PALEOLIMNOLOGY OF LAKE BIWA
AND
THE JAPANESE PLEISTOCENE

(VOLUME 11)

(*Edited by;* SHOJI HORIE)

1983

Contribution on the "Paleolimnology of Lake Biwa and the Japanese Pleistocene"No. 530

CONTENTS

PRELIMINARY RECONSTRUCTION OF THE LATE QUATERNARY CLIMATIC HISTORY OF THE CENTRAL NAMIB DESERT, SW AFRICA, BASED ON NEW ^{14}C DATES.

Klaus Heine, University of Regensburg
Department of Geography
P.O.Box 397, D - Regensburg, FRG

1. Introduction

The Namib is a long, narrow desert situated in southwestern Africa between the Atlantic Ocean and the Great Western Escarpment. In the central Namib the desert extends for approximately 140 km inland. The coastal aridity of the Namib desert results from strong, widespread subsidence in the high pressure belt and may be enhanced by the advectional temperature inversion maintained by the onshore winds of the South Atlantic anticyclone.

The remarkable phenomenon of the occurrence of the coastal Namib desert has attracted the attention of scientists for a long time; the age and the origin as well as climatic changes during the Quaternary have in recent years been the focus of much research (VAN ZINDEREN BAKKER 1983).

The question of the late Quaternary climatic evolution in the central Namib has been discussed by several authors (see HEINE & GEYH 1984, VAN ZINDEREN BAKKER 1983, LANCASTER 1983). In particular, the landforms and sediments of the Kuiseb valley have been used to reconstruct Late Quaternary palaeoclimates of the Namib desert. Yet, the Kuiseb has its headwater far outside the Namib desert, so that much of the geomorphic and sedimentary evidence of the Kuiseb valley may not provide the best information for palaeoclimatic reconstructions of the Namib desert. On the other hand, the speleothems of a small cave near the Rössing Berge, about 100 km north of the Kuiseb valley, give evidence for Late Quaternary variations in precipitation. Both, the Kuiseb sedimentary sequence and the speleothems formation, can be used for palaeoclimatic reconstructions. The correlation of both chronostratigraphies provide a scheme of the Late Quaternary history of the Namib which can be tested, modified, improved, or even refuted by future workers.

2. The Kuiseb valley

The Kuiseb drainage system, a component of South West African Atlantic drainage, rises in the Khomas Highlands to cross the central Namib desert and reach the coast near Walvis Bay. In the course of a project to date

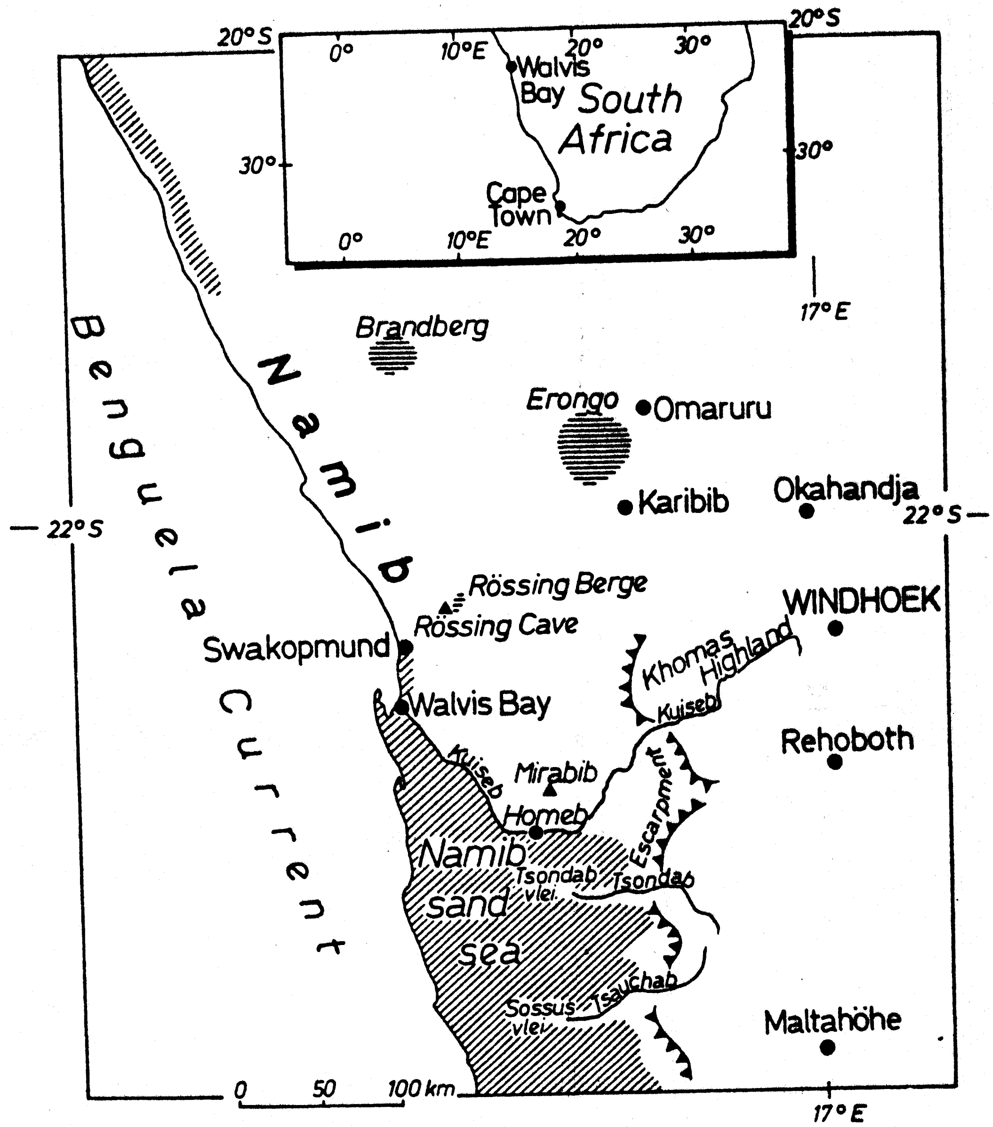


Fig. 1: The central Namib desert. Reference map.

geomorphic features in the Namib desert and by so doing to gradually reconstruct the Late Quaternary climatic history, isotopic and radiometric analyses have been undertaken by VOGEL (1982) on the silt sediments and related deposits in the Kuiseb river canyon at Homeb. These lacustrine silt deposits or vlei sediments have been referred to and discussed by various authors (SCHOLZ 1972, GOUDIE 1972, RUST & WIENECKE 1974, MARKER 1977, OLLIER 1977, MARKER & MÜLLER 1978, HÖVERMANN 1978, RUST & WIENECKE 1980, RUST & WIENECKE 1981, VOGEL 1982, WARD 1982)(Fig.2).

Radiocarbon dates, presented by VOGEL (1982), indicate that carbonate cementation of pebble conglomerate (40 m terrace) and pedogenic calcrete formation took place between 33 000 and 28 000 BP. According to the relatively consistent set of radiocarbon dates the Homeb silt beds were accumulated between ca. 23 000 and 19 000 BP (VOGEL 1982). After the carbonate cementation of the Homeb silts the removal of the 40 m terrace conglomerate must have taken place at or after 28 000 BP (VOGEL 1982). Subsequent to 19 000 BP the silt infilling of the valley was more or less completely removed; in the course of this degradation some of the silt was possibly redeposited as the 12 m terrace (VOGEL 1982). After 19 000 BP - and before the erosion of the Homeb silts - glacis II developed. After the deposition of the 12 m terrace (ca. 9 600 BP ?) glacis I was formed. During the Holocene four small Kuiseb terraces accumulated or were developed as rock terraces respectively. In terrace II a horizon of wood fragments and seeds were dated: 1520±240 BP (Hv 9882).

A scheme of the Late Quaternary sediments, geomorphic processes, and palaeoclimatic evaluation for the Kuiseb valley near Homeb is shown in Fig.3. Absolute dates exists for the following phases: The calcrete development represents a phase of relatively humid and windy conditions. Observations in the eastern Namib indicate that in siliceous substrates calcretes can be formed only by allothic (eolian) increment (BLÜMEL 1982); it can be supposed that more humid conditions (up to ca. 600 mm rainfall?) cause the origin of the ca-horizon by descending infiltrations; more arid phases (up to <100 mm) cause diagenesis and macro-structure (BLÜMEL 1982). Thus the calcrete formation phase between 33 000 and 28 000 BP may document alternating "humid" and arid conditions. During the accumulation of the Homeb silts the climate must have been arid, because the sedimentation took place without participation of local processes expect for eolian

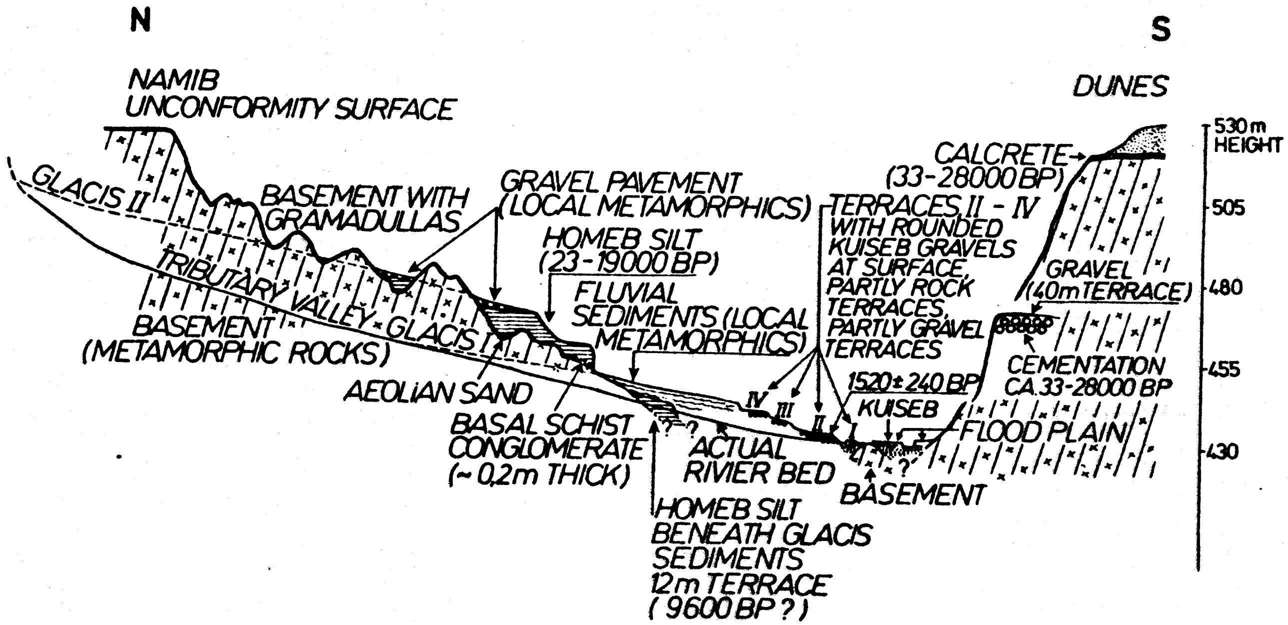


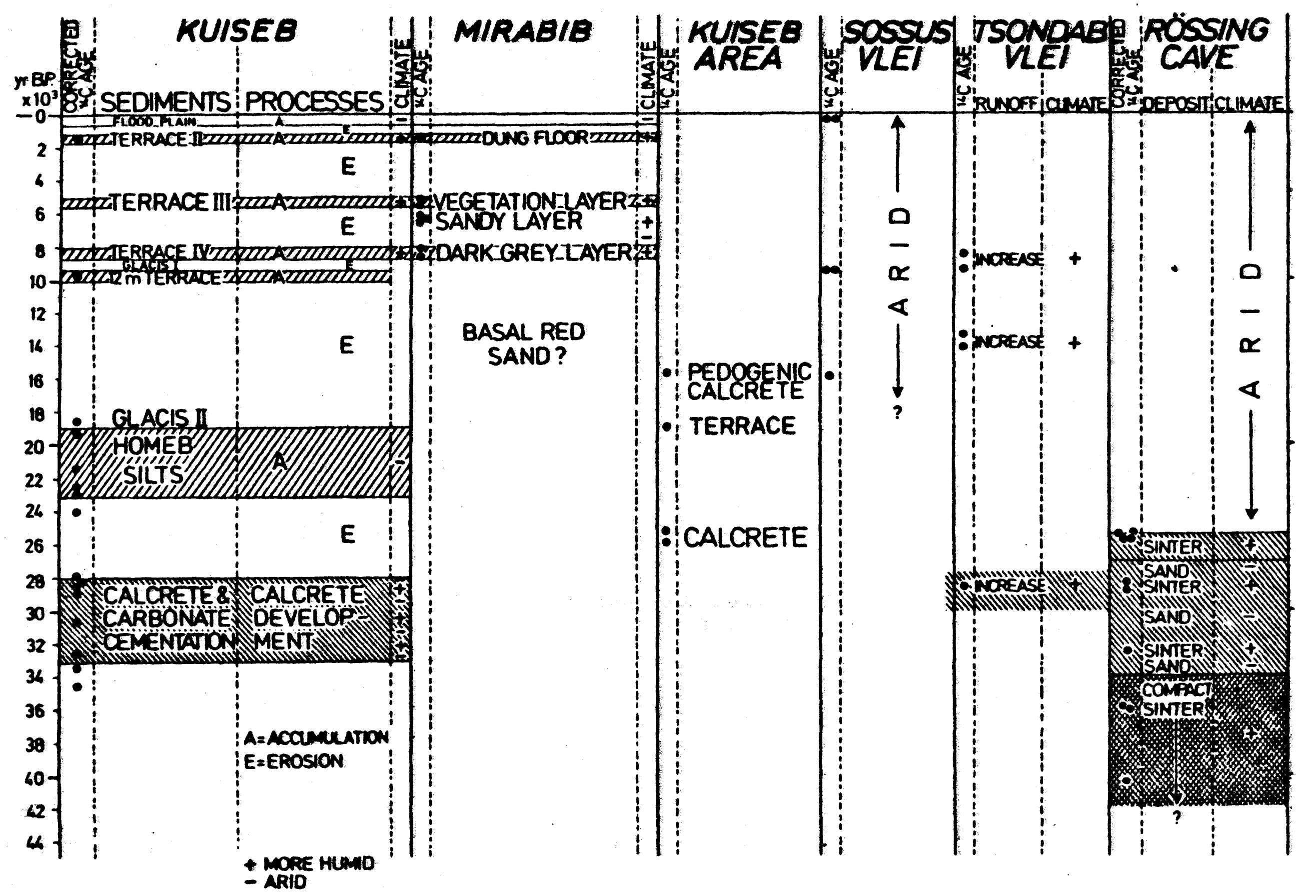
Fig. 2: Schematic cross-section of the Kuiseb river valley.

deposition (HÖVERMANN 1978). The accumulation of the gravels of terrace II occurred about 1500 BP; the gravels derived from the gramadullas document intensiv slope processes (debris formation, see HÖVERMANN 1978). The phase of the terrace II formation was more humid than today.

A correlation of the radiocarbon dated Kuiseb sediments and calcretes with the results obtained for environmental changes at the Mirabib Hill Shelter (SANDELOWSKY 1977)(Fig.3) shows a good agreement of the last moist phase about 1500 BP. The Mirabib dung floor and the terrace II were accumulated at the same time. It was a short but relatively moist phase in the central Namib. Tentatively we may correlate the terraces III and IV of the Kuiseb with the both other moist phases of the Mirabib archaeological site. In doing so we can notice at least three Holocene moist phases in the central Namib: 1500 BP, 5000 - 5500 BP and 8200 - 8400 BP. If the date of the accumulation of the 12 m terrace of the Kuiseb is correct (see VOGEL 1982), then the phase between around 10 000 and 8000 BP was characterised by alternating more "humid" (moister) and arid conditions according to the stratification of silt with local schist gravels in the 12 m terrace.

The Kuiseb evidence for climatic changes should not be regarded as indicative of changes in the central Namib region. The data from the Kuiseb should be seen in relation to other palaeoclimatic data of the central Namib. At the Tsondab Vlei (Fig.3) an increase in runoff occurred about 28 000 BP; the waters could reach a vlei about 10 km west of Tsondab that is now blocked by sand dunes from the Tsondab Vlei. It is not quite clear, whether the Late Glacial around 14 000 BP was moister. An increase in runoff is postulated by LANCASTER (1983). In the Tsondab and Tsauchab radiocarbon dates for vlei silts of 8640 and 9500 BP suggest (LANCASTER 1983) an early Holocene period of increased moisture.

The first results of palynological studies on the central Namib desert (Sossus Vlei) are described by VAN ZINDEREN BAKKER (1983). The conclusions are that the northern part of the Namib erg did not receive significantly more rainfall over the last ca. 18 000 years and that the Tsondab and Tsauchab rivers were blocked by dune invasion prior to 18 000 BP (VAN ZINDEREN BAKKER 1983). According to VAN ZINDEREN BAKKER (1983) the floods caused by stronger (?) precipitation on the escarpment from 19 000 BP onward, which gradually removed the Homeb silts, were not strong enough to force their way through the dune barrier.



<u>Fig. 3:</u> Late Quaternary sequences of the central Namib desert. (See VOGEL 1982 for the Kuiseb, SANDELOWSKY 1977 for Mirabib, BESLER 1980 for the Kuiseb area calcretes, VAN ZINDEREN BAKKER 1983 for Sossus Vlei, HEINE & GEYH 1984 for the Rössing Cave).

It should be realized that there is no evidence during the Late Glacial and Post Glacial by the complex pattern of the Kuiseb river incision/aggradation cycles, changes in sediment load and changes in channel morphology for a major humid/moister phase in the central Namib desert; furthermore, from the geomorphic features of the adjacent areas (Mirabib, Tsondab, Tsauchab, Sossus Vlei) it can be inferred that since the Last Glacial Maximum (ca. 18 000 BP) at least this part of the desert was not affected by more than normal rainfall.

3. The speleothems of the Rössing Cave

Significant conclusions may be drawn from the above data only by comparison with the dates from the Rössing Cave speleothems (HEINE & GEYH 1984). About two kilometers west of the Rössing Berge at about 340 m a.s.l., a small cave system with stalactites, stalagmites, flowstone, popcorn, and other sinter formations reflects the climatic evolution in the vicinity of the Rössing Berge. Two $^{230}Th/^{234}U$ data of speleothems exceeding 300 000 years support the geomorphic evidence that the cave and the oldest sinter formation might be of Tertiary origin. Speleothems from arid regions can be considered as "closed systems" in respect to carbon isotopes. Therefore, such samples are most suitable for ^{14}C dating. The calibration uncertainty of the data is about $\pm$ 1000 yr. Inspite of this, ^{14}C ages seem to be more reliable than that of any other samples from the Namib desert as calcretes or fluviatile sediments which are often diagenetically changed (see HEINE & GEYH 1984).

The results of radiometric datings together with that of sedimentologic observations at the sampling sites yield a rather differentiated Late Quaternary evolution of the climate in the central Namib desert. Various phases can be distinguished for the Middle Weichselian pluvial and the time until now (HEINE & GEYH 1984). Phase 5 ($>$ 40 500 - 34 000 BP, see Fig.3) was a "humid" phase with a closed plant cover in the central Namib desert; compact sinter formation as well as popcorn development indicate moist condition in the cave. Phase 4 (34 000 - 27 000 BP) was the beginning of the aridification in the central Namib. At least three noticeable climatic fluctuations occurred with alternating arid and more humid conditions. This is indicated by a sequence of thin sinter and sand layers. Phase 4 corresponds with the phase of calcrete formation and carbonate cementation in the Kuiseb river valley. During phase 3 (ca. 27 000 - 25 500 BP) again "humid" conditions dominated.

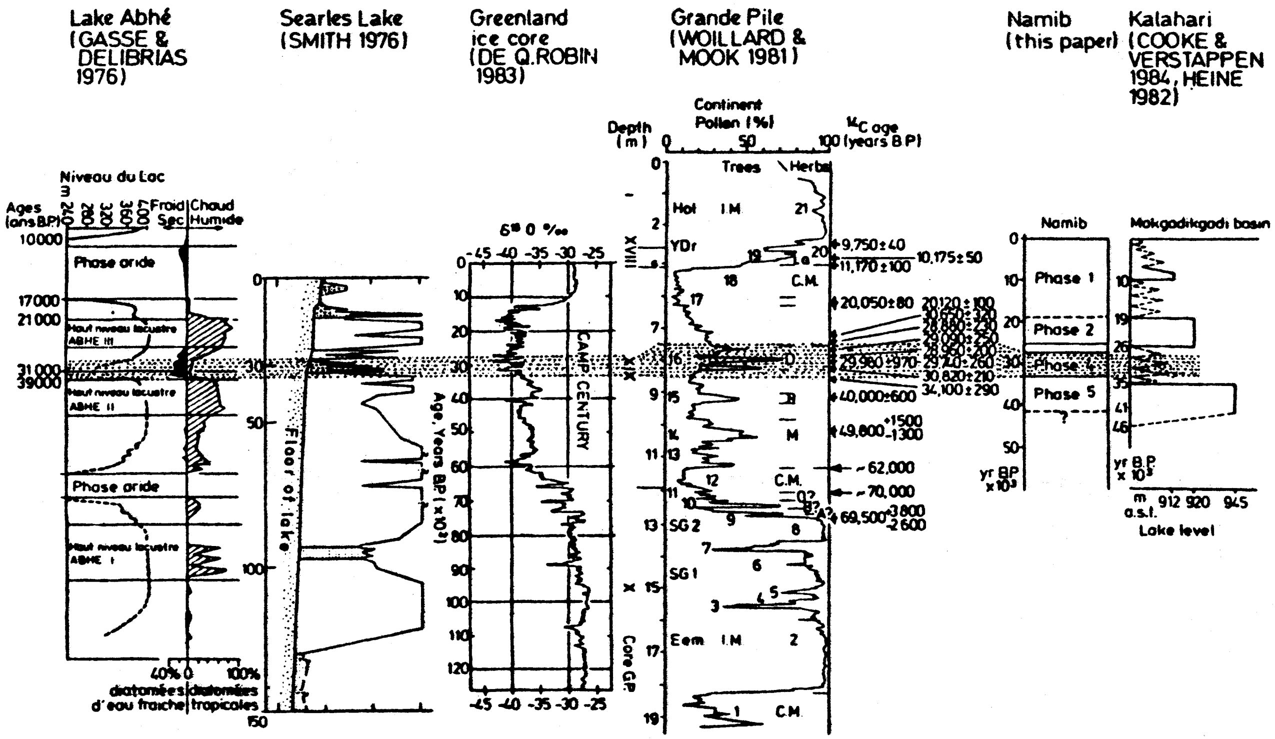


Fig. 4: Correlation of phase 4 (34/33 000 BP - 27 000 BP) with selected sequences from various regions.

From phase 2 onwards (25 000 - 19 000 BP), the central Namib desert prevailed dry. No further sinter formation occurred in the Rössing cave. In the Kuiseb valley the Homeb silts were accumulated. There is no evidence according to the Rössing cave data that during phase 1 (after 19 000 BP) the central Namib desert experienced other than arid climates.

4. Discussion

A key feature of palaeoclimatic reconstructions derived by the interpretation of fluvial stratigraphic sequences is to realize the climatic influence on the geomorphic and sedimentologic phenomena of the area close to the section on one hand and of distant regions on the other hand. The comparison of the Kuiseb valley sequence with the chronostratigraphies of adjacent areas may help to solve this problem. The cave speleothems reflect the local conditions in humidity of the central Namib desert. So do the calcretes and carbonate cementation processes in the Kuiseb valley.

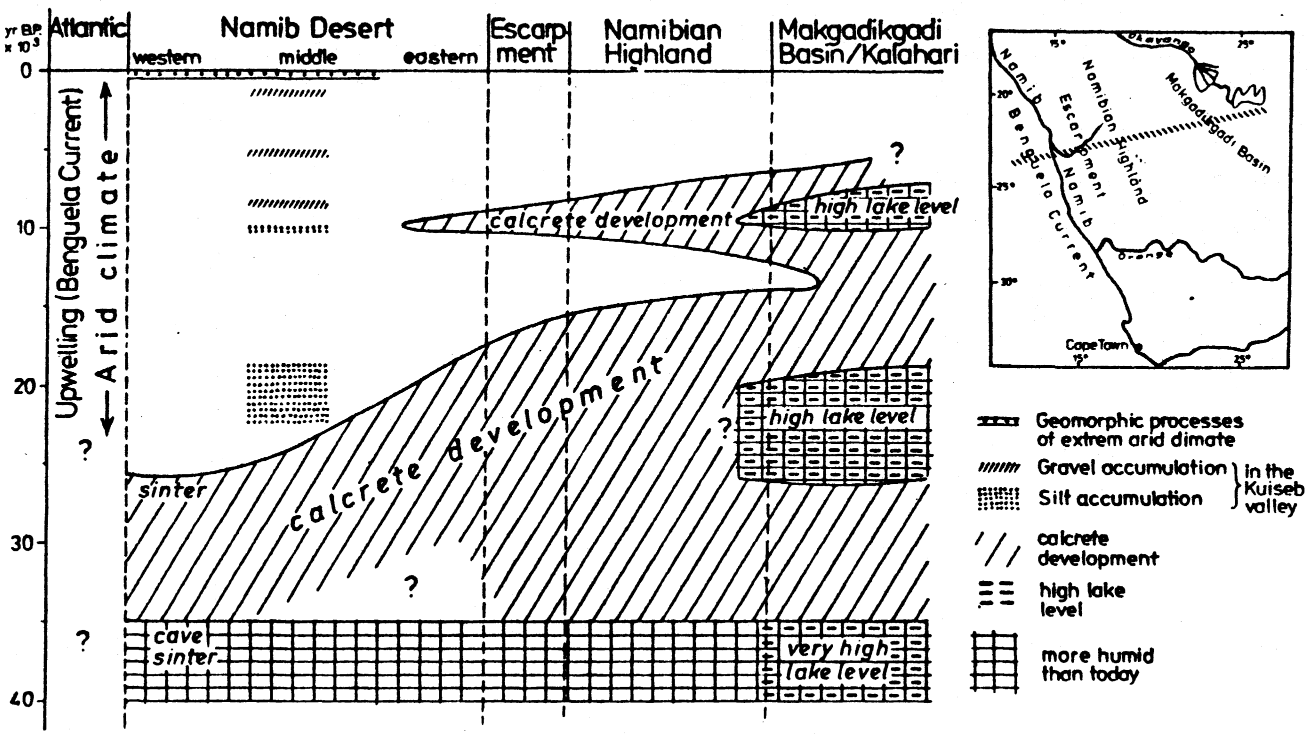
Owing to the data (Fig.3), relatively humid climatic conditions prevailed between >40 500 BP and 34 000/33 000 BP not only in the central Namib desert but also in the interior of southern Africa (COOKE & VERSTAPPEN 1984).

The phase between 34 000/33 000 BP and ca. 27 000 BP must have had climatic conditions controlled by alternating arid and "humid" stages. This ties in with observations about calcrete development in the eastern Namib (BLÜMEL 1982), the ages of the last calcrete generation (BLÜMEL 1982, VOGEL 1982), and the alternating lamination of eolian sand horizons and flowstone layers (HEINE & GEYH 1984). The broad picture of phase 4 (Fig.4) with alternating arid and "humid" conditions in the central Namib desert is, however, amply confirmed by studies of lake level fluctuations and climatic phases of the western Makgadikgadi basin, Kalahari region (HEINE 1982, COOKE & VERSTAPPEN 1984), Lake Abhé, central Afar (GASSE & DELIBRIAS 1976), Searles Lake, California (SMITH 1976), of climatic record from Greenland ice cores (DE Q.ROBIN 1983), and of the chronology for the continuous continental pollen record of Grande Pile, France (WOILLARD & MOOK 1981). The three sand layers of phase 4 of the Rössing sinter section reflect three stages during which eolian sand was accumulated in the cave; at that time the climate oscillations are well correlated with the oscillations of the oxygen isotope profile from Camp Century between about 33 000 and 27 000 BP and of Grande Pile pollen diagram between 34 000 and 28 000 BP. As a result of this worldwide correlation, the interval between about 34 000 and 27 000 BP seems to be a unique Late

Quaternary climatic phase without any parallel situation since about 40 000 BP until today. In Lake Abhé, the high level stages II and III are separated by sediments that clearly differ by their physico-chemical and biological traits from other sediments (GASSE & DELIBRIAS 1976). The corresponding statigraphic unit in Searles Lake is characterized by a unique sequence of interbedded salines and mud (SMITH 1976). Furthermore, the calcretes and the carbonate cementations of the Kuiseb valley sediments as well as the sandy layers of the Rössing cave section prove that only the interval between 34 000 and 27 000 BP experienced arid and extremely windy conditions; during the Late Quaternary period no other phase was characterized by a similar eolian sand transport over the Namib surface. Wind erosion forms (SWEETING & LANCASTER 1982, SELBY 1977) and data derived from Landsat images indicate high velocity palaeowinds from NNE during times of eolian sand transport. Because after 27 000 BP wind-blown sand has no longer entered the Rössing cave and because there is no evidence that after 28 000 BP large quantities of eolian sand were blown by northeasterly palaeowinds into the Kuiseb valley, we assume that the last phase with strong winds from NNE corresponds to the interval between 34 000 and 27 000 BP. Observations off South West Africa from the Walvis Ridge can be attributes to our conclusions: detailed down-core analysis and accumulation rates of quartz do not suggest any systematic difference between Holocene and Last Glacial times (18 000 BP) (KOLLA, BISCAYE & HANLEY 1979, see also CARTINI & TISSOT 1982). We interpret this with regard to the arid climatic conditions that can be deduced from the Kuiseb sediments and Rössing cave speleothems since about 25 000 BP, that the wind might have been blowing onshore rather than offshore during Last Glacial Maximum times.

Phase 3 (27 000 - 25 500 BP) can only be traced by the sinter formation in the Rössing cave (HEINE & GEYH 1984). During this phase, erosion took place in the Kuiseb valley. Calcretes of the youngest generation (BLÜMEL 1982, NETTERBERG 1978) may date to this phase.

Phase 2 (25 500 - 19 000 BP) and phase 1 (19 000 - Present) are not characterized by variations in humidity in the central Namib desert. Neither sinter development occurred in the Rössing Cave (HEINE & GEYH 1984) nor did the central Namib receive more rainfall according to the pollen studies of Sossus Vlei (VAN ZINDEREN BAKKER 1983). The different incision and aggradation cycles of the Kuiseb river, the Tsondab, and Tsauchab were controlled by the climatic or rather environmental situation of the eastern Namib, the escarpment, and the Khomas Highland. At least three minor hygric variations to



<u>Fig. 5:</u> Time-transgressive diagram with periods of calcrete formation, sinter development, lake level fluctuations etc. for southern Africa about 20 - 25° S.

moister conditions in the central Namib during the Holocene are documented by the three radiocarbon dated organic horizons of the Mirabib Hill Shelter that may correlate with three terraces of the Kuiseb river. Since about 500 BP evidence for greater aridity in the Namib desert comes from a variety of sources, such as the Mirabib Site (SANDELOWSKY 1977, BRAIN & BRAIN 1977) and Sossus Vlei where about 600 - 550BP *Acacia* trees died and deflation of vlei sediments started; archaeological material older than ca. 500 BP is very frequent in the Namib desert compared with archaeological sites of the last 500 years.

A time-transgressive diagram with the periods of calcrete formation, sinter development, lake level fluctuations etc. for southern Africa about 20 - 25^{o}S is shown in Fig.5.

5. Conclusions

1. During the Late Pleistocene, the available dated evidence for the central Namib desert makes certain that the phase from 40 500 BP and a little earlier to 34 000/33 000 BP was considerably wetter than today.

2. During the period 33 000 BP to 27 000 BP calcrete development and the interbedding of eolian sand and flowstone in cave sediments prove alternating arid/windy and moist periods. This phase is characterized by unique climatic conditions from all over the world.

3. After a short moist phase between 27 000 and 25 500 BP the central Namib desert remained arid until today.

4. Several short periods with somewhat moister conditions occurred during the Holocene. The climate in the central Namib desert has fluctuated since ca. 25 500 BP about a generally arid mean, becoming drier in the last five centuries.

5. The Kuiseb river incision and aggradation cycles (terraces, glacis, sediments) are not suitable for a reconstruction of Late Quaternary palaeoclimates. Only the calcretes and carbonate cementations may be interpreted in connection with the speleothems.

6. The geomorphic and sedimentary evidence provide a detailed record of local, regional, and global climatic fluctuations. Tentative correlations with chronostratigraphies from neighbouring areas only can imply the extent of climatic change.

7. The pluvial record from the central Namib desert provides data on time-transgressive variations in humidity.

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Acknowledgements

The author is grateful to M. A. Geyh (Hannover) for radiocarbon age determinations and the DEUTSCHE FORSCHUNGSGEMEINSCHAFT for financial support.