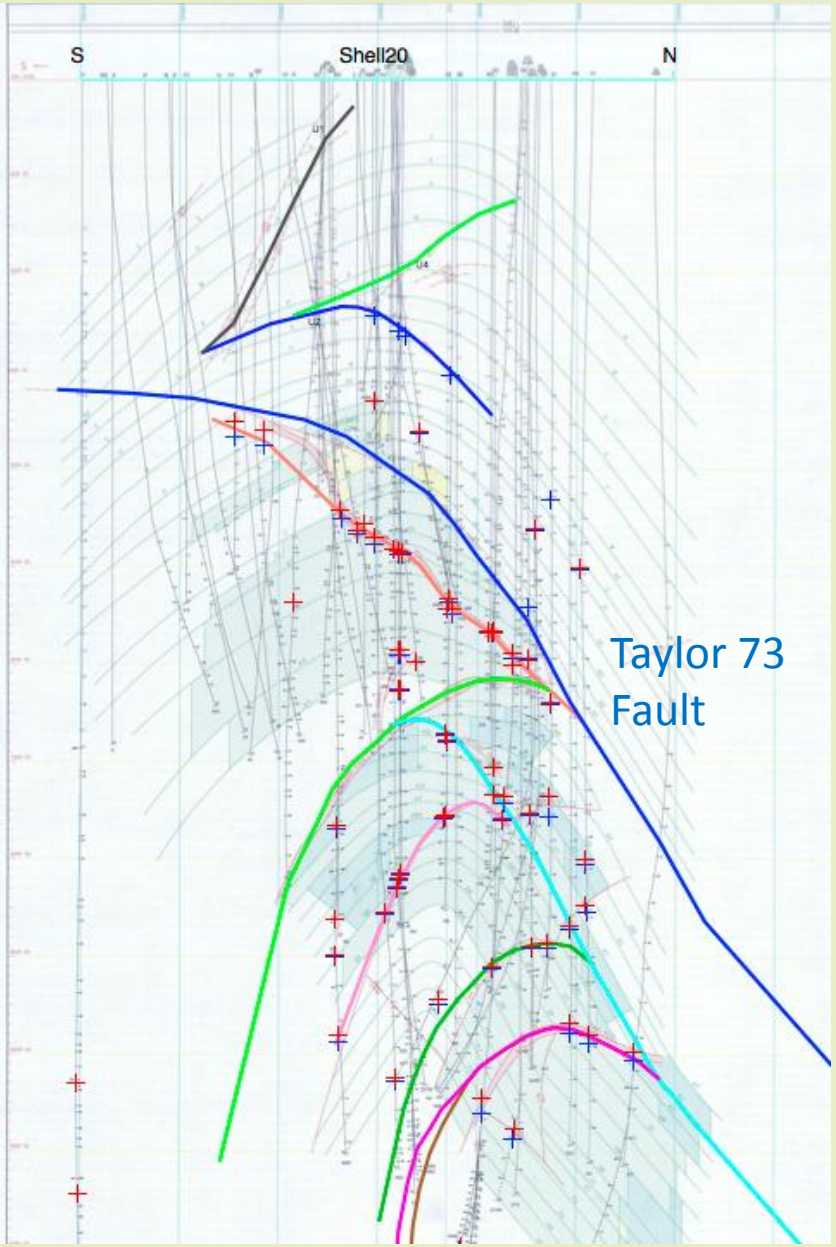
-3000’

-5000’

-7000’

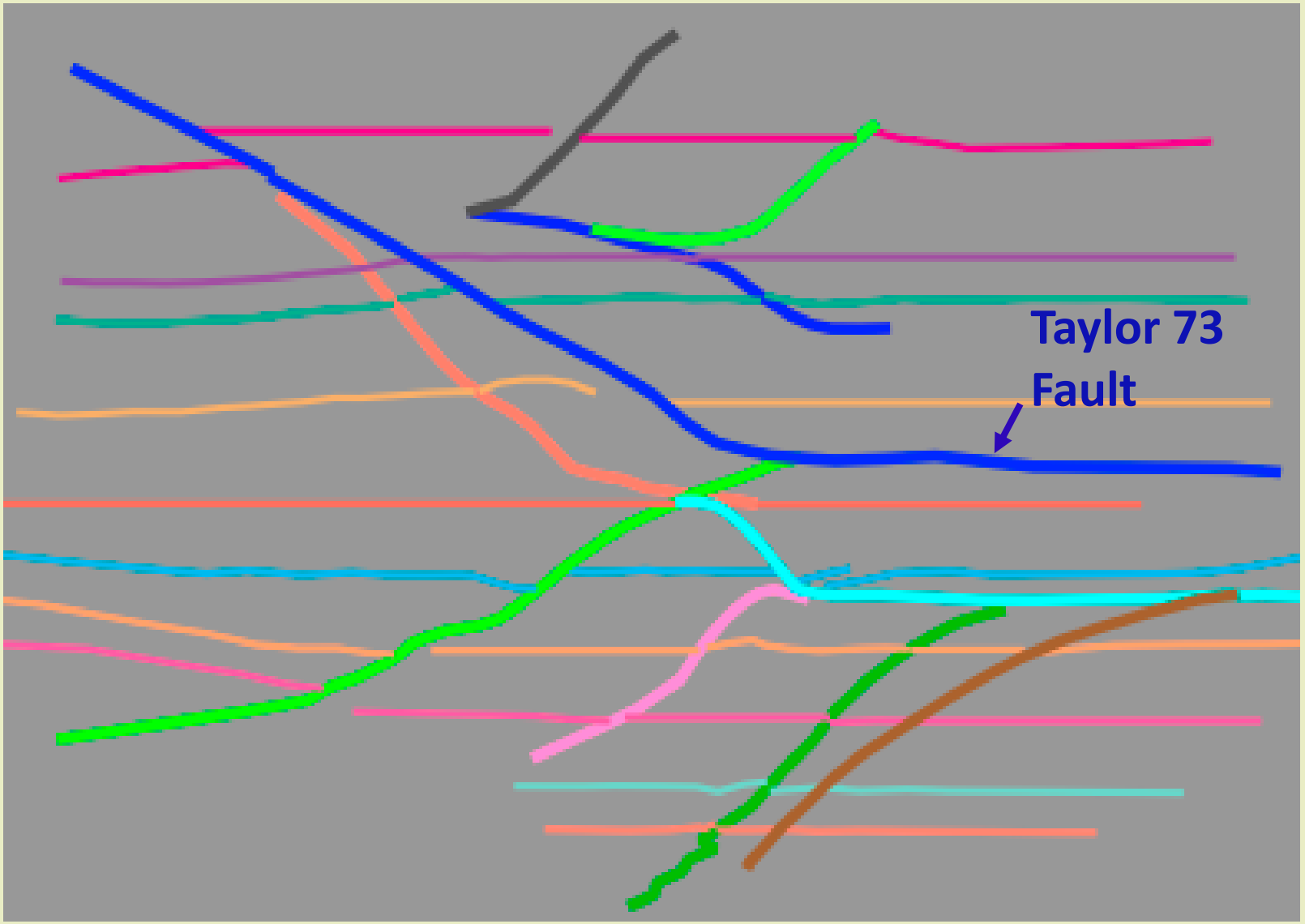
-9000’

-11000’



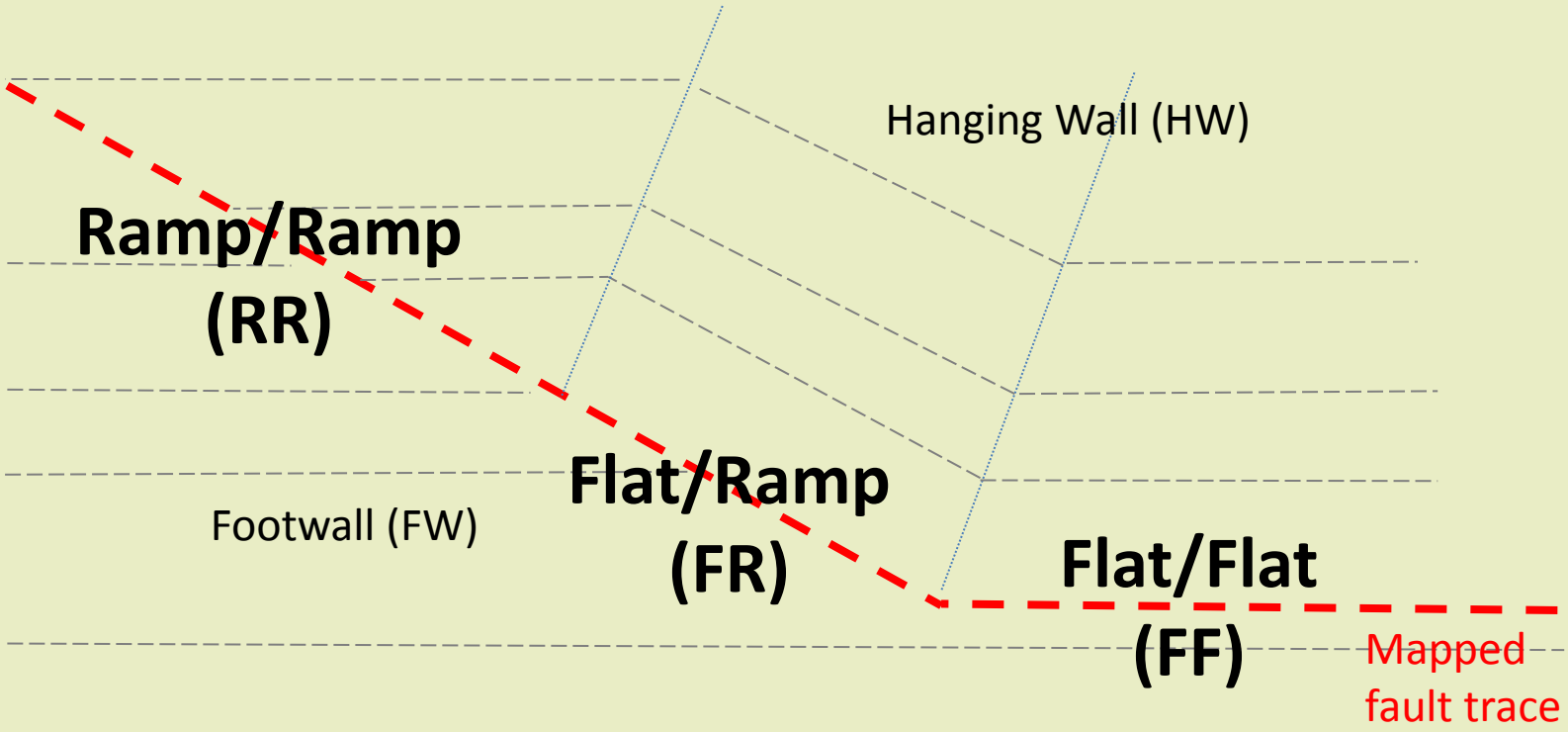
Revised

Cross Section Restoration



"Unfolding" the structure using first-pass horizon interpretations and restoring slip on faults reveals geometries generally compatible with fault-bend folds

Domains of fault-bend fold represented in Ventura data for Taylor 73 Fault



S

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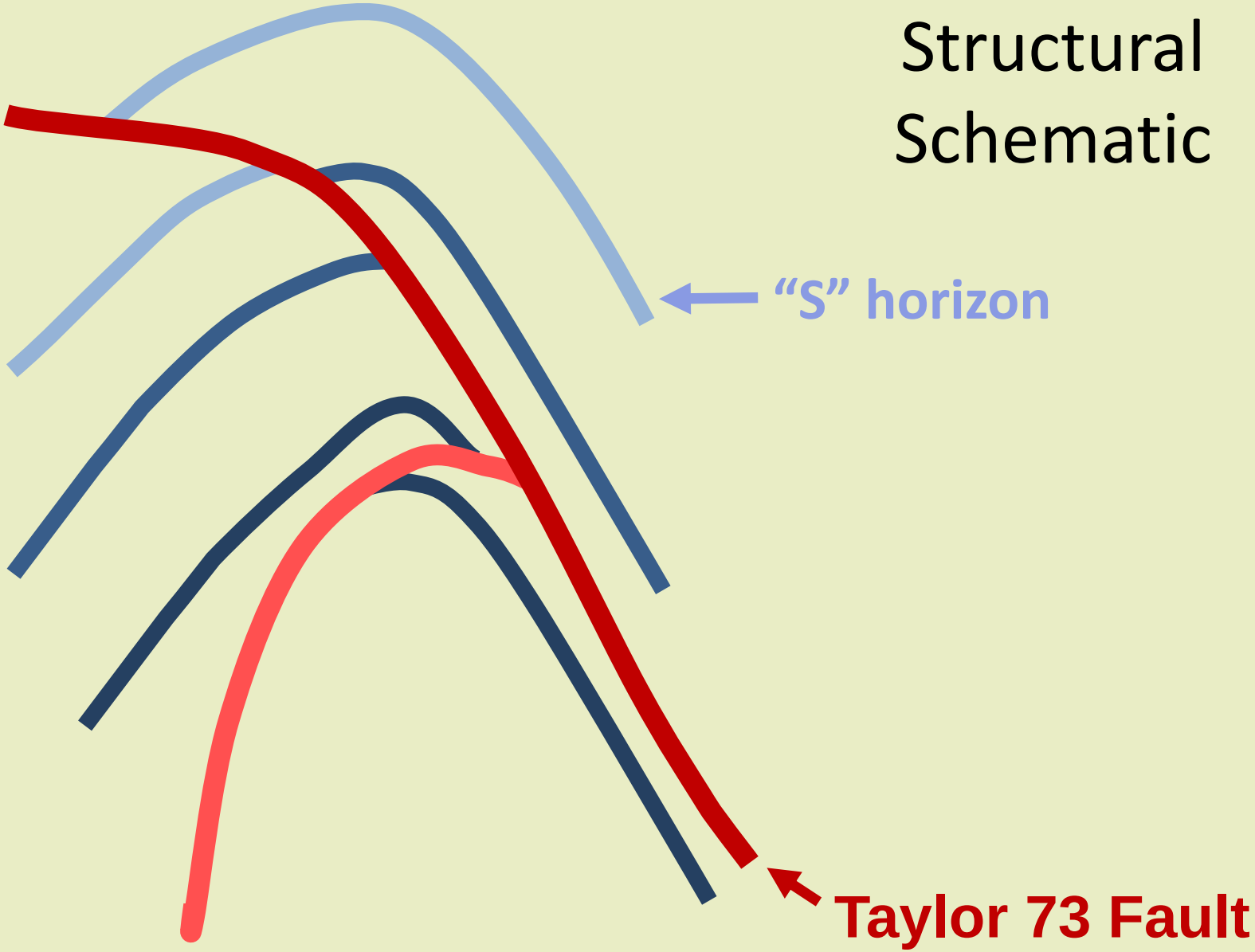
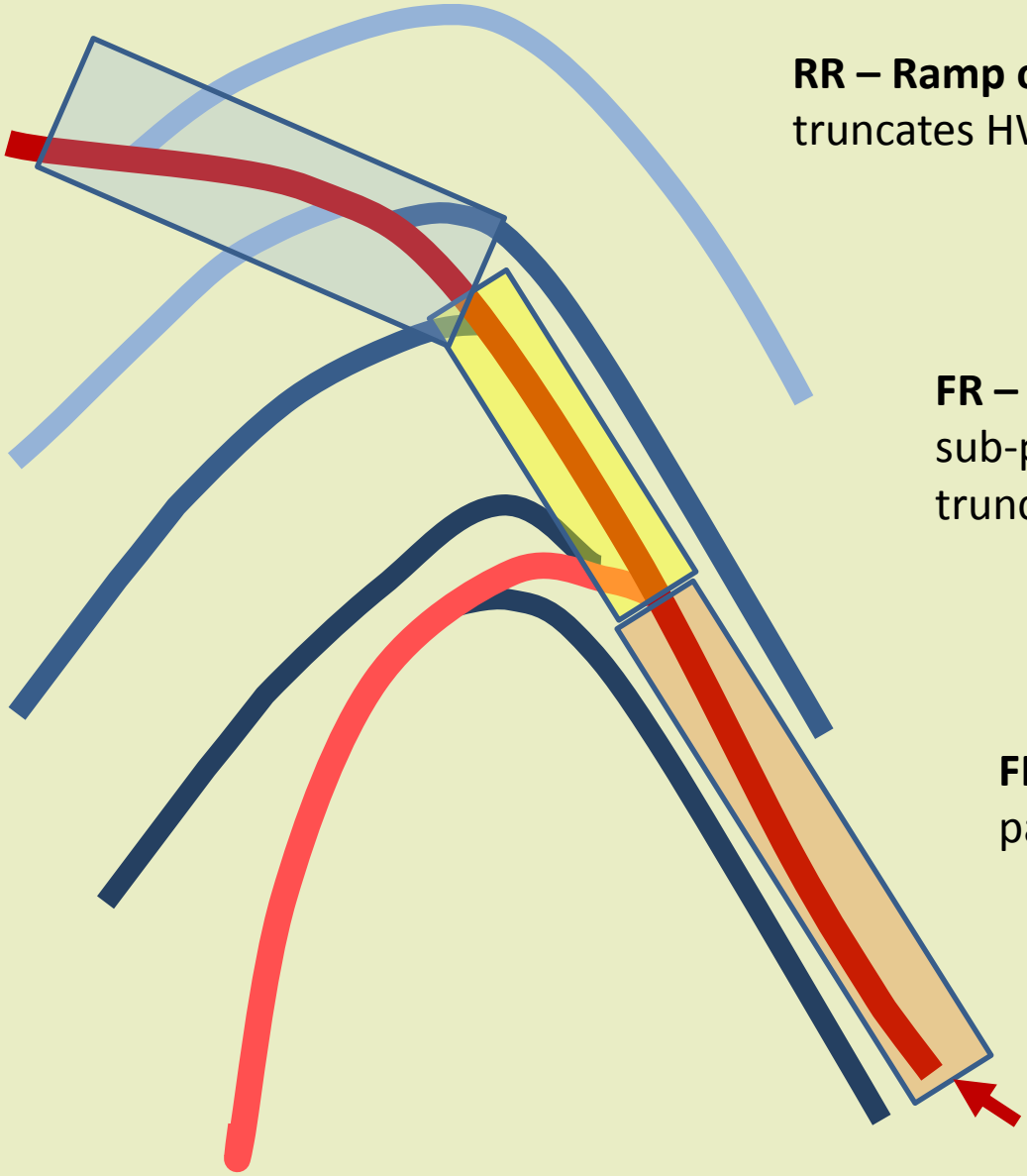
Simplified Structural Schematic



3 Structural Domains



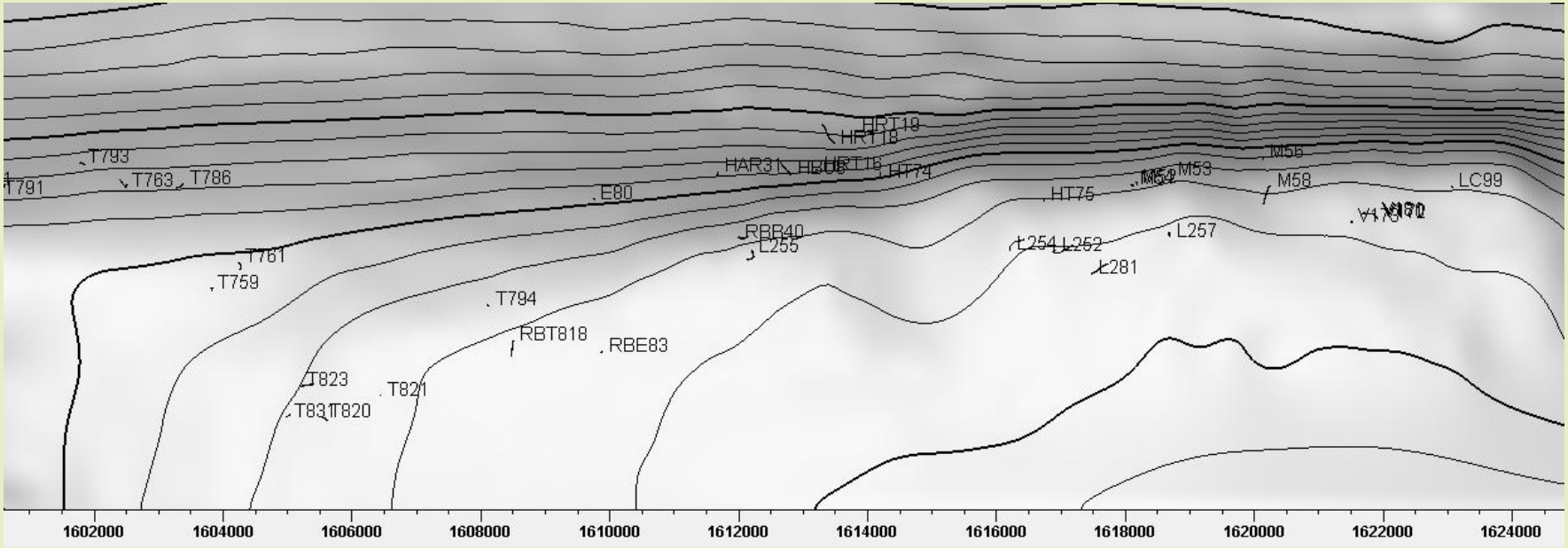
RR – Ramp on Ramp, Fault truncates HW and FW beds

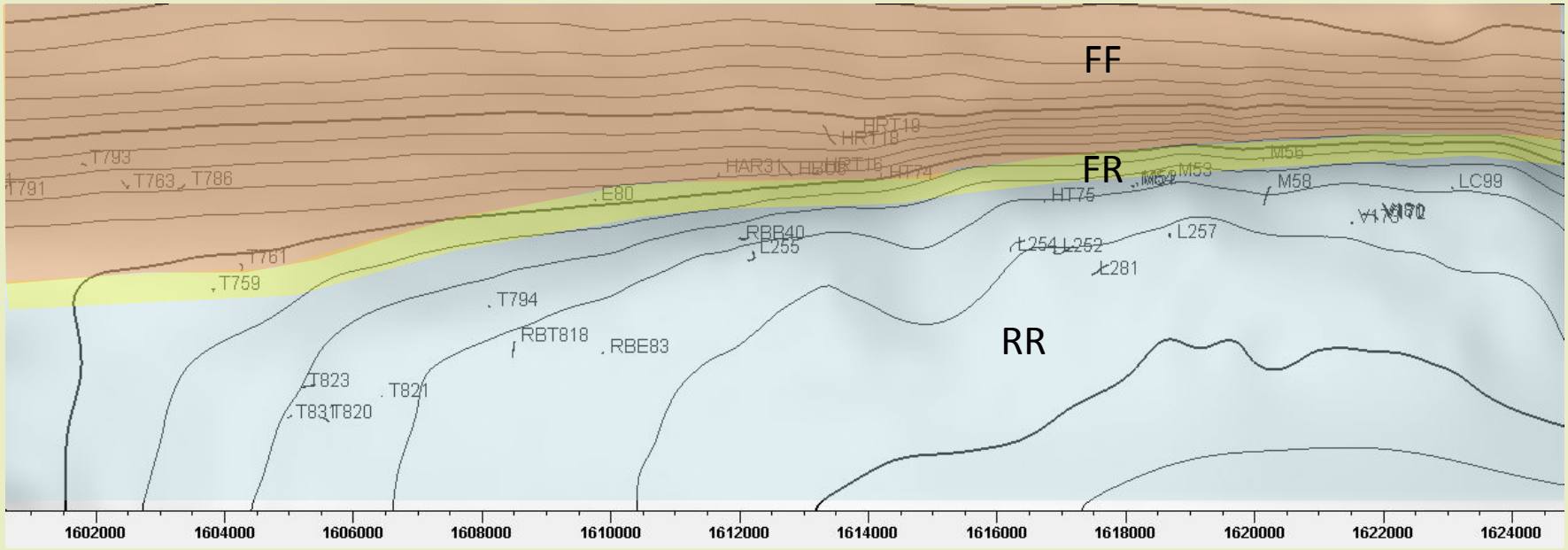
FR – Flat on Ramp, Fault sub-parallel to HW beds, truncates FW beds

FF – Flat on Flat, Fault sub-parallel to HW and FW beds

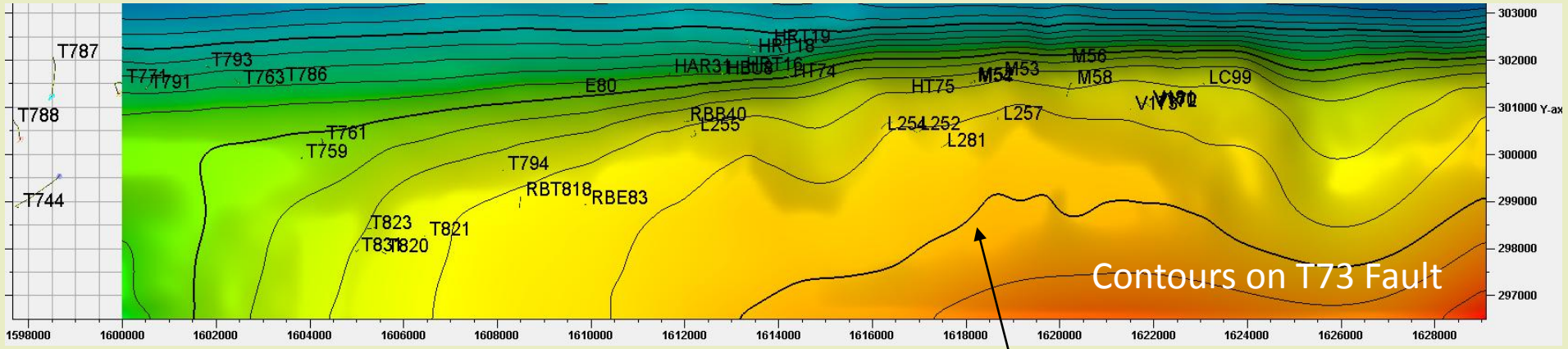
Taylor 73 Fault

Contour maps of T73 fault

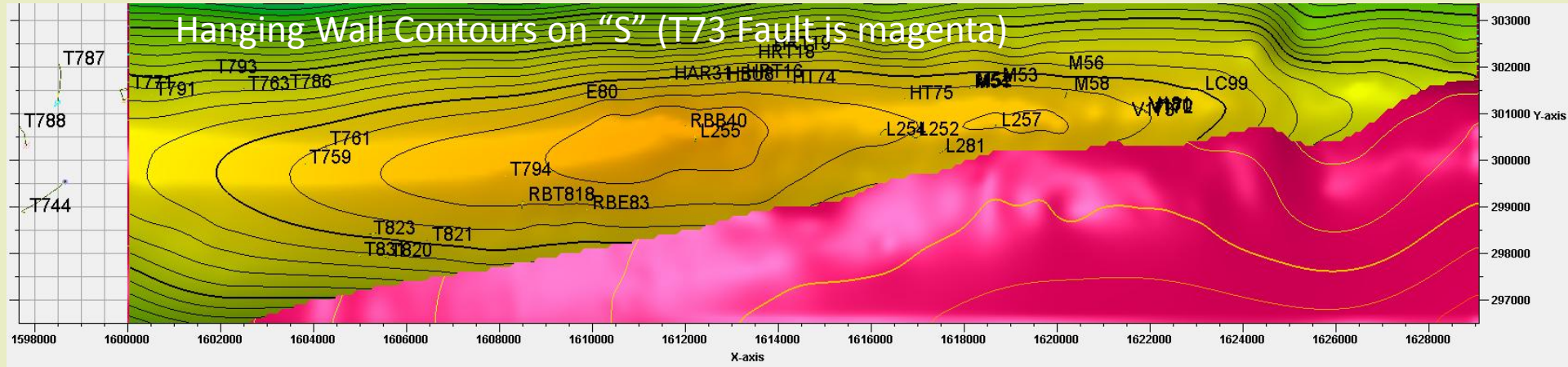


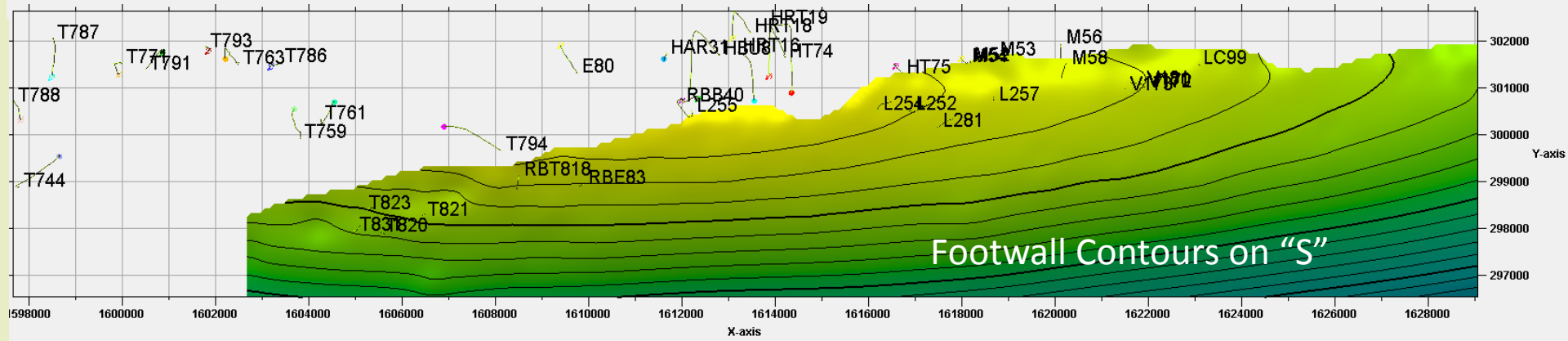


Structural domains: FF - Flat on Flat, FR – Flat on Ramp, RR – Ramp on Ramp

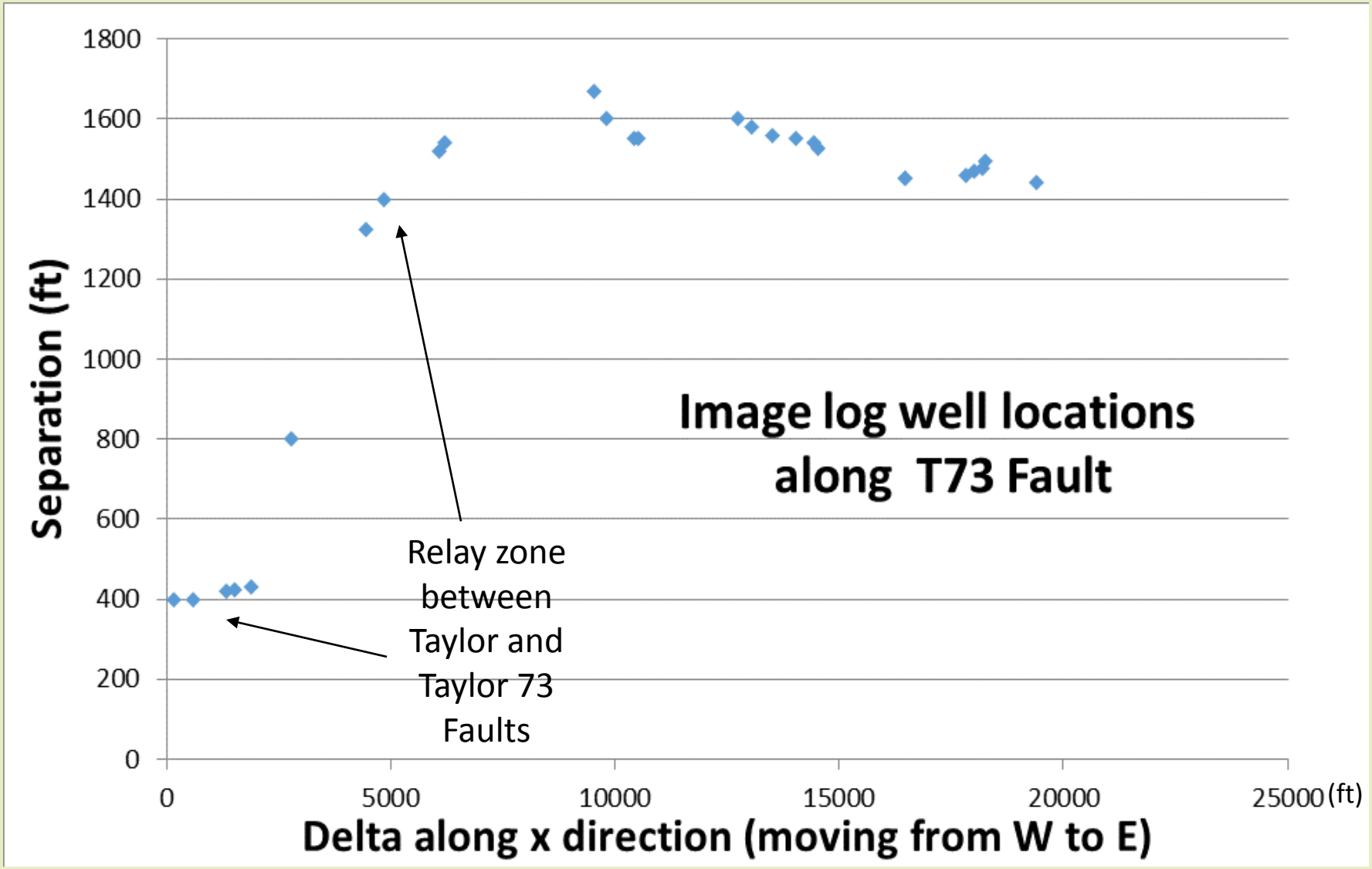


(-2500', 500' intervals)

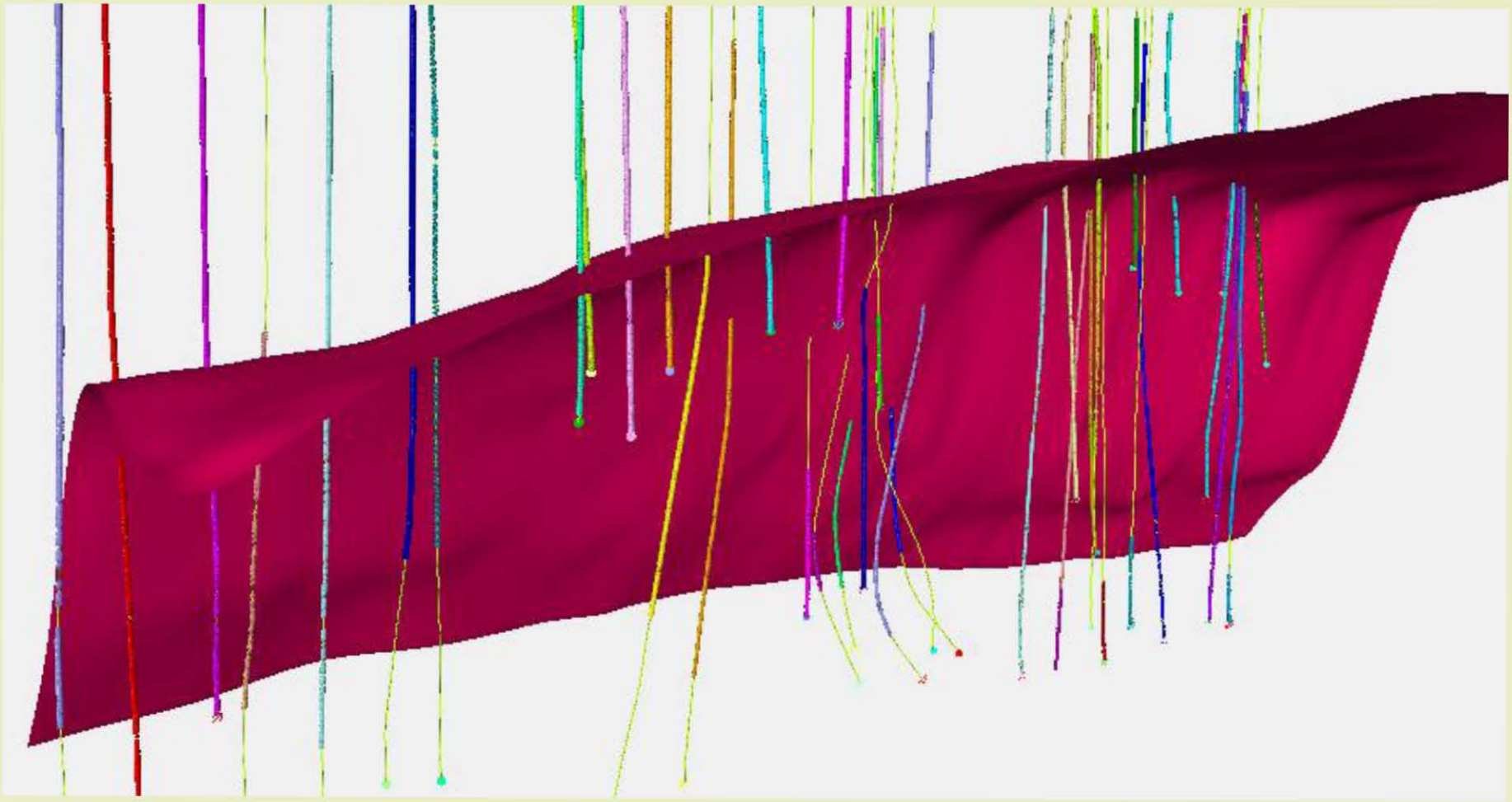




Fault Separation Measured at S Horizon along Taylor 73 Fault

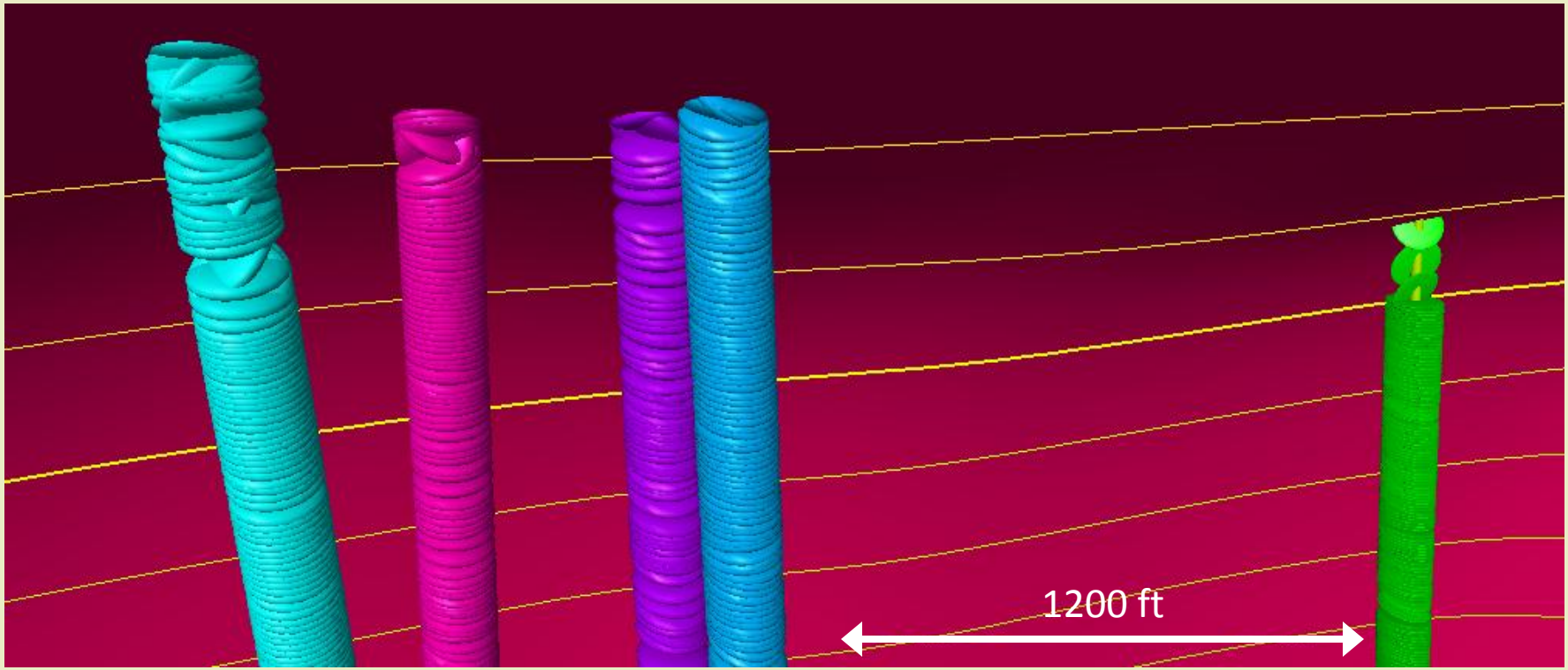


3D view of Taylor 73 Fault



View looking from the south showing wells with image logs. We'll look at image logs from wells in various positions along the fault, focusing on hanging wall/foot wall geometry.

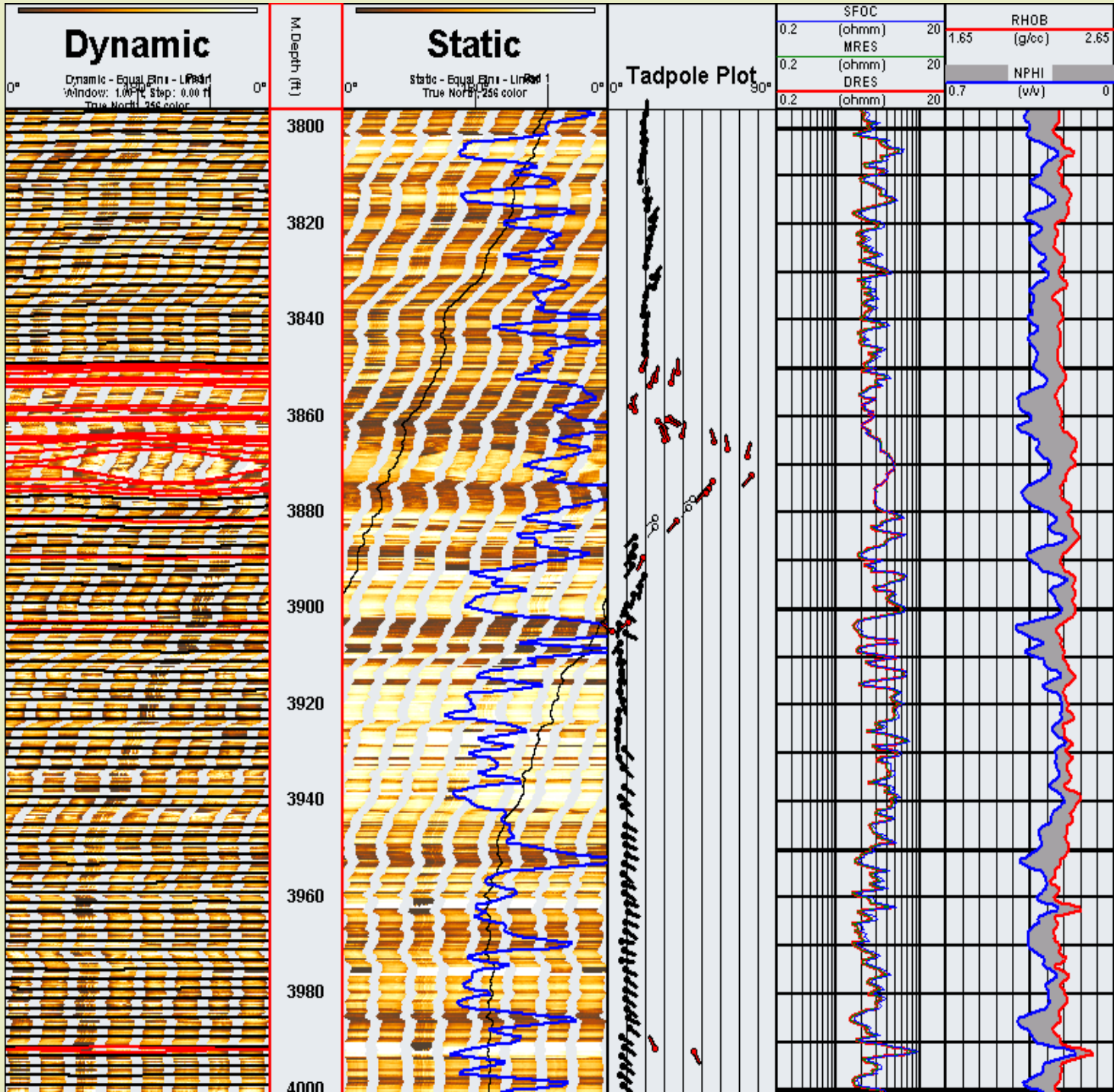
View of Taylor 73 Fault (from below, from South)



Ramp-on-Ramp domain, discs represent bed dips.
Note disruption in the vicinity of Taylor 73 Fault.

Ramp/Ramp Well #1

- Discrete HW (hanging wall) and FW (footwall) dip panels
- Fault Core and Damage Zone <100’ thick
- Mudstones act as boundaries between mechanical layers
- High-resistivity sandstone below major mudstone boundaries

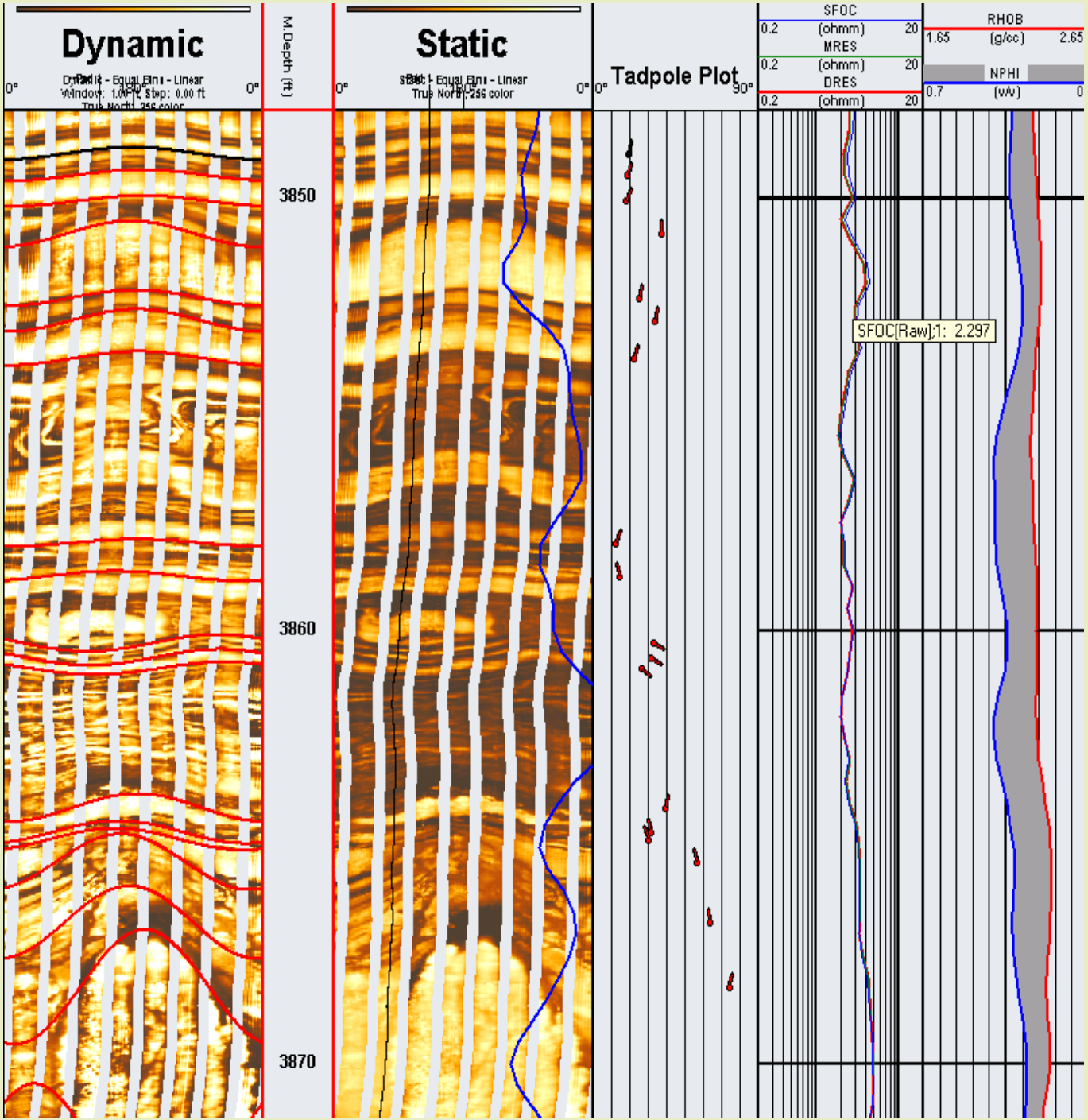


Protolith

Mudstone detachment

Deformed mudstone

Sheared, folded mudstone

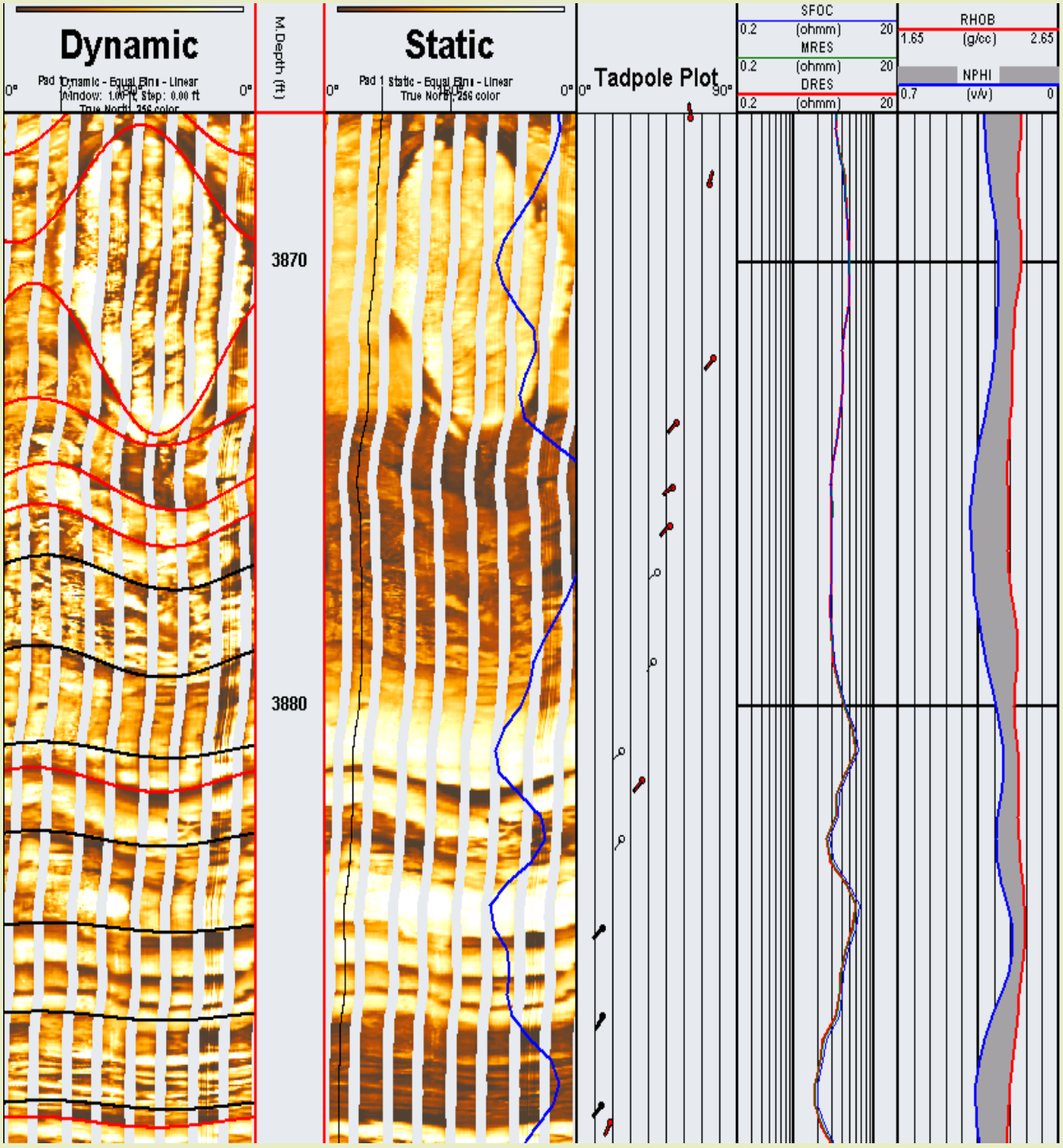


Ramp/Ramp Well #1

Ramp/Ramp
Well #1

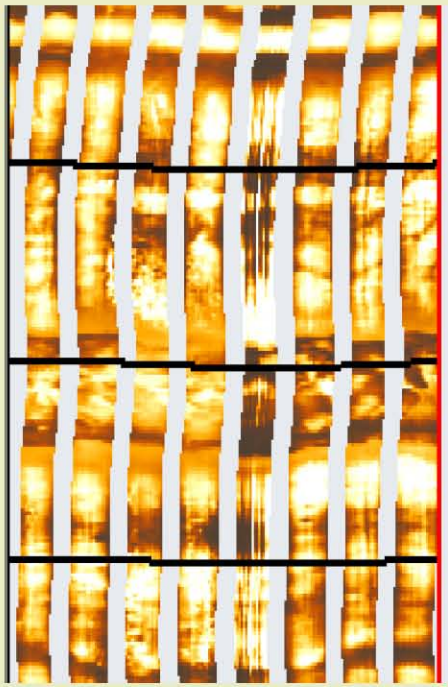
Deformed
sandstone

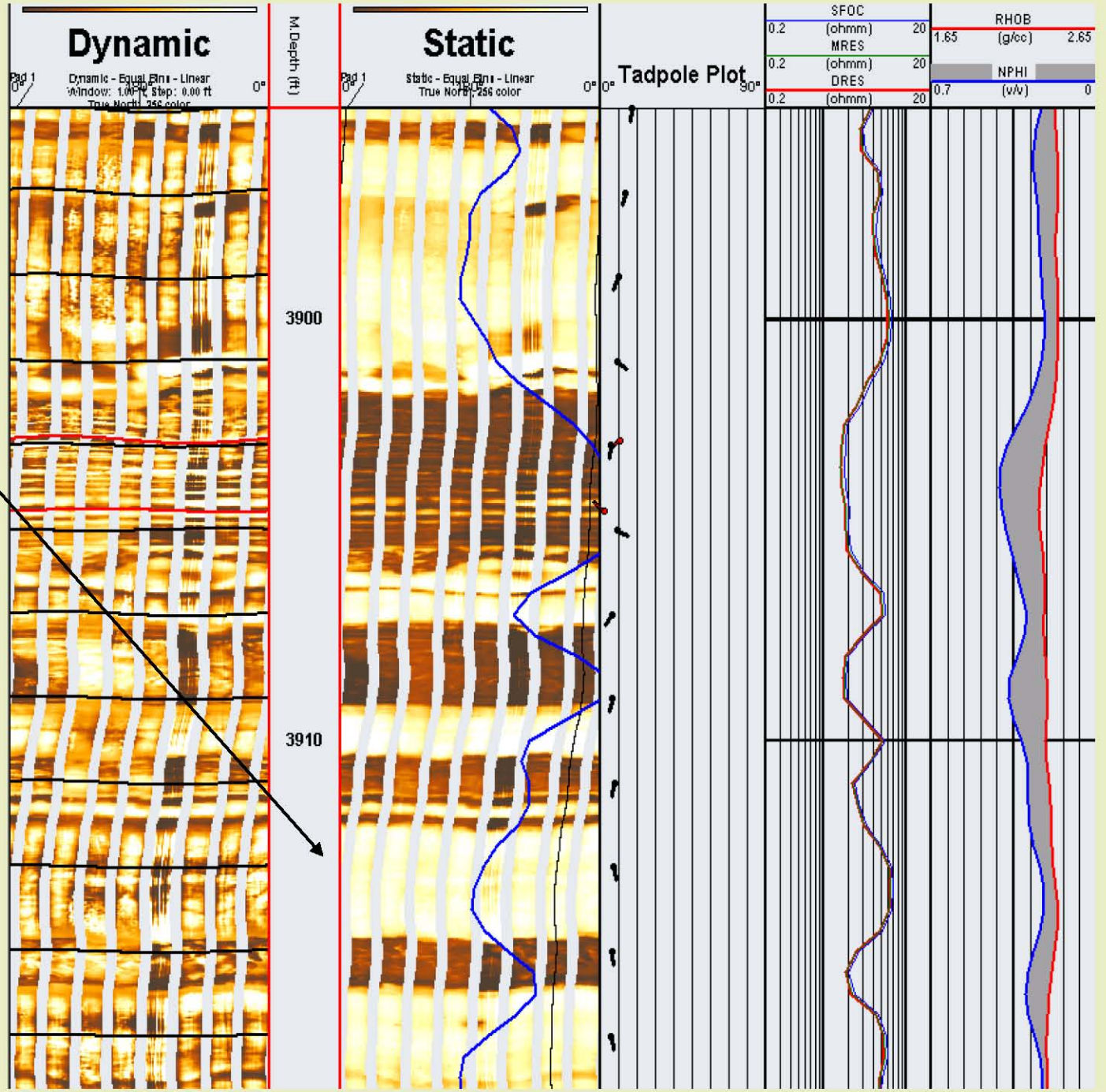
Deformed
mudstone



Ramp/Ramp Well #1

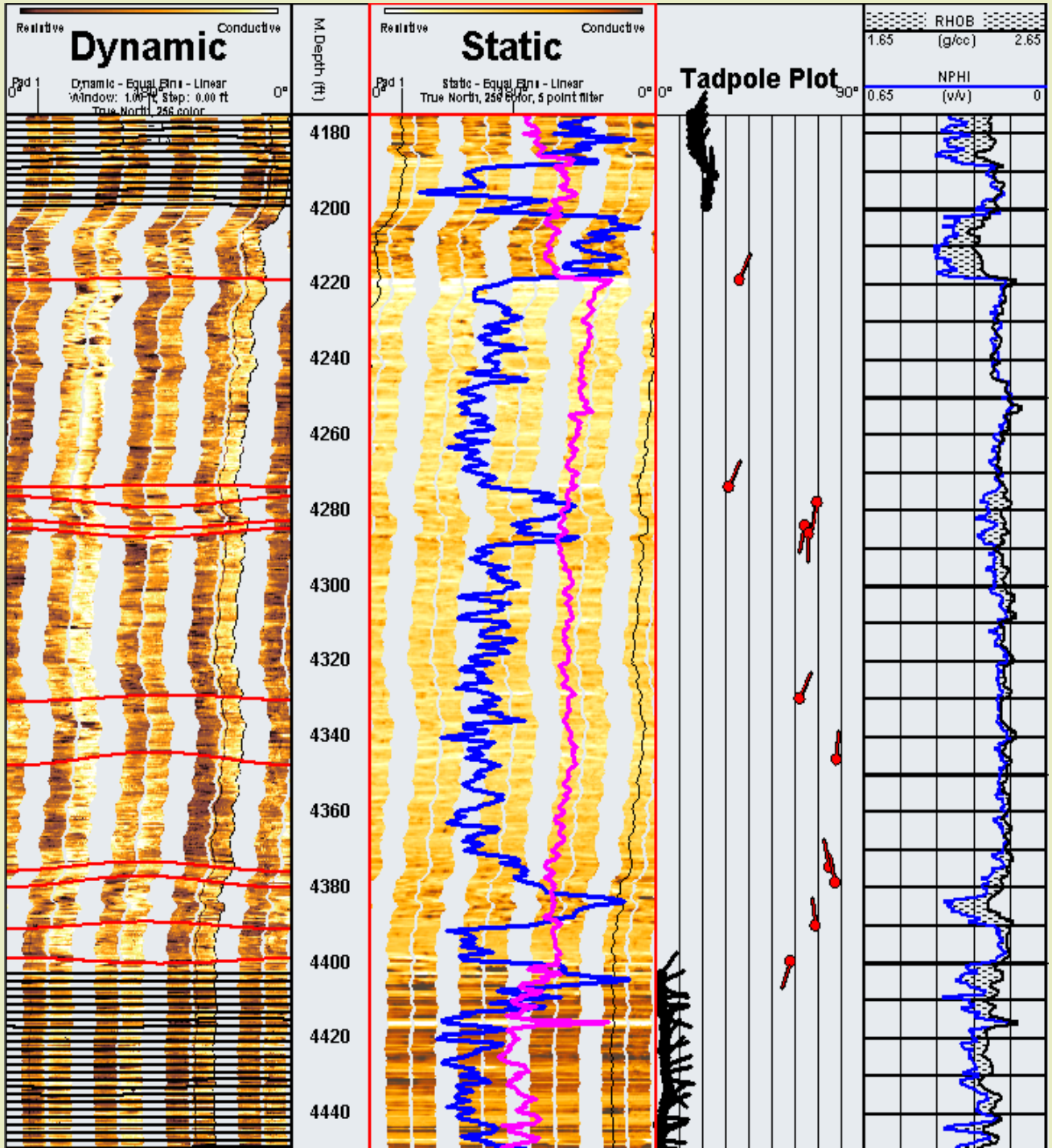
High resistivity cemented sandstone





Ramp/Ramp Well #2

- Discrete HW (hanging wall) and FW (footwall) dip panels
- Fault Core and Damage Zone approx. 200’ thick
- Mudstones act as boundaries between mechanical layers
- Thick interval of high-resistivity sandstone below upper detachment

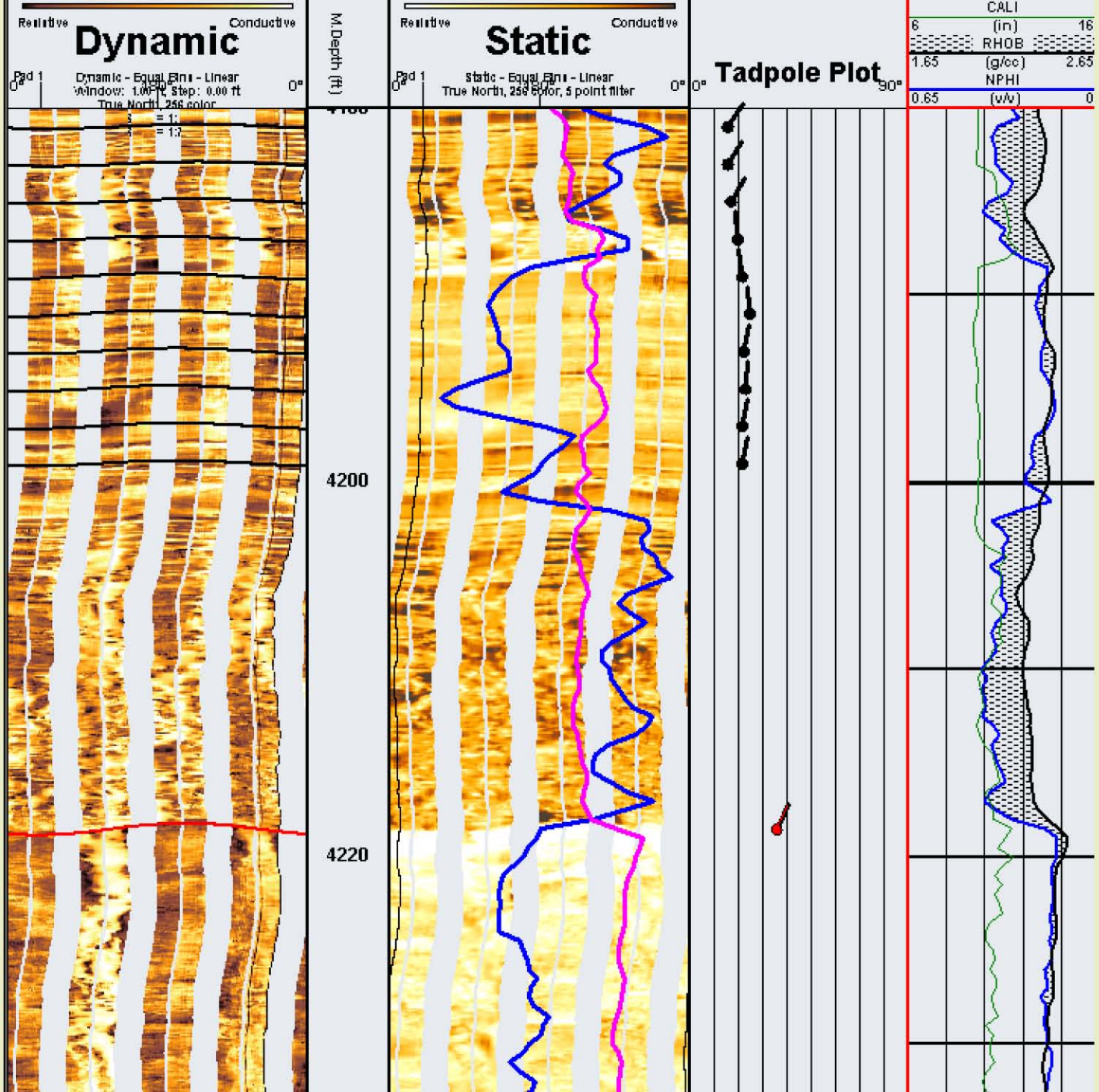


Ramp/Ramp Well #2

Protolith

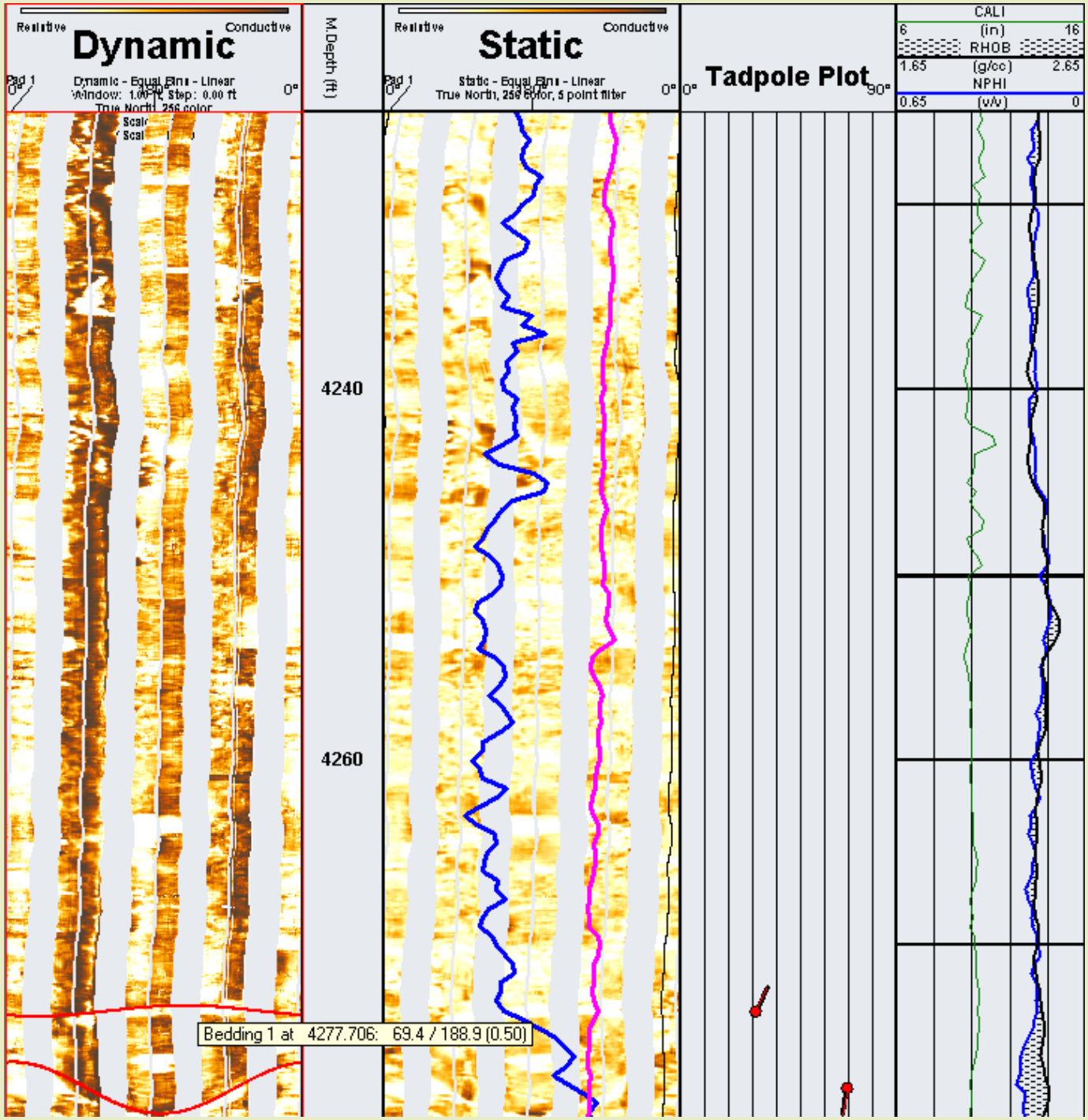
Mudstone serves as upper detachment

High-resistivity sandstone



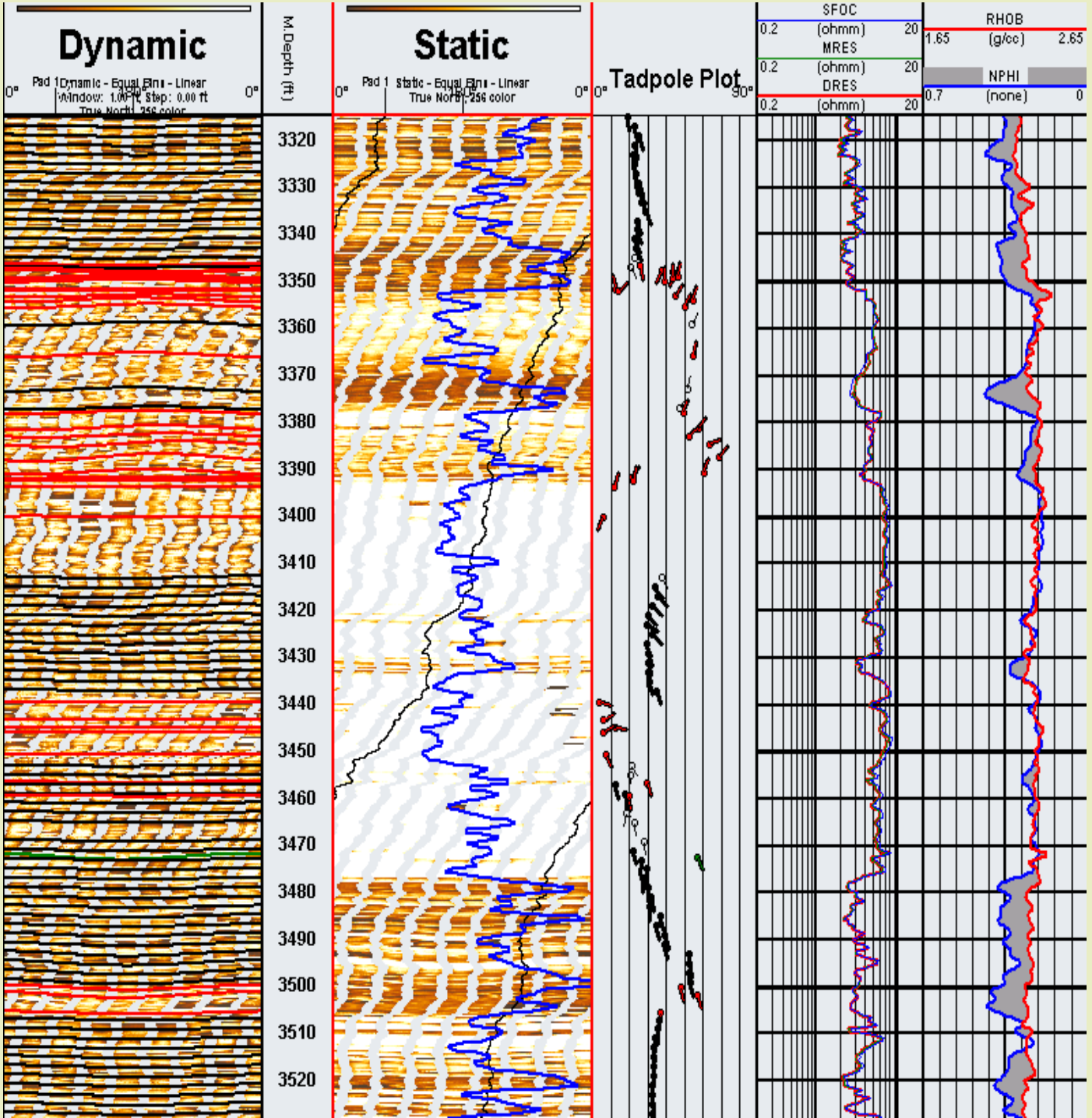
Ramp/Ramp
Well #2

Cemented
Sandstone,
Cataclasis?



Ramp/Ramp Well #3

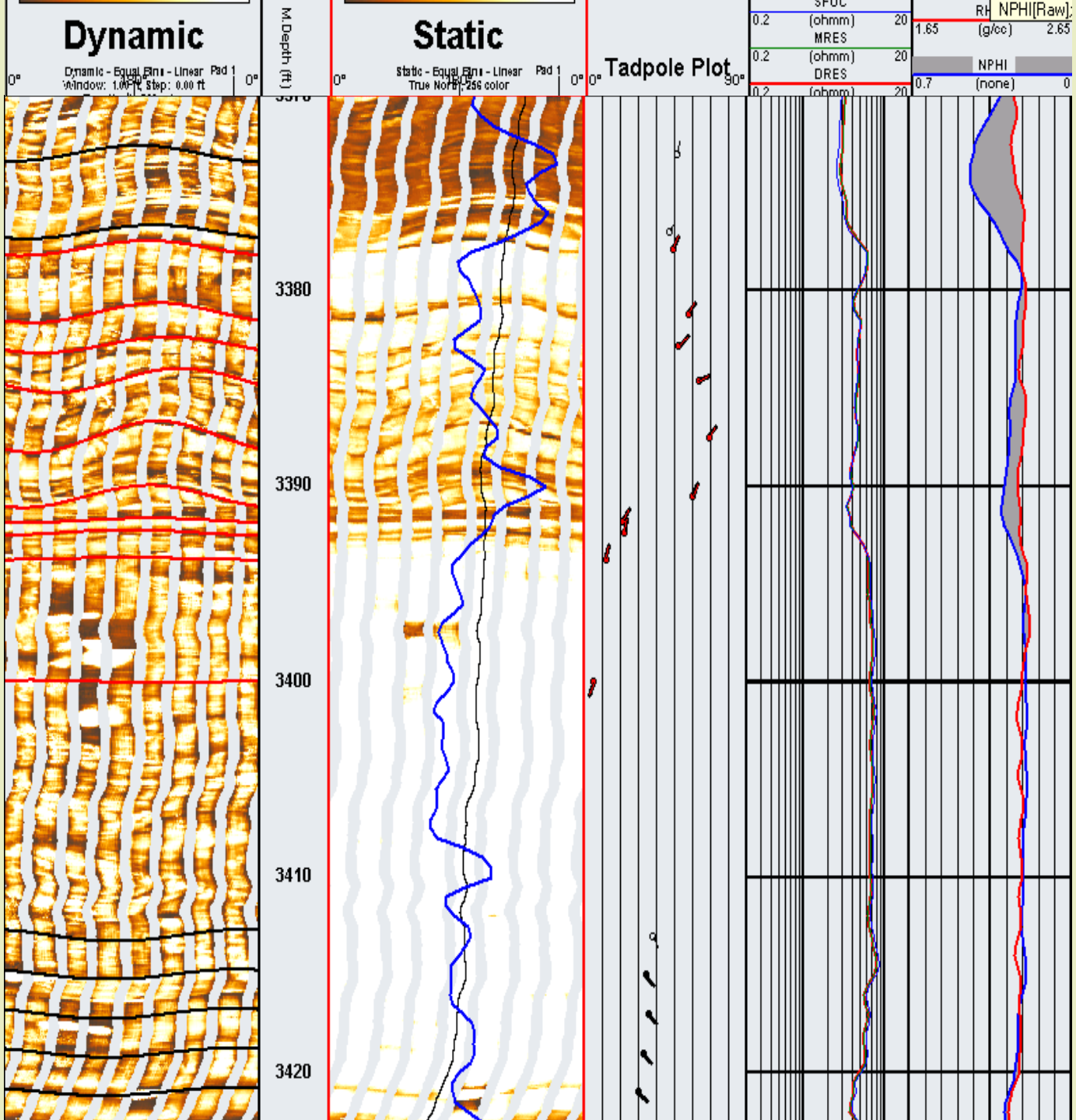
- Mudstone layer boundaries
- High-resistivity sandstones
- Rotated blocks



Ramp/Ramp Well #3

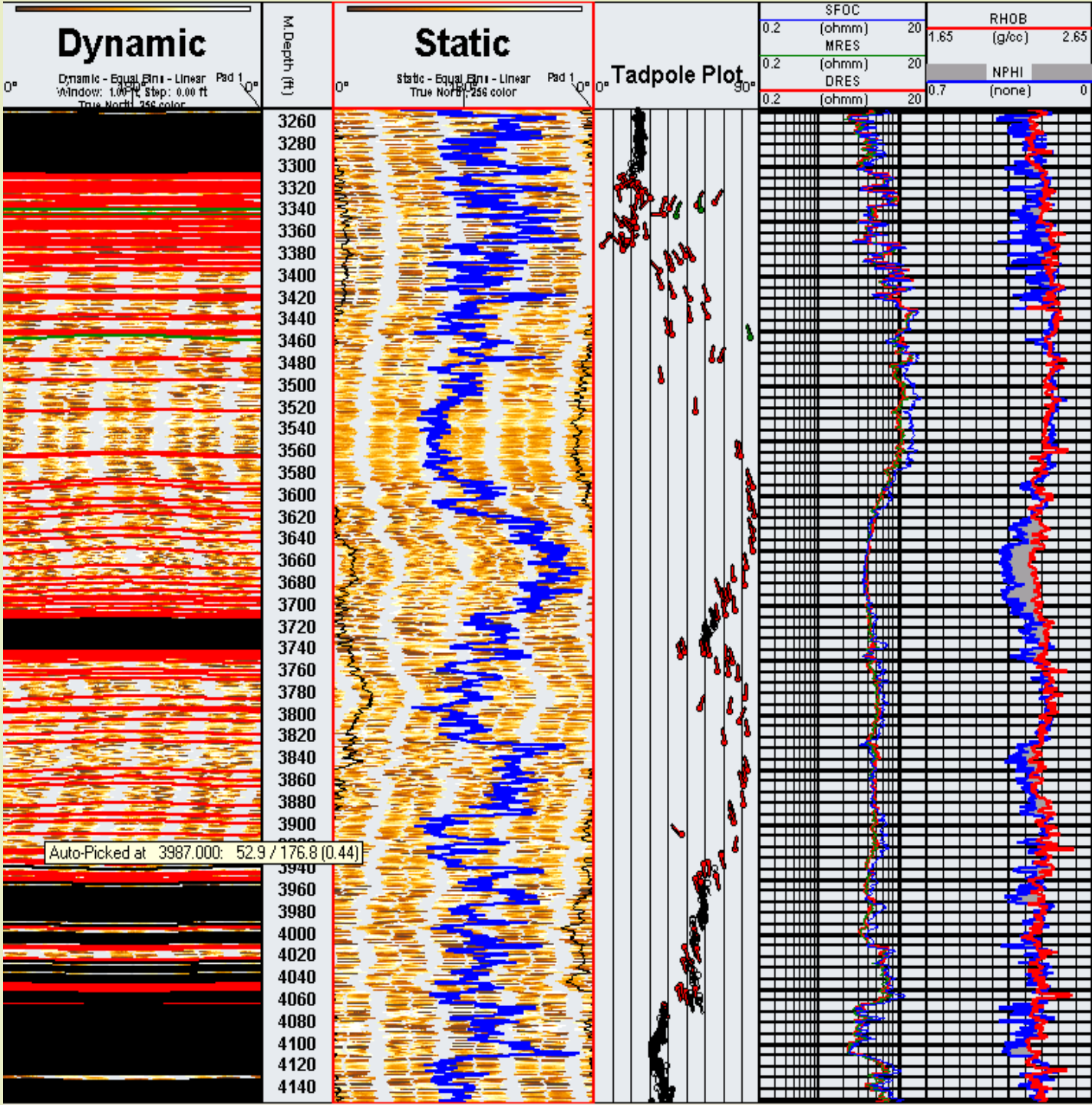
Rotated block with internal mudstone detachment

High-resistivity cemented sandstone



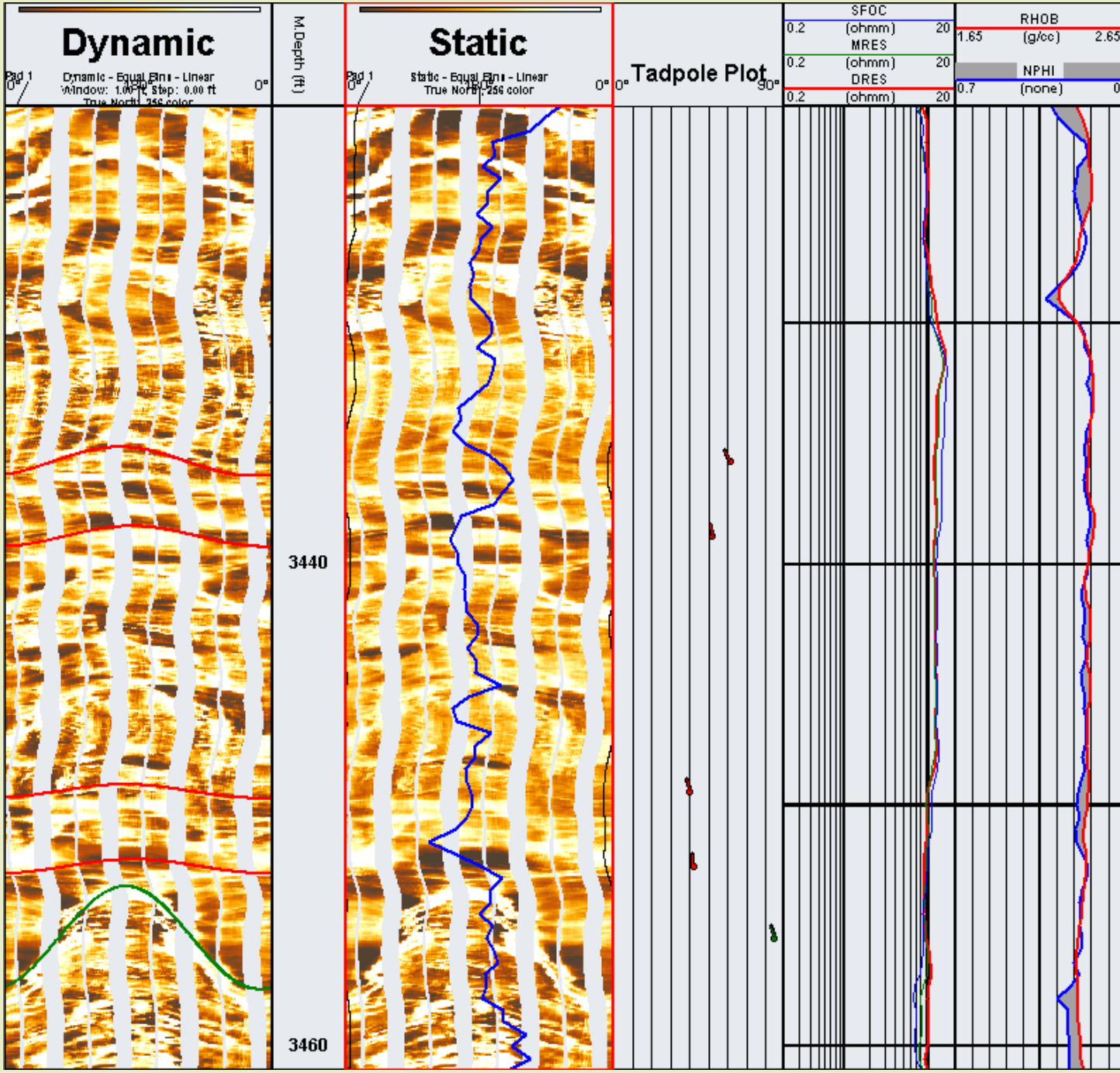
Ramp/Ramp Well #4

Complicated by proximity of multiple faults (relay zone)



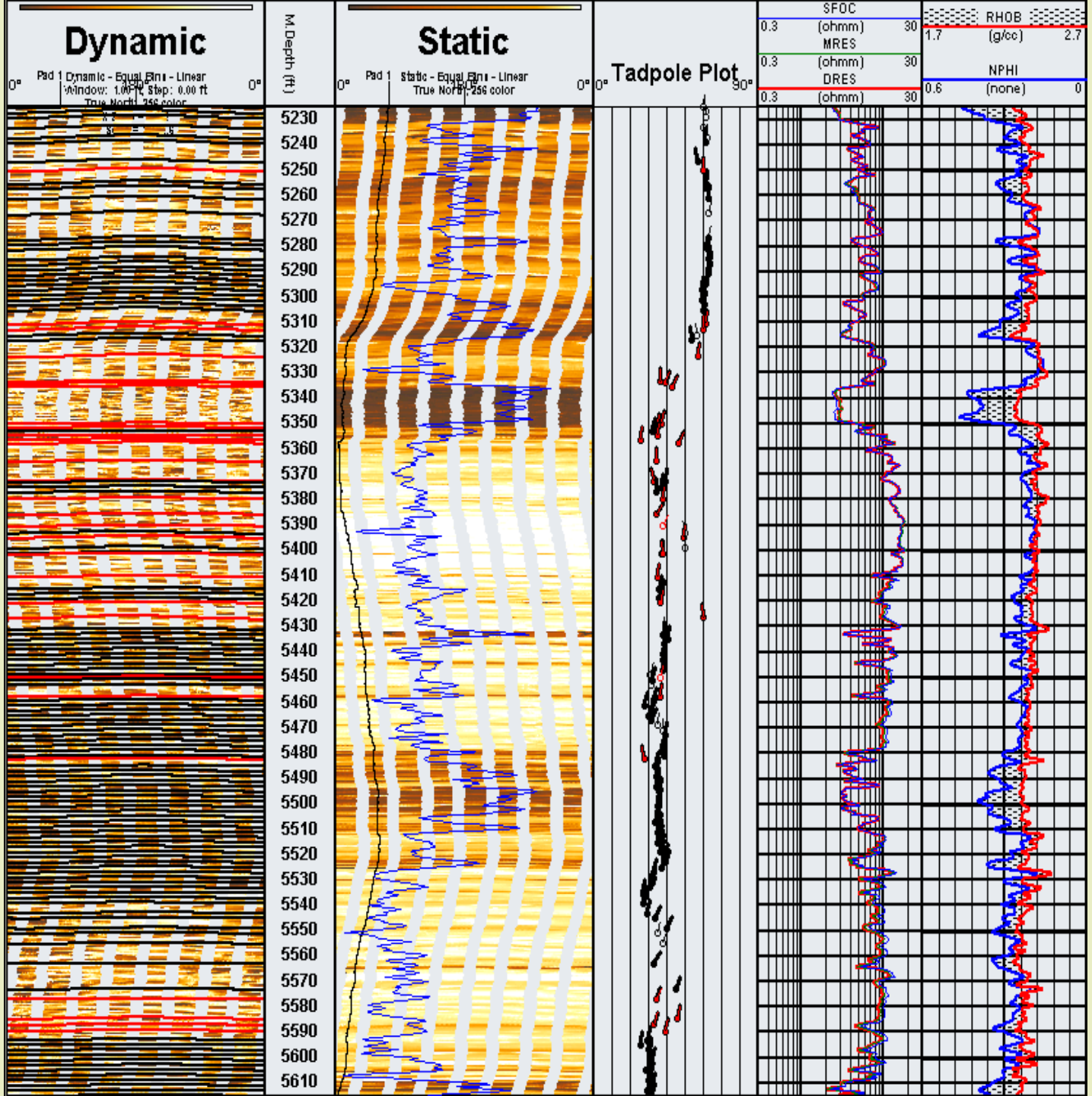
Ramp/Ramp
Well #4

White “resistive” features in sandstones represent deformation bands



Flat/Ramp Well #1

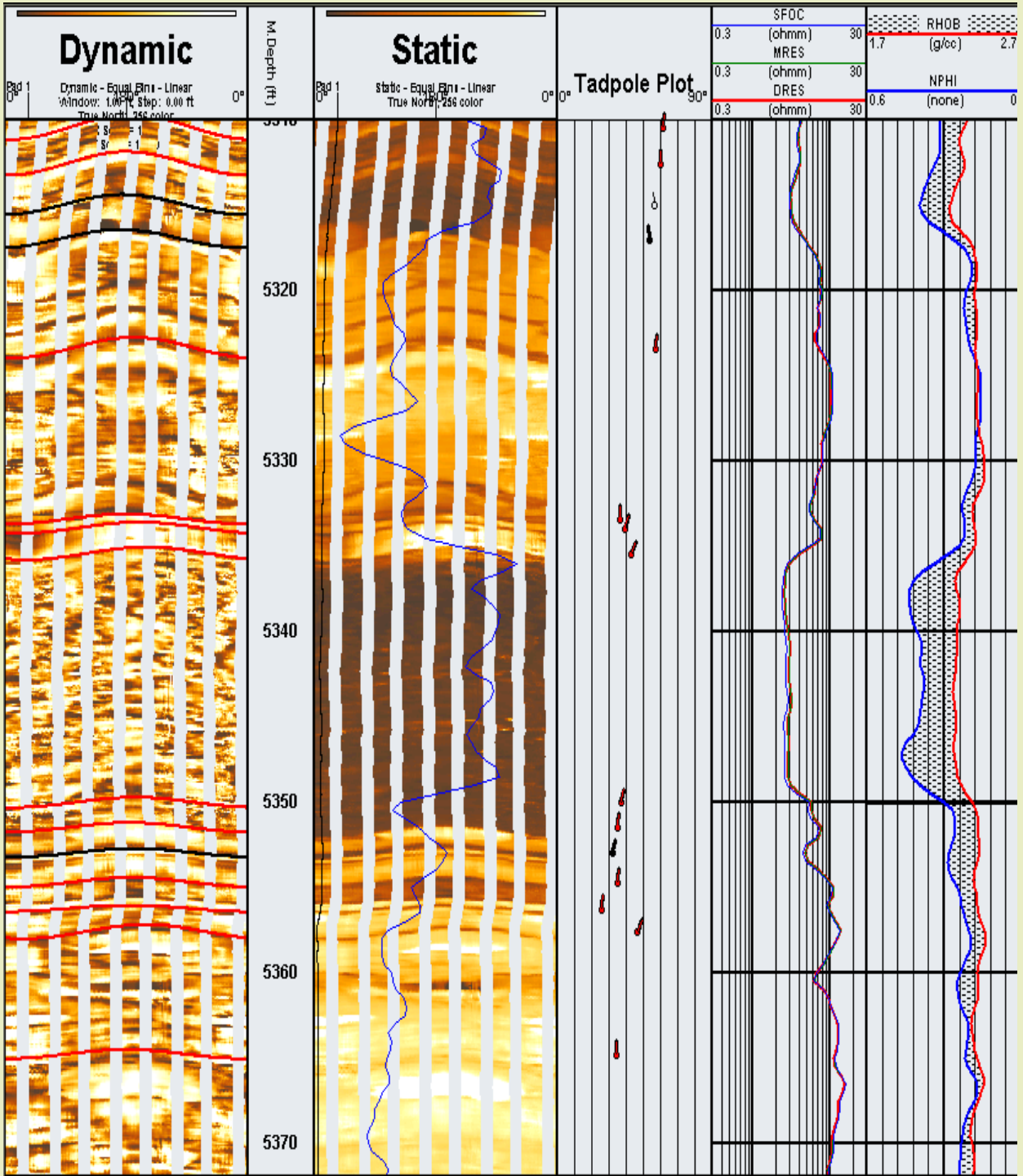
- Distinct dip panels separated by mudstone layer boundary
- Limited damage zone, thin high-resistivity sand



Flat/Ramp
Well #1

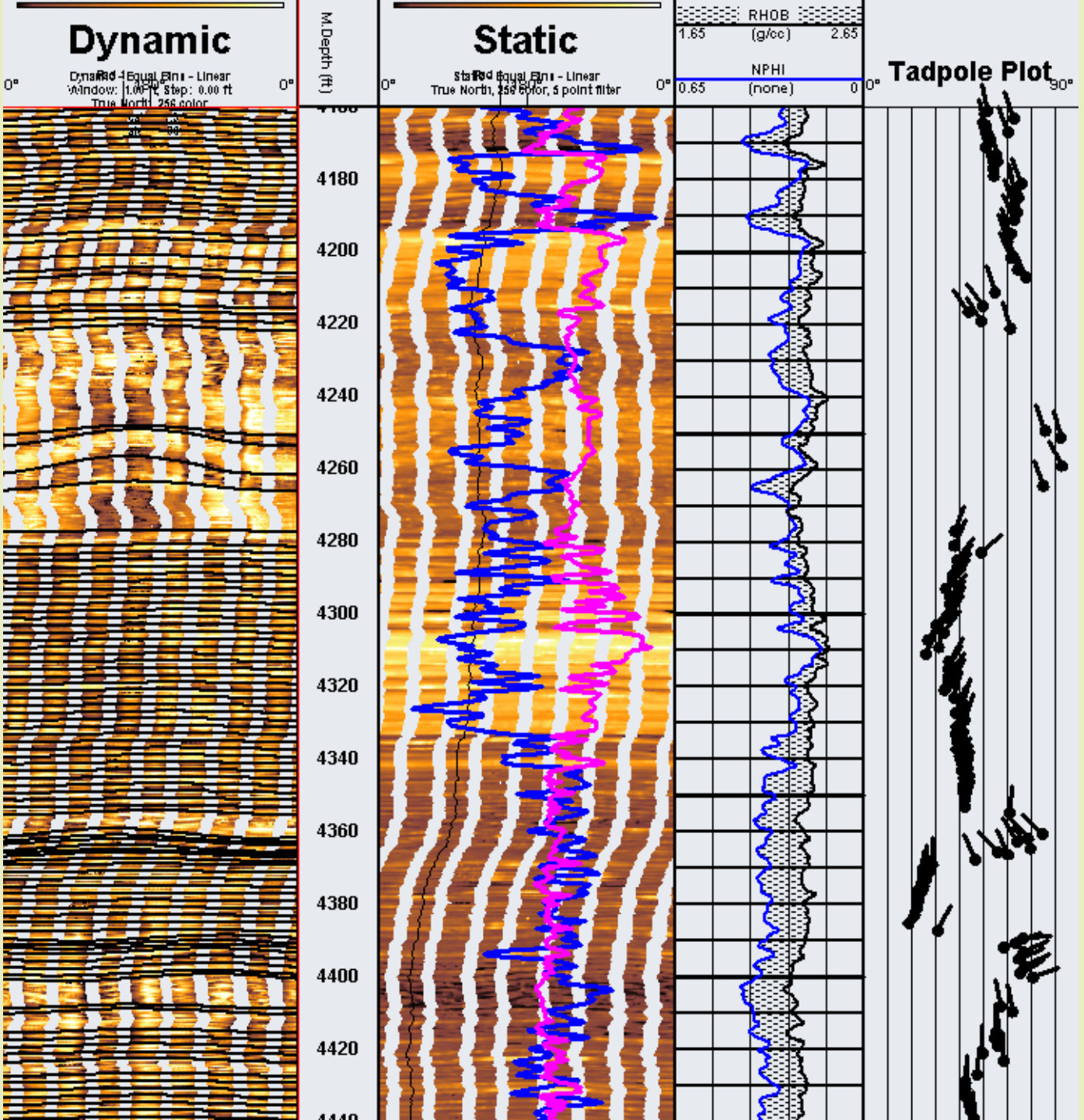
Fault “core” is a 15’ thick mudstone

Very little “damage” to surrounding strata



Flat/Ramp Well #2

- Broader interval of deformation (200’)
- Mudstone mechanical layer boundaries
- Rotated blocks

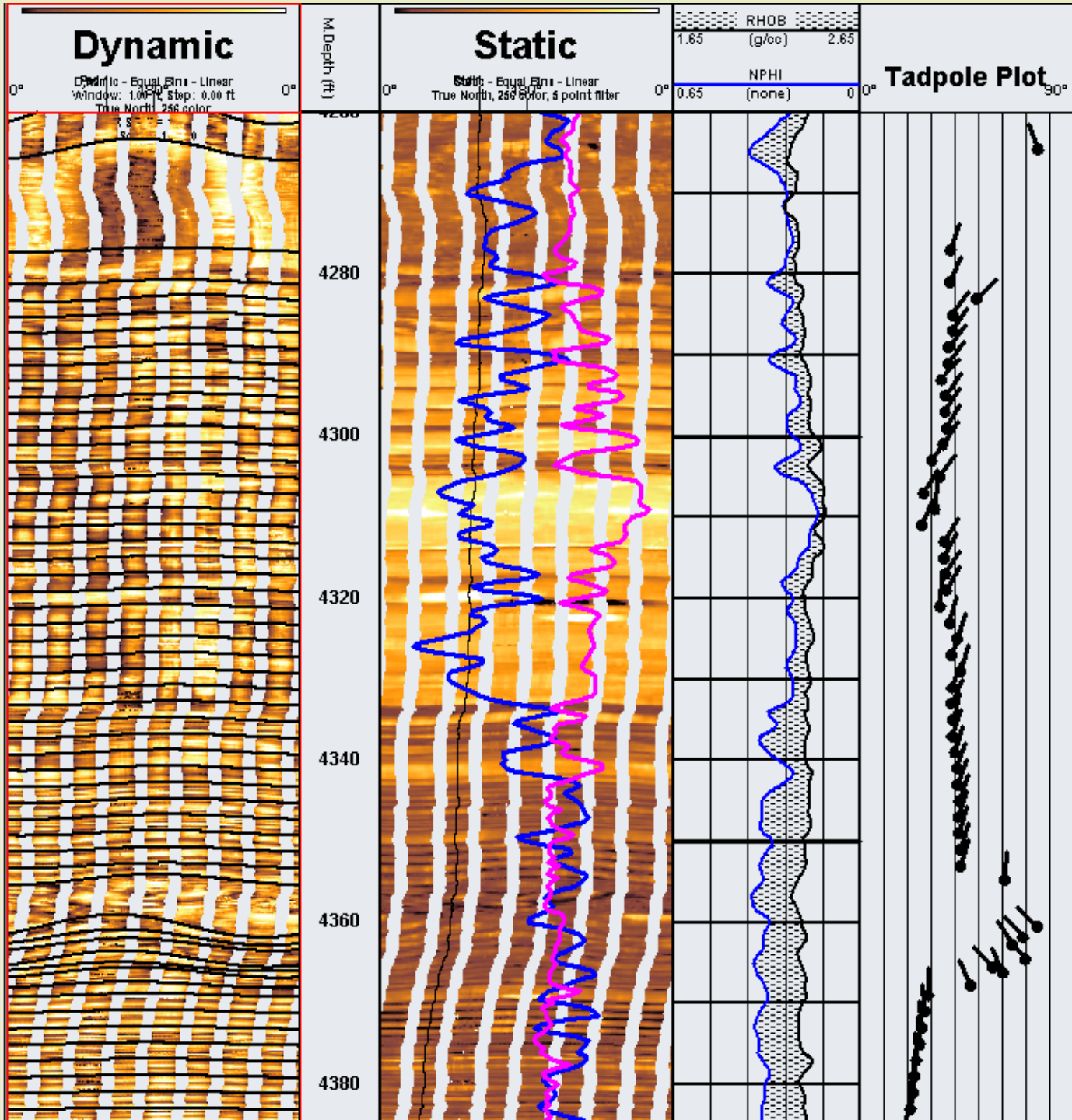


Flat/Ramp Well #2

Mudstone layer boundary

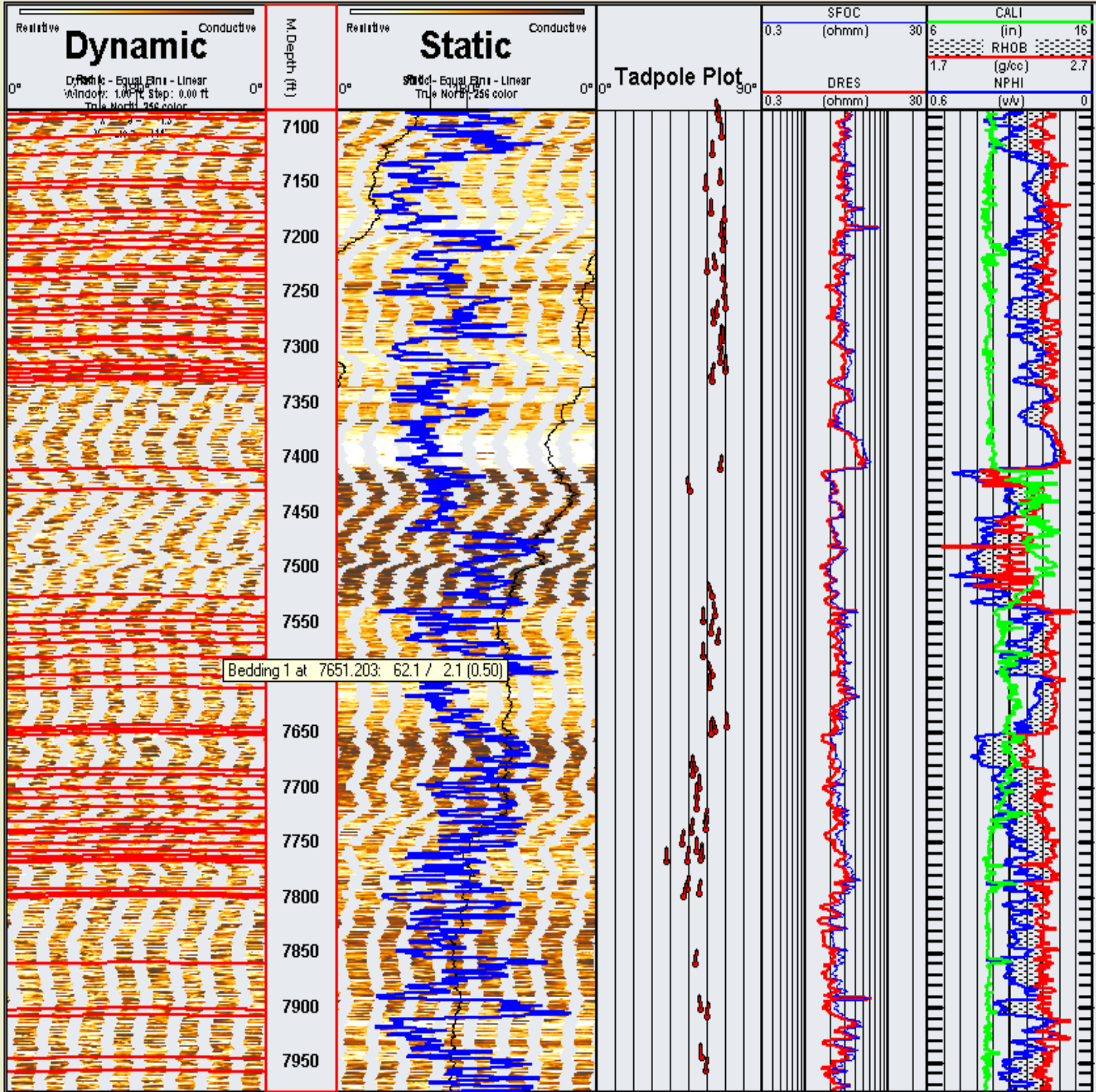
Rotated block of relatively intact strata

Mudstone layer boundary



Flat/Flat
Well #1

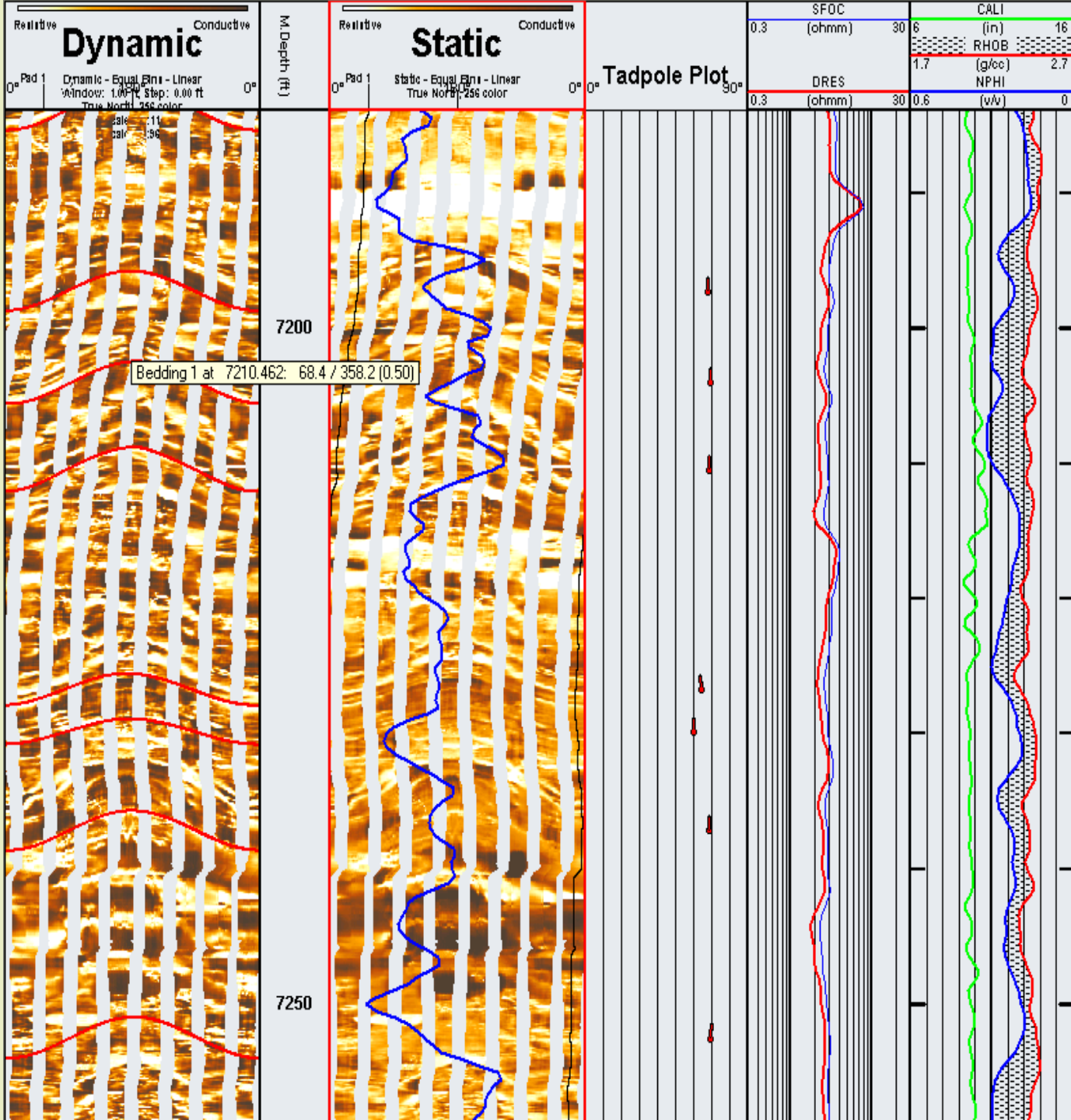
- Dip panels less obvious
- Mudstone mechanical layer boundaries
- Broad zones of distributed deformation



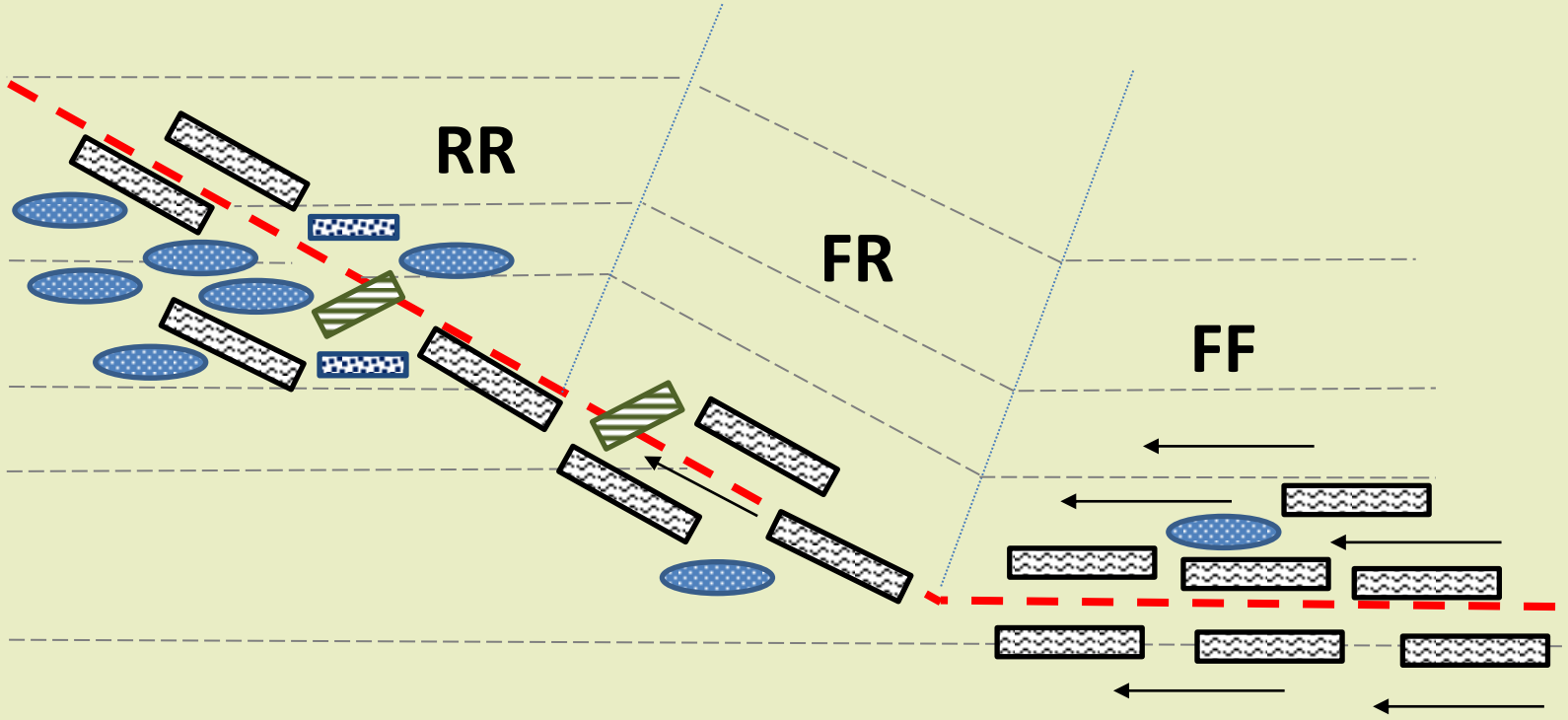
Flat/Flat
Well #1

Numerous resistive and conductive planes parallel and subparallel to bedding

Localized bed and bedset-scale detachments



Schematic Element Distribution For Taylor 73 Thrust Fault



Approx. mapped fault trace

Deformed mudstone
layer boundary, detachments

Bedset-scale deformed
mudstone, detachments

Deformation bands,
crushed grains, cataclasis

Rotated blocks

Cemented sandstone,
concretions

Summary Observations

- Fault character varies significantly over short distances, both within and between structural domains, but specific domains seem to have characteristic elements
- Faults in ramp settings are generally easy to identify with image logs (and dipmeters) but image logs give added information about the deformation zones around the faults
- Ramp-on-ramp settings appear to have more pervasive cementation of sands, particularly below mudstone layer boundaries
- Our data suggest distributed deformation is common in the flat-on-flat environment, but we may be biased by faults that have been subsequently folded
- Fault seal and leak interpretations may be refined with correlations to image log character
- Rotated stratigraphic blocks in ramp settings might be viable targets for hydrocarbon production