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Lake Level Variations for the Last 30,000 Yr B.P: New Palaeoclimatic Synthesis in Northern Hemisphere of Africa

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ABSTRACT

Lake level fluctuations are one of the most important sources of palaeohydrological and palaeoclimatic information for continental areas over the late Quaternary. We have compiled old and new published lake status data from North African basins, over tree periods: between 30,000 and 21,000 yr B.P, ca 9,000 yr B.P and ca 6,000 yr B.P.

Between 30,000 and 21,000 yr B.P, one or two relatively humid episodes have been identified in northern hemisphere of Africa. However, at 21,000 yr B.P, Low or intermediate lake status was registered in the Sahara, in west and east Africa north equator. The scarcity of data in this period globally reflects severe desiccation, deflation and erosion in many basins. It's clear that the late glacial maximum was significantly dry in this area.

At 9,000 yr B.P, many lakes began to rise. Some of them receded dramatically after 11,000 yr B.P. The majority of lakes with this initial amelioration was in north-east Africa in equatorial zone. The large perturbation is occurred in northern Africa. Between 0° and 22°N, nearly all lakes were high. The water status responded first near the equator (between 0° and 10°N) and subsequently rises progressively in Sahara and Sahel. The main period of positive hydrological conditions was recorded simultaneously in lacustrine systems in interdunal depression and in Sebkhas in Mauritania, Mali, Eastern Niger and Sudan.

At 6,000 yr B.P, the lakes show a more positive water balance over northern Africa. The southern margin of the zone of wetter conditions is unchanged relative to 9,000 yr B.P, but evidence from two sites in the Libyan desert suggests that the northern boundary may have been slightly further north. There is a suggestion that conditions became wetter than 9,000 yr B.P (and today) in the Maghreb.

Keywords: *Climate, Lakes, data, Africa northern Hemisphere, last glacial maximum, Holocene*

1. INTRODUCTION

The African continent is dominated by the trade wind system that moves seasonally northward and southward with the high sun. These winds bring rain from the south Atlantic and Indian Ocean, the Atlantic being the main source of moisture for the tropical part of Africa. The Atlantic monsoon penetrates into central Africa and into the western Rift Valley in the East. Another source of rainfall in East Africa besides the Atlantic monsoon is the South-East monsoon, which reaches the region during the southern summer [63].

The south African interior rainfall occurs during the austral summer months (DJF) and is most strongly influenced by tropical northerly airflow, which is enhanced by periodic coupling with temperate troughs; a quasi-monsoonal circulation results. Summer heating establishes a persistent cyc1onic low pressure cell over Zaïre which draws moisture from the western Ocean into the continental interior, from where it is adverted southwards over southern Africa. The region becomes cool and dry during the winter months (JJA) as the land surface cools relative to the oceans and a broad anticyc1onic (high-pressure) circulation prevails. Interannual variations in South African rainfall have been linked to the Southern Oscillation-El Nino changes in western Indian Ocean sea-surface temperatures [63].

A number of recently published research papers have reviewed the field of paleohydrology. Lake fluctuations are one of the most important and widely distributed sources of palaeohydrological and palaeoc1imatic information for continental areas over the late Quaternary (Fig 1) [6, 7, 9, 10, 17, 20, 25, 30, 46, 55, 56, 57, and 68].

2. METHODS

Changes in lake status (a measure of relative water depth or lake level) can be reconstructed from stratigraphic (lithology, granulometry etc), geochemical, palaeoecological (diatoms, ostracods, molluscs) and archeological data. In c1osed basin lakes in semi-arid regions, higher lake levels are frequently recorded by wave-cut terraces, beach ridges, or exposures of lacustrine sediments around the basin margin (Street-Perrott and Harrison, 1985). The geochemical and mineralogical records have been shown to be useful indicators of changes in the ionic composition and concentration which are commonly related to fluctuations in the hydrological budget of the lake. Isotopic studies have been frequently applied to lacustrine sequences in order to evaluate biological productivity, temperature, evaporation / precipitation ratio, and source of lake waters [59]. Changes in the nature of the lake sediments and variations in sedimentation rate, also provide an important source of information about past water depth [6, 9].

The reconstructed lake-status histories discussed in this paper are based on the consensus interpretation of all the available lines of evidence. The chronology of lake-status changes can be established by radiocarbon dating, U/Th dating, dated tephras, laminae counting [6]

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and palaeomagnetism [65]. The reliability of the dating method and the quality of the dating control were developed for the Cooperative Holocene Mapping (COHMAP) Project [64].

The number of status classes that can be identified at an individual site depends on the type and quality of the sedimentological and biostratigraphical record. At some sites, it is possible to derive a rather detailed record of depth changes (e.g., with up to seven different status classes) while at other sites the information is only sufficient to distinguish intervals when the lake is higher or lower than present. The fluctuations in lake status in each basin, was divide in three category scheme: (1) for low; (2) for intermediate and (3) for high. The class "high" corresponds to the upper quartile and the class "low" to the lower quartile of that lake's variation in depth or level during the entire period of record. This definition was adopted to en sure compatibility with the carling, in the global data set (Fig. 1) [57].

New and updating sites have been added to the Oxford lake level data bank (OLLDB) [6, 7, 30, 52, 53, 54, 55, and 57].

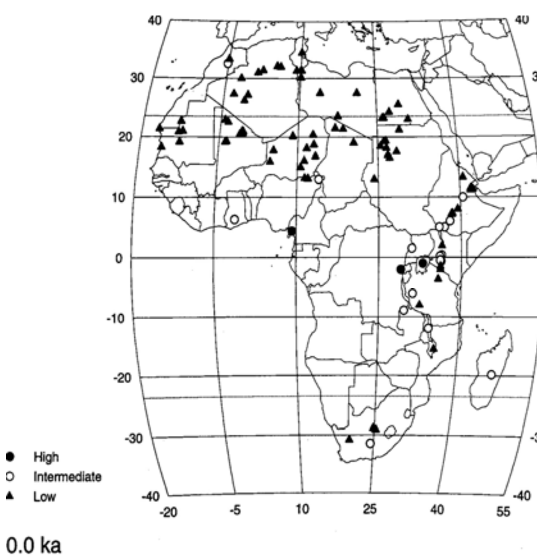

Fig 1: Actual lake level particularly in northern Hemisphere of Africa

3. RESULTS

3.1 Between 30,000 and 21,000 yr B.P (Figs 2 and 3)

Some rare data show an intermediate lake episode between 38,000 and 22,000 yr BP at Chad, at Sudan between 28,000 and 24,000 yr BP, and between 24,000 and 22,000 yr BP in the Sahel [13, 41].

An episode of high lake level between 40,000 and 20,000 years BP is recorded, especially in North-East African lakes at Abhe, Ziway-Shala (Ethiopia) [19]; Turkana [1], and at Baringo-Bogoria [61, 62]. At Barombi Mbo (Cameroon) the sedimentation has been characterized by the accumulation of laminated sediments some time irregular laminae suggesting relatively intermediate water level between 24,000 and 20,000 yr B.P [23].

At Lake Bosumtwi (Ghana) numerous turbidities, slump zone, bioturbation, fine laminae and plant rich muds indicated an intermediate water level between ca 24,500 and 20,000 yr B.P [37, 38, 58, and 59].

At Lake Ifrah (Morocco) between 30,000 and 24,000 yr B.P, the mineralogy and the geochemistry show that the terrigenous sediments are dominated by silty fraction originates mainly from the catchment area. The pollen record shows that although the main tree taxa (oak, pine and cedar), were present, the landscape was strongly dominated by Gramineae, Artemisia, and Chenopodiaceae which are herbaceous steppe elements. Such ecosystem composition confirms the low annual amount of rainfall [3, 8, 10, and 50].

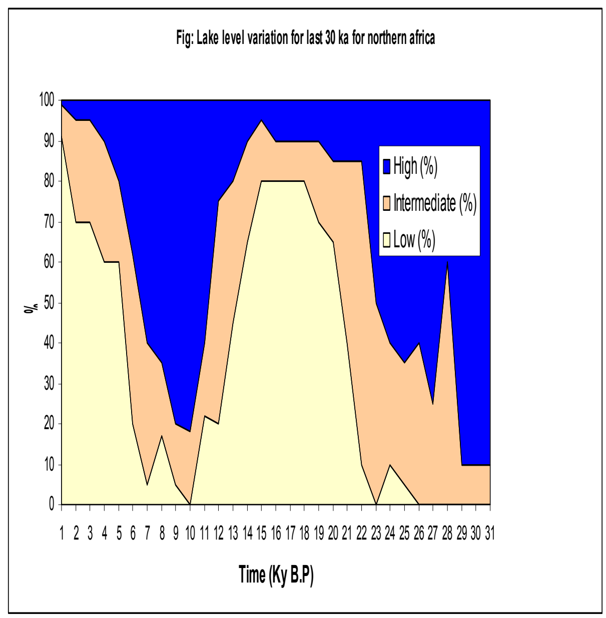

Fig 2: Histogram of lake level variation for the last 30,000 yr B.P in northern Hemisphere of Africa.

3.2 Late Glacial Maximum Phase (LGM) (21,000 yr B.P) (Figs 2 and 3)

Lake Abhe (Ethiopia) was dry by circa 17,000 yr B.P. During this regression silts and marls dominated. The diatoms flora seems to register a marker drop in water temperatures. A soil with a horizon of carbonate accumulation, containing montmorillonite and attapulgite produced by in situ weathering proves that the lake was practically dry [18]. At Ziway-Shala (Ethiopia) basin, between 21,000 and 14,000 yr B.P., pumice beds (up to 13 m thick) were deposited. The pumice beds are thought to be ash fall deposits. Apparently they accumulated on the exposed lake floor under very dry and possibly cold conditions which were unfavourable for pedogenisis [19].

At Baringo-Bogoria (Kenya) basin, there is a hiatus circa 18,000 yr B.P, the lake was probably low.

Anoxic sedimentation occurred particularly in the northern part of the basin (Tiercelin et al., 1982). In West Africa, in lake Barombi-Mbo (Cameroon); low sedimentation rate and thicker brown laminae and relatively coarser suggest a minor variation of water level (relatively 10m) [23, 37, 38]. At Lake Bosumtwi (Ghana), Brown muds with abundant plant debris, laminae enriched in granules of dolomite in association with Mg-calcite and zeolite. The mineral association suggests a saline-alkaline lake [37, 58, and 59].

In northern African sites (Maghreb), At Kadda (Algeria) lacustrine deposits of upper Pleistocene in Chech Erg were observed and studied by Conrad [5]. Four units have had sampled and dated. Among this unit carbonate and sandstone were dated at about 17,700±290 yr B.P by ^{14}C method [5] and at about 102,000 + 16,000 - 14,000 yr B.P and 75,000±7000 yr B.P using U/Th method [2]. The existence of these differences is probably related to the recrystallization of aragonite into secondary aragonite [2]. At Wadi Saoura (Algeria), the sedimentation is rich in organic matter and mollusc shells dated circa 16,300±350 yr B.P. This period is correlated with high lake status [57]. At Agdal, the Saoura river has incised a 10 m thick section of fine-grained deposits containing carbonate concretions, calcified macrophytes, indurated carbonates, shelly beds, and silt levels rich in organic matter. Finite radiocarbon dates range from 13,900 to 34,800 yr B.P [17]. Preliminary U/Th measurements suggest older ages ranging up to 200,000 yr B.P [22]. At Wadi el Akarit (Tunisia), the Saille chronological problems were observed [16, 17]. At Tin Ouffadene (Niger), the base of the cores is characterised by a very pure, laminated diatomite, the flora which reflects freshwater, palustral to lacustrine conditions [12, 14]. The lake was relatively deep. Six AMS ^{14}C dates on the diatomite range between 20,400 and 15,400 yr B.P.

These dates are probably untrue. At Ifrah (Morocco) dry period occurred between 21,000 and 16,000 yrs BP, with very high aeolian transport shown by the mineralogy [8]. Micro charcoal concentration was very low, this may be explain by a pattern of low fire activity [46]. Palynological study indicates that during the last glacial period steppic vegetation comprised more than 90 % of the landscape around the lake [3, 50].

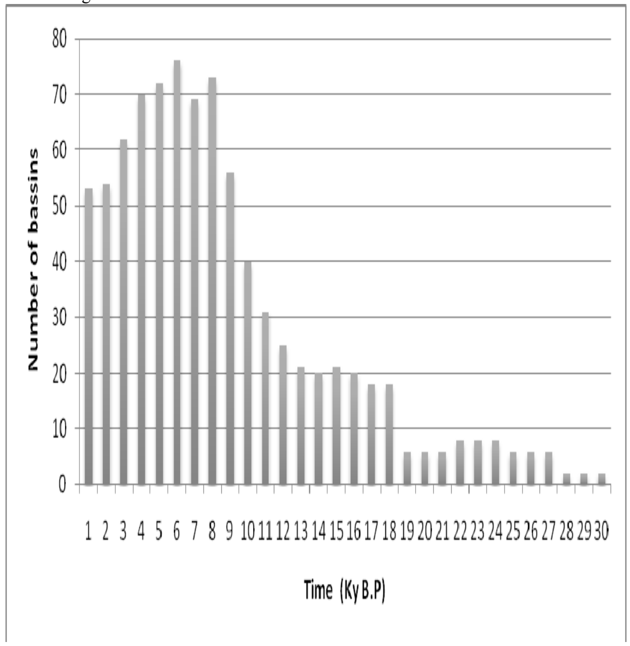

Fig 3: Number of lacustrine basins with registered time records for the last 30,000 yr B.P in northern Hemisphere of Africa

3.3 The early and middle Holocene phase (ca 9,000 and 6,000 yr B.P) (Figs 2 and 3):

In north hemisphere Africa, nearly all lakes were high. Figure of lake status indicate that water status responded first near the equator (between 10°N and 10°S) and subsequently rose progressively in Sahara and northern Africa. The main period of positive hydrological conditions occurred from circa 9,500 yr B.P. and 8,000 yr B.P. and was recorded simultaneously in lacustrine systems in interdunal depression and Sebkhas in Mauritania, Mali and Eastern Niger, travertines in the Hoggar massif, terraces in the Tibesti massif and interdunal lakes in Sudan. So, at Chemchane the sedimentation is characterised by marls, calcium carbonate and few centimetre thick layers with shells (gastropods, Melania tuberculata, Ostracods etc, [35]. All of these communities are common in Holocene sediments of the Sahara and North Africa and indicate a relatively relevant to salinity. This lacustrine episode was accompanied also by the development of the stromatolites dated between 8,000 and 6,500 yr B.P, which corresponds to a 9 m deep bathymetric distribution with reference to the former Chemchane Lake [35]. At Taoudenni, laminated clays, organic matter, carbonate mud with ostracods and fresh water molluscs indicate low water salinity occurred between 8,300 and 6,700 yr B.P. [43]. At Sbeita, travertines and gypsum enriched in Melania tubercula is dated about 8,700±100 and 8,600±100 yr B.P. [43]. At Bilma, Mellala, Bougdouma the sedimentation is marked by diatomite and lacustrine carbonate between circa 9,000 and 8,000 yr B.P, some time at about 7,000 yr B.P. [15, 17, 20]. A dating of a section at Haijad using Melania tuberculata gives an age circa 8,300±100 yr B.P. [43]. At Adrar Bous, between 9,700 and 8,400 yr B.P., there is carbonate accumulation the water status was intermediate. The high water status occurred between 8,000 and 7,000 yr B.P. with fresh water diatomite. The lake begins to drier ca 6,700-6,500 yr B.P. [17]. At Tin Ouffadene, continuous diatomaceous carbonate deposited between 9,000 and 7,800 yr B.P. (dating organic matter and carbonate material) corresponding to lacustrine optimum. Gypsum and clayey sand then registered the regression dated at about 7,300 yr B.P. [17].

In Eastern Sahara, the limnological evidence at Selima, El Atrun and Oyo is explicable in terms of the presence of deep, meromictic lakes depositing primary sediment. In fact, at Selima the basal charcoal layer is 9,700±200 yr B.P. Between 9,700 and 7,900 yr B.P., the sedimentation is laminated with periphytic diatoms [27]; the lake status begin to increase and the high lake status occurred ca 8,000 yr B.P. with lamination rich in organic matter, ostracods and abundance planktonic diatoms [27]. At El Atrun, the basal sediment dated between 9,220±70 and 8,060±70 yr B.P. with sapropel material, fine organic laminae and carbonates muds [48]; suggests a high water status. At Wadi Howar, fresh water Mollusc and ostracods was radiocarbon dated to 9,195±95 yr B.P. [40].

In north eastern Africa, all lakes were high at this time and many of them were greatly enlarged (Nakuru-Elemnteita, Naïvasha-Small Lake, Ziway-Shala, Abhe, etc) with for some lakes overflow [1, 18, 57].

This transgression phase showed at 9,000 yr seems to continue ca 6,000 yr. The sedimentation is similar to the early Holocene sedimentation. It's marked by clayey lamina deposits, by abundant well-preserved algal filaments and by alternation of shelly beds and carbonate indicating lacustrine episode [17, 20, 23, 42, 44, 47, 48, 51, and 58].

4. DISCUSSION

In general the period between 30,000 and 21,000 yr B.P is characterised by less data and rare and/or bad chronology. However the existed data show a very instable period with high and intermediate Lake status in connection with relatively humid phase.

The last glacial maximum was the most arid period in northern hemisphere of Africa. Most of the lakes were dry or extremely low. Only few basins registered this period (figure 1 and 2). The scarcity of data for 21,000 yr B.P globally reflects severe desiccation and deflation in many basins. Aeolian flux was 7 times the present-day flux [24], and large pollen amounts in marine (Atlantic Ocean) sediments reflect vigorous trade wide transport and abundant desert vegetation in a large part of NW Africa [29]. Winter conditions were dominant leading to strong dust-laden offshore winds (Harmattan) blowing from high-pressure cells centred over North Africa (Sahara) [39]. However, atmospheric trajectories computed at 850 hPa level during the LGM by Wyputta and Grieger [66] on deep sea core GIK 1645 (9°34N, 19°06W) exhibit a pronounced annual variation in direction as well as in velocity.

The lake evidence of wetter conditions in south of Algeria region may reflect probably a chronological problem. For Kaddda and Saoura, the reason for the inconsistency of Pleistocene ages obtained on carbonates, the U/Th results lead to the concept of the absence of any significant humid phase in the 35,000-18,000 yr B.P as previously proposed for the northern Sahara. The last great humid period before the Holocene is much older and probably centred on 90,000 yr B.P [2, 45].

In contrary, the lake data show that conditions were generally wetter than today during the early and middle Holocene (ca 9,000 yr B.P and ca 6,000 yr B.P). Many basins registered this period (Figs 2 and 3).

The drastic rise in lake status in Africa ca 9,000 yr B.P and ca 6,000 yr B.P, coincided with the increase in northern hemisphere summer solar radiation enhanced the thermal contrast between the north African landmass and the adjacent Atlantic and Indian oceans, stregthened monsoonal circulation and brought increased rainfall to this region. It explains the high increase of continental precipitation in major part of Africa [4, 32, 33, and 34]. Geological evidence suggests that the monsoonal rains (Indian monsoon and Atlantic monsoon) were more abundant, more prolonged than they are now [7, 21, 23, 35, 37, 38, 49, 59].

Kutzbach (1980) [32], Hastenrath and Kutzbach (1983) [26] used the water balance model to estimate the Holocene precipitation for some African Lake basins. For Lake Chad, this model gives an estimate of about 300 mm above the current average during the period between 10,000 and 5,000 years B.P when the lake reached its maximum. For the big lake Ziway-Shala, this model estimates the precipitation approximately about 450 mm.

Other estimates of rainfall during the wet Sahara optimum have been proposed. This estimate ranges from 100 mm [31], 200 mm [27] to 400 mm [47]. In Western Sahara the estimated precipitations range from 250 mm to 300 mm between 22°-23° N latitude and from 400 mm to 500 mm between 18°-19°N latitude [44]. Lezine et al., (1990) [35] give a minimum estimate of about 300 mm above the modern precipitation.

This moisture suggests also a northward migration of the mean intertropical convergence zone (ITCZ) during the early and middle Holocene, particularly in summer [30].

These results are on agreement with all of the climatic models showing enhancement of the African monsoon [67] in this time period.

5. CONCLUSION

Between 30,000 and 21,000 years B.P, one or two humid episodes have been identified in northern hemisphere of Africa. However, the existence of this wet phase is based on radiocarbon dates. The use of a new radiometric method is recommended. The period between 21,000 and 12,000 years B.P is characterized by a scarcity of lacustrine data. Indeed, there is a dry period for all sites northern hemisphere of Africa. Therefore, this interval is characterized by the absence of deposits and the existence of hiatus. The upper and Middle Holocene are characterized by the increase of lake data and site number; the rainfall was enhanced causing an increase of lake status. This wet period is correlated with response of insulation forcing, northward displacement of the ITCZ and an increase of summer monsoon from Equator to 22°N-23°N. From ca 5,000 years BP, there was installation of more arid conditions.

This paper is a call to the international scientific community, particularly to the scientist working in paleosciences and paleoclimate reconstruction in Africa for more cooperation North/South, South/South (African Scientist), East/West and for more projects. There's a very big gap of continental data for the chronological periods before 12,000 yr B.P (between 30,000 and 12,000 yr B.P and before 30,000 yr B.P).

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