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Building a better basin model

Software advances improve pore pressure prediction ahead of the bit in a complex GoM subsalt well.

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As fast-paced technological development expands the possibilities for hydrocarbon exploration in prolific deepwater basins, oil and gas companies are recognizing the importance of advanced geological workflows to support ambitious drilling campaigns where cost and risks pose steep challenges.

In the complex subsalt fields of the Gulf of Mexico (GoM) reliable and comprehensive pore pressure and fracture gradient predictions to address drilling hazards such as faults and isolated overpressured sands and optimize well casing design are critical for boosting efficiency and safety in wells that typically cost $100 million or more. Accurate pore pressure prediction can significantly reduce operational costs and improve well performance in these promising basins.

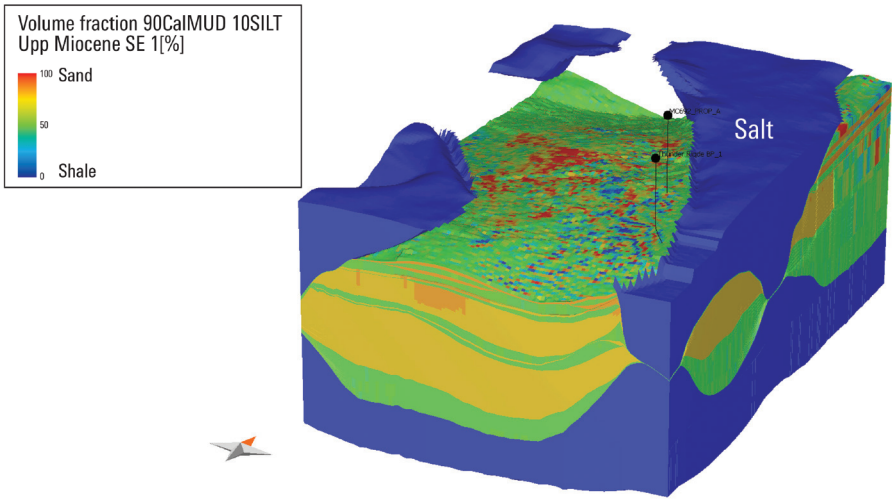
Traditional workflows for determining pore pressure include 1-D logs from offset wells or seismic data such as calibrated seismic velocities and acoustic impedance. These methods, while suitable for conventional formations, do not provide the high resolution and real-time understanding that is required in geologically challenging regions such as the GoM subsalts, Southeast Asia, South America and areas of the Middle East.

In the GoM salt formations, for example, 1-D models do not adequately predict overpressure in high-permeability rocks, an occurrence known as the centroid effect. Accurately modeling this geological phenomenon is critical for predicting vertical and lateral extensions and designing the correct mud weight. Misunderstanding of the centroid effect prior to drilling can lead to costly measures for overcoming pressure problems or result in drilling failures.

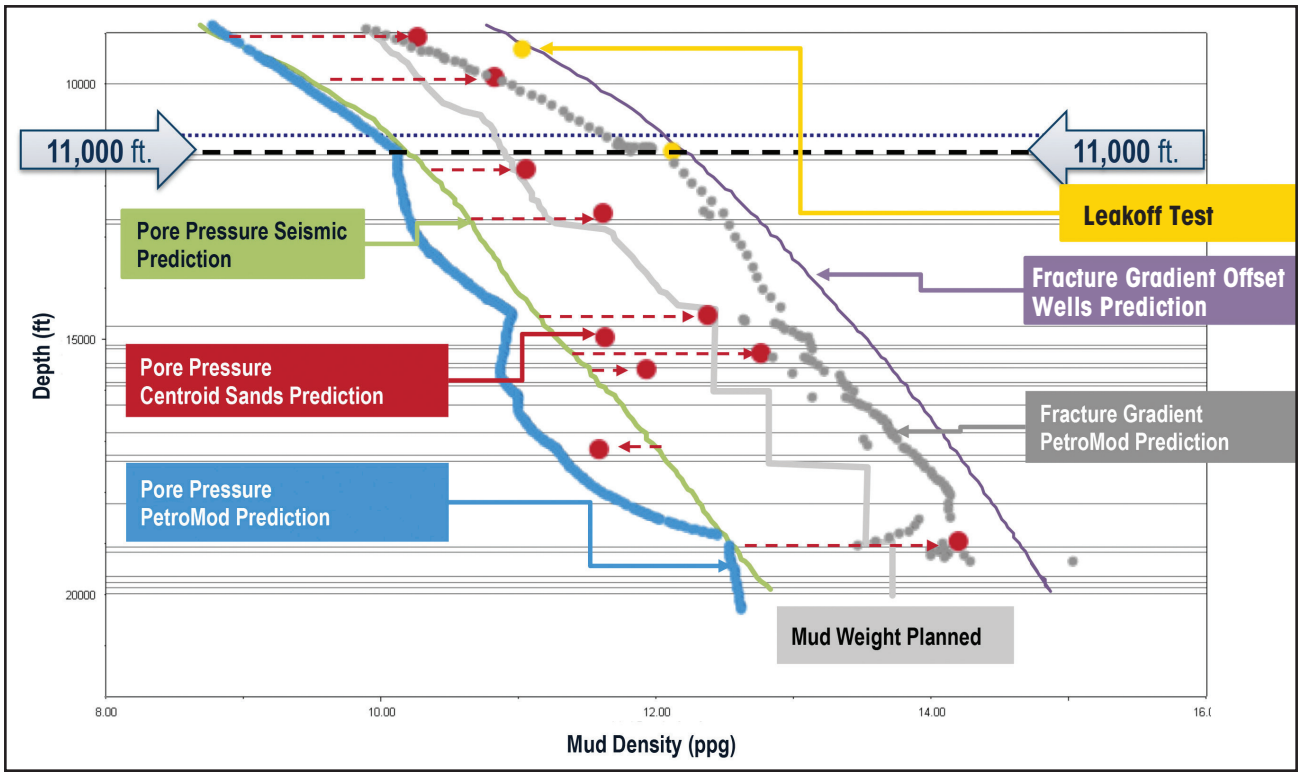
Pore pressure prediction also can be achieved using basin modeling, which involves the development of a 3-D earth model to simulate the processes of pressure formation through geologic time. Basin modeling has been enhanced in recent years with the ability to combine stress and pressure predictions and implement models for rock changes and failures.

A new approach based on the understanding that all geological processes affect pore pressure integrates well log, seismic, geological and real-time drilling data with 3-D petroleum system modeling to more accurately predict pore pressure or pressures in the system and stress regime, which is a critical aspect of exploration risk assessment. Understanding pressures and stresses in the petroleum system provides valuable information for drillers and is also beneficial when acquiring seismic data. The new workflow accurately models all geological processes responsible for increasing pressure over time and, importantly, has the capability to capture new information while drilling.

Murphy Oil Co. successfully applied the new approach in the real-time drilling of a complex deepwater exploration well in the Mississippi Canyon, a subsea canyon that is part of the Mississippi Submarine Valley in the north-central GoM. The region is characterized by the presence of salt diapirs, which induce smaller sub-basins that result in closed systems for pressure distribution and compartmentalize pressure. In this case, the drilling targets were disconnected turbidite sand reservoirs



In high-resolution petroleum systems, modeling the seismic attributes drive the facies. (Source: Schlumberger)



The workflow helped the operator predict pressures and stresses while drilling. (Source: Schlumberger)

with varying degrees of overpressure depending on their geometry and pinch-out toward the salt. The isolated, overpressured sands presented multiple risks for drilling.

The operator had previously implemented traditional basin modeling workflows in the field without encountering significant issues that jeopardized the drilling program but wanted to test the integrated geological approach to better identify potential hazards during drilling and improve the accuracy and time lines of pore pressure prediction to enhance efficiency and safety.

Integrating all geological processes

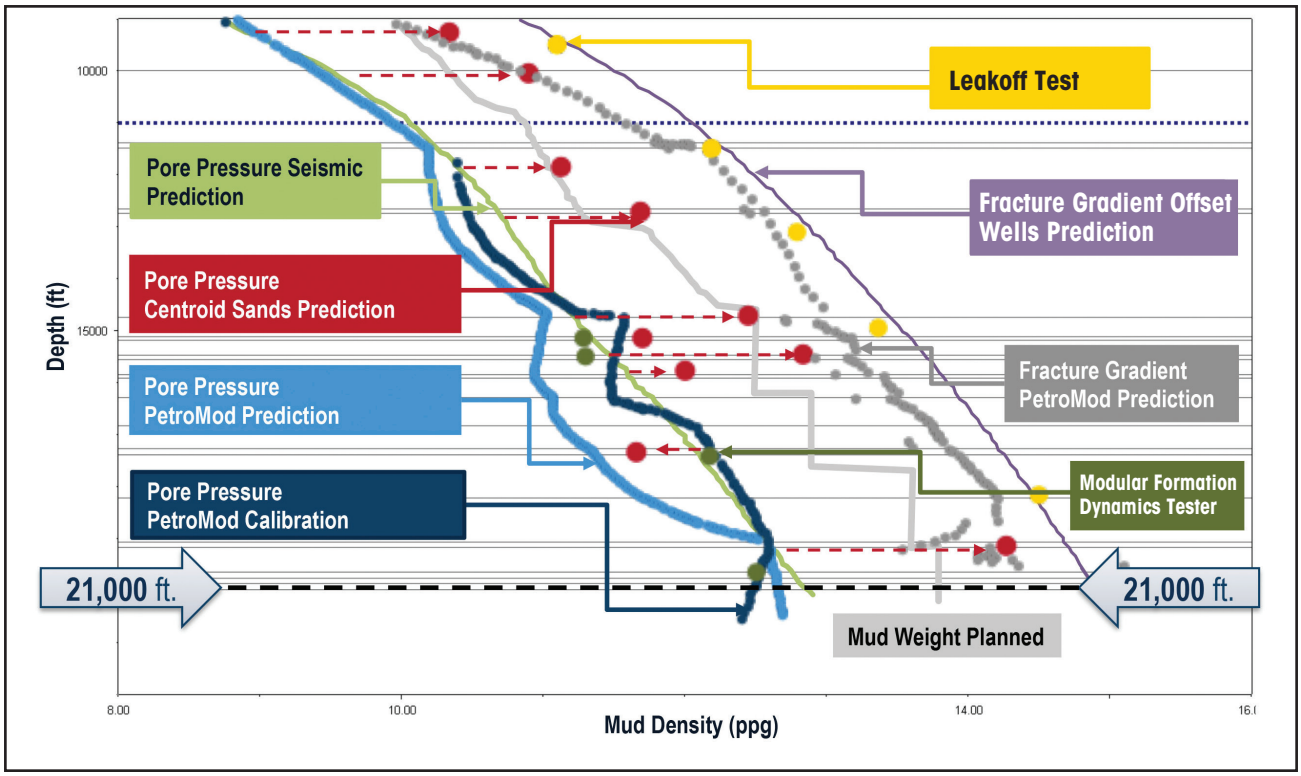
To meet this objective, Schlumberger proposed building a calibrated 3-D earth model in the PetroMod petroleum systems modeling software. The software had recently been updated with the capability to fully integrate seismic attributes, geological information, well log data and drilling information for predicting pore pressure with a high degree of accuracy to prepare a geomechanical analysis before drilling. The modeling software would be supported by expertise at the Schlumberger Exploration Hub in Aachen, Germany.

The petroleum systems modeling software has been successfully applied in basins worldwide to model the evolution of sedimentary basins, predicting if and how the reservoir has been charged with hydrocarbons, including the source and timing of hydrocarbon generation, migration routes, and quantity and type of hydrocarbons in the subsurface or at surface conditions.

The PetroMod software enabled classic pore pressure models to be paired with 3-D stress models, principally for fracture gradient prediction. This resulted in a more accurate understanding of significant 3-D effects such as compaction history and pore pressure development coupled to three-component stress behavior through geological time in areas of salt.

The project involved the development of a two-step workflow, with models built by the Murphy Oil team in Houston and supported by Schlumberger geologists at the Exploration Hub. The first step was to develop a regional pore pressure model by identifying the layers responsible for overpressure and modify their lithological composition to match calibration data from three offset wells and the area of interest, which covers an area of about 388 sq km (150 sq miles).

This model accounted for faults in the area, pressure relief points, sub-basin distribution and salt deformation over time. Faults, most of which exhibited low permeability, were an important consideration as their behavior can affect pressure distribution by creating connected



This image shows the final calibrated pressures and stresses. The calibration was a daily process based on information acquired while drilling using well measurements. (Source: Schlumberger)

or closed pressure compartments and isolating or connecting sand bodies.

In the second phase a more refined geological model was built over the specific area of interest using high-resolution structural and facies maps based on seismic character. Seismic interpretation included the mapping of 144 faults that were imported into the model, with particular focus on the faults along the proposed drilling path. In the two-month mapping phase 10 structural and related facies maps were interpreted for the sea bottom and various layers of the subsalt formation.

Predictions ahead of the bit

The enhanced capabilities of the petroleum systems modeling software, notably improvements in simulator speed, allowed the high-resolution model for the area of interest to be run overnight in less than 12 hours by experts at the Exploration Hub, who provided accurate pore pressure prediction results ahead of the bit in time for morning drilling team meetings.

The workflow in the petroleum systems modeling software integrated all the available data into the geological model for daily updating and simulation. Following an initial regional calibration, the most important aspect of any basin modeling project, the model was calibrated daily using leakoff test results, LWD formation pressure data and information on specific drilling events.

When the well reached a depth of 2,896 m (9,500 ft), about 1,219 m (4,000 ft) below the mud line, leakoff tests were performed at each casing point. Those data and the real-time mud weight were used to calibrate the pressure profile and predict the pore pressure ahead of the bit until the next casing point.

Simulation results yielded valuable information for determining mud weight and whether to follow the original drilling plan or modify it to avoid drilling hazards. The model's performance was continually refined by calibrating it to the measured data.

The successful application of the fully integrated petroleum systems modeling software enabled Murphy Oil to gain accurate predicted pore pressure and fracture data to optimize well performance and reduce drilling costs and hazards in the high-risk subsalt drilling environment. The well was successfully drilled under budget with no safety issues. The company plans to implement the workflow for two new wells in the region in early 2018. E&P

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