

Paleoclimate reconstruction of the quaternary sediments near the Gulf of Aqaba (Southern Jordan)

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Received: 30 June 2015 / Accepted: 20 January 2016 / Published online: 26 April 2016
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Abstract In this paper, the “Aqaba Formation” formed at the margins of the Aqaba Gulf, during the Quaternary, is sedimentologically studied. This formation consists mainly of clayey beds intercalated with friable silty, medium to coarse-grained sandstones, commonly with planar cross bedding, bioturbated by vertical burrows, and poorly cemented polymict conglomerate. It is also comprised of beds of clay-supported conglomerates occasionally displaying intertonguing relationships. The age of the formation is from Lower Pleistocene.

Due to the presence of greenish clay layers within the Aqaba Formation, this means that it was deposited under a stream fresh water environment. It is also noticed that the overlain Pleistocene sediments are rich in Ostracods suggesting a fresh water environment, too. Generally, wetter climatic conditions were prevailing at this period as indicated by the absence of evaporite deposits (e.g., halite and/or gypsum). The clay mineral constituents (kaolinite and illite/smectite intermixed layers) and the absence of palygorskite are supported by the wetter conditions. It is worth to mention that the essential non-clay minerals are quartz and feldspars.

This study presents the developments of the margins of the Gulf of Aqaba during Quaternary and reflects the climatic changes during this period.

Keywords Gulf of Aqaba (South Jordan) · Pleistocene sediments · Lithology · Paleoclimate · Wetland

Introduction

Quaternary period is a very good example for the succession and changes of glacial, interglacial, and dry periods. It is considered as the most important period of the Earth history, despite its short duration, about 2.6 Ma. The Quaternary period is the most recent period, so its materials cover the landscape and support the soil for agriculture and other human activities (Bowen 1978).

Stratigraphically, the Quaternary period includes the Pleistocene and Holocene epochs, as well as the latest chapter of the Earth history (Gradstein et al. 2012). It was a period of major climatic and environmental changes in the last 2.6 million years.

Nevertheless, an understanding of the climatic changes during the Quaternary period is essential not only to appreciate significance features of the natural environment today but also to better comprehend our present climate (Bradley 1999).

The Quaternary deposits of Jordan are widely distributed throughout the country. As a result, they are not recorded in a specific geological group, except those located in the Jordan Rift Valley “Jordan Group” (Abed 2000). The Quaternary sediments of Jordan are deposited in two main localities, namely, the Jordan Rift Valley and the Jordan plateau.

The Quaternary sediments of the Jordan Plateau are deposited in a widespread area lacking geographical distribution (Table 1 and Fig. 1). Many works have been done on the Pleistocene lake sediments in the northern part of the country.

As a paleoclimatic records to provide more information on the Last Glacial Maximum (LGM), about 17–25 Ka, the variations of the climate during that time triggered the researchers

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Table 1 Pleistocene lake sediments of southern Jordan and its assigned ages and references (after Mischke and Al-Saqarat unpubl. data)

Site name	Age (?- Assumed)	Based on	Reference
Al- Hasa	(~ 70–45 ka?, ~32–27 ka, ~14–12 ka, and ~12–8 ka)	^{14}C for geological and prehistoric materials.	Winer 2010
Jurf Ed Darawish	>111 ka through to 640 ka)	3 OSL ages	Moumani 1996
Gregra	Mid Pleistocene (?)	Age of rocks at base and artifacts	Bender 1968
Jafr Qa'a	(16.030 \pm 140 years B.P and 24.470 \pm 240 years B.P)	2 ^{14}C ages	Davies 2005
Mudawwara	(125 ka through to 77 ka)	11 U/Th ages	Petit-Maire et al. 2010
Aqaba	Early Pleistocene (?)	Age of rocks based on geological situation	Abbas 2014

to investigate these sites to understand the paleoclimate of the area (e.g., Lake Lisan and lake Kinnert, Abed and Yaghan 2000a; Hazan et al. 2004).

However, all these studies were referred to the Pleistocene, which might be influenced by the Dead Sea depression during the Quaternary period.

Abed (2000) was the first who described the Pleistocene sediments which are exposed in the Jordan Rift between the Yarmouk River and the Dead Sea and named them “Jordan

Group”. Many researchers studied these sediments and find out that they were deposited in ancient lakes formed during the Pleistocene and thereby could be used as paleoclimatic archives (Picard 1943; Huckriede and Wiesemann 1968; Bender 1968; Horowitz 1979; Abed 1985; Abed et al. 2000b).

In the southern part of Jordan, information about the Quaternary sediments related to the time of deposition, as well as to the paleoclimatic and paleoenvironmental settings is rare (Moumani 2002; Mischke et al. 2011). The existence of lakes

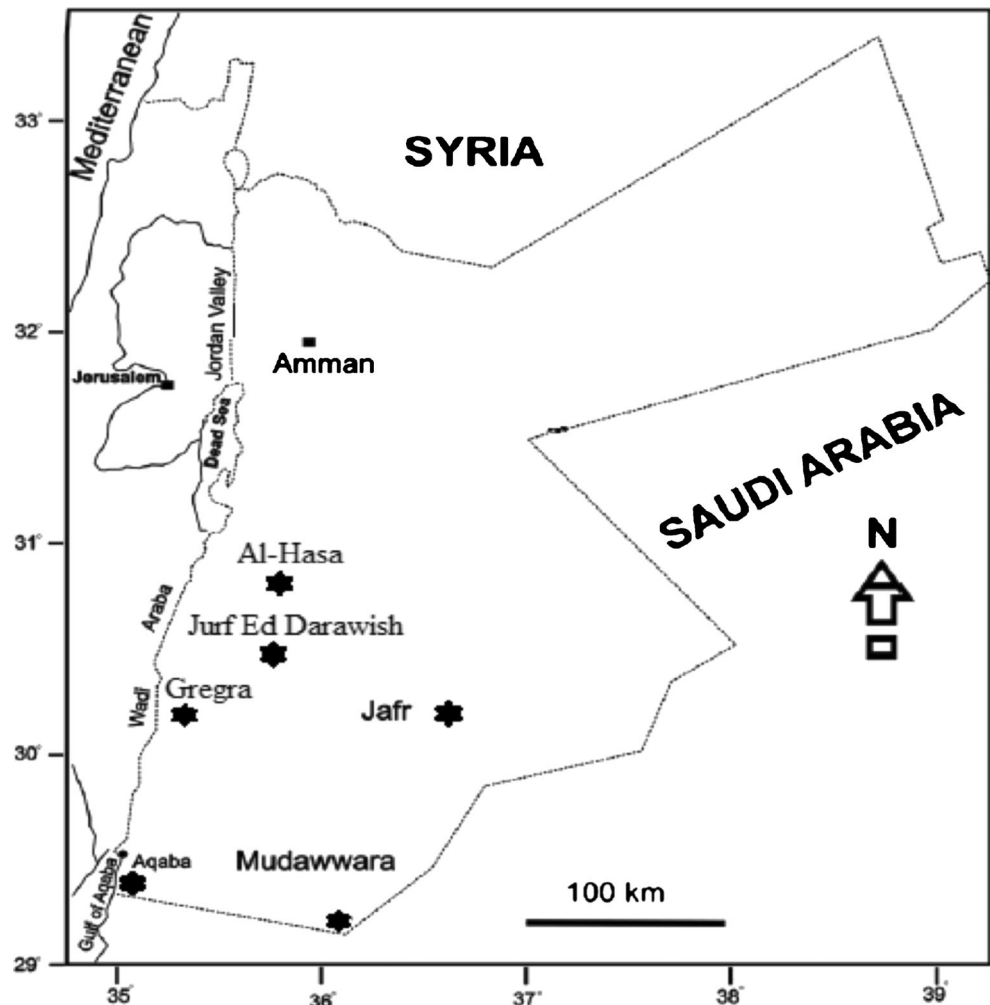
Fig. 1 Sites of Pleistocene lake sediments in southern Jordan

Table 2 The geographical coordinates of the studied localities

Site number	Latitude	Longitude	Elevation (m)
Site #1	29° 25' 42.35" N	34° 58' 35.04" E	24
Site #2	29° 23' 58.77" N	34° 58' 48.28" E	16
Site #3	29° 21' 46.08" N	34° 58' 9.66" E	17
Site #4	29° 21' 54.97" N	34° 58' 45.22" E	23
Site #5	29° 23' 57.80" N	29° 27' 38.27" E	74
Site #6	29° 27' 38.27" N	34° 59' 18.60" E	104
Site #7	29° 23' 53.12" N	29° 23' 22.67" E	112
Site #8	29° 23' 22.67" N	34° 58' 47.32" E	72

during the Pleistocene in this part of the country was proposed by several authors, but information on the spatial extent and permanency of the water bodies and the related water sources was not well constrained (Mischke unpubl. data).

As a consequence, it is essential to investigate the palaeoclimate of the Arabian Peninsula, Jordan in particular, to understand the consequences of Quaternary climate change on the regional landscape development and related land-surface processes.

This study aims to describe a new Formation of Quaternary of Jordan and name it. Also, it aims to understand and reconstruct the paleoclimate and paleoenvironment of this new formation on the basis of its sedimentological and paleontological characteristics.

Location of the study area

The investigated area is located adjacent to the coastline of the Gulf of Aqaba, Southern Jordan, along the highway to Al-Durra border center to Saudi Arabia on its southern limit and High Truck way to Amman on its eastern limit.

The Quaternary sediments cover about 20 km² of the study area and are limited by the following coordinates 29° 23' N and 29°27' E. The Gulf of Aqaba lies in arid climate zone with mean annual precipitation of 37 mm/year on the coast and 50–100 mm/year inland (Freiwan and Kadioglu 2008).

The field work was conducted in 2012, 2013, and 2014. Eight selected sites (Table 2 and Fig. 2) had been chosen to be studied intensively which show a diversity in the characteristics of the sediments.

Geological setting

The investigated area is characterized by outcropping of igneous, metamorphic, and sedimentary rocks of the Arabian Shield.

The igneous and metamorphic rocks are of the Neoproterozoic basement (900 ~ 542 Ma) separated age which is divided into two major complexes, namely, the Aqaba and the Araba Complex, divided by a regional unconformity at nearly 605 Ma (Powell et al. 2015).

Many researchers studied the Aqaba Complex (e.g., Jarrar et al. 1983; Rashdan 1988; McCourt and Ibrahim 1990;

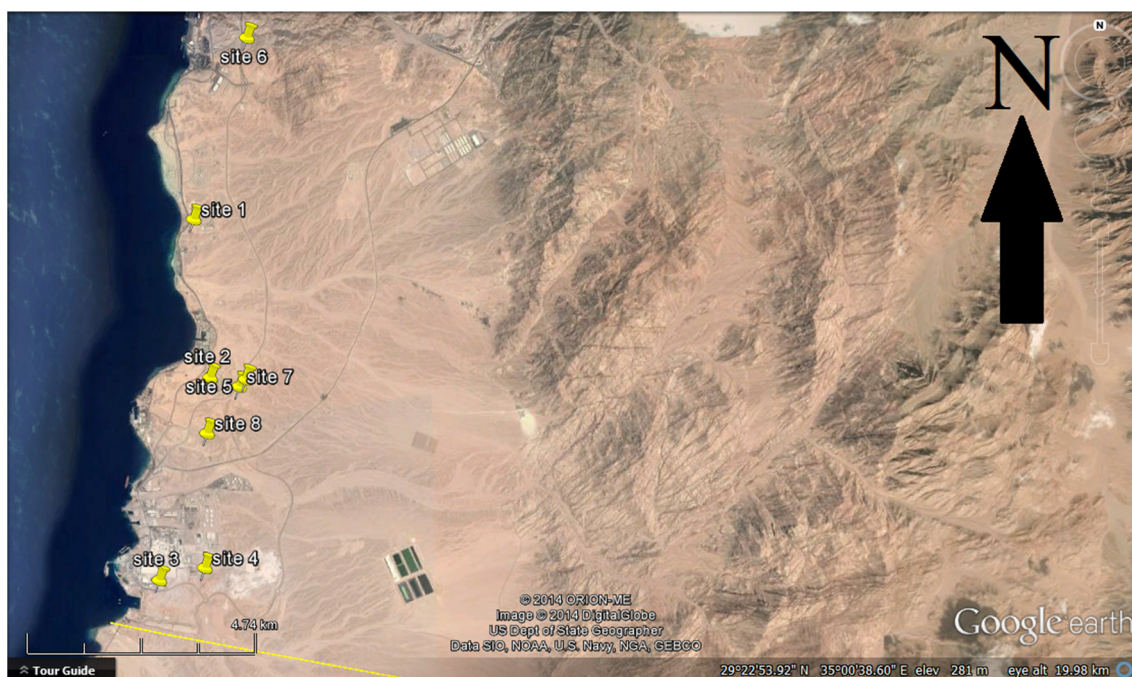
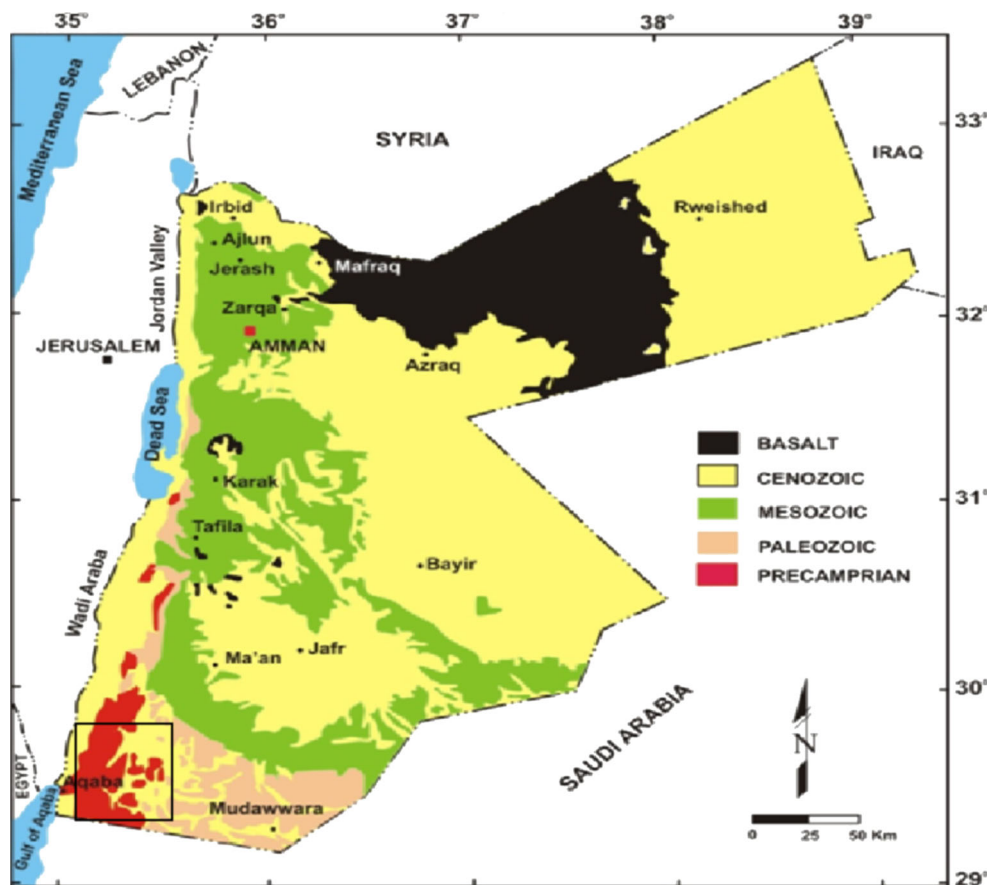


Fig. 2 Google earth image showing the locations of eight selected outcrops investigated in the study area

Fig. 3 Generalized geological map of Jordan showing the location of outcropping Proterozoic rocks (after Andrews 1991)



Ibrahim and McCourt 1995). The metamorphic rocks of the Aqaba Complex (Fig. 3) are found as relatively small outcrops within intrusive rocks with a maximum age of 700–800 Ma (Jarrar et al. 2013), whereas the igneous rocks consist of highly weathered granites, granodiorites, and quartzdiorite and their volcanic equivalence with age of 630–580 Ma (Jarrar et al. 1983; Powell et al. 2015).

Quaternary sediments near the Gulf of Aqaba were mapped in a regional map of Al-Yamanyya and Wadi Al-Hashim map sheet by Alkhatib (1987) as a part of the National Mapping Project by Natural Resources Authority in Jordan. These sediments have been referred to Alkhatib (1987) as Quaternary sediments without any information about their subdivisions or development.

Later on, many investigations have been done on the Uplifted Coral Reefs which were deposited near the shoreline of the Gulf of Aqaba as a result of regression combined with uplifting processes about 120 to 250 Ka (see Al-Rifa'i and Cherif 1988; Gvirtzman et al. 1992; El-Asmar 1997; Strasser and Strohmenger 1997; Shaked et al. 2002; Alhejoj 2013). This is actually motivated the authors to carry out this study to understand and reconstruct the paleoclimate of these sediments and their evolution.

Methodology

A detailed description of lithological variations was carried out at eight different sites. Cross and columnar sections were

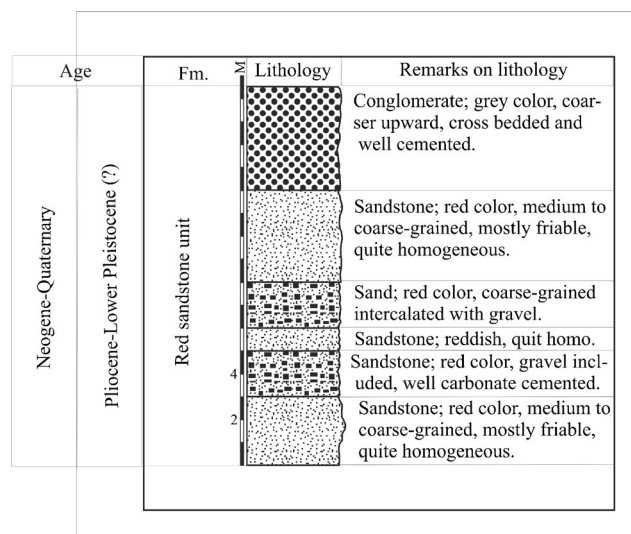


Fig. 4 Graphic log of the Red Sandstone Unit with a stratigraphical description of each layer

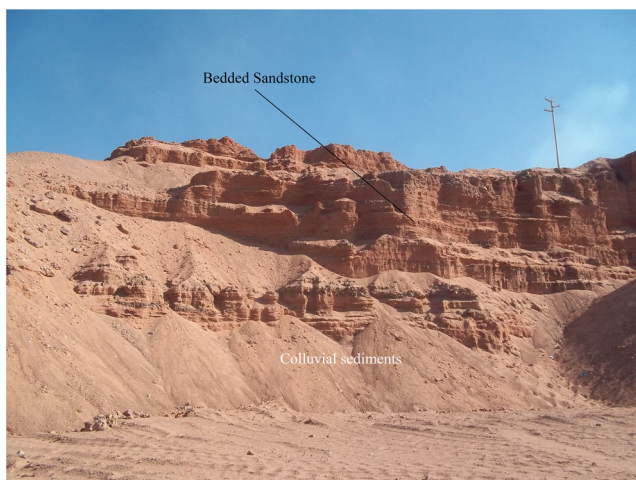


Fig. 5 General view showing the reddish bedded sandstone and the colluvial sediments, about 6 m thick. Photo was taken from site three (29° 21' 46.08" N, 34° 58' 9.66" E)

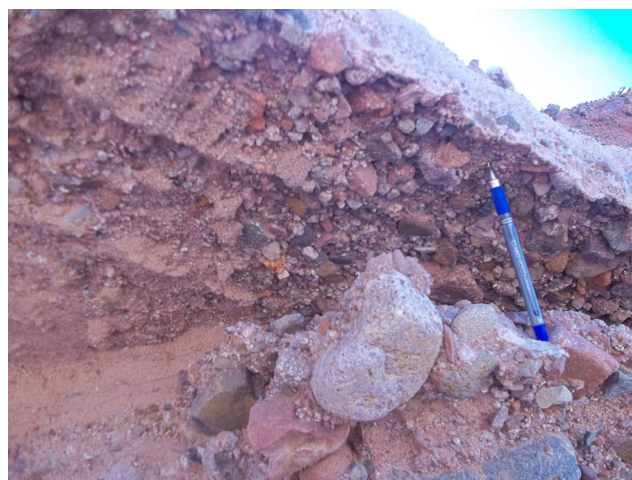


Fig. 7 General view showing the poorly sorted conglomerate in sand matrix in the upper part of the Red Sandstone Unit. Photo was taken from site 3

drawn using Coral Draw software to mark the borders between the layers within the same site, as well as to point out the spatial relationship between the different units. As for the units studied, two cross sections trending (N-E and S-W) were generated to observe the lateral and vertical relationships and variations.

During the field visits, 50 samples were collected for mineralogical analysis from the Red Sandstone Unit (sites 3, 4, and 6) and the Aqaba Formation (sites 2, 5, 7, and 8), and 64 samples were collected from the Aqaba Formation for micro-paleontological analysis.

The Red Sandstone Unit and the Aqaba Formation deposits are more significant to use the collected samples from them, that is, both are have sediments size ranges from sandy to clayey grain size, so these sediments can be pretreated and analyzed.



Fig. 6 General view showing the Red Sandstone Unit overlain by the Aqaba Formation at the top of the section. Photo was taken from site (29° 21' 54.97" N, 34° 58' 45.22" E)

To identify the fossil species, 64 samples from different sites of the Aqaba Formation (sites 2, 5, 7, and 8) were pretreated. One hundred grams of the original samples were disaggregated. The samples were then placed in a diluted H₂O₂ for 24 or 48 h, according to their hardness. The samples were then boiled gently for 30 min, dried and sieved using 30#, 60#, and 120# mesh sieves to separate the macro and microfossils. All four fractions, including the pan, were picked by means of a binocular microscope. A scanning electron microscope was used to help in identifying the microfauna (Abed et al. 2008).

X-ray diffraction (XRD) was used to study the mineralogical composition. For this purpose, 50 samples from different sites of the Red Sandstone Unit and the Aqaba Formation were pretreated. Five grams of each sample were finely ground by pestle in an agate mortar. All samples were run using a scanning rate of 2°/min. From 2 to 65° 2θ, range 4 × 103, and a chart speed 2 cm/min on a Philips Xpert MPD housed in the Institute of Earth and Environmental Sciences, Al-AI Bayt University. Major peak height of minerals in randomly-selected slides and the 001 peak of clay minerals in normally oriented slides were used for semi-quantitative analysis of the minerals present (Banat 1980).

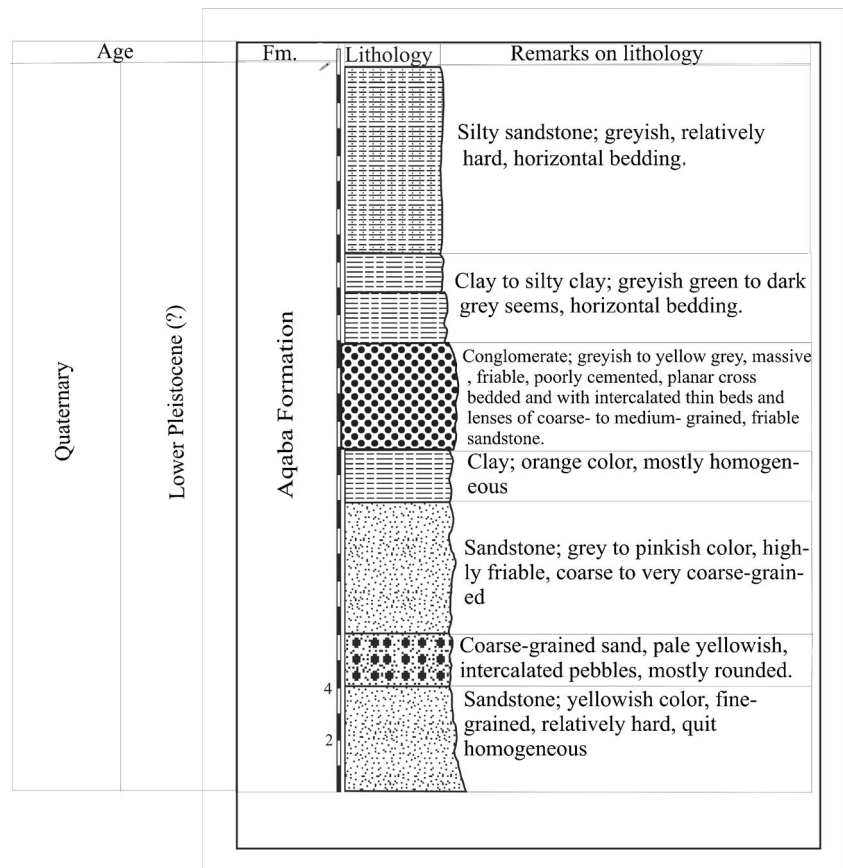
Results

Lithology of the study area

The lithological results of this research present a description of a new rock formation “Aqaba Formation” and other units of Quaternary Period near the Gulf of Aqaba.

The study area is characterized by the presence of Quaternary sediments deposited near the present beach of

Fig. 8 Graphic log of the Aqaba Formation unit with a detailed description of each layer



the Gulf of Aqaba which includes alluvium and wadi sediments, beach deposits, alluvial fans, red sandstone, mud flats, Pleistocene gravels, clay deposits, and raised reefs.

Five units were observed in the study area including the suggested formation: the Red Sandstone Unit, the Aqaba Formation, the Conglomerate Unit, the Uplifted Coral Reefs Unit, and the Alluvium Unit from top to base, respectively.

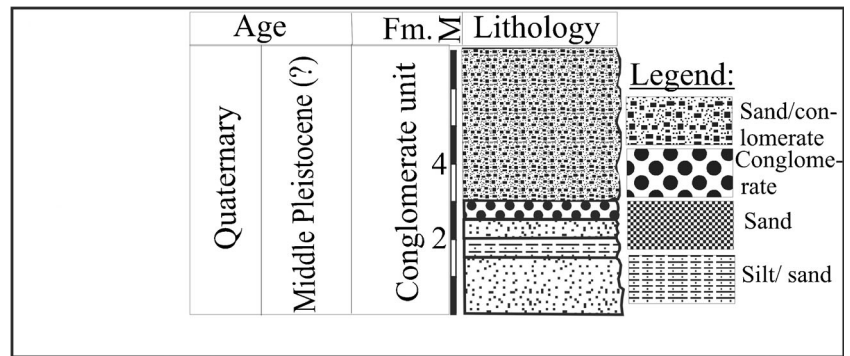


Fig. 9 General view showing an exposure of the Aqaba Formation, site 2, which is located in the western side of the study area along the main road to Saudi Arabia borders near the Tala Bay area. The blue area corresponds to the Red Sea, Gulf of Aqaba (29° 23' 58.77" N, 34° 58' 48.28" E)



Fig. 10 Normal faults resulted from the divergent movement of the Red Sea in site 7 which is located at the northeast of the study area at the high truck way (29° 23' 53.12" N, 29° 23' 22.67" E)

Fig. 11 Graphic log of the conglomerate unit



Red sandstone unit

Three sites were investigated and show a similarity in their lithological and stratigraphical characteristics (sites 3, 4, and 6, respectively) with a maximum thickness at site 4 (up to 20 m). The distances between these sites are 3 km.

In general, the red sandstone unit (Fig. 4) is mainly composed of reddish unconsolidated, fine to coarse grained sand with some gravel. It is mostly homogeneous, and poorly sorted, except in site 3, which shows coarse grained size gravel with cross and horizontal bedding (Fig. 5). At site 4, the Aqaba Formation exposed at the top of the section which indicates that it is younger than the Red Sandstone Unit (Figs. 6 and 7).

Sites 3 and 4 are located to the south of the study area, 1 km before the Saudi Arabia border center (Al-Durra) near KEMABKO-MAIN PLANT factory, and they are a little bit similar in their content. Site 6 is present above in the third highway trucks road to the northeast of the study area, and it is mainly composed of loose reddish fine-grained sand, denser and well cemented by carbonates from rainfall precipitation. Poor gravel content dominates the basal part.



Fig. 12 Sorted conglomerate found in well-cemented sand matrix and overlain by the Uplifted Coral Reefs

The red sandstone unit probably results by weathering of the Paleozoic Nubain sandstone, the high amount of plagioclase, and the paleocurrent direction towards the Gulf. The age of the Red sandstone unit is Pliocene-Lower Pleistocene.

Aqaba formation

The Aqaba Formation refers to the Al-Yamaniyya clay deposits developed close to the shoreline of the Gulf of Aqaba. This formation extends for about 12 km along the coast with an average width of 6 km. Ibrahim and Abdelhamid (1991) described these deposits and assigned them to Pleistocene. They reported that the clay bearing beds occur at several levels and vary in their thicknesses from 20 cm to 3 m.

This formation mainly consists of clayey beds which are intercalated with friable silty, medium to coarse-grained sandstones, commonly with planar cross bedding, bioturbated by vertical burrows, and poorly cemented polymict conglomerate. It also comprises beds of clay supported fine sand and occasionally displaying intertonguing relationships with the Conglomerate unit.

Four sites have been investigated during the field survey (sites 2, 5, 7, and 8), and the distance between these

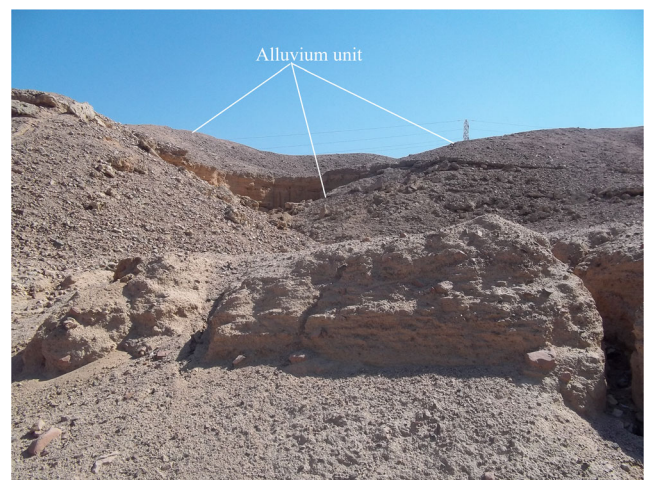


Fig. 13 The widely distributed alluvium unit in the study area

Table 3 The various representative types of clay minerals indicated from the XRD diagrams. Samples were derived from the Aqaba Formation. (s.t refers to site number)

Sample no.	I/S	K	I/M	P	C
SJ14-s.t 2-4	††	†††	†††	–	–
SJ14-s.t 2-8	††	†††	†††	–	–
SJ14-s.t 5-6	†††	†††	††	–	–
SJ14-s.t 7-5	†††	†††	††	–	–
SJ14-s.t 8-7	†††	†††	††	–	–

Note: I/S illite/smectite, K kaolinite, I/M illite/montmorillonite, P palygorskite, C chlorite

††† indicates major, †† indicates minor, and † indicates trace

sites is about 4 km from each other. All of them show similarity in their lithological and stratigraphical characteristics (Figs. 8, 9 and 10). Site 2 is a representative site for the Aqaba Formation located at the Tala Bay area in the western part of the study area with thickness up to 40 m. It is composed mainly of greenish, reddish, grayish clay beds, intercalated with silt, fine to coarse-grained friable sand, and conglomerate. Sites 5, 7, and 8 lie at the North-East of the study area and are also characterized by the presence of varied colors clayey beds with silt, sand, and conglomerate.

The thickness of the formation increases towards the southwest of the study area and reaches its maximum thickness at site 2. The distribution of the formation was determined by the presence of greenish beds which were considered as marker beds and are distributed and extended along widespread area and appear at the outcrops of the formation.

Conglomerate unit

The northwestern part of the study area consists of poorly sorted conglomerates. This formation consists mainly of igneous and metamorphic gravels which are accumulated in a sandy matrix and found underneath the Coral Reefs Unit and displaying intertonguing relationship with the Aqaba Formation. This unit varies in thickness, from 3 to 6 m, and its maximum thickness is

Table 4 The various representative types of non-clay minerals in the Red Sandstone Unit as explained from the XRD diagrams. Samples were derived from the Red Sandstone Unit. (s.t refers to site number)

Sample no.	Quartz	Feldspars	Calcite	Halite	Gypsum
SJ14-s.t 4-6	†††	†††	†	–	–
SJ14-s.t 3-2	†††	†††	†	–	–
SJ13-s.t 6-1	†††	†††	††	–	–

††† indicates major, †† indicates minor, and † indicates trace

up to 6 m (Figs. 11 and 12). Some beds of gravel conglomerate can also found in sandstone showing an indication of the paleocurrent direction towards the present coastline (southwest of the study area).

Uplifted Coral Reefs Unit

Coral reefs are carbonates build ups, tropical to subtropical, coastal ecosystems comprising very diverse organisms. Their ancient counterparts, reef deposits, provide important, high-resolution records of geologic events in tropic to subtropical shallow waters, such as vertical and lateral tectonic movements, sea-level fluctuations, paleoclimatic changes, and paleoceanographic variations.

The shoreline of the Gulf of Aqaba is well habituated with fringing coral reefs that are considered as the main element of the ecological system. Fringing coral reefs and marine Sea Grass in the Gulf enhances a typical environment for marine living organisms (Silverman and Gildor 2007).

Well-preserved uplifted coral reefs were observed in four locations along the shoreline of the Gulf, namely:

- East of the Marine Science Station,
- Opposite to the national camp site,
- Opposite to the northern end of the marine park, and
- Opposite to the Royal Diving Center (data from Alhejoj 2013; Al-Rashdan 2013).

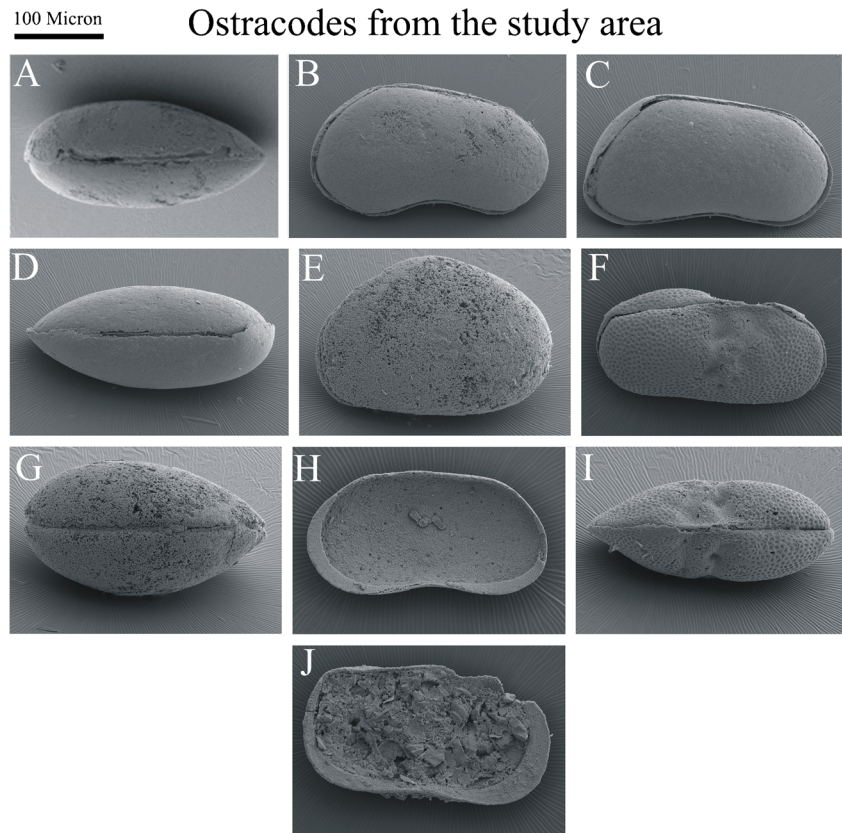
The Natural Resources Authority (1988, cited in Al-Rashdan 2013) reported that there are three major cycles of the uplifted fossil coral reefs in the forementioned locations that can be attributed to the eustatic sea level changes during the glacial and interglacial episodes of the Late Pleistocene.

The age of marine reefs was constraint between 120 and 250 ka by (Lazar et al. 2004; Shaked et al. 2005). At the present time, the height of the coral reefs ranges between 5 and 50 m (Alhejoj 2013) and probably deposited as a result of the regression of the Gulf of Aqaba during the Late Pleistocene.

Alluvium unit

The uppermost Pleistocene alluvium covers about 50 % of the study area. They form the main feature of the mountain front facing the coast of the Gulf, where they are deposited as a result of a series of coalesced old alluvial fans. Towards the Gulf, the gravels are deeply dissected, up to 50 m, by the recent wadis. The gravels and alluvium deposits are accompanied with wadi sediments, together with the formation of fans (Fig. 13).

Fig. 14 Scanning electron microscopy photo micrographs of ostracodes from the studied area. **a** Dorsoal view caparace of *Candona neglecta*. **b** *Candona neglecta*, male. **c** *Candona neglecta*, female. **d** caparace of *Candona neglecta*. **e** Poorly preserved valve. **f** *Ilyocypris* sp. **g** Dorsoal view of caparace. **h** Internal view of *Candona neglecta*. **i** *Ilyocypris* sp. dorsoal view. **j** Internal view of *Ilyocypris* sp. note that samples **a–d** were derived from site 2. **e, h, f** site 5. **i, g, j** site 8



Mineralogy

The studied samples were derived from two rock units; the Aqaba Formation and the Red Sandstone Unit. The samples that derived from Aqaba Formation consist mainly of clay minerals showing abundance of kaolinite illite/smectite mixed layers and illite/montmorillonite mixed layers (Table 3).

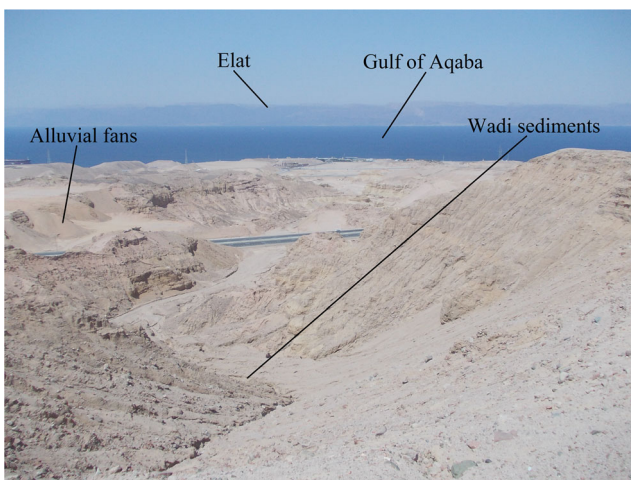


Fig. 15 Courses of the sediments to the Gulf of Aqaba through the wadis generated by floods in times of high rainfall

Chlorite, palygorskite and evaporites such as gypsum and halite were not recognized.

The studied samples from the Red Sandstone Unit were selected from three different localities (sites 3, 4, and 6) and show similarity in their mineralogical components which is comprised mainly of quartz and feldspars with minor amount of calcite in site 6 and traces in sites 3 and 4. This probably explains that the sandstone at site 6 is denser than that in sites 3 and 4 which acts as a cement material at site 6, while sandstone at sites 3 and 4 is more loose (Table 4). The amount of feldspars supports that the origin of the Red sandstone unit is from the Upper Paleozoic sandstone, Salab formation, which contains high amount of feldspars.

Paleontology

Macrofossils were not observed in the study area, except those in the uplifted coral reefs unit. As a result, microfossils analysis was carried out in order to obtain a clear image of the paleoclimate and paleoenvironment of the study area.

The microfossils analysis was carried out on samples of the Aqaba Formation, since the other units observed in the studied area are coarse-grained and friable. As a consequence, the conditions are not suitable for preserving microfossils. Ostracodes were preserved in the fine grains of Aqaba Formation and were poorly preserved and sparse (Fig. 14)



Fig. 16 Marker bed of the Aqaba Formation and its extension westward to the Gulf. Photo was taken from the third high truck way of the study area

probably due to the high energy environmental conditions. Samples from site 7 of the Aqaba Formation did not include any species of microfossils.

Discussion

As previously mentioned, the Quaternary sediments were deposited near the shore of the Gulf of Aqaba and the thicknesses of the layers increase towards the shore.

The role of the Gulf during Pleistocene is still a matter of debate especially with the presence of the fossil coral reefs at about 500 m of the present shore of the Gulf and about 70 m a.s.l. This led to raise questions about the development history of the Gulf since Miocene to present.

The presence of three major cycles of fossil reefs development which have been recognized at the Gulf of Aqaba suggest that the eustatic changes of the sea level, as well as, the coastal erosion processes and faulting has led to the formation of various terraces of the uplifted fossil coral reefs which correspond to glacial and interglacial episodes of the Late Pleistocene Epoch (Al-Rifaiy and Cherif 1988).

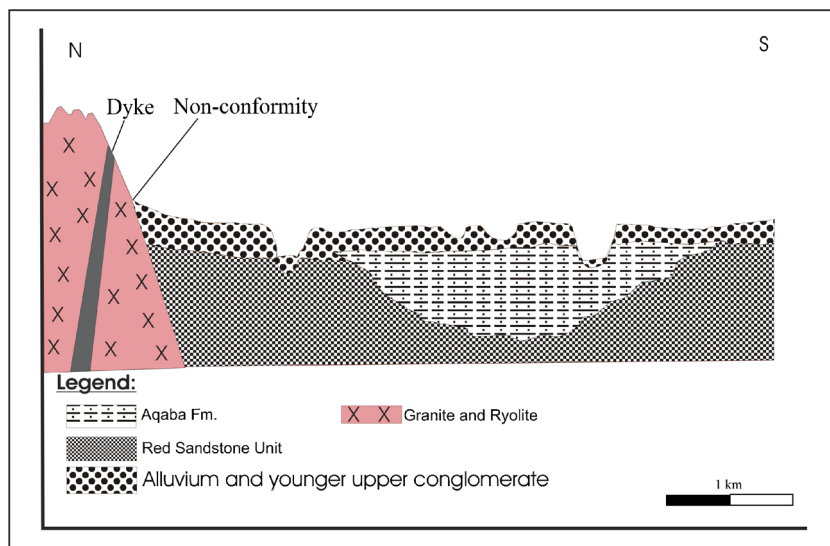
The sea water of the Gulf of Aqaba reaches depths of over 1800 m, and its coast is steeply by step faults (Friedman 1965). The living reefs tend to disappear, even beneath the water, within the part of the reefs near land; however, they are actively growing towards the sea (Gabrie and Montaggioni 1982).

These reefs developed since a minimum of 306,000 years at the area (Gvirtzman and Friedman 1977; Reiss and Hottinger 1984). Within the Gulf itself, which is a site of active carbonate deposition, coarse siliciclastic have been deposited representing submarine fans. Additionally, alluvial fans cover the coast ahead of the most wadis (Fig. 15).

The ages of the different units in the study area were not determined, but on the basis of the field survey it was noted that the Red Sandstone Unit is the oldest. Probably, it belongs to Pliocene-Lower Pleistocene followed by the Aqaba Formation (Fig. 16) which is most probably deposited during Lower Pleistocene, Conglomerate Unit follows Middle Pleistocene. The age of the Coral reefs unit between 120 to 250 ka dated by (Lazar et al. 2004; Shaked et al. 2005) and eventually Alluvium and younger Upper Conglomerate Unit is most probably deposited during the Upper Pleistocene (Figs. 17 and 18).

There are many works which dealt with the reconstruction of the paleoclimate and paleoenvironment of Quaternary sediments on the basis of their sedimentological characteristics (Moumani 1996, 2002; Ginat et al. 2003; Moumani et al. 2003; Winer 2010; Pigati et al. 2014).

Fig. 17 N-S cross section of the units at the lower part, the red sandstone overlain by the Aqaba formation, the Alluvium and younger Upper Conglomerate at the upper part



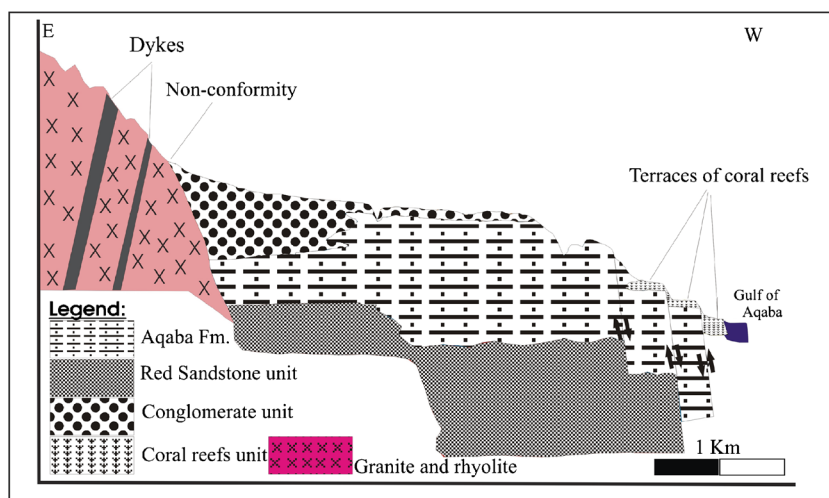


Fig. 18 E-W cross section of the different units in the study area from the older Red Sandstone Unit to the younger Alluvium and Upper Conglomerate Unit

The Quaternary sediments at the southern Aqaba area are represented by alluvium and wadi sediments, beach deposits alluvial fans blown sand, mud flats, Upper Pleistocene gravels, clay deposits, and raised reefs. The Aqaba Formation which is mainly composed of clay and marl beds is intercalated with sand and silt and overlain by the conglomerate unit supports the water body covering part of the area.

The conglomerates suggest a stream environment and the presence of it in such cobbly and pebbly unsorted grains might indicate a flash flood high energy environment. This assumption could be also supported by the presence of poorly preserved and highly recrystallized Ostracodes types (see Fig. 19).

The clay minerals with an average value of 53% (Khoury 2002) such as kaolinite which formed as a result of chemical weathering of feldspar from the upper Proterozoic rocks, and smectite, mainly derived from red clay of site 7, which transformed to palygorskite in a saline alkaline water with the absence of evaporites and palygorskite. Consequently, the depositional environment cannot be hypersaline or evaporative.

Most of the clay deposits of the Aqaba Formation are detrital in origin from the highly weathered surface of the Proterozoic rocks. The weathering products were transported and deposited close to the shoreline of the Gulf. Kaolinite is the final degradational alteration product during the wet periods (Khoury pers. Comm.)

Mineralogical results are matched with the previous work on the mineralogy of Al-Yammaniyya clay deposits (e.g., Ibrahim and Abdelhamid 1991; Abdelhamid et al. 1994; Saqqa et al. 1995).

The microfossils analysis shows the preservation of different types of Ostracodes also supports a wetter conditions and living in a stream fresh water body (Meisch 2000). These findings suggested wetter conditions with a fresh water body

which have been accumulated by a kind of a wetland that was fed by springs were probably beside or even at the exposures of these sediments. The conglomerates that cover the clay beds deposited in streams drained to the Gulf of Aqaba.

Conclusions

This study was performed in order to investigate and describe for the first time the Quaternary sediments near the Gulf of Aqaba, southern Jordan, aiming at the determination of their origin, paleoclimate, and paleoenvironment of deposition.

The main conclusions of this study are summarized below:

- 1) Five units were observed in the study area showing differences on the basis of their lithological characteristics.
- 2) The paleoclimate of the study area is much wetter than the present day climate. This can be noted on the basis of



Fig. 19 Uplift fossil reefs at about 70 m above the present sea level

lithological, mineralogical, and paleontological characteristics of the study area.

- 3) Red Sandstone Unit was probably deposited from the weathering of the upper Arabian Nubian Shield rocks. The reddish color might be attributed to the high amount of feldspar due to the paleocurrent direction towards the Gulf deeply support this argument.
- 4) Aqaba Formation prevailed by fresh water body that might have accumulated by kind of a wetland that fed by springs which were probably beside or even in the bottom mountains. The deposition of kaolinite which originated from the upper Proterozoic rocks by the action of water from the upper mountains supports that. Additionally, the ostracods species gathered from the Aqaba Formation also supported the conclusion that fresh water body covered the area during their deposition.
- 5) The non-clay mineralogical results show abundance of quartz and feldspars, notably from the Red Sandstone Unit. On the other hand, the clay mineralogical results show that kaolinite and illite/smectite mixed layers are the major constituents which are all detrital in origin from the upper Proterozoic rocks and support the assumption that a fresh water body prevailed the area during their deposition in a wetter climate conditions.
- 6) The poorly sorted conglomerate was deposited as a result of floods with high energy environment.
- 7) Uplifted Coral Reefs Unit was deposited by changes in eustatic sea level accompanied with uplifting processes 120 to 250 ka before present.

Acknowledgments The authors would like to thank the team who has participated in the field, the discussions and suggestions during the preparation of this manuscript. This research is a part of the project entitled “Pleistocene Lakes in Southern Jordan: the environmental conditions of the first step out of Africa” and funded by the Deutsche Forschungsgemeinschaft (DFG) (grant no. MI 730/18-1). Bety Al-Saqarat is thankful to the DFG for their fund and support.

Many thanks for Prof. Ghaleb Jarrar -The University Of Jordan, Dr. Mohammed Al-qudah, Yarmouk University, for reviewing and Mr. Khaled Moumani for intensive and fruitful discussion.

References

- Abbas M (2014) Investigation and reconstruction the paleoclimate quaternary sediments near The Gulf of Aqaba, Southern Jordan. In: MSc thesis, Al-Albayt University. Jordan, Mafraq
- Abdelhamid, G., Ibrahim, K., and Mortimer, C., 1994. The Geology of Ayn Al Hashim, Jabal Al Mubarak and Al Yamaniyya, map sheets No.3048I, 3048IV and 2948 I, NRA, Amman, Bull No. 27.
- Abed A (2000) Geology of Jordan. Jordanian Geologists Association, Amman
- Abed A, Yaghan R (2000a) On the palaeoclimate of Jordan during the last glacial maximum. *PALAEO* 160:23–33
- Abed A (1985) Geology of the damya formation. *Dirasat* 12:99–108
- Abed A, Carbonel P, Collina-Girard J, Fontugne M, Petit-Maire N, Reyss J-C, Yasin S (2000b) Un paléolac du dernier interglaciaire pléistocène dans l'Extreme-sud hyperaride de la Jordanie *Comptes Rendus de l'Académie Des Sciences—Series IIA. Earth Planet Scie* 330:259–264
- Abed A, Yasin S, Sadaqa R, Al-Hawari Z (2008) The paleoclimate of the eastern desert of Jordan during the marine isotope stage 9. *Elsevier, Quaternary Research* 69:458–468
- Alhejoj I (2013) Macroaquatic fossils in the Pliocene- Pleistocene deposits of Jordan and their living environments as compared with surviving relatives. Ph.D. thesis. Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany.
- Alkhatib F (1987) Al Yamaniyya and jabal Al Mubarak map sheet no. 2948I, 3048IV. NRA, Geological mapping subdivision.
- Andrews J (1991) Paleozoic lithostratigraphy in the subsurface of Jordan Hashemite Kingdom of Jordan, Natural Resources Authority. *Subsurface Geology Bulletin* 2:75p
- Al-Rashdan M (2013) Geochemistry and mineralogy of sediments across the fringing reef of Aqaba. Implications for Coastal Management. MSc thesis, Yarmouk University. Jordan, Red Sea
- Al-Rifaiy I, Cherif H (1988) The fossil coral reefs of Al-Aqaba, Jordan. *Facies* 18:219–230
- Banat K (1980) Principle of clay minerals. Baghdad University, Iraq(54)
- Bender, F., 1968. Geologie von Jordanien. Beiträge zur regionalen geologie der erde. Vol. 7. Gebrüder Bomtraeger, Stuttgart, 230 pp.
- Bowen, D., 1978. Quaternary Geology. First Edition, British Library Cataloging in Publication Data. p. 1–7.
- Bradley S (1999) Paleoclimatology: reconstructing climates of the quaternary, 2nd edn. Academic Press, USA
- Davies C (2005) Quaternary paleoenvironments and potential for human exploitation of the Jordan Plateau desert interior. *Geoarchaeology: An International Journal* 20(4):379–400
- El-Asmar M (1997) Quaternary isotope stratigraphy and paleoclimate of coral reef terraces Gulf of Aqaba, South Sinai, Egypt. *Quaternary Science Reviews* 16:911–924
- Freiwan M, Kadioglu M (2008) Climate variability in Jordan. *Int J Climatol* 28:69–89
- Friedman M (1965) A fossil shoreline reef in The Gulf of Elat (Aqaba), Israel fringing reefs: space and time constraints from The Gulf of Aqaba. *Coral Reefs* 24:165–172
- Gabrie C, Montaggioni L (1982) Sedimentary facies from the modern Coral Reefs, Jordan Gulf of Aqaba, Red Sea. *Coral Reefs* 1:115–124
- Ginat H, Zilberman E, Saragusti I (2003) Early Pleistocene fresh water lake deposits in Nahal Zihor, Southern Negev, Israel. *Quat Res* 59: 445–458
- Gradstein M, Ogg G, Smith G (2012) A geologic time scale, 2004. Cambridge University Press, Cambridge, p. 589
- Gvirtzman, G. and Friedman, G., 1977. Progressive diagenetic sequences of scleractinian corals—studies in geology 4, Tulsa (Amer Ass Petrol Geol)
- Gvirtzman G, Kronfeld J, Buchbinder B (1992) Dated coral reefs of Southern Sinai (Red Sea) and their implication to late Quaternary Sea levels. *Mar Geol* 108:29–37
- Hazan N, Stein M, Agnon A, Marco S, Nadel D, Negendank J, Schwab M, Neev D (2004) The late quaternary limnological history of Lake Kinneret (sea of galilee). *Quat Res* 63:60–77
- Horowitz, A (1979) The quaternary of Israel. Academic Press, New York
- Huckriede R, Wiesemann G (1968) Dr Jung Pleistozane pluvial see von El jafir und weitere daten zum quattar joraniens. *Geol Palaeontol* 24: 73–95
- Ibrahim K, Abdelhamid G (1991) AL Yamaniyya clay deposits. *Int. Rep. NRA, Amman*
- Ibrahim K, McCourt W (1995) Neoproterozoic granitic magnetism and tectonic evolution of the Northern Arabian Nubian Shield: evidence from southwest Jordan. *J Afr Earth Sci* 20(2):103–118
- Jarrar G, Baumann A, Wachendorf H (1983) Age determinations in the Precambrian basement of the Wadi Araba area southwest Jordan. *Palnet Sci Letts*, 63, 292–304. *J Earth Sci* 14:86–90

- Jarrar G, Theye T, Yaseen N, Whitehouse M, Pease V, Passchier C (2013) Geochemistry and P-T-t evolution of the Abu-Barqa Metamorphic suite, SW Jordan, and implications for the tectonic of the Northern Arabian-Nubian shield. *Precambrian Research*. 239:56–78
- Khoury H (2002) Clays and Clay Minerals of Jordan. Publications of the deanship of scientific research, University of Jordan, Amman, pp. 84–86
- Lazar B, Enmar R, Schossberger M, Bar-Matthews M, Halicz L, Stein M (2004) Diagenetic effects on the distribution of uranium in live and Holocene corals from the Gulf of Aqaba. *Geochimica et Cosmochimica Acta*. 68:4583–4593
- McCourt W, Ibrahim K (1990) The geology, geochemistry and tectonic setting of the granitic and associated rocks in the Aqaba and araba complexes of Southwest Jordan. In: *Bulletin geological mapping division 10*, 96P. Jordan, NRA, Amman
- Meisch C (2000) Fresh water ostracoda of Western and Central Europe. *spektrum akademischer verlag Gmb H*. Berlin, Heidelberg
- Mischke S, Ginat H, Saqarat B, Levin A (2011) Ostracods from water bodies in hyperarid Israel and Jordan as habitat and water chemistry indicators. *Ecological Indicators* 14:82–86
- Moumani K (1996) Quaternary sediments of the jurf Ed Darawish area. University of Wales, Cardiff, United Kingdom, Central Jordan. MSc thesis
- Moumani K (2002) The geology of jabal Al Batra' (jibal thlaja), map sheet (3149-IV). NRA, Amman, Bull No. 52
- Moumani K, Alexander J, Bateman D (2003) Sedimentology of the late quaternary wadi hasa marl formation of Central Jordan: a record of climate variability. *PALAEO* 191:221–242
- Petit-Maire N, Carbonel P, Reyss L, Sanlaville P, Abed A, Bourrouilh R, Fontugne M, Yasin S (2010) A vast eemian palaeolake in Southern Jordan (29 °N). *Glob Planet Change* 72:368–373
- Picard L (1943) Structures and evolution of Palestine with comparative notes on neighbouring countries. *Jerus Hebrew Univ Dept Geol Bull* 4:1–134
- Pigati J, Rech J, Qaude J, Bright J (2014) Desert wetlands in the geologic record. *Earth Sci Rev* 132:67–68
- Powell J, Abed. A, Jarrar. G (2015) Ediacaria Araba Complex of Jordan. *GeoArabia* 20(1):99–156
- Rashdan, M., 1988. The Regional Geology of the Aqaba-Wadi Area Area. Map Sheets 3049 III. 2949II. Geological Bulletin No. 007. NRA.
- Reiss, Z., and Hottinger, L., 1984. The Gulf of Aqaba–EcologicalMicropaleontology, *Ecological Studies*, 50, 354p., 205 Figs,14Tab., Berlin - Heidelberg - New York.
- Saqa W, Dwairi I, Akhal H (1995) Sedimentological, mineralogical evaluation and industrial application of the Pleistocene Al-Yamaniyah clay deposits near Aqaba, Southern Jordan. *Elsevier, Applied Clay Science* 9:443–458
- Shaked Y, Lazar B, Marco S, Stein M, Tchernov D, Agnon A (2005) Evolution of fringing reefs: space and time constraints from The Gulf of Aqaba. *Coral Reefs* 24:165–172
- Shaked Y, Marco S, Lazar B, Stein M, Cohen C, Sass E, Agnon A (2002) Late Holocene shorelines at the Gulf of Elat: migrating shorelines despite tectonic and sea level stability. *EGS Stephan Mueller Special Publication Series* 2:105–111
- Silverman J, Gildor H (2007) The residence time of an active versus passive tracer in The Gulf of Aqaba: A box model approach. *J Mar Syst* 71(1–2):159–170
- Strasser A, Strohmenger C (1997) Early diagenesis in Pleistocene coral reefs, sedimentation and Tectonics in Rift Basins. Red Sea -Gulf of Aden. Chapman & Hall, London, pp. 583–593
- Winer E (2010) Interpretation and climatic significance of late Quaternary Valley-fill deposits in wadi hasa. Miami University, USA, West Central Jordan. MSc thesis