Integrating P-Wave and S-Wave Seismic Data to Improve Characterization of Oil Reservoirs

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ABSTRACT

Conventional seismic stratigraphy is one of the major traditional tools used to detect the internal complexities and heterogeneities within oil reservoirs. But the concepts and principles of conventional seismic stratigraphy are based only on P-wave seismic data, with little or no applications of S-wave seismic data to reservoir characterization. The complete understanding of reservoir characterization can be achieved only by expanding the principles and concepts of conventional seismic stratigraphy to a new approach described as vector-wavefield seismic data in which geologic systems are interpreted using both P-wave and shear (S) wave (both fast-S, and slow-S data) images of the subsurface sequences. This is so, because, sometimes spatially coincident P and S seismic profiles do not show the same reflection sequences or the same lateral variations in seismic facies character. This observation leads to the conclusion that in complex geologic systems, the sedimentary record must be described by one set of P-wave seismic sequences (and facies) and also by a second, distinct set of S-wave seismic sequences (and facies).

Laboratory studies of P-wave velocity (Vp) and S-wave velocity (Vs) in cores have shown that the ratio Vp/Vs has a distinct value for different types of rocks. Also, these Vp/Vs ratios are consistent over a wide range of porosities and confining pressures, whereas, each velocity (Vp or Vs) varies when either porosity or confining pressure changes. Thus the combination of P and S seismic data provides a capability to identify subsurface distributions of rock types through Vp/Vs ratios that is not available from P-wave seismic data alone. Particularly important is the phenomenon that S-wave split into fast-S and slow-S components when they

encounter strata that are highly anisotropic. This petrophysical sensitivity has been utilized to detect and map fractured rocks with surface-recorded S-wave reflection data. P-waves exhibit little sensitivity to anisotropic rock properties, compared to the sensitivity of S-waves. Thus, 9-component seismic data allow seismic stratigraphy concepts to be expanded into anisotropic rocks where conventional P-wave-based seismic stratigraphy does not apply, or applies in a limited, and weak fashion.

The 3-D, 9-component data being used in the study were recorded using midpoint imaging concepts that are standard practice in the oil and gas industry. Three orthogonal vibrators used to generate 9C (9-component) VSP (vertical seismic profile) are vertical vibrator, inline horizontal vibrator and crossline horizontal vibrator. The geometry of the three orthogonal vibrators created stacking bins measuring 110 ft x 82.5 ft across the image space, with a stacking fold of 20 to 24 in the full-fold area of each data acquisition grid. The recording template that moved across the image space consisted of six parallel receiver lines, each spanning 96 receiver stations. Three-component geophones were deployed at each receiver station of this 3-D grid. Each receiver string deployed at a receiver station contained three 3-C geophones, and all three geophones were positioned in an area spanning 3 to 5 feet to form a point array. The geophones were planted carefully to position one horizontal element in the inline direction (the direction that the receiver line was oriented) and the second horizontal element in the crossline direction.

Large (52,000 lb) vibrators were used to generate the 9-component data. Three distinct sets of vibrator units occupied each of the source stations. Vertical vibrators comprised one of these source arrays. These vertical vibrators generated a wavefield that was dominated by P-waves, and that wavefield was recorded by the rectangular grid of 3-component sensors in the recording template that was centered on the source station. S-wave dominated wavefields were generated by horizontal vibrators. One set of horizontal vibrators applied a shearing motion in the inline direction at each source station, and a second set of horizontal vibrators applied a shearing motion in the crossline direction. The wavefields produced by these two distinct polarized S-wave sources were recorded as individual records by the 6-line template of 3-C receivers centered on the active source station.

Preliminary analysis of data from the study area shows that incident full-elastic seismic wavefield reflected four different wave modes, P, fast-S (SH) , slow-S (SV) and C. These four wave modes image unique geologic stratigraphy and facies and at the same time reflect independent stratal surfaces. It was also observed that P-wave and S-wave do not always reflect from the same stratal boundaries. At inline coordinate 2100 and crossline coordinates of 10,380, 10430, 10480 and 10,520 the P-wave stratigraphy shows coherency at time slice 796 m/s and C-wave stratigraphy shows coherency at time slice 1964 m/s at the same inline coordinate and crossline coordinates of 10,400 to 10470. At inline cordinate 2800 and crossline coordinate 10,650, P-wave stratigraphy shows coherency at time slice 792 m/s and C-wave stratigraphy shows coherency at time slice 1968 m/s.

ARTICLES AND PRESENTATIONS

Conference Presentations

- **Aluka, I.J. “Integrating P-Wave and S-Wave Seismic Data to Improve Characterization of Oil Reservoirs” US DOE HBCU/OMI Contract Review, Pittsburgh, PA, June 5-6, 2001.**
- **Aluka, I.J. “Integrating P-Wave and S-Wave Seismic Data to Improve Characterization of Oil Reservoirs” US DOE HBCU/OMI Contract Review, Pittsburgh, PA, June 3-4, 2002.**
- **Aluka, I.J. “Elastic Wavefield Seismic Stratigraphy” US DOE HBCU/OMI Contract Review, Pittsburgh, PA, June 3-4, 2003.**