Improved Interpretation of Over Thrust Geology using Depth Imaging Tools

Beaver Creek Field, Fermont County, Wyoming

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Background

The Beaver Creek Field in Fremont County, Wyoming is a classic Rocky Mountain thrust anticline with productive intervals from the Cretaceous down to the Mississippian. The deepest reservoir is the Madison Limestone which was discovered in 1954 and had by 2008 produced ~45 MMBO. To try to boost production in 2008 Devon Energy decided to initiate a CO2 flood. This required drilling several new wells which encountered unexpected structural complexity. At that time the existing seismic data was processed through prestack time migration (PSTM). The PSTM images could not resolve the complexity of the geology. Following a significantly improved imaging using prestack depth migration (PSDM) at the adjacent Big Sand Draw field, a project was launched in 2016 to apply PSDM to the existing 3-D dataset at Beaver Creek.

The Beaver Creek Field was formed by a west verging Laramide thrust fault (Green fault in Figure 1) with an additional seal on the east formed by a back thrust (Orange fault). The Madison structure map of the field, as imaged by the PSTM data, is shown in the first panel of Figure 1. When the CO2 flood was initiated, several additional wells were required to properly drain the edges of the field. One of these, intended for the southern fault block, landed in the main fault block, indicating that the PSTM seismic imaging was not quite correct.

PSDM was applied to the legacy 3-D surveys in an attempt to produce a clearer image of the structure. The legacy data was limited in offset and azimuth. Recorded over such a complex structure it was clear that large offsets data is required to produce a good image. Therefore the PSDM reprocessing project had some attendant risk that it would not yield an improved image.

The Madison structure map, shown in the second panel of Figure 1, depicts the interpretation based on the PSDM processed data. The structure appears to be simpler overall. The southern fault block is narrower with few splay faults disrupting it, and the bounding faults have shifted slightly which brings them into better agreement with well control. However, the faults are still present, which explains why tracers injected into the southernmost injection well were not observed in nearby producers that were on the other side of the bounding faults. In the main block of the field, the grey fault visible on the PSTM data has disappeared from the PSDM data. The presence of this fault was not supported by the results of the CO2 flood, which showed no baffles or barriers in this area. This fault appears to have been the result of energy being mispositioned due to a faulting in the shallow section.

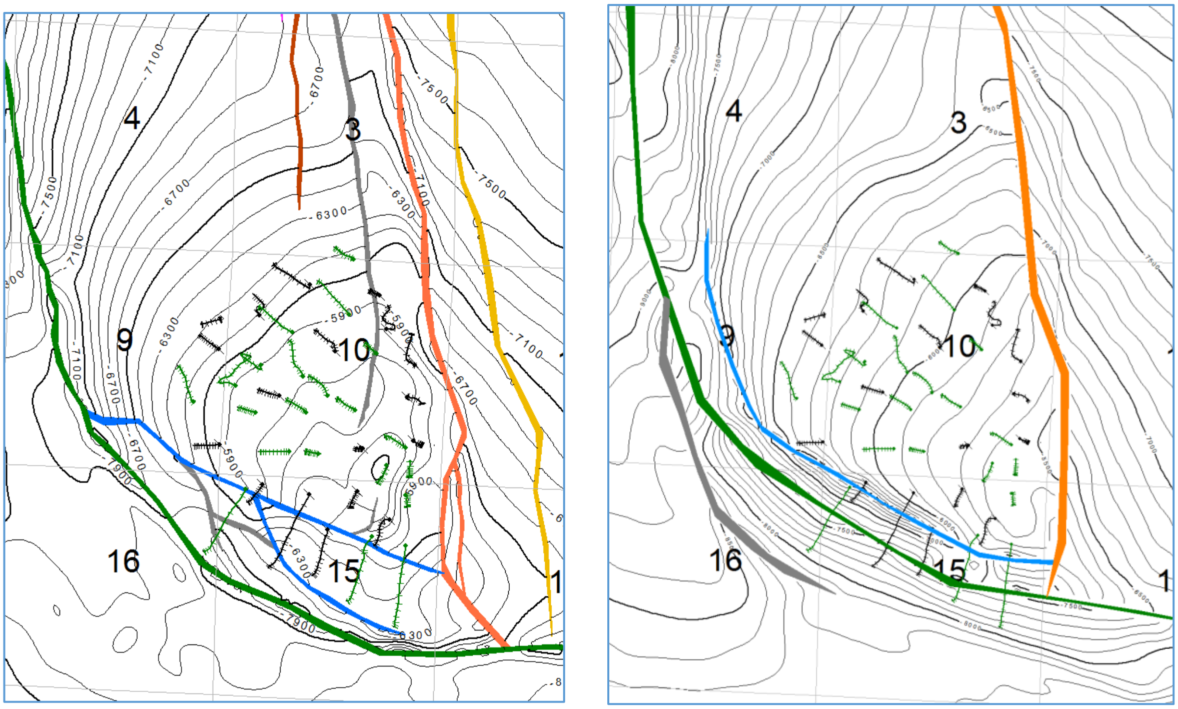

Figure 1. Beaver Creek Field structure based on PSTM data (Left) and PSDM data (Right). Only wells utilized in the CO2 flood are posted.

Processing Technology

Today, application of PSDM is integral part of seismic data processing rather than an add-on step. However, the challenge in application of PSDM is the ability to construct the optimal earth model used as input to PSDM. Application of PSDM will result with a reliable seismic image only in one condition – if the appropriate anisotropic model is constructed and used as an input to PSDM. For the complex geology of the Beaver Creek field this means construction of a faulted anisotropic model. In the application of PSDM for imaging of the Beaver Creek field, the construction of the optimal faulted model was the main part of the work. This is done in several steps using an iterative process.

First, an initial smooth model is built. The initial model is constructed using both velocity information obtained from time domain processing as well as velocity information obtained from well log data. Having sufficient amount of well data, the initial model consists of both the velocity field as well as the anisotropic field. The anisotropic field is optimized using iterations of velocity and anisotropic updates using reflection tomography, followed by full volume PSDM. Several iterations of model update generated a PSDM image that is clear enough for interpretation.

As the second phase of depth model building, the preliminary PSDM volume generated with the initial model is used for interpretation of the main geological units. The result of this phase is a 3-D faulted model that includes a series of faults and horizons that together form the geological framework and units of the work area. The geological model constructed for the Beaver Creek field is shown in Figure 2.

Having a geological model with distinct faulted units we can now optimize both the velocity and anisotropic field at each fault compartment. This third phase of the model building workflow is iterative where the interpretation of the fault boundaries is updated as the anisotropic model is being optimized.

Including well data into the final model ensures minimal depth discrepancy between the PSDM image and well formation tops. Reflection tomography is used to update the model to generate an optimal time to depth conversion of the seismic data as part of the prestack depth migration process.

The last step of the processing work is the actual depth migration. Two types of PSDM algorithms are used for final imaging. The first is a ray based Kirchhoff summation PSDM. This algorithm is very flexible and relatively lower in computational cost. Utilizing high fidelity travel time computation based on the wavefront reconstruction algorithm, the algorithm can produce a very reliable image even with complex models like Beaver Creek faulted model. To ensure the best PSDM image possible, a much higher computational cost PSDM algorithm, Reverse Time Migration (RTM) is used as well. RTM uses the total recorded wavefield to produce a final PSDM image. The RTM PSDM algorithm is based on use of recursive operators for solution of the wave equation enabling use of the entire amplitude spectrum in implementation of RTM PSDM. Figure 3 shows both the Kirchhoff summation algorithm depth image and the RTM PSDM depth image. Close examination shows areas beneath the fault where the RTM PSDM image matches the geology better compared to the ray based Kirchhoff summation PSDM.

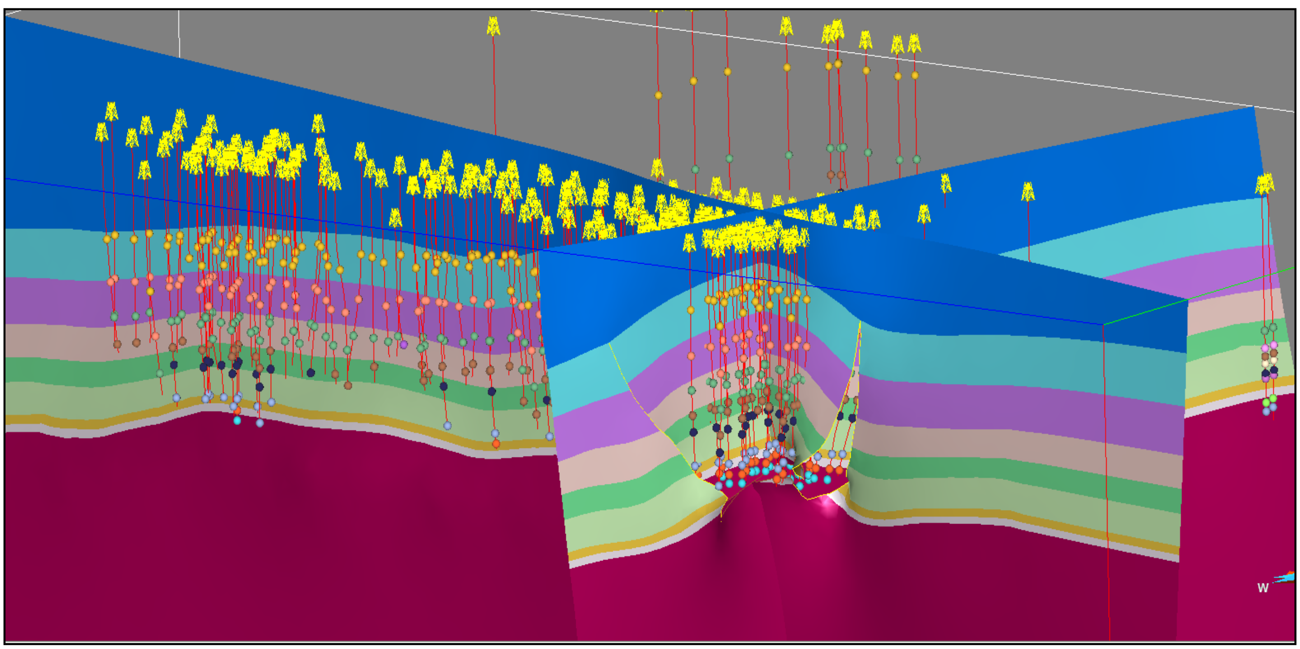

Figure 2: Faulted model constructed using both seismic and well data.

Summary

The new PSDM data over Beaver Creek has helped improve our understanding of the structure of the producing field. The structure appears to be simpler with few internal baffles which is in agreement with results of the CO2 flood. The southernmost injector is now seen to be in a separate fault block which explains the lack of response to the tracers injected into that well. The back thrust forming the eastern boundary of the field, has thrust Madison over itself, creating a potential sub thrust target.

Application of PSDM is an iterative process where interpretation is done as part of the model building work. Advances in model building technology enable us to construct complex 3-dimentional earth models that result in superior imaging. Advances in implementation of PSDM algorithms enable us to use both ray based and wave based algorithms resulting in seismic images that reveal both the large scale geological features as well as small features such as correct positioning of faults. Utilizing these new advances in processing technology enabled us to optimize the production plans of Beaver Creek field.

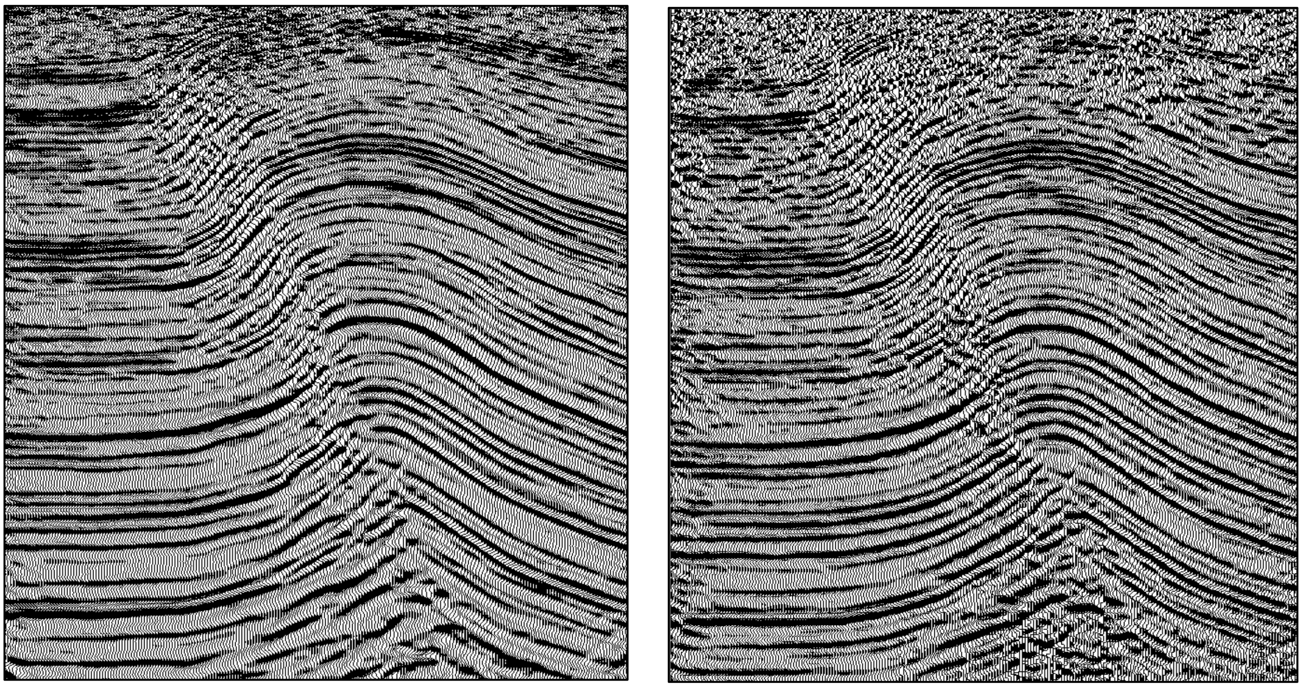

Figure 3: PSDM of the Beaver Creek field. Left: Kirchhoff summation PSDM. Right: High frequency (60 Hz) Reverse Time Migration (RTM) PSDM.

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Rob Horine has 28 years of experience in both exploration and production of oil and gas. Rob is currently with Devon Energy Corporation and is working in the Wind River, Bighorn, and Powder River Basins of Wyoming.

After graduating with a Ph.D from the University of Tulsa in 1990, Rob worked for BP America in the Gulf of Mexico. In 2000 his evolution continued and he began working onshore in the Green River and San Juan Basins. He has also worked the Williston Basin for Hess and the Permian Basin for Forest Oil. In 2014 he joined Devon Energy to work various Rockies basins.