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Future Of Geophysics Guided By Quest To Accurately Describe Reservoir Rock Properties

"The important rock properties comprise a relatively short list: Useful information that can go toward answering most, if not all, of the questions is contained in seismic data. Progress may be defined as any technique that captures more useful information or renders the information more easily and unambiguously interpretable."

Roger A. Young and Robert D. LoPiccolo

HOUSTON–The future of geophysics is where it has always been, in the rocks. To best serve the oil and gas exploration business, the ultimate–if unobtainable–goal of geophysics would be a complete and accurate rendition of all of the important properties of rocks in the subsurface. Achieving this idealistic goal would not only allow us to say where there were deposits of oil and gas, but how large the deposits were, how fast the products would come out of the ground, the optimum number of wells needed to exploit the reserves, and what kind of conditions would be encountered while drilling and producing.

The important rock properties we need to know comprise a relatively short list:

- What is the lithology–is it a reservoir rock, a nonreservoir rock, a seal?
- What is the geometry of the rocks–how deep are they and are the reservoirs in a trapping configuration?
- What is the porosity of the reservoir rock?
- What is the permeability of the reservoir rock?
- What is the fluid type in the reservoir?
- What are the pore pressures in the rocks?

Most, if not all, of the answers to these questions is contained in seismic data. Progress may be defined as any technique which captures more useful information or renders the information more easily and unambiguously interpretable.

And, our progress has been remarkable. Powered by the large research and development budgets of the majors, we have seen the advent of common depth point imaging, three-dimensional and multicomponent data acquisition, a myriad of energy sources, geophysical workstations, and room-sized interpretation centers where one can literally immerse himself in his data. Recent progress in depth imaging, pre-stack interpretation, and 3-D visualization will certainly continue with more sophisticated algorithms and more powerful computers.

Data Preparation

Interpretation will always be a critical part of the process of making seismic data useful. One may consider three levels of data preparation leading to an interpretable data set:

- The first level is the set of operations (statics, muting, moveout) generally leading to a stacked record section. The object of this operation is to get a clean-looking data set with events in their spatially correct, relative positions.
- Next, various attributes may be extracted which emphasize characteristics not easily discernible in the stacked (or unstacked) section. These second-level attributes would include things such as the Hilbert-transform products (instantaneous phase, frequency, and amplitude), lambda-rho, mu-rho, AVO classes, near and far trace stacks, impedance, and velocity. This second level of data preparation yields data in a format that skilled interpreters may use to guide or constrain interpretations.
- The third level is the extraction of fundamental rock properties (lithology, porosity, permeability, fluid type, and pore pressure) from the seismic data. This level is a key part of the process known as rock-based integration; data are rendered in such a way as to be useful to all disciplines engaged in the finding and exploitation of oil and gas deposits. This is the area where future developments will have the greatest impact.

Early (and ongoing) attempts to relate various second-level seismic attributes to fundamental rock properties generally were approached through a statistical analysis. Statistical relationships quickly lose their reliability as you move away from the control points used to derive the relationship. Deterministic approaches are, by definition, based on the laws of physics and therefore should be relatively invariant throughout a data set. Both approaches have their place, and statistical techniques are especially useful where fully deterministic tools have not been developed yet.

A few examples of some work in the realm of rock-based integration are illustrative of how the future may evolve.

Seismic Petrophysics, AVO

Seismic petrophysics has been practiced in some quarters of the geophysical community for nearly a decade, but its impact is growing and it is discussed here because it is evolving into an integral part of rock-based integration.

As the name suggests, it borrows from well log analysis, where measurements of disparate physical rock properties are compared to derive estimates of useful, fundamental rock properties. For example, two commonly used well logs measure the concentration of electrons and the concentration of hydrogen atoms; neither of these values is of any great use, by itself, but when converted into appropriate units and cross-plotted, a good estimate of the porosity and lithology of the rocks is obtained. Similarly, in seismic petrophysics two independent parameters are measured and cross-plotted in order to obtain fundamental rock properties. In its most common application, seismic petrophysicists extract estimates of the shear and compressional impedances from the seismic data and cross plot them to obtain lithology, porosity, and fluid information.

AVO analysis is a technique that has a fairly long history in the ongoing effort to relate seismic data to rock properties. This deterministic approach has proven to be powerful in finding hydrocarbon-bearing reservoirs in sand-shale sequences with normal to moderate overpressures.

It is not necessarily model driven, but does require some sophisticated interpretation; not the least of which is that the AVO-type is appropriate for the geologic setting in which it was found. Attempts to apply it in highly overpressured environments and in areas with complex lithologies have resulted in more limited success. The technique is not burdened, however, with many assumptions. Calculations are straightforward and only require access to the unstacked gathers. Some proposals to expand and define the various AVO-types promise to broaden the range of application of this technique to include more lithologies through a greater range of pressure regimes.

A fourth class was added to the traditional AVO classification several years ago. This allowed interpreters to catalog and deliberately explore for another sand type in the same kinds of rocks where traditional AVO techniques had worked in the past. Perhaps as importantly, the addition of a new class signaled that a new look at AVO was in order, and a few years later, a fifth class was added.

A new scheme, which was first published last fall, encompasses a total of 10 classes or types (Figure 1). As illustrated, in this scheme conforming sands are those in which the effect of gas and cleaner lithology (less shalyness) are the same–they move points to the southwest. In nonconforming sands, gas has the same effect of moving sands to the southwest, but cleaner lithologies plot to the northeast. The traditional AVO classes correspond to type 1, 2, 3, and their characteristics are well known. Types 1 and 2 are often found in overpressured sands, and where they contain gas, they become conforming. Types 4 and 5 typically correspond to shallow sands and may signal water flow hazards. In other environments, these types may correspond to coal beds.

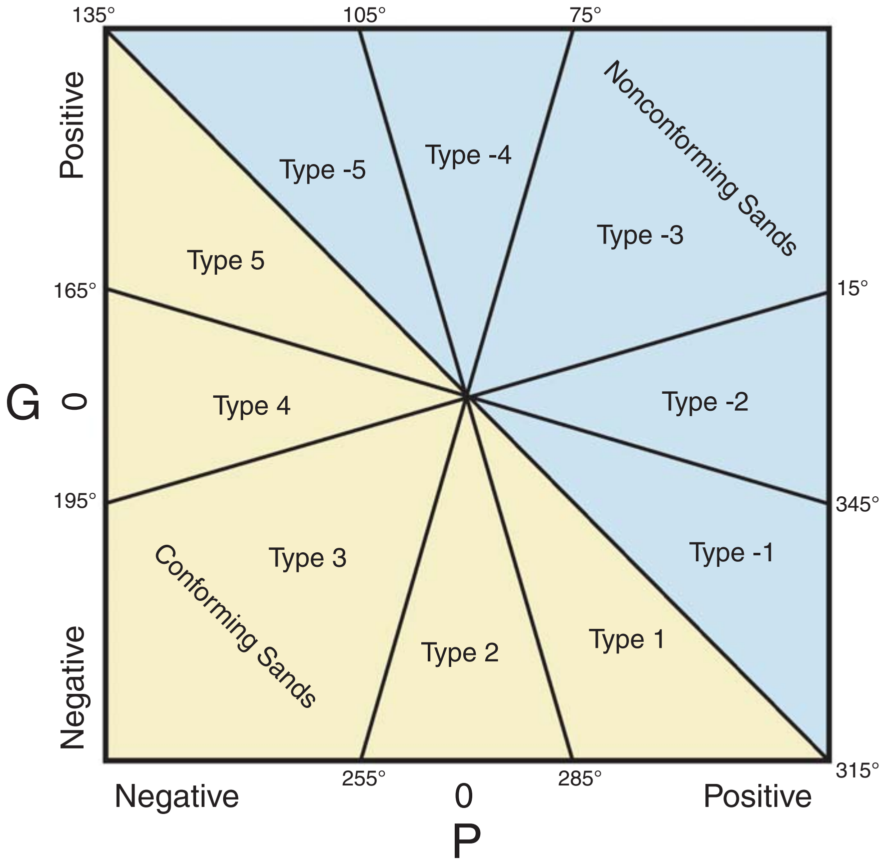
As work progresses, additional relationships will be revealed. The ramifications of the new scheme are only beginning to be understood, but it is clear already that different rock types occupy different categories.

The development of algorithms to detect the shale/nonshale boundaries in seismic data is well under way and the application of seismic petrophysics to lithology prediction is showing some very promising results. Some of the power of this new approach is displayed in Figure 2. A lot of the real beauty of the new approach is not that it provides a direct hydrocarbon indicator (in some cases it does), but that it takes information already contained in the seismic data and transforms it in such a way as to make it readily accessible to all disciplines–rock-based integration.

Predictions

Pore pressure prediction is another area where a renewed effort at determinism is yielding new ways of extracting

FIGURE 1



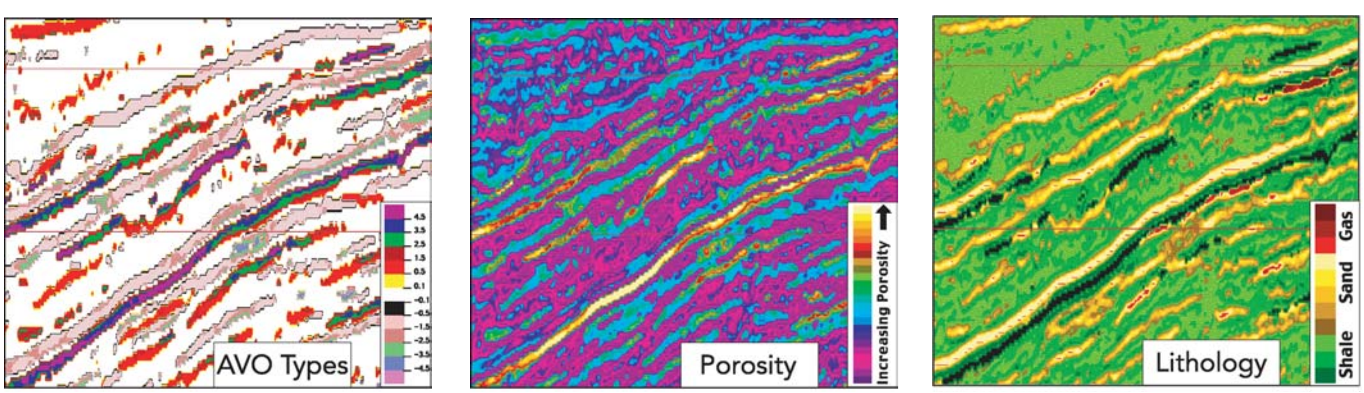
New classification of AVO types is a function of both the gradient of the amplitude variation with offset (G) and the magnitude of the amplitude when the gradient is projected back to the zero-offset (P). P and G are both dimensionless and are scaled to have the same range of values.

information. The basis for the approach, in common use today, is the empirical observation that the onset of overpressuring is usually associated with a decrease in the sonic velocity of the overpressured shales, relative to the normally pressured shales above. Historically, the approach has been to calculate a velocity field, usually converted from stacking or move-out velocities, and compare that with the velocity field expected had the shales been allowed to compact normally. Incremental improvements have come from better velocity pickers, a better understanding of the centroid effect and how to calculate it, and a better understanding of what is meant by normal compaction.

It is still not universally appreciated that the presence of sand in the section will also have the effect of speeding the move-out velocity, which may in turn mask the slower velocities of overpressured shales. The concept of centroids does seem to be generally known, but good techniques for handling them have only recently become available through the integration of lithologic predictions (using seismic petrophysics) with pore pressure predictions.

Figure 3 illustrates the centroid concept and the importance of knowing the geometry of overpressured sands in another example of rock-based integration. It illustrates how rock-based integration as it applies to a typical drilling problem. A steeply dipping sand bed is identified through seismic petrophysics as potentially being filled with gas. An exploratory well targeting the updip edge of the sand is proposed. Shale pore pressures are calculated from the seismic, using one of the described techniques, and the shale pore pressure, where the well bore is expected to encounter the sand, is prognosed to be 13 ppg. If the centroid pressure for the sand is taken back to be the maximum shale pore pressure near the base of the sand (13.6 ppg, a high, but conservative number), then by calculat-

FIGURE 2

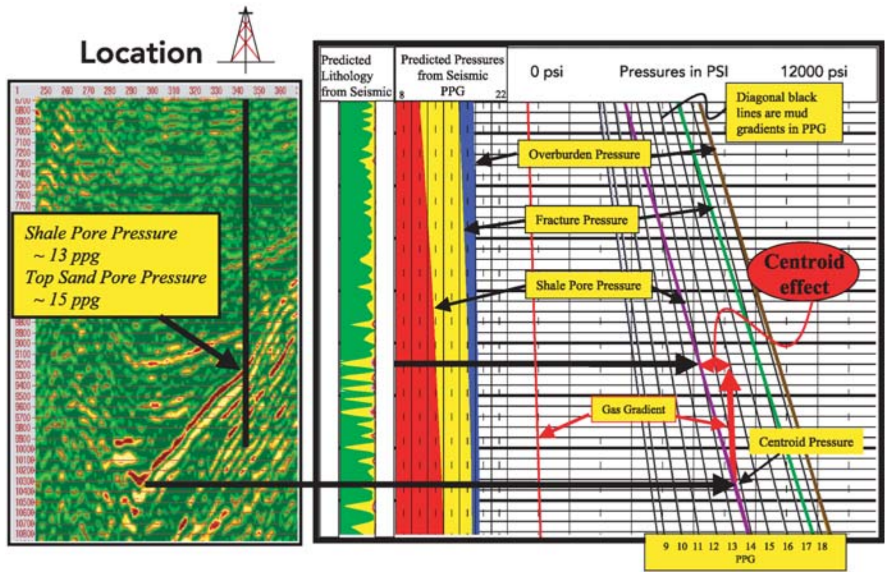


Seismic petrophysical analysis combined with AVO analysis yields fundamental rock properties, including the distribution of coal seams in this example from the Green River Basin in Wyoming. Seismic petrophysics (left) originally provided a two-lithology interpretation of shales (green) and nonshales (yellows) along with porosity estimates (center). The observation that coals correspond to AVO types 4 and 5 (left) with very high porosities and very clean nonshale lithologies allowed the construction of the lithology panel (right).

ing the gas gradient to the top of the sand, the centroid effect can be calculated. In the case shown in Figure 3, the driller should be prepared for a 2 ppg kick.

A sea change in pore pressure prediction promises to come with the advent of an independent technique based on the relationship between effective stress and the fidelity of frequency transmission. An increase in pore pressure is associated with a decrease in effective stress and a degradation in the transmission of the higher frequencies. By quantifying this relationship, two different estimates of pore pressure (frequency-based and velocity-based) are available and may be compared for greater accuracy. As we learn more about when and where differences occur, the reliability of each technique will be enhanced. Because this is a fundamental relationship, the goal of rock-based integration is served by going directly from level-one data to a level-three attribute.

FIGURE 3



Rock-based integration as applied to a typical drilling problem.

The Future Of Geophysics

If the long-term future of geophysics is in the rocks, the bridge to that future is in rock-based integration. Seismic data are unique in that they provide a full, three-dimensional, volume that not only yields valuable information, but also a framework for relating that information.

In a world where the geologists talk about lithofacies, the petrophysicists talk about porosity, and the engineer wants permeability, a geophysical solution, which serves up impedances (or nears and fars), does little to provide really valuable information or a really useful framework for relating the information of interest to the other disciplines.

Seismic petrophysics is a relatively new science aimed at getting petrophysical type information out of the seismic data. But more specifically, seismic petrophysics should be aimed at getting information such as lithology, porosity and fluid content from the seismic data and not be as concerned about properties that do not help the reservoir engineer or geologist, such as lambda-rho or impedance.

The future of geophysics is clear, it is in the rocks. Log analysis provides a useful analog and the history of log analysis shows us that useful rock properties such as lithology porosity and fluid content can be obtained from an abstract set of measurements. With this process in mind, the future of seismic and more specifically seismic petrophysics will lie in innovative approaches to invert the seismic data into terms that the rest of the team needs to know: lithology, porosity, and fluids–the key elements to rock-based integration and the bridge to the future of geophysics. ❒

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