[EA]Which Fault Matters: Evaluation of Reservoir Compartmentalization by Integration of Borehole Image and Real-Time Isotope Data $\delta^{13}C_1$*

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Abstract

Between November 2016 and February 2018, Shell Malaysia drilled 11 development wells targeting two reservoirs (R1 and R2) in a deepwater field offshore North West Borneo. The field is a complex faulted 4-way dip closure, comprising a turbiditic depositional environment with R1 reservoir being dominated by unconfined distributary channels consisting of high permeability sandstones and R2 reservoir being dominated by channel levee consisting of fine laminated sand sequences.

Pressure data taken during the appraisal stage indicates that prior to production, each reservoir comprised a single tank. Faults are major structural features that have a critical impact on the field's reservoir behaviour in terms of hydrocarbon flow and could compartmentalize the field during production. Thus, understanding the presence and behaviour of seismic and sub-seismic scale faults at the start of production, helps to optimise recovery, forecasting and economic value as production continues.

An integrated method was used to identify and validate presence of faults and its barrier behaviour during drilling. High resolution resistivity and density-based borehole images (BHI) have been acquired for (1) fault and fracture interpretation, (2) formation tops identification, and (3) lithofacies analysis. Real-time isotope ($\delta 13C_1$) data was acquired in each well during drilling to aid identification of potential flow barriers and baffles. BHI interpretations were integrated with real-time isotope interpretations and seismic to identify and validate fault and other barriers in order to interpret compartmentalization.

Technology

Borehole Image Tools

Borehole imaging tools provide an image of the borehole wall that is typically based on physical properties contrast of the formation drilled. Borehole imagers have evolved over the last 30 years from single-button, wireline-deployed dipmeter pads on an articulated arm measuring spontaneous potential (SP) or microelectrical (galvanic) responses, to true circumferentially and longitudinally measuring imagers (Ekstrom et al., 1987; Lofts and Morris, 2010). In the field, Logging-While-Drilling (LWD) density and resistivity-based borehole images have been acquired in the drilled wells. LWD imaging device provides imaging of the borehole wall before any significant mud invasion and possibly before any borehole degradation.

In comparison, LWD resistivity imaging tool have higher resolution compared to the density-based imaging tool. The LWD image acquired during drilling includes: Density-based Azimuthal Density Neutron (ADN) and LithoTrak^{TM} Resistivity-based geoVISION (GVR), MicroScope and StarTrak^{TM}
In addition to LWD imaging tools, a high-resolution wireline-based Simultaneous Acoustic and Resistivity Imager (STAR) has been acquired in one of the wells.

Real-Time Isotope Tool

The Isotope Logging tool coupled with the Advanced Mud Gas Logging (AMGL) system provides quantitative analyses of C_1 to C_5 (hydrocarbons from the formation) to further enhance the interpretational potential of stable isotope values. The extraction of gaseous hydrocarbons from the drilling fluid takes place as close to the bell nipple as possible under fully controlled conditions, including stable mud and air flows, stable temperature and stable pressure. The AMGL analysis is performed using Gas Chromatograph-Mass Spectrometer, whereas the isotopic analysis is performed simultaneously by near infrared absorption spectroscopy.

The $\delta 13C_1$ Isotope logging service delivers a continuous real-time log of 13C/12C isotopic methane ratio, enabling identification of sub-seismic scale features that would otherwise be missed. Additionally, the isotopic ratios logged allow preliminary geochemical characterization of hydrocarbons with regards to source, generation and fluid-alteration processes. Through this method, uncertainties, delays and risks associated with collection, shipment and analysis of spot samples are reduced and eliminated. (Di Daniel and Murlidhar, 2018)

Methodology and Application

Borehole Image Tool

R1 and R2 reservoirs are a thin-bedded field made up of unconsolidated heterolithic sandstones. Borehole imagers are responding well to density and resistivity contrasts caused by shaly layers within the sandy heterolithic rock, leading to the finer resolution in parallel laminations of bright and dark banding in the image. All dips have been picked manually at a high frequency that should form the basis of any interpretation from the BHI datasets. The consistent shape of the bedding sinusoids indicates parallel lamination layers. Faults and fractures are readily observed in the LWD and wireline borehole images. Structural features are generally discordant to bedding. A discrete truncation feature cutting the sedimentary structure/beddings at higher angle dip is a common response of a fault on the image.

Real-Time Isotope Tool

The main objective of deploying the real-time $\delta 13C_1$ Isotope tool is to record the geochemical variation within the subsurface to enable identification of barriers. Trends and isotopic shifts with depth are being investigated. A minimum shift of ~ 0.5‰ variation is considered significant. This allows us to improve our understanding of compartmentalization and connectivity of conduits during drilling of wells and with respect to production and injection behavior of the field. (Di Daniel and Murlidhar, 2018). The integration of BHI with geochemistry data allows for greater understanding of geological features, which includes:

1) Structural features include sub-seismic to seismic scale faults and its sealing properties, and fractures.

2) Sedimentological features include lithotype, image fabric and facies variation, formation tops depth identification.

Well A Example

Well A was drilled when production of the R2 reservoir had already started. Pressure data acquired in this section shows differential depletion suggesting compartmentalization during production. An integrated approach was used to identify and validate presence of fault and its barrier behaviour during drilling. High resolution LWD resistivity-based MicroScope image in R2 reservoir has been acquired in Well A. Real-time images from MicroScope service are acquired azimuthally in 56 oriented sectors while rotating and using two high-resolution button sensors. These images provide full coverage around the borehole with nearly any combination of drilling and rotational speed even in stick/slip environments (Schlumberger).
The R2 reservoir was drilled with 6.75-inch hole section. Prior to drilling, no seismic-scale faults were interpreted along the wellbore path in the R2 reservoir. However, on MicroScope image, six clear sub-seismic scale faults were identified. The real-time isotope log highlights two significant isotope shifts within the lower half of the section indicating potential compartments within R2 reservoir inferring sealing faults. Figure 1 below illustrates the faults identified on MicroScope image and the changes noted on isotope log.

Figure 2 shows the schematic drawing for fault interpretation from Well A. Several plausible concepts may explain the interpretations (Figure 3).

The interpreted BHI faults were overlain with seismic (Figure 4), some of which correlate well with potential discontinuities identified on seismic (green dotted lines) post drilling. Through integration of seismic, BHI, isotope and pressure data, confidence on barriers were recognised, thus highlighting the potential presence of three reservoir compartments in production time.

Conclusion

This integrated approach has been demonstrated to be invaluable in aiding us to better understand the complexity of the field's compartmentalization. LWD high-resolution borehole images have demonstrated a benefit of increased fault interpretation confidence. The changes in isotope signature across identified faults enable identification of barriers giving insights to compartmentalization, which benefits production and future development of the field.

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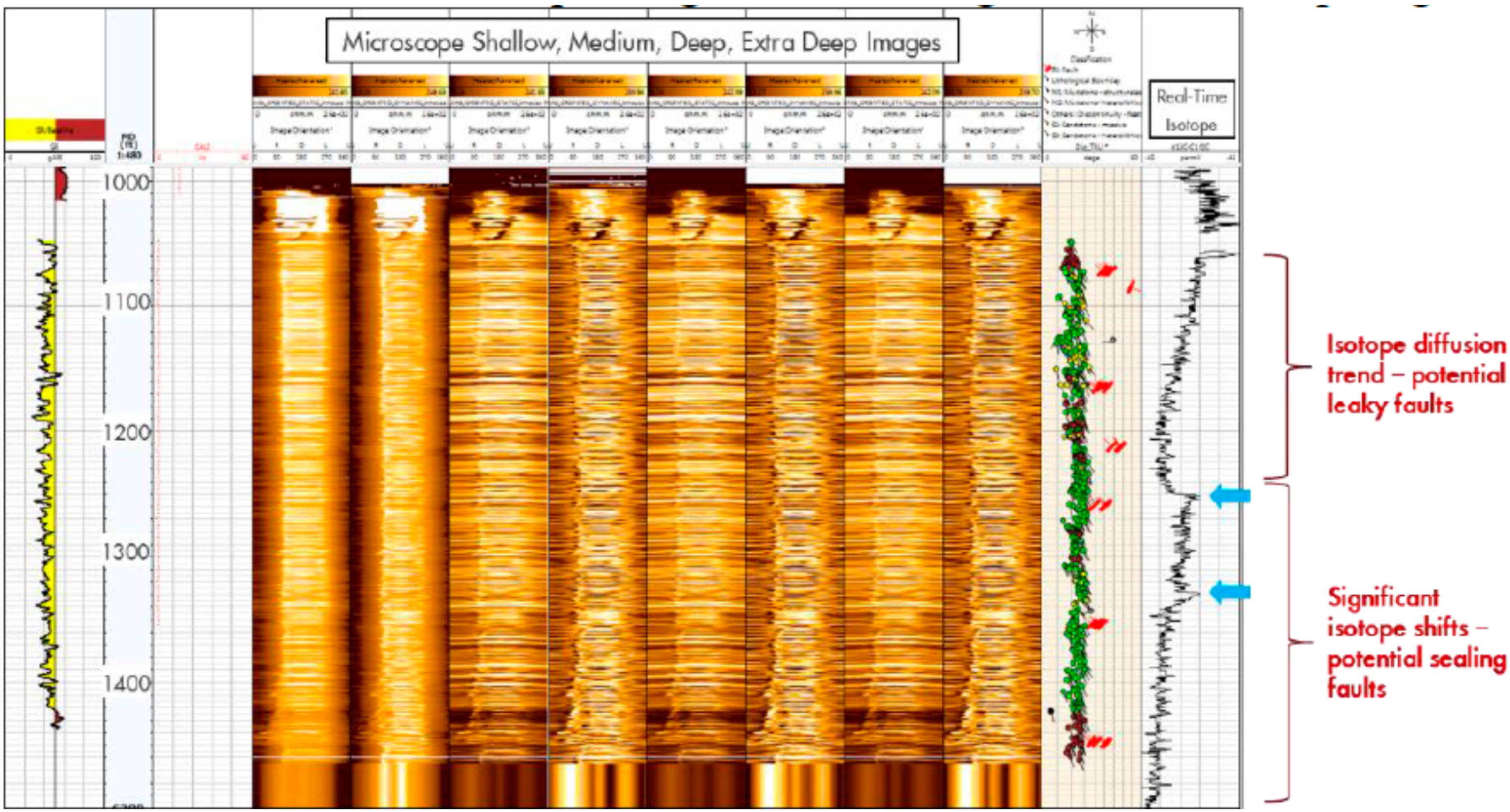

Figure 1. MicroScope static and dynamic normalised image from R2 reservoir showing well defined parallel laminated sandy heterolithics beds and fault features. Real-time isotope log on right track expresses zone with diffusion trend and isotopic shift. Faults identified between 1000-1250 ft shows no major shift in isotope signature, portraying potential transmissible faults. Faults identified between 1250 ft to TD records significant isotope shifts, portraying less-transmissible or potential sealing faults. GR= Gamma Ray; MD= Measure Depth, CALI= Caliper, d13C= Real-time isotope log.

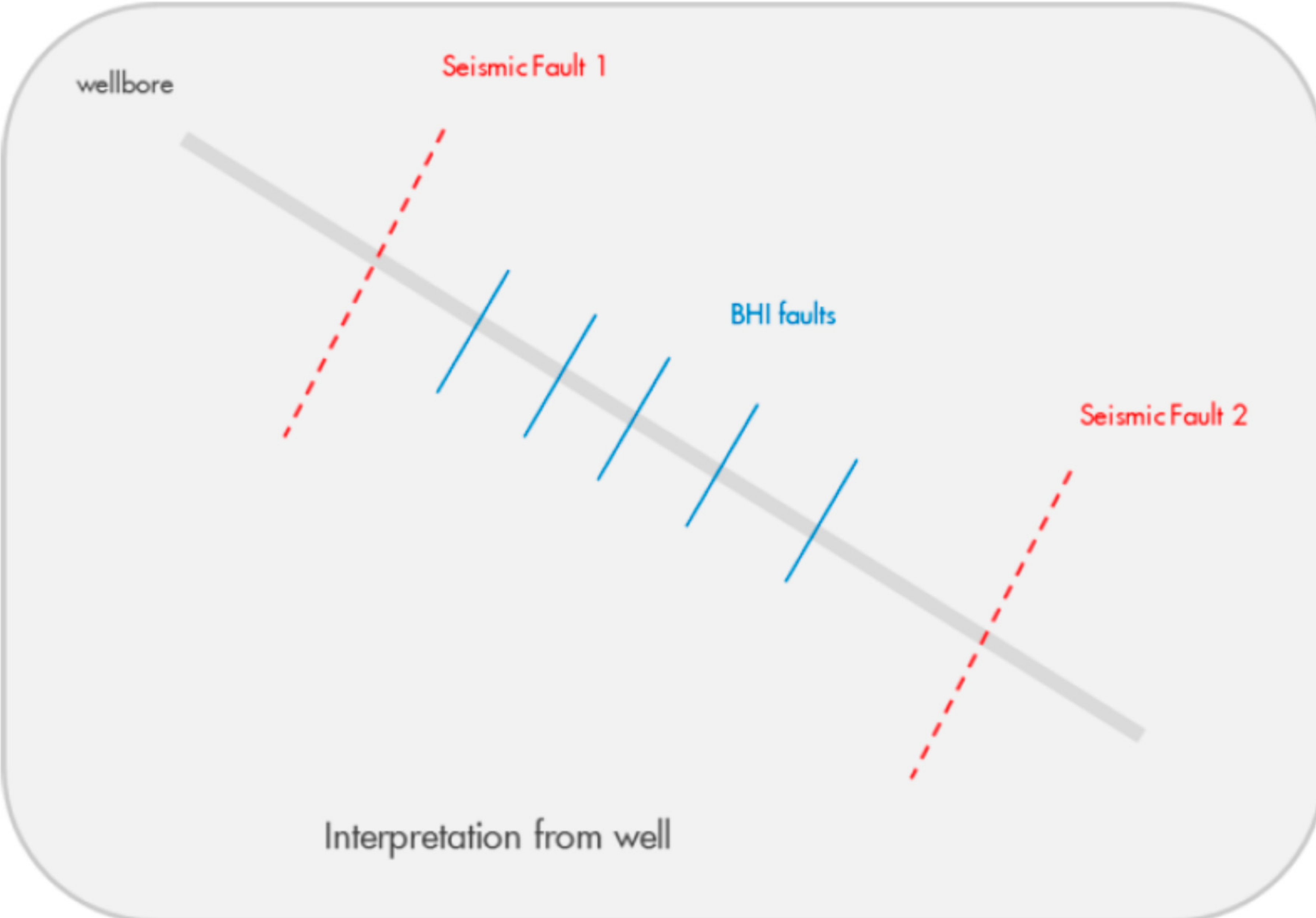

Figure 2. Fault interpretation from MicroScope image from Well A, illustrating sub-seismic faults to be present.

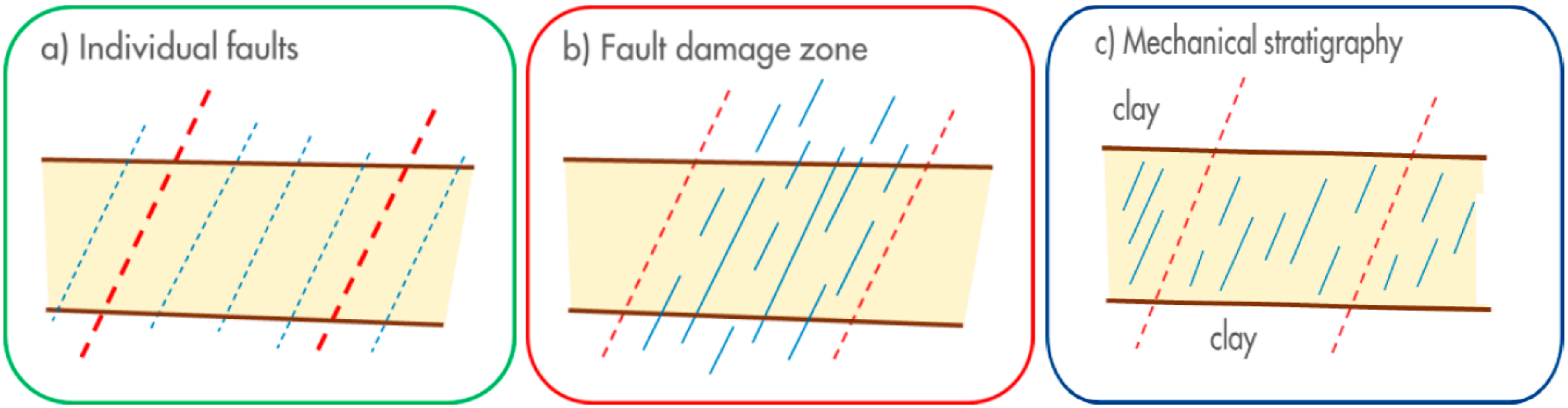

Figure 3. (a) All the faults picked on MicroScope image are individual faults; (b) The 6 faults picked on MicroScope image are fault damage zones constrained by the 2 main bounding faults (Figure 4); (c) Faults are related to mechanical stratigraphy and are only present in the reservoir sands.

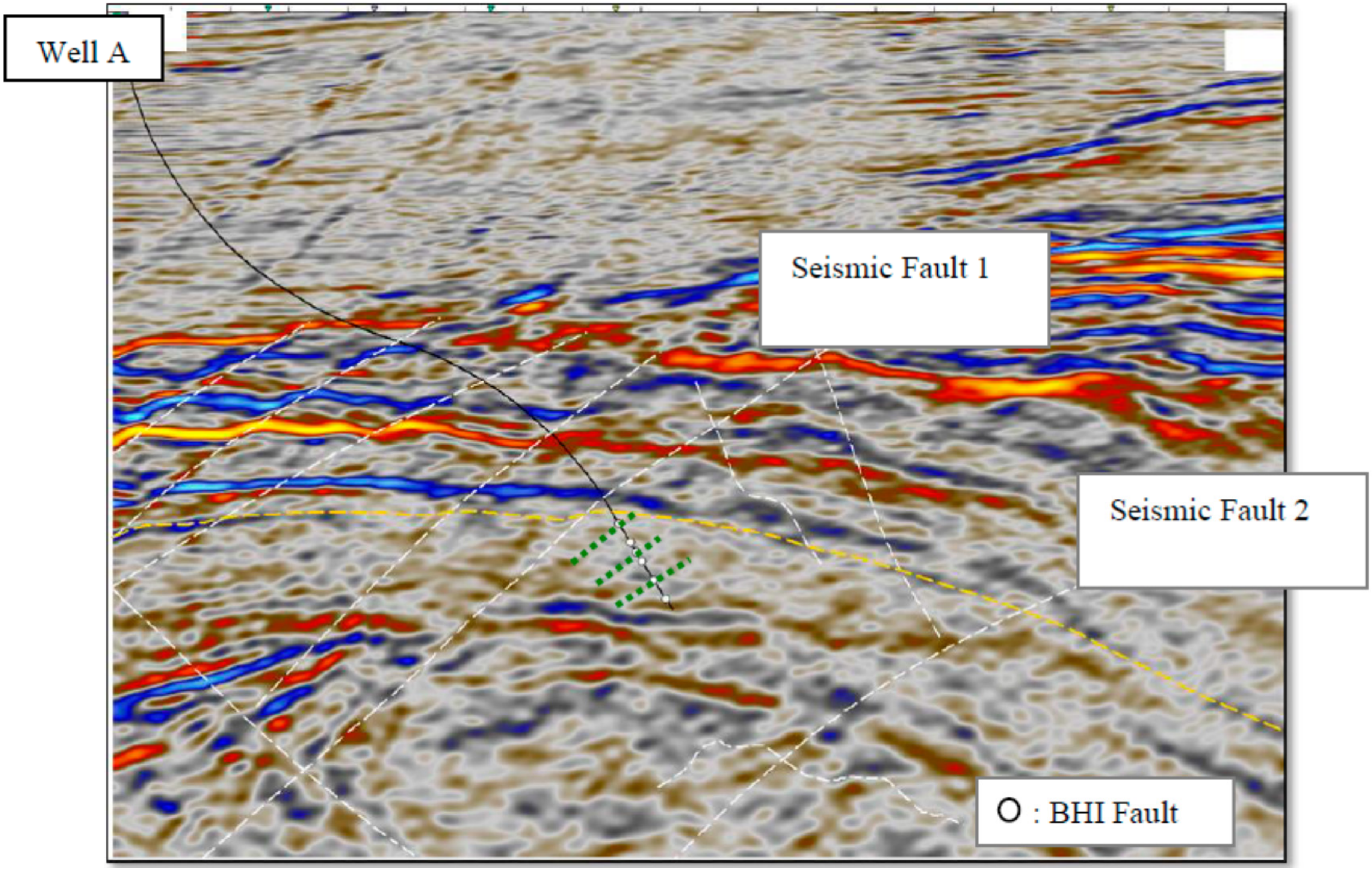

Figure 4. Seismic cross section across Well A with BHI identified faults marked along well path.