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

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Abstract

It is a common observation that laterals completed in different stratigraphic intervals seldom perform the same. Wells in different locations frequently yield different results in the same stratigraphic interval and in different strata. A single lateral sees production variation from different zones. While uncertainty is omnipresent, what can be done to improve our ability to see changes in the rock that influence production potential?

We present investigation results of a reservoir feature comparison from 2 wells located 3.5 miles apart. We integrate borehole image fracture system data and the intensity of syn-sedimentary deformation with mass spectrometer-based organic geochemistry. Our approach assesses how changes in rock properties and fracture system dynamics influence hydrocarbon composition and flow. This integrated study reveals a high-degree of longitudinal and vertical heterogeneity in rock properties that are significant to hydrocarbon recovery and well economics.

Two horizontal wells, approximately 10,000' in length, were drilled 3.5 miles from each other within the Delaware Basin. The wells were landed in different horizons in the Late and Middle Permian. A water-based mud borehole image logging tool was used to acquire horizontal image log data for both wells. A detailed image analysis was performed to determine lithology, rock texture, bedding structural dip, prevalence of mass-flow deposits and natural and drilling-induced fracture geometry. Average fracture strike orientation was similar between the wells while significant differences were observed in fracture abundance and distribution, structural dip character, and the abundance and depth distribution of mass-flow deformation.

Mass-spec and inorganic gas analyses identified major differences and some similarities between the 2 wells such as hydrocarbon composition, inorganics, and aromatic soluble species. These data reveal changes in relative GOR, water saturation, porosity, permeability and hydrocarbon abundance that correlate with changes in image log rock characteristics. Changes in hydrocarbon chemistry in different natural fracture types could indicate connection to different sources, possibly revealing degree of compartmentalization.

In the lateral completed in the younger rock (Well #1), mass flow deposits (n-=986) inversely correlate with fracture abundance (n=731). Intervals with increasing fracture intensity, especially open fractures, are marked by increases in gas, condensate and oil with decreases in GOR. In the lateral completed in the older stratigraphic unit (Well #2), there are many fewer mass-flow deposits (n=187) and a large increase in the total number of fractures (n=2059). A striking transition from mineralized to open fractures divides the lateral in half and is accompanied by changes in geochemistry. In the heel section, high frequency of mineralized fractures is accompanied by elevated concentrations of gas and a high GOR. Proceeding along the lateral, fracture frequency declines are attended by a decrease in gas and an increase in condensate and oil. The transition to open fractures halfway along the lateral to the toe is marked by decreased gas and condensate and fluctuating oil with a low GOR.

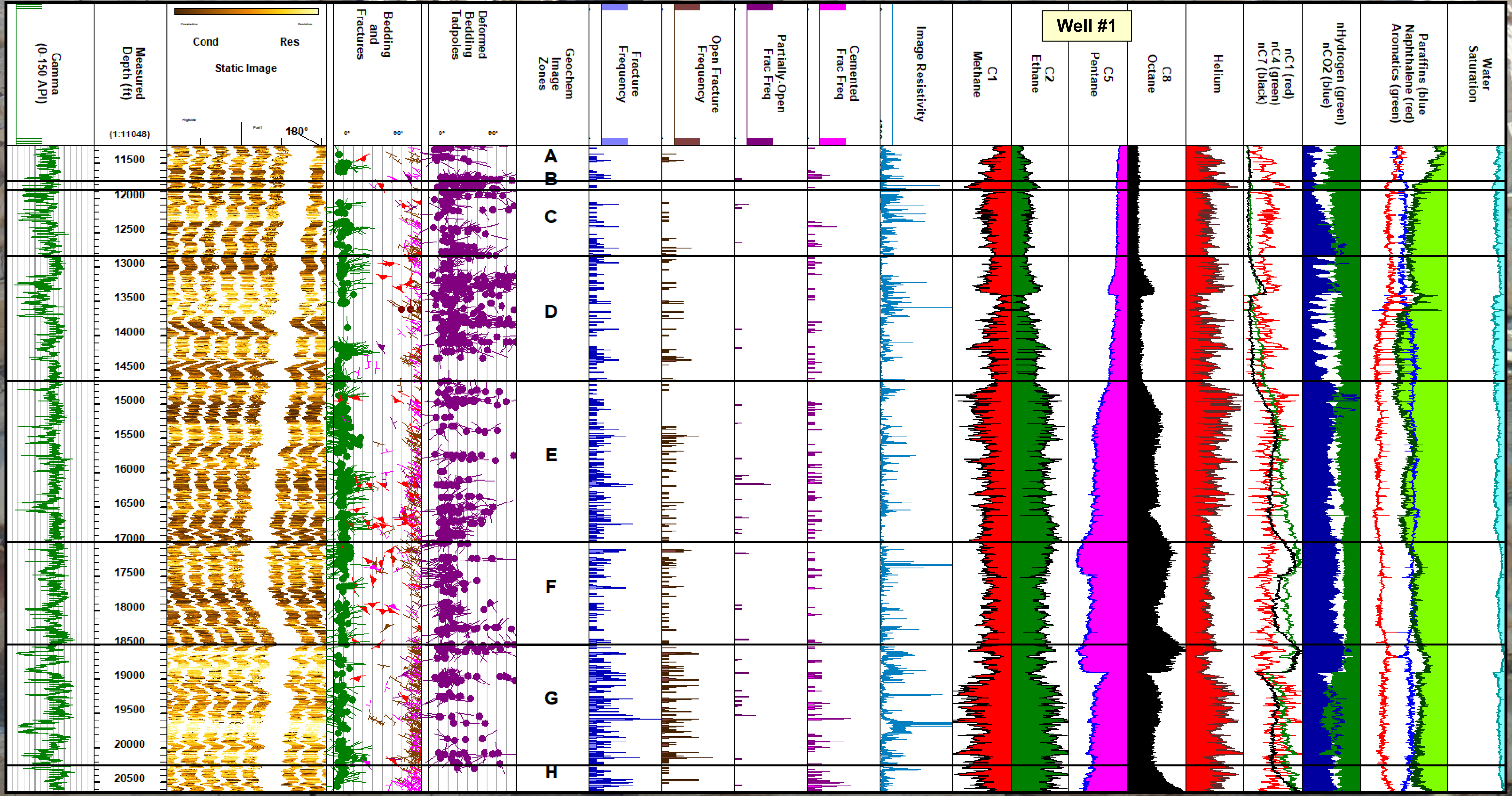
These examples illustrate that understanding reservoir heterogeneity can help with the drilling and completion of wells. Image log analysis and mass spectrometry are capable of identifying lateral changes in rock characteristics and fluid properties within a formation. The image log can be used to ground-truth the response of the mass spec data in a formation. Then, gas geochemistry can be used to map lateral variability of the formation across the field. Combining these data with tailored completion designs and production histories can lead to a better understanding of how rock property variance affects the production potential.

Introduction

Mass spectrometer data identifies the concentration of fluid constituents liberated by drilling. These data are used to elucidate reservoir properties such as porosity, permeability and water saturation and the composition, concentration and flow properties of subsurface fluids. Image log data is used to define the spatial geometry and the intensity of fractures of different kinds, and other geological features, along the lateral length.

This 2-part poster compares and contrasts image log and geochemistry data from 2 horizontal wells drilled within Upper and Middle Permian strata from the southern Delaware Basin, West Texas. The wells are 3.5 miles apart, with laterals that drilled in opposite directions.

Hydrocarbons curves give relative amounts of methane (C1), ethane (C2), condensate (C5) and oil (C8). Helium is a proxy for porosity. Norm C1,C4 & C7 curves display ratios of gas, condensate, and oil to define the relative Gas to Oil Ratio (GOR). Inorganics (H, CO_2) indicate porosity, permeability, and volatility into the mud system. PNA ratios give an indication of the degree of chemical compartmentalization. Integrated with borehole image data, these geochemical indicators establish the nature and degree of heterogeneity along a lateral.



Geochemistry – Image Log Feature Zones for Well #1

Zone A (11,226'-11,744'): Hydrocarbon values show minor fluctuations in gas (C1, C2), but condensate (C5) and oil (C8) remain low contributing to a high relative GOR (nC1>nC4=nC7 curves). PNA ratio shifts indicate crossing compartment boundaries. Fracture density is low with mostly cemented fractures. Deformed bedding is abundant.

Zone B (11,744'-11,882'): Increases in volatility of hydrocarbon composed of gas with minor condensate. Very high GOR indicated by nC1>>nC4=nC7. PNA ratios suggest a compartmental transition. Extremely high occurrence of deformed bedding with very few fractures.

Zone C (11,882'-12,838'): Hydrocarbon volatility remains elevated, but slightly decreased from the previous zone. High GOR as C1remains >>C4=C7. Deformed bedding remains abundant. Fractures pick up in frequency toeward which is associated with an increase in CO_2.

Zone D (12,838'-14,663'): A broad increase in condensate (C5) and oil (C8) associated with an increase in gas volatility (aromatics) correlates with a shift in gamma, indicating that the wellbore traversed an interval with higher porosity, permeability, and volatility into the mud system. Deformed bedding density is high throughout, except the last 300', which is without deformed bedding. Fracture frequency is high.

Zone E (14,663'-17,000'): Increases observed in all hydrocarbon signals (C1, C2, C5 and C8). An abrupt increase in gases correlates with a lower gamma ray which suggests the wellbore moved into a different stratigraphic position. Deformed bedding present throughout but with diminished frequency. Fracture density remains high.

Zone F (17,000'-18,500'): A drop in C1 and C2 with increasing C5 and C8 lead to a very low GOR. Deformed bedding abundant; fractures plentiful with a slow decline toeward.

Zone G (18,500'-20,250'): Increasing gas signal (highest C1 and C2) with associated condensate (C5) and oil (C8) increases accompany lower gamma and higher resistivity. A GOR is low at the heelward end of this zone, then jumps upward with a decrease in C5 and C8 at 18,900'. Numerous changes across this depth indicates crossing a compartment boundary.

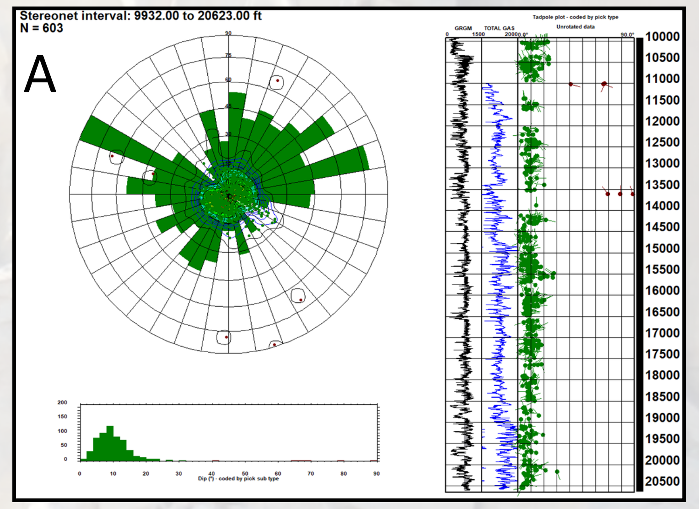
Zone H (20,250'-20,650'): An increase in condensate (C5) and oil (C8) is matched by a decrease in gas for a declining GOR toeward. Fractures are dominantly cemented. Deformation absent.

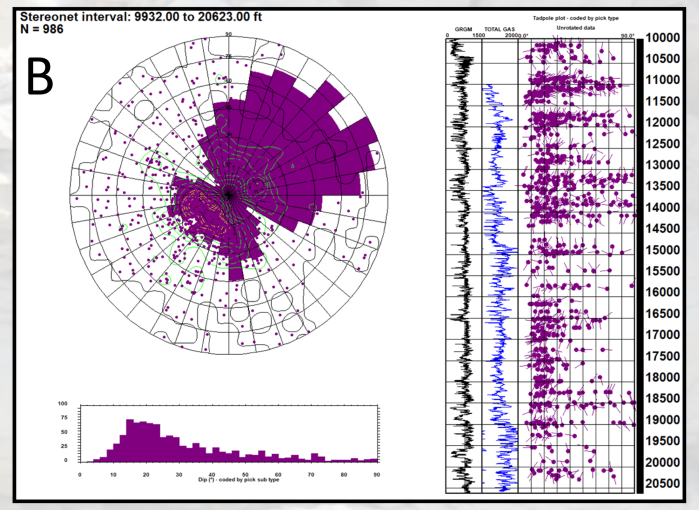
General Observations—Well #1

- Fracture frequency is lower than in Well #2 with an intermingling of fracture types that are more evenly spaced, There is gradual increase in the density of open and cemented fractures toward the toe of the lateral.
- Deformed bedding is pervasive throughout although it diminishes in abundance somewhat bellow ~14,300'. The most deformed material (Zones A-D) corresponds with the lowest hydrocarbon values, suggesting a rock mechanical influence.
- Microfaults (triangular symbols on the "Bedding and Fractures" tadpole track) are associated with deformed beds. These features are much more plentiful than in Well #2.
- The increasing trends of C1, C2, C5 and C8 crudely mimic the gradual increase in fracture frequency from heel to toe.
- There is less movement in the PNA curves relative to Well #2, suggesting a lesser degree of compartmentalization.

Image Analysis Bedding

Image log analysis identified a large number (n=603) of bedding planes in Well #1. Bedding was classified as either general bedding (green symbols on Figure A) or deformed bedding (purple symbols in Figure B). A cut-off of 15° dip angle was used to discriminate these bedding classes. The general bedding displayed a wide array of bedding dip directions with crude maxima directed to the NE and the SW.

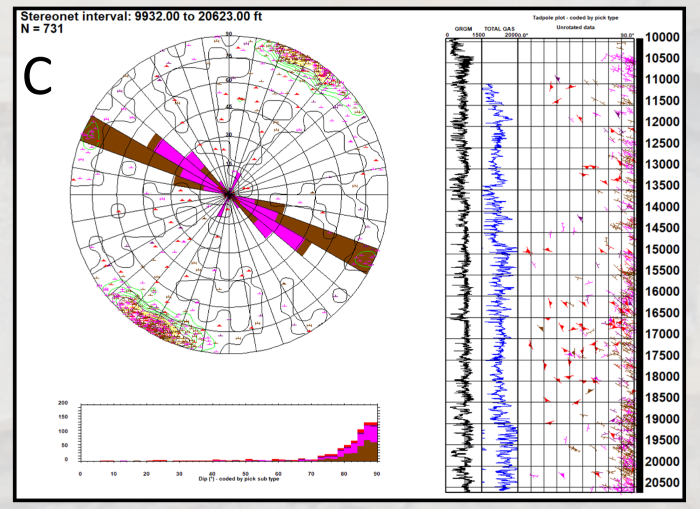




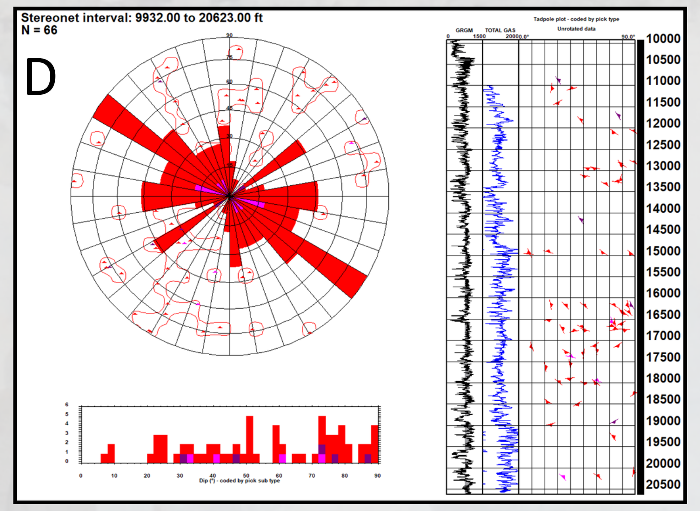
Deformed bedding was observed across the entire image data set, in stark contrast with the distribution of deformed bedding in Well #2. The vast quality of deformed bedding suggests that the depositional environment of these sediments was an unstable slope prone to slope failure, soft sediment deformation, and debris flows. Deformed bedding displays a crudely bi-modal distribution of dip directions to the NE and SW.

Fractures

A total of 731 fractures (Figure C) were mapped from the image log data. Fractures display a dominant, tightly-constrained strike trend oriented NW-SE. This strike trend is in general and comprised of open, partially open, and cemented fractures that dip at high angle (>70°) to the SSW and NNE. A secondary strike trend, comprised only of cemented fractures, is oriented NNE-SSW. This fracture system is quite different from that observed in Well #2. (Well #2 has much wider swings in fracture frequency with position along the lateral. Well #2 displays a dramatic shift in the dominant type of fracture—cemented fractures heelward; open fractures toeward).



Well #1 exhibits another marked difference from Well #2: abundant microfaults (Figure D). Microfaults, or shear fractures, are discontinuities across which there have been slight displacements. Microfaults are insignificant in Well #2 image data. Here, the microfaults are a reflection of the surplus of deformed beds. The forces which caused microfaulting are the same that initiated the deformed bedding.



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