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Changes in the climate and vegetation of the Sudan since 20 000 B.P.

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SUMMARY

The orientation of the sand dunes indicates that the isohyets were 450 km to the south of their present position from 20 000 to 15 000 B.P.[1] and 200 km to the south from 7000 to 6000 B.P. Palaeobiological evidence suggests that there were northward shifts of 400 km between 12 000 and 7000 B.P. and 250 km 6000 to 3000 B.P. There were corresponding parallel shifts of the vegetation.

RÉSUMÉ

L'orientation des dunes de sable indique que les isohyètes devraient être à 450 km au sud de leur position actuelle entre 20 000 et 15 000 unités B.P. et à 200 km au sud entre 7000 et 6000 B.P. D'autre part, les données paléobiologiques indiquent qu'il y avait un déplacement vers le nord de 400 km entre 12 000 et 7000 B.P. et de 250 km entre 6000 et 3000 B.P. et qu'il y avait des déplacements analogues de la végétation.

Climatic changes in tropical Africa

Our understanding of the palaeoclimates and palaeobiology of the Sudan can only be interpreted in relation to present-day conditions within the Sudan and from past and present conditions elsewhere in Africa. In northern tropical Africa south of the Sahara, the present-day climatic belts for the savanna and semi-arid regions run more or less parallel to the equator (Walter & Lieth, 1967). Similarly, the vegetation belts shown in the AETFAT vegetation map of Africa (UNESCO, in press) are also more or less parallel to the equator, which is to be expected if the vegetation is climatically controlled. This climatic control acts along a very broad front, as demonstrated by the present serious drought in the semi-arid regions of northern tropical Africa and extending into south-east Asia.

There is now increasing evidence for even larger regional climatic changes in the past, which in turn must have influenced the palaeobiology of the region. Williams & Adamson (1973) have produced evidence for higher levels in the Blue and White Nile during the period 12 000 to 8000 B.P. Grove & Goudie (1971a) refer to high

[1] For technical reasons B.P. dates (which are referred to 1950 A.D.) are not directly convertible to the B.C./A.D. system.

lake levels in the Ethiopian Rift Valley from 9000 to 5500 B.P. and Butzer & Thurber (1969) have noted high levels for Lake Rudolf, on the Kenya-Ethiopian border, earlier than 20 000 years ago, between 10 000 and 8000 B.P., and again from 6000 to 4000 B.P. In Eritrea, the Danakil Depression lake sediments have been dated between 9000 and 5600 B.P. by Grove & Goudie (1971b). The same authors (1971a) refer to the lakes in the Ténéré Desert from 9500 to 7000 B.P., and Lake Chad, which was high from 40 000 to 20 000 B.P., was also high from 9500 to 7000 B.P. and again 5400 B.P. Rivers from Tibesti draining into Mega-Chad formed deltas that have been dated between 12 000 and 6000 B.P., while in the mountains, deposits have accumulated from between 12 000 and 8000 B.P. At Adrar Bous in the Aïr Mountains, Clark & al. (MS) obtained dates for lake deposits of over 7000 B.P. and from 6000 to 4000 B.P.

From the Lake Victoria basin in Uganda, Kendall (1969) has inferred a dry period from before 14 500 to 12 000 B.P., a moderately wet period from 12 000 to 10 500 B.P., with a moderately dry spell from 10 500 to 9500 B.P. This being followed by a wet period from 9500 to 6000 B.P. with slightly drier conditions or a more seasonal rainfall after 6000 B.P. From Ruwenzori, also in Uganda, Hamilton (1972) has described a cold dry climate before 12 600 B.P. changing to moister and warmer conditions, with a slightly warmer and wetter climate between 6000 and 2000 B.P.

The general regional conclusions from all these observations are admirably summarized by Grove (1973) who writes: "The general picture is that over large areas of tropical Africa, especially in lands now semi-arid or sub-humid, we have evidence of a distinctly drier climate than now about 20 000 to 15 000 years ago, a period wetter than now 12 000 to 7000 B.P., possibly a short dry phase lasting a thousand years, and then, at least in some areas, one or more phases when the climate was more humid than at present." To this should be added the conclusions of Zinderen Bakker & Coetzee (1972) that the evidence from Lakes Victoria, Rudolf, Chad and Afrera indicate a brief dry interlude about 10 500 to 10 000 B.P.

Climatic changes in the Sudan

Very little has been published about the climates and biology of the Sudan during the Quaternary. The Soil Conservation Committee's report, summarized by Whyte (1951), estimated that at some stage during the Quaternary there was a minimum northerly shift of the present-day 200 mm isohyet of about 550 km. This estimate was partly based on the distribution of Neolithic implements and subfossil shells scattered over a wide area of the Libyan Desert. These implements and shells were concentrated along the natural drainage lines, such as the Wadi Howar, which presented the most favourable conditions for Neolithic man to travel.

At least for some months of the year there is still sufficient water and vegetation to support animals as the oryx, addax, ril, gazelle, giraffe, ostrich, hyaena, jackal, fox, red hussar monkey, antbear, porcupine, lion and hunting dogs in the Wadi Howar (Shaw, 1936). At Bueira (15°45′N, 23°41′E), also in the Wadi Howar, there is even sufficient moisture for the survival of the amphibious snail *Pila wernei* (syn. *Ampullaria wernei*). Although large numbers had perished either from desiccation or predators, some had been able to survive in sheltered places (Arkell, 1945). These snails were found in an area with an estimated rainfall of about 200 mm per annum, well outside the usual distribution range for the species, which is normally in areas receiving upwards of 400 mm (Tothill, 1946).

There are very few permanent sources of water in the Wadi Howar today, yet the 1:250 000 Sudan Survey Map, sheet 44-M, Wadi Howar, bears the rather surprising note "Wadi Howar much used by natives as a road from North West Darfur to El Atrun and Dongola." The evidence suggests that a very little increase in rainfall would have enabled Neolithic man to have survived in the Wadi Howar area.

In an admirable summary of the then available archaeological and historical data by Jackson (1957) there is reference to a rather surprising suggestion by Bagnold (1954) that an increase in the average rainfall by as little as 24 mm would have made nomadic life possible over much of the Libyan Desert. This additional rainfall was expected to produce an effective storm every other year, instead of at thirty to fifty year intervals as they occur at present. Jackson (1957) suggests that 100 mm would appear to be the minimum for habitation away from oases and rivers, and considers Bagnold's estimate as possibly rather low.

The Conservation Committee would appear to have underestimated the significant response that can be obtained from quite a small increase in the annual precipitation in the low rainfall areas. Even a northerly shift of the 200 mm isohyet by approximately 250 km would have been sufficient, for it would have included much of the Wadi Howar area and supported life away from the natural drainage lines. Today permanent settlements with cultivation exist in northern Kordofan and Darfur Provinces where the rainfall is certainly not more than 200 mm.

Geomorphic evidence of climatic changes in the Sudan

Warren (1970) from his studies of the orientation of the dune systems of Kordofan Province in relation to sand-moving wind directions, has been able to postulate a series of shifts in the climatic belts of the Sudan. Although his studies enabled him to calculate the amounts of the southerly shifts, the techniques used did not enable the northerly shifts to be calculated. Furthermore, in the absence of carbon dating, Warren loosely correlated his work with the now outdated chronology of Grove & Warren (1968) for West Africa and with that of Berry & Whiteman (1968) for the Nile. For the purposes of this paper Warren's work is correlated with the more recent general chronology of Grove (1973).

Warren recognizes four climatic sequences before the present prevailing climate. Period I represents a very arid phase during which both wind and rainfall belts were some 450 km to the south of their present positions. Sands were believed to have been moved as far south as 10°N in the region of the little known Qozes Salsigo and Dango, to the south of Jebel Marra. According to D. Parry (verbal information, 1972) who had recently carried out a soil survey in that area, the soils of the Qoz Dango are probably of local origin, forming part of the reworked Wadis Ibra and Bulbul inland delta system and are not part of the general Pleistocene sand sheet.

This Period I may be correlated with the period of Grove (1973) from about 20 000 to 15 000 B.P. The fossil assemblage on the Blue Nile at Singa (12°11′N

33°55′E) and Abu Hugar (12°52′N, 34°00′E) would appear to belong to this dry period (Bate, 1951). Berry & Whiteman (1968) have given a possible radiocarbon date of 17 300 ± 200 B.P., but have reason to suspect that the specimen sampled may have been contaminated by younger radiocarbon (Whiteman, 1971).

Period II represents a very wet phase, for which Grove (1973) has indicated dates of between 12 000 and 7000 B.P. Warren suggests a possible correlation with the former White Nile Lake, whose existence is based on beach terracing at the 386 and 382 m A.S.L. Radiocarbon datings from gastropod shells collected from the 382 m level indicate that the shells were deposited between 11 300 ± 400 and 8130 ± 225 B.P. (Williams, 1966; Williams & Adamson, 1973). At the upper level the lake would have been up to 40 km wide, at the lower level about 20 km. The lake was probably impounded at the junction of the Blue and White Niles and must have streched southwards from between 650 and 500 km to Malakal (9°31′N, 31°40′E) and Melut (10°27′N, 32°13′E) respectively (Berry, 1967; Berry & Whiteman, 1968). The present northern extent of the "sudd" is to the south of Malakal (Andrews, 1948), where the White Nile enters Lake No, while Tothill (1948) has shown that the soils of the "sudd" extend as far north as Jebel Ahmed Agha (10°59′N, 32°40′E), a little to the north of Melut. Presumably the "sudd" was once contiguous with the southern end of the White Nile Lake.

Recently Williams & Adamson (1973) have recorded freshwater lake deposits from 20 km northwest of the Jebel Aulia Dam and some 10 km to the west of the Nile at 15°23′N, 32°22′E and at 15°22′30′N, 32°21′30′E, for which they have obtained radiocarbon dates from between 8400 ± 150 and 6990 ± 100 B.P. These lakes are above the high levels of the Nile. This is a very important discovery because it is the only dating so far recorded for the Sudan away from the actual Nile valley. It confirms that there was a period of high rainfall in the Sudan coeval with the high levels of the Nile, indicating that the Nile levels were not necessarily due to a higher rainfall in East Africa and Ethiopia.

Period III represents a brief dry phase, but not as dry as Period I. According to Warren (1970) there was a southward shift of over 200 km in both the wind and rainfall belts, followed by a northward retreat of the wind pattern, during which the vegetation was slow to colonize the high dune formations. This phase would have been between 7000 and 6000 B.P. (Grove, 1973). Unfortunately there are, as yet, no radiocarbon datings from the Sudan that fit this period, neither is there any biological evidence of such a dry spell.

The following wet phase, Period IV, was from 6000 B.P. to about 3000 B.P. The climate, although wet, was not as wet as for Period II. The Neolithic site at Esh Shaheinab (16°03′N, 32°33′E), 50 km to the north of Omdurman and dated between 5446 ± 380 and 5060 ± 450 B.P. (Arkell, 1953) belongs to this period.

Following Period IV the climate, although fluctuating, became gradually drier and finally attained conditions pertaining today.

Biological evidence of climatic changes in the Sudan

There is very little fossil evidence of the flora of the Sudan during the Pleistocene. In Darfur Province fossil impressions of *Cyperus papyrus* had been reported by

Colchester (1927) from the Malha Crater, (15°04′N, 26°11′E); specimens of which are in the British Museum (Natural History). A crater lake is an unlikely habitat for this sedge, which on re-examination was found to be *Phragmites* sp. (Wickens, 1975). The nearest known present-day locality for *Phragmites* is from the southern flanks of Jebel Marra, 350 km to the south-west.

The present-day rainfall from the Malha area is about 150 mm. Nearby, to the northwest of the Wadi Mareiq wateryard (borehole and stock watering point) about 14°54′N, 26°37′E, Dr. L. Clark, a geologist with Hunting Geophysics, discovered a recent limestone bench with shells (personal communication, 1971). The dating of both these records would be of considerable interest.

Also from Darfur, near Nyama Suq (12°45′N, 24°10′E), on the southern flanks of the Jebel Marra massif, leaf impressions of *Combretum molle*, *Saba florida*, *Lippia* sp. *(? L. multiflora)*, *Oxytenanthera abyssinica* and the oil palm, *Elaeis guineensis*, were discovered in the upper levels of the ash piedmont (Wickens, 1975); all these species except the oil palm are present in the area today. The deposit is tentatively dated between 3500 and 12 000 B.P. (Wickens, 1975). It is estimated that a northward shift in the climatic and vegetation belts of at least 400 km would be required to explain the presence of *Elaeis* on Jebel Marra. A migration along the rivers would not be a sufficient explanation unless accompanied by a rainfall of at least 1100 mm per annum with a dry season of less than six months (Wickens, MS). The nearest known locality for *Elaeis* today is from 600 km further south and just across the border into the Central African Republic.

In Kordofan Province fossil fragments of *Phragmites* sp. were collected by my colleagues, Messrs D. O. Hughes, F. W. Collier and myself from a calcareous lake deposit at Mazrub (13°54′N, 29°19′E); unfortunately it was not possible to date the material. Associated pollen identified at Cambridge were from the *Chenopodiaceae*, suggesting seasonal swamp conditions (Hunting Technical Services, 1964). The present-day rainfall at Mazrub is about 200 mm. The nearest known locality for *Phragmites* today is from near Semeih (12°43′N, 30°53′E), some 85 km to the south of Mazrub, with a rainfall of about 400 mm.

Similar lacustrine deposits have also been observed at En Nahud (12°42′N, 28°26′E) and also from near Umm Dam (12°44′N, 31°50′E). Warren (1970) suggests that these calcareous swamp and lake deposits found in the interdune hollows associated with the High Qoz dune formation (Hunting Technical Services, 1964) may be coeval with the sub-humid period 6000 to 3000 B.P.

From Early Khartoum, Arkell (1949a) has reported the discovery of the fossil fruits of *Celtis integrifolia;* the fruits are believed to have been collected for food, as they are today. From the nearby Neolithic site at Esh Shaheinab, Arkell (1949b, 1953) again recorded the presence of *Celtis integrifolia* fruits as well as a carbonized fragment of the oil palm, *Elaeis guineensis.*

The oil palm occurs in Equatoria Province, to the north of Yei, under conditions suggesting that it is indigenous (Andrews, 1956). This is an area receiving approximately 1200 mm rainfall per annum. It is inconceivable that the necessary conditions for the growth of *Elaeis* were ever found to the north of the Bahr el Ghazal. Consequently, the Esh Shaheinab specimen must either have been transported down the

Nile by either man or flood waters, or, what is perhaps more likely, brought from Darfur by travellers (Wickens, 1975).

The situation regarding *Celtis* is far simpler. It is essentially a riverine tree whose present-day northern limit of distribution is approximately that of the 400 mm isohyet (Monod, 1964). The present-day rainfall of Khartoum is 163 mm (Walter & Lieth, 1967) while that at Esh Shaheinab is estimated to be about 100 mm. The minimum climatic shift necessary to obtain a rainfall of 400 mm at Esh Shaheinab is in the order of 150 km, based on the present-day rainfall of 406 mm at Tayiba (14°29'N, 33°17'E), 110 km to the south of Khartoum.

A representative sample from a rather pulverized collection of charcoal from Jebel Tomat (13°36'N, 32°44'E) has been identified at the Jodrell Laboratory, Kew, as consisting of *Acacia* sp. (too poor for determination of species), *Salvadora persica*, *Ziziphus* sp., probably *Z. spina-christi*, and *Ficus* sp. These species are not representative of any particular community; they are merely suggestive of a dry-land vegetation rather similar to that found in the area today. The age of the sample is between 1930 and 1705 ± 60 B.P. (J. D. Clark, personal communication, 1974).

A further source of information are the gallery forests of Jebel Marra with such forest species as *Trema orientalis*, *Casearia barteri*, and *Polyscias fulva*, representing isolated outliers from the main areas of distribution (Wickens, 1971). The nearest known locality for the first two species is Yalinga in the Central African Republic not far from that of *Elaeis guineensis*, thus supporting the idea of a northward migration route to Jebel Marra. The rainfall for the Jebel Marra massif is in the region of 900 to 1000 mm. (F.A.O., 1968). A possible migration route from the south is also suggested by the 700 mm isohyet which produces a noticeable salient towards the massif from the southwest (F.A.O., 1968). An estimated climatic shift of about 300 to 400 km would probably have ensured a satisfactory migration route, via the course of the Wadi Azum.

The only good fossil mammal records for the Sudan are those obtained from the banks of the White and Blue Niles. These records are listed in Table 1. Although fossil mammals have also been observed in the Libyan Desert, e.g. by Shaw (1936), they are undated and therefore of little value.

The fossil mammal fauna from the Nile area requires to be very carefully analysed before being used to interpret local environmental conditions. The two Niles represent permanent sources of water and consequently have an ameliorating effect on the vegetation present along their banks. This lusher vegetation could therefore encourage the presence of animals that would not normally occur within that particular climatic zone. The river banks form a natural corridor along which animals may conveniently move.

Furthermore, mammals differ in their respective values as indicators of local habitat conditions. Some, such as the Nile lechwe, are restricted to swamps, the oryx and addax indicate arid and semi-arid conditions. Others, such as the buffalo and elephant can tolerate both swampy and dry land conditions. Seasonal migrations also have to be considered. The giraffe, for example, lives in the woodlands of the south during the dry season and moves northwards into the savanna and even the semi-desert during the rains. Shaw (1936) observed giraffe in the Wadi Howar area of northern Darfur. In this context it is perhaps interesting to note that Happold

(1966) did not record the giraffe for Jebel Marra, yet in the previous year they were to be seen in the Jebel Marra foothills, presumably en route to the Wadi Howar (F. Hasselar, verbal information, 1965). The tiang is perhaps unusual in that it migrates southwards during the rainy season and returns to its northern habitats for the dry season (Sidney, 1965). Predatory animals such as the lion would also be obliged to migrate, as they follow the migrations of their prey.

It seems reasonable to assume that the mammalian subfossils found in association with habitation sites were hunted within a day's, or at the most, two day's journey from the homestead; indeed it is necessary to make such an assumption when reconstructing the environment.

The effect of man upon the fauna must also be considered. There is ample evidence from the literature to show that the vegetation of the Sudan, in common with many other African countries, has greatly deteriorated since the beginning of this century. There is similar evidence of a decrease in both numbers and areas of distribution of many African ungulates (Sidney, 1965) and other mammals. Consequently the present-day conditions of flora and fauna will give a false impression of the natural environment in relation to the climate, which until recently has remained relatively static. With this in mind, Table 1 has been drawn up to show the changes in the northern limits of distribution of a number of mammals during historical times, when climatic conditions were fairly uniform (Jackson, 1957). For comparison, the fossil mammals are also shown on the same table.

The recent drastic reduction in the density of the mammals can be attributed to a number of factors. The rapid increase in the human population has resulted in increased pressure upon the natural resources. More land is being required for cultivation and grazing, resulting in a rapid deterioration of the vegetation due to cultivation malpractices, overgrazing, burning etc. (Wickens, 1968). The increase in the use of motor transport has led to the opening up of remote areas, which, with the improvement in firearms, has increased the chances of both hunter and poacher. More and more animals are being slaughtered for "sport", food or to protect cultivation and stock. The mammal populations have had to change because their habitats have been destroyed, their migration routes interfered with, their numbers reduced or because they have learnt to avoid man.

In prehistoric time the environmental conditions were believed to have been at about their optimum in relation to the then prevailing climate. The impact of man upon the environment would have been insignificant, partly because man was then a relatively inefficient hunter and partly because he was not present in sufficient density. On such an assumption, any changes in the environment can be attributed to natural causes, such as major changes in climatic conditions or changes resulting from natural soil erosion or accretion. It is also assumed that, where mammals are used for interpreting the environment, the individual species have not changed their habitat requirements.

Apart from the fossil assemblage at Singa already mentioned (p. 45), the fossil mammals do not appear to be very satisfactory indicators of climatic change. Their value would appear to be as indicators of local habitat conditions; they have a corroboratory value without typifying the degree of climatic change.

By contrast, the semi-fossil mollusc fauna which is so extensively distributed within the region of the two Niles is of considerable interest and value to the palaeoecologist. The presence and distribution of the aquatic and amphibious species serve as good indicators of the extent of riparian, palustral and lacustrine habitats (Tothill, 1946, 1948; Williams & Adamson, 1973). The land species are a valuable guide to climatic conditions.

As an indicator of climate, the land snail, *Limicolaria cailliaudi* (syn. *L. flammata*—see Crowley & Pain, 1970) is regarded as the most significant. Its main area of distribution is in areas receiving upwards of 400 mm rainfall per annum, although it can survive in lower rainfall areas provided the microhabitat is sufficiently moist. It is unable to tolerate extreme aridity even for a single day. However, in periods of extreme stress the snail is capable of forming an epiphragm, thereby making aestivation possible.

The abundance of subfossil *Limicolaria cailliaudi* at Khartoum (Arkell, 1949a) indicated that the snail was flourishing and therefore suggestive of a rainfall in excess of 400 mm. However, Arkell points out that the sandy mound of the Epi-palaeolithic site at Khartoum enabled the snails to burrow and aestivate so that a direct comparison with their present-day distribution, which is largely on clay soils, may not be strictly valid. Bell (1966) also makes a similar point in that the snail distributions have not been properly investigated outside the valleys of the Nile.

Arkell (1949a) favourably compares the subfossil Khartoum population of *Limicolaria* with that to the south of Singa (13°09′N, 33°56′E), with a rainfall of 559 mm and with that found some 80 km to the south of Jebelein (12°36′N, 32°48′E), with an estimated rainfall of about 550 mm. These sites are respectively 300 and 400 km to the south of Khartoum. While bearing in mind the reservations expressed regarding comparisons with sandy and clay habitats, these distances agree closely with the 400 and 300 km northward climatic shifts indicated by *Elaeis guineensis* and the gallery forests of the Jebel Marra massif (p. 47 and p. 48).

Limicolaria cailliaudi is again described as being plentiful at the Neolithic site of Esh Shaheinab (16°03′N, 32°33′E), 40 km to the north of Khartoum (Arkell, 1953), although less plentiful than at Khartoum. Shells from Esh Shaheinab have been dated 5446 $\pm$ 450 B.P., while charcoal from a Neolithic hearth have been dated 5060 $\pm$ 380 B.P. The record of *Limicolaria kambeul* recorded by Arkell (1953) from Esh Saheinab is considered by Crowley & Pain (1970) as a misidentification of a somewhat unusually globose specimen of *L. calliaudi*. Arkell suggests a rainfall in excess of 500 mm, but this estimation is also based on the presence of the fruits of *Celtis integrifolia*, whose minimum rainfall requirements are, as has already been pointed out (p. 48) 400 mm and not 500 mm as believed by Arkell. As a compromise a rainfall in the region of 450 mm is suggested. The annual rainfall at Hag Abdullah (13°58′N, 33°35′E) is 443 mm (Walter & Lieth, 1967), which suggests a northward shift in the region of 250 km. This is considerably in excess of the 150 km *minimum* shift indicated by the presence of *Celtis* (p. 48). However, as the entire approach to the problem is based on the minimal northward shift necessary to cover all possibilities, the 250 km is accepted. This is reasonable because within a climatic phase the northward or southward shift forms a parabolic curve that starts from zero (present-day), rises to a maximum and returns to zero (Fig. 1). The precise shape of

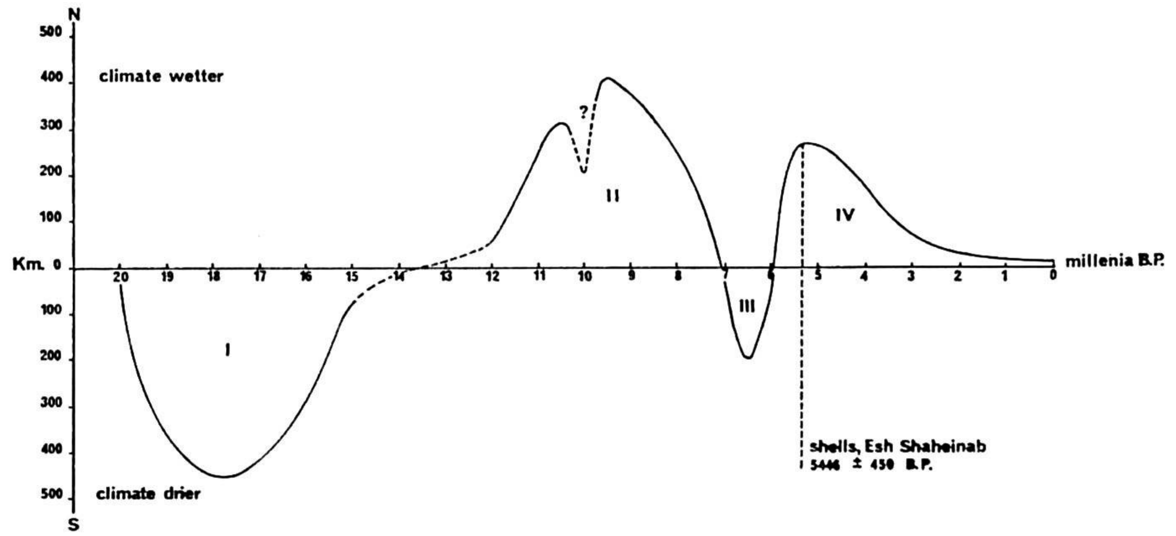

Fig. 1. — Climatic shifts in the Sudan from 20 000 B.P. to present.
Note: the shape of the curve for each climatic period is not accurately known.

the curve is dependant upon the point in time to which a particular piece of evidence refers, and the *Celtis* fruits may or may not be coeval with the *Limicolaria.*

Reconstruction of the environment

In order to reconstruct the vegetation the possibility of a change in the floristic composition must be considered. There appears to be no evidence of a floristic change in the flora of the lowland vegetation of the Sudan during the period under consideration. While there is evidence that a number of tropical savanna species must have entered Egypt via the Nile, there is no evidence to suggest that the Nile valley might have been used in the reverse direction by temperate species entering the Sudan. Even during the height of the very wet period it is suspected that the dry season would have been too harsh for survival. Tertiary boreal and montane-Mediterranean elements however did extend as far south as Kurkur Oasis (23°54′N, 32°19′E) in Egypt (Van Campo & al., 1968).

The Red Sea Hills were formerly better afforested and it is undoubtedly along the line of these hills that temperate species reached the mountains and uplands of Ethiopia and East Africa. This is evident from the distribution of a number of these species (Wickens, 1971). Indeed, the climatic diagrams for the Red Sea area today (Walter & Lieth, 1967) are suggestive of a very dry Mediterranean-type climate, which under higher rainfall or cooler conditions would have readily facilitated the passage of a number of temperate species from the Mediterranean area.

The present-day vegetation of the Sudan is shown in Figure 2, which has been modified from that of Harrison & Jackson (1958) in order to emphasize the physiognomic aspects of the vegetation and the distribution of the major soil types as recognized by Lebon (1961). The following vegetation units are recognized :

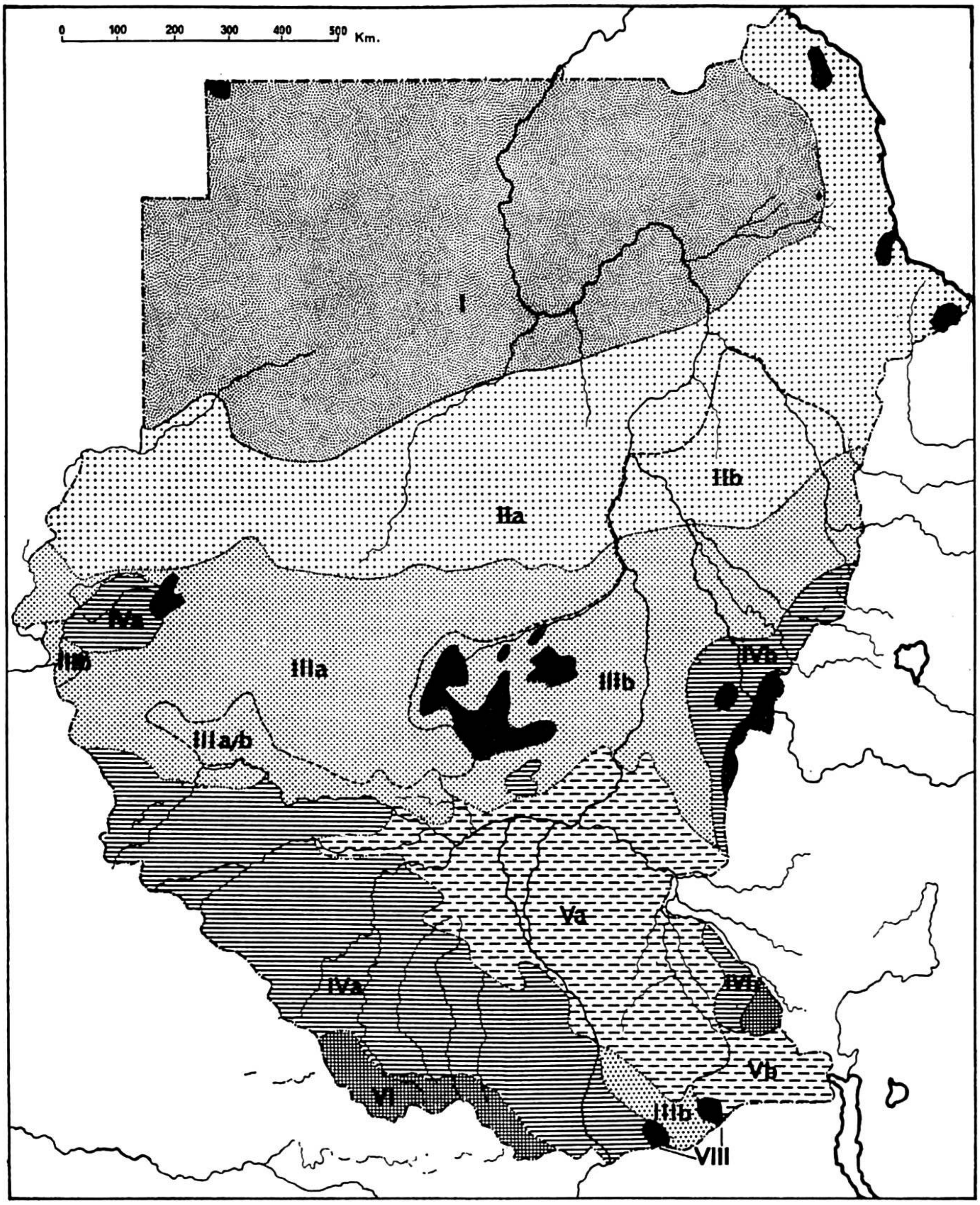

Fig. 2. — Present-day vegetation (key to the vegetation units below).

I. *Desert:* average rainfall less than 75 mm per annum, with the vegetation, if any, confined to the seasonal watercourses.

II. *Semi-desert scrub and grassland:*

a. *on lithosols:* average rainfall from 75 to 250 mm per annum. Scrub vegetation includes such species as *Acacia tortilis* subsp. *tortilis*, *Leptadenia pyrotechnica*, *Salvadora persica*, with *Aristida* spp. as the dominant grasses; *Panicum turgidum* occurs on the sandy soils.

b. *on clay soils:* average rainfall from 75 to 400 mm. Shrub species include *Acacia mellifera, Capparis decidua, Ziziphus spina-christi* and *Balanites aegyptiaca* along the drainage lines, with *Schoenefeldia gracilis* and *Sehima ischaemoides* as the dominant grasses.

III. *Thorn savanna and scrub:*

a. *on sandy soils:* average rainfall 280 to 450 mm. *Acacia senegal* is the dominant tree with *Aristida sieberana* and *Eragrostis* spp. as the dominant grasses.

b. *on clay soils:* average rainfall 400 to 800 mm. Pure stands of *Acacia mellifera* scrub occur between 400 and 500 mm, with *Acacia seyal* and *Balanites aegyptiaca* dominant in the higher rainfall areas. The major grasses include *Schoenefeldia gracilis, Cymbopogon* spp., and *Brachiaria obtusiflora.*

IV. *Deciduous savanna woodland:*

a. *on latosols:* average rainfall 450 to 1300 mm. *Combretum glutinosum, Anogeissus leiocarpus, Terminalia brownii, Albizia amara* subsp. *sericocephala, Khaya senegalensis,* and *Isoberlinia doka* are the major tree constituents, with *Aristida* spp., *Eragrostis* spp., *Pennisetum* spp. and *Hyparrhenia* spp. among the important grasses.

b. *on clay soils:* average rainfall 800 to 1000 mm. The major tree constituents are *Combretum hartmannianum* and *Anogeissus leiocarpus,* with *Hyparrhenia* spp. as the dominant grasses.

V. *Flood region:*

a. *swamp and wetland savanna:* average rainfall 800 to 1000 mm. This includes the *Cyperus papyrus* perennial swamps of the "sudd" and the seasonally flooded "toich" area with *Hyphaene thebaica, Borassus aethiopum, Acacia seyal, A. sieberana* and *Balanites aegyptiaca* among the tree species present.

b. *grassland:* average rainfall over 1100 mm. Known as the Toposa, area, with *Hyparrhenia* spp., *Setaria* spp., *Chrysopogon plumulosus (C. aucheri* var. *quinqueplumis), Bothriochloa insculpta,* etc. among the more important grasses, with thickets of *Acacia mellifera* in places.

VI. *Lowland forest:* average rainfall over 1300 mm. Consisting of relic forest areas with *Celtis zenkeri, Chrysophyllum albidum,* etc. as well as areas derived from forest with *Albizia zygia Vitex donania, Terminalia glaucescens,* etc.

VII. *Hill vegetation:* regarded as isolated areas of savanna and woodland vegetation surviving on hill slopes in areas where similar formations are no longer to be found in the surrounding lowlands.

VIII. *Montane vegetation:* upland areas usually with temperate and tropical species that are only known from similar upland areas in Africa.

The soils are an important factor in the distribution of species in the Sudan. Smith (1949) has very ably demonstrated that there is a definite relationship between the vegetation and the available soil moisture as determined by soil texture and rainfall. Thus, a species growing on level sandy soils requires 2 x mm of rainfall, while on clay soils the same species will require 3 x mm; plants growing in shallow depressions etc., obviously receive supplementary moisture from run-off.

It has already been shown that the evidence for a climatic change reflects regional movements on a continental scale and not just local changes. For the Sudan we have the calculations of Warren (1970) to show that during the arid period, 20 000 to 15 000 B.P., the climatic belts were 450 km to the south of their present position and for the dry period, 7000 to 6000 B.P., the southerly shift was 200 km. The deductions for the northerly shift of the climatic belts for the wet period, 12 000 to 7000 B.P., is 400 km and 250 km for the humid period, 6000 to 3000 B.P. These shifts are shown diagrammatically in Figure 1.

The effectiveness of an increase or decrease in the annual rainfall will depend upon two factors, the amount and the temperature. Even a slight increase or decrease is likely to have a spectacular effect in the arid and semi-arid areas. In the higher rainfall areas the vegetation is likely to be less susceptible.

The changes in the rainfall are expected to be accompanied by changes in the temperature. Zinderen Bakker & Coetzee (1972) have concluded from a survey of a number of widespread records that the temperature changes coeval with those of the Northern hemisphere also occurred in tropical Africa and that the changes in humidity were correlated with these temperature changes. Thus the climate during an interglacial period would be both warmer and wetter, encouraging the extension of lowland forest, while during a glacial period the climate would become colder and drier, thereby encouraging the extension of lowland desert and the downward spread of the montane uplands.

Moreau (1966) has suggested that the decreased evaporation associated with a decrease of 5°C could suggest "pluvial" conditions without any increased precipitation. This is a concept that can be applied to montane areas without too much difficulty but virtually impossible to apply to lowland areas.

With the limited data at present available it is necessary to assume that there has been a parallel shift of the climatic and vegetation belts of the Sudan relative to their present positions. This is undoubtedly an over-simplification of the effect of a general increase or decrease in precipitation. Furthermore, it must be borne in mind that the greater the postulated climatic shift, the greater the possible error in interpreting the change in the vegetation.

It is also assumed that any change in the vegetation would tend to lag behind any change in the climate. With increased aridity, deep rooted species would perhaps survive for several generations, until the underground water resources were no longer available to the plants. Conversely, with an increase in precipitation, colonization would be delayed until suitable habitats had developed and sufficient propagules become available etc.

20 000 to 15 000 B.P.

A partial reconstruction of the vegetation during this arid period is shown in Figure 3. This map was made by projecting the southern limits of the present-day desert region 450 km to the south of their present position, allowing for the protection afforded to the movement of sand by the Jebel Marra massif. The Gemini VI series of satellite photographs clearly show the protection afforded by the massif.

Because of our very limited knowledge of the palaeosoils and geomorphology of central and southern Sudan during this period it is not possible to suggest the nature of the vegetation to the south of the desert. The clay soils immediately to the south of the sand sheet mainly post-date this arid period.

The only known fossils that can be attributed to this period are from Singa (13°11′N, 33°55′E) and Abu Hugar (12°52′N, 34°00′E) on the Blue Nile. They include the oryx, rhinoceros, an equine, and four extinct species of which the long horned buffalo is regarded as a forest animal (Table 1). The oryx is an antelope living in arid and semi-arid areas, hence its presence at Singa, with a then estimated rainfall of about 70 mm, is not unexpected. The other two species are often regarded as savanna species. Arkell (1949a) acknowledges the ability of the black rhinoceros to survive in an arid environment. There is also a report in Pliny's account (Kirwan 1957) of that remarkable expedition by Praetorian soldiers in 61 A.D. along the Nile to the "sudd" and their finding of the tracks of both rhinoceros and elephant in the

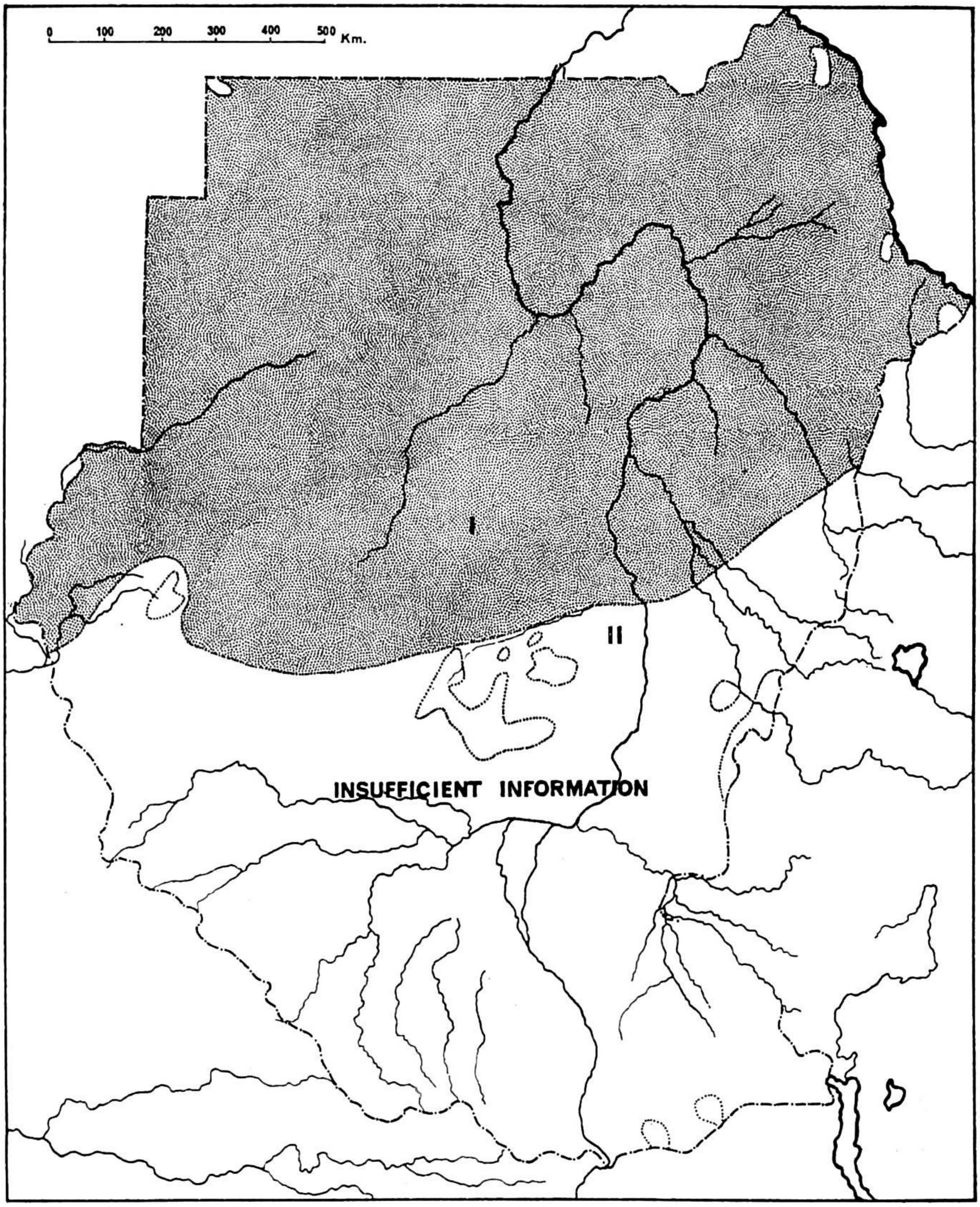

Fig. 3. — Dry period, 20 000-15 000 B.P. when climatic and vegetation belts 450 km south of their present positions.

neighbourhood of Meroe (16°56′N, 33°43′E). The present-day rainfall at Meroe is about 80 mm and would not have differed greatly in Nero's time.

The equine from Abu Hugar, 30 km to the south of Singa, is known from three superficial upper cheek teeth, which is insufficient to determine whether it is a zebra

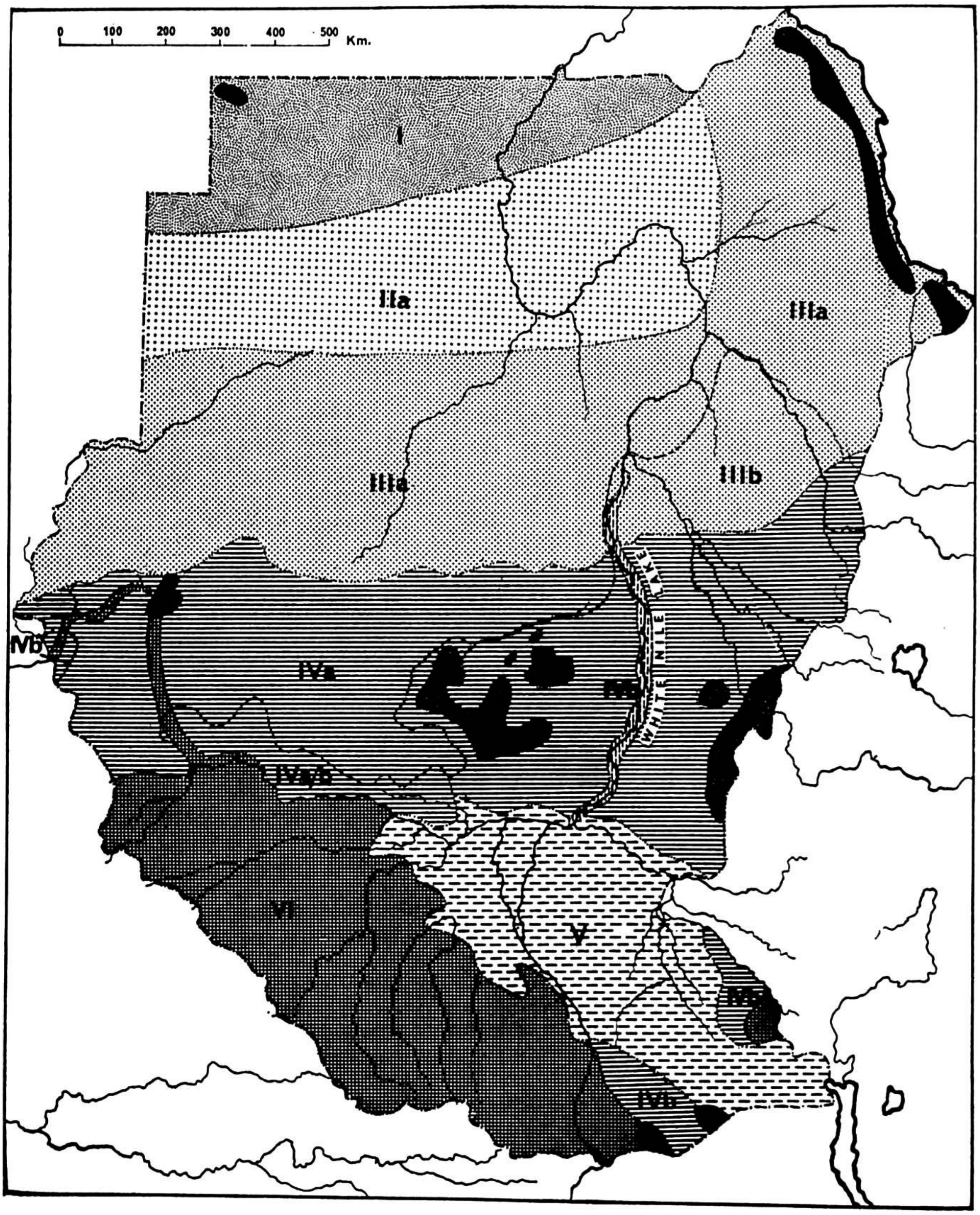

Fig. 4. — Very wet period, 12 000-7000 B.P. when climatic and vegetation belts 400 km north of their present positions (key to the vegetation units on pp. 52-53).

or a species of wild ass (Bate, 1951). In the Sudan the zebra is now only found in the south-eastern part of Equatoria Province (Brocklehurst, 1931; Sidney, 1965), in the high rainfall areas of savanna woodland; it is not a beast of the semi-desert like the wild ass, to which it should probably be referred.

The dorcas is believed to be among the fossils present (Bate, 1951). This again, is a creature of the desert and semi-desert and hence compatible with the suggested environment. Another antelope has been questionably identified as Grant's gazelle (Bate, 1951). This like the zebra, is only found in the south east of the Sudan (Brocklehurst, 1931); it is a grazer and browser, capable of surviving without surface water and hence compatible with the environment.

12 000 to 7000 B.P.

A possible reconstruction of the vegetation during the supposed peak of this wet period is shown in Figure 4. The reconstruction is based on a supposed northward shift of the climatic and vegetation belts by 400 km. The degree of shift is suggested by the presence of *Elaeis guineensis* on Jebel Marra and the abundance of the snail, *Limicolaria cailliaudi*, at Khartoum; the two localities are 950 km apart! It is suggested that lowland forest may have extended as far north as the Bahr el Ghazal. The precise extent of the flood region is more difficult to postulate because we have no knowledge as yet of the former extent, topography and age of the southern clay deposits. The reconstruction of the vegetation on the sand sheet and desert soils is more easy to predict because their extent and environmental problems are better known. The desert area (I) is shown to have retreated to a fraction of its former extent, with Jebel Uweinat (21°54′N, 24°58′E) still isolated in the Libyan Desert. Although some 550 km east of the Nile and north from the Wadi Howar, Jebel Uweinat today still has a surprisingly rich fauna and flora (Léonard, 1969; Osborn & Krombein, 1969), despite the sparseness of the rainfall. During the wet period the 1934 m high massif must have attracted a reasonable precipitation and had a much richer fauna and flora. Traces of Epi-palaeolithic man have been discovered in that area (Williams & Hall, 1965).

Without detailed pedo-geomorphic and palaeontological investigations in the southern provinces of the Sudan there is no evidence to suggest that any of the mapping units shown are necessarily contemporaneous.

The large collection of vertebrate animal remains from the Epi-palaeolithic site at Khartoum collected by Arkell (1949a) represents some 22 species (Table 1), one of which, Arkell's reed rat (*Thryonomys arkelli* Bate), is extinct. The larger carnivors, such as the hyaena, Egyptian wolf-jackal, and the leopard are represented by only one or two teeth. The antelopes are the best represented, followed by the buffalo. The fact that the majority of the bones are broken indicates that the animals were hunted and killed for food. The fauna indicates a mixture of swamp and savanna conditions that are in no way incompatible with the vegetation as interpreted for the area.

The mammal fauna from Shabona (14°41′N, 32°18′E) is probably contemporary with that from Khartoum (Clark, 1973) and is also suggestive of swamp and savanna conditions, although the buffalo is believed to be the forest form, subsp. *aequinoctialis* (J. D. Clark, personal communication, 1974) as is also the early Khartoum record.

Figure 5 which represents a northward shift of the climatic and vegetation belts by 250 km is also compatible with the subfossil mammal record from the Nile valley. It is also conceivable that the forest species now present in the gallery forests of Jebel Marra could have migrated northwards to the massif via the Wadi Azum or the Wadis

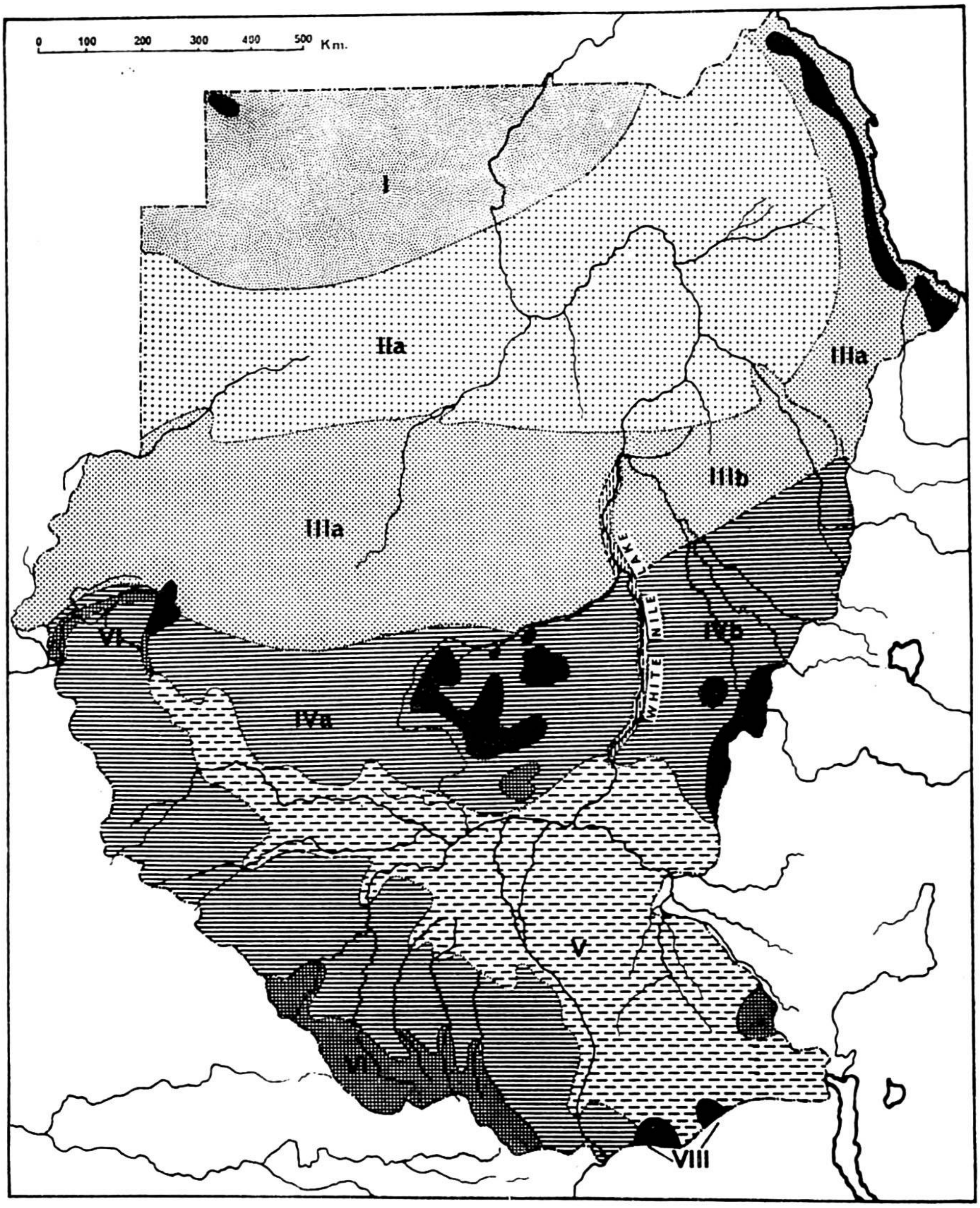

Fig. 5. — Wet period, 6000-3000 B.P. when climatic and vegetation belts 250 km north of their present positions (key to the vegetation units on pp. 52-53).

Ibra and Bulbul under these conditions, but it is much more likely that the migration would have taken place earlier when the climatic belts were 400 km to the north of their present position. It is extremely unlikely that the oil palm, *Elaeis guineensis*, would have been present in these rivers under low rainfall conditions, although once established in the gallery forests of the massif they would have been able to survive.

7000 to 6000 B.P.

Warren (1970) suggests the climatic and vegetation belts were over 200 km to the south of their present position during this period, but, as yet, there is no biological evidence to support this.

6000 to 3000 B.P.

A possible reconstruction of the vegetation during this sub-humid period when the climatic and vegetation belts were believed to be 250 km to the north of their present position is shown in Figure 5. The area of desert was then considerably smaller in extent than at present, presenting the Wadi Howar and Wadi el Milk as possible east to west routes for Neolithic man, who even penetrated the desert as far as Jebel Uweinat (Léonard, 1969). Thorn savanna would have extended over the sand sheet to the south of the desert and over the northern part of the Gezira. To the south, deciduous savanna woodland is believed to have extended over much of the area.

It is suggested that *Terminalia brownii* was firmly established in the vicinity of En Nahud (12°42′N, 28°26′E) during this period. This is an area receiving about 420 mm rainfall, which is considered marginal for the establishment of the species today (Hunting Technical Services, 1964; Wickens & Collier, 1971). Its survival in the area is now dependent upon an arcuate vegetation pattern, which ensures the maximum utilization of direct precipitation and run-off. Such patterns are believed to have evolved over a long period of time, following the retreat of the climatic belts to their present-day position, a view that is in keeping with the information presented above.

The presence of *Anogeissus leiocarpus* in association with *Terminalia brownii* in the longitudinal depressions to the south of Umm Ruwaba (12°54′N, 31°13′E), with a rainfall of about 435 mm, is also attributed to this period (Hunting Technical Services, 1964). The *Anogeissus* is here well outside its normal distribution requirements of a rainfall upwards of 700 mm.

The full extent and exact nature of the vegetation of the flood plain is not known. Areas of "sudd" and "toich" and perhaps areas of inland delta vegetation known as the Baggara and Raqaba repeating patterns are likely, similar to the present-day vegetation.

The southern lowland forest would have contracted considerably during the preceding short dry period and can be expected to have expanded slightly beyond its present day limits, with a few tenuous stretches of gallery forest, perhaps extending as far north as the Jebel Marra massif.

Montane vegetation would be expected to be present on the higher mountains such as the Imatongs, Didinga and Dongotona Hills, Jebel Marra and the Red Sea Hills, while the lower ranges such as the Nuba Mountains and the Ingessana Hills would have what is regarded as hill vegetation.

The fauna that can be referred to this period is from the Neolithic site at Esh Shaheinab (Arkell, 1953). This consists of 32 species of mammals, of which 3 are domestic. The bones represent some 2000 to 3000 specimens, of which the buffalo, giraffe and the hippopotamus were the most abundant. There is a noticeable absence

Date	Location	Lat. et long.	Fauna	Rainfall Estimated	Rainfall Present	Reference	Habitat notes
17 300±200 B.P. or earlier	Singa Abu Hugar	13°09′N, 33°56′E 12°52′N, 34°00′E	Equine, *rhinoceros*, *hippopotamus*, *oryx*, ? *dorcas gazelle*, ? Grant's gazelle, large antelope, extinct short legged giraffoid, extinct antilopine, extinct long horned buffalo, extinct porcupine.	c.70 mm	559 mm	Bate (1951)	Dry land species of semi-arid areas.
c.8000 B.P.	Khartoum	15°36′N, 32°32′E	*Hyaena*, Egyptian wolf-jackal, water mongoose, *leopard*, wild cat, *porcupine*, Arkell's reed rat (extinct), white nosed rat, spiny field rat, *hippopotamus*, *wart-hog*, Nile lechwe, white-eared cob, oribi, *buffalo*, equine, black rhinoceros, *African elephant*.	c.550 mm	163 mm	Arkell (1949a)	Mixture of swamp and savanna species.
c.8000 B.P.	Shabona	14°41′N, 32°18′E	*Mongoose*, red rat or dassie, *hippopotamus*, *wart-hog*, Nile lechwe, *giraffe*, *buffalo*, *African elephant*.	c.800 mm	270 mm	Clark (1973)	Mixture of swamp and savanna species.
5446±380 — 5060±450 B.P.	Esh Shaheinab	16°03′N, 32°33′E	*Grivet monkey*, *jackal*, *striped hyaena*, *lion*, *leopard*, African wild cat, African civet, honey badger, otter, genet cat, black-tipped mongoose, *porcupine*, *hare*, *gerbil*, *ground squirrel*, *hippopotamus*, *wart-hog*, *roan antelope*, *oryx*, *greater kudu*, *red-fronted gazelle*, bushduiker, *buffalo*, *giraffe*, black rhinoceros, *African elephant*, twisted-horned sheep or goat, domestic sheep, dwarf domestic goat.	450 mm	c.100 mm	Arkell (1953)	Predominantly savanna species.
c.4000 B.P.	Jebel Tomat	13°36′N, 32°44′E	? *Dorcas gazelle*, klipspringer, *bush pig*, cane rat, *mongoose*, *porcupine*, *hare*, hedgehog, genet cat.	c.850 mm	c.450 mm	Clark (1973)	Predominantly savanna species.
61 A.D.	Meroe	16°56′N, 33°43′E	Rhinoceros, African elephant, monkeys.		c.80 mm	Pliny ex Kirwan (1957)	Riverine savanna.
1150 A.D.	Old Dongola	18°05′N, 30°57′E	Giraffe, African elephant.		c.30 mm	Idrisi (1836)	Riverine savanna.
1770 A.D.	Upper Atbara	c.15°28′N, 36°24′E	African elephant.		c.325 mm	Bruce (1790)	Savanna.
1822 A.D.	Ed Debba	18°03′N, 30°57′E	Lion.		c.30 mm	Bellefonds ex Cloudsley-Thompson (1967)	Riverine savanna.
1840 A.D.	Gash, nr. Kassala	c.15°28′N, 36°24′E	African elephant, rhinoceros, giraffe, hyaena, lion.		328 mm	Werne (1849)	Savanna.

1840 A.D.	Khartoum	15°36′N, 32°32′E	Gazelle.	163 mm	Werne (1849)	Semi-arid.
1840 A.D.	Aba Is.	13°20′N, 32°37′E	Buffalo.	c.485 mm	Werne (1849)	Savanna or swamp.
1852 A.D.	Berber	18°01′N, 33°59′E	Hippopotamus.	c.70 mm	Churi ex Cloudsley-Thompson (1967)	Riverine grassland.
1860 A.D.	Qoz el Merikh [Walled el Meck]	15°22′N, 32°28′E	Hippopotamus.	c.160 mm	Petherick & Petherick (1869)	Riverine grassland.
1868 A.D.	Wad Shal'ai [Wad Shellay]	14°32′N, 32°13′E	Hippopotamus.	c.300 mm	Schweinfurth (1873)	Riverine grassland (hippopotamus retreating southwards).
1875 A.D.	Soderi	14°25′N, 29°05′E	Lion, hyaena.	220 mm	Friederichsen (1878); Wickens (1970)	semi-desert scrub.
1876 A.D.	Ain Hamed	c.16°36′N, 29°34′E	Lion.	c.100 mm	Ensor (1881)	Semi-desert.
1920 A.D.	Areidida	15°24′N, 33°41′E	African elephant.	560 mm	Grabham (1920)	Savanna.
1935 A.D.	Wadi Howar	c.16°00′N, 24°30′E	Addax, addra gazelle, dorcas gazelle, white oryx, barbary sheep, giraffe, red hussar monkey, ant bear, porcupine, jerboa, gerbil, hyrax, hare, lion, African hunting dog, striped hyaena, jackal, Fennec-fox, ? cheetah, civet cat.	c.100 mm	Shaw (1936)	Desert drainage-line seasonal habitat.
19 - A.D.	Abu Haraz	14°29′N, 33°31′E	African elephant.	c.400 mm	Jackson (1957)	Savanna.
1965 A.D.	Merkhiyat Jebels	15°04′N, 32°25′E	Fox, mongoose, ground squirrel, jerboa, hare, ? jackal, ? hyaena.	c.165 mm	Cloudsley-Thompson (1966, 1968)	Rocky hills in semi-desert.
1973 A.D.	Dinder National Park	c.12°30′N, 35°00′E	African elephant, giraffe, buffalo, roan antelope, water buck, tiang, greater kudu, red-fronted gazelle, Soemmering's gazelle, reed buck, bush buck, oribi, duiker, Salt's dik-dik, wart-hog, bush-pig, lion, leopard, cheetah, hyaena, wild dog, grivet monkey, red hussar monkey, baboon, hippopotamus.	c.800 mm	Cloudsley-Thompson (1973)	Predominantly savanna species with some swamp and riverine.

Table 1. — Records of mammals, mainly in the Nile Valley. Fossil records that are in italics occur also in the historical records.

of swamp-loving animals such as the Nile lechwe, which were recorded from the Epi-palaeolithic site at Khartoum. This absence does not, per se, imply a reduction in rainfall as Arkell (1953) suggested, merely an absence of swamps. A clear distinction must be drawn between rain-fed swamp and flood-water caused by an overspilling of the Nile. The evidence of Williams & Adamson (1973) is suggestive of flood-water swamps along the Nile to the southwards from Khartoum, consistent with the White Nile Lake. Such swampy conditions did not extend to the north of the junction of the Blue and White Niles. The mammal fauna (Table 1) is suggestive of predominantly savanna conditions except for the presence of the oryx, which is an inhabitant of the semi-desert. The fauna, except for the oryx, is compatible with the vegetation as interpreted in Figure 5.

Unfortunately neither the excavations at Khartoum or Esh Shaheinab (Arkell, 1949a, 1953) give any indication of the stratification of the fossil remains. Thus there is no indication as to whether the oryx represents a later, drier phase of the Neolithic settlement; neither is it clear whether the dated mollusc shells are contemporary with the mammal remains, although the dated charcoal from a Neolithic hearth is suggestive that they are. It is also possible that the extent of the climatic shift has been misinterpreted from the abundance of the *Limicolaria* shells. The mammal fossil assemblage could be satisfactorily explained by a climatic shift of only 100 km.

Brocklehurst (1931) has recorded that the oryx in its southern migration can come as far south as latitude 14°N, and has even been seen on the road between El Fasher (13°37′N, 25°22′E) and Umm Keddada (13°33′N, 26°35′E) Thus, the presence of the oryx at Esh Shaheinab could be from a southward migrating animal killed during a dry season and consequently there is no error in the interpretation of the vegetation for that particular period.

3000 B.P. to present

This period is admirably surveyed by Jackson (1957), with a gradual diminishing in the rainfall to that of the present-day. The present-day vegetation is shown in Figure 2. The writings of early travellers along the Nile suggested a much heavier afforestation. Much of the loss of vegetation can be attributed to clearances by man for cultivation purposes etc. Over much of the northern half of the Sudan there is now a serious risk of accelerated erosion due to man's activities. The soil erosion and the consequential destruction of the vegetation is such that there is little chance of recovery (Wickens, 1968). The situation in the southern half of the Sudan is probably not as bad, but because of the recent political disturbances very little is known about the present state of the vegetation.

Concluding remarks

It is clearly evident from this present exercise that rather sweeping deductions have had to be made from very little evidence. Never-the-less, it has the great benefit of showing where further investigations are urgently required—in central Kordofan, midway between the Nile and Jebel Marra, and in the southern provinces. Pollen cores and additional C^{14} dating would be of immense value to our understanding of the vegetation history.

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