LATE GLACIAL-EARLY HOLOCENE ENVIRONMENTAL CHANGES IN TROPICAL AFRICA: A COMPARATIVE ANALYSIS WITH DEGLACIATION HISTORY

Hiroshi KADOMURA*

Abstract In tropical Africa, glacial-postglacial contrast in precipitation pattern is very great; glacial maximum extreme aridity was followed by the period of increased rainfall during 12,000-5,000 yr B.P. A map showing environmental conditions prevailed in the culmination of the early Holocene wet period at 9,000-8,000 yr B.P. was constructed using published data. The timing of onset and interruptions of the wet period by marked dry episodes at 10,500-10,000 yr B.P. and *c*. 7,500 yr B.P. were analyzed in connection with the deglaciation history.

1. Introduction

During the past 15 years, a considerable number of radiocarbon-dated lake levels and other geomorphological evidence, alluvial and superficial sediments, pollen and diatom spectra, and oxygen isotope and sedimentological profiles of deep-sea cores have been presented to reconstruct the late Quaternary histories of various parts of tropical Africa in the past 20,000 years. The last glacial maximum extreme aridity in tropical Africa during 20,000-12,000 yr B.P. has now been fairly well established (*e.g.*, Hamilton, 1976, 1982; Rognon, 1976; Street and Grove, 1976, 1979; Zinderen Bakker, 1976, 1982; Rognon and Williams, 1977; Nicholson, 1978; Flenley, 1979; Kadomura, 1980, 1982; Street, 1981; also see Table 1). It is now also possible to overview the late glacial-early Holocene history of tropical Africa in relation to the deglaciation and climatic histories in the higher latitudes (*e.g.*, Street and Grove, 1979; Flohn and Nicholson, 1980; Klaus, 1980, 1981; Street, 1981; Rognon, 1983; also see Table 1).

This paper summarizes and reviews the present knowledge on environmental changes that took place in tropical Africa during the late glacial-early Holocene, the time of switchover from the glacial to postglacial conditions. The emphasis is placed on the examination of regional variability in the timing of onset of postglacial wet period and

* Laboratory of Fundamental Research, Graduate School of Environmental Science, Hokkaido University

Table 1 Tentative correlation of the late Quaternary climatic and environmental changes in Afirca with the worldwide climatic events

North ← → South

KBP	0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26
Large-Scale Events 1)	Opt Arctic; Disap. Laur. Ice; Opt Europe; Disintegr. Hudson B. Ice; Disap. Scand. Ice; Opt Antarctic; Ice Retreat; Max.Ext.N. Ice-Sheets; Max.Ext. Ice Drift both Hemisphers
European Climate	SA; SB; AT; BOR; PB; YD; AL; OD; BO; OLD; Last Glacial
Sahara – North 1)	Arid; Desiccation; Wet, Warm; ?; Dry, Wet(?) *; Semiarid with Fluctuations; Semiarid Cold; Transition → More Humid
Sahara – South 1)	Arid; Hyperarid; Wet, Warm **; Dry Interval; Lacustrine ***; Wetter with Fluctuations; Hyperarid; Transition → Hyperarid
Equatorial – W.-C. Africa – West 2) 7)	Humid (Forest); Dry; More Humid (Forest); Transition; Subhumid -Semiarid (Savanna); Humid (Forest)
Equatorial – W.-C. Africa – Cameroon 3)	Humid (Forest); More Humid (Forest); Transition; Subhumid -Semiarid (Savanna)
Equatorial – W.-C. Africa – Congo 4) 8)	Humid (Forest); More Humid (Forest); Transition; Subhumid -Semiarid (Savanna -Steppe)
Equatorial – E. Africa 5)	Semiarid; Wet; Semiarid; Wet; Lacustrine; Transition → Wetter; Semiarid
Kalahari – North 6)	Sl. Wetter; Semiarid; Wet; Semiarid; Wet; Semiarid; Lacustrine; Hyperarid; Wetter; Lacustrine
Kalahari – South 6)	Semiarid; Arid; ?; Transition; Wetter; Dry, Cool; ?

* Highlands Wet, Cool ** Excluding Humid Tropics *** All-Season Rains

Source 1) Flohn & Nicholson,1980; 2) Thomas & Thorp,1980; 3) Kadomura,ed.,1982; 4) De Ploey,1968; 5) Butzer et al.,1972; 6) Heine,1981,1982; 7) Talbot et al.,1984; 8) Peyrot et Lanfranchi,1984 its interruption by dry espisodes corresponding with the coling and glacier readvance in the deglaciation history.

2. Deglaciation and Related Climatic Fluctuations

General trend

It is generally accepted that in the northern hemisphere the inland ice sheets began to retreat at *c*. 13,000 yr B.P. and the Scandinavian ice sheet finally disappeared near 8,000 yr B.P. and the Laurentide ice sheet at around 4,500 yr B.P. (Table 1). Climatic fluctuations in Europe from the last glacial maximum onward are already well established and are correlated with the climatic records in the Greenland ice-core oxygen-isotope profile (Table 1 and Fig. 1). In northwestern Europe, increased warmth during the Bölling and Alleröd (12,500-11,000 yr B.P.) followed by the Younger Dryas cold episode and the middle Holocene climatic optimum are the well-known events.

Two-stepped deglaciation

In addition to these established climatic histories, recent studies of Atlantic Ocean deep-sea oxygen-isotope profiles have shed a new light on the reconstruction of deglaciation history and its correlation with the African environmental history. In the high-latitude Atlantic Ocean (40°-65°N), the last deglaciation warming occurred in three discretre steps: in the southeast and central regions at 13,000 yr B.P.; in the central and nothern sectors at 10,000 yr B.P.; and in the western (Labrador Sea) sector between 9,000

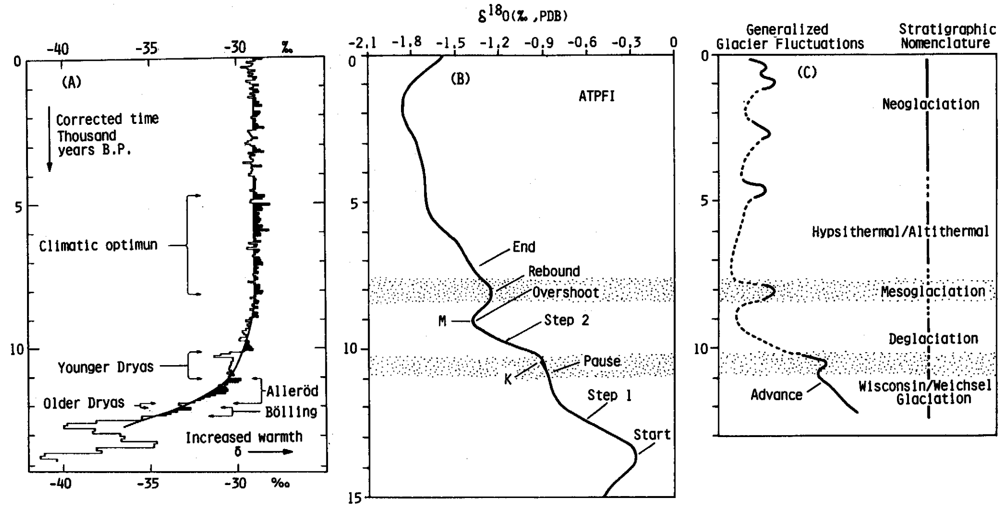


Fig. 1 Oxygen-isotope records showing climatic fluctuations in Greenland (A : after Dansgaard *et al.*, 1971) and SST fluctuations in the equatorial Atlantic Ocean (B : stacked records by Berger *et al.*, 1985), and generalized worldwide glacier fluctuations (C : Beget, 1983) for the late glacial-early Holocene.

and 6,000 yr B.P. (Ruddiman and McIntyre, 1981). According to them, this regionally time-transgressive sequence was punctuated by a brief but strong oceanic cooling roughly coincident with the European Younger Dryas (11,000-10,000 yr B.P.).

In the tropical Atlantic Ocean (16.5°N-17.5°S), Berger *et al.* (1985) have revealed that the deglaciation began at 13,500 yr B.P. and ended near 7,000 yr B.P. They shows: deglaciation took place in two steps at *c.* 12,000 yr B.P. (Step I) and *c.* 9,500 yr B.P. (Step II) which are separated by a pause in the Younger Dryas near 10,500 yr B.P.; and Step II was followed by an overshoot at *c.* 8,500 yr B.P. and the post M rebound centered near 7,500 yr B.P. (Fig. 1). They have correlated M excursion (Fig. 1) with the Gulf of Mexico meltwater event and the post M rebound with the early Holocene worldwide glacier advance during "Mesoglaciation" (8,500-7,500 yr B.P.) proposed by Beget (1983).

These recent studies of Atlantic Ocean deep-sea oygen-isotope records have confirmed that the late glacial-early Holocene is not a period of continuous warming but interrupted by major coolings at least twice. During the Younger Dryas cold episode, the sea surface temperatures in most of the high-latitude North Atlantic Ocean returned to almost full-glacial age level (Ruddiman and McIntyre, 1981). At that time extremely cold waters reached the Bay of Biscay (Duplessy *et al.*, 1981). This climatic crisis (Rognon, 1983) was severest in Western Europe and was revealed by glacier readvance everywhere. Of the "Mesoglaciation" event, Beget (1983), from the distribution of moraines in alpine areas, has estimated that the temperatures at that time were 1.0° to 1.5°C cooler than at present.

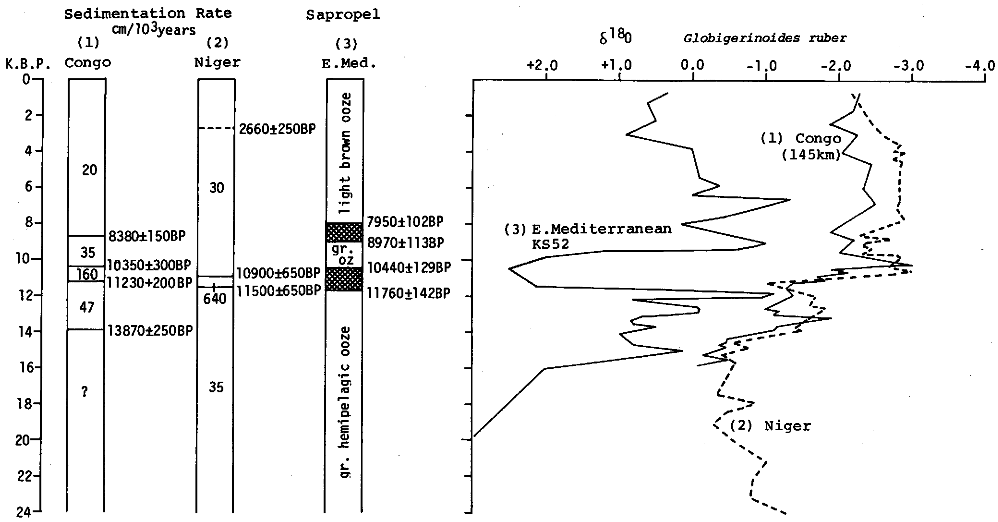


Fig. 2 Sedimentation rates in the off Congo estuay core (Giresse et Lanfranchi, 1984) and the off Niger delta core (Pastouret *et al.*, 1978), the sapropel age in the East Mediterranean KS52 core (Rossignol-Strick *et al.*, 1982), and oxygen-isotope records in the three cores.

3. Onset of Wet Period in Tropical Africa

As schematically shown in Table 1, during the last glacial maximum, tropical Africa, from the southern Sahara to the Congo basin and from the Atlantic Ocean coast to the Indian Ocean coast, experienced drastic aridity; the Sahara extended southwards and most of lowland forests were replaced by savannas or woodlands. In contrast, in tropical Africa, the time of deglaciation and warming in the higher latitudes was characterized by the return of increased rainfall and wet conditions (Table 1 and Fig. 2).

Evidence from deep-sea cores

Off Congo estuary

The records of a deep-sea core drilled on the continental shelf 145 km off the Congo estuary have shown that (warm) Guinean waters first arrived there at *c.* 13,000 yr B.P. and the semipelagic sedimentation reached its maximum rate between 11,230 and 10,350 yr B.P., 160 cm/10^3 yr. (Fig. 2). This high rate of sedimentation, six times larger than the rate for the preceding years (13,870-11,230 yr B.P.), has been attributed to the influx of alluvial mud rich in silt and quartz sand which was produced by a sudden return of heavy rainfall over denuded hillslopes in the Congo catchment (Giresse et Lanfranchi, 1984).

Off Niger delta

Postglacial acceleration in sedimentation rate is much more pronounced in the off Niger delta core in which peak discharges accompanied by deluge due to freshwater influx are recorded at 13,000-11,800 and 11,500-4,000 yr B.P. (Fig. 2). Pastouret *et al.* (1978) have shown that between 11,500 and 10,900 yr B.P. the sedimentation rate is accelerated by 20 times from the pre-11,500 yr B.P. level. The actual rate reaches 640cm/10^3 yr and is far faster than that recorded in the off Congo estuary core. This may be explained by the fact that during the last glacial arid period, in the Niger basin the land surface was much more denuded than in the Congo basin. Sudden overflow of Lake Chad waters into the Niger via the Benoue may also be responsible for this acceleration in sedimentation rate and the deluge recorded in the oxygen-isotope profile (Fig. 2). The changes in precipitation and denudation regimes in the Niger basin are also confirmed by the change in clay mineralogy in the sediment. The change in clay mineralogy from smectite to kaolinite that occurred shortly before 13,600 yr B.P. has been attributed to the return of heavy rainfall over and increased runoff from denuded interfluves overlain by lateritic tropical soil (Pastouret *et al.*, 1978; Street, 1981).

East Mediterranean

In equatorial East Africa, the headwaters of the Nile, very heavy rainfall began at 12,500 yr B.P. and culminated between 10,000 and 8,000 yr B.P. (Butzer *et al.*, 1972; Williams and Adamson, 1974; Street and Grove, 1979; Adamson *et al.*, 1980; Rossignol-Strick *et al.*, 1982). This late glacial-early Holocene increased rainfall in the Nile headwaters is recorded in the East Mediterranean deep-sea cores. The two-layered upper sapropel in the core KS52 from the East Mediterranean, dated at 11,800 10,400 yr B.P. and 9,000-8,000 yr B.P. (Fig. 2), has been accounted for a low-salinity surface layer due to the freshwater influx that was channeled by the Nile over 6,700 km from its headwater areas (Rossingnol-Strick *et al.*, 1982). The interruption of sapropel formation occurred between 10,400 and 9,000 yr B.P., roughly coincides with the European Younger Dryas cold event.

West African Coast

Along the Senegal coast, between 12,500 and 5,500 yr B.P., the time following the last glacial maximum drastic aridity, the change in climatic regime and the return of humid conditions over the continent have been revealed by: a sudden disappearance of Mediterranean and pre-Saharan pollen and an increase in Sudano-Guinean elements peaked at 12,000 yr B.P. which are followed by an increment of Sudanese (7,000 yr B.P.) and Sahelian elements (5,500 yr B.P.) (Rossignol-Strick and Duzer, 1979). This reflects a regionally time-transgressive return of heavy rainfall from the equator northwards.

The contrast in glacial and interglacial wind regimes over the eastern subtropical Atlantic and North-West Africa is also detected by studies of aeolo-marine dust deposits in the eastern Atlantic Ocean (*e.g.*, Sarnthein and Koopmann, 1980; Sarnthein *et al.*, 1981). However, the onset of the postglacial mode of wind regimes has not been dated as yet.

Mangrove

There are abundant reports describing that mangrove forest reached its maximum extent during 10,000-7,000 yr B.P.; from the Senegal lower course (Rossignol-Strick and Duzer, 1979), Ivory Coast (Fredoux et Tastet, 1978; cited from Rossignol-Strick *et al.*, 1982), the Niger delta (Sowunmi, 1981a, 1981b), Gabon coast (Lebigre et Weydert, 1984), and Congo coast (Giresse et Lanfranchi, 1984). For the mangrove development, however, in addition to precipitation changes, the effect of sea-level changes must be considered.

Lake-level changes

In interior Africa, the most reliable data for the reconstruction of environmental histories come from the analysis of lake-level changes and lake sediments. Environmental and climatic implications of lake-level fluctuations in Africa have been synthesized by Faure (1966, 1969), Grove and Goudie (1971), Butzer *et al.* (1972), Street and Grove (1976, 1979), Gasse (1980), Maley (1981), Street (1981), Street and Gasse (1981), Hamilton (1982, p. 44-67), Goudie (1983), Servant (1983), Street-Perrott and Roberts (1983), Street-Perrott and Harrison (1985) and Street-Perrott *et al.* (1985). It is, therefore, enough to give here following summarization.

General trend

Between 12,500 and 12,000 yr B.P., synchronous with the period of increased warmth in the Atlantic Ocean and Europe, lake levels began to rise in most of tropical Africa, from the southern Sahara to northern Kalahari, that are fed today by rains from the South Atlantic Ocean (Street and Grove, 1979). This event is well represented by the onset of the Niger-Chadian lacustrine transgression at *c.* 12,000 yr B.P. of Lake Chad (Servant, 1973, 1983; also see Fig. 3), the catchment area of which extends as far south as the present-day Sudanic belt. Lake Victoria and lakes situated in the Western Rift Valley share this tendency and an overflow of Lake Victoria into the White Nile began by 12,500 yr B.P. (Kendall, 1969; Gasse, 1980; Livingstone, 1980; Williams and Adamson, 1980). The lakes in Afar and the Main Rift-Eastern Rift Valley, from Ethiopia to northern Tanzania also show first signs of rising between 12,500 and 12,000 yr B.P. after a prolonged low stand (*e.g.*, Grove and Goudie, 1971; Butzer *et al.*, 1972; Gillespie *et al.*,

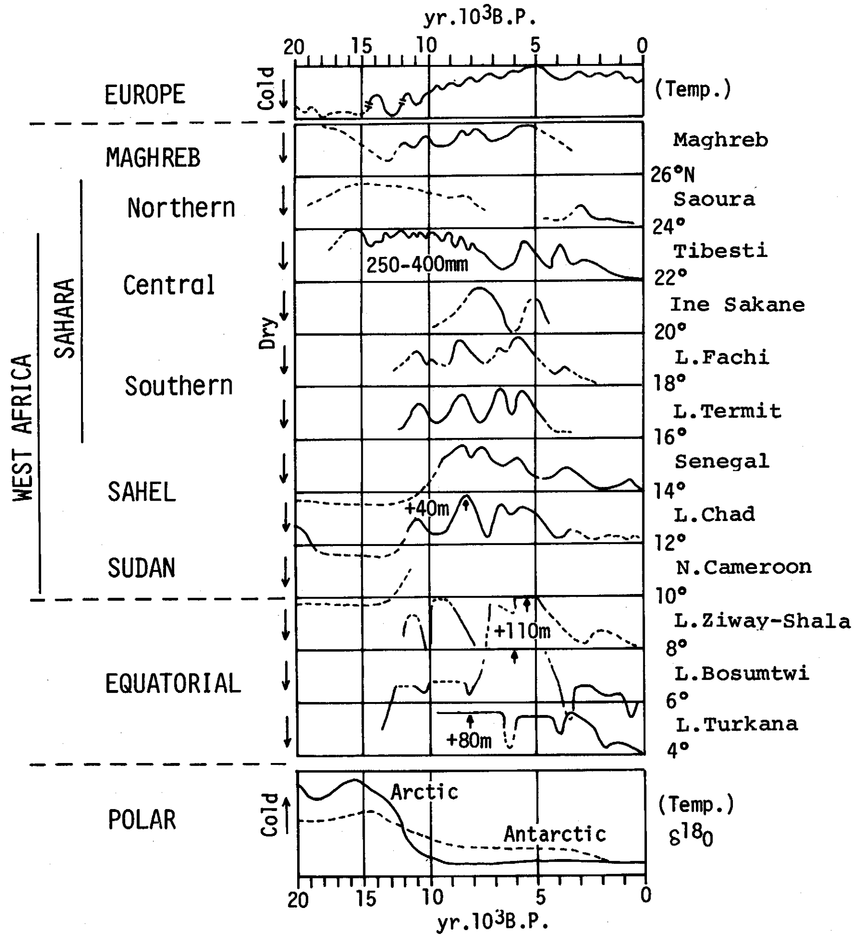


Fig. 3 Precipitation and lake-level fluctuations in northern hemisphere Africa since 20,000 yr B.P. (modified from Kadomura, 1982 which is based on Klaus, 1980, 1981 and Rognon, 1976). Arrows indicate overflow occurring. Data from: Maghreb: Couvert (1972; from Rognon, 1976), Saoura: Conrad (1969; from Rognon, 1976), Tibesti: Jäkel (1979), Ine-Sakane: Riser *et al.* (1983), L. Fachi, Termit and Chad: Servant (1983), Senegal valley: Michel (1973), N. Cameroon: Hervieu (1970), L. Ziway-Shala: Gillespie *et al.* (1983), L. Turkana: Owen *et al.* (1982). Oxygen-isotope curves simplified from Camp Century, Greenland and Byrd cores from Johnsen *et al.* (1972).

1983). But rapid rising was not registered until *c*. 10,000 yr B.P. (*e.g.*, Gasse, 1980; Owen *et al.*, 1982). This may coincide with the data that the Indian Ocean did not warm up until 10,000 yr B.P. (Vincent, 1972), as suggested by Street and Grove (1979).

Western West Africa

Interdunal lakes and lakes formed on depressions in the southwestern Sahara of Mauritania, Mali and Niger did not also extend until 10,000 yr B.P. (Faure, 1969; Chamard, 1976; Elouard, 1976), A morphochronology constructed by Michel (1971, 1973) for the Senegambia basin has illustrated that the postglacial humid phase in this region started at *c*. 11,000 yr B.P. In the Taudenni basin of northeastern Mali (21°-23°N), the present-day hyperarid belt, lacustrine extension occurred between 9,500 and 4,500 yr B. P. (Petit-Maire et Riser, eds., 1983). The delay in the onset of humid period in the southern Sahara and the northern Sahelian areas can be explained by the tim-transgressive nature of postglacial return of increased rainfall as mentioned earlier. The timing of rainfall return over these areas may relate to the timing of warning-up of the Canaries Current.

Extratropical areas

In the extratropical areas of both South and North Africa, lakes receded or dried out during the late glacial-early Holocene deglaciation and warming-up period, as in the case of mi-latitude pluvial lakes in Middle East (Rognon, 1982), Western United States and elsewhere (*e.g.*, Street and Grove, 1979; Smith and Street-Perrott, 1983).

Pollen and other terrestrial evidence

East Africa

In East Africa, Hamilton (1982, p. 190-191) summarizes an environmental history on the basis of pollen spectra. According to him, in East Africa, major forest spread occurred earlier (12,500-12,000 yr B.P.) in the (present-day) climatically moister areas of Ruwenzori and northern Victoria and then (11,000-10,000 yr B.P.) in the drier areas of Mt. Elgon and Mt. Kenya in Kenya, and Mt. Badda in Ethiopia. This coincides with the above interpretation of regional variability in lake-level fluctuations.

Central Africa

In the southern part the Congo basin in Central Africa, pollen analytical data and/or geomorphological evidence have illustrated the timing of onset of humidification at *c*. 12, 000 yr B.P. at Kamoa, southern Zaire (Moeyersons, 1975; Roche, 1975; cited from Van Noten, 1981), and at *c*. 10,000 yr B.P. at Lunda, northeastern Angola (Clark and Zinderen Bakker, 1962) and at Kalambo Falls, northern Zambia (Clark and Zinderen Bakker, 1964).

In western Zaire, a radiocarbon-dated morphostratigraphic sequence by De Ploey (1965, 1968) has shown that a semi-arid climate during the Leopoldvillian period (30,000-14,500 yr B.P.) was followed by a transition towards the Kibangian humid climate that began at *c*. 12,000 yr B.P. and enabled forest reestablishment from *c*. 10,000 yr B.P. In the Niari valley of Congo, Leopoldovillian dry phase (25,000-12,000 yr B.P.) was also replaced by a wet phase lasting from 10,000 to 2,600 yr B.P., synchronous with De Ploey's Kibangian period (Peyrot et Lanfranchi, 1984). In the coastal areas of Congo, Giresse et Lanfranchi (1984) have speculated that forest underwent a major extension between 12,000 and 4,000 yr B.P.

West Africa

According to a table showing climatic fluctuations in the West African humid tropics prepared by Faniran and Jeje (1983, p.134), the beginning of the late glacial-early Holocene wet period ranges from 13,500 to 12,000 yr B.P. In the monsoon forest of Sierra Leone, Thomas and Thorp (1980, 1985) have postulated that coarse alluvial sediment and interfluve stone-lines were formed by agents of enhanced stream flood and strong sheet wash which were generated during the time of increased rainfall before reforestation under climatic conditions of late glacial mode between 12,500 and 10,000 yr B.P. This interpretation agrees well with environmental reconstructions for the Niger and Congo basins speculated from the records of deep-sea cores off Niger delta (Pastouret *et al.*, 1978) and off Congo estuary (Giresse et Lanfranchi., 1984), respectively. It is also worthy of note that Ojany (1976) has an opinion that stone-lines in the Machakos area, Kenya were the product of East African "pluvial" phases.

The pollen spectra from the Niger delta core have shown that drastic reduction of rainforest occurred sometimes between 35,000 and 8,000 yr B.P. and that freshwater swamps and rainforests recovered only during 7,600-6,950 yr B.P. (Sowunmi, 1981a, 1981b). Retardation of onset and shortness of wet period reconstructed in this study may be due to the lack of detailed radiocarbon chronology. This may also apply to the case of rainforest belt in Cameroon where radiocarbon-dated data are available only for fine-grained superficial deposits indicating already reestablished forest environment that dates back to 8,500 yr B.P. or later (Hori, 1982; Kadomura *et al.*, 1986).

In general, the evidence that comes from alluvial and slope deposits is of low-resolution for both dates and environmental conditions compared with those from lake levels and deep-sea cores. This is partly due to the scarcity of organic remains in the sediment under tropical humid environment and partly to the difficulties in interpretation of environmental conditions under which sedimentation took place.

4. Environmental Conditions at 9,000-8,000 yr B.P.

Except a few poorly dated data, all the evidence from lake levels, pollen spectra, alluvial and superficial deposits has demonstrated that wetter environmental conditions prevailed throughout tropical Africa between 10,000 and 8,000 yr B.P. after a brief but severe drought episode between 11,000 and 10,000 yr B.P. (Table 1, Fig. 3). In most parts of tropical Africa wet conditions culminated at 9,000-8,000 yr B.P. Maximum rising and/ or transgression of lakes in the West African Sahara-Sahel belt and in East Africa, greater extension of tropical lowland rainforest, and maximum retreat of the Sahara Desert are the three striking features during this culmination. Environmental conditions that prevailed during the culmination of the early Holocene wet period were mapped using hitherto published data (Fig. 4.).

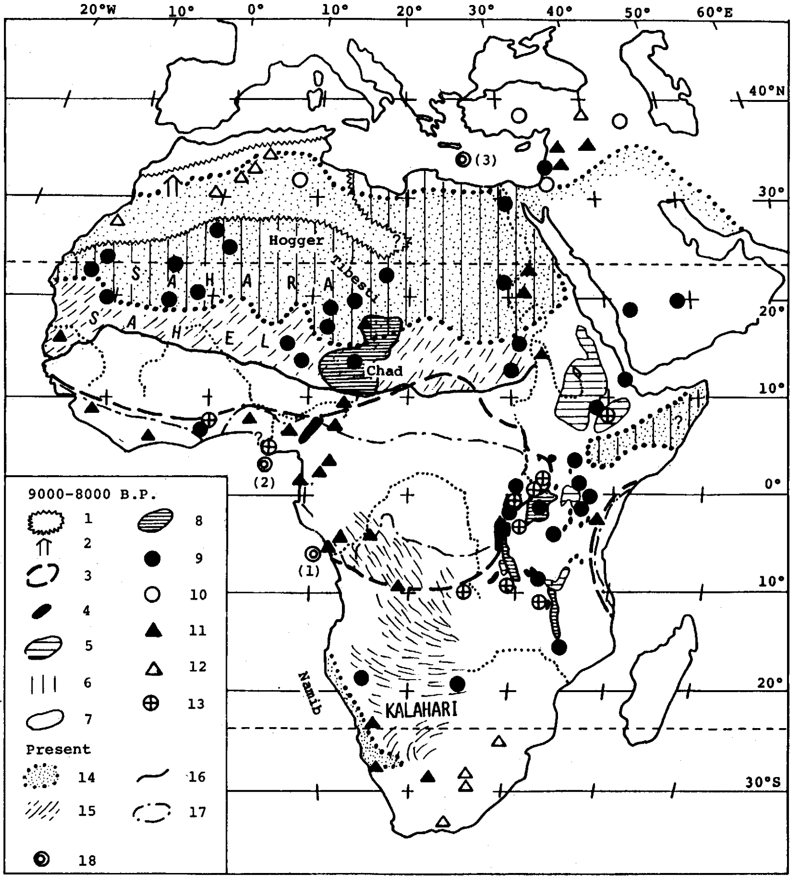
Regional aspects

Sahara-Sahel

It is during this wet period that the Sahara enjoyed a climate far wetter than today that enabled the greater expansion of steppe or savanna vegetation into the now hyperarid desert areas (*e.g.*, Faure, 1966, 1969; Butzer, 1971, p.329-334, 581-594; Maley, 1977; Petit-Maire et Riser, eds., 1983; Petit-Maire, 1984; Williams, 1984; Rognon, 1985). In the southern and central Sahara, between 9,000 and 7,500 yr B.P., lacustrine tradition was established on the basis of material culture related to aquatic fauna hunting and fishing, representing widespread surface water in the form of perennial lakes (Smith, 1980). The level of Lake Chad rose by 40m or more above its present level. Its area may exceed 320, 000km, an estimate for the later wet period at 6,000 yr B.P. (Schneider, 1967; cited from Servant, 1983) and extended into the present-day desert up to 18°N. In western West Africa, hydrographic basins of the Niger and the Senegal were connected and lacustrine conditions prevailed throughout northern Mali between 20° and 23° 30'N (Petit-Maire et Riser, eds., 1983).

East Africa

In East Africa, closed-basin lakes also reached their maximum level, and overflow and interconnection occurred everywhere as evidenced in the Kenyan and Ethiopian Rift



Valley lakes. Lake level rose above the modern level by 180 m in the Nakuru-Elementeita basin (Butzer *et al.*, 1972), *c.* 80 m at Lake Turkana (Butzer *et al.*, 1972; Owen *et al.*, 1982), at least 108 m in the Ziway-Shala basin (Gillespie *et al.*, 1983), and 160 m or more at Lake Abhe (Gasse, 1975). Between 9,900 and 7,900 yr B.P. waters of Lake Turkana overflowed into Pibor-Shobat, a tributary of the White Nile (Butzer *et al.*, 1972; Adamson *et al.*, 1980). Lake Victoria, which once fell to 12 m below the present level and became a closed-lake at around 10,000 yr B.P., overflowed again into the White Nile after 9,500 yr B.P. (Kendall, 1969; Butzer *et al.*, 1972).

Rainforest

Contrary to our expectations, data showing environmental conditions of the now rainforest zone during the early Holocene are rather scarce (Fig. 4). A pollen analytical study of the sediment cores from Lake Bosumtwi, Ghana, which is situated near the northern limit of the present-day rainforest, has disclosed that the forest surrounding the lake was established after 9,000 yr B.P. by replacing grassland vegetation (Talbot *et al.*, 1984). As mentioned earlier, the mangrove forest along the West-Central African Coast fully developed between 10,000 and 7,000 yr B.P. The closed forest in western Congo showed a major expansion during 12,000-4,000 yr B.P. (Giresse et Lanfranchi, 1984).

Fig. 4 Environmental conditions of Africa during the early Holocene: 9,000-8,000 yr B.P.

9,000-8,000 yr B.P.

1 and 2: desert and its extension (Rognon, 1985); 3: tropical lowland forest (Hamilton, 1976); 4: tropical montane forest (Hamilton, 1976); 5: reestablished forest from impoverishment (Hamilton, 1976); 6: vegetated Sahara (Rognon, 1985); 7: woodland, savanna and grassland; 8: extended lakes; 9: high lake level indicative of more humid climate than today (Whole Africa: Street and Grove, 1976, 1979; North Africa and Middle East: Rognon, 1976, 1982; West Africa: Rognon, 1976; Maley, 1981, Hillaire-Marcel *et al,* 1983: Riser *et al.,* 1983; Servant, 1983; Durand *et al.* 1984; Talbot *et al.,* 1984; East Africa: Butzer *et al.,* 1972; Adamson *et al.,* 1980; Gasse, 1980; Gasse *et al.,* 1980; Gillespie *et al.,* 1983; Shaw *et al.,* 1984; South Africa: Heine, 1982); 10: low lake level or desiccation indicative of more arid climate than today (Rognon, 1982); 11: alluvial and colluvial deposits indicative of humid conditions or increased vegetation cover (North Africa: Adamson *et al.,* 1980; Rognon, 1982; West Africa: Fölster, 1969; Hervieu, 1970; Burke and Durotoye, 1971a, b; Hurault, 1971; Michel, 1973; Thomas and Thorp, 1980; Hori, 1982; Faniran and Jeje, 1983; Kadomura *et al.,* 1986; Central Africa: Clark and Zinderen Bakker, 1962; De Ploey, 1965, 1968; Peyrot et Lanfranchi, 1984; Southern Africa: Brock, 1982; Heine, 1981, 1982); 12: alluvial and colluvial deposits or geomorphological evidence indicative of drier conditions or reduced vegetation cover (North Africa: Rognon, 1982; Southern Africa: Brock, 1982; Heine, 1981, 1982); 13: pollen evidence indicative of more humid conditions (West Africa: Sowunmi 1981a, b; Talbot *et al.,* 1984; southern Central Africa: Clark and Zinderen Bakker, 1964; Roche, 1975; East Africa: Hamilton, 1982).

Present

14: desert; 15: fixed dune field; 16: southern limit of Sahelian fixed dune field; 17: natural limit of tropical lowland forest; 18: location of deep-sea cores recording late glacial-early Holocene intensified runoff and sediment transport from tropical rivers (*cf.* Fig. 2).

Although detailed radiocarbon chronology is still very scarce, all the geomorphological and sedimentological evidence from the now rainforest zone has manifested that the closed forests already reestablished at the time between 9,000 and 8,000 yr B.P. (Fig. 4).

Climatic conditions

A considerable number of attempts have been made to illustrate the climate that brought about the early Holocene wet period of tropical Africa.

(1)There is general agreement that accelerated deglaciation warming of the equatorial Atlantic Ocean is the most likely cause of the dramatic intensification of summer monsoon rains in the equatorial regions (*e.g.*, Rognon, 1976; Street and Grove, 1979; Flohn and Nicholson, 1980).

(2)In addition, the decrease of northeastern trade winds in summer seems to allow the ITCZ to migrate polarwards, hence the deep penetration of monsoon rains into the Sahara.

(3)In contrast, in winter, the polar front that was accompanied by cyclonic rains, which now can only encroach northern Sahara, could reach as far south as southern Sahara and even Sahelian areas.

The diatom and pollen spectra from Lake Chad which are dominated by Mediterranean and temperate elements during the early Holocene lacustrine period support this third account (Servant et Servant-Vildary, 1980; Maley, 1983; Servant, 1983). Recent palaeoecological studies in northeastern Mali also verify to this (Petit-Maire et Riser eds., 1983). Thus, all-season rains climate during the early Holocene (Flohn and Nicholson, 1980) is now a fairly well established palaeoclimatic reconstruction for the central and southern Sahara (Table 1).

Increased rainfall during the early Holocene wet period has been estimated both from the interpretation of reconstructed vegetation and from the analysis of lake-level fluctuations. In the Chad basin which now receives an annual rainfall of 150-500 mm, Kutzbach (1980), based on water and energy balance model, has estimated that annual rainfall increased by 300 mm over the basin during the early Holocene lacustrine period. A similar estimate has also been undertaken for the Kenyan Rift Valley lakes by Hastenrath and Kutzbach (1983). According to them, amount of precipitation required to maintain the enlarged palaeolakes existed between 10,000 and 7,000 yr B.P. must have been at least 150-300 mm/yr (10-30%) above the modern average. These authors have stressed that temperature changes are not too important for changing the lake level.

In the Ziway-Shala basin in the Ethiopian Rift Valley, Street (1979), taking the effect of temperature 2°C lower than the present into account, has given an early Holocene precipitation estimate; 128% of the present value. Based on the similar method, the increase in rainfall over the Kenyan lakes has been calculated to be 25-65% above the present level (Butzer *et al.*, 1972), somewhat larger than the estimates by Hastenrath and Kutzbach (1983).

Global data on lake-level fluctuations have revealed that wetter climate prevailed not only over tropical Africa but also over Arabia and India during the early Holocene (Street and Grove, 1979). It is very likely that this event was primarily resulted from widespread intensification of summer monsoons in the low latitudes. Climatic experiments for 9,000 yr B.P. using a low-resolution general circulation model have shown that the intensification of monsoons in Africa and Asia must have been caused by increased summer radiation in the northern hemisphere which was induced by the changes of earth's orbital parameters, precession, obliquity and eccentricity (Kutzbach, 1981; Kutzbach and Otto-Bliesner, 1982; Kutzbach, 1983).

5. Dry Episodes

The early Holocene wet period between 10,000 and 8,000 yr B.P. in tropical Africa was preceded by a short but severe drought episode and was followed by a widespread dry spell. Geomorphological and sedimentological data indicating these two dry episodes are mapped in Fig. 5 with radiocarbon ages.

Figure 5 shows that the first dry episode occurs between 10,500 and 9,000 yr B.P. and

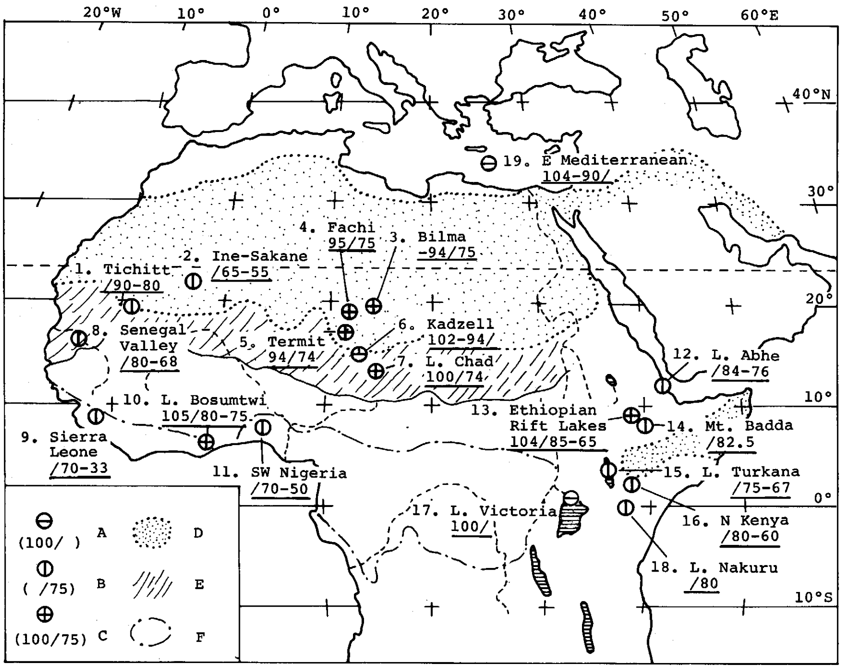


Fig. 5 Dry episodes during the late glacial-early Holocene (ages in hundred years B.P.). A : first dry episode synchronous with Younger Dryas, B : second dry episode, C : both episodes, D : present desert, E : fixed dune and its southern limit, F : present rainforest. Data from 1 : Hugot (1977) ; 2 : Hillaire-Marcel *et al.* (1983), Riser *et al.* (1983) ; 3-5, 7 : Servant (1983) ; 6 : Durand *et al.* (1984) ; 8 : Michel (1973) ; 9 : Thomas and Thorp (1980) ; 10 : Talbot *et al.* (1984) ; 11 : Bruke and Durotoye (1971a) ; 12 : Gasse (1980) ; 13 : Gillespie *et al.* (1983) ; 14 : Gasse (1980) ; 15 : Owen *et al.* (1982) ; 16 : Mäcker and Walther (1984) ; 17 : Kendall (1969) ; 18 : Butzer *et al.* (1972) ; 19 : Rossignol-Strick *et al.* (1982).

is centered somewhat before 10,000 yr B.P. A statistical analysis of lake regressions by Street-Perrott and Roberts (1983) has shown that this dry episode culminated at 10,200 yr B.P. This event can be correlated wih the European Younger Dryas cold spell and the dramatic cooling of Atlantic Ocean that took place near 10,500 yr B.P. In the Nile headwaters, Lake Victoria closed and ceased to overflow into the White Nile at *c.* 10,000 yr B.P. (Kendall, 1969), as a result of decreased monsoon rains. This hydrographic change is well recorded as an interruption of sapropel formation in the East Mediterranean deep-sea core during 10,400-9,000 yr B.P. (Rossignol-Strick *et al.*, 1982). Ethiopian Rift Valley lakes also receded at around 10,200 yr B.P. (Gillespie *et al.*, 1983).

In the Chad basin, the first dry episode, which has been deduced from lake-level fluctuations, is dated between 10,200 and 9,400 yr B.P. (Servant, 1983). However, no counterpart event has been reported for the western Sahel areas. In the now rainforest areas, Lake Bosumtwi offers only one available record that suggests a low stand at around 10,500 yr B.P. (Talbot *et al.*, 1984). Any data have been reported for the humid areas of Central Africa. The information, therefore, hitherto available is too fragmentary to speculate the changes in environmental condition that might have taken place in the now rainforest areas in response to "Younger Dryas dry episode".

In contrast, the records suggesting the second dry episode, although the ages scatter between 9,000 and 5,500 yr B.P., are more widespread across the Sahel and East Africa (Fig. 5). In the Chad basin, the dates are centered near 7,500 yr B.P., synchronous with the cold event of the post M rebound in the equatorial Atlantic Ocean and the "Mesoglaciation" (Fig. 1). The records from the East African lakes indicate that a severe drought episode occurred between 8,500 and 6,500 yr B.P., also centering at 7,500 yr B. P. According to Street-Perrott and Roberts (1983), a dramatic regression of African lakes culminated at *c.* 7,400 yr B.P. These data, again, like in the case of the "Younger Dryas dry episode", have led to a speculation that the "7,500 yr B.P. dry episode" or "aridity crisis" (Rognon, 1983) in tropical Africa must also have been caused by a sudden decrease of summer monsoon rains.

Flohn and Nicholson (1980) have interpreted that the onset of the dry episode in the Sahara after 8,000 yr B.P. was possibly caused by the catastrophic disintegration of Laurentide ice sheet at Hudson Bay, the Hudson Bay 'surge' of *c.* 3 million km^3 of continental ice into the Atlantic Ocean.

In the southwestern Sahara, the ages of the second episode is not concordant with those of the Chad basin and are too old (9,000-8,000 yr B.P. at Tichitt) or too young (6, 500-5,500 yr B.P. at Ine-Sakane; *cf.* Fig. 3). The former dates fall within the full-wet period in the other regions. In the latter case, if the ages are correct, in northeastern Mali, a dry spell did not occur at the time corrsponding to the 7,500 yr B.P. cold event in the Atlantic Ocean but occurred during the European climatic optimum when the other parts of the Sahara experienced the Middle Holocene or Neolithic wet phase (Table 1). However, as stressed by Hillaire-Marchel *et al.* (1983), interregional comparisons of lake levels in terms of palaeoclimates *are risky inasmuch as lake level oscillations are closely related to ground water response times in the Erg Ine Sakane area* (p. 64).

The dates from the West African rainforest areas are also younger than 7,500 yr B.P. It is, however, uncertain whether this reveals the time-lag of response in the equatorial forests or results from the low-resolution in chronology and environmental interpretation inherent to alluvial and slope deposits. The data are too scarce to allow detailed reconstruction of environmental changes that might have occurred in the now rainforest areas in response to the 7,500 yr B.P. cold event in the Atlantic Ocean.

In the central and southern Sahara, the "7,500 yr B.P. dry episode" is the time of desertification that led to the failure of the lacustrine tradition in the early Holocene (Smith, 1980). Similar event also took place in northeastern Mali during the dry spell between 6,500 and 5,500 yr B.P. (Petit-Marie et Riser, eds., 1983). The return of wet conditions after 7,000 yr B.P. has been believed to have contributed to the establishment of the Neolithic tradition in the central and southern Sahara which was characterized by live-stock and food-producing activities (*e.g.*, Butzer, 1971, 591-594; Smith, 1980). The Neolithic or Middle Holocene wet period in the Sahara-Sahel areas lasted through the time of the European climatic optimum until 5,000 yr B.P. and finally ended at *c*. 4,500 yr B.P. with the onset of severe aridification (*e.g.*, Rognon, 1976, 1985; Street and Grove, 1979; Maley, 1981; Petit-Maire et Riser, eds., 1983, Servant, 1983). This onset of aridification correlates with the timing of final disappearance of the Laurentide ice sheet and the Arctic climatic optimum (Table 1).

6. Conclusion and Discussion

Close connections can be recognized between the deglaciation history and climatic and environmental changes in tropical Africa during the late glacial-early Holocene. In response to the onset of deglaciation of northern ice sheets, in equatorial areas, the first signs of the return of heavy summer monsoon rains appeared at 13,500-13,000 yr B.P. after a prolonged dry period. Between 12,500 and 12,000 yr B.P., synchronous with the period of increased warmth in the Atlantic Ocean and Europe, a marked wet period began in most parts of equatorial areas that receive today rains from the South Atlantic Ocean. But, the onset of wet period is of regionally time-transgressive: in the southwestern Sahara after 10,000 yr B.P.; and in East Africa also at around 10,000 yr B. P. The latter may be related with the timing of warming-up of the Indian Ocean.

The culmination of the early Holocene wet period occurred between 9,000 and 8,000 yr B.P. in all parts of tropical Africa, and was characterized by maximum extension of tropical lowland forests and lacustrine conditions, and greater retreat of the Sahara Desert. In the central and southern Sahara, in addition to increased summer monsoon rains, winter cyclonic rains have been believed to contribute to the widespread humidification of the now hyperarid desert.

It must be noted that the priod between 9,000 and 8,000 yr B.P. almost corresponds with the climatic optimum in the Antarctica. The warming-up of the Antarctica and adjacent seas may bring about the weakening of the Benguela Current and its upwelling along the southwestern Africa, contributing to the warming of the waters of the Bay of Guinea, the main source of summer monsoon rains (*e.g.*, Zinderen Bakker, 1976).

The late glacial-early Holocene wet period lasted until 5,000 yr B.P. was punctuated by the two short but notable dry episodes: at 10,500-10,000 yr B.P., synchronous with the

European Younger Dryas cold phase and the Atlantic Ocean cold event; and at around 7,500 yr B.P., corresponding to the second cold event in the Atlantic Ocean and worldwide glacier readvance. These two dry episodes have been widely recorded in the now arid and semi-arid regions. In contrast, in the present-day humid rainforest areas, the evidence indicating the dry episodes is almost lacking. It is, however, still early to draw a conclusion that wet conditions have persisted without interruptions in the rainforest areas. The data hitherto available are too sparse to allow a regional comparative analysis of the timing and severity of the dry spells in a continental scale.

In this paper, I have placed an emphasis on the time-sequence correlations between deglacial events and tropical African environmental changes. I have not touched on the mechanisms resulting in these correlations. These apparent correlations need to be tested through a comprehensive analysis of global change in the process-response system of cryosphere-ocean-atmosphere-land (Webb *et al.*, 1985).

Acknowledgements

I am grateful to the following researchers for providing me relevant data and suggestions: R. Bonneville, J. De Maret, J. De Ploey, H. Faure, H.H. Hagedron, C.A. Hamilton, K. Heine, N. Hori, L.K. Jeje, P. Michel, F.F. Ojany,P. Rognon, M.R. Talbot, T. Tamura, M.F. Thomas, A. Vincens, and M.A.J. Williams. I also thank M. Takahashi for bibliographic assistance and drawing maps and diagrams. Financial support came from the Grant-in-Aid of the Ministry of Education, Science and Culture, for Overseas Scientific Survey (Grant No. 60043004) and for Scientitic Research (Grant No. 59460215).

I wish to dedicate this paper to Professor Hiroshi Toya, who gave me the opportunity to initiate my geomorphological and environmental studies in tropical Africa, on the occasion of his retirement from Tokyo Metropolitan University.

References Cited

Adamson, D.A., Gasse, F., Street, F.A. and Williams, M.A.J. (1980): Late Quaternary history of the Nile. *Nature*, **288**, 50-55.

Beget, J.E. (1983): Radiocarbon-dated evidence of worldwide early Holocene climate change. *Geology*, **11**, 389-393.

Berger, W.H., Kjllingley, J.S., Metzler, C.V. and Vincent, E. (1985): Two-step deglaciation: ^{14}C-dated high-resolution δ^{18}O records from the tropical Atlantic Ocean. *Quat. Res.*, **23**, 258-271.

Brock, G.A. (1982): Stratigraphic evidence of Quaternary climatic change at Echo Cave, Transvaal, and a paleoclimatic record for Botswana and northeastern South Africa. *Catena*, **9**, 334-351.

Burke, K. and Durotoye, A.B. (1971a): Late Quaternary climatic variation in south-western Nigeria: evidence from pediments and pediment deposits. *Étude sur le Quaternaire dans le Monde*, **1**, VIII Congrès INQUA, Paris 1969, 143-153.

—— (1971b): Geomorphology and surficial deposits related to late Quaternary climatic variation

in south-western Nigeria. *Z. Geomorph, N. F.*, **11**, 430-444.
Butzer, K.W. (1971): *Environment and Archeology*. Aldine, Chicago, 703p.
——, Isaac, G.L., Richardson, J.L. and Washbourn-Kamau, C.K. (1972): Radiocarbon dating of East African lake levels. *Science*, **175**, 1069-1076.
Chamard, Ph.C. (1976): Essai sur les paléoclimats du sud-ouest saherien au Quaternaire récent. In: *La Désertification au Sud du Sahara, Colloq. de Nouakchott, 17-19 déc. 1973*, NEA, Dakar-Abidjan, 21-26.
Clark, J.D. and Zinderen Bakker, E.M. van (1962): Pleistocene climates and cultures in north-eastern Angola. *Nature*, **196**, 639-642.
—— (1964): Prehistoric cultures and Pleistocene vegetation at the Kalambo Falls, northern Rhodesia. *Nature*, **201**, 971-975.
Conrad, G. (1969): *L'évolution Continentale Post-hercynienne du Sahara Algérien (Saoura, Erg Chech-Tanezrouft, Ahnet-Mouydir)*. Publ. CNRS, Centre Rech. Zones Arides, Paris, **10**, 527p.
Couvert, M. (1972): Variations paléoclimatiques en Algérie. *Libyca*, **20**, 45-48.
Dansgaard, W., Johnsen, S.J., Clausen, H.B. and Langway, C.C. (1971): Climatic record revealed by the Camp Century ice core. In Turekian, K.K. (ed.): *The Late Cenozoic Glacial Ages*, Yale Univ. Press, New Haven, 37-56.
De Ploey, J. (1965): Position géomorphologique, génèse et chronologie de certains dépôts superficiels au Congo Occidental. *Quaternaria*, **7**, 131-154.
—— (1968): Quaternary phenomena in the western Congo. In: *Means of Correlation of Quaternary Succession* **8**, Proc. VII Congr. INQUA, Univ. Utah Press, 501-515.
Duplessy, J.C. Delibrias, G., Turon, J.L., Pujol, C. and Duprat, J. (1981): Deglacial warming of the northeastern Atlantic Ocean: correlation with the paleoclimatic evolution of the European continent. *Palaeogeogr. Palaeoclimat. Palaeoecol.*, **35**, 121-144.
Durand, A., Fontes, J.-Ch., Gasse, F. Icole, M. et Lang, J. (1984): Le nord-ouest du Lac Tchad au Quaternaires: étude de paléoenvironnements alluviaux, éoliens, palustres et lacustres. *Palaeoecol. Afr.*, **16**, 215-243.
Elouard, P. (1976): Oscillation climatiques de l'Holocène à nos jours en Mauritanie atlantique et dans la vallée du Sénégal. In: *La Désertification au Sud du Sahara, Colloq. de Nouakchott, 17-19 déc. 1973*, NEA, Dakar-Abidjan, 27-36.
Faniran, A. and Jeje, L.K. (1983): *Humid Tropical Geomorphology*. Longman, London, 414p.
Faure, H. (1966): Évolution des grands lacs sahariens à l'Holocène. *Quaternaria*, 8, 167-175.
—— (1969): Lacs quaternaires du Sahara. (International Symposium on Paleolimnology, Tihany, 1967).*Mitt. Internat. Verein Limnol.*, n°17, 131-146.
Flenley, J.R. (1979): *The Equatorial Rain Forest: A Geological History*. Butterworth, London, 162p.
Flohn, H. and Nicholson, S.E. (1879): Climatic fluctuations in the arid belt of the 'Old World' since the last glacial maximum: possible causes and future implications. *Palaeoecol. Afr.*, **12**, 3-21.
Fölster, H. (1969): Slope development in SW-Nigeria during Late Pleistocene and Holocene. *Gießener Geogr. Schrift.*, **20**, 3-56.
Fredoux, A. and Tastet, J.P. (1976): Apport de la palynologie à la connaissance paléogéographique du littoral ivorien entre 8,000 et 12,000 ans B.P. *7th Afr. Micropalaeontol. Colloq.*, Ile-Ife, Nigeria.
Gasse, F. (1975): *L'Évolution des Lacs de l'Afar Central du Plio-Pléistocene à l'Actuel. Reconstruction des Paléomilieux Lacustres à Partir de l'Étude des Diatomées.* Thèse Doct. Etat, Univ. Paris, 383p.
—— (1980): Late Quaternary changes in lake-levels and diatom assemblages on the southeastern margin of the Sahara. *Palaeoecol. Afr.*, **12**, 333-350.

——, Rognon, P. and Street, F.A. (1980): Quaternary history of the Afar and Ethiopian Rift lakes. In Williams, M.A.J. and Faure, H. (eds.): *The Sahara and the Nile*, A.A. Balkema, Rotterdam, 361-400.

Gillespie, R., Street-Perrott, F.A. and Switsur, R. (1983): Post-glacial arid episodes in Ethiopia have implications for climatic prediction. *Nature*, **306**, 680-683.

Giresse, P. et Lanfranchi, R. (1984): Les climats et les océans de la région congolaise pendant l'Holocène—Bilans selon les échelles et les méthodes de l'observation. *Palaeoecol. Afr.*, **16**, 77-88.

Goudie, A.S. (1983): The arid earth. In Gardner, R. and Scoging, H. (eds.): *Mega-geomorphology*, Clarendon, Oxford, 152-171.

Grove, A.T. and Goudie, A.S. (1971): Late Quaternary lake levels in the Rift Valley of southeastern Ethiopia and elsewhere in tropical Africa. *Nature*, **234**, 403-405.

Hamilton, C.A. (1976): The significance of patterns of distribution shown by forest plants and animals in tropical Africa for the reconstruction of upper Pleistocene palaeoenvironments: a review. *Palaeoecol. Afr.*, **9**, 63-97.

—— (1982): *Environmental History of East Africa: A Study of the Quaternary*. Academic Press, London, 328p.

Hastenrath, S. and Kutzbach, J.E. (1983): Paleoclimatic estimates from water and energy budgets of East African lakes. *Quat. Res.*, **19**, 141-153.

Heine, K. (1981): Aride und pluviale Bedingungen während der letzten Kalzeit in der Südwest-Kalahari (südliches Afrika): Ein Beitrag zur klimagenetischen Geomorphologie der Dünen, Pfannen und Taler. *Z. Geomorph. N.F.*, Suppl.-Bd., **38**, 1-37.

—— (1982): The main stages of the late Quaternary evolution of the Kalahari region, southern Africa. *Palaeoecol. Afr.*, **15**, 53-76.

Hervieu, J. (1970): Influence des changements de climat Quaternaries sur le relief et les sols du Nord Cameroun. *Ann. de Géogr., n°* 433, 386-398.

Hillaire-Marcel, C., Riser, J., Rognon, P., Petit-Maire, N., Rosso, J.C. and Soulie-Marche, L. (1983): Radiocarbon chronology of Holocene hydrologic changes in northeastern Mali. *Quat. Res.*, **20**, 145-164.

Hori, N. (1982): Formation and chronology of superficial deposits in the forested south Cameroon. In Kadomura, H. (ed.): *Geomorphology and Environmental Changes in the Forest and Savanna Cameroon*, Hokkaido Univ., Sapporo, 13-28.

Hugot, G. (1977): *Un Secteur du Quaternaire Lacustre Mauritenien: Tichitt.* Inst. Maurit. Rech. Sci., Nouakchott, 190p.

Hurault, J. (1971): La signification morphologiques des lavaka. *Rev. Géomorph. Dyn.*, **20**, 121-128.

Jäkel, D. (1979): Run-off and fluvial formation processes in the Tibesti Mountains as indicators of climatic history in the Central Sahara during the late Pleistocene and Holocene. *Palaeoecol. Afr.*, **11**, 13-44.

Johnsen, S.J., Dansgaard, W. and Clausen, H.B. (1972): Oxygen isotope profiles through the Antarctic and Greenland ice sheets. *Nature*, **253**, 429-434.

Kadomura, H. (1980): Reconstruction of palaeoenvironments in tropical Africa during the Würm Glacial Maximum: a review. *Environ. Sci., Hokkaido*, **3**, 147-154.

—— (1982): Late Quaternary climatic and environmental changes in tropical Africa: an introduction. In Kadomura, H. (ed.): *Geomorphology and Environmental Changes in the Forest and Savanna Cameroon*, Hokkaido Univ., Sapporo, 1-12.

Kadomura, H., Hori, N., Kuete, M., Tamura, T., Omi, G., Haruki, M. and Chujo, H. (1986): Late Quaternary environmental changes in southern Cameroon: a synthesis. In Kadomura, H. (ed.): *Geomorphology and Environmental Changes in Tropical Africa: Case Studies in Cameroon and Kenya*, Hokkaido Univ. Sapporo. (in press)

Kendall, R.L. (1969): An ecological history of the Lake Victoria basin. *Ecol. Monogr.*, **39**, 121-176.

Klaus, D. (1980): Climatological aspects of the spatial and temporal variations of the southern Sahara margin. *Palaeoecol. Afr.*, **12**, 315-331.

—— (1981): *Klimatologische und klima-ökologische Aspekte der Dürre in Sahel.* Erdwissenschaftliche Forschung, Bd. **16**, Franz Steiner, Wiesbaden, 175p.

Kutzbach, J.E. (1980): Estimates of past climate at paleolake Chad, North Africa, based on a hydrological and energy-balance model. *Qudt. Res.*, **14**, 210-223.

—— (1981): Monsoon climate of the early Holocene: Climate experiment with the earth's orbital parameters for 9000 years ago. *Science*, **214**, 59-61.

—— (1983): Modeling of Holocene climates. In Wright, H.E. Jr. (ed.): *Late Quaternary Environments of the United States, 2: Holocene*, Univ. Minnesota Press, Minneapolis, 271-277.

Kutzbach, J.E. and Otto-Bliesner, B. (1982): The sensitivity of the African-Asian monsoon climate to orbital parameter changes for 9000 years B.P. in a low-resolution general circulation model. *J. Atmos. Sci.*, **39**, 1177-1188.

Lebigre, J.M. et Weydert, P. (1984): Cadre sédimentologique de la séquence mangrove—Tanne de la Moka (Baie de la Mondah-Gabon). *Palaeoecol. Afr.*, **16**, 89-107.

Livingstone, D.A. (1980): Environmental history of the Nile headwaters. In Williams. M.A.J. and Faure, H. (eds.): *The Sahara and the Nile*, A.A. Balkema, Rotterdam, 339-359.

Mäcker, R. and Walther, D. (1984): The age and geomorphological interpretation of late Pleistocene and Holocene deposits in the Nyiru-Ndoto Mountain region and adjacent plains, northern Kenya. *Palaeoecol. Afr.*, **16**, 343-350.

Maley, J. (1977): Paleoclimate of Central Sahara during the early Holocene. *Nature*, **269**, 573-577.

—— (1981): *Études Palynologiques dans le Bassin du Tchad et Paléoclimatologie de l'Afrique Nord-tropicale de 30000 ans à l'Époque Actuelle.* Travaux et Documents de l'ORSTOM, n°129, 586p.

Michel, P. (1971): Chronologie du Quaternaire des bassins des fleuves Sénégal et Gambie. In: *Études sur le Quaternaire dans le Monde*. VIII Congrès INQUA Vol. I, Paris, 1969, 49-61.

—— (1973): *Les Bassins des Fleuves Sénégal et Gambie. Étude Geómorphologique*. Thèse Strasbourg 1970. Mémoire de l'ORSTOM, n°63, 3t, 752p.

Moeyersons, J. (1975): Évolution paléogéographique du site de la Kamoa. *AMRAC*, **84**, 18-46.

Nicholson, S.E. (1978): Comparison of historical and recent African rainfall anomalies with late Pleistocene and early Holocene. *Palaeoecol. Afr.*, **10**, 99-123.

Noten, F. van, Maret, P. de, Moeyersons, J., Muya, K. and Roche, E. (1981): The prehistory of Central Africa, Part II. In Ki-Zerbo, J. (ed.): *General History of Africa*, **I**, Unesco, Heinemann, California, 550-567.

Ojany, F.F. (1976): Denudation surfaces and origin of stone-line in the Machakos area of Kenya. *Intern. Geogr. '76, Section 1: Geomorph. Paleogeogr.*, 22th I.G.C., Moscow, 69-72.

Owen, R.B., Barthelme, J.W., Renaut, R.W. and Vincens, A. (1982): Palaeolimnology and archaeology of Holocene deposits north-east of Lake Turkana, Kenya, *Nature*, **298**, 523-529.

Pastouret, L., Chamley, H., Delibrias, G., Duplessy, J.-C. and Thiede, J. (1978): Late Quaternary climatic changes in western tropical Africa deduced from deep-sea sedimentation off the Niger Delta. *Oceanologica Acta*, **1**, 217-232.

Petit-Maire, N. (1984): Le Sahara, de la steppe au désert. *La Recherche*, **15**, 1372-1382.

Petit-Maire, N. et Riser, J. (eds.) (1983): *Sahara ou Sahel? Quaternaire Récent du Bassin de Taoudenni (Mali)*. Lamy, Marseille, 473p.

Peyrot, B. et Lanfranchi, R. (1984): Les oscillations morphologiques récents dans la vallée du Niari (République Polulaire du Congo). *Palaeoecol. Afr.*, **16**, 265-281.

Riser, J., Hillaire-Marcel, C. et Rognon, P. (1983): Les phases lacustres holocènes. In Petit-Maire, N. et Riser, J. (eds.): *Sahara ou Sahel?* Lamy, Marseille, 65-86.

Roche, E. (1975): Analyse palynologique du site archéologique de la Kamoa. In Cahen, D. (ed.): *Le Site Archéologique de la Kamoa (Région du Shaba, République du Zaïre), De l'Age de la Pierre Ancienne à l'Age du Fer,* Musée royal de l'Afrique centrale, Tervuren.
Rognon, P. (1976): Essai d'interprétation des variations climatiques au Sahara depuis 40.000 ans. *Rev. Géogr. Phys. Géol. Dyn.,* **18**, 251-282.
—— (1982): Modification des climats et des environnements en Afrique du Nord et au Moyen Orient depuis 20.000 B.P. In Bintliff, J.L. and Zeist, W. van (eds.): *Palaeoclimates, Palaeoenvironments and Human Communities in the Eastern Mediterranean Region in Later Prehistory*, BAR International Series, **133**, 67-97.
—— (1983): Essai de définition et typologie des crises climatiques. *Bull. Inst. Géol. Bassin* d'Aquitaine, Bordeaux n°34, *et CNRS Cahiers du Quaternaire*, n° spécial, 151-164.
—— (1985): Désert et désertification. *Total Information*, n°100, 4-10.
—— and Williams, M.A.J. (1977): Late Quaternary climatic changes in Australia and North Africa: a preliminary interpretation. *Palaeogeogr. Palaeoclimat. Palaeoecol.,* **21**, 285-327.
Rossignol-Strick, M. and Duzer, D. (1979): A late Quaternary continuous climatic record from palynology of three marine cores off Senegal. *Palaeoecol. Afr.*, **11**, 185-188.
——Nesteroff, W., Olive, P. and Vergnaud-Grazzini, C. (1982): After the deluge: Mediterranean stagnation and sapropel formation. *Nature*, **295**, 105-110.
Ruddiman, W.F. and McIntyre, A. (1981): The North Atlantic Ocean during the last deglaciation. *Palaeogeogr. Palaeoclimat. Palaeoecol.*, **35**, 145-214.
Sarnthein, M. and Koopmann, B. (1980): Late Quaternary deep-sea record on Northwest African dust supply and wind circulation. *Palaeoecol. Afr.*, **12**, 239-253.
——, Tetzlaff, G., Koopmann, B., Wolter, K. and Pflaumann, U. (1981): Glacial and interglacial wind regimes over the eastern subtropical Atlantic and North-West Africa. *Nature*, **293**, 193-196.
Schneider, J.L. (1967): *Carte hydrogéologique au 1/500.000ème. Feuille de Fort-Lamy.* I: *Rapport de Synthèse.* 61p., II: *Notice Explicative*, 13p., Rap. B.R.G.M., Fort-Lamy.
Servant, M. (1973): *Séquences Continentales et Variations Climatiques: Évolution du Bassin du Tchad au Cénozoïque Supérieur.* Thèse dactyl. Univ., Paris, 348p.
—— (1983): *Séquences Continentales et Variations Climatiques: Évolution du Bassin du Tchad au Cénozoïque Supérieur.* Travaux et Documents de l'ORSTOM, n°159, 573p.
—— et Servant-Vildary, S. (1980): L'environnement quaternaire du Bassin du Tchad. In Williams, M.A.J. and Faure, H. (eds.): *The Sahara and the Nile*, A.A. Balkema, Rotterdam, 133-162.
Shaw, P., Crossley, R. and Davison-Hirschmann, S. (1984): A major fluctuation in the level of Lake Chilwa, Malawi, during the Iron Age. *Palaeoecol. Afr.*, **16**, 391-395.
Smith, A.B. (1980): The Neolithic tradition in the Sahara. In Williams, M.A.J. and Faure, H. (eds.): *The Sahara and the Nile*. A.A. Balkema, Rotterdam, 451-466.
Smith, G.I. and Street-Perrott, F.A. (1983): Pluvial lakes. In Porter, S.C. (ed.): *Late Quaternary of the United States, 1: The Late Pleistocene*, Univ. Minnesota Press, Minneapolis, 190-212.
Sowunmi, M.A. (1981a): Aspects of late Quaternary vegetational changes in West Africa. *J. Biogeogr.*, 8, 457-474.
—— (1981b): Nigerian vegetational history from the Quaternary to the present day. *Palaeoecol. Afr.*, **13**, 217-234.
Street, F.A. (1979): Late Quaternary precipitation estimate for the Ziway-Shala basin, southern Ethiopia. *Palaeoecol. Afr.*, **11**, 135-144.
—— (1981): Tropical palaeoenvironments. *Progress in Physical Geography*, **5**(1), 157-185.
—— and Gasse, F. (1981): Recent development in research into Quaternary climatic history of the Sahara. In Allan, J.A. (ed): *Sahara: Ecological Change and Early Economic History*, Menas Press, London, 7-28.

—— and Grove, A.T. (1976): Environmental and climatic implications of late Quaternary lake-level fluctuations in Africa. *Nature*, **261**, 385-390.

—— (1979): Global maps of lake-level fluctuations since 30,000 yr B.P. *Quat. Res.*, **12**, 83-118.

Street-Perrott, F.A. and Harrison, S.P. (1985): Lake levels and climatic reconstruction. In Hecht, A. (ed.): *Paleoclimate Analysis and Modelling*. J. Wiley and Sons, NewYork, 291-340.

——and Roberts, N. (1983): Fluctuations in the closed-basin lakes as an indicator of past atmospheric circulation patterns. In Street-Perrott, F.A., Beran, M. and Radcliffe, R.A.S. (eds.): *Variations in the Global Water Budget*, D. Reidel, Dordrecht, 331-345.

——,—— and Metcalfe, S. (1985): Geomorphic implications of late Quaternary hydrological and climatic changes in the Northern Hemisphere tropics. In Douglas, I. and Spencer, T. (eds.): *Environmental Change and Tropical Geomorphology*, George Allen & Unwin, London, 165-183.

Talbot, M.R., Livingstone, D.A., Palmer, P.G., Maley, J., Melack, J.M. Delibrias, G. and Gulliksen, S. (1984): Preliminary results from sediment cores from Lake Bosumtwi, Ghana. *Palaeoecol. Afr.*, **16**, 173-192.

Thomas, M.F. and Thorp, M.B. (1980): Some aspects of the geomorphological interpretation of Quaternary alluvial sediments in Sierra Leone. *Z. Geomorph. N.F.*, Suppl.-Bd., **36**, 140-161.

—— (1985): Environmental change and episodic etchplanation in the humid tropics of Sierra Leone: the Koidu etchplain. In Douglas, I. and Spencer, T. (eds.): *Environmental Change and Tropical Geomorphology*, George Allen & Unwin, London, 239-267.

Vincent, E. (1972): Climatic change at the Pleistocene-Holocene boundary in the southwestern Indian Ocean. *Palaeoecol. Afr.*, **6**, 45-54.

Webb, T., Kutzbach, J. and Street-Perrott, F.A. (1985): 20,000 years of global climatic changes: palaeoclimatic research plan. In Malone, T. and Roederer, J.C. (eds.): *Global Change*, Cambridge Univ. Press, Cambridge, 182-218.

Williams, M.A.J. (1984): Late Quaternary prehistoric environments in the Sahara. In Clark, J.D. and Brandt, S.A. (eds.): *From Hunters to Farmers: The Causes and Consequences of Food Production in Africa*, Univ. California Press, Barkley, 74-92.

—— and Adamson, D.A. (1974): Late Quaternary desiccation along the White Nile. *Nature*, **248**, 584-588.

—— (1980): Late Quaternary depositional history of the Blue and White Nile Rivers in Central Sudan. In Williams, M.A.J. and Faure, H. (eds.): *The Sahara and the Nile*, A.A. Balkema, Rotterdam, 281-304.

Zinderen Bakker, E.M. van (1976): The evolution of late Quaternary palaeoclimates of southeren Africa. *Palaeoecol. Afr.*, **9**, 160-202.

—— (1982): African palaeoenvironments 18,000 years B. P. *Palaeoecol. Afr.*, **15**, 77-99.