Seismic imaging and interpretation over Antep Block, southeast Turkey

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Summary

The Antep Block is a relatively unexplored exploration block in southeast Turkey, adjacent to the border with Syria. There are multiple prospective zones in both carbonate and clastic rock reservoir units from the Ordovician to the Cretaceous.

New 2D seismic data over the block was processed through time and depth migration with the goals of identifying and mapping large structures and of building a reliable structural model of the area. At least two potential zones have since been mapped in the area: the Ordovician Bedinan sandstone and Cretaceous Mardin carbonates. The seismic data is over rough terrain with stratigraphic and structural complexity above the exploration targets.

To meet the exploration objectives, we processed the seismic data through prestack time and depth imaging. Processors and interpreters worked closely together throughout the imaging project to focus the processing on the exploration objectives and for the interpreters to understand the uncertainties in the data. This close co-operation is seen a key contributory factor in the overall success of the project.

The subsequent interpretation of the grid of 2D lines shows several interesting leads, including zones of overlap between Cretaceous and Ordovician targets

Introduction

The Antep Block is in a relatively unexplored area adjacent to the Turkish border with Syria (Figure 1). The primary exploration targets are the carbonates in the Cretaceous Mardin Group and the deeper clastics of the Ordivician Bedinan Formation. The tectonic setting is primarily extensional, with a high density of faulting throughout the area.

In addition to the structural complexity resulting from the extensional tectonics, this area also shows stratigraphic complexity that brings further variation to the subsurface velocity structure. Figure 2 shows a stratigraphic model of the area. The vertical and lateral variation of lithology above the two target zones resulted in complex seismic velocity variation.

Figure 1: Location map showing Antep exploration block.

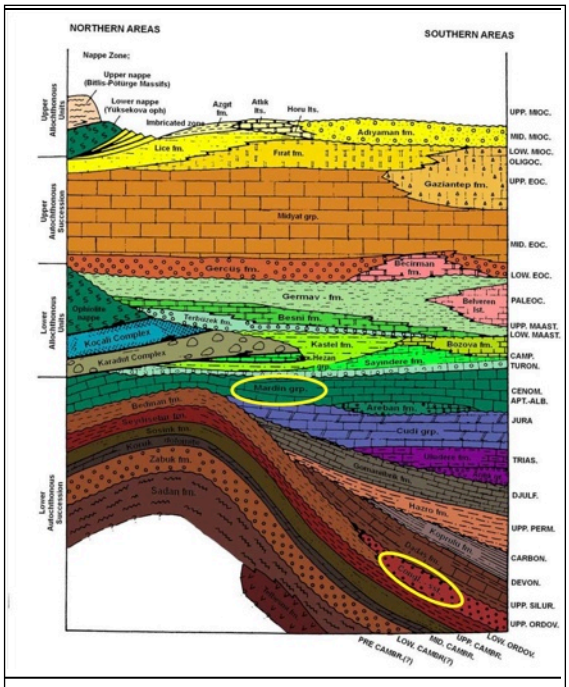

Figure 2: Stratigraphic units of Southeast Turkey (Günay et al. 1995, after Perinçec 1990). Target units are circled in yellow.

2D seismic data was acquired in 2011 and continued in 2012. Rough topography and structural complexity provided significant challenges to the processing of these data. To get the most out of the seismic imaging, we focused on the fundamentals. We tested a variety of algorithms at each step of the processing sequence, with the goal of incremental improvements at each stage. A key lever creating an interpretable image was tight integration between processor and interpreter, especially to geologically constrain time and depth migration velocities.

We took an interpretive approach to estimating velocities for both prestack time and depth migrations. We interactively picked RMS velocities for PSTM that offered the most geologically reasonable image. We interpreted a geologically constrained velocity model for TTI anisotropic depth migration. The PSTM gave us our most robust image, but the PSDM improved the imaging in the deeper section below the structural complexity.

Time processing

The objectives for the data-processing were as follows:

- Manage rough topography and near-surface weathering
- Optimize imaging around multiple target zones

- Integrate interpretation input to the prestack-time-migration velocity analysis
- Sharpen edges of faults and stratigraphic features.
- Test a range of algorithms and parameters to ensure that all available signal is imaged

With rough topography and stratigraphic variability, weathering statics were a key factor in obtaining a subsurface image. There is significant variation in velocity in the near-surface, so theoretically we anticipated that the first-arrival tomography would deliver the most accurate weathering solution of the first-arrival statics methods. We tested a time-term solution, a generalized-linear-inversion method, and a first-arrival tomography algorithm on a few test lines in this area. We used the stacked section as QC with interpreter input to decide which algorithm offered the strongest coherency at the target levels in this particular case.

The time-term solution produced the best stack response over the 2D test lines. Figure 3 shows the most dramatic example from a subset of one of the 2D lines in the area. Figure 3a shows a region of the NMO stack with time-term statics applied. Figure 3b shows the same region of the NMO stack with the tomographic statics applied. The gaps in the shooting and large amount of topographic relief along the survey may have caused instability in the tomographic solution. Even though the assumptions inherent to the time-term solutions are violated by the complexity of our geologic setting, the stability of the more simplified algorithm resulted in an improved stack response. From our experience, each area responds differently to the various refraction-statics algorithms, so we tested multiple algorithms on these data.

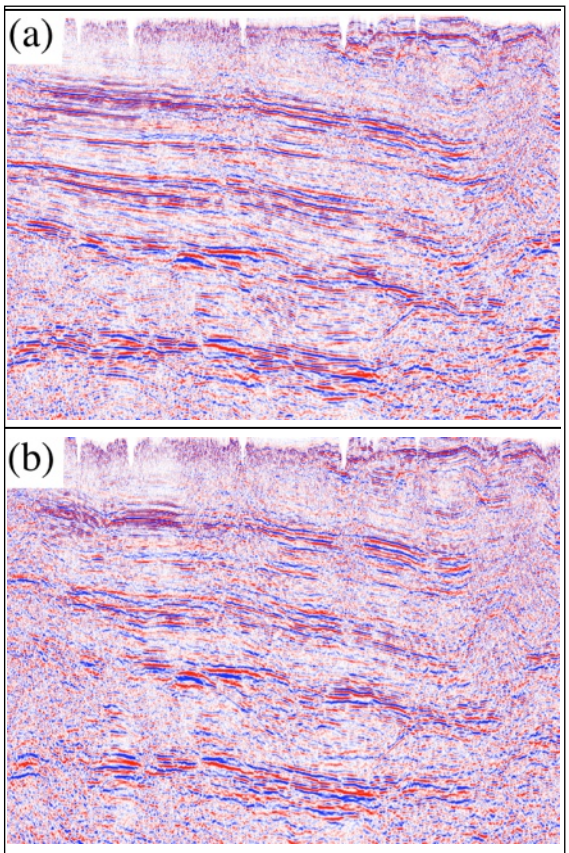

Figure 3: Part of an NMO stack from a 2D line in the area with (a) time-term statics and (b) tomographic statics.

With a strong statics solution, basic noise attenuation and spiking deconvolution, we were ready for prestack time migration. As described in detail in Vestrum et al (2011), for each line, we ran 40 constant-velocity prestack time migrations and interactively picked optimum imaging velocities by assessing reflector coherency on the stack and flatness of the prestack gathers.

The velocity analysis method we chose is interpretive, in the sense that different velocity picks on the migrated stacks may result in a different interpretation of the final image. The interpretation team was involved in the velocity QC for prestack time migration, to ensure that the final result was an interpretable image.

Even though subsurface complexity violates the assumptions inherent to prestack time migration, the method continues to be a workhorse for seismic imaging because of the freedom to optimize the imaging without the consequences of errant depth scaling. If one desires a seismic image using one velocity field that accurately images the seismic data in depth, then a migration algorithm that corrects for subsurface velocity complexity, including heterogeneity and velocity anisotropy should be used.

Depth imaging

One line was taken through prestack anisotropic depth migration for two reasons: (1) to assess the need for a more accurate imaging method than prestack time migration to optimize the imaging and (2) to determine if any structural risks existed resulting from overburden velocity variation pulling up or pushing down target reflectors.

We approached the TTI depth migration as an interpretation exercise, building a subsurface model and refining the model interpretation to optimize the image.

Figure 4 shows a subset of the 2D line for comparison between time (Figure 4c) and depth (Figure 4b) with the preliminary velocity model in Figure 4a. Here we see a common result, where the robustness of prestack time migration offers improved resolution and coherency in the shallow section, whereas the accuracy of the prestack depth migration improves imaging of deeper reflectors below the velocity complexity.

Interpretation

The Antep Block is a new exploration area interpreted to have multiple prospective horizons. At the Ordovician level, around 2600m below the surface the Bedinan sandstone has been mapped. The Bedinan is a regionally-extensive shallow marine sandstone facies often with excellent reservoir characteristics, and is a proven oil reservoir to the northeast of Antep. The Bedinan formation is overlain by a thick Silurian shale section which has also been mapped across the Antep block using the 2D seismic data. The Dadas shale is a proven source rock and can provide a top-seal for the porous Bedinan. The potential for shale oil production in the Dadas is also under evaluation and will be greatly assisted with accurate seismic structural imaging. In the shallower

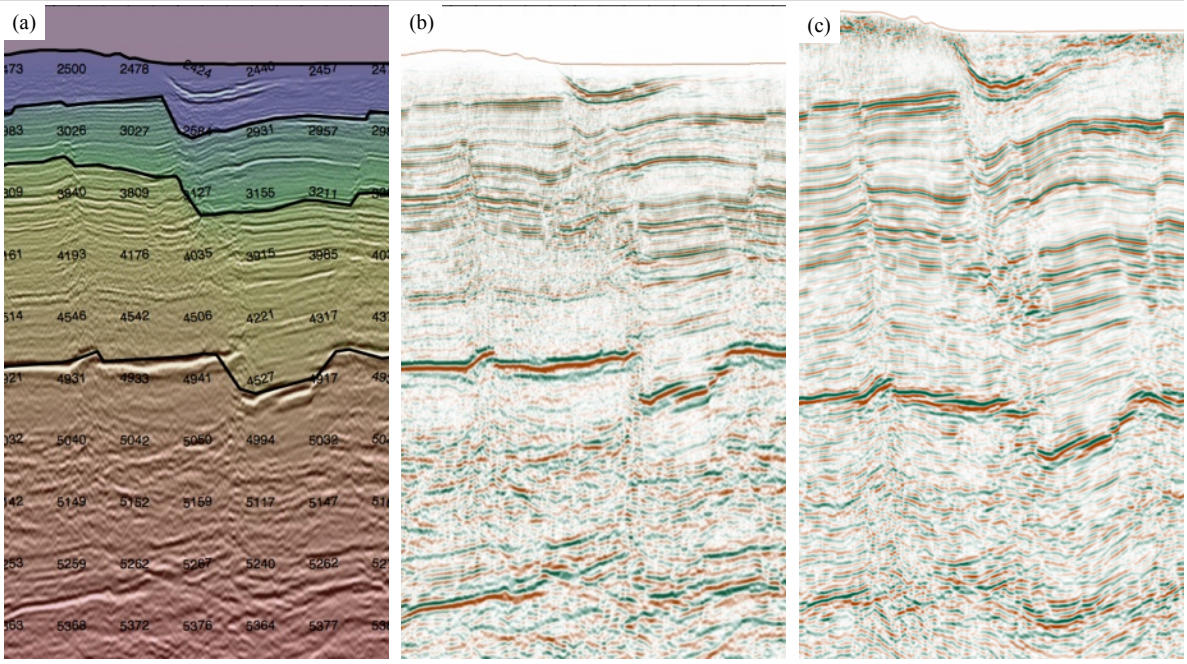

Figure 4: Subset of depth-migrated test line. (a) Velocity model overlaid on depth image. Velocity numbers on the display are oriented parallel to bedding of the TTI model dip. (b) Prestack depth migration displayed in depth. (c) Prestack time migration displayed in time for comparison.

zones the well-documented Cretaceous reservoirs in the Mardin Group are also seen as highly prospective in the Antep area.

The grid of lines was dense enough to build robust structure maps of various horizons across the Antep Block. There were some issues tying the 2D lines, because some dipping reflectors would image out of the plane of the intersecting line, but overall, mapping horizons in three dimensions went smoothly.

Figure 5 shows a time structure map of the Ordovician Bedinan horizon. The mapped horizon displays significant amounts of faulting in a variety of orientations, magnitudes and ages. In order to assess the exploration risk associated with each structure it was important to understand the history of the principal faults, and their potential role with respect to hydrocarbon migration and entrapment. As the map shows, the area displays large amounts of structural variation with both very high and very low areas bounding the prospective blocks. Hydrocarbon traps at the Ordovician level are

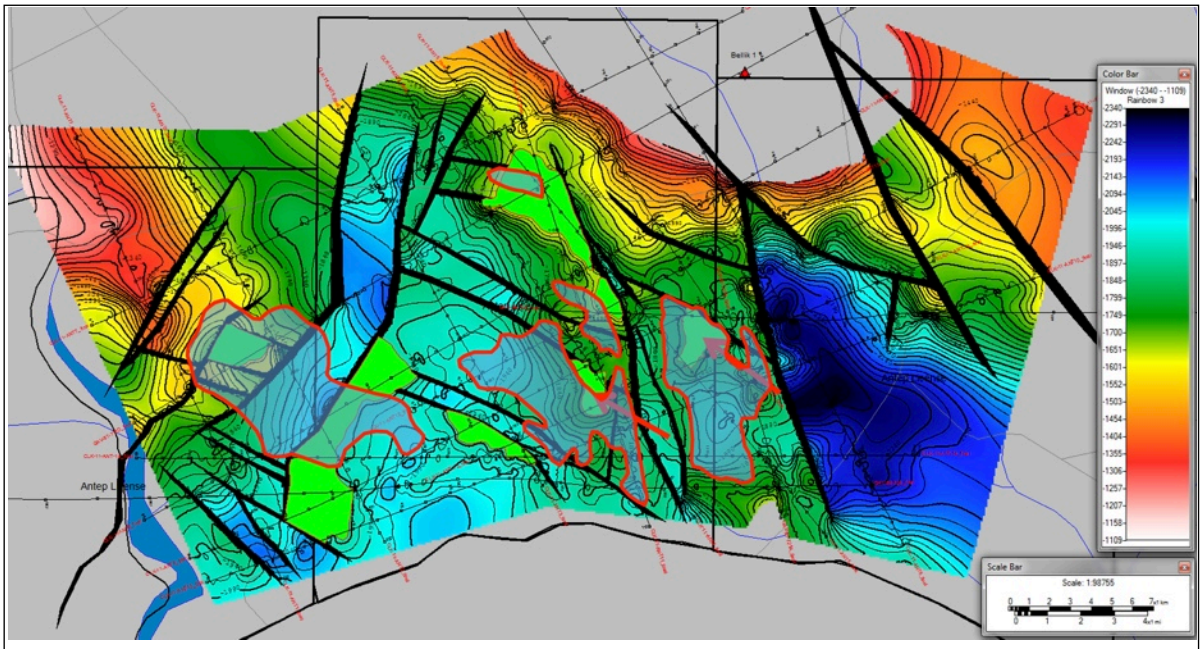

Figure 5: Structure map of Bedinan formation showing overlap between potential targets at both Bedinan and Karababa levels. Identified leads are outlined by the green polygons. The red polygons outline leads mapped in the Karababa.

formed by normal faults which provide up-dip closure to the porous sandstones against the overlying Silurian shales. In the structure map in Fig. 5 the green polygons represent several such closures at the Bedinan interval.

The Cretaceous (Karababa) formation is also seen as highly prospective and several fault-dependent structures were also mapped. Some of these leads are shown in red in Figure 5. Note there are several opportunities to define well paths to intersect prospective areas at both Karababa and Bedinan levels.

Another item of interest that arose from the interpretation of the 2D grid was the identification of possible Cretaceous-age reefs. Figure 6 shows an example of one such stratigraphic anomaly.

Conclusions

Using a workflow that focused on basic, robust processes, we imaged a variety of structural and stratigraphic features in time and depth over the Antep block. Key levers to success were tight integration with the interpretation team and extensive testing of a variety of algorithms and parameters.

New lines beyond the Antep block have recently been processed, particularly to the north where structural complexity increases in a more compressional environment. Two examples are given showing significant improvements on lines obtained from TPAO. In this case the imaging of thrust faults, steep dips and rapid lateral variations in structure have all been improved through the methods described in this paper.

Interpretation of the resulting images yielded the delineation of multiple leads over two major pay zones. Further work includes additional depth imaging and drilling of major targets.

Acknowledgements

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References

Perincek, D., 1990. Stratigraphy of the Hakkari Province, Southeast Turkey. Turkish Association of Petroleum Geologists Bulletin 2 (1), 21-68 (in Turkish with English Abstract).

Vestrum, R.W., Dolgov, V., Wittman, G., Csontos, L, and Gittins, G., 2011, 3D seismic imaging over two structurally complex seismic surveys in the foothills of Pakistan: First Break **29**, no. 4, 61.

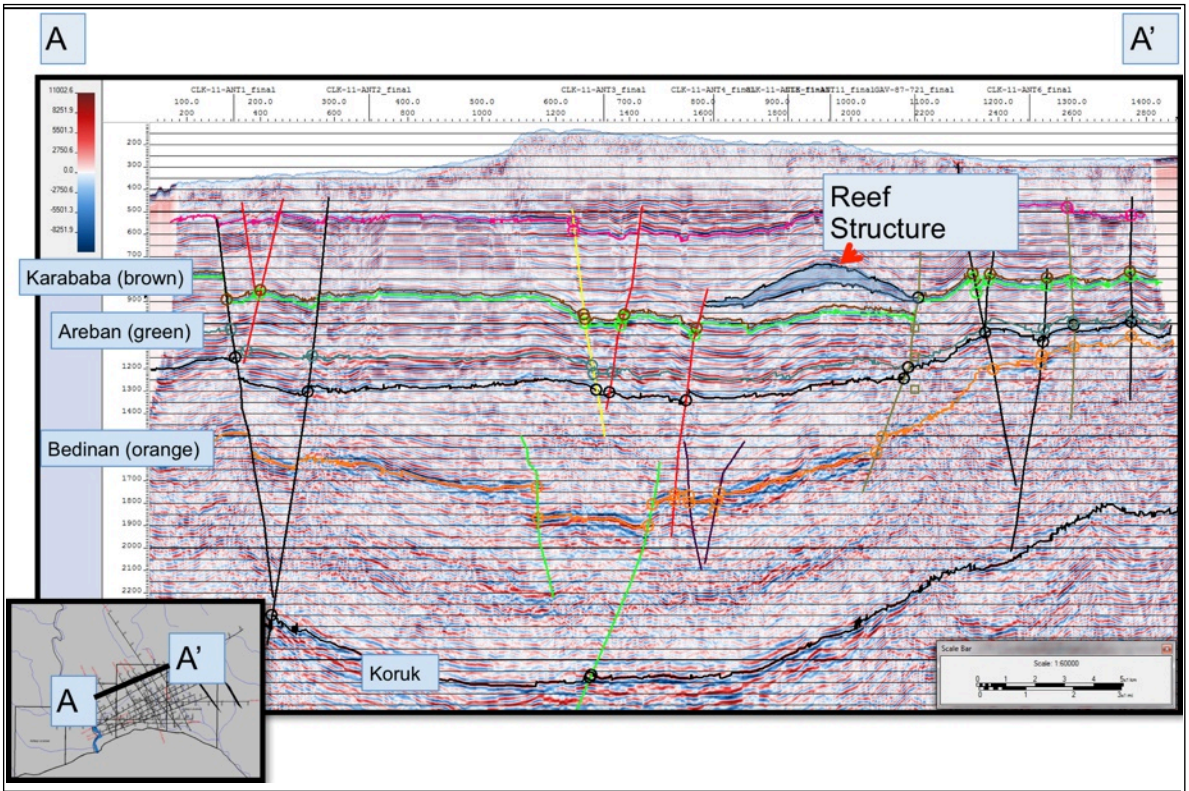

Figure 6: 2D interpretation showing the major faults and the stratigraphic anomaly that is a potential Createaceous reef structure.