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The Seismic Image of The Direct Hydrocarbon Indicators in Offshore Syria

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Abstract

The easternmost Mediterranean Basin is a candidate to be one of the most important hydrocarbon regions in the world, especially after significant gas discoveries in Levantine Basin in 2009. Offshore Syria is one of the easternmost Mediterranean areas which is still an unexplored virgin area. The seismic interpretation results of the study area showed encouraging evidences of considerable hydrocarbon accumulations within different sedimentary successions, which are Direct Hydrocarbon Indicators (DHIs). Indicators such as reflectivity anomalies (flat spots and dim spots) and polarity reversal were found within significant structural highs of Tertiary or/Late Cretaceous and Early Jurassic successions. Also, gas chimney and a lot of bright spots were observed within a Plio-Pleistocene succession above tops and flanks of Messinian Salt diapirs and pinch-outs.

The seismic attributes such as instantaneous frequency and phase and reflection strengths were used in this study to improve the seismic interpretation image in the gas-affected area, with the purpose of exhibiting strong amplitude abnormalities and confirming the occurrence of a polarity reversal and the low frequencies within and below some of the structural anticlines. These attributes suggest that there are potential hydrocarbon reservoirs.

Keywords: *Offshore Syria, seismic attribute, hydrocarbon indicators (DHIs).*

الصورة الزلزاليه (السيزمية) للمؤشرات المباشرة للهيدروكربون في المياه الاقليميه السورية

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الخلاصة

تتوضع المياه الاقليميه السورية في اقصى شرق حوض البحر المتوسط, المرشح لأن يصبح أحد أهم المناطق النفطية في العالم خصوصاً بعد الاكتشافات الغازية المهمة الاخيرة (في حوض اللفنتاين) عام 1999. تعد منطقة المياه الاقليمية السورية احدى المناطق المتوسطية البكر التي لم تستكشف حتى الان.

أشارت النتائج الاولية للتفسير الزلزالي لخطوط المسح الثنائي الابعاد المنفذة في منطقة الدراسة الى وجود أدلة زلزالية مهمة و مشجعة على تواجد الهيدروكربون مصائد تركيبية و ستراتيغرافية في التكوينات الرسوبية المختلفة و التي تدعى بالمؤشرات الزلزاليه المباشرة للهيدروكربون. لقد رصدت هذه المؤشرات مثل شواذات الانعكاس (البقع المسطحة و الخافتة) وانقلاب قطبية الاشارة في قمم التراكيب الكبيرة ضمن التكوينات الرسوبية

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العائدة لفترة الجوراسي و الكريتاسي. كما شوهدت مؤشرات أخرى مثل المداخن الغازية و البقع المضيئة ضمن مصائد ستراتيغرافية فوق قمم وعلى اجنحة القباب الملحية في التكوينات الرسوبية الحديثة العائدة لفترة البليو- بليستوسين.

استخدمت الخصائص الزلزاليه مثل التردد و الطور اللحظي و قوة الانعكاس على نطاق كبير في هذه الدراسة بهدف تحسين التفسير الزلزالي خاصة في النطاقات المتأثرة بالغاز ومن أجل ابراز شواذات الانعكاسات القوية و تأكيد حدوث الانقلابات القطبية و تحديد نطاقات الترددات المنخفضة ضمن و تحت بعض المصائد التركيبية. فقد أشارت هذه الخصائص الى وجود مكامن نفطية معتبرة في المنطقة.

Introduction

A conventional seismic interpretation is generally made to characterize structural oil traps where oil and gas may be gathered. More recently, bright spots technique was utilized to distinguish reflectivity anomalies on seismic stack profiles that would denote the accumulation of hydrocarbons. These anomalies are called direct indicators of hydrocarbons (DHIs), which can be defined as a seismic expression of particular events distinguishable on seismic data. These indicators were originally utilized by Sheriff [1] and Millahn *et al*. [2] to announce the existence of hydrocarbons in a reservoir. Other features concerning gas accumulation such as gas chimney, dim spots, and flat spots, along with related events, such as depression of the velocity (time sag), push down, reduction of frequencies, and polarity reversal apparent in seismic profiles, can also serve as indicators. They are generated as a result of the acoustic impedance difference between the hydrocarbon-filled reservoir and the overlying seal strata.

Interpreted seismic data of the Offshore Syria display a portrait of the subsurface geological features. Besides, they also stand out some other characteristics that are not geologically-related concerning information, such as constantly uncommon reflections which are the most important events that capture the attentiveness during the seismic analysis as clear evidences of gas.

The aim of this paper is to explain the essential features and characteristics of the direct indicators of hydrocarbons through analysis of the seismic reflectivity anomalies and using seismic attributes over the study area.

Study Area and Database

The Offshore Syria lies to the west of Syria, between N 34^{o} 42'– N 35^{o} 55' and E 35^{o} 06' - E 35^{o} 48', and is located in the easternmost Mediterranean Basin (Figure-1) that is one of the potential hydrocarbon areas in the world due to considerable gas discoveries that have occurred over the past two decades in this region.

The 2D-seismic survey was carried out in the Syrian Offshore by CGG Veritas in 2005. They comprised 72 2D-multi-channel seismic profiles were performed in NW-SE and NE-SW trends on a regular grid of 4 x 4 km and on a denser grid 2 x 4 km in two certain areas, in the north and middle of the study area. This survey involved an overall area of nearly 9500 km^{2} (Figure-2) [3].

The quality and resolution of 2D seismic profiles of the study area differs noticeably across the area. In general, the quality of these data in the northern parts of the study area are low and poor compared with those in the central and southern parts, because of the dense Messinian Salt beneath Plio-Pleistocene successions. In addition, some seismic profiles located in the northeastern parts of the study area near coastline are of poor quality due to the presence of an ophiolite emplacement beneath the sea bed.

Tectono-stratigraphic setting

Offshore Syria is structurally located in a very complex region because of its existence close to boundaries of three large tectonic plates which are the African, Eurasian and Arabian plates (Figure-1) [4,5]. Continental collision of these plates is thought to be initiated during the Cenomanian age [6] and persisted into the Pliocene and Quaternary age.

The study area is delineated to east by Dead Sea fault zone that separates the African (Levantine Basin) and Eurasian plates from the Arabian Plate with a triple junction located along Nahir El keber Fault in the northwestern part of Syria [7, 8] (Figure-1).

In Late Triassic age, the continental rifting caused the creation of the Mesozoic Tethys Ocean in the region. This ocean comprised a number of small ocean basins and continental blocks [9]. The rifting came to a climax with the evolution of inactive margins during the Middle Jurassic to Late Cretaceous ages to the south of Cyprus, while simultaneously a sophisticated style of terrain growth and setting up of new continental crust commenced to the north. Shallow to deep marine carbonate sediments with clastics prevailed on the region as result of a transgression that took place in the Late Triassic age and persisted to the Jurassic [10]. The Onshore wells situated close to Latakia region point out that thickness of the Triassic reach to more than 450 m, and this thickness increases towards the Levantine Basin, where it may reach to 1600 m as indicated in seismic data (profiles 106 and 206) [3].

The continental convergence of the African and Eurasian plates has prevailed the easternmost Mediterranean since Early Tertiary age. This caused to creation of the closure of ocean basins as well as incorporation of small continental blocks, occurrence of subduction, and formation of ophiolites emplacement (Figure-1). Moreover, it led to generating the current crust exposed in Onshore Syria (North of the Latakia region).

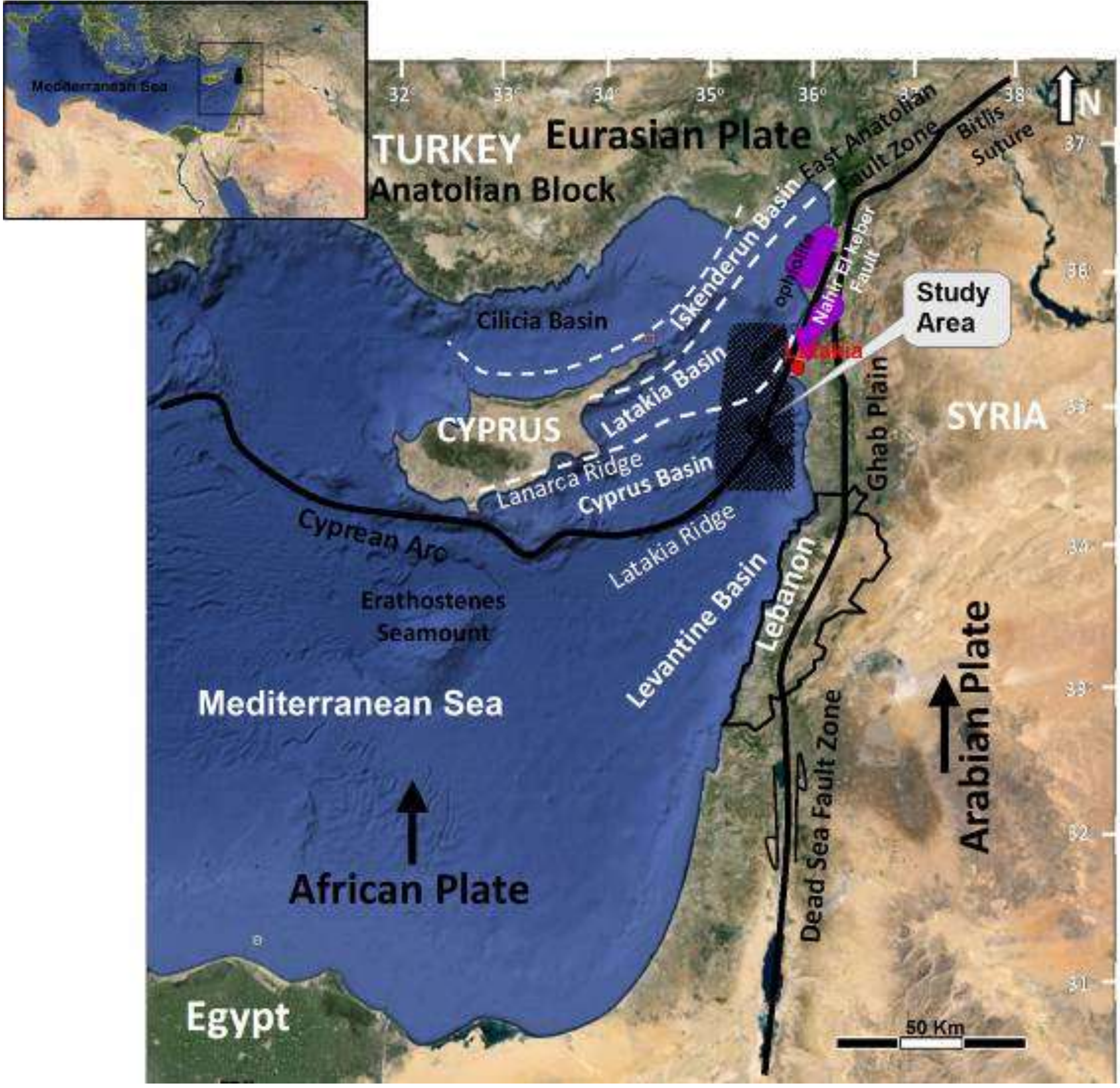

Figure1- The tectonic map of the easternmost Mediterranean area displaying the structural elements and plate movement directions, ophiolite emplacement and location of the Syrian Offshore (modified after [11, 12]).

In the Late Miocene (Messinian) age, the easternmost Mediterranean Basin was affected by an essential fall in sea level [13] due to its separation from the Atlantic Ocean, which caused sedimentation of large thicknesses of the evaporites in the Levantine and Latakia Basins [12]. Then these evaporites were followed by a transgression phase of the basin and deposition of Plio-Pleistocene successions.

The Miocene age was considered as the ultimate transformation to continental event in Offshore

Syria. Indeed, two salt basins in Syrian Offshore were observed on the seismic profiles, indicating that there were various smaller basins which became separated. Many of the salt basins contain reefs at different stratigraphic intervals throughout the Messinian time.

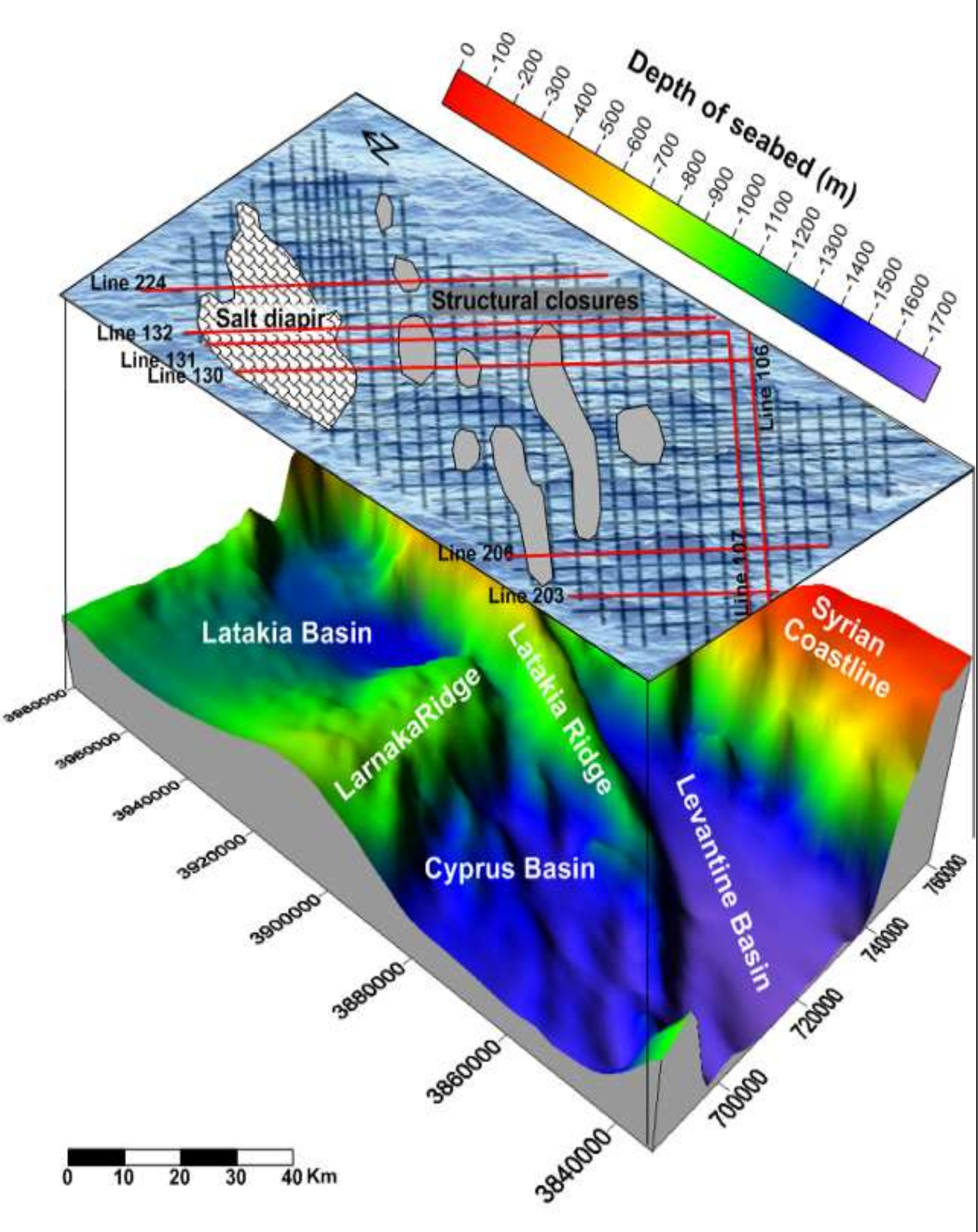

Figure 2- 3D-view of the seabed in the study area showing the local sedimentary Basins and its depths and also showing the 2D seismic lines over the Syrian Offshore, locations of the structural closures and Messinian Salt diapirs.

The Plio-Pleistocene deposits in the study area, especially the Latakia Basin, indicate that the region is still active so far, because some diapirs almost reach to the sea bed in Iskenderun Basin located north Latakia Basin[3].

The seismic interpretation and the local sedimentary basins

The different sedimentary formations were defined on the seismic data of the study area using the geological and seismic information available in the Levantine Basin. This basin was used as a reference or a starting point in the interpretation of the study area covered by the 2D- seismic profiles. The seismic profiles 106 and 206 were utilized to the different packages at the intersection in the center of the basin Figures-(2, 3) [3]. The interval velocities derived from the seismic stacking velocities were applied for the depth calculation of mapped horizons in the study area.

Several seismic reflectors or horizons were interpreted to evaluate the sub-seabed geological structures of the area. But only three horizons were mapped across the whole study area, which are the Seabed, Base Pliocene, and Base Messinian Salt (Figure-3).

The sea bed map delineated by seismic data reveals the structural elements of the Offshore Syria (Figure-2) and matches largely to the characterization presented based on former regional seismic data [14]. However, the interpretation results indicate that there are three local basins, namely Levantine, Cyprean, and Latakia which are isolated by ridges (Latakia Ridge, Larnarka Ridge) in Offshore Syria. These results also denote that the water depth varies between 100 and 1700 m within the study area (Figure-2).

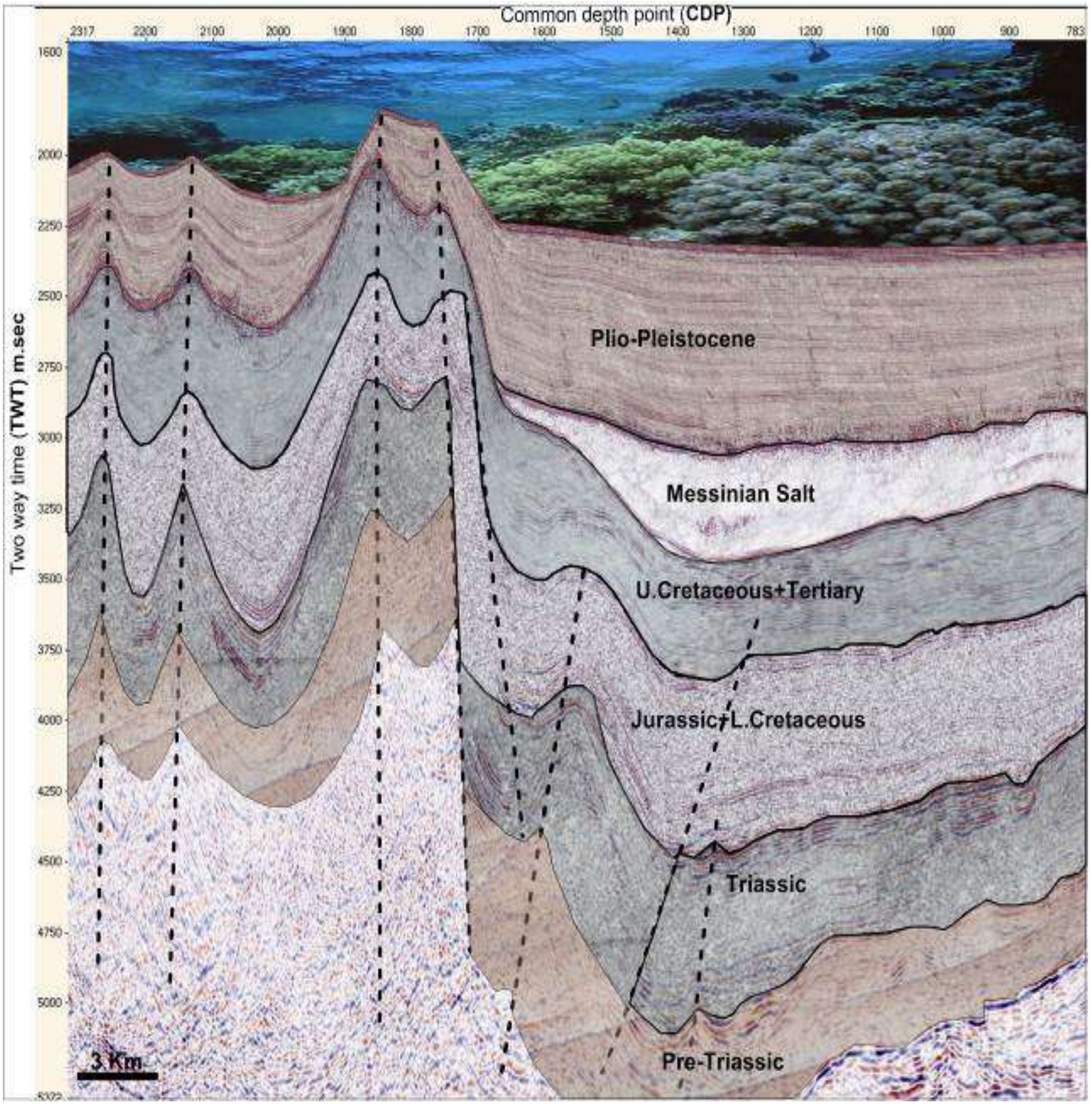

Figure 3- The interpreted seismic image displaying different sedimentary successions obtained from the intersection of two seismic profiles (106 and 206) in the Levantine Basin in the Syrian Offshore.

The Levantine Basin

The Levantine Basin which lies in the southeastern of the Syrian Offshore is a triangularly shaped basin. It is situated over the African Plate and delineated to the west by a major suture under which the basin is submerged, while to the east it is limited by a series of block faults creating the edge of Onshore Syria. The depth of water increases along the southwesterly directed axis. The Levantine Basin continues onshore into the Nahir El Keber depression. This Basin constitutes the connection between the Syrian Offshore and the onshore areas.

The Cyprus Basin

The basin is located north of the Levantine Basin within the Eurasian Plate at water depths that reach to 1400 m (Figures-1, 2). It is delineated by the Latakia Ridge in the east and the Larnaca Ridge to the west. The Latakia Basin was well developed during the deposition of the Messinian salt.

The Latakia Basin

The Latakia Basin (Figures-1, 2) is a northeast-southwest trending basin in the northern portion of Offshore Syria. The basin is limited to the north by Iskenderun Basin and to the south by the Lanarca Ridge. The thickness of sediments is about two-way travel time (TWT) of 1.1 sec in the southwest and to more than 2.5 sec (TWT) in the northeast. The seismic data show thickening of Plio-Pleistocene sediments in Latakia Basin towards the north. This indicates that there is still an active tectonic movement in the region.

In general, the reflections of Plio-Pleistocene successions over the Offshore Syria area has a very characteristic seismic pattern which includes a complex series of stratigraphic features, in particular in zones such as channels, anticlines, slumps, levee deposition, and complex onlap and offlap features. The base of the Plio-Pleistocene strata was included in the whole study area. These characteristics indicate that the tectonic events were active during deposition of these successions. Besides, they contain a numerous bright spots, in particular above tops and sides of Messinian Salt diapirs and pinch outs. Subsequently, this area has a lot of structural and stratigrapic traps, because most seismic bright spots lie on tops of the structural anticlines which are likely related with gas pools [15, 16]. Seismic interpretation mapped several significant structural closures and stratigraphic traps, most of which are located in Lattakia and Larnaca Ridges. Axis of these structures has a trend of NE-SW perpendicular to African Plate movement direction (Figures-1, 2). The largest structure located on the Latakia Ridge shows a complex structural evolution that is attributed to the region's exposure through geological history to two different phases of tectonic forces. Initially, the region was exposed to the extensional tectonic events in the Triassic age that led to creation of normal faults. At end of the Cretaceous age, the region became subjected to compressional tectonic events and the formation of ophiolites emplacement.

Direct Hydrocarbon Indicators (DHIs)

The seismic interpretation and analysis of the study area indicated the existence of direct hydrocarbon indicators by which the presence of a hydrocarbon accumulation can be prognosticated in the region. They were first identified in the exploration of clastic deposits for more than three decades and then became an effective tool that could be used extensively in all other sedimentary rocks.

Direct indicators of hydrocarbon were seen at different levels of depth within the sedimentary successions from Plio-Pleistocene until Late Triassic age. These indicators comprise gas chimneys, bright spots, flat spots and dim spots. Moreover, local depressions (push down), phase change, and low-frequency areas were observed.

The flat, dim and gas chimney events were detected within the structural highs (Figure-2), whereas most bright spots were found within the sedimentary successions of the Plio-Pleistocene age.

The seismic attribute analysis was used in this study for two main goals; the first is to mark the strong amplitudes (bright spots) and their extent, while the second is to reveal invisible features in the seismic data within certain intervals or zones. The seismic attribute is an effective tool in standing out strong reflectivity anomalies because it fundamentally represents the acoustic impedance contrast of a reflector [15, 16]. Every attribute was applied differently to be of service to various clarification goals. These attributes are also able to manifest the phase changes and low frequencies that are evidences of the hydrocarbon presence within a structural or stratigraphic trap.

Characterizing gas chimney in seismic profile

Gas chimney (cloud) is one of the direct hydrocarbon indicators which denotes the existence of a significant gas reservoir in a region of interest [17]. The gas chimney forms as a result of upward leakage of gas from the deeper reservoir. It appears as a smoggy style like a cigar smoke [18].

Gas leakage on seismic profiles is considered as a seismic exception, which implies that it causes deformation to the reflections, as indicated in Figure-4. Low quality of seismic reflections within gas leakage area is attributed to dispersion, absorption of seismic energy, and lowering velocity of seismic waves coming through the gas-saturated area [18]. Figure 4 indicates that the gas chimney area is situated above a potential reservoir (possibly indicating carbonate rocks) of the Tertiary age at the time 2.75 sec (TWT). This area extends along Plio-Pleistocene successions until sea bed. The seismic anomalies in the gas chimney area (the closed polygon) appear as low quality seismic reflections (dimmed area), with low continuity and vertical shapes of changing magnitude, being entirely different from the adjacent reflections.

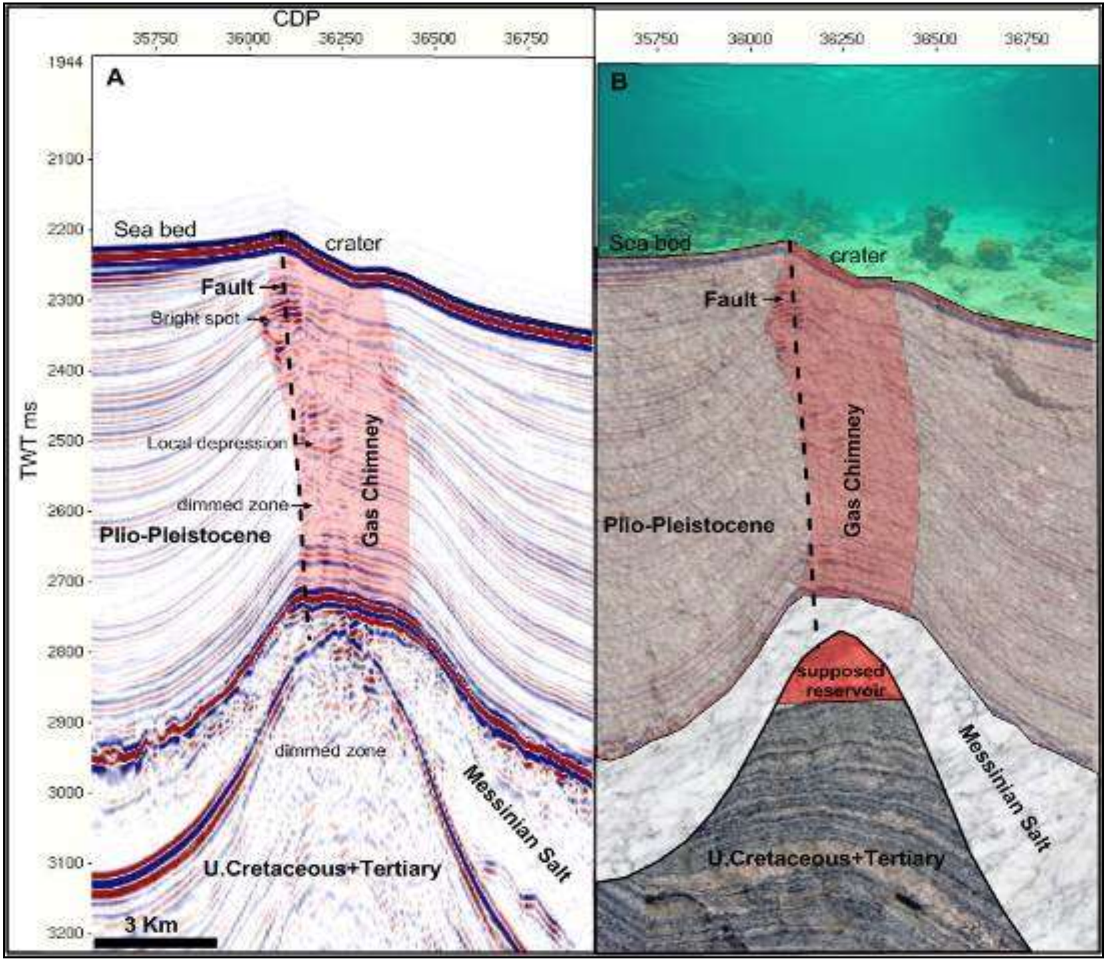

Figure 4- Seismic profile (203) showing the existence of gas chimney within the closed polygon above a structural high or closure, (A) Seismic profile displaying the gas cloud located above an anticline structure. It consists of amplitude anomalies along the left side of the gas chimney, bright spot, dim spot, local depressions, and a crater on the sea bed. In addition, the main fault is considered a conduit for the leakage of the gas from deeper the supposed reservoir based on the prominent faulting of the horizons. (B) Geological model interpreted based on the seismic profile (A) showing the candidate reservoir.

Other seismic features such as high amplitude (bright spots) and time local depressions (push down) at the upper parts of the gas chimney area can also be seen. These aforementioned observations are a clear evidence of gas. We believe that there are gas assemblages at the crest of the gas chimney area at the time 2.25-2.40 sec (TWT) on the side of the fault. They appear in the form of repeatedly bright spots (high amplitude abnormality) which can be probably attributed to continuous gas supply by the aforementioned fault under good conditions for interconnected fractures network in host sedimentary strata [18, 19]. A large fault is clearly shown in Figure-4 (dashed line) that probably had a major role in the upward movement of the gas. Thus, a leakage of the gas probably migrated from the supposed reservoir because of structural deformation in the overlying and host sedimentary strata as a result of the continuous compressional tectonic activity caused by the continental collision of Eurasia, Africa, and Arabian plates in the easternmost Mediterranean basin, which generated good pathways or conduits for the gas to move through the faulted zones.

Local depressions (push down phenomena) within the reflections in the gas chimney area are clearly seen (as indicated with the arrow in Figure-4). They might arose as a result of attenuation of seismic wave velocity over gas assemblage and influenced the seismic reflections by delay of the travel time (TWT). This is surely due to a decrease of gas velocity [20].

In addition, a crater or pock mark can also be seen above the gas cloud at the sea bed that was probably created as result of gas leakage through sedimentary strata upwards to the seabed [21]. Figure 4 shows that the chimney concludes close to the seabed at the time 2.25 sec (TWT).

All the aforementioned characteristics are almost identical with other patterns of seismic chimneys illustrated in the scientific publications and papers [e.g. 18, 22, and 23] and were explicated as a seismic chimney related to upward leakage gas.

Characterizing bright spots in seismic profiles

Remarkably strong amplitude anomalies of the depths (less than 1000 m) close to sea bed, particularly in clastic sediments, are one of the famous direct hydrocarbon indicators (DHIs) [24], in particular if these anomalies are located in positions considered appropriate places for trapping of hydrocarbons, such as tops and flanks of salt diapirs and pinch outs.

The seismic data over the study area were interpreted and analyzed as an endeavor to map these bright events being potential hydrocarbon traps. Within reflections of the Plio-Pleistocene successions over Latakia Basin, there are a lot of bright spots situated adjacent to the faults, above structural highs, and on their flanks. In addition, pinch outs of stratigraphic traps can be observed on the seismic profiles (Figures-5A, 6A and 7A).

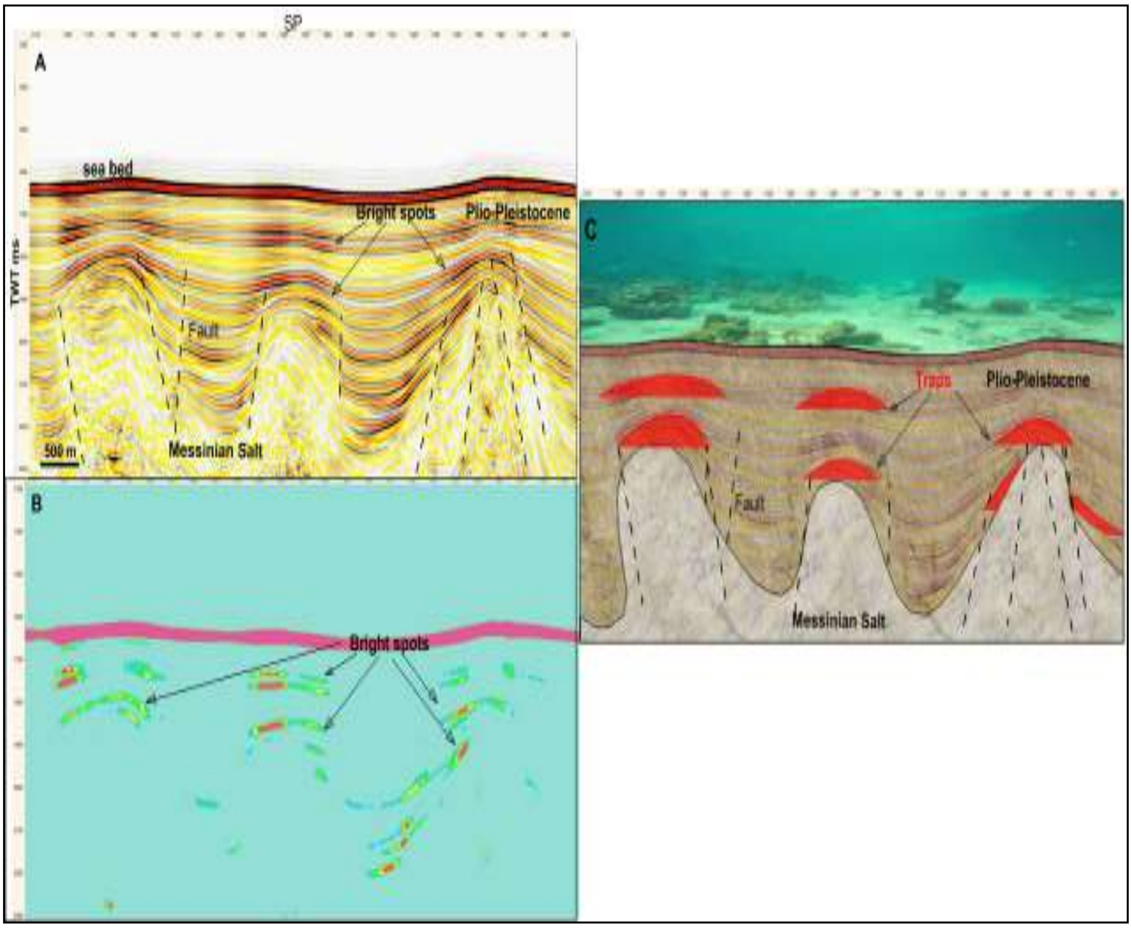

Figure 5- (A) Seismic profile or line (132) showing bright spots within clastic sediments of Plio-Pleistocene age over tops and flanks of salt diapirs. (B) Reflection strength-related attributes applied on seismic profile (132) showing the clearly aforementioned bright spots. (C) Geo-seismic model of the above profile displaying the supposed traps over tops and flanks of salt diapirs.

The Plio-Pleistocene successions contain a considerable amount of apparent evidence such as incised channels, channel-levee systems, and slumped sediments which indicate that these successions are sand-rich. This implies that there are great chances of sandy reservoirs that can trap hydrocarbons and generate high amplitude anomalies (Figures-5, 6 and 7).

We strongly believe that these abnormalities that are present in the Plio-Pleistocene successions are caused by hydrocarbon pools. This is attributed to the fact that the gas-filled reservoir has a seismic velocity which is notably smaller than that of the embracing or covering strata. This can cause a strong reflectivity with negative polarity from the crest of the gas reservoir [20]. However, increasing the seismic signal reflectivity and polarity reversal to a negative reflectivity (a black trough event) can clearly be seen in the seismic profiles (130, 132) in figures 5A and 6A, which surely are direct indicators of hydrocarbons.

To confirm the meaningful high amplitude events observed on these seismic profiles, attribute analysis was applied using the Schlumberger Geoframe software (version 4.4). The reflection strength-related attribute obviously showed the zones with strong reflectivity or bright spots at top and flanks of salt diapirs and pinch outs (Figures 5B, 6B and 7B). It is known that the pinch outs are forms of stratigraphic traps that occur when a permeable layer lies between two layers of impervious seal rock, with the thickness of the permeable layer is gradually decreased to create a wedge which can confine hydrocarbons.

The pinch outs are predominantly formed in sand-clay layers in the sedimentary basins that have large tectonic movement [25] (Figure 7).

Unlike structural traps, pinch out traps cannot be mapped with classical seismic interpretation techniques. Therefore, we need to apply new techniques such as seismic attributes which can detect these traps through marking bright spots.

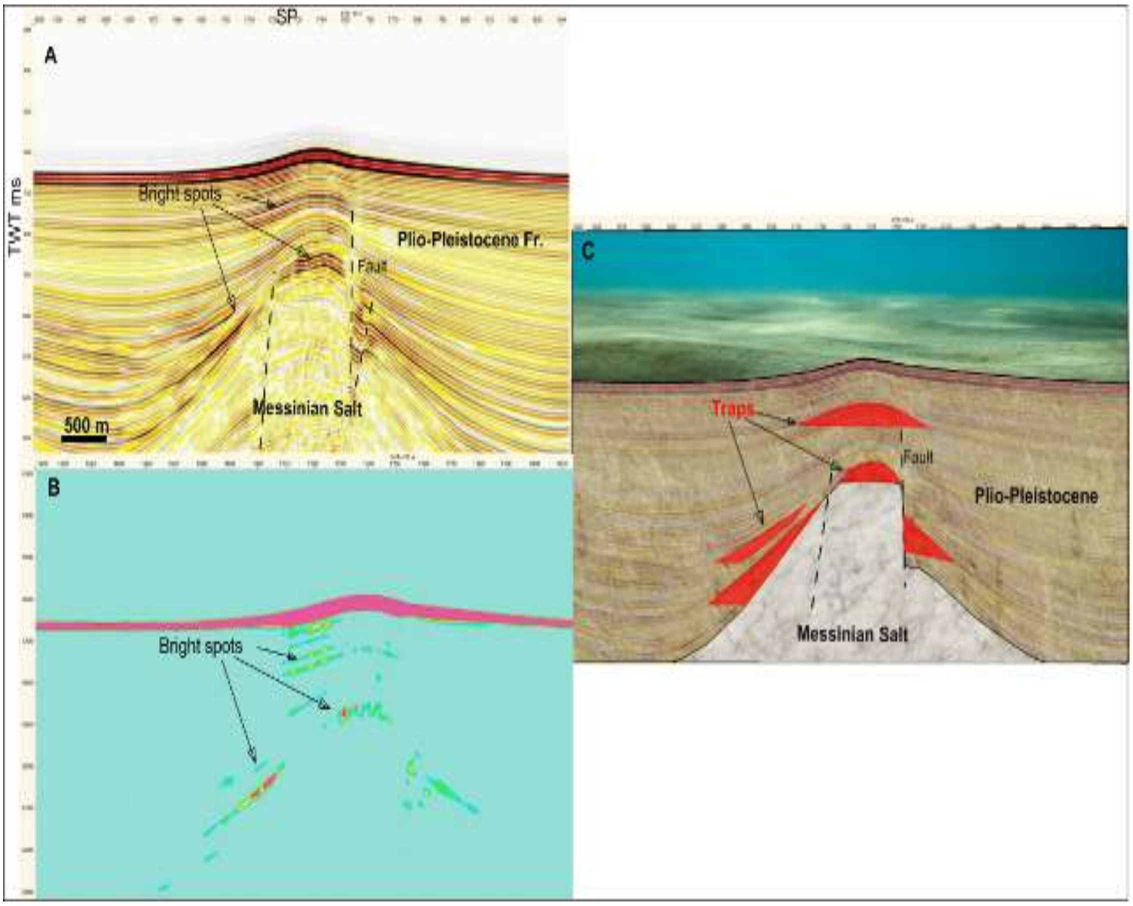

Figure 6- (A) Seismic profile or line (130) showing bright spots within clastic sediments of Plio-Pleistocene age over and flanks of salt diapir. (B) Reflection strength-related attribute applied on seismic profile (130) showing clearly the aforementioned bright spots. (C) Geo-seismic model of the above profile displaying the supposed traps over top and flanks of salt diapir.

The Reflection Strength-related attribute applied on the aforementioned seismic profile (132) Figure-(7A, B) displayed the bright spot anomalies caused by stratigraphic traps.

A careful examination of figure 7A reveals that the bright spots which are obviously sitting down in layers have thicknesses that decrease in the form of a wedge. These spots certainly represent pinch out traps Figure-(7C). In the pinch out area, the black negative reflection (as illustrated by the arrow in Figure-7A of the bright spot is quite observed above the reservoir top.

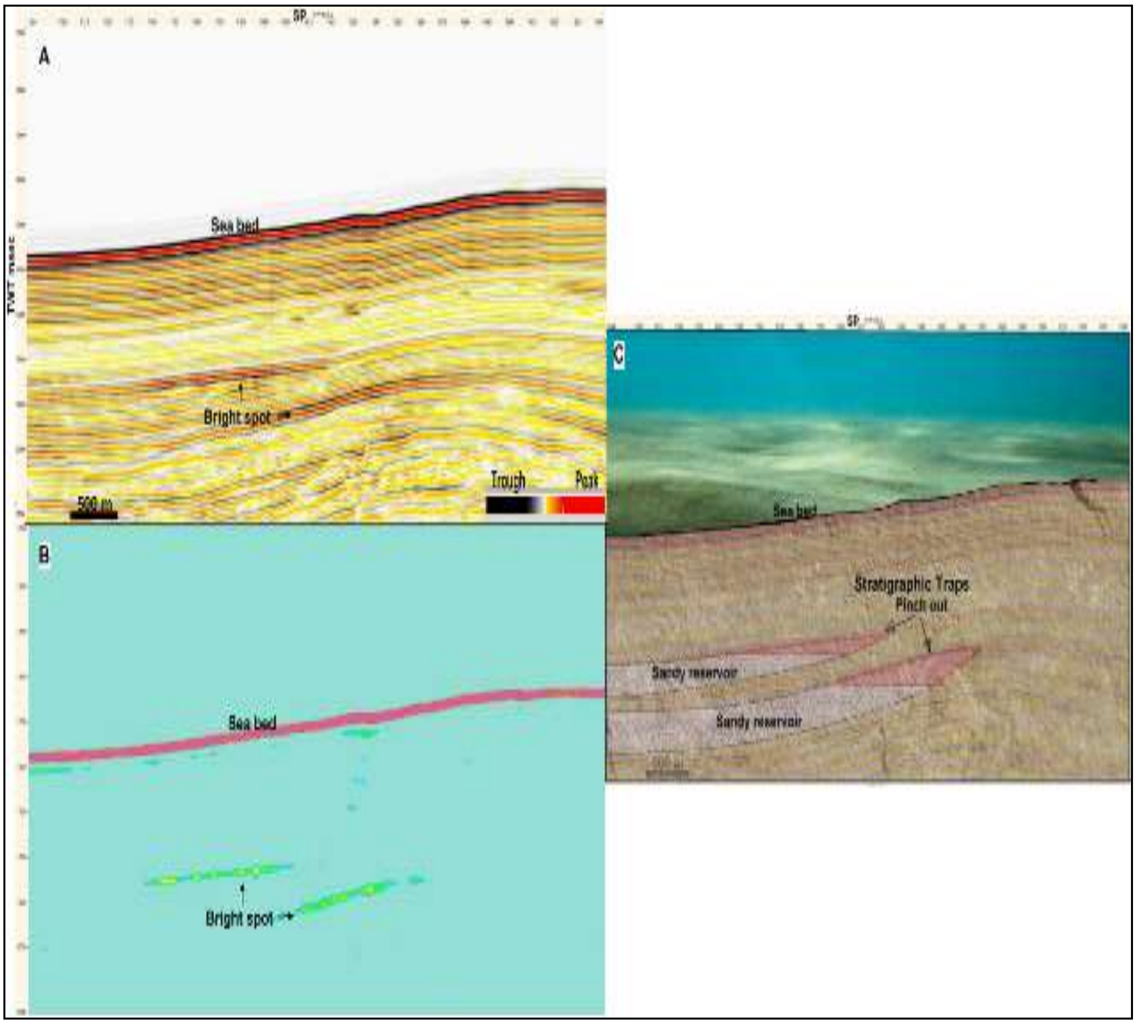

Figure 7- (A) Seismic profile or line (132) showing bright spots caused by stratigraphic traps (pinch outs) within clastic sediments of the Plio-Pleistocene age. (B) Reflection strength-related attribute extracted from seismic profiles (132) showing clearly bright spots. (C) Geo-seismic model of the above profile displaying the supposed pinch out traps.

Characterizing flat spots on the seismic profiles

A flat spot or event is defined as a horizontal seismic reflection and appears on the seismic profile as a limited event. Flat spot is considered a robust proof of the existence of gas sub-surface [15]. It can represent the gas-water contact surface.

Flat events were observed on finite profiles of the study area. They exactly appear in three seismic profiles, 107, 131 and 224, within reflections of the Plio-Pleistocene, Early Tertiary successions and Late Triassic or/ Early Jurassic carbonates over the two Basins of Latakia and Levantine Figures-(8, 9, 10).

On seismic profile 224, a flat event was detected in the Early Tertiary successions within a large anticline structure over Latakia Basin, with this flat spot being observed at the time 2.22 sec (TWT). The enlarged image of the seismic profile 224 shows a supposed gas reservoir delineated in figure 8B, where the lower arrow in the left side points to a flat spot that appears as a red positive event at the time 2.22 sec (TWT). Whereas, the upper arrow at the middle on this image at the time 2.12 sec

(TWT) indicates a yellow negative event interpreted as a reflection from the cap rock /gas reservoir boundary (the reservoir top) that was mapped based on the flat event. There is no bright event at the crest of the reservoir, but there is an obvious dim spot observed on the reservoir, as indicated in Ffigure-8. The dim spot seems as a weak seismic reflection due to low gas velocity, which minimizes the difference in acoustic impedance between the gas-filled reservoir and the covered rocks [15].

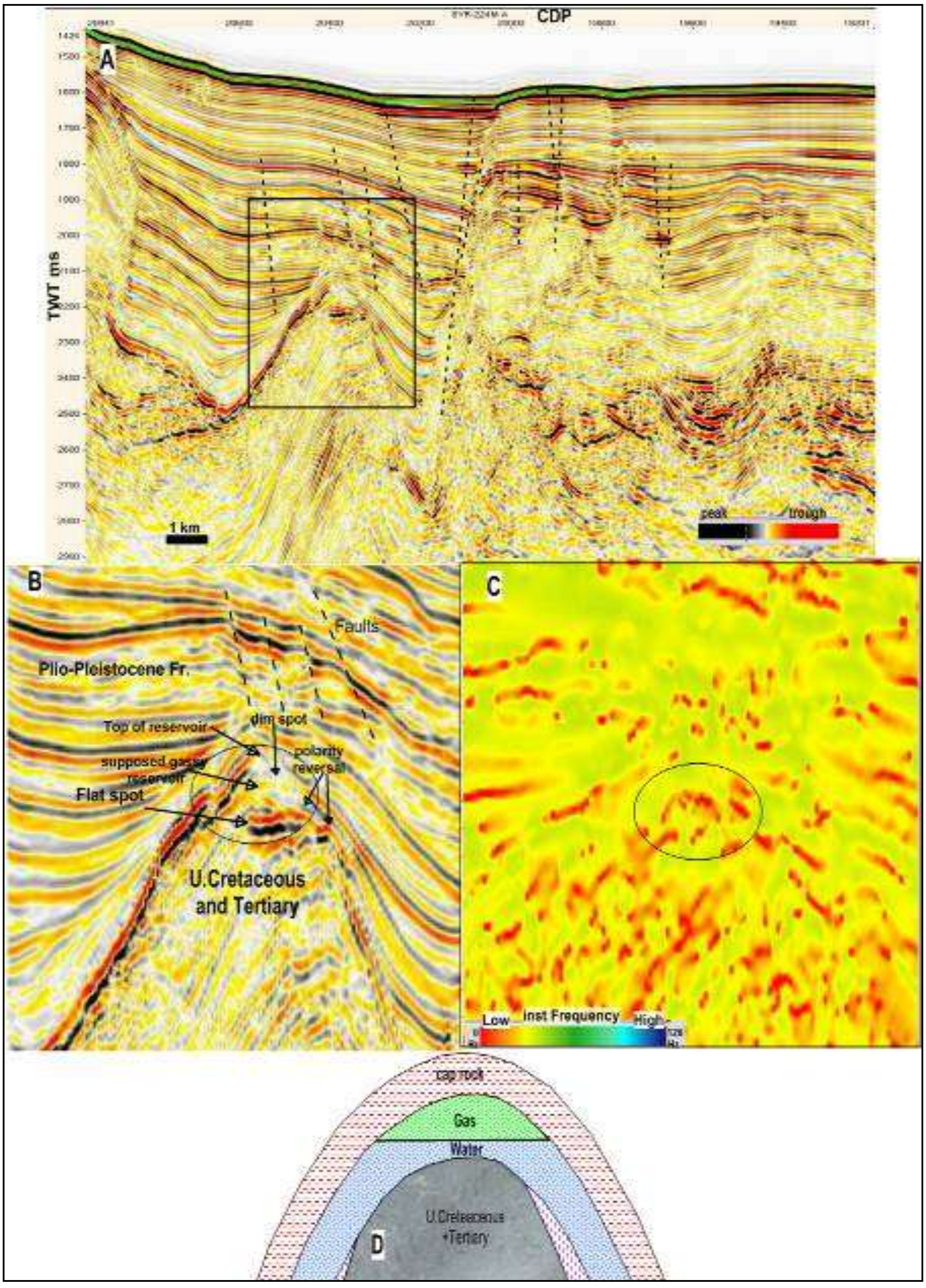

Figure 8- (A) Uninterpreted 2D seismic line or profile (224) showing sedimentary formations of study area and also showing the flat spot in the structural closure. (B) Enlarged image of flat spot (black color) area within sedimentary successions reflections of U. Cretaceous and Tertiary age. (C) The Instantaneous Frequency-related attribute displaying a low frequency zone over and below the flat event denoting the existence of gas. (D) Geo-seismic model of seismic section (B) displaying the supposed gas trap over crest of structural closure.

The instantaneous frequency-related attribute derived from the seismic profile (224) was used to enable finding spectral alterations caused by gas or oil. These alterations are evidently observed in figure 8C, where gas led to a fall off of high frequencies, creating a low frequency area within and beneath the hydrocarbon reservoir. This area continued to a larger depth.

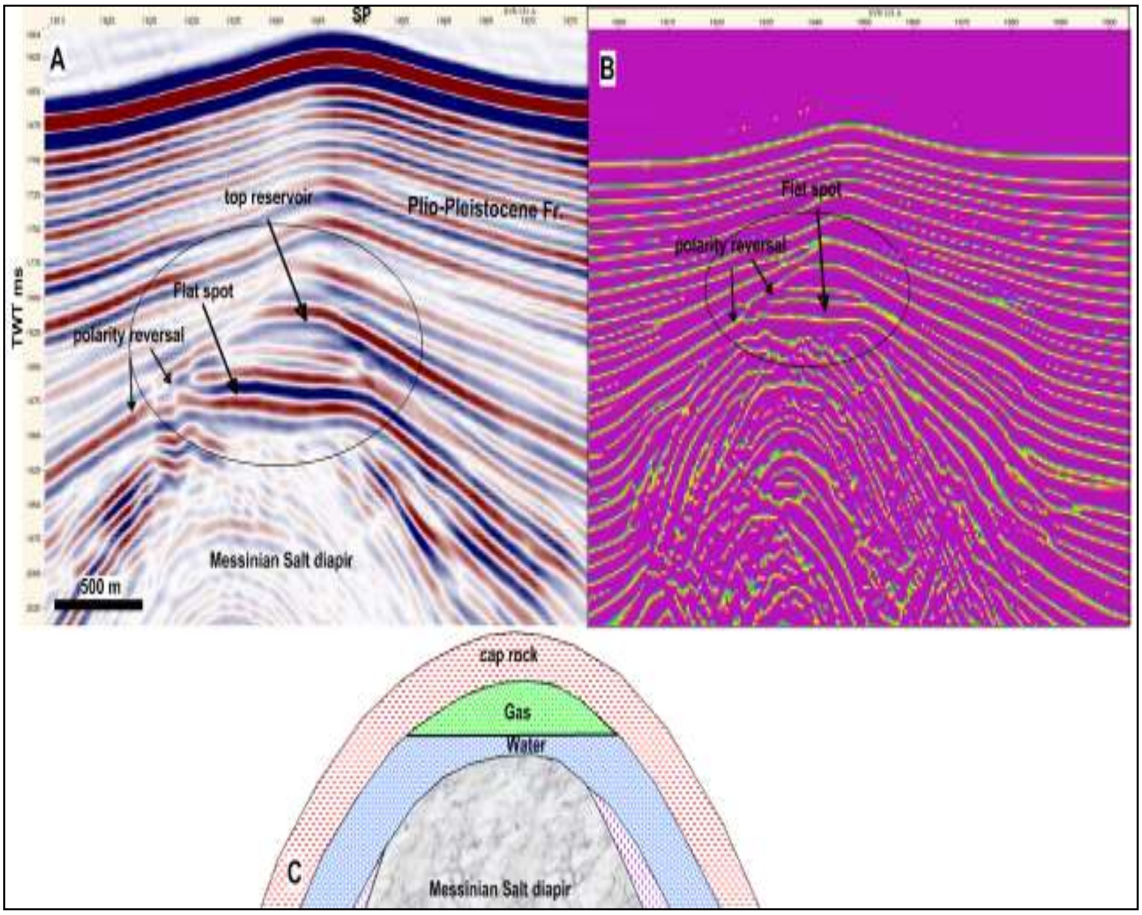

Figure 9- (A) Seismic line or profile (131) showing flat spots (red color) on anticline structure within sedimentary rocks of Plio-Pleistocene age. (B) The instantaneous polarity-related attribute displaying polarity reversal at the left side of supposed reservoir. (C) Geo-seismic model of seismic section (A) displaying shape of the supposed gas reservoir at crest of anticline structure.

Figure-9 displays another seismic profile (line 131) of a flat event located above the Messinian Salt diapir within reflections of the Plio-Pleistocene successions at the time 1.87 sec (TWT), which contains sand and shale strata.

The flat spot is visibly observed as an incompatible or discordant event with neighboring strata reflections and with restricted extent (Figure-9A). Since the neighboring reflections of the flat event comply with the supposed reservoir strata shape, the flat event is often explained as the gas/water contact in a sand reservoir.

By following up the top of the supposed sand reservoir, we notice that it changes to negative reflection with a blue color when it is filled with gas.

Instantaneous phase-related attribute was calculated for seismic profile (line 131) to characterize variations of the phase within the supposed reservoir. The image of this attribute in figure 9C indicates a phase inversion of the seismic signal on the left side of the supposed sand reservoir due to a seismic wave passing from gas to brine sand reservoir. This implies that the seismic signal turned from negative reflectivity to be positive in the water-filled reservoir.

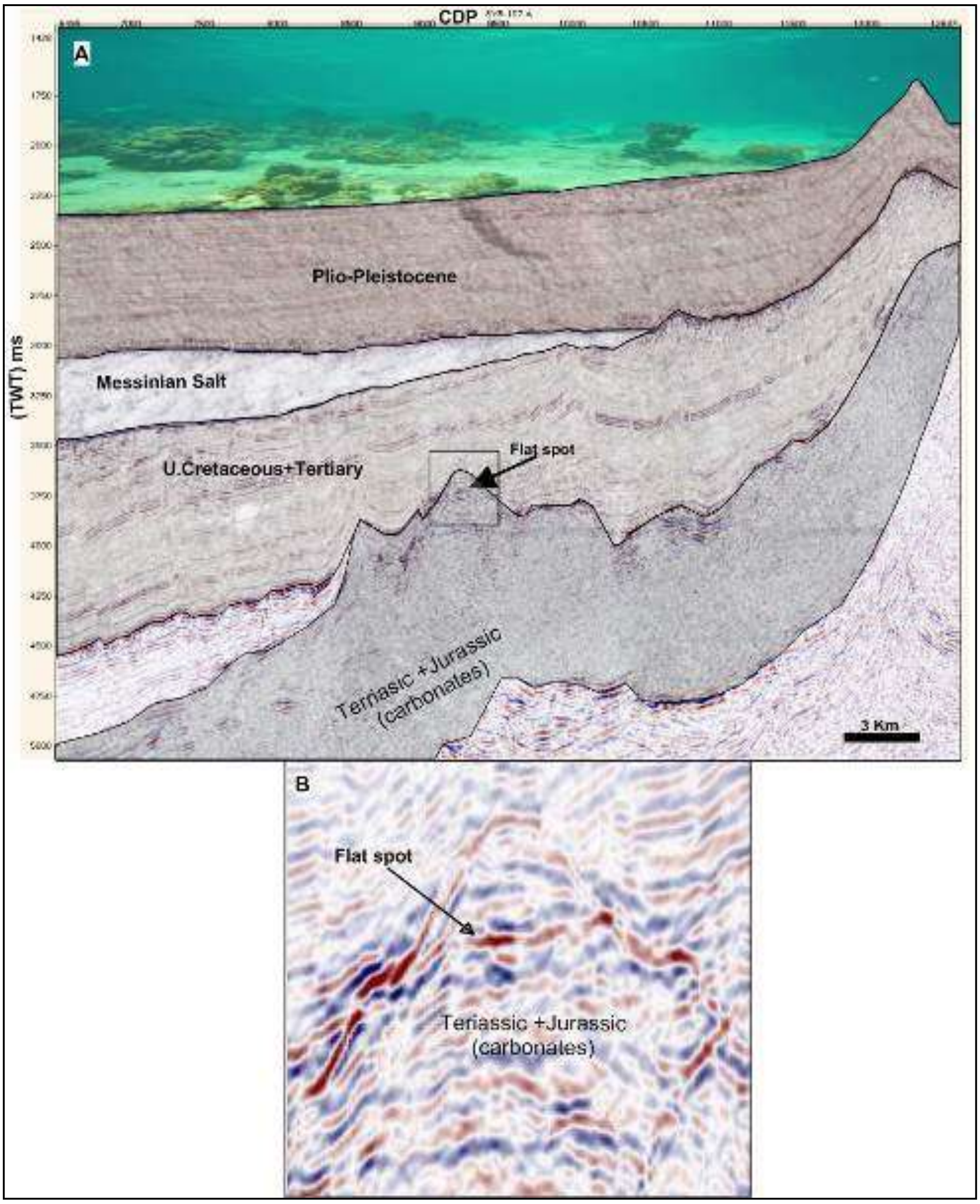

Figure 10- (A) Seismic profile (107) showing sedimentary formations of study area and flat spot area (B) Enlarged image of seismic profile (107) displaying flat spot (red flattened surface) on structural closure within successions of Jurassic and Triassic age (possibly indicating carbonate rocks).

Also, there is another profile (107) that displays a flat spot situated in a significant structural high at the time 3.75 sec (TWT) in the Early Jurassic successions (possibly indicating carbonate rocks) (Figure 10B). The flat spot does not appear to be a full-flatted event, possibly because of the tuning and velocity phenomena, but it does not conform with the reservoir's reflections. As a consequence, it is interpreted as the gas/water interface.

The supposed reservoir is located at great depths. Therefore, we might not be able to well describe it because of the low vertical seismic resolution.

A flat spot has another benefit; it may provide important information about reservoir thickness which is certainly equal to at least a quarter of the wavelength [26], where the thickness of this reservoir is somewhat large.

Conclusion

Based on all the aforementioned observations, gas chimney on seismic profiles can be identified by the following features:

- Appearance of signal unrest and interference area in the host strata covering the gas reservoir due to gas migration.
- Coincidence of highly reflective abnormality in a certain zone of the gas chimney area.
- Occurrence of a time-sag or push down phenomenon caused by a low gas velocity which is another marker seen in the gas leakage area.
- Formation of a crater or pock mark above the gas chimney area at the sea bed.

It was observed that the majority of the bright spots are located in structural and stratigraphical positions capable of trapping oil and gas, such as tops and on flanks of salt diapirs and pinch outs. Therefore, these bright spots can be considered as confirmed hydrocarbon traps.

It was observed that the flat spot appears to be an incompatible or a discordant event with the neighboring bed reflections, in addition of being a limited event. For this reason, it often represents the gas/water contact surface.

The existence of DHIs points to an efficient and active oil system in the region. In addition, it can also be beneficial for lowering hazards of exploration, guiding future exploration priorities, and encouraging decision makers to start exploratory drilling operations in the offshore area.

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References

1. Sheriff, R. E. **1973.** *Encyclopedic Dictionary of Exploration Geophysics*, Society of Exploration Geophysicists 70, Tulsa, Oklahoma.
2. Millahn, K. O. H., Koitka, J. D. and Jankowsky, W. S. **1978.** *Direct detection of hydrocarbons using seismic procedures*. Hanover, Germany, Prakla-Seismos GmbH, p. 133.
3. Sagex , **2006.** The geology of Offshore Syria. Exploration assessment.The unpublished report submitted to Syria Petroleum Company based on the CGG Veritas 2005 seismic survey.
4. Robertson, A.H.F. **1998.** Mesozoic-Tertiary tectonic evolution of the easternmost Mediterranean area: integration of marine and land evidence. *Proceedings of the Ocean Drilling Program. Scientific Results*, **160**(7): 723-782.
5. Aksu, A.E. Hall, J. and Yaltirak, C. **2005.** Miocene to recent tectonic evolution of the Eastern Mediterranean: new pieces of the old Mediterranean puzzle. *Marine Geology*, **221**: 1-13.
6. Pralle, N.M.A. **1994**. Structural evolution of the Neogene Adana and Iskenderun basins, South Turkey. PhD Thesis, Rice University.
7. McClusky, S., Balassanian, S., Barka, A., Demir, C., Ergintav, S., Georgiev, I., Gurkan, O., Hamburger, M., Hurst, K., Kahle, H., Kastens, K., Kekelidze, G., King, R., Kotzev, V., Lenk,O.,Mahmoud, S., Mishin, A., Nadariya, M., Ouzounis, A., Paradissis, D., Peter, Y., Prilepin, M., Reilinger, R. , Sanli, I., Seeger, H., Tealeb, A., ToksöZ, M. N., and Veis, G.. **2000.** Global Positioning System constraints on plate kinematics and dynamics in the eastern Mediterranean and Caucasus, *J. Geophys. Res*,**105**: 5695– 5719.
8. El-Motaal, E.A. and Kusky, T.M. **2003.** Tectonic evolution of the intraplate s-shaped Syrian Arc fold-thrust belt of the Middle East region in the context of plate tectonics. The 3rd International Conference on the Geology of Africa: 139-157.
9. Flexer, A. M., Gardosh, I. and Dror, A.Y. **2000.** The tale of an inverted basin: eastern Mediterranean. Abstracts, American Association of Petroleum Geologists, International Conference, Cairo.
10. May, P.R. **1991.** The Eastern Mediterranean Mesozoic Basin: evolution and oil habitat. *American Association of Petroleum Geologists Bulletin*, **75**(7): 1215-1232.
11. Bowman, S. A. **2011.** Regional seismic interpretation of the hydrocarbon prospectivity of offshore Syria. *Geo-Arabia*, **16**(3):95-124.
12. Roberts, G. and Peace, D. **2007.** Hydrocarbon plays and prospectivity of the Levantine Basin, offshore Lebanon and Syria from modern seismic data. *GeoArabia*, **12**(3): 99-124.
13. Maillard, A., Gorini, C., Mauffret, A., Sage, F., Lofi, J. and Gaullier, V. **2006.** Offshore evidence of polyphase erosion in the Valencia Basin, *Sedimentary Geology*, **188**: 69-91.

14. Vidal, N. and Alvarez-Marron, J. **2000.** The structure of the Africa-Anatolia plate boundary in the eastern Mediterranean. *Tectonic*, **19**(4):723-739.

15. Brown, A. R. **2004.** Reservoir Identification, *AAPG Memoir 42 and SEG Investigations in Geophysics*, **9**(5):153-197.

16. Chen, Q. and Sidney, S. **1997**. Seismic attribute technology for reservoir forecasting and monitoring, *The Leading Edge*, **16**:445-450.

17. Judd, A.G. and Hovland, M. **2007.** *Seabed fluid flow. The impact on geology, biology and the marine environment*, Cambridge University Press, New York, pp 442.

18. Løseth, H., Gading, M. and Wensaas, L. **2009.** Hydrocarbon leakage interpreted on seismic data, *Marine and Petroleum Geology*, **26**(7):1304-1319.

19. Ligtenberg, J.H. **2005.** Detection of fluid migration pathways in seismic data: implications for fault seal analysis. *Basin Research*, **17**: 141–153.

20. Semb, P. H. **2009.** Possible seismic hydrocarbon indicators in offshore Cyprus and Lebanon. *Geo-Arabia*, **14**(2):49-66.

21. Petersen, C. J., Bünz, S., Hustoft, S., Mienert, J. and Klaeschen, D. **2010.** High-resolution P-Cable 3D seismic imaging of gas chimney structures in gas hydrated sediments of an Arctic sediment drift: *Marine and Petroleum Geology*, **27**(9): 1981-1994.

22. Barsoum, K., Della, M., and Kamal M. **2002**. Gas chimneys in the Nile Delta slope and gas field occurrence. In: MOC 2002, Alex, Egypt.

23. Schroot, B.M. Klaver, G.T. and Schüttenhelm, R.T.E. **2005.** Surface and subsurface expressions of gas seepage to the seabed, *Marine and Petroleum Geology*, **22**: 499-515.

24. Mangal, S., Hansa, G.L., Savanur, S. R., Rao, P.H. and Painuly, S.P. **2004.** Identification of Shallow Gas Prospects from DHI and Inversion Studies of 2D Seismic Data, Kosamba Oil field, South Cambay Basin, Gujarat, India – A Case Study :5th Conference & Exposition on Petroleum Geophysics, Hyderabad, India : 782-787.

25. Caldwell, J., Chowdhury, A., Bemmel, P., Engelmark, F., Sonneland, L. and Neidell, N. S. **1997**. Oilfield Review (Winter): 48-61.

26. Badley, M. E. **1985.** *Practical Seismic Interpretation*, D. Reidel Publishing Company, Boston, USA.