IMAGING PRE-MESSINIAN TARGETS IN THE EASTERN MEDITERRANEAN SEA - A CASE STUDY USING FWI

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Summary

Following pre-Messinian gas discoveries in the Eastern Mediterranean Sea, there has been a great interest in recent years to enhance imaging beneath Messinian salt layers. In order to adequately image the pre-Messinian, various problems must be overcome, including correctly illuminating the sub-salt portion. The Eastern Mediterranean's illumination issues are largely caused by a complicated combination of shales and salt. Another challenge for velocity model building (VMB) here is that the Messinian layer is not typically uniform, and it might consist of a mixture of salt and clastics known as 'dirty salt.' In this paper a VMB workflow solution, including FWI, has been presented for the complex Messinian salt layers and post-Messinian carbonates in order to improve pre-Messinian imaging. The workflow has been applied on recently acquired data in east Mediterranean Sea using multisensor streamer and triple source acquisition configuration.

Imaging pre-Messinian targets in the Eastern Mediterranean Sea - A case study using FWI

Introduction

In the last few years, there has been an increase in interest for improved imaging beneath Messinian salt layers after large pre-Messinian gas discoveries in the Eastern Mediterranean Sea. There are several challenges for accurately imaging the pre-Messinian, including correctly illuminating the sub-salt section. This involves both optimizing acquisition parameters and building accurate geological models. The Eastern Mediterranean area is sparsely populated with multi-azimuth streamer surveys; most are narrow azimuth. A lack of azimuthal diversity can affect the imaging of sub-salt targets even when using accurate velocity models.

Illumination issues in the Eastern Mediterranean are primarily caused by a complex interaction of shales and salt. The Messinian layer is not always homogeneous, and can be a mixture of salt and clastics, termed 'dirty salt'. This is a challenge for model building. We focus on a couple of blocks of Eastern Mediterranean Sea, acquired using multisensor streamer triple-source seismic data. Optimal velocity model building for depth imaging involves the application of complementary imaging technologies to mitigate assumptions in any single process (Whitmore and Crawley, 2012, Brandsberg-Dahl et al., 2017). Using this strategy, we demonstrate a solution for the complex post-Messinian carbonates and Messinian salt layers, in order to improve the pre-Messinian imaging and reduce uncertainty in the seismic amplitudes.

Velocity Model Building Workflow in the Eastern Mediterranean

Figure 1 shows Velocity Model Building (VMB) workflow adopted for the work presented in this paper. A schematic diagram on left top corner highlights various key layers targeted at different stages of the VMB workflow. The VMB started with the water velocity layer. During seismic acquisition, temperature-salinity (TS) measurements were recorded at different locations across the survey, and a TS driven 1-D function was used for the water layer velocity profile.

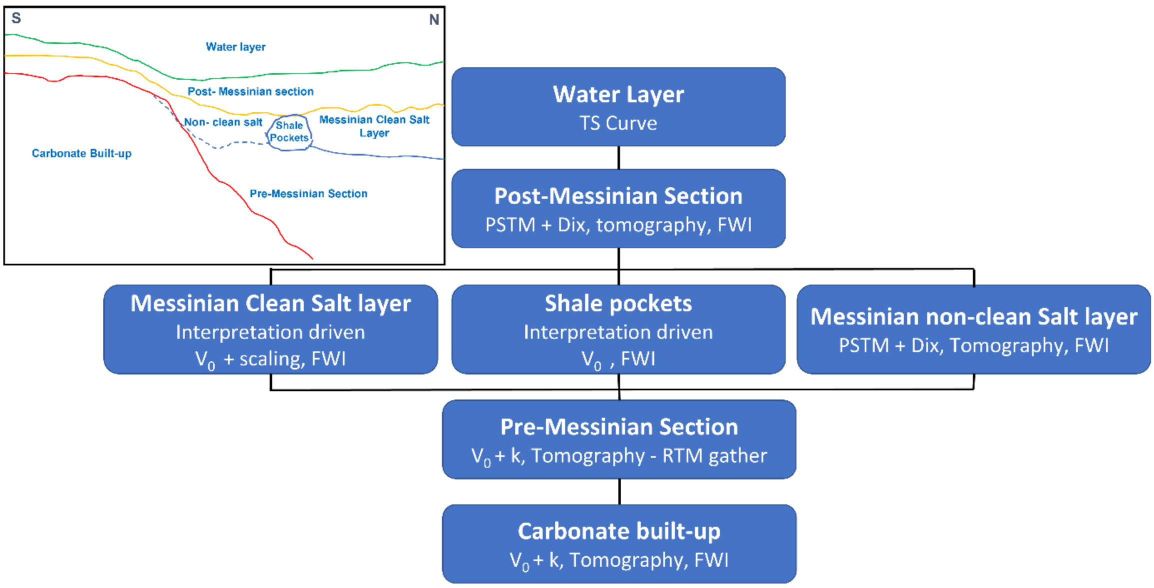

Figure 1 *VMB Workflow. Top left corner shows schematic diagram highlighting key geological layers which has been targeted at different stages of the VMB workflow presented as flowchart.*

For the post-salt section, and in the absence of sonic well information, a smooth Dix interval velocity model (Dix, 1955) was derived from a Pre-Stack Time Migration (PSTM) interval velocity field and used as the initial isotropic model. The post-salt tectonic regime varies, thus it is crucial to get an accurate velocity profile before introducing anisotropy. Anisotropy was added after several isotropic reflection tomography updates. Several ray-based wavelet-shift (Sherwood et al., 2011) gridded tomography passes were performed using Tilted Transverse Isotropy (TTI), resulting in an accurate post-salt section.

The main challenge in imaging the pre-Messinian section is determining an accurate model for the main Messinian section. The distribution of salt in the two major basins, the Herodotus and the Levant, is interrupted primarily by detrital deposits from the Nile Delta (El-Bassiony et al., 2018). At the basin margins, the salt body geometry changes from horizontal bedding in a compressive regime, to a more diapiric system closer to the cone of the Nile Delta. Away from the diapiric region, the salt layer shows intra-salt reflectivity, suggestive of complex heterogeneities. In the area of study described in this paper, the Messinian layer can be split in two different types. First type is where a clear top and base salt interpretation can be clearly observed, which is termed as clean salt area. Second type is heterogeneous and intruded by an inflow of shales, softening the velocity contrast at the top Messinian boundary. For the first type, the layer model was built using top and base salt interpretation. Despite the heterogeneity in the salt layer, a constant salt velocity provides a simpler structure of the base of salt (El-Bassiony et al., 2018) and a good average velocity to assist further tomographic updates. In this case a constant velocity of 4500 m/s was used. A further spatially varying salt velocity was obtained by picking the errors at the base salt moveout on gather. For the second type as velocity contrast is softened, the model building for this layer was not interpretation-driven. In few locations, shale pockets have also been identified, for which the model was built by scanning different velocity scenario testing.

The post-Messinian and Messinian layers were further improved by applying Full Waveform Inversion (FWI) using the wavelet-shift tomography model as an input. When scale-lengths of homogeneities, such as those found within the complex Messinian layer, cannot be represented by rays and Snell's Law, waveform-based back-propagation methods, like FWI, provide the resolution in the model that ray-based back-projection approaches cannot. FWI iteratively solves a model using numerous repeated waveform propagation modeling steps as the velocity model evolves. For this velocity model building phase, data with a maximum frequency of 12 Hz were used to build an accurate FWI velocity model, consequentially improving the pre-Messinian imaging.

The velocity in the pre-Messinian layer has gentle gradient with velocity starting from anywhere between 2000 to 2400 m/s. The starting velocity increases to 3200 m/s to 4200 m/s in the presence of carbonates build-ups located underneath the base Messinian towards the Southern edge of the area. The velocity inside the carbonates built-up progresses at a much higher gradient compared to pre-Messinian layer with reaching up to 6000 m/s. The presence of strong reflectors at the top of and within the Messinian sections resulted in a series of interbed beds which were clearly present in the sub-Messinian section. Therefore, for the pre-Messinian model building sequence, angle gathers generated by Reverse Time Migration (RTM) were used for ray-based tomography. RTM angle gathers showed less pronounced multiple energy as two-way wave energy can correctly map internal multiple in image domain. This helped the residual moveout picking to be less impacted by internal multiples from the Messinian layer, maintaining an accuracy in the pick constraints used for the inversion, and resulting in a model that further improved the pre-Messinian imaging.

Data Example

The seismic data example was acquired as part of a multi-client campaign in the Eastern Mediterranean Sea, western offshore Egypt, with water depths ranging from 700 m to 2300 m. The survey was acquired using a triple-source configuration and sixteen 8025 m long multisensor streamers separated by 75 m. The upgoing wavefield was generated through a wavefield separation process. The data was further processed using a standard pre-processing workflow including full 3D denoise and demultiple processes.

Figure 2 shows an inline section of the uplift achieved during the velocity model building phase. Left image is showing the velocity model from an early stage in the VMB workflow overlaid on its corresponding migrated stack. One can see the distortion of events in pre-Messinian section due to unresolved overburden complexity. The right image, showing the final velocity model overlaid on corresponding migrated stack, demonstrates how the proposed VMB workflow successfully captured the overburden complexity, simplifying the structure and improved the seismic image in the pre-Messinian section.

Figure 3 shows an example of a depth slice (left) and an inline section (right) of the final velocity model overlaid on the Kirchhoff migrated seismic section. The depth slice is taken in the post-Messinian section. As shown by arrows, shallow channels in the post-Messinian section are clearly delineated by the velocity model obtained thanks to FWI, improving the pre-Messinian image. The inline section shows the lateral velocity variation in pre-Messinian and Messinian sections has been resolved by the VMB workflow.

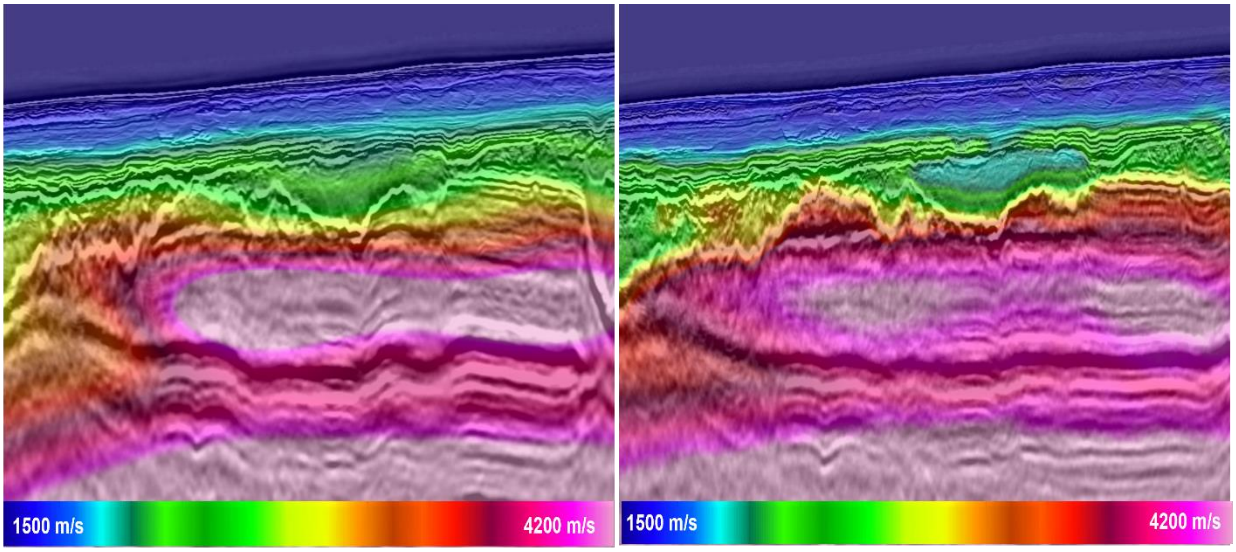

Figure 2 *Inline showing the uplift through the velocity model building workflow. Left image is showing velocity overlaid on its corresponding migrated stack at early stage in VMB workflow whereas the right image is showing the final velocity model overlaid with its corresponding migrated stack.*

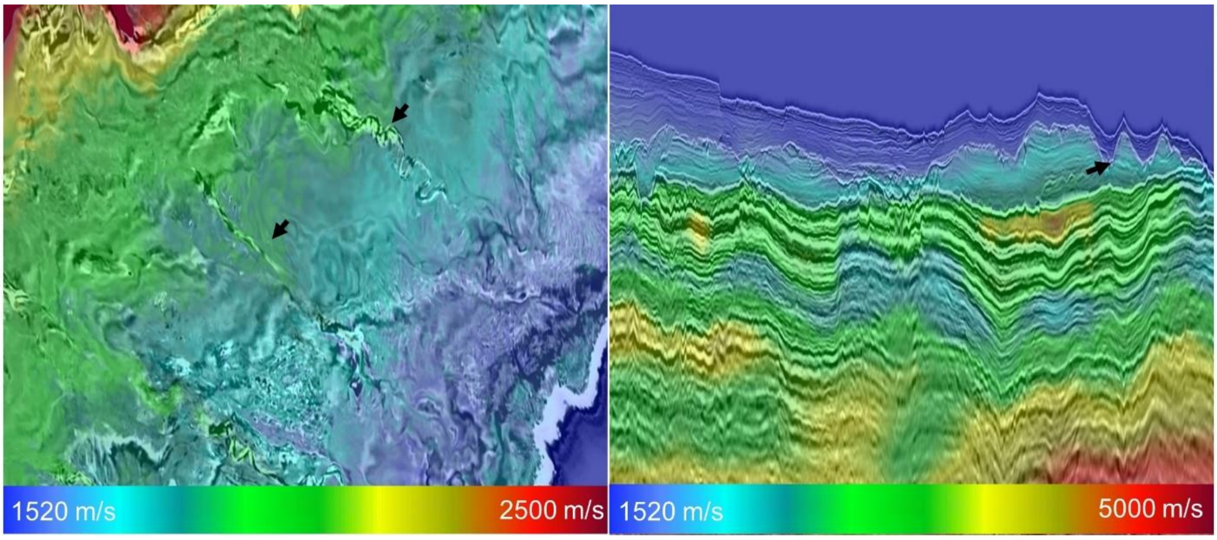

Figure 3 *Depth slice (left) and Inline (right) of the final velocity model overlaid with its corresponding migrated stack. Small channel features have been accurately delineated.*

Figure 4 shows an example of depth slice (left) and inline section (right) of the final velocity model overlaid on its corresponding migrated seismic section in a clean salt area. In this part of the survey one can observe a thick layer (shown by black arrow) on top of transparent and clean salt layer (shown by orange arrow). These sediments are within the Messinian layer and mostly made up of various salts, which has a velocity much higher than the post-Messinian layer but lower than clean halite salt layer. The depth slice is taken through the Messinian layer. The velocity variations within this layer have been well constrained to the Messinian layer. The inline section also shows how well the velocity variation within the Messinian has been derived and helped in simplifying the base salt and the pre-Messinian layer.

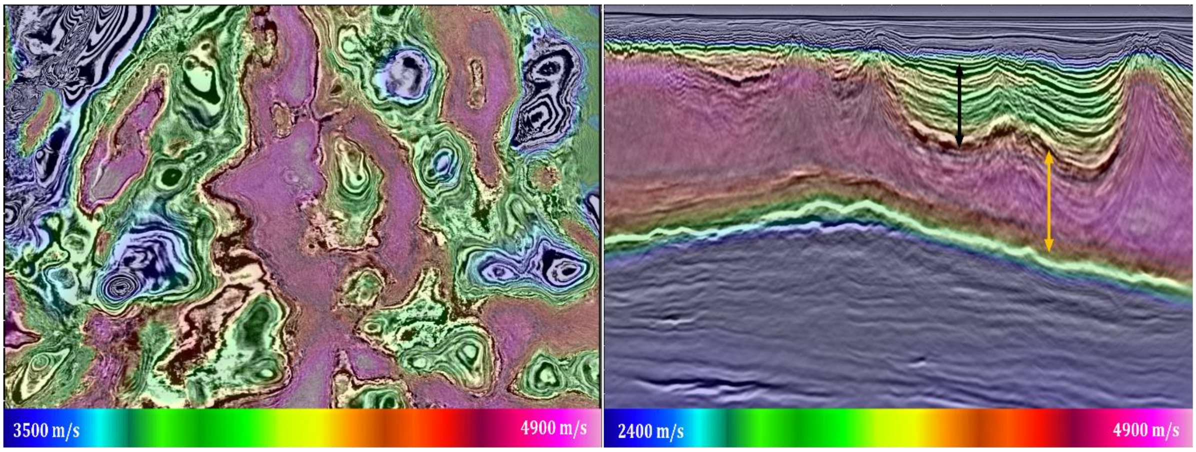

Figure 4 *Depth slice (left) and Inline (right) of final velocity model overlaid with its corresponding migrated stack. Heterogeneity in the salt layer has been well captured by the VMB workflow.*

Conclusions

The Messinian layer complexity in the Eastern Mediterranean Sea contributes to uncertainties in the imaging of the pre-Messinian targets. In this region, the Messinian layer is heterogenous and complex, and to obtain the optimum pre-Messinian image, it is vital to resolve the complexities of this layer. Using state-of-the-art technology such as FWI and RTM gathers, the proposed VMB workflow has been successful in capturing most of the post-Messinian and-Messinian complexities, helping in improving the image of the pre-Messinian target.

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