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# Soft-Sediment Deformation Structures and Depositional Environment of the Middle Eocene Carbonates, Al-Kornish Al-Janoubi Section, Latakia Ridge Basin, Syria

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## Abstract

Latakia Ridge Basin has a critical location in northwestern Syria as part of a remnant of collision zone between the Eurasian and Afro-Arabian plates. The basin contains up to 3000m of Late Maastrichtian-Recent sediments. The bitumen-rich beds occur in the Middle Eocene succession. Within the basin, the thicknesses of this interval vary (15m-350m), reflecting the structural history of the basin that formed after the obduction of external Late Maastrichtian-aged Baer-Bassit Ophiolitic Massive.

Al-Kornish Al-Janoubi section in the City of Latakia, close to the Eastern Mediterranean, show the Middle Eocene organic-rich Carbonates. The detailed study of this succession is a necessary step leading to reconstructing of geological structures that may be targets for oil prospecting. The exposed succession consists mainly of rhythmic alternation of chalky limestone and marl, some of which show soft-sediment deformation structures (SSDS), and contains large-scale slumps, that consist of sets of turbidites. This field-based study focuses on the Middle Eocene carbonates in Al-Kornish Al-Janoubi section and provides new insights on the depositional environment of this area. Soft-sediment deformation structures and facies interpretation results were combined to show that the Middle Eocene carbonate sequence was deposited as part of lobes of turbidites in a deep marine environment that formed part of a remnant basin with a compressional tectonic regime.

**Keywords** Northwestern Syria; Latakia Ridge Basin; Sedimentary Structures; Slumps; Turbidite

## Introduction

The unique tectonic setting of northwestern Syria and the Baer-Bassit Ophiolite has focused geological research on the sedimentary and Ophiolite stratigraphy of Syria. In this area, three sedimentary basins may be distinguished: Levantine Basin, Nahr El-Kabir Basin and Latakia Ridge Basin, (Fig. 1). Each basin has a unique structural and stratigraphic history. Located in northwestern Syria the Latakia Ridge Basin extends from Baer-Bassit Ophiolitic Massive, some 30km southwestward, to Nahr El-Kabir half graben. On the north and west it is bounded by Syrian coast. The plate tectonic convergence in the Late Maastrichtian led to the formation of Latakia Ridge Basin. It is filled with about 3000m of Maastrichtian-Quaternary sediments (Adjemian, 1997, unpublished data). The investigated area is located to the southernmost part of Latakia Ridge Basin

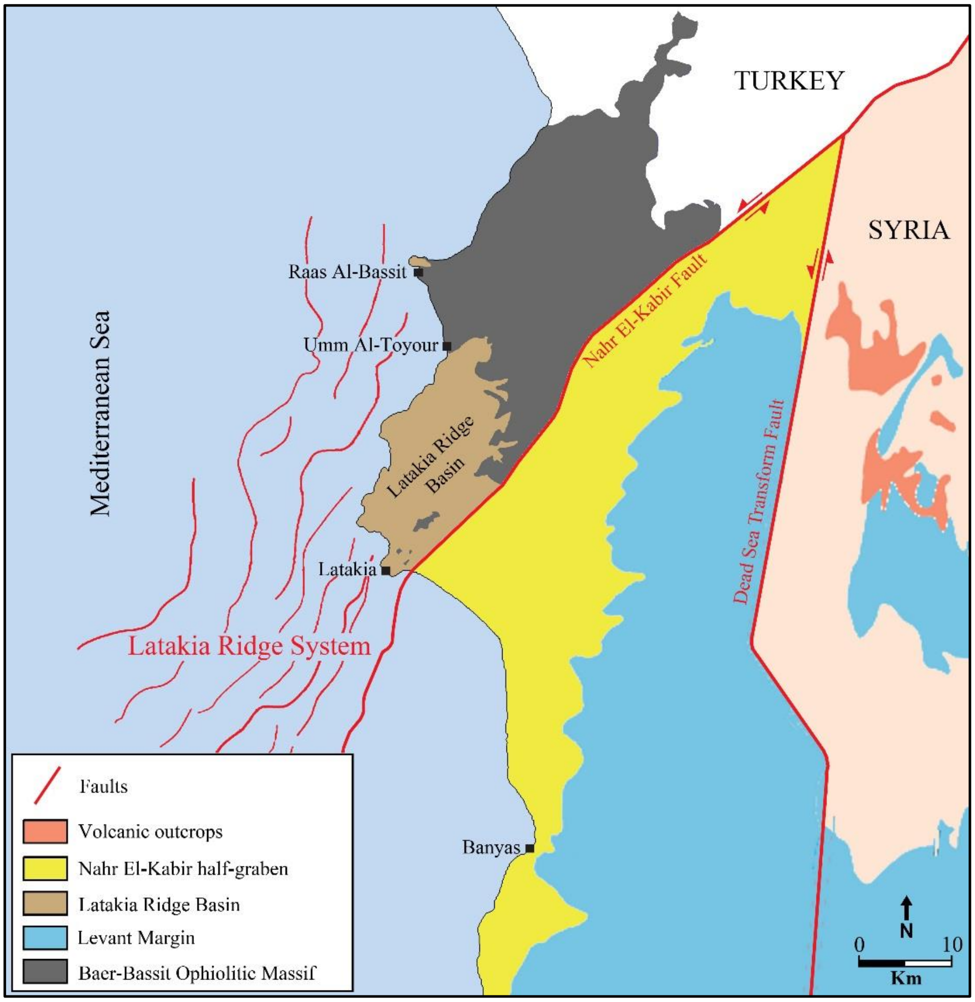


**Fig. 1. Major tectonic elements and geological setting of northwestern Syria.**

along the beachfront of the town of Latakia. It extends over an area of about 0.5km$^2$ and characterized by the presence of rhythmic alternation of chalky limestone and marl of Middle Eocene age. Sedimentary structures are essential tool for understanding the environmental conditions at, or very shortly after, the time of deposition. Not a simple matter to distinguish between penecontemporaneous structures and tectonic folds. However, synsedimentary folds and faults are identified by the sum of many principle criteria. They are characteristically chaotic and display little symmetry. In addition, another argument that rule out a synsedimentary structures is the slumping folds in one layer are of a different size and orientation than the structures in adjacent layers (Van der Pluijm and Marshak, 2004). The aim of this research is to present new ideas in attempt to reconstruct the evolution of the depositional basin, here termed the Latakia Ridge Basin that was located between the Mediterranean coast and the Baer-Bassit Ophiolite. Also, this study is describe the soft-sediment deformation structures encountered within the Middle Eocene carbonates in Al-Kornish Al-Janoubi section as a tool for interpreting the ancient depositional environment of the rock succession.

## Previous Studies

Northwestern Syria has attracted scientists, especially geologist, long time ago because of its geographical and structural important position. It is tectonically a complex region located at the boundary between the Eurasia and Afro-Arabia plates, which pass through it and led to the presence of a slice of oceanic crust that was thrust over continental crust during collisional orogeny (i.e. Baer- Bassit Ophiolite). Science 1890 several publications have described the structural elements and stratigraphy of the Ophiolite and sedimentary cover in this complex area (e.g. M. Blanckenhorn, 1890, Ponikarov, 1966; Kazmin and Kulakov, 1968; Lovelock, 1984; Leonov et al., 1989; May, 1991; Sawaf et al., 1993; and Brew et al., 1997and 2000).

Al-Riyami et al. (2002) discussed the composition and structure of the Baer–Bassit Ophiolite and its metamorphic sole and provided a tectonic model for the emplacement of external Baer- Bassit Ophiolite onto the Arabian continental margin in Maastrichtian time. This Late Triassic and Early Jurassic Tethyan oceanic crust can be observed as NE–SW-trending thrusting belt of Ophiolitic rocks includes the Troodos Ophiolite (Cyprus), the Baer–Bassit Ophiolite (northwestern Syria) and the Hatay, Amanos and Koçali Ophiolites (southern Turkey) and intervening offshore areas, (Fig. 2) (Robertson, 2002; Parlak et al., 2009). Observations from seismic data indicated that the Baer-Bassit Ophiolite extends in offshore Syria via the Latakia Ridge System, which defines the boundary between the Eurasian and Afro-Arabian plates, to connect with Troodos Ophiolite in Cyprus (Ben-Avraham et al. 2006; Roberts & Pearce 2007; Bowman 2011).

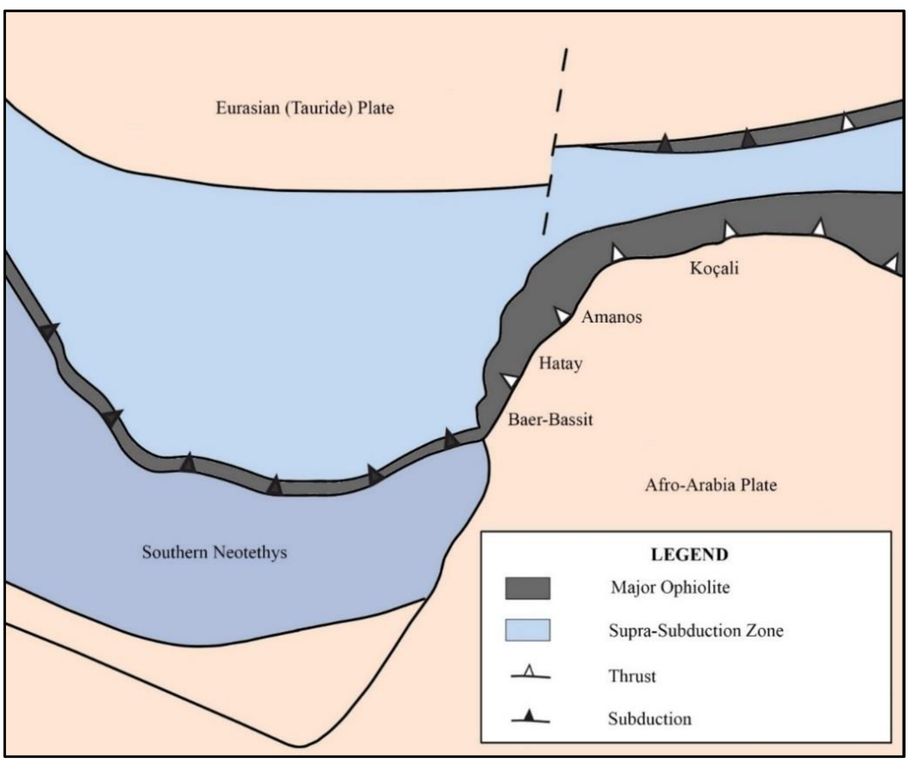


**Fig. 2. Tectonic model of the Eastern Mediterranean region during the Late Cretaceous, modified mainly from Robertson & Dixon (1984).**

More detailed and focused study on the tectonic evolution and sedimentation of northwestern Syria is found in the work of Hardenberg (PhD, Edinburgh University, 2003). The research should significantly increase our knowledge of the uppermost Cretaceous–Recent sedimentation in northwestern Syria. The work mainly concentrated on the Nahr El-Kabir half-graben and paid the first modern description and interpretation of the rock successions in this region. This basin is attributed to extension or transtension along the strike-slip Nahr El-Kabir Fault. He gave important attention to the succession of chalky limestone and marl of Middle Eocene age (i.e. Al-Kornish Al-Janoubi section) and described the distribution of major faults and folds in Latakia City beachfront. However, soft-sediment deformation structures (SSDS) can provide information about the sedimentary and tectonic setting during the accumulation of the sedimentary section under study. The Al-Kornish Al-Janoubi section contains such SSDS in the turbidite strata that built almost the complete section.

## Geological Setting

Two tectonic sequences can be recognized in northwestern-most Syria (Fig. 1). They are (1) the Allochthonous Sequence (Baer- Bassit Ophiolitic Massive) and (2) the Late Maastrichtian-Recent sedimentary cover (Latakia Ridge Basin). Ophiolites are important markers of convergent margin processes. The principal tectonic setting of most extensive Ophiolites is the subduction zone, known as a supra-subduction zone setting (Fig. 2) (Pearce et al., 1984). It is generally accepted that during Late Triassic and Early Jurassic the Eastern Mediterranean region was location of a seafloor spreading led to development of the Allochthonous Sequence (Parrot, 1980) and that, during the Late Maastrichtian time, the Baer- Bassit Ophiolite obducted over the Afro-Arabian continental margin (Kazmin & Kulakov, 1968). Therefore, the latest Cretaceous Baer- Bassit Ophiolite related to regional plate convergence, consistent with the northward drift of the Afro-Arabian Plate relative to Eurasian (Tauride) Plate (Livermore & Smith 1984; Savostin et al., 1986).

The emplacement of Latest Cretaceous Ophiolite was one of the most important tectonic events to have affected the northwestern margin of the Afro-Arabian Plate and associated with the Nahr El-Kabir Fault (Fig. 3) (Trifinov, 1991; Leonov, 2000). The fault extends approximately 150km northeastward, crossing Turkish border. It is described by Ponikarov et al. (1963, 1966) as the “Latakia geosuture”. More recently, detailed seismic data analysis enabled scientists to trace Nahr El-Kabir Fault in offshore Syria. It is considered as the northeastern extent of the Latakia Ridge System in onshore Syria (Bowman, 2011). The fault is most likely a strike-slip fault system because it laterally offset any geology and a system of positive flower structures was observed in 2-D seismic profiles throughout the Latakia Ridge System. The fault activity is marked in the interval Paleogene-Recent after the Baer-Bassit Ophiolite obducted onto Afro-Arabian continental margin (PhD, Edinburgh University, 2003).

The Paleocene–Eocene was characterized by continued convergence of the Afro-Arabia and Eurasian plates (Brew et al., 2001). During this period, the regional stress field was compressional and the Latakia Ridge Basin was in a deep-sea setting undergoing pelagic carbonate deposition and overlying the obducted Ophiolitic basement. The compressional stress was echoed on the basin by reverse faulting and asymmetric folding.

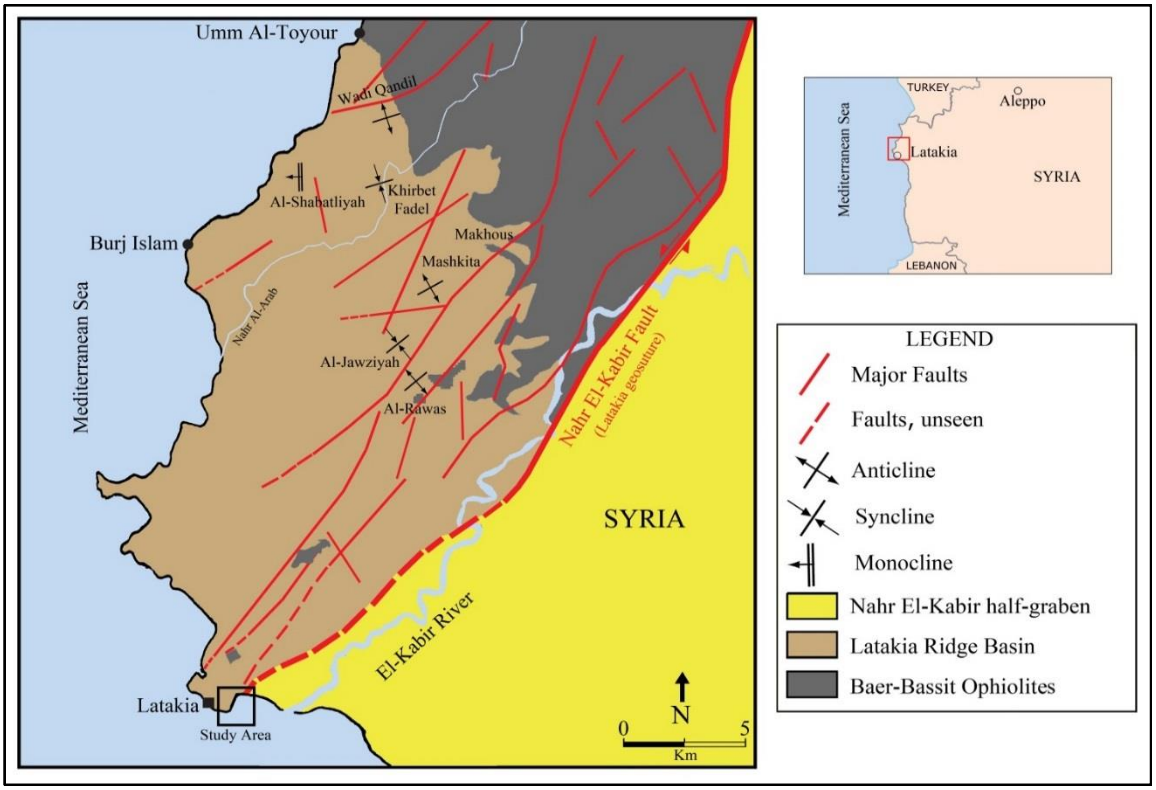


**Fig. 3. Generalized structural map of the Latakia Ridge Basin showing the Tertiary folds and the distribution of faults in the region, modified mainly from Adjemian (1997).**

# Structural Setting

The thick sedimentary succession in Latakia Ridge Basin can be considered as an asymmetrical anticline gently dipping toward the west, delineated in the east by the strike-slip Nahr El-Kabir Fault (Adjemian, 1997). However, the studied Al-Kornish Al-Janoubi section provides some exceptional exposures. These outcrops affected by tectonic, related to final closure of the Neotethys Ocean during the Eocene-age. This issue is discussed in the next sections.

Late Maastrichtian and Tertiary sedimentary sequence and the underlying allochthonous rocks of the Ophiolite complex exposed within the basin are folded, faulted and uplifted in a complex pattern due to Tertiary-age deformation along the northwestern leading edge of the Afro-Arabian Plate (see Fig. 3). Wadi Qandil anticline, Khirbet Fadel syncline, Al-Shabatliyah monocline, Mashkita anticline, Al-Jawziyah syncline and Al-Rawas anticline provides examples of structures produced by the post-obduction deformation of the Late Cretaceous-Tertiary sedimentary rocks. The folds have a northeasterly trend parallel to the Latakia geosuture. The style of the folds varies according to the type and stratigraphic position of the rock units involved in the folding. Folds were developed in both the allochthonous and sedimentary units at Wadi Qandil and Al-Rawas areas. Elsewhere, for example at Al-Shabatliyah village, only the Tertiary sedimentary rocks were folded as monocline dipping gently ($8^0$-$25^0$) toward the west, whereas the Eocene sediments were folded as syncline at Al-Jawziyah village.

The area is dissected by a complex pattern of faults: NW-SE to NE-SW as well as E-W trending faults within the Latakia Ridge Basin, and NE-trending strike-slip Nahr El-Kabir Fault bounding the southern margin of the basin (Fig. 3). More investigations are needed to understand the geometry and displacement of these faults.

## Stratigraphic Framework

In this section, it will review the stratigraphic successions within the Latakia Ridge Basin from Late Maastrichtian to Late Eocene forming depositional megasequence (Fig. 4). It is bounded by two unconformities. The lower boundary of this megasequence is Late Cretaceous Unconformity (SB-1) and its upper boundary the Late Eocene Unconformity (SB-2) (briefly discussed below).

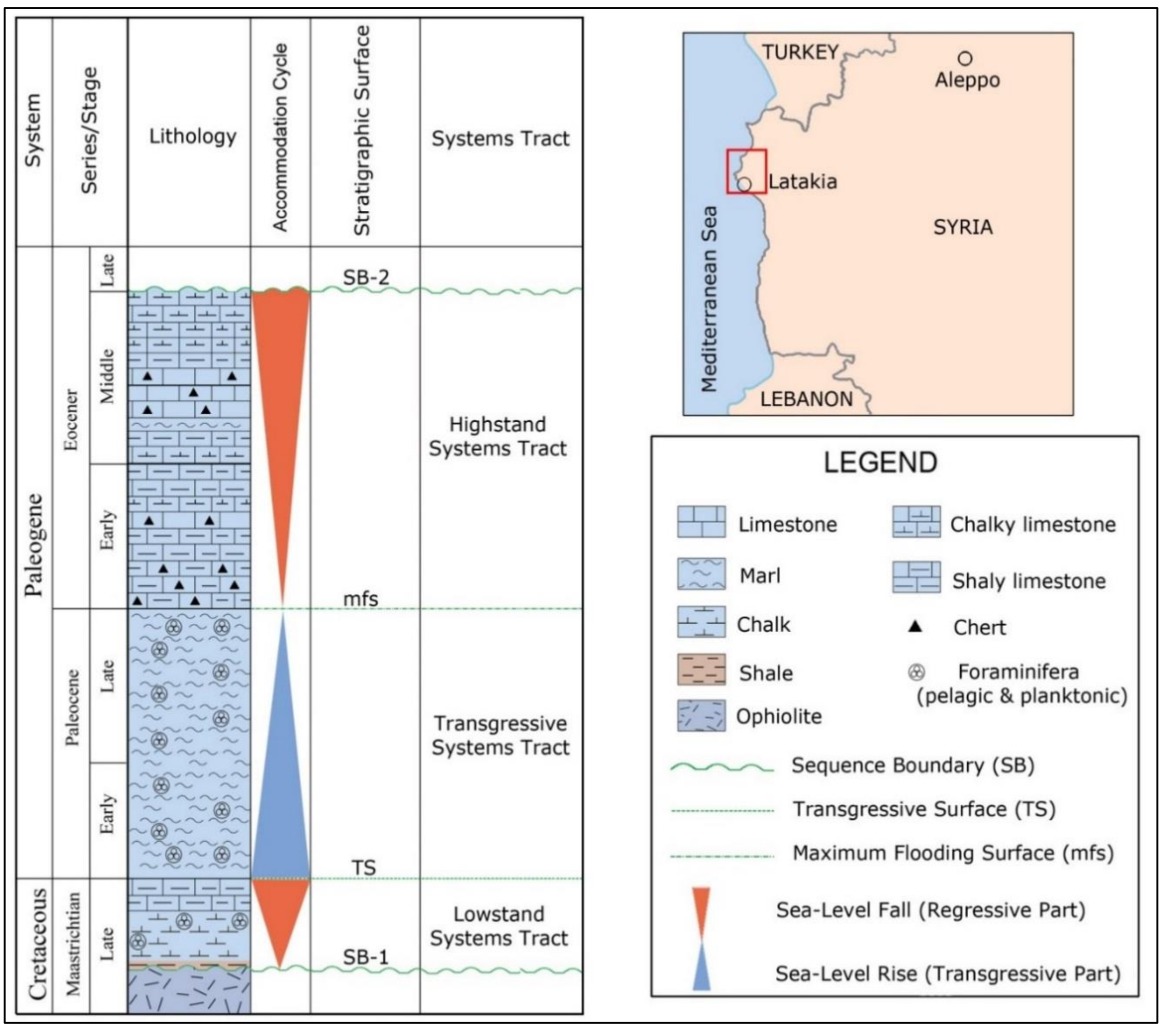


**Fig. 4. Stratigraphic column of the Late Maastrichtian - Late Eocene strata in the Latakia Ridge Basin illustrating main unconformities and sequence divisions. See text for discussion (modified from Adjemian, 1997).**

The oceanic basin, here termed the Latakia Ridge Basin, developed over oceanic crust (i.e. Baer-Bassit Ophiolitic Massive) and dates from the Latest Cretaceous (Late Maastrichtian). Thus the oldest rock unit exposed within the basin belongs to the Ophiolite complex (Fig. 5). It consists generally mainly of harzburgitic mantle peridotites, ultramaflc to mafic cumulates, gabbros, sheeted dike complex, plagiogranite, isolated dikes and volcanic rocks.

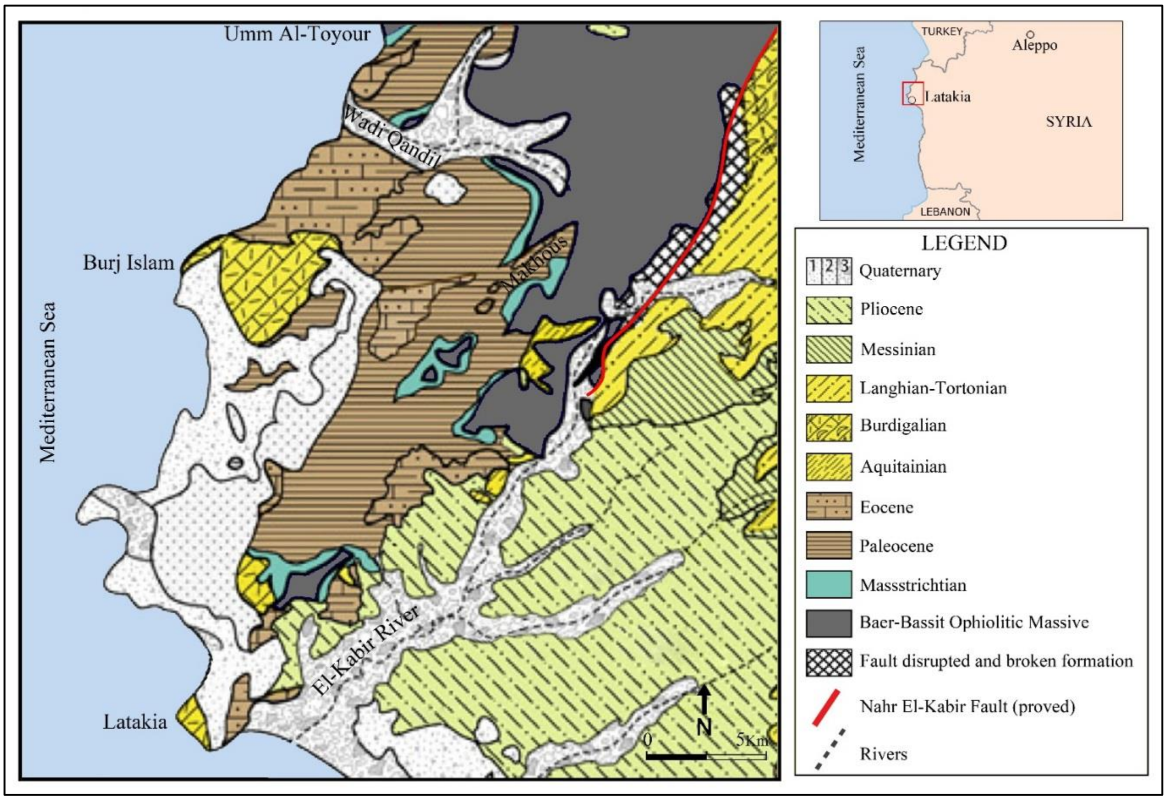


**Fig. 5. A simplified surface geological map of Latakia Ridge Basin and part of Nahr El-Kabir Basin, modified mainly from Ponikarov (1966).**

The age of the sedimentary fill in the Latakia Ridge Basin ranges from Late Maastrichtian to Recent. Figure 4 displays the stratigraphic column of the strata near Ain Al-Beida village where complete successions of the depositional megasequence are preserved. The basin was filled with thick marine sequence of turbidite beds and gravity mass flows, contains deep-water fauna, and is incorporated into the folds.

During the Late Maastrichtian, the deposition began with deep-marine facies onlap across the Baer-Bassit Ophiolitic Massive. This onlap unconformable contact represents a sequence boundary (SB-1) and termed here the Late Cretaceous Unconformity (Fig. 4). In most places, the Late Maastrichtian rock interval is readily distinguishable from the underlying Ophiolitic rocks, but difficulty discernible from the overlying Paleocene carbonate deposits. The sediments of Late Maastrichtian are restricted narrow strips along the borders of Ophiolitic rocks (Fig. 5). They are characterized by the accumulation of chalky limestone and marl with relatively large amounts of foraminifera (15-25%)

(Adjemian, 1997). Deposition of pelagic foraminifera-rich carbonate marks a rapid sea-level rise (Miller et al., 2005). The basal part of the Late Maastrichtian sequence is characterized locally by brittle shale-rich horizon of Late Maastrichtian age, greenish grey to red in colour. It measures up to 15m in thickness and is characterized by sharp contact to Ophiolitic unit below. Within the large-scale cycle, the basal Late Maastrichtian unit represents a lowstand system tract (LST) (Fig. 4). The total thickness of this cover over Ophiolitic rocks is variable in the basin (20m-60m) reflecting the geometry of the Latakia Ridge Basin.

The Paleocene carbonate is well exposed and covers large parts of the basin (Fig. 5), especially in the northwestern portion of the basin. Here, an important outcrop is locate near the Wadi Qandil River and shows the greatest thickness of about 884m (Adjemian, 1997). These carbonate exposures consist of interbedded grey marl and chalky mudstone characterized by very high amounts of planktic foraminifera (30-70%) suggesting a sea-level rise. The Transgressive Surface (TS) is only delineated paleontologically with increasing planktic content. The Transgressive Systems Tract (TST) starts with open-marine Paleogene sediments and ends at the Maximum Flooding Surface (mfs) (Fig. 4). The Paleocene succession displays significant thickness variation across the basin and is in the range of 64m-884 m.

The Early Eocene continued the general depositional setting and environment exemplified by the Maastrichtian– Paleocene succession, slightly higher ratios of benthic to planktonic foraminifera are suggestive of generally sea-level fall (Hardenberg and Robertson, 2007). The highstand systems tracts (HST) is marked by a gradual upward decrease in planktic content. The greatest thickness is attained near Al-Jawziyah village in the outcrop type section where it attains a thickness of 325m. The thickness of this interval within the basin is highly variable from 55m to 325m (Adjemian, 1997).

The Middle Eocene succession has unconformable contact with the underlying and overlying intervals. It overlies the Early Eocene shaly limestone and is overlain by the Upper Miocene deposits with a disconformable contact (Late Eocene Unconformity). At some localities, the Middle Eocene interval overlies the Ophiolitic rocks such as Makhous village (Fig. 5). Also, it is well exposed along the cliffs of Burj Islam village and Latakia City (i.e. the studied Al-Kornish Al-Janoubi section). The deposits are characterized by chalky wackestone and marl and interpreted as a number of stacked shallow channels oriented approximately east–west, and deepen westwards (Hardenberg and Robertson, 2007). The total thickness of this interval is about 15m to 350m. Notably, bitumen was identified in the marl and chalky limestone of Middle Eocene interval, especially when this deposits overly the Ophiolitic rocks (Fig. 6). Bitumen content recorded up to 13% (Adjemian, 1997).

The Late Eocene-Oligocene deposits are missing in this area, suggesting a hiatus in deposition. This unconformity is referred to as Late Eocene Unconformity and represents the sequence boundary (SB-2) of the depositional supersequence.

**Fig. 6. Bitumen-stained trough interbedded Middle Eocene chalky limestone and marl, Latakia City; hammer length 0.33m (photo by I. Babbo).**

# Latakia Ridge Basin Modeling

The depositional basin, here termed the Latakia Ridge Basin is bordered by the Baer-Bassit Ophiolitic Massive to the northeast, the Nahr El-Kabir half-graben to the south. The northern and western extending of the basin is hidden beneath the Mediterranean Sea. It is a narrow and small basin and has an area of approximately 450km$^2$. The topography of the basin is smooth up to 532m. It oriented northeast-southwest and originated following the emplacement of the external Baer-Bassit Ophiolitic Massive in the Late Maastrichtian.

The structural morphology of the basin appears complex and poorly known. The Late Cretaceous and early Tertiary were dominated by plate convergence and its effects on the platform. From northwestern Syria, and along the Taurus-Zagros front into southern Turkey, obducted Ophiolites, and flysch overthrust during the Late Maastrichtian, frame the northern part of Afro-Arabian Plate (Temple and Perry, 1962; Rigo de Righi and Cortesini, 1964; Delaune-Mayere and Parrot, 1976). The Nahr El-Kabir Fault is a plate boundary characterized by a wide diffuse zone dominated with sinistral strike-slip movement (Kempler & Garfunkel, 1994; Robertson, 1998; Vidal, Alvarez-Marron & Klaeschen, 2000; Harrison et al., 2004).

The scenario suggested that the basin was formed as a result of closing of the Neotethys Ocean and consequent collision between Afro-Arabian and Eurasian plates. The basin is interpreted as an ancient remnant basin because it floored by oceanic crust (i.e. Ophiolitic complex). The oblique collision (zipper-like collision) of the Afro-Arabian Plate and Eurasian Plate created the remnant Latakia Ridge Basin. It is resulting from subduction confined on one side by Afro-Arabian passive margin and on the other side by approaching overthrust belt shedding relatively large volumes of carbonates in the form of turbidites and mass flow deposits into the basin. Such interpretation is further supported by the Middle Eocene carbonate Flysch in the studied Al-Kornish Al-Janoubi section, here the Flysch sediments deposited along the front of the overthrust belt where an older flysch is overthrust onto younger flysch deposits (Fig. 7).

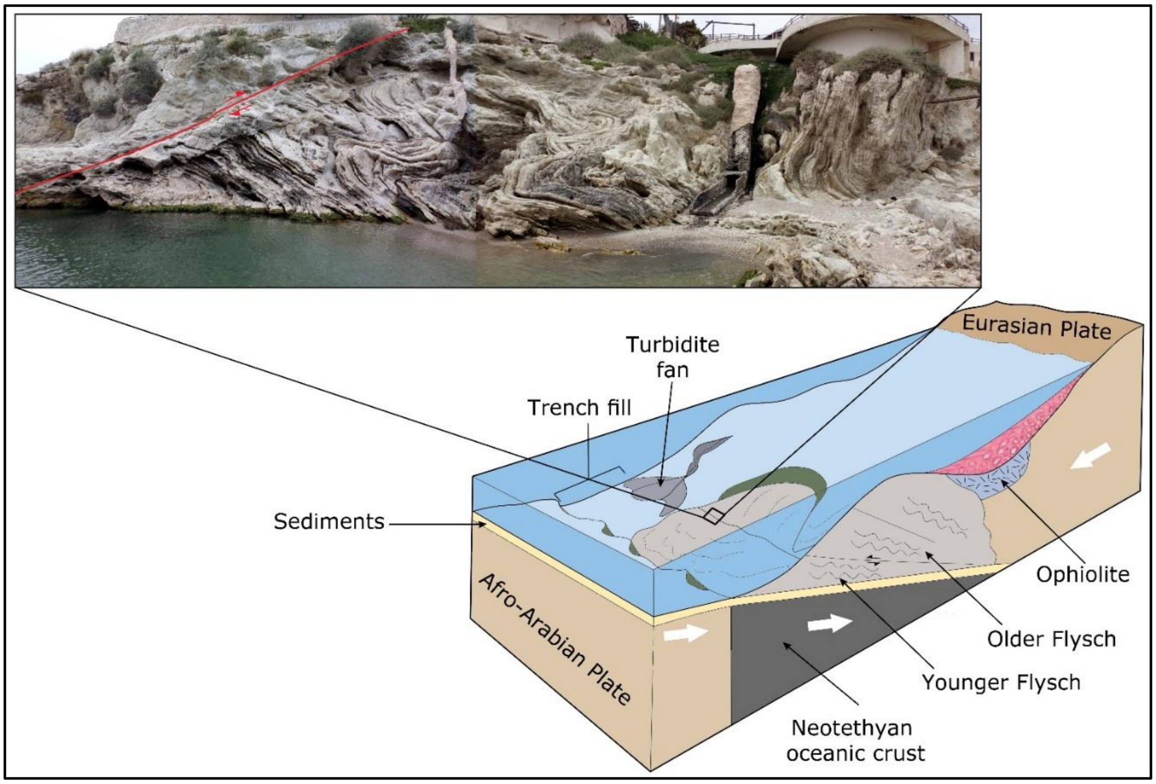


**Fig. 7. Model showing Latakia Ridge Basin with successive flysch deposits in Al-Kornish Al-Janoubi section (photo by I. Babbo).**

# The studied Section

As indicated above, the study area is located in southeastern margin of the Latakia Ridge Basin and close to the Nahr El-Kabir Fault. It is a sea-cliff section outcropping on the coast of Latakia City (Fig. 8). The surface area is merely 0.5 $km^2$, with a maximum elevation of 15m above sea level. The studied Al-Kornish Al-Janoubi section provides an exceptional exposure. This outcrop is about 1.5km long extends from north to south and covered partially by vegetation (Fig. 8). The section is broadly continuous, being interrupted by major faults and lineaments. It was associated with penecontemporaneous Large-scale gravitational slumping-folds which indicate tectonic instability at time of deposition. The presence of such topographic and structural features tells us that motion along the fault is not perfectly strike-slip. They form in response to transpression, a combination of strike-slip displacement and compression.

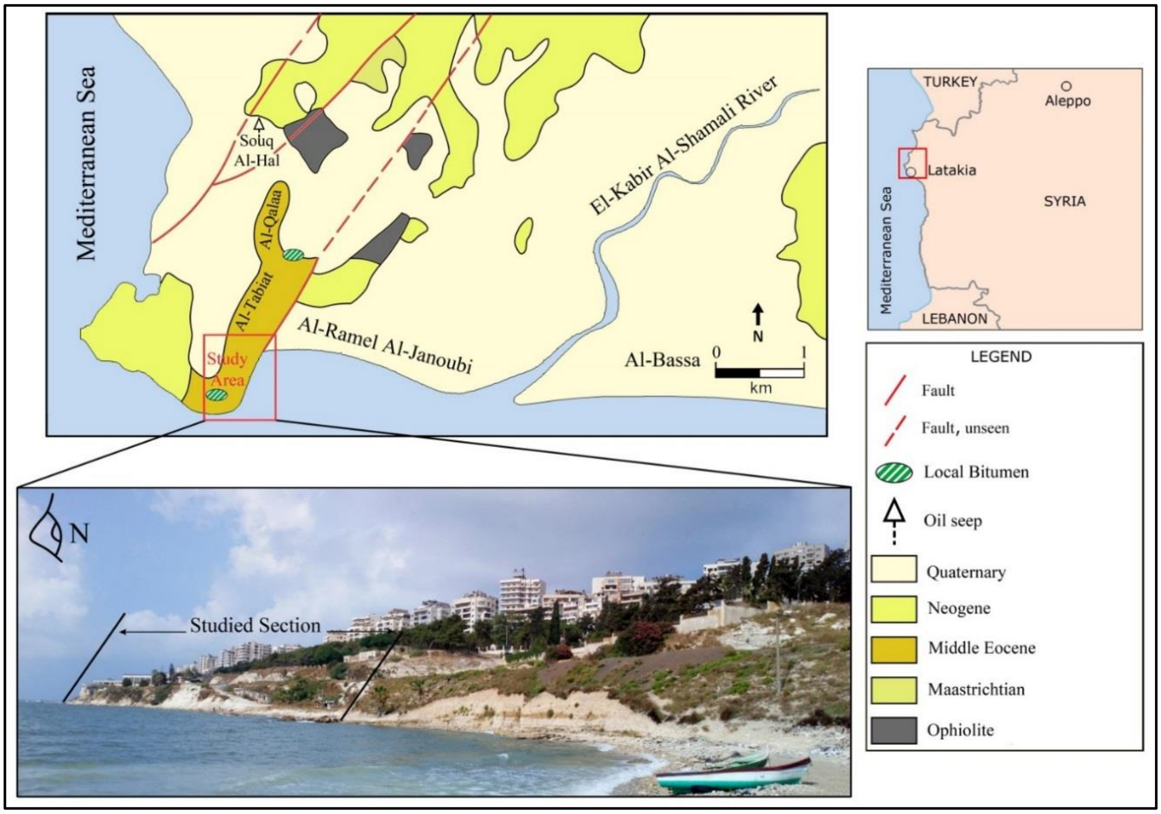


**Fig. 8. Location map of the study area with a simplified geological sketch of the studied section. The regional geological map is modified after Adjemian, (1997).**

According to the geological map of Latakia City, the area comprises Ophiolitic complex and Late Cretaceous- Recent sedimentary succession enclosing the studied Middle Eocene section (Fig. 8). The Middle Eocene strata have an economic significance with oil seeps and bitumen-bearing horizons (Figs. 7&8). The occurrence of oil seeps in Souq Al-Hal area within Latakia City suggests that the Latakia Ridge Basin can be prospective (MEES, 2008; see www.mees.com). The oil leak is interpreted as the migration of hydrocarbon from basin center to flanks. The faults affected the sedimentary successions may play a role in this tertiary hydrocarbon migration pathways. In addition, the Latakia-03 Well was drilled in 1983–1984 to a total depth of 4,325m on the southern border of the basin. It encountered heavy oil shows and asphalt in the deepest section of the well with gas shows also recorded within the Eocene strata (Bowman, 2011). The bitumen in the Middle Eocene strata, the minor shows in the exploration onshore Latakia-3 Well and the natural oil seep in Souq Al-Hal area all indicate working petroleum system in the Latakia Ridge Basin.

# Result and Discussion

The study area can be divided horizontally into three zones (Fig. 9). It stand out in its complex tectonic pattern characterized by two almost parallel lineaments (F1 and F2). The tertiary tectonic phase affected the study area. It was subsequently overprinted by intense folding and faulting of Middle Eocene strata.

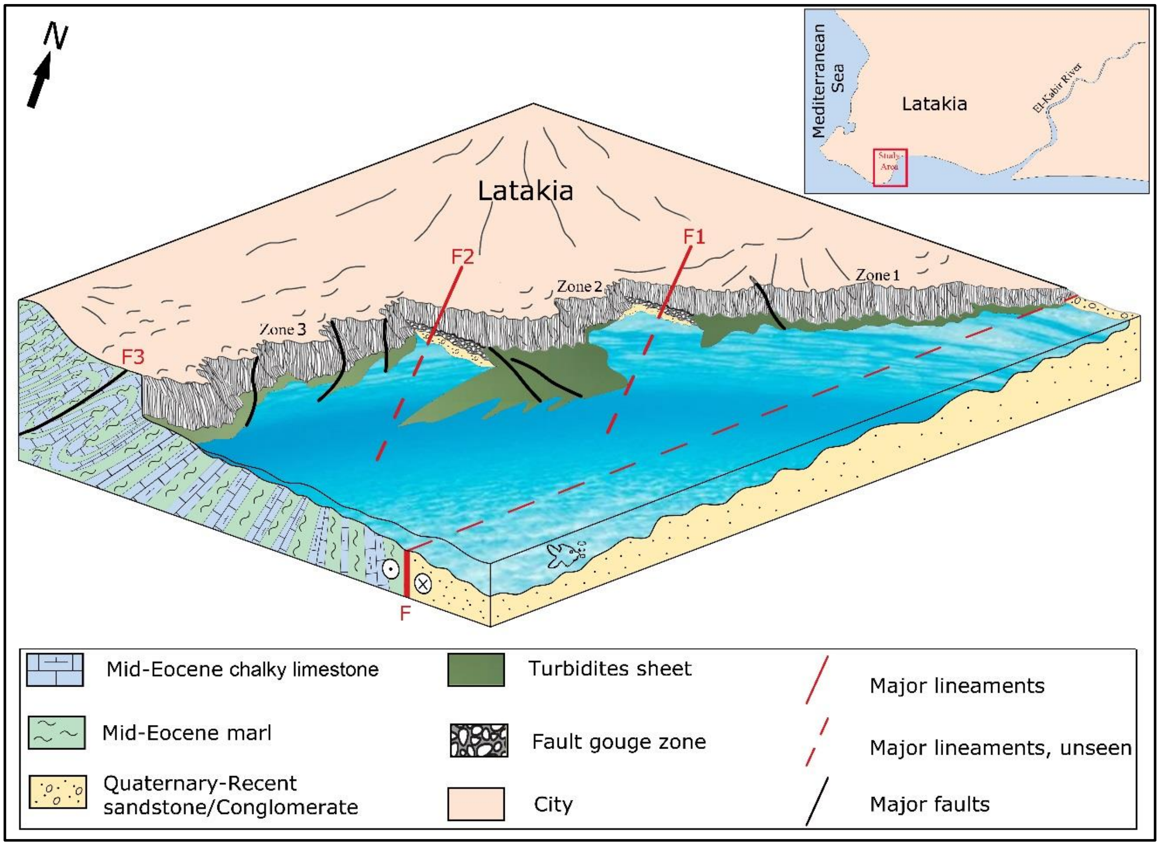


**Fig. 9. 3D diagram of Al-Kornish Al-Janoubi section. Expected locations of major lineaments F1 and F2 and location of strike-slip fault F as proposed by Hardenberg (2003). Not to scale, (photo by I. Babbo).**

The present detailed field investigation in the town of Latakia indicate that folding of Middle Eocene carbonate rocks produced a raised platform (up to 20m high) crop out from Al-Kornish Al-Janoubi across Al-Tabiat to Al-Qalaa areas (Fig. 10). Above this, these folds tend to have parasitic folds. They were cut by large faults (actually belong to the Nahr El-Kabir Fault zone) that produce a scarp-and-cliff ridge landscape.

The type of a rocky coast in Latakia City is a horizontal shore platform. It is flat or almost so. Obviously, the Middle Eocene carbonate outcrop has a regular sheet geometry that corresponds to the outline of the turbidites (Fig. 11). Such regular and parallel-sided with sharp contacts bedding is typical of more distal (basin plain) turbidite successions.

The Middle Eocene intensely disturbed rocks are overlain by Quaternary-Recent deposits. Four lithologies are recognized in the Middle Eocene interval: chalky limestone, marl, conglomerate and chert. The chalky limestone and marl are the most abundant lithology, whereas the conglomerate and chert are rare. The facies of the total succession referred to as carbonate Flysch. It is delivered to the basin and emplaced downslope via gravity mass movement processes. Rockfall, gravitational slump folds and sediment gravity flows in the study area indicate subaqueous slope environment and tectonic

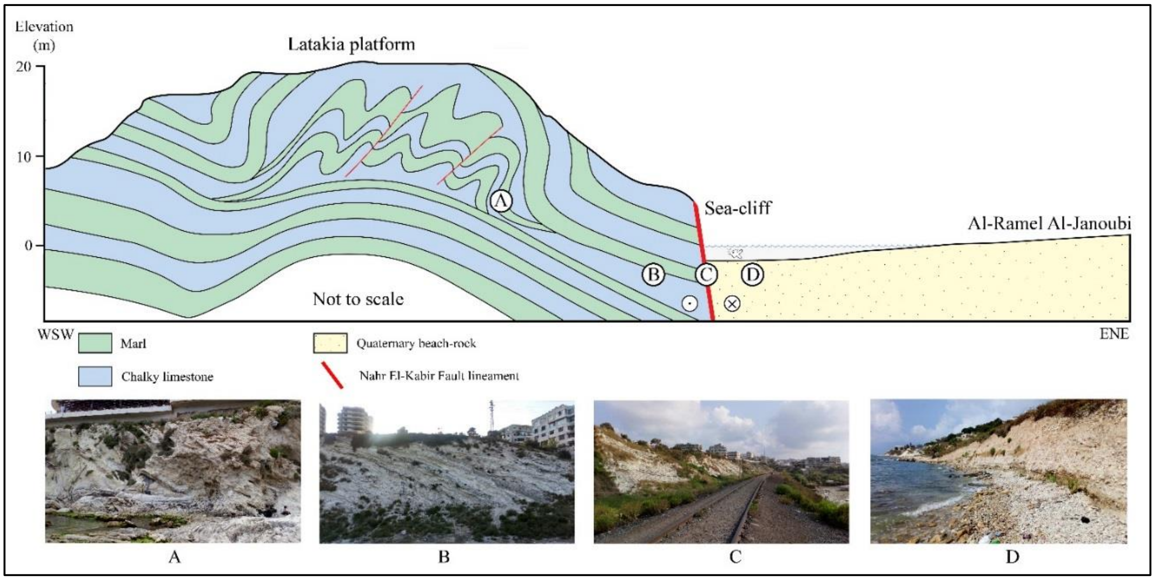


**Fig. 10. Schematic WSW-ENE structural cross-section, showing parasitic folds (photo by I. Babbo).**

**Fig. 11. Thin to medium bedded chalky limestone–marl turbidites crop out in zone 2. Such regular and parallel-sided bedding is typical of more distal (basin plain) turbidite successions.**

instability because during the transport, consistency of the slump masses is disturbed, resulting in faulting, contorted, and chaotic bedding and internal structures. Furthermore, the carbonate rocks display sequences of structures (i.e. Stow sequence) and sedimentary structures such as load casts, lamination, current scours and channels suggest turbidite slope-apron origin for these sediments. These issues will be discussed individually in the next sections.

## Folds

Since Al-Kornish Al-Janoubi section extends along the rocky coast of Latakia City, field work was carried out on the northern, middle and southern parts of the section (zone 1, zone 2 and zone 3, respectively). Generally, the turbidites and slumps are good exposed and show a wide variety of folds. The northern portion of the section (zone 1) is about 700m long. It shows deformation in the form of recumbent folds (Fig. 12). The limbs of the fold extend to form the shore platform of Latakia City. Two styles of deformation are observed along the inverted limb toward the south within zone 1 and zone 2:

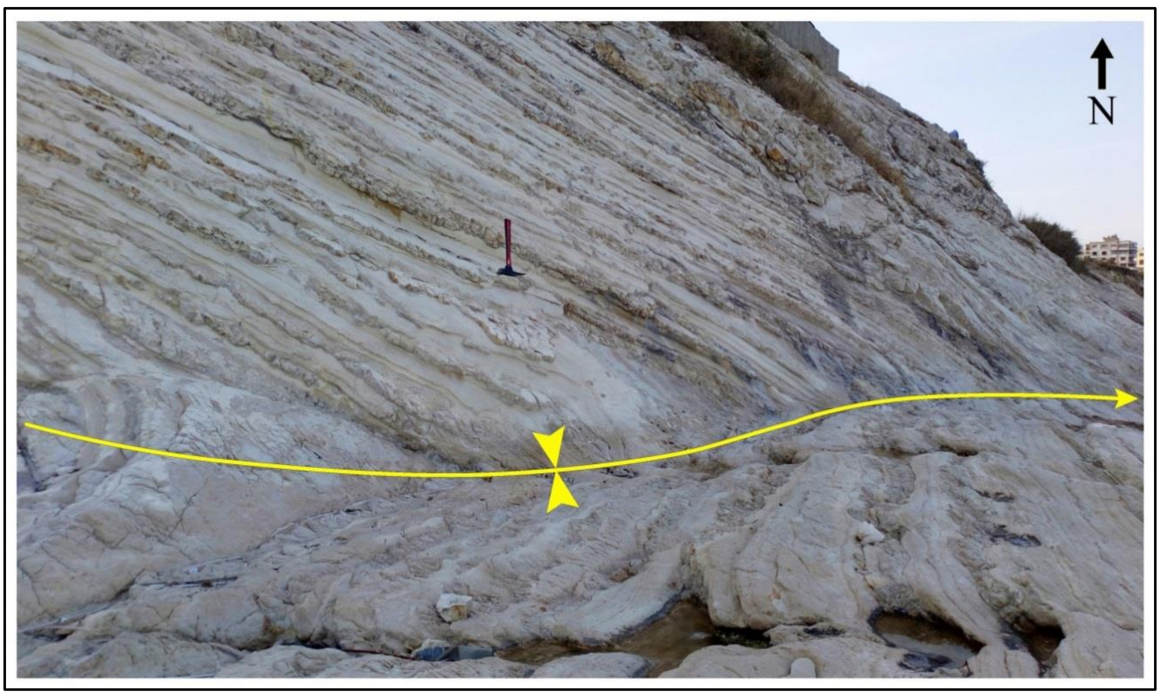


**Fig. 12. Recumbent fold developed in zone 1.**

a mildly deformed and then a strongly deformed. This is evident from the contrast between the weak deformation of the gently to moderately dipping beds to the east in zone 1 and then the intense deformation, where the beds are steep to sub-vertical dips in zone 2. Such variations indicate increasing deformations toward the south of the studied section.

The middle sector of the studied section (zone 2) is about 400m long. The major fault (F1) separates this zone from the previous zone 1 (Fig 9). This zone, noted above, comprises steeply dipping beds of inverted recumbent fold limb (Fig 11).

The southern sector of the study area (zone 3) is about 300m long. It reveals thrusts and associated isoclinal folds in m-scale (Fig 13). This part of the section is more disrupted and folds become very tight. The zone 3 with weak basal layers also shows box folds (Fig. 14). They are the results of the intersection of conjugate kink bands. In order for a box fold to form, a layer must be detached from the underlying and overlying layers.

The extensive folding in zone 3 abruptly ceases at the major fault (F2) to cut the succession (Fig. 9). Hardenberg (2003) interpreted the folding in the study area to simply represent a soft-sediment slumps. He attributed the slumping to the lack of predominant orientations of folds and intensifying convolution near a major inferred fault (F2).


**Fig. 13. Isoclinal fold developed in zone 3.**


**Fig. 14. Box fold shows in zone 3. Note that it has thin limbs and a relatively thick hinge area.**

# Faults

Faults can occur in water-saturated, unconsolidated sediments. Under such conditions, faulting can take place if a sudden instability occurs, for instance by overloading or shocks (e.g. earthquakes). Such synsedimentary faults are present, indeed, in the Al-Kornish Al-Janoubi section. The study area has been affected by tectonic activity along the NE-trending Nahr El-Kabir Fault during Middle Eocene resulting in faulting of the already lithified rocks. These penecontemporaneous faults almost exclusively form strike-slip and normal faults (Fig. 15 a,b), although some rare examples of reverse faults are present (Fig. 15c). Hardenberg (2003) inferred the extremely large faults (F, F1 and F2) based on geomorphological evidence. The inferred major fault (F2) may play a role in a tensional glide plane. The rotational movements on F2 causing intense internal deformation in zone 3 mentioned above.

The type of brittle deformation related to fault movement is cataclastic breccias (Fig. 16a). These are very well cemented and thus completely tight. They are formed in situ by the mechanical fragmentation of pre-existing Middle Eocene carbonate rocks due to intense folding and faulting. Also, some major fault zones (F3) marked by mylonitic foliation associated with folds (Figs. 9 & 16b).

In addition, the displacement on a few faults in the study area involves frictional sliding, which may provide information about the direction of net slip. The fault surfaces have been polished by the process of frictional sliding and created slickensides (Fig. 16c). They show a predominant east-west trend in fault orientation.


**Fig. 15. Examples of penecontemporaneous faults developed in the studied section. a) A strike-slip fault shows an E-W trend in fault orientation. b) The faults shown here are, just like the great majority of fields in the turbidite succession, normal faults. c) One of the relatively few synsedimentary reverse fault.**

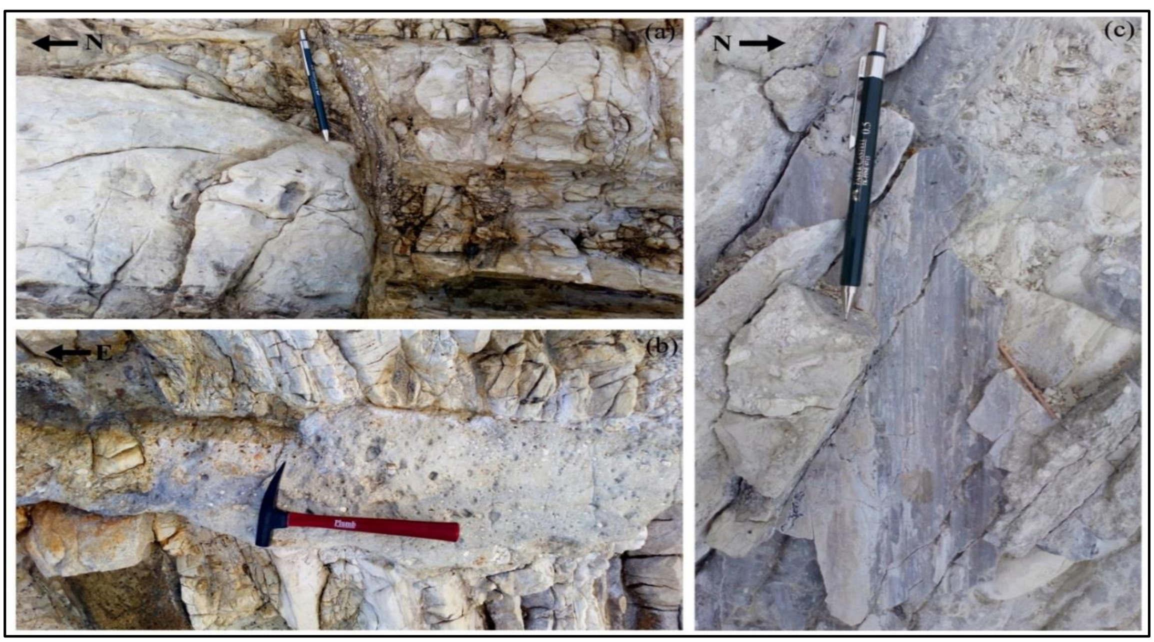


**Fig. 16. Examples of fault surfaces. a & b) Strike-slip faults in zone 2 & 3 shows cataclastic breccias. c) Slickensided surface, pencil indicates displacement direction.**

# Turbidites

Turbidites constitute one of the major advances in sedimentology of the twentieth century (Mutti et al., 2009). The concept of the turbidity flow was introduced to geology by Bell (1942). This facies, typical of subduction zone, is identified by sum of many criteria. A turbidity flow is a cloud of sediment that moves down a slope under water because the density of the sediment-water mixture is greater than that of clean water, and denser liquids sink through less dense liquids. Turbidite flows are triggered by major storms or earthquakes (because of their association with seismicity, the occurrence of turbidites may indicate that the sediment source region was tectonically active), and move down gentle slopes at considerable speed.

The turbidite that constitutes the majority of sediments in the Al-Kornish Al-Janoubi section don’t show the classical properties. They tend to show sharp lower and upper boundaries, partly due to the heightened tectonic activity that accompany a final closure of the Neotethys Ocean during the Eocene. Tectonic activity, prior to and during deposition, influenced the sediment loading where rapid sedimentation and oversteepened slope lead to instability. Synsedimentary folds and faults are common in the turbidites of Al-Kornish Al-Janoubi section. Bottom structures, such as load casts, groove casts, dish and pillars and bounce mark are well developed at the contacts between chalky wackestone and marl. Stow sequences ($T_a$-$T_b$-$T_c$) are also present (Fig. 17), showing a massive lower part, horizontal laminated in the middle part and cross-laminated in the upper part.


**Fig. 17. Turbidite unit showing Stow sequence of structures (divisions ABC) as marked over sharp erosive base. Note that various cracks are due to weathering and jointing.**

## Sedimentary Structures

The sedimentary setting of the deep marine part of the Middle Eocene carbonate was favourable for the development of sedimentary structures. These structures are, obviously, pre-depositional. There are, however, also deformation structures that formed soon after or immediately following deposition, while the sediments are still unconsolidated or only partly consolidated, by the process of soft-sediment deformation. Detailed examination of Al-Kornish Al-Janoubi section shows that it contains many different types of post-depositional deformational sedimentary structures.

## Load Casts

Load casts are the most common feature of turbidite deposits in Al-Kornish Al-Janoubi section. These post-depositional structures occur most commonly at the contacts between relatively light (marl) and relatively heavy (limestone) layers as a result of reversed density gradients. Such a situation frequently resulted in load casting (Fig. 18A). Also, these structures occur within limestone units. Load casts on soles of limestone beds are irregular lobes of variable size and relief without any preferred elongation or orientation. They are encountered in all zones of the section and also occur in isolation and cover the whole bedding surface (Fig. 18B).

## Ball and Pillow

Large-scale ball and pillow or pseudonodules are also abundant in Al-Kornish Al-Janoubi section (Fig. 18C). They are common within zones 2 & 3. Where load casts ultimately sagged down so far in the underlying muddy sediment, they eventually became transformed into pseudonodules because the marly material from the underlying layer was pushed up so far that it completely embedded the load cast. Their sizes range from 5cm to more than 40cm. The sediments are bent or folded in some of these ball and pillow structures, or even mixed up with each other.

## Bounce Mark

Bounce marks are less common and recorded in one locality within zone 3 (Fig. 18D). These erosional structures are roughly symmetrical in cross sectional shape. Their sizes range from very delicate forms to 5cm long. Discontinuous marks on the soles of turbidite beds owing to shell fragments, pieces of wood, or other tools that are carried in the base of turbidity current flows being dragged across a mud bottom.

## Channel

The turbidite facies in Al-Kornish Al-Janoubi section locally displays deeply incised channels, especially within deeper part of zone 2 & 3. The channels are filled with deposits of conglomeratic debris flows and cut into thinly bedded turbidite (Figs. 15A&18E). They were formed by mass movement along the slope and filled with sediments that is texturally similar to the beds it truncated. The gravel grains are sub-rounded to rounded and poorly sorted, and the conglomerate sample did not contain any shell material. This facies indicates the initial high-power erosive phase of the turbidity current.

## Rip Up Clasts

Flouting clasts of variable size and shape were found in turbidite succession in Al-Kornish Al-Janoubi section. Some floating clasts are nearly 0.5 m long, but most are less than 15 cm (Fig. 18F). Rip up clasts are angular to subrounded, and they exhibit random orientations. Some clasts in these units are contorted suggesting synsedimentary deformation. Clasts possibly derived from local channel-bank collapse. These structures form from more intensive bed disruption and partial or complete erosion of the underlying bed, through the passage of a strongly erosive current, and also from bank collapse into a passing flow. They are common at the bases of chalky limestone turbidite beds especially in zone 3. Rip up clasts are attributed to turbulent flow conditions in high-density channelized turbidity currents.


**Fig. 18. Soft-sediment deformation structures: (A & B) load casts (C) ball and pillow structures (D) bounce mark (E) channel (F) rip up clasts.**

## Trace Fossils and Chert

Trace fossils are evidence of the activity of an organism and are rare in Al-Kornish Al-Janoubi section. Trace fossils of *Zoophycos* have been identified within the section, but are not sufficiently well preserved (Fig. 19A). The trace fossils are thought to have been formed on or very close to the sea floor and generally to have suffered erosion by bottom currents or by the turbidity currents.

Some individual layers are characterized by chert nodules or bands (Fig. 19B). Many of the chert are of turbidite origin (lamination and grading visible on close inspection), deposited within a mainly pelagic carbonate slope basin setting. This lithofacies occurs only throughout the section in zone 3 as thin intervals (a few cm thick) between chalky limestone and marl.

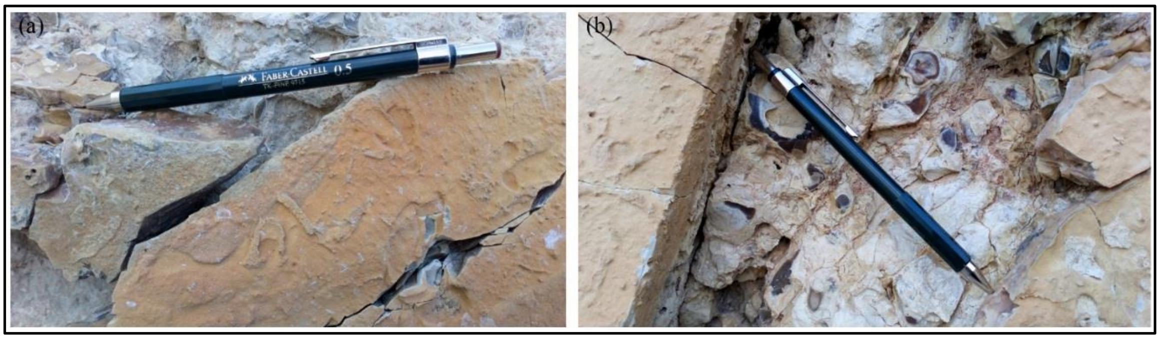


**Fig. 19. Bedding planes view: (A) part of trace fossils (b) small concretions of light to dark grey chert in chalky limestone.**

## Conclusions

The main conclusions from this study are as follows:

1. Al-Kornish Al-Janoubi section in Latakia City is part of what is named here the Latakia Ridge Basin, which is considered an ancient remnant basin originated following the emplacement of the Baer-Bassit Ophiolitic Massive in the Late Maastrichtian and formed as a result of closing of the Neotethys Ocean and consequent collision between Afro-Arabian and Eurasian plates.

2. From field studies and facies analysis, I conclude that the Middle Eocene succession at Al-Kornish Al-Janoubi section consists of chalky limestone, marl, conglomerates and chert deposited in deep marine environment, accompanied by slumps that also are built of turbidites.

3. The turbidites and slumps in Al-Kornish Al-Janoubi section show a wide variety of soft-sediment deformation structures. Load cast, ball and pillow, channel and bounce mark are four of the commonest sole markings found as interbed sedimentary structures. They are erosional and deformational bed forms and all are best seen in, indicating turbidite facies.

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