Carbon-14 Dating and Stable Isotopes of Carbonates of Late Pleistocene Lacaustrine Sediment in Qa´a Selma (Jordanian Badia)

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Abstract

A 3.5m borehole was drilled at the northern part of Qa´a Selma in the northern Jordanian Badia, and is analyzed for radiometric chronology (^{14}C) and stable isotopes ($\delta^{18}O$ and δ^{13} C) at selective depths (50, 85, 150, 310, 350) cm and (30, 50, 85, 130, 150, 190, 230, 270, 310, 350) cm respectively.
It provides Late Pleistocene record, with Holocene is missing and not represented.
Variations in $\delta^{13}C$ and $\delta^{18}O$ reveal changes in environmental conditions, induced by climate change. Most of the Late Pleistocene record of the Qa´a is marked by an arid climatic conditions except for two wet periods (37-32 ka BP) and (15.5-13.9 Ka BP), which are indicating positive precipitation-evaporation balance leading to wetter and/ or cooler climatic conditions.
Whereas the arid climatic conditions prevailed the area during the periods (~ 32-15.5 ka BP) and (13.9-13.4 Ka BP). The latter dry period may represent one of the short dry episodes that had occurred at the end of the Pleistocene toward the Holocene.

الخلاصة

بئر بعمق (3.5)م تم حفره عند الجزء الشمالي لقاع سلمى في البادية الاردنية، وتم تحليل رسوبياته لاغراض تحديد العمر باستخدام طريقة الكاربون-14، وكذلك تحليلات النظائر المستقرة للكاربون والاوكسجين لاعماق مختارة من البئر، (50، 85، 150، 310، 350) سم لاغراض تحديد العمر بالكاربون -14. والاعماق (30، 150، 85، 130، 150، 190، 230، 270، 310 ,350)سم لاغراض تحليلات النظائر المستقرة للكاربون والاوكسجين. زودنا السجل الرسوبي للقاع بسجل نهاية البلايستوسين، في حين ان الهولوسين لم يمثل بهذا السجل الرسوبي.

التغيرات في $\delta^{18}O,\delta^{13}C$ تظهر تغيرات في الظروف البيئية نتيجة للتغير المناخي. معظم سجل نهاية البلايستوسين لقاع سلمى يؤشر ظروف مناخية جافة ماعدا لفترتين رطبيتين (37-32 Ka BP) و(15.5-13.9 Ka, BP)، واللتان تؤشران موازنة موجبة للساقط المطري- التبخر مؤدية الى ظروف مناخية اكثر رطوبة و/او اكثر برودة في حين سادت المنطقة ظروف مناخية اتسمت بالجفاف خلال الفترات (32-15.5Ka BP) و(13.9-13.40Ka BP). قد تمثل الفترة الجافة القصيرة الاخيرة (13.9- 13.4 Ka BP) احد الفترات الجافة القصيرة التي حدثت في نهاية البلايستوسين باتجاه الهولوسين. وقد تتزامن هذه الفترة مع احداث فترات الجفاف التي حدثت في مناطق مختلفة اقليمياً وعالمياً في نهاية البلايستوسين باتجاه الهولوسين.

Introduction

Late Quaternary palaeoclimate record is of great importance in understanding and evaluating the global climatic models. There are abundant geomorphological and lithological evidence showing that major climatic changes have affected many regions in the world during the Quaternary. Such climatic changes can be inferred from the well preserved fossil landforms and deposits, particularly lacustrine features that provide evidence for wetter conditions.

Pluvial lakes are most widespread today in arid to sub-humid regions especially in tropics, reflecting Late Quaternary climatic changes (1).

The concept of pluvial lakes are those closed basins lakes which lack surface outlets, as their high water levels stages have been attributed to wetter climatic phases known as pluvial.

Reconstructing climate change from lake-level evidence relies heavily on closely dated lacustral sequences and the basis for regional correlation.

Chronologies have usually been based on radiocarbon dates from carbonate material. Stable isotopes of both carbon and oxygen vary with changing climatic and other environmental conditions, of great importance in Quaternary research, however, there are variations in the ratio of oxygen isotopes (2).

The northeastern Jordanian Badia is marked by flat-bottomed vegetation free depressions, carpeted by fine and very fine sediments. In Jordan the local name of such features is Qa´a but the general geologic term is dry pluvial lake or playa (3). The material in the playa is derived by fluvial and aeolian processes from within and outside the catchments (4). The clastic sediments are usually fine-grained consisting of clay, silt and granular particles. These are mainly derived from standing water bodies (5). Playa deposits has received much attention due to their value in determing the nature of climatic and ecological changes in desert basin during the Quaternary (6, 7).

Qa´a Selma is one of the playas that had spread in northeastern Jordanian Badia, has been chosen for this study in a try to detect palaeoclimatic and palaeoenvironmental changes prevailed in the region during the Late Quaternary.

Qa´a Selma is located on northern basaltic flow of northeast Jordan, about 35 km northeast of town Safawi (Figure.1). The Qa´a lies at 32̊ 24́ N and 37° 22́ E. It has an east –west trend.

Lithological, geomorphological, radiocarbon dating and stable isotopes for carbon and oxygen, information are used here to deduce the nature of Late Quatermery climatic and environmental variations that had prevailed in the region and controlled the longterm behavior of the playa.

Sampling and analyses

A borehole of 3.5m at the northern part of Qá a Selma was excavated (Figure-2). For stable isotopes ($\delta^{18}O$ and $\delta^{13}C$) analyses. (10) samples at different depth intervals (Table-1) were analyzed. The analysis was performed on the > 40 µm size fraction of carbonate material, using a FINIGAN MAT ratio mass spectrometer, located at the Water Authority laboratories in Amman, Jordan.

Five Radiocarbon ^{14}C measurements for age determination Table-1 were performed. ^{14}C age determination are in years before present (Yr. B.P.), the presents being defined as 1950.

Lithology and ^{14}C chronology

The Qá a sediments are mainly composed of lacustrine deposits, which varied from silty clay to silty clay loam. They are interbedded with thin layers of aeolian and calcrete deposits. Whereas, the surface layer (~15cm) consists of fan debris. Lateral changes in colour from gray to reddish sediments locally occur toward the shoreline, to suggest variability in duration and frequency of ponding. Ponding and organic matter production were insufficient to reduce detrital red upland clays.

Carbon-14 is different from the other two ^{13}C and ^{12}C, in that it is isotopically unstable, in other words, it decays to form stable ^{14}N over time (8). Most importantly of all, unstable isotopes such as ^{14}C decay at fixed rate. ^{14}C formed in the upper atmosphere by cosmic ray bombardment of Nitrogen (N) atoms. The resulting carbon- isotope is rapidly oxidized to form carbon dioxide (CO_2), and is then mixed uniformally and rapidly through the atmosphere. Photosynthesis leads to ^{14}C being taken up by plants, which in turn is passed on to higher organisms including humans, consequently, ^{14}C content is no longer replenished and the isotopic clock is set in motion (8).

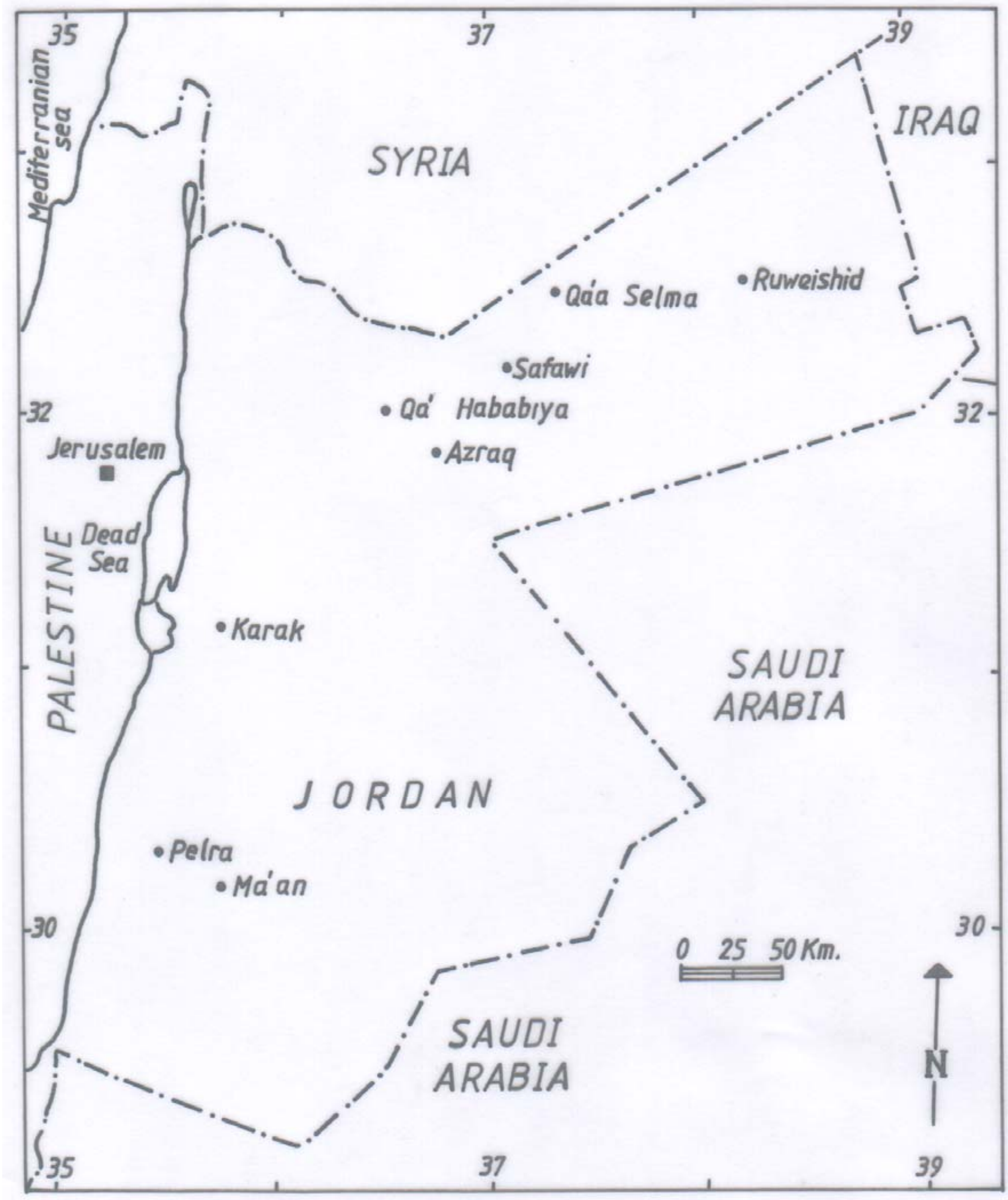

Figure – 1: Location map of Qa'a Selma

Table 1: Isotopic composition of Qaóó a Selma Sediment with ^{14}C chronology

^{14}C Age (yr.BP.)	Depth (cm)	$\delta^{18}O$ (PDB) ‰	$\delta^{13}C$ (PDB) ‰
	30	1.45	1.18
13400	50	2.28	0.89
13900	85	2.68	0.65
	130	1.95	1.44
14000	150	1.35	1.05
	190	2.35	1.55
	230	2.95	1.35
	270	1.8	0.95
32.900	310	1.01	0.7
40.000	350	2.15	0.4

The five ^{14}C measurment of the Qaó a sediments gave ^{14}C ages ranging from ~ 32.9-40 Ka BP for depths (310-350) cm to ~13.4-13.9 Ka BP for depths (50-85) cm, whereas ~14 Ka BP for the depth (150) cm (Table-1) and (Figure-3). Suggesting therefore, unfortunately that the Holocene is missing in this record.

It is clear that the sedimentation rate at the Qaó a is not uniform with the upper half meter of the sediments (Figure-3) was formed within 13Ka, whereas the depths (50-150) cm has taken only 600 year to form. Depth (150-300) cm formed in ~17Ka BP, and the lowest part (300-350) cm, probably has formed through 7 Ka BP. These variations in the sedimentation rates can be attributed to many factors. Errors of the preparation method and with initial carbonate radiocarbon content may cause small errors on the calculated dates. Another source of error can be due to detrital carbonate present in the sediments, whereas the surrounding area of the Qaó a mainly basalt. Therefore, it is probably safe to say the age limits estimated, are upper limits (3).

Stable isotopes

Most natural elements are a mixture of several isotopes, which have the same chemical properties and atomic numbers but different numbers of neutrons and hence different atomic masses. One isotope is always dominant for each element. Some of them, like ^{14}C are isotopically unstable and undergo radioactive decay with time, but others are stable and provide information instead on past environmental conditions.

Among the most important are the isotopes of carbon and oxygen. The ratio between the heavy isotopes oxygen-18 (^{18}O) and the lighter, and much more common, oxygen-16 (^{16}O) varies with the temperature. Temperature has been a more important control on fresh water lake sediment and other systems. Oxygen isotopes can indicate seasonal as well as annual variation in temperature or rainfall (8). In salt lakes, the stable oxygen-isotope ratio varies primarily according to the intensity of evaporation from the water surface, and here they reflect past salinity changes (9).

Stable carbon-isotope analysis provides a way to determine past changes in the type of plants and in the global carbon cycle, for example as the atmospheric concentration of greenhouse gases has fluctuated. The ratio of two stable isotopes of ^{13}C and ^{12}C expressed as $\delta^{13}C$, has been analyzed in plant macro-fossils, soils, ostracods, land snails, timbers and peat among others (10, 11, 12). In lake sediments the stable carbon-isotope ratio will have been affected by the productivity of aquatic algae, as well as the type of vegetation in the lake catchment (8).

In lake where large number of submerged aquatic plants and algae, use dissolved CO_2 for photosynthesis, an insoluble carbonate (marl) is precipitated, the oxygen isotope content of the lake is related to the isotopic composition of the lake water at time of precipitation.

In so far as the ratio $^{18}O/^{16}O$ ($\delta^{18}O$) variation of lake water will be related to former precipitation and temperature levels. So the isotopic analyses record of lake carbonate provides a potential means of reconstructing the palaeoclimate (13).

Evolution towards high $\delta^{18}O$ values of authigenic carbonates may be due: [1] heavy isotope enrichment of precipitation linked to the origin and to the type of condensation of air moisture (14, 15); [2] higher average temperature during the rainy season, although this does not apply to monsoon controlled climate; [3] longer residence time and related evaporative enrichment in heavy isotopes; [4] lower relative humidity with the same result as for [3]. Opposite variations of these parameters induce a decrease in ^{18}O content of authigenic carbonates.

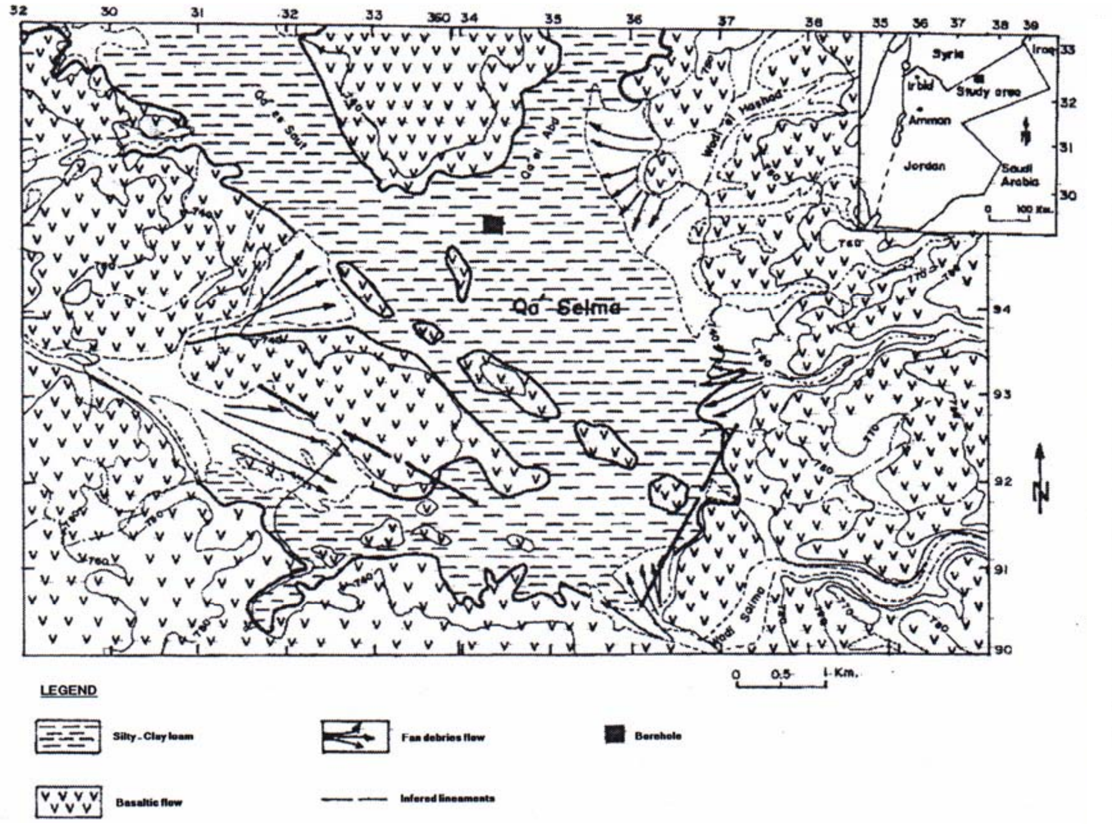

Figure-2: Show the location of the borehole at Qa'a Selma

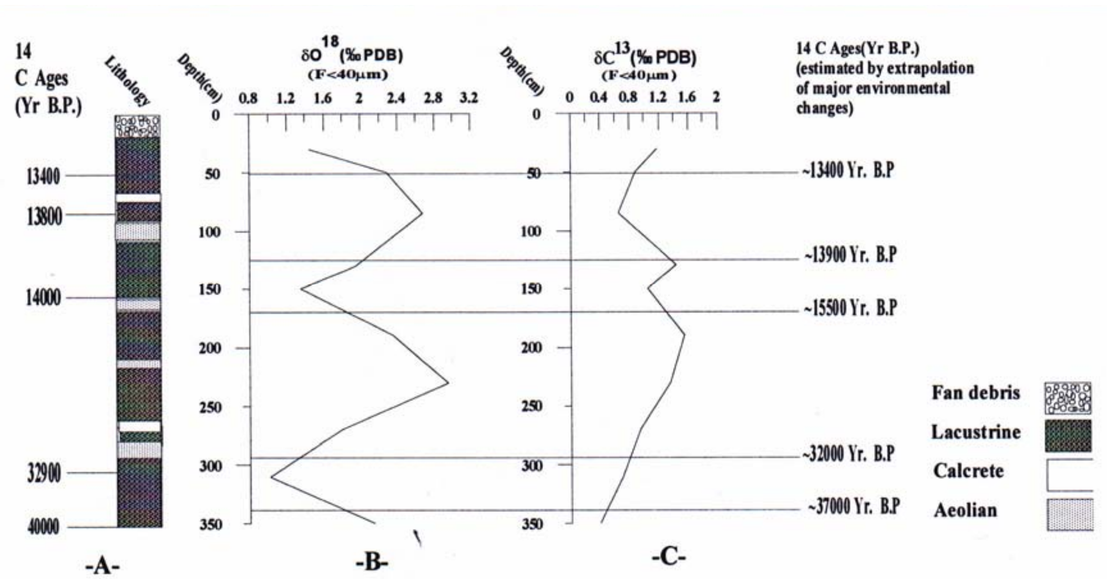

Figure-3: Qa'a Selma stable isotopes record (A) C14 chronology and lithology (B,C)δO^{18} and δC^{13}

In lakes from humid regions with relatively rapid through-flow, the ^{18}O content of water reflect, the mean ^{18}O composition of precipitation on the catchment. In contrast it is established from the isotope mass balance equations (see 16) that the main controlling factor of ^{18}O content of closed lake water submitted to dry climate is the residence time and the related effects of evaporation and isotope exchange with atmosphere. Whereas increase in ^{13}C content of authigenic carbonate precipitated in lake water may be due to [1] extensive isotope exchange of TDIC with the atmospheric CO_2, induced by long residence time of the water (and of the TDIC) in the lake; [2] development on the catchment of a vegetal cover dominated by C_4 plants (see 17); [3] enhanced aquatic photosynthesis which uptakes preferentially light carbon isotopes and tends thus to increase the ^{13}C content of the TDIC (18,19); [4] methanogenic in highly reducing environments, like marshes, whereby the co-genetic CO_2 and resulting TDIC are enriched in heavy carbon isotopes; [5] emanation of deep CO_2 through deep vertical faults; [6] reduced partial pressure of soil CO_2 in the catchment area leading to elevated ^{13}C content in the newly formed TDIC. Low ^{13}C content of authigenic carbonates may be due to the lessening of the above cited factors, and/ or to oxidation of bottom organic matter (9, 14, 15, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33).

The cause of ^{13}C variations in lacustrine authigenic carbonates are thus complex and are strongly dependent on local lacustrine conditions, and especially on biotic activity and corresponding limiting factors like water transparency and nutrient supplies (33). In this study the isotope exchange with the atmospheric CO_2 [Cause (1)] is considered probably the main driving force to move the ^{13}C content of inflowing TDIC toward higher value.

Interpretation of Qa´a Selma stable isotope profiles:

The ^{18}O value of carbonates is a function primarily of evaporation/ precipitation and to a large degree of temperature; although in lake margins or in shallow lakes, large temperature fluctuations may contribute significantly to variation in the recorded ^{18}O values of carbonate (34) in (35).

Excursion of the oxygen isotope curve toward positive values represent evaporative regimes and indicate dry or/ warm climates. Excursions toward negative values represents non-evaporative conditions, and indicate cool and/ or wet climates.

The oxygen isotope variation curve shown in (Figure-3) has an amplitude of +1.94‰, ranging between +1.01‰ and 2.95‰, under dry climate, the influence of evaporation on the ^{18}O content of lake water (and on that of precipitated carbonate) is predominant.

The carbon isotope variation curve (Figure 3) has an amplitude of +1.15‰ and ranging between +0.4‰ and +1.55 ‰. Increase in ^{13}C content of authigenic carbonates precipited in lake water may be due to [cause (1) long residence time of water which lead to extensive isotope exchange of TDIC with the atmospheric CO_2 and/ or (cause (3) enhanced aquatic photosynthesis which uptakes preferentially light carbon isotope ^{12}C and tends to increase the ^{13}C content of TDIC) (33).

The observed decrease in ^{13}C values at the bottom of the section is being interpreted due to absence of the influence of the above factors and/ or to oxidation of bottom organic matter (33).

Climatic intervals deduced from Oxygen$^{18}O/^{16}O$ and carbon$^{13}C/^{12}C$ isotopes profiles at Qa´a Selma.

Four climatic intervals have been deduced from the stable isotope record (Figure 3) reflecting the climatic change that had occurred in the Jordanian Badia during Late Pleistocene are as followed:

1-The interval 335-290cm (~ 37-32 Ka BP)

The lowest value for ^{18}O and ^{13}C are ~+1‰ and +0.7‰. respectively. Considered as almost the lowest values in the record. Low ^{18}O (~+1‰) reflecting period of short residence time which coincide with low ^{18}O contents of lake water close to that of precipitation, and low ^{13}C (+0.7‰) content close to the inflowing TDIC which is controlled by the pH (23) and by the partial pressure and ^{13}C content of the soil CO_2 in the catchment (36), relative lowering of $\delta\ ^{18}O$ and $\delta\ ^{13}C$ as observed during this interval reflecting wetter and/ or cooler climatic condition than present might be prevailed in the region and led to Mediterranean steppe vegetation to grow at the northern Jordanian Badia during the period ~ 37-32Ka BP.

This cool and/ or wet period concides with global Late Pleistocene pluvial period in the Middle East and Arabian Deserts which is confirmed by many workers (37, 38, 39, 40, 41, 42, 43).

2-The interval 290-170 cm (~ 32-15.5ka BP)

High $\delta^{18}O$ and $\delta^{13}C$ values (~+2.95‰, and ~+1.55‰ respectively) reaching almost their maximum within the record, to reflect a period of high residence time induced by extensive evaporation. This is attributed to the closure of the lake under arid condition. Magaritz and Goodfriend (44) defined dry and semi-arid conditions during the period 32-31 Ka BP for the deposits of Naqab deserts, SW Palestine. Macumber and Head 1991 (45) showed that sediment dated 23Ka BP in Wadi Al-Hammeh, Lake Lisan, Jordan reflect a dry climatic condition. Whereas Abboud, (42) deduced on pollen evidence that the period ~ 25-19 Ka BP was dry and warm in the Northern Jordanian Badia.

3-The interval 170-125 cm (~15.5-13.9 Ka BP).

Lowering the $\delta^{18}O$ and $\delta^{13}C$ values within this interval (~+1.35‰ and +1.05‰ respectively) indicates a sudden decrease in residence time which implies the opening of the hydrological system induced by the establishment of a positive precipitation-evaporation balance, leading to wetter climatic condition, that most probably had occurred during this period (~+15.5-13.9 Ka BP) in the region.

These climatic conditions were supported by many other workers in the Levantine region and different parts of Jordan; Neev and Hall 1977 (46) mentioned that more wet environment prevailed in lake Lisan, Jordan during the period 16-11 ka BP; Goldberg, 1984 (47) defined more wet and dry/ cool conditions for deposits of northeastern Sinai at about 14 Ka BP.

Macumber and Head, 1991 (45); Davies, 1995 (48) and Awawdeh, 1998 (35) defined the more wet/ dry period in different parts of Jordanian Desert between 16-10Ka BP. Whereas Petite-Maire, 1994 (40) reffered to, that the first effect of deglaciation result in a short wetter episode around 14-12 Ka BP in Arabia. Dry and cool climatic conditions have prevailed in different parts of Iraq during the time interval ~ 14-18 Ka BP deduced from pollen evidence (41, 43, 48, 50, 51).

4- The interval 125-50cm (~ 13.9-13.4 Ka BP)

Increase in $\delta^{18}O$ value (~+2.65‰) at depth 85 cm and the decrease in $\delta^{13}C$ value (~+0.65‰) at the same depth. These opposite trends for $\delta^{18}O$ and $\delta^{13}C$ are most difficult to explain and can be due to several causes, dependent or independent on the lake hydrological behavior a possible mechanism is a change from reducing to oxidizing conditions in lake bottom environments. The most labile organic compounds preserved during reducing phases are readily oxidized with production of isotopically light biogenic CO_2 (33).

These results reflect arid to semi-arid climatic conditions probably prevailed in the region during this period and may represent one of the short dry episodes that occurred at the end of the Pleistocene to reflect the fluctuation in the climate during Late Pleistocene toward the pluvial condition of the Early Holocene.

This short dry period may a gree with the timing of younger dryas event in East Africa, with the extreme aridity and lowest lake levels occurred between 12.8-10 K BP (52).

Conclusion and Discussion

The sedimentary record of Qa′a Selma (3.5m) represents the time scale around 40Ka, so it is clear that most of Late Pleistocene is represented here. Whereas the transitional period and the Holocene are, missing from the record.

Most of Late Pleistocene of the Qa′a is marked by an arid climatic regime except for two wet periods. One might have occurred around (37-32 Ka BP) which is represented by the depths (335-290cm), with the sedimentation rate of ~7cm/1000 yrs. Covariance of stable isotopes, low ($\delta^{18}O$ and $\delta^{13}C$), means that the lake system here was influenced by regional climatic variation, represented by wetter and cooler climate than present. Low $\delta^{18}O$ values would suggest a relative increase in winter rains rather than overall changes in effective moisture (53). Griffths as well (54) argues for changes in the seasonality of the rains as an important factor in determining the nature of sediments. This agrees with nature of the Qa′a sediment record, where the lacustrine sediments interbeded with the non lacustrine ones, even within the wet period. Such climatic conditions might have prevailed in the area during the period (37-32 Ka BP).

This cool and wet period (~37-32Ka BP) coincides with Late Pleistocene pluvial episode in the Middle East and Arabian deserts, which is confirmed by many workers in these regions (37, 38, 39, 40, 41, 42, 43).

Whereas the other wet or pluvial episode (~15.5-13.9 Ka BP), which is represented by the depths (170-125 cm). The stable isotopes results show low ($\delta^{18}O$ and $\delta^{13}C$), indicating positive precipitation-evaporation balance leading to wetter and cooler climatic conditions, than present. Such climatic conditions supported during this period (15.5-13.9 Ka BP), is confirmed by many other workers in Levantine region and other parts of Jordan (35, 40, 45. 49, 50, 51).

The other two periods (~32-15.5 Ka BP) and (13.9-13.4 Ka BP) which are represented by the depths, (290-170cm) and (125-50cm) respectively, are characterized by arid or inter-pluvial conditions.

The long-term covariance trends, high ($\delta^{18}O$ and $\delta^{13}C$) for the depths (290-170cm), the period (~32-15.5Ka B), to suggest long residence time and evaporative related effects, represent the most common case in closed lake (31). Such arid climatic condition during the time period (~32-15.5 Ka BP) is confirmed by many other workers (45), who deduced dry climatic conditions from the sediments of wad Al-Hammeh, Lake Lisan, Jordan, dated 23Ka BP, whereas Abboud (42), referred to the period ~25-19 Ka BP, as a dry and warm on basis of pollen evidence at Qa´a Burqu, Albadia, northeast Jordan.

The negative correlation between $\delta^{18}O$ and $\delta^{13}C$ for the depths (125-50) cm for the period ~ (13.9-13.4 Ka BP), to suggest, a change from reducing to oxidizing conditions at lake bottom environment. The most liable organic compounds preserved during the reducing phases are readily oxidized with the production of isotopically light biogenic CO_2 (33).

The latter dry period (~13.9-13.4 Ka BP) may represent one of the short dry episodes that had occurred at the end of the Pleistocene towards the Holocene. This short dry episode may coincide with the timing of the younger dryas event in East Africa, with the extreme aridity and lowest lake level occurred between (12.8-10 Ka BP), (52). Low water levels in tropics reflect a brief arid phase, which would appear to have been a product of the same disturbance to the climatic system that produced the northwest European Younger Drayas stadial (13000-11500 Cal. Yrs. BP). There is more than a suggestion that the hydrological cycle was weakened at this time, perhaps because glacial melt water reduced evaporation from ocean surface water in the northern hemisphere (8). It is obvious here that the record of the transitional period (Pleistocene/ Holocene) and the Holocene are unfortunately missing and were not represented in the sedimentary record of the Qa´a (3.5m). Whereas other workers in the neighbouring areas (northeastern Jordanian Deserets), have managed to detect the Early Holocene pluvial period to be at ~ 10-7 Ka BP (35) at Qa´a Al-Hababyya and ~9-5 Ka BP of Qa´a Burqne (42).

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