Using Geological Constraints to Improve Velocity Model Building for Depth Imaging in Frontier Areas - Case Studies

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Introduction

The use of geological constraints and non-seismic information to build and update seismic velocity models in depth imaging is established practice in the Gulf of Mexico, North Sea and other well explored and developed oil provinces. Elsewhere it is limited to the use of potential field data for regional velocity models; in recent years there have been improvements with use of gravity gradiometry data (Houghton et al., 2014) and controlled electromagnetic and induced magnetic data (Zerilli et al., 2014). Our approach makes use of well data to develop a velocity-stratigraphy relationship, and combine with time migrated seismic datasets to extrapolate for key horizons across the survey. The workflow we use involves a cross-disciplinary collaboration (mainly between geoscientists and geophysicists) at each stage of the work cycle as well as in the quality control of the subsurface models. We find that some useful constraints and approximations can be derived, even where very limited non-seismic data is available. We show 2D seismic data examples from two different frontier areas where using geological and other non-seismic constraints has significantly improved image quality, and given more confidence in the geometries of the observed structures.

Using Geological Information in the Seismic Velocity Model Building Workflow

Conventional velocity model building workflows consist of creating a starting or initial model, using the seismic data itself to both create this model, and then invert to update the velocities. Issues can arise whereby the resolved velocity field fails to fully follow geological boundaries and structures. In particular for 2D data, anomalies can start to appear where remnant multiples and out-of-plane events start to be flattened (Jones, 2010).

We use well log data to develop stratigraphy trends for the survey area. Well check shot velocity data (Figure 1a) is blocked between the key horizons to produce an average interval velocity for each formation, at each of the well locations. The stratigraphy-velocity relationship is then extrapolated laterally with the picking of key horizons in the time migrated data. A 3D initial velocity is output from the interpreted horizons to a set of time grids and then converted to depth domain using the velocity maps derived from checkshot data interpolation or by using constant velocities (Figures 1b and 1c). The velocity model for any individual 2D line can then be extracted from the generated 3D velocity volume and edited further to provide the initial velocity model for velocity inversions.

2D Marine Data Adriatic Sea, Offshore Croatia

This study comprises 4000 km of 2D data taken from the 2013 CRO2D-13 survey. Data was acquired using a conventional flat streamer, and 5000 cubic inch airguns at 2000 psi. A single 8100 m streamer, 648 channels at 12.5m group interval, 2ms sampling rate, and 10sec record length. The dataset used for model building went through a conventional pre-processing workflow that included SRME, Radon demultiple, and diffracted noise attenuation. The main geological features in the data are Triassic-Jurassic rifting, with thick carbonate platforms laid in shallow water conditions, pelagic limestone in deeper water (Bosellini, 2004), and halo-kinesis in the shallow and deep water paleo-domains. During the Mesozoic-Tertiary, the carbonates give way

Figure 1: Building geologically constrained models from available well data and interpretation. Interval velocity display for a key well overlaid with an unconstrained velocity model (a) horizon depth model grids (b) and map of top carbonates horizon (converted to depth using well derived velocities) (c)
to siliciclastic deposits with a much lower seismic velocity compared to the underlying units (Figure 2). Early depth imaging trials used an unconstrained initial velocity model derived from time migrated RMS velocities, edited and converted to depth. Iterations of grid tomography were used to update the velocity model (Figure 3a). Depth gathers were relatively well flattened, but the velocity model did not follow the regional structural features. The model had noticeable anomalous lateral velocity variations within the carbonate formations that were geologically improbable (Figure 3c).

We proceeded, integrating 13 wells, and 4 key horizons: water-bottom, base Pliocene clastic deposits, top carbonate, and Top Lower Triassic “base carbonate”. We linearly interpolated and extrapolated well velocities along a set of tied depth horizons to create 3D velocity grids. We then extracted individual 2D line velocity fields from these grids, to use as the initial models. After two to three iterations of automatic grid tomography to update the shallow events, the section below the base carbonates was “reset” to a constant velocity, followed by one to two iterations of grid tomography using manually picked residual moveout. This was found to be the optimal method to update areas with poor S/N and remnant multiples present. As the initial model is closer to true model it takes less iterations of tomography to achieve the similar gather flatness, based on stacked image improvements and calculated residual moveout fields. The final velocity models match the observed events more closely (Figure 3d). The imaging of the steeply dipping edges of the carbonate platform has been significantly improved, along with the overall geometry of the carbonate structures. The horizons in the deep section of the Lower Triassic now appear continuous across the line.

Figure 3: Final velocity models without (a) and with (b) the use of geological constraints and the respective depth Kirchhoff image stacks (c and d). Note overall stronger amplitude response and improved continuity of deeper events on the image migrated with the geologically constrained velocity model.

Figure 2: Seismic transect joining the re-processed legacy data (left) with the new data Croatia (right).
2D Marine Data Orange Basin, Offshore Namibia

This study comprises a subset of 5 lines (1000 km) from the SCOB12 survey, acquired in 2012. Data was acquired with the source specifications as in previous example but using a longer 10050m streamer, 804chs at 12.5 m grp int, with 2ms sampling and 10sec record length. Comparing to previously mentioned pre-processing workflow, additional demultiple steps where needed to remove residual multiple energy.

We incorporated geological constraints into the velocity model building workflow from the start. However, there are only two wells, of limited depth located in shallow water, suitable to provide some velocity control (Figure 4). The key horizons interpreted from the time migrated dataset for use in the initial model covered the water bottom, shallow clastic of the Late Cretaceous, and the break-up unconformity which separates post-rift and syn-rift sequences.

Due to the limitations on well velocity control, a single constant velocity was assigned to each key horizon interpreted. The velocity model update methodology was modified, with one to two iterations of horizon tomography run first to provide a lateral update to the velocities and depths of each formation (Figure 5). Iterations of grid tomography follow, using automatically picked residual moveout for the shallower post and syn-rift sequences, and manually picked residual moveout for the deeper pre-rift sequence.

The final velocity model again closely follows with the main horizons, with grid tomography consistently resolving inversions in the post-rift sequence below the shallower clastic deposits (Figure 6). Comparing with a depth converted time migration, the geometry of the syn-rift structures are more geologically plausible.

Figure 4: PSTM velocities converted to depth compared with well interval velocities.

Figure 5: Models and data from different stages of workflow. Interval velocity model derived from well info and interpretation, used as initial model (a), after horizon tomography update (b) and final iteration of tomography (c); d), e) and f) are decimated Kirchhoff image gathers in respective order.
Conclusions

We have shown that robust model building in frontier basins, which includes geological constraints in the depth imaging processing, leads to a superior depth image and a more consistent geometry of the structural features. The resolution of the geological constraints depended largely on the distribution of the wells available, but even with severe restrictions in this coverage, the approach used can be seen to be of benefit. An initial velocity model tied in 3D and calibrated to well velocities allows for a consistent velocity update process across all the 2D lines, and minimises the potential velocity misties and anomalies.

We see a future development of our approach incorporating different geological and geophysical constraints, for example potential field data (Jackson et al., 2013) as well as gravity gradiometry or electromagnetic data, that provide a more extensive and uniform resolution compared to well data.

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References


