Egypt's West Mediterranean Sea – a global exploration hotspot

Mark Hamilton[1]* gives an overview of recent drilling and exploration activity in Egypt's west Mediterranean as it emerges as a key area for hydrocarbon exploration.

Introduction

There has been a rush of exploration activity in Egypt this year with two high-impact Nile delta wells completed before the end of February and substantial 3D acquisition in 2024 meaning the western delta will be almost entirely covered in 3D seismic data once processing is finalised. In the last decade, the Eastern Mediterranean has emerged as a key region for hydrocarbon exploration, with Egypt playing a leading role due to its well-developed infrastructure and strategic location. Egypt has been at the forefront in terms of exploration and production, with development in Egypt's Mediterranean beginning in the 1970s (Abu Madi – El Qara field, 1975) leading to extensive well-developed infrastructure, network of pipelines, oil refineries and gas processing plants, including LNG facilities. This makes Egypt an ideal hub in the Eastern Mediterranean and adds to its reputation as an exploration hotspot.

The Nile Delta Basin can be regarded as a mature hydrocarbon province, although new plays continue to rejuvenate the region (Lottaroli and Meciani, 2022). Exploration drilling began onshore in the 1950s, with initial discoveries being made in the 1960s. The Nile Delta Basin is largely a gas and condensate province, with shallower Plio-Pleistocene-aged clastic reservoirs typically yielding drier gas and deeper Oligo-Miocene-aged clastics reservoirs containing more condensate and some liquids.

The deeper-water regions and stratigraphically deeper reservoirs have only been targeted in more recent decades as the continued technology advancements allow. This includes discoveries in the Levantine Basin (including in Israel and Cyprus), where significant gas volumes have been found in pre-Messinian clastic reservoirs (e.g. Leviathan), as well as within pre-Messinian carbonate buildup structures (e.g. Zohr).

The northern onshore Western Desert Basins in Egypt are Mesozoic-to-Tertiary rift systems, and are very mature in terms of exploration, with the first discoveries made in the mid-1960s (Alamein 1, 1966). There are source intervals at multiple levels, with reservoirs present throughout the Jurassic to Lower Cretaceous succession. This northern Western Desert Basin extends into the offshore region and has not been extensively tested in this domain. The 1976 Sidi Barrani 1 well is one of the few offshore shelf tests, which targeted Cenomanian clastics, the Alamein Dolomite and possible reefal and clastic developments within the Lower Cretaceous and Jurassic sections. The well encountered oil staining in the Cretaceous and Jurassic, as well as fair reservoir quality in both the Barremian-aged Sidi Barrani Formation and Jurassic Khatatba Formation sands. It is thought to have failed due to the trap not being well defined on 2D seismic data a risk that should be mitigated in areas with recent 3D seismic acquisition.

Surrounded by the mature Nile Delta and onshore Western Desert areas, is Egypt's West Mediterranean Sea (EWMS) a frontier area in terms of hydrocarbon exploration (Figure 1). There are undoubtedly several reasons why this region has been neglected until very recently, some of which include the relatively deep water, lack of infrastructure, lack of seismic data and com-

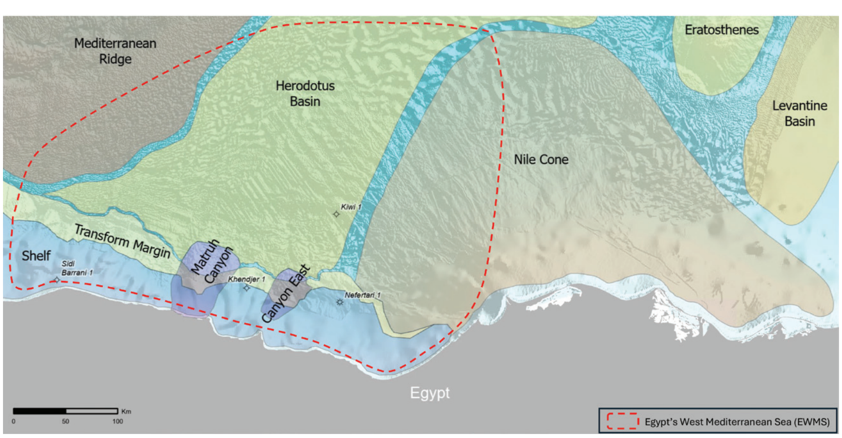

Figure 1 Overview of structural elements and geological domains, modified after Baer et al. (2017). EWMS includes the western part of the Nile Delta Cone, the Herodotus Basin, the southeastern part of the Mediterranean Ridge, as well as the offshore extension of the onshore Western Desert Basin (shelf, transform margin and canyon systems). Also included are locations of some of the exploration wells referenced.

[1] TGS
* Corresponding author, E-mail: mark.hamilton@tgs.com
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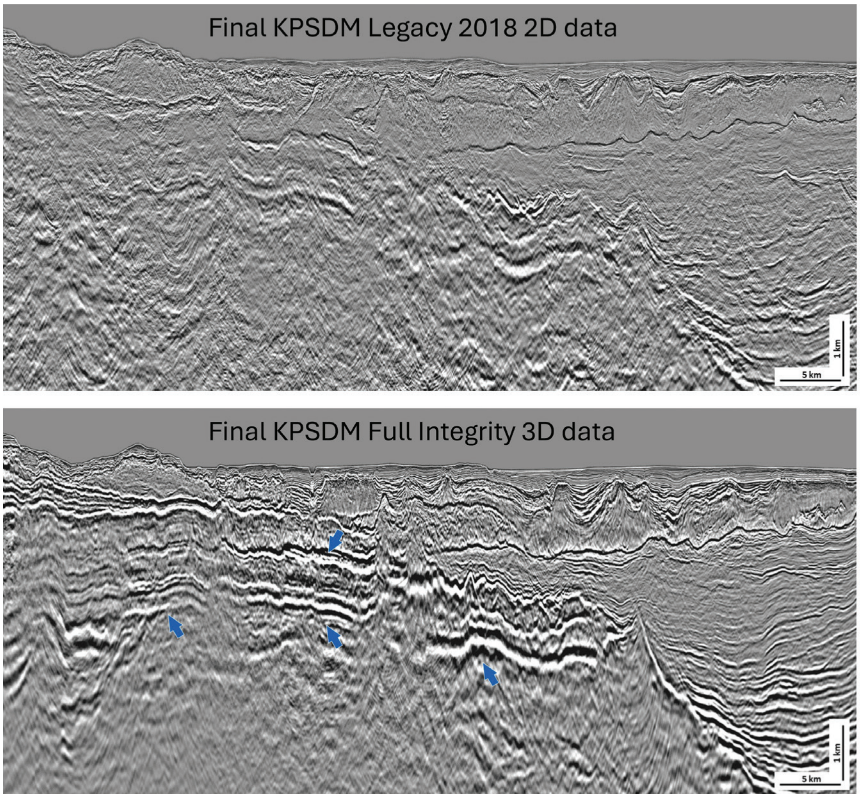

Figure 2 An example of the improved imaging gained from 3D seismic (lower panel) versus 2D seismic (upper panel). While the 2D data are suitable for regional-scale work, the 3D data are essential for trap definition and detailed stratigraphic work. Some examples of areas of uplift are indicated by the blue arrows in the lower panel.

paratively challenging seismic imaging. The last two aspects have been vastly improved over the last decade.

New data

Until approximately 2015, the region was covered by very little seismic data that was readily available to the industry. Approximately 10,000 km of legacy 2D data and 10,000 km^2 of legacy 3D data were reprocessed and made available to the industry in 2016. This reprocessing was followed up with two regional broadband multi-sensor 2D seismic data acquisition campaigns during 2016 and 2018, totalling 7300 km and 22,400 km respectively. These 2D seismic data formed the basis of a regional geological understanding and were used by companies to secure hydrocarbon exploration concessions in EWMS. This was a significant development in an area where there were no held concessions and little past exploration activity. Since the award of concessions and between 2020-2024, eight broadband multi-sensor 3D seismic surveys were acquired spanning over 29,400 km^2 in areas where there was no existing 3D seismic data and over both held concessions and open acreage. Along with improved imaging (e.g. Figure 2), these 3D data allow explorers to focus on stratigraphic elements and have more confidence in structural interpretation than is possible with 2D data.

New technologies

Seismic imaging in EWMS / Herodotus Basin is generally more complex compared to the Levantine Basin, despite a Messinian evaporite section of similar thickness. Figure 3 illustrates an example of a seismic section through the Levantine Basin, compared with some examples in EWMS. Although generally tabular in the deeper water areas, the evaporites are not simply clean high velocity halite as observed in other salt provinces but contain a significant amount of complexity and heterogeneity, as discussed in detail by other authors (e.g. Roveri et al. 2014; Feng et al. 2016). High amplitude events within the Messinian evaporite section are likely clastic layers. The level of deformation of these layers can give an indication of the deformation that this layer has undergone and the broader tectonics influencing the region (e.g. Evans and Jackson, 2021). The Messinian interval provides a significant challenge to the underlying seismic image due to distortion, attenuation, and complex diffractions.

Depth imaging has proven critical for high quality seismic imaging in the Eastern Mediterranean (e.g. El-Bassiony et al., 2018). An important factor in obtaining an accurate velocity model is obtaining a reasonable velocity for the complex Messinian evaporites, discussed above. As observed in Figure 3, the thickness of the layer, the amount of clastic inclusions, the deformation of the layer and the vertical level at which the clastic inclusions are located differ throughout the area. It is therefore essential that there is a variable velocity used within the Messinian evaporite layer to flatten the seismic gathers and have a reliable velocity model for the imaging, resulting in a more accurate pre-salt image. Velocity analysis of the Messinian salt reveals an interval velocity range from 3900 to 4800 m/s.

Mobile shales are recognised as an additional challenge for seismic imaging in the Herodotus Basin (e.g. Van Simaeys et al. 2021). They have an unclear seismic expression as they generally have a low acoustic impedance contrast with many other sedimentary rocks. Typically, they appear as transparent bodies on the seismic. They can have complex geometries and spatial variations and their seismic response and velocities can depend on the overpressure and fluid content, which are difficult to predict and may change quickly within a survey area. These shales can be both intruded into the base of the Messinian evaporites, extruded above them, and in some cases in the Mediterranean, extruding to seabed to form present-day mud volcanoes. In terms of velocity model building, the larger shale bodies are mapped and included in the velocity model-building process during imaging and a range of velocities are tested to obtain an optimal representation.

Imaging tools that are typically utilised for updating the velocity model and interpretations in areas with these evaporites and mobile shales include manual velocity insertion using interpretation, velocity scans, tomography, and Full Waveform Inversion (FWI) (e.g. Davies et al., 2024). More recently, elastic FWI has proven to solve some of the shortcomings of the acoustic FWI in areas with strong velocity contrasts. This is the capability to remove a halo above the Top Messinian and resolve the Messinian layer complexity more accurately due to a more complete description of the physics that accounts for mode conversion from the top of the layer. The increase in model resolution at Messinian level has been shown to a have hugely beneficial effect on the structure and residual move-out of the pre-Messinian targets (Romanenko et al., 2025). Another imaging technique that has been successfully applied in the region to improve seismic volumes is mode conversion removal (Kumar et al., 2018). Recorded converted mode energy is generated where there are strong acoustic velocity contrasts (e.g. where we have Messinian salt) and can sometimes cause interference in the vicinity of pre-Messinian exploration targets.

While high-end imaging workflows and migration algorithms are one way to address the seismic imaging challenges in this frontier area, another option that can be used in conjunction with this is to utilise alternative acquisition options. The benefits of multi-azimuth acquisition have been recognised for many years in this region, such as over the Raven field (e.g., Marten et al., 2007). Baptiste et al. (2024) describe the benefits of a recent node survey over the Atoll field, a first for the Nile Delta. Donaldson et al. (2024) outline the advantages of a wide-azimuth configuration with multiple vessels and low-frequency sources to better define subsalt reservoir presence. The lower frequencies and longer offsets from these higher-end innovative acquisitions allow for deeper FWI updates and a better image, particularly in the pre-Messinian section. They are typically applied in more targeted and field-specific surveys and mostly on a proprietary basis to better define targets and follow up drilling.

High impact exploration

Geophysically and geologically, with the improved data coverage as well as the improved data quality, the EWMS region has started to become an exploration hotspot. The region offers a diversity of plays depending on location, with three main sub-areas that will be the immediate focus for exploration.

The eastern part of the area is essentially the deep-water Nile Delta (Figure 1), where the primary targets are likely to be pre-Messinian clastics, and would need to contain substantial hydrocarbons to be economic in deeper waters. Secondary Plio-Pleistocene targets may add further volumes for any discovery that gets developed. It is possible to identify channel systems in the Pre and Post-Messinian stratigraphy using seismic attributes extracted on interpreted surfaces (e.g. Figure 4). In both the Oligo-Miocene and Plio-Pleistocene sections, the channels are generally weakly confined, low gradient slope channel systems

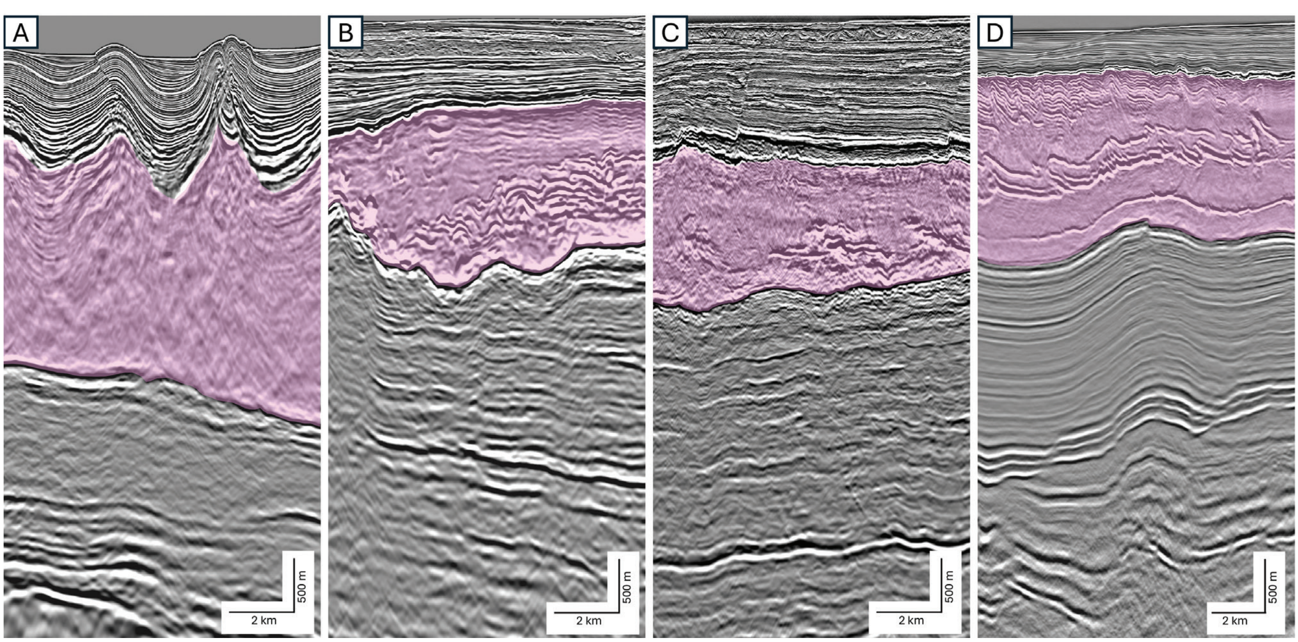

Figure 3 Example seismic sections through the evaporite layer in the Levantine Basin (panel D) compared with examples in EWMS (panels A-C). All examples are KPSDM imaging in depth. The evaporite inclusions are less complex and less deformed in the Levantine when compared with panels B and C. Combined with a less complex post-evaporite section, this leads to easier imaging of the pre-Messinian section, despite panel D being an example of an older survey with a lower end imaging workflow. Panel A shows an example of the very west of the EWMS, where we start to see the influence of the Mediterranean ridge. In this area, the evaporites tend to be inflated/thicker and cleaner or more halite-rich. However, the imaging remains challenging as the post-evaporite section is severely deformed due to compression related to the Mediterranean ridge subduction.

with moderate sinuosity. The reservoir presence risk should be low, but there could be high variability in reservoir quality in this kind of system. Very similar Oligo-Miocene reservoirs have proven successful in other parts of the Nile Delta at this level, for example the Atoll and Nargis discoveries.

Farther to the west of the area, in the deeper Herodotus Basin, it is expected that these channel systems transition to lower gradients and become less confined, with the potential for terminal fan systems with sheet sand lobes becoming increasingly likely. The Kiwi-1 well is the only exploration well located within this deeper basin area (Figure 1). It was drilled in 2010 and targeted a pre-salt structural closure. The well encountered no reservoir within the structure, but did encounter a good quality Early Oligocene (Rupelian age) reservoir in a deeper secondary target that appears to have lacked a valid trap. This well penetrated approximately 3000 m below mud line and so details on the deeper stratigraphy of the basin (more than 15 km in places) is still unknown.

The third sub-area is the offshore continuation of the onshore Western Desert rift systems. Here, Mesozoic to Tertiary rift systems are expected to extend onto the shelf area in the offshore (Figure 1). The Sidi Barrani well results should be encouraging with oil staining and suitable reservoirs encountered. Recent drilling campaigns, including the Khendjer-1 well (2024 in the North Dabaa concession) and Nefertari-1 well (2025, in the North Marakia concession) have targeted this region, though the exact plays these wells targeted have not been detailed. The Khendjer-1 well was reported as dry. However, details on which play elements were proven have not been disclosed. The Nefertari-1 well was announced as a gas discovery at relatively shallow depths (~1km below mud line), likely indicating a Cretaceous or younger-aged reservoir. The advantage of this area is the shallow water and therefore comparatively reduced drilling and development costs for any discoveries. There are numerous untested faulted traps within this shelfal domain (e.g. Figure 5), with the potential for multiple stacked reservoir intervals within these traps, as is observed in many discoveries onshore in the Western Desert. An interesting question is whether the charge for this discovery is biogenic or thermogenic, and if so, whether it is coming from a source rock similar to that of the Western Desert or charged from a kitchen within the deeper water Herodotus Basin. The latter would confirm a working source rock in the deeper-water area, derisking other areas of the EWMS for further exploration.

Summary

Looking ahead, EWMS is primed to build on its recent activity and success. With extensive data coverage and open acreage, there is opportunity for new entrants to the area. If the Nefertari discovery is developed, new offshore infrastructure may allow follow on discoveries to be developed at lower cost. It is likely that the deep-water west Nile Delta area will have Oligo-Miocene clastics targeted, similar to proven analogue discoveries in the Nile Delta Basin. Lastly, the deeper basin is more frontier and exploration may progress at a slower rate given the process of derisking observation driven exploration ideas, but it certainly holds high potential over a vast area.

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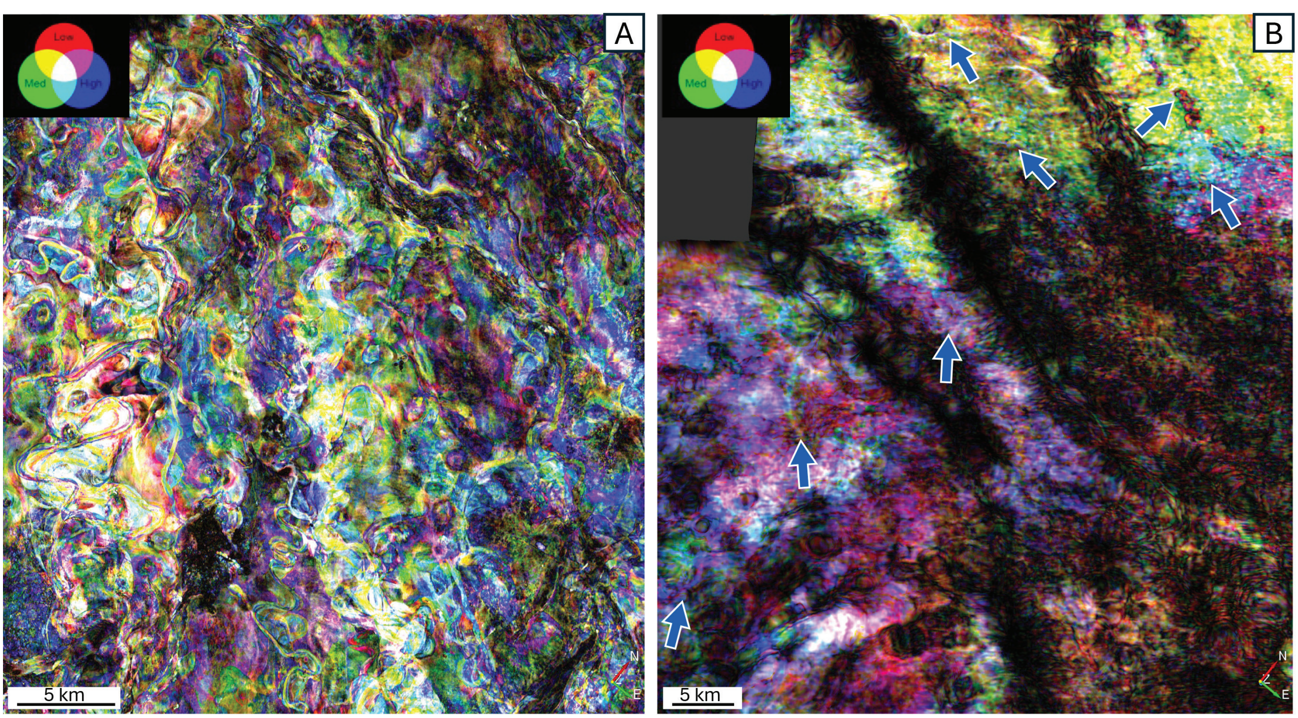

Figure 4 Example of a spectral decomposition (RGB blend) extracted on a horizon in the Pliocene section (panel A) and in the Oligo-Miocene section (panel B). Channel systems with potential reservoir facies can be clearly observed at both levels, with some examples indicated by the blue arrows in panel B.

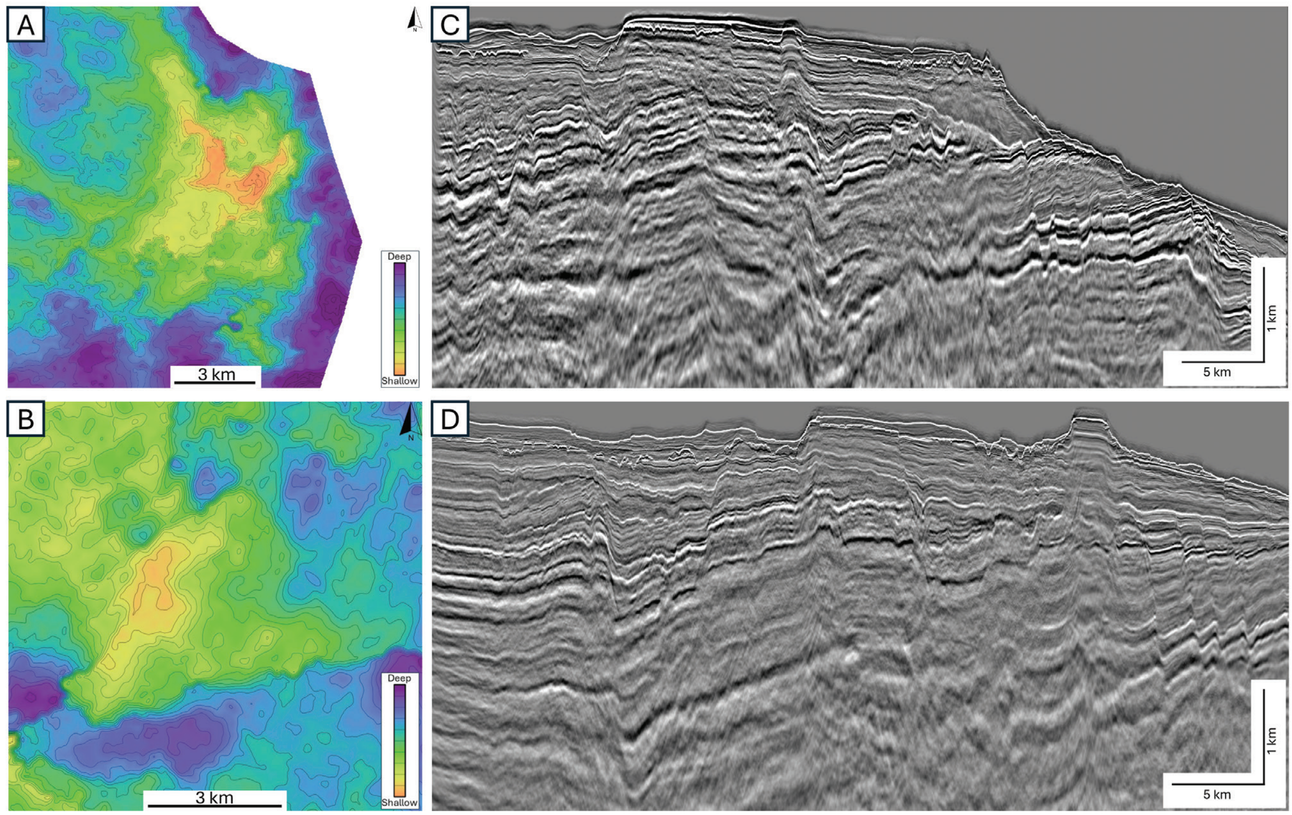

Figure 5 Examples of some structural traps in the offshore extension of the onshore Western Desert. Panels A and B are mapped depth surfaces within the Cretaceous section on the shelf. Panels C and D are seismic sections through a fast-track KPSDM depth volume, indicating the structural trapping potential at multiple depth intervals.

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