The Miocene hydrocarbon play in Southern Lebanon

Neil Hodgson[1] reports on how recent 2D and 3D seismic in the Eastern Mediterranean suggests that assumptions about the geological history and hydrocarbon plays may need some revision.

This is a breath-taking era to be an exploration geoscientist. High and stable oil prices have let the industry be efficient at exploring the commercially accessible continental shelf, yet the rapid development and transfer of the technology of deep-water drilling has outstripped exploration activity. The effect of this is to steadily increase the unexplored and accessible area of the global continental shelf, and to allow us into basins and water-depths our exploration forebears could only dream of. That there were indeed dreamers though is clear as reconnaissance seismic has been acquired in water depths that were fantastic to the drilling capabilities of their day – and it is on the shoulders of these pioneers (or more specifically their seismic) that we now aspire to stand. Deep water passive margins around the world have been vying for attention, and since Noble's startling success in 2009, the deep water of the Eastern Mediterranean has been in the spotlight. Yet things did not always look so promising.

In the race for the best prospects in the new deep water world, the basins that had clear working oil plays were high graded, and even in the late 1990s the Eastern Mediterranean looked to be very challenged. Miocene and Pliocene plays in Egypt's Nile Delta had drawn the attention of the industry and the march from onshore to shallow water exploration had been extremely rewarding. The discovery of oil offshore North Sinai demonstrated that the Eastern Mediterranean had a working oil system, but it seemed that gas, biogenic in origin, dominated the area. This view was supported by early gas successes in shallow water offshore Israel which seemed to be tapping into very localized sediment sources. With a lack of a well-developed local gas market, or export route, the prospect of commercializing gas in more than 1500 m of water seemed daunting. Significant risks remained on all the play elements: reservoir presence and effectiveness, hydrocarbon charge and trap, and commercial uncertainties on reservoir organization, hydrocarbon phase, and overpressure. Despite 3D seismic being shot and suggesting strong encouragement, such geological risks could not be reduced except by drilling. Compounded by the sheer technological challenges of potential development, it looked like we would be waiting a long time to explore this basin.

The drilling of the Tamar discovery offshore Israel by Noble and partners in 2009 was brave and visionary and, with success in the follow-up wells in Dalit, Leviathan, Aphrodite and Tannin, the major uncertainties appeared to have been addressed. More than 30 tcf of gas appears recoverable from the offshore Israel and Cyprus discoveries, and the Levant Basin was now a major biogenic dry gas basin. Normally pressured Lower Miocene sandstones provenanced from the Arabian Plate to the southeast had been trapped in large Syrian-arc inversion structures, and by 2011 the biggest of these had been drilled leaving only minor mopping up to be done in the basin.

Or so we might have thought. However, 2D data from the northern part of the Levant Basin, offshore South Lebanon, was also available to show that this area has a different geologic history and hydrocarbon play system to offer than the area offshore Israel. The differences are so marked that it is useful to compare and contrast the hydrocarbon plays systems as we know them from public-domain data and evaluation of multi-client 2D and 3D data (acquired by Spectrum).

Study area seismic dataset

The data upon which this study of the Eastern Mediterranean is based was acquired over a 35-year period, starting with super regional surveys and culminating most recently with a 2012 3D acquisition. The earliest data had revealed the basic geometry of the basin (1975 regional survey – pink lines in Figure 1 inset)). However, it was a survey in 2000 comprising 12,300 km of 2D seismic data (blue lines in Figure 1 inset), that really shed light on Miocene play fairway. In 2002, a further 2000 km of inshore Lebanon data (orange lines in Figure 1 inset) was recorded. All these data were reprocessed in 2011, forming the 20,000 line km dataset upon which an area offshore Lebanon was high graded for 3D acquisition (red area in Figure 1 inset). Some 2320 km^2 was acquired in autumn 2012, and a further 1500 km^2 acquisition to the south of this area is planned. Preliminary results (fast-track volume) of the 2012 3D support the conclusions of this review.

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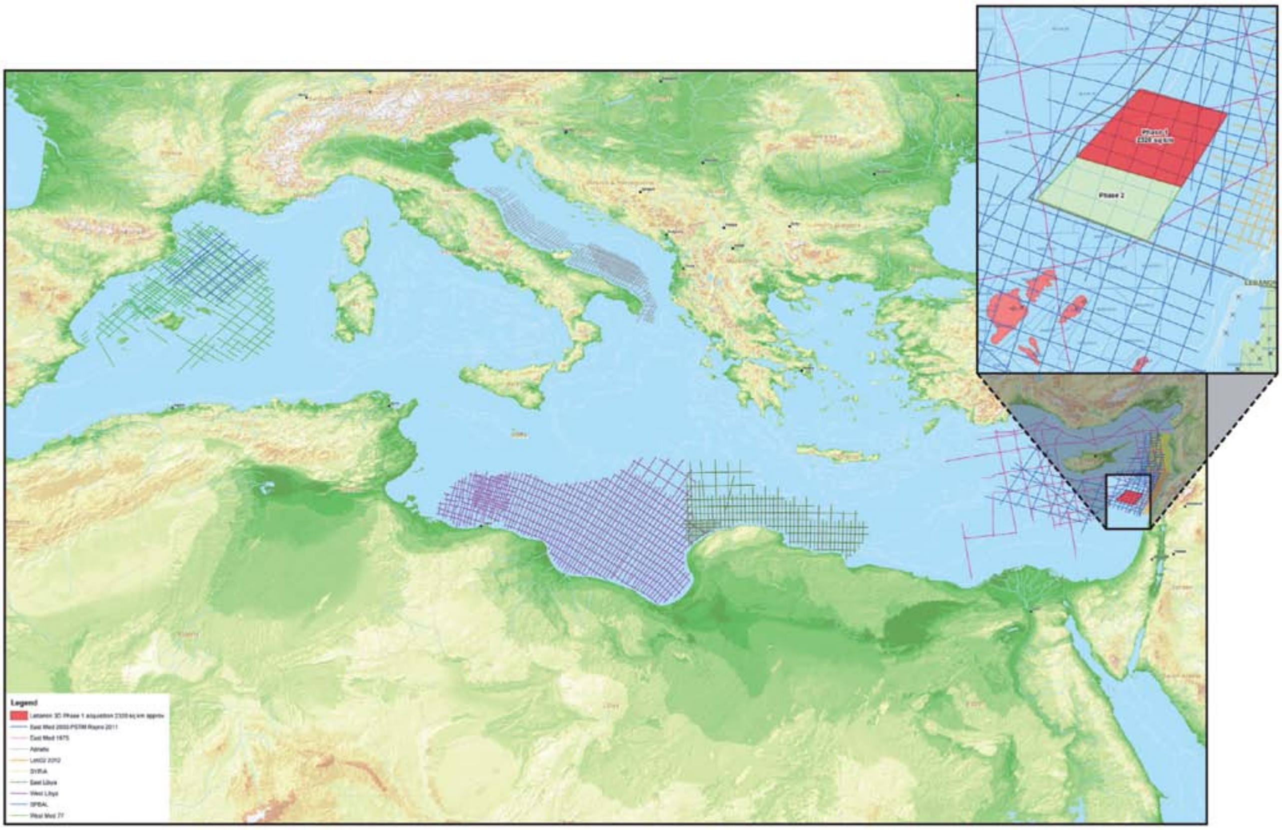

Figure 1 *Spectrum's 2D and 3D dataset in the Mediterranean.*

Tectonic evolution of the Eastern Mediterranean

Following the disintegration of the Pangea supercontinent in the Permian, the area offshore Lebanon can be identified as a passive continental margin from Middle Jurassic to Late Cretaceous times. Marginal carbonate platforms appear to have surrounded a deep basin throughout the Jurassic to Cretaceous period, accumulating both pelagic and margin sourced carbonates, in addition to more distal deep marine shales and source rocks.

Sequences deposited in the Palaeogene to recent are the focus of this study. Most of this section comprises clastics deposited in passive deep water settings with two notable exceptions. In the Late Miocene, compression that is expressed in North Africa at a variety of times, migrating out of Egypt's Western Desert, and through to the Palmyrid fold belt of Syria, reached the Southern Levant basin, inverting Cretaceous and Jurassic tilted fault blocks. These inversion structures are known as Syrian Arc folds and are oriented SE to NW offshore Israel. In contrast, just to the north at the same time, the dramatic extensional faulting that characterizes the Miocene play offshore Lebanon developed. The variation in the geology across the deep water basins from south Levant basin to the north Levant Basin is illustrated in Figure 2. Only shortly after this episode, the Mediterranean took another key step in its development with the Messinian Salinity crisis and the deposition of the Messinian Salt–evaporite sequence. Subsequently only a thin clastic cover sequence has been deposited in the basin, insufficient to instigate halokinesis in the underlying salt. However, internally, the Messinian evaporites appear to be very heterogeneous (see the pink-purple sequence on Figure 2) curiously suggesting significant syn-depositional salt movement had occurred, peneplaned by the post evaporitic inundation of the Mediterranean.

The top and base of the Messinian salt sequence are marked at the pink and purple horizon respectively on Figure 2, indicating the lack of structuration in the basin post Messinian.

Below the Messinian salt a thick Miocene section is observed (purple to yellow). The upper section when penetrated by wells offshore Israel is largely mudstone; however, undrilled high impedance contrast reflectors are observed that may represent sands (or tight calcilutite sheets). The top of the Lower Miocene (orange in Figure 2) is a prominent and strong reflector correlating to the thick sands providing the reservoir in Tamar, Leviathan, Aphrodite, and Tannin discoveries of Israel.

The Miocene overlies a Tertiary sequence possibly unpenetrated to date in deep water. The Oligocene has been recorded in near-shore wells off Israel in organic mudstone facies; however, amplitude variations also suggest (at least locally) that additional sandstone reservoir targets may be present.

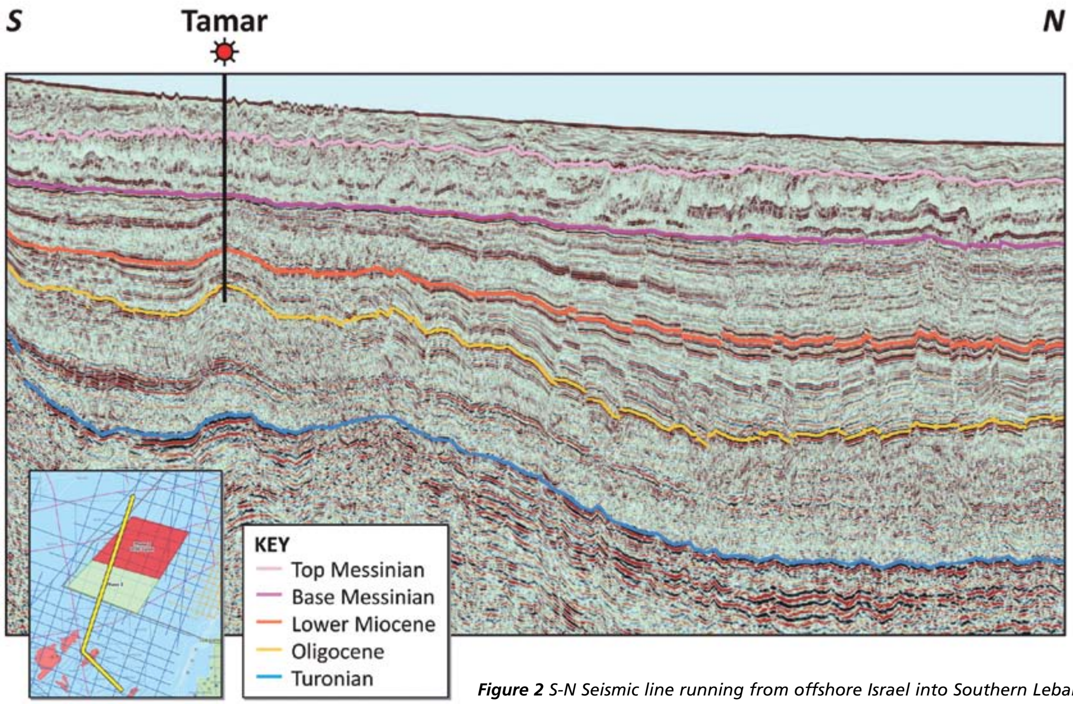

Figure 2 *S-N Seismic line running from offshore Israel into Southern Lebanon.*

Although unexplored in deep water, the Base Tertiary and the Turonian Unconformity (green and blue Horizons in Figure 2) provide the structural palimpsest upon which the drama of Tertiary deposition is written, and offset well data suggests strongly that the Mesozoic sequence provides candidate source rocks of Cretaceous and Jurassic age.

The successful hydrocarbon play in the Lower Miocene offshore Israel comprises Lower Miocene sands of high quality (>20% porosity, high net to gross), in large, faulted structural closures formed prior to the Messinian salinity crisis, charged by biogenic gas. If the geology of southern Lebanon was similar to that of Israel, then a high potential gas play would be an obvious target for exploration. However, the geology is in fact subtly different in Southern Lebanon. Yet curiously, in each of the main play elements we can say that South Lebanon is either lower risk or more oil prospective than offshore Israel was prior to exploration beginning. To investigate this we will discuss each play element for the two areas – reservoir, structure, and charge in turn.

North and South Levant Basin

Reservoir

Within the Lower Miocene, the variation in thickness from south to north is dramatic (orange to yellow sequence in Figure 2). North of the border between Israel and Lebanon the pre-salt basin deepens, and the isochron of the Lower Miocene sand unit trebles. The feature that controls this thickening is a structural feature known as the Levant Ramp (Figure 3). The Lower Miocene thins again to the far north of the Levant basin, in Syria, such that the Lower Miocene wedge is thickest in southern Lebanon.

On Figure 2 the Lower Miocene sequence is seen to be thinnest in Israel and it is here that the Tamar, Leviathan,

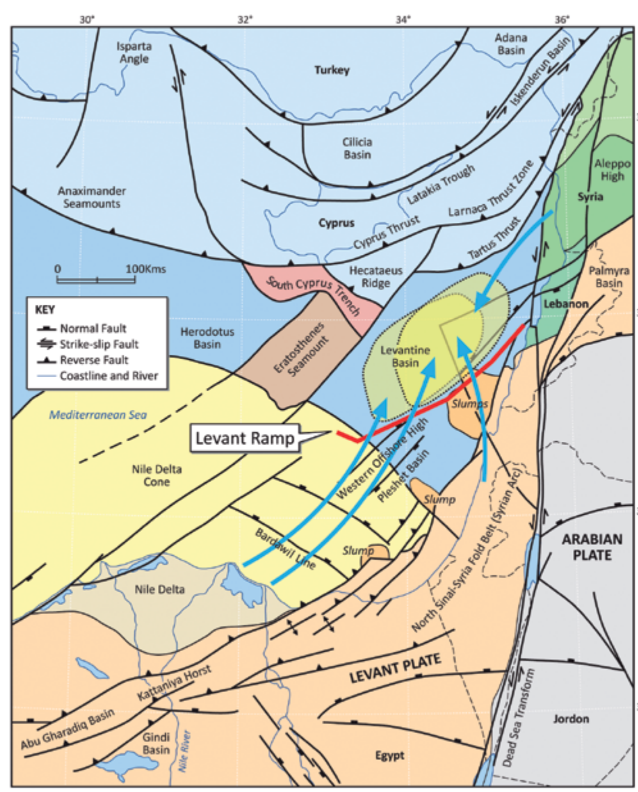

Figure 3 *Provenance of Lower Miocene sands in the Levant Basin.*

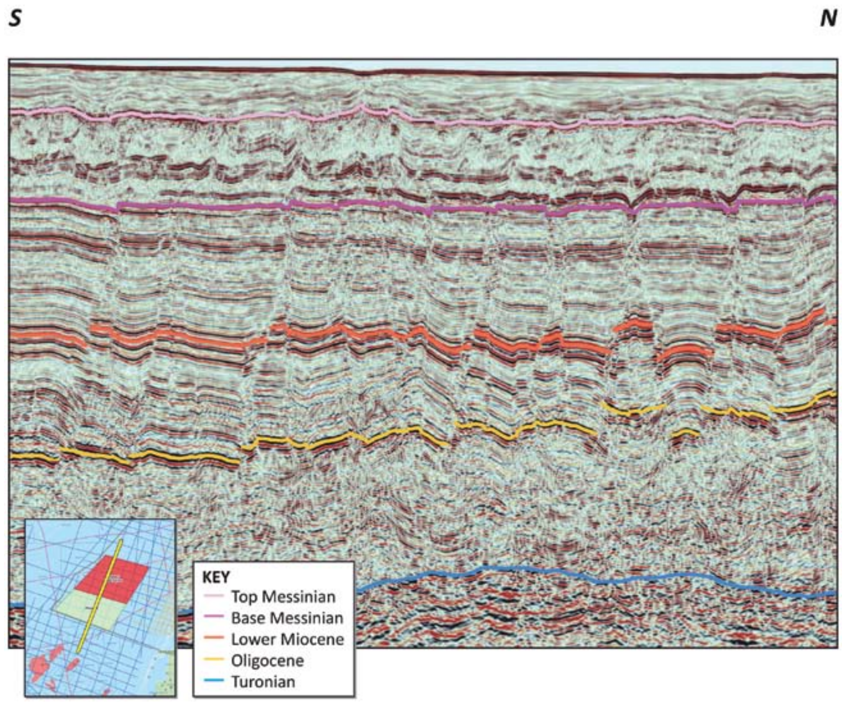

Figure 4 *2D seismic line detail running S-N through South Lebanon, the line approximates to the area covered by 3D in 2012.*

Aphrodite and Tannin discoveries display between 40 and 150 m of net sand (as reported by operator Noble). On the northern side of the Levant Ramp high acoustic impedance reflectors suggest strongly the presence of sands extending across the basin, suggesting thick net sands may be encountered in Southern Lebanon.

There is some uncertainty regarding the sedimentological geometry of the Lower Miocene sands in Israel that is difficult to resolve in the absence of well data. On 2D seismic the reservoir seismic facies appears somewhat chaotic within the discoveries suggesting the presence of anastomosing stacked channel systems running SE- to NW across the basin. These channel systems could have keyed into synforms defined by the structural grain of the Syrian arc system, and represent deep water channel systems bringing sands from the Nile Delta across the southern Levant basin (Figure 3). Miocene deep water channelized sand transport systems are demonstrated to the NW, N, and NE of the Nile Delta, and analogues operating at this scale can be found in outcrop in many areas (for instance the Pab range of eastern Pakistan). Westward from the Nile we interpret vast quantities of sediment being transported across the southern Levant basin, to be shed over the Levant ramp in a series of northward prograding clinoforms.

Structure

As previously discussed the Tamar and Aphrodite structures appear to correlate to inverted Syrian Arc half graben. However, this isn't the only play-making mechanism in action offshore Israel as both the Leviathan and Tanin structures can be interpreted as a basement drape structures. The underlying basement blocks may also have been structured in the Syrian Arc event. But all of these structural traps offshore Israel express a high degree of faulting and complexity. Whilst appearing as simple domes on SE-NW lines, Tamar and Aphrodite are seen to be heavily faulted on orthogonal SW-NE lines, reflecting inversion line length extension in the SW-NE direction. Leviathan and Tannin are cut by very complex fault swarms reflecting a lack of a single stress field. The reported reservoir continuity across these fields is presumably

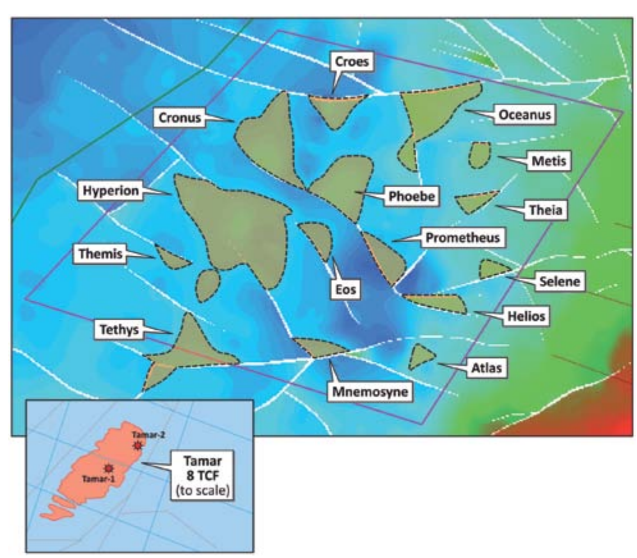

Figure 5 *Structures in Southern Lebanon mapped on 2D data. The 3D area acquired in autumn 2012 is indicated.*

a testament to the high net to gross of the reservoir allowing pressure communication across the faulting.

By contrast in southern Lebanon the traps are simple rotated fault blocks (Figure 4). These extensional faults may be analogous to extensional Canyonland horst-grabens of Utah (Tari et al 2012). Faults sole out in the underlying Oligocene (below the yellow horizon on Figure 4) and extend up to the upper Miocene. At Lower Miocene level the throw on these faults can exceed 200 ms – juxtaposing the thick stacked turbidite sheets of the Lower Miocene against mudstones of the Upper Miocene and creating very low risk traps.

Rarely do these normal faults appear to cut the base Messinian. This extensional faulting is curious in origin as it is synchronous with the compression on the Syrian Arc system. The boundary of the compressional to extensional behaviour coincides with the Levant ramp structure. We consider that the Levant ramp is a reactivated Mesozoic feature at the limit of the stable Southern Levant Basin platform, which was hijacked by the complex tectonics operating at the time of the Syrian Arc inversion, releasing stress developed by movement of the Arabian plate on the Dead Sea Transform, and the Tartarus thrust East of Cyprus.

Therefore, whilst it is true that in southern Lebanon we see no direct analogues to the Tamar/Leviathan structures, the many large structures we do see are simpler (three-way dip and one-way fault closed) and less complexly faulted. On 2D data we are able to map these structures as well-defined independent fault blocks (Figure 5). The new 3D preliminary fast track data shows these structures even more clearly.

Source

The gas discoveries in deep water offshore Israel are all reported as biogenic gas. Whilst it is possible that the structures in Southern Lebanon have the same fill, and will therefore offer a continuation of the dry gas play, a basin modelling evaluation has been undertaken utilizing the 2D dataset to look at an alternative. An investigation of the maturity of the potential source rocks in the southern and northern Levant basin intended to study factors such as timing of hydrocarbon generation, expulsion, and migration relative to basin tectonic history has been completed with intriguing results.

Integrating 2D seismic mapping with offset well and outcrop data, a 3D geological model was constructed by constraining the burial history for the basin and estimating the amounts of erosion during major unconformities, and defining the thermal history of the basin. Basin modelling then allowed the determination of potential kitchen areas for each potential source, the estimation of the time of hydrocarbon generation and expulsion, and the delineation of migration pathways. Data from 17 key exploratory wells and outcrop data was

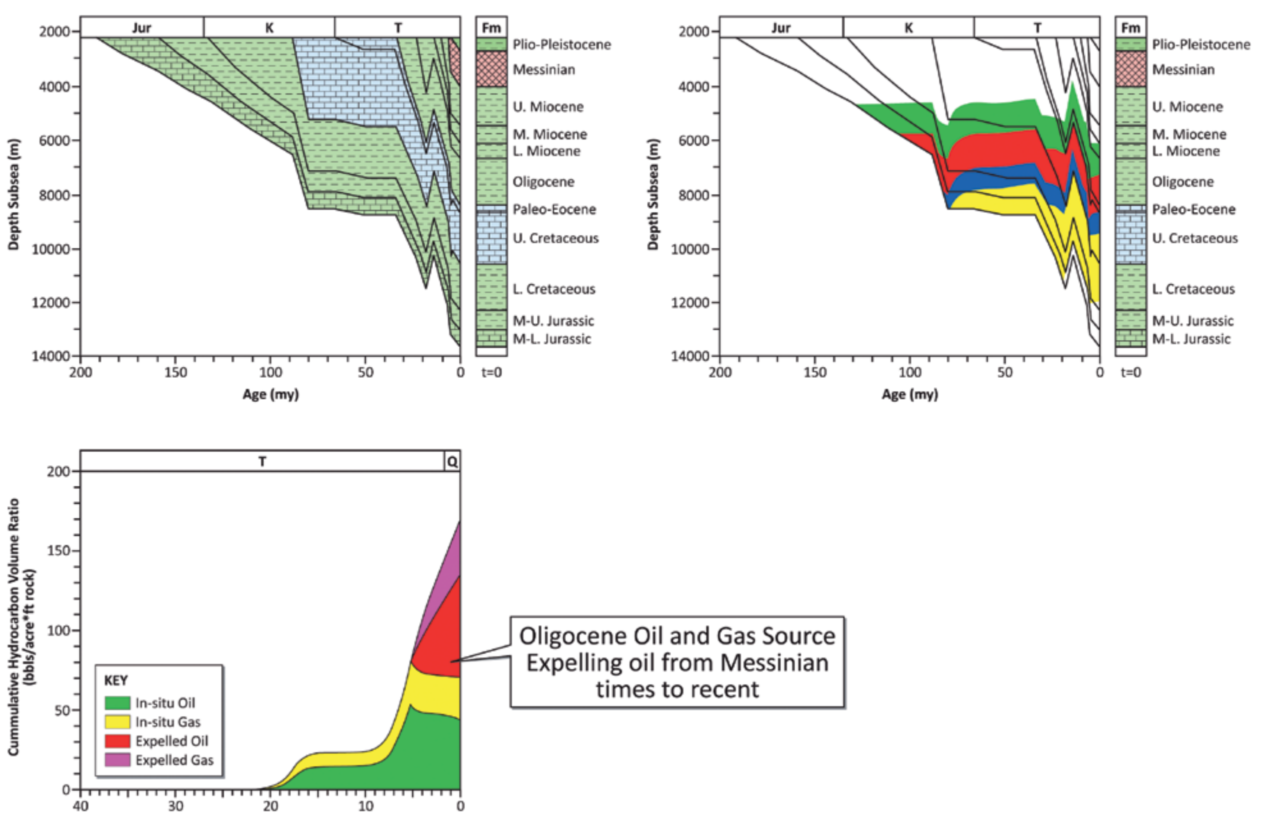

***Figure 6** Oligocene basin modelling results of a location offshore southeast Lebanon.*

utilized from onshore Lebanon, offshore Israel, the Nile Delta, and the North Sinai shelf. Outcrop data from Lebanon included the Paleocene-Eocene Chekka formation where oil and gas prone source rocks are indicated. Four separate source rock systems are identified; the Oligocene, Paleocene-Eocene, Upper Cretaceous (Senonian and Cenomanian-Turonian), and the Middle to Upper Jurassic.

Heat flow from the eastern Mediterranean region was assumed to be low (Eckstein, 1978). Indeed the average of the marine heat flow measurements in the Levantine Sea is 25 ±8 mW/m^2. This suggests a relatively thin crustal thickness.

This 3D basin modelling study concluded that Mesozoic source rocks are fully transformed to hydrocarbons within the deepest basinal areas, whereas of lower maturity though still wet gas mature towards the basin margins across the whole of the Levant basin. The Upper Cretaceous source rocks are in the main gas generation phase (1.3-2.6% Ro) and the Jurassic source rocks show even higher maturity. The timing of charge from these Mesozoic sources may be an issue as the main generation phase is relatively early, and the Lower Miocene structures are late Miocene in age.

However, the younger Tertiary source rocks show a lower maturity relative to the Mesozoic source rocks and are at present below the condensate window in even the deepest basinal areas (Figure 6). In the area around Tamar and Leviathan, the Tertiary source rocks are immature for oil expulsion, yet it is clear from Figure 2 that the Oligocene and Palaeogene sequence is much deeper in the northern Basin. Thus in South Lebanon the Tertiary section is currently in the Mid-Mature Stage (~1.0% Ro), expelling oil but still not in the condensate window. The key observation from the modelling is that the Oligocene and Palaeocene-Eocene source rocks have started expelling oil only post Messinian times, i.e., when the structures in the basin (offshore Israel and offshore Lebanon have been formed. This supports the case for a recent oil charge from the Tertiary source rocks in the area of south Lebanon.

In support of the oil case, in 1999, a seep-seismic correlation interpretation was carried out off the Lebanese coast, based on combining seep locations identified in the NRSC-Infoterra satellite natural oil seep study with the earlier reprocessed seismic data. The results of this seep-seismic correlation work were very encouraging, demonstrating natural oil seepage occurring along the Lebanese margin (Peace and Johnson, 2001).

Noble has reported that the deepening of the Leviathan–1 discovery encountered thermogenic gas. The lack of maturity of Tertiary sources below Leviathan suggests that this gas could either have a Mesozoic source, or a liquid component could have migrated out of the northern Levant Basin into Leviathan.

Conclusion

Deep water exploration In the Eastern Mediterranean has just begun. Early success in the Lower Miocene Play offshore Israel has shown remarkable results, discovering >30 tcf biogenic gas. To the north, offshore Southern Lebanon, we see the same excellent potential – however with some subtle and intriguing differences. Sand supply from the Nile Delta appears to have deposited a far thicker sequence on the northern margin of the Levant Ramp. Thick and multiple stacked sand reservoirs can be expected. Whilst the structures offshore Israel are inverted Syrian Arc or complex basement drape features, in Southern Lebanon structures appear to be simple extensional tilted fault blocks. Lastly, whilst the Mesozoic may be gas prone across the whole area, it may have matured early relative to Lower Miocene trap formation. Although the Tertiary below Tamar offshore Israel is immature even for oil, in Southern Lebanon the Oligocene has been mature and expelling oil since the Messinian was deposited, i.e., post trap formation. It may be that the area is just biogenic gas prone like offshore Israel – yet the intriguing possibility of an oil play is suggest by basin modelling.

New 3D will allow us to more accurately map the structures, map reservoir facies and potentially seek direct fluid fill information. This may assist the industry in opening up offshore Lebanon and ushering in a new hydrocarbon province - possibly even an oil province.

So what is the view like standing on the shoulders of the seismic pioneers who started acquiring data over deep-water Lebanese waters nearly 40 years ago? Well thanks to their foresight – the future looks very exciting from here.

References

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