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Pore pressure prediction sees improvements

A calibrated pressure model offers pressure attributes for a holistic solution.

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Pore pressure prediction is regularly conducted by oil companies in practically all pre-drill technical evaluations. The most widely used and proven theory is to transform seismic information into pore pressure data. In recent years, the industry has successfully employed pore pressure prediction to design cost-effective wells and avoid drilling hazards. Pore pressure prediction technology continues to improve, taking advantage of newly acquired knowledge from recent deepwater drilling, new seismic acquisition, new algorithms, and powerful computation power.

To meet today's challenge of high drilling costs and green environmental requirements, the areas outlined in this article need to be well understood and executed to obtain accurate and quantitative pore pressure information.

Know abnormal pressure causes

This article uses the term "abnormal pressure" instead of overpressure to describe the geopressure distribution because overpressure — by definition — happens when pore pressure exceeds normal hydrostatic pressure and is only part of the pressure problem. Therefore, abnormal pressure is more precise since pore pressure encountered by drill bits in a rock formation can be higher or lower than the surrounding shale or impermeable formations.

There are many causes for abnormal pressure, and failure to consider all factors may produce poor pore pressure prediction and eventually result in well abandonment, expensive sidetracks, well blowout, and stuck drillpipe, not to mention other potential drilling hazards associated with abnormal pressure. Three categories of causes for abnormal pressure are discussed below.

The interaction of compaction and under-compaction (i.e., stress changes in rock matrix) is the primary and the most well understood cause for abnormal pressure, especially in sedimentary formations and basins. During the burial process, if the pore fluids cannot escape (dewatering) at an efficient rate (due to a low-permeability overlying formation) to keep up with vertical stress from overburden, under-compaction or abnormal pressure occurs.

Burial history is a secondary cause. The process of dewatering and expulsion of pore water can further be triggered by hydrocarbon maturation, thermal effect, clay diagenesis, and duration time after deposition. These so-called "unloading" mechanisms can introduce abnormal pressure in the formation of pore spaces as the rock matrix constrains the increased pore fluid volume. Unloading can also happen in a structural uplift, either by a sys-depositional tectonic episode or by erosion. The effective reduction of overburden can also reduce effective stress and abnormal pressure.

Fluid dynamics is a secondary cause on top of compaction for abnormal pressure. It is a sub-branch of fluid mechanics that deals with fluid flow. Oil, gas, or water (fluids and gases) from a higher pressure formation can be injected into another formation under compaction. This fluid movement or lateral transfer in the subsurface can happen between two formations along fault planes or through an interconnected network of porous reservoirs and faults. A product of lateral transfer is a centroid, which is the point where the pore pressure in a formation reaches equilibrium. This is why a well at the crest of a structural reservoir can have a much higher pore pressure than the surrounding sealing formation.

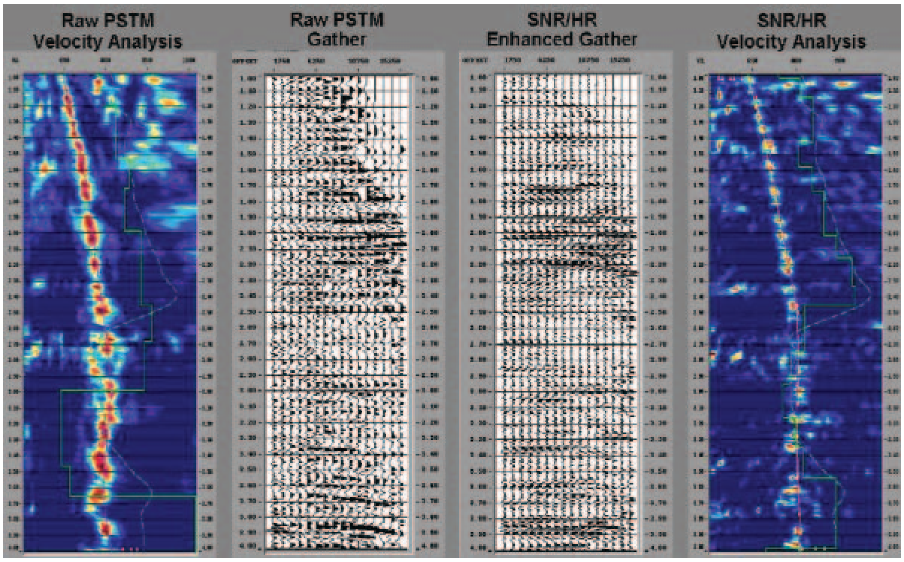

Figure 1. *This figure shows the quality and resolution improvements of a PSTM gather and its corresponding velocity analysis before and after SNR and HR enhancements. (Images courtesy of Geotrace)*

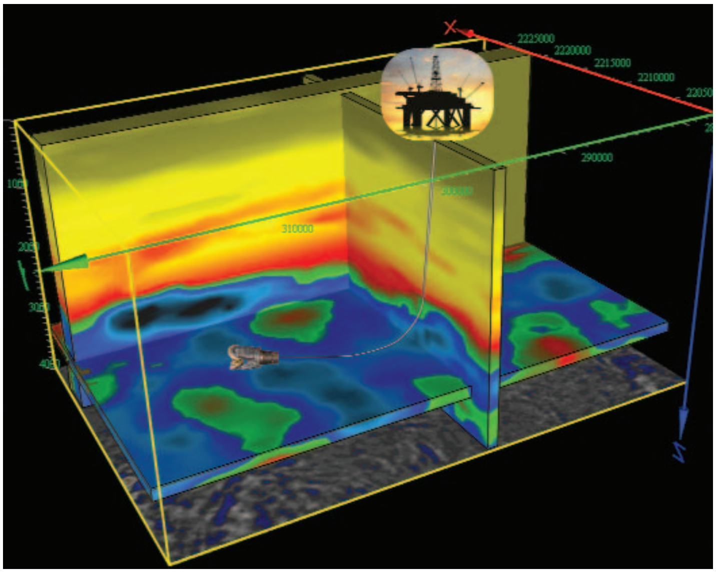

Figure 2. Co-rendering of pore pressure and seismic 3-D attributes for geoscientists to design a better well plan and lay out a drill path that avoids drilling hazards.

Know what to improve

Transforming seismic velocity into pore pressure information is a proven technology. However, two areas are often overlooked to derive accurate pore pressure: (1) seismic data quality and (2) the transformation model.

There are three means to extract seismic velocity for pore pressure prediction: normal moveout, tomography, and prestack inversion. When an operation needs to balance cost, turnaround time, and resolution, a normal moveout approach is often the logical choice. To extract the best moveout velocity, it is essential to have the best prestack time migrated (PSTM) data with highest signal-to-noise ratio (SNR) and highest temporal resolution (HR). The HR velocity elevates the conventional seismic velocity a step closer to log scale.

The next critical step is to use a high-order velocity analysis such as "sixth order curved-ray velocity analysis with anisotropy" to obtain the most accurate seismic velocity. A well-implemented velocity program can mine the velocity for every sample at every common-midpoint location to provide the highest density (HD) HR velocity volume that will capture the true spatial variation. Finally, the HDHR velocity is then calibrated with known wells to make it a geological velocity, as demonstrated in Figure 1.

Build a good model

Once the causes of abnormal pore pressure are understood, the key to successful pore pressure prediction is to construct a pressure model that accounts for those causes. First, a theoretical pressure model, a combination of Dutta (1993, 2002) and Bowers (1995, 2002), was developed to transform geologically calibrated seismic interval velocities to pore pressure, taking into account undercompaction, burial history, and fluid dynamics. Secondly, well and drilling information, including logs, mud weights, temperature gradient, leak-off test, repeat formation test, etc., are incorporated to build the final calibrated pressure model by fine-tuning certain coefficients in the theoretical formulas. This calibrated pressure model is more accurate and applicable for local geology and a client's particular project.

The calibrated pressure model produces a volume of pore pressure data for evaluating pore pressure distribution. In addition, it also provides fracture pressure data computed from overburden, pore pressure, and a matrix stress coefficient.

The proprietary calibrated pressure model described in this article offers not only pore pressure and fracture pressure, but also other pressure-related attributes such as seismic-derived geological velocity, overburden pressure, equivalent mud weights, and effective stress. By integrating all these pressure attributes, drillers and reservoir engineers can make proper decisions on well design, casing string purchase, casing seat position, and mud programs to optimize drilling without formation damage, circulation loss, stuck tools, and well blowout.

There are also other applications for these attributes. For example, geoscientists can use seismic-derived geological velocity for time-to-depth conversion in mapping and initial velocity model building for depth migration. Moreover, pore pressure can also be used for evaluating seal integrity, hydrocarbon accumulation column height, and potentially fluid migration.

This calibrated pressure model offers a plethora of pressure attributes for a holistic solution. It encapsulates the information in such a way that when used within a powerful 3-D visualization system, it provides a level of detail never seen before. It is in this context that technology can unleash the full power of integration of seismic data, pore pressure attributes, geological/geophysical information, and engineering well information to provide better well planning, safer drilling, and easier risk management. E&P