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22

A CASE STUDY SOLVING VMB OVERBURDEN COMPLEXITIES IN THE EASTERN MEDITERRANEAN SEA USING FWI AND RTM

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Summary

Improving imaging beneath Messinian salt layers has garnered a lot of attention, especially due to recent pre-Messinian gas discoveries in the Eastern Mediterranean Sea, which has proven promising hydrocarbon potential in the region. The primary challenges of imaging the pre-Messinian targets are related to enhancing the overburden velocity resolution, including Messinian layer which is very heterogeneous in this region. Advanced technology like Full Waveform Inversion (FWI) and Reverse Time Migration (RTM) can help in developing an optimized velocity model building (VMB) workflow. In this paper, one such VMB workflow has been proposed demonstrating different overburden solutions to improve the pre-Messinian Image. The proposed workflow has been implemented on recently acquired data from some of the blocks in the Eastern Mediterranean region.

Introduction

The Eastern Mediterranean region holds significant hydrocarbon potential, marked by proven Jurassic/Cretaceous oil and gas reserves, Pliocene Nile-sourced sandstones, and the possibility of pre-Messinian carbonate buildups akin to the Zohr discovery. Precise imaging of the pre-Messinian targets faces several challenges, primarily the need to enhance the velocity resolution of the overburden geo-bodies. These challenges encompass understanding the interaction between clastic sediments and Messinian evaporites, capturing the required velocity details for the Messinian layer's heterogeneity, and addressing illumination issues arising from the complex relief of the Messinian layer, which involves optimizing acquisition parameters (Kumar et al., 2022).
Optimizing the depth velocity model building process necessitates the application of advanced imaging technologies such as Full Waveform Inversion (FWI) and Reverse Time Migration (RTM) to mitigate the limitations of individual processes (Brandsberg-Dahl et al., 2017). Through this approach, we present diverse solutions to the various overburden challenges, enhancing the pre-Messinian image. In this abstract we showcase a few data examples from recently acquired blocks in the Eastern Mediterranean area to illustrate these solutions.

Velocity Model Building (VMB) Workflow

The thickness of the post-Messinian section is limited in the Eastern Mediterranean region but the presence of the Messinian evaporites causes a strong velocity contrast near the sea bottom, which presents a major challenge for VMB. The left part of Figure 1 shows four types of overburden challenges and the associated VMB strategies that have been used to improve the velocity resolution and overcome the poor imaging of deep reflectors. A schematic diagram, on the right of Figure 1 illustrates the different geological scenarios encountered during the velocity model building work on this dataset.

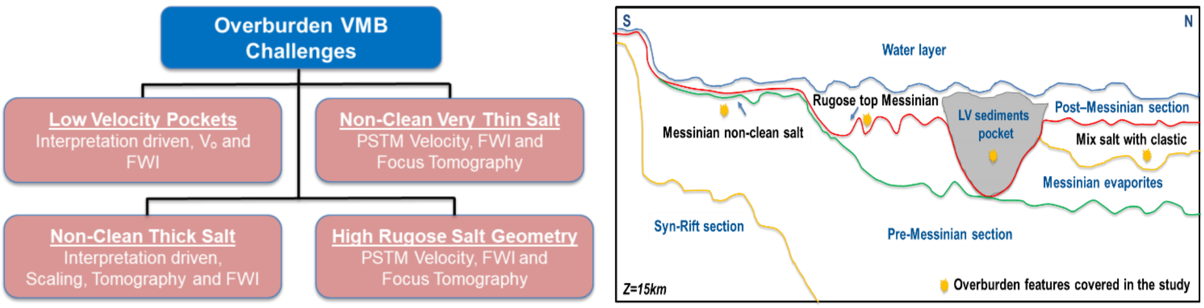

Figure 1 *Left chart shows four overburdens' challenges and the proposed VMB Workflow. The right hand-side schematic diagram highlights the key geological layers.*

Here below we describe the model building techniques used for the four VMB challenges shown in the schematic in Figure 1.

Low Velocity Pockets: The Messinian evaporites distribution in the two major basins, Herodotus, and Levant, is interrupted by detrital deposits from the Nile Delta. In some areas near the basin margins high-pressured Miocene turbidities beneath the salt layer have pierced and injected above the salt, forming clastic ‘pockets’ taking a mushroom shape (El-Bassiony et al., 2018). Gather flatness analysis suggests that velocity as low as 1700m/s to 2000m/s are required for these sedimentary ‘pockets’. To accommodate these clastic geo-bodies in the VMB process the top and base were interpreted, and a constant velocity fill was used. Further passes of wavelet shift reflection tomography (Sherwood et al., 2011) were performed to update the geo-bodies velocities further.

Non-Clean Salt: In both the Levant and Herodotus basin, the Messinian salt layer shows complex intra-salt reflectivity. Analysis of the deep basin depth migrated seismic and borehole data suggests that the transparent seismic layers of the Messinian are composed of pure and uniform halite while the more reflective layers are bundles of thin clay layers interbedded in the matrix (Manzi et al., 2016). The salt velocity varies depending on the amount of clay present. Therefore, the local velocity estimation was performed by comparing the gather flatness variation at the base of salt (gamma field) with the RMS amplitude maps extracted in the salt section (El-Bassiony et al., 2019). This showed that the salt has a lower average velocity where there was significant intra-salt reflectivity.

The thin clay sheets result in a soft velocity contrast at the top Messinian boundary. In this study, the velocity of the main Messinian layer was derived from Dix converted smoothed PSTM interval velocities. This was followed by the application of a few passes of gridded ray-based wavelet-shift tomography. As a result, the velocity errors in the upper part of the Messinian were significantly reduced. The velocity model for the lower part of the Messinian layer was built by picking the top and the base of what was interpreted as the clean salt layer and filled with a constant 4500 m/s velocity.

The Messinian evaporites thin out at the basin margins, especially towards the shelf area. In this region, the Messinian average velocity is variable and slower than the salt, reaching 3200 m/s with variable thickness and geometry. The presence of this layer close to the seabed affects the azimuth and arrival time behavior of the recorded waves from the syn-rift section. A few passes of gridded wavelet-shift reflection tomography were performed using a smooth Dix-converted PSTM interval velocity model as an input.

Refraction FWI was used to improve the velocity resolution below the seabed. Some residual errors were observed in the syn-rift section, thus few passes of the controlled sensitivity tomography (focus tomography), (El-Bassiony et al., 2016) were applied on top of FWI to improve the gather flatness and structure distortion of the syn-rift section.

High Rugose Salt Geometry: The Mediterranean Ridge area is characterized by very complex salt geometries because of the complex faulting and possible strike-slip tectonics (Reston, et al., 2002). The main imaging challenge in this area is to compensate for the variable illumination caused by the highly rugose top salt. Choosing the right migration algorithm is therefore key to improving the pre-Messinian targets. We selected Reverse Time Migration (RTM), with its ability to handle the complex wave pathing and build the velocity model in pre-Messinian by using RTM angle gathers in our tomography updates (Kumar et al., 2022).

Irrespective of the specific VMB methodologies described above Full Waveform Inversion (FWI) was used up to a maximum frequency of 12 Hz to estimate velocities in the shallow overburden.

Data Examples

The data example described here are the result of merged regional dataset which was created by combining 7 different multisensor datasets acquired between 2008 and 2021. Principally three different acquisition configurations were used ranging from 12 x 10 025m (150 m streamer separation) to 16 x 8 025m (75 m streamer separation). Almost all surveys were acquired using triple sources.

The merged dataset is located in the Eastern Mediterranean Sea, offshore Egypt, with water depths ranging from 50 m to 3 000 m. The upgoing wavefield data was generated through a wavefield separation of the multisensory recordings. The data was further processed using a standard pre-processing workflow including full 3D denoise and de-multiple processes.

Figure 2 A and B, show an example of low velocity pockets with a depth slice through the Messinian (2A) and inline section (2B) of the final migrated image overlain with the final velocity model. High pressured turbidites underneath the salt layer have fully pushed into the salt, creating shale deposits above the Messinian top. The shale pocket looks transparent on the seismic and has an average velocity of only 1700m/s.

Figure 2 C and D, illustrates an example of Messinian thick salt with a depth slice through the Messinian (2C) and an inline section (2D) of the final migrated image overlain with the final velocity model. In this example, a thick sediment pocket (shown by black arrow) is present on top of transparent and clean salt layer (shown by orange arrow). These sediments are included in the Messinian layer, are mostly composed of various evaporites, and have a velocity much higher than the post-Messinian layer but lower than clean halite salt layer. This example shows how well the shale pocket velocity and the velocity variation within the Messinian have been derived by the VMB flow and helped in simplifying the base salt and the pre-Messinian layer.

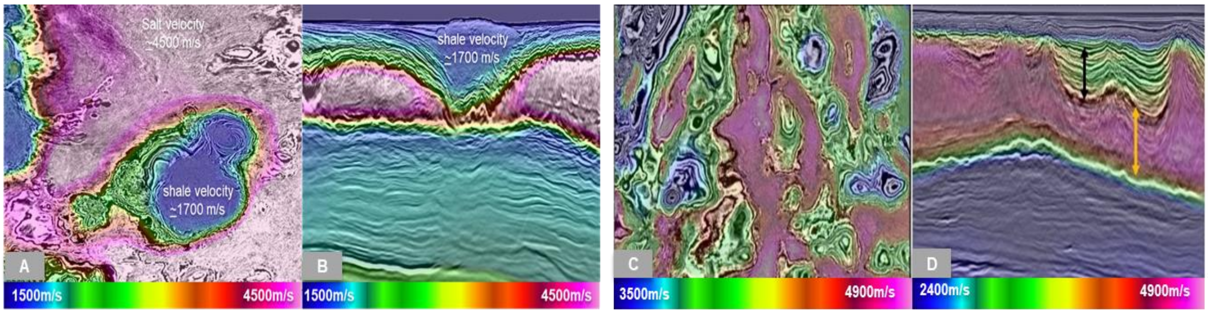

Figure 2 *Depth slice (A/C) are taken through Messinian section and Inline (B/D) of the final migrated image overlain with the final velocity model. Heterogeneity in the Messinian and post-Messinian have been well captured by the VMB workflow.*

Figure 3 A & B, shows an inline example of the uplift achieved after updating the velocity of the very thin Messinian layer. The velocity update results in this example were obtained from an early stage of the VMB sequence. The residual move-out distortion observed in depth migrated gathers were further corrected after solving the overburden complexity by the application of FWI and tomography (A&B). (C&D) show the velocity model before and after the velocity update, overlaid on its corresponding migrated stack. As shown by arrows, this example demonstrates how the proposed workflow successfully captured the overburden complexity well, simplifying the structure and improving the syn-rift image.

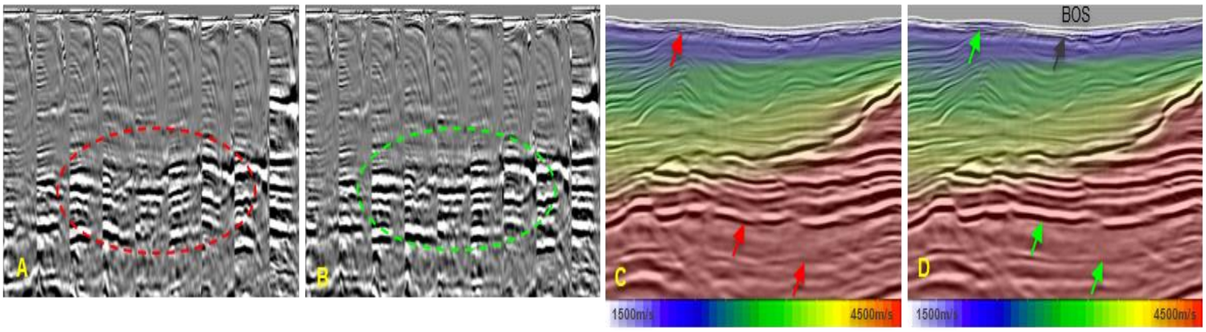

Figure 3 *Inline shows the migrated image gathers (A/B), and the migrated image overlaid with the corresponding velocity model (C/D) (before / after) velocity model update.*

Figure 4, shows an inline example in the Mediterranean Ridge area, where the Messinian salt geometry is very complex. Image (B) is Kirchhoff depth image, while image (C) is the corresponding RTM image. Both images used the same velocity model (overlaid on Kirchhoff image 4A). As shown by the arrows, the Kirchhoff depth image result is missing the very steep-dip base of salt and deep structure reflectivity, The RTM can better map the energy to the right place, dealing with the complex wave pathing and multi-pathing. In addition, the level of noise is significantly less with RTM, especially at the BOS. In this case, the overburden model was built using ray-based tomography and FWI, while RTM images to pick the salt geometry and pre-Messinian velocity update.

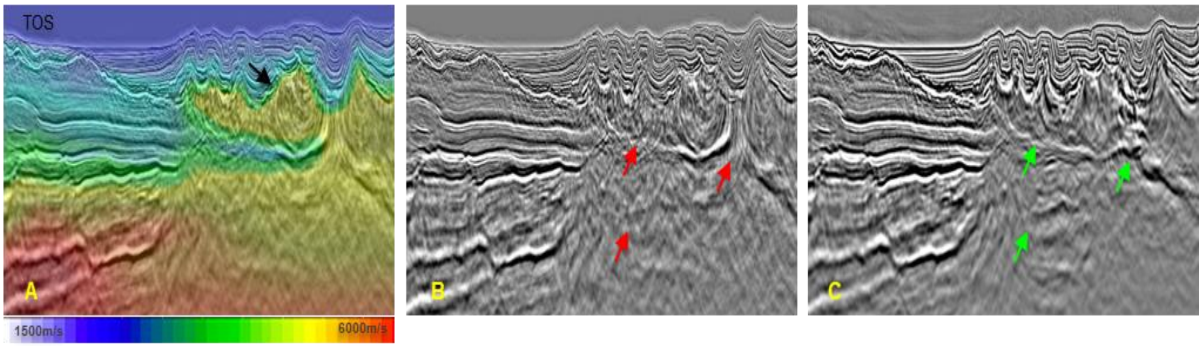

Figure 4: *Example of an inline with the final velocity model overlain with the Kirchhoff depth migrated stack (A). Comparison between Kirchhoff Depth image (B) versus RTM image (C). Clear image improvements of the pre-Messinian section can be observed (arrows).*

Conclusions

The overburden in the Eastern Mediterranean Sea contributes to the imaging uncertainties of the pre-Messinian targets. In this region, the Messinian layer is very heterogenous, and it is crucial to resolve the velocity complexities of the overburden to achieve the optimum pre-Messinian image. The proposed VMB workflow including FWI and RTM, have 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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