[GC]Extracting Large-Scale Fracture Networks*

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General Statement

This work demonstrates a modern workflow that directly extracts high-resolution, large-scale fracture networks from seismic inversion-based structural attributes. The workflow is successfully applied to a thrust-belt controlled, Lower Triassic siltstone reservoir in the Montney Formation of the Farrell Creek area in northeast British Columbia to extract a 3-D fracture network orthogonal to the primary stress direction. Subsequently, these extracted seismic scale fractures are applied to analyze completions, production interference and well planning.

High-Resolution Fracture Network Extraction

The principal objective of this exercise is to provide asset teams with a rapid and independent view of the seismic-scale fracture networks present within an area of interest for integrated hydraulic fracturing, production and drill target analysis. A high-resolution fracture extraction workflow from seismic data has been developed to address this need.

A “systems” approach allows us to conceptualize the seismic data as the vertical fractional change in the geology that has been modified by seismic-wave propogation and earth-filtering effects. Minimization of these effects, as well as random noise, through seismic inversion enables a more accurate and complete understanding of the subsurface geology and delivers an optimal input for computing various structural attributes.

Figure 1 shows a block diagram illustrating the workflow employed to exploit this concept for the computation of a higher fidelity and higher resolution structural attribute. The final processed seismic (a band-limited interface property) is transformed to compressional (P-wave/acoustic) impedance (a layer-based bandwidth enhanced rock property) by simultaneously integrating well-log and lithostratigraphic information, as well as minimizing random noise, earth filter and seismic-wave propagation effects. Through a phase rotation, it yields the compressional-to-compressional mode reflectivity (i.e. the P-wave reflectivity) without loss of vertical resolution.

Exploiting the marginal 90-degree phase relationship between reflectivity and impedance avoids the inherent loss of resolution due to directly computing the reflectivity as the vertical derivative of the impedance. The polarity (standard/reverse) of the input seismic determines whether a positive 90-degree or a negative 90-degree phase rotation is required to obtain reflectivity from impedance. This is the base data from which structural attributes are computed since it is richer in information than the full-offset stack.

Although the reflectivity is the optimal starting point for structural analysis, it can be improved further by geological preconditioning. This is achieved via small window median filtering along structural dip in good signal-to-noise ratio (S/R) areas and diffusion filtering in areas with a poor signal-to-noise ratio. As a result, the reflectivity is cleaner and yields a fracture attribute with sharper boundaries or "edges."

High-resolution fracture sets orthogonal to the primary stress are computed via stereonet-controlled directional steering of the enhancement algorithm. Should image log or dip meter analysis be available, stereonets can then be built to enhance the extraction of specific structural elements observed via downhole analysis. Displaying the enhanced fracture attribute in 3-D orthogonal perspective with opacity set to highlight strong discontinuities allows the first order lineaments to be visualized. These discontinuities are then extracted as geobodies for a data-driven fracture model that can be applied as needed.

Application to the Montney Formation

The workflow is applied to a thrust belt controlled unconventional siltstone reservoir that lies in the dry gas, distal shelf portion of the Montney Formation, northeast British Columbia, Canada (see Figure 2). This formation (comprised of an upper and lower portion, each having several drillable lithostratigraphic zones) is a succession of clastic and carbonate shelf facies that have been deposited via westward progradation, with proximal facies deposited in the east and basinal facies deposited in the west. Its isopach averages 360 meters in the study area.

Figure 3 shows an application of the workflow to an anomalous completions result for a producing well in the distal shelf region of the Montney Formation discussed earlier. The 3-D top-down view, on the left, shows that the fracture network locally isolates the thicker portion of the reservoir.

Furthermore, the fracture network directs and contains the production-tied microseismic events. On the right is a section view, taken along the length of the lateral. This shows the lateral section of the well intersecting two major seismic-scale fracture corridors. These "throw"-related (the blue lineament) and "anticline"-related (the orange lineament) fracture-related attributes constrain the microseismic and promote downward, out of reservoir, growth.

In Figure 4, we see an application of the discussed workflow to production analysis. On the production pressure curves, as Well A is shut-in there is an observed response in Well B and Well C. An explanation for this production interference is fracture connectivity between the wells. Extracting the fracture network confirms this, as seen in the lower right-hand panel.

A final application is shown in Figure 5. Here we see near well-bore sweet spots for brittleness, hydraulic fracture-ability, porosity and organic richness extracted as geobodies. These are co-rendered in 3-D with the extracted seismic fracture network and an integrated sweet spot is identified. Knowledge of previous, nearby well plans and production information allows this well to be planned knowing that intersecting certain fracture attribute patterns at a high angle is preferred to drilling these same patterns in a roughly parallel, or slightly oblique, manner. As such, this well can be planned such that about two-thirds of the lateral can be ideally placed and completed.

Conclusion

This work demonstrates that a seismic data-driven approach to fracture identification and characterization is an added-value process. The fracture attributes delivered via this workflow are a first step and should be correlated to downhole evidence (i.e. image logs) of fracturing.

Acknowledgements

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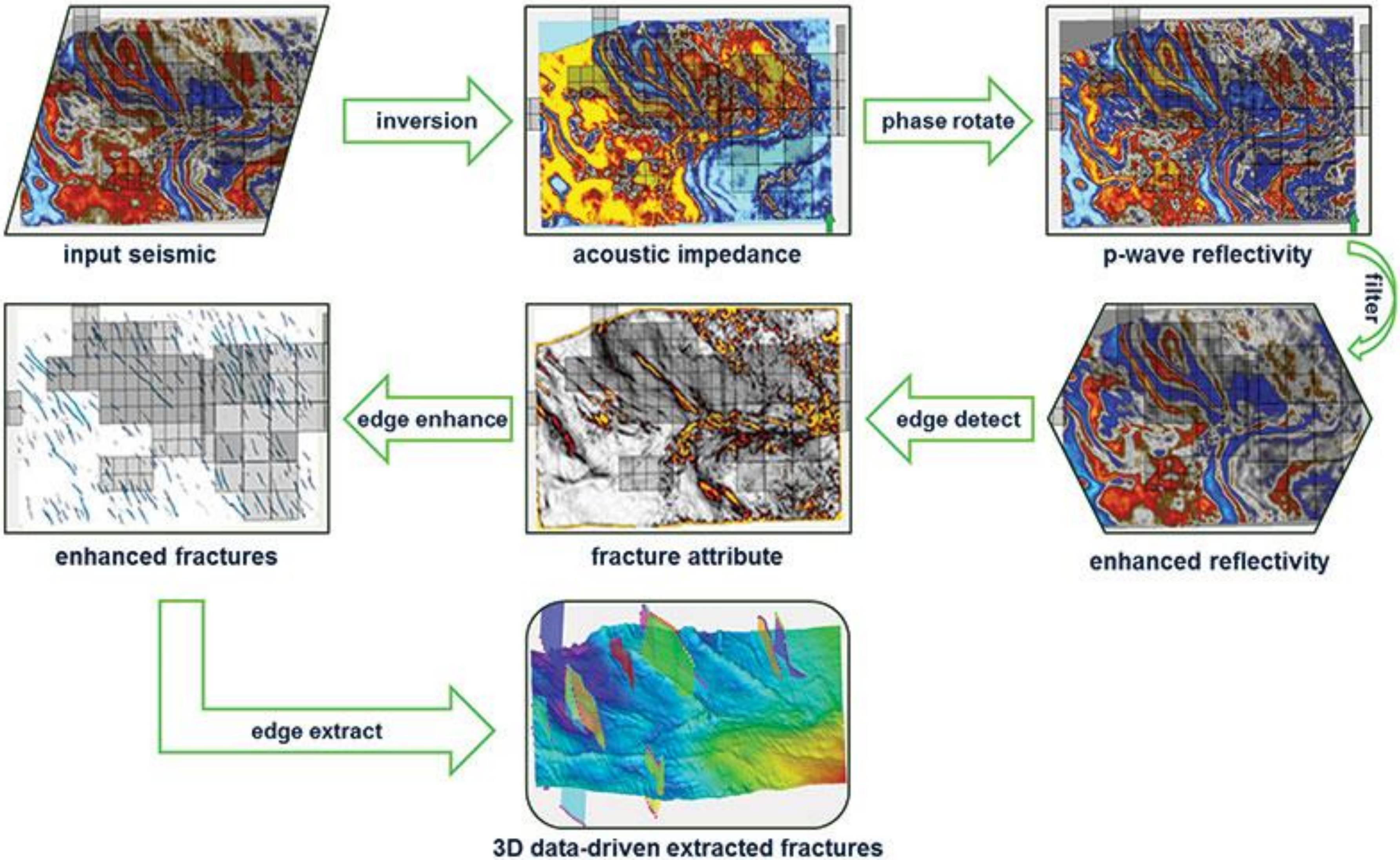

Figure 1. Seismic data-driven high-resolution fracture extraction workflow.

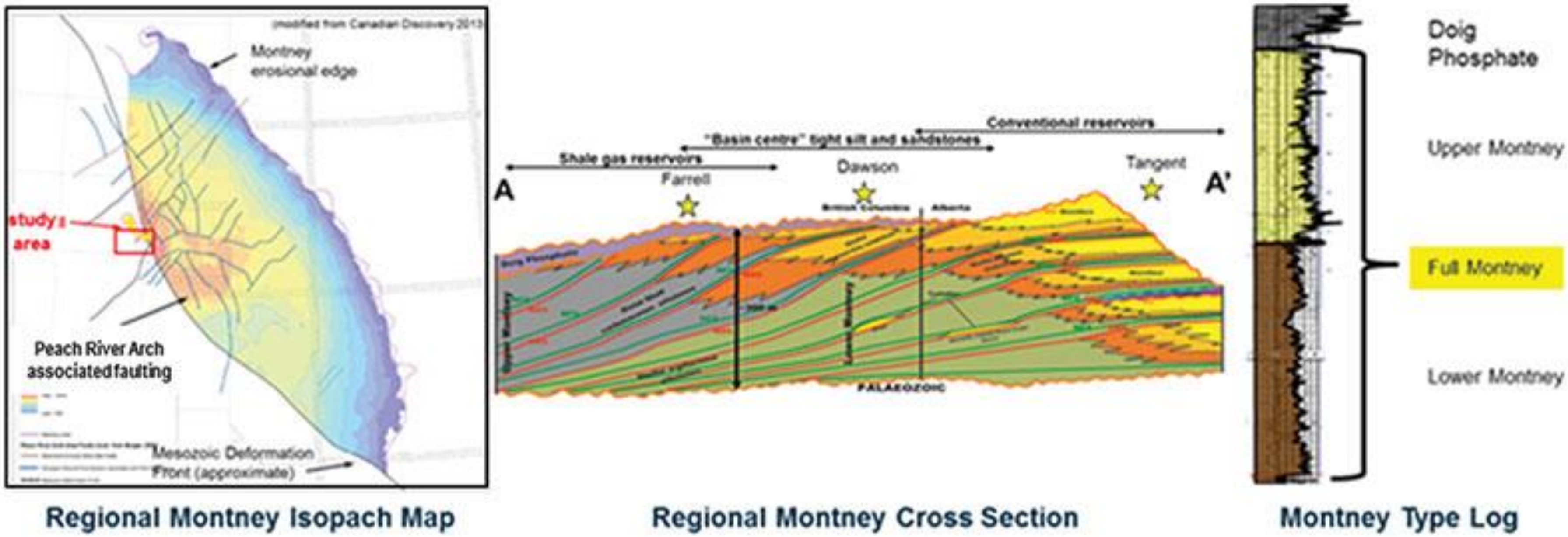

Figure 2. The regional geology of the Montney Formation.

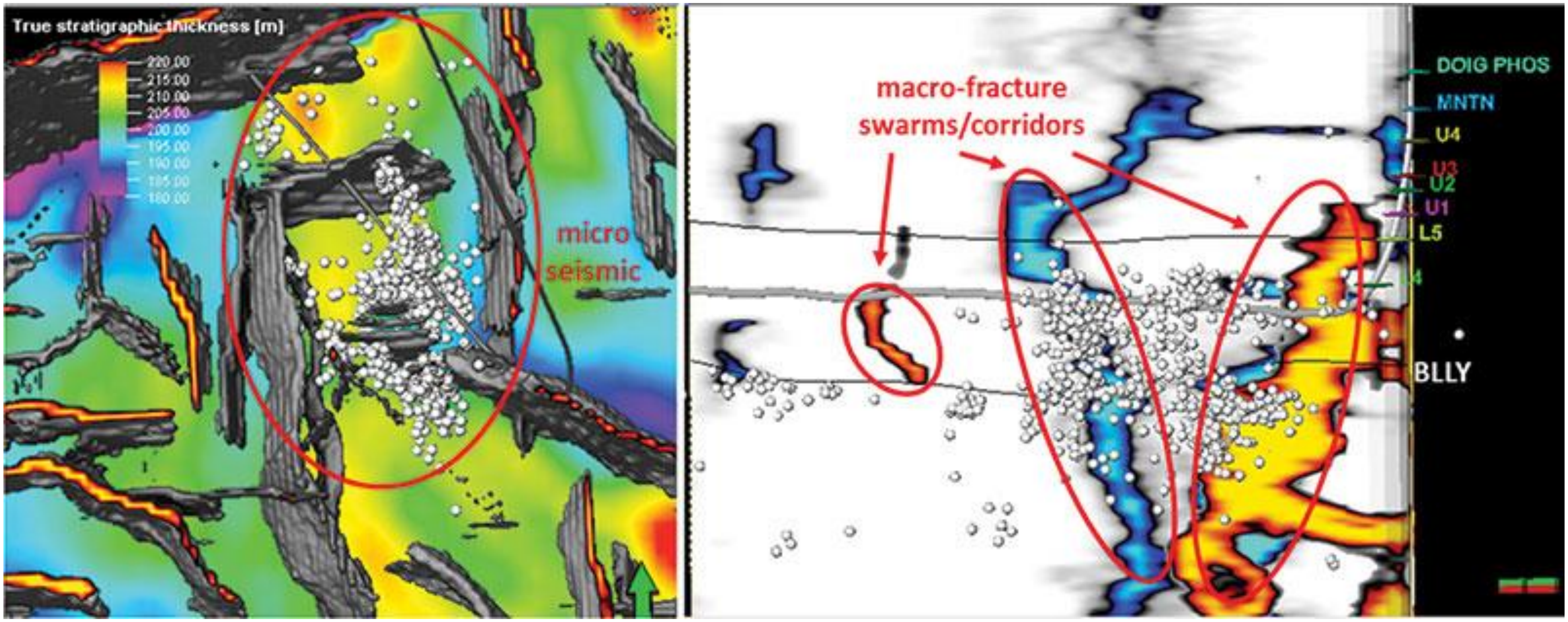

Figure 3. Applying extracted seismic fracture networks to completions analysis.

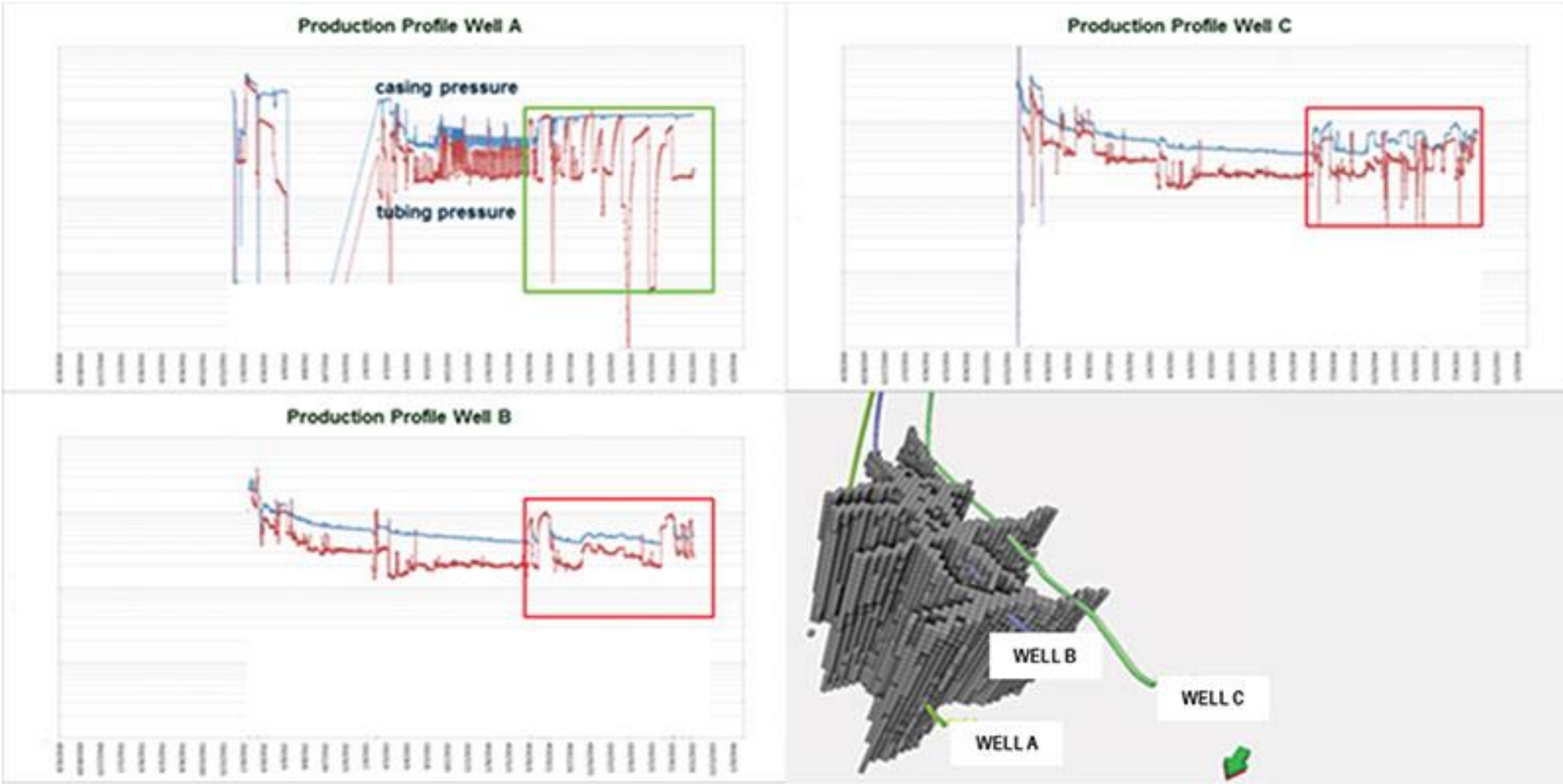

Figure 4. Applying extracted seismic fracture networks to production analysis.

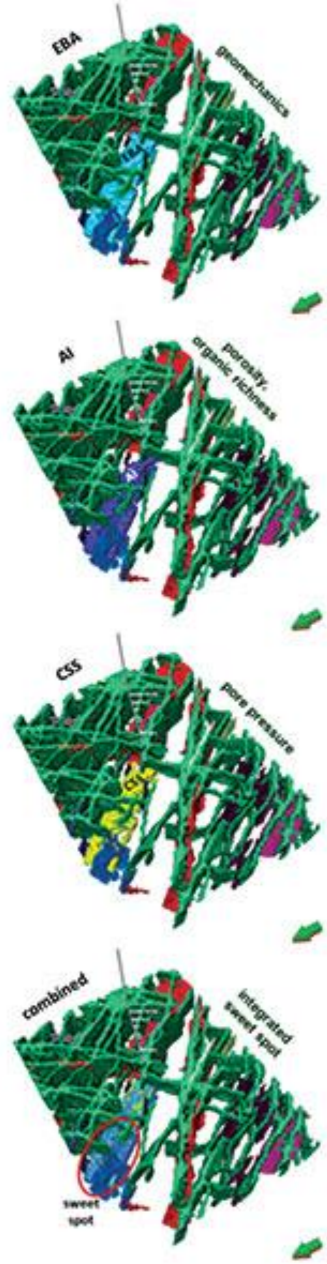

Figure 5. Applying extracted seismic fracture networks to well planning.