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Velocity Model Building Challenges And Solutions In The Eastern Mediterranean: Case Studies From The Region

A. El-Bassiony[1]*, J. Kumar[1], T. Martin[1], M. Bell[1]

[1] PGS

Summary

Recent large sub-salt discoveries in east Mediterranean waters have steered the focus on imaging beneath complex salt structures, where the main challenge is to correctly illuminate the sub-salt section. This involves optimizing acquisition parameters as well as building an accurate subsurface geological model. Only limited regions in the east Mediterranean are covered by multi-azimuth surveys; most of the 3D surveys available are narrow-azimuth. A lack of data diversity degrades the imaging of sub-salt zones even when using accurate subsurface models. Optimal model building for depth imaging involves the application of many complimentary imaging technologies to mitigate assumptions in any singular process. Illumination issues in the east Mediterranean are primarily caused by the complex interaction of shales and salt. The geometry of the salt layer and the velocity contrast across neighbouring lithologies determine the illumination and imaging quality beneath the salt layer. Using accurate interpretation of the top and base salt, and inserting a reliable velocity in the model, enhances the sub-salt imaging. This work focuses on the salt layer model building in three zones across the east Mediterranean Sea and the optimization of the salt/shales, and salt/carbonates velocities to enhance the sub-salt imaging and improve the reliability of amplitude data.

Introduction

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Optimal model building for depth imaging involves the application of many complimentary imaging technologies to mitigate assumptions in any singular process (Whitmore, 2016, and Brandsberg-Dahl et al., 2017). Illumination issues in the east Mediterranean are primarily caused by the complex interaction of shales and salt. The geometry of the salt layer and the velocity contrast across neighbouring lithologies determine the illumination and imaging quality beneath the salt layer. Using accurate interpretation of the top and base salt, and inserting a reliable velocity in the model, enhances the sub-salt imaging. This work focuses on the salt layer model building in three zones across the east Mediterranean Sea and the optimization of the salt/shales, and salt/carbonates velocities to enhance the sub-salt imaging and improve the reliability of amplitude data.

Velocity Model Building Methods in the East Mediterranean

Velocity model building (VMB) started with the water velocity layer. Constant velocity scans were performed to determine a water depth variable velocity function. A Vo+kZ function was generated, where Vo is a starting velocity, Z is the depth of the water bottom (WB) and k is the gradient that determines the rate of change in velocity. Some surveys included temperature-salinity (TS) measurements at different locations across the survey. In areas of salinity or temperature changes, like in the Nile delta, or abrupt variations in WB depth across continental shelves and sea mounts, a TS driven function was used.

For the post-salt section, and in the absence or sparsity of sonic well information, a smooth Dix interval velocity model was inverted from a Pre-Stack Time Migration (PSTM) interval velocity and used as an initial model. The compaction or tectonic regime of the post-salt varied, and accordingly a simple anisotropic initial model did not compensate for these variations. Therefore, the initial model was built for an isotropic medium, followed by several isotropic tomography updates before the anisotropy was inserted. A number of wavelet shift gridded tomography passes (Sherwood et al., 2011) were performed using Tilted Transverse Isotropy (TTI) on the isotropic updated model; resulting in a final post-salt section that was well imaged in depth.

The main challenge in imaging the pre-Messinian section is the Messinian salt 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. At the basin margins the salt body geometry changes from a horizontal bedding in a compressive regime, to a more diapiric system closer to the cone of the Nile Delta. Away from the diapiric region, in both the Levant and Herodotus basins, the salt layer shows complex intra-salt reflectivity. Despite this, a constant velocity layer flattens the structure of the base of salt (BOS) (El-Bassiony et al., 2018). In regions where the BOS shows clear salt velocity variations, a variable salt velocity was imbedded. Feng and Rashef (2018) showed that the intra-salt reflectivity takes the form of thin clay beds with much lower velocities than salt, as recorded by well logs. Bell et al. (2018) approached the variable salt velocity modeling by comparing the variation of the gather flatness at BOS (gamma field) with the RMS amplitude map extracted in the salt section (Figure 3a and 3b). This showed that the salt has a lower average velocity where there was significant intra-salt reflectivity. The salt layer was split into clean and dirty regions, where the clean salt velocity that flattened the gathers was 4350 m/s, and the dirty salt velocities varied depending on the salt thickness. This yielded a velocity model that both flattened the base-salt reflector and improved the flatness of the intra-salt events (Figure 3c). In some areas, the salt layer is completely intruded by an inflow of the shales. For velocity insertion, the modeling of this complex intercalated shales/salt is a required but challenging task for the interpreter. The Messinian salt layer velocity changes from 4200 m/s in the Herodotus basin to 4300 m/s in the Levant basin. The pre-Messinian flood velocity starts from 2400 m/s s with a gradient k=0.2 m/s/m, where the detrital Miocene section are present. The starting velocity increases to 2700 – 4000 m/s in locations characterized by carbonate build-ups that reach the salt layer base (Figure 4). The model inside the carbonate built-up progresses has a gradient of 1.0-3.0 m/s/m, where the maximum velocity are 5000 m/s.

Case studies -*West Egypt*

PGS MultiClient data library includes 17500 line km of 2D offshore West Egypt and around 6000 sqkms of 3D acquisition over the 2D data (Figure 1). The two 3D surveys acquired offshore Matrouh City cover the shallow Matrouh Canyon and a deeper survey in the Herodotus Basin.

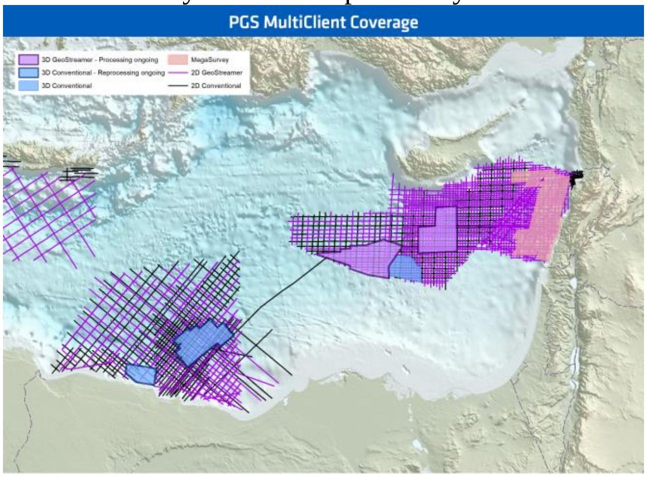

***Figure 1** East Mediterranean map showing the PGS 2D and 3D MultiClient data acquired using dual-sensor streamers and conventional acquisition (Widmaier and Lie, 2016).*

The shallow area covered the Matrouh Basin where no salt layer is present, while the deeper survey revealed the compressive salt layer with high pressure shale intrusions from beneath the salt. Figure 2a shows an example from the deeper West Egypt 3D survey.

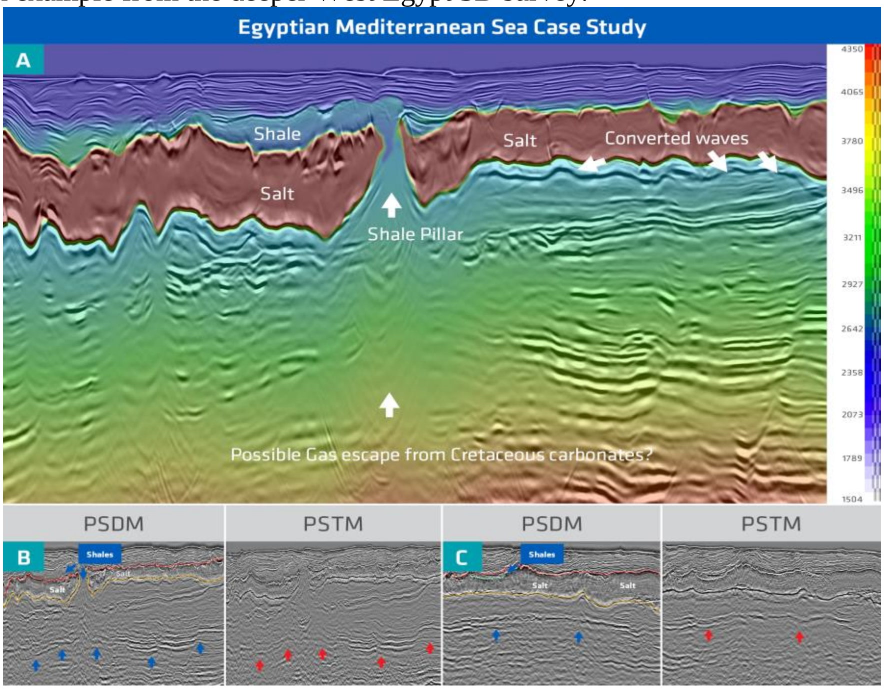

***Figure 2** Different examples of shales/salt interactions in Egypt's West Med.*

The high pressured shales beneath the salt layer have completely intruded the salt, forming a pillar cutting through the entire salt layer, leaving a mushroom-like shale deposit above the salt top. The depth model included these contrasts using an inserted gradient velocity for the shale intrusions simulating the compaction differences between the sediments above and beneath the salt. A second example shows another shale/salt complex where the shale pocket occurs at the top of the salt layer (Fig. 2c). Inclusion of this structure in the model results in an observed structural uplift in the Pre-Stack Depth Migration (PSDM) seen in Figure 2b, and 2c. All examples show a complete depth remapping of the BOS and pre-salt reflectivity. The model was built beneath the salt with a simple Vo=2400 m/s and a gradient k=0.2 m/s/m, and was followed by a sequence of global long wavelength tomographic updates.

Cyprus - Eratosthenes Sea Mount

Salt and carbonate structural plays are important in recent hydrocarbon discoveries in the northern edge of the Herodotus basin. Data southwest of the Eratosthenes Sea Mount (ESM), was acquired using dual sensors streamers over an area of 6000 sq.km bordering Cyprus and Egypt (Figure 1). The water layer was built using a TS function, while the post-salt section was built from the PSTM velocities and followed by a sequence of TTI wavelet-shift tomography updates (Sherwood et al., 2011). Using quantitative metrics to measure gather flatness, the inserted salt velocity showed localized errors at the BOS. This is shown in Figure 3a. A variable salt velocity was inserted according to Bell et al. (2018). The pre-salt sequence was split into four components (Figure 3d); a slower carbonate/sediment package with a velocity of 2600 m/s; a mid-carbonate (3500 m/s); an older carbonate cap with a velocity of 4500 m/s at the top increasing to 5500 m/s as it transitions to the carbonate basement (Fig. 3d).

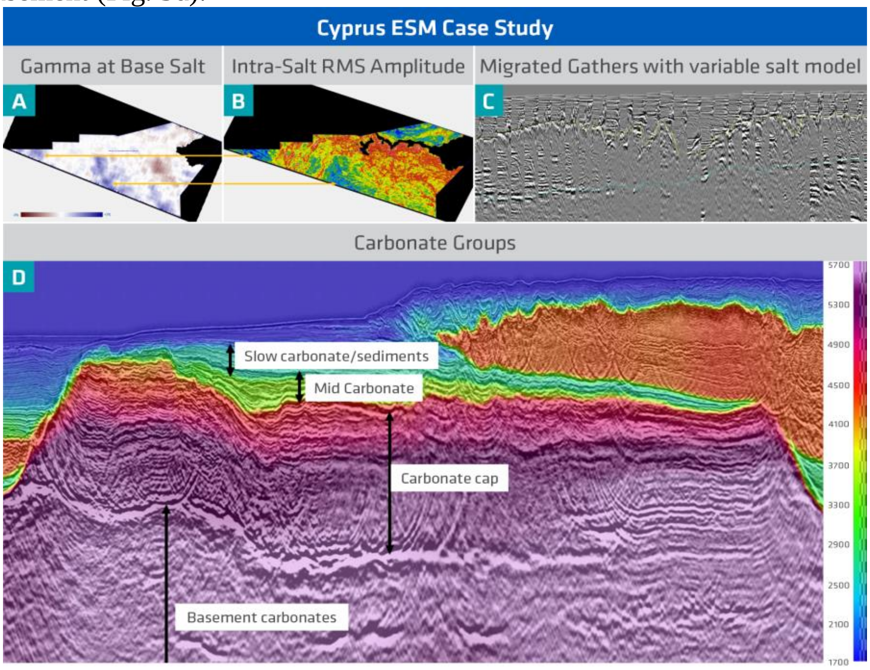

Figure 3 *South west ESM - spatially variable salt velocity and vertical different carbonate groups.*

Global tomographic updates augmented the initial model optimizing gather flatness. The final images show a variable carbonate environment; a faster velocity at the carbonate barriers/reefs, and slower shallower velocities representing carbonate build-ups, which are very similar to the Zohr field.

Lebanon

PGS acquired a 2D survey comprising 9000 line km of dual-sensor data and 10000 sq. km of 3D data from offshore Lebanon. A variable water bottom velocity function was used for the water layer in the initial model, and was followed in the post-salt section by the PSTM velocities. A sequence of TTI wavelet-shift tomographic updates where performed on the initial model. The salt layer showed good consistency using a higher interval velocity than those used in the Egyptian region. A salt velocity of 4300 m/s flattened the gathers at the BOS (Figure 4). A pre-salt model was inserted in this region using 2400 m/s as the starting velocity at the BOS and a gradient of 0.2 m/s/m. closer to the continental shelf the gradient increased to 0.3 m/s/m. Figure 4 shows an example from the Lebanon area. Analogous to the ESM example, a carbonate starting velocity of 4000 m/s was used, with a gradient of 0.1 m/s/m away from the continental shelf. Nearer the shelf, the carbonate velocities changed laterally to the carbonate basement value of 5000 m/s.

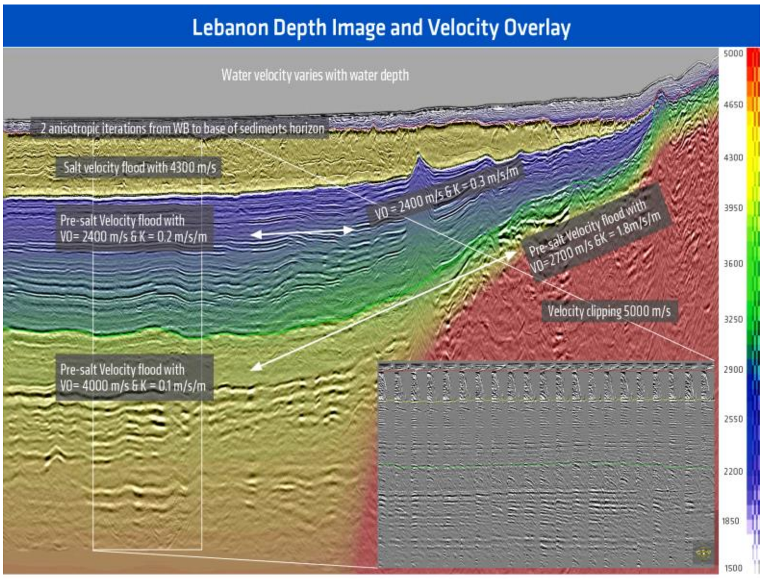

Figure 4 *Example from offshore Lebanon showing a constant salt velocity, and a laterally varying gradient for the pre-Messinian section.*

Conclusions

Salt layer complexity in the east Mediterranean Sea contributes to uncertainties in the imaging of the Pre-Messinian salt sequence. Accuracy of the interpretation of the salt sediment contacts is vital, as is a reliable velocity estimation for both salt and sediments. Regions of the east Mediterranean Sea, show variable salt velocities as well as disparate carbonate sequences. The simplest geological scenario resulting in the least complex model was illustrated in offshore Lebanon.

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