# Holocene environmental changes in Namibia inferred from pollen analysis of swamp and lake deposits

**Article** *in* The Holocene · March 1991

DOI: 10.1177/095968369100100103

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*The Holocene*, 1,1 (1991) pp. 8–13

# Holocene environmental changes in Namibia inferred from pollen analysis of swamp and lake deposits

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Received 6 September 1990; Revised manuscript accepted 1 October 1990

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**Abstract:** Spring deposits exposed during building operations in downtown Windhoek, and lake sediments retrieved from underneath 50 m of water in a sinkhole (Lake Otjikoto), contain pollen profiles which reflect environmental changes in Namibia during the Holocene. At Windhoek moist local conditions are reflected by pollen in the spring deposits which were radiocarbon-dated to between ca. 7000 and 6000 BP. They remained relatively favourable until 5630 BP despite signs of drying. Weedy Compositae (Lactucoideae or Liguliflorae) increased until the end of this record ca. 2410 BP, indicating local disturbance. Deposits from Lake Otjikoto were dated to the late Holocene although an accurate chronology could not be established for the sequence due to unexpected results with radiocarbon measurements. Pollen accumulation values and composition indicate relatively dry conditions after 3500 BP which were followed temporarily by a wetter climate during more recent times.

**Key words:** Pollen analysis, late Holocene, Namibia, swamp deposits, lake deposits, principal components analysis.

## Introduction

As a result of its position on the west side of the African continent and in the subtropical high pressure system of the Southern Hemisphere, the climate of Namibia is relatively dry (Figure 1). It ranges from extremely arid along its long coastline and southern parts, to sub-humid in the northeast. Vegetation zones correspond to the climatic pattern, with a narrow strip of desert along the west coast changing into dry grassland, open savanna and bushveld savanna above the escarpment towards the east and north.

Although some information about Holocene climate in the region exists (e.g., Vogel, 1989), very little is known about the vegetation history during this and earlier times. Since anoxic lake and swamp deposits which preserve fossil pollen, are very scarce in Namibia, as in other arid and semi-arid regions of the world, successful pollen analysis of sediments has not been possible. Palynological studies attempted on pan sediments from Sossus Vlei in the Namib Desert and on west coast ocean deposits provide virtually no data on Holocene environments (van Zinderen Bakker and Müller, 1987). Van Zinderen Bakker found, however, a useful pollen spectrum in association with the remains of a butchered elephant of about 5200 years old, in spring deposits at Windhoek (MacCalman, 1967).

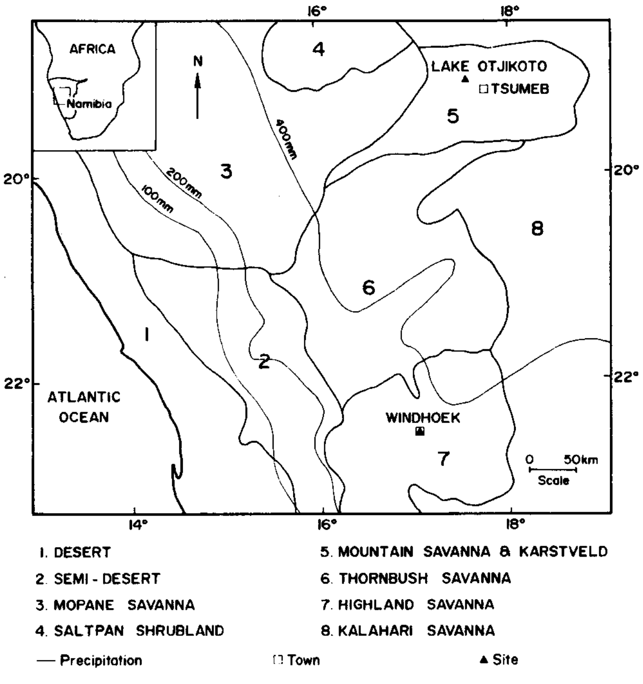

**Figure 1** Locality map of the study area.

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Apart from a potentially abundant new source of fossil pollen in hyrax middens (Scott, 1990a), polleniferous deposits in Namibia have been found in some caves, spring sediments and sinkholes in limestone. This paper deals with the latter two types of material, reporting radiocarbon dates, describing pollen spectra and providing preliminary palaeoenvironmental interpretations of 1) old spring deposits in downtown Windhoek, and 2) sediments in Lake Otjikoto, a >50 m deep karstic sinkhole, near Tsumeb (Figure 1). Although local plant communities differ at the two sites, which are 380 km apart, both occur in woodland areas (Giess, 1971, Figure 1). It is intended here to throw more light on the development of vegetation in this semi-arid to subhumid part of Namibia.

## Windhoek

The town of Windhoek is situated in a basin on the Khomas Hochland, at c. 1700 m above sea-level (Figure 1). The average rainfall is 365 mm, the summers are hot with daily maximum temperatures of about 30°C, while winters are mild, with occasional frost at night. Before modern development, deep circulating, hot ground water (<80°C) emerged from several springs along 1.5 km of a north-south running fault on the western flank of a ridge in the centre of town (Gevers, 1932). This spring water used to seep down the slope towards the present day central business district. After cooling, it must have created a sloping swampy area with a relatively lush vegetation, in comparison with the dry 'Highland Savanna' on the surrounding hills of schist and quartzite (Giess, 1971; SACS, 1980). In the course of time, spring deposits of several metres built up on the slope. In 1961 an elephant kill-site with stone artefacts was discovered in the upper portion of this deposit in the Zoo Park on the eastern side of the main Kaiser Street (Sydow, 1961, 1963; Cholnoky, 1963; MacCalman, 1967; Clark and Haynes 1970). Bone from this elephant was radiocarbon-dated to 5200 BP.

During recent excavations for a large new building between Stübel and Kaiser Streets, some 300 m to the west of the spring fissure, a sequence of spring deposits was exposed underneath 50 cm of modern rubble on the Stübel Street side. From top to bottom, it is composed of 40 cm of light grey sand, 140 cm of dark grey to grey spring silts, and 120 cm of grey diatomaceous material, including about 35 cm of black and dark grey silts (Figure 2).

### Dating

The hot spring water has a considerable age. Two analyses of the carbon in the water gave the following radiocarbon ages: GrN-5292: 20 800 ± 160 BP, Pta-0599: 19 500 ± 170 BP. Aquatics living in this water would thus reveal similar apparent ages, which may complicate the dating of the spring sediments. After sufficient equilibration with the atmosphere lower down the slope, the effect of the old ground water would disappear. Fortunately the $^{13}C$ content of the organic carbon that was radiocarbon dated (Table 1), does not suggest that it is derived from aquatics, and the dates are therefore considered reliable.

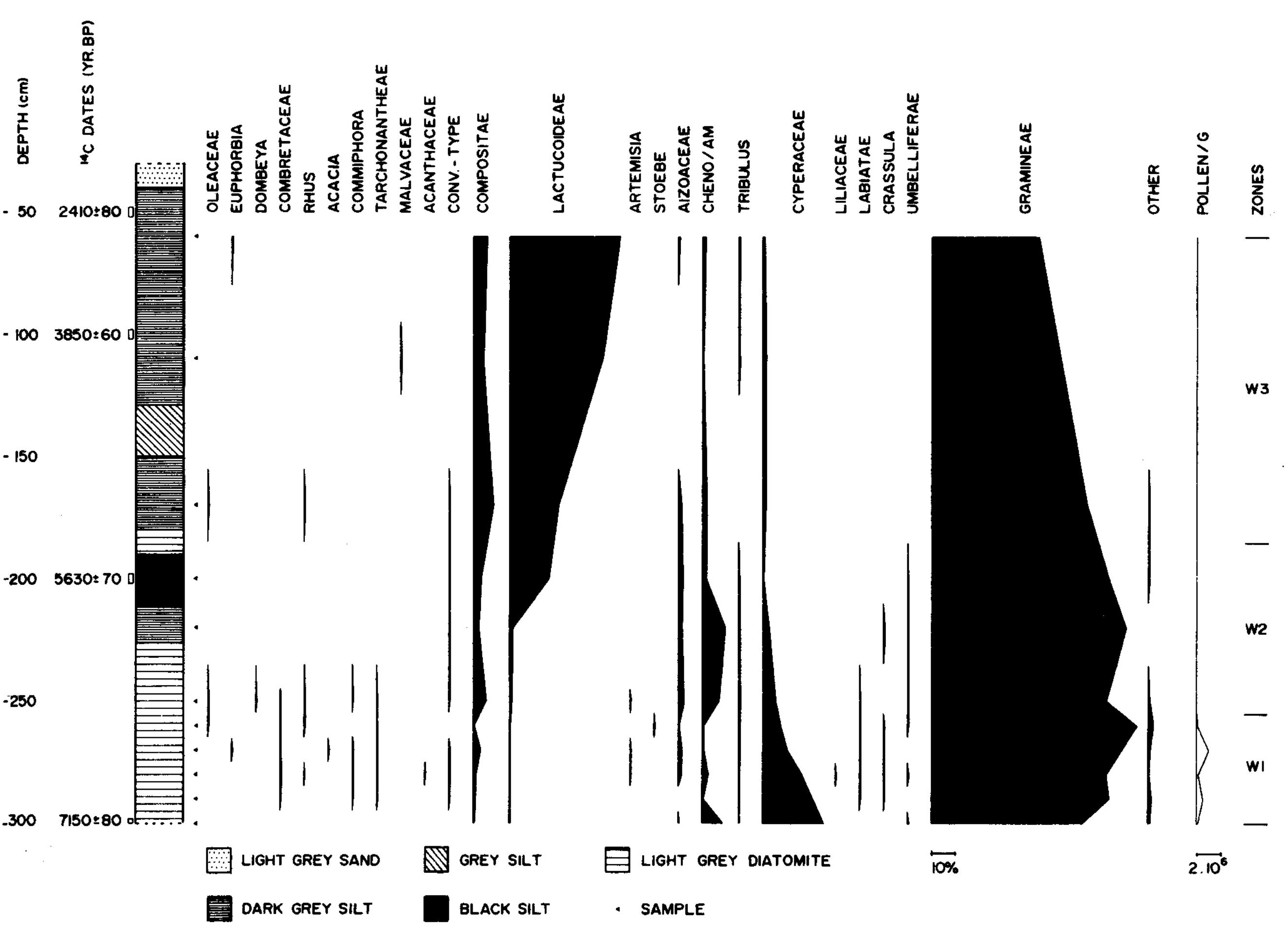

**Figure 2** Pollen diagram of the Stübel Street spring section, Windhoek. Shaded curves show pollen percentages and the open one pollen per gram.

**Table 1** Radiocarbon dates

| Number | Depth | C cont. | $\delta^{13}C$ | Age |
|---|---|---|---|---|
| Windhoek, Stübel Street Section | | | | |
| Pta-5020 | 50 cm | 1.7% | −14.7% | 3750±60 BP |
| Pta-5348$^+$ | 50 cm | 0.6% | −24.0% | 2410±80 BP |
| Pta-5044 | 100 cm | 1.5% | −20.8% | 3850±60 BP |
| Pta-5030 | 200 cm | 1.8% | −23.8% | 5630±70 BP |
| Pta 5179 | 300 cm | 3.2% | −25.6% | 7150±80 BP |
| Lake Otjikoto | | | | |
| Pta-5001 | 20 cm | 5.4% | −14.2% | 2730±40 BP |
| Pta-5375* | 20 cm | 3.2% | −23.8% | 1290±80 BP |
| Pta 4740 | 41 cm | 5.5% | −18.6% | 1830±60 BP |
| Pta 4755 | 94 cm | 6.6% | −15.6% | 3800±50 BP |
| Pta-5013 | 119 cm | 4.3% | −13.0% | 3170±60 BP |

$^+$ more rigorous pretreatment than Pta-5020
* more rigorous pretreatment than Pta-5001

Four levels which looked relatively rich in organic matter were selected for radiocarbon dating. The material was found to contain increasing amounts of calcium carbonate and decreasing amounts of organic carbon towards the top. The results of the radiocarbon analysis are given in Table 1. Initially the uppermost sample, at 50 cm depth, gave a date of 3750 ± 60 BP (Pta-5020) that was inconsistent with the age-depth relationship derived from the other three samples. Re-examination of the material revealed that the chemical pretreatment had been insufficient. More rigorous treatment subsequently produced the date of 2410 ± 80 BP (Pta-5348), which is compatible with the other dates (Figure 3).

The sedimentation rate of the deposit ranges from 0.66 mm/yr between 2 and 3 m depth, to 0.35 mm/yr between 0.5 and 1 m depth.

## Pollen analysis

Only 11 of the 29 samples contained enough pollen for meaningful counts. Pollen concentrations which were measured by the exotic pollen method (Stockmarr, 1971), were found to be high in the lower diatomaceous levels, and poor in the upper silts (Figure 4). Barren samples in the top half of the sequence are responsible for large intervals between records.

Grass pollen is the most important constituent throughout the sequence, while Lactucoideae (Liguliflorae) also assume prominence in the upper section of the sequence. On the basis of its pollen content, the profile can be subdivided into three pollen zones, W1, W2 and W3, from bottom to top (Figure 2).

Zone W1 is characterised by a high proportion of Cyperaceae pollen (up to 25.5%), which declines towards the top of the zone. The Cyperaceae pollen, the diatomaceous nature of the deposits, and the good pollen preservation suggest waterlogged conditions between 7150 and c. 6000 years ago. Some Cheno/Am pollen (Chenopodiaceae and Amaranthaceae) indicates evaporative conditions, possibly in locally dry areas surrounding the swamp. Small numbers of arboreal pollen (AP), including Combretaceae, *Commiphora*, Tarchonantheae and *Rhus*, represent woody elements on surrounding hill slopes.

Zone W2 shows a further decline of Cyperaceae, an increase in Cheno/Am and Compositae pollen, and the gradual increase of Lactucoideae. Together with the nature of the deposits in the zone this indicates that, although swampy conditions persisted locally, there was a degree of drying between ca. 6000 and 5630 BP. AP is present at the base of Zone W2 but not in the upper part.

Zone W3 shows a further increase of Lactucoideae pollen (up to 46.8%), equalling that of Gramineae (44.4%) and is possibly representative of local weed development in the basin between 5630 and 2410 BP.

## Principal components analysis

Principal components analysis of the Windhoek pollen data sheds light on the environmental change which took place at the site. The first component, representing the main change in the sequence, accounts for 40% of the variance in the data. First component weights contrast woody elements, Tarchonantheae (0.34), Combretaceae (0.34) and *Commiphora* (0.31), together with herbs such as Labiatae (0.34), *Artemisia* (0.29), Gramineae (0.29), etc., against Lactucoideae (−0.32) and other Compositae (−0.18). This points to a dichotomy in the sequence between diverse regional and weedy local pollen spectra. A plot of the first principal component (Figure 4) suggests that the most important change in pollen composition occurred during deposition of Zone W2. Apart from the deepest pollen spectrum (300 cm), the lower part of the sequence reflects some regional pollen trapped under waterlogged conditions, while the upper part contains more autochthonic pollen from local weeds (Figure 2).

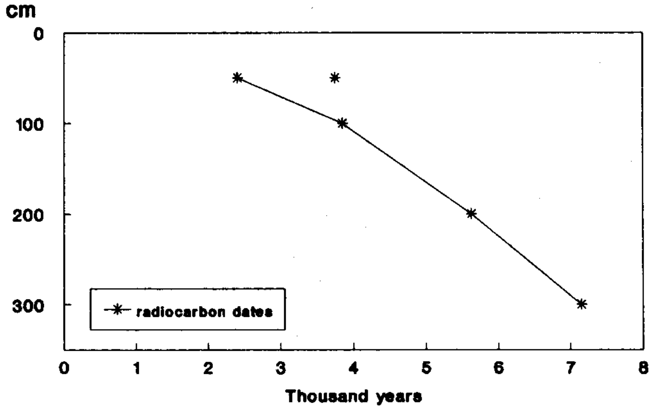

**Figure 3** Radiocarbon dates from the Stübel Street spring section, Windhoek.

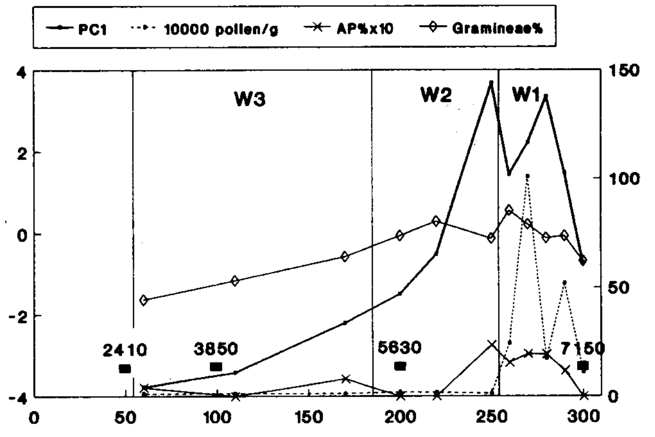

**Figure 4** Principal components values of the Windhoek pollen data (right scale), percentages of selected pollen taxa, and total pollen concentrations (left scale).

### Discussion

The transition from Zones W1 through W3 possibly reflects a change from relatively wet to drier climatic conditions on that part of the slope. The change to more Lactucoideae is difficult to explain in palaeoclimatic terms. In the semi-arid western Orange Free State this group has been found in high numbers in springs of the Late Holocene, associated with moist local conditions (Scott, 1988). The change in the upper part of the diagram could be the indirect result of climatic factors. The relatively large proportion of local elements in these impoverished pollen spectra obscures regional pollen necessary for accurate climatic interpretations.

It is possible that after partial drying of the local spring area at Windhoek, it became either more accessible to grazers and their hunters, or in greater demand by them. The establishment of Lactucoideae, a typical indicator of local disturbance, and other Compositae might be the result of this. If conditions remained relatively dry, strong demands would have been made on the springs, just as in historical times. Local activity is manifested by the elephant butchery, and could have caused erosion in the upper layers. The increase in minerogenic sediments and the inwash of older carbonate are possibly reflected by the original radiocarbon determination at the 50 cm level (Table 1, Pta-5020). At the beginning of the record, before 6000 BP when the region was better-watered, disturbance of the springs might not have been necessary. The possibility of a slight improvement of climatic conditions before the end of the record can, however, not be excluded.

The strong presence in the lower diatomaceous zone of AP which reflects regional vegetation on the surrounding slopes, could be an indication of optimal temperature conditions with a relatively low occurrence of frost between 6000 and 7000 years. AP in the upper layers were rarely recorded but this may partly be due to masking by relatively high proportions of local elements.

## Lake Otjikoto

In the district of Tsumeb (Figure 1) two large sinkholes in dolomite of the Damara Sequence (SACS, 1980) intercept the ground water table as the only permanent open water bodies in the country. One of these, Lake Otjikoto, is situated about 17 km northwest of Tsumeb in subtropical bushveld. The mean annual rainfall in the area is 535 mm, while the average monthly temperature in summer exceeds 33°C. In winter virtually no frost is experienced.

The vegetation of the surroundings belong to the so-called Mountain Savanna and Karstveld (Giess, 1971), with typical bushveld tree genera such as *Combretum*, *Terminalia*, *Sclerocarya*, *Kirkia*, *Ficus*, *Peltophorum*, *Dombeya*, *Ximenia*, *Commiphora*, *Acacia*, *Croton*, *Dichrostachys*, *Boscia*, etc. (Dinter, 1921).

Lake Otjikoto has a diameter of 100 to 110 m and is surrounded by vertical cliffs. The depth of the water in the centre is about 50 m, but this is known to have fluctuated in the past. Due to the vertical sides of bare rock there is practically no vegetation directly associated with the lake.

A 1.3 m core of sediments from a sloping platform at about 52 m depth in the central part of the lake was obtained with the help of the Windhoek Diving Club. The divers pressed an open perspex tube into the soft sediment and sealed both ends after retrieving the core. The tube was later cut open in the laboratory for sampling. The core consisted of a grey homogeneous fine silt with small white and darker specks and vague white laminations between 44 and 65 cm. Apart from some wood fragments and *Acacia* thorns, no other inclusions were recorded.

### Dating

Attempts were made to date the core with radiocarbon, but owing to the small size of the samples it was not possible to chemically pretreat the material thoroughly and the ages obtained are, therefore, not accurate. The inorganic carbon in the water of the lake previously gave an apparent radiocarbon age of 3110 ± 60 (Pta-0077). Aquatics growing underneath this water would thus appear too old by this amount. The results obtained from carbon recovered from four different levels in the core should, therefore, be considered maximum ages, and the younger of the two groups of samples at the top and bottom respectively, are probably closer to the real ages. If the younger dates are accepted the sedimentation rate for the central part of the core would be 0.52 mm/yr. (Figure 5, Table 1.)

### Pollen analysis

Grass pollen is the most important constituent throughout the Otjikoto sequence (Figure 6). Other prominent taxa are *Tribulus*, Cyperaceae, Aizoaceae and those of trees like

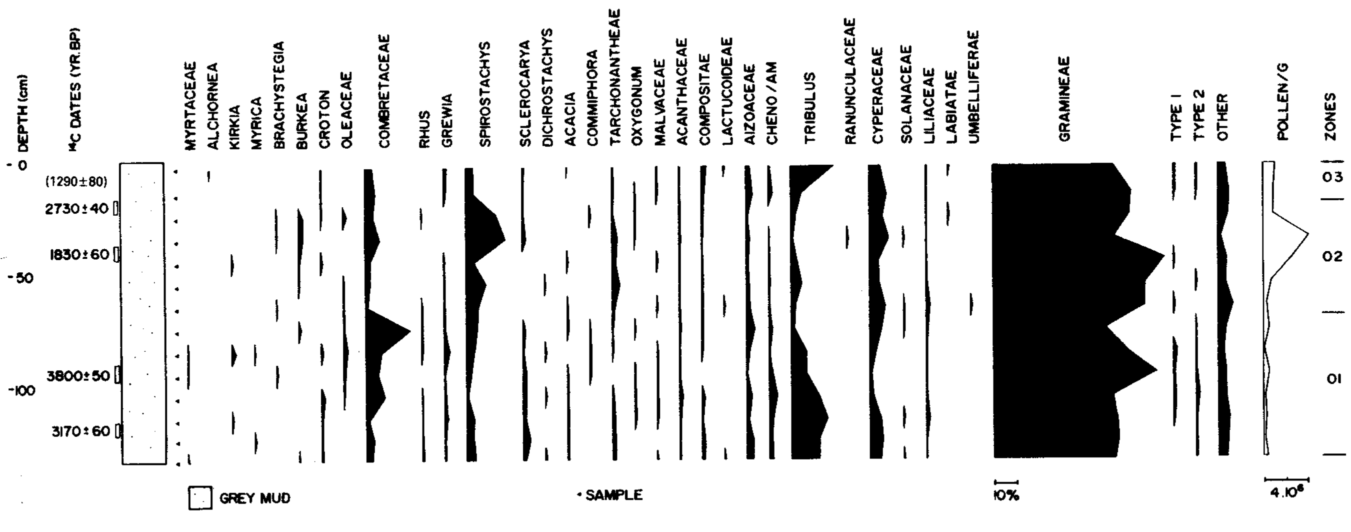

**Figure 5** Pollen diagram of the Lake Otjikoto pollen core. Shaded curves show pollen percentages and the open one pollen per gram.

Combretaceae and *Spirostachys*. The percentages of AP are much higher than at Windhoek because tree cover is denser than in the dry Khomas Hochland and pollen spectra do not contain relatively abundant local swamp pollen. The variation in the pollen spectra is smaller than in the Windhoek sequence as changes reflect regional input from the surrounding savanna veld rather than local succession. Variation in the spectra shows that vegetation changes took place in the surroundings of the lake during the late Holocene. The pollen sequence can be subdivided into three main Zones, O1, O2 and O3 (Figure 6).

The bottom Zone O1 is characterised by strong but declining percentages of *Tribulus* pollen and increasing numbers of Combretaceae pollen, suggesting savanna with incomplete ground cover under warm, relatively dry conditions.

Zone O2 shows a decline in pollen of both *Tribulus* and Combretaceae while *Spirostachys*, Cyperaceae and Tarchonantheae are relatively important. *Spirostachys* attains peak values at the top of the zone where *Burkea* pollen is also present. Zone O2 is apparently representative of slightly more moist climatic conditions than the previous one.

The top Zone O3 again contains higher *Tribulus* pollen percentages while the numbers of tree pollen show no peaks. This is possibly reflective of the moderately dry conditions of recent times.

## Principal components analysis

Principal components analysis of the pollen data from Otjikoto lake helps to describe environmental changes at the site. The first principal component, accounting for 28% of the total variance, allots positive weighting to taxa like Type 2 (unidentified, 0.32), *Grewia* (probably *G. flava*, 0.28), Cheno/Am (0.27), *Tribulus* (0.26), *Croton* (0.24), Type 1 (0.24), other Acanthaceae (0.23) and *Dichrostachys* (0.22), and negative weighting for *Spirostachys* (−0.28), *Burkea* (−0.27), Cyperaceae (−0.22), *Petalidium* (grouped under Acanthaceae in Figure 6, −0.22), Tarchonantheae (−0.13) and Gramineae (−0.1). This contrasts taxa generally associated with dry conditions (positive loadings) against those generally belonging to wetter environments (negative loadings). The plot of principal components in Figure 7 can therefore be taken to show changes in moisture conditions in the savanna surrounding the lake, suggesting that the wettest phase corresponds with the top of Zone O2.

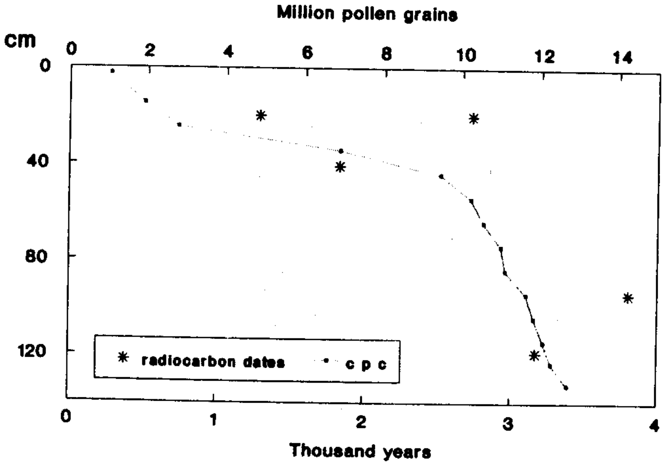

**Figure 6** Radiocarbon dates from the Lake Otjikoto pollen sequence with cumulative pollen concentrations (cpc).

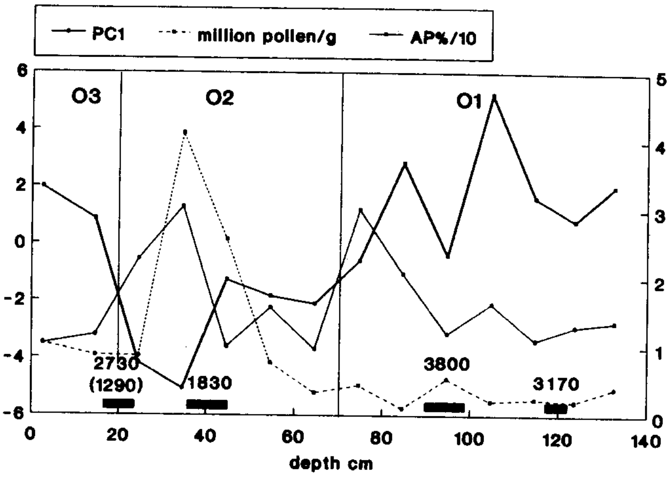

**Figure 7** Principal components values (right scale) of the Otjikoto pollen data, percentages of aboreal pollen (AP), and total pollen concentrations (left scale).

## Discussion

The change in principal component values in the Otjikoto sequence, which is based on all the pollen types in general, suggests that combinations of trees and shrubs with relatively more Combretaceae, *Grewia*, *Sclerocarya*, *Croton* and *Acacia*, as found in Zone O1, are favouring drier environments than communities with more *Burkea*, *Spirostachys* and Tarchonantheae as in Zone O2. The latter two genera have often been associated with dry bushveld plains in the Transvaal (Scott, 1982), so that this interpretation may seem unjustified. *Spirostachys* is, however, common in lower-lying and locally wetter areas of bushveld plains, while *Tarchonanthus* (the concerned genus under Tarchonantheae) has also been found on rocky slopes of cooler subhumid mountains, e.g., in the eastern Orange Free State (Scott, 1989a). These genera are therefore not always confined to dry situations. The subtle environmental changes which determine the proportions of different woody species over relatively short periods in the Holocene, nevertheless, remains difficult to explain.

The calculated cumulative pollen grain count per square centimetre (Middeldorp, 1982) gives a reflection of pollen concentration values (Figure 5). Two alternative explanations for the shape of the curve support deductions based on the pollen spectra. Firstly the possibility of a slower sediment accumulation rate, and secondly that of an increased pollen production rate between 54 and 24.5 cm, are both not in conflict with an interpretation of relatively wet conditions. The wettest indications are between these levels, at the top of Zone O2, implying either denser vegetation with more pollen production, or decreased erosion, or both.

# Conclusion

Together the two pollen sequences from Windhoek and Lake Otjikoto cover large sections of the Holocene. The optimal conditions suggested between c. 7000 and 6000 BP at Windhoek conforms with the results of other southern African pollen sequences (Scott, 1989b; 1990b). However, indications for dry conditions during the time between 8300 and 4200 in the Namib Desert (Heine, 1988; Rust and Vogel, 1988; Vogel, 1989) generally do not agree with the present interpretation.

On the basis of pollen data the wet period suggested at Windhoek is followed by slightly drier local conditions which apparently lasted until 5630 BP. The sediments from the Zoo Park with diatoms, pollen and butchered elephant remains of c. 5200 BP represents a local swamp surrounded by semi-arid savanna under lowered evaporative conditions (MacCalman, 1967; Cholnoky, 1963). Interpretation of the climate which prevailed until 2410 BP cannot be made with any certainty on the basis of the present pollen study although a strong local vegetation change to weedy Lactucoideae occurred, possibly as result of more local demands on the springs by prehistoric inhabitants.

The Otjikoto sequence apparently gives an indication of conditions during later Holocene times, after the formation of the studied sediments from Windhoek. A relatively dry climate seems to have occurred here, after 3500 years ago, which gradually developed into a temporary wetter phase probably before 1000 BP. The significance and timing of this wetter interval at Otjikoto is not clear in view of the uncertainty with the dating and the scarcity of well dated pollen sequences elsewhere in southern Africa for comparison (e.g., Scott, 1988; Scott and Bousman, 1989). It is not certain if the termination of the wet cycle can be associated with indications for desiccation after 900 BP in the northern Namib Desert (Vogel and Rust, 1987; Rust and Vogel, 1988; Vogel, 1989).

## Acknowledgements

We wish to thank the Windhoek Diving Club for extracting the sediment core from under 50 m of water in Lake Otjikoto. The Department of Water Affairs, Namibia, gave assistance with sampling of the Stübel Street section. Dr W. Hegenberger, Geological Survey, Namibia, provided information about the study areas.

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