Integrating Borehole Image and Mass Spectrometry Data to Characterize Longitudinal and Vertical Heterogeneity in Proximal Horizontal Wells, Delaware Basin, Texas

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Geochemistry — Image Log Feature Zones for Well #2

These zones have been defined as having unique geochemical signatures that link to specific changes in image log features moving from heel to toe in the lateral.

Zone A (11,000'-14,100'): Maximum C1 and C2 against a stable C8 indicate a high GOR. C5 indicates gradually increasing condensate. The elevated oil lacks change in values suggesting a lower permeability into the mud system. Helium (He), a proxy for porosity, shows significant fluctuation in Zone A (and Zone B). PNA ratios indicate that both Zones A and B have consistent compartment chemistry. Hydrogen (H) and CO_2 values are elevated and indicate a greater amount of porosity, permeability and volatility. The changes in Zone A are attended by moderately-high values of fracture frequency, dominated by cemented fractures, and an elevated presence of deformed bedding.

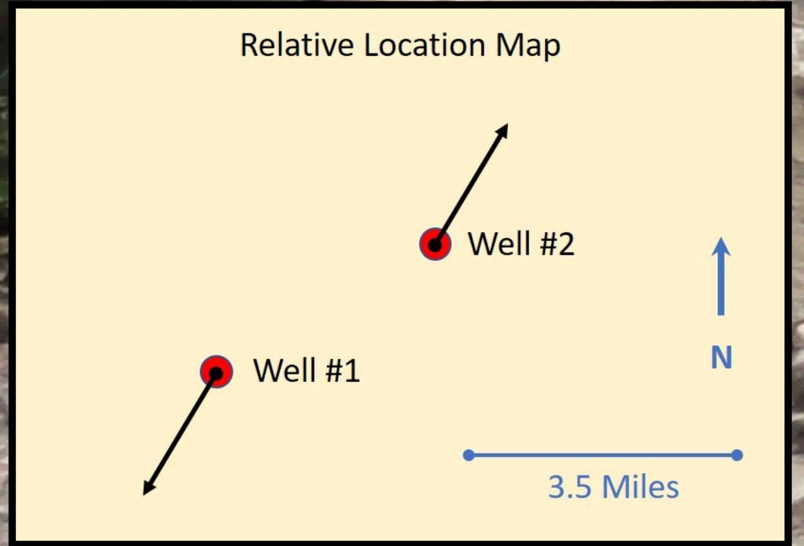
Zone B (14,100'-15,950'): Zone B is shares many of the geochemical characteristics of Zone A. Continued high C1 and C2 shows diminish toeward. A slight decrease in C5 and variable C8 accompany a zone of quiet fracture presence. He, H, CO_2, and PNA values are stable across this Zone. The fractures, however, are quite different, decreasing markedly in abundance. Deformed bedding abundance diminishes. GOR decreases a lot, as indicated by the higher nC4 and nC7 relative to nC1.

Zone C (15,950'-16,900'): This Zone reflects a pronounced transition to a different chemical equilibrium state. This change corresponds with a more active gamma, a decrease in mapped bedding picks, a dramatic increase in fractures (mostly cemented) and a paucity of deformed bedding. The transition is comprised of a lower GOR manifest by an abrupt decrease in C1 and C2, a slow drop in C5 and an upward jump in C8 and other oil indicators suggesting increased liquid phase permeability. PNA ratios display a rapid shift indicating a unique chemical compartment that does not comingle with Zones A and B.

Zone D (16,900'-17,900'): This zone shows a pronounced change in fracturing, changing from a high frequency of cemented fractures to a higher density of open fractures. An initial increase in C8 oil indicators and a drop in C1 and C2 reveals decreases in GOR and Sw ratio (suggesting that oil is displacing water saturation). PNA ratios define the C8 increase as gradationally compartmentalized. A drop in inorganics indicates porosity decrease.

Zone E (17,900'-18,900'): Zone E shows increase in gas (C1, C2), condensate (C5), and oil (C8). These changes are tied to an increase in gamma, a drop in resistivity and a dearth of fractures, suggesting more ductile rock. The abrupt nature of these changes suggests strong compartmentalization. Helium increase indicates higher porosity. GOR is higher.

Zone F (18,900'-21,200'): Decreases observed in gas (C1, C2), condensate (C5) and oil (C8) with some spikes. There is an abrupt drop, then a slow increase in the concentration of PNA values. Stiffer rock is suggested by lower gamma, higher resistivity and the occurrence of 75% of the open fractures in this zone.



The 2 wells are in the southern Delaware Basin in West Texas. The wells are situated 3.5 miles apart and their laterals were drilled in opposite directions (SSE and NNE). These horizontal wells traverse different strata.

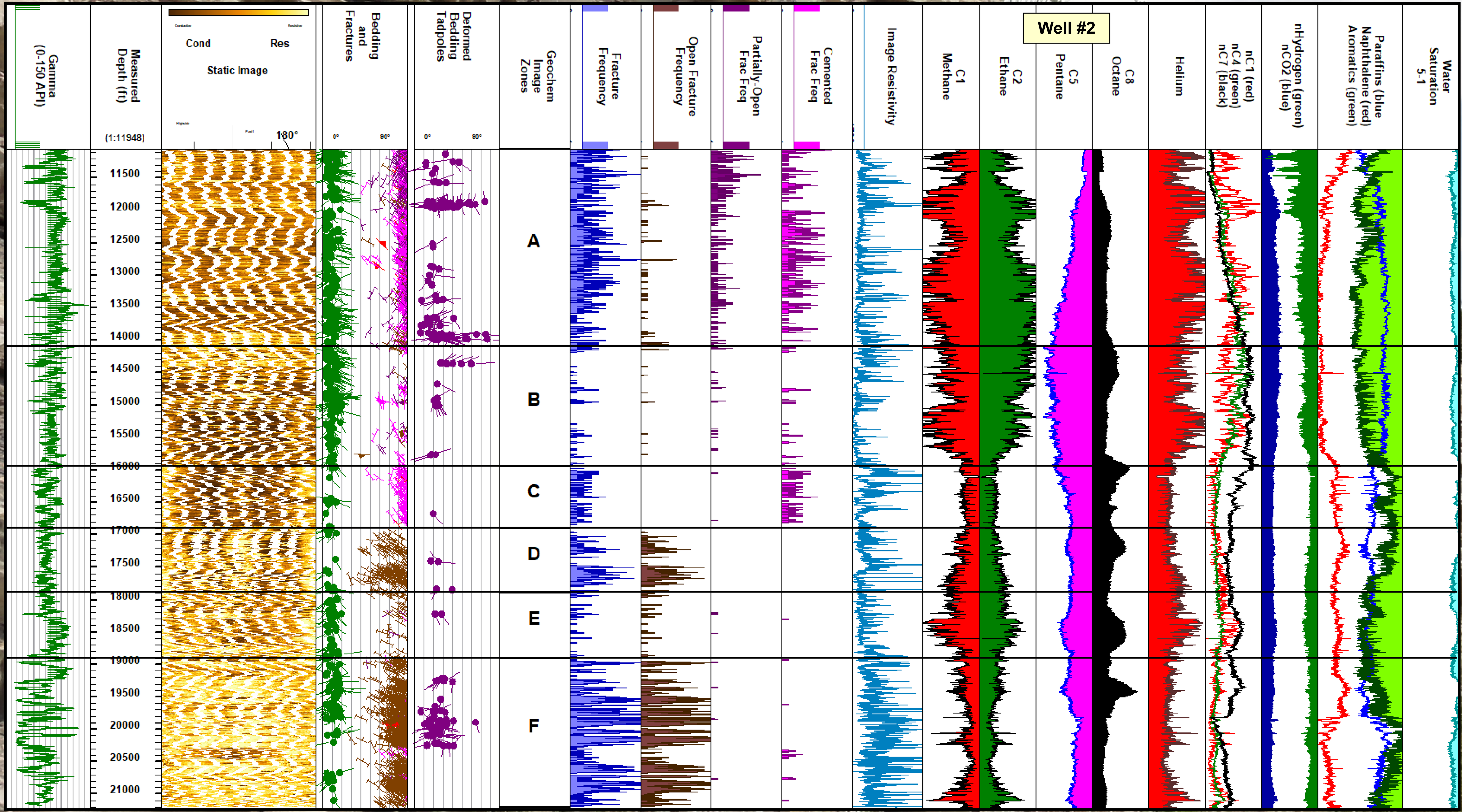
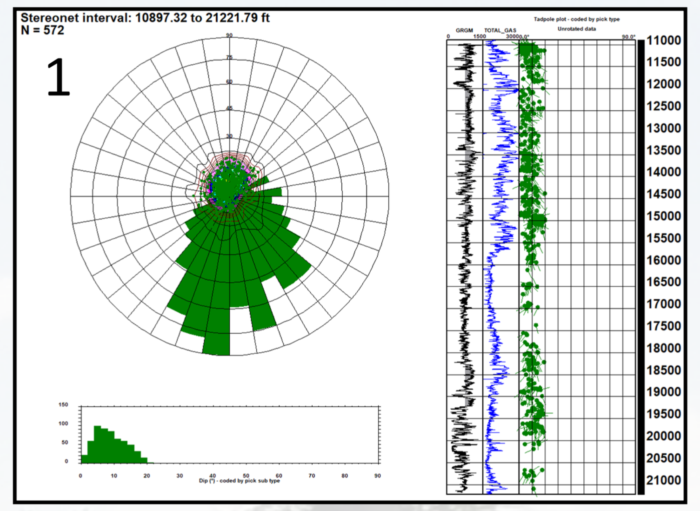
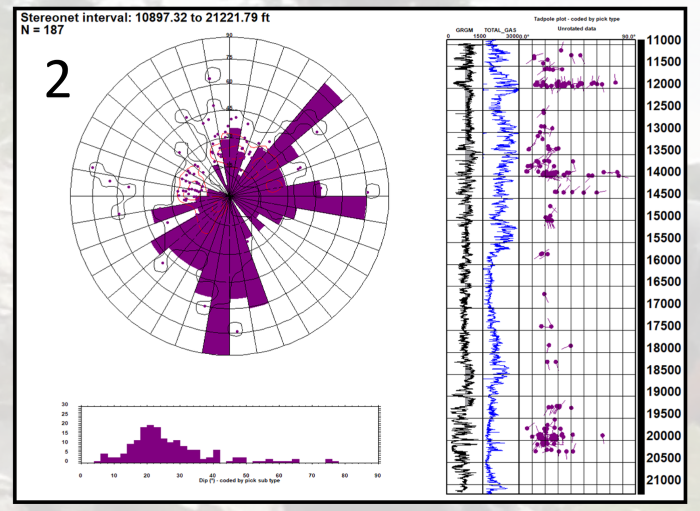


Image Log Analysis: Bedding

Image log analysis of Well #2 identified bedding (Figure 1) and deformed strata (Figure 2). A cut-off dip angle of 15° was used to segregate deformed from undeformed bedding. Undeformed bedding was more frequently observed toward the heel of the well, as shown in the tadpole plot in Figure 1. Bedding mapped in this lateral displays a strong preferential dip to the south.

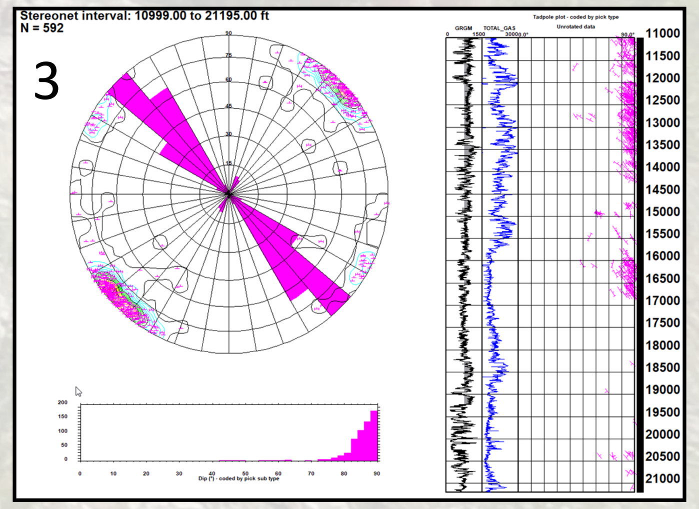




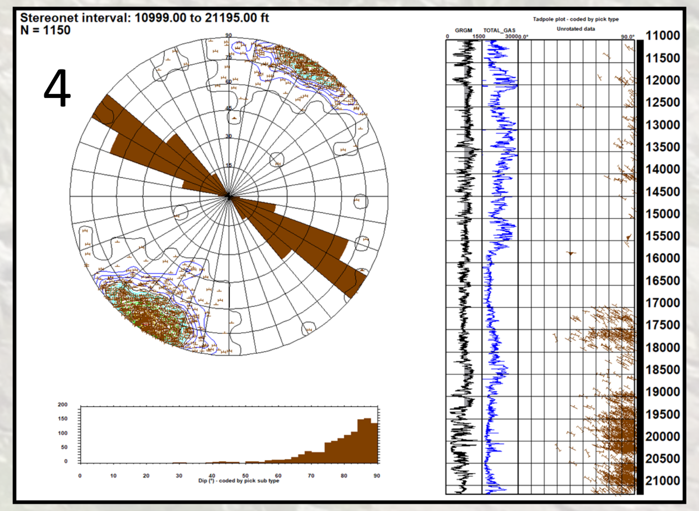
Deformed bedding is unequally distributed along the lateral. Several clusters of concentrated deformation appear to correlate with lower gamma ray sections. Zones of abundant deformation are interpreted as thin debris-flow deposits surrounded by more laminated, clay-rich sediment with higher gamma ray signatures. Deformed beds display dip directional scatter, trending toward the south, east and northeast.

Fractures

The 2,059 fractures observed in Well #2 display a well-constrained strike trend oriented NW-SE. This strike geometry agrees with that of the fractures from Well #1. Unlike Well #1, however, the fractures observed in Well #2 display distinct changes in frequency and type with position along the lateral length. Fractures in Well #2 are not uniformly distributed and they display an abrupt change from cemented fractures to open fractures.



From 16,800' and up (heelward), fractures are almost entirely comprised of cemented features (n= 592, Figure 3). Cemented fractures are almost exclusively high-angle, they strike NW-SE and they dip to both the NE and the SW. Cemented fractures display a very high overall fracture frequency with a quiet zone separating an upper and a lower zone of high density (see the tadpole plot to the right of the stereonet in Figure 3).



Open fractures (n=1,150) are concentrated toward the toe of the lateral, mostly below 16,800' MD (see tadpole plot in Figure 4). Open fractures display a strike trend that is rotated counterclockwise of the cemented fracture strike (but still is NW-SE). Open fractures are mostly high-angle features.

General Observations

- Image data from Well #1 display a high degree of heterogeneity in the type and intensity of fracturing and in the distribution of deformed strata along the length.
  - Natural fractures are dominantly cemented above ~16,800' MD and dominantly open below ~16,800' MD.
  - Fracture frequency fluctuates for each of these fracture types.
- The type and density of fracturing are strongly correlated with changes in geochemical response.
  - A large amount of gas and a high GOR close to the heel of the well correlate with an abundance of cemented fractures and increased deformation.
  - Lower gas concentrations and a lower GOR correspond with a pronounced increase in the density of open fractures and less regular deformation. The drop in gas concentration with increased open fracture abundance hints at potential fluid escape.
- Compartmentalization is indicated along the length of the lateral by changes in PNA (paraffin, naphthalene and aromatics) ratios.

Conclusions

- Although it is commonplace to assume that a target horizon is characterized by uniform geological and geochemical properties along a lateral, our data prove otherwise. In fact, each of the horizontal wells in our study exhibit a high-degree of heterogeneity along the lateral length and the character of this heterogeneity differs between the 2 wells.
- Variability in rock properties that we measured along 2 horizontal wells (fracture type and abundance and intensity of deformation) are linked to changes in geochemical characteristics.
  - In Well #1, fractures are fewer in number (n=731) but are more uniformly distributed with depth. The number of deformed strata (n=986) is much higher than in Well #2. Lower fracture frequency and greater abundance of deformed beds corresponds with a higher GOR. Increases in fracture frequency and a drop in deformation link with lower GOR, as condensate and oil increase with less compartmentalization.
  - In Well #2, fractures are more numerous (n=2059), but display distinct changes in abundance and type along the lateral length. Deformed beds are fewer in number (n=187) than for Well #1. High GOR corresponds with large numbers of cemented fractures and deformation; low GOR with open fractures. The distinct fracture and deformation zonation are tied to a higher degree of compartmentalization.
- Running an image log establishes the degree of fracture, bedding, and rock heterogeneity along the length of a lateral and can be used to "see" what is causing mass spec data responses. As other wells are drilled on the pad the mass spec can be used to identify these heterogeneities in the lateral to improve completion design and understand production variability during the pad development.

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