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Holocene vegetation of the Eastern Sahara: charcoal from prehistoric sites

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Abstract

This paper is dedicated to Prof. Dr K. U. Leistikow on the occasion of his 60th birthday.

The investigation of 320 charcoal samples from prehistoric sites in the Eastern Sahara furnishes evidence for a fundamental change of vegetation during the early and middle Holocene. Two ecological regions can be distinguished. In Egypt desert formations prevailed, consisting of the same vegetation elements as today though with a wider distribution, while in the Sudan tropical savannas occurred. Around 7000 bp the Sahelian vegetation zones were 500–600 km north of their present range, and 300–400 km around 5700 bp. The Sudanian flora of Fachi-Dogonboulo in Niger, dated *ca* 7000 bp, points to a simultaneous shift of the vegetation zones in the Eastern and in the Central Sahara. With increasing desiccation from 5200 bp onwards, the savanna formations retreated to the south until their present position was reached by 3300 bp.

Résumé

L'étude de 320 échantillons de charbons de bois provenants de sites préhistoriques du Sahara Oriental, met en évidence un changement important dans la végétation au cours de l'Holocène ancien et moyen. Deux régions écologiques peuvent être distinguées: en Egypte les formations désertiques étaient prédominantes, comprenant les mêmes éléments qu'aujourd'hui mais avec une plus large extension. A la même époche le Soudan connaissait une végétation de savanes tropicales. Autour de 7000 ans bp, la zone de végétation sahélienne se situait à 500–600 km plus au nord de sa limite actuelle, et vers 5700 ans bp elle était encore à 300–400 km. La flore soudanienne de Fachi-Dogonboulo, Niger, datée de 7000 ans bp, indique un déplacement simultané des zones de végétation au Sahara Oriental et Central. Sous l'effet d'un assèchement croissant à partir de 5200 ans bp, les formations de savane se sont retirées vers le sud, jusqu'à atteindre leur situation actuelle vers 3300 ans bp.

Introduction

The Eastern Sahara (i.e. Egypt and Northern Sudan west of the Nile) is one of the most arid regions of the world. The larger part of the area is an absolute desert with almost no

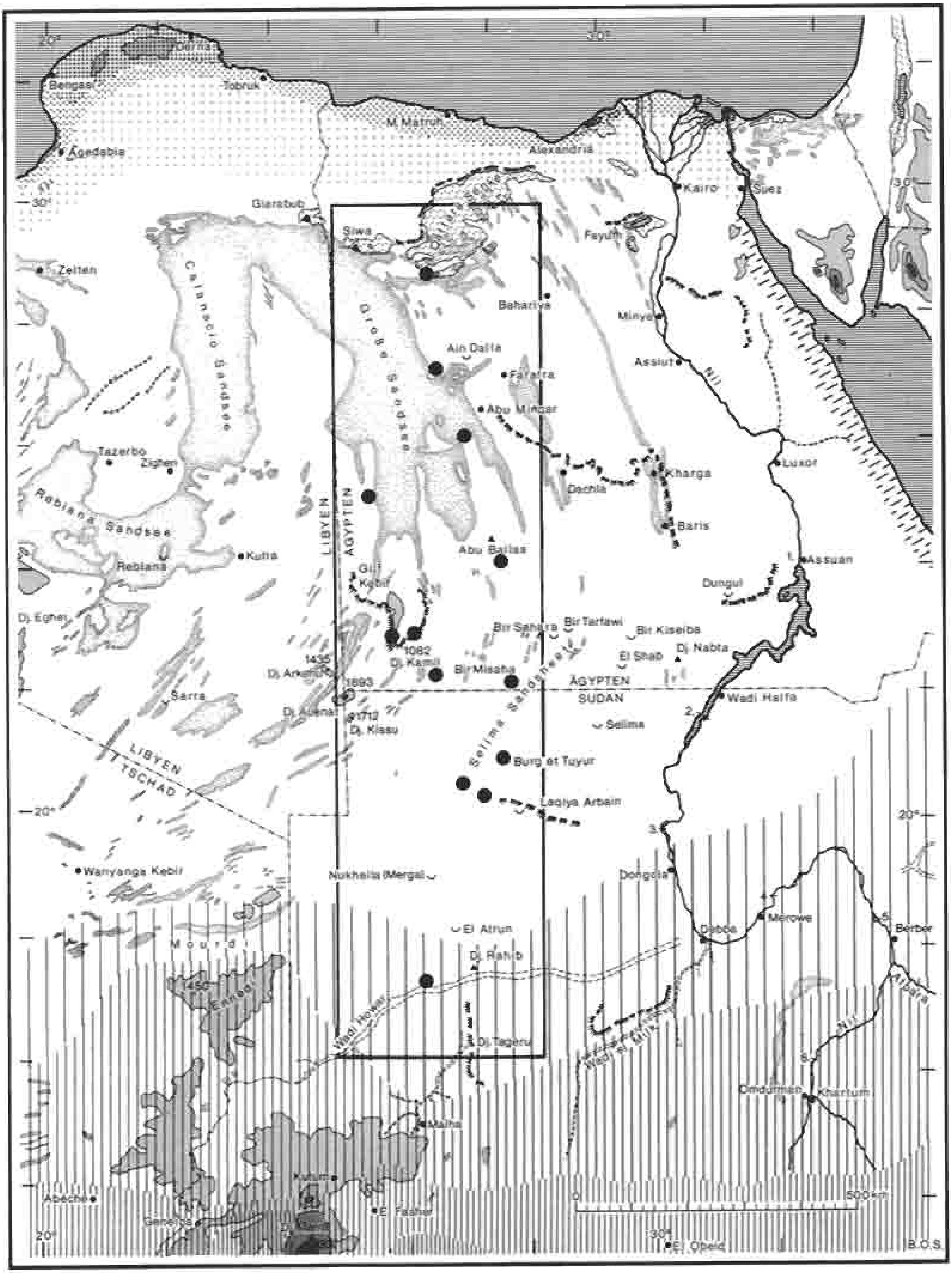

Figure 1 The Eastern Sahara: vegetation zones and areas where identifiable charcoal was found (after Kassas 1971, UNESCO/AETFAT/UNSO 1983 and Wickens 1982, modified).

vegetation (Fig. 1), and one can easily travel for hundreds of kilometres without coming across a single plant. In contrast to this harshness, a great number of prehistoric settlement remains provide evidence for rich environmental resources in the past. Many studies on Quaternary sediments, on prehistory and on faunal remains have demonstrated a more humid period in the Eastern Sahara during the early and middle Holocene which may have coincided with a savanna-like environment. Yet direct evidence for such a savanna was lacking, and the reconstruction of vegetational changes was based almost entirely on data provided by other disciplines (Wickens 1975, 1982). The interdisciplinary project 'Settlement History of the Eastern Sahara' (B.O.S.) of the University of Cologne, funded by the German Research Foundation, researches the relations of Neolithic culture development and the changes of natural environment during the early and middle Holocene (Gabriel 1986; Kuper 1981, 1986, 1988, *in press*; Van Neer *in prep.*), relying especially on botanical evidence. Five hundred and fourteen prehistoric sites along a north-south transect of 1300 km were registered and partly excavated in the years 1980–5. During the field campaigns more than 1500 botanical samples were recovered, most of them consisting of charred wood.

Most previous research concerning Holocene Saharan vegetation history has been conducted in the Central Sahara. The first palynological studies interpreted the presence of mediterranean and temperate elements in the Late Pleistocene and Holocene pollen spectra

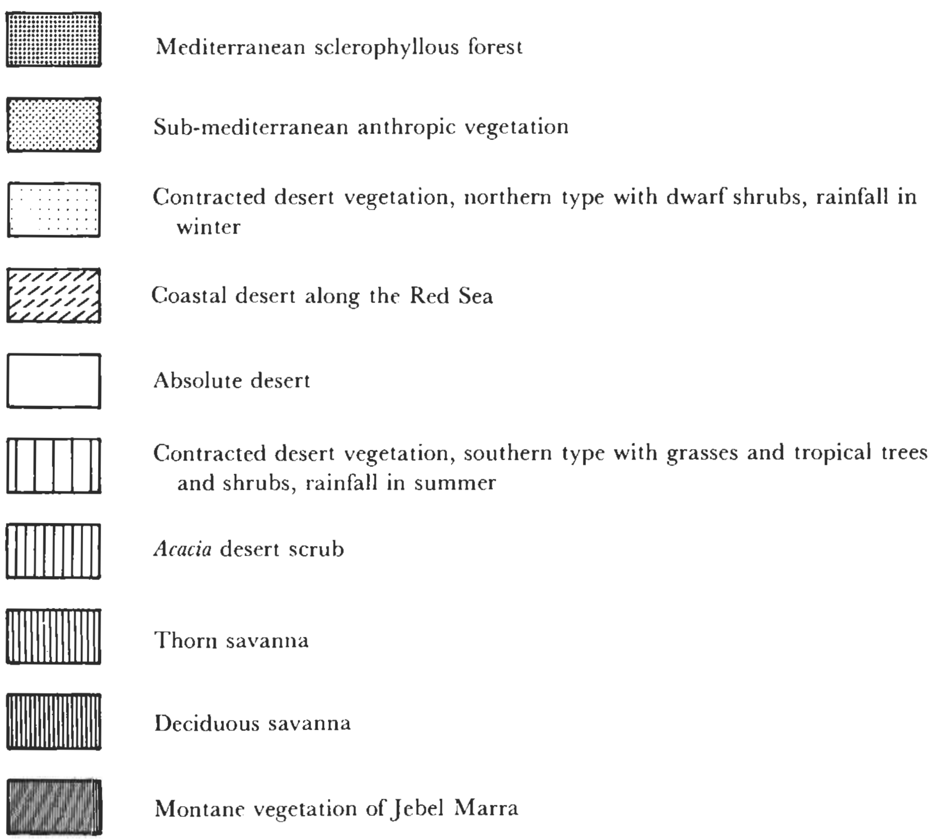

Figure 1 Key.

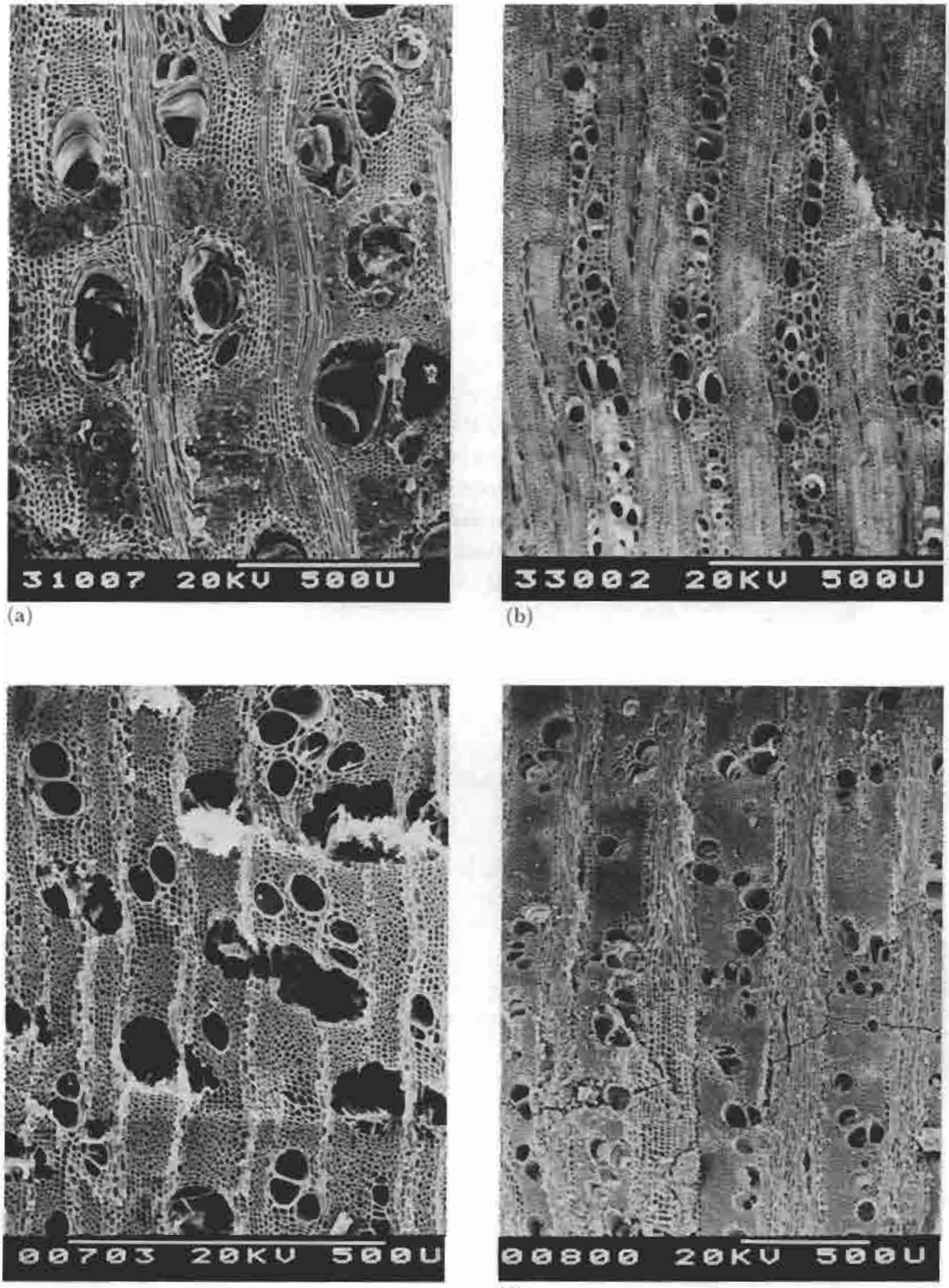

Figure 2 SEM photographs of charred woods from the Eastern Sahara, transverse planes. a) *Acacia* sp., b) *Boscia* cf. *senegalensis*, c) *Salvadora persica*, d) *Tamarix* sp.

as resulting from northern influence (Quézel and Martinez 1958–9; Van Campo *et al.* 1964). Later, when the recent pollen rain was investigated, it became clear that most of this 'northern' pollen was due to long-distance transport. It was evident that additional methods were needed to obtain a more distinct picture of the plant cover in the past. The identification of charcoal from prehistoric sites provides a good tool with which to reconstruct the woody vegetation at a particular place. In general, pieces of charred wood can be regarded as direct evidence for the species which grew on the site or close by. This method is complementary to palynology and can give precise information on the local woody flora, or at least on that part of it that was selected by man for firewood. Charcoal samples can be radiocarbon-dated after microscopic examination which permits an exact temporal association of each sample.

In contrast with the elaborate archaeobotanical research that has taken place in Europe, there are only a few scattered studies of botanical macro-remains from African sites. The first attempts at the identification of charcoal failed to yield broadly applicable results because of preparation difficulties. In the 1960s, Couvert embedded the charcoal pieces in synthetic resin to produce thin sections and also tried to reconstruct past climate and vegetation with the help of archaeobotanical data (Couvert 1970, 1976). The use of scanning electron microscopy (SEM) has provided new opportunities for the identification and documentation of botanical macro-remains. It allows well-focused photographs to be taken of the irregular charcoal surfaces without complicated preparation, and also permits observation of even the finest anatomical details (Fig. 2).

This paper refers only to the general results of the archaeobotanical investigations. A detailed version will be published elsewhere (Neumann in press). It will include ^{14}C-dates, the complete results, figures of recent and reconstructed vegetation types and an atlas of the wood anatomy of 27 taxa.

Recent climate and vegetation

There are only four meteorological stations in the Eastern Sahara – all in Egypt, none in the Sudan – and most of the data have to be extrapolated from adjacent stations. The area is affected by two climatic regimes: 1 – in the north the mediterranean one with winter rains, 2 – from approximately 22°N. southwards the tropical regime with higher temperatures and summer rains. Precipitation decreases from 50–100 mm at the northern and southern margins to almost zero in the centre (Walter and Lieth 1967). Mean annual temperatures rise from 10°C. at Siwa in the north to 28°C. at Khartoum in the south. In Egypt winter frosts are common (Alaily *et al.* 1987) which set distribution limits for thermophil tropical plant species.

The greater part of the research area is a rainless desert where perennial plant life is only found in oases depending completely on fossil groundwater. Outside the oases an 'accidental' vegetation may occur, consisting of potential perennials which can survive as long as there is some soil moisture derived from the incidental rains (Kassas 1971). However, the greater part of the Eastern Sahara is completely bare of vegetation.

In the southwestern corner of Egypt there are two mountain areas which receive slightly higher rainfall supporting a comparatively richer vegetation than that of the surrounding plains. In some of the wadis which dissect the northwestern and the southeastern cliffs of the Gilf Kebir plateau, trees (*Acacia tortilis* subsp. *raddiana*, *Acacia ehrenbergiana*, *Maerua crassifolia* and *Balanites aegyptiaca*) and occasional shrubs can be found (Alaily *et al.* 1987). For Jebel Uweinat Léonard (1969) even states that he collected more than 100 plant species during a three months field survey. Above 1250 m he found mediterranean elements whereas in the lower-lying parts Saharo-Sindian and Sudano-Sahelian species prevail. Another mountain, Jebel Kissu, with a height of more than 1700 m, is situated 50 km southeast of Jebel Uweinat. It carries a very poor vegetation which remains completely unknown up to now.

North of Laqiya Arba'in, three connected wadis stretch along the sandstone escarpments: Laqiya Valley, Wadi Shaw and Wadi Sahal. At the lower-lying parts of the valleys there are groundwater-dependent shrubs of *Acacia ehrenbergiana*, *Capparis decidua* and hummocks of *Tamarix articulata* which can reach a maximum height of 12 m. In smaller runnels coming down the escarpment, some acacias grow which seem to be supported merely by precipitation, despite the fact that the mean annual rainfall probably does not exceed 5–10 mm. Further south, areas with 'accidental' vegetation increase, and solitary specimens of *Maerua crassifolia* and *Capparis decidua* are found on the plains where they can draw some water from the cleft sandstone.

Wadi Howar is a band of vegetation 2–5 km wide that stretches 640 km from the mountainous regions between Ennedi and Jebel Marra into the southern Libyan Desert. Its southwestern part is situated in the Sahelian *Acacia* desert scrub while in the greater part of the wadi desert conditions prevail. The vegetation between 25°00′E. and 27°25′E. (Jebel Rahib) is monotonous and comprises only four woody species: *Acacia ehrenbergiana*, *Acacia tortilis* subsp. *raddiana*, *Capparis decidua* and *Salvadora persica*. East of Jebel Rahib, the wadi is bare of plant growth. In the sandy areas south of Wadi Howar and west of Jebel Tageru, the perennial grass *Panicum turgidum* gains a diffuse distribution and in the depressions scattered trees are found. This 'Saharan savanna', already described by Schulz (1988) for West Africa, marks the southern border of the Sahara.

Charcoal identification: material and methods

Flotation of the desiccated charcoal was not possible because the pieces disintegrated to dust during the procedure. On the site the charcoal was therefore separated from the sediment by dry sieving through 2-mm and 1-mm mesh and packed carefully in sterile sand; alternatively it was removed with parts of the coarser sediment and picked out by hand. Three hundred and twenty representative samples from different sites, covering a time-span from 9000 to 3300 bp, were chosen for examination, containing altogether more than 10,000 pieces. The smaller samples (<200–300 pieces) were identified completely, whereas a random 10–30% was taken from the larger ones after the method described by Van der Veen and Fieller (1982).

The charcoal pieces with a size from 1 mm to 15 mm were fractured manually in the diagnostic transverse, tangential and radial planes. For the SEM examination, the pieces were fixed on aluminium stubs with conductive carbon cement and coated with gold. For the 'everyday' determination, however, most of the charcoal pieces were not treated in this way. Instead, after fracturing they were transferred into a small plastic box filled with fine sand, and the box was mounted on a slide. The sand allowed adjustment of the pieces' position during examination under a microscope with light coming from above. Furthermore, these charcoal samples can be ^{14}C-dated afterwards. As the relevant diagnostic features do not change significantly during the charring process, a slide collection of recent woody species can be used for checking the identity of the charcoal.

The interpretation is based on comparison of the species' relative frequency in the archaeological samples with that in recent plant communities. The ecological conditions under which the trees and shrubs grow today need to be considered, while information on environmental factors at the sites themselves furnish the basis for the reconstruction of the former vegetation. No associations in terms of 'plant sociology' can be reconstructed for three reasons: 1 – the herbal flora is not represented in the samples, 2 – plant sociological studies on the present vegetation of the Sahara and the Sahel are very limited, 3 – savanna and even desert vegetation has been altered by man to a very large extent which limits the use of present types as models for the past. Rather, I prefer using the 'formations': these are plant communities defined by the presence of dominant plant species. There is a good chance that these dominants will appear also in the charcoal samples, especially when they make good firewood.

Results

Egypt north of 25°N.

From this region 48 samples were examined, from Sitra in the south of the Qattara depression and from the southwestern and eastern edges of the Great Sand Sea (*cf.* Cziesla *in press*, *in prep.*; Klees *in press*). They cover a time-span from 9000 bp to 6150 bp with one exception from the western Sandsea which was dated around 5400 bp. The species are few (*Tamarix* sp., *Acacia* sp. and Chenopodiaceae), and there are no differences between the early Holocene and the middle Holocene samples. It seems that the vegetation consisted of the same elements as today, but with a wider distribution. A contracted desert vegetation of trees and shrubs grew along escarpments, in wadis and depressions. The slightly higher precipitation, indicated by the occurrence of woody plants, would also have supported dwarf shrubs, grasses and herbs, the remains of which unfortunately are not preserved in the charcoal samples. Yet, pollen diagrams from Saudi Arabia show Gramineae, Cyperaceae and a number of dwarf shrubs as evidence for a semi-desert similar to the northeastern Sahara or the An Nafud in Saudi Arabia (Schulz and Whitney 1986). Like the An Nafud today, the sandy areas of the Egyptian Sahara, especially the Great Sand Sea, were occasionally visited by nomads who found there a rich wildlife and pastures for their stock. Today this whole region is completely devoid of plant life.

Abu Ballas Mudpans

South of the Abu Ballas escarpment there is an area of deflation hollows filled with fine-clastic playa sediments dated between 10,000 and 6400 bp which are interpreted as resulting from interacting eolian processes and flooding (Pachur and Braun 1980:352). The three sites 83/39, 85/56 and 85/50 (Kuper *in prep.*) yielded very rich botanical material from which 99 samples were selected for examination. The results indicate a marked change of vegetation and climate over a period of 1700 years. The species spectrum of 83/39 (dated ca 8200 bp by three ^{14}C-dates) and of 85/56 (dated *ca* 7500 bp by eight ^{14}C-dates) is quite poor. As in the samples from the other parts of the Egyptian Sahara, acacias and tamarisks prevail, with additional presence of solitary pieces from *Maerua crassifolia*, *Leptadenia pyrotechnica* and Chenopodiaceae. This combination points to a contracted desert vegetation along runnels and in depressions, as has been described for the present central Sahara by Schulz (1980:40–3).

Around 7000 bp climatic conditions changed, resulting in a richer species combination in the samples from site 85/50, with five ^{14}C-dates between 7000 and 6500 bp. Besides *Acacia* sp. and *Tamarix* sp., still dominant in the samples, *Maerua crassifolia*, *Grewia tenax*, *Calotropis procera*, *Leptadenia pyrotechnica*, *Ziziphus* sp. and cf. *Cassia senna* appear. These are the northernmost outposts of the tropical savannas which reached their maximum northward expansion during this period. Nevertheless, the vegetation at Mudpans was not a diffuse savanna: rather was it characteristic of the Sahel. Due to the cleft sandstone and the marked relief with high runoff, Mudpans offered favourable conditions for Sahelian elements arranged in 'contracted' patterns: this type of vegetation is characteristic of desert habitats which receive additional runoff water encouraging plant growth at the lowest parts of the terrain.

Some of the species found in the samples have edible fruits, and propagation of these plants outside their original distribution area might have been supported by man. The occurrence of *Calotropis procera* points to a human disturbance of the natural vegetation; this species is regarded as an indicator of desertification (Batanouny 1983). A situation comparable to site 85/50 is found today in the Bayuda at the southern margins of the Libyan desert. Annual precipitation from 25 to 50 mm supports an extra-zonal Sahelian woody vegetation which is used by the nomads as pasture and for firewood and charcoal production (Pflaumbaum 1987:24–5).

Gilf Kebir

The Gilf Kebir is a plateau of 'Nubian' sandstone reaching 1000 m above sea level. Its southeastern cliffs are dissected by numerous wadis, in two of which, the Wadi (Ard) el Akhdar (arabic: wadi with the green floor) and the Wadi Bakht (arabic: happy wadi), the main archaeological work was conducted (Schön *in press*). The lower parts of both wadis are filled with thick layers of playa sediments. The playas developed during the early and middle Holocene behind fossil dunes which blocked the wadi entrances (Kröpelin 1987, *in press*). From the excavated charcoal samples, 46 were examined covering a time span from 7700 bp to 4300 bp.

The most abundant taxon in the samples is *Tamarix* sp. This points to a more-or-less arid environment throughout the early and middle Holocene. The drier phases of this period witnessed a sparse tree cover whereas, during the moister phases, the vegetation may have consisted of dense stands of tamarisk (*Tamarix articulata*?) in the lower parts of the wadis. These 'gallery forests' are known today from some wadis in the Hoggar and Tibesti (Quézel 1965:179f) and northern Egypt (Kassas 1952; Kassas and Iman 1954) where the average rainfall is 50–100 mm. Although there is no evidence of a permanent groundwater table in Wadi el Akhdar and Wadi Bakht (Kröpelin *in press*), the sandy layers of the playa sediments were capable of water storage and supplying the trees with sufficient moisture. Temporary pools, indicated by thick pelitic playa layers (Kröpelin 1987:195–7), probably carried at their margins dense stands of sedges and other hygrophyllous herbs mixed with *Tamarix*. Today we can find this plant community around shallow depressions in the wadis of the Central Saharan mountains (Quézel 1965:203f).

The second dominant taxon in the samples, though much less abundant, is *Ziziphus* sp. A clear identification of this wood to species level, as was formerly claimed (Neumann 1987:184), is not possible because of the quantitative changes which occur during the charring process. Probably the wood does not belong to the Irano-Turanian *Z. lotus*, but rather to one of the Sahelian species *Z. mauritiana* or *Z. spina-christi*. Because of their edible fruits, both might have been introduced from the south by man. Today, *Z. mauritiana* is a common plant in the Ennedi where it sometimes forms impenetrable thickets (Carvalho and Gillet 1960:73). *Z. spina-christi* occurs as a rare element of the 'desert woodland' in some wadis of northern Egypt (Kassas and Iman 1954).

In contrast with other contemporary samples from the Eastern Sahara, the Gilf Kebir samples rarely contain *Acacia* wood. This might be because the fine-grained nature of the playa sediments was not suitable for the acacias, which prefer coarser ground. In most of the samples where *Acacia* is present, it occurs in combination with one or more of the tropical species *Maerua crassifolia*, *Ziziphus* sp. and *Balanites aegyptiaca*. This assemblage is present around 6600 bp, 5700 bp, and 5000 bp. During these phases, climatic conditions were slightly more favourable and tropical plants were able to invade the Gilf Kebir, whereas the drought-resistent tamarisk could survive even under extreme conditions. The isolated presence of *Acacia albida* around 6150 bp also points to a slightly moister period with precipitation between 50 and 100 mm, which is the minimum under which the recent *Acacia albida* survives in the Central Sahara.

Generally speaking, the archaeobotanical data fit with the results of the sedimentological (Kröpelin 1987, *in press*) and the archaeozoological investigations (Peters 1988). Both sources indicate arid to, at best, semiarid conditions for the Gilf Kebir throughout the Holocene. Kröpelin postulates a 'semiarid' phase from 6000 to 5000 bp, but according to the botanical evidence the more humid climate lasted only for a short period around 5700 bp. From 5600 bp onwards, the environment must have been very dry because the samples from this period contain only *Tamarix* wood. The assumption of Kröpelin (1987:203) that there was either a climatic optimum or an unique millenial rainfall event not long after 5000 bp is confirmed by the occurrence of *Ziziphus* sp., *Maerua crassifolia*, *Acacia* sp. and *Balanites aegyptiaca* between 5100 and 4800 bp.

In spite of the arid climate the Gilf Kebir offered a favourable environment for prehistoric nomads because of the seasonal availability of surface water. A slight increase in precipitation created extensive stands of ephemeral grasses and herbs and thus furnished a basis for nomadic cattle-keeping and for gathering activities. The episodic visits of nomads to the Gilf Kebir continued up to the hyperarid twentieth century (Almasy 1939:131,163), even though the surrounding lowlands were then a hostile and almost barren landscape.

Selima Sand Sheet

The Selima Sand Sheet covers an area of *ca* 60,000 km^2 north and south of the modern frontier between Egypt and Sudan. Eolian sands form a featureless landscape of vast flat plains and gently undulating dunes without any vegetation (Fig. 3). Plant remains were

Figure 3 Burg et Tuyur, recent view.

found in one sample from the excavations at Bir Misaha and 22 samples from Burg et Tuyur (*cf.* Schuck *in prep.*).

The Bir Misaha sample from around 6300 bp consists only of *Acacia* wood while the samples from Burg et Tuyur, dated between 6000 and 5700 bp, yielded an assemblage of the following nine taxa: *Acacia* sp., *Acacia albida*, *Maerua crassifolia*, *Leptadenia pyrotechnica*, *Ziziphus* sp., *Boscia senegalensis*, *Balanites aegyptiaca*, cf. *Cassia senna* and Chenopodiaceae.

Comparison between the Burg et Tuyur samples and those from Mudpans 85/50 shows that the sites have five species in common. However, since the ecological conditions of both sites are not the same, a different type of vegetation has to be reconstructed for Burg et Tuyur. As Walter (1979:16) and Rognon (1980:47) have shown, sandy soils in arid regions are capable of storing a larger amount of water than clay soils and rock surfaces where runoff is high. On sands, precipitation infiltrates the soil quickly and evaporation is reduced. Under slightly higher rainfall, these areas are immediately colonized by grasses which take advantage of the moisture in the upper layers. To begin with, tree growth is very sparse and confined to depressions where some runoff water accumulates. With an increased moisture content in the deeper layers, flat-rooted woody plants will be found also on the upper parts of the dunes. This is what we call a savanna in the sense of Walter (1979:92): a homogenous tropical grassland with scattered trees and shrubs. The most important feature of a savanna is its diffuse distribution of plant growth, whereas all desert formations are characterized by a concentrated pattern.

The Sahelian savannas comprising the same species as those found in the Burg et Tuyur samples are called '*Acacia* desert scrub' (Smith 1949) in the Sudan. The situation at Burg et

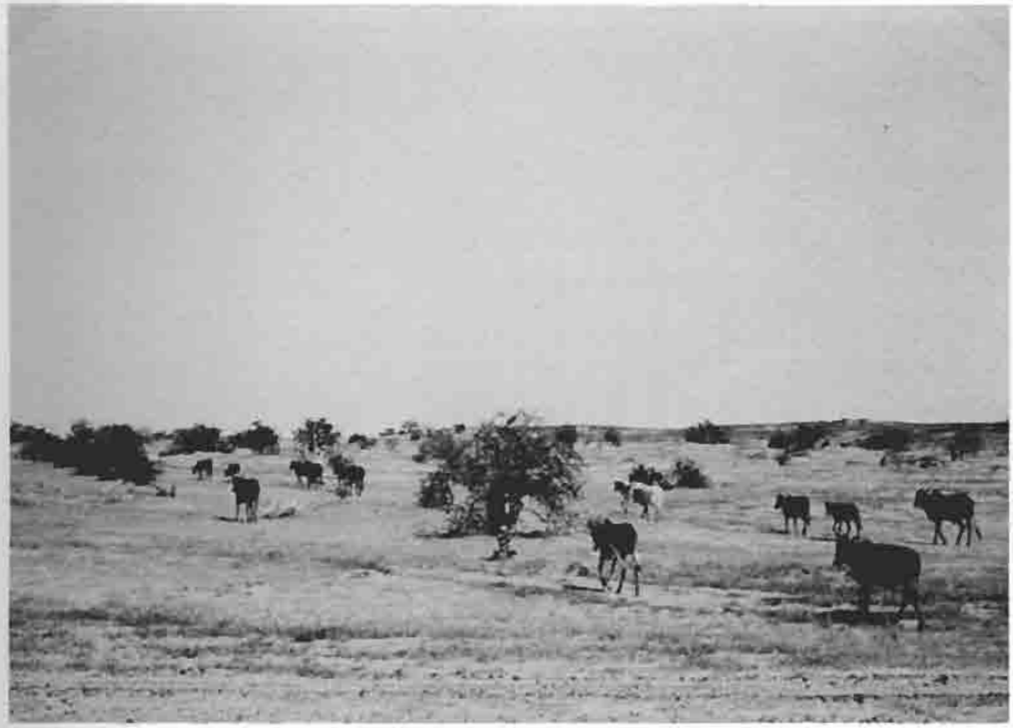

Figure 4 Comparable vegetation for Burg et Tuyur around 5700 bp: *Acacia* desert scrub at Abalak in Niger (photograph by E. Schulz).

Tuyur around 5700 bp is comparable with the recent dune formation in northern Darfur and northern Kordofan. However, the density of tree growth on the dunes cannot serve as a model for the middle Holocene Selima Sand Sheet because it has been severely modified by human activity during the last decades.

Gabriel and Kröpelin (1983) have claimed a low density of settlement remains on the Selima Sand Sheet which they attribute to the penetrable sands and deep groundwater table that was not easily accessible to Neolithic man. Yet hundreds of prehistoric sites were discovered during the recent surveys of the B.O.S. project. The presence of *Acacia albida* in the charcoal samples points to comparatively high groundwater at Burg et Tuyur. In general, this species is regarded as a reliable indicator of groundwater (Carvalho and Gillet 1960:56; Maydell 1983:89), and the Zaghawa say: 'When we find *teli* in a place, we dig wells and we are sure to find water' (Tubiana 1977:35).

To sum up, the Sahelian savanna of Burg et Tuyur around 5700 bp was suitable for cattle-keeping (Fig. 4) because of its groundwater reserves, its grass cover and the trees and shrubs, most of which can be used for fodder (Maydell 1983:50–2; Tubiana 1977:95–8). Periodic settlement of the site seems likely, and the famous rock picture of a cow may belong to this period.

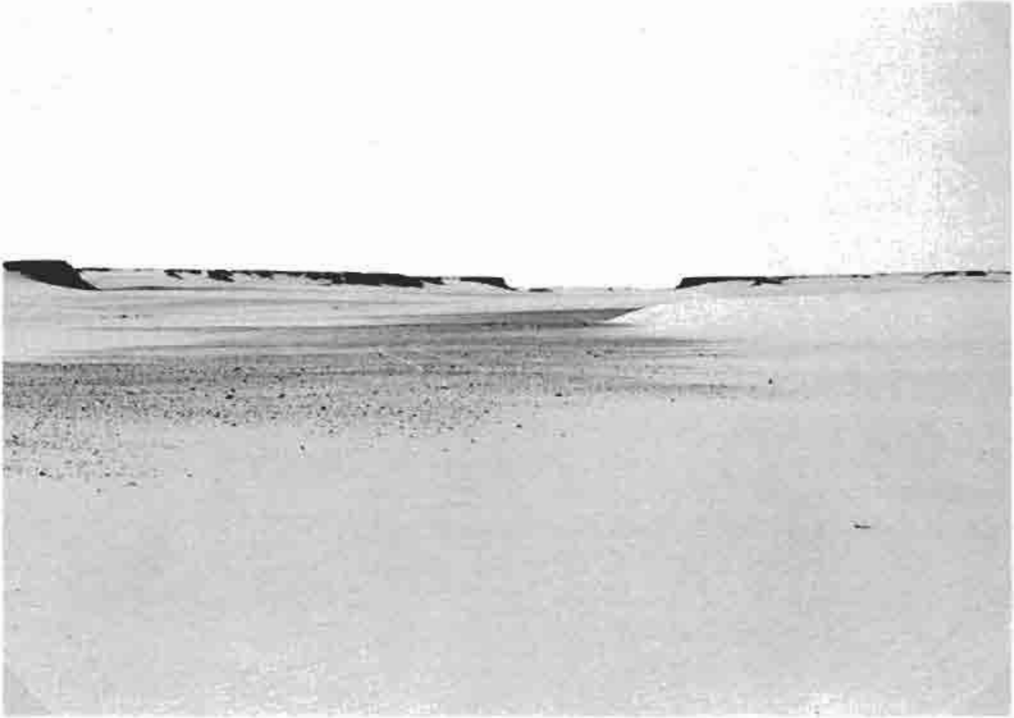

Figure 5 Wadi Shaw, recent view.

Wadi Shaw/Wadi Sahal

The tectonically induced wadi-like depressions Wadi Shaw and Wadi Sahal cut about 30–60 m into the slightly undulating rocky plains of the southern Libyan Desert (Fig. 5). In the depressions, there are a number of playa-like deposits which always show a similar stratigraphic record of two limnic accumulations separated and accompanied by sandy layers (Gabriel and Kröpelin 1983, 1984). Most of the settlement remains and the charcoal samples were found in deposits younger than 6000 bp, above the limnic accumulations (Francke 1986; Schuck 1988, *in press*). During the main phase of settlement, permanent lakes no longer existed, and drinking water had to be obtained from wells. Seventy one charcoal samples were examined; from the results three phases can be distinguished.

Phase 1 started around 5700 bp and ended around 5400 bp. The samples contain *Acacia* sp. and *Tamarix* sp., together with the Sahelian taxa *Maerua crassifolia*, *Balanites aegyptiaca*, *Ziziphus* sp., cf. *Grewia tenax*, *Boscia* cf. *senegalensis*, *Acacia nilotica*, *Grewia* type *villosa/bicolor* and cf. Rubiaceae. The spectrum is similar to that from Burg et Tuyur and it seems that both areas were included in the same vegetation zone, the northern Sahelian *Acacia* desert scrub. No Sudanian influence is apparent except, possibly, badly preserved wood of cf. Rubiaceae; no woody Rubiaceae grow in the Sahel today and only a few relics survive in the Ennedi (Gillet 1968:159).

Due to the pronounced relief and high runoff, the valleys probably carried a dense woody and herbal vegetation as described by Murat (1937:28) and Gillet (1968:130) for the Ennedi. At the edge of temporary pools grew larger specimens of *Acacia nilotica*, *Ziziphus* sp. and

Balanites aegyptiaca (Fig. 6). On the slopes tree growth was sparser, including *Maerua crassifolia*, *Boscia senegalensis* and the two *Grewia* species. The grass cover was not as dense as in Burg et Tuyur because water supply on the cleft sandstone was more favourable for deep-rooted woody plants.

The wood of *Tamarix* sp. does not seem to fit well into the Sahelian assemblage. The recent distribution of tamarisks in the Eastern Sahara is limited to the area north of the transition zone between Sahara and Sahel. In the Sahel tamarisks occur only around brackish pools (Aubréville 1950:76; Carvalho and Gillet 1960:33); and they are replaced by other species, especially *Acacia nilotica*, when freshwater conditions prevail. The presence of *Tamarix* sp. and *Acacia nilotica* in the same samples might be explained by the assumption of an arid period around 6000 bp when tamarisks were the only plants to survive. The humid phase that followed around 5700 bp was of short duration, so that the Sahelian woody plants were not able to replace the tamarisks completely.

During phase 2, from 5200 to 4400 bp, the environment was very dry and in the samples from this period only *Tamarix* sp. and *Acacia* sp. are present. In the samples from phase 3 (4000–3300 bp) *Tamarix* sp., *Acacia* sp. and *Capparis decidua* are the main constituents, with occasional admixture of *Salvadora persica*, cf. *Grewia tenax*, *Maerua crassifolia* and *Boscia* cf. *senegalensis*. The presence of the Sahelian taxa may be due to the great number of the identified samples and their excellent preservation which increases the probability of discovering rarer species. A desert-like environment, comparable with the recent Wadi Howar, would not offer very rich resources for man and his animals. However, the high

Figure 6 Comparable vegetation for Wadi Shaw around 5700 bp: seasonal lake in El Fasher, Sudan, with *Acacia nilotica*.

groundwater table in the valleys created favourable conditions for tree growth and temporary settlement, even with cattle (*cf.* Cziesla 1986), while on the surrounding plains the sparse vegetation gave way to absolute desert.

Wadi Howar

Wadi Howar is an ancient river system that was connected with the Nile during the early and middle Holocene (Pachur and Kröpelin 1987). Excavations were conducted in the area east of Jebel Rahib, between 26°30′ and 27°30′E. (Keding *in prep.*; Richter *in press*). From the sedimentological, archaeological and zoological data it can be stated that local rainfall was markedly higher from 9500 to 4000 bp (Pachur *et al.* 1987:359). This, on the other hand, led to a deterioration of the conditions for the preservation of plant material. Seventeen botanical samples from sites dated between 4600 and 4000 bp were examined. The reconstruction of the vegetation for the earlier periods has to rely on archaeobotanical results from other sites.

There is evidence that Wadi Howar was part of the Sudanian or southern Sahelian savanna zone during middle Holocene times. Comparison between palynological data from the Eastern (Ritchie *et al.* 1985) and the Central Sahara (Schulz 1987) suggests that a northward shift of the vegetation zones occurred simultaneously in both areas around 7000 bp. Therefore, it seems possible to transfer the archaeobotanical interpretation from Fachi-Dogonboulo in Niger (18°18′N.) (Neumann 1988; Neumann and Schulz 1987) to the Wadi Howar (17°30′N.).

At Fachi-Dogonboulo, in the heart of the hyperarid Erg de Ténéré, a charcoal layer resulting from a bush fire was found between limnic sediments. A sample from this layer contained the following 12 woody taxa: *Terminalia* cf. *macroptera*, *Anona senegalensis*, cf. *Rhus* sp., *Crateva adansonii*, *Celtis integrifolia*, *Ximenia americana*, *Ficus* sp., *Boscia* cf. *salicifolia*, *Balanites aegyptiaca*, *Cadaba farinosa*, *Ziziphus* sp. and *Acacia albida*. All these species have their recent main distribution area in the Sudan zone, 550–600 km further south (Aubréville 1950). They can be associated, firstly, with the alluvial habitats near the lake and along the drainage lines and, secondly, with the more xerophytic vegetation on the slopes of the escarpment. Typical Sahelian taxa, especially the acacias, are missing in the sample; probably Fachi-Dogonboulo was not an extrazonal outpost of the Sudanian savannas but rather situated in the Sudan zone itself. The formation was either savanna or even woodland, with a rather dense cover of trees and shrubs. A similar vegetation can be assumed for the dunes of Wadi Howar around 7000 bp. The deeper lying parts of the wadi were periodically inundated and apparently some of these lakes existed for decades (Pachur *et al.* 1987:359). They were surrounded by a swampy environment with a dense grass cover and only scattered trees, as has been described for central Chad by Pias (1970:29).

With increasing aridity from 5300 bp onwards, the Sudanian vegetation in Wadi Howar was replaced by Sahelian types. In the charcoal samples *Acacia* sp. is dominant; minor constituents are *Acacia nilotica*, *Ziziphus* sp., cf. *Grewia tenax* and Capparidaceae. This poor assemblage cannot be attributed to a particular formation. Most likely the environmental changes between 5300 and 3300 bp were more quantitative than qualitative in nature: the density of the savanna formations outside Wadi Howar decreased, and woody plants became confined to the wadi-bed. The dry conditions resulted in a concentration of settlement in the wadi, in intensified use of its plant resources and, finally, to desertification – a man-made degradation of the plant cover.

In 11 of the archaeobotanical samples from Wadi Howar uncharred kernels of *Celtis integrifolia* were found. This is a species with a mainly Sudanian distribution; in the southern Sahel it is confined to the edge of lakes and river courses. In the case of Wadi Howar, we cannot use this plant as an indicator for a Sudanian savanna in the fifth millenium bp because it occurs together with charred wood of northern Sahelian species in the samples. The tree bears edible fruits which are collected today by the people in the Sahel. Around 4000 bp, either the fruits were imported from the savanna regions of the upper Wadi Howar or the tree was planted and was able to survive because of human care and the extaordinary water-supply in the wadi.

Palaeoclimatic interpretation

The poor species assemblage in all the early Holocene samples from Egypt seems to be in contradiction with the sedimentological evidence which is believed to indicate increased precipitation during this period (Pachur and Braun 1980; Pachur *et al.* 1987; Wendorf and Hassan 1980; Wendorf and Schild 1980). This might be explained by reference to another climatic factor that has not been taken into consideration so far: if the temperatures had been lower than today, a slight increase of precipitation would have led to temporary lakes due to reduced evaporation. At the same time tropical elements were prevented from expanding further to the north. Under cooler conditions, a mean annual rainfall of 30–50 mm should have been sufficient to support a quite dense desert vegetation. The lack of mediterranean plants in the samples points to a plant cover that consisted of the same elements as today but with a wider distribution.

Unfortunately there are no early Holocene charcoal samples from sites in the Sudan. From the investigations of Ritchie and Haynes (1987) and Richie *et al.* (1985) we know that from 10,000 bp onwards, the lake levels of Selima and Oyo were rising and the tropical savannas starting to expand northwards. Around 7000 bp a climatic change, notably a rise in temperature, took place, and tropical elements migrated into the Gilf Kebir and the area of Mudpans. Even if we admit that the richer flora of Mudpans was an outpost of the Sahelian savannas and was not included in the Sahel itself, we must assume a northward shift of the tropical vegetation zones by about 500–600 km. The vegetation was *Acacia* desert scrub on the Selima Sand Sheet, thorn savanna at Laqiya Arba'in and deciduous savanna in Wadi Howar (Fig. 7). Most likely the southern and the northern 'wetting fronts' (Haynes 1987) touched each other somewhere in central Egypt during this climatic optimum between 7000 and 6500 bp; so did the vegetation zones, and the absolute desert disappeared.

Around 6000 bp, a dry phase followed the climatic optimum. Tamarisks replaced the tropical plants in Wadi Shaw and the lake of Oyo became shallower (Ritchie *et al.* 1985). Around 5700 bp, a second, minor shift occurred and the vegetation zones were situated 300–400 km north of their present range (Fig. 8). Nomadic cattle keeping was possible as far north as Burg et Tuyur. In Egypt, a very dry environment prevailed from 6000 bp onwards and there are no charcoal samples from later sites, except from the Gilf Kebir where settlement continued until 4300 bp. But even in the Sudan, the second 'wetter' phase did not last for a very long time. At least from 5200 bp onwards the savanna formations retreated to the south, until the present position was reached by 3300 bp.

Through the early and middle Holocene, the Eastern Sahara comprised two ecological

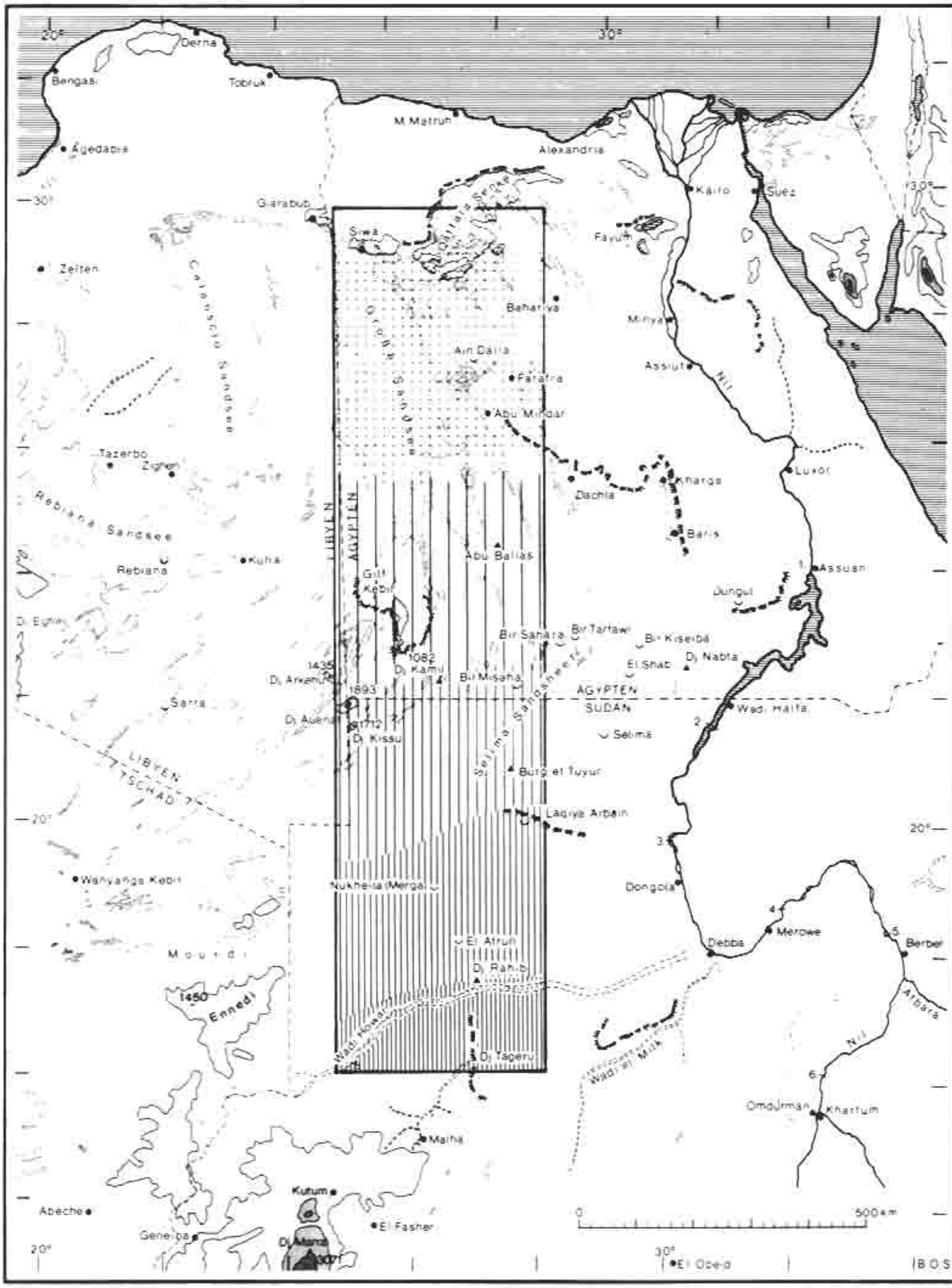

Figure 7 Vegetation zones in the B.O.S. research area *ca* 7000–6500 bp (for key, see Figure 1).

regions: Egypt always had a desert-like environment, though with a much denser plant cover than today, and precipitation probably never exceeded 50–100 mm. In the Sudan, south of 22°N., tropical savannas prevailed. Comparable recent vegetation types occur under a mean

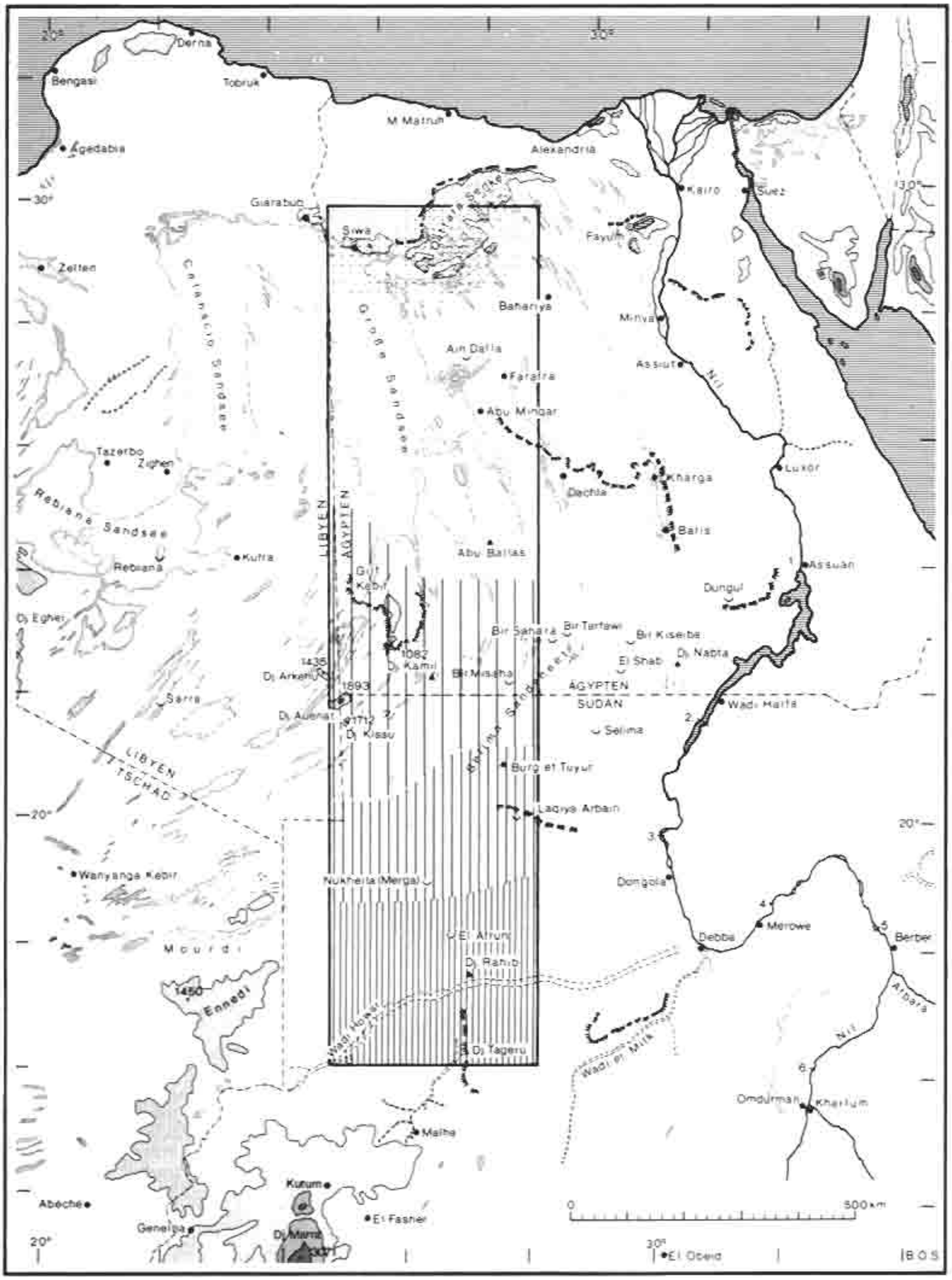

Figure 8 Vegetation zones in the B.O.S. research area *ca* 5700 bp (for key, see Figure 1).

annual rainfall of 100–500 mm. There is no doubt that the middle Holocene savannas of the Eastern Sahara can be traced back to a climate that was distinctly different from that of today. However, the last few years, and especially 1988 with its extreme downpours, have again shown that a green desert may also be the result of an extraordinary oscillation of the 'normal' Sahelian climate.

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