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Integrating Geology and Depth Imaging in a Mature Overthrust Area - A Case History

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SUMMARY

Mature hydrocarbon provinces are increasingly being re-explored to extend the productive lives of existing fields by testing outlier or deeper objectives for additional reserves. In recent years the introduction of affordable 3-D pre-stack depth migration (PSDM) has allowed very complex geology to be properly imaged to more fully assess hydrocarbon potential in many of these mature areas. This paper discusses a 3-D seismic depth reprocessing program undertaken in a complex U.S. Overthrust area to assess the validity of a deep structure (approx. 5500m) identified on 3-D time-processed data in this mature prolific gas producing province. The 1998 vintage seismic 3-D acquisition method did not allow a seismically derived velocity model capable of accurately representing the subsurface to be defined in this older/fast rock regime. A 3-D pre-stack depth migration velocity model-building solution is presented that overcame the limited sensitivity to velocity of these 1998 3-D seismic data. By collaborating with client geologic expertise to integrate key geologic insights into the 3-D velocity model-building process and tightly constraining the seismically derived velocity with available well control, a subsurface velocity depth model was obtained that provided an accurate depth image of the deep target zone in this geologically complex area.

Introduction

The targeted area is a major gas field discovered in 1978 in the Overthrust Belt of Utah/Wyoming where tectonic movement along the Absaroka thrust has created major structural distortions of the Mesozoic and Paleozoic rocks below a Tertiary overburden. A representative geologic cross-section is shown as Figure 1. The primary objective for this project was to aid in the economic assessment of deeper levels between 5200 and 5800 metres below the primary gas producing zones in this complexly faulted overthrust regime. Before committing to an expensive deep well test, it was necessary to confirm the deep structural configuration and its dimensions. A state-of-the-art Kirchhoff pre-stack depth migration and velocity model-building solution was selected for a 45 square mile area of 1998 vintage 3-D seismic data.

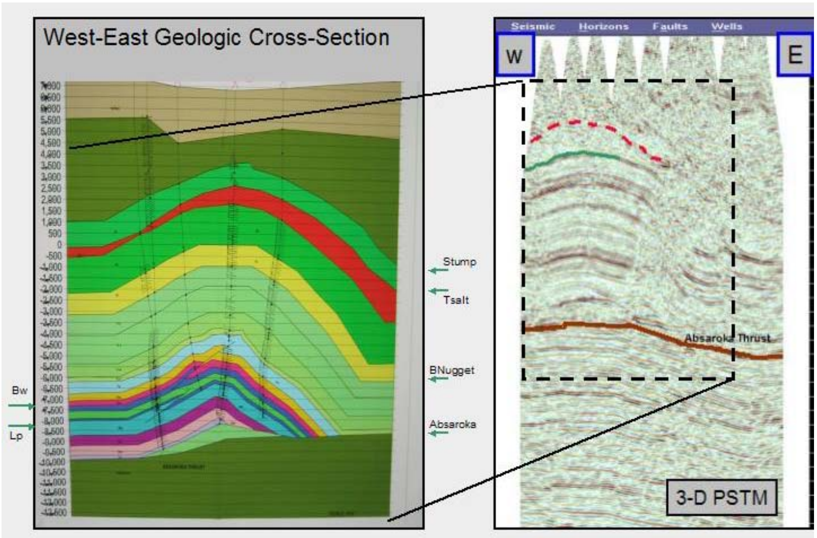

Figure 1: Geologic cross-section and time seismic representation

3-D Depth Velocity Model Building Process and Issues

Once 3-D near-surface refraction modeling and careful pre-processing were satisfactorily completed, attention turned to defining an accurate velocity model for the Kirchhoff PSDM solution. An iterative tops-down workflow was adopted to progressively establish the upper layer velocities and horizon positions before moving deeper to define the next series of formations. The workflow used the pre-stack time migrated velocity volume and a series of mapped horizons to provide key interval velocity boundaries. The initial velocity model would be high-graded using Kirchhoff PSDM image gather and residual curvature (velocity) estimates from semblance analyses for subsequent and deeper iterations. Well data would act as a calibration mechanism for the seismically derived velocity volume to assess the fidelity of the PSDM volume as an accurate spatial representation of the subsurface.

After several early iterations targeting the top 3000 – 4500m of the geologic section, no convergence on a stable velocity model was achieved. On analysis, several issues emerged that were affecting the stability of the imaging results.

- The interval velocity regime in this highly consolidated rock environment was “fast”, typically in the 5000 m/sec range or greater.
- In the shallower section, because of the field acquisition geometry, all offsets across the full range were not available to assist the velocity estimation process. Longer offsets out to 5200m (often helpful to velocity resolution) did not contribute for the shallower depths.

- As a second order effect to the above, the 3-D acquisition geometry caused variable offset distributions across the available offset range within, and between, bins that resulted in varying sensitivity to velocity.
- The fast velocity regime resulted in low curvature across the offset range for large velocity variation (i.e. only small residual moveout error represents large velocity variation).

The net effect was that residual curvature estimates from image gathers were relatively insensitive to velocity change. This caused hypersensitivity in the velocity model updating process to minor variations and/or "noise" in the residual curvature estimates, to which depth imaging is highly sensitive since positioning in space is directly linked to velocity. An example line extracted from the 3-D volume before and after a PSDM iteration update (Figures 2) demonstrates the dilemma. The PSDM images show similar stack response but very noticeable changes in the depth position of the major reflectors. The variability in the velocity after residual velocity updating from semblance/residual curvature analysis can be observed (Figure 3). Also, image gathers before and after residual velocity update suggest that the updating had no stabilizing effect (Figure 4). As a result, each iteration provided variation in the velocity field, but not convergence.

Following identification of this particular geology/acquisition interaction, an alternative strategy for velocity modeling and updating was pursued. The seismically-derived velocities were tightly constrained by available geologic and well data, with seismically-derived updating only included where it was *strongly* and *consistently* supported by the subsurface data. Fortunately, a good suite of well velocity information was available in the area (but did tend to be clustered in an approximately north-south trend along the crest of the major structure). For the subset of wells with both good quality check shot and formation top data available in the vicinity of the PSDM prospect area, interval velocities were derived between the major horizons of interest (Figure 5). With these interval velocity profiles, a "keep it simple" modeling approach was adopted with strong adherence to the well-derived interval velocity trends except where strongly and consistently contra-indicated by the seismic. At each stage, a close tie to known formation tops would act as a primary criterion for velocity model accuracy. This approach was especially helpful in reducing the high variability experienced in the early velocity models and providing trend guidance in areas of no/low well control, especially to the east.

After each iteration, data were assessed for image quality; tie to formation top information; and curvature consistency, with a horizon review/update of the model before the next iteration. With this strategy in place, the PSDM process proceeded rapidly through a series of iterations to produce the final PSDM volume. An early Base Tertiary iteration was followed by iterations to Twin Creek, Base Weber, and Absaroka with a final full iteration to maximum depth.

Results

The final volume based on the geology-constrained modeling approach exhibited good image quality (Figure 6). It closely tied key formation top data within this Overthrust Belt project area and exhibited good reflector continuity in the primary zones of interest. In addition to tying available well data, confidence in the accuracy of the volume was re-inforced by the stability of the deeper section (Absaroka and below) where the reflection energy in the final depth volume closely matched the known regional attitudes of these beds. The stability and geologic plausibility of the final result was evident versus the implausible reflector topography seen in the early iterations. The structural attitudes at depth were also noticeably changed from the time-based data (Figure 7). We believe that the final velocity model used in this project contained the essential information for an accurate subsurface image in depth across the project area.

Conclusions

A geologically-integrated velocity model-building solution was successfully developed for this project. It used well-derived interval velocities between the major formation boundaries as a constraint on the seismic residual curvature/velocity estimates to define a narrow range of velocities. This allowed the greatly reduced parameter space to be explored systematically with a small number of pre-stack depth migration iterations. The method successfully overcame the insensitivity to velocity of the 1998 vintage data and provided good convergence on the best-fit model that met project objectives in this difficult subsurface imaging area.

Thus, with an awareness of key success factors, effective subsurface depth imaging using legacy or vintage seismic data sets is a very practical option for mature areas. These success factors include:

- Keen awareness of the capabilities and limitations inherent in legacy data sets
- Understanding the rocks
- Information access and integration leverage of all available well, geologic, and associated subsurface data
- Continuous interpreter involvement.
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References

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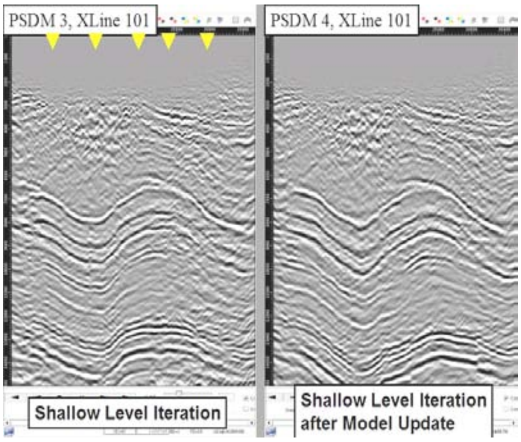

Figure2: Structural variations between iterations

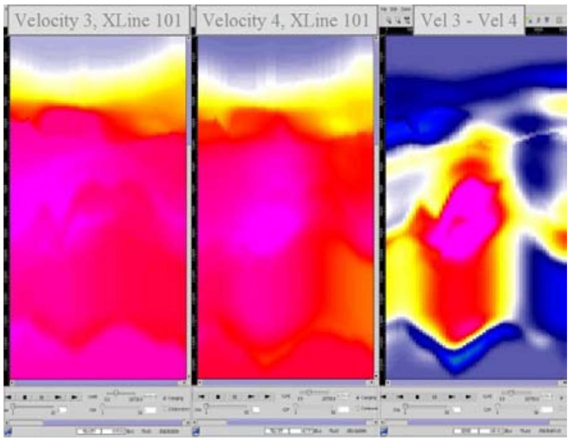

Figure 3: Velocity variations between iterations

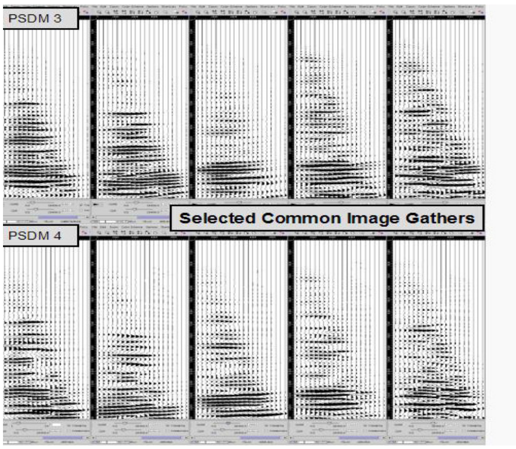

Figure 4: Image gathers between PSDM iterations

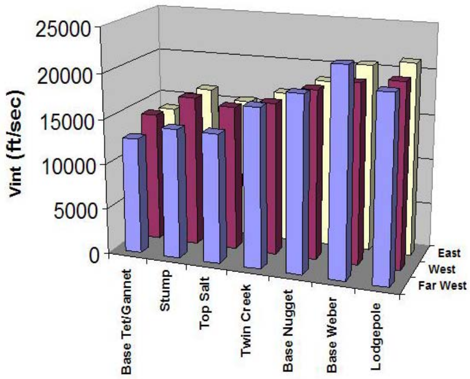

Figure 5: Well-based interval velocity distribution

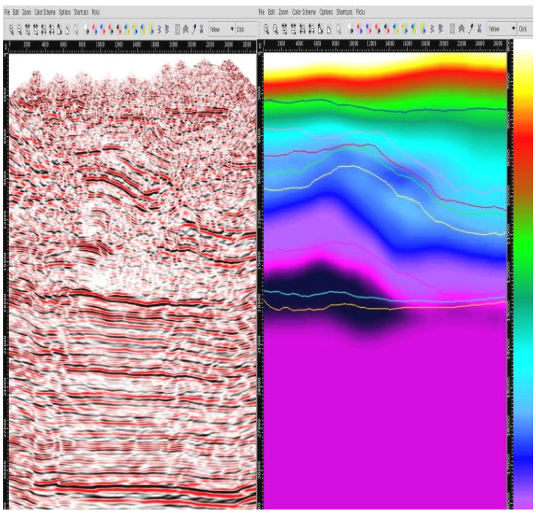

Figure 6: Final PSDM and Velocity model profiles

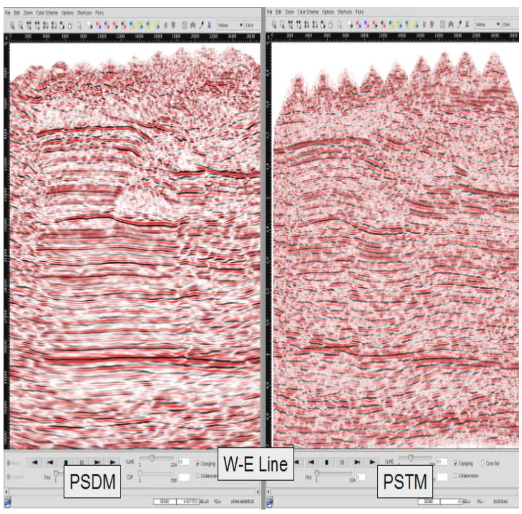

Figure 7: Final PSDM profile versus PSTM result