Characterizing Sandstone Reservoirs

The application of Poisson impedance inversion proves to be a favorable attribute for sandstone reservoir characterization.

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One of the challenges in characterizing sandstone reservoirs is to be able to differentiate lithology and fluids in the reservoir. Rock physics constants such as bulk modulus (k), shear modulus (μ), Young's modulus (E), and Lambda-rho (λρ) attributes are commonly used for discriminating lithology (sandstones vs. shale) or fluids (gas, oil, and water). P-wave velocity (VP) and S-wave velocity (VS) or P impedance (IP) and S impedance (IS) plus density (ρ) are prerequisites for the computation of all the attributes mentioned above.

Over the last few years, prestack seismic inversion has been used to estimate these attributes. This seismic inversion yields IP, IS, Poisson's ratio (via VP/VS ratio), and density. The robust determination of density from seismic requires very long offsets and noise-free data, which are seldom available. In order to avoid this stringent requirement of density, it is usually computed as its product with other attributes such as $\lambda\rho$, $\mu\rho$, kρ, and Eρ. Finally, the cross-plotting pair of these attributes is used for discriminating lithology and fluid content.

It is usually noticed that the cross-plotting of IP vs. IS for data from a thin zone enclosing a gas sand reservoir yields a cluster of points corresponding to gas sand somewhat separated from the cluster of points coming from the background shale. The separation between these clusters depends on the impedance contrast between the litho-fluid and background lithology. Moreover, for enhanced separation between gas sand and background shale, another attribute combination such as the $\lambda\rho$-$\mu\rho$ cross-plot is used. This cross-plot exhibits more separation since gas sand shows lower values of $\lambda\rho$ and higher values of $\mu\rho$ than the background shale.

On these cross-plots it may be difficult to discriminate the litho-fluid distribution where clusters are not completely separated. But in such cases rotating the axes to be parallel with the trends would ensure a distinct discrimination of the litho-fluid distribution. This rotation can be achieved by computing an interesting attribute, Poisson impedance (PI). It incorporates the information of Poisson's ratio and density. Mathematically, it can be expressed as PI=IP-cIS where c is the term that optimizes the rotation. The value of c needs to be determined from the regression line of the cross-plot of the IP and IS logs for the wet trend. The inverse of the slope can be used as the c value. Additionally, the target correlation coefficient analysis (TCCA) method can be used to calculate c.

The automatically generated correlation coefficient between the PI curve with different c values
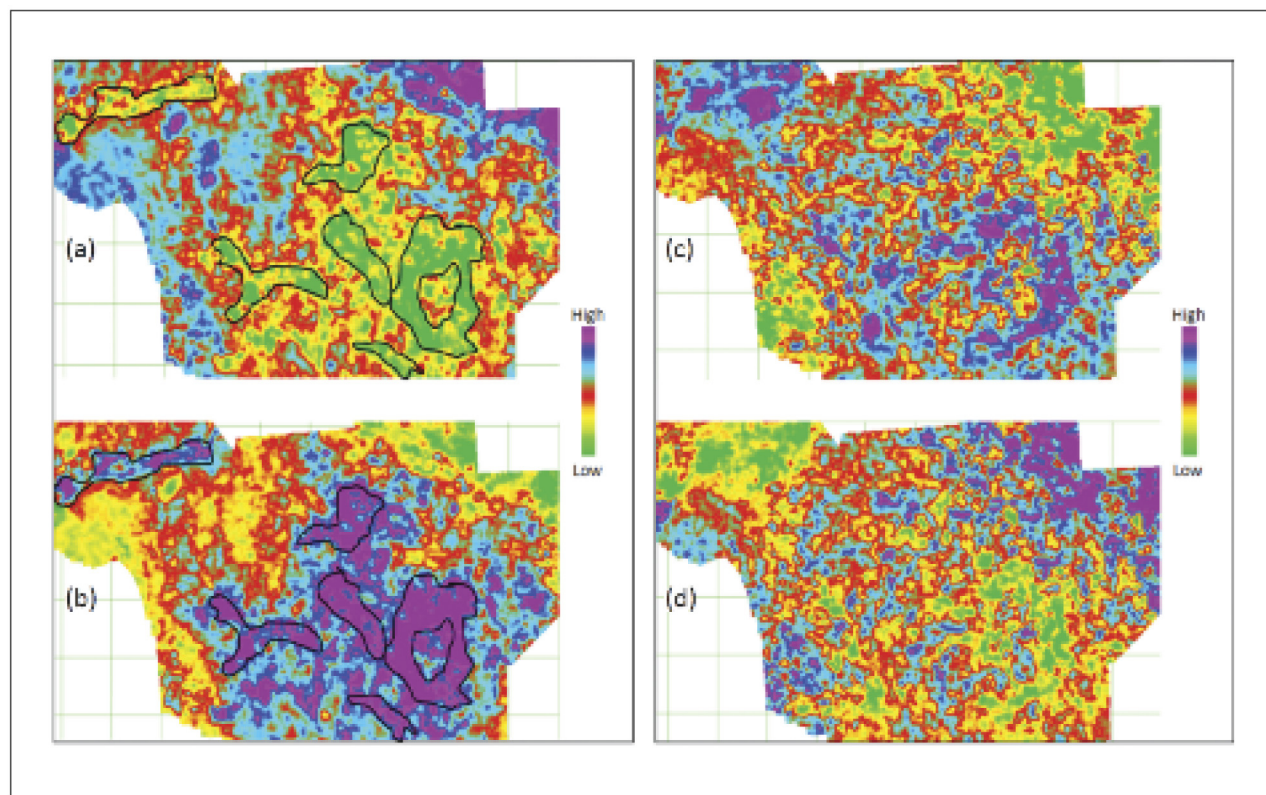
Horizon slices of (a) LI and (b) FI over the 10-ms window are centered at the halfway horizon. As low LI and high FI correspond to the sandstone, the presence of sandstone has been mapped laterally. Similar horizon slices over the 10-ms window are centered at the halfway horizon, which is shifted 30 ms below. Note the disappearance of the lateral spread of the sandstone. (Image courtesy of Arcis Seismic Solutions, TGS)

and the gamma-ray and porosity curves is computed. The c value corresponding to the maximum correlation coefficient for GR is used to compute an attribute that would emphasize lithology and so is known as lithology impedance (LI). Similarly, fluid impedance (FI) is computed using a c value that corresponds to the maximum correlation coefficient for the porosity curve. Cross-plots between LI and GR can now be constructed that show the advantage of LI in distinguishing sandstone from shale. Fluid content is predicted using the linear relationship exhibited on the cross-plot of FI vs. porosity.

The workflow for PI involves computing IP and IS volumes from prestack seismic data. For computing these prerequisites, simultaneous inversion is performed. This inversion method facilitates the estimation of the P and S impedance directly from the prestack seismic gathers without first estimating the P and S reflectivities from prestack seismic data and then transforming them to impedance. This inversion starts with an initial low-frequency model and generates synthetic traces from it. For generating synthetic traces, angle-dependent wavelets are computed statistically from the input data by assuming it to be zero phase and are then convolved with the modeled reflectivities. Further, the model impedance

value is changed in such a manner that the mismatch between the modeled angle gather and the real angle gather is minimized in a least-squares sense. Having IP and IS volumes, LI and FI are then derived using equations derived from well log curves analysis.

Figure 1a shows the horizon slice of LI taken at the halfway horizon. The same horizon slice of FI is shown in Figure 1b. From the analysis carried out on well log curves, it was concluded that low LI and high FI correspond to the sandstone; with that in mind, the presence of sandstone laterally was mapped on these slices as indicated with the black outline. Similarly, the horizon slices of LI and FI are shown in Figures 1c and 1d, respectively, when the halfway horizon is shifted 30 milliseconds (ms) below. It is noticed here that the presence of sandstone disappears on these slices.

In conclusion, PI is a very favorable attribute for sandstone reservoir characterization. Using the TCCA method, two attributes of PI can be derived, LI and FI. The results on log data show that sandstone and shale can be well distinguished by LI. Also, FI provides a potential pore space content identification. By integrating geological, petrophysical, and well test data, the sandstone reservoirs can be characterized properly, and new prospects can be identified directly. ■