

UPSTREAM TECHNOLOGY



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The Power of 3D Visualization Using Pore Pressure Data

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The financial and environmental consequences of exploring and producing in basins without a proper understanding of 3D pressure cell distribution can be disastrous, from increased drilling costs, pollution and unrealized potential to a full-scale blowout. The oil and gas industry estimates that the annual cost associated with these problems reaches into the billions.

Now more than ever, it is critical to understand and quantify the formation of pore pressure when evaluating prospects. Recently, high-density and high-resolution seal capacity estimation and pore pressure prediction, as well as the joint utilization of other attributes derived from pre-stack 3D seismic data and 3D visualization, have become part of the integrated technical evaluation workflow and risk management in many phases of exploration and production.

The oil and gas industry embraced and benefited tremendously from seismic technology, especially 3D seismic. Although Exxon shot the first 3D survey in 1967, it wasn't until 1972 that six oil companies – Chevron, Amoco, Texaco, Mobil, Phillips and Unocal – joined forces to evaluate the 3D seismic applications better. Thanks to technological advances, the industry can now quickly access and process very large volumes of pre-stack 3D data to produce subsurface imaging for prospect and risk evaluation and management.

The industry also has employed pre-stack migrated data to invert and downscale seismic data to resemble well log information (rock and fluid properties), further mitigating the risk in prospect evaluation, exploitation and production management.

These new tools have led to the development of a different set of technical criteria for well planning. One of these is knowledge about formation pore pressure, which leads to better decisions about mud programs and casing strings, and ultimately to control the wellbore stability.

The standard practice in drilling has been to use past experience in the area together with pore-pressure data from nearby wells to design drilling programs. This ap-

proach has been successful when offset wells are close, the prospect target is known and the drilling area is well explored. On the other hand, when existing wells are limited, the results are less reliable and risk is significantly increased.

To mitigate this risk, more oil companies are recognizing the need to use seismic data for pore pressure prediction to make up for the scarcity of well data, not only for exploration, but for exploitation and mature fields as well. The advent of 3D seismic has made it possible to produce and examine 3D pressure solutions, including pore pressure, fracture gradient, effective stress, equivalent mud weights and overburden pressure. 3D pore pressure solutions have become an invaluable tool for oil companies, giving them a much more accurate and reliable solution compared to that obtained by simply using nearby wells or 2D seismic.

Methodology

A sound methodology and the right experience are needed to properly transform seismic interval velocity into a high-density and high-resolution pore pressure 3D volume. The methodology employs a rigorous, two-step workflow:

1) Pre-stack Data Conditioning

To extract the best seismic velocity, it is essential to have the best pre-stack time/depth migrated (PSTM/PSDM) data in terms of high signal-to-noise ratio (SNR) and a broadband signal. The broader the bandwidth, the higher the seismic resolution, and consequently the higher the velocity resolution.

2) HD/HR Velocity Analysis

The next critical step is to use a velocity analysis theory, such as “high-order curved-ray velocity analysis with anisotropy” on migrated data to obtain the most accurate seismic velocity. A well implemented velocity program can mine the velocity for every sample at every common

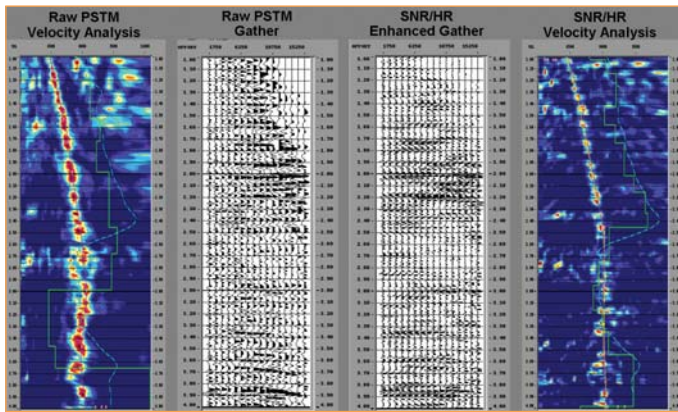


Figure 1. Comparison of PSTM gather and velocity analysis before and after SNR and HR enhancements.

mid-point (CMP) location to provide the highest density (HD), highest resolution (HR) velocity volume that will capture the true spatial variation.

Figure 1 shows the quality and resolution improvement of a PSTM gather and its corresponding velocity analysis before and after SNR and HR enhancements. The proper data conditioning has not only improved the confidence in the velocity selection, but also increased the vertical resolution from thousands of feet to tens of feet in true thickness.

3) Build Pore Pressure Model

The main causes of abnormal pressure can include under-compaction, fluid expansion, burial depth, temperature, lateral transfer and tectonic loading. The key is to establish a proper pressure model that accounts for the causes of abnormal pressure and predicts the pore pressure in the area properly and accurately. Well and drilling information, including logs, mud weights, temperature gradient, leak-off tests, repeat formation tester (RFT) data, etc., should be incorporated in building the model.

Case Studies in 3D Visualization

One of the many applications of pore pressure information is to evaluate the seal integrity of a trap and the seal capacity of a certain hydrocarbon column height. Geotrace has

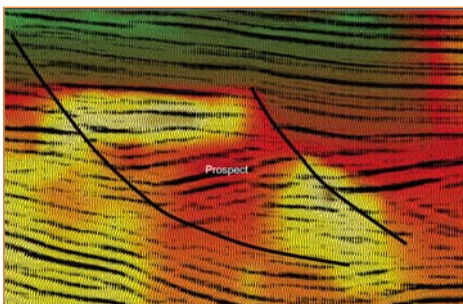


Figure 2a. Pore pressure prediction for seal integrity evaluation. The prediction of good fault and top seal was confirmed by the drill bit. Darker red indicates high pressure sealed by faults and top formation at the prospect level.

performed many projects using this methodology to evaluate the fault seal integrity and drilling hazards in many basins worldwide.

For an onshore Gulf Coast gas play, Figure 2a depicts 2D seismic in the

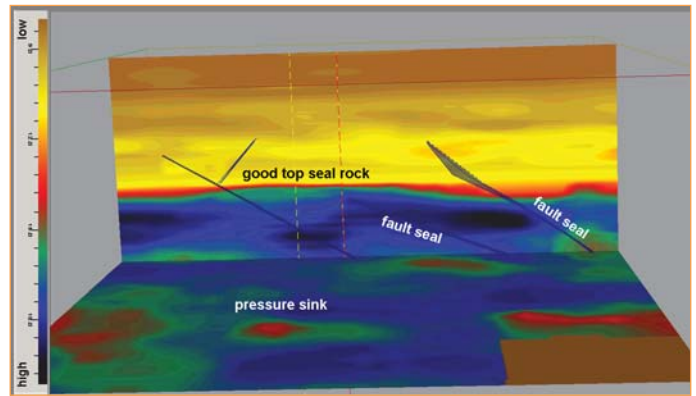


Figure 2b. Pore pressure prediction for seal integrity evaluation and drilling hazard to visualize and evaluate top, lateral and fault seals, as well as any pressure plumes for leakages and pressure sinks for drilling hazards.

prospective fault block (black and white wiggle traces) overlaid with the pore pressure prediction (color shows pressure distribution). This illustration demonstrates that the prospect has good fault and top seals. It shows no pressure leakage on the other sides of two growth faults (in black) and no leakage to the overlying formation (high pressure in dark red is bounded by faults and sealing rock). The prediction proved to be successful, as gas was found when the area was drilled.

Besides qualitative evaluation for seal integrity, quantitative calculation can be used to evaluate the column heights for different fluids at a prospect. Since the pore pressure and fluid pressure gradient are known, the column height for each fluid can be estimated before it begins leaking. The exercise can become more elaborate in cases where the prospect has a strong structural component, complex geometry and spatially varied reservoir body. For example, even for a relatively simple case, such as two connected structural highs that can potentially communicate with each other, column height would vary depending on the type of fluid, whether brine, oil or gas.

2D presentations may provide detailed images for evaluation and subtle changes for a specific location. However, 3D offers a comprehensive picture by showing the overall variation in a larger area, as well as the interaction among different structural, stratigraphic elements and pressure.

Figure 2b is a 3D visualization of the same derived pore pressure volume showing the same vertical section with fault interpretation and a thin 3D pressure volume at the bot-

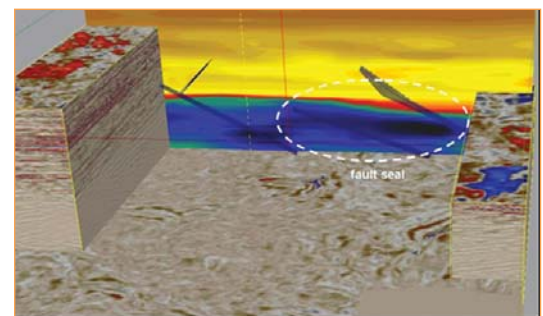


Figure 2c. 3D visualization of pore pressure and seismic volumes enables geoscientists and engineers to integrate structural, stratigraphic and pore pressure interpretation together for prospect evaluation and well planning.

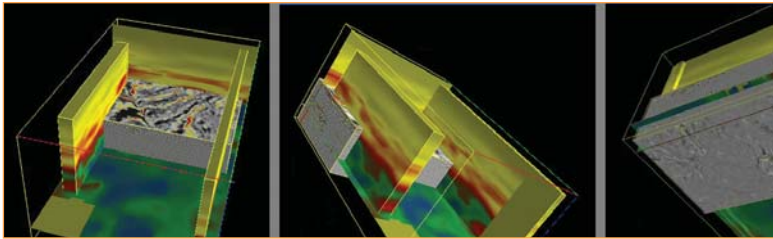


Figure 3a-c.

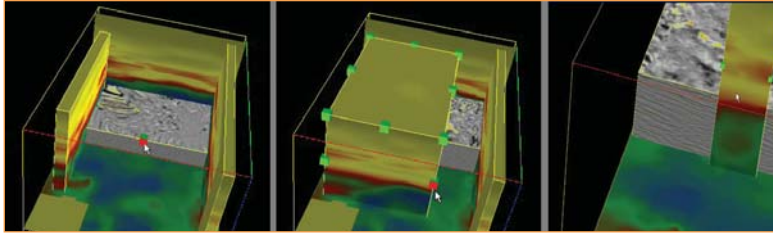


Figure 3d-f.

tom. This 3D chair-type display helps geoscientists visualize the distribution of 3D pressure cells, pressure plumes and pressure sinks in the region. In turn, this helps them quickly grasp the pressure dynamics with structural style and assess any potential sealing (top, lateral and fault seals) problem.

Another powerful use of 3D visualization is the ability to combine multiple 3D attributes for better interpretation. Figure 2c is also a 3D visualization of pore pressure volume and PSTM seismic volume that allows explorationists, drillers and reservoir engineers to work together to visualize the pore pressure variation and interaction with structure and stratigraphy. This integration not only allows geophysicists and geologists to evaluate the prospect, but also permits drillers and reservoir engineers to plan wells and

evaluate risk from a regional perspective to a well-specific location.

It is difficult to demonstrate the true value of 3D visualization and interpretation on paper. The following images of a 3D visualization and interpretation in Figure 3 may provide a more valuable illustration. Figures 3a to 3f illustrate how different 3D seismic (black-white-yellow) and pore pressure (blue-green-yellow – same color scale in Figure 2) volumes can be combined and visualized in various settings of inlines, crosslines, time slices, sub-cubes and cubes to visualize and interpret the interaction among structure, stratigraphy and pore pressure most efficiently and ultimately understand seal integrity, column height calculation, drilling hazard and casing design.

For example, from Figures 3a to 3c, one can quickly appreciate how pressure varies vertically and laterally, and how they relate to the geology. If improper mud weights are used, the formation may be damaged or there may be a wellbore stability problem. In Figures 3d to 3f, moving, stripping or intercepting various sub-cubes of seismic and pore pressure volumes offers an excellent means of evaluating the interaction between geology, structure and pressure dynamics.

Figure 4 is part of a pore pressure solution for a well-specific drilling purpose in the deepwater Gulf of Mexico. To the left is the mud weight chart computed from a pore pressure model at a calibration well location. To the right is the predicted mud weight chart with an uncertainty fairway using the same pressure model at a blind test well location that is tens of kilometers away from the calibration well. The predicted pressure solution, including the mud weights shown here, matched the well results quite satisfactorily within 0.5 ppv.

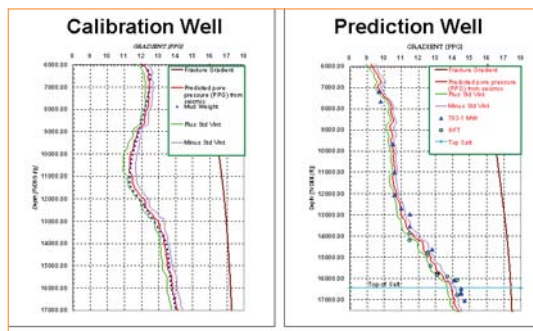


Figure 4. Pressure model (left) at the calibration well and predicted model (right) at the blind test well. The prediction matched quite well with the real mud weights and RFT results.

Game-Winning Technology and Strategy

The right technology applied for the right reason can be a game-winning strategy in a competitive world. The oil and gas industry is no exception, as it faces the challenges of globalization and environmental issues. Applying seismic-derived pore pressure and its related 3D attribute volumes – fracture gradient, effective stress, mud weights and overburden pressure with 3D visualization and interpretation – will tie prospect evaluation, drilling and production and the management of risk all together.



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