Géo-Eco-Trop, 1978, 2, 291-300

LATE QUATERNARY CLIMATIC CHANGE AND THE CONDITIONS FOR CURRENT EROSION IN AFRICA

by

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RESUME

Le paysage est sensible d'une part à des phénomènes cycliques et plus ou moins fortuits et d'autre part, pour des périodes plus étendues, à des modifications plus radicales du milieu. A la fin du Quaternaire, l'Afrique tropicale et équatoriale ont subi les effets de mouvements tectoniques, de variations du niveau de la mer et de changements du climat. Pendant la dernière glaciation, les températures étaient plus basses et la plus grande partie du continent plus sèche que de nos jours. Par la suite, les climats ont été à la fois plus humides et légèrement plus chauds qu'actuellement. Certaines observations faites en Afrique équatoriale et tropicale montrent qu'au cours de ces périodes (plus sèches ou plus humides) les précipitations moyennes annuelles devaient s'écarter bien plus des moyennes actuelles que les quantités exceptionnelles enregistrées depuis le commencement du vingtième siècle. Il est suggéré que les paysages terrestres pourraient avoir supporté avec moins de difficulté les effets d'années exceptionnellement humides ou arides, et même les effets destructeurs de l'homme, si le climat n'avait pas été soumis à des oscillations aussi violentes dans un passé récent.

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The components of the physical landscape adjust over time to the processes at work on them with the eventual attainment, ideally, of some kind of equilibrium. However, the intensity and nature of the processes operating at a place vary through time so that equilibrium is never in fact attained. There is a continual response to variations of a cyclic nature, to moderate and extreme events of a quasi-random type, and also to longer-term changes the sequence of which makes up the environmental history of a place. Quaternary climatic changes form an important part of that environmental history.

In Africa and low latitudes generally, the cyclic variations involve alternating wet and dry seasons with associated fluctuations in wind action and the various processes operating on slopes and in rivers.
Amongst quasi-random events are heavy storms plus unusually wet and dry years and groups of years with recurrence intervals that increase with the magnitude of the events. The environmental history of a place includes these cyclic variations and quasi-random events, but because of the longer term changes involved it must be studied as historical rather than statistical phenomena.

The environmental history of a place is comprised of geologic, climatic and man-made events occurring in a certain sequence through time. Their influence on the present-day landscape depends not only on their magnitude but also on the time that has elapsed since they occurred. Here we are concerned with the Late Quaternary, especially with the last thirty thousand years, a period which is now relatively well-known because it falls within the range of C 14 dating. Although it includes only 2 per cent of the span of the Quaternary, its importance to the present-day landscape is great because its impress is so recent and because the range of variation in environmental conditions has been so wide.

The most disturbed part of Africa in the Late Quaternary has been the rift valley system. The margins of the western rift in Uganda were uplifted, reversing rivers flowing towards the Congo or Zaire system and ponding back a lake in the Victoria basin marked by high level deposits at Nsongezi near the Kagera river. (W.W. BISHOP, 1969). Volcanic lavas extruded over 15,000 years ago dammed back rivers flowing north into Lake Edward to form Lake Kivu which now drains south into Lake Tanganyika. In coastal regions, changes of base level associated with glaciation have been more important than earth movements. Sea level fell about 110–115 m between 30.000 and 18.000 years ago and rivers cut deeply into their lower courses. Then, during and since the transgression, which was completed about 6000 B.P., deltas and barrier beaches have smoothed out the embayed coasts.

The sequence of climatic events in the Late Quaternary is now known in outline for that part of the continent between the equator and the northern tropic.

Throughout Africa temperatures were lowered by about 6°C during the Last Glacial period between, say, 20.000 and 15.000 years ago. As a result, mountain vegetation belts shifted vertically 1000 m downslope, freezing and thawing of soil also occurred at lower altitudes and glaciers, notably in Ethiopia, occupied mountain valleys now quite free of ice.

With, surface waters of the Atlantic several degrees lower than now, evaporation from the ocean surface must have been reduced to something like half that of the present. Perhaps it was for this reason that tropical Africa, or at least that part of it north of the equator was drier than now, with desert dunes being shaped by the wind as much as five hundred kilometers south of the present limits of mobile sand and with vegetation of a drier kind than now nearer the equator.

Evidence is accumulating which suggests that south-central Africa was wetter when North America and north-west Europe were last covered with ice. A large dry pan at Alexandersfontein near Kimberley was full of water about 16.000 years ago (K.W. BUTZER, 1973), and I have obtained a date of 20.990 ± 1100 B.P. (Gak 4310) from lacustrine sediments that accumulated in the Makarikari depression of Botswana when it was occupied by a lake with half the area of Lake Victoria. At that time the valleys leading into the central Kalahari from the highlands of Namibia must have carried large rivers instead of being always dry as they are now, and much more water must have passed through the Okovango delta from the Angolan Plateau. It is thus possible that the equatorial rain belt, associated with the equatorial westerlies, was further south during the Last Glaciation, leaving the West African coastlands and the northern Congo basin drier but bringing more rain to the Congo-Zambezi watershed. However, it is conceivable that the lacustrine period in southern Africa is to be explained in similar terms to that of the south-western United States of America, as a consequence of lower temperatures and reduced evaporation losses. It might also be added that there is still a possibility that the Makarikari Lake may at some time have been supplied by the Zambezi, for the land between them is flat and the region is believed to be unstable tectonically (A.T. GROVE, 1969).

Between about 15.000 and 9.500 years ago the climate between the equator and the northern tropic became warmer and wetter. Temperatures rose throughout the continent to reach present-day levels and eventually, about 8000 B.P., to exceed them by about 2°C. Lake Kivu showed an initial rise about 12.000 years ago and, after a short fall, rose higher still to overflow by the Ruzizi river into Lake Tanganyika (R.E. HECKY and E.T. DEGENS, 1973). Lake Victoria, some 12.500 years ago, overflowed north to feed Lake Kyoga and the Sudd region of the southern Sudan (R.L. KEN-

DALL, 1969). Supplied also by water from southern Ethiopia, which reached the Pibor river via Lakes Stefanie and Rudolf (A.T. GROVE et al, 1975) the White Nile between Malakal and Khartoum assumed the form of a long narrow lake which was probably dammed back by a delta formed by the Blue Nile. This river must have been bringing down much larger volumes than now, spreading over a greater fan and building up what are now the clay plains of the Gezira. Further downstream in Nubia and Upper Egypt the river cut through the Sebilian silts and at the coast formed its delta. West of the Nile, conditions in southern Libya were much more humid than now (H.J. PACHUR, 1975) ; Mediterranean type vegetation grew on the Tibesti mountains and an enormous lake stretched from the foot of the mountains for a thousand kilometers to the south. This lake, Mega-Chad, overflowed to the Benue bringing larger volumes of water than at present to a Niger river swollen by lakes in its inland basin and receiving great streams draining Air. The Senegal broke through dune fields to reach the sea and constructed a delta, smaller than that of the Niger, but still of considerable size. (P. MICHEL, 1973). Basins in the southern Sahara that had been intensely arid were filled with water ; the Galla lakes in the Ethiopian rift rose as much as 100 m and overflowed to the Awash ; in Kenya Lake Nakuru rose 200 m and spilled into Menegai caldera while water from Naivasha escaped south, cutting Hell's Gate Canyon. The high lake levels persisted until about 5.000 B.P. and, as temperatures for some thousands of years were higher than now, it may be concluded that precipitation was also higher. Savanna animals roamed tracts that are now arid wildernesses and lake shores were occupied by fisher fold who used harpoons and made a characteristic kind of Wavy-line pottery. (J.E.G.SUTTON, 1974).

What was happening south of the equator at this time ? It seem likely that Lake Rukwa reached high levels about 8500 BP and overflowed to Lake Tanganyika (A.T. GROVE, 1975) ; this suggests that south-west Tanzania participated in the pluvial experienced about this time to the north of the equator. However, the region to the south-west may have been relatively dry between 14,000 and 4,500 years ago and it is possible that the dune fields of the Kalahari were shaped or reshaped in this period. More evidence is needed before we can be sure.

Early in the third millenium BC, that is between 5000 and 4500 years ago, a final major climatic shift took place. The lakes north of the equator, including Tanganyika, shrank and many of them dried up completely. The discharge of the Nile, so far as one can tell from archaeological records, diminished markedly and within a few centuries aridity returned to wide areas north of the equator. Pastoralists evacuated regions where they had grazed their flocks and herds and it is possible that the difficulties experienced by the lacustrine people at this time may have stimulated the settlement of the Nile valley for irrigation and accelerated the domestication in the

Sahel zone of several cereals that are now widely cultivated. There are signs in the northern Kalahari that the climate may have ameliorated about this time with conditions becoming more humid than they had been for ten thousand years.

Everywhere in Africa over the last 4500 years there have no doubt been decades and centuries when the climate has differed from the mean conditions we calculate from our meteorological records, but the amplitude of these fluctuations has probably been low and they are not easy to detect.

With these broad outlines in the background we now need to fill in the detail, to discover how fast temperatures rose between 15000 and 8000 years ago and the way in which precipitation changed, rapidly or by degrees. These matters are important to us with our interests in present-day geomorphological processes. We might hope to learn whether vegetational changes kept pace with climatic changes or whether they lagged behind. If it happened that precipitation suddenly increased some 10,000 years ago (about 4500 years ago in the Kalahari region), there may have been rapid erosion in areas that had been arid or semi-arid before a more protective plant cover became established, and certain landforms we see today may be explained in those terms. Again, if the climate north of the equator became somewhat drier and cooler rather suddenly about 4500 BP, the vegetation cover in many areas may have been in disequilibrium with the climate for many centuries and more susceptible to human interference than it would have been otherwise. Such disequilibrium and sensitiveness might be expected to have been most marked at the northern fringes of the rain forests (in the high deciduous forest), at the northern margins of the savanna woodland (in the Sahel), and near the limits of the mountain rain forest.

Comparisons of present-day climates and those of the past can best be made for those few places where good estimates have been made of Late Quaternary rainfall. Here we have selected Nakuru in the Kenyan rift valley, Khartum, Kano and Abidjan.

Nakuru On the floor of the rift valley at 1830 m and almost on the equator, Nakuru's mean annual temperature is 16.9°C. The mean annual rainfall over the basin of Lakes Nakuru and Elmenteita has been calculated by C.K. WASHBOURN (1967) as 956 mm for the period 1938-66, with extremes of 628 mm in 1965 and 1340 mm in 1951, i.e. 67 and 144 per cent of the mean.

The lakes in the rift seem to have been dry between 20,000 and 15,000 years ago in spite of the mean annual temperature having been down to about 14°C with frequent night frosts. A reduction in mean annual rainfall to about 80 per cent of the present would, in Washbourn's opinion, have been sufficient to cause the lakes to dry, but the precipitation may of course have been much less than this. (Studies of Lake Kivu suggest mean precipitation there fell to 700 mm, compared with 1300 mm at present, according to (R.E. HECKY and E.T. DEGENS, 1973).

In the succeeding lacustrine period, with mean annual temperatures up to 18.9° C, evaporation from the Nakuru lake may have been more than that of the present. If the run-off coefficient from the catchment was 10 per cent as compared with today's 3.26 per cent, the mean annual rainfall required to maintain the lake at the 180 m level is calculated to have been about 1590 mm, i.e. 165 per cent of the present and well above the 1951 extreme. (K.W. BUTZER at al. 1972). Climatic fluctuations of a similar magnitude seem to have affected the rift valley of southern Ethiopia.

Khartum The mean annual rainfall of Khartum at the present day is about 164 mm as compared with Nouakchott, 144 mm and Agades, 167 mm. Precipitation records since 1900 show extremes of 47 mm in 1949 and 382 mm in 1938, representing movements of the climatic belts 200 km south in the dry year and 300 km north in the wet one.

During the Last Glaciation it seems from the run of the linear dunes in the Qoz to the south-west of Khartum that wind directions were not very different from those of the present but with an overall displacement of 450 km to the south (A. WARREN, 1971). If we also use the southern limit of fixed dunes as a guide and assume that this corresponded with the 150 mm isohyet it would seem that the mean annual rainfall of Khartum was about 25 mm, a value with a recurrence interval of say 200 years under the present climatic regime.

Under such dry conditions, with lower rainfall but reduced evaporation in Ethiopia, the mean annual discharge of the Nile may well have dropped to less than the extreme minimum recorded over the last century, that is, $47\frac{1}{2}$km^3 as compared with its mean of about 85 km^3. Without a supply from the White Nile at this time, the late dry season flow may have ceased entirely at Khartum and one may visualise sand being swept into the channel by NNW winds (A.T. GROVE, 1973).

The presence of the land snail *Limicolaria flammata* Caill. near Khartum about 8000 years ago suggests that the rainfall may have been 400-800 mm (Williams, 1973). It has also been argued that Early Holocene leaf impressions of the oil-palm *Elaeis guineensis* on Jebel Marra and relic gallery forest in the wadis there indicate that the northward movement of the climatic belts was through at least 400 km (G.E. WICKENS, 1975). This would have brought Khartum an annual rainfall of about 500 mm. It is known that there were a number of small lakes in the vicinity but well above river level between 7000 and 8500 years ago, and we can picture the old dunes west of the river as covered with savanna woodland. To the south-east, the Blue Nile flooded widely over a delta ponding back a lake stretching far up the White Nile valley. The mean annual discharge of the combined flow of the Blue and White Niles through Nubia was probably well in excess of the maximum annual discharge for which we have reliable records, namely 137 km^3 in 1875.

This pluvial period came to an end about 5000 years ago when the Nile valley was already well settled. Since then the woodland and fauna have been greatly altered by human action and in recent years the vegetation cover has been reduced to such an extent that it probably bears a greater resemblance to conditions some 15,000 years ago than to any time since then.

Kano Situated at a height of about 460 m on the Niger-Chad watershed, has a mean annual rainfall of about 870 mm, as compared with Dakar 519, Niamey 685, Kayes 753, Ouagadougou 887 and Tambacounda 909 mm. Kano's extremes for this century are 414 mm in 1973 and 1248 mm in 1909, about 48 per cent and 144 per cent of the mean values.

To the east of the city fixed dunes believed to have been formed in the Last Glacial period extend as far south as the 750 mm isohyet (A.T. GROVE, 1958). The direction of the formative winds seems to have been easterly, similar to those of the present day dry season. With temperatures 6°C lower than now, 21°C instead of 27°C, conditions would have been similar to those in parts of highland Darfur in the latitude of Khartum.

In the succeeding pluvial the rainfall at Kano may perhaps have been 150 per cent of that of the present day, but there is not much evidence to provide guidance on this. Under such conditions the dunes would have been washed flatter and deeply weathered, with leached, somewhat acid soils developing under a cover of tall closed woodland. Lakes occupied hollows between the dunes in the lee of rocky hills ; inselbergs were weathered and the aridity of the dry season was moderated by the easterly winds approaching across a greatly enlarged Lake Chad and the widely meandering rivers of a flooded Hadeija valley. There was probably no Harmattan dust because the present source areas for the dust, the basins of the southern Sahara, were occupied by lakes. Rivers crossing the old dune fields would have carried abundant loads of sand towards Chad and down the Gongola into the Benue which was aggrading its bed as sea-level rose.

With the onset of drier conditions some 5000 years ago it is not unlikely that forest would have continued to survive in the rocky hills and ravines, but stripping away of the weathered layer revealed core stones and caused aggradation of broad valleys, producing gently sloping plains underlain by deep colluvium and alluvium such as one sees exposed in the opencast tinmines of the Jos Plateau and the Abuja areas well to the south of Kano. In the southern Sahara, fine diatomaceous sediments in the lake basins, possibly disturbed by grazing herds and wild animals, were blown south-west by the wind. On the floor of Mega-Chad, montmorillonitic clays that had accumulated under lagoonal conditions were laid bare as the lake shrank hesitantly.

Abidjan On the coast, with a mean annual rainfall of about 200 mm and mean temperature of 27°C, is in the humid forest region. Its extreme annual rainfall totals (1941-1971) were 1511 mm in 1945 and 3413 mm in 1957.

At present we know little about the Late Quaternary history of the rain forest in West Africa. There are no known instances of dunefields there as in Amazonia and, it has been claimed, the Congo basin. Pollen from core material that accumulated during the last major regression of the sea consists largely of *Gramineae* and *Cyperaceae*, indicating dry savanna vegetation nearby (L. MARTIN, 1972). Evidence of calcareous algae in coastal waters at this time suggests that they were clear and receiving little in the way of fine fluvial sediments. With mean temperatures of, say, 21°C mean annual rainfall may have been of the order of 1500 mm.

In the course of the last marine transgression the nature of the pollen changes. *Rhizophora racemosa* is most abundant (mangrove) and in addition pollen from oil-palms and high forest trees such as *Pentaclethra macrophylla*. Core material from this time includes abundant spores of ferns, all of which indicate the presence nearby of forest vegetation possibly of a more open nature than that of the present day. With the wetter conditions, rivers cut gorges in escarpments, and deep valleys near the coast were later flooded by the rising sea.

It may be possible to reconstruct the past climates of other places and compare them with means and extremes for the period of meteorological records. What emerges from this initial excursion is that, so far we can tell, mean annual rainfall in both the drier and wetter periods of the Late Quaternary in northern tropical Africa was further removed from present-day means than are extreme annual values recorded in this century.
The landscapes of tropical Africa have thus experienced over centuries and even thousands of years within the Late Quaternary the impact of conditions far removed from those to which they are at present subjected. It may then be argued that they may have developed a greater resilience to unusually wet or unusually dry years, and even to the destructive efforts of mankind, than would have been the case had the climate not oscillated so violently.

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