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LATE QUATERNARY PALAEOENVIRONMENTS OF THE SAHARA REGION

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ABSTRACT

The climatic evolution of the Sahara has been studied very intensely during the last decennium. Prior to this time only some important palynological investigations have been published on the region. All this research was mainly concentrated on the Late Quaternary.

The environmental evolution of the Sahara region was dominated in Late Pleistocene and Holocene times by the energy balance between the bipolar glaciations. The drastic lowering in temperature which occurred during the last glacial maximum over Europe and the adjoining seas brought heavy cyclonic winterrains accompanied by a cool climate to northwestern Africa. The central Sahara and particularly the Sahara mountains also received rainfall by the intervention of tropical depressions while the rest of the Sahara was arid. This tipe of rainfall persisted until ca. 6500 BP, after which the monsoon rains of sahelian type invaded the southern and central Sahara until ca. 4400 BP.

The various stages of this process are discussed for the different regions using geomorphological, biogeographical, palynological and oceanographic evidence. The sediment sequences of the central Sahara mountains and the lakes of the southern Sahara have provided invaluable material for the dating and correlation of these events.

THE GLACIAL CLIMATE

The repeated cooling of the Arctic in Quaternary times and the development of extensive ice sheets since 2.5 M Y ago had a profound effect on the geology, the climate and biogeography of the Northern Hemisphere and for that matter on the entire globe. During the last glaciation the ice sheets in North America were much larger than those in Europe and the Alps. South of the glaciers vast plains were covered with fluvioglacial deposits, tundra and loess steppe, while the deciduous forests of Europe were driven far away into a great number of niches and sheltered habitats in the mountains bordering the Mediterranean.

The change in climate was extraordinary as can be concluded from the data on palaeotemperatures that has been published. Permafrost occurred in Europe as far south as southern France and the Black Sea from which a decrease in temperature of 15 - 18^{0}C has been inferred by Butzer, (1976). The same author estimates that the southward shift of the Arctic tree line from northern Scandinavia to southern France and the central Volga Basin over a distance of 3000 km implies a drop in summer temperature of 7 - 10^0 C, while the winters were much colder.

The first results of the Climap Project, which are concentrated on the simulation of the climate during the last glacial maximum 18 000 years ago, show that the temperature of the surface water of the oceans was lowered significantly, but the decrease was of an entirely different degree in different parts of the world (McIntyre, 1976). The oceanic polar fronts were displaced equatorward especially in the North Atlantic, which north of 42^0 N, was transformed into a polar sea. Permanent pack ice covered the seas around Labrador, Iceland and Scandinavia and winter sea ice extended in the North Atlantic to approximately 45^0 N (McIntyre et al, 1975). In the Southern Ocean conditions were in winter much more severe and sea ice reached much lower latitudes than at present (Hays et al, 1976). The facts that permafrost in southern France reached 45^0 N latitude and the Arctic Ocean moved to 42^0 N make it plausible that the western Mediterranean was 10 - 12^0 C cooler than at present. In the eastern part of this sea the temperature decrease was probably only 1 - 2^0.

The decrease in temperature for the Atlas was even 13^0 C (Gates, 1976). The consequences of this considerable drop in temperature are to be found on the northern slopes of these mountains where two horizons of 'cold landforms' occur below the present level of 2440 m (Couvreur, 1965).

50-43000
32-12000

Important proof of cold conditions along the Mediterranean coast has come forward from Cyrenaica where Hey (1972) described two periods of active frost wedging on Pleistocene screes, viz. from 50 000 - 43 000 BP and from 32 000 - 12 000 BP. The process was less active during the second period, probably because the climate of Cyrenaica was dry during the last Würm maximum. The current winter temperature in this northern part of Libya is 14^0 C which confirms the former drastic deterioration of the climate.

These enormous changes in temperature can only be explained in terms of changes in the Earth's energy budget and the results of such changes were of an intricate nature as they affected the upper atmospheric circulation. In a number of cases correlations can be indicated with some confidence as is shown in the general study of Rognon (1976) on the late Quaternary of the Sahara (see also: Rognon & Williams, 1977).

These changes must have had a dramatic influence on the palaeoenvironment of the Mediterranean coast and the Sahara region. This can be substantiated by the simulated differences in July surface air temperatures at 18 000 BP (Gates, 1976). Although this data has not reached its final form and has to be upgraded the information so far shows unequivocally that 18 000 BP the entire region comprising Europe, the northern Atlantic, the western Mediterranean and the northern Sahara, was transformed into a large very cold to cool part of the world (Paskoff et al, 1977). The consequence of this situation must have been that the climatic system had changed profoundly. The stable high pressure system of the ice cap extended its influence well over the western Mediterranean and the descending divergent cold air brought aridity to this region.

THE NORTHERN AND EASTERN MEDITERRANEAN COASTLANDS

The Mediterranean coastlands have supplied important circumstantial evidence on environmental changes which occurred in the northern Sahara.

It has for a long time been assumed that during glacial times the deciduous forests of Europe migrated southward and covered the Iberian, Italian and Balkan peninsulas. Pollen analysis of deposits of glacial age has, however, shown that this assumption was totally wrong.

Round Lago di Monterosi near Rome the vegetation consisted ca 25 000 BP and later of a treeless dry steppe (In lit. Beug, 1967). Similar conditions existed in Granada in southern Spain, where some pine trees occurred widespread in the open vegetation (Ibid).

In eastern Macedonia the evergreen oak forest of the Eemian was from 60 000 to 14 000 BP replaced by dry open steppe in which Kochia and Eurotia indicated that the environment was much colder than at present and resembled present day conditions in the Pamir in Central Asia (Van der Hammen, et al, 1971). Forest remnants occurred at higher elevation on the mountain slopes which received more rainfall.

The Artemisia - Chenopodiaceae steppe also occurred in S.W. Turkey between 20 000 and 10 000 BP and was gradually invaded by trees when the climate became more humid and warmer in Late Glacial times (Van Zeist et al, 1975). The forest became established here only after 8000 BP.

Even in western Iran trees were completely absent in the steppe round Lake Zeribar between ca. 23 000 and 14 000 BP (Van Zeist, 1969).

All these studies of fossil pollen lead to one conclusion viz. that during the last glacial maximum the northern and eastern border lands of the Mediterranean were exposed to a very cold, dry and windy climate.

THE NORTHERN AND WESTERN SAHARA DURING QUATERNARY TIMES

It is very difficult to subdivide the vast Sahara region into areas which had a more or less uniform climatic history. The central Saharan mountains and also the southern part of the desert each form definite entities while the rest of the desert and the extensive coastal areas belong to a far less homogenous section.

Although a remarkable amount of work has been done in the northern and western Sahara, especially by French researchers such as: H. Alimen, F. Beucher, P. Chamard, C. Conrad, R. Coque, P. Elouard, H. Faure, P. Michel and several others, many problems have not yet been solved.

In some periods during the Pliocene, particularly the uppermost part warm and semi-arid conditions prevailed in the northern Sahara and extensive lacustrine deposits were laid down between the Hoggar and the Atlas mountains (Conrad, 1969b; Maley, 1978). The large basins of the Ahnet-Mouydir and of the N.W. Sahara were at one stage united to one extensive lake. The climate in this vast region was

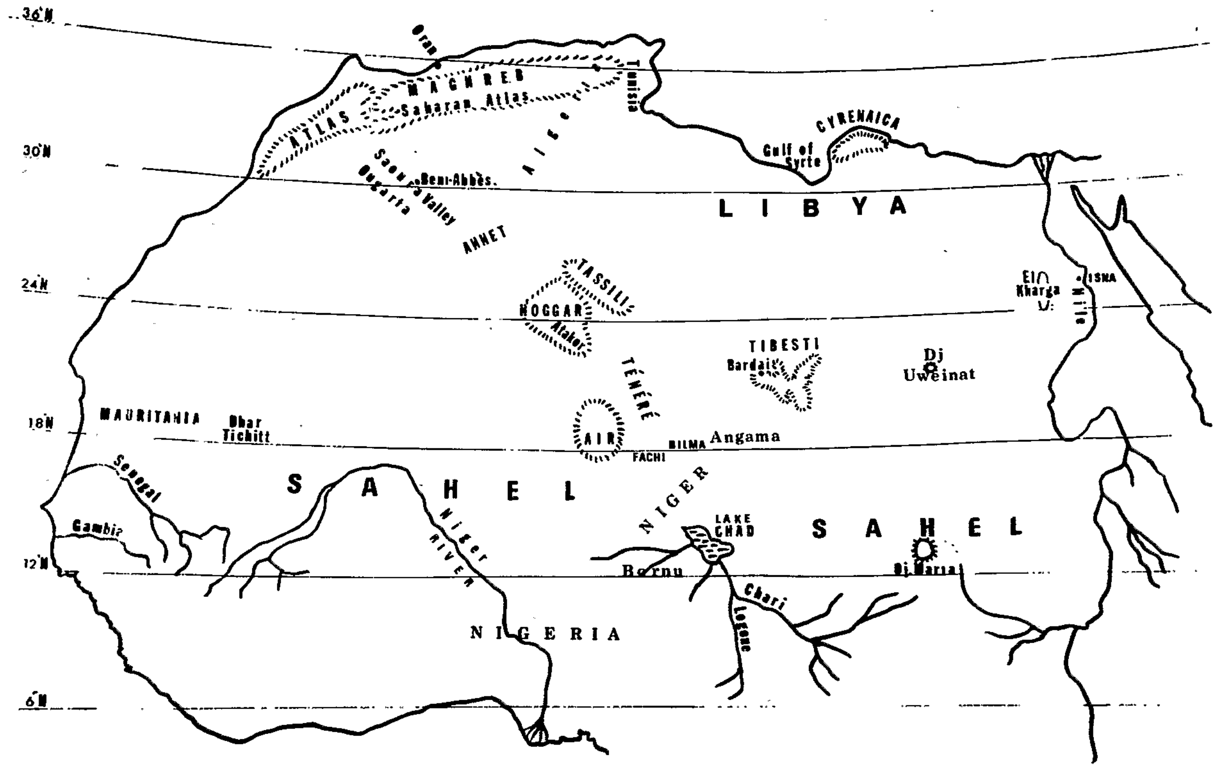

Fig. 1. Locality map of the Sahara.

ranging from tropical in the south to mediterranean temperate in the north. Geological data on the lower and middle Pleistocene is at present very limited. In the course of the upper Pleistocene a climatic amelioration can be detected which made it possible for Acheulian people and probably also for plants and animals to spread into the desert, as has been observed in Mauritania, the Saoura (Conrad, 1969c) at Bilma (Maley et al, 1971), in the Djebel Uweinat (de Heinzelin et al, 1969), in the southern Libyan desert (Haynes, 1977) and in Nubia (Wendorf, 1968, 1977). (Fig.1).

In the central Sahara after a new arid cycle a sub-arid to sub-humid phase followed from ca. 40 000 to 20 000 B.P., which was probably sub-divided into two or three stages (Conrad, 1969; Servant, 1973; Maley, 1976). These different phases may have been related to rain caused by tropical depressions (Maley, 1976, 1977a). From this period dates the extension of different cultures in the Sahara, particularly the Aterian (Camps, 1973; Clark et al, 1973) and the first industries which showed characteristics of the upper Palaeolithic; assemblages of this last type are known from Bilma (Maley et al, 1971), Nubia (Wendorf, 1968) and Libya (Mc Burney, 1967).

The extensive ice sheets of the Northern Hemisphere certainly had a dominating influence during this interstadial and the strong anticyclone over northern Europe together with the low temperature in the Arctic activated the atmospheric circulation. The cyclonic tracks were forced southward and brought much precipitation to the Maghreb (Rognon, this volume) while the northern Sahara proper as far as the Red Sea coast of Mersa Alam (25° N; Butzer, 1972b) did not receive much rainfall.

The climate deteriorated drastically during the ensuing last cold maximum of the Würm. The considerable lowering in temperature over the entire region of Europe and the northern Atlantic has already been alluded to. The central Atlantic was also cooler than at present (Gates, 1976). According to the Climap simulation model the West African coastal waters between the latitudes of 22 and 15° N were 6 - 8° C colder in February than at present (McIntyre et al, 1975; Rognon, 1976). The Canaries Current, which is accompanied by cold upwelling, flows at present near the coast between 30° N and 21° N. This data indicates that the current was forced equatorward during glacial times just as its southern counterpart the Benguela Current (Bornhold 1973; van Zinderen Bakker, 1967, 1975).

The cyclones originated at an unusual low latitude and travelled over the Maghreb and Israel where they caused high rainfall enhanced in the Atlas by orographic precipitation (Rognon, 1976). In the Maghreb and the desert region south of the Atlas lakes persisted for a long time. They received much water from the mountains through a profusion of oueds which also transported pollen of mountain plants and mediterranean elements to lower altitudes (Beucher, 1975, p. 265). The hygrophyllous and mountain vegetation represented in the pollen spectra is therefore not representative for the overall climatic conditions (ibid.). The climate of the desert proper was according to Conrad (1969) semi-arid during the period ranging from >39 000 - 14 500 BP, while Chamley et al (1977) indicate that this desert region north of 20° N was fairly humid, in contrast with further south

		SENEGAL	MAURITANIA	MAGHREB	N. DESERT TUNISIA-RED SEA
HOLOCENE		humid	present day clim. 2000 BP drier 3500-3000 Neolith. 6500-4300 pluvial 9000-7000 maxima	present day clim. Pluvial 9000 10500-10000 Pluvial	present day clim. ± 3000 dry 4500 Neol. Pluvial 8000
LATE WÜRM	LATE GLACIAL	humid	semi-arid	12000 peaks lakes south of Atlas	16000
	LAST GLACIAL MAXIMUM	dry	semi-arid	wet, cold	sub-arid colder
MIDDLE WÜRM		humid	dry	humid	arid, warmer
EARLY WÜRM		dry	semi-arid	wet, colder	semi-arid colder

Fig. 2. The late-Quaternary climatic evolution in the western, northern and eastern parts of the Sahara.

where the climate was dry.

Palaeobotanical studies have provided valuable evidence for former environmental conditions. The pollen spectra from southern Tunisia indicate a semi-arid and cool climate with a steppe vegetation consisting of Compositae, Gramineae, Artemisia and Chenopodiaceae (Leroi-Gourhan, 1958; Van Campo & Coque, 1960).

Coque (1969) also concludes that the climate must have been colder. He describes fossil gelifraction from altitudes of 900 - 1000 m on S.E. slopes in Tunisia and mentions fossil pollen of Cupressus and Erica which demonstrates lower temperatures. Similar evidence for cold conditions has come from Algeria where Baudrimont (1974) showed that during the late Pleistocene ("3me pluvial froid") cosmopolitan and eurytherm diatoms replaced the tropical species in the waterbodies.

A new situation developed during the warming up in Late Glacial and Holocene times. A short rainfall peak occurred in the Maghreb round 12 000 BP and again between 10 500 and 10 000, while a real maximum in precipitation started at 9000 B P But it seems that the northern Sahara still remained fairly dry during the beginning of the early Holocene (Conrad, 1969c).

During the early Holocene, until 6500 B P lacustrine and fluviatile deposits were numerous throughout the central Sahara; this humid phase during which the evaporation was lower than the precipitation could have been caused by tropical depressions (Maley, 1977b). The simultaneous appearance of Neolithic pottery from ca. 8100 B P onward right through the central Sahara from Nubia to the Hoggar is a phenomenon of great importance (Maley, 1977b). An important arid phase with dune formation in the plains (Wendorf, 1977) has interrupted this humid phase near 7500 B P

Near the time of the Climatic Optimum of Europe, after ca. 6500 BP., humid conditions penetrated the entire Sahara. At this time the tropical depressions were replaced by the monsoon which reached the central Saharan regions regularly. This more humid period lasted until 4400 B P.

The Climatic Optimum was marked by a high sea-level, the Nouakchottian of the West African coast (Elouard, 1973). The warm ocean surface supplied more water vapour which the monsoon could transport far into the continent as the northern anticyclone held its most northern position and was weakened (Beaudet et al, 1976).

The end of the temperature optimum can be dated at about 5 000 B P The Climatic Optimum terminated at a time coeval with the first part of the Priora glacier advance in the Alps between 5 300 and 4 900 B P (Patzelt, 1974). Frenzel (1968) describes a coinciding sudden cooling of the Northern Hemisphere between 5 000 and 5 400 B P and Van Zinderen Bakker (1969a) mentions dates for this period between 5 500 and 4 700 B P The cooling marks the beginning of the Subboreal in Europe, a period with less precipitation, colder winters and warmer summers. This cooling will have been responsible for the strenghtening of the anticyclone and probably for some aridification in the Sahara. But afterwards conditions again became favourable as can be concluded from many neolithic sites in the central and meridional Sahara which date until 4 400 B P An important arid phase occurred subsequently until 3 600 B P. (Maley, 1977a).

The Holocene climatic evolution along the western coastal region of the Sahara depended on the shifts of the cyclonic tracks and the monsoon, the first bringing winter rain and the last 'tropical' summer rain. After the mid-Holocene; 'pluvial' conditions had again improved so much that Neolithic people could live along the coast (Ortlieb and Petit-Maire, 1976; Petit-Maire, 1972). The vegetation was then marked by Chenopodiaceae, Gramineae and Cyperaceae. By 2 000 B.P conditions resembled the present day dry desert (Petit-Maire et al, 1977).

This data is corroborated by the findings of Munson (1976), who studied the origin of seed crop agriculture in the Dhar Tichitt region in central Mauritania. During the period prior to 4 000 B P large lakes existed in the area. These dried out completely and were followed by a new lacustrine phase which lasted from 3 500 - 3 000 B P.

Studies on desert dust blown into the ocean off the West coast of Africa also give interesting information on the meridional movements of the Sahara during the Quaternary. It appears that during the colder periods of the last 1,8 MY the southern Sahara must have been more arid. Cores taken off the coast of Sierra Leone (8^0 38' N) and near the Cape Verde Islands off the coast of Mauritania contain many more opal phytoliths and freshwater diatoms blown in from the Sahara in the glacial sections than in those of interglacial age (Parmenter & Folger, 1974).

Recent investigations by Diester-Haass (1975, 1976, 1977) and Chamley et al. (1977) along the same coast corroborate these findings for the last glacial. These cores were collected between 15 - 27^0 N latitude and the sections of Holocene and Middle Würm age contained a high percentage of desert quartz and $CaCO_3$, except in the Senegal area where river action indicated a humid climate. During the cold Early and Late Würm the rivers south of 17^0 N had apparently ceased to flow and the vegetation north of 20^0 N consisted of a steppe with Ephedra, Artemisia and Chenopodiaceae which points a semi-arid climate (Michel, 1969; Burke et al, 1971). A broadly similar pattern has been described by Olausson (1972) for the Somali basin on the east coast of Africa.

QUATERNARY PALAEOENVIRONMENTS OF THE SAHARAN MOUNTAINS

The vast mountain complexes of the Ahaggar or Hoggar, the Tibesti and the Aïr of the central Sahara have in recent times been the focus of extensive investigations of a geological, biological and archaeological nature. These mountains occupy a very exceptional position as they are in many ways islands which differ in every respect from the surrounding sand ocean. They are rich in Quaternary deposits which are invaluable for the understanding of the changes which took place in the vast surrounding desert.

The research in these mountains has mainly been organised by the "Institut de Recherches Sahariennes" (for the Hoggar), "das Geomorphologische Laboratorium der Freie Universität Berlin" in the Bardai Oasis (Tibesti), the ORSTOM (Office de la Recherche Scientifique et Technique Outre-Mer) and the British Expedition to the Air Mountains (Adrar Bous). In this section extensive use will be made of the reports of these activities. An absolute chronology is unfortunately only available from Late Glacial times onward.

In Pliocene times the southern Sahara had evolved to a tropical dry desert but near the end of that epoch the climate became cooler and deep, extensive lakes occurred in the uplands of Tibesti (Maley et al., 1970), the Hoggar , Ethiopia and in the now arid lowlands of Chad (Servant, 1973) and the Afar (Faure & Williams, 1977). Rognon (1967) describes the climate of the Atakor in the Villafranchian as more humid as a consequence of prolonged steady rain and more mountain fog. These conditions favoured the development of a dense vegetation cover and the growth of forests in sheltered habitats at higher altitudes. Fossil records indicate that the tropical fauna disappeared during this cooler period. During the Pleistocene, at high altitudes snow fell regularly and 'cold landforms', characterised by gelifraction, névés and solifluction, developed on an enormous scale. On certain slopes even rock glaciers appear to have occurred. It is, however, questionable whether truly periglacial conditions and permafrost existed during any of the glacial periods on the high Tibesti or Hoggar (Butzer, 1973).

In the lower valleys swamps and lakes developed. This favourable climate was, however, limited to the high mountain areas as the extensive surrounding plains were still semi-arid.

The Hoggar is situated in a marginal position so that at certain times in the early Quaternary tropical climate accompanied with heavy rainstorms could invade the mountain region. During the transition periods leading from a warmer humid climate with intensive weathering to a cold episode extensive erosion took place and fluvial terraces were built up. The heavy storms were responsible for the downslope transportation on the pediments of rocks of considerable size. During the following dry phase of the cycle the surrounding ergs were activated. In the mountain some of these dry-wet-dry cycles have been recognised. The last cold period, which was of Mousterian-Aterian age, was less severe or was of a shorter duration than the two previous ones.

In the Saharan mountains the chronology of events older than the Late Würm is uncertain. Rognon (1967) describes a tropical humid phase in the Hoggar which is followed by an arid period. This dry phase may partly belong to the Middle Würm (Rognon, 1976) or warm Kalambo interstadial of East Africa (Coetzee, 1967). Rognon (1976) assumes that the central mountains of the Sahara during that period were under the influence of a narrow anticyclonic zone, while the southern Sahara received much rainfall. A comparable dry period of Kalambo age has been described for the Adrar Bous in the N.E. Aïr (Clark et al, 1973).

During the last Würm maximum the fairly sudden cooling of the northern Atlantic and Europe resulted in a very distinct pluvial in the central Sahara, particularly in the high Saharan mountains as a consequence of the interaction of the polar front and surges of the monsoon, which caused tropical depressions (Maley, 1977b). The steep temperature gradient between the Arctic and the equator accelerated the wind system, while the climatic zones were compressed meridionally and moved equatorward. The rainfall which these depressions brought to the Hoggar was responsible for cold water diatoms in lakes and large névés, probably dated for this period, were found at altitudes

		HOGGAR	TIBESTI	CHAD
HOLOCENE		B.P. 5000 WET 8000 LACUSTRINE DEPOSITS	DESERTIFICATION 2800 4400 MONSOON WETTER 6400 7500 DRIER 8100 WETTER OSCILLATIONS	B.P. MINOR OSCILLATIONS 3600 4000 ARID REGRESSION 5000–6500 PALAEOCHAD MAXIMUM 7500 ARID 9200 ARID 9700–10200 III ARID 11000–11800 II ARID 12500–13000 I TRANSGRESSIONS 6600 COOL
LATE WÜRM	LATE GLACIAL	12000	12000	LARGE ERG
	LAST WÜRM MAXIMUM	COLDER WET	COLDER WET ~18000	~20000–22000 WARMER
MIDDLE WÜRM (KALAMBO)				TRANSGRESSIONS COLDER

Fig. 3. Late-Quaternary climatic changes in the Sahara mountains.

above 2 300 - 2 400 m (Rognon, 1976).

In the Tibesti the periglacial phenomena were apparently much less important (Messerli, 1972, 1973), but humid conditions must have existed there as the Trou au Natron showed a high lake level probably from 17 000 - 18 000 B P onward. Two metres of diatomite have been deposited here under a horizon dated at about 15 000 B P (cf. Faure, 1969).

In Upper Egypt, near Isna (25° 22' N), at 11 km from the Nile, *prehistoric sites containing an industry of* Upper palaeolithic type with large fauna (including: Bos, Hippopotamus, Hartebeest, Gazelle, Rabbit, etc), have been discovered. These sites have been dated 17 980 ± 330 BP and 17 590 ± 300 B P (Wendorf and Schild, 1976).

Maximum aeolian activity of the central Sahara occurred approximatively between 20 000 and 18 000 B P During this period the Nile alluvials were interstratified with important aeolian deposits (Ballana Formation) (Wendorf, 1968; Wendorf and Schild, 1976). Subsequently the aeolian activity appears to have spread southward. The studies of fluviatile deposits in Nubia (Butzer and Hansen, 1968; Wendorf and Schild, 1976) and in the Tibesti (Geyh and Jäkel, 1974; Jäkel, this volume; etc.) have produced evidence on an impressive sequence of climatic changes which have been very well dated. From these dates it appears that the so-called 'Middle Terrace' was laid down between ca 17 000 - 18 000 B P to ca. 5 000 - 5 500 B P. (Maley, 1977b). Jäkel (this volume) points out that the Tibesti was exposed to a cool humid climate with cyclonic rains of a mediterranean type from 16 000 until 8 000 B.P., while the southern monsoon affected it from 13 000 to 5 000 B.P. Maley (1977b) using geological and palynological data proposed another interpretation, viz. that between ca. 17 000 and 6 500 B P. the rains were primarily due to tropical depressions caused by the interaction of the polar front and surges of the monsoon during the intermediate seasons of spring and autumn. He contends that after 6 500 B.P until ca 4 400 B.P the monsonal rains of sahelian type predominated.

More to the west Conrad (1969c) has shown that in the erg Chech (ca. 26 - 27°N - 2°W) lacustrine deposits resting on aeolian sands form a continuous sequence between 15 000 and 8 000 B C (ca. 17 000 - 10 000 B P). These could have been formed as a consequence of the adjustment of the water table. Slightly more to the south (25° 35'N) lakes containing Cardium have been in existence in the Ahnet - Mouydir basin. The base of the deposits is older than 35 000 B P and the top considerably younger than 18 000 B P ("largement postérieur à 18 000 B P , " Conrad, ibid.) Their water supply was related to precipitation on the basin (Conrad, ibid.)

Prehistoric studies showed that after 7 000 B P until about 4 000 B.P nomads with their cattle herds could move into the grass-covered plains of the central Sahara. The widespread assemblages of stones which they left behind from their fire hearths still testify of their former presence (Gabriel, 1976, 1977).

It is interesting to note that at 10 000 B.P. the climate was considerably colder than at present and that cold water diatoms persisted in Lake Chad till about 6 600 B.P. (Servant - Vildary , 1977 and this volume; Maley 1977a).

In the Gulf of Guinea the analysis of a core taken not far away from the Niger delta has shown that an important warming of the ocean water happened shortly after 6 750 ± 410 B P (Pastouret et al, 1978). Further important information on temperature changes is that at the end of the mid-Holocene, the temperature must have been lower near 5 100 B P (Jäkel, 1977 and this volume). This event coincided with the world wide cold spell from about 5 500 - 4 700 B P at the beginning of the cool Subboreal.

A climatic sequence covering the last 30 000 years, has been described for the Adrar Bous in the Aïr Mountains (Clark et al, 1973). The continuous occupation by prehistoric man from the Upper Acheulian through the Middle Stone Age to the Aterian shows that conditions must have been fairly favourable. It is of interest to note that at the end of the Aterian, humid conditions in the Adrar Bous must, according to well dated lake levels, have persisted at least until 11 000 B P (Clark et al, 1973).

Pollen analysis of Pliocene samples from different parts of the Sahara has shown that the xerophytic vegetation was already established (Maley, 1978). These pollen spectra contain a certain percentage of mediterranean or temperate taxa, which are probably of long distance origin.

Several studies have been conducted on the wind transport of pollen in the Sahara (Cour et al, 1971), Tibesti (Schulz 1974, 1976), round lake Chad (Maley, 1972) and particularly an extension survey on air-borne pollen has been organised from Oran (34° N) to the southern Sahara (20°N) (Van Campo, 1973; Cour et Duzer, 1976). All these investigations show that the following long-distance pollen, coming from as far as Europe, can occur in small percentages in the present day spectra of the Sahara and can cause misleading interpretations of fossil pollen spectra: Alnus, Betula-Carpinus, Castanea, Cedrus, Corylus, Fagus, Fraxinus, Juglans, Mercurialis, Phyllirea, Pinus, Platanus, Tilia, Ulmus, Vitis, etc.

Schulz (1972, 1974) infers from pollen found in fluviatile sediments in Tibesti with ages dating from 14 000 to 6 000 BP the occurrence of galery forest along the wadis with mediterranean macchia growing on the mountain slopes, the higher parts being covered by deciduous oaks and other trees. He also implies that the plateaux of an altitude of 2 000 - 2 200 m were dominated by a dry grass - Chenopodiaceae - Artemisia steppe. It could be argued that part of the mediterranean type pollen had an extra- saharan origin.

It has been suggested that mediterranean vegetation could during the Holocene migrate from the Maghreb to the mountains of the central Sahara (Pons and Quézel, 1957; Quézel and Martinez, 1961). Such migrations are still equivocal as certain pollen of mediterranean or temperate type could have been transported by atmospheric circulation as aeropalynological studies under present day conditions have shown. These recent findings do not change the palaeoclimatic conclusions significantly as these are also based on geological evidence and autochtonous pollen, but they prove that pollen analysis is a sensitive tool which can lead to misinterpretations.

It can be concluded that the Quaternary climatic evolution of the different central Saharan mountains is similar in broad outline and only differs somewhat in timing in the various mountains.

THE QUATERNARY LACUSTRINE PHASES OF THE SOUTHERN SAHARA

The southern Sahara has become a classical site for the study of the late Quaternary climatic evolution of Africa. During the late-Pleistocene and Holocene, and probably in earlier times, lakes covered vast areas between the latitudes of 13 and 20° N in Mauritania, Niger, Chad and Sudan. The many stages which are known of these lakes in this extensive desert belt are generally of the same age. The Sahara invaded the Sahel during the last great arid period (ca. 20 000 - 13 000 BP) and moved 400 - 800 km southward. In comparing the lacustrine events in the different lakes it must be noted that the hydrology and morphology of the lake basins differ (Faure, 1969; Servant & Servant, 1973). The detailed correlation of the different lake levels before 20 000 BP is hampered by the uncertain ^{14}C-age determinations, which have mostly been done on calcareous crusts or nodules and other material likely to contain different quantities of old carbon.

The sequence of events in Mauritania, eastern Niger. (Facchi, Bilma), Chad and the Afar can be compared very well. Deep lakes occurred in this region during the warmer Middle Würm or Kalambo Interstadial and the first part of the cold Late Würm (ca. 40 000 - 20 000 BP) (Servant, 1973; Rognon & Williams, 1977). In the Afar desert and in Chad psychrophilic diatoms have been found in the deposits of these former lakes (Gasse, this volume; S. Servant, ibid) some 15 palaeoarctic species occur in Chad in deposits with an age of ∿ 36 000 and of ∿ 26 000 - 20 000 years BP. These species may, however, not be such reliable indicators of palaeotemperatures as they occur only in oligotrophic water (Gasse, op cit.; Servant, op cit.) In Lake Chad these psychrophilic species disappeared in the Holocene near 6 600 BP when the climatic regime changed and the lake became eutrophic. The palaeoarctic diatoms disappeared much earlier in the Afar lakes (Gasse, 1976, p. 215). In some instances where the diatoms disappeared and water chemistry did not change, a rise in temperature can be inferred, eg. at 11 700 BP at Chad (S. Servant, this volume).

Rognon (1976) gives a very intriguing explanation for these humid conditions which occurred during the Würm interstadial. He assumes that the jet stream, because of the extensive ice masses, which even during this interstadial covered N. America and Europe, was forced in a southward position. It made a northward bend over the North Atlantic and then moved equatorward along the African coast. Subsequently it could have crossed the Sahara region from the S.W. to the Near East. This configuration would have brought rain in the southern Sahara as this region was situated well south of the high pressure system.

During the very cold last glacial maximum the situation changed and the jet stream moved equatorward which brought aridification south of the Saharan mountains. The present day southern Sahara and Sahel were at that time under the influence of the very strong dry N.E. trades. The lakes dried out completely in Mauritania (during the Ogolian), Chad (during the Kanemian) and also in the Afar. The aridity spread far south into the Sudanese and Guinea zones (Burke et al, 1971; Maley, 1976) into the Congo basin (De Ploey, 1969; Van Zinderen Bakker, 1976b) and even as far as the region of the Red Sea and the Gulf of Aden (Deuser et al, 1976).

Practically at the same time when the Camp Century isotopic temperature curve shows that the world temperature was rising at about 12 400 BP, (Dansgaard et al, 1971) the Bølling Interstadial set in in N.W. Europe, coeval with the Xanthi Interstadial in eastern Macedonia (Van der Hammen et al, 1971). From that time onward the once hyper-arid southern desert zone, stretching from the Atlantic via S.W. Iran to the Thar desert, received much more rain and lakes started to develop. This synchronous lacustrine phase was interrupted during the short cold Younger Dryas stadial of N.W. Europe, between about 10 500 and 10 000 BP (Van Zinderen Bakker, 1972). The lacustrine maximum which followed lasted from about 9 200 to about 4 000 BP. The lake Chad which developed during this period attained between 6 000 and 5 000 BP the approximate size of the present Caspian Sea.

Between about 6 500 and 4 400 BP the monsoon coming from the equatorial Atlantic, probably with some minor interruptions, penetrated so far into Africa that it brought rain to the central Sahara. Early Holocene deposits are well known from Mauritania (Chamard, 1973), the Chad basin (Faure, 1966 ; Servant, 1973), and the Sudan (Williams, 1966, Williams et al, 1975a. 1975b). The Holocene levels of lake Chad and the associated climatic conditions have recently been studied with the aid of fossil pollen by Maley (1977a).

During the late Holocene two climatic optima have been recognised in Mauritania between ca. 3 600 - 3 000 BP and ca. 2 500 and 2 000 BP (Elouard, 1973). During the first optimum lakes were formed again in the present hyper-arid Ténéré (Faure, 1966; Servant, 1973), in Mauritania and Mali (Alimen et al., 1966; Munson, 1976; Petit-Maire et al, 1977). Man and large game could during these two optima spread widely into the Sahara (Camps, 1974).

This impressive sequence of events which was caused by changes in temperature and rainfall is not easily explained. As mentioned earlier the hydrology of the various lake basins differs (Faure, 1969) which can explain certain differences in lake levels. A very important factor for the survival of a lake, especially in a tropical country, is the ratio rainfall : evaporation (Faure, 1969; Servant & Servant, 1973); this ratio has been positive during some periods of Holocene age.

DISCUSSION

The discussions on the climatic history of the Sahara lead to the conclusion that the term 'pluvial' is very inadequate as it has no quantitative or qualitative parameters. More detailed investigations of the different humid periods are needed before a better terminology can be coined. Geomorphologists are inclined to abandon the pluvial concept and to concentrate instead on the geologically stabilising or dynamic characteristics of certain periods (Rohdenburg, 1970).

Looking at the events in a broader context it is clear that the energy budget of the Earth and therefore temperature changes of a world wide nature have, as the primary causes, been responsible for the climatic oscillations which took place. These variations determined the steepness of the temperature gradient from the poles to the equator, the position of the jet stream and consequently the geographic position of the high pressure cells. (Flohn, 1966).

These factors drive the oceanic and atmospheric circulations, determine the evaporation and finally the rainfall of a certain area (Van Zinderen Bakker, 1969b, 1972; 1976a). The interplay of many processes results in shifts of climatic systems which do not always take place in an orthodox meridional direction. These shifts are not so easily understood as has sometimes been anticipated.

The time difference which exists between the end of the Middle Würm and the onset of the Late Würm desert phase shows that these broad correlations are not of a simple nature. The pluvial and non-pluvial phases seem, however, to be fairly closely correlated with important steps in the trend of the world temperature curve (Mörner, 1973). It would be very unwise to ignore this correlation and to throw "the baby out with the bath water" because of certain contradictions. Compulsory evidence for a fairly close correlation of the energy - temperature factor and the pluvial phases of the Saharan and also the East African lakes (Van Zinderen Bakker, 1972) has already been mentioned for the start of the 12 000 BP - pluvial. The maximum of the early Holocene pluvial coincided with the Climatic Optimum of Europe, while the world wide cold spell from about 5 500 - 4 700 BP (Van Zinderen Bakker, 1969a) coincided with the onset of the cool Subboreal of N.W. Europe. Although we do not yet know the mechanism of the chain reactions concerned, these facts can hardly be fortuitous coincidences.

Many processes are involved in climatic changes and their interactions and feedbacks are not yet understood in quantitative terms. It is certain that the position and the strength of the subtropical anticyclones of both hemispheres finally has a very great influence on the surface climate of the Earth (Maley, 1973a & b) (Rognon & Williams, 1977). In this connection very different situations have existed during the Quaternary. In pre-glacial Quaternary times the Antarctic must have had a dominating influence on the equilibrium between the two hemispheres (Maley, 1978). An entirely different situation existed during the last glacial maximum when the low temperature of the Antarctic and its enlarged albedo effect were overruled by the much larger northern ice sheets. The Antarctic events pushed the Antarctic Polar Front northward (Hays et al, 1976), but the influence of the Arctic, especially in the Atlantic section, forced the thermal equator southward. In mid-Holocene times the bipolar equilibrium had changed completely after the Arctic ice sheets had practically disappeared.

This combined influence of the two hemispheres on the atmospheric circulation of the tropical zone could perhaps explain the complexity of the climatic variations. In effect Maley (1977a, b), using geological evidence (Faure, 1966; Servant, 1973), as well as diatom (Servant-Vildary, 1977) and pollen data from the Chad basin, comes to the conclusion that in the course of the Holocene climatic changes have often been out of phase between the tropical dry zone (the Sahel) and the tropical semi-humid zone (the Sudanese-Guinean Zone). The Sudanese Zone acts like a "hinge-joint" in this process. The pollen curve giving the climatic evolution of the Sudanese-Guinean zone follows in general terms the curve of the warming up of the Tardiglacial with a maximum between ca. 8 000 and 5 000 BP. However, during the secondary periods of lowering in temperature, especially near

7 500 BP, the Sudanese-Guinean curve presents strongly opposite tendencies. The climatic evolution in the Sahelian zone in contrast closely follows the temperature fluctuations of the Northern Hemisphere, sothat the climatic optima coincide with periods of warming up. In this way out of phase climatic stages can develop between the Sahelian and the Sudanese-Guinean zones. For instance around 7 500 BP when severe aridity spread over the Sahelian zone, precipitation increased in the Sudanese-Guinean zone; the Chari and Logone rivers, which originate here, increased their run off to Lake Palaeo-Chad causing a lacustrine transgression. These out of phase climates are not constant as during certain periods of decrease in temperature the decline in precipitation not only affected the Sahel, but also the Sudanese and the Sudanese-Guinean zones, as was the case ca. 4 000 BP and again during the drought of recent years.

In the course of the last millenium an out of phase climatic development can be shown at the beginning of the Little Ice Age (17th century). A relatively high lake level of lake Chad would have existed during that period (at about 286 m) and originally (Maley, 1973) this high level was attributed to a general rise in humidity in the different climatic zones of the Chad basin and especially in the Sahelian zone. The explanation was mainly based on not dated hearsay evidence according to which a range of villages existed south of the Ténéré between Fachi and the Bornu. (Fig.1). This extension of the occupation to the north would have occurred during this important lacustrine transgression. From this it could be inferred that the monsoon was strengthened over the Sahelian zone and the southern Sahara during a phase of lowering in temperature. But this explanation is now untenable as the study of other historic data of the Chad region and the bend of the Niger, as well as the reinterpretation of pollen data on a new basis has shown that the climate of the Sahelian zone was arid during the 17th century (Maley, in preparation and 1977a). It therefore appears at present that the high level of lake Chad in the 17th century was only due to the southern fluviatile influx, in other words to an increase in precipitation in the tropical semi-humid zone, which is essentially the Sudanese-Guinean zone. This situation must have been comparable, for instance, to what happened round 7 500 BP (Maley 1977a) or again towards the middle of the first millenium AD (Maley. in preparation).

One of the causes of these out of phase situations could perhaps result, amongst others, from the combined and more or less antagonistic action at different time scales of the atmospheric circulation of the two hemispheres (Maley, 1977c).

REFERENCES

Baudrimont, R. 1974, Recherches sur les diatomées des eaux continentales de l'Algérie. Ecologie et paléoécologie. Mém. Soc. D'Hist. Nat. de l'Afrique du Nord 12 N.S. 249 pp, 22 pl.

Beaudet, G., P. Michel, D. Nahon, P.Oliva, J. Riser, A. Ruellan, 1976, Formes, formations superficielles et variations climatiques du Sahara occidental. Revue de Géogr. Phys. et de Géol. Dynam. (2) 18(2-3) : 157-174.

Beucher, F. 1975, Etude palynologique de Formations Néogènes et Quaternaires au Sahara Nord-Occidental. Centre Rech. sur les Zones Arides. Géologie 20. C.N.R.S. Paris. 285 pp. 23 pl.
Beug, H.J. 1967, Probleme der Vegetationsgeschichte in Südeuropa. Ber. Dtsch. Bot. Ges. 80 (10): 682-689.
Bornhold, B.D. 1973, Late Quaternary sedimentation in the eastern Angola Basin. M.I.T. and Woods Hole Ocean. Inst. Thesis. 213 pp.
Burke, K., A.B. Durotoye, & A.J. Whiteman, 1971, A dry phase south of the Sahara 20,000 years ago. W. African J. Archaeol. 1: 1-8.
Butzer, K.W. 1972 , Late Pleistocene beaches and wadi alluvia near Mersa Alam, Red-Sea coast, Egypt, Palaeoecology of Africa 6: 125-126.
Butzer, K.W. 1973, Past climates of the Tibesti mountains, Central Sahara. Geogr. Review 63: 395-397.
Butzer, K.W. 1976, Pleistocene Climates. Geoscience and Man 13: 27-43.
Butzer, K.W., C.L. Hansen, 1968, Desert and river in Nubia. Wisconsin Press. 562 pp.
Camps, G. 1973, L'âge de l'Atérien nord-africain et saharien. In: Estudios dedicados al Profesor Dr Lüis Pericot. Univ. Barcelona: 29-46.
Camps, G. 1974, Les civilisations préhistoriques de l'Afrique du Nord et du Sahara. Doin eds. Paris, 373 pp.
Chamard, P.C. 1973, Monographie d'une sebkha continentale du sud-ouest saharien: la sebkha de Chemchane (Adrar de Mauritanie). Bull. Inst. Fond. Afr. N. Dakar. Sér. A. 35: 207-249.
Chamley, H., L. Diester Haass, & H. Lange, 1977, Terrigenous material in East Atlantic sediment cores as an indicator of N W African climates. "Meteor" Forsch. - Ergebnisse, C26: 44-59.
Clark, J.D., M.A.J. Williams, & A.B. Smith, 1973, The Geomorphology and Archaeology of Adrar Bous, Central Sahara: a preliminary report. Quaternaria 17: 245-297.
Climap Project Members, 1976, The Surface of the Ice-Age Earth. Science 191 (4232): 1131-1137.
Coetzee, J.A. 1967, Pollen analytical studies in East and Southern Africa. Palaeoecology of Africa 3: 146 pp.
Conrad, G. 1969a, Contribution à l'histoire continentale post-Hercynienne du Sahara Algérien (Saoura, Erg Chech-Tanezrouft, Ahnet-Mouydir). Palaeoecology of Africa 4: 37-41.
Conrad, G. 1969b, L'évolution climatique du Sahara occidental algérien pendant le Quaternaire récent. Palaeoecology of Africa 4: 42-47.
Conrad. G. 1969c, L'évolution continentale post-hercynienne du Sahara algérien. C.N.R.S. ed. Paris, sér. Géologie, 10, 527 pp.
Coque, R. 1969, Recherches sur la géomorphologie et la géologie du Quaternaire de l'Afrique aride. Palaeoecology of Africa 4: 32-36.
Cour, P. & D. Duzer, 1976, Persistance d'un climat hyperaride au Sahara central et méridional au cours de l'Holocène. Revue Géogr. Phys. et de Géol. Dynamique 18 (2-3): 175-198.
Cour, R., Ph. Guinet, J. Cohen, & D. Duzer, 1971, Reconnaissance des flux aéropalynologiques et sédimentation pollinique au Sahara occidental. Novosibirsk Int. Palynol. Conference (Manuscript).
Couvreur, G. 1965, Periglacial formations in the Central High Atlas of Morocco, Abstracts VII INQUA Congress. Boulder-Denver: 79.

Dansgaard, W., S.J. Johnson, H.B. Clausen, & C.C. Langway, 1971, Climatic record revealed by the Camp Century ice core. In: Late Cenozoic Glacial Ages. K.K. Turekian, (ed.) Yale Univ. Press, New Haven: 37 - 56.
De Heinzelin, J., J. Haesaerts, F. van Noten, 1969, Géologie récente et préhistoire au Djébel Uweinat. Africa. Tervuren, 15(4): 120-125.
De Ploey, 1969. Report on the Quaternary of the western Congo. Palaeoecology of Africa. 4: 65-68.
Deuser, W.G., E.H. Ross, & L.S. Waterman, 1976, Glacial and Pluvial Periods: Their relationship revealed by Pleistocene sediments of the Red Sea and Gulf of Aden. Science 191 (4232): 1168-1170.
Diester-Haass, L. 1975, Sedimentation and climate in the Late Quaternary between Senegal and the Cape Verdi Islands. "Meteor" Forsch. Ergebnisse C20: 1-32.
Diester-Haass, L. 1976, Late Quaternary climatic variations in Northwest Africa deduced from East Atlantic sediment cores. Quat. Res. 6: 299-314.
Diester-Haass, L. 1977, Influence of carbonate dissolution, climate, sea-level changes and volcanism on neogene sediments off northwest Africa (Leg 41). In: Y. Lancelot, E. Seibold et al (eds.) Initial Reports on the Deep Sea Drilling Project XL1: 1033-1047.
Elouard, P. 1973, Oscillations climatiques de l'Holocène à nos jours en Mauritanie atlantique et dans la vallée du Sénégal. Colloque de Nouakchott. Les problèmes de la désertification du sud du Sahara: 27-36.
Faure, H. 1966, Evolution des grands lacs sahariens à l'Holocène. Quaternaria 8: 167-175.
Faure, H. 1969, Lacs Quaternaires du Sahara. Mitt. Internat. Verein. Limnol. 17: 131-146.
Faure, H. & M.A.J. Williams, 1977, Quaternary environments in northern Africa: Evidence from continental deposits, deepsea cores, and prehistory. Abstracts X INQUA Congress, Birmingham, 133.
Flohn, H. 1966, Warum ist die Sahara trocken? Z. Meteor. 17 (9-12): 316-320.
Frenzel, B. 1968, Climatic change in the Atlantic/sub Boreal transition on the Northern Hemisphere: botanical evidence. In: World Climate from 8000 to 0 BC. Proc. intern. Symp. Imperial College, Roy. Met. Soc. London: 99-123.
Gabriel, B. 1976, Neolithische Steinplätze und Paläökologie in den Ebenen der östlichen zentral Sahara, Palaeoecology of Africa, IX: 25-40.
Gabriel, B. 1977, Zum ökologischen Wandel im Neolithikum der östlichen Zentralsahara, Berliner Geogr. Abh. 27: 111 pp.
Gasse, F. 1976, Intérêt de l'Etude des Diatomées pour la Reconstruction des Paléoenvironnements lacustres, Revue de Géogr. Phys. et de Géol. Dynam.(2) 18 (2-3): 199 - 216.
Gates, W.L. 1976, Modelling the Ice-Age Climate. Science 191 (4232): 1138-1144.
Geyh, M.A. & D. Jäkel, 1974, Spätpleistozäne und holozäne Klimageschichte der Sahara aufgrund zugänglicher ^{14}C-Daten. Z. Geomorph. N.F. 18 (1): 82-98.
Haynes, V. 1977, Quaternary lakes of the Lybian Desert, Egypt and Sudan, Abstracts X INQUA Congress, Birmingham: 198.

Hays, J.D., J.A. Lozano, N. Shackleton, & G. Irving, 1976, Reconstruction of the Atlantic and Western Indian Ocean sectors of the 18,000 BP Antarctic Ocean. Geol. Soc. America Mem. 145: 337-372.
Hey, R.W. 1972, The Quaternary geology of the Jabal al Akhdar Coast. In: Geology and Archaeology of Northern Cyrenaica, Libya. F.T. Barry (ed.): 159-171.
Jäkel, D. 1977, Run-off and fluvial processes in the central Sahara as indicators in the reconstruction of a climatic history of the Tibesti Mountains. Abstracts X INQUA Congress, Birmingham, 225.
Leroi-Gourhan, A. 1958, Résultats de l'analyse pollinique du gisement d'El Guettar (Tunisie). Bull. Soc. Prêh. France 55: 546-551.
Maley, J. 1972, La sédimentation pollinique actuelle dans la zone du Lac Tchad (Afrique centrale). Pollen et Spores 14 (3): 263-307.
Maley, J. 1973a, Mécanisme des changements climatiques aux basses latitudes. Palaeogeogr. Palaeoclim., Palaeoecology 14: 193-227.
Maley, J. 1973b, Les variations climatiques dans le bassin du Tchad durant le dernier millénaire, Le Quaternaire.Comm. Nat. Français. de l'INQUA, Paris: 175-181.
Maley, J. 1976, Essai sur le rôle de la zone tropicale dans les changements climatiques; l'exemple africain. C.R. Acad. Sc. Paris, D. 283: 337-340.
Maley, J. 1977a, Analyses polliniques et paléoclimatologie des douze derniers millénaires du bassin du Tchad (Afrique centrale). In: Recherches françaises sur le Quaternaire hors de France, édit-Comité Nat. fr. X ème Congr. INQUA, Birmingham, Suppl. Bull. Ass. fr. Et. Quat., 1, 50: 187-197.
Maley, J. 1977b, Palaeoclimates of the central Sahara during the early Holocene. Nature, 269, 573-577.
Maley, J. 1977c, Palynologie et variations climatiques en Afrique nord tropicale. In: Aspects modernes des recherches sur l'évolution. Colloque de Montpellier, Mém. Trav. Ec. Prat. Htes. Et., Inst. de Montpellier, 4, 14 pp.
Maley , J. 1978, Les changements climatiques de la fin du Tertiaire en Afrique: leur conséquence sur l'apparition du Sahara et de sa végétation. In: M.A.J. Williams and H. Faure (eds.) The Sahara and the Nile (in preparation).
Maley, J. et al, 1970, Quelques formations lacustres et fluviatiles associés à différentes phases du volcanisme au Tibesti. Cahiers ORSTOM Sér. Géol. 2: 127-152.
Maley, J., J.P. Roser, M. Servant, 1971, Nouveaux gisements préhistoriques au Niger oriental; localisation stratigraphique, Bull. Ass. Sénégal. Et Quat. Ouest Afri., Dakar, 31: 9 - 18.
Mc Burney, C.B. 1967, The Haua Fteah (Cyrenaica) and the stone age of the south east mediterranean. Cambridge Univ. Press, 380 pp.
McIntyre, A. et al, 1975, Thermal and oceanic structures of the Atlantic through a glacial-interglacial cycle. In: Proc. WHO/ IAMAP Symposium on Long-Term Climatic Fluctuations, Norwich, WMO, Geneva: 75-80.
McIntyre, A. et al, 1976, The Surface of the Ice-Age Earth. Science 191 (4232): 1131-1137.
Michel, P. 1969, Les bassins des fleuves Sénégal et Gambie. Etude géomorphologique, thèse Fac. Lettres Strasbourg, 3 vol. roneoed, 1169 pp.

Messerli, B. 1972, Formen und Formungsprozesse in der Hochgebirgs-region des Tibesti. Hochgebirgsforschung, Univ. Innsbrück - München Publ., 2: 23 - 26.
Messerli, B. 1973, Problems of vertical and horizontal arrangement in the high mountains of the extreme arid zone (central Sahara). Arctic and Alpine Res. 5(3): 139-147.
Mörner, N.A. 1973, Climatic changes during the last 35,000 years as indicated by land, sea and air data. Boreas 2 (1): 33-53.
Munson, P.J. 1976, Archaeological data on the origins of cultivation in the southwestern Sahara and their implications for West Africa. In: J.R. Harlan, J.M.J. de Wet, & A.B.L. Stemler (eds.), Origins of African plant domestication, Mouton, The Hague: 187-209.
Nicholson, S. 1977, A climatic chronology for Africa: Synthesis of geological, historical, and meteorological information. Abstracts X INQUA Congress, Birmingham, 324.
Olausson, E. 1972, Evidence in Indian Ocean cores of Late Pleistocene climatic change, Palaeoecology of Africa, 6: 41-44.
Ortlieb, L., N. Petit-Maire, 1976, The Atlantic border of the Sahara in Holocene times. Palaeoecology of Africa 9: 4-6.
Parmenter, C., D.W. Folger, 1974, Eolian biogenic detritus in deep sea sediments: A possible index of equatorial ice age aridity. Science 185 (4152): 695-698.
Paskoff, R.P., P. Arnould, R. Karray, 1977, Observations on Quaternary marine and terrestrial deposits in the outskirts of Tunis, Tunisia, Abstracts, X INQUA Congress, Birmingham, 347.
Pastouret, L., H. Chamley, G. Delibrias, J.C. Duplessy, J. Thiede, 1978, Late Quaternary climatic changes in Western Tropical Africa deduced from deep-sea sediments off the Niger delta. Oceanologica Acta, 1 (2): 217-232.
Patzelt, G. 1974, Holocene variations of glaciers in the Alps. In: Les méthodes quantitatives d'étude des variations du climat au cours du Pléistocène - C.N.R.S. Paris: 51-59.
Petit-Maire, N. 1972, Découvertes de nécropoles néolithiques en Mauritanie occidentale. Palaeoecology of Africa 6: 215-218.
Petit-Maire, N., G. Delibrias, L. Ortlieb, 1977, New radiometric date for the Atlantic Sahara (Holocene, 19° to 28° N). Tentative interpretations, Abstracts X INQUA Congress, Birmingham, 353.
Pons, A., P. Quézel, 1957, Première étude palynologique de quelques paléosols sahariens. Trav. Inst. Rech. Sahara. Univ. Alger, 16: 15-40.
Quézel, P., C. Martinez, 1961, Le dernier interpluvial au Sahara central. Essai de chronologie palynologique et paléo-climatique -Libya, Alger, 6-7: 211-227.
Rognon, P. 1967, Le massif de l'Atakor et ses bordures (Sahara Central), Etude géomorphologique. Centre Rech. sur les Zones Arides. Géologie 9. CNRS Paris 551 pp. 32 pl.
Rognon, P. 1976, Essai d'interprêtation des variations climatiques au Sahara depuis 40,000 ans. Revue Géogr. Phys. et de Géol. Dynamique 18 (2): 251-282.
Rognon, P., M.A.J. Williams, 1977, Late Quaternary climatic changes in Australia and North Africa: A preliminary interpretation. Palaeogeogr., Palaeoclim., Palaeoecology, 21: 285-327.

Rohdenburg, H. 1970, Morphodynamische Aktivitäts- und Stabilitätszeiten statt Pluvial- und Interpluvialzeiten. Eiszeitalter u. Gegenwart 21: 81 - 96.
Servant, M. 1973, Séquences continentales et variations climatiques: évolution du Bassin du Tchad au Cénozoique Supérieur. thèse, Univ. Paris VI, 348 pp. 12 pl.
Servant-Vildary, S. 1977, Evolution des diatomées et paléolimnologie du Bassin tchadien au Cénozoique supérieur. Thèse. Sc., Paris.
Servant, M., Servant, S. 1970, Les formations lacustres et les diatomées du Quaternaire récent du ford de la cuvette tchadienne. Rev. Géogr. Phys. Géol. Dyn., 12: 63-76.
Servant, M., S. Servant, 1973, Le Plio-Quaternaire du Bassin du Tchad. Le Quaternaire. Comm. Nat. Français de l'INQUA Paris: 169-175.
Schulz, E. 1972, Pollenanalytische Untersuchungen Pleistozäner und Holozäner Sedimente des Tibesti-Gebirges (S. Sahara). Palaeoecology of Africa 7: 14 - 16.
Schulz, E. 1974, Pollenanalytische Untersuchungen quartärer Sedimente des Nordwest-Tibesti. Informationen aus Lehre und Forschung Freie Univ. Berlin 5: 59-69.
Schulz, E. 1976, Aktueller Pollenniederschlag in der zentralen Sahara und Interpretationsmöglichkeiten quartärer Pollenspektren. Palaeoecology of Africa 9: 8-14.
Van Campo, M., R. Coque, 1960, Palynologie et géomorphologie dans le Sud Tunisien. Pollen et Spores 2 (2): 275-284.
Van Campo, M. 1973, Pollen analyses in the Sahara. In: F. Wendorf & A.E. Marks (eds.) Problems in Prehistory, North Africa and the Levant. South Meth. Univ. Press. Dallas: 45-64.
Van der Hammen, R. et al, 1971, The floral record of the Late-Cenozoic of Europe. In: K.K. Turekian (ed.), The Late Cenozoic Glacial Ages. New Haven & London, Yale Univ. Press: 391-424.
Van Zeist, W. 1969, Late Quaternary environmental studies in the Near East. Palaeoecology of Africa 4: 169-172.
Van Zeist, W., H. Woldring, D. Stapert, 1975, Late Quaternary vegetation and climate of southwestern Turkey. Palaeohistoria 17: 53 - 143.
Van Zinderen Bakker, E.M. 1967, Upper Pleistocene and Holocene stratigraphy and ecology on the basis of vegetation changes in sub-Saharan Africa. In: W.W. Bishop & J. Desmond Clark (eds.) Background to Evolution in Africa. Univ. Chicago Press: 125-147.
Van Zinderen Bakker, E.M. 1969a, Cold spell of world wide nature at about 5 500 - 4 700 B.P. Palaeoecology of Africa 4: 8.
Van Zinderen Bakker, E.M. 1969b, Intimations on Quaternary Palaeoecology of Africa. Acta Bot. Néerl. 18 (1): 230 - 239.
Van Zinderen Bakker, E.M. 1972, Late Quaternary lacustrine phases in the southern Sahara and East Africa. Palaeoecology of Africa 6: 15 - 27.
Van Zinderen Bakker, E.M. 1975, The origin and palaeoenvironment of the Namib Desert biome. J. Biogeogr. 2: 65-73.
Van Zinderen Bakker, E.M. 1976a, Palaeoecological background in connection with the origin of agriculture in Africa. In: J.R. Harlan, J.M.J. de Wet & A.B.L. Stemler (eds.), Origins of African Plant Domestication. Mouton Publ. The Hague: 43-63.
Van Zinderen Bakker, E.M. 1976b, Palaeoecology of Africa 9: p. IV, frontispiece.

Wendorff, F. (ed) 1968, The prehistory of Nubia. 2 vol. South Meth. Univ. Press, Dallas.
Wendorff, F. 1977, Late pleistocene and recent climatic changes in the Egyptian Sahara, Geogr. J. 143 (2): 211-234.
Wendorf, F., R. Schild, 1976, Prehistory of the Nile valley. Acad. Press, 404 pp.
Williams, M.A.J. 1966, Age of alluvial clays in the western Gezira, Rep. of the Sudan. Nature, 211: 270-271.
Williams, M.A.J., D.A. Adamson, 1975a, The physiogeography of the central Sudan, Geogr. J. (London), 139: 498-508.
Williams, M.A.J., J.D. Clark, D.A. Adamson, R. Gillespie, 1975b, Recent quaternary research in central Sudan. Bull. Ass. Sénégal. Et. Quatern. ouest afr., Dakar, 46: 75-85.

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