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GEOPHYSICALcorner

China Study: Detecting Fractures

(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.)

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

This month we detail the data-acquisition technology and the data-processing workflow that produced high-resolution images and yielded fracture information that correlated with well production.

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.

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Legacy seismic data correlate poorly with existing wells, and the quality of existing seismic data is insufficient to define reservoir targets. Attention was focused on implementing a seismic program that would allow the fracture network to be understood so future drilling locations could be determined.

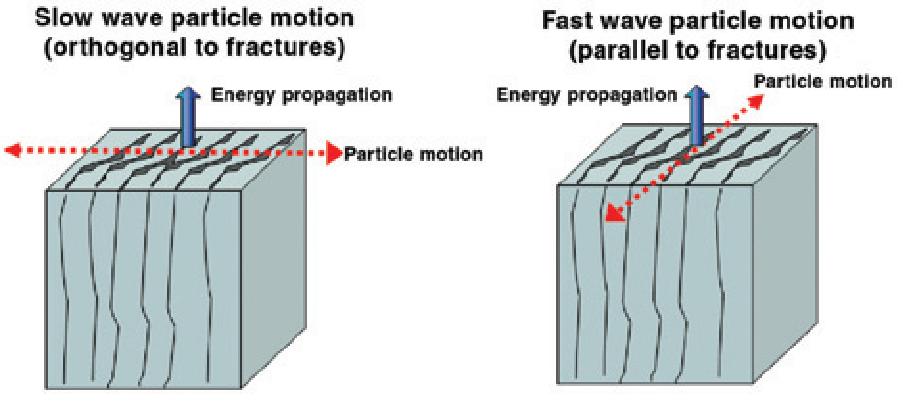

Figure 1 – Polarized shear-wave: parallel and orthogonal to fractures.

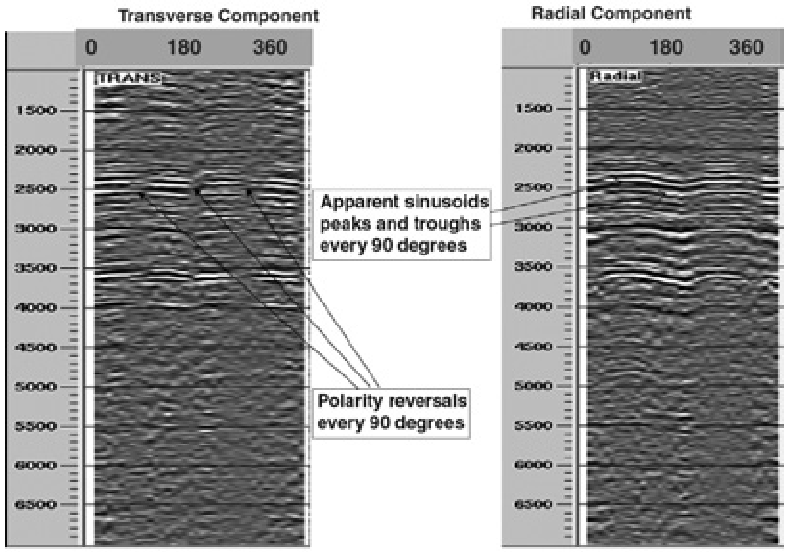

Figure 2 – Azimuth-sector gathers displaying characteristic signatures for radial and transverse components.

In this effort, a task force of ION and SWPB geoscientists found that the region produces high levels of coherent converted-shear (C-wave) energy. The team concluded that C-waves had the potential of providing stratigraphic, lithologic and fracture detail that would be crucial for understanding the reservoir and for optimizing well placements and reducing drilling risk.

The design team recommended a data-acquisition program involving dense spatial sampling, full offset and azimuth distributions, and the adoption of 3C digital sensors.

With the design approved, a new survey was acquired in 2004 using an

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I/O System Four® recording system and VectorSeis® full-wave 3C sensors.

It became apparent shortly after data-acquisition began that the new P-wave data were high quality, and that bandwidth and signal-to-noise ratios were a step change improvement over legacy seismic data. In addition, high-quality, full-azimuth C-wave data were also recorded.

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The data-processing workflow that was implemented resulted in high-resolution C-wave images. An important byproduct of this workflow was information related to fracture orientation and to fracture intensity.

The first step in the data processing was to rotate horizontal components from their recorded field orientations to their source-receiver azimuths, or “radial,” directions.

If seismic data are azimuthally isotropic, all C-wave reflection energy would be concentrated on the radial component, and data acquired by the transverse sensor could be discarded. However, after rotating the XinChang data to radial/transverse coordinates, a significant amount of C-wave energy remained on the transverse component.

This data behavior confirmed the presence of shear-wave splitting, which occurs when a shear wave encounters an azimuthally anisotropic layer such as one of the XinChang fractured reservoir units.

In S-wave splitting, the C-wave polarizes into two new waves, a phenomenon known as “birefringence.” One of the new split waves is polarized parallel to, and the second orthogonal to, the fracture orientation.

The velocities of the two waves differ – the faster wave being polarized parallel to the fractures, and the slower wave polarized orthogonal to the fractures (figure 1).

In addition, each of the new waves splits again when it encounters a new anisotropic layer, resulting in a complicated mix of waves arriving at each sensor.

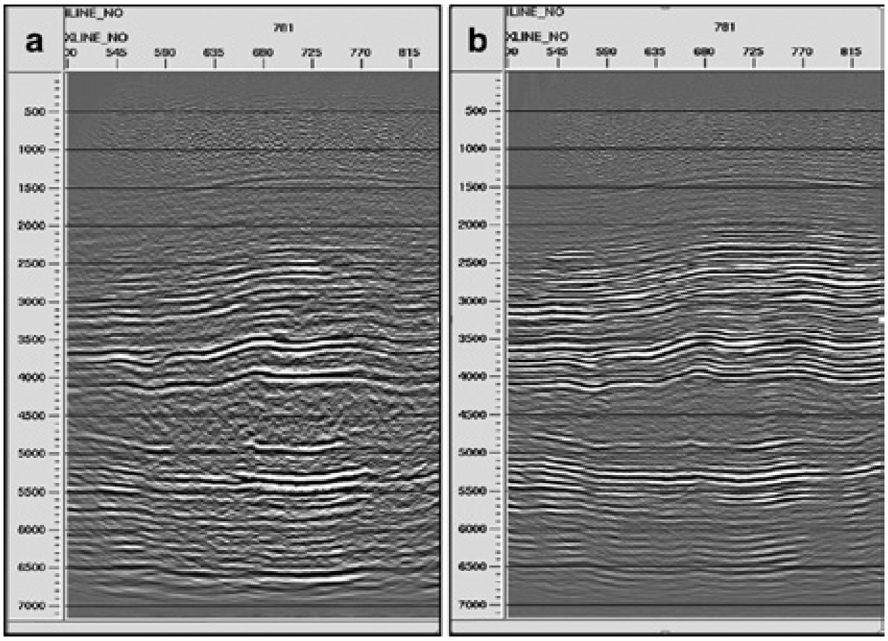

Figure 3 – Converted-wave images before (a) and after (b) layer-stripping anisotropic corrections.

Shear-wave splitting can yield valuable information regarding fractures; however, unless addressed correctly, wave-splitting reduces the bandwidth of stacked or migrated C-wave images. Thus, our data-processing workflow was modified to capitalize on the shear-splitting that was detected.

After sensor rotation to radial/transverse coordinates, the main components of the workflow included surface wave attenuation, resolution of shear-wave statics, surface-consistent signal processing and Q compensation. These steps were performed independently on the radial and transverse components.

Next, the data for each component were sub-divided into 36 10-degree, azimuth sectors. Each azimuth sector was migrated separately via a prestack C-wave time migration. This migration step required a velocity model for both P and S wavefields.

Because it is difficult to derive shear-wave velocities from converted-wave data, we developed a novel scheme in which P and S velocity fields were re-parameterized into new variables that could be estimated from the C-wave data.

Following migration, each sector volume was subjected to residual move-out correction, muting and stacking. The azimuth volumes were then re-assembled into azimuth-sector gathers for each migration bin.

For any migrated output location, a C-wave reflection has a characteristic signature on the radial and transverse components as a result of interference patterns between the polarized fast and slow waves. Typically, radial data have a sinusoidal type of behavior with azimuth, while transverse data exhibit polarity reversals every 90 degrees of azimuth (figure 2, previous page). If these two C-wave responses were stacked as is, the result would be a low-resolution image (figure 3a, previous page).

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The most important step in the data processing was our layer-stripping anisotropic correction. This procedure removed the effects of shear-wave spitting at each anisotropic boundary by simulating the effect of an isotropic medium.

A single anisotropic layer was stripped to form an isotropic layer in the following manner:

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✓ Step 1 – Knowing that azimuths corresponding to polarity reversals observed on the transverse component define fracture orientation, these azimuth angles were used to rotate the data from radial/transverse to fast/slow directions.

✓ Step 2 – A cross-correlation between fast and slow data determined the time lag between these two wave modes; a static correction was then done to time align slow and fast data.

✓ Step 3 – An additional rotation back to radial and transverse coordinates concentrated all of the energy onto the radial component and produced azimuthally isotropic data. These adjusted data were stacked to form a high-resolution C-wave image (figure 3b, previous page).

An important byproduct of step one is fracture orientation. For any particular layer, maps of fracture orientation throughout the entire data volume were generated using the azimuth angles determined in this data-processing step.

Second, the amount of fracturing is related to travel-time differences between fast and slow shear-waves, and the cross-correlation in step two yielded time-difference information that was used to infer fracture intensity.

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Next month's article will detail the post-processing and interpretation workflow that led to 19 new drilling locations.

Three of these sites have been drilled and completed as gas wells, and one of these wells is now the most productive well in the area. ❑

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