Creating accurate velocity models in mature fields: Poza Rica Field, Veracruz, México

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Summary

We introduce an iterative approach to velocity-model building that accommodates the problematic nature of integrating seismic and well data in mature fields. An initial velocity model may be created by combining seismic velocities and check shots. The model is then calibrated by combining interpreted seismic horizons with the equivalent well tops. The calibrated velocity model is then smoothed over twice the nominal well spacing. The smoothing is intended to introduce the constraint of geologic consistency to the model.

Next begins an iterative approach to model refinement. The smoothed model is recalibrated with the well tops and depth errors between the two are used to flag problematic wells or seismic data. In mature fields, it is common to encounter incorrect well postings or inconsistencies in the interpreted tops. Seismic data may have acquisition problems, variations in the correlation, or local velocity changes that contribute to the error.

During the iterations, depth errors must be reconciled. Well positions are confirmed, tops reviewed, and seismic interpretations reevaluated. As the sources of error are reduced, and eventually become small and random, the smoothing radius is reduced to the nominal well separation.

Introduction

Poza Rica Field is a giant oil and gas field in Veracruz, México (Figure 1) with production from the Cretaceous Tamabra carbonates. In some paleoenvironmental models the field is described as a turbiditic talus-slope fan from the Faja de Oro reef trend to the east. In terms of the seismic response, a Tamabra seismic time versus well-depth plot (Figure 2) indicates a strong lateral velocity gradient that poses a challenge to the accurate integration of seismic and well data.

Precise depth conversion is a critical step for creating static and dynamic reservoir models that incorporate seismic attributes (Marhx, 2004). It is also mandatory for accurate planning of horizontal wells. However, there are many challenges to creating accurate velocity models in mature fields. For well data, record-keeping issues commonly result in incorrect well positioning. Additionally, interpretive differences in well tops can be a significant source of error.

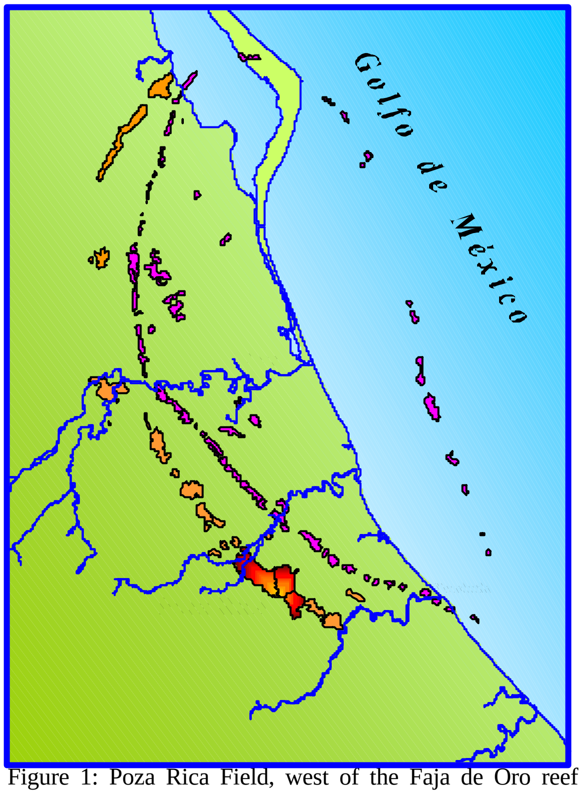

Figure 1: Poza Rica Field, west of the Faja de Oro reef trend (purple).

Seismic data, often considered a softer data point than the well data, can help resolve the well errors. However, even with 3D data, illumination problems are common in older fields due to restricted access. Local velocity variations also introduce an ambiguity in the conversion of time to depth. Even with prestack depth migration, and its ability to mitigate local velocity variations, the level of depth accuracy needed for reservoir description is such that calibration to the well control is still a primary objective.

We will next describe an iterative approach to velocity-model building that helps to identify and reduce the sources of depth error.

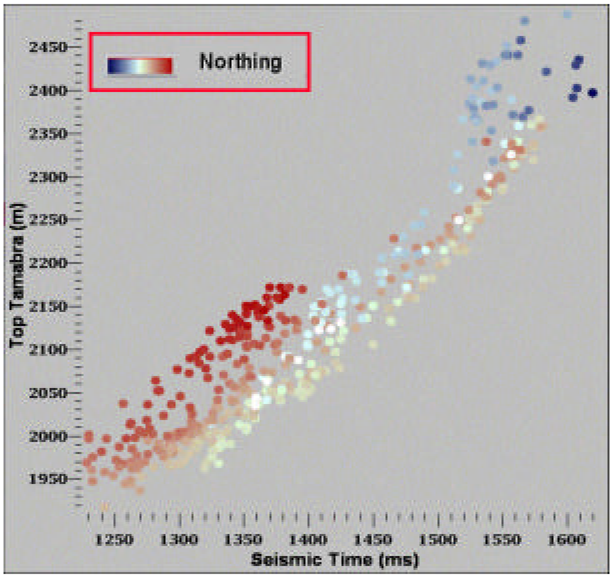

Figure 2: Seismic time versus well depth for the Tamabra formation. There is a significant lateral velocity variation that precludes simple time to depth conversion.

Initial velocity model

The initial velocity model is typically a combination of seismic velocities and check shots. Seismic velocities, usually supplied as RMS, are required to be converted to interval velocity. However, this must be done in a manner that constrains the interval velocities to a range consistent with the geology. This preconditioning is an effective filter for eliminating local interval-velocity aberrations that may be introduced in the stacking field. Interval-velocity constraints also reduce the contamination of the velocity field during the next step of preconditioning, smoothing.

Some amount of spatial smoothing of the interval velocities is also important to stabilize potentially erratic velocities produced by the picking process. A minimal smoother is one that spans the neighboring analyses. However, longer smoothers may be needed in the presence of local, lateral velocity variations where time imaging often introduces distortions.

Calibration with check shots is a problematic process. Without interpreted horizons to guide the calibration process, it is easy to contaminate the seismic velocity field with high- or low-velocity zones that are extrapolated to improper positions within the stratigraphic column. Therefore, a vertical smoother of approximately 100 meters helps make the check shot suitable for calibrating seismic velocities. In other words, only the low-frequency trend of the check shot is needed.

In practice, seismic velocities are calibrated to check shots by creating a time/velocity-error array at the check-shot control points. The velocity error is extrapolated and subtracted from the seismic field. In the case of Poza Rica Field, the sparse check shots were of an older vintage that were judged to be a source of distortion and were not used. Figure 3 shows the depth errors (well minus seismic depths) using the initial velocity model comprised of the preconditioned seismic velocities from prestack time migration. As expected, there is a bias in the values. However, the errors, after removing the bias, still range over more than 50 meters.

Once the initial velocity model is formed, the next step involves calibration of the model with the interpreted seismic horizons and the well tops.

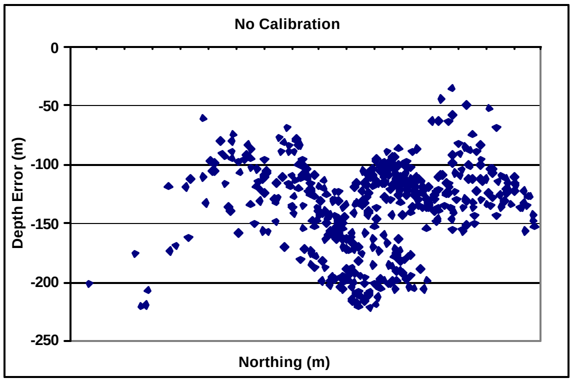

Figure 3: Depth error of Tamabra defined by well depths minus the seismic interpretation converted to depth with the initial velocity model.

Model calibration

Starting with the initial velocity model, the next level of calibration involves equating the seismic time interpretation with the equivalent well tops. A basic assumption is that the interpreted event corresponds to the correlation of the well top. If a phantom horizon is used, or a change in the correlation occurs across the field, this variation will be converted to a velocity change. This is often a reasonable exchange since it is difficult for an interpreter to vary the correlation in a consistent manner across a field. However, if acoustic impedance volumes are to be calibrated, this could result in an erroneous mapping of seismic attributes.

In practice, the well calibration may be performed by depth converting the time interpretation with the initial velocity model. Next, the depth errors are calculated between the wells and the seismic depth map. The depth errors are then extrapolated and removed from the seismic depth. Finally, the time and the corrected depth maps are combined to create a calibrated average-velocity map to the horizon(s) of interest.

Model smoothing and iterative refinement

The formation of the calibrated model begins the iterative approach to velocity refinement. The basic assumption is that velocities vary smoothly between wells. Therefore, the first step of the iteration is to smooth the calibrated model over a distance equal to twice the nominal spacing between the wells. Next, the smoothed model is recalibrated with the wells to determine the depth error between the wells and the smoothed model. It is the reconciliation of these depth errors with the well and seismic data that constitutes the model refinement process. Figure 5 shows the depth errors between the wells and a 1 by 1 km smoothed velocity field (the nominal distance between wells is approximately 400 m). The depth errors for the smoothed model are reduced to +/- 20 m, compared to Figure 3.

In term of identifying sources of depth error from the wells, it is common in mature fields to encounter miss-posted wells, inaccurate or missing deviation surveys, errors in the KB. For example, in Poza Rica Field, positive depth errors of approximately 30 meters (well greater than seismic depth) typically imply problems with the deviation survey. Figure 5 shows several large positive values that corresponded to such deviation errors.

Well log correlations are also a source of depth error. Despite being a strong seismic marker, the top Tamabra is more difficult to define in well logs because the gamma-ray and resistivity responses vary, resulting in inconsistent log picks. In our study, top Tamabra picks were primarily defined by sonic log response, corresponding to the acoustic change recorded by the seismic data. Also, during the study, we identified an extensive shale marker above the top Tamabra that may represent a regional surface of sediment starvation (a marine condensed section). This was used as a datum for flattening, thus adding confidence to the revised top Tamabra pick.

Seismic sources of depth error include changes in correlation, local velocity variations, or poor data. Figure 4 shows a seismic section where the target Tamabra formation had a significant negative error (-18 m) when the well top (red bar, right) was compared to the original seismic interpretation (green line). Closer examination indicated the presence of a possible channel feature (black dashes) that complicated the interpretation. Two options for reconciling this error include reinterpretation (yellow line) or excluding this well from the calibration process and allowing neighboring wells to define the local velocity field. The first option was chosen.

After reviewing the largest depth errors, the corrected well and seismic data were recalibrated and smoothed again. Figure 6 shows the data used for the second iteration of velocity refinement. For this iteration, we reviewed wells with errors greater than 10 m. Many of the remaining, large-error values corresponded to areas of structural relief, where horizontal positioning errors of tens of meters could reconcile the data. Some errors also corresponded to zones below shallow, local stratigraphic variations.

Finally, to accommodate local velocity variations, we used a final smoothing of 500 m (Figure 7). In this manner, there is still a locally-smooth velocity field between the wells. The final depth errors for the 478 wells had a standard deviation of less than 4 m. This is of the same range as errors in picking the tops from the well logs or approximately one sample in the seismic data. Figures 8 and 9 are the time and depth maps of the Tamabra formation for Poza Rica Field, respectively.

Conclusions

We have introduced an iterative approach to velocity-model building that accommodates the problematic nature of seismic and well data in mature fields. Iterative reduction of depth errors between the well and seismic data produces an accurate velocity model. The ability to integrate seismic and well data allows for the creation of high-confidence static and dynamic reservoir models. Finally, the planning of horizontal wells for optimal production is also enhanced.

References

Marhx, A., Velasco, G., Addy, S., Flair, W., Petit, G., Torres, M. and Diaz, F., 2004, Determining the location of remaining oil using acoustic impedance: Poza Rica Field, Mexico, 74th Ann. Internat. Mtg.: Soc. of Expl. Geophys., 2577-2577.

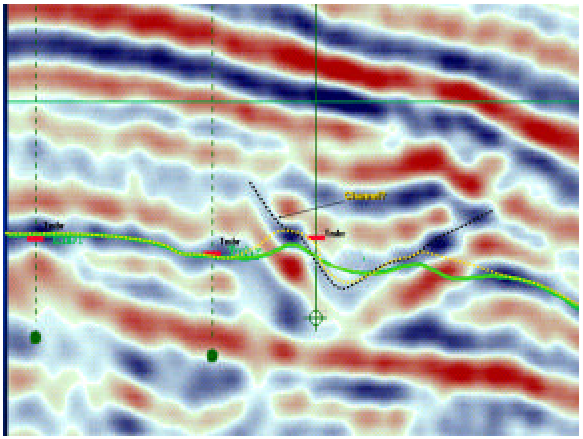

Figure 4: Tamabra formation with a negative error (red bar, right) compared to the original seismic interpretation (green line). A channel feature has complicated the interpretation (black dashes). The updated interpretation is in yellow.

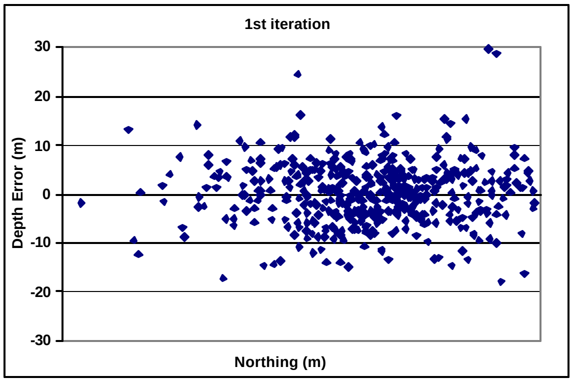

Figure 5: First iteration depth error of the calibrated model after 1 km smoothing. Large positive values correspond to well deviation errors.

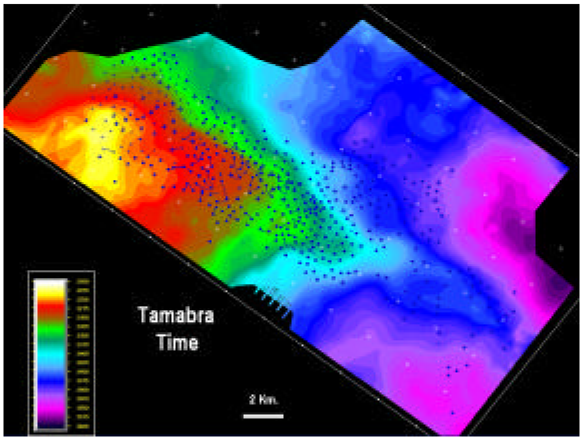

Figure 8: Tamabra time map.

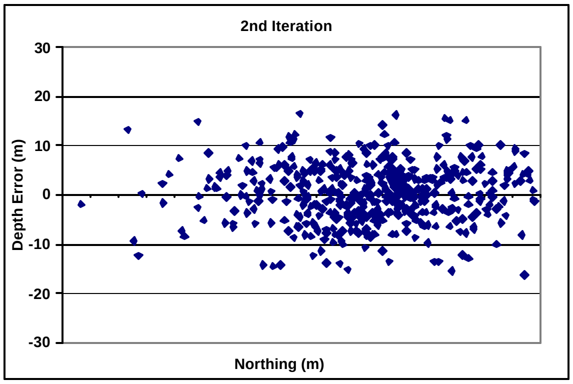

Figure 6: Second iteration depth error of calibrated model after 1 km smoothing.

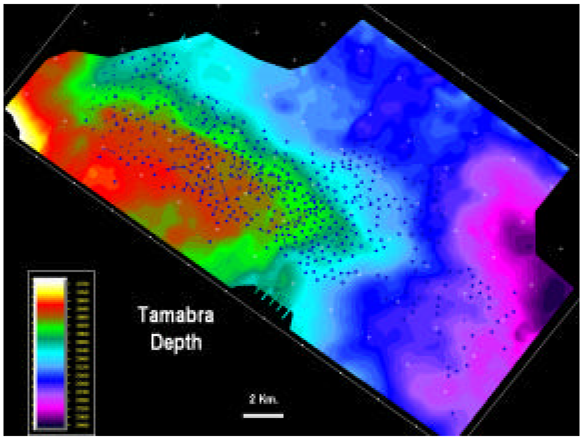

Figure 9: Tamabra depth map from final iteration.

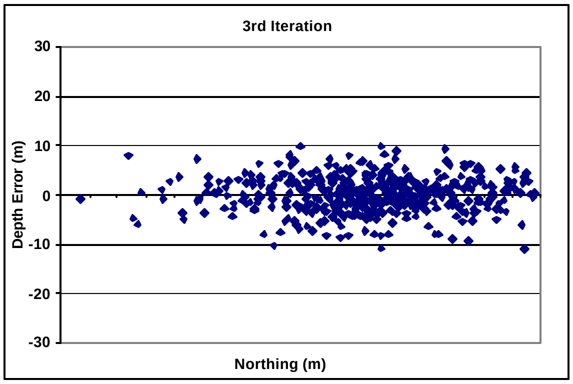

Figure 7: Third iteration depth error of calibrated model after 500 m smoothing.