The Main Stages of the Late Quaternary Evolution of the Kalahari Region, Southern Africa

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Klaus Heine
Universität Regensburg

THE MAIN STAGES OF THE LATE QUATERNARY EVOLUTION OF THE KALAHARI REGION, SOUTHERN AFRICA

KLAUS HEINE
Lehrstuhl Physikalische Geographie, Universität des Saarlandes, Saarbrücken

ABSTRACT

The palaeogeographical and palaeoclimatic development of the Kalahari region provides strong evidence that South African climatic changes in precipitation and temperature, as well as in surface winds are closely related to variations in intensity of the general circulation rather than in shifts of the climatic belts.

According to the great diversity of palaeoclimatic evidence, the palaeoclimatic reconstruction is incomplete. Further finds of datable material will supplement this record and possibly add to the complexity of the evidence.

The Middle Wisconsin interstadial period is characterized by pluvial conditions in the Kalahari (>30,000-ca.19,000 yr BP).

Last glacial maximum climatic conditions prevail between ca.19,000 and 13,000 yr BP. A large increase in meridional and, over southern Africa, in W-E temperature gradients cause a change in the frequency of occurrence and in velocity of winds. The last glacial maximum was more arid in South West Africa than today, but more humid in the southern Kalahari than today. It is not quite clear whether the phase of greater glacial humidity in the Kalahari is restricted to only a short time span, probably between ca.17,000 and 15,000 yr BP.

The period between ca.13,000 and 10,000 yr BP presents the transition from glacial climatic conditions to the post-glacial climatic optimum.

During the Holocene temperature maximum around 9,500 yr BP geomorphic and palaeopedologic features indicate wetter conditions in the Kalahari.

The results show that different palaeoclimatic indicators (geomorphic, sedimentological, palaeobotanical, palaeontological, archaeological, etc.) yield different time-stratigraphic periods for the Late Quaternary. That may be the reason, apart from the fact that many deposits have alternative explanations, that a great variety of palaeoclimatic and palaeogeographic reconstructions exist for southern Africa.

INTRODUCTION

Late Quaternary geomorphological and climatic reconstructions for the

Kalahari region have, until now, depended largely upon the implications of evidence derived from areas outside the Kalahari, especially from the Cape Province, the Orange Free State, and Transvaal, and from East Africa (Figure 1). This evidence has been reviewed by Van Zinderen Bakker (1976) and Butzer et al. (1978). Butzer et al. (1978) come to the conclusion, that the palaeoclimatic record of much of the Kalahari region is long, complex informative, and distinctive; this broad climatic province responded differently to global circulation anomalies than did other African areas. Inter-regional comparisons show both similarities and deviations that should serve as a basis for a creative palaeoclimatic model. In glacial times the Benguela Current, which largely controls the arid climate of southwestern Africa, had a greater vigour and an even more aridifying effect upon the coastal regions (Namib desert) than it had in interglacial times (Gardner & Hays 1976, Selby, Hendy & Seely 1979). In the southern Kalahari moist intervals (glacial times) were primarily, although not exclusively, a response to variations in the penetration and persistance of summer, rather than winter rains (Butzer et al. 1978, Lancaster 1979). Furthermore, the Late Quaternary lake-level fluctuations of the Makgadikgadi basin indicate a huge palaeo-lake from about 30,000 to 19,000 yr BP and about 12,000 yr BP and a low lake-level (the lake dried out) between 19,000 and 12,000 yr BP (Heine 1978a, b).

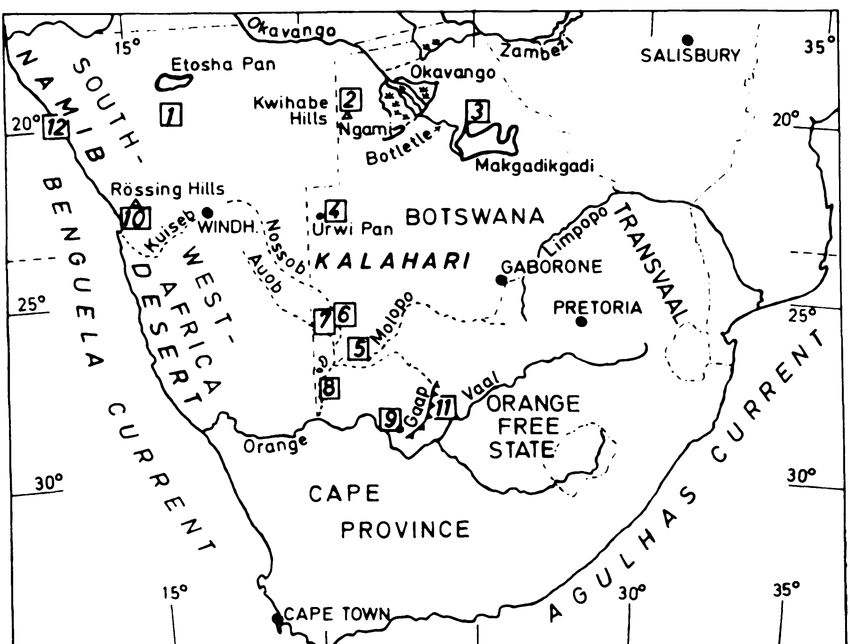


Figure 1. Locality map. The numbers (1) to (12) refer to Table 1.

In this paper I present some conclusions from geomorphogical studies in the Kalahari region. I provide evidence that, although there are many contradictions concerning the interpretation of the geomorphological observations and facts, it is now possible to reconstruct the main phases of the Late Quaternary evolution of the Kalahari region.

THE KALAHARI REGION

The Kalahari extends from the Okavango river in the north to close to the Orange river in the Republic of South Africa in the south. The Kalahari is situated on a plateau generally more than 1,000 m above sea level in Botswana, eastern South West Africa/Namibia, the northern Cape Province, and northwestern Transvaal. It is flat or gently undulating, with sand dunes more frequently occurring in the southwest. The true Kalahari is a huge sand-filled basin (De Vos 1975). The zone is semiarid. Rainfall is erratic, confined mainly to the period November to April and decreases from about 500 mm annually in the north and east to about 200 mm in the southwest. From 22° latitude southward the zone is covered with dry grassland and savanna, receiving only little and unreliable rainfall (De Vos 1975, Diem 1977). The summer climate is dry and continental. Scarcity of surface water and poor soils are the main limiting factors to vegetative growth (Cole & Brown 1976, Werger 1978). Ground waters in the northern Kalahari are directly, and in some cases rapidly, recharged by rain (Verhagen, Mazor & Sellschop 1974). Surface water is available in only a few areas for a short time after the rains, when it collects in pans or shallow depressions. These pans play an important role in the ecology of the area (De Vos 1975). With the exception of the Botletle river, which takes off from the Thamalakane river at the margin of the Okavango swamps and flows east and then south into the Makgadikgadi basin, there are no rivers between the swamp zone in the north (Okavango swamps of Ngamiland, Chobe and Linyanti swamps and Zambezi swamps in Barotseland) and the Orange river in the south. In Botswana the Kalahari forms a broad watershed between the Okwa and Mmone dry river systems (Bakalahari-Schwelle), which are directed towards the Makgadikgadi depression (Okwa), and the Nossob and Molopo, both of them dry rivers, which form the southern border of Botswana. Here the principal geomorphic features are the thousand or so small pans which break the monotony of this otherwise almost featureless sand plain (Lancaster 1978). Detailed descriptions of the physiography of the Kalahari are available elsewhere (Passarge 1904, Wellington 1955, Grove 1969, Grey & Cooke 1977, Wright 1978).

THE MIDDLE WISCONSIN (MIDDLE WEICHSELIAN) INTERSTADIAL PERIOD

The reconstruction of the palaeogeography and the palaeoclimatology of the Kalahari is based on radiocarbon dating (Van Zinderen Bakker 1976, Grey &

Cooke 1977, Heine 1978a, Lancaster 1979); therefore the critical question is to what degree radiocarbon determinations are of real chronometric value. I will not discuss this problem here (Rafter 1975).

From the Kalahari region only a few stratigraphically consistent ^{14}C dates are known. Cooke (1975), Grey & Cooke (1977) and Cooke & Verhagen (1977) report on ^{14}C dated sinter from Drotsky's cave in western Ngamiland (Botswana) and calcretes from the adjacent area; the dates range from 22,700 ± 500 yr BP to > 45,000 yr BP for the old calcrete CI and CII and from 29,300 ± 1,000 yr BP to > 45,000 yr BP for cave sinter SII; the ages are likely to be infinite and should be regarded with appropriate caution. According to Cooke (1975) and Grey & Cooke (1977) a major wet phase occurred in western Ngamiland before the SIII sinter deposition which is dated 16,000-13,000 yr BP. During this major wet phase a high water-table flooded the old cave passages, resulting in extensive enlargement and the concomitant removal of much of the SII sinter.

This major wet phase prior to about 16,000 ± 200 yr BP (corrected age, Cooke & Verhagen 1977) or 17,300 ± 200 yr BP (conventional age, Cooke 1975) can probably be correlated with a major highstand of Lake Palaeo-Makgadikgadi, which is dated between 19,170 ± 660 and > 30,250 ± 520 yr BP (Heine 1978a). The distribution of lacustrine deposits and molluscs in the Ngami/Makgadikgadi area indicate quite clearly that the 30,000-19,000 yr BP high lake-level belongs to the most extensive lake which existed during the Late Quaternary (ca.40,000-0 yr BP) and which might correspond to the 945 m level mentioned by Grey & Cooke (1977).

The evidence for greater humidity during the period 30,000-19,000 yr BP is not confined to the Makgadikgadi basin. In the southwest Kalahari between the Auob and Nossob dry valleys (25°56′S, 20°25′30″E), a fossil soil buried under red sand dunes and a calcrete layer, was found (Figure 3). The ^{14}C age of this soil of $28{,}000^{+4{,}900}_{-3{,}020}$ yr BP (Hv 9502) is methodically reliable (personal communication Prof. M.A.Geyh, Hannover). The fossil A-horizon that is rich in organic matter indicates wet conditions during the period of soil formation.

Furthermore, stromatolite-like concretions of the surface of Klein Awas Pan (26°34′S, 20°28′30″E) yield a radiocarbon age of $23{,}410\ ^{+980}_{-875}$ yr BP (Hv 9885), thus documenting more humid conditions in the southwest Kalahari.

In the northwest Kalahari, the age of a mollusc-rich tufa is 22,250 ± 330 yr BP (Hv 9883); the tufa is situated at the southern shore of the Etosha Pan, northwest of Homob. Although there is no evidence for a fossil lake shore, this dated tufa layer represents a higher water-level of the Etosha Pan.

At the Gaap Escarpment (southern Kalahari margin, South Africa) a chronostratigraphy for the last 30,000 yr BP is provided by ^{14}C dating (Butzer et al. 1978); the last Pleistocene cold-moist interval began after 35,000 yr BP and ended 14,000 yr BP. About 150 km southwest of the Gaap Plateau lacustrine chalk of a large pluvial lake was dated at 24,890 ± 695 yr BP (Hv 9504); this means an additional indication for wetter conditions compared with today.

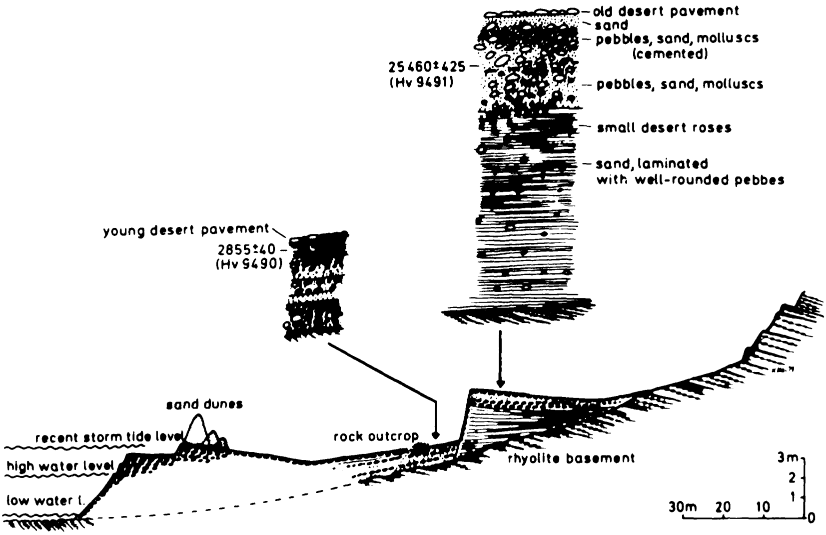
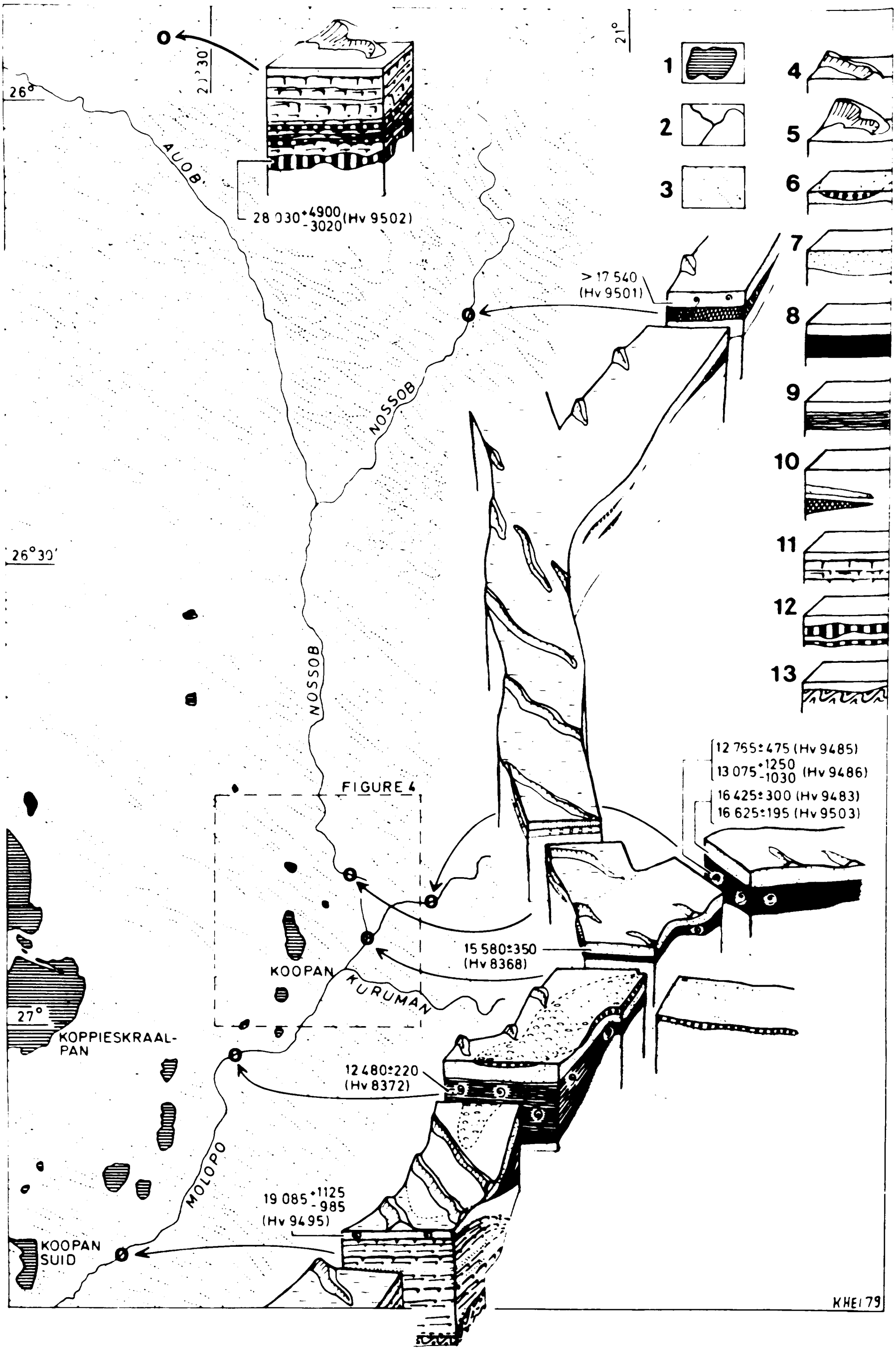


Figure 2. Cross-section of Terrace Bay beach and nearshore region.

According to ^{14}C dating of molluscs, the youngest fluvial sediments of the Molopo river near Koopan Suid (27°14'S, 20°22'30"E) were deposited about $19{,}085 ^{+1{,}125}_{-985}$ yr BP (Hv 9495). After the deposition of the mollusc bearing fluvial sands, white sand dunes were formed in the dry river valley (Figure 3), thus indicating that the last wet phase with fluvial sedimentation ended about 19,000 yr BP. A similar development of the fluvial sediments can be proved for the Nossob valley north of Twee Rivieren (26°13'30"S, 20°48'30"E). Fragments of molluscs which were found in the youngest fluvial layer of sand date > 17,540 yr BP (Hv 9501).

A further evidence for widerspread more humid conditions about 25,000 yr BP in the Kalahari region and adjacent areas comes from the Namib desert. In a small cave west of the Rössing Mountains near Swakopmund, cave sinter is deposited. Although the investigations of this sinter deposit are not finished yet, the first obtained ^{14}C ages of the youngest cave sinter yield 26,530 ± 920 yr BP (Hv 9489), 26,680 ± 540 yr BP (Hv 9910), and $29{,}680 ^{+1{,}480}_{-1{,}250}$ yr BP (Hv 9909). The cave sinter was also dated by $^{230}Th/^{234}U$ to > 300,000 yr BP (two ages determinations). Yet it is not known why the ^{14}C and the $^{230}Th/^{234}U$ age determinations differ so much from each other. Further investigations concerning the absolute age of the Namib cave sinters are under way.

It is of great interest that the youngest sinter of the Namib cave seems to be of the same radiocarbon age as a eustatic high sea-level stand in the coastal Namib desert. Wienecke & Rust (1975) obtained radiocarbon dates of Middle



26°
21°30'
21°
26°30'
27°
AUOB
NOSSOB
NOSSOB
KURUMAN
MOLOPO
KOOPAN
KOPPIESKRAAL-PAN
KOOPAN SUID
FIGURE 4
28 030 +4900 -3020 (Hv 9502)
> 17 540 (Hv 9501)
12 765±475 (Hv 9485)
13 075 +1250 -1030 (Hv 9486)
16 425±300 (Hv 9483)
16 625±195 (Hv 9503)
15 580±350 (Hv 8368)
12 480±220 (Hv 8372)
19 085 +1125 -985 (Hv 9495)
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Weichselian age (ca.26,000 yr BP) for the last high stand of the sea-level (ca.2 m above the recent storm tide level). This high sea-level is documented by a fossil beach which can be traced from the Swakopmund area northward to the Skeleton Coast. About 1 km south of Terrace Bay Diamond Mine this high sea-level was dated to 25,460 ± 425 yr BP (Hv 9491) (Figure 2). Yet the assumption that the sea-level at about 25,000 yr BP is comparable with that of the present, may result from errors involved in ^{14}C dating (Geyh, Kudrass & Streif 1979).

THE LAST GLACIAL MAXIMUM

A reconstruction of the palaeogeography and palaeoclimatology of the Kalahari during the last glacial maximum is difficult, partly because of the lack of absolutely dated sediments and molluscs, and of landforms of clear palaeoenvironmental significance.

The first radiocarbon dates of the Kalahari region were published by Cooke (1975). From the study of Drotsky's cave in the Kwihabe hills and the deposits it contained, the Kwihabe valley and its calcretes, and the incidence of faulting in the hills, a sequence of stages of development of these landforms and accumulations, linked to a series of climatic changes is postulated. Two of these stages have been dated by ^{14}C age determinations on cave sinters. Cooke (1975) assumes that one major wet phase appears to have been contemporaneous with the last glacial maximum. In this connection Cooke & Verhagen (1977), Grey & Cooke (1977), and Cooke (1979) refer again to the dates that indicate caves sinter formation between 16,000 and 13,000 yr BP. Wet conditions during the last glacial maximum should not only be proved by the cave sinters but also by associated geomorphic features both inside and outside the cave. A re-interpretation of Cooke's observations suggests that the time of valley re-excavation with erosion and cave enlargement in the Kwihabe hills does not correspond to the last glacial maximum as Cooke (1979) assumes, but to the pluvial period between 30,000 and 19,000 yr BP (Heine 1979).

High lake-levels in the Makgadikgadi depression some 18,000 yr BP are reported by Street & Grove (1976). The same authors (Street & Grove 1979) recently presented selected world maps of lake-level fluctuations, showing

Figure 3. Schematic sections of Late Quaternary dry valley deposits in the southwest Kalahari.
1 – Pan; 2 – Dry valley; 3 – Dunes; 4 – Dunes in dry valleys; 5 – Longitudinal dunes (Upper Pleistocene); 6 – Recent to subrecent fluvial sediments; 7 – Late Pleistocene fluvial deposits; 8 – Fluvial deposits of last glacial maximum age (c.18,000-12,000 yrs BP); 9 – Lacustrine/fluvial deposits of last glacial maximum age; 10 – Late Pleistocene fluvial deposits (>18,000 yr BP); 11 – Calcretes (Late Pleistocene); 12 – Palaeosol (Middle Wisconsin); 13 – Schist.

for the period 18,000-17,000 yr BP a low lake status for the Makgadikgadi depression.

Lancaster (1979) postulates a widespread last glacial maximum humid period in the Kalahari. He suggests that ^{14}C dates obtained from stromatolites recovered from a site 1-1.5 m above the present level of Urwi Pan indicate that shallow lacustrine conditions prevailed in the pans 17,000-15,000 yr BP.

For the Gaap Escarpment region Butzer et al. (1978) give evidence for sub-humid conditions according to a regional stratigraphy which is based on morphological context, facies sequences, tufa diagenesis, and ^{14}C dates.

The results of a preliminary attempt to establish the age of a series of Late Quaternary sediments and fluvial deposits in the Kalahari have been reported earlier (Heine 1978a, b). In the Ngami/Makgadikgadi basin there are several indications for erosional and depositional processes caused by surface water between ca.19,000 and 12,000 yr BP. In the Ngami/Makgadikgadi area these are represented by fine sands, interbedded with layers of calcareous clay and silt; these deposits are free of molluscs, but contain occasional components of the red aeolian Kalahari sand. The morphology and sedimentology of these deposits testify to their fluvial origin; between 19,000 and 12,000 yr BP episodical runoff of the Okavango waters to the Makgadikgadi pans must have occurred. Sixteen stratigraphically consistent ^{14}C dates have been obtained from deposits underneath and above the fluvial sediments so that the period of their accumulation in the Makgadikgadi is restricted to the time of the last glacial maximum. Between ca.19,000 and 12,000 yr BP Lake Paleo-Makgadikgadi underwent a very pronounced regression; periodically the lake dried out completely.

Evidence for the existence of a perennial river during the last glacial maximum is only found in the Molopo valley (Figure 3), where the freshwater mollusc *Bulinus* sp. is quite common in the last glacial maximum deposits; the distribution of *Bulinus* today is restricted to the Transvaal and eastern Botswana (Brown 1978) and does not extend to the southern Kalahari. The numerous occurrence of the freshwater mollusc *Corbicula fluminalis* in the Molopo sediments of last glacial maximum age reflects extremely humid ecological conditions; so does the genus *Unio* of which some specimens were found in the fluvial sediments of glacial age. The obtained ^{14}C dates for these molluscs range from 16,625 ± 195 (Hv 9503) to 12,480 ± 220 yr BP (Hv 8372). It cannot be excluded, because of field observations and sedimentological indications, that some dated molluscs are contaminated by younger ground water. I therefore assume that the three age determinations between ca. 12,000 and 13,000 yr BP are too young.

During the time of perennial runoff in the Molopo valley, no discharge can be traced from the Nossob and Auob valleys as well as from the Molopo valley south of Koopan Suid. Situated on the boundary between the south-west Kalahari and the Orange River, several pans are of considerable geomorphic interest. My investigations of these pans concentrated on the proof for changing hydrological conditions. Evidence for Late Quaternary lacustral phases are scarce. With the exception of the occurrence of some thin carbonate precipitates along a rock outcrop in Koppieskraalpan that consist of irregularly alternating layers of crystalline aragonite or calcite which may indicate a period of a shallow inundation of the pan, neither sediments nor geomorphic features show evidence of high water-levels. All recent pan levels are produced by deflation, though the slopes of the pans are formed by overland and channel flow after heavy rains. Even today, ephemeral water bodies occur quite frequently during the rainy season.

At about the same time that the perennial river existed in the Molopo valley, extensive deflation in the pans and dune formation took place (Heine 1981). Grain size analyses of the river sediments as well as morphoscopical observations of the sand grains show a high percentage of dune sand mixed with the mollusc bearing deposits. Furthermore, only one ca.1-1,5 m thick layer of fluvially deposited sand with molluscs *in situ* gives evidence that the period with extremely humid conditions must have been of very short duration. According to the geomorphic features this period of pluvial conditions is limited to the Molopo valley and does not extend to the valleys of the Auob and Nossob in the west (Figure 3). There was no accumulation of fluvial material that postdates ca.19,000 yr BP in the dry valleys of the Auob and Nossob and in the fossil Molopo valley south of the Koopan Suid. As it is indicated by the stratigraphy of the sediments of the lower Molopo valley, the pluvial period is followed by a period with climatic conditions that favour deflation, transport, and accumulation of sand on the one hand, and episodical runoff in the Molopo valley on the other hand, thus leading to the deposition of dune sand under fluvial conditions in the lower Molopo valley. This characteristic layer (Figure 3, no. 7 of caption) contains reworked shells of the preceding pluvial phase which are eroded and broken because of their fluvial transportation, and different kinds of snails which are more or less undamaged. The snails (*Xerocerastus* sp., *Prestonella* sp.?) lived during the time of the fluvial accumulation of the dune-type sand; unfortunately the content of carbon of the gathered snail shells was too low, so that no ^{14}C age can be given (Hv 9484).

Much stronger winds during the last glacial maximum for the southwest Kalahari can also be inferred from the geomorphology of the pans. On the southeastern side of most of the pans lies an area of fixed sand dunes. The sand ridges are directed northwest-southeast; only along the southern and eastern pan margins the sand ridges follow the configuration of the pans (Figure 4). The colour of the sand is light brown near the pans, becoming more and more red a few kilometres away. The origin of the enclosed pan depressions is assumed to be the result of deflation of unconsolidated, sandy surface sediments by strong unidirectional winds. The pan surfaces are extremely flat; rock outcrops are seldom, although the mother rock is to be found in only a few decimeters below the pan surface. Nowhere in the pans, deposits of a greater thickness are found. The upper pan sediments are occasionally composed of material with a similar nature as the rocks of the

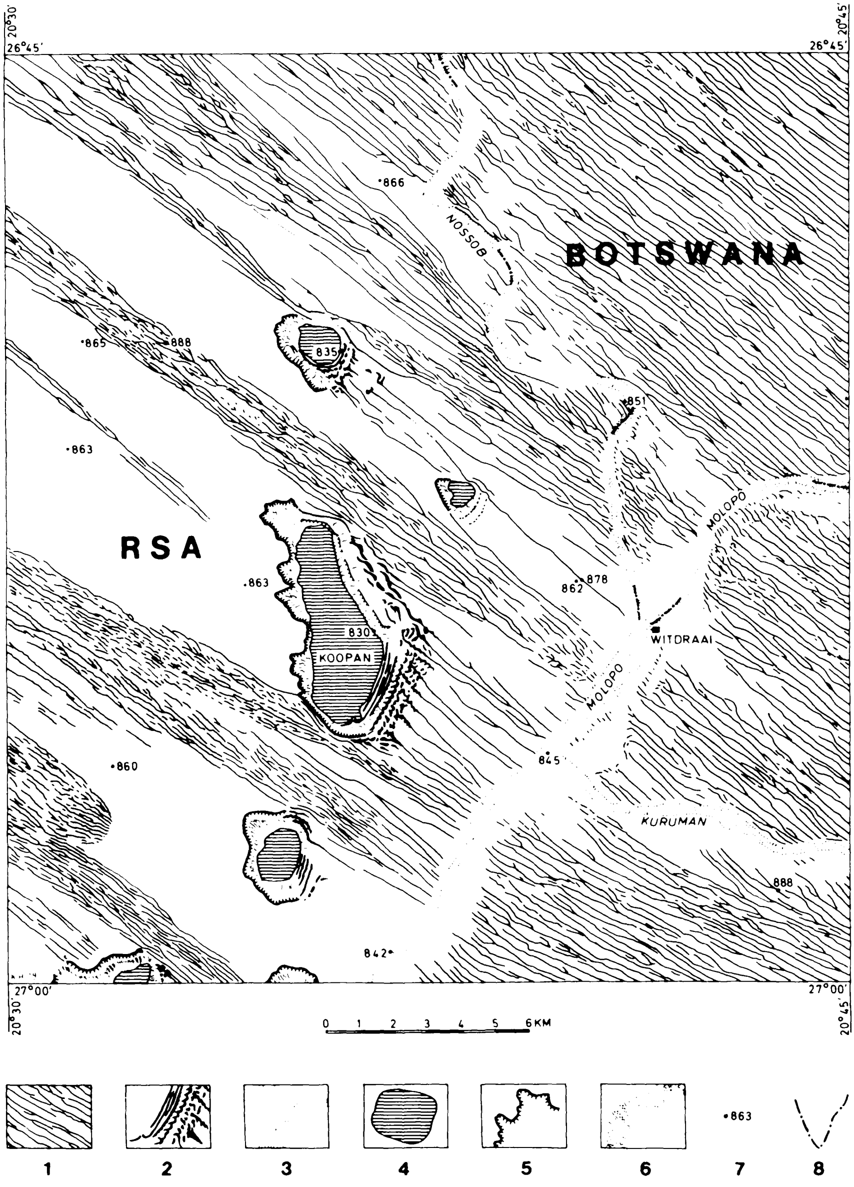

Figure 4. Pans and dune systems of the southwest Kalahari.
1 – Longitudinal dunes; 2 – Drab grey lunette-like sand mounds and sand ridges; 3 – Dry valley; 4 – Pan; 5 – Cuesta; 6 – Fluvial erosion on pan slopes; 7 – Height above sea level in metres; 8 – International boundary.

surrounding pan slopes. Thus the pans of the southwestern Kalahari differ from the thousands of small pans in the Kalahari watershed area between the Makgadikgadi depression and the Nossob and Molopo with respect to their pan deposits (Lancaster 1978). West of the Nossob and Molopo valleys, the absence of pan deposits, the flat pan surfaces, the cuesta-like edges of the pans in the west and north, and the parallel sand ridges with different heights above the pan levels in the south and east document that the origin of the pans is not only due to the strong winds, but also to ephemeral inundation of the pan floor. These ephemeral pan lakes exist after heavy rains which cause denudation on the cuesta slopes. After being transported into the pan and after desiccation of the ephemeral lake, the eroded slope material is swept away by the wind. So the formation of the pans is a result of the fluvial erosion and denudation along the cuesta-like slopes in connection with the deflation from the pan surface, leading to the enlargement of the pans near their western and northern margins and to sand accumulation along their southern and eastern slopes. Different steps on the southeastern slopes and the alignment of the dunes indicate that the formation, or rather the deflation of the pans occurred in several phases. Under recent climatic conditions neither significant enlargement of the pans along the cuesta slopes, nor a rapid deflation from the pan floor can be observed. Today, the youngest inner dunes at the southeastern margin of the pan floor are dissected by erosion channels caused by the action of water and partly by wind. The grains of the inner dunes are slightly cemented. The morphological and sedimentary evidence suggests that the main stages of development of the pans were formed during periods with stronger winds and episodical rains. These climatic conditions are likely to have existed during the last glacial maximum in the southwest Kalahari.

THE LATE GLACIAL (ca.12,000 yr BP)

From the Kalahari region, the evidence for late glacial palaeogeographical and apalaeoclimatic conditions are scarce and there is a lack of absolute age determinations.

Along the Gaap Escarpment, the period between 13,500 and 11,500 yr BP is mainly semiarid (Butzer et al. 1978). According to ^{14}C dates from the lower Molopo valley and adjacent areas, no rivers existed at about 12,000 yr BP. In the northern Makgadikgadi depression the occurrence of land molluscs (*Succineidae, Xerocerastus* sp.) and lacustrine sediments indicate relatively moist conditions about 12,000 yr BP (11,920 $^{+1,630}_{-1,270}$ yr BP, Hv 8367). Further evidence for a pluvial period around 12,000 yr BP in the Kalahari region north of about 20°S is provided by lacustrine sediments in the Etosha Pan; the radiocarbon dates of lacustrine chalk of a well traceable layer are 13,680 ± 175 (Hv 9494) and 12,720 ± 165 yr BP (Hv 9492); molluscs of the western shore of the Etosha Pan (mostly *Xerocerastus* sp.) are dated at 10,670 ± 465 yr BP (Hv 9493). These determinations are in certain agreement with the dates of the younger Makgadikgadi pluvial phase (Heine 1978a, b). In the Kwihabe valley the calcrete CIV (Cooke 1975) sometimes contains fresh water mollusc shells; Cooke & Verhagen (1977) date the calcrete CIII or CIV at 9,800-11,000 yr BP; perhaps the calcrete CIV with fresh water molluscs represents the late glacial/Early Holocene pluvial phase (ca.12,000-9,000 yr BP, Heine 1978a, b). Wright (1978) reports on a younger calcrete which developed most markedly in the vicinity of fossil valleys or pans in the northern Kalahari and which might be correlated with calcrete CIV of Cooke (1975). The structure of this calcrete may be massive, conglomeratic, nodular, laminated or tubular, the latter suggesting formation in a reed or sedge bed (Wright 1978, see also Passarge 1904:200-221).

THE EARLY HOLOCENE (10,000-8,000 yr BP)

Along the southern margin of the Kalahari (Gaap Escarpment), the period 9,700 to 6,500 yr BP is relatively wet (Butzer et al. 1978). Such conditions are also indicated at 8,705 ± 165 yr BP (Hv 8385) by a fossil $CaCO_3$-horizon of a vertisol-like soil in the western Kalahari. Even in the central Namib (Mirabib archaeological site), a dark grey layer contains organic carbon, charcoal, ash and fossilized plant and animal matter and could imply denser vegetation and higher rainfall about 8,500-8,000 yr BP (Sandelowsky 1977). Unfortunately I cannot provide the Early Holocene palaeographic reconstruction with ^{14}C dates from the central Kalahari and the Ngami/Makgadikgadi region. Only laminated calcrete formations of the fossil valley area between Maun and Toteng in Ngamiland document sedimentation under conditions moister than today in the valley about 9,000 yr BP (9,390 ± 80 yr BP, Hv 8378; 8,720 ± 95 yr BP, Hv 8383). Outcrops of these laminated calcretes occurring within, or close to, the most recent incised channels, sometimes enclose gastropod shells (Wright 1978). According to the field observations of Cooke (1975), Wright (1978), and myself in Ngamiland, it is possible that the formation of the calcrete CIII/CIV (Cooke 1975) or the younger calcrete mentioned by Wright (1978), respectively, covers the period from about 12,000 to 8,500 yr BP, and thus cannot be used for a detailed Late Pleistocene/Early Holocene stratigraphy.

THE HOLOCENE PERIOD FROM 8,000 yr BP TO PRESENT

After the Holocene climatic optimum in southern Africa about 10,000-9,000 yr BP, the general climatic evolution of the Kalahari region cannot be reconstructed because of the lack of detailed dated information. There exist some observations of a succession of wetter and drier periods (Cooke 1975, Butzer et al. 1978, Lancaster 1978, Van Zinderen Bakker 1976). The Holo-

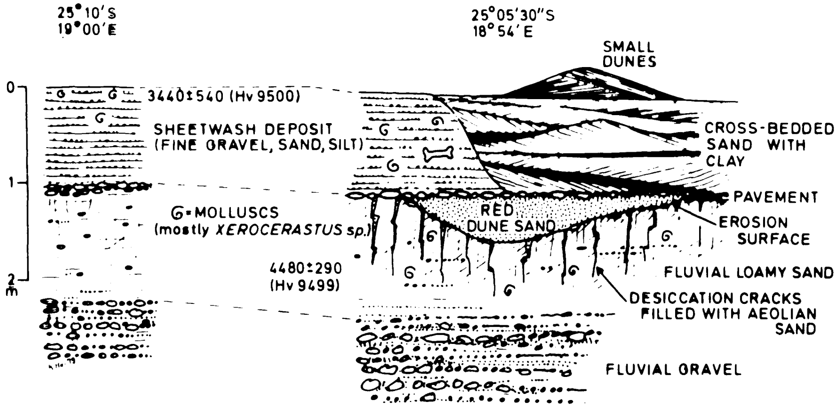

Figure 5. Cross-sections of Holocene deposits in the Auob valley south of Gochas (SWA/Namibia).

cene of the Gaap Escarpment, southern Kalahari, exhibits a threefold palaeoclimatic subdivision; mainly subhumid 9,700 to 6,500 yr BP, then semiarid, again mainly subhumid 4,500 to 400 yr BP, with drier conditions ca.2,400 yr BP (Butzer et al. 1978). In the Kwihabe hills, Cooke (1975) observed wet periods around the dates 4,350 yr BP and 1,500 to 2,000 yr BP. In a more recent publication Grey & Cooke (1977) date the late Holocene wet period between 2,500-750 yr BP.

In the northern Makgadikgadi depression I obtained a ^{14}C date for the youngest calcrete of 4,025 ± 110 yr BP (Hv 8689).

In the western Kalahari, according to ^{14}C dates of molluscs and sedimentological data moister periods occur around 4,500 yr BP (4,480 ± 290 yr BP, Hv 9499) and 3,500 yr BP (3,440 ± 540 yr BP, Hv 9500). Greater aridity and stronger winds during the period between 4,500 and 3,500 yr BP are documented by coarse gravels, erosion surfaces, desert pavements, and the accumulation of red dune sand in the Auob valley (Figure 5). In the same region some geomorphic features, e.g. cross-bedded deltaic sands and clays of fluvial origin, may indicate the wet late Holocene phase which is postulated by Grey & Cooke (1977) for Ngamiland.

PALAEOGEOGRAPHICAL AND PALAEOCLIMATOLOGICAL INTERPRETATION

Table 1 presents the geomorphic and palaeoclimatic events in the Kalaharian region and adjacent areas. Figure 6 gives a palaeoclimatic interpretation of

Table 1. Geomorphic and palaeoclimatic events in the Kalaharian region. Apart from my own investigations, the following references are used: Butzer et al. (1978), Cooke (1975), Cooke & Verhagen (1977), Grey & Cooke (1977), Lancaster (1979), Sandelowsky (1977), Street & Grove (1979).
Bold type indicate geomorphic and palaeoclimatic events that are dated by radiocarbon. Numbers of column headings refer to Figure 1.

x 10^3 years BP	Makgadikgadi-Ngami-Okavango 3	Kwihabe Hills and cave 2	Etosha Pan 1	Namib 10 12	Auob-Nossob 6 7	Urwi Pan 4	Molopo 5	Southwest Kalahari 8 9	Gaap Escarpment 11
1 –				**Arid**					**Tufa VIb and**
2 –	**Slightly**	**Sinter SIV**		**Wetter**					**VIc**
3 –	**Wetter**				**Molluscs more**				**subhumid**
4 –	**Calcrete**				**moisture**				**condition**
5 –				Mirabib:					
6 –				Wetter?	calcretes		no	dunes	semiarid
7 –					**Soil and**				**Tufa VIa**
8 –				Mirabib:	**calcrete**		discharge		**subhumid**
9 –	**Calcretes**	**Calcrete CIII**		**Wetter**	**wetter**				
10 –		**CIV**, fresh	**Fresh**	Lüderitz:	calcretes		episodical		
11 –		water molluscs	**water**	**Wetter**			river		
12 –	**Lakes**	in CIV	**molluscs**						**Erosion semi-**
13 –	**Calcretes**		**Lake**	arid			runoff		**arid**
14 –	fluvial sediments,	**Sinter SIII**	**Calcrete**	morpho-	sand dunes,		river	dunes	
15 –	runoff dunes	**and SIV**	fluvial	dynamic	strong NE-				
16 –	(stronger winds)		deposits		winds	**Stroma-**	**Perennial**	slope	**Tufa Vb**
17 –			in pans	extreme		**tolites**	**river**	debris	**subhumid**
18 –				arid			(episodical?)		
19 –		major wet			fluvial		river	**River**	
20 –		phase			deposits			**deposits**	
21 –	**Lakes, very high**	erosion of			before			**molluscs**	
22 –	**lake-level**	CI and CII			18,000 BP				
23 –	**fresh water**	cave	**Tufa**		Kl.Awas Pan				
24 –	**molluscs**	enlargement			**Stromatolite**	high			
25 –	**Lacustrine chalk**				**fossil soil**	water		**Lake?**	**Subhumid**
26 –					**Wetter**	level			
27 –	**Lakes**			**Sinter**		phase?			
28 –		**Calcrete CII**		**Wetter**					
29 –		**Sinter SII**							
30 –	**Calcrete**								
>30		>45 000 BP							35 000 BP

the sediments, molluscs, cave sinters, etc. that are dated by ^{14}C. The sparse network of these data does not permit much broad-scale analysis. It is difficult, therefore, to reconstruct the outlines of a continuous palaeogeographic and palaeoclimatic evolution. Nevertheless, 56 new ^{14}C dates, new geomorphologic, sedimentological, and palaeontological criteria, supported by a literature survey, have encouraged me to attempt some remarks on the Late Quaternary environmental development in southern Africa.

27,000-25,000 yr BP

This phase began before 30,000 yr BP and ended around 19,000 yr BP. It is remarkable for widespread lacustrine sedimentation in the Makgadikgadi/ Ngami area. Fresh water molluscs indicate pluvial conditions, too. In the area of the Bakalahari Schwelle (Passarge 1904) the high water level of the pans and the deposition of the clayey phase of the pan deposits, observed by Lancaster (1978, 1979) may correspond to this period. In the coastal Namib desert near Swakopmund, cave sinter formation indicates wetter conditions than today. In the southwestern Kalahari, about 70 km north of the Auob/ Nossob confluence, wetter conditions are responsible for the distinctive evolution of a palaeosol with a mighty A-horizon which is dark in colour and rich in organic matter. Subhumid conditions characterize the southern Kalahari during this phase (Butzer et al. 1978).

Unfortunately it is not possible to give detailed information about the temperature conditions of this phase. A tentative Late Quaternary sequence from interior environments of southern Africa (Vaal and Upper Orange drainage) is reported by Van Zinderen Bakker & Butzer (1973), postulating a temperature decrease of at least 6°C beginning 29-25,000 yr BP and terminating 17-16,000 yr BP.

Along the Namib desert coast, a high sea-level is documented by numerous geomorphic and sedimentologic features. As a result of the extremely arid desert climate, the geomorphic and sedimentary structures of marine terraces are well preserved; according to ^{14}C datings they indicate a regression after about 25,000 yr BP. Yet little is known about the discrepancy between my observations and the results of Geyh, Kudrass & Streif (1979) who equate the often-reproduced sea-level curves with a high sea-level around 30,000 yr BP, because of the use of mobile carbonate material (shells, ooids, etc.) which would result in dubious ^{14}C ages and erroneous sea-level indications.

Butzer et al. (1978) present a 5,000,000-yr record of climatic variation in the Kalahari summer-rainfall belt that can be related to complex anomalies of the general atmospheric circulation. The authors propose that late Cenozoic moist intervals in the southern Kalahari were primarily, although not exclusively, a response to variations in the penetration and persistence of summer, rather than winter rains. During the period 27,000-25,000 yr BP the widespread pluvial conditions in the Kalahari were probably the result of greater summer rainfall (Figure 6). Along the Namib coast a relatively weak

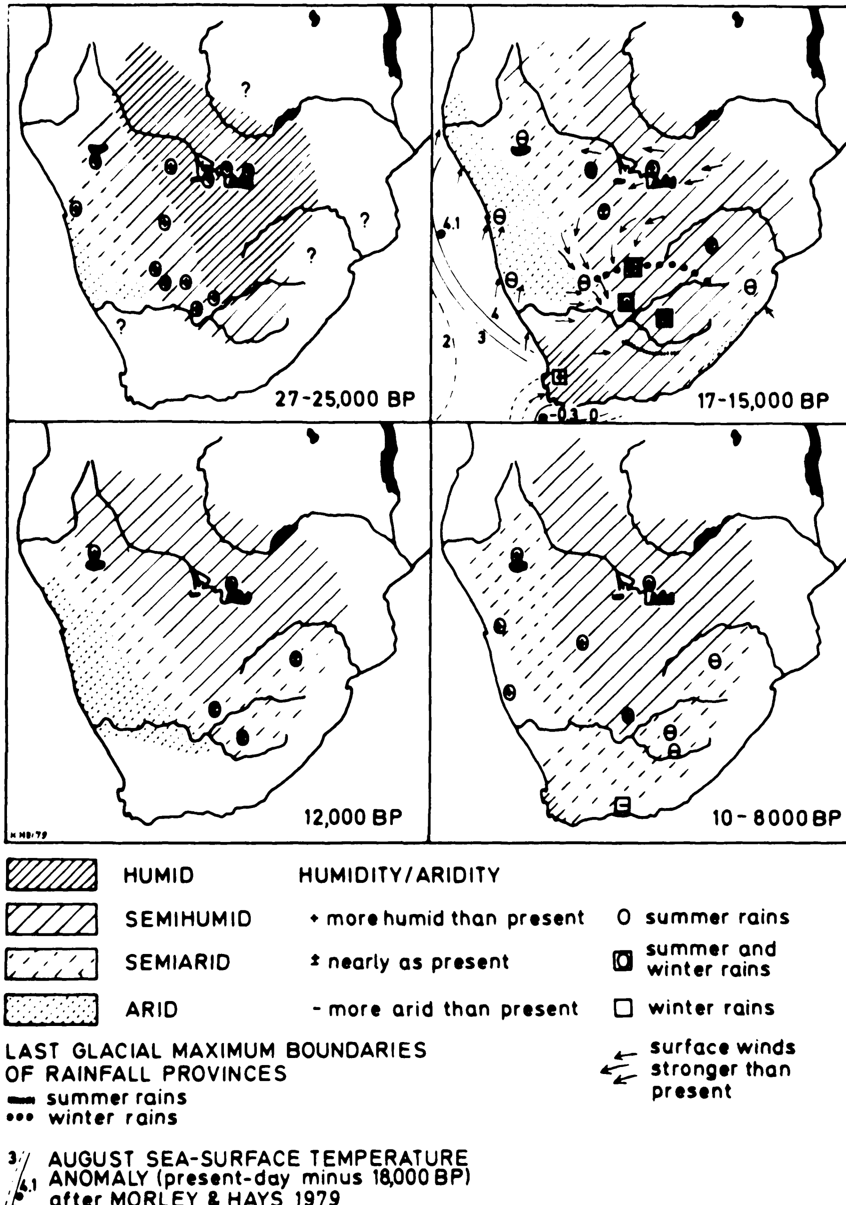

Figure 6. Maps showing hypothetical climatic regions in the Kalahari for the periods 27,000-25,000 yr BP, 17,000-15,000 yr BP, c.12,000 yr BP, and 10,000-8,000 yr BP, based on palaeoclimatic interpretations of ^{14}C dated deposits, molluscs, cave sinters, etc.

upwelling must have been responsible for the increased rainfall, which is documented by the cave sinter formation. The temperature gradient between the surface water off the southwest African coast and the surface water of the southwest Indian ocean was relatively small, thus leading to a more or less warm, humid, and less windy period in the Kalahari. To explain this pluvial Kalaharian period, it is not necessary to postulate a more southerly position of the ITCZ (personal communication Prof. H.Flohn, Bonn).

After about 25,000 yr BP the temperature decreased. Between ca.25,000 and ca.20,000 yr BP the southern Kalahari became cooler and drier (Molopo valley), whereas in the northern Kalahari (Makgadikgadi depression) still humid conditions, documented by lake sediments and molluscs, existed.

17,000-15,000 yr BP

This phase began about 19,000 yr BP and ended around 13,000 yr BP; it comprises the last glacial maximum and equals the younger part of the deep-sea isotope stage 2 (26,000-13,000 yr BP). The palaeoenvironmental reconstructions discussed earlier (Cooke 1975, 1979; Grove 1969, Lancaster 1979, Butzer et al. 1978, Heine 1978a, b, Van Zinderen Bakker 1976), are of a very heterogeneous nature, perhaps because they are related to palaeoclimatic evidence from different sources (geological, geomorphological, palaeontological, palaeobotanical, biogeographical, and archaeological).

In the Makgadikgadi/Ngami area the period between ca.19,000 and ca. 13,000 yr BP is represented by minimum lake-levels on the one hand and maximum sedimentation rates on the other hand. The morphologic, sedimentologic, and palaeontologic evidence proves episodically inundated pans in the Makgadikgadi depression. At no time during the last glacial maximum does the depression seem to have been occupied by deep fresh water lakes.

In the Kwihabe hills cave sinter formation documents vadose development as a result of subhumid to humid climatic conditions, dated at 16,000 to 13,000 yr BP (Grey & Cooke 1977). Further south, stromatolites from Urwi Pan indicate shallow lacustrine conditions in the pan 17,000-15,000 yr BP (Lancaster 1979).

The sediments and molluscs of the lower Molopo valley indicate a perennial discharge or at least very wet conditions of the river sediments. Evidence from the Gaap Escarpment, Alexanderfontein (OFS), and Wonderkrater (Transvaal) corroborates the idea of a humid to subhumid climate at the last glacial maximum. Although the above mentioned data show relatively humid climatic conditions, in the southern Kalahari and the Orange Free State an increase in precipitation is only documented during the last glacial maximum (Figure 6).

When reconstructing the palaeoenvironment of southern Africa, the most surprising fact is that southwest Africa received less precipitation and that there existed a marked limit between the western regions with last glacial maximum aridity and the eastern regions with last glacial maximum humidity,

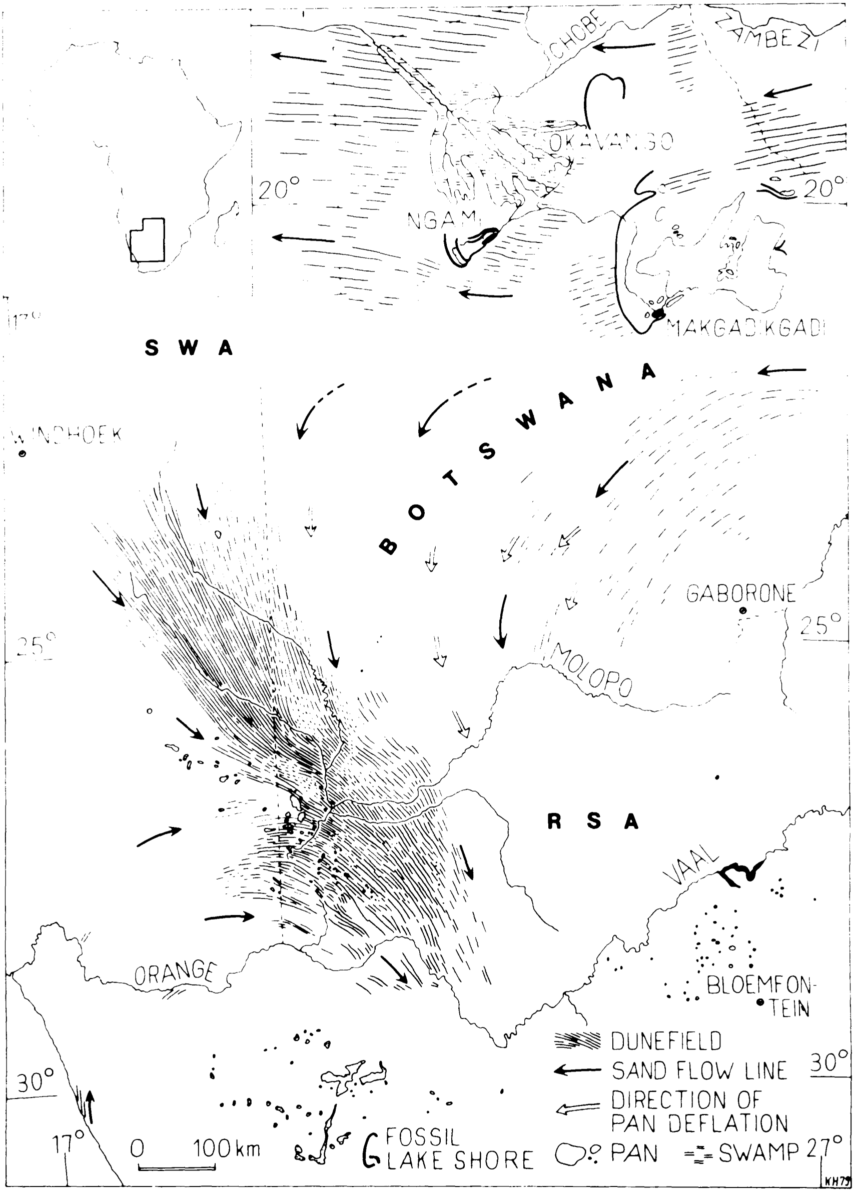

Figure 7. Map showing distribution of major dunefields. Sand flow lines constructed from trends of longitudinal dunes and lunette-like pan dunes provide resultant directions of winds during period of intensified dune building phase. This period, dated in the Kalahari to between >18,000 and c.13,000 yr BP, coincided with last glacial maximum.

Moreover, both regions meet in the southwest Kalahari, where widely spaced sand ridges (longitudinal dunes) with interdune corridors extend northwest-southeast for hundreds of kilometres, diverging and converging, but essentially maintaining a parallelism with each other. West of the Nossob and Molopo valleys the ridges evolve from lunette-like mounds deposited on the lee sides of the pans (Figure 4), whence the debris is carried by water from the pan slopes, lake waves of seasonal lakes, and then by wind. Initially, the dune sands are a drab grey, like those of the pan surface, but within a few kilometres they have acquired their characteristic red colour, due to the release of iron oxides during the weathering of clays deposited with the sands. Although there is little doubt that the sand ridges are migrating in a southeast direction, there is some evidence to suggest that sand transport during the Holocene has only been of a local nature.

Figure 7 shows a reconstruction of the sand flow lines during the last glacial maximum. Although it is very difficult to date the aeolian processes because of a lack of absolutely dated dune sands, there are many detailed descriptions that allow to reconstruct sand flow lines representing the trends of dunes believed to have been active during the last glacial maximum. It seems that the glacial winds in the Kalahari followed a similar pattern as today. Even along the Namib desert coast, the dunes indicate a glacial wind regime similar to recent conditions. The most remarkable difference between the glacial and present wind systems concerns the wind velocity; all over southern Africa the winds were much stronger during the last glacial maximum.

The picture of the climatic conditions during the glacial maximum in southern Africa which is now emerging seems to be different from that of the rest of Africa. The increased humidity in the southern Kalahari (Molopo valley, Gaap Escarpment, Alexanderfontein) during the last glacial maximum (17,000-15,000 yr BP) was probably the result, not of increased penetration in the subcontinent by cyclonic winter rains as I suggested earlier (Heine 1978b), nor of greater summer rainfall due to a more southerly position of the ITCZ as Lancaster (1979) and Butzer et al. (1978) suggest, but of a strengthening of the circulation pattern over and around the South African subcontinent. Van Zinderen Bakker (in press) pointed out that during the last glacial maximum the thermal gradient was steeper, the atmospheric and oceanic circulation strengthened and consequently more vigor of the trade winds. Van Zinderen Bakker (1980) also suggests that the climatic belts did not move equatorward. A strengthened circulation over South Africa can be inferred from the last glacial maximum temperature conditions of the southwest Indian Ocean and the Benguela Current along the southwest African coast. The temperature difference between 18,000 yr BP and today in the Indian Ocean indicates that conditions there were slightly cooler 18,000 yr BP than today (0 to 2°C cooler, Hutson 1978). Along the west coast, the upwelling (Benguela Current) increased (Morley & Hays 1979), thus being there responsible for a cooling; the result is a steeper thermal gradient over southern Africa. During the last glacial maximum, summer rains spread all over the Kalahari, but did not penetrate into South West Africa as regularly as they do today. Because of the strengthening of the circulation system, winter rainfall reached the southern Kalahari more frequently. The stronger upwelling of the Benguela Current effected an extremely arid Namib desert and greater aridity in South West Africa. According to the ^{14}C dates, the last glacial maximum's wettest phase occurred around 17,000-15,000 yr BP. The question arises whether this phase is characteristic for the period between ca.19,000 and 13,000 yr BP, or only for a relatively short phase during this period (i.e. the last glacial maximum). The cave sinter of Ngamiland (Cooke 1975) formed from 17,000-14,000 yr BP, the stromatolites from Urwi Pan date ca.16,000 yr BP (Lancaster 1979), and in the lower Molopo valley there is strong evidence that a short wet phase is responsible for the accumulation of the mollusc-rich sediments around 17,000-15,000 yr BP. As a consequence of these data we have to consider possible climatic fluctuations within the period between ca.19,000 and 13,000 yr BP in southern Africa.

12,000 yr BP

The time around 12,000 yr BP represents the terminal Pleistocene phase. In the Makgadikgadi depression probably the first renewed transgression occurred within the pan area after the last glacial arid phase (the pans dried out). Some ^{14}C dates from the Etosha Pan imply that rainfall increased around that time. There exist no ^{14}C dates from the Kalahari; only the occurrence of some fresh water molluscs of the lower Molopo valley dated to about 12,500 yr BP (Heine 1978a), may indicate that the humid conditions prevailed in the southern Kalahari until that time, if we assume that there was no rejuvenation of carbon by contamination. On the other hand, Butzer et al. (1978) postulate a semiarid to arid period between 13,500 and 11,500 yr BP for the Gaap Escarpment. In the Republic of South Africa, at Aliwal North, the pollen spectra show a number of climatic alternations from cooler and wetter to warmer and drier climates between ca.13,200 and 9,500 yr BP (Van Zinderen Bakker & Butzer 1973).

The sparsely dated palaeoclimatic evidence does not permit a palaeo-environmental reconstruction.

10,000-8,000 yr BP

In southern Africa the time span between ca.10,000 and 8,000 yr BP seems to have been the climatic optimum (Van Zinderen Bakker 1980). Warm and relatively humid conditions are indicated by palaeosols in the Kalahari. A weak Benguela Current is responsible for the higher precipitation around 9-8,000 yr BP in the Mirabib area in the Namib desert (Sandelowsky 1977). The palaeoclimate of the Gaap Escarpment is mainly subhumid between 9,700 and 6,500 yr BP (Butzer et al. 1978). An assemblage of fossil bones of different mammalia near Lüderitzbucht (Heinz 1935) has obtained a ^{14}C date of 9,960 ± 390 yr BP (Hv 1098).

South of the Orange and Vaal rivers warm and drier conditions prevailed. At Aliwal North the optimum of a very dry and warm period is just before 9,650 ± 150 yr BP (GrN-4012) (Coetzee 1967).

These data correspond with the Early Holocene climatic history of the Antarctic seas. In the Holocene, sub-Antarctic surface waters reached a temperature maximum 9,400 yr BP and have been cooling since (Hays 1978). Furthermore, the southern hemisphere dates which are closely and unequivocally related to glacial activity, or to other phenomena considered to have resulted from cool climate, indicate that the longest warm part of the Holocene seems to have been about 9,000-6,000 yr BP (Burrows 1979).

CONCLUSIONS

1. The palaeogeographic and palaeoclimatic development of the Kalahari region provides strong evidence that South African climatic changes in precipitation and temperature, as well as in surface winds are closely related to variations in intensity of the general circulation rather than in shifts of the climatic belts.

2. Although the South African climatic development does not show a close synchroneity with the rest of Africa, certain large scale changes are represented, i.e. the Middle Wisconsin interstadial period, the last glacial maximum, and the Holocene.

3. According to the great diversity of palaeoclimatic evidence, the palaeoclimatic reconstruction is incomplete. Further finds of dateable material will supplement this record and possibly add to the complexity of the evidence.

4. The Middle Wisconsin interstadial period is characterized by pluvial conditions in the Kalahari (> 30,000-ca.19,000 yr BP). The record of lake-level fluctuations during around 30,000 to ca.19,000 yr BP does not refer to a major climatic change that occurred at about 26,000 yr BP (i.e. deep-sea isotope stage 2/3 boundary). On the other hand, it is assumed that after about 25,000 yr BP the temperature decreased (palynological evidence), but that not earlier than about 19,000 yr BP the great lakes of the Kalahari (Ngami, Makgadikgadi, Etosha?) dried out.

5. Last glacial maximum climatic conditions prevailed between ca.19,000 and 13,000 yr BP. A large increase in meridional and, over southern Africa, in W-E temperature gradients caused a change in the frequency of occurrence and in velocity of winds. In glacial times strong winds may produce large increases in evaporation rates. Such winds would have been capable of drastically changing the hydrologic balance, a change that dried the Makgadikgadi pluvial lake out about 19,000 yr BP. A corresponding change took place in Eastern Africa (Gasse & Street 1978), in the Chad area (Servant & Servant 1970), and in southeastern Australia (Bowler 1978).

6. The last glacial maximum (ca.19,000-13,000 yr BP) was more arid in South West Africa than today, but more humid in the southern Kalahari

than today. It is not quite clear whether the phase of greater glacial humidity in the Kalahari is restricted to only a short time span, probably between ca. 17,000 and 15,000 yr BP.

7. The distribution of rainfall during the last glacial maximum in southern Africa depends on the northward penetration of winter rains on the one hand, and on the eastward extension of the Namib desert on the other hand. The result is an arid southwest Africa and a humid southern Kalahari.

8. ^{14}C dates of palaeosols and calcretes indicate a climatic change in southern Africa around 14,000 yr BP. Hence, in the northern and central Kalahari more moisture is documented, in the southern Kalahari more aridity.

9. The period between ca. 13,000 and 10,000 yr BP presents the transition from full glacial climatic conditions to the post-glacial climatic optimum. Repeated oscillations are known, but it is not possible to explain the variations because of a lack of reliable chronostratigraphies.

10. During the Holocene temperature maximum around 9,500 yr BP geomorphic and palaeopedologic features indicate wetter conditions in the Kalahari.

11. The results show that different palaeoclimatic evidence (geomorphical, sedimentological, palaeobotanical, palaeontological, etc.) yield different time-stratigraphic periods for the Late Quaternary. That may be the reason, apart from the fact that many deposits have alternative explanations, that a great variety of palaeoclimatic and palaeogeographic reconstructions exist for southern Africa.

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