The paleoclimate of Jordan during the Pleistocene as a possible indicator for future climate change: an overview

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ABSTRACT

Several fresh to brackish water paleolakes were formed and sustained in Jordan during the warmer and wetter periods of the Pleistocene: including Umari Lake during the Marine Isotope Stage MIS 9 at 330 Ka (thousand/year), Mudawwara and Samra Lakes during the MIS 5 130-70 Ka, Lisan and Jafr Lakes 30-33 and 25-27 Ka respectively, and the Burqu' Lake during the Holocene Optimum 9-6 Ka.

Studies on the mineralogy of the lake sediments and of their fossil remains all indicate that the water of the lakes was initially fresh but became more brackish at times depending on the climate change. Most of these lakes were more than 1000 km2 in area and from 10 to few hundred metres deep, with possible water temperature of between 15-20°C.

Present-day climate cannot account for the presence of such lakes in the arid to semi arid area of Jordan. Therefore more intense and wetter Mediterranean cyclones in winter coupled with Arabian monsoon or even Arabian-Indian monsoon in summer would have affected major parts of Jordan up to latitude 31° 32´ during the warmer periods of the Pleistocene and brought more rain to establish and sustain such lakes.

However, summer monsoon rains currently postulated for Jordan and adjacent areas remain controversial and are not fully accepted by other workers in this area of research. Consequently, more detail work on the paleoclimate of the Jordan is needed

Key words: Paleoclimate, Paleolakes, Monsoon rain, Jordan, Arabia, Sahara

INTRODUCTION

Paleoclimatology is a branch of Earth sciences which deals with determining the type of climate prevailing on Earth or certain area of it in the ‘near’ past. It tries to understand and explain the factors controlling those climates. Its overall aim is to help predict future trends in climate possibly associated with global warming either across the whole world or on smaller parts of it; e.g. the Sahara, Arabia or the Middle East.

Paleoclimate research work in Jordan and nearby countries is rather limited and cannot be compared with the volume of papers produced in other areas of the world like Europe. Only few papers have been published in the last two decades on the paleoclimate of Jordan. Abboud (2000) reported a humid period at the Holocene Optimum 10-6 ka in Wadi Muqat (Burqu’ Lake) at site 1 (Fig. 1, L1), followed by dry conditions after 5 ka. Jericho first appeared as a village in the Jordan Valley at around 8 ka or slightly earlier (Kenyon, 1979; Neev and Emery, 1995). Huckriede and Wiesemann (1968) described a 1000-1800 km2 fresh water lake in the Jafr basin (Fig. 1, L6) in southern Jordan at 27-25 ka which subsequently disappeared completely during the Last Glacial Maximum (LGM). Abboud (2000) also recorded a humid interval at 25 ka and one dry interval at 21-15 ka in Wadi Muqat Basin (Fig. 1, L1). Abed (1983) and Abed and Yaghan (2000) demonstrated a shrinkage of the huge Lisan Lake in the Jordan Valley-Dead Sea (Fig. 1, L4) to a smaller sabkha during the last glacial maximum LGM. A fresh water area, Lake Damya (L4), reformed in the Jordan Valley around 14-12 ka (Abed, 1985).

Moumani (1996) documented the formation of a 4 km^2 shallow, fresh water lake at Al-Hisa (Fig.1, L5) between 182-82 ka based on 3 OSL (optically stimulated luminescence) dates. A *Cardium* fresh to brackish lake was recorded in the Mudawwara area (Fig.1, L7) at 130-70 ka (Marine Isotope Stages (MIS) 7–5a-e (Masri, 1987; Abed et.al., 2000; Yasin, 2001; Petit-Maire et al. 2002). At the centre of the Azraq Basin (Fig.1, L2), Davies (2000) and Khoury (2003) found that the central part of the Basin was occupied by a lake between 500-250 ka. Turner and Makhlouf (2005) investigated a 652 ± 47 ka, 15 m thick friable sandstone horizon with roots, beta calcrete and gypcrete from the Azraq Formation at the southern periphery of the Azraq Basin (Fig. 1, L3).

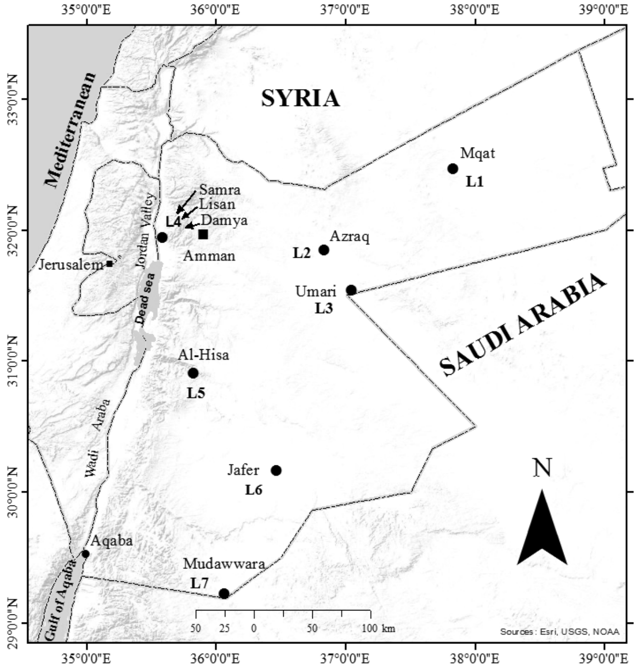

Fig. 1: Location map for the sites of paleolakes studied in Jordan.

They concluded that this sandstone correlates with MIS 17 at 659 ka, which was a wetter/warmer period. Abed et al. (2008) described a warm humid climate producing a fresh water lake or lakes which occupied the area between the Umari border post with Saudi Arabia and the Azraq during the marine isotope stage 9 (MIS 9).

All these works suggest that the climate was wetter and warmer in parts of Jordan during the late Pleistocene. More lakes were formed during those periods and areas with drier climates were less common. This notion is supported by paleoclimate findings in the Sahara, Arabia, and SE Asia, with well-established evidence that previous climates during the glacial periods were cold and dry with the advance and expansion of deserts. By contrast the warmer interglacial periods were wetter with smaller areas of desert (e.g. the Sahara: COHMAP, 1988; Prell and Kutzbach, 1987; Gasse et al., 1987; Yan and Petit-Maire, 1994; Gasse, 2000; Larrosoana, et al., 2003), Arabia (McClure, 1976; Al-Sayari and Zotl, 1978; Fleitmann et al., 2003) and SE Asia (Petit-Maire and Guo, 1997; Zhuo et al. 1998).

On the other hand, several other workers maintained the idea that the area was cold and wet (pluvial) during the glacial periods of the Alps and Europe, and warm and dry (interpluvial) in the interglacial periods (e.g. Horowitz, 1979 to 1992; Bowman, 1990; Neev and Emery, 1995). Thus the aim of this work is provide an overview of the paleoclimate of Jordan and adjacent areas during the Pleistocene and suggest how it could influence our understanding of future climate change in the area.

CLIMATE

The locations of all the paleolakes in Fig.1 are, at present, in the arid areas of Jordan except the Samra, Lisan and Damya lakes which formed in the Jordan Valley-Dead Sea basin. Average annual rainfall, as short duration storms, is less than 150 mm in the north, with the southern ones having less than 50 mm/y (Fig. 2). The weather is characterized by two defined seasons; hot, dry, and dusty with relatively strong northwesterly wind in summer (May-October), and cold, semi dry, windy in winter (November-April) (National Water Master Plan, 2004).

The rainy season in Jordan extends from early October to late April. Figure 2 displays the temporal distribution of rainfall, most of which falls between November through March. During the months November through February, frontal depressions (cyclones) sweep across the Eastern Mediterranean producing westerly to southwesterly wind circulation, lower temperatures, and an increase in humidity and rainfall. Occasional snow events occur at higher elevations in the west. Annual rainfall tapers off towards the east. In February, occasional cold spells and dry easterly winds, driven by the Siberian anticyclones, may cause frost conditions which can be potentially damaging to winter crops. Instability during the fall and spring months (interference between cold Mediterranean cyclones and warm Red Sea cyclones) can lead to torrential rain events and can cause flooding in low laying terrain.

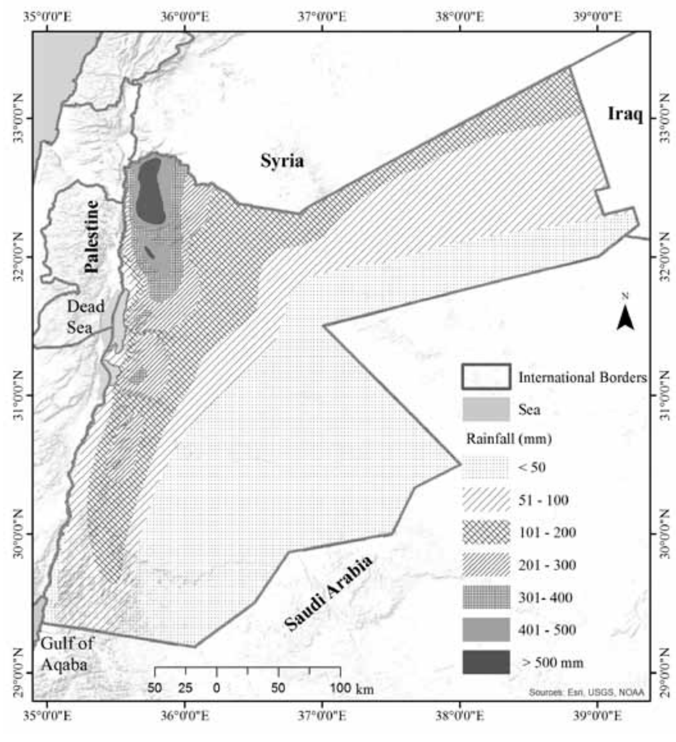

Fig. 2: Rain fall distribution in Jordan.

April and early May are dominated by the Khamaseen cyclones. These cyclones originate in the Mediterranean and pass through eastern North Africa and produce large amounts of dust associated with rains in Jordan. Furthermore, Indian monsoon cyclones affect Jordan and almost all the eastern Mediterranean for days at a time each summer. The weather becomes very hot with maximum temperatures reaching as high as 42° C. Most of the vegetation in the area consists of desert shrubs (salt tolerant plants) and grass along wadis. Farms are developed near the two Azraq towns and east of the mudflat and are irrigated by shallow wells of acceptable salinity.

CASE STUDIES

A brief account of some of the best documented studies on the paleoclimate of Jordan is presented here to provide substance for the current review. Three case studies are presented here to reflect the paleoclimate conditions (temperature and precipitation) in Jordan during the Pleistocene: Samra/Lisan lakes, Mudawwara lake and Umari lake.

Samra/Lisan lakes

The Samra and Lisan are two successive lakes which were present in the Jordan Valley-Dead Sea basin. The Samra lake was a fresh water lake that lived between 135-70 thousand years before present; 135-70 Ka. The Lisan lake (Fig. 3) was of mixed salinities and spanned the period around 65-15 Ka (Picard, 1943; Begin et al. 1974; Abed, 1985; Abed and Yaghan, 2000).

The **Samra Lake** is approximately coeval with marine isotope stage 5 (MIS 5) 130-70 Ka. The MIS 5, especially MIS 5e or the Eemian period, is well known for being one of the warmest and wettest periods throughout the glacial period of 2.6 million years (Ma) (Ogg et al. 2008; Cronin, 2010). The deposits of the lake in Kherbet El Samra, some 6 km north of Jericho (Picard, 1943) and elsewhere in the Jordan Valley, consist of limestone, sandstone, clays and conglomerates with no evaporates. The lack of evaporites is clear evidence that the lake water was fresh. The Samra Lake was separated from the Mediterranean due to the continuous uplift of the mountains on both sides of the rift (Quennell, 1958; Bender, 1974; Powell, 1989). Thus the source of water for the lake was the rain fall from its catchment area on both side of the Jordan Valley-Dead Sea basin. Consequently, the precipitation at the Samra time must have been much higher when compared to that of today in order to produce a fresh water lake several times larger than the Dead Sea and Lake Tiberias. In conclusion, the climate of Jordan was much wetter and warmer than that of today.

The **Lisan Lake** was studied in much more detail compared with the Samra Lake because of to its extensive sediment outcrops extending from Lake Tiberias in the north to northern Wadi Araba in the south, a distance of more than 200 km (Fig. 3). The life time of the Lisan Lake is around 65 – 15 Ka (Abed and Yaghan and the references therein).

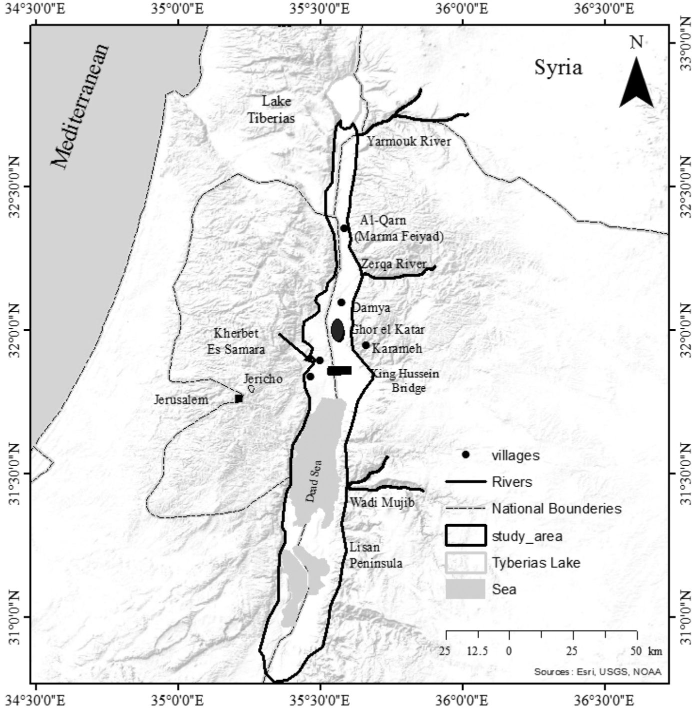

Fig. 3: The extent of the Lake Lisan occupying the rift valley from Lake Tiberias in the north to more than 25 km south of the Dead Sea. Also shown are the localities mentioned in the text.

There are three different and distinct types of lithologies of the Lisan sediments reflecting the prevailing salinities of the water body. They are from north to south:

1. The northern basin extending from Lake Tiberias in the north to the Qarn (Marma Fayad) in the north central Jordan Valley (Fig. 3). The Lisan sediments in this basin consists of alternating varves of aragonite and fresh water diatomites. No evaporates are reported and the lake water should be fresh (Begin et al. 1974; Abed, 1985). The presence of a fresh water lake in the northern most Jordan Valley can be understood by the fact that it is situated proximal to the main fresh water resources in the Upper Jordan and Yarmouk Rivers (Abed, 2014).

2. The middle area of the Jordan Valley from the Qarn in the north to the area opposite to the town of Karameh. The Lisan sediments in this area consists of alternating lamina (varves) of aragonite and clays with no evaporates up till the topmost few metres called the white cliff which consists of alternating gypsum and aragonite (Fig. 4). Abed and Yaghan (2000) demonstrated that the sediments below the white cliff (65-23Ka) were deposited from a fresh to brackish water bodies. The salinity of the lake at this time interval is indicated by the non presence of any evaporate minerals in addition to several fresh to brackish water fossil species. Abed and Helmdach (1981) studied the fossil content, especially the ostracods, of the Lisan sediment in a section near the Damya Bridge (Table 1).

Table (1) Example of fossil content, especially the ostracods, of the Lisan sediment.

Fresh to slightly brackish water environment	**Brackish water environment**
Cypredeis torosa	*Cyprinotus salinus*
Candona hartwigi	*Ilyocypris cf. gibba*
Darwinula sp	*Ilocypris dentifera*
Candonopsis kingsleweii	
Darwinula cf. stevensoni	

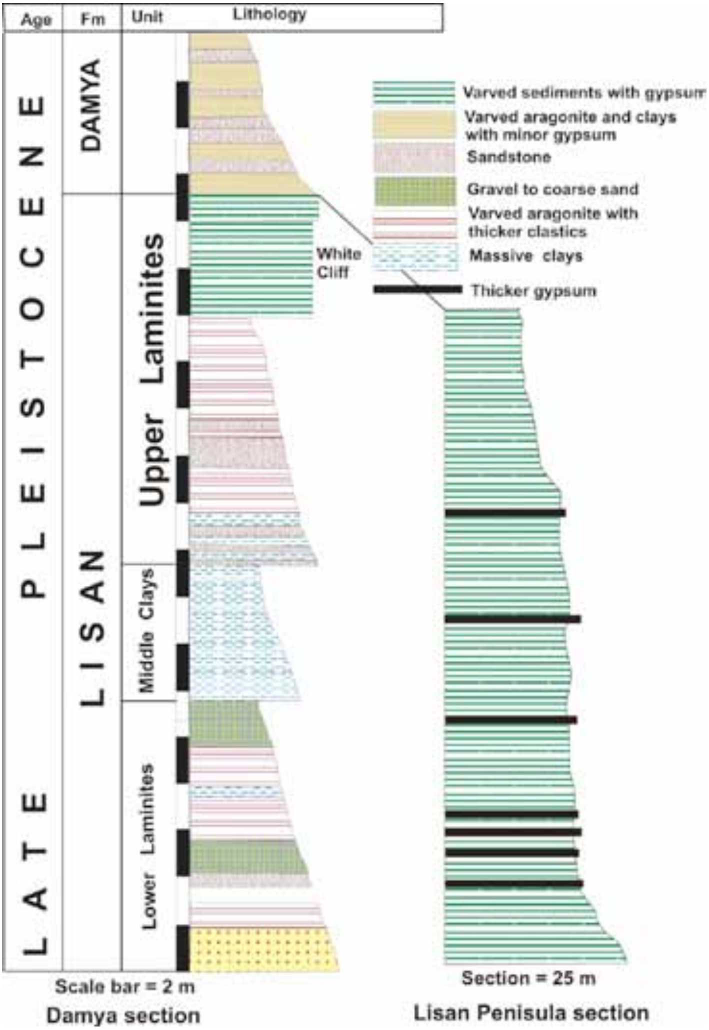

Fig. 4: Lithology of the Lisan Lake sediments in the intermediate area west of the Karameh town (left) and in the Lisan Peninsula (right) (Abed, 1983; Abed and Yaghan, 2000).

The white cliff itself (23-15 Ka), which has gypsum, was deposited from salt water with a salinity in the range of 100-120 ‰ (part per thousand or ppt), much too high for organisms to live in. The time of deposition of the White Cliff is interpreted by Abed and Yaghan (2000) coincides with the Last Glacial Maximum (LGM); the last maximum glaciations during the Pleistocene. Obviously, the climate was globally cold and seemed to have less rain fall, thus, allowing for the higher salinities in this area of the Lisan Lake. It should be emphasized that Lake Lisan disappeared almost completely by about 15 Ka and became a sabkha; i.e. during the LGM cold period. This is confirmed by the absence of Lisan sediments above the white cliff in this area.

3. The southern basin involves all the Dead Sea area especially its central part. The Lisan sediments are well displayed in the Lisan Peninsula and consist completely of alternating varves of aragonite and gypsum (Fig. 5). This means that the water within this basin of

Fig. 5: Field photo showing the thin lamination (varves) in the Lisan Lake sediments in the Lisan Peninsula, Dead Sea.

the Lisan Lake was saline throughout. This is most probably due to less water arriving to the Dead Sea area from the north as well as to greater evaporation.

As explained above, Lake Lisan became drier at about 15 Ka during the LGM. A warmer climate prevailed after that, and a new smaller fresh water lake called Damya Lake formed and continued for about 2000 years from 14-12 Ka, indicating a warmer and wetter climate (Abed 1985). This is evident from the presence of 14 m laminated sediments in the Ghore El-Katar - Damya area representing the Damya Lake. Damya Lake also became smaller because of a short-lived cold period called the Younger Dryas at around 11 Ka which led to the formation of the Dead Sea with its present day shape at around 11-10.5 Ka. Again, changes to Lake Damya during the Younger Dryas period would indicate a cold and dry climate.

In the opinion of the author, but see also Begin et al. (1974) and Abed and Yaghan (2000) for more details, two reasons were responsible for the segmentation of the salinities of the Lisan Lake. The first reason is the presence of a paleohigh (natural dam) in the Qarn area which regulated the flow of water to the lake. The second, is that the source of water to the lake was from the Upper Jordan River and the Yarmouk River both in the north, as the situation is at present. The northern basin receives enough fresh water overtops the paleohigh and enters to continue as a fresh water lake, with the excess water the paleohigh enters the middle area and the Dead Sea basin in the south. Evaporation within the Dead Sea basin area can also be added to explain the precipitation of the evaporate gypsum facies.

The Lisan Lake water level was not the same throughout its history. Abu Ghazleh (2011) mapped and dated in details the fluctuations of the lake levels. She concluded that the Lisan Lake levels were highest during the warmer intervals between 33 – 25 Ka when conditions were wetter. This conclusion was supported by the work of Huckriede and Wiesemann (1968) on Lake Jafr, a fresh water lake that occupied the Jafr basin east of Ma’an at the same time with a surface area of 1000-1800 km^2, at around 27-25 Ka. Both lakes occurred during the same period of wet and warm climate in Jordan.

The Mudawwara Lake

The sediments of this lake were studied by Suha Yasin in her Ph. D thesis at the University of Jordan (Abed et al. 2000; Yasin, 2001; Petit-Maire et al. 2002). Masri (1987) named this Lake Halat Ammar Lake. The lake lies at the southern border with Saudi Arabia and includes parts of both countries (Fig. 6). The lake was about 1200 km^2 in

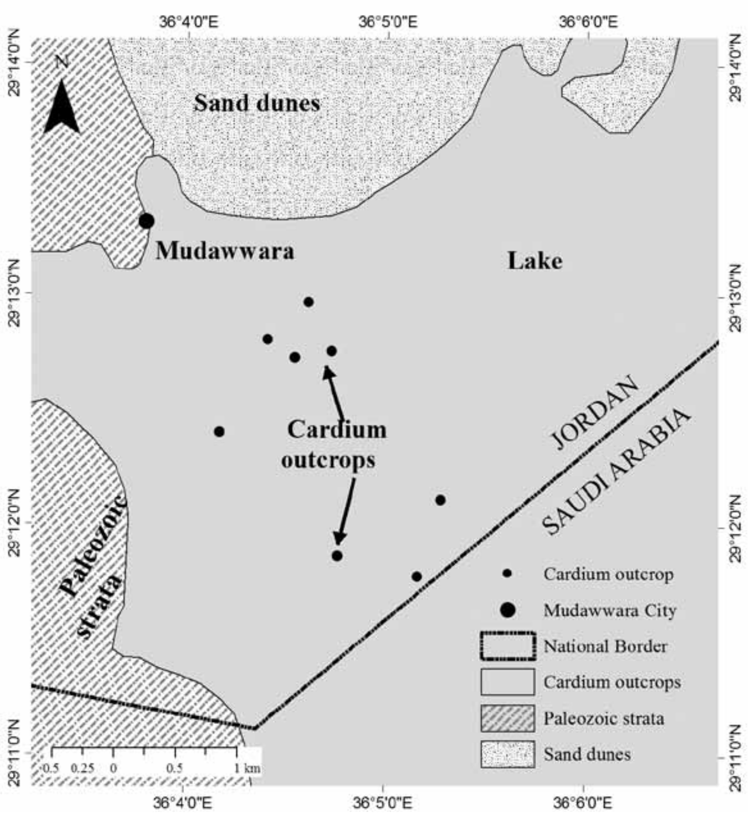

Fig. 6: The Mudawwara Lake at the extreme southern Jordan which includes Saudi Arabia. The limits of the lake are approximate.

area with a depth of between 10-12 m. It existed between 135-70 Ka with a peak being at the Eemian stage of the MIS 5. Consequently, it was coeval with the Samra Lake in the Jordan Valley. The macro and micro fossils recovered from the sediments show that it was a freshwater lake at that time.

The abundant rainfall for the Samra Lake may be explained by the Mediterranean cyclones which usually occur in winter, similar to those of today except possibly being more intense. The nearness of the catchment area, in Lebanon, Syria and Palestine to the Mediterranean Sea can help in this interpretation. However, the Mudawwara Lake is more than 300 km to the south and present winter cyclones rarely arrive to that area now. In fact, the annual rainfall cannot exceed 20mm/year and the Mudawwara area, at present, is a desert. The question is how a fresh water lake, 1200 km^2 and 10 m deep could be produced and maintained in such a desert environment unless the rainfall was many times higher than at present. For this reason, monsoon (summer rain) rain is advocated to have affected the area at the time of the Mudawwara Lake (Cohmap, 1988; Abed et al. 2000; Yasin, 2001; Petit-Maire et al. 2002). It seems possible that the Arabian monsoon was more intense during MIS 5, consequently it was able to bring summer rain to southern Jordan to a latitude of 30°. The Mudawwara area was probably affected by the Mediterranean cyclones in winter and the monsoon cyclones in summer, a pattern which could explain the rain fall needed to form and sustain a large fresh water lake during the Eemian stage of MIS 5.

The Umari – Azraq Lake

Two *Cardium* shell beds representing this lake are present at the Umari border point with Saudi Arabia, coordinates 31° 32’ N, 37°06’ E, and at about 10 km NE of the Azraq Druz town at the highway to Iraq, coordinates 31° 55’ N, 36° 45’ E (Fig. 7).

The shell beds form the uppermost part of Azraq Formation (Ibrahim, 1996; Raba’a, 1998; Turner and Makhlouf, 2005; Abed et al. 2008). Abundant macro and micro fossils making the shell beds are

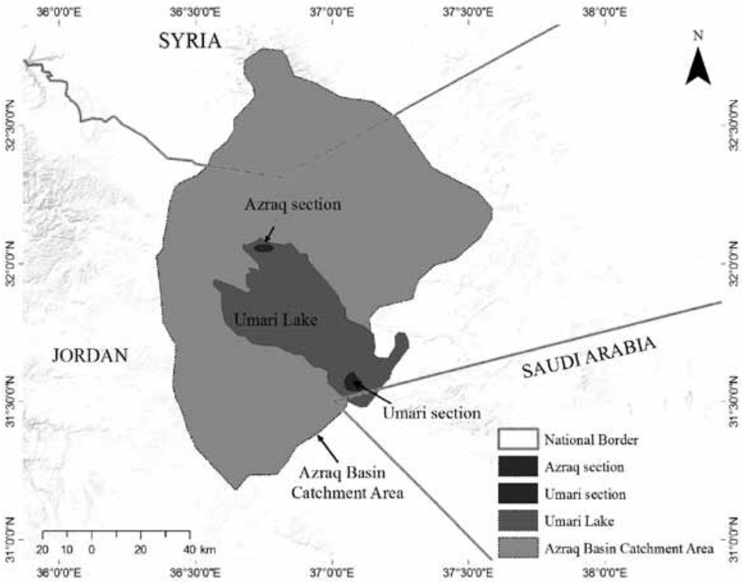

Fig. 7: The location and extent of Lake Umari.

shown in Fig. 8 and 9. Cardium shells dominate, but other fossils such as gastropods, ostracods, foraminifera and charophytes are also recorded. The fossil assemblage, and the absence of evaporite minerals, indicates a fresh to brackish water lake or possibly several smaller lakes that occupied the area between the Umari and Azraq (Gaillard and Testud, 1980; Feist et al. 1995; Abed et al. 2008).

The age of the shell beds is 330 Ka determined by U/Th method on the shells, which puts these beds within the MIS 9. The MIS 9 is the warmest and wettest isotope stage in the last half million years of the Earth history. Consequently, the *Cardium* shell beds provide another example of a warm and wet climate in Jordan during the Pleistocene.

The Umari-Azraq area now receives 150-60 mm of rain per year, a much wetter weather must have been prevailing at the area during the warm MIS 9. Again, what is the source of such intensive rain fall? No exact answer can be provided except through more extreme Mediterranean cyclones and summer monsoons.

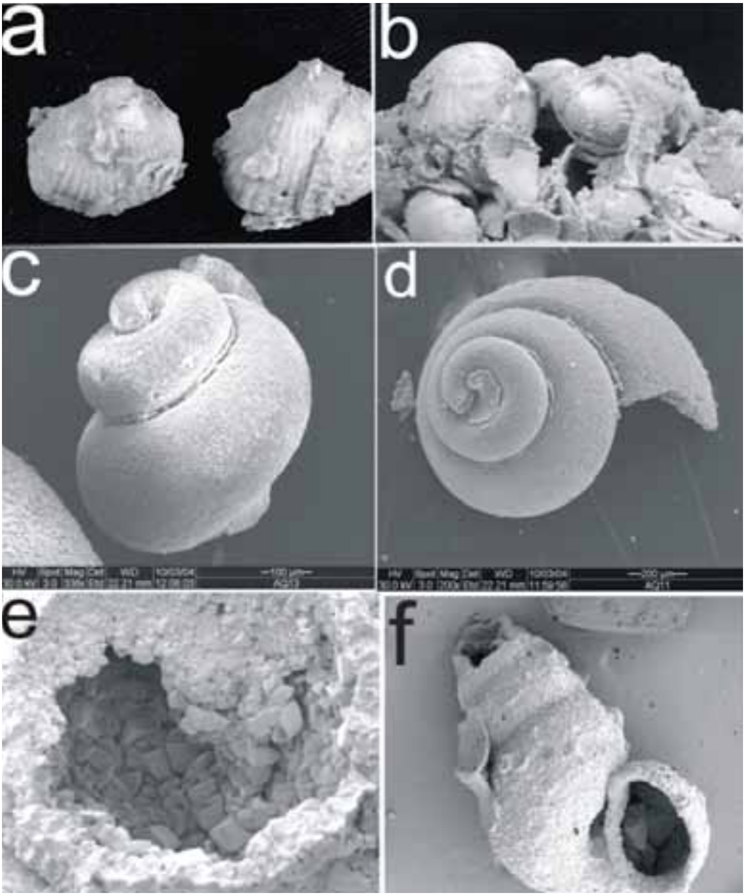

Fig. 8: Molluscan fossils from the studied sequence: a. *Cardium* shell from Azraq, b. *Cardium* shell from Al Umari, c. *Bythinia* sp, d. *Gyraulus* sp., Highly diagenetic gastropod shell, f. *Hydrobia* sp.

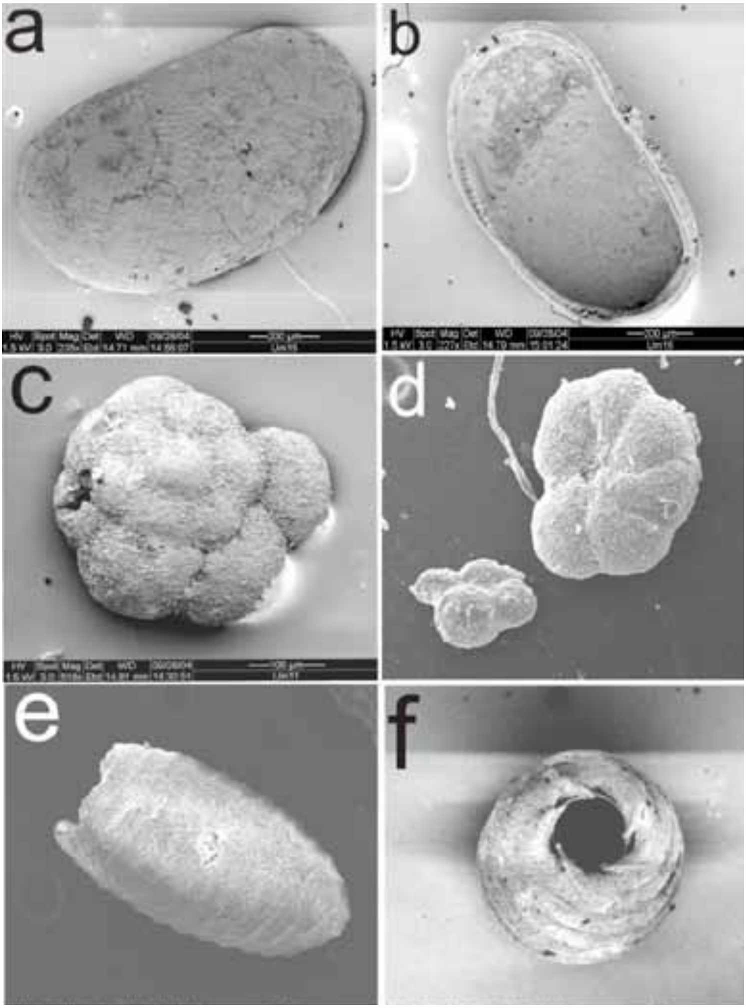

Fig. 9: Ostracods and Charophyte fossils: c. Ammonia beccarii tepida ventral view, d. Ammonia beccarii tepida dorsal view, a. Cyprideis torosa gr., smooth and sieve like, exterior right valve, b. Cyprideis torosa gr.enterior left valve, e. Charophyte gyrogonite of Croftiella cf escheri, f. Charophyte top view.

Arabia

Several works have been conducted on the paleoclimate of Arabia during the Pleistocene indicating that Arabia climate was wetter during the warmer periods. McClure (1976) and Sanlaville (1995, 1996) demonstrated a shrinkage of deserts in Arabia during the warmer periods and their expansion during the cold period with stronger wind deflation and dune forming processes.

Al-Sayari and Zötl (1978) investigated the Pleistocene (not exactly dated) surface calcareous duricrust in Arabia extending almost continuously from Rub Al-Khali (about 20° N) to the Sakaka in the extreme NW Saudi Arabia (30–31° N). They postulated semi-arid climatic conditions for its formation with precipitation ranging from 200 to 600 mm/y or more, a much higher range than the present day.

COHMAP (1988) placed the northern limit of the summer monsoon rain in Arabia at around 27°N during the Holocene Optimum. Thus, during the Holocene optimum, 9500-6500 years before present, Arabia up to latitude of 27°N was much wetter than today; i.e. up to 250 km south of the Jordanian border. Further south in Arabia, Fleitmann et al. (2003) studied the Hoti Cave speleothems in northern Oman and reported a rapid deposition during 5 warm MIS stages including the Holocene Optimum, Eemian, and MIS 9 due to the northward penetration of the monsoon rains. From these works, it seems reasonable to conclude that Arabia was much wetter during the warmer periods in the recent geological past.

North African Sahara

The Sahara in North Africa has received more studies of its paleoclimate by several European scholars (e.g. Kutzbach and Street-Perrott, 1985; Yan and Petit-Maire, 1994; Gasse, 2000; Emeis, et al. 1998; Larrasoana et al. 2003; Weldeap et al. 2007; Cole et al. 2009; Abouelmagd, 2012 amongst many others). Whilst it is difficult to review all these works fully some generalizations are given below.

The Sahara retreated northwards for a considerable distance during the warmer periods such as MIS 5 and the Holocene Optimum (Fig. 10). The Savanna expanded northwards and occupied for example, southern Libya and Algeria with abundant remains of large herbivores and the presence of human fire places. Then, the Sahara expanded southwards during the cold periods including the Last Glacial Maximum where the Savanna retreated towards the Equator. It is generally agreed that the increased rainfall was caused by an intensification of the monsoon rains that extended to 30°N or possibly further north during the warmer period.

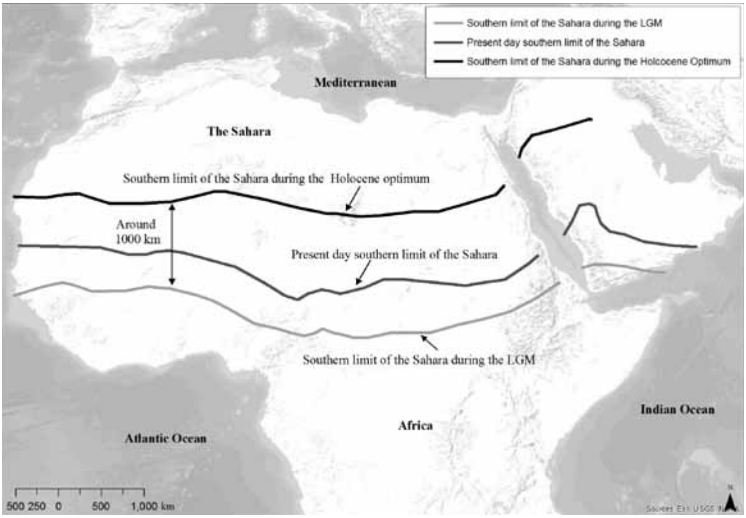

Fig. 10: A map of Africa and Arabia showing the northwards retreat of the Sahara during the warmer Holocene Optimum (9-6 Ka) and its advancement southwards during the Last glacial Maximum (LGM) at around 18 Ka. (Modified after COHMAP, 1988; Petit-Maire and Guo 1997)

DISCUSSION

From the above case studies and others, it is clear that several lakes were formed in Jordan during warmer interpluvial periods of the

Pleistocene. The presence of Charophytes and Planorbid snails in the Umari, Mudawwara, Umari and Jafr lakes (Brasier, 1980; Murray, 1991; Yasin, 2001; Petit-Maire et al. 2002), fresh water diatoms in the northern Lisan basin sediments (Begin et al. 1974) fresh to brackish water ostracods in the intermediate area of the Lisan sediments in the Jordan Valley (Abed and Helmdach, 1981) all indicate that these lakes were fresh to brackish water at some time in the past, or possibly more appropriate alternating fresh and brackish depending on the changes in climate during the life time of the lakes.

The area of each lake was in excess of 1000 km^2 with a depth varying from about 10 metre in the Mudawwara Lake (taken from the Charophytes and the *Ammonia beccarii tepida*) to few hundred metres as in the Lisan Lake (e.g. Abu Ghazleh, 2011). This clearly indicates that the climate at the time of each of these lakes must have been much wetter than present day climate in order to form and sustain such lakes for a considerable period of time for both. Consequently, the warmer interpluvial periods were much wetter than the cold pluvial periods.

Paleotemperature of the lake water may be estimated to have been about 20°C at a minimum, since *Cardium* requires at least this temperature for reproduction and *Ammonia beccarii tepida* is best developed at temperatures of 15-20°C. This is comparable to the average Eastern Mediterranean surface temperature during the interglacial sapropel formation times of 20-22°C (Kroon et.al., 2000; Emeis, et al. 1998).

With lakes established during the warmer interpluvial periods, a major question needs answering: what was the source of the increased humidity during those periods compared with present day climate? The source of precipitation, at present, is from the Mediterranean cyclones during the winter season (October-May). Figure 2 shows that this source provides the lake areas with <50 – 160 mm/y rain, except Samra and Lisan Lakes which can receive higher rain fall in the Upper Jordan River catchment area (up to 1200 mm/y).

Clearly, the present-day climate cannot sustain lakes in the investigated arid area such as the huge Samra and Lisan Lakes in the Jordan

Valley. The general trend in the distribution of rain throughout the Eastern Mediterranean decreases in amount from north to south and to a lesser extent from west to east (Fig. 2). However, the extensive Samra and Lisan Lakes that occupied the central Jordan Valley and the Dead Sea Basin were both fed essentially from the north; probably through the Mediterranean cyclones (Abed, 1983 amongst many others). It should be emphasized that the main source of water for both lakes was the Mediterranean cyclones located only a few tens of kilometers away.

When the area cooled down during the LGM, the Lisan Lake shrank to a sabkha, in response to a drastic decrease in rain with falling temperatures. Does that mean the increase in incoming solar radiation due to orbital forcing increases the atmospheric water vapor and causes the Mediterranean cyclones to become more productive? This contention would be supported by the work of Arz et al. (2003) who explained that the humid period for the early Holocene in the northern Red Sea-Gulf of Aqaba was sourced from the Mediterranean.

What about lakes hundreds of kilometers away from the Mediterranean such as Umari, Jafr and Mudawwara Lakes, had the Monsoon (Summer rain) rain participated in the formation of those lakes? More detailed work is required before this question can be answered conclusively. However, some insight can be gained from the small amount of existing research.

COHMAP (1988) placed the northern limit of the summer monsoon rain in Arabia at around 27°N during the Holocene Optimum. Abed et al (2000), Yasin (2001) and Petit-Maire et al. (2002) explained the 1200 km2, 20m deep, Eemian, fresh water Mudawwara Lake (L7 in Fig. 1) at 29°N by both winter rain from the north and monsoonal summer rain from the south. The 1000-1800 km^2 Jafr lake (L6) at 30oN disappeared completely during the LGM (Huckriede and Wiesemann, 1968). The authors did not discuss the source of humidity but further south in Arabia, Fleitmann et al. (2003) studying Hoti Cave speleothems in northern Oman reported a rapid deposition during five intervals including the Holocene Optimum, Eemian, and MIS 9 due to the northward penetration of the monsoon rains. See also the maps in Sanlaville (2000). From these examples, the

Arabian monsoon with summer rain seems to have reached 29°N and possibly 30°N.

Can Monsoonal summer rain be pushed further north to reach the Umari Lake at 31° 32´ during MIS 9, so that the Umari Lake was affected by both the monsoon from the south and the Mediterranean cyclones from the north? The evidence suggests that Jordan was wetter/warmer and drier/colder than today at times during the Late Pleistocene. Monsoon intensification is primarily related to the 'heat engine' produced by insolation forcing (Emeis, et al. 1998; Larrasoana, et al. 2003 amongst others). A better fit to paleoclimatic data, would require other factors beside the solar radiation forcing including oceanic, vegetation and soil moisture. The latter three factors would increase water vapor in the atmosphere and consequently precipitation (deMenocal, et al. 2000; Gasse, 2000; Liu, et al. 2003). Globally the MIS 9 period is documented as having more greenhouse gases and being warmer than any other stage during the last 420 Ka (Petit et al., 1999). MIS 9 is also recognized as a warm and wet interglacial period (Kroon et.al., 2000, Hodell et al., 2000; Fleitmann et al., 2003 amongst others). Furthermore, the Indian monsoon cyclones which is now affecting Jordan every summer, from May through August, with temperatures up to 39°C (e.g 2006) and dry conditions (Local daily weather forecasts, Jordan Meteorological Department). Thus, it seems possible that Arabian monsoons or even the Arabian-Indian monsoon had penetrated further north during the MIS 9 and produced summer rain in the study area, in addition to the winter Mediterranean precipitation.

However, it should be noted that we are the first group of workers that have advocated summer monsoon rains reaching Jordan during the warmer interpluvial periods (Abed and Yaghan, 2000; Abed et al. 2000; Yasin, 2001; Petit-Maire et al. 2002; Abed et al. 2008). This idea is further supported by the extensive research on the North African Sahara where the monsoon rains reached to latitudes of 30o and possibly 32o N (e.g. Larrasoana, et al. 2003). This idea is currently under review since other workers do not agree with our conclusions and maintain that the paleolakes discussed above are explained by a wetter climate during the cold pluvial periods (Begin et al. 1974; Neev and Emery. 1968, 1995; Horowitz, 1979, 1992).

CONCLUSIONS

1. Several fresh to brackish water paleolakes were established and sustained in Jordan during the warmer and wetter periods of the Pleistocene including Umari Lake during the MIS 9 at 330 Ka, Mudawwara, the Samra Lakes during the MIS 5 130-70 Ka, Lisan, the Jafr Lakes 30-33 and 25-27 Ka, and the Burqu' Lake during the Holocene Optimum 9-6 Ka.

2. Mineralogy of the lake sediments and their associated fossils indicate that the water of the lakes was fresh becoming brackish at times depending on the climate change.

3. The lakes were more than 1000 km^2 in area, and from 10 to few hundred metres deep, with possible water temperature of between 15-20°C.

4. Present-day Mediterranean rain cannot support the presence of lakes in such an arid environment. More intense Mediterranean cyclones during the warmer periods might have carried more rain than today. Because most of the lakes are far from the Mediterranean, intensified Arabian monsoons or even Arabian-Indian monsoons may also have penetrated further north into Jordan up to latitude 31° 32´ producing summer rain to establish and sustain such lakes.

5. Summer monsoon rains in Jordan and adjacent areas are still controversial and are not accepted by all workers in the field as is the case for events in the North African Sahara. Consequently, more detailed work on the paleoclimate of the area is needed.

REFERENCES

Abboud, I.A., 2000. Palaeoenvironment, Palaeoclimate, and Palaeo hydrology of Burqu' Basin, Al-Badia, NE Jordan. Ph.D. Thesis, Baghdad University.

Abed , A. M. and Helmdach, F. F., 1981. Biostratigraphy and mineral ogy of the Lisan Series (Pleistocene) in the Jordan Valley. Ber liner Geowiss. Abh., 32, 123-133.

Abed, A. M., 1985, Geology of the Damya Formation. Dirasat, 12, 99-108.

Abed, A. M., 1985, Geology of the Damya Formation. Dirasat, 12, 99-108.

Abed, A. M., 2014. The water budget of River Jordan Basin and its implications on the water needs in Jordan. Water International (In press).

Abed, A. M., Yasin, S., Sadaqah, R. and Al-Hawari, Z., 2008. The paloclimate of the eastern desert of Jordan during marine stage MIS 9. Quaternary Research, 69, 458-468.

Abed, A.M., 1983. Paleoclimates of the Upper Pleistocene in the Jordan Rift. Proc. 2nd. Intern. Cong. Archeol. Jord., 2, 81-95.

Abed, A.M., Carbonel P., Collina-Girard J., Fontugne M., Petit-Maire N., Reyss J.C., Yasin, S., 2000. Un Paléolac du Dernier Integlaciaire Pléistocène Dans l'Extrême-Sud Hyperarid de la Jordanie. C.R. Acad. Sci. Paris, Science De La Terre et des Planétes, 330, 259-264.

Abed, A.M., Yaghan, R., 2000. On The Paleoclimate of Jordan During the Last Glacial Maximum. Palaeogeography, Palaeoclimatology, Palaeoecology, 160, 23-33.

Abouelmagd, A., 2012. Paleoclimatic Regimes of the African Sahara desert during Pleistocene and the Origin of Groundwater in the Nubian Sandstone Aquifer System. Ph. D Thesis, Department of Geosciences, Western Michigan University.

Abu Ghazleh, S. 2011. Lake Lisan and the Dead Sea: Their level changes and the geomorphology of their terraces. Ph. D thesis (unpublished), Darmstadt University of Technology, Germany.

Al-Sayari, S.S., Zötl, J.G., 1978. The Quaternary Period in Saudi Arabia. Springer, Vien.

Arz, H.W., Lamy, F., Paetzold, J., Mueller, P.J., Prins, M., 2003. Mediterranean moisture source for an early Holocene humid period in the northern Red Sea. Science, 300, 118-122.

Ayed, R., 1986. Surface Water Resources in the Azraq Basin. Uupubl. Report, Water Authority, Amman, Jordan.

Begin, Z.B., Broecker, W., Buchbinder, B., Druckman, Y., Kaufman, A., Magaritz, M., Neev, D., 1985. Dead Sea and Lake Lisan levels in the last 30,000 years. Geological Survey of Israel, Preliminary Report GSI/29.8. 18 pp.

Bender, F., 1974. Geology of Jordan. Brontraeger, Berlin.

Bowman, D., 1990. Climatically triggered Gilbert-type lacustrine fan deltas, the Dead Sea area, Israel. SEPM Special Publ. 10, 273–280.

Brasier, M.D. 1980. Microfossils. George Allen & Unwin.

COHMAP Members, 1988. Climatic changes of the last 18,000 years: observations and model simulations. Science, 241,1043-1052.

Cole JM, Goldstein SL, deMenocal PB, Hemming SR, andGrousset FE. 2009. Contrasting compositions of Saharan dust in the eastern Atlantic Ocean during the last deglaciation and African Humid Period.Earth Planet Sci Lett 278:257–266.

Cronin, Thomas M., Paleoclimates: understanding climate change past and present, Columbia University Press, 2010

Davies, C.P. 2000. Reconstruction of Paleoenvironments from Lacustrine Deposits of the Jordan Plateau. Ph.D Thesis. Arizona State University.

DeMenocal, P., Ortiz, J., Guilderson, T., Adkins, J., Sarntein, M., Baker, L., Yarusinky, M., 2000. Abrupt onset and termination of the African humid period: rapid climate responses and gradual insolation forcing. Quaternary Series Reviews, 19, 347-361.

Emeis, K.-C., Sculz, H.-M., Struck, U., Sakamoto, T., Doose, H., Erlenkeuser, H., Howell, M., Kroon, D., Paterne, M., 1998. Stable Isotope and Alkenone Temperature Records of Sapropels from Sites 964 and 967: Constraining The Physical Environment of Sapropel Formation in the Eastern Mediterranean Sea (Section 26). In: Robertson, A.H.F., Emeis, K.-C., Richter, C., and Camerlenghi, A., (Eds.), Proceedings of the Ocean Drilling Program, Scientific Results, Vol. 160: College Station TX (Ocean Drilling Program).

Feist, M., Lake, R.D. and Wood, C.J., 1995. Charophyte Biostratigraphy of the Purbeck and Wealden of Southern England. Palaeontology, 38, 407-442.

Fleitmann, D., Burns, S., Neff, U., Mangini, A., Matter, A., 2003. Changing Moisture Sources over the Last 330,000 Years in Northern Oman from Fluid-Inclusion Evidence in Speleothems. Quaternary Research, 60, 223-232.

Gaillard, J.M., Testud, A.M., 1980. Comparative Study of Quaternary

Gaillard, J.M., Testud, A.M., 1980. Comparative Study of Quaternary and Present-Day Lagoon Populations of Cardium Glaucm (Syn. Cerastoderma Glaucum (Bruguiere) Mollusca, Bivalvia. In: M.J. Salem and M.T. Busrewil, (Eds), The Geology of Libya, Academic Press, London, III, pp. 809-814.

Gasse, F., 2000. Hydrological changes in the African tropics since the Last Glacial Maximum. Quaternary Science Reviews, 19, 189-211.

Gasse, F., Fontes, J.C., Plaziat, J.C., Carbonet, P., Kaczmarska, I., De Deckker, P., Soulie-Marche, I., Callot, Y., Dupeuple, P., 1987. Biological remains geochemistry and stable isotopes for the reconstruction of environmental and hydrological changes in the Holocene lakes from the Northern Sahara. Palaeogeogr. Palaeoclimatol. Palaeoecol. 60, 1–46.

Hodell, D.A., Charles, C.D., Ninnemann, U.S., 2000. Comparison of interglacial stages in the South Atlantic section of the southern ocean for the past 450 kyr: implications for Marine Isotope stage (MIS) 11. Global and Planetary Change, 24, 7-26.

Horowitz, A., 1979. The Quaternary of Israel. Academic Press, New York. 394 pp.

Horowitz, A., 1992. Palynology of Arid Lands. Amsterdam, Elsevier. 546 pp.

Huckriede, R. and Wiesemann, G.. 1968. Der Jungpleistozane Pluvial-See Von El Jafr und Weitere Daten Zum Quartar Jordaniens. Geol. et Palaeontol. 2, 73-95, Marburg.

Ibrahim, K., 1996. The Regional Geology of Al Azraq Area (Map Sheet No. 35531). Natural Resources Authority, Bulletin 36. 67p.

Jordan Meteorological Department web site, http://www.jmd.gov.jo

Kenyon, K. M., 1979. Archaeology in the Holy Land. 4th Ed., London, E. Benn.

Khoury, H. 2003. Diatomite and Diatomaceous Earth (Kieselguhr) In El-Azraq Depression, Jordan. University of Jordan.

Kroon D., Reijmer J.J.G, Rendle R., 2000. Mid- to Late-Quaternary Variations in the Oxygen Isotope Signature of Globigerinoides Ruber at Site 1006 in the Western Subtropical Atlantic1. In: Swart, P.K., Eberli, G.P., Malone, M.J., and Sarg, J.F., (Eds.), Proceedings of the Ocean Drilling Program, Scientific Results, Vol. 166: College Station TX (Ocean Drilling Program).

Kutzbach, J.E., Street-Perrott, F.A., 1985. Milankovitch forcing of ?uctuations of tropical lakes from 18 to 0 kyr BP. Nature 317, 130–134.

Larrasoana, J., Roberts, A., Rohling, E., Winklhofer, M., Wehausen, R., 2003. Three million years of monsoon variability over the northern Sahara. Climate Dynamics, 21, 689-698.

Liu, Z., Otto-Bliesner, B., Kutzbach, J., Li, L., Shields, C., 2003. Coupled climate simulation of the evolution of global monsoon in the Holocene. Journal of Climate, 16, 2472-2490.

Masri, A., 1988. The geology of Halat Ammar and Al Mudawwara. Map sheet Nos. 3248 III, 3248 IV. Geological Mapping Division Bulletin 13, Geology Directorate, NRA, Amman.

McClure, H.A., 1976. Radiocarbon chronology of the late Quaternary lakes in the Arabian Desert. Nature, 263, 755-756.

Moumani, K.A., 1996. Quaternary Sediments of the Jurf Ed Darawish Area Central Jordan. Thesis, University of Wales.

Murray, J., 1991. Ecology and Palaeoecology of Benthic Foraminifera. Longman Scientific.

National Water Master Plan 2004. Surface water resources. Ministry of Water and Irrigation, Amman, Jordan.

Neev, D., and Emery, K. O., 1995. The Destruction of Sodom, Gomorrah and Jericho. Oxford University Press, New York.

Ogg, James George, Ogg, Gabi, Gradstein F. M., The Concise Geologic Time Scale, 2008, Cambridge University Press, 2008

Petit, J.R., Jouzel, J., Raynaud, D., Barkove, N.I., Bamola, J.M., Basile, I., Bender, M., Chappellaz, J., Davis, M., De Laygue, G., Delmotte, M., Kotlyakov, V.M., Lefrand, M., Lipenkov, V.Y., Lorius, C., Pepin, L., Ritz, C., Saltzman, E., Stievenard, M., 1999. Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. Nature, 399, 429-436.

Petit-Maire N., Sanlaville P., Abed, A.M., Yasin S., Bourrouilh R., Carbonel P., Fontugne M., Reyss J., 2002. New Data for an Emian Lacustrine Phase in Southern Jordan. Episodes, 25, 279-280.

Petit-Maire, N., Guo, Z.T., 1997. Holocene paleoprecipitation over the present-day Sahara desert. Continental Signals in Paleomonsoon Dynamics in Africa, Inter-Hemispheric Perspectives. SIWA Workshop, Paleomonsoon Project 33.

Picard, L., 1943. Structures and evolution of Palestine with comparative notes on neighbouring countries. Jerus. Hebrew Univ. Dept. Geol. Bull. 4, 1–134.

Powell, J.H., 1989. Stratigraphy and sedimentation of the Phanerozoic rocks in central and south Jordan, part B. Natural Resources Authority, Bulletin 11.

Prell, W.L., Kutzbach, J.E., 1987. Monsoon variability over 150,000 years. J. Geophys. Res. 92, 8411–8425.

Quennell, A.M., 1958. The structures and geomorphic evolution of the Dead Sea rift. Geol. Soc. Lond. Quart. J. 14, 1–24.

Rabba'a, I. 1998. The Geology of Al Umari (Abar Al Hazim) (Map Sheet No. 3453-III). Natural Resources Authority, Bulletin 43.

Sanlaville, P., 1995. Marge septentrionale du desert arabioue: la zone sud-levantine eu Pleistocene superieur et a l'Holocene. Mem. Soc. Geol. Fr. 167, 57–66.

Sanlaville, P., 1996. Changements climatiques dans la region Levantine a la ?n du Pleistocene superieur et au debut de l'Holocene. Leurs relations avec l'evolution des societes humaines. Paleorient. 22, 7–30.

Sanlaville, P., 2000. Le Moyen-Orient arabe. Armando Colin, Paris.

Turner, B.R., Makhlouf, I., 2005. Quaternary sandstones, northeast Jordan: Age, depositional environments and climatic implications. Palaeogeography, Palaeoclimatology, Palaeoecology, 229, 230-250.

Weldeab, S., . Lea, D. W., Schneider, R. R., and Andersen, N. 2007. 155,000 Years of West African Monsoon and Ocean Thermal Evolution. Science, 316, 1303-1307.

Yan, Z.W., Petit-Maire, N., 1994. The last 140 ka in the Afro-Asian climatic transitional zone. Paleogeography, Paleoclimatology, Paleoecology, 110, 217-233

Yasin, S., 2001. Quaternary Paleolimnology in the Mudawwara Area (Southern Jordan, 29° N), Paleoclimatic Implications. Ph.D. Thesis, Univ. of Jordan.

Zhuo, Z., Baoyin, Y., Petit-Maire, N., 1998. Paleoenvironments in China during the last glacial maximum and the Holocene optimum. Episodes, 21, 152-158.