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GEOPHYSICALcorner

China Study II: Detecting Fractures

The authors thank the management of Sinopec and Southwest Petroleum Branch for granting permission to present this paper – especially Xu Xiangrong, president of Southwest Petroleum Branch Company, whose commitment to cutting-edge technologies and ongoing leadership ensured the ultimate success of this full-wave imaging project.

The authors also thank the other contributors to the interpretation project, including AAPG member Roger Palomino and Doug Allinson, Felix Diaz, Reinaldo Nossa, Santi Randazzo and Jim Simmons.

(The Geophysical Corner is a regular column in the EXPLORER, edited by Bob A. Hardage, senior research scientist at the Bureau of Economic Geology, the University of Texas at Austin. This month's article is the first of a two-part series: A full-wave case study detecting fractures with 3D3C seismic data in the XinChang Field of China's Sichuan Province.)

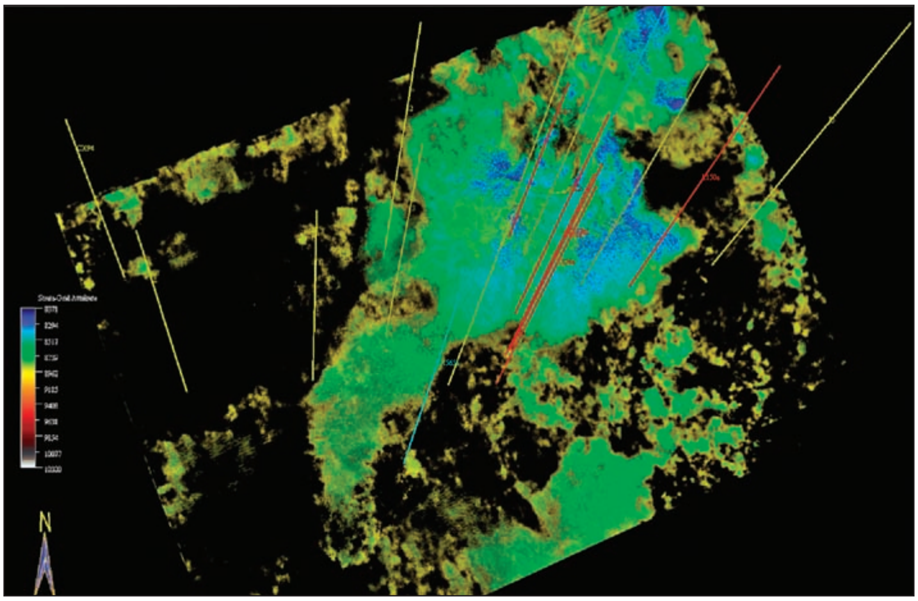

Figure 1 – Shear impedance used to identify location of the source rock in the XinChang survey area.

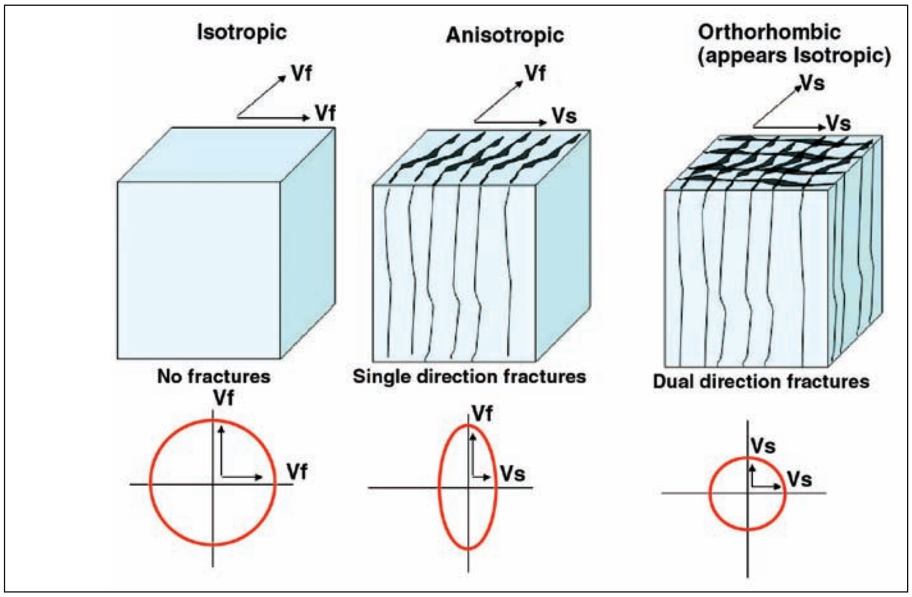

Figure 2 – Isotropic vs. anisotropic effects on velocity. V_f = fast S-wave velocity; V_S = slow S-wave velocity.

By JOHN TINNIN
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This two-part series describes how Sinopec's local operating company, Southwest Petroleum Branch, utilized full-wave seismic data to improve production from a fractured tight-gas reservoir in XinChang Field, Sichuan Province, China.

Historically, this region has been a prolific gas producer – shallow prospects were depleted early, and the reservoirs currently targeted are now at the base of a terrestrial sequence some 20,000 feet thick.

These deeper Triassic reservoirs are low porosity (less than 4 percent) – but specific areas within the reservoir can be highly fractured.

Production has been declining, and the region now needs an injection of new technology to sustain production.

Upon completion of the 3D3C seismic data processing described in last month's column, we initiated post-processing and interpretation activities. This portion of the workflow involved integrating available well, outcrop and core data with the processed 3D3C seismic data.

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The post-processing included:

✓ Acoustic, shear and elastic inversions.

✓ Generation of seismic attributes.

✓ Shear-wave splitting analysis to help define lithology, stratigraphy and fracturing.

These steps built better structural and stratigraphic models, mapped fracture patterns and intensity, and provided an improved understanding of the region's geologic and tectonic history.

* * *

The Sichuan Basin underwent dramatic subsidence rates during the early Mesozoic. Burial of the reservoir to depths of 20,000 feet or more occurred soon after deposition and before gas was generated in surrounding and underlying source rocks.

The resulting compaction reduced reservoir porosities to less than 4 percent, causing reservoir rocks to be almost impermeable. As a result, production in XinChang Field is fracture dependent.

The fracture network:

✓ Made gas charge possible.

✓ Created a major part of the gas storage capacity.

✓ Is the mechanism by which gas stored in matrix porosity can be accessed during production.

Interbedded sand-shale sequences are the best exploration targets – these thinner-bedded, brittle layers fracture more easily and with higher density than do their thicker counterparts.

The integration of geological history with production data resulted in a model showing that storage capacity in the reservoir depends on interconnection of fractures in fault-damage zones and on the connections that these damage zones make with naturally fractured sandstone reservoir beds.

* * *

The densely sampled, full-azimuth P-wave data acquired in this study supplied higher frequencies than existed in legacy seismic data, resulting in an improved structural picture with excellent fault resolution. However, because sands and shales had similar acoustic impedances, lithology could not be determined from P-wave data alone.

Fortunately, converted-shear (C-wave) data were valuable for discriminating lithology in these rocks and delivered vital insights into the stratigraphic architecture of targeted reservoirs. The C-wave data provided a means to define interbedded, sand-shale sequences that were areas of optimal fracture intensity and enabled delineation of source rock (figure 1).

Because fractures dominate storage and movement of gas in XinChang Field, developing a tool to identify and map the best fractured zones was a high priority. The C-wave dataset

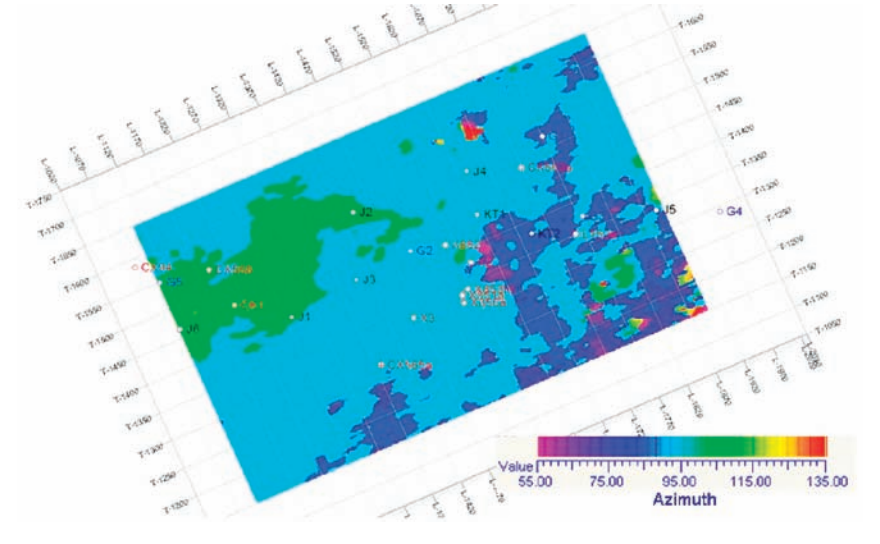

Figure 3 – Azimuth of shear fast direction from the shear-wave splitting analysis.

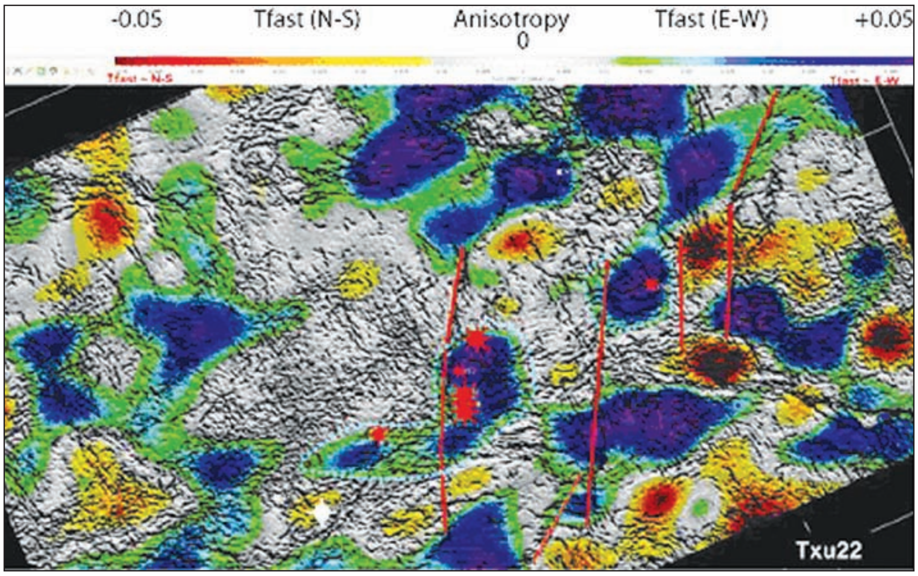

Figure 4 – This display shows a combination of attributes including similarity, fracture orientation and density from shear-wave splitting, and small faulting. The size of the well symbols shows the relative production from the wells. The color bar is scaled to show anisotropy, with 0 being isotropic (gray), and gets more anisotropic in the east-west direction as it approaches +0.05 (colors go from light green to deep purple). The scale in the other direction toward -0.05 (colors go from yellow to deep red) indicate more anisotropy in the north-south direction.

proved to be that needed tool, because the data provided azimuthal definitions of S-wave velocity differences that could be used to map variations in fracture orientation and intensity.

As illustrated in figure 2, seismic wave propagation is minimally affected **parallel** to the dominant fracture trend in rocks that have a simple one-directional fracture system (the “fast direction,” V_{fast}), but a maximum velocity reduction (the “slow direction,” V_{slow}) is aligned **perpendicular** to the oriented fractures.

With multiple sets of fractures, such as the third orthorhombic case in figure 2, velocity is reduced in all directions, and V_{fast} approaches V_{slow}, resulting in this type of fractured volume appearing to be an isotropic medium. This model implies multidirectional, interconnected fracture sets should be located in areas where there are smaller amounts of anisotropy and also reduced C-wave velocity.

This information can be utilized to search for well locations that will penetrate multi-directional fracture zones.

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As described last month, fracture orientation was determined by deriving the azimuths of V_{fast} from shear-wave splitting analyses performed in a layered-Earth approach.

In the XinChang survey area, regional geology, borehole breakout and FMI log results all indicate that the current maximum horizontal stress is oriented along azimuths of 80-110 degrees. This information validated the shear-wave splitting results for orientation in the uppermost Earth layer, which has an average orientation of 95 degrees (figure 3).

It also is important to note that fractures oriented close to this principle stress direction are more likely to be open, though the extreme overpressure in this area keeps other fractures open as well.

Knowing fracture orientation in zones of higher anisotropy, where a single set of parallel fractures is more likely to exist, can help in designing directional or horizontal wells that will intersect more fractures, yielding higher production in these areas.

Fracture density was determined from the analysis of the shear-wave splitting, specifically by measuring the time difference between reflections observed in V_{fast} and V_{slow} shear volumes.

Figure 4 shows a display of the V_{fast} – V_{slow} time difference data (in color) overlain on a similarity plot. Note that the light green areas, where the best producing wells are located, show less anisotropy than do areas with less productive wells and also correlate with the slower V_{fast} velocity zones (as predicted above).

FMI logs available in some of these wells confirm multi-azimuthal fractures, not a single set of oriented fractures, are present in the better producers and support the model of less anisotropic behavior with dual direction fractures.

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Insights from similarity processing, curvature attributes and shear-wave splitting analysis provided three independent fracture density measures that were integrated into discrete fracture network (DFN) models and fracture maps. The integration of interpretations from all disciplines – outcrop analysis, seismic, core, well log, and well production data – enabled the interpretation team to select 19 new well locations – three of which have been drilled and completed as producers.

One of these new wells is the most productive well in the area. The Xin-2 and Xin-3 wells were mentioned in the January 2008 EXPLORER as two of the most significant wells in the Far East, producing 18 mmcfgd and 8.2 mmcfgd, respectively, from a 500-foot gas column. ❏

(Editor’s note: AAPG members John Tinnin, James Hallin and Jim Granath, and Peter Stewart are all with ION Geophysical/GX Technology.)