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Rock Physics Guided Velocity Modelling for Migration and Pore Pressure Prediction

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SUMMARY

We present a workflow using geology in conjunction with thermal history modelling and rock physics principles for velocity modelling and imaging is presented. A novel feature of this workflow is to use predicted pore pressure as a guide to improve the quality of Earth model. Thus, we are not only flattens the CIP gathers (a necessary imaging condition) but also limits the velocity field to its physically and geologically plausible range without well control. This has yielded both improved image and more accurate pore pressure.

Introduction

Earth models are primarily based on gather flattening criteria or well velocities. The gather flattening objective function of tomography may lead to non-unique models, especially in the presence of anisotropy or subsalt where incidence angles are small. The latter is a major problem for subsalt pore pressure prediction and well planning. Low-incidence angles and the focussing effects of salt affect the reliability of the tomographic updates from conventional offset domain common-image-point gathers and highlight the non-uniqueness of the conventional velocity modelling approach. One of the approaches to reduce the uncertainty is to use well velocities if available, but this non-uniqueness still remains in the geologic space between wells and beyond the total depth of a well. There is the danger of tomography converging to false minima due to inherent non-uniqueness and the lack of a reliable starting velocity model that is physically possible and geologically plausible. Hence, a more integrated approach using geology, rock physics, and imaging is needed in the Earth model building workflow to reduce the uncertainty.

Methods

In the method proposed here, we use geology in conjunction with thermal history modelling and rock physics principles to build a workflow for velocity modelling and imaging. This workflow is termed rock physics-guided velocity modelling for migration and pore pressure prediction. A novel feature of this technology is to use predicted pore pressure as a guide to improve the quality of Earth model. We first create a rock physics template that captures the relationship between rock velocity and effective pore pressure. Next, we use this relationship to create 3D iso-pressure velocity models from a subsurface horizon. These models are also called pore pressure scans, which can be used in reverse-time migration to generate angle gathers or stacks to be used as criteria to determine the starting model and the bounds (pore pressure-based) to be used in tomography as a constraint. This workflow has yielded both reduced uncertainty in the velocity model and an improved image of complex areas such as subsalt and the space between controlling wells. The process is described in Figure 1.

The rock physics template incorporates a host of rock physics principles: a lithology dependent compaction model that includes suspension, mechanical compaction, and chemical compaction that leads to type-II overpressure as postulated by Dutta (1986); a lithology-dependent relationship between porosity and slowness; and an integration of a thermal history model with porosity and effective stress. From this approach, the effective stress regime for normal compaction (lower bound of pore pressure) and the fracture pressure (highest possible pore pressure prior to hydraulic fracturing of rocks) can be predicted using a velocity-effective stress model. Figure 2(a) represents an example of a rock physics template, where the curves correspond to velocity functions at an interval of 0.5 ppg (pounds per gallon – a unit for mud weights used by drillers) pore pressure. Figure 2(b) represents 12-, 14-, and 16-ppg iso-pressure velocity models below salt for an example from the Gulf of Mexico.

Examples and observations

In this workshop, we will show examples of using rock physics-guided velocity modelling workflows to improve both the imaging quality and pore pressure for complex geology areas such as subsalt and deep targets. We were able to predict pore pressure accurately and reduce the uncertainty. We also find the resulting pore pressure volume to be not only more accurate, but also geologically more plausible and physically possible. We observed that velocity lows coincide with the crests of anticline structures. This is characteristic of pressure transfer in permeable units due to the centroid effect and results in transmission of overpressure up-dip. This has also led to a more-focussed image and better-defined structure, facilitating the structural interpretation.

References

Dutta, N.C. [1986] Shale compaction, burial diagenesis, and geopressures: A dynamic model, solution and some results. J. Burrus, ed., *Thermal Modeling in Sedimentary Basins*. Editions Technip, Paris.

Figure 1 (Left) A conventional velocity modelling workflow. (Right) The rock physics guided velocity modelling workflow.

Figure 2 (a) A rock physics template created taking into account suspension, mechanical compaction, and chemical compaction. (b) The 12-, 14-, and 16-ppg iso-pressure velocity models below salt. These models are also called pore pressure scans (*Patent pending).