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Regional seismic interpretation of the hydrocarbon prospectivity of offshore Syria

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ABSTRACT

Analysis of 5,000 km of multi-client long-offset 2-D seismic data has led to the identification of three sedimentary basins, Levantine, Cyprus, and Latakia, located in offshore Syria. Each basin has a unique structural and stratigraphic history. They are separated from each other by the middle to Late Cretaceous aged Latakia Ridge System that initiated as a compressional fold-thrust belt and was re-activated under a sinistral strike-slip regime that developed during the Early Pliocene in response to a re-organisation of the plate-tectonic stresses. There is significant evidence for a working petroleum system in offshore Syria with numerous onshore oil and gas shows, DHIs (direct hydrocarbon indicators) observed on seismic, and oil seeps identified from satellite imagery. Prospective reservoirs range in age from Triassic to Pliocene – Quaternary and include Lower Miocene deep-water turbidite sands as encountered in recent discoveries in the offshore southern Levantine Basin. The complex structural evolution of each of the three sedimentary basins has produced an array of potential structural and stratigraphic trapping mechanisms.

INTRODUCTION

Exploration activity has increased in the Eastern Mediterranean in recent years following a series of major multi-TCF (trillion cubic feet) gas discoveries made in the offshore southern Levantine Basin (Figure 1). Licensing rounds are scheduled to be announced during 2011 for areas in offshore Syria, Lebanon, and Cyprus, which are believed to share strong geological similarities with these discoveries. The second offshore Syria licensing round will be supported by multi-client long-offset 2-D seismic data acquired by CGGVeritas in 2005 (Figure 2). This dataset forms the basis of this paper, which aims to describe the structural and stratigraphic development of offshore Syria within a regional context.

The Eastern Mediterranean is a tectonically complex region with offshore Syria located above the plate-tectonic boundary between the African and Eurasian plates defined by the Latakia Ridge System (Figure 1). Further to the east the Dead Sea Transform fault system separates the African and Eurasian plates from the Arabian Plate with a triple junction situated onshore in northwestern Syria. Three sedimentary basins, Levantine, Cyprus, and Latakia, have been identified in offshore Syria that are defined by the Latakia Ridge System. No exploration wells have been drilled in offshore Syria, which represents a truly frontier area of exploration, and as such assigning ages to seismic horizons and events is very difficult. Following recent exploration drilling in the offshore southern Levantine Basin the Cenozoic sedimentary section in offshore Syria is now interpreted as being much thicker than previously thought and as such enhances the area's hydrocarbon prospectivity.

DATASET

The dataset used in this paper comprises 5,000 km of multi-client long-offset 2-D seismic data acquired by CGGVeritas in 2005 (Figure 2). It is the only officially recognised modern seismic dataset in offshore Syria. The seismic lines were acquired in NW-SE and NE-SW directions such that they are parallel and perpendicular to the main structural trends. They were acquired on a relatively dense grid of 4 km by 4 km and on a denser grid of 2 km by 4 km in certain areas in the north and south. The following acquisition parameters were selected:

- Sercel Seal streamer towed at 8 m,
- Streamer length of 7,000 m,
- Bolt airgun source of 1,995 cubic inches at a depth of 6 m,

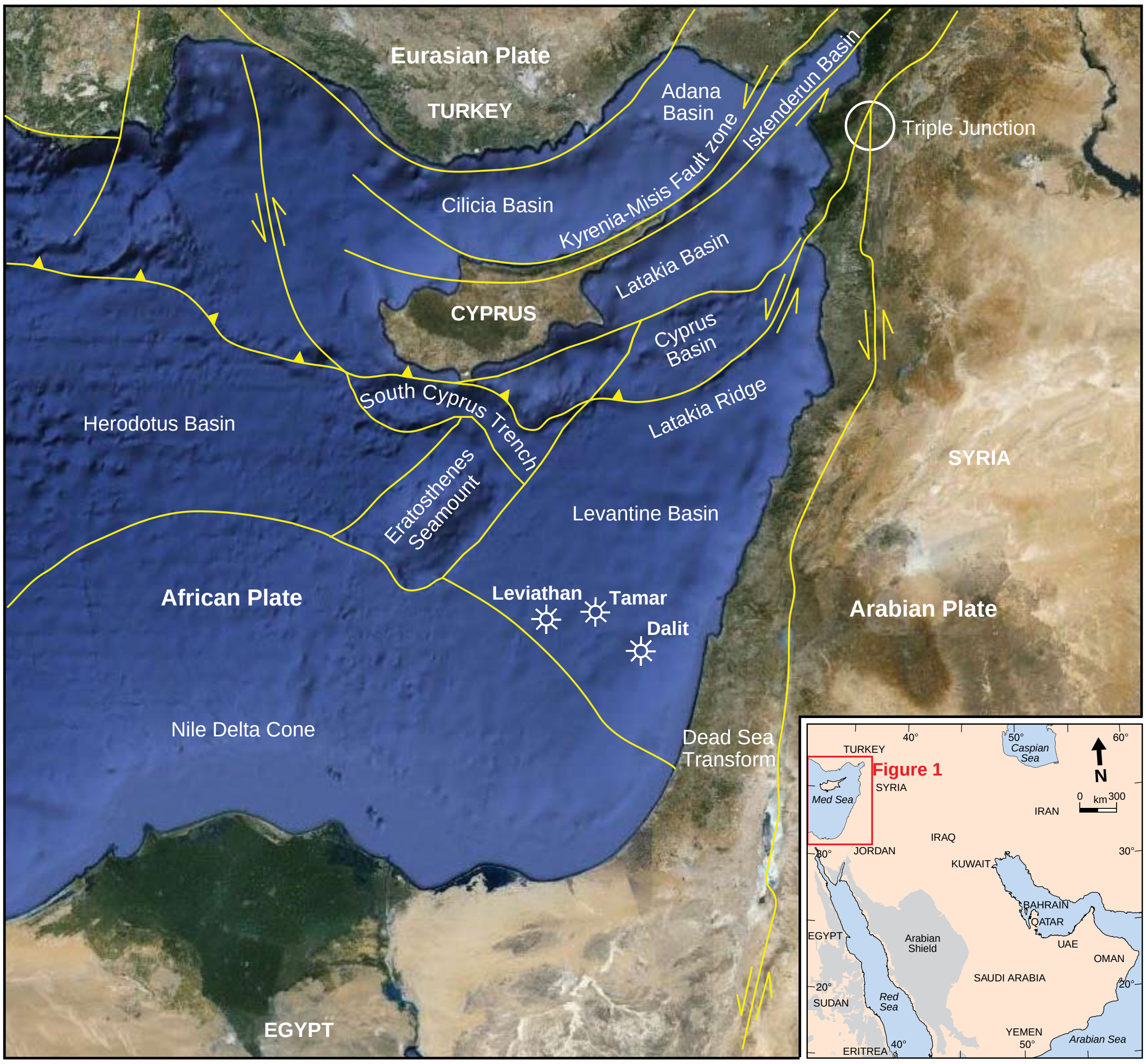

Figure 1: Regional map of the Eastern Mediterranean showing the tectonic plates and basins present. The recent gas discoveries in the offshore southern Levantine Basin (Dalit, Leviathan and Tamar) are also displayed (modified from Breman, 2006; Roberts and Peace, 2007).

- Group interval of 12.5 m,
- Shot point interval of 25 m, and
- Recording length of 9 seconds.

The long-offset acquisition gives the best amplitude *versus* offset (AVO) imaging at all levels and significantly improves imaging of the deeper structure, particularly below the Messinian salt where present. CGGVeritas have recently re-processed two of the seismic lines and plan to re-process the whole dataset following encouraging results. The latest processing techniques were applied with the aim of further attenuating multiples, increasing the signal-to-noise ratio, enhancing reflector continuity, and improving the imaging of steeply dipping reflectors. The result is a much clearer and more easily interpretable image.

A total of seven seismic horizons have been interpreted using the dataset. Four of these horizons have been picked across the entire dataset defining the (1) Seafloor, (2) Top Messinian, (3) Base Miocene, and (4) Late Cretaceous unconformity. (5) Base Messinian Surface has been interpreted in the presence of Messinian evaporites except in the northwestern part of the Latakia Basin where the Messinian evaporites have been heavily re-mobilised making imaging of the Base Messinian difficult.

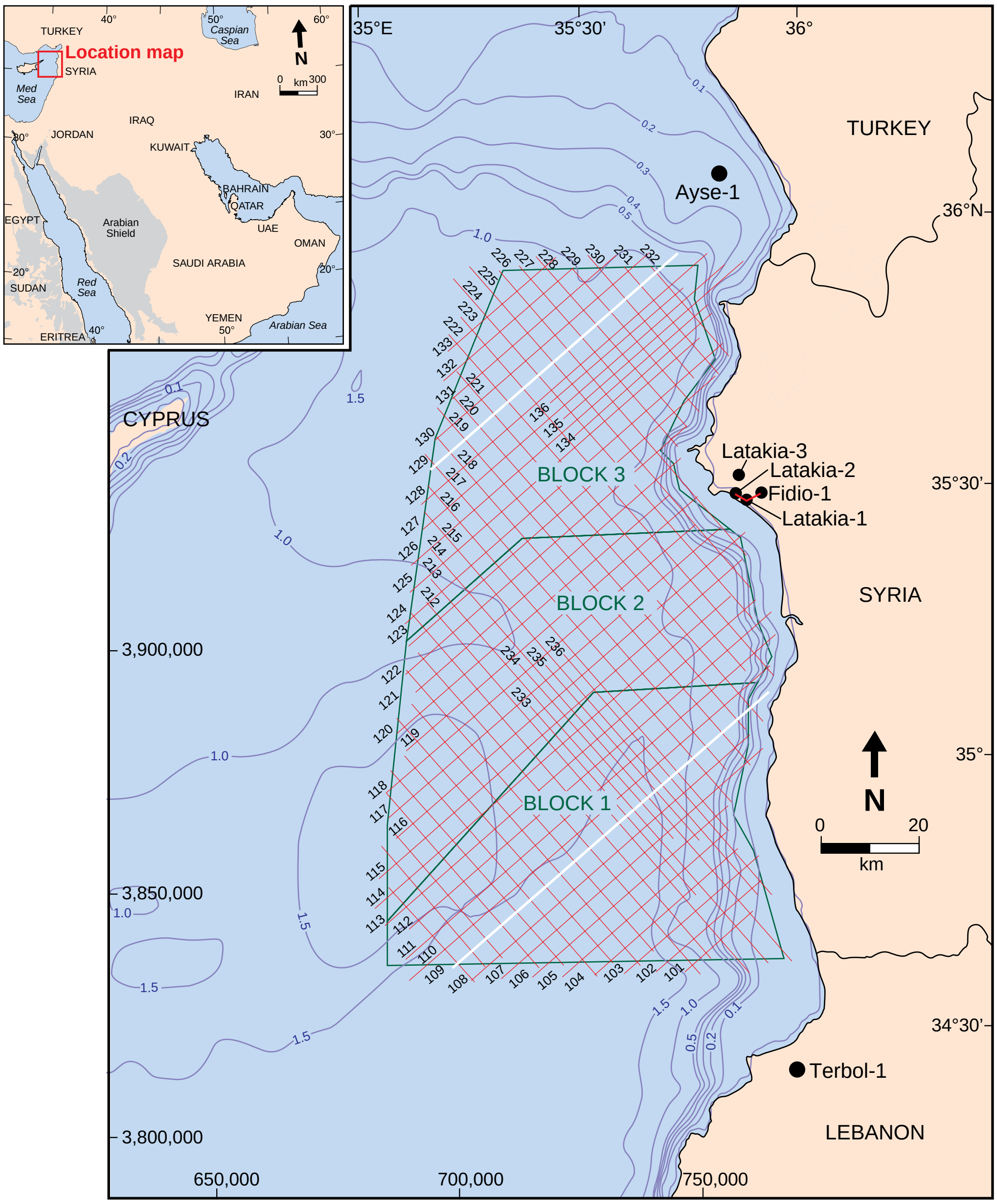

Figure 2: CGGVeritas's database of multi-client long-offset 2-D seismic data in offshore Syria acquired in 2005. Two lines, shown in white, have been re-processed. Water depth shown in kilometre.

The (6) Base Mid Miocene and (7) Top Eocene have been interpreted within the Levantine Basin only. The Base Mid Miocene horizon is also present across the Cyprus Basin, but due to its low acoustic impedance there it is difficult to correlate across the Latakia Ridge. The Top Eocene is interpreted to converge with the Late Cretaceous unconformity across the Latakia Ridge due to a period of non-deposition.

The age assignments for the interpreted horizons are based on correlation with the tectonic and structural evolution of the basins and available published literature. Following the drilling of the first deep-water exploration wells in the Eastern Mediterranean several of the age assignments in the published literature will now have to be revised after the recognition of a much thicker Cenozoic sedimentary package within the Levantine Basin. For example, what are referred to as the Top Cretaceous and Top Jurassic, in some older publications, are now believed to actually represent the Base Miocene and Late Cretaceous unconformity, respectively.

EXPLORATION HISTORY

The Eastern Mediterranean is an under-explored region but has recently become the focus of increased industry interest due to three major gas discoveries, Tamar, Dalit, and Leviathan, made by a Noble Energy-led consortium in the offshore southern Levantine Basin (Figures 1 and 3). The Tamar discovery was made in 2009 by the Tamar-1 Well drilled in a water depth of 1,676 m to a total depth of 4,900 m to test a Lower Miocene structure. Formation logs identified over 140 m of net gas pay in three high-quality Lower Miocene sandstone reservoirs. The Tamar discovery was flow-tested over a limited 18 m interval of the lowest reservoir yielding a flow rate of 30 mmcf/d gas (million cubic feet of gas per day). An appraisal well, Tamar-2, was drilled later in 2009 located approximately 5.6 km northeast of the original discovery. The results confirmed the reservoir thickness and quality encountered in Tamar-1 with pressure data confirming that the two wells are connected with a consistent gas/water contact. Total recoverable reserves are estimated at 8.4 TCF.

The Dalit discovery was made in 2009 by the Dalit-1 Well drilled in a water depth of 1,372 m to a total depth of 3,658 m. Formation logs indentified over 33 m of net gas pay in a high-quality Lower Miocene sandstone reservoir. The Dalit discovery was flow-tested over a limited 13 m interval yielding a flow rate of 33 mmcf/d gas. Total recoverable reserves are estimated at 0.5 TCF. In March 2010, following the Tamar and Dalit gas discoveries the US Geological Survey (USGS) estimated the undiscovered, technically recoverable, mean oil and gas reserves of the Levantine Basin to be 1,689 million barrels, with a range of 483–3,759 million barrels, and 122.4 TCF gas, with a range of 50.1–227.4 TCF (Schenk et al., 2010). The Leviathan discovery was made in late 2010 by the Leviathan-1 Well drilled in a water depth of 1,645 m to a total depth of 7,200 m. Formation logs identified over 67 m of net gas pay in several high-quality Lower Miocene sandstone reservoirs. At the time of writing the Leviathan discovery is yet to be tested. Total recoverable reserves are estimated at 16–18 TCF making it the largest of the three discoveries.

A total of 45 exploration and appraisal wells have been drilled offshore within the Levantine Basin resulting in six gas discoveries. Offshore Syria, as well as offshore Lebanon and Cyprus, can be considered as areas of frontier exploration given that no wells have currently been drilled. Although no wells have been drilled in offshore Syria four wells have been drilled onshore east of the city of

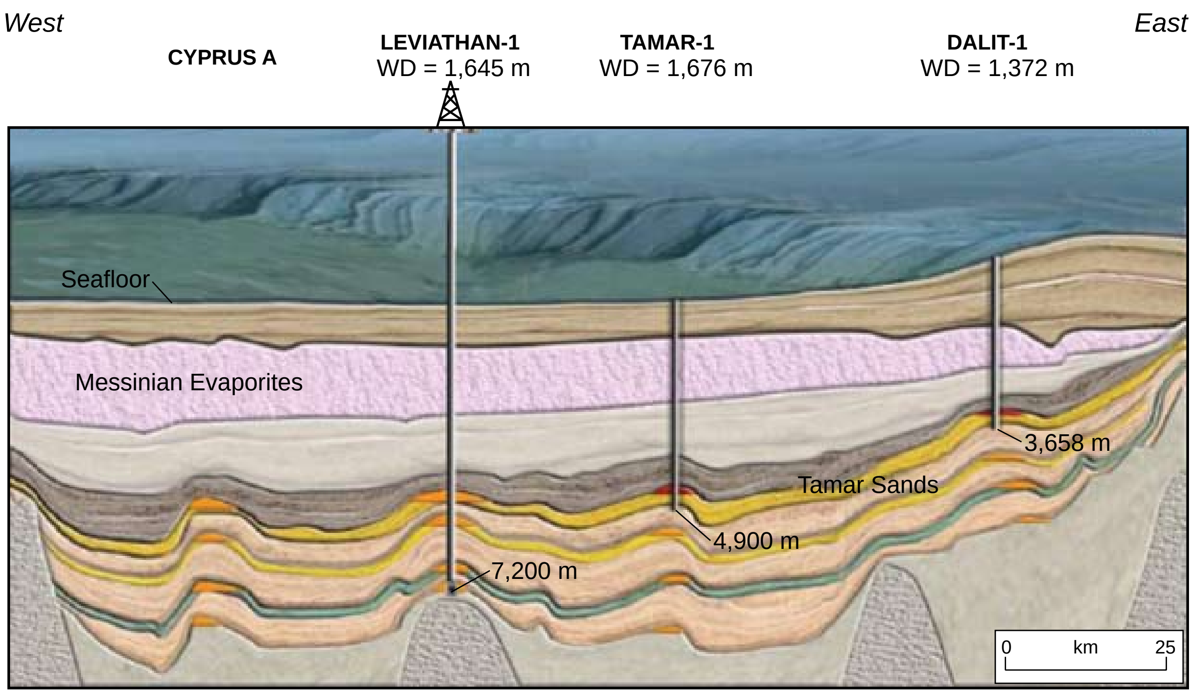

Figure 3: Representative geologic section across the Tamar-1, Dalit-1, and Leviathan-1 discoveries as well as the undrilled Cyprus A prospect (from Delek Energy website). WD = Water Depth.

Latakia within 5 km of the coastline (Figure 4). Three of the wells, Fidio-1, Latakia-1, and Latakia-2, were drilled within the Levantine Basin whereas the fourth well, Latakia-3, was drilled above the Latakia Ridge.

The first of these four wells to be drilled was Fidio-1, which was drilled in 1980–1981 to a total depth (TD) of 4,112 m within Triassic carbonates. The well was declared as being dry, although small amounts of gas were encountered within Lower Cretaceous carbonates. The Latakia-1 Well was drilled in 1981–1982 to a total depth of 4,237 m within Jurassic – Triassic carbonates. Gas shows were encountered within Upper Cretaceous and lower Tertiary carbonates but the traps are thought to have been flushed by active underground water. Oil shows were also encountered within fractured Lower Cretaceous clastics. The Latakia-2 Well was drilled in 1982–1983 to a total depth of 3,939 m within Lower Cretaceous clastics. Combustable gas was recovered from Eocene and Oligocene carbonates and heavy oil and gas shows were encountered over an 18 m interval within Upper Cretaceous carbonates.

The above three wells were all drilled within the northern extension of the Levantine Basin. The Latakia-3 Well was drilled further to the north above the Latakia Ridge System, which bounds the Levantine Basin to the northwest. The well was drilled in 1983–1984 to a total depth of 4,325 m within

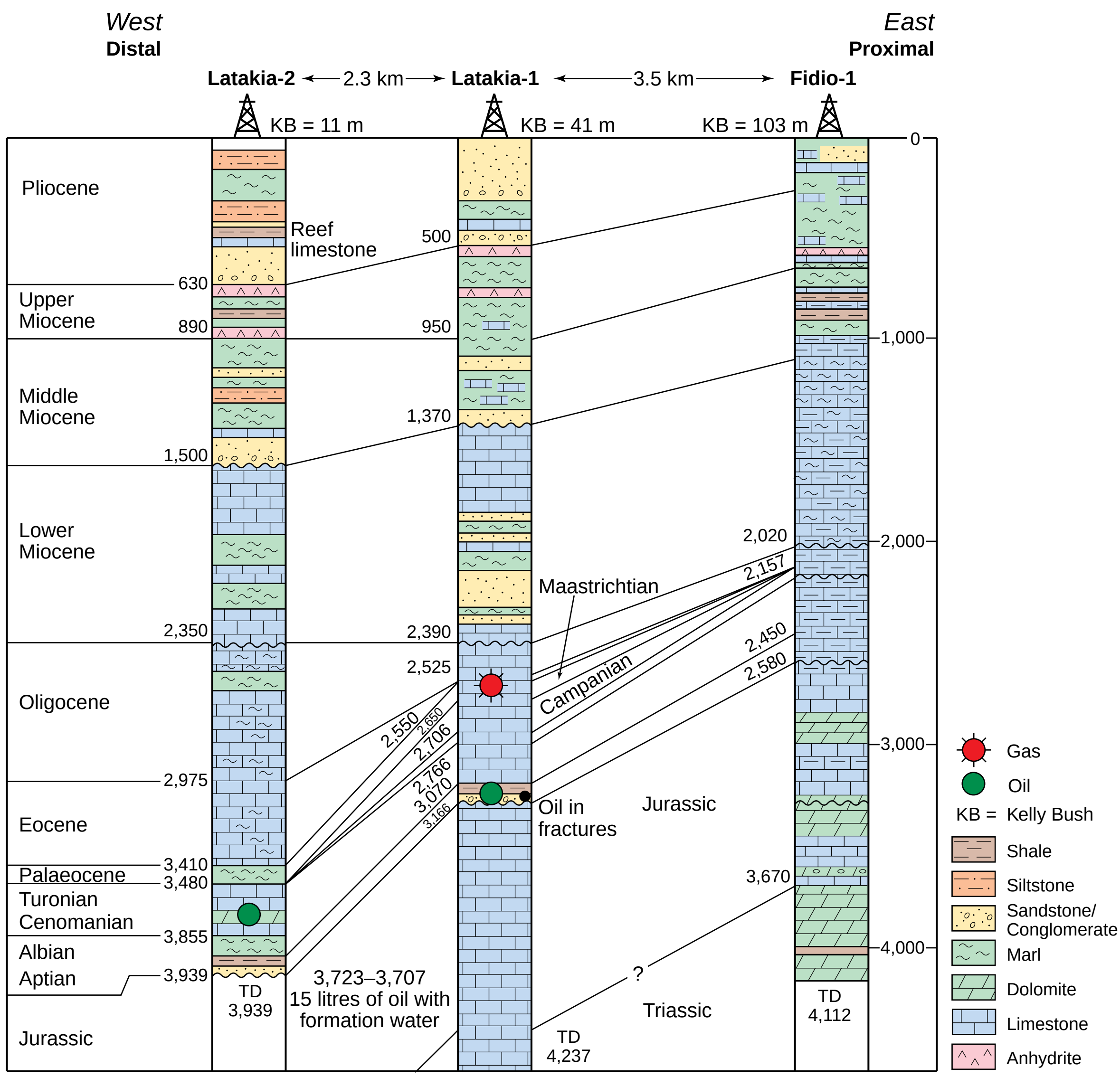

Figure 4: Well correlation panel through the Latakia-1, Latakia-2, and Fidio-1 wells. The wells provide a roughly East-West transect from a proximal to a distal setting. See Figure 2 for location.

Upper Cretaceous carbonates. It was declared as being dry although heavy oil shows and asphalt were encountered within the deepest section of the well and gas shows were recorded at several intervals within the Oligocene and Eocene. The section encountered by the Latakia-3 Well was repeated up to four times or more within the Cretaceous and Tertiary indicating that the area is intensely faulted and compressed. Another significant onshore well, Terbol-1, is located less than 25 km to the south of Syria in Lebanon within the Levantine Basin less than 3 km from the coast. It was drilled in 1947–1948 to a total depth of 3,065 m and encountered abundant traces of bitumen with total organic carbon (TOC) of up to 10% recorded in the Jurassic.

The closest well drilled offshore to Syria is the Ayse-1 Well located just over 10 km to the north of the Syria-Turkey maritime border (Figure 2). It was drilled in 1981 within the Iskenderun Basin to a total depth of 1,675 m within Maastrichtian-aged ophiolites. A total of 13 exploration wells have been drilled in offshore Turkey within the Adana and Iskenderun basins resulting in only a single discovery. The Gulcihan-1 Well was drilled in 1985–1986 within the Iskenderun Basin to a total depth of 4,699 m within Maastrichtian-aged ophiolites. It discovered oil within Middle Miocene Horu Formation carbonates with recoverable reserves estimated at 4.2–13.5 million barrels. Although Gulcihan-1 is the only classified discovery several other offshore wells, e.g. Efe-1, have encountered oil and gas shows demonstrating a working petroleum system within the Iskenderun Basin.

REGIONAL TECTONIC AND DEPOSITIONAL SETTING

The tectonic evolution of offshore Syria and the Eastern Mediterranean as a whole is extremely complex. Given that the Latakia Ridge System represents the plate-tectonic boundary between the Eurasian and African plates the tectonic evolution of each plate will need to be studied independently prior to convergence. The following section will provide a summary of the tectonic evolution of offshore Syria since the Triassic based upon published literature.

Triassic Period

The timing of initial continental breakup and Tethyan rifting is generally considered to have occurred during the late Permian to Early Triassic (Gardosh et al., 2010). During the continental breakup of Gondwana several continental fragments of various scales and locations, including the Tauride microcontinent, episodically fragmented and rifted from its northern margin and drifted northwards, many towards Eurasia (Figure 5). This led to the opening of the Neo-Tethys Ocean, which was palaeo-geographically varied, and was characterised by a number of mainly elongate continental fragments which subdivided it into several small ocean basins (Robertson, 2007). The Levant Margin and the present-day Eastern Mediterranean, which is considered a relic of the southern branch of the Neo-Tethys, were formed during the rifting of the Tauride microcontinent (Sengör and Yilmaz, 1981; Garfunkel, 2004).

The majority of the Tethyan rifted margins appear to correspond to an "intermediate" type between the ideal Volcanic rifted and Non-volcanic rifted margins. They are characterised by pulsed rifting extending over more than 50 million years (My), limited rift volcanism, and a narrow continent-ocean transition zone. Continental breakup and Tethyan rifting is thought to have been triggered by a combination of long-term asthenosphere flow, slab-pull related to subduction beneath Eurasia, and melt-induced crustal weakening associated with pulsed rifting or plume effects. Final continental breakup during the latest Triassic to earliest Jurassic corresponds to a major convergent phase along the opposing Eurasian margin further supporting the role of plate boundary forces in Tethyan rifting (Robertson, 2007).

Tethyan rifting within the Levantine Basin, above the African Plate, is not believed to have led to seafloor spreading, with the basin interpreted as an intra-continental rift that reached only an early magmatic phase. Seismic refraction, gravity, and magnetic data show that the crust underlying the onshore Levant Margin thins from 35 km to 10 km within the centre of the offshore Levantine Basin. It is therefore suggested that the basement of the Levantine Basin is composed of stretched, thinned,

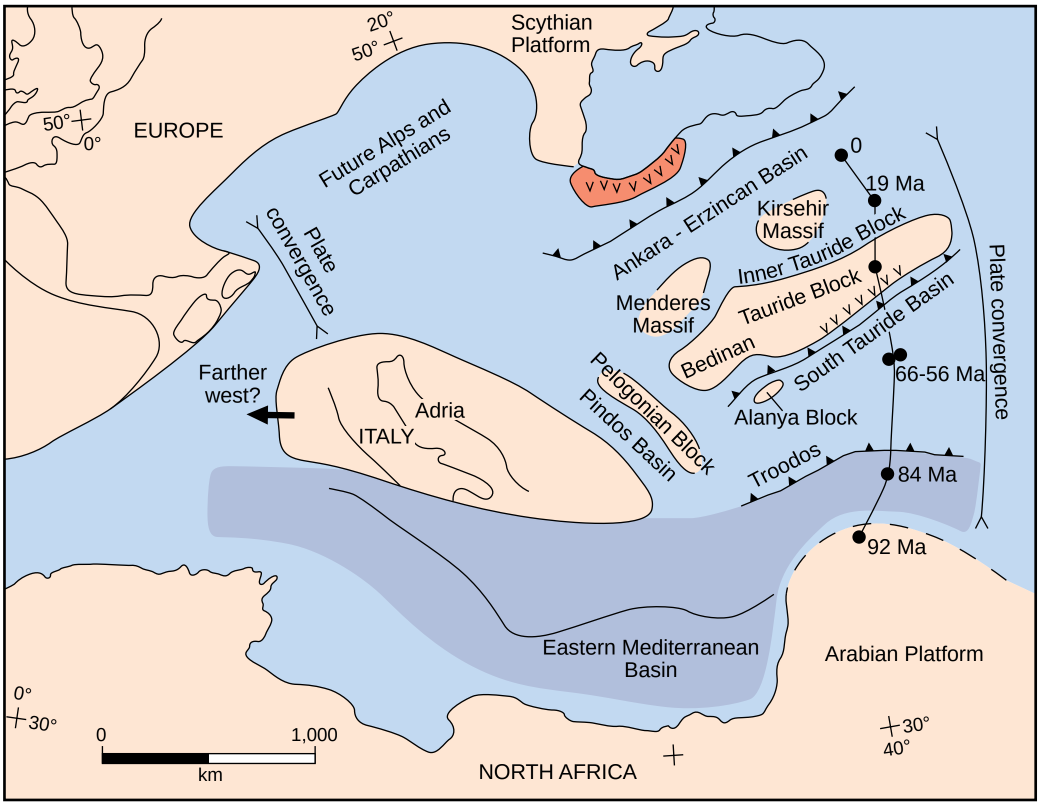

Figure 5: Summary map of plate-tectonic movements north of the Eastern Mediterranean Basin at ca. 90 Ma, before the closure of the Neo-Tethyan seaways within the Anatolian domain (modified after Garfunkel, 2004).

and probably highly intruded continental crust with an estimated β-factor of 2.3–3.0 (Gardosh and Druckman, 2006; Netzeband et al., 2006). No Triassic volcanism is associated with the Levantine Basin.

The southern margin of the Tauride microcontinent, above the Eurasian Plate, records initial rift volcanism during the Early to Middle Triassic, which was mainly tuffaceous and accompanied by subsidence and extensional faulting. This was followed by continental breakup and extensive outpouring of volcanic rocks during the Late Triassic. These volcanic rocks are of alkaline-transitional MORB-type and provide evidence of Tethyan seafloor spreading (Robertson, 2007). Examples of Late Triassic and Early Jurassic Tethyan oceanic crust can be observed in ophiolites at Baër-Bassit in NW Syria (Figure 6), Hatay in southern Turkey, and Troodos in Cyprus, which were emplaced during the late Maastrichtian as part of the southernmost 'external' belt of ophiolite nappes that were thrust onto the northern Arabian Platform following continental collision (Parrot, 1980). These ophiolites all exhibit close similarities indicating that they are part of the same geo-tectonic structure (Parrot, 1980).

It is not known whether the Levantine Basin was a deep-marine basin during the Triassic and Early Jurassic. The Triassic section of the onshore southern Levantine Basin is characterised by shallow-marine to continental environments. The continuous, high-amplitude reflections that characterise the Palaeozoic to Middle Jurassic interval on offshore seismic lines may be interpreted as shallow-marine and shelfal deposits, which would imply that Tethyan rifting did not result in the development of a deep-water basin within the Levantine (Gardosh et al., 2010). By contrast, the southern margin of the Tauride microcontinent records deep-water deposition of Halobia limestones and ribbon radiolarites during the Late Triassic (Delaune-Mayere, 1984).

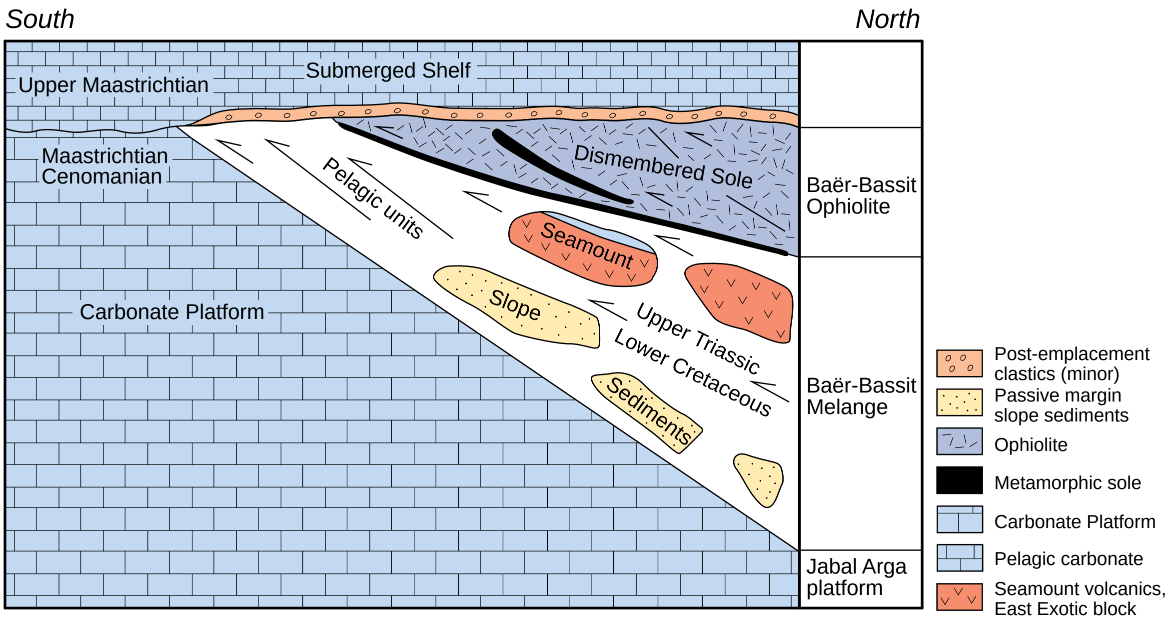

Figure 6: Simplified tectono-stratigraphic relations of rifted margin and ophiolitic units emplaced from the Southern Tethyan Ocean onto the Arabian Margin at Baër-Bassit in northern Syria (from Robertson 2007).

Jurassic Period

Tethyan rifting likely continued into the Jurassic with final continental breakup occurring in the latest Triassic to earliest Jurassic (Robertson, 2007). This final rifting stage is interpreted as being the most intense within the Levantine Basin and was accompanied by extensive magmatic activity. Thick alkaline volcanics, basalts and pyroclastics, approximately 2.5 km thick have been encountered in the onshore southern Levantine Basin. Within the offshore Levantine Basin magnetic anomalies found in the Eratosthenes Seamount and Jonah High are interpreted to represent Early Jurassic volcanism (Gardosh et al., 2010). Early Jurassic tholeiitic basalts have also been recorded along onshore Lebanon and Syria indicating that volcanism extended along the whole Levant Margin (Brew et al., 2001).

Beginning in the Middle Jurassic following significant post-rift thermal subsidence, a continental shelf-and-slope system developed along the eastern margin of the Levantine Basin with its shelf edge identified close to the present-day coastline (Gardosh et al., 2010; Garfunkel, 2004). A large carbonate platform existed across the entire continental shelf with the deposition of thick, massive, monotonous, fine-grained limestones with abundant benthic foraminifera inter-bedded with dolomites and dolomitic limestones (Collin et al., 2010). Continental slope-and-basin deposits consist of poorly fossiliferous shales, inter-bedded with detrital calciclastics, which were transported downslope from the carbonate platform (Garfunkel, 2004). At the end of the Jurassic, the basinward slope along the edge of the shallow-water carbonate platform was at least 2 km high indicating that the adjacent Levantine Basin was already a deep-water basin (Garfunkel, 1998).

Towards the end of the Jurassic two regressional phases are observed within the Levantine Basin. The first of these occurred during the Kimmeridgian and is marked by a regional unconformity and relatively minor block faulting associated with rifting linked to a period of alkaline volcanic activity identified in Syria and Lebanon (Brew et al., 2001; Collin et al., 2010). Shallow-marine carbonate platform deposits are observed again in Lebanon during the Kimmeridgian and Tithonian indicating a marine transgression (Collin et al., 2010). A second major regression occurred during the latest Jurassic, which continued well into the Early Cretaceous. It is marked by an extensive unconformity and significant block faulting associated with rifting together with widespread Early Cretaceous alkaline volcanism thought to be related to mantle plume activity centred beneath Syria (Wilson et al., 1998; Brew et al., 2001).

Along the southern margin of the Tauride microcontinent Tethyan rifting and volcanism generally ceased in the Late Triassic (Robertson, 2007). This was followed by major subsidence which caused the margin to subside below the carbonate compensation depth leading to a major change in sedimentation from carbonate to siliceous sediments, consisting of mudstones, siltstones, and cherts, which spanned the entire Jurassic and Early Cretaceous (Delaune-Mayere, 1984).

Cretaceous Period

Within the Levantine Basin, rifting and widespread alkaline volcanism continued well into the Early Cretaceous (Brew et al., 2001). The associated marine regression led to widespread subaerial exposure of the shallow-water carbonate platform resulting in intense erosion and karstification (Collin et al., 2010). An Early Cretaceous marine transgression covered the eastern margin of the Levantine Basin with thick fluvio-deltaic and shallow-marine sandstones represented by the Palmyra and Rutbah sandstones in Syria and the Grés de Base sandstones in Lebanon (Brew et al., 2001). The southern margin of the Tauride microcontinent records continued deposition of deep-water siliceous sediments throughout the Early Cretaceous with a renewed influx of detrital material (Delaune-Mayere, 1984).

Plate-tectonic convergence between the African and Eurasian plates is thought to have begun during the Cenomanian in the middle Cretaceous (Figure 5). There is evidence for subduction activity within the Pontides of northern Turkey during this time (Pralle, 1994). Plate-tectonic convergence was partitioned between several subduction and suture zones as the small ocean basins located between the rifted microcontinents began to close. The total amount of plate-tectonic convergence has been estimated at ca. 1,800 km with approximately one third of this taking place along the southern margin of the Tauride microcontinent (Garfunkel, 2004). A significant amount of the total convergence was taken up by the “softer” East Anatolian Complex further to the north (Pralle, 1994).

The initial closure of the Neo-Tethys Ocean due to plate-tectonic convergence came to an end during the late Maastrichtian and was accompanied by the emplacement of ophiolites (Garfunkel, 2004). The initial closure of the Neo-Tethys corresponding to the present-day Eastern Mediterranean is represented by the southernmost external subduction zone, which marks the plate-tectonic boundary between the African and Eurasian plates. An ophiolite belt is observed along this boundary including the ophiolites of Baër-Bassit, Hatay, and Troodos.

A maximum marine transgression is recorded within the Levantine Basin and adjacent margins during the early Cenomanian to early Turonian representing a rise in eustatic sea level (Brew et al., 2001; Gardosh and Druckman, 2006). Within the Coastal Ranges and Anti-Lebanon Cenomanian facies record increasing amounts of marl with occasional planktonic foraminifera and pelagic, open-marine facies, which indicate a rise in sea level. Throughout the Late Cretaceous subsidence continued with the basin-fill along the Coastal Ranges recording progressively deeper facies (Brew et al., 2001). Along the southern margin of the Tauride microcontinent sedimentation ceased during the Cenomanian – Turonian although the final stages of the continental passive margin prior to collision remain to be defined (Delaune-Mayere, 1984).

Tertiary Period

The final closure of the Neo-Tethys Ocean due to plate-tectonic convergence came to an end during the Eocene. Although subduction had ceased along the southernmost subduction zone during the late Maastrichtian another subduction zone further north, recording the closure of the South Tauride Basin, persisted into the Eocene (Figure 5). Still further north another subduction zone existed until the early Tertiary, which records the closure of the Ankara-Erzincan branch of the Neo-Tethys (Garfunkel, 2004). The Middle to Late Eocene was a time of major plate-wide compression corresponding to the initial period of continental collision along the northern Arabian Margin. It explains the numerous occurrence of Middle to Late Eocene compressional structures and corresponds to the main stage of Syrian Arc deformation (Brew et al., 2001).

Uplift and compression has continued to the present day caused by the ongoing convergence of the African, Arabian and Eurasian plates. The compressional features which began in the Late Cretaceous and Middle to Late Eocene have continued to deform albeit at a slower rate (Brew et al., 2001). The Late Miocene records a shift in the maximum stress direction from NW-SE to N-S corresponding to the initiation of the Dead Sea Transform fault system, which separates the Arabian Plate from the African Plate (Feraud et al., 1985; El-Motaal and Kusky, 2003). This shift in maximum stress direction caused a change from a compressional regime to a sinistral strike-slip regime during the Pliocene to present along the African – Eurasian plate boundary in offshore Syria (Hall et al., 2005). The strike-slip deformation profoundly changed the pre-existing compressional structures by superposing new structural elements in the form of back thrusts, creating pop-up structures, and parasitic folds which are not in keeping with the southerly vergence of the earlier fold-thrust structures (Hall et al., 2005).

During the Messinian in the latest Miocene the whole of the Mediterranean was affected by a substantial fall in sea level estimated at ca. 1,500 m (Ryan, 1976; Maillard et al., 2006). This was caused by a combination of tectonic uplift, combined with other factors, that caused a narrowing and closing of the connection between the Mediterranean Sea and Atlantic Ocean. The shortage of water combined with the high evaporation rates in the Mediterranean region resulted in a drop in sea level, and an increase in salinity, which led to the precipitation of evaporites (CIESM, 2008). In simple terms the evaporitic deposits of the Messinian Salinity Crisis can be subdivided into three units, the "Messinian trilogy", comprising of the Lower Evaporites, Halite or Mobile Unit, and the Upper Evaporites (Montadert et al., 1970; Decima and Wezel, 1971).

In the Eastern Mediterranean the Lower and Upper Evaporites are believed to be absent based on seismic evidence with only the Mobile Unit present. Within the Levantine Basin the Mobile Unit reaches a maximum thickness of ca. 2 km (CIESM, 2008). The initial depth of the basin prior to deposition has been estimated by Netzeband et al. (2006) to have been 2–3 km. Deposition of the Mobile Unit occurred at ca. 5.59 Ma (Krijgsman et al., 1999). It records a shallowing-up sequence as sea level continued to fall, and the accumulation of halite out-paced the rate of subsidence causing the basins to become infilled (CIESM, 2008). The entire Mobile Unit is estimated to have been deposited in a short period of only 90,000 years (Ky), the "Messinian Gap", calculated as the time interval between the astronomically tuned Lower and Upper Evaporites recorded in the Western Mediterranean (Krijgsman et al., 1999). This is in good agreement with modern solar studies, which estimate the rate of halite precipitation as 100 m/Ky (Schreiber and Hsü, 1980).

STRUCTURAL DEVELOPMENT OF THE LATAKIA RIDGE SYSTEM

The Latakia Ridge System is a prominent series of roughly NE-trending structural lineaments in offshore Syria defining the boundary between the African and Eurasian plates (Figure 7). At present this boundary is characterised by sinistral strike-slip movement and deformation (Hall et al., 2005). There are considerable changes in the style of structural deformation along strike with the northeastern part of the ridge markedly different from the southwestern part. The Latakia Ridge System continues onshore Syria, where it is partly exposed as the Baër-Bassit Ophiolite, for approximately 60 km where it is terminated by the NS-trending Dead Sea Transform fault system marking a triple junction between the African, Arabian, and Eurasian plates.

The northeastern part of the Latakia Ridge System is characterised by a prominent NNE-trending narrow ridge, observable on the seafloor bathymetry, less than 20 km in width with maximum uplift of approximately 3,600 m (Figures 7 and 8). For simplicity this part of the Latakia Ridge System will be referred to as the Tartus Ridge as in Kempler (1994) and Kempler and Garfunkel (1994). A significant amount of uplift along the Tartus Ridge post-dates the deposition of the Messinian evaporites indicating that much of the uplift and deformation is the result of recent sinistral strike-slip movement.

Towards the southwest the Latakia Ridge System diverges into a broad zone of deformation at least 50 km in width characterised by three arcuate ridges that extend towards Cyprus. These are from south to north, the NE-trending Latakia Ridge, NE-trending Margat Ridge, and the EW-trending

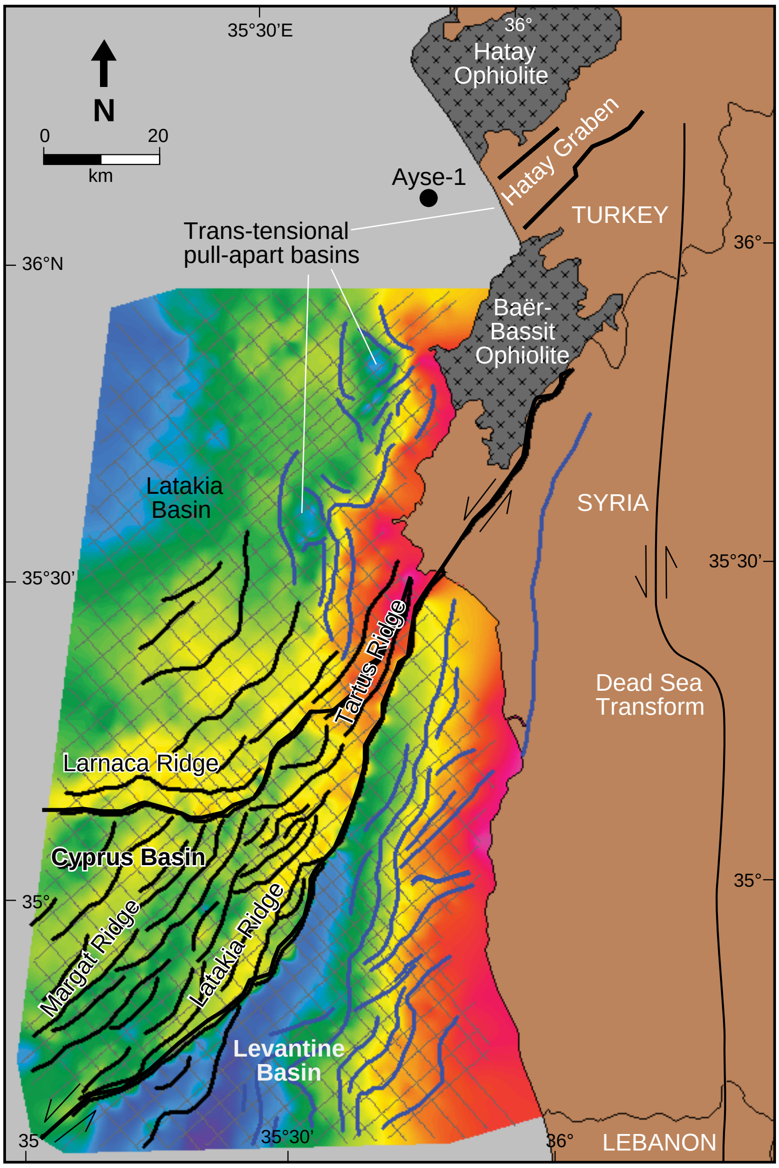

Figure 7: Structural lineaments displayed on the Late Cretaceous unconformity seismic time structure map illustrating the Latakia Ridge System that defines the Levantine, Cyprus, and Latakia basins. Compressional and strike-slip faults are displayed in black and extensional faults in blue.

Larnaca Ridge (Figures 7 and 9). The maximum amount of uplift observed along these ridges is ca. 2,500 m. Based on the published literature combined with seismic observations these three ridges, along with the Tartus Ridge, are interpreted to have initiated as compressional fold-thrust belts during the middle to Late Cretaceous contemporaneous with plate-tectonic convergence between the African and Eurasian plates which was directed NW-SE, perpendicular to the overall trend of the ridges.

Compression continued throughout the Late Cretaceous as the Neo-Tethys continued to close with its intial closure during the late Maastrichtian culminating in the emplacement of the external ophiolites (Parrot, 1980; Garfunkel, 2004). The Late Cretaceous event is observed as a major regional unconformity across offshore Syria with significant uplift and erosion observed on seismic data (Figures 8 and 9). Flattening of the Base Miocene horizon on the seismic data suggests that the Latakia Ridge had a maximum topographic relief of approximately 1,250 m following the emplacement of the external ophiolites.

The increased loading on the lithosphere along the Latakia Ridge System, as a result of folding and thrusting and the emplacement of the external ophiolites, led to the creation of a foreland basin along the northern margin of the Levantine Basin (Figures 9 and 10). The basin was infilled with late Maastrichtian, Palaeocene and Eocene sediments. Towards the far southwest the Latakia Ridge

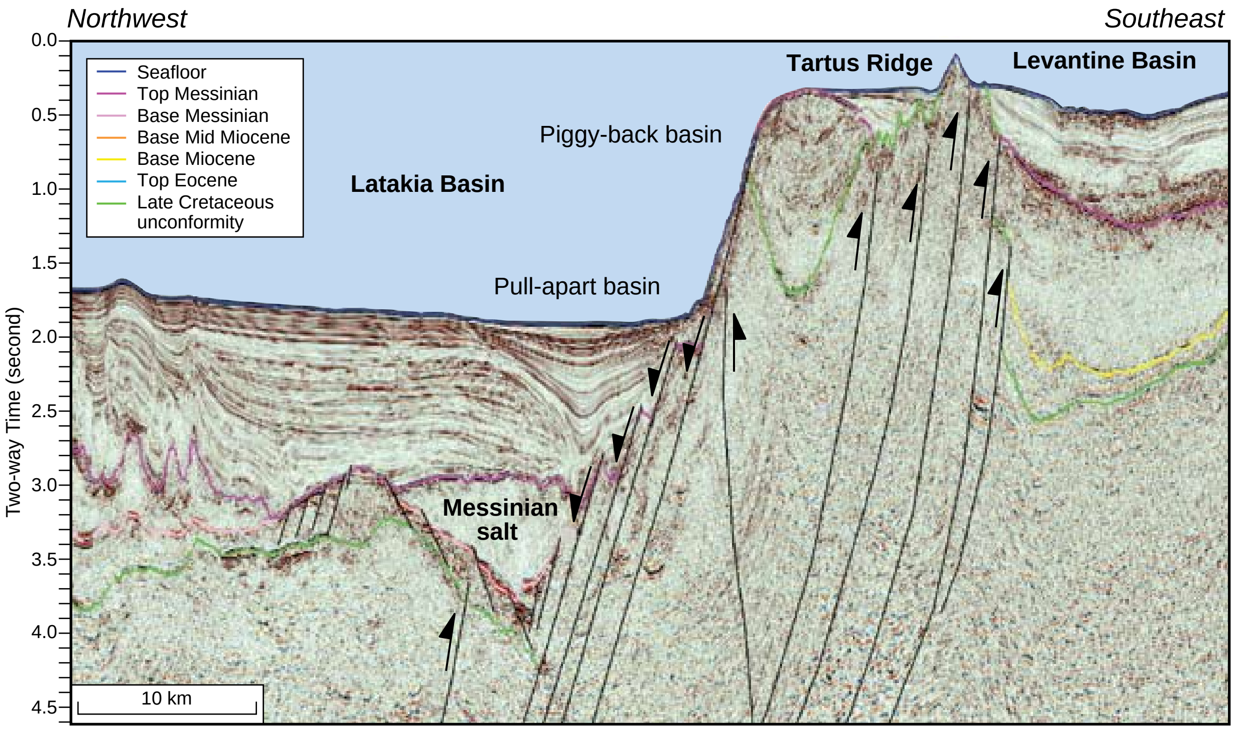

Figure 8: Seismic section across the Tartus Ridge illustrating the intense uplift and deformation that has been active since the mid Cretaceous. The Tartus Ridge is now active under a sinistral strike-slip regime with the presence of a deep trans-tensional pull-apart basin along its northwestern margin.

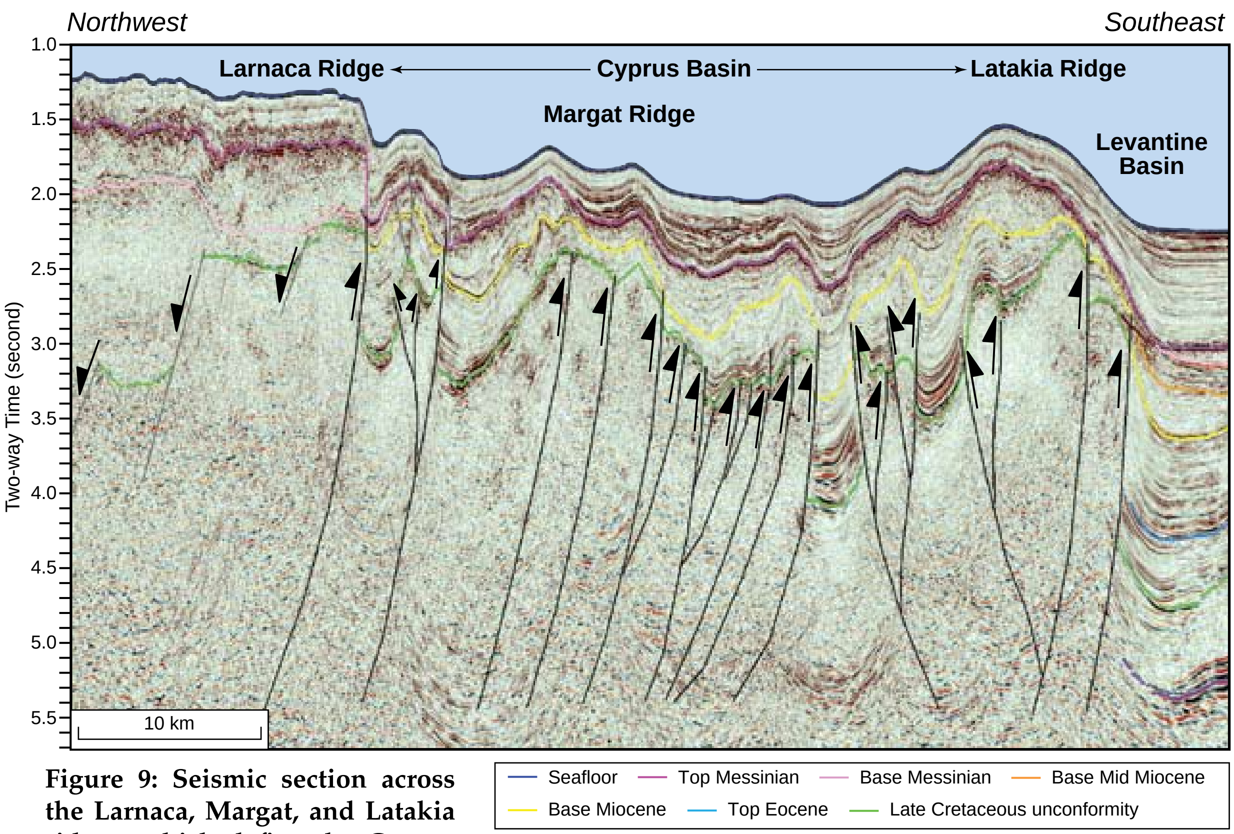

Figure 9: Seismic section across the Larnaca, Margat, and Latakia ridges, which define the Cyprus Basin. This is a broad zone of deformation in contrast to the Tartus Ridge. The original compressional structures have been re-activated under sinistral strike-slip deformation leading to the initiation of positive flower and pop-up structures.

displayed very little topographic relief at this time with uniform and conformable deposition of Oligocene – Miocene sediments across the ridge (Figure 10). This implies that the Latakia Ridge, and other ridges, initiated as a series of smaller, en-echelon, thrust fault segments, which later merged via fault segment linkage to form continuous ridges (Figure 7). The Margat Ridge had a maximum topographic relief of approximately 1,000 m at the end of the Cretaceous. No such estimate can be made across the Larnaca and Tartus ridges due to their intense deformation. Observations from seismic data indicate that the Baër-Bassit Ophiolite complex extends in offshore Syria and along the Tartus, Latakia, Margat and Larnaca ridges.

The final closure of the Neo-Tethys Ocean came to an end during the Eocene and is associated with a major phase of uplift and compression and corresponds to the main stage of Syrian Arc deformation (Brew et al., 2001). The Latakia-3 Well was drilled onshore along the faulted margin of the Tartus Ridge and encountered a faulted section, repeated up to four times, within the Cretaceous – Eocene, confirming that major thrusting occurred during this time. Compression continued through to the Late Miocene, albeit at a slower rate, when a shift in the maximum stress direction caused a change from a compressional regime to a sinistral strike-slip regime during the Pliocene to present (Brew et al., 2001; Hall et al., 2005).

The style of strike-slip deformation along the ridges varies significantly. The most intense deformation occurs along the Tartus Ridge as would be predicted given that the amount of strain is focused along just a single ridge. Towards the southwest the Larnaca Ridge appears relatively unaffected by strike-slip deformation, which is largely accommodated between the Latakia and Margat ridges. The style of strike-slip deformation along the ridges would have been dependent on the applied strain rate as well as the pre-existing compressional fault pattern (Schreurs and Colletta, 1998).

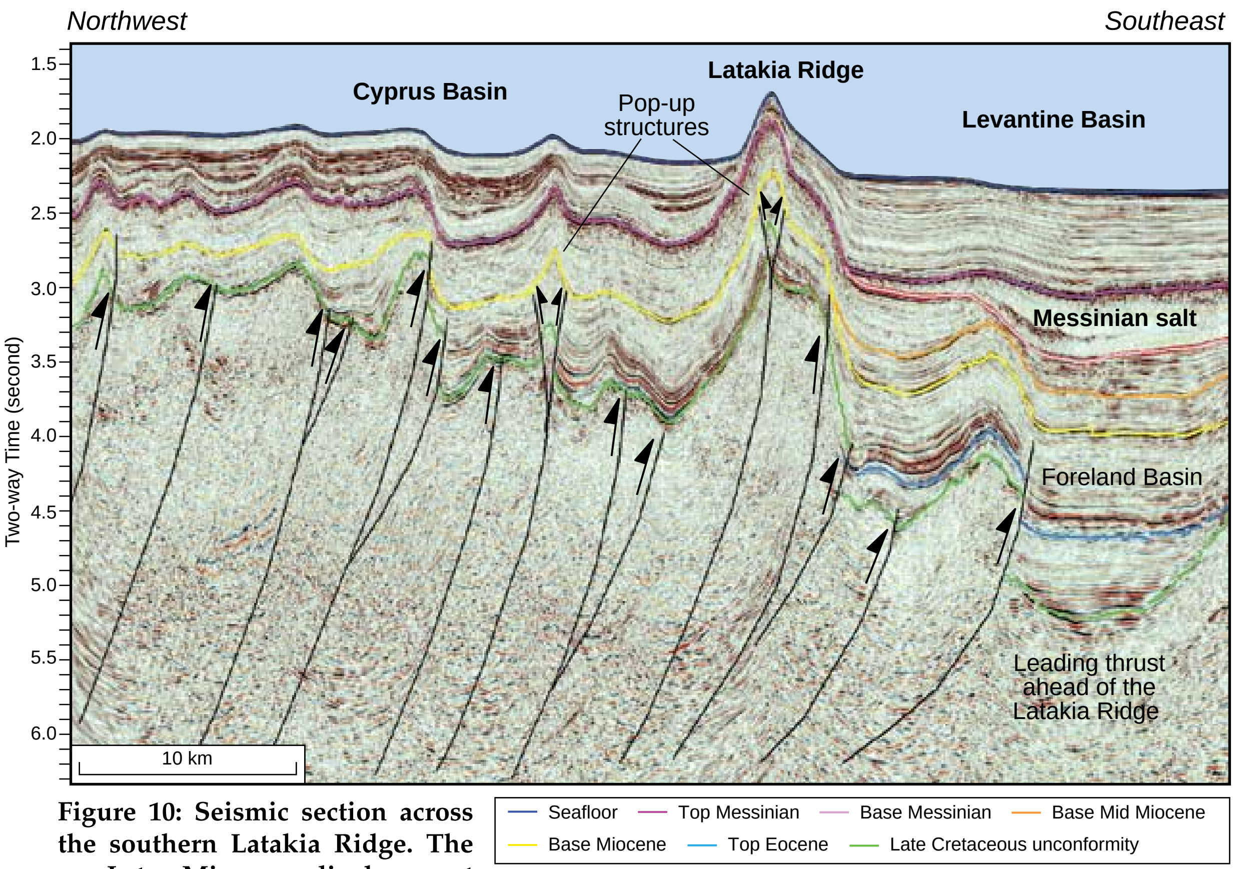

Figure 10: Seismic section across the southern Latakia Ridge. The pre-Late Miocene displacement on the Latakia Ridge is relatively minor at this location with the Oligocene section, between the blue and yellow horizons, displaying a relatively constant thickness across the ridge. Following the emplacement of ophiolites during the late Maastrichtian a foreland basin formed ahead of the Latakia Ridge System in response to lithospheric loading.

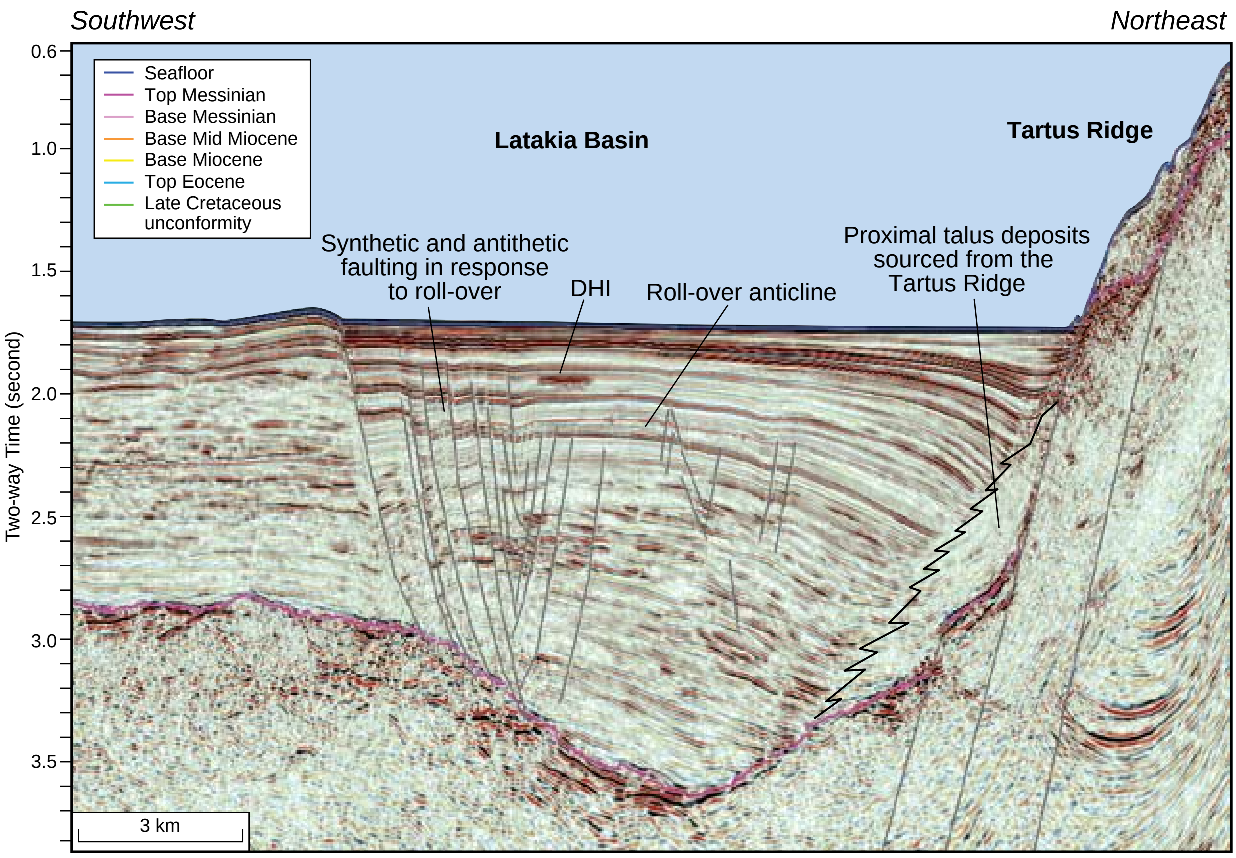

Figure 11: Seismic section across the northern trans-tensional pull-apart basin along the northwestern margin of the Tartus Ridge. It is characterised by a large roll-over anticline and associated extensional faulting and is infilled with sand-prone facies.

Seismic observations indicate that approximately 50%, and possibly more, of uplift along the Tartus Ridge occurred during the Pliocene to present. Strike-slip deformation within the Tartus Ridge is expressed by sub-vertical faulting along the margins with significant uplift created in between (Figures 8, 9, and 10). There is the presence of some back-thrusting with anti-clockwise rotation of the unfaulted domains, which is indicative of a high strain rate (Schreurs and Colletta, 1998, Figure 8). Along the northwestern flank of the ridge there are two small, deep Pliocene – Quaternary basins, less than 9 km in width with a maximum thickness of sediments of 2,450 m, that clearly post-date the Messinian evaporites (Figures 7 and 11). These basins are interpreted as trans-tensional, pull-apart basins produced by sinistral strike-slip movement along the Tartus Ridge. They may represent an extension of the onshore Hatay Graben further to the northeast that is believed to have formed under similar conditions (Boulton and Robertson, 2008, Figure 7).

Along the Latakia and Margat ridges seismic observations indicate that locally up to 60% of uplift occurred during the Pliocene to present although this figure is generally around 40%. The amount of deformation along these ridges is much less than that along the Tartus Ridge with improved imaging of deeper events making seismic interpretation much easier. Strike-slip deformation along the Latakia and Margat ridges, and the intervening area, is characterised by the re-activation of earlier SE-verging compressional thrusts and the formation of oppositely verging back-thrusts to create pop-up and flower structures (Figures 9, 10, and 12). This style of deformation is indicative of a lower strain rate compared to the Tartus Ridge (Schreurs and Colletta, 1998). The pop-up and flower structures are best developed in between and along former locations of fault segment linkage of the Latakia and Margat ridges. Although the majority of strike-slip deformation is observed between the Latakia and Margat ridges some deformation is also observed along and in between the Larnaca and Margat ridges.

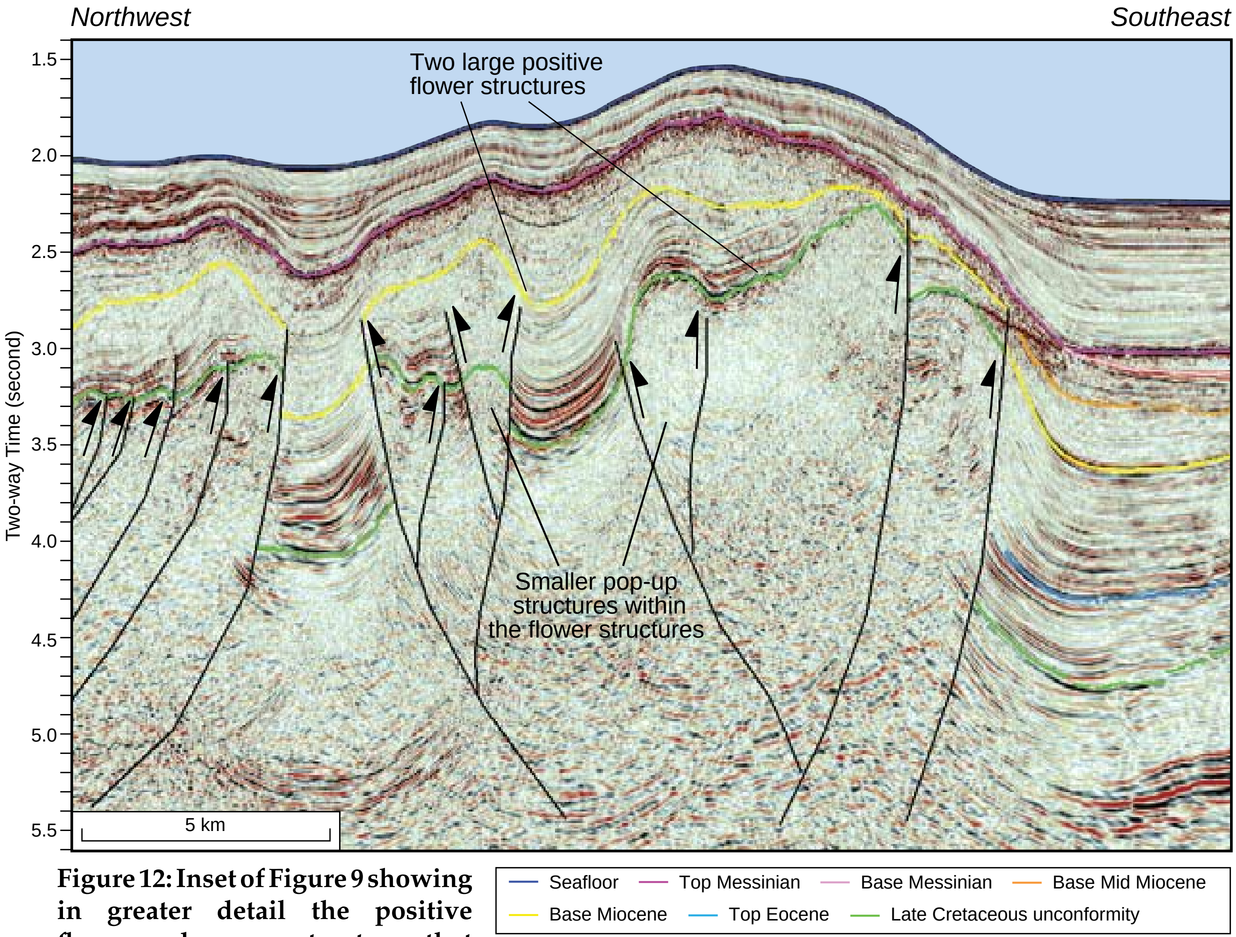

Figure 12: Inset of Figure 9 showing in greater detail the positive flower and pop-up structures that developed in response to the shift from a compressional to a sinistral strike-slip regime.

The Tartus, Latakia, Margat, and Larnaca ridges have a significant impact on the distribution of the Messinian evaporites indicating that at the time of deposition they formed major bathymetric highs. The ridges largely constrain the Messinian evaporites to the Levantine and Latakia basins although some Messinian evaporites are observed within the deeper part of the Cyprus Basin towards the southwest (Figure 13).

Levantine Basin

The Levantine Basin is bound to the east by the Dead Sea Transform fault system, to the north by the Latakia and Tartus ridges, to the northwest by the Eratosthenes Seamount, to the west and southwest by the Nile Delta Cone, and to the south by compression within the Sinai (Figure 1). The Levantine Basin is situated in the African Plate and originated as a result of Tethyan rifting during the late Permian to Early Triassic (Gardosh et al., 2010). At its deepest point, the offshore southern Levantine Basin contains up to 10,000 m of Cretaceous and Tertiary sediments deposited above a rifted Permian – Triassic to Jurassic section with a maximum thickness of 4,000 m (Roberts and Peace, 2007). Only the northernmost part of the Levantine Basin is observed in offshore Syria where the sedimentary section is considerably thinner (Figure 14). A maximum thickness of 4,300 m of uppermost Cretaceous and Tertiary sediments above up to 3,500 m of Permian – Triassic to Cretaceous strata is observed.

The Permian – Triassic to Jurassic strata are characterised by thinning and stretching due to extensional faulting as a result of Tethyan rifting (Gardosh and Druckman, 2006) with significant variations in thickness observed. Since the Middle Jurassic, when a continental shelf-and-slope system developed close to the present-day Levant Margin, the Levantine Basin has developed under deep-water passive-

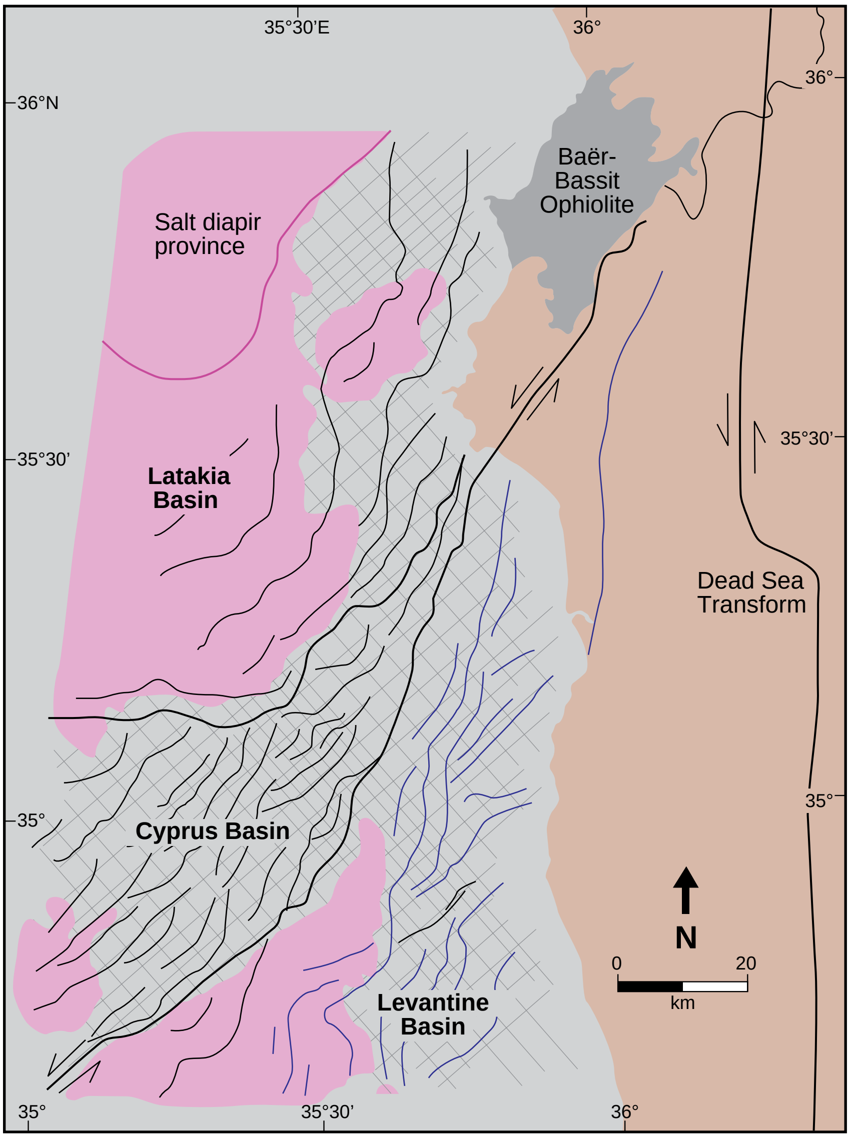

Figure 13: Facies map showing the distribution of Messinian evaporites (halite) shown in pink that were deposited in offshore Syria.

margin conditions (Gardosh et al., 2010; Garfunkel, 2004). Following the emplacement of the external ophiolites along the Latakia Ridge System during the late Maastrichtian the northern Levantine Basin in offshore Syria developed as a foreland basin characterised by a major Late Cretaceous unconformity, which formed in response to lithospheric loading. Deep-water sediments continued to be deposited within the basin, onlapping the major unconformity, and have been gently folded and faulted as a result of the ongoing collision between the Eurasian and African-Arabian plates (Brew et al., 2001).

The sedimentary fill of the Levantine Basin, starting with the rifted Permian – Triassic to Jurassic section is likely to consist of shallow-marine platform carbonates similar to those found in various onshore wells along the Levant Margin (Gardosh and Druckman, 2006). Following the development of passive-margin conditions in the Middle Jurassic, poorly fossiliferous shales inter-bedded with detrital calciclastics that were transported downslope from the carbonate platform were deposited within the basin and along the continental slope (Garfunkel, 2004). A major regression related to mantle plume activity, marked by an extensive unconformity and significant block faulting, occurred during the latest Jurassic and continued well into the Early Cretaceous (Wilson et al., 1998; Brew et al., 2001).

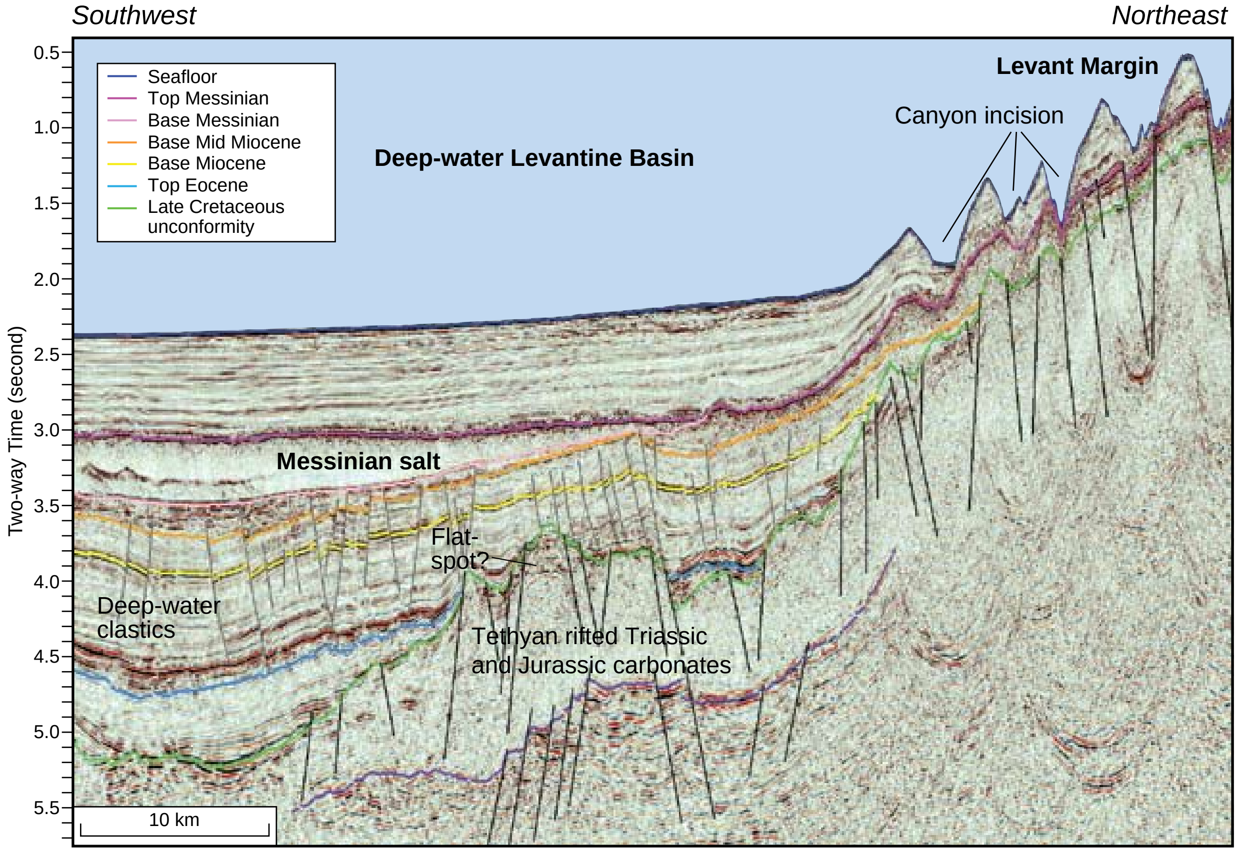

Figure 14: Seismic section across the Levant Margin and deep-water Levantine Basin. The Cenozoic section is characterised by deep-water siliciclastic deposition and is significantly faulted as a result of continued uplift and compression of the basin. Note the presence of a potential flat-spot below the Late Cretaceous unconformity in the centre of the line.

Widespread subaerial exposure of the shallow-water carbonate platform along the Levant Margin resulted in intense erosion and karstification (Collin et al., 2010). An Early Cretaceous marine transgression covered the eastern margin of the Levantine Basin accompanied by an influx of siliciclastic and detrital carbonate sediments (Brew et al., 2001; Gardosh and Druckman, 2006). A maximum marine transgression is recorded within the Levantine Basin and adjacent margins during the early Cenomanian to early Turonian representing a rise in eustatic sea level (Brew et al., 2001; Gardosh and Druckman, 2006). A thick succession of progressively deeper hemipelagic to pelagic facies consisting of chalk, marl, and shales were likely deposited during the Late Cretaceous (Brew et al., 2001; Gardosh and Druckman, 2006).

Hemipelagic to pelagic facies continued to be deposited throughout the latest Cretaceous, Palaeocene, and Eocene within the foreland basin that had formed ahead of the Latakia Ridge System. These sediments exhibit a relatively low-amplitude seismic character with their upper boundary marked by what has been interpreted as the Top Eocene, which is overlain by a high-amplitude package of reflectors with a thickness of approximately 300 m (Figure 15). Elsewhere in the Levantine Basin a biostratigraphic hiatus has been recognised between the Middle Eocene and Early Oligocene with a change in sedimentation from carbonates to siliciclastics along the basin margin (Gardosh and Druckman, 2006). Therefore the high-amplitude Lower Oligocene package is interpreted to represent a sand-rich facies possibly associated with coincident tectonic uplift that may have led to regression and increased erosion (Brew et al., 2001). The middle to Late Oligocene deposits once again exhibit a relatively low-amplitude seismic character indicating a return to hemipelagic and pelagic facies.

Well data, Yam West-1 and Yam Yafo-1, from the offshore southern Levantine Basin, indicate that Miocene deposits consist of deep-water pelagic marl and shale. Thick deposits of coarse-grained

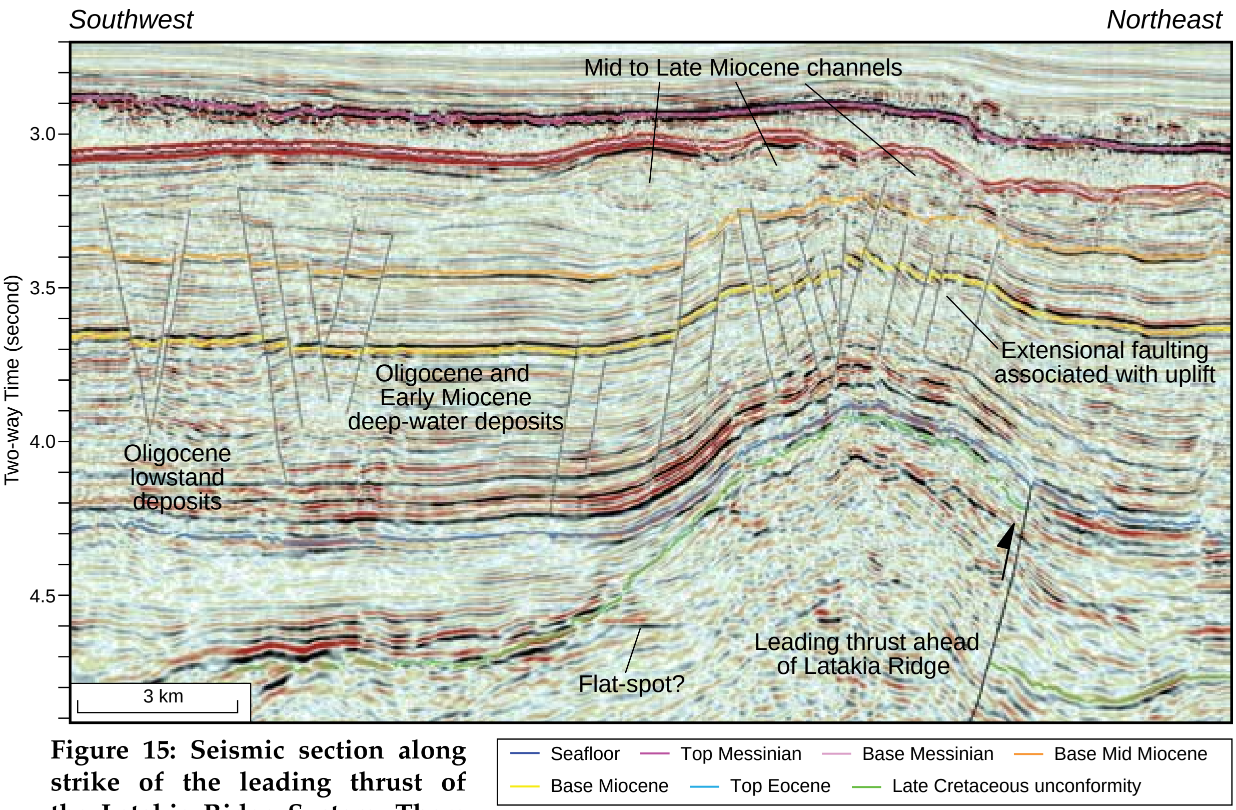

Figure 15: Seismic section along strike of the leading thrust of the Latakia Ridge System. There is clear evidence of channelling within the Middle to Upper Miocene deposits with turbidite reservoirs likely in the deeper Lower Miocene and Oligocene intervals. Note the presence of a potential flat-spot within the thrust fault anticline below the Late Cretaceous unconformity.

sandstone and conglomerate have been encountered in wells, e.g. Hof Ashdod-1, along the Levant Margin that are interpreted to represent canyon-fill deposits associated with several cycles of subaerial and submarine erosion and incision of the Oligocene – Miocene shelf. Mounded reflections identified offshore on seismic data have been interpreted as siliciclastic, deep-water turbidites and basin-floor fans which may be the distal equivalents of the proximal canyon-fill deposits encountered onshore (Gardosh and Druckman, 2006). These observations have been proven by the recent Tamar, Dalit, and Leviathan discoveries which are all located within inter-bedded, laterally extensive, coalescing, high-quality Lower Miocene turbidite sandstone reservoirs.

In offshore Syria the Miocene deposits have a maximum thickness of less than 900 m. The base of the Miocene deposits is represented by a strong, regionally correlatable reflector representing an increase in acoustic impedance (Figure 15). The Lower Miocene deposits have a maximum thickness of 600 m and comprise laterally extensive, mounded, variable amplitude reflectors that are interpreted to represent deep-water turbidites and basin-floor fans inter-bedded with pelagic marls and shales. An interesting, and perhaps unexpected, observation is that the Lower Miocene deposits actually thicken landwards towards the northeast in the opposite direction to the overall thickening of sediments within the Levantine Basin. This provides good evidence of a provenance along the Levant Margin corresponding to the onshore Nahr Al Kebir depression where over 2 km of Neogene sediments are present (Brew et al., 2001).

The Middle and Upper Miocene deposits have a maximum thickness of approximately 500 m and are generally more chaotic and higher amplitude with clear evidence of channels and erosional incision, especially within the deeper part of the basin (Figure 15). The entire Oligocene and Miocene interval is extensively faulted and is likely related to tectonic uplift and compression associated with the ongoing collision between the Eurasian and African-Arabian plates (Brew et al., 2001). The numerous extensional faults would have initiated in response to uplift and folding of the basin in order to accommodate the increased strain.

The Messinian evaporites are present within the deeper part of the Levantine Basin (Figure 13), towards the southwestern part of offshore Syria, where they have a maximum thickness of less than 1,000 m. They appear as a relatively transparent facies, composed of halite, on the seismic data with the exception of a prominent reflector within the lower part of the evaporites (Figure 14). The exact nature of this reflector is not known but it likely corresponds to an influx of either intercalated clastic material or alternating deposits of halite, anhydrite, limestone, or potash due to chemical sedimentation processes (CIESM, 2008). The Messinian evaporites are overlain by Pliocene to Recent clastics which attain a maximum thickness of 800 m.

Onshore, the Latakia-2, Latakia-1, and Fidio-1 wells provide a useful, roughly West–East transect across the Levantine Basin (Figure 4). The total distance between the wells is only 6 km, but provides a useful insight into the lithologies encountered and the rapid lateral facies transitions from a proximal to more distal setting within the basin. The rifted Permian – Triassic to Jurassic section was encountered by the Latakia-1 and Fidio-1 wells and is composed of thick carbonates and dolomites. In the proximal Fidio-1 Well the Lower Cretaceous section consists of carbonates but in the more distal Latakia-1 and Latakia-2 wells it is composed of conglomerates, sands, and marls located above a Late Jurassic unconformity. The Late Cretaceous and Palaeogene are largely represented by carbonates and dolomites within all of the wells although some intervals of marl are present within the most distal Latakia-2 Well.

The Lower Miocene section displays a clear facies transition from carbonates in the proximal Fidio-1 Well to sandstones, conglomerates, and marls in the Latakia-1 Well to marls within the distal Latakia-2 Well. An overall deepening of the basin is observed into the Middle and Late Miocene with thick marls inter-bedded with occasional sandstones, carbonates, and anhydrite observed in all of the wells. Basal conglomerates and sands are observed within the more distal Latakia-1 and Latakia-2 wells in the Pliocene section corresponding to the re-filling of the Mediterranean Sea following the Messinian Salinity Crisis. A marl interval is encountered at this level in the more proximal Fidio-1 Well. Above this interval a thin carbonate layer of relatively constant thickness is observed in all of the wells and is overlain by varying amounts of sands and marls.

Cyprus Basin

Extending across offshore Syria, northernmost Lebanon and Cyprus, the Cyprus Basin is bound to the north by the Larnaca Ridge, to the southeast by the Latakia Ridge, and to the west by the Hecataeus Rise. The Cyprus Basin is situated within the Eurasian Plate overlying an area of broad deformation resulting from the initial convergence of the Eurasian and African plates, which culminated in the late Maastrichtian (Garfunkel, 2004) with the emplacement of ophiolites along the Latakia Ridge System. The Cyprus Basin is interpreted to have developed during the Late Cretaceous with sediments located above poorly imaged and strongly deformed ophiolites and rifted Tethyan sediments. No exploration wells have been drilled within the offshore Cyprus Basin.

The Cyprus Basin in offshore Syria contains up to 2,900 m of Oligocene and Neogene sediments and is sub-divided by the NE-trending Margat Ridge (Figure 9). The structural evolution of the basin is characterised by folding and thrusting due to uplift and compression caused by plate-tectonic convergence and sinistral strike-slip movement. This resulted in the development of several thrust-related anticlines forming structural closures, which may be prospective for hydrocarbon exploration. Since the Early Pliocene the Cyprus Basin developed under a sinistral strike-slip regime that resulted in the re-activation of previously formed SE-verging thrusts and the development of oppositely verging back-thrusts forming characteristic pop-up and flower structures (Figures 10 and 12). The southeastern part of the Cyprus Basin, located between the Latakia and Margat ridges, has been most intensely deformed by the strike-slip motion. The northwestern part of the Cyprus Basin, located between the Larnaca and Margat ridges, has suffered comparatively little strike-slip deformation.

Since its development in the Early Oligocene the Cyprus Basin has experienced a very similar history of sedimentation to the Levantine Basin. The sand-rich Lower Oligocene deposits directly overlie the thrusted ophiolitic basement that was emplaced during the late Maastrichtian with the latest

Cretaceous, Palaeocene, and Eocene interpreted as a period of non-deposition. The Oligocene deposits display a similar thickness to those in the Levantine Basin across the Latakia Ridge implying that this was a period of tectonic quiescence with limited uplift along the Latakia Ridge System (Figure 10). Within the Cyprus Basin the Base Miocene is observed as a significant unconformity indicating that there was a significant amount of uplift prior to the deposition of Neogene sediments which are markedly thinner within the Cyprus Basin, compared to the Levantine Basin, due to its structurally elevated position following uplift of the Latakia Ridge System.

There is therefore a question mark over the presence of Lower Miocene turbidites, which if present would have to have been locally sourced from the Latakia Ridge System. The turbidite deposits sourced from the Levant Margin would likely have been ponded within the Levantine Basin by the Latakia Ridge System, which would have acted as a major barrier to sediment transport. The Messinian evaporites are much less extensive within the Cyprus Basin in offshore Syria compared to both the Levantine and Latakia basins, again due to its structurally elevated position (Figure 13). They occur only within the deeper part of the basin towards the southwest where they have a maximum thickness of 600 m.

Latakia Basin

Extending across offshore Syria, Cyprus, and southernmost Turkey the Latakia Basin is bound to the east by the Tartus Ridge, to the north by a continental rise marking the transition to the Iskenderun Basin, to the west by the Misis Kyrenia zone and Cyprus continental margin, and to the south by the Larnaca Ridge. The Latakia Basin is situated in the Eurasian Plate and originated following the emplacement of the external ophiolites in the late Maastrichtian following the initial closure of the Neo-Tethys. Sediments within the basin are interpreted to be entirely Tertiary in age overlying an obducted ophiolitic basement corresponding to the Kizildag Complex. Similarly to the Cyprus Basin, no exploration wells have been drilled within the Latakia Basin. However, several exploration wells have been drilled within the Iskenderun Basin to the north, including the Ayse-1 exploration well drilled just 11 km north of the Syria – Turkey maritime boundary. The transition between the Latakia and Iskenderun basins is not well defined and they could be considered as part of a larger basin.

The Latakia Basin in offshore Syria contains up to 4,400 m of Neogene sediments including a thick layer of Messinian salt (Figure 16). The structural evolution of the basin is characterised by the onlap of Neogene sediments onto the obducted ophiolitic basement as well as extensive salt diapirism within the northwestern part of the basin (Figure 7). Along the northwestern margin of the Tartus Ridge there are two small, deep Pliocene – Quaternary pull-apart basins less than 9 km in width with a maximum thickness of sediments of 2,450 m (Figure 7). They are interpreted as being produced by trans-tension as a result of sinistral strike-slip motion along the Tartus Ridge and may represent an extension of the onshore Hatay Graben further to the northeast that is believed to have formed under similar conditions (Boulton and Robertson, 2008). The basins clearly post-date the deposition of the Messinian evaporites, which were not deposited in the area, which at the time formed a palaeo-high prior to strike-slip deformation. Alternatively the Messinian evaporites may have been squeezed out of the basins via sediment loading.

Since the beginning of the Pliocene there has been significant uplift of over 1,800 m in the Latakia Basin towards the south along the Larnaca Ridge and to the east along the Tartus Ridge. The uplift and associated compression is clearly dated as being post-Messinian given that the thickness of the Messinian salt is relatively uniform across the uplifted areas (Figure 16). Following deposition of the Messinian salt its upper surface would have been relatively flat allowing the amount of subsequent uplift to be calculated fairly easily. This Pliocene uplift and compression is also observed within the Iskenderun Basin further to the north where NW-SE compression deformed the basin on two levels. In the deeper level the compression re-activated older structures involving the ophiolitic basement whereas in the shallower level the top of the Messinian salt acted as a detachment surface (Pralle, 1994). A similar style of deformation is also observed within the Latakia Basin where in the deeper level there has been reactivation of both thrust and extensional faults involving ophiolitic basement producing the inversion of small intra-basins.

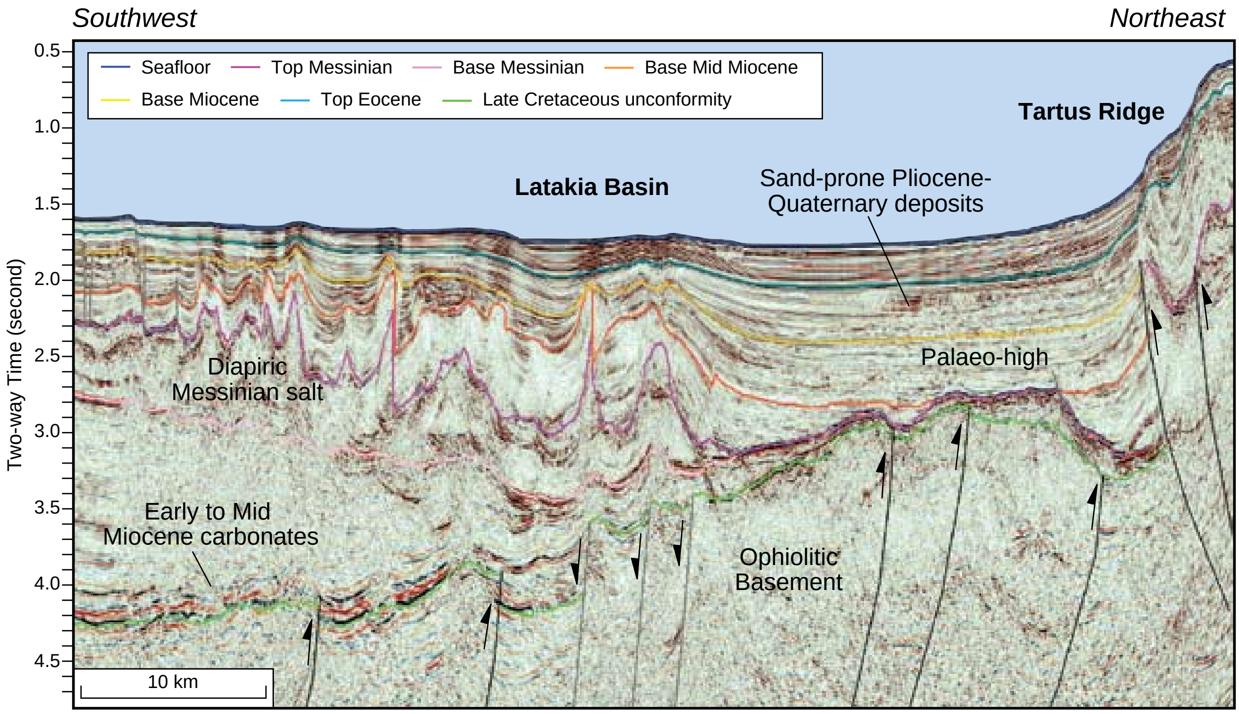

Figure 16: Seismic section across the Latakia Basin. Significant uplift is observed towards the Larnaca Ridge (not shown) to the south. This is best illustrated by the Messinian evaporites, which would have been deposited on a relatively flat surface.

Given that no exploration wells have been drilled within the Latakia Basin the lithostratigraphy remains untested. However, as previously stated the Iskenderun Basin is thought to provide a good analogue and may in fact be part of the same, larger basin system. Within the offshore Iskenderun Basin Lower Miocene deposits sit directly above the obducted Maastrichtian-aged ophiolites of the Kizildag Formation with Palaeocene, Eocene, and Oligocene deposits absent. Basal conglomerates corresponding to the Kaleçik Formation are present in some of the offshore wells including Ayse-1. They are overlain by the Lower to Middle Miocene carbonates of the Horu Formation, which has a thickness of approximately 212 m within the Ayse-1 Well. They are capped by organic-rich marls and shales of the Menzelet Formation and shales of the Kizildere Formation, which have a thickness of 176 m in the Ayse-1 Well. In more proximal areas of the Iskenderun Basin the Kizildere Formation is replaced by sands and conglomerates of the diachronous Aktepe Formation, which becomes more widespread in the Late Miocene and Early Pliocene as a result of a relative fall in sea level due to uplift and compression.

The majority of the Latakia Basin in offshore Syria is covered by Messinian salt, which has a maximum undeformed thickness of approximately 1,360 m, except for the eastern part of the basin along the Latakia Ridge where it is absent (Figure 13). The Messinian salt is also absent in the Ayse-1 Well. The style of deposition and deformation of the Messinian salt is significantly different to that in the Levantine Basin. The northwestern part of the Latakia Basin is characterised by extensive salt diapirism with some salt diapirs reaching a maximum height of almost 1,000 m (Figures 7 and 16). In contrast to the Levantine Basin there are two prominent reflectors within the Messinian salt, both of which display evidence of syn-depositional deformation.

On several seismic lines the top Messinian surface is relatively planar and conformably overlain by Lower Pliocene deposits yet considerable deformation and folding can be observed within the Messinian salt. This would imply that there was movement of the salt almost as soon as it was deposited, which is likely related to the uplift of the Latakia Basin. Similar observations within the southern Levantine Basin have been made by Netzeband et al. (2006) and Bertoni and Cartwright (2007). The intra-Messinian folds are generally southerly verging with steeply dipping forelimbs.

This observation is consistent with syn-depositional uplift of the Latakia Basin towards the south, which would have resulted in differential compaction in the north leading to salt flow towards the south. Given the nature of the two prominent intra-Messinian reflectors and their involvement in the deformation of the Messinian salt it is suggested that they are the result of alternating deposits of halite, anhydrite, limestone, or potash due to chemical sedimentation processes as opposed to the presence of intercalated clastics.

The Messinian salt is overlain by Pliocene to Recent sands and shales of the Aktepe and Erzin formations which reach a maximum thickness of 2,450 m within the pull-apart basins located along the northwestern margin of the Tartus Ridge (Figure 11). The Ayse-1 Well recorded 874 m of Pliocene to Recent shales inter-bedded with decimetre-scale sands. Analysis of the seismic data reveals the presence of erosive channels, channel-levee systems, and slumped deposits proximal to the Latakia Ridge System. Towards the west above the salt diapir province the sediments thin significantly, becoming more distal, with a seismic facies response characteristic of marls and shales (Figure 16). The sediments also thin onto the Larnaca Ridge to the south where they become more chaotic and harder to interpret due to thinning and syn-depositional salt movement.

PETROLEUM SYSTEM

Source Rocks

In the Levantine Basin source rocks can be found within Triassic and Jurassic shallow-water, lagoonal marls and shales and Upper Cretaceous and Cenozoic deep-water marls and shales. The Triassic to Middle Jurassic has been interpreted as a time of shallow-marine and shelfal carbonate deposition both onshore and extending offshore (Gardosh et al., 2010). Along the Levant Margin in Lebanon several facies are recognised within Middle Jurassic formations indicating carbonate-dominated palaeo-environments. These include both deep and shallow-water, low-energy, lagoon-type depositional environments which are conducive to the accumulation of source rocks, with the presence of plant debris with very high total organic content recognised within some facies (Collin et al., 2010). These depositional environments are also likely to have existed during the Early Jurassic and Triassic. It has been reported that these source rocks are often gas-prone (Nader and Swennen, 2004).

Following significant post-rift thermal subsidence, which initiated during the Middle Jurassic, the Levantine Basin is believed to have developed as a deep-water basin offshore (Gardosh et al., 2010; Garfunkel, 2004). During the Late Cretaceous and Cenozoic deposition of thick deep-water marls and shales occurred which have good source rock potential (Tannenbaum and Lewan, 2003). There is good evidence of a working petroleum system within the Levantine Basin all along the Levant Margin. A biogenic gas play has recently been proven in the southern Levantine Basin with the Tamar, Dalit, and Leviathan discoveries.

There is also good evidence of an oil-prone petroleum system along the Lebanese coastline where *in situ* asphalt shows have been recorded in Upper Cretaceous marls and carbonates rich in organic material that were deposited in an anoxic basin (Nader and Swennen, 2004). Late Cretaceous aged oil shows have also been encountered in the El Qaa Well where traces of bitumen were observed. In the Terbol-1 Well oil shows were observed within the Upper Jurassic where the total organic content was 10% (Roberts and Peace, 2007). The Leviathan discovery well was deepened in order to test the potential of the Cretaceous interval with the expectation of finding oil derived from thermogenic source rocks.

In Syria, all four of the wells drilled near Latakia encountered hydrocarbon shows (Figure 4). The first of the wells to be drilled, Fidio-1, encountered small amounts of gas within Lower Cretaceous carbonates. The Latakia-1 Well encountered gas shows within Upper Cretaceous and lower Tertiary carbonates with oil shows also encountered within Lower Cretaceous clastics. The Latakia-2 Well recovered combustable gas from Eocene and Oligocene carbonates and also encountered heavy oil and gas shows within the Upper Cretaceous. The Latakia-3 Well, which was actually drilled on the Latakia Ridge, encountered heavy oil shows and asphalt in the deepest section of the well with gas shows also recorded at several intervals within the Oligocene and Eocene.

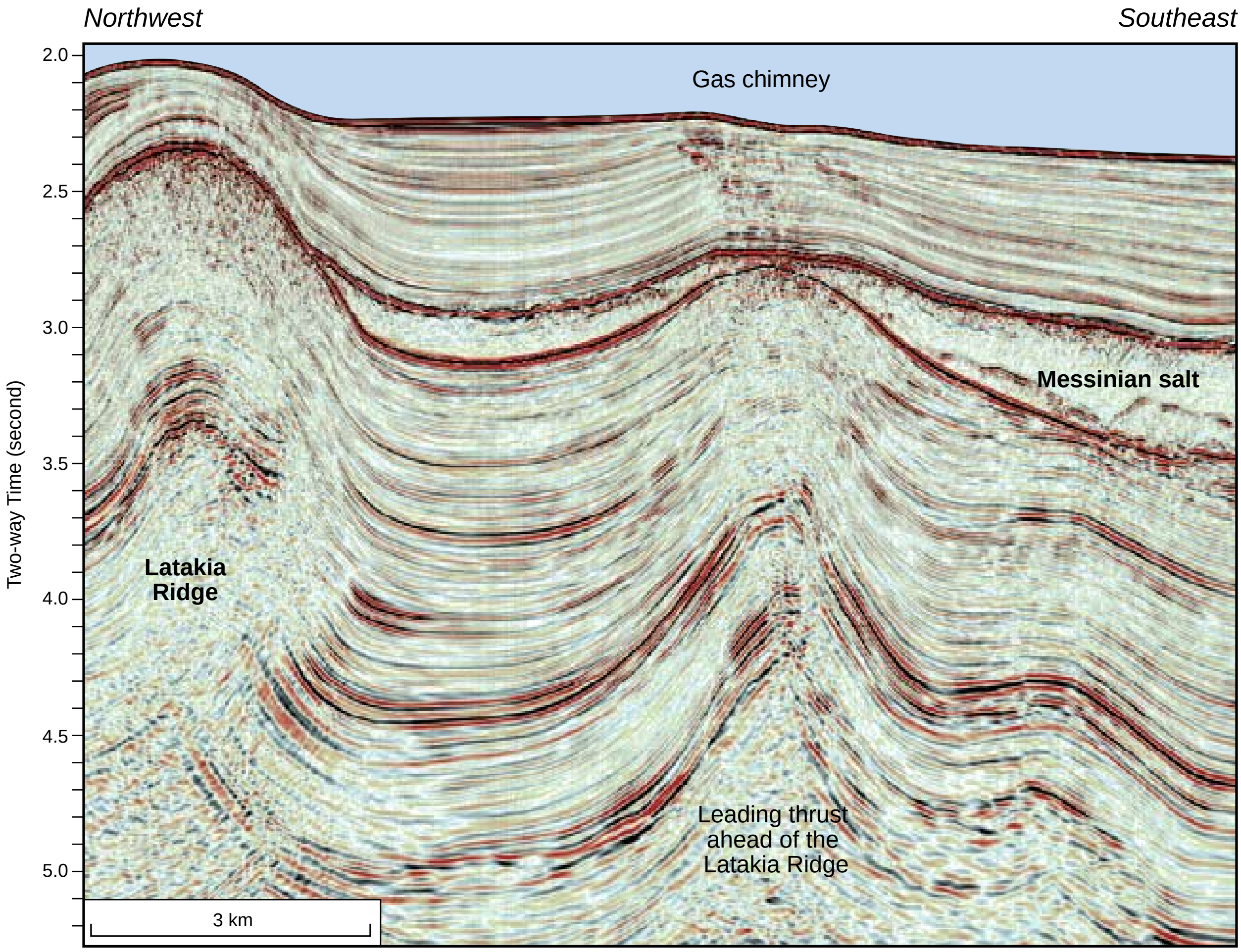

Figure 17: Gas chimney present above the leading thrust of the Latakia Ridge.

Offshore, observations from seismic reveal the presence of several gas chimneys, possible flat-spots, and other DHIs. Similar seismic hydrocarbon indicators have been interpreted further west by Semb (2009) and in the Nile Cone by Shell oil company. The gas chimneys are observable on several seismic lines above the leading thrust of the Latakia Ridge and may be either biogenic or thermogenic (Figure 17). The possible flat-spots have been identified below the gas chimneys (Figure 15) and also within tilted fault blocks stepping down into the basin (Figure 14). If the flat-spots are indeed real they will represent billion-barrel/multi-TCF drilling targets given the scale and volumetrics of the structures within which they occur. There are relatively few bright-spots within the Oligocene – Miocene section although there are some examples that occur trapped against the numerous extensional faults that affect the interval.

Further evidence of a working petroleum system within the Levantine Basin in offshore Syria comes from Offshore Basin Screening (OBS) provided by Fugro NPA. Using satellite synthetic aperture radar (SAR) images of the ocean surface, OBS maps and analyses slicks that form when oil and gas bubbles reach the sea surface, coalesce, and form oil slicks that are detectable by satellite radar senses. OBS endeavours to discriminate oil and non-oil slicks and between seeped and polluted oil. Although there are ambiguities, the discrimination, relying on expert interpretation and repeat data, is achieved with a good to excellent degree of confidence, especially when compared with interpreted seismic data.

Good, repeating oil slicks attributed as naturally occurring oil seeps can be observed along the Latakia Ridge (Figure 18) and also within the basin centre. Oil seeps would be expected to occur along the Latakia Ridge due to the presence of several large faults, some of which continue to the seafloor, and its position adjacent to the foredeep of the northern Levantine Basin where source rocks are likely to

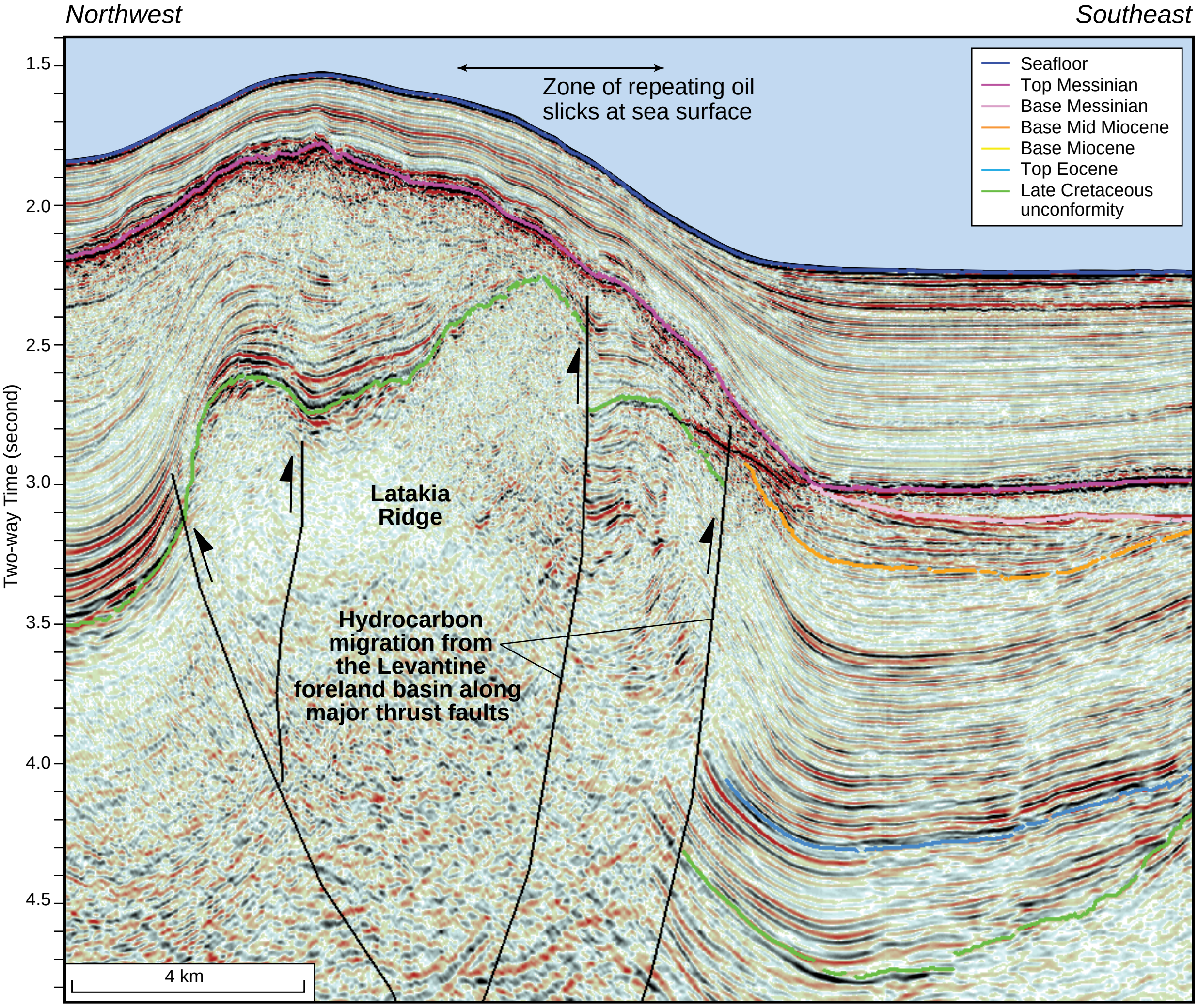

Figure 18: Oil slicks are observed along the Latakia Ridge. Hydrocarbons likely matured within the Levantine Basin and migrated vertically upwards along thrust faults of the Latakia Ridge.

be thermogenically mature. The occurrence of oil seeps within the centre of the Levantine Basin may be somewhat limited by the presence of Messinian salt (Figure 13) which will act as a very effective barrier to hydrocarbon migration. However, some oil seeps are observed corresponding to the limit of the Messinian salt where they are able to escape towards the seafloor.

Within the Cyprus Basin similar source rocks to the Levantine Basin are likely to exist within the Cenozoic section. However, given the obduction of ophiolites during the late Maastrichtian the underlying Triassic, Jurassic, and Cretaceous source rocks are not likely to be productive. The relatively shallow burial depth of the Cenozoic section within the Cyprus Basin means that the presence of hydrocarbons will be reliant on either *in situ* biogenic gas or alternatively migration of hydrocarbons from the adjacent Levantine and Latakia basins along the Latakia and Larnaca ridges, respectively. There are fewer DHIs within the Cyprus Basin although some small well-defined flat-spots and bright-spots can be observed on seismic lines.

There are no clear, repeating oil slicks within the centre of the Cyprus Basin although they can be observed along the bounding Latakia and Larnaca ridges (Figure 18). This is not unexpected given the shallow burial depth of the potential Cenozoic source rocks and the absence of any older, more deeply buried source rocks. This does not mean, however, that the Cyprus Basin is non-prospective because the presence of oil seeps along the Latakia and Larnaca ridges proves that migration of hydrocarbons is possible from the deeper, adjacent Levantine and Latakia basins. Additionally, the OBS technique is in general only an indicator of oil seeps and not gas seeps and as such cannot be used as an indicator for the presence of biogenic gas.

Within the Latakia Basin the prospective source rocks are interpreted as being the equivalent of the Early to Middle Miocene Menzelet marls and shales as in the analogous Iskenderun Basin to the north where it is oil-prone. The depth of burial of the source rocks offshore Syria means that they will likely be early-mature for oil generation and the charging of reservoirs may indeed be dependent on lateral migration of hydrocarbons from the deeper part of the basin towards the northwest. An oil discovery, Gulcihan-1, has been made in the offshore Iskenderun Basin less than 50 km north of the Syria-Turkey maritime border with estimated reserves of 13.5 million barrels of oil, proving up the presence of an oil-prone petroleum system.

As with the Cyprus and Levantine basins there is also the potential for biogenic gas from Neogene marls and shales. A number of post-Messinian DHIs have been observed on seismic lines often above diapiric Messinian salt where they are recognised as flat-spots and bright-spots trapped against salt diapir anticlines (Figures 11 and 19). Several zones of fluid escape from the Messinian evaporites can also be observed on seismic lines, which may contain hydrocarbons. Good, repeating oil slicks can be observed within the Latakia Basin along the Larnaca and Tartus ridges as well as in the basin centre where they are seen to correlate with faulting to the seafloor and zones of fluid escape above the Messinian salt (Figure 20).

Reservoirs

Within the Levantine Basin the current exploration focus is on Lower Miocene deep-water turbidite sands sourced from the Levant Margin, which are also interpreted to be present across the northern part of the basin offshore Syria. They form the principal reservoir within the recent Tamar, Dalit and Leviathan discoveries with combined recoverable gas reserves of approximately 25 TCF. For more details on these discoveries see the above section entitled "Exploration History". A secondary reservoir target, and the reason for deepening the Leviathan discovery well, is the Lower Cretaceous section. Additional reservoir targets within the central Levantine Basin could include Pliocene – Quaternary, Middle and Upper Miocene, and Palaeogene deep-water turbidites, as well as potential in the deeper Jurassic and Triassic carbonates. Along the Levant Margin the main reservoir targets are likely to be carbonate build-ups, which have continued to develop, intermittently, since the Triassic.

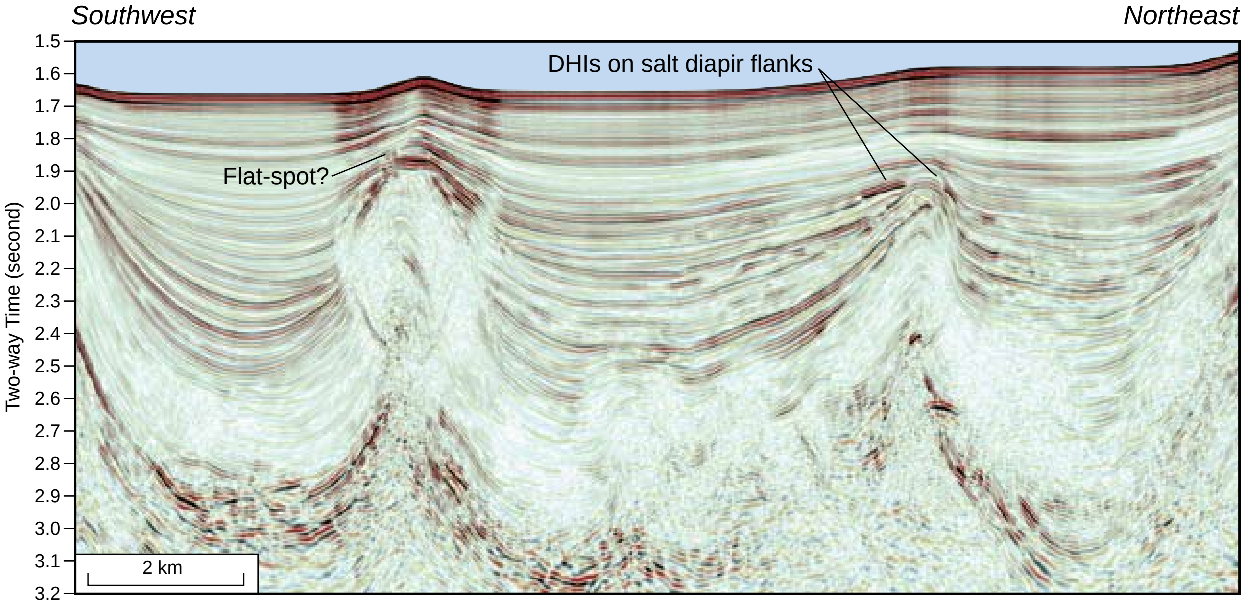

Figure 19: DHIs observed above Messinian salt diapirs in the Latakia Basin.

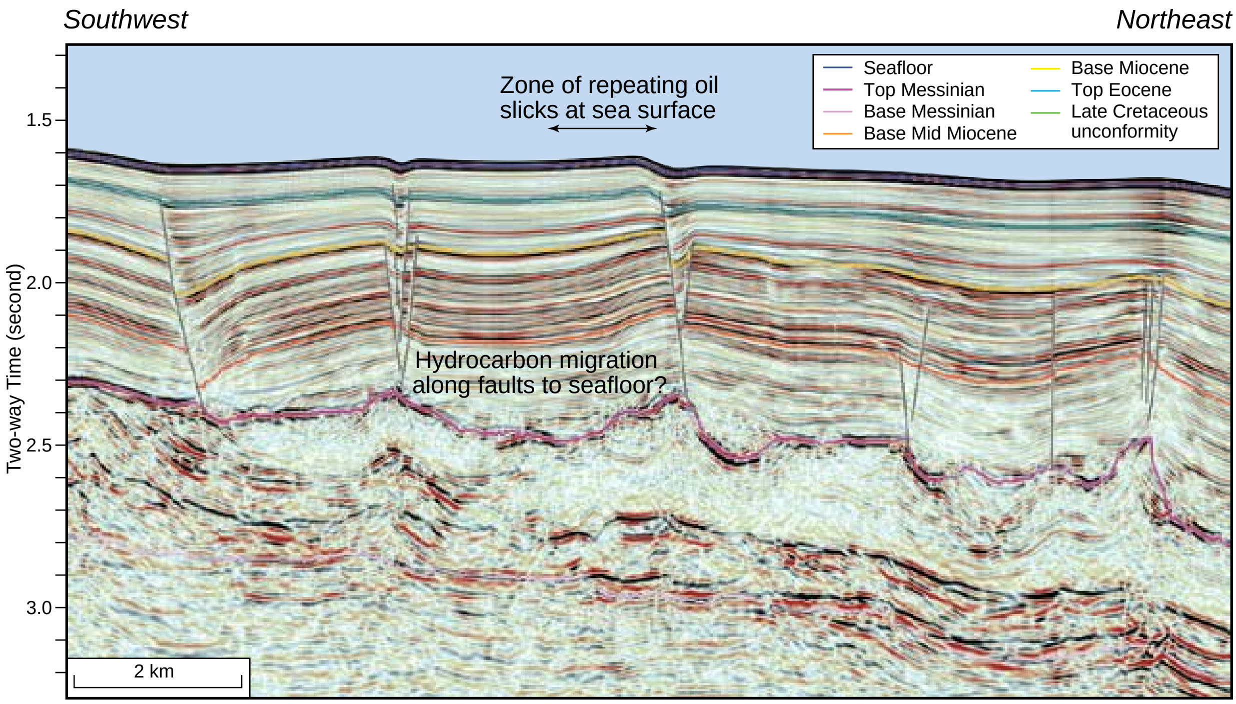

Figure 20: Oil slicks are observed above zones of fluid escape and faulting to the seafloor within the Latakia Basin.

The reservoir targets within the Cyprus Basin will be similar to those in the Levantine Basin with the main exploration focus once again on the Lower Miocene deep-water turbidite sands. Due to the younger age of the basin additional reservoir targets will be limited to Pliocene – Quaternary, Middle and Upper Miocene, and Oligocene deep-water turbidites and possibly contemporaneous carbonate build-ups above folded and thrusted highs.

The lateral equivalents of the Lower Miocene deep-water turbidite sands present within the Levantine and Cyprus basins are unlikely to be present within the Latakia Basin, which is interpreted to have initiated during the Early to Middle Miocene with the earliest deposits represented by basal sands and conglomerates overlain by carbonates. Prospective reservoirs are anticipated to be present within Early to Middle Miocene carbonates and Middle to Late Miocene and Pliocene – Quaternary deep-water turbidites. The Early to Middle Miocene carbonates are thought to be equivalent to the Horu Formation of the Iskenderun Basin to the north where it is a proven reservoir in the Gulcihan-1 discovery for example. The Middle to Upper Miocene and Pliocene – Quaternary intervals reach a significant thickness within the Latakia Basin with maximum thicknesses of ca. 1,800 m and 2,450 m, respectively. It is difficult to image the Middle to Upper Miocene section in detail due to the overlying, relatively thick, diapiric Messinian salt, but there are clear examples of erosive channels, channel-levee systems, and slumped deposits within the Pliocene – Quaternary section indicating that it is sand-rich (Figure 11).

Trapping

There is no shortage of potential trapping mechanisms offshore Syria with a multitude of structural and stratigraphic traps recognised. Within the Levantine Basin structural trapping mechanisms include thrust fault anticlines ahead of the Latakia Ridge System, basin inversions, and tilted fault blocks. As a consequence of almost continuous uplift and compression, which has been especially intense since the Early Pliocene, several of the thrust fault anticlines and basin inversions are prevalent all the way to either the Base Messinian or the seafloor and as such offer the potential for multiple, stacked reservoirs. There are several large tilted fault blocks stepping down into the Levantine Basin, which likely formed during the formation of the foreland basin ahead of the Latakia Ridge System during the Late Cretaceous. As noted earlier, potential flat-spots have been identified within both thrust fault anticlines and tilted fault blocks (Figures 14 and 15) and highlight the potential for billion-barrel/multi-TCF drilling targets.

Stratigraphic trapping mechanisms within the Levantine Basin may include basin-margin onlaps/pinchouts, inter-bedded deep-water turbidites, and carbonate reefs. The Late Cretaceous unconformity displays significant topographic relief and as such there are numerous possibilities for onlap/pinchout plays ranging in age from latest Cretaceous to Miocene (Figure 14). Due to their environment of deposition deep-water turbidite sands are a possible stratigraphic play should they be encased within hemipelagic and pelagic marls and shales. Carbonate reefs are expected to be present along the entire Levant Margin and may also fringe large tilted fault blocks within the basin.

Within the Cyprus Basin structural trapping mechanisms will include thrust fault anticlines, flower structures, and pop-up structures (Figure 12). Once again there is the potential for multiple, stacked reservoirs with the majority of the structural features observable on the seafloor. The flower and pop-up structures are relatively young features, which have developed since the Early Pliocene as a result of sinistral strike-slip movement, which resulted in uplift and the initiation of back-thrusting. Stratigraphic trapping mechanisms are likely to be similar to those within the Levantine Basin, with the potential for carbonate reefs fringing palaeo-highs above thrust fault anticlines.

The Latakia Basin is less influenced by folding and thrusting as it is situated on the back-limbs of the obducted external ophiolites. The main structural trapping mechanisms will be basin inversions, roll-over anticlines, and salt-influenced traps. The basin has been subjected to significant uplift towards the south since the Early Pliocene due to movement along the Larnaca Ridge, which has led to the development of both regional and localised basin inversions. Roll-over anticlines can be observed within the Pliocene – Quaternary section within two small, deep pull-apart basins along the northwestern margin of the Tartus Ridge (Figure 11). The northwestern part of the Latakia Basin is characterised by extensive diapirism within the Messinian salt, which has produced a multitude of anticlinal and salt diapir-flank plays often associated with prominent DHIs (Figure 19).

Stratigraphic trapping mechanisms within the Latakia Basin will likely include onlaps/pinchouts onto the obducted ophiolitic basement, inter-bedded deep-water turbidites, and carbonate reefs. Sediments can be observed onlapping and pinching out towards the obducted ophiolitic basement on the back of the uplifted Latakia Ridge System throughout the whole sedimentary sequence providing an array of potential traps (Figure 16). Similarly to the Levantine and Cyprus basins, Middle to Late Miocene and Pliocene – Quaternary deep-water turbidites may be encased within hemipelagic and pelagic marls and shales. In the northeastern part of the Latakia Basin a significant palaeo-high, developed following the emplacement of the external ophiolites, can be observed upon which there is clear evidence of carbonate deposition with the seismic reflectors displaying a chaotic, variable amplitude, and often mounded character.

CONCLUSIONS

Following the acquisition, processing, and interpretation of 5,000 km long-offset 2-D seismic data in offshore Syria three sedimentary basins, Levantine, Cyprus, and Latakia, have been identified each with a unique structural and stratigraphic history. The basins are defined by large structural lineaments, Latakia, Larnaca and Tartus ridges, that define the Latakia Ridge System. They developed as compressional fold-thrust belts during the middle to Late Cretaceous contemporaneous with plate-tectonic convergence between the African and Eurasian plates. Compression continued through to the Late Miocene when a re-organisation of the plate-tectonic stress regime caused the ridges to be re-activated under a sinistral strike-slip regime that has created significant uplift and deformation.

The Levantine Basin is interpreted to have developed in the Middle Jurassic although offshore Syria the main phase of sedimentation occurred from the Late Cretaceous onwards within a foreland basin setting that developed ahead of the Latakia Ridge System due to lithospheric loading. This is a relatively new interpretation of the data based on the results of the first-ever deep-water wells to be drilled within the Eastern Mediterranean in the offshore southern Levantine Basin. The Cenozoic section is now believed to be much thicker offshore Syria than previously thought with what was initially recognised as a Late Jurassic unconformity now assigned a Late Cretaceous age.

The Cyprus Basin developed during the latest Cretaceous above the Latakia Ridge System following the emplacement of the external ophiolites during the late Maastrichtian. It is characterised as a broad zone of deformation defined by thrusting and folding which was subsequently re-activated under sinistral strike-slip compression during the Early Pliocene leading to the initiation of back-thrusting that formed large positive flower and pop-up structures. The basin can be sub-divided to the northwest and southeast by the Margat Ridge with the southeastern part of the basin more highly deformed and subjected to greater sinistral strike-slip re-activation. The youngest of the three basins is the Latakia Basin where sedimentation is interpreted to have initiated during the Early to Middle Miocene analogous to the Iskenderun Basin further to the north. The northwestern part of the basin is characterised by thick, diapiric Messinian salt that produces an array of potential hydrocarbon traps.

There has been a renewed focus on exploration in the Eastern Mediterranean since the Tamar gas discovery in 2009, which has subsequently been followed up by the Dalit and Leviathan discoveries. There is significant evidence for a working petroleum system, both thermogenic and biogenic, in offshore Syria within each of the three sedimentary basins. Numerous oil and gas shows have been observed in wells along the Levant Margin, which are likely to have migrated from the deeper basin centre offshore. Seismic observations reveal the presence of multiple DHIs in the form of gas chimneys, flat-spots, and bright-spots. Offshore Basin Screening (OBS) using satellite imagery reveals the presence of several good, repeating oil slicks interpreted as naturally occurring oil seeps that correspond to geological features observed on seismic including steep ridges, faulting to surface, absence of Messinian salt, and zones of fluid escape.

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