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A Holocene pollen diagram from El Atrun, northern Sudan

Susanne Jahns

Deutsches Archäologisches Institut, Leipziger Strasse 3-4, D-10117 Berlin, Germany

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Abstract. Palynological investigations on a 3.36 m core from El Atrun, Nubia, show vegetation development and climatic change during a period from approximately 9800 to 7000 uncal B.P. From a dry period with a steppe-like vegetation at about 9800-9500 B.P. (zone A), a change to a period with a more favourable climate and a tree covered savanna-like vegetation can be observed in zone B (about 9500-8900 B.P.). In zone C (8900-8400 B.P.), a climatic setback is indicated, with spreading of steppe vegetation and an increase in swamp vegetation as a result of a low lake level. For zone D (about 8400-7000 B.P.), renewed spreading of wooded savanna is inferred.

Key words: Holocene – Northern Sudan – Vegetation history – Lacustrine sediments

Introduction

Several botanical, geoscientific, palaeozoological and archeological investigations in west Nubia have indicated that during the first half of the Holocene the area was covered by a more dense vegetation than today, as a result of the different environmental conditions (Oyo, Ritchie et al. 1985; El Atrun, Ritchie 1987, Ritchie and Haynes 1987; Selima Oasis, Neumann 1989; Haynes et al. 1989). Furthermore, the tropical vegetation spread further north and hydrological conditions were characterized by a high ground water level and episodical to periodical rivers (Pachur and Hoelzmann 1991).

Further evidence of humid phases in the Sahara during the Holocene has been provided by findings from El Atrun Oasis (Goschin 1989, 1992) and other sites from the Nubian basin (Pachur and Hoelzmann 1991, Hoelzmann 1992). The data indicate a phase of lake formation between 9300 and 5300 B.P., with several changes in sedimentary environment. After 9700 B.P. the deposition of lacustrine sediments at El Atrun is evident for a period of 4000 years. They comprise lake carbonates and partially rhythmically bedded carbonate muds. At about 7000 B.P. a freshwater lake existed.

The evidence corresponds well with reports from many other sites (Gabriel and Kröpelin 1984; Hagedorn and Baumhauer 1988; Haynes et al. 1979; Petit-Maire and Riser 1983; Pachur et al. 1987). The increased humidity at Atrun Oasis was due to an extensive rise in the water table caused by local rainfall and by groundwater emerging in the depressions (Pachur and Hoelzmann 1991).

A pollen diagram from El Atrun published by Ritchie (1987) shows the vegetation development at the site during the period from 9800 to 6000 B.P. In that study, however, little was known about the conditions of sediment deposition and size of the ancient lake.

From 1985 to 1989 a geochemical study was carried out on the lacustrine sediments from a *sebhka* (salt lake) at El Atrun (Goschin 1989). Palynological studies were undertaken on a parallel core taken in 1989 with the aim of comparing the pollen data with the results of the geochemical analyses.

Site description

The group of ancient lakes at El Atrun in northern Sudan (18°N/26°E) is situated along the 50 m high escarpment of the Kabbabish Formation (Cretaceous) which stretches north to south. The oasis lies at a height of approximately 600 masl. The surrounding landscape consists of extensive *ergs* (parts of the desert covered with sand), *hammadas* (open rock) and *regs* (desert plain covered with fine stones and gravel) (Ritchie 1987). Wadi Howar lies about 50 km to the south and the Ennedi Massif and Dafur uplands 450 km to the southeast (Fig. 1). To the south and the west of the oasis, the area passes into dune fields. El Atrun is the northernmost habitation in the northwestern Sudan. It consists of fossil lake basins, two *sebkhas* and some tamarisk hills. The northern *sebkha* measures about 1 km², the southern one is about twice that (Goschin 1989).

Climate and vegetation

El Atrun is located near the southern limit of the hyperarid zone of the eastern Sahara, with very hot summers and mild winters, and at the southern limit of an

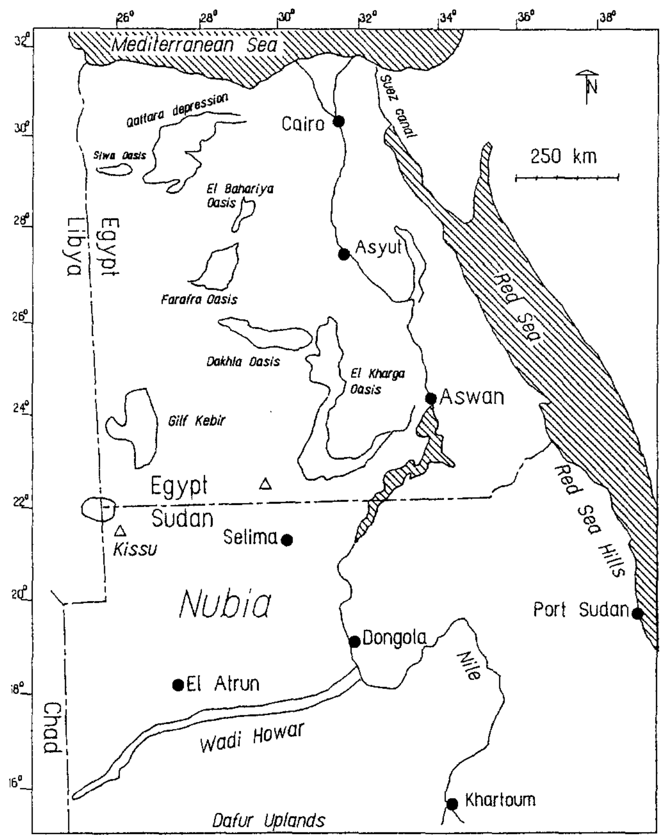


Fig. 1. Location of the study area

area without rain. Annual precipitation is estimated at 15 mm.

The modern vegetation is mapped in Fig. 2. El Atrun lies within a zone of absolute desert (Wickens 1976). Vegetation occurs rarely and scattered in places with high water table. Ritchie (1987) found isolated specimens of *Capparis decidua*, *Acacia ehrenbergiana*, *Tamarix nilotica*, *Cornulaca monacantha*, *Fagonia*

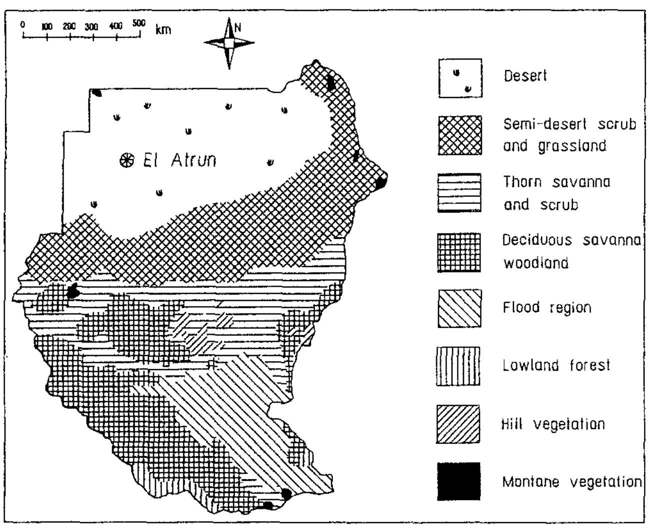


Fig. 2. Map of the modern vegetation of Sudan, after Wickens (1976)

arabica and *Zygophyllum* sp. around the oasis. The northern fringe of the *gizzu* vegetation (ephemeral herbaceous meadow communities) (Wilson 1978), is situated north of Wadi Howar, ca. 50 km south of El Atrun (Fig. 1). In times of extraordinary precipitation it is possible that the *gizzu* vegetation reaches El Atrun. At 18°50'N, Pachur et al. (1990) found six species in the *gizzu*: *Cornulaca monocantha*, *Stipagrostis acutiflora*, *S. plumosa*, *Tephrosia* cf. *purpurea*, *Fagonia cretica* and *Centropodia forsskalii*. The steppe-like shrub vegetation of the Sahel lies about 200 km to the south (Ritchie 1987).

Material and methods

A 6 m borehole was made in the *sebkha* by members of the research group of the Geographical Institute of the Free University of Berlin, using a Livingstone piston corer to obtain a core of 2.5 cm in diameter. Only the lower 3.36 m contained pollen-bearing sediments, and 39 samples (volume 2-9 ml) were selected from this part of the core for pollen analysis.

The volume of the samples was measured by water displacement. Then the samples were decalcified with 33-35% HCl, and *Lycopodium* tablets were added to calculate pollen concentration (Stockmarr 1971). Samples containing a high percentage of organic material were treated with hot KOH (10%). All samples were treated with HF (ca. 73%), acetolysed and finally cleaned of particles smaller than 10 m by ultrasonic sieving.

The reference collection of the Institute of Palynology and Quaternary Sciences at Göttingen was used for identification purposes as well as studies published by Caratini and Guinet (1974), Ybert (1979), Bonnefille and Riollet (1980), Schulz (1980) and Ritchie (1987). Between 1000 and 10,000 pollen grains per sample were counted. This effort was necessary because about 90% of the pollen derived from local plants such as Poaceae, Cyperaceae and *Typha*. The results are presented as percentages excluding Poaceae, Cyperaceae, *Typha* and aquatic taxa (Fig. 3), because these are considered to be mostly of local origin.

Classification of pollen taxa

The pollen taxa were classified into seven groups based on phytogeographical and ecological aspects, following the outlines given by Wickens (1976), Ozenda (1977), Knapp (1973), Schulz (1980, 1984), Neumann (1987), Ritchie (1987), Pachur et al. (1990) and Dupont and Agwu (1991, 1992).

Group I = European-Temperate, II = Mediterranean-Mountainous, III = Saharo-Sahelian, IV = Sahelo-Sudanian, V = Sudano-Guinean, VI = no classification, VII = Locals (aquatic taxa), see Appendix.

Group I contains pollen taxa that have been transported over long distances from non-Mediterranean Europe to the study area. Pollen of group I regularly occur in the present-day pollen rain of the Sahara (van Campo 1975, Schulz 1980) and therefore any former occurrences of these taxa in the higher Saharan mountains must be proved by other methods.

Group II contains taxa from the Mediterranean area and the high regions of the Sahara, such as *Artemisia*, *Pinus*, *Olea* (Knapp 1973, Schulz, 1980), and of the East African mountains, e. g. *Podocarpus* and *Olea* (Hedberg 1954, Hamilton 1972, Wickens 1976).

Herbs and shrubs from the families Chenopodiaceae and Amaranthaceae provide most of the pollen of Group III. According to Schulz (1984), pollen of Chenopodiaceae/Amaranthaceae are most abundant in the northern Sahara. Furthermore, Group III contains pollen deriving from the Saharan and Sahelian vegetation zone (e.g. *Maerua*, *Acacia*, *Cassia*, *Blepharis*, *Salvadora*, *Hyphaene*, *Zizyphus*, Capparidaceae).

Group IV contains pollen taxa which mainly occur in the savannas and forests south of the Sahara (Sahelian and Sudanian vegetation zone) like Combretaceae, *Phyllanthus*, *Pterocarpus*, *Lannea*, *Celtis*, *Grewia*, *Piliostigma* and *Indigofera*.

Group V contains pollen of taxa mainly from elements of the tree savannas and the tropical rain forest of the Guinean-Congolian area.

Group VI comprises pollen taxa which cannot be attributed to one of the phytogeographical regions such as Asteraceae, Caryophyllaceae, Brassicaceae, Ranunculaceae and Rosaceae.

Group VII contains local taxa including *Typha*, Poaceae, Cyperaceae, ferns and the aquatic vegetation, indicating the existence of an open water surface. The first three taxa are frequently represented in the fossil spectra with high values.

Poaceae and Cyperaceae are abundant in all pollen spectra of the Sahara (van Campo 1975; Maley 1981; Schulz 1979a, 1979b, 1980, 1984; Ritchie 1987; Ritchie and Haynes 1987). Besides the fact that grasses play an important role in ephemeral and perennial desert grassland vegetation (Mahmoud and Obeid 1971), the high values of Poaceae pollen must be attributed to the high pollen production of grasses. This results, for instance, in highest Poaceae pollen percentages in modern pollen spectra from regions that are completely free of vegetation (Schulz 1980, 1984). Therefore, in addition to large local sources of grass pollen (such as *Phragmites* in wet places), the Poaceae pollen signal has a strong regional component. In contrast to the Chenopodiaceae/Amaranthaceae records, high Poaceae pollen percentages are found in modern pollen spectra of the savannas south of the Sahara. Cyperaceae show a similar record, although they display a higher local significance than Poaceae, either as elements of reedbeds and swamps in wet areas or as members of dune vegetation, such as *Cyperus conglomeratus* (Schulz 1984, Ritchie et al. 1985, Ritchie 1987).

For the interpretation of the fossil pollen spectra it is essential to keep in mind that the local taxa - being anemophilous and having a high pollen production - are greatly overrepresented in the diagram compared to the regional taxa, especially tropical trees, which are mostly zoophilous (Lezine 1987, Ritchie 1987).

Results and interpretation

The pollen diagram (Fig. 3) is divided into four sections A-D, mainly based on the amounts of Group III and IV pollen taxa. The ages, interpolated from two radiocarbon dates (Hv 14454: 6750±295 B.P.; 493.74 masl, UZ 2270: 9180±200 B.P.; 490.1 masl.) are as follows:

Zone A: about 9700-9500 B.P.
Zone B: about 9500-8900 B.P.
Zone C: about 8900-8400 B.P.
Zone D: about 8400-7000 B.P.

The European-temperate pollen taxa are irregularly represented throughout the diagram, owing to the location of El Atrun at 18°N. The southward transport of pollen from European taxa and the northward dispersal of pollen of tropical taxa are described in detail by Schulz (1980). While the European taxa are still quite frequent in the northern central Sahara, they are scarce at 13°N. The Guinean elements are represented rather steadily, but with only small values in the El Atrun diagram.

Zone A

Around 9700-9500 B.P. (zone A), a steppe-like vegetation with only a few trees apparently predominated in the area of El Atrun. In the diagram this is indicated by the high values of the Chenopodiaceae/Amaranthaceae dominating this zone with values up to 70%. Either the climate was comparatively dry or trees had not yet immigrated into the area. Within the Saharo-Sahelian group *Maerua* is represented, as are *Ephedra* and *Acacia*.

In the lowermost part of zone A, the Cyperaceae have a maximum exceeding 3000%, possibly owing to the presence of reeds indicating a permanently high water table. This is corroborated by findings of fish bones in west Nubian lacustrine sediments of that age (Pachur and Hoelzmann 1991).

The basal sediments of the lake, formed between 9700 and 9200 B.P., consist of laminated carbonate mud deposited under saline and moderately alkaline conditions. The carbonate mud has a high percentage of organic carbon, indicating a high biogenic activity in the lake (Goschin 1989).

Zone B

With the start of zone B from about 9500 B.P., the situation changes. The values of Chenopodiaceae/Amaranthaceae are lower. The Sahelo-Sudanian taxa and later also the Saharo-Sahelian taxa increase both in percentage and number of taxa. Here, *Lannea* and the Combretaceae which are nowadays widespread in the dry savannas south of the Sahara (Knapp 1973, Wickens 1976) are of interest. So are *Phyllanthus* and *Salvadora*, *Grewia*, *Hyphaene*, *Zizyphus* and *Piliostigma*. Apparently a more favourable climate and better water supply as indicated by higher lake levels (Pachur and Hoelzmann 1991) resulted in a wooded savanna, which nowadays grows hundreds of kilometres further south.

Regular occurrences of aquatic taxa, mainly represented by pollen of the *Myriophyllum spicatum*-type, indicates that open water was available in El Atrun.

Further confirmation for a more humid climate is provided by the carbonate mud deposited during this period under less saline and less alkaline conditions than those of the preceding layers (Goschin 1989).

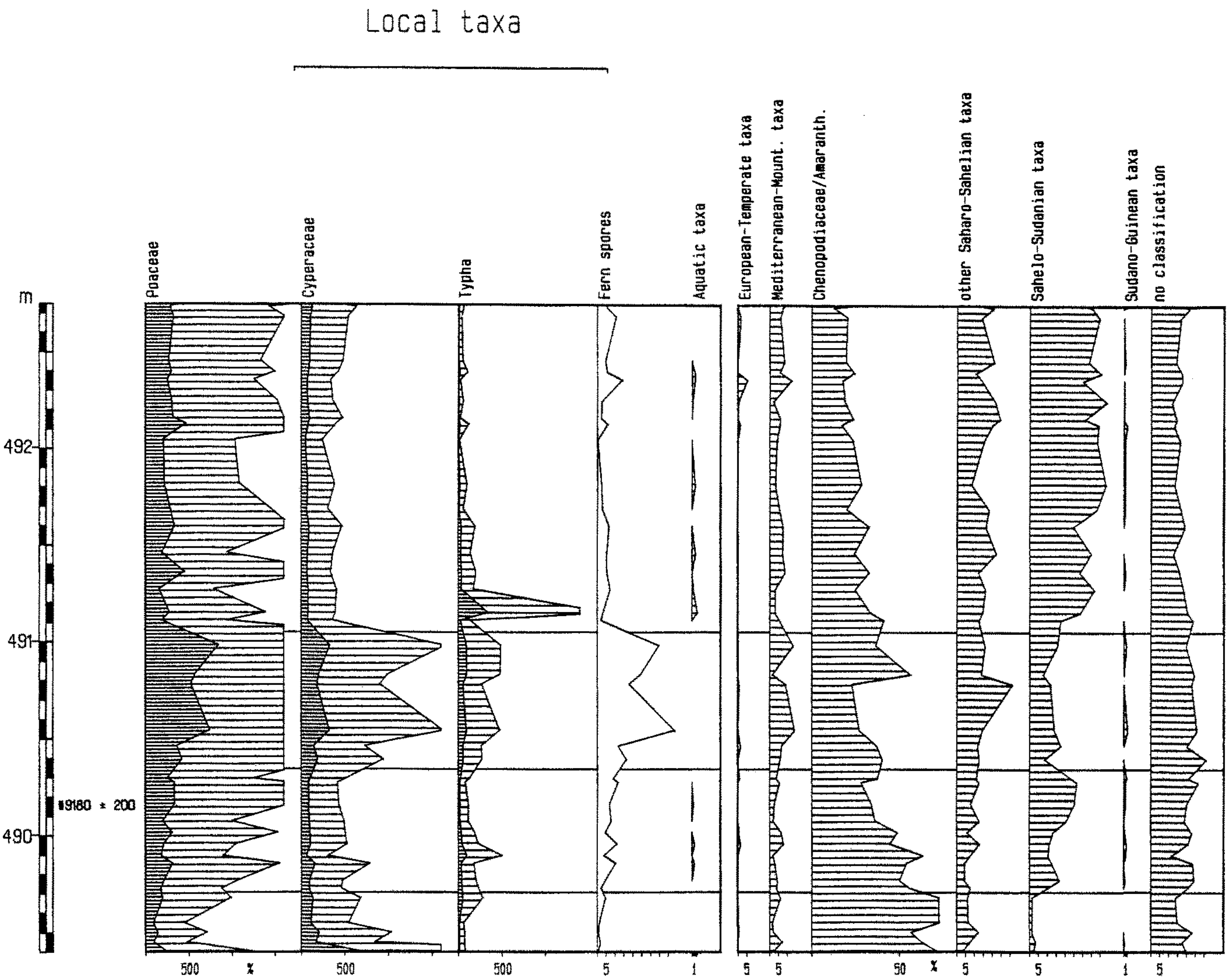


Fig. 3. Pollen diagram of the Sebkha El Atrun, phytogeographical groups and selected taxa. Values are given as percentages, very high values on a 1/5 reduced scale denoted by denser hatching

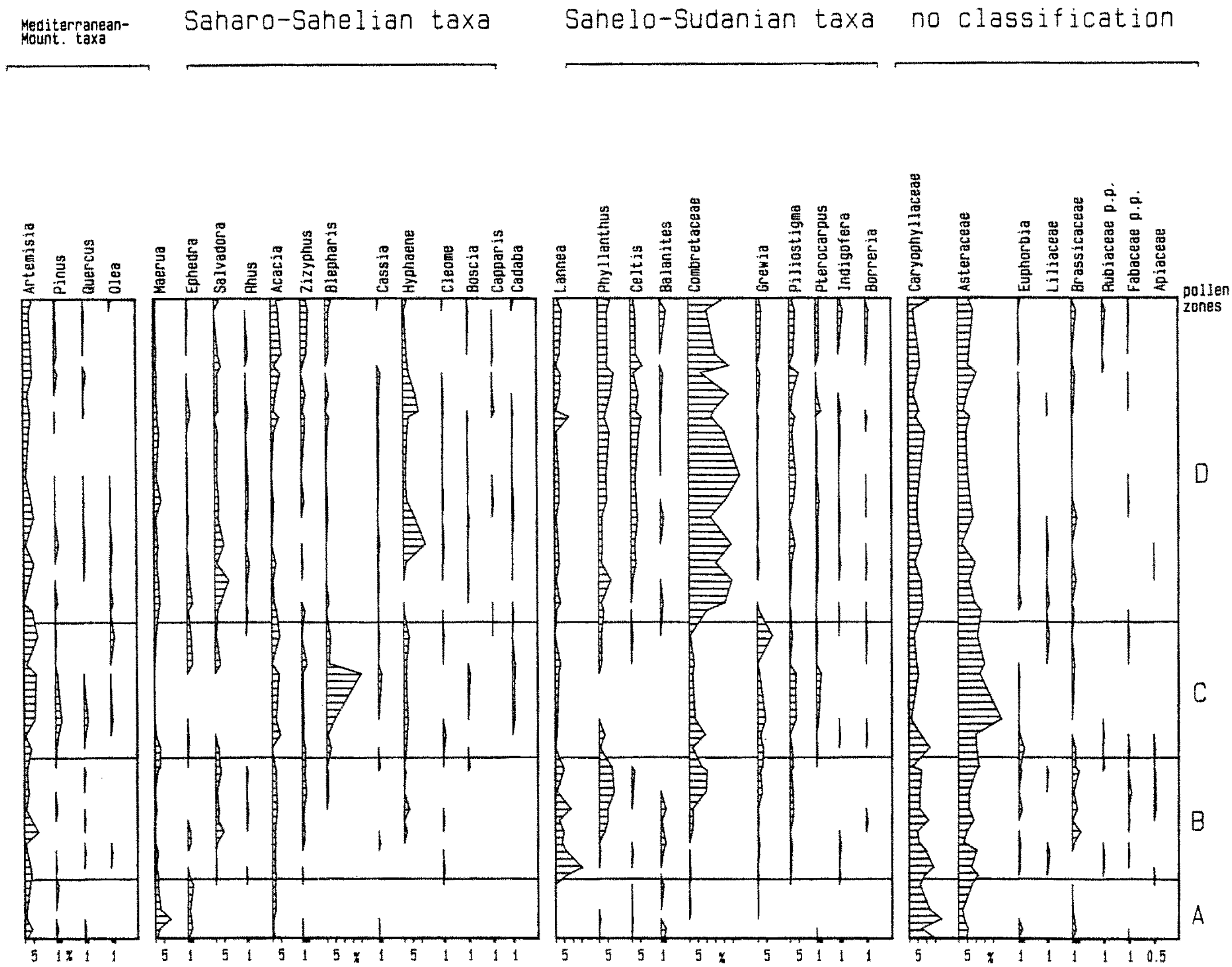
Zone C

Zone C, which dates to approximately 8900-8400 B.P., indicates a climatic setback which again promoted the spread of a steppe-like vegetation. Most of the Sahelo-Sudanian taxa decrease, such as the Combretaceae and *Phyllanthus*, while *Celtis* and *Balanites* even disappear. Within the Saharo-Sahelian group, *Maerua*, *Ephedra*, *Rhus* and *Salvadora* decrease. The climatic situation for the savanna vegetation probably did not become as unfavourable as in zone A, because the decrease does not apply to all taxa in the same way. The curve of *Grewia*, a genus typical of the deciduous savanna, and that of *Pterocarpus* increase. The values of *Piliostigma* remain on the same level, and those of *Acacia* also increase. Altogether, percentages of the Saharo-Sahelian group remain on the same level as in zone B. One peak is due to values of *Blepharis* at 20% which remains surprising. *Blepharis* is a herbaceous taxon, which nowadays occurs in the northern Sudan (Wickens 1976, Neumann 1987, Pachur et al. 1990).

In this section of the diagram, the group of local taxa is represented with extremely high values. The high percentage of *Typha* most probably represents an increased reed and swamp belt in the littoral zone during a phase of low lake levels. This shrinking of the lake extension is corroborated by the absence of indicators of open water, such as *Myriophyllum*, in the previous and the following zone. The same comments on *Typha* probably also apply at least partly to Poaceae and Cyperaceae. On the other hand, a joint occurrence of high Cyperaceae and Poaceae values is described by Schulz (1987) as typical for large dune areas in the southern margin of the Sahara. The high values of various fern spores is probably of merely local significance (Schulz 1980).

The pollen concentration in zone C is very low (Fig. 4), caused either by a high sedimentation rate or by a low production of pollen by the vegetation at that time.

The sediments of zone C were probably deposited under alkaline conditions again (Goschin 1989). Carbonate precipitation from 8900-8400 B.P. indicates fresh



water conditions. The carbon content of more than 6.5% is the highest in the entire profile and indicates a high organic production. The higher productivity of the lake probably resulted in a higher sedimentation rate, resulting in lower pollen concentration values (Fig. 4). The high manganese content points to a less ventilated water body, which fits in well with the palynological interpretation that open water was absent. But the hypothesis of a reduction of lake size at that time is not in agreement with other observations of lake development in west Nubia, which point in the other direction (Pachur and Hoelzmann 1991).

Zone D

From approximately 8300 B.P. onwards, the values of the local taxa decrease again and the pollen concentration increases. At the same time the indicators for an open water surface return and indicators of the wooded savanna vegetation are again widespread. Now the Sudanian elements reach their maximum percentages and maximum variety of taxa. Again, the Combretaceae values reach particularly high rates. In addition, *Celtis*, *Piliostigma* and especially *Hyphaene*, *Phyllanthus* and *Salvadora* show high values. In the upper part of zone D, *Acacia*, *Zizyphus* and *Lannea* are more abundant.

The sediments in zone D were formed under more saline and alkaline conditions than the sediments of zone A to C (Goschin 1989).

Discussion

Fig. 5 shows the ratio of arboreal (AP) to non-arboreal pollen (NAP). It clearly displays the increase of woody taxa from zone A to zone D. Chenopodiaceae/Amaranthaceae are listed separately, though in general they are counted as NAP. However in desert areas, bushes or shrubs are represented in these two families as well, so that they are treated as a separate group. This also gives credit to their quantitative significance. In

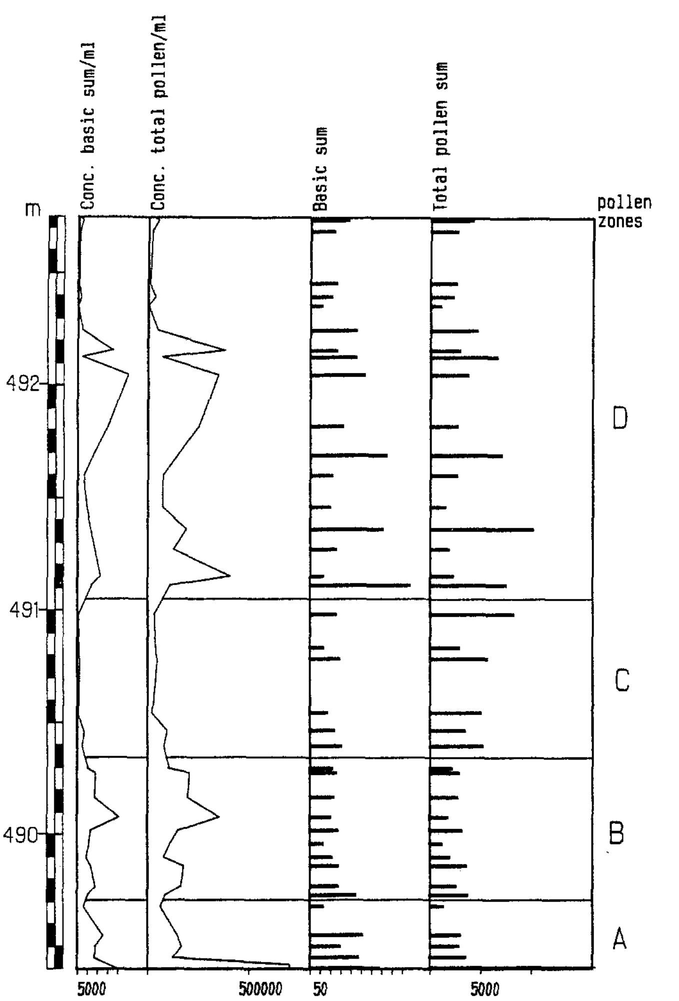


Fig. 4. Pollen sums and concentrations

zone B and zone D, the diagram indicates a more dense cover of trees and bushes. This is attributed to the fact that the taxa from the Sudanian area are mainly woody plants.

The pollen concentration is very high in zone B and D, with a setback in zone C, as shown in Fig. 4. The curve of the concentration of the sum of regional pollen taxa runs parallel to that of the sum including local elements, permitting the conclusion that the pollen concentration mainly depends on the sedimentation rate.

Ritchie's pollen diagram of El Atrun (1987) nearly covers the same period. Here the clustering of taxa is slightly different and the percentage values are calculated with the local taxa included in the pollen sum. In general, the diagram agrees with Fig. 3 regarding the high values and the pattern of Poaceae, Cyperaceae, *Typha* and Chenopodiaceae/Amaranthaceae, and the temporal and quantitative occurrence of the most important Sahelian and Sudanian elements. Both diagrams show maximum values after about 8500 B.P. which are due to the same taxa, such as Combretaceae, *Piliostigma*, *Hyphaene*, *Balanites*, *Celtis*, *Grewia*, *Lannea*, *Zizyphus* and *Salvadora*. Ritchie's diagram, however, does not show clearly the transition from dry to humid conditions about 9000 B.P., which allowed a wooded savanna to develop. In the new diagram this change is clearly visible at the transition form zone A to B. A partial replacement of the savannas by semi-desert scrub after 8500 B.P. is indicated in Ritchie's diagram, but is interpreted by the author only as a suggestion. The pollen data from the new diagram clearly show this oscillation in the values of the group of the Sahelian-Sudanian taxa in zone C.

During the early Holocene, the area around Selima, Oyo and El Atrun in the eastern Sahara bore a vegetation similar to that now found further south in the savanna region (Ritchie et al. 1985, Ritchie 1987, Ritchie and Haynes 1987, Haynes et al. 1989).

Moreover, a groundwater rise in the Selima oasis occurred between 8400 and 8000 B.P., too. The resulting lake had its maximum depth around 7000 B.P. From 8500-6100 B.P., a deep lake also existed in the area of Oyo. In Wadi Howar, a more favourable climate allowed a denser vegetation which made a long-term human occupation of the wadi possible during the early Holocene (Pachur and Röper 1984; Gabriel et al. 1985). In East Africa (Lake Turkana in Kenya,) a more dense vegetation than today is indicated for the corresponding period,

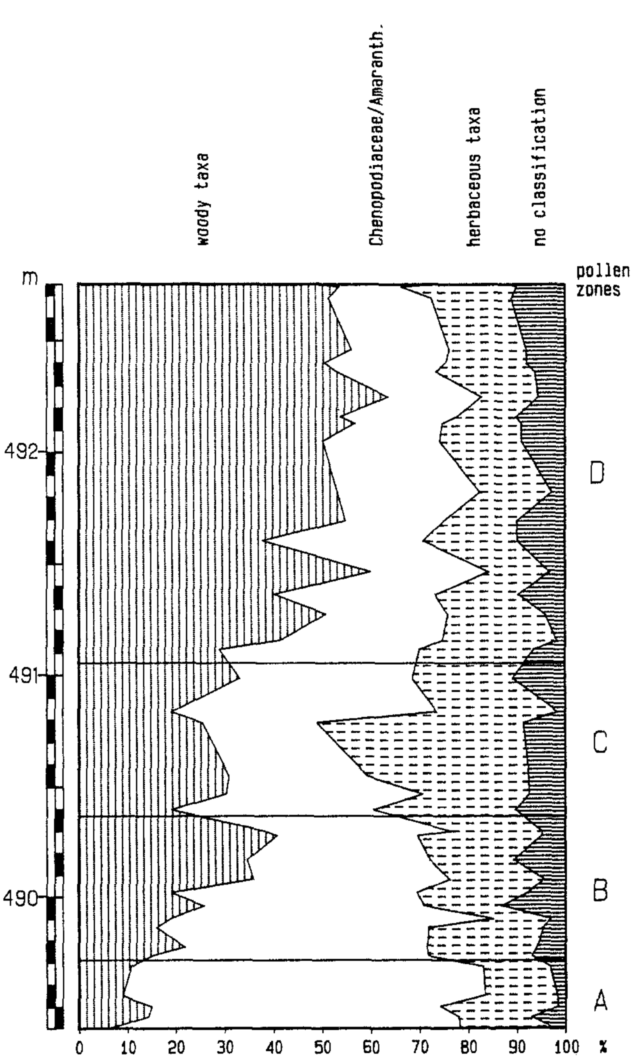


Fig. 5. Ratio of arboreal (AP) to non-arboreal pollen (NAP)

too (Vincens 1989). Studies on plant macrofossils in the eastern and central Sahara likewise indicate a 500 km northward shift of the Sahelian vegetation at around 7000 B.P. (Neumann and Schulz 1987; Neumann 1989).

Schulz (1987) describes the same phenomenon for the area of Taoudenni (central Sahara). So does Maley (1981, 1983) for the Chad basin, whereas in the Murzuk basin and the Tibesti the same type of vegetation as today's can be assumed, yet probably more dense and extensive (Schulz 1987).

For the oasis El Atrun a change from a dry to a more humid climate can be shown, which is in agreement with the observations from other sites in the eastern and central Sahara. Furthermore there is evidence for a temporary oscillation to a drier climate after 8500 B.P.

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Appendix

Group I, European-Temperate elements:
Alnus, *Betula*, *Carpinus*, *Corylus*

Group II Mediterranean-Mountainous:
Artemisia (also Saharan), *Centaurea*, *Fraxinus ornus* type, *Gypsophila*, *Olea*, Oleaceae p.p., *Ostrya*, *Phillyrea*, *Pinus*, *Quercus*, *Vitis*, *Podocarpus* (only mountainous), *Nauclea* (only mountainous)

Group III, Saharo-Sahelian:
Chenopodiaceae/Amaranthaceae, *Acacia*, *Blepharis*, *Boerhaavia*, *Boscia*, *Cadaba*, *Capparis*, *Cleome*, *Maerua*, Capparidaceae p.p., *Calligonum*, *Cassia*, *Cissus*, *Commicarpus*, *Ephedra* (also Medit.), *Hyphaene*, *Nitraria*, *Phoenix*, *Plantago*, Plumbaginaceae, *Ocimum*, *Rhus* (also Medit.), *Rhynchosia*, *Salvadora*, *Sesbania*, *Tamarix*, *Tribulus*, *Zizyphus*

Group IV, Sahelo-Sudanian:
Balanites, *Borassus*, *Borreria*, *Celtis*, Combretaceae, *Commiphora*, *Corchorus*, *Crossandra*, *Enicostema*, *Grewia*, *Hypoestes*, *Icacina*, *Indigofera*, *Justicia*, *Lannea*, *Lawsonia*, *Leonotis*, *Leucas*, *Phyllanthus*, *Piliostigma*, *Protea*, *Pterocarpus*

Group V, Sudano-Guinean:
Alchornea, Arecaceae p.p., *Cardiospermum*, *Diospyros*, *Elaeis*, *Ixora*, *Leptaulus*, *Mitracarpus*, *Sherbournia*, *Syzygium/Myrtus*, *Trichilia*, *Uapaca*

Group VI, no classification:
Acanthaceae p.p., Anacardiaceae p.p., Apiaceae, Asteraceae, Brassicaceae, Caryophyllaceae, *Detarium*, *Euphorbia*, Euphorbiaceae p.p., Fabaceae p.p., Liliaceae, *Linociera*, Malvaceae, *Mitriostigma*, *Pouchetia*, Ranunculaceae, Rosaceae, Rubiaceae p.p., *Spondias*

Group VII, Local vegetation:
Cyperaceae, Poaceae, *Typha*, aquatics (*Eichhornea*, *Myriophyllum spicatum*-type, *Potamogeton*, *Utricularia*)