Introduction to this special section: Imaging faults and fractures

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The exploration and management of subsurface reservoirs relies heavily on unraveling the intricate complexities of faults and fractures. In this special section, we present a collection of papers that, in the absence of world-class outcrop exposures such as that shown on this issue's cover, utilize various data sets and geophysical processing techniques to illuminate fault and fracture networks. The collected papers address a spectrum of fault- and fracture-related topics pertinent to scientists across disciplines, spanning hydrocarbon plays to geothermal systems and carbon storage sites.

Chatellier provides valuable insights into identifying faults and fractures in the Western Canadian Sedimentary Basin (WCSB) using simple geologic tools and approaches, without relying on seismic reflection data. The author's work reveals extensive strike-slip fault systems, detachment planes, and examples of fault locking and alternate fault activity — important considerations for hydrocarbon exploration and production. Notable takeaways include alignments of earthquakes, drilling/production anomalies, and surface features that elucidate complex subsurface fault networks; detachments that impact reservoir quality and compartmentalization; and outcrop analogs that demonstrate intricate fault interactions. This paper underscores the power of geologic observations and multidisciplinary integration to recognize influential structures. Geoscientists will benefit from its unique perspectives and structural concepts that can aid seismic interpretation and drive prospect generation in the WCSB and other basins worldwide.

Gaiser et al. examine the relatively untapped potential of using shear-wave splitting reflectivity contrast ($\Delta\gamma^{(S)}$) for imaging faults and fractures. Through analysis of 3D nine-component data from the Midland Basin and 3D three-component data from the Washakie Basin, the authors demonstrate the high sensitivity of $\Delta\gamma^{(S)}$ for detecting subsurface fractures. They highlight cases where $\Delta\gamma^{(S)}$ from converted PS waves reveals fracture lineaments and faults that pure P waves do not image. After reviewing quantitative development of $\Delta\gamma^{(S)}$ over the past 35 years, they derive the PS-wave response and show that residual S-wave energy remaining after splitting analysis is proportional to $\Delta\gamma^{(S)}$. Though scarcely utilized to date, the authors build a compelling case that high-resolution $\Delta\gamma^{(S)}$ has valuable application for fracture characterization and could provide key insights undiscovered by P waves alone. They encourage further investigation by the exploration community into this relatively untapped S-wave attribute.

Salazar Florez and Bedle demonstrate the usefulness of geometric seismic attributes such as aberrancy for enhancing fault visualization, especially for subseismic faulting scenarios. Using 3D seismic data over the Kevin Dome CO_2 storage site, the authors compare conventional attributes such as coherence and curvature to aberrancy for mapping faults. They find that including aberrancy attributes reveals additional fault planes aligned with fracture orientations seen in wells, which were missed by classic seismic attributes. The authors also show that integrating aberrancy with other geometric attributes improves results from multiattribute analysis and unsupervised machine learning techniques such as self-organizing maps and generative topographic mapping. This study makes a strong case for interpreters to incorporate aberrancy attributes when mapping complex fault networks, particularly where seismic resolution challenges standard approaches. The workflows presented could aid in fault characterization and risk assessment for carbon storage and geothermal site selection.

The collection of papers in this special section underscores the pivotal role of imaging intricate fault and fracture networks across critical subsurface applications, from conventional oil and gas to emerging fronts such as carbon sequestration. As demonstrated throughout these studies on the WCSB, the Midland Basin of West Texas, and the Kevin Dome site in Montana, unraveling structural complexities hinges on multidisciplinary integration and novel seismic attributes attuned to small-scale features. Key takeaways for the interpretation community include leveraging fundamental geologic observations where seismic falls short; recognizing the largely untapped potential of shear-wave splitting reflectivity for fracture detection; and incorporating aberrancy and other geometric attributes to enhance visualization, particularly for subseismic faulting. By highlighting innovative workflows and overlooked data potentials, these complementary approaches collectively pave the way for overcoming persistent challenges in fault and fracture characterization. As demands grow for accessing unconventional reservoirs and engineering complex subsurface projects, the novel concepts and attributes showcased here may prove instrumental in tipping the scales from risky prospects to safe, sustainable resource management. TLE

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