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Paleocurrent Analyses of the Sahabi and Wadi al Farigh Areas, Southeast Ajdabiya, Sirt Basin, Libya

Moftah H. El-Shawaihdi[1], Ahmed S. El Hawat[1], Tawfik M. Altrabelsi[2], Ibrahim Ikhlaif[3],

[1]*Department of Earth Sciences, Faculty of Science, University of Benghazi, P.O.Box 1984*

[2] *General Water Authority, P.O. Box 2845, Benghazi, Libya*

[3]*Department of Geology, Arabian Gulf Oil Company, P.O. Box 263, Benghazi, Libya.*

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الملخص:

هذا البحث يهتم بتحليل التيارات القديمة للطباقية المتقاطعة المسجلة من رواسب النيوجين في منطقتي الصحابي ووادي الفارغ. هذه الرواسب المتكشفة ترجع إلى تكوين الصحابي (الوحدات 1، 2، 3 والجزء السفلى للعضو V)و عضو وادي الفارغ وعمرها ما بين عصري المايوسين العلوي والبليوسين. التيارات القديمة للطباقية المتقاطعة في الوحدة 1 تمثل تيارات ناتجة من اتجاه الجنوب الغربي بينما التيارات القديمة للطباقية المتقاطعة في الوحدات 2 و3 ناتجة من اتجاه الشمال الشرقي. التيارات القديمة للطباقية المتقاطعة في طبقات عضو وادي الفارغ فهي متذبذبة ما بين الشمال الغربي والجنوب الشرقي. بناء على هذه النتائج، مصدر رواسب عضو وادي الفارغ من قادمة من اتجاه الشمال الغربي بسبب تقدم البحر المتوسط بينما رواسب الوحدات 1، 2، 3 والجزء السفلى للعضو V مصدرها من الاتجاه الجنوب والجنوب الغربي بسبب نهر الصحابي. وعليه فإن رواسب عضو وادي الفارغ شكلت حاجز من الرمل الجيري المهاجر او المتحرك الذي عزل الأراضي الداخلية لمنطقة الصحابي في الجنوب عن الشواطئ في الشمال. هذا العزل لمنطقة الصحابي جعل البيئات الترسيبية تنحصر في أسباخ وبحيرات محصورة أو شبه مغلقة التي كانت السبب الرئيس في تكون رواسب المتبخرات.

الكلمات المفتاحية:

منطقة الصحابي، النيوجين، التيارات القديمة، تكوين الصحابي، وادي الفارغ.

Abstract

Cross-beddings paleocurrents recorded from the Neogene sediments in the Sahabi and Wadi Al Farigh areas, northeast Libya were analyzed. The exposed rocks contained cross-bedding in the Sahabi area belonging to the upper Miocene "upper member" (Units 1, 2, 3) and the Pliocene lower part Member "V" of the Sahabi Formation. Cross-beddings in Unit 1 and Member "V" are represented by a paleocurrent towards the southwest direction, whereas in Units 2 and 3, the paleocurrent is towards the northeast direction. Cross-bedded strata in the Wadi Al Farigh area belongs to Wadi Al Farigh Member of the Sahabi Formation. Cross-beddings were originated by a paleocurrent flow that oscillated between northwest and southeast. Based on this data from both areas, sediments of the Wadi Al Farigh Member originated from the northwest probably due to the Mediterranean Sea, whereas sediments of Units 1, 2, 3, and Member "V" originated from the south and southwest most likely due to the Eosahabi River supply. Wadi Al Farigh Member may have acted as a migrated barrier bar of lime-sand shoal, which isolated the inland the Sahabi area at the south from the coastal area at the north. The isolation that occurred in the Sahabi area has restricted the depositional environments to sabkhas and lagoons, which are responsible for evaporitic deposits in the area.

Keywords: Al-Sahabi; Neogene; Paleocurrent; Sahabi Formation; Wadi Al Farigh

1. INTRODUCTION

Planar and trough cross-beddings are essential directional structures for constructing the paleoflow pattern in sedimentary basin analysis [(1)]. Planar cross-beddings are a good indicator of fluvial systems formed by the lateral and downstream migration of (1) major bars, especially transverse bars, and (2) smaller scale, straight-crested bedforms superimposed upon margins and tops [2,3,4,5,6,7,8,9]. Trough cross-beddings are typically formed by the primary current and therefore correlate strongly with the flow directions [6,9,10,11,12,13,14,15,16]. These cross-beddings are informative to the directional range, patterns, and types of the contained sediments. Al-Trabelci [(17)] and El-Shawaihdi [(18)] were the first to analyze the paleocurrents in Wadi Al Farigh area.

*__Correspondence__:

Moftah. H. El-Shawaihdi

Moftah.elshawaihdi@uob.edu.ly

El-Shawaihdi and Al-Trabelci [19] updated the study of the Wadi Al Farigh cross-bedding during fieldwork in 2006–2008 that was organized by the East Libya Neogene Research Project (ELNRP). The cross-beddings in the Sahabi area were also studied by Ikhlaif[(20)]. The study areas are located about 225 km south-southwest of Benghazi city and ~ 65 km, south-southeast of Ajdabiya city (Fig. 1). Both areas are bounded by longitudes (19° 30`–21° 00` E) and latitudes (30° 00`–31° 00` N) as part of the geological map of Libya, Ajdabiya Sheet (NH 34–6) [(21)]. This study focuses on paleocurrent analysis on cross-beddings recorded from the Neogene sediments in The Sahabi and Wadi Al Farigh areas, northeast Libya. Cross-stratifications in both areas help to provide important information regarding the paleoflow direction that precipitate sediment, which will help in gaining knowledge about the provenance and the depositional environments of the Sahabi strata in the research area.

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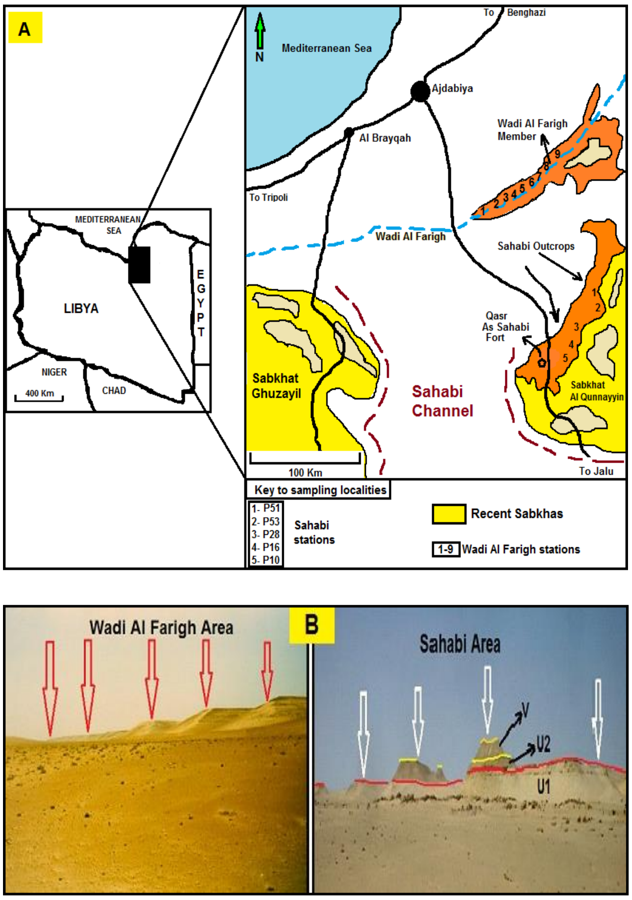

Figure 1. A– Location maps of the study areas. Stations 1–9 represent Wadi Al Farigh localities and stations 1–5 represent the Sahabi localities. B–General views of Wadi Al Farigh area (left) and the Sahabi area (right).

2. METHODS

In the Sahabi area, the outcrops were covered by a recent sand dune; however, we managed to dig several hand trenches to expose the desired sediments (Fig. 1A). The Wadi Al Farigh area was subdivided into nine stations distributed along the outcrops of Wadi Al Farigh Member, although these outcrops are mostly covered by recent sands and rocks (Fig. 1B). All outcrops in both areas were studied separately by general descriptions of the strata, drawing sketches of the outcrops, measuring cross-bedding orientations (dip and strike), taking samples, and finally taking photographs. Rock samples from both research areas were collected and prepared for thin sections whenever the type of lithology permitted. The thin sections were petrographically studied to identify the rock texture. The collected cross-bedding data were plotted as an azimuthally reading, which was analyzed by performing rose diagrams for each cross-bedded lithology, in each station. For all stations, a composite rose diagram has been prepared for each area. A computer program "Stereo" was used to analyze and statistically calculate the mean vectors of the effective direction of the paleocurrent.

3. SEDIMENTOLOGY AND STRATIGRAPHY

3.1 Wadi Al Farigh Area

Magnier [22] the first who identified strata in the Wadi Al Farigh area as Wadi Al Farigh Limestone. Twenty years later, Giglia[21] introduced the term Wadi Al Farigh Member. The sedimentological package of this member is quite uniform, consisting of cross-bedded, pelmicrite, oomicrite, and oosparite facies at some places, alternating with restricted deposits of siltstone, shale, and clay, at some outcrops (Fig. 2). Wadi Al Farigh Member is exposed along a dominant NE–SW small hill ~20 km long and 0.5 km wide (Fig. 1B).

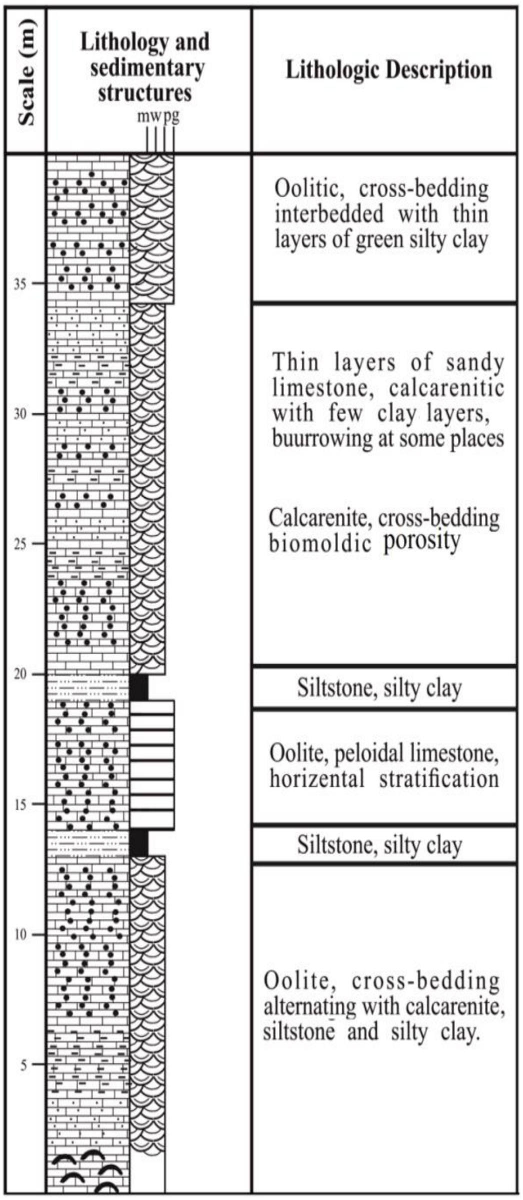

Figure 2. Columnar section showing lithology and sedimentary structures of Wadi Al Farigh Member of the Sahabi Formation (Modified from El-Shawaihdi [18]). Key symbols are shown in Figure 4.

3.2. The As Sahabi area

The name the As Sahabi originates from the ancient Qasr As Sahabi (Qasr means Castle or Palace in Arabic). de Heinzelin and El-Arnauti [23,24,25], divided strata in the the Sahabi area into three depositional formations, including Formation "M", Formation "P", and Sahabi Formation, which was further subdivided into six informal members, from bottom to top, which are "T", "U1", "UD", "U2", "V", and "Z". Giglia [21] however, subdivided the same strata into Sahabi and Qarat Weddah Formations. Furthermore, Giglia[21] subdivided Sahabi Formation into three members from bottom to top; Sabkhat Al Hamra, Sabkhat Al Qunnayyin, and Wadi Al Farigh Members. More recently, El-Shawaihdi et al. (26) proposed a revised stratigraphic nomenclature for the the Sahabi area. They subdivided the Sahabi Formation into "lower member" (previously Formation "P"/lower-"T") and "upper member" (previously Members upper "T", "U1", "UD", and "U2"). The Qarat Weddah Formation, on the other hand, includes Members "V" and "Z". Muftah et al.[2] raised Member "Z" to Formation "Z" and it is not the focus of this study. In this research, strata of Members "U1", "UD", and "U2" that contain cross-bedding are referred to as Units 1, 2, and 3. The main outcrops of the Sahabi Formation are located ~25km-30km south-southwest of Wadi Al Farigh area, south of Ajdabiya city (Fig. 1).

3.3. Upper Member of Sahabi Formation

3.3.1. Unit 1

This unit is 5–25 m thick and is composed of highly cross-bedded sands with clays (small balls and lenses) (Fig. 3). It also contains large sandstone concretions, gypsified and petrified wood fragments, which occur locally in the lower part. The upper contact in the southern sectors of the Sahabi area is characterized by a bed of fish remains, whereas, in the northern sectors, the contact is marked by dolomitic beds. According to Boaz[28], this unit contains the highest percentage of the vertebrate fossil remains among the Sahabi Formation and is considered as the main vertebrate horizon in the Sahabi area. The vertebrate remains belong to land and marine mammals and they are mostly well-preserved. This unit was deposited in tidal channels along a shallow sandy coast.

3.3.2. Unit 2

This unit is approximately 2 m thick (Fig. 3) and composed of dolomitic sandstone with low and high angle planar and herringbone cross-bedded. It is represented by a few discontinuously small exposures that are only exposed in the northern sectors, accepted as a marker bed[23,24,25], and interpreted as a continental dune deposit called "fossil dune". However, Muftah, *et al* [29] suggested a transgressive carbonate barrier bar that is obviously overprinted by the extensive bioturbation.

3.3.3. Unit 3

This unit is 4–10 m thick and consists of cross-bedded sands interbedded with clay and shale. The unit is bounded top and bottom by two dolomitic beds (Figs. 3,4). The lower dolomitic bed is hard and usually strongly bioturbated, containing shell beds of mollusks and it was considered a biomarker bed throughout the region. The upper dolomitic bed is rich in dolomitized gastropods. It also contains ostracods, fish remains, whale bones, and shell beds of Gryphaea. This unit was deposited within a lagoonal to shallow neritic marine waters.

3.4. Member "V"

The lower unit of this member is 10–40 m thick and consists of white and green sands with clay balls, cross-bedded, sandy clays, with lenses of gray calcite and gypsum crystals (Fig. 3). It also contains laminated, slightly gypsiferous sandstones and clays, with brackish water mollusks. The upper part contains medium to coarse sands, usually pebbly to conglomeratic. A few scarce and rolled bones are present in the upper part. Silicified wood is found in two main stratigraphic levels; the lower level is slightly above Unit 4 of the "upper member" of the Sahabi Formation and the upper one is about 15m – 20m higher. This lower part was deposited within lagoonal conditions, whereas the upper part was deposited in a tidal channel.

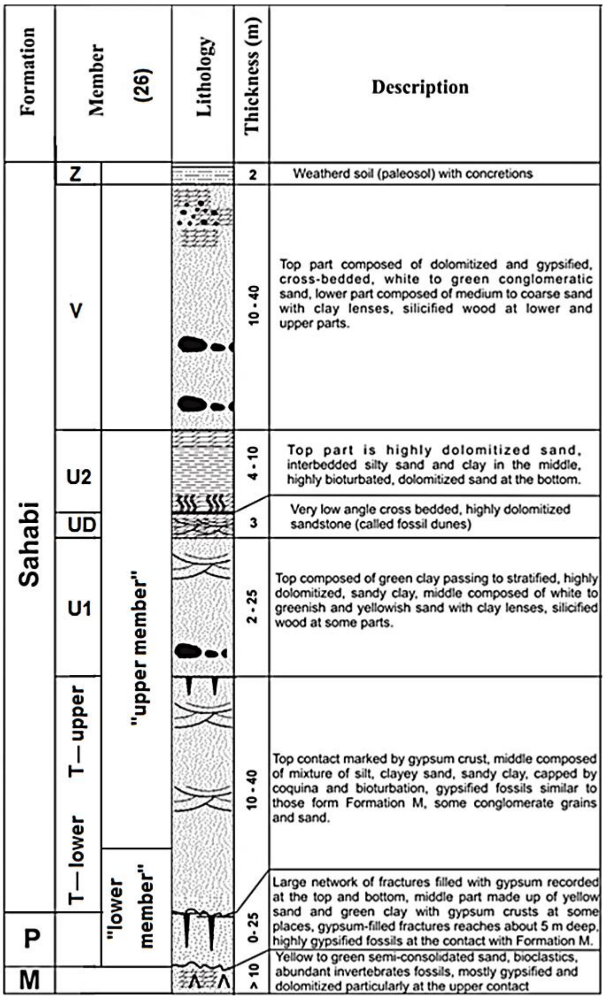

Figure 3. Columnar section showing lithology and sedimentary structures of the Sahabi Formation with its members. (Note: members U1, UD, and U2 are referred to as units 1,2, and 3 respectively). Key symbols are shown in Figure 4.

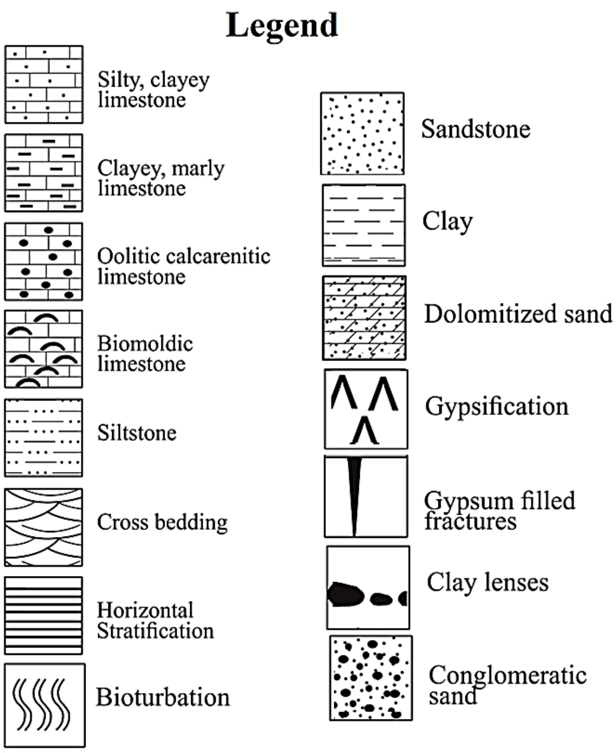

Figure 4. Key symbols used in Figures 2 and 3.

4. RESULTS

4.1 Paleocurrent Analysis in the Wadi Al Farigh Area

Cross-beddings in the Wadi Al Farigh area are very common and mostly characterized by tabular planar and herringbone types (Figs. 5, 6, 7). In stations 1, 2, and 9, the paleocurrent patterns are unimodal with vector mean values of 341, 45, and 71, respectively, and directions of NW, NE, and NE, respectively. This indicates a NE-ward paleocurrent direction for station 1 and an SW-ward direction for stations 2 and 3. In stations 3, 4, 5, 6, 7, and 8, the paleocurrent patterns are bimodal, except in station 5, which is polymodal, with vector mean values of 135, 131, 115, 129, 127, and 133, respectively, but all are in the SE direction. This indicates that the current flew mostly from the NW in these stations. According to the composite rose diagram for the nine stations, the dominant paleocurrent direction was southeast (SE) with a polymodal pattern and vector mean value of 111 (Fig. 7). This effective southeast trend indicates a common northwest (NW) flood current flow, which probably originated from the Mediterranean marine seawater.

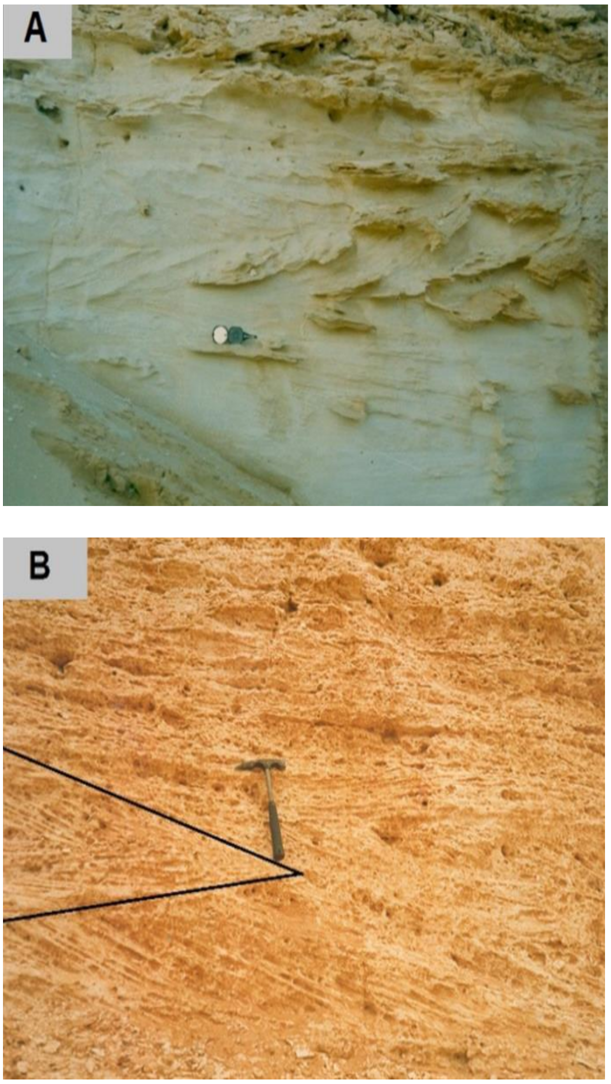

Figure 5. Close-up views of the outcrop in station 3 (A) and station 4 (B) showing the large scale cross-beddings. (Note: herringbone cross-bedded in B).

Figure 6. Close-up views of the outcrop at Wadi Al Farigh area (A) station 8 and (B) station 9 showing planar large-angle cross bedding pattern (A–looking NE; B–looking SW).

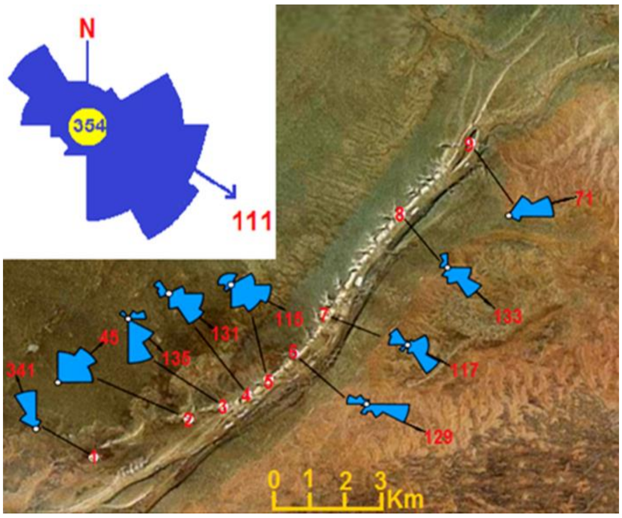

Figure 7. Location map of Wadi Al Farigh area showing the nine studied stations and their paleocurrent directions. Wadi Al Farigh is about 65km southeast of Ajdabiya city. The inset is the composite rose diagram of 354 cross bedding recorded from all stations.

4.2. Paleocurrent Analysis in the Sahabi area

Cross-beddings in the Sahabi area are also very common and mostly represented by a planar pattern with dipping angles up to 30 degrees (Fig. 8A). The paleocurrent pattern in Unit 1 is represented by a dominant bimodal-oblique with a current trend mostly from the southwest (SW) and a mean value of 49. In Units 2 and 3, the cross-beddings are almost horizontal with a low dipping angle, less than 5 degrees (Fig. 8B&C). Figure 9 shows the paleocurrent direction and the mean current of each studied locality in the Sahabi area. In Unit 2, it is a unimodal pattern with current fl0w totally from the northeast (NE) and a vector mean value of 250. In Unit 3, the pattern is mostly bimodal-bipolar with currents flow mainly from the northeast (NE) and an effective mean value of 214. In Member "V", the paleocurrent is characterized by a bimodal-bipolar pattern with current flow mostly from the southwest (SW) and a vector mean value of 25.

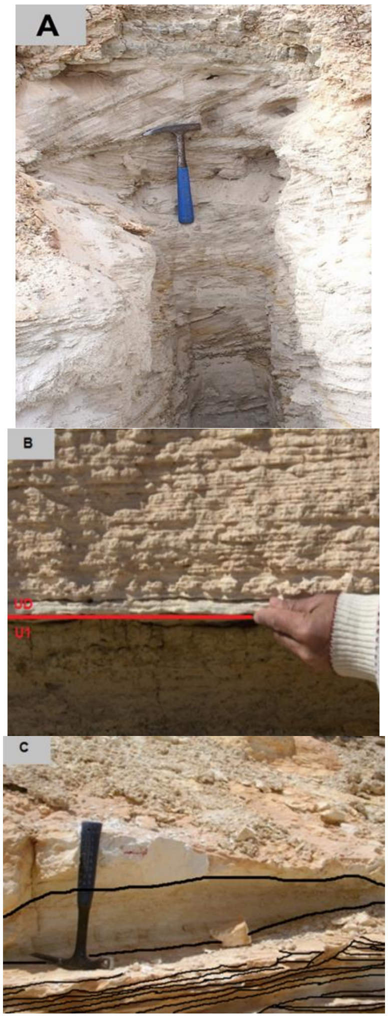

Figure 8. (A) Hand-excavated trench in the middle part of the sequence at locality P 28 in Unit 1. (B) Close-up view showing the very low-angle cross-bedding near the top of the sequence in Unit 2 at locality P134 west of the Sahabi area. (C) Close-up view showing the low angle cross-bedding occurring in dolomitic beds of Unit 3.

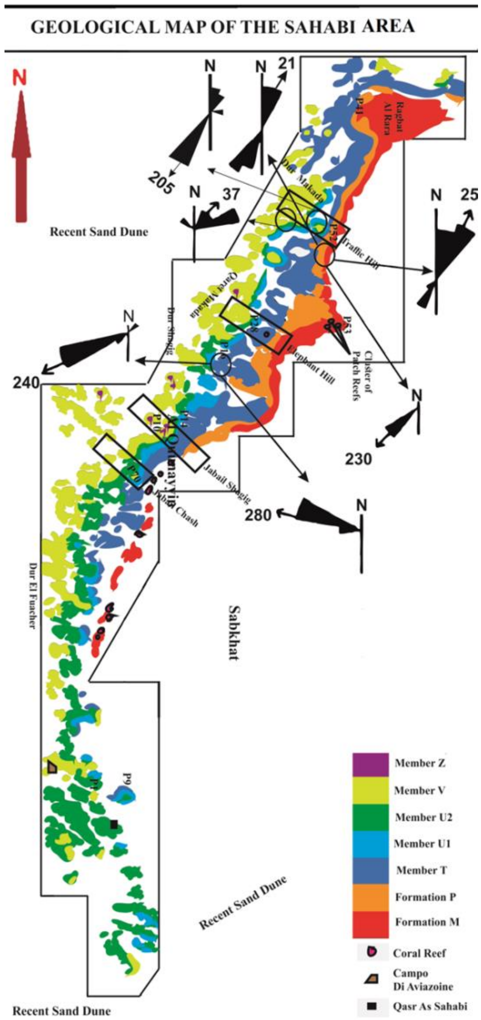

Figure 9. Geological map of the Sahabi area showing the studied stations and their paleocurrent directions and mean current. (Modified from de Heinzelin and El-Arnauti [25]).

5. DISCUSSION AND ENVIRONMENT INTERPRETATION

The lithology of oolites and calcarenites of the Wadi Al Farigh, as an oolitic barrier bar at the north of the area is important to explain low energy mobile water in the Sahabi area at the south. On the other hand, the lithology of siltstone, clays, and shales in the Sahabi and Wadi Al Farigh areas contains no cross-bedding, representing deposition in immobile water. The general bimodal with the bi-directional paleocurrent pattern throughout the Wadi Al Farigh area resulted in different layers of cross-bedding will dip in different directions and this is typical for tidal flows to form herringbone cross-bedding. The presence of a herringbone structure is indicative of flood and ebb tidal current oscillation occurring within inlets scattered along the Wadi Al Farigh Barrier bar (Fig. 10). The flood tidal current flowed from the northwest the majority of the time probably through the Mediterranean invasion (Fig. 10). A minor ebb tidal current flowed from the southeast throughout the inlets probably through the Mediterranean Sea retreat. This indicates that during Late Miocene (Messinian) the Mediterranean Sea fluctuated back and forth throughout the area. The cross-bedding structure and lithology indicate mobile shoal water with water depth probably ranging from 60 cm to 1 m. The evolution of the oolitic barrier bar of Wadi Al Farigh Member would have completely isolated the open shelf, in this case, represented by the Mediterranean Sea, from the inner basin, which is represented by the Sahabi area (Fig. 11). This isolation restricted the deposition of evaporite minerals in sabkhas and lagoons, which represented the Sabkhat Al Hamra Member (Formation "M") and "lower member" (Sabkhat Al Qunnayyin Member/Formation "P") (Figs. 12 & 13). The evolution of the oolitic barrier bar of the Wadi Al Farigh and the retreat of the Mediterranean Sea caused the Eosahabi River to become active. This may explain the current flow from the south and southeast that represent deposition of Units 1, 2, 3, and the lower part of Member "V". The general model demonstrates the direction of flooding, ebbing, and the flow out currents out of the Wadi Al Farigh is illustrated in (Figs. 12 & 13).

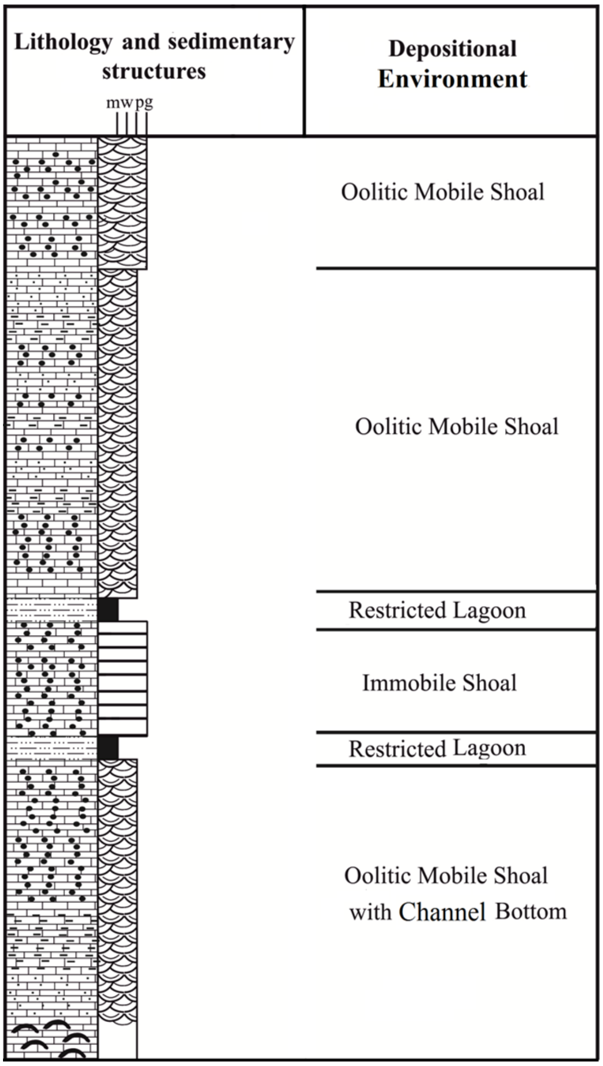

Figure 10. Lithologic composite columnar section showing the major depositional environments of the

studied stations at Wadi Al Farigh area. Key to symbols are shown in Figure 4.

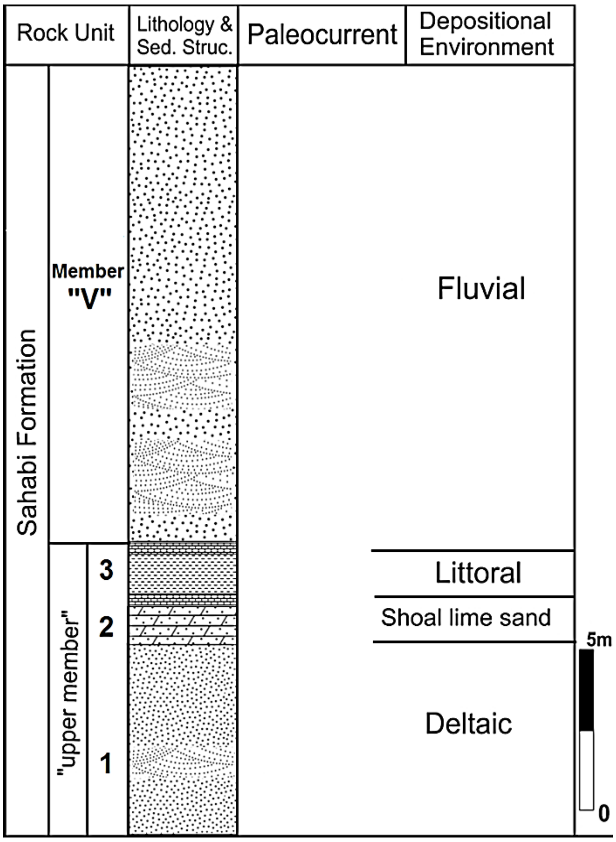

Figure 11. Simplified stratigraphic columnar section showing the major depositional environments of the Sahabi Formation, and lower part of the Member “V”. Key to symbols are shown in Figure 4.

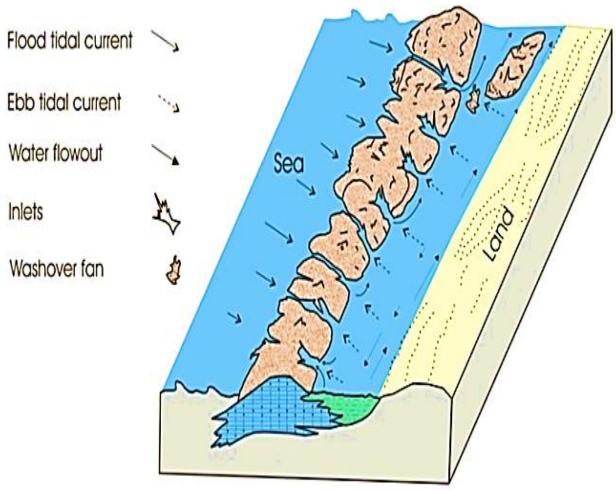

Figure 12. Schematic diagram showing the flood and ebb tidal paleocurrent directions in the Wadi Al Farigh study area (not to scale).

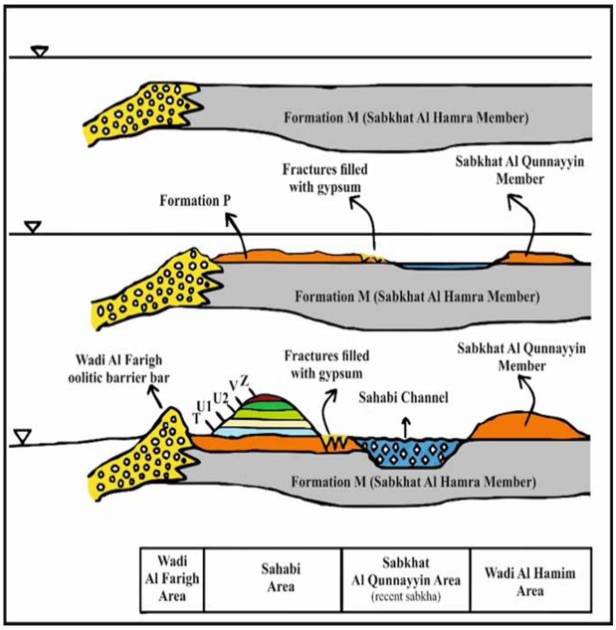

Figure 13. Schematic diagram showing stages of the depositional environments in the Wadi Al Farigh and As-Sahabi areas (not to scale).

6. CONCLUSIONS

- Paleocurrent in the Wadi Al Farigh area is mostly bimodal and originated from NW, which may indicate a Mediterranean Sea periodical invasion.
- Wadi Al Farigh Member constitutes a barrier bar shoal formed by oolitic and calcarenitic sand migration.
- Paleocurrent in the lower member of the Sahabi Formation is unimodal and bimodal and originated from the SW which indicates different palaeocurrent directions in several environments, which range from restricted lagoons and deltaic probably fed by a fluvial supply from the Eosahabi River.
- The lower member of the Sahabi Formation constitutes back-barrier sediments formed by sands, clays, evaporite, and dolomite.

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