Journal of Arid Environments (1978) **1**, 3–24

Climatic variations in the Sahel and other African regions during the past five centuries*

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Several significant climatic fluctuations occurred in the Sahel and other parts of Africa during the past five centuries. From about the 16th through the 18th centuries, wetter conditions prevailed throughout the Sahel. Beginning about 1680, several severe droughts occurred there, but geographical descriptions suggest an overall more humid character until sometime in the late 18th century. Then a marked trend toward the present Sahelian aridity began, which was interrupted by a period of increased rainfall in the late 19th century. A survey of these periods and a comparison with Pleistocene climatic variations show the complexity of the Sahelian climate.

Introduction

The recent, devastating drought in the African Sahel from 1968 to 1973 and the various hypotheses it provoked concerning causative mechanisms of drought gave the impetus for this study of long-term climatic variation in Africa. Characteristics of this particular drought and theories derived from studies devoted only to this short episode were being generalized and applied on a longer time scale with little supporting evidence for the validity of such. The work discussed here involves primarily an African climatic chronology for the past five centuries which can help us examine current ideas concerning climatic fluctuation and drought in the Sahel.

The climatic reconstruction represents a synthesis of geological, historical and meteorological information and data. This paper begins with a brief description of the methodology, then proceeds to the results of the climatic chronology. Precipitation anomaly types derived from rainfall departure patterns from 1901 to 1973 and climatically anomalous periods of the previous four centuries provide some modern analogues to Quaternary periods. A comparison of climatic variation in recent and historic times, considered together with Quaternary examples of climatic change in Africa, create a basis for the paper's conclusions concerning drought and climatic variation in the Sahel.

The methodology of climatic reconstruction

To describe climatic conditions during periods prior to the commencement of modern records, various types of proxy or indirect information and data are available. Geologic and

* Paper presented at X INQUA Congress, Birmingham, England; August 1977.

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0140-1963/78/0101–0003 $02.00/0

palynologic studies present information on lake-level variations, vegetation, changes in stream regimes and deposits characteristic of particular types of environment; all of these relate more or less directly to climate. Tree rings also provide a good measure of inter-annual climatic variability. Historical and geographical sources, such as archives, chronicles, travel journals and settlers' diaries, ships' logs, maps and early geographical journals contain useful information on landscape and vegetation, lakes and rivers, famine, drought and floods, as well as climatic descriptions and frequently actual meteorological observations. Colonial weather observations and other weather observations lost from the modern climatic record complement these geological, historical and geographical sources.

These proxy data lead most directly to reconstruction of past environments, which are determined principally by climatic elements, especially precipitation. Because the significance of these indicators is often ambiguous, their use in extrapolating large-scale climates and climatic fluctuations requires a cautious interpretation supported by convergence of numerous points of independent evidence. This ambiguity centers on two questions: (1) is climate or some other factor responsible for the indicated environmental or cultural (e.g. famine) situation, and (2) is the indicated change of only local significance or widespread? If the evidence of environmental changes relates synchronously to numerous regions and to known global climatic shifts, a large-scale climatic fluctuation is suggested. Similarly, while a few isolated references to famine can be challenged as local food shortages possibly caused by disease, war or other political phenomenon, or drought, several severe famines in widespread regions occurring simultaneously with known meteorological drought implicate a large-scale and significant climatic anomaly.

Use of information derived from regional integrators such as rivers and lakes further helps distinguish climatic fluctuations from local environmental change. Yet even these are not unambiguous measures of climate and precipitation, and valid conclusions require the concurrence of several independent types of indicators, such as lake levels, drought and landscape descriptions. Information directly related to weather and climate, such as meteorological observations and description of the rainy season, and geological deposits indicative of a particular rainfall regime (such as varves and the sorting of stream deposits) can further support the various indicators of environmental and climatic fluctuations.

In considering the above-mentioned difficulties inherent in historical climatic reconstruction, this study emphasizes numerous independent types of evidence related to numerous and widespread regions and derived from several disciplines. Descriptions of climatically anomalous periods selected on the basis of synchronous fluctuations in several of 23 African regions for which chronologies have been established comprise a major part of the study. General climatic trends as well as these individual climatically anomalous periods are described in the rest of this paper.

Results of the climatic chronology

The 23 regions for which climatic chronologies have been established span all of the African continent north of 10° S. This includes many diverse climate types and rainfall regimes dominated by two main climatic systems (Fig. 1). The rainfall north of the Sahara is primarily associated with the Mediterranean cyclones, which reach the continent in winter. Areas south of the Sahara receive rainfall associated with the Inter-tropical Convergence Zone (ITCZ). In lower latitudes, especially near the equator, rainfall is distributed over most of the year, but in higher latitudes toward the southern margin of the Sahara rain is confined to the late summer months, when the ITCZ lies relatively far north. The Sahel and Soudan zones are semi-arid regions to the south of the Sahara, with precipitation between 150 and 800 mm falling mainly in the summer months and a pronounced dry season over the rest of the year. The climatic fluctuations described below refer principally to these zones. Figure 1 presents a map of mean annual rainfall in Africa and the locations of several cities and areas discussed in the rest of the text.

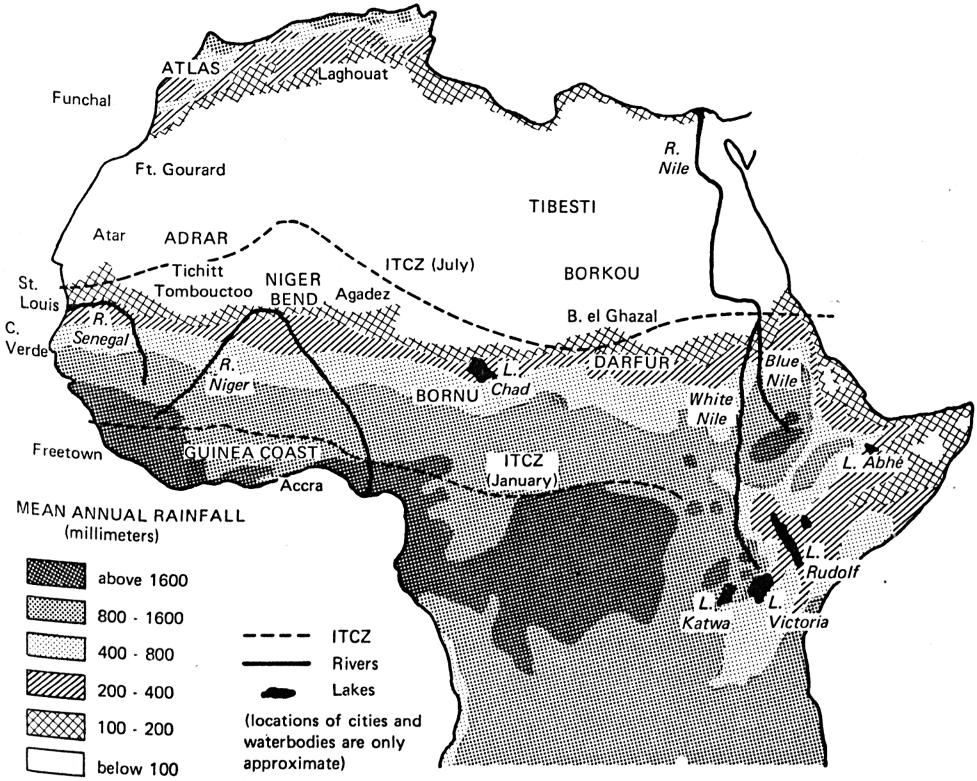

Figure 1. Map of mean annual rainfall in Africa, and certain geographical locations. (From Nicholson, 1976. All subsequent figures in this article are taken from the same source.)

Wetter conditions along the Saharan margins in the 16th through the 18th centuries

Six long-term chronologies are an appropriate starting point for developing the hypothesis that in 16th through the 18th centuries more humid conditions prevailed in the Soudano–Sahelian region, along at least the southern margin of the Sahara and possibly in North Africa as well (Nicholson, 1976). The height of the Nile flood (Fig. 2), determined by precipitation on the Ethiopian highlands, increased dramatically in these three centuries; while the summer minimum level, which is determined by rainfall in the lakes region of East Africa, sharply decreased. Recent transgressions of certain East African lakes—Rudolf (Butzer, 1971), Katwa (van Zinderen Bakker & Coetzee, 1972) and probably Abhé (Gasse, 1975)—date also to this period. Lake Chad (Maley, 1977) rose to 4 m above its modern level between about 1600 and 1750. Two long-term chronologies for Senegal and Mauritania, based on several independent studies discussed later in more detail, similarly indicate increased rainfall in the 16th through the 18th centuries (Fig. 2).

These six chronologies are not in themselves conclusive, but famine and drought chronologies for Chad, the Niger Bend region and Senegal (Fig. 3) also suggest a decreased frequency of drought in the 16th and 17th centuries (Nicholson, 1976). Several notable droughts occurred in the 18th century, but geographical descriptions suggest that more humid conditions prevailed until about 1800. For the Niger Bend, Cissoko (1968) reviews the Arab chronicles, concluding that conditions in the 16th century were so good that famine simply 'could not break out'; the occurrence of several notable floods and information suggesting that the Niger flood normally reached to Tombouctoo (Mali) at that time support his conclusions. The Bornu Chronicles for the region near Lake Chad similarly talk of the great prosperity in the 16th through the 17th centuries and the absence of famine and drought; these agree closely with the variations of Lake Chad. Also in the region of

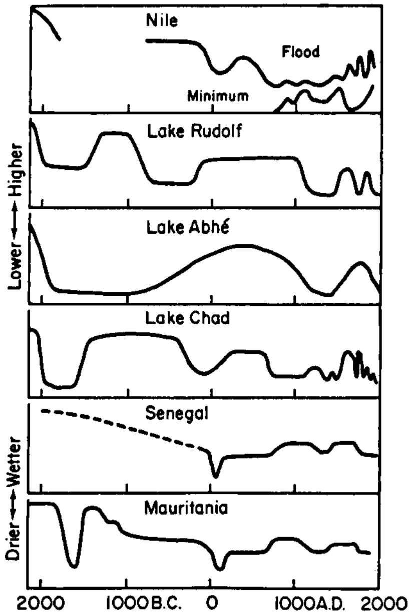

Figure 2. Fluctuations of lake levels and climate in Africa during the past 2000 years.

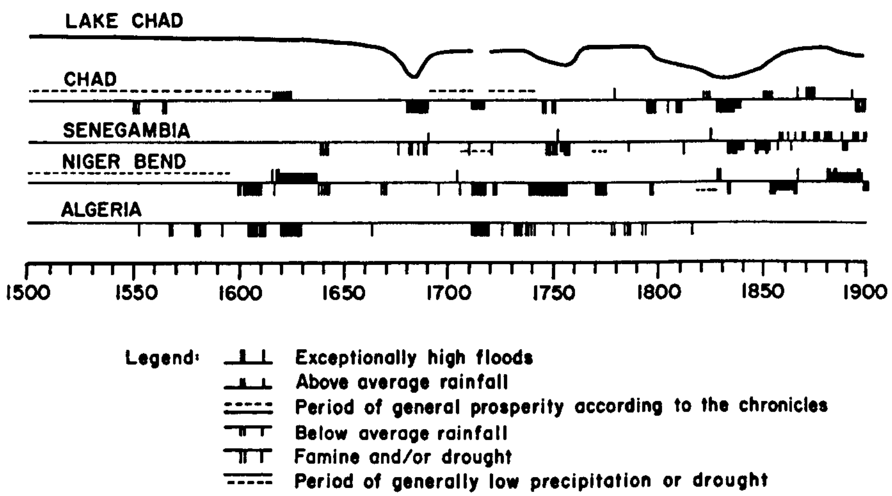

Figure 3. Chronology of famine and drought in Chad, Senegambia, the Niger Bend and northern Algeria, 1500 to 1900.

Senegambia and in North Africa (particularly Algeria) the frequency of famine and drought was lower in the 16th and 17th centuries.

Geographical descriptions relating to regions in Chad, the Sudan, Senegal, Mauritania and the Guinea Coast also support the conclusion that wetter conditions characterized the 16th and 17th centuries, but they further suggest that the increased rainfall prevailed throughout most of the 18th century, despite the severe droughts of the 1680's and mid-1700's indicated by the famine and drought chronologies.

Both geographical description and geological evidence implies wetter conditions prevailing in Senegal and Mauritania well into the 18th century (Nicholson, 1976). A beach ridge in the Ndiéguer depression in northern Senegal dates to no earlier than 1400, but it actually may stem from a somewhat later period; waterways and former mouths of the Senegal, navigated by the Portuguese in the 16th century, were not covered by sand until sometime toward 1800. Several descriptions from the late 1600's and mid-1700's indicate a vegetation cover characteristic of wetter regions: thick stands of trees along the Senegal River, which is presently bordered by mostly bare sand; wet, marshy lands along the river near Podor; forests in the near-desert regions of southern Mauritania; and several lakes presently desiccated. Architecture of the Mauritanian cities Atar and Tichitt suggests a denser vegetation cover and perhaps a nearby forest. The buildings of Tichitt, for example, constructed a few centuries ago, lack protection from blowing sands: this would be extremely unusual in the present desert environment. In the Adrar–Baffor Serra region of Mauritania, descriptions of agriculture, stream flow and rainfall also indicate wetter conditions in the 16th and early 17th centuries and perhaps a change in the winter rainfall regime.

In Chad, natives in the 1850's reported that in the late 1700's it was still possible to travel by boat as far north as Borkou via the lakes of Djourab and Borkou (Plote, 1974). This implies complete flooding of the Bahr el Ghazal, which never occurred in the 19th and 20th centuries. Browne (1799) also describes a river flowing into the Bahr and a forest near its banks in the late 1700's. Sedimentary strata in this now-dry valley date to 140 ± 90 B.P. and thus may have been deposited in the 18th century (from Servant, cited in Shaw, 1975). It is not clear, however, if this situation relates to increased rainfall in the Chad area or in the region of the headwaters of streams flowing into the lake, i.e. near Cameroun and Central African Republic. Elders in Tibesti, in far northern Chad, retain a memory of a recent forest cover (Maley, 1973), perhaps contemporaneous with the recent flooding of the Bahr el Ghazal, in this presently desertic area.

Browne's description of Darfur (east of Lake Chad) in the 1790's similarly suggests increased rainfall relative to today. He describes the verdure of the now very dry countryside and a rainy season longer and wetter than present.

Radiocarbon dates varying from 155 ± 70 to 335 ± 60 B.P. for fireplaces *in situ* at semi-arid sites in Niger, the Sudan and Ethiopia might also suggest, if not wetter conditions there, at least a more reliable rainy season than at present (Talbot & Williams, 1976).

Looking at the wetter Guinea Coast region to the south of these semi-arid zones, we find further evidence of climatic fluctuations which indirectly supports the hypothesis of wetter conditions in the Soudano–Sahelian region in at least part of the 16th through the 18th centuries. Frequent 17th century references to harvests and weather state that rainfall was anticipated in April and May, one or two months earlier than today. Several descriptions and observations (Bosman, *c.* 1705; Hillier, *c.* 1697; Matthews, *c.* 1780; Winterbottom, *c.* 1790; cited in Nicholson, 1976) from around the 18th century similarly imply that the Gold Coast was then drier and the rainy season shorter. This could logically mean that rainfall was greater in the more arid Soudano–Sahelian region and the rainy season there, longer: both areas receive rainfall in association with the presence of the ITCZ; and the earlier this convergence zone progresses northward, the shorter and drier is the rainy season in the south of Guinea Coast, and the longer and wetter it is in the north, or Sahel. This inverse relationship is illustrated by the rainfall departure patterns of the 1950's (Fig. 4), a period of abundant rainfall in the Sahel and Soudan zones.

Turning far to the north of these regions, we find indications in North Africa and Israel of a climate in parts of the 16th through the 18th centuries significantly different from today's. A tree-ring study from Algeria (near Laghouat) (Fahn, Wachs & Ginzburg, 1963) shows increased rainfall for the mid-1600's to the mid-1700's; a study for Tunisia (Ginestous, 1927) indicates more rapid tree growth, i.e. probably greater rainfall, from the early 1700's to about 1850; and a study from the Sinai (Waisel & Liphsitz, 1968) concludes that rainfall was greater there from 1500 to the late 1600's. This evidence is not as strong as that for the other regions discussed and is unrelated to climatic fluctuations in these regions, but it suggests that the 16th through the 18th centuries saw a contraction of the Saharan desert belt, rather than a southward shift. This conclusion is still tentative, however.

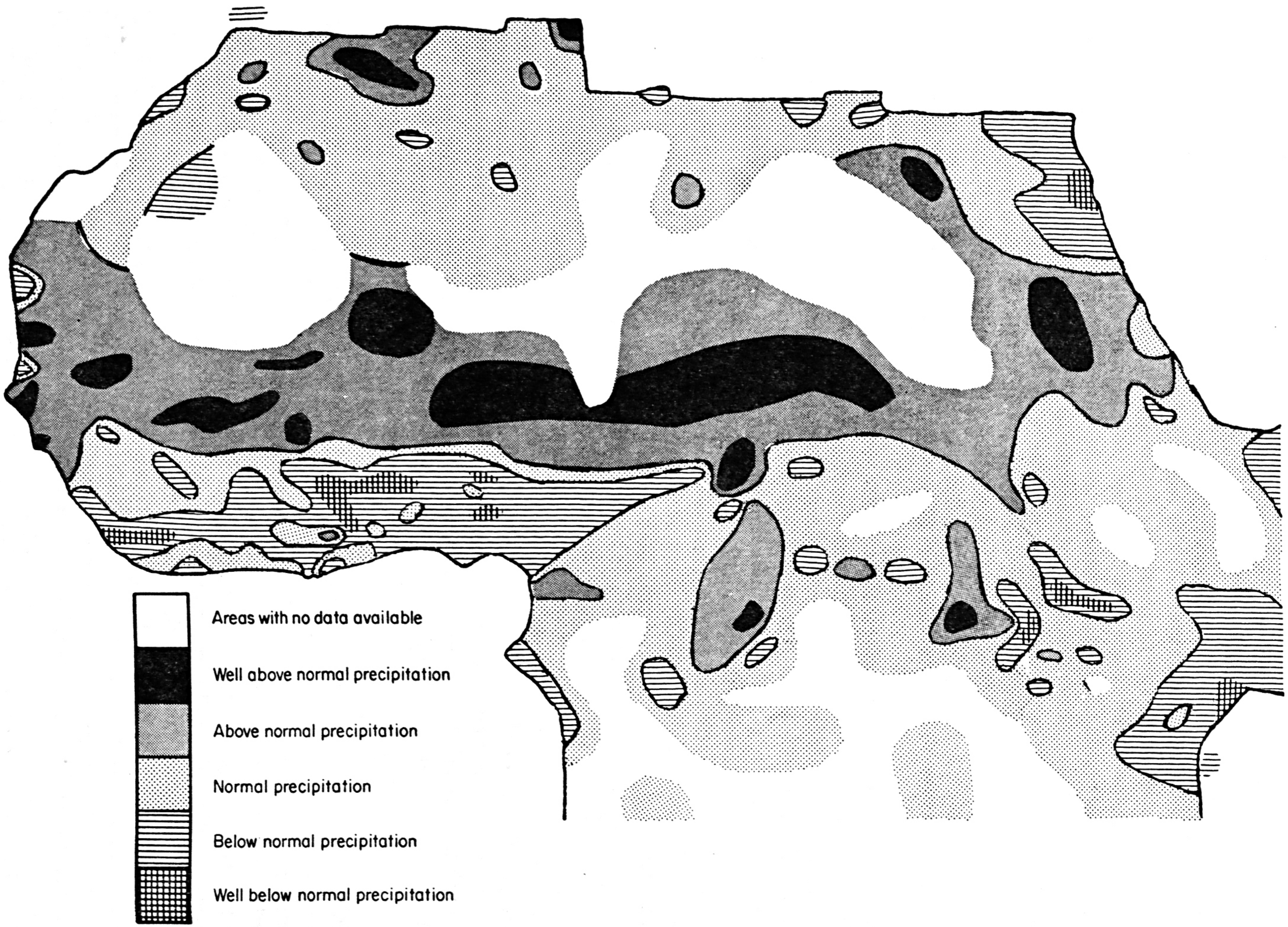

Figure 4. Precipitation anomaly map for a composite of 1936, 1950, 1952, 1956, 1958.

Rainfall observations from Madeira (Nicholson, 1976) in the mid-1700's show a change of the rainfall regime at that time; increased precipitation and a pronounced December–January maximum rather than the present weak November maximum. This can probably be understood as increased southward penetration of Mediterranean cyclones into the semi-arid regions just north of the Sahara. It then suggests wetter conditions along the temperate margins of the Sahara.

In summary, the conclusion from the above descriptions and studies of the Soudano–Sahelian regions and the Guinea Coast is that conditions significantly wetter than those of today prevailed in the semi-arid regions south of the Sahara in at least long periods of the 16th through the 18th centuries, if not during most of these three centuries. Sporadic evidence for northern Africa and the Mediterranean suggests wetter conditions there as well, implying a contraction of the Saharan desert belt at that time.

Further study is needed to establish more firmly the temporal continuity of this situation, the synchroneity of wetter conditions in the various regions and the climatic conditions prevailing at that time in northern Africa. Both increased spatial and temporal detail is required. It is also necessary to determine more securely what climatic conditions are reflected by the various described indicators. Maley (pers. comm., 1977) has pollen evidence that rainfall fluctuations are out of phase in the Sahelian and Soudano–Guinean zones. He suggests that while Lake Chad and most of the Senegal and Niger Rivers are in the Sahel, their levels and discharge are more dependent on rainfall in the Soudano–Guinean zone further south.

As for the Sahel and Soudan zones, vegetation and geological evidence suggests that the wetter conditions prevailed until well into the 1700's, although periodic severe droughts which began as early as 1680 marked a degradation of rainfall conditions which eventually gave way to the present aridity. The most severe of these droughts are discussed in the next section.

Severe drought episodes after 1680

Three major drought episodes which affected nearly the entire Sahel occurred *c.* 1681–7, *c.* 1738–56 and *c.* 1828–39; precipitation anomalies of these periods are depicted in Figs 5, 6 and 7. Minor, more localized droughts occurred in the early 1700's, the 1770's and the 1790's.

The drought of the 1680's (Fig. 5) seems to have affected the entire east–west extent of the Sahel and Soudan zones (Nicholson, 1976). It is referred to in chronicles and reports from Ouaddai (Chad) and Darfur (Sudan) as a great 'seven-year' famine. This cannot be taken literally to mean seven years, as such a reference is quite common and is traditionally based on the biblical story of Joseph's seven lean years and seven fat years (Vansina, 1976, pers. comm.), but it does imply a long and severe famine in both these areas. The Funj area of the Sudan was plagued by famine and drought from 1680 to 1692. The drought is similarly reported at Agadez (Niger), Bornu (near Lake Chad), Dahomey, Ghana and Senegambia. At about this time a remarkable occurrence of snowfall was reported in central Zaire.

In the mid-18th century an extremely long and severe drought (Fig. 6) ravaged the entire Sahel–Soudan zone of central and West Africa from the 1730's to the 1750's, killing half the population of Tombouctoo and other parts of the Niger Bend. This period of famine and drought, perhaps the most severe one ever recorded, was reported in Senegambia, Mauritania, Mali, Upper Volta, Dahomey, Ghana, Nigeria and Chad. It was accompanied by very high floods of the Nile (the highest of the entire period 1700–1840), implying increased precipitation in the Ethiopian highlands, and was probably synchronous with increased precipitation in northern Algeria (Nicholson, 1976).

After the famine of the mid-18th century, the more humid conditions of the two previous centuries may have dominated once again until about 1795 or 1800 (Nicholson, 1976). For the 1780's, there are several indications of remarkably wet years or periods, but it cannot be shown whether or not these were singularities. A tremendous flood at Agadez (mean

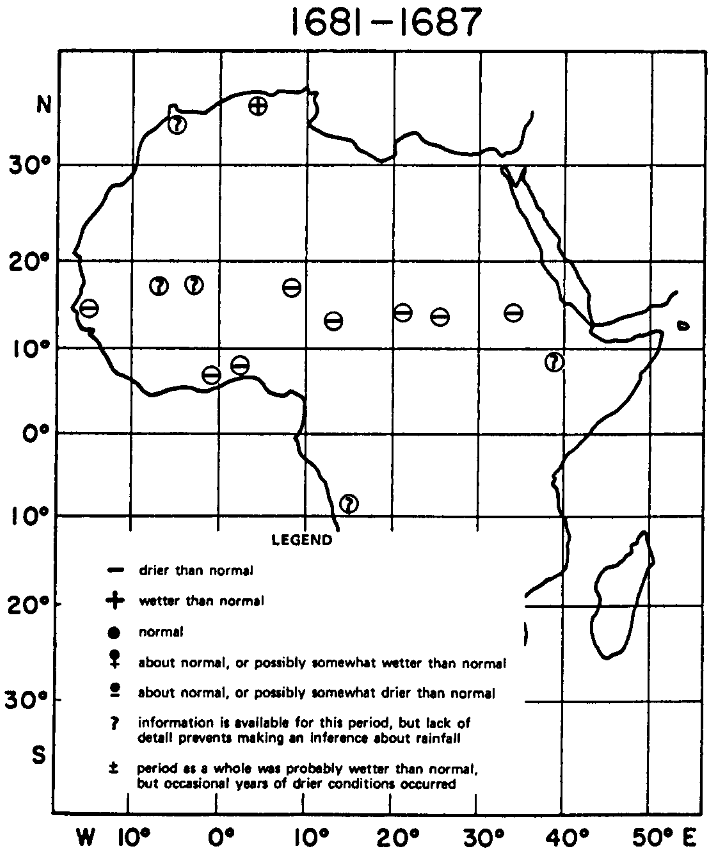

Figure 5. Precipitation anomaly map for 1681–87. (Circled symbols denote indirect information; squares denote lakes or rivers; others, actually measured precipitation.)

annual precipitation = 159 mm today) in Niger destroyed many buildings and ruined the town in *c.* 1780. According to the Asben Chronicles (Palmer, 1936), 'God sent rain to Agadez from early morning until early afternoon'. In about the 1780's a 'deep and rapid stream' flowed near Tessawa in the Libyan desert (near Murzuq), but was overwhelmed by moving sands by the end of that decade (Dalzel, 1793). The now dry Bahr el-Ghazal valley of Chad was probably flooded also at that time—recall the reports of travelling up the Bahr by canoe from Lake Chad to Borkou, Browne's (1799) report of a forest and river there, and sedimentary deposits in the valley dated to about that time.

By the end of the 18th century, however, a marked change began throughout tropical (northern-hemisphere) Africa. In the 1790's a severe drought plagued Chad, Bornu and the Kano area of Nigeria, forcing the evacuation of Agadez (Lovejoy & Baier, 1975), where only a few years earlier a tremendous flood occurred; and the level of Lake Chad began to fall continuously.

This trend toward increased aridity culminated in a severe drought *c.* 1828–39. This appears to have been the climax of a dry period (Nicholson, 1976) which plagued much of tropical Africa and the Sahara from the early 1820's to the 1850's or 1860's.

The map in Fig. 7 illustrates the core of this dry period. Chad appears to have been the most badly affected area: in all, 12 years of famine and drought were reported in Ouaddai and near the lake; and the lake was partially desiccated for the entire 12-year period, equalling its minimum stage during the droughts of the mid-18th and early 20th century. Other regions of drought (Nicholson, 1976) include parts of Zambia, Rhodesia and Angola; Tete (Mozambique); Senegal; parts of Ethiopia: Bornu; Oualata and Takrour (Mauritania);

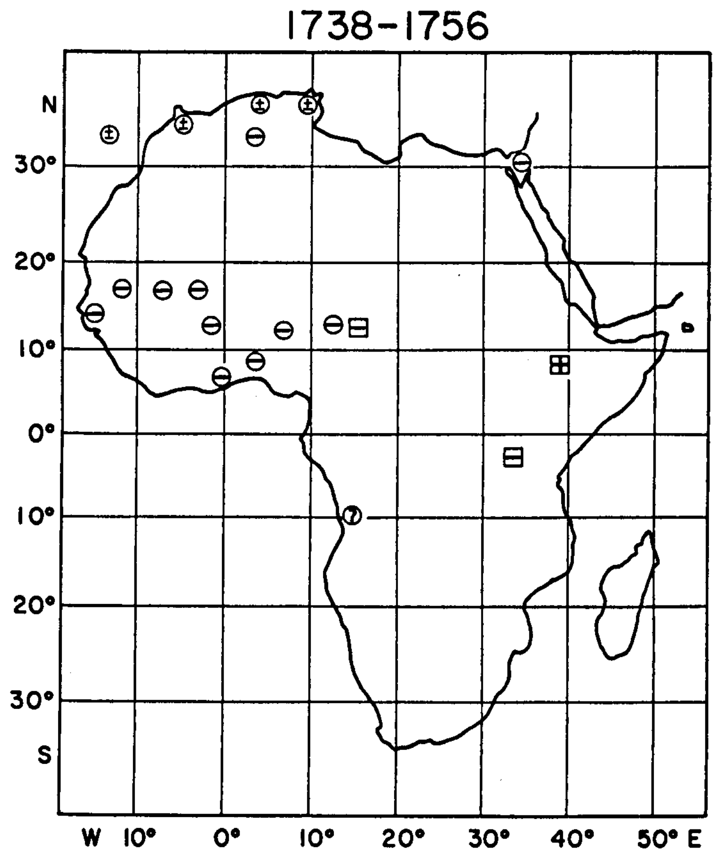

Figure 6. Precipitation anomaly map for 1738–56. (See Fig. 5 for legend.)

Araouane and much of Mali; much of South Africa; and Ghat (Algeria), which was without rain for eight or ten years from *c.* 1835 to 1845. Tripoli and Madeira experienced below-average rainfall, and the flood and minimum levels of the Nile and the level of Lake Tanganyika indicate drought over much of eastern Africa from Ethiopia to Tanzania. Parts of northwestern Africa and perhaps the Guinea Coast were, however, relatively wet at this time. Stations with above-average precipitation include Constantine and Algiers, in Algeria, and Christiansborg, in Ghana (near Accra), where rainfall was measured for the years 1829–34 and 1839–42. Saint Louis and Cairo showed precipitation totals just above average in the early 1830's, but in 1828 and 1829 Oualata experienced a magnificent harvest, and no famines are reported during the entire period 1828–39 in the Tichitt Chronicles (Marty, 1927; Monteil, 1939) of Mauritania.

A return to wetter conditions in the late 19th century

The increased aridity described for earlier in the 19th century gave way to wetter conditions toward 1870. From about 1875 to 1895 precipitation was continuously above the present normal on both the tropical and temperate margins of the Sahara, in the central Sahara, throughout East Africa and in parts of northern Africa. Meteorological information for this period is quite plentiful and allows for accurate and detailed characterization of this period. This includes fluctuations of lake levels and river discharge, as well as information on harvest quality and rainfall information derived from chronicles and other historical sources, and actual (measured) precipitation records.

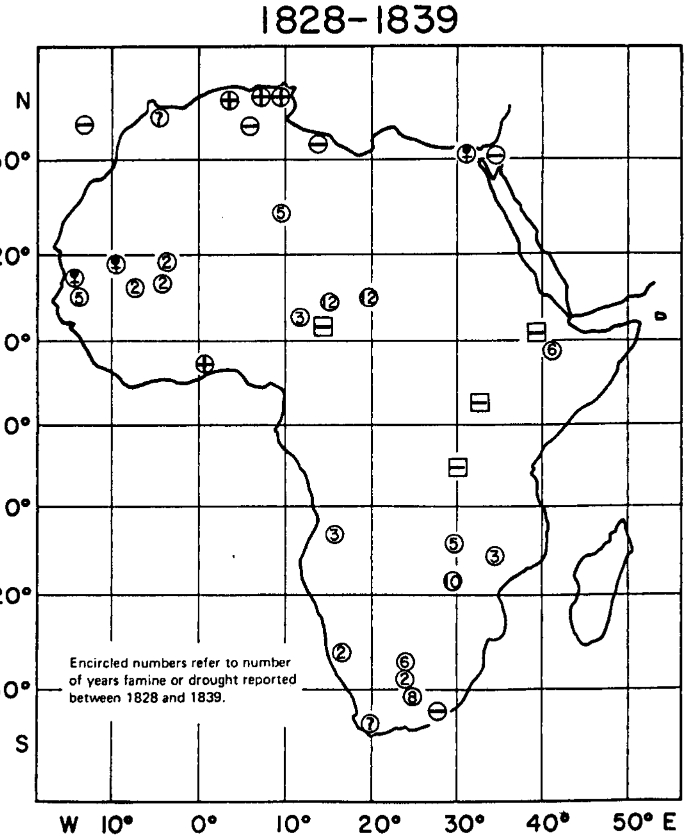

Figure 7. Precipitation anomaly map for 1828–39 (See Fig. 5 for legend. Numbers plotted within circles are the number of years, during this period, that famine or drought occurred.)

The recent fluctuations of several lakes are shown in Fig. 8. The curve for Lake Chad is from Nicholson (1976). The curve for Lake Rudolf comes from Butzer (1971); that for Lake Stefanie, from Grove, Street & Goudie (1975), Hobley (1914) and Butzer (1971); and the curve for Lake Rukwa is from Hobley. Curves for other lakes are derived primarily from Lamb (1966), supplemented by information in Bruckner (1890) and Grove (1972).

Notable in all curves is a tendency toward very high lake levels (several meters higher than at present) in the late 19th century, with a sharp decrease generally toward 1900, and a sharp rise again in the 1960's. This late-19th-century oscillation is indicated also for the East African lakes Magadi, Nakuru, Jilore, Ngami and Baratuma, and the Lakdera and Juba Rivers; these lakes continuously diminished until about 1914 (Hobley, 1914). Lakes Awasa and Shala in the Ethiopian rift (Grove, 1972) also appear to have been higher at the end of the 19th century than at any time since. Most of the lakes then remained stable in the 20th century until the 1960's; the level of Lake Victoria, for example, varied by only 1·5 m between 1902 and 1960. But the rise in the early 1960's was remarkable; Lake Victoria's surface rose 2 m in 1961 alone and from 1960 to 1964 the level of Lake Tanganyika rose 3 m.

Similar trends are seen for the Nile (Grove, 1972). The annual discharge at Aswan was on the average 109 gigatons (i.e. 109×10^9 tons) for the period 1870 to 1899, but only 83 gigatons for the period 1900 to 1949. Discharge for the decade 1899 to 1908 was below the 20th-century mean, thus there was a large drop toward 1900; for 1899–1900 it totaled 64 gigatons, the second lowest value ever recorded. During the 1870's and 1880's there was also

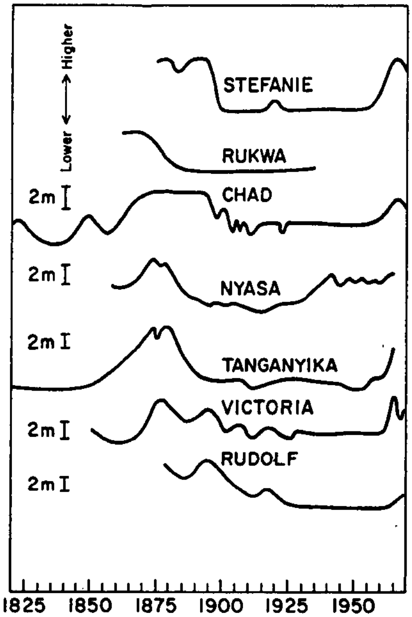

Figure 8. Variation of the levels of African lakes in the 19th and 20th centuries.

increased discharge of the Senegal and Niger Rivers in West Africa and increased stream flow out of the Atlas near Biskra (Pejml, 1963; Plote, 1974). As we will see in the next section, these trends are confirmed by rainfall measurements and other evidence.

Figure 9 shows the period 1870–1920 for parts of West and North Africa (Nicholson, 1976). The chart describes year-to-year fluctuations, with + implying wetter than normal (i.e. as known in the 20th century), 0 implying average conditions, and – indicating drier than normal conditions. Information for the Hoggar, Ahnet and Tefedest is based on harvest quality reported by the Touareg, and the curve relates to winter rains (Dubief, 1947). That for Mauritania is derived mainly from the chronicles; in the upper curve for Tichitt/Néma/Oualata years of excess precipitation refer primarily to winter rains. The graphs for Niger (near Agadez) and the Niger Bend are based on reports of harvest quality, level of the Niger flood, conditions of wells, famine and drought. That for Senegal is based primarily on precipitation at Saint Louis, supplemented by reports of famine and drought and desiccation of certain lakes. The graph for Chad is derived primarily from lake-level fluctuations. The graphs for Biskra, Laghouat, Ghardaia, Oran, Constantine and Algiers are based on measured precipitation.

Thus we see in Fig. 9 that the climatic fluctuations in West Africa and northern Africa for the late 19th and early 20th centuries tend to parallel those already shown by the lakes of East Africa and Lake Chad. The floods of the Niger were exceptionally high and the harvests in the region of the Niger Bend were exceptionally good throughout the period 1880–96, whereupon a period of weak and moderate floods began (Plote, 1974), and Lenz's (1886) travels across the desert from Morocco to Tombouctoo covered a landscape wetter than the present one along that route. The Niger Bend and the lake area near Goundam had become the most important wheat-producing area in West Africa in the late 19th century, but the reduced floods and the tremendous droughts after *c.* 1896 gradually brought about the decline of agricultural activity. This trend toward increased aridity culminated in severe drought toward 1913–14 (Plote, 1974). Such a trend was also seen in the rainfall in Mauritania

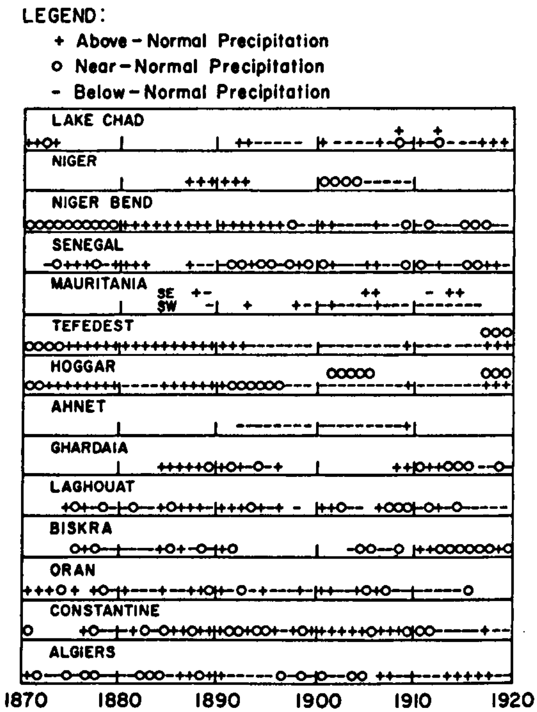

Figure 9. Variation of precipitation in West Africa, 1870–1920, inferred principally from harvests, famine/drought, floods, lake levels and measured precipitation.

(Bonte, 1974) and Senegal, and toward 1900 certain water bodies dried up in the vicinity of Dakar and the discharge of the Senegal was considerably reduced (Plote, 1974).

Farther north, in the central Sahara, a similar trend is seen in the Touareg region of southern Algeria, a region generally beyond the limit of the penetration of the summer monsoon rains. The Touareg harvests, dependent on winter rainfall, were exceptionally good from *c.* 1872 to 1892, the period of high lake levels in East Africa and high Niger floods. From about 1892 the harvest quality rapidly declined, bottoming out in a long period of drought at the beginning of the 20th century (Dubief, 1947). Similar trends can be seen in the rainfall (Fig. 9) at Ghardaia and Laghouat, and to a lesser extent at the coastal stations Algiers, Oran and Constantine.

By the late 19th century, rainfall was being measured regularly at many stations in Africa. These records have been compiled (Nicholson, 1976) and added to the information presented earlier in this section in order to draw a series of precipitation anomaly maps. Maps have been drawn for the six periods 1870–4, 1875–9, 1880–4, 1885–9, 1890–4, 1895–9 (Nicholson, 1976), but only three are included here and they well illustrate the general character of the entire three decades. During the period 1870–95 there was increased precipitation throughout most of northern-hemisphere Africa, including both the tropical and temperate margins of the Sahara and the central Sahara itself (Figs 10 and 11). In East Africa, this increase was particularly marked from about 1870 to 1880, but within the 1880's (Fig. 11) several lakes in the area exhibited sharp falls, although they were still probably above their 20th-century levels. The situation quickly reversed itself toward 1895 (Fig. 12), and in nearly all the regions studied a marked tendency toward lower rainfall culminated in severe drought *c.* 1910–20 (Nicholson, 1976). Some improvement in rainfall conditions occurred after *c.* 1920; and there was once again relatively abundant rainfall in the Sahel in the 1950's (Fig. 4) and in East Africa in the 1960's, though conditions probably never reached the optimum of the late nineteenth century. After the mid-1960's the rainfall regime abruptly gave way to a period of long and severe drought which was particularly severe in the Sahel.

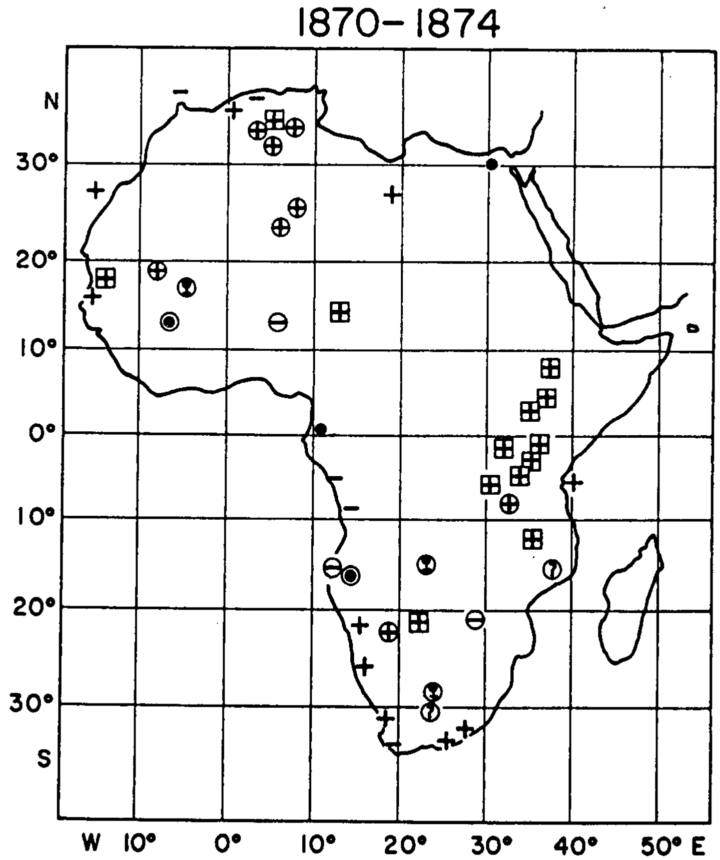

Figure 10. Precipitation anomaly map for 1870–4. (See Fig. 5 for legend.)

Conclusions

In looking at these recent climatic fluctuations as Quaternary analogues we begin by summarizing the climatic conditions for three Quaternary episodes, the Wisconsin or Wuerm glacial *c.* 20,000–15,000 B.P. (Fig. 13), the rapid change to interglacial conditions *c.* 10,000 B.P. (Fig. 14) and the Altithermal period *c.* 5000 B.P. (Fig. 15). A southward shift of climate and vegetation zones in Africa characterized the first of these episodes: increased aridity throughout the southern Sahelian margin of the Sahara and south of it and in the lake regions of East Africa. A similar climatic anomaly pattern probably prevailed during the 1830's, which was also a period of glacial advance, but the precipitation anomalies of modern drought periods may differ considerably from this situation.

The most frequent 20th-century drought type (Fig. 16) resembles the Würm in that above-normal precipitation characterized the humid West African tropics and East Africa, but this anomaly type dissimilarly includes increased rainfall in northwestern Africa. However, a less frequently occurring drought pattern typified by the years 1907, 1949, 1965, 1971 and 1973 (Fig. 17) shows much similarity to the climatic situation of *c.* 20,000–15,000 B.P.: decreased rainfall over most of the continent but a large area of above normal precipitation in northwestern Africa.

The period *c.* 10,000 B.P. showed a reversal of this situation, with a very marked increase of rainfall throughout the semi-arid regions south of the Sahara and in East Africa. There appears to be no recent, complete analogue to these conditions; a somewhat comparable situation existed *c.* 1870–95, but with increased rainfall extending throughout North Africa as well. Thus the late 1800's bear more resemblance to the Altithermal *c.* 5000 B.P.; during

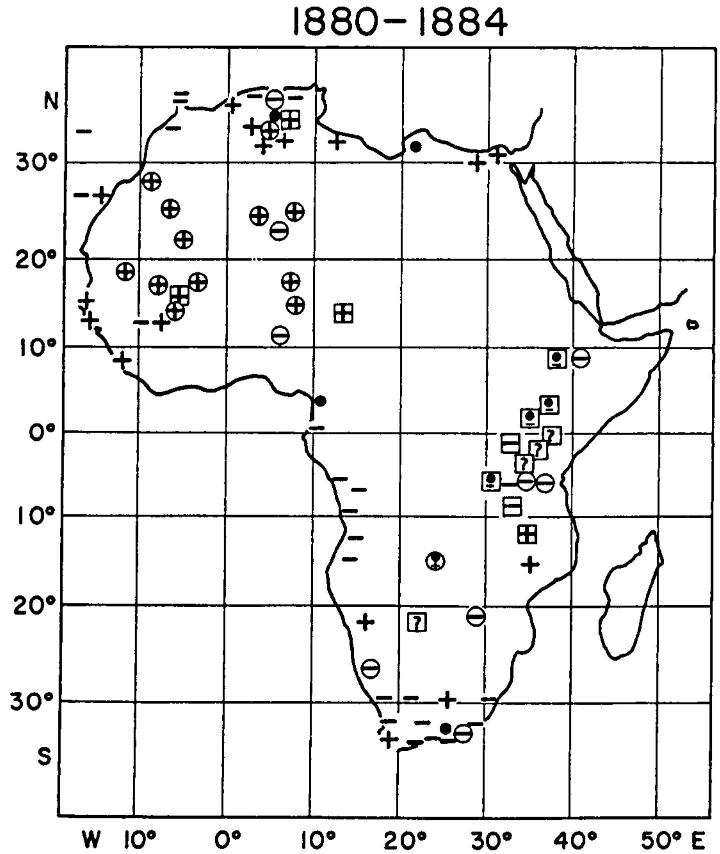

Figure 11. Precipitation anomaly map for 1880–4. (See Fig. 5 for legend.)

both periods rainfall increased over most of the African continent and very markedly in the Sahel, but the later period was associated with cooler global temperatures, as compared to the warmer climatic optimum of the Altithermal.

The most recent episode of increased rainfall in the Sahel, the 1950's (Fig. 4), bears little resemblance to either the Altithermal or the late 1800's, as it is marked also by decreased rainfall in East Africa and in the humid tropics of West Africa south of the Sahel. The rainfall anomaly which characterizes the 1950's is actually similar to that described for approximately the 16th through the 18th centuries, and contemporary with the period frequently referred to as the 'Little Ice Age'. The increased rainfall in the semi-arid regions south of the desert during this period sharply contrasts with the markedly increased aridity of the last glacial. This contrast underscores the inaccuracy of the anomaly between the 'Little Ice Age' and the Pleistocene glacials.

This comparison of recent and past climatic anomalies in the African Sahel illustrates the complexity of the climatic fluctuations affecting this region and other parts of Africa. Some periods of increased rainfall in the Sahel (e.g. the Neolithic, the 1950's) are synchronous with a general contraction of the Saharan desert belt, and conversely certain droughts such as the one *c.* 1968–73 are associated with a general expansion of the Sahara on both sides (Nicholson, 1976). At other times, such as the last glacial (Fig. 13), the arid zone is displaced northward or southward. These changes relate variously to conditions in other parts of Africa. There are probably several sets of meteorological circumstances which result in drought in the Sahel; what these circumstances are remains to be established.

The simple scenario of Mediterranean cyclones bringing rain into northern Africa in winter and the ITCZ-related rains bringing varying amounts of precipitation into the Sahel,

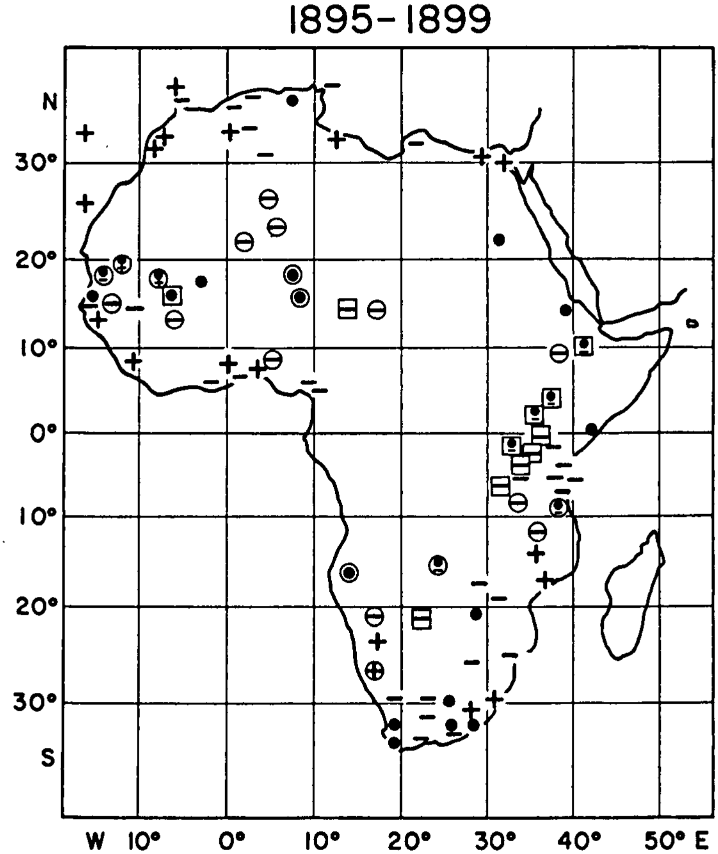

Figure 12. Precipitation anomaly map for 1895–9. (See Fig. 5 for legend.)

depending on its north–south displacement, must be altered to explain the numerous observed modes of African climatic variation. There is evidence, for example, that the Saharan depressions which bring rainfall into much of northern Africa during the transition seasons may have played a much more important role in the past, even as recently as the late 19th century (Nicholson, 1976). These depressions may have had an effect on Sahelian climate as well in the past. The Sahel's position between the major circulation systems of the southern and northern hemispheres means also that climatic fluctuations there are governed by the interaction of both hemispheres. The modes of interaction may best be identified by study of the climatic teleconnections between various African regions in recent times, and can then be applied to explaining climatic variation during the Quaternary through case studies of Quaternary analogues.

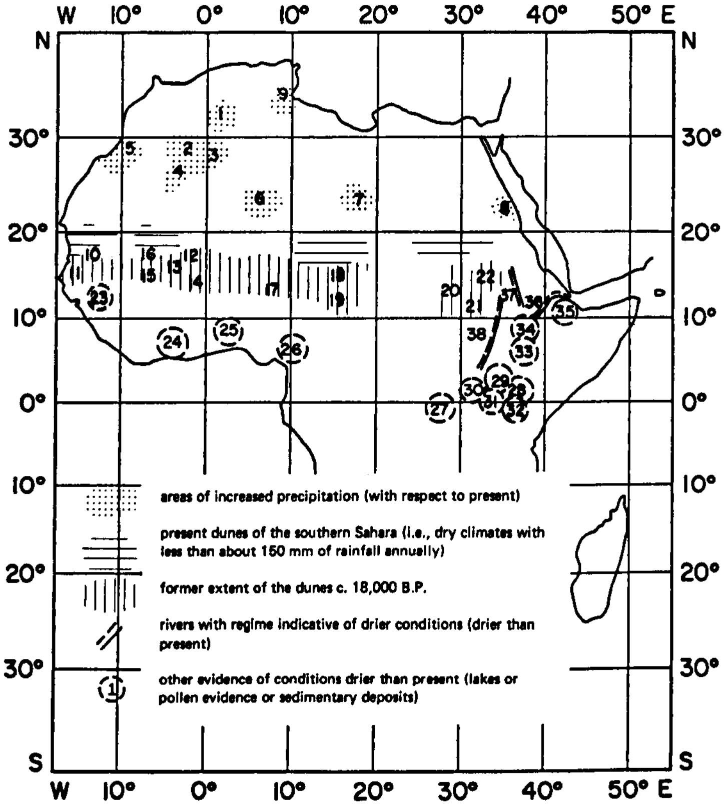

Figure 13. Summary map of climatic conditions *c.* 20,000–15,000 B.P.

Key to numbered locations

1 Great Western Erg: humid period
2 Saouara terrace formation
3 Touat: humid period
4 Erg Chech: humid period
5 Soltanian terrace of Morocco
6 The Hoggar: probably wetter than today, winter rains
7 Tibesti: probably wetter than today, winter rains
8 Nubia: strong wadi activity (related to winter rains)
9 Southern Tunisia: pollen indicates vegetation indicative of more humid climates
10 Southward advancement of Mauritanian ergs, River Senegal cut-off by dunes
11 Dunes near Dakar, Mbour, Cayor and Thies
12 Dunes in the region of the Niger Bend
13 Dunes cut the course of the Niger near Mopti
14 Erg of Ouagadou and dunes in northern Upper Volta
15 Dunes at foot of the Bandiagara plateau
16 Dunes near Dhar Néma
17 Kano erg
18 Dunes near Fort Lamy (Lake Chad desiccated)
19 Dunes in northern Cameroun
20 Dunes near El Obeid in Kordofan
21 Dunes in the Qoz region
22 Dunes blocked the course of the White Nile
23 Portuguese Guinea: fluvial deposits indicative of semi-arid conditions
24 Ivory Coast littoral: pollen indicates vegetation indicative of more arid conditions
25 Western and southwestern Nigeria: deposits of pediment gravel (today found only in Sahara and Sahel), suggests drier conditions
26 Cameroun: gully erosion suggests reduced vegetation cover
27 Ruwenzori: pollen evidence of drier conditions
28 Mount Kenya: pollen evidence of drier conditions
29 Cherangani Hills: pollen evidence of drier conditions
30 Muchoya Swamp: pollen evidence of drier conditions
31 Lake Victoria: lower than today or desiccated
32 Lakes Magadi and Nakuru: lower than today or desiccated
33 Lake Rudolf: lower than today or desiccated
34 Four Galla Lakes: lower than today or desiccated

35 Lakes in the Afars Territory: lower than today or desiccated
36 Awash and Bulbula Rivers: decreased discharge
37 Blue Nile: flood regime indicative of more arid conditions
38 White Nile: lower discharge than today, probably seasonal

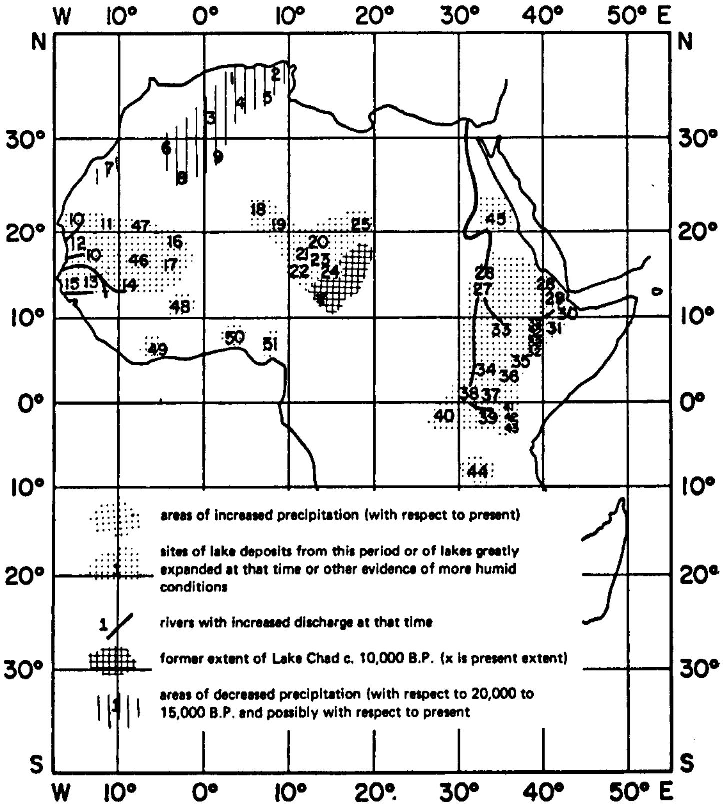

Figure 14. Summary map of climatic conditions *c.* 10,000–8,000 B.P.

Key to numbered locations

1 Laghouat: deposits of aeolian sand
2 Biskra: wadis indicate semi-arid conditions
3 Great Western Erg: became active
4 Ouarghla: evaporites and dunes
5 Southern Tunisia: pollen evidence of drier conditions
6 Saouara: decreased flow
7 Tarfaya: migration of dunes onto Pleistocene sediments
8 Erg Chech: became active
9 Touat: drier conditions
10 Wadis Touierja, Ogol, Atoui and Kteyane: increased flow, reached the Atlantic Ocean
11 Sebkha de Chemchane and lakes in the Adrar and Tagant
12 Sebkha de N'Drahmacha and coastal streams
13 Senegal River
14 Baoulé River
15 Gambia River
16 Araouane: fish remains and lacustrine deposits
17 Lake Faguibine: diatomite and lacustrine deposits
18 Hoggar: fluvial deposits and lacustrine deposits
19 Adrar Bous: lacustrine deposits
20 Lake Bilma
21 Lake Fachi
22 Lake Termit
23 Lake Agadem
24 Lake Manga
25 Tibesti: deltas, terraces, fluvial deposits, tropical herbivores, lacustrine deposits (see pp. 45–46)
26 Jebel Aulia: lake deposits
27 Kosti: lake deposits
28 Danakil depression: lake deposits
29 Lakes of the Afar
30 Lakes of the Afar
31 Awash River: increased discharge
32 Galla Lakes
33 Blue Nile
34 White Nile
35 Lake Stefanie
36 Lake Rudolf

37 Cherangani Hills and Muchoya Swamp: pollen evidence of wetter conditions
38 Lake Albert
39 Lake Victoria (pollen evidence from the area also, as well as from Mount Kenya)
40 Ruwenzori: pollen evidence of wetter conditions
41, 42, 43 Lakes Nakuru, Rukwa, Naivasha, Magadi
44 Lake Kivu
45 Kom Ombo: strong wadi activity (related to winter rains)
46 Majâbat al-Koubrâ: lake deposits
47 Hodh: hydrological systems (also Dhar Tichitt–Néma–Oualata)
48, 49, 50, 51 Upper Volta, Ivory Coast, Nigeria, Cameroun

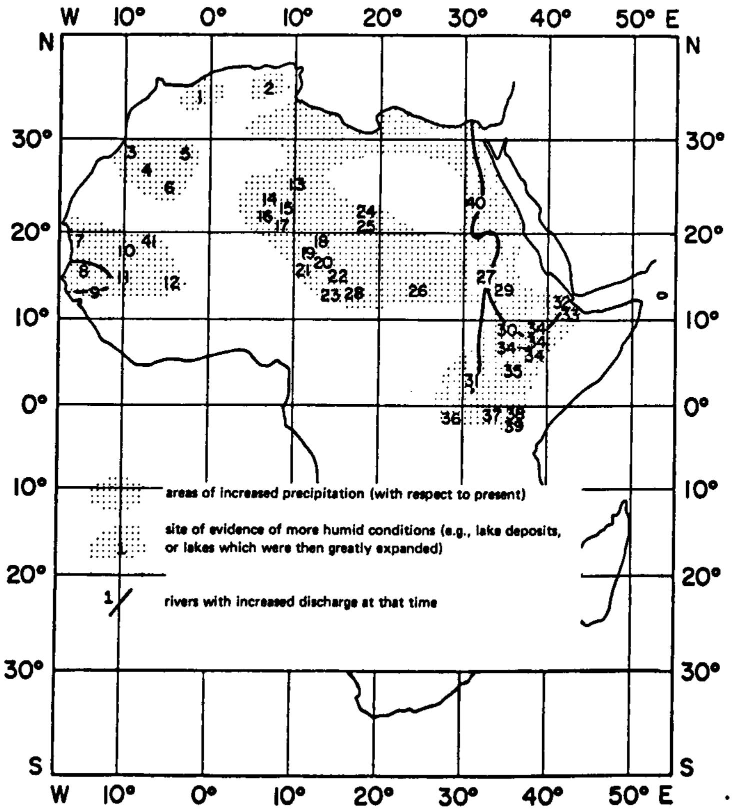

Figure 15. Summary map of climatic conditions *c.* 6500–4500 B.P.

Key to numbered locations
1 Maghreb: pollen evidence of humid episode
2 Biskra and Laghouat: humid episode
3 Tarfaya: humid episode
4 Ougarta: humid episode
5 Saouara: humid episode
6 Touat and erg Chech: humid episode
7 Sebkha N'Drahmacha: sedimentation implies humid episode
8 Senegal River
9 Gambia River
10 Tichitt and Aouker: lakes and landforms of wetter climates
11 Yelimané: active gullies
12 Lake near Mopti
13 Ghat: humid episode
14 Tihodaïne: marshy lands imply increased precipitation
15 Djanet: humid episode
16 Hoggar: marshy lands and Neolithic civilization
17 Adrar Bous: lacustrine deposits
18 Lake Bilma
19 Lake Fachi
20 Lake Agadem
21 Lake Termit
22 Lake Manga
23 Lake Chad
24 Northern Tibesti: lakes and vegetation imply wetter climate
25 Southern Tibesti: lakes and vegetation imply wetter climate
26 Jebel Marra: faunal and floral evidence of wetter climate
27 Khartoum: Neolithic civilization
28 Lake Tjeri
29 Ethiopian highlands: flow of Blue Nile suggests wetter climate

30 Blue Nile
31 White Nile
32 Afar Lakes
33 Awash River
34 Four Galla Lakes
35 Lake Rudolf
36 Ruwenzori: pollen evidence of wetter climate
37 Lake Victoria
38 Lake Nakuru
39 Lake Naivasha
40 Main Nile
41 Majâbat al-Koubrâ: lacustrine deposits

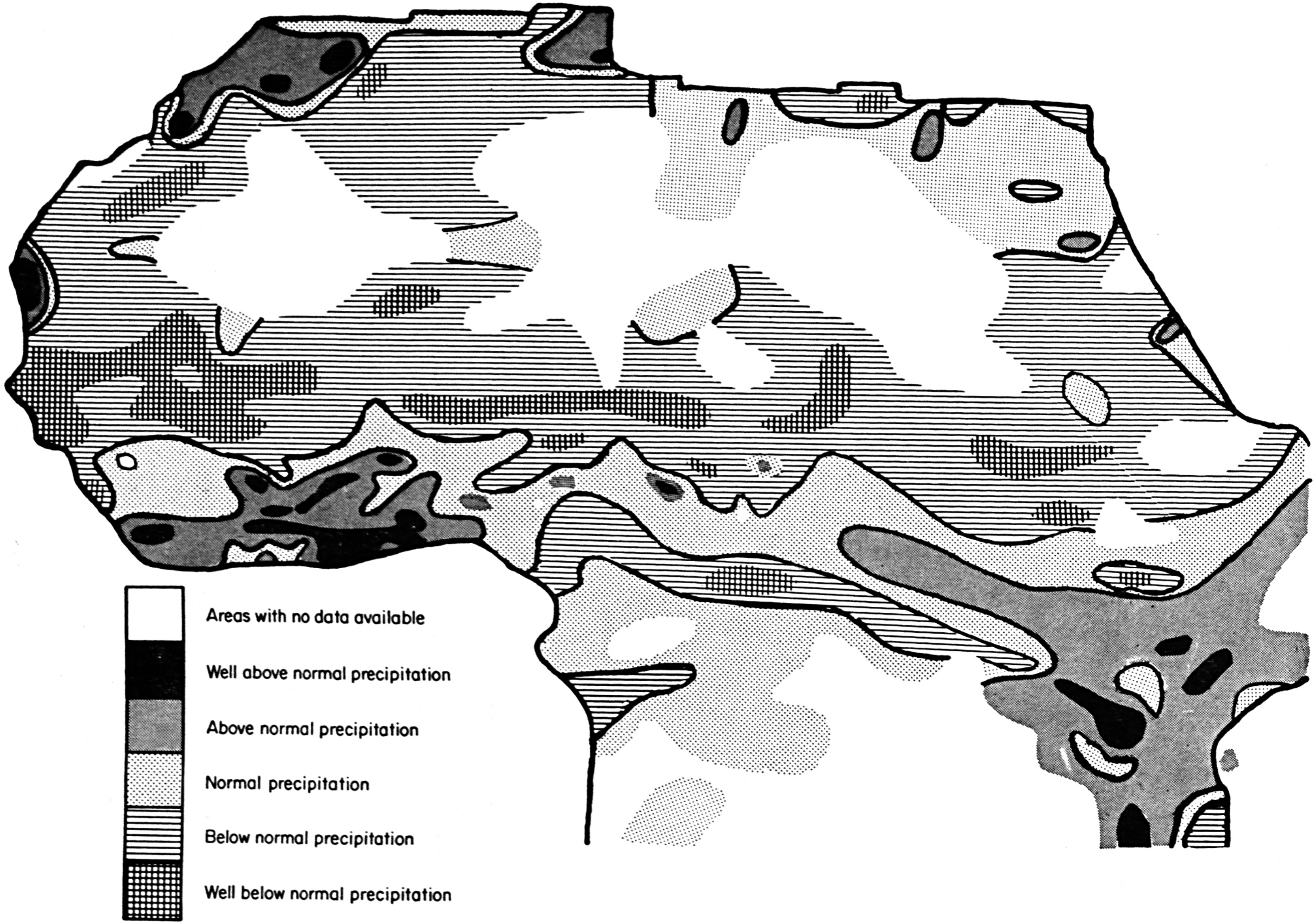

Figure 16. Precipitation anomaly map for a composite of 1913, 1963, 1968, 1972, 1973.

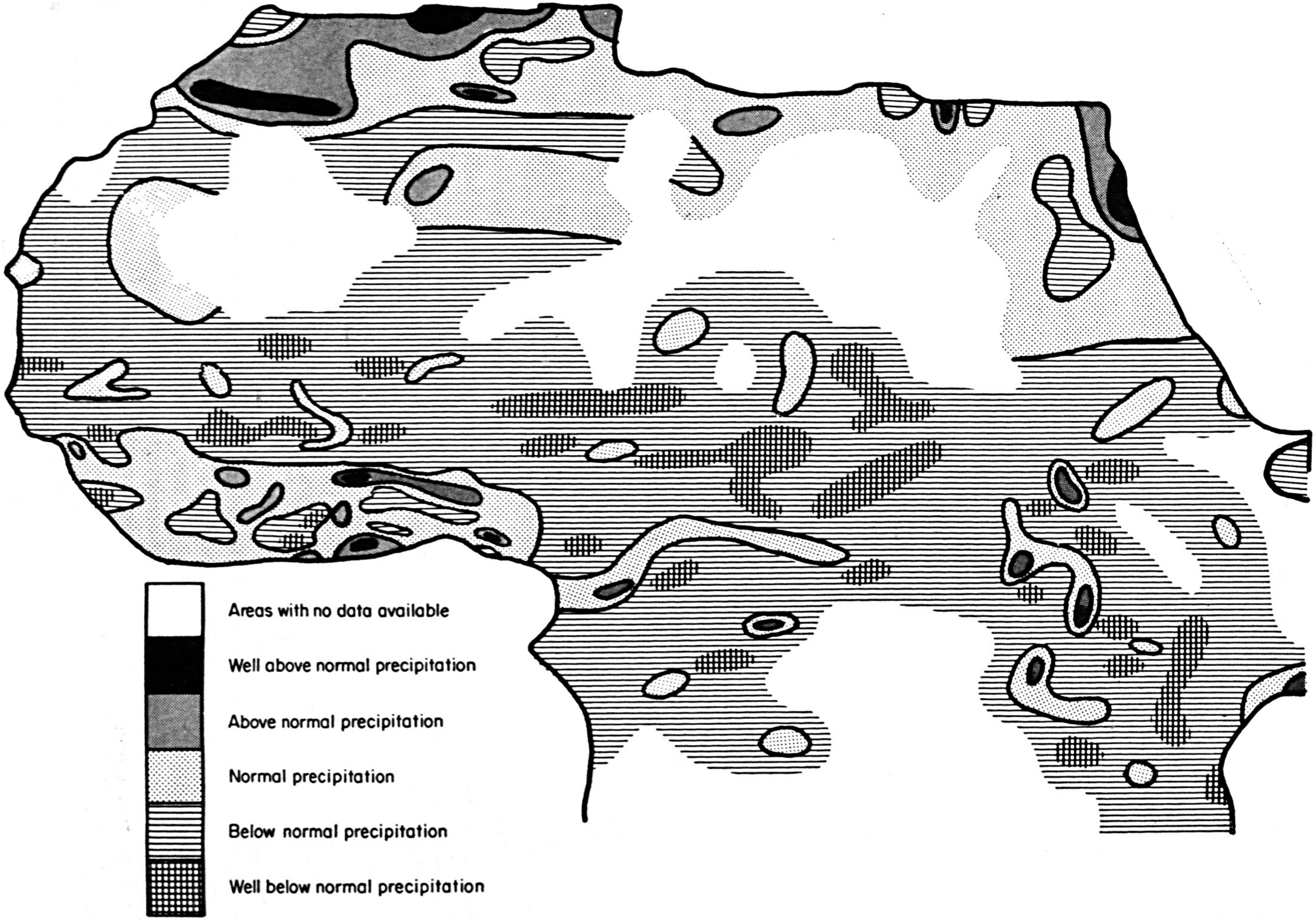

Figure 17. Precipitation anomaly map for a composite of 1907, 1949, 1965, 1971, 1973.

References

Bonte, P. C. (1974). Sécheresse et imperialisme en Afrique. *Notes économie et politique études.*

Browne, W. G. (1799). *Travels in Africa, Egypt, and Syria.* London: Cadell & Davies, 496 pp.

Bruckner, E. (1890). *Klimaschwankungen seit 1700.* Vienna: E. Holzel, 324 pp.

Butzer, K. W. (1971) Recent history of an Ethiopian delta. *University of Chicago Geographical Department Research Papers,* **136**: 184 pp.

Cissoko, S.-M. (1968). Famines et épidemies à Tombouctoo et dans la Boucle du Niger du XVIe au XVIIIe siècle. *Bulletin de l'Institut française d'Afrique Noire,* **30**: (B) 806–821.

Dalzel, A. (1793). *The History of Dahomey* (reprinted, 1967). London: Frank Cass, 230 pp.

Dubief, J. (1947). Les pluies au Sahara central. *Travaux de l'Institut de Recherches sahariennes,* **4**: 7–23.

Dubief, J. (1963). Contribution au problème des changements de climat survenus au cours de la période couverte par les observations météorologiques faites dans le Nord de l'Afrique. In *Les Changements de Climat, Actes Coll.,* pp. 75–79. Rome: UNESCO. *Recherches sur la Zone Aride.*

Fahn, A., Wachs, N. & Ginzburg, C. (1963). Dendrochronological studies in the Negev. *Israel Exploration Journal,* **13**: 291–299.

Gasse, F. (1975). L'évolution des lacs de l'Afar Central (Ethiopie et T.F.A.I.) du Plio-Pléistocène à l'Actuel. Ph.D. Thesis, Université de Paris VI, Vol. 1. 406 pp.

Ginestous, G. (1927). Le chêne zeen d'ain Draham. *Bulletin. Direction générale de l'Agriculture Commerce et Colonisation,* pp. 3–12. Tunis.

Grove, A. T. (1972). Climatic change in Africa in the last 20,000 years, Colloque de Ouarghla (Sept. 1971). *Les Problèmes de Developement du Sahara Septentrional.* Algiers. Vol. 2, *c.* 30 pp.

Grove, A. T., Street, F. A. & Goudie, A. S. (1975). Former lake levels and climatic change in the Rift Valley of southern Ethiopia. *Geographical Journal,* **141**: 177–201.

Hobley, M. (1914). The alleged desiccation of East Africa. *Geographical Journal,* **44**: 467–470.

Lamb, H. H. (1966). The climate in the 1960's. *Geographical Journal,* **132**: 183–212.

Lenz, O. (1886). *Timbouctoo, Voyage au Maroc, au Sahara, et au Soudan,* Paris: Hachette (2 Vols.).

Lovejoy, P. E., & Baier, S. (1975). The desert-side economy of the central Sudan. *International Journal of African Historical Studies,* **8**: 1–42.

Maley, J. (1973). Mécanisme des changements climatiques aux basses latitudes. *Paleogeography, Paleoclimatology, Paleoecology,* **14**: 193–227.

Maley, J. (1977). Analyses polliniques et paléoclimatologie des 12 derniers millénaires du Bassin du Tchad (Afrique Centrale). In volume edited by Comité Français pour 10ème INQUA Congrès, Birmingham, England, August 1977.

Marty, P. (1927). Chroniques de Oualata et de Nema. *Revue des Études Islamiques,* pp. 355–426, 531–575.

Monteil, V. (1939). Chroniques du Tichitt. *Bulletin de l'Institut française d'Afrique Noire, 1*: 282–313.

Nicholson, S. E. (1976). A climatic chronology for Africa: Synthesis of geological, historical, and meteorological information and data. Ph.D. Thesis, University of Wisconsin, Dept. of Meteorology, Madison. 324 pp.

Palmer, H. R. (ed.), (1936). *Bornu, Sahara, and Sudan,* London: John Murray. 296 pp.

Pejml, K. (1963). *Studie o Kolísáhí Klimatu v Severní Africe v Prehistorických a Historických Dobách.* Prague: Hydrometeorologicky Ustav. 93 pp.

Plote, H. (1974). *L'Afrique Sahélienne se dessèche-t-elle* ? Orleans, France: Bureau de Recherche géologique et minières, Service géologique national. 61 pp.

Shaw, B. (1975). Appendix to Ph.D. Thesis. *Economy and Society of the Maghreb during the Period of the Roman Empire.* University of Cambridge: Classics Faculty. *c.* 60 pp.

Talbot, M. R. & Williams, M. A. J. (1976). Dune erosion and alluvial fan formation at Janjari, Central Niger. (Unpublished manuscript, 26 pp.)

van Zinderen Bakker, E. M. & Coetzee, J. A. (1972). A re-appraisal of late-Quaternary climatic evidence from tropical Africa. *Palaeoecology of Africa,* **7**: 151–181.

Waisel, Y. & Lipschitz, N. (1968). Dendrochronological studies in Israel: *Juniperus phoenica* of north and central Sinai. *La-Yaaran,* **18**: 1–22.