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The editors of CATENA take the view that the emphasis on interdisciplinary aspects of PEDOLOGY, HYDROLOGY, GEOMORPHOLOGY and the related aspects of GEOLOGY, CLIMATOLOGY and the BIOLOGICAL SCIENCES can contribute to the *advancement of these disciplines* in their own right, as well as relating them to each other. Certainly there are at the present large gaps between specialisms, which it is worth attempting to fill.

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Reply to Cooke's discussion of:
K. Heine: Radiocarbon Chronology of Late Qauternary Lakes in the Kalahari, Southern Africa

K. Heine
Geographisches Institut der Universität Bonn
FranziskanerStr. 2, 5300 Bonn

I refer to COOKE's Discussion of my above mentioned paper (CATENA, vol. 5, 145 - 149 and vol. 6, 107).

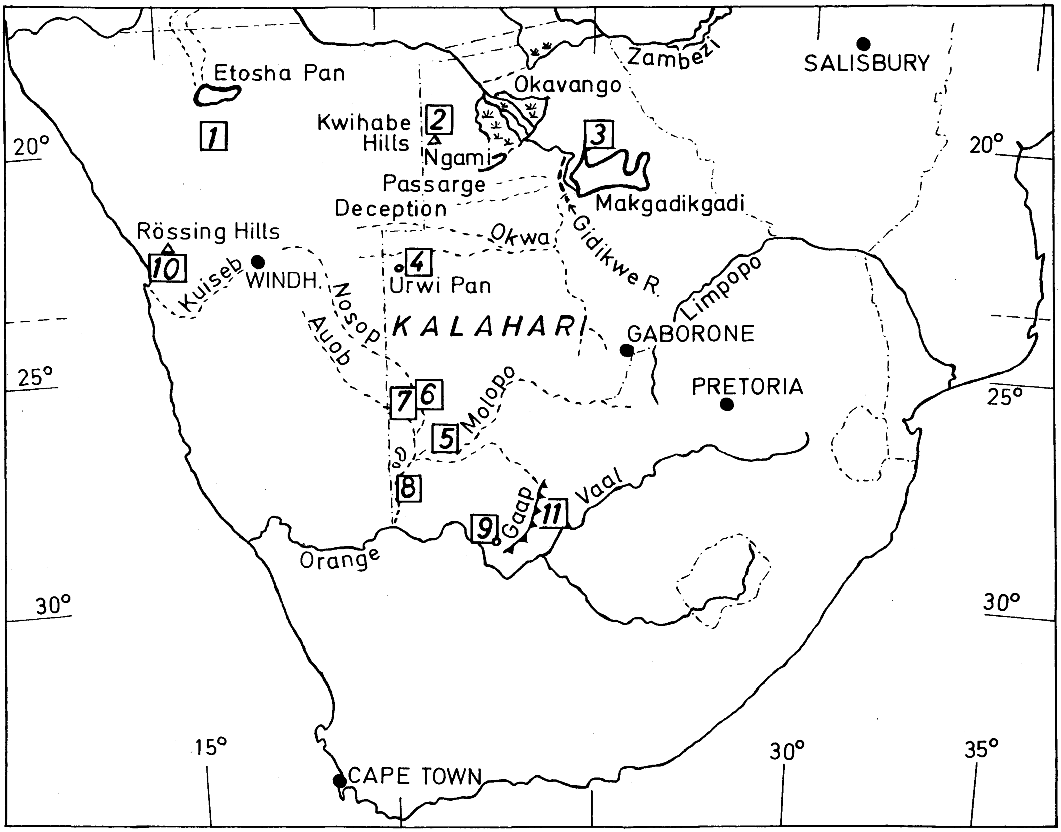

Fig. 1: Location map of places mentioned in the text. The numbers (1) to (11) refer to table 1.

Tab. 1: GEOMORPHIC AND PALAEOCLIMATIC EVENTS IN THE KALAHARI 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 (1976).

x 10^3 years B.P.	Makgadikgadi-Ngami-Okavango area ③	Kwihabe Hills and cave ②	Etosha Pan ①	Namib ⑩
1 -				
2 -	SLIGHTLY WETTER	SINTER SIV		ARID
3 -				
4 -	CALCRETE		?	
5 -				Mirabib: WETTER?
6 -				
7 -				
8 -	CALCRETES			Mirabib: WETTER
9 -				
10 -		CALCRETE CIII,CIV, fresh water molluscs in CIV	FRESH WATER MOLLUSCS LAKE	Lüderitz: WETTER?
11 -				
12 -	LAKES			
13 -	CALCRETES			arid morpho- dynamic
14 -	fluvial sediments, (episodical?) runoff, dunes (stronger winds), discharge in Okwa valley	SINTER SIII AND SIV	CALCRETE fluvial deposits in pan	
15 -				
16 -				
17 -				
18 -		major wet phase erosion of CI and CII		?
19 -				
20 -				
21 -	LAKE, VERY HIGH LAKE LEVEL FRESH WATER MOLLUSCS	cave enlargement		
22 -			?	
23 -				
24 -	LACUSTRINE CHALK			
25 -				
26 -	discharge in Passarge-, Deception-, Okwa-Valley			SINTER WETTER
27 -				
28 -		CALCRETE CII		
29 -		SINTER SII		
30 -	?CALCRETE			
>30		> 45000 B.P.		

| CALCRETE = ^{14}C dated event

⋮ calcrete = age and/or period of event is hypothetical

$x\ 10^3$ years B.P.	Auob-Nosop ⑥ ⑦	Urwi Pan ④	Molopo ⑤	Southwest Kalahari ⑧	⑨	Gaap Escarpment ⑪
1 -	dunes					TUFA VI b and VI c SUBHUMID CONDITION
2 -						
3 -						
4 -	MOLLUSCS MORE MOISTURE	inner dunes?	dunes			
5 -						semiarid
6 -	calcretes			dunes	dunes	
7 -	SOIL AND CALCRETE WETTER					TUFA VI a SUBHUMID
8 -						
9 -						
10 -	calcretes		episodical river			
11 -						
12 -			PERENNIAL RIVER?			EROSION SEMIARID
13 -			(episodical) river dunes (stronger winds)			
14 -	sand dunes, strong NE-winds					
15 -					slope debris	
16 -		STROMAT-OLITES	PERENNIAL RIVER			
17 -						TUFA Vb SUBHUMID
18 -			(episodical?) river			
19 -	fluvial deposits before 18000 B.P.					
20 -				RIVER DEPOSITS MOLLUSCS		
21 -						
22 -						
23 -						
24 -	FOSSIL SOIL WETTER	high water level phase?				SUBHUMID
25 -					LAKE?	
26 -						
27 -						
28 -						
29 -						
30 -		outer dunes?				
>30						35000 B.P.

(1) According to COOKE (1975), COOKE & VERHAGEN (1977), and GREY & COOKE (1977) a number of ^{14}C dates from cave sinters and valley calcretes in the Kwihabe hills area in NW Ngamiland, Botswana at latitude 20°05'S and about 300 km west of Makgadikgadi, indicate wet conditions in the area between 16 000 and 13 000 B.P. Unfortunately COOKE did not find any material for radiocarbon dating of this 'major wet phase', namely the initially phreatic condition of his stage 7 (see COOKE 1975; GREY & COOKE 1977). COOKE himself characterizes stage 7: 'The river Kwihabe re-establishes itself, initially across a sand surface, but eventually re-excavating its old valley across the hills, and in places following new fault lines. Erosion removes CI and CII calcretes from the newly uplifted blocks and the river cuts through the same calcretes to form the present gorge. Initially a high water-table floods the old cave passages, resulting in extensive enlargement and the concomitant removal of much of the SII sinter. As the river re-incises and the water-table falls, the caves are drained once more, and as humid conditions continue, the SIII sinter is widely deposited in the cave' (COOKE 1975, 442). With regard to my own observations relating to pluvial condition in the Lake Ngami/Makgadikgadi area between > 30 000 and 19 000 B.P. I would like to give the following re-interpretation of COOKE's observations: Firstly the valley re-excavation with erosion of CI and CII calcretes. The initially phreatic conditions in the cave with re-solution of sinter SII and cave enlargement (see also GREY & COOKE 1977, 131) may correspond to my pluvial phase between 30 000 and 19 000 B.P.; the subsequently further vadose development and extensive sinter growth (SIII dated at 13 000 to 16 000 B.P.) may correspond to my low lake level phase with deposition of fluvial sand, near the Okavango delta, and dune sand (HEINE 1978a, table of p. 147). If we correlate the time of valley re-excavation with erosion and cave enlargement in the Kwihabe hills with the pluvial phase of the Ngami/Makgadikgadi area (table 1), none of the ^{14}C dates of COOKE's sinter SIII or SIV mentioned (COOKE & VERHAGEN 1977, 124) will run counter to my chronostratigraphic sequence. On the contrary, COOKE's stage 7 will be divided into two parts, (a) an initial part with major wet conditions with erosion (with a duration of maximal ca. 10 000 yrs., this allows sufficient time for all the erosion processes described by COOKE after the sinter SII deposition and before the formation of the sinter SIII and/or SIV) and (b) SIII sinter deposition between 16 000 and 13 000 B.P.

(2) COOKE refers in his discussion to LANCASTER's observation that the central part of the Kalahari was wet at about 16 000 B.P.; LANCASTER (1977, 1979) describes a new occurrence of lacustrine stromatolites from Urwi Pan, Botswana in latitude 22°50'S. As far as I know (personal communication dated 13.9.1978) LANCASTER only found stromatolites in the Urwi Pan; he could not find during his intensive investigations of the Kalahari pans any other material suitable either for radiocarbon dating or for palaeoenvironmental interpretation, such as molluscs or plant remains. According to LANCASTER the occurrence of the stromatolites indicate that shallow lacustrine conditions prevailed in the pans 17 000 - 15 000 B.P. There are several other indicators for erosional and depositional processes in the Kalahari between ca. 19 000 and 12 000 B.P. caused by surface water. In the Ngami/Makgadikgadi basin this is 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 their fluvial origin (episodical runoff of the Okavango waters to the Makgadikgadi pans). Sixteen stratigraphically consistent ^{14}C dates have been obtained from deposits underneath and above so that the period of the accumulation of the fluvial sand in the Makgadikgadi is restricted to the time between 19 000 and 12 000 B.P. We cannot decide yet, whether the central part of the Kalahari was more or less arid (with or without occasionally penetrating rains) or at certain times during the last glacial maximum more or less humid (the humidity then must have been caused by greater summer rainfall). Nevertheless, during the last glacial (19 000 - 12 000 B.P.) Lake Palaeo-Makgadikgadi must have dried out; perhaps this arid episode was due to reduced summer rainfall compared with the period > 30 000 - 19 000 B.P. and the period ca. 12 000 - < 9000 B.P.; during the glacial maximum

semiarid conditions might have affected the growth of the cave sinter SIII/SIV (16 000 - 13 000 B.P.) and the formation of the Urwi Pan stromatolites (ca. 16 000 B.P.). The stromatolites form a layer above calcareous sandy clay which was deposited during a high water level phase (LANCASTER 1978, 95); so it is possible that this high water level phase of the Kalahari pans corresponds to my older Lake Palaeo-Makgadikgadi (ca. 30 000 - 19 000 B.P.). In the central Kalahari, during the last glacial maximum there existed neither perennial rivers nor lakes; on the contrary in the southern Kalahari, my investigations of the Molopo valley (26°52'S) indicate that a perennial river existed there between ca. 17 000 and 12 000 B.P. according to radiocarbon dates of molluscs (*Corbicula* sp., *Bulinus* sp., *Unio* sp., *Xerocerastus* sp.). At the same time the Nosob and Auob valleys south of 25°S show more or less arid conditions; the stratigraphy of the fluvial sediments and the occasional occurrence of fresh water molluscs indicate that the last wet phase ended there about 19 000 B.P. Figure 2 shows the regional distribution of the records for dry and wet environments during the different Late Pleistocene periods.

(3) In his discussion COOKE mentions that a further fact which I ignore 'probably because of lack of field knowledge of the area' is that the shoreline features at the 920 m level of Lake Palaeo-Makgadikgadi are much more dissected than those at the 945 (946) m level and may thus be older. I do not ignore this fact which is clearly set out in the article by GREY & COOKE (1977), but according to my field investigations in the Ngami/Makgadikgadi area, only those sections show lacustrine sediments and/or lacustrine molluscs of the 12 000 - 9000 B.P. pluvial phase, that are enclosed by the 920 m level shoreline, whereas lacustrine deposits and molluscs of the older > 30 000 - 19 000 B.P. pluvial phase are situated within the 945 (946) m level shoreline; the distribution of the older and younger lacustrine deposits and molluscs indicate quite clear that the older lake was the more extensive one and might correspond to the 945 (946) m level and that the younger one did not exceed the Gidikwe Ridge in the west of the Ntwetwe Pan. The mere morphology of the shorelines does not contradict my stratigraphic evidence, if we assume that the older shoreline is the result of the wettest period of the whole Late Quaternary (since ca. 40 000 B.P.). There are many facts that prove a major wet phase in southern Africa between ca. 30 000 and ca. 19 000 B.P., (a) the sediments and molluscs of the Ngami/Makgadikgadi area which are radiocarbon-dated, (b) a fossil soil buried under red sand dunes and a calcrete layer in the SW Kalahari (25°56'S, 20°25'30''E), ^{14}C date: 28 030^{+4900}_{-3020} (Hv 9502), (c) lacustrine chalk of a large pluvial lake in Griqualand, Cape Province, ^{14}C date: 24 890±695 (Hv 9504), (d) cave sinter from a cave in the Namib desert near the Rössing hills, ^{14}C date: 26 530±920 (Hv 9489), (e) in the Gaap Escarpment area (Kalahari margin, South Africa) the last Pleistocene cold-moist interval began after 35 000 B.P. and ended 14 000 B.P. (BUTZER et al. 1978), (f) in the Makgadikgadi basin many dry valleys (Passarge valley, Deception valley) end at the 945 (946) m beach, thus indicating running water with erosion during the maximum lake level and dessication after the disappearance of the huge palaeo-lake; only the Okwa is regarded as an exception with its large catchment; as a much reduced river the Okwa cut a narrow valley which meandered across the old lake floor (see GREY & COOKE 1977, 128 - 129); the Okwa valley originates in the central Kalahari, an area which could have been affected by rains during the glacial maximum, so that episodically (like in the Urwi Pan) surface water played a part; among other things the interpretation of the morphology of the dry valleys (GREY & COOKE 1977) verifies the concept that the rains of the glacial maximum decreased from south to north in the southern and central Kalahari (perennial river in the Molopo valley, stromatolites in the Urwi Pan, traces of fluvial erosion in the Okwa valley in the Makgadikgadi basin, no fluvial erosion in the Deception and Passarge valleys beyond the 945 m shoreline). There are many reasons for correlating the 945 (946) m level with the > 30 000 - 19 000 B.P. pluvial phase; the much more dissected shoreline features of the 920 m level cannot definitely be correlated with the younger pluvial phase (ca. 12 000 - 9000 B.P.), although it is possible that the dissection of the shoreline is a

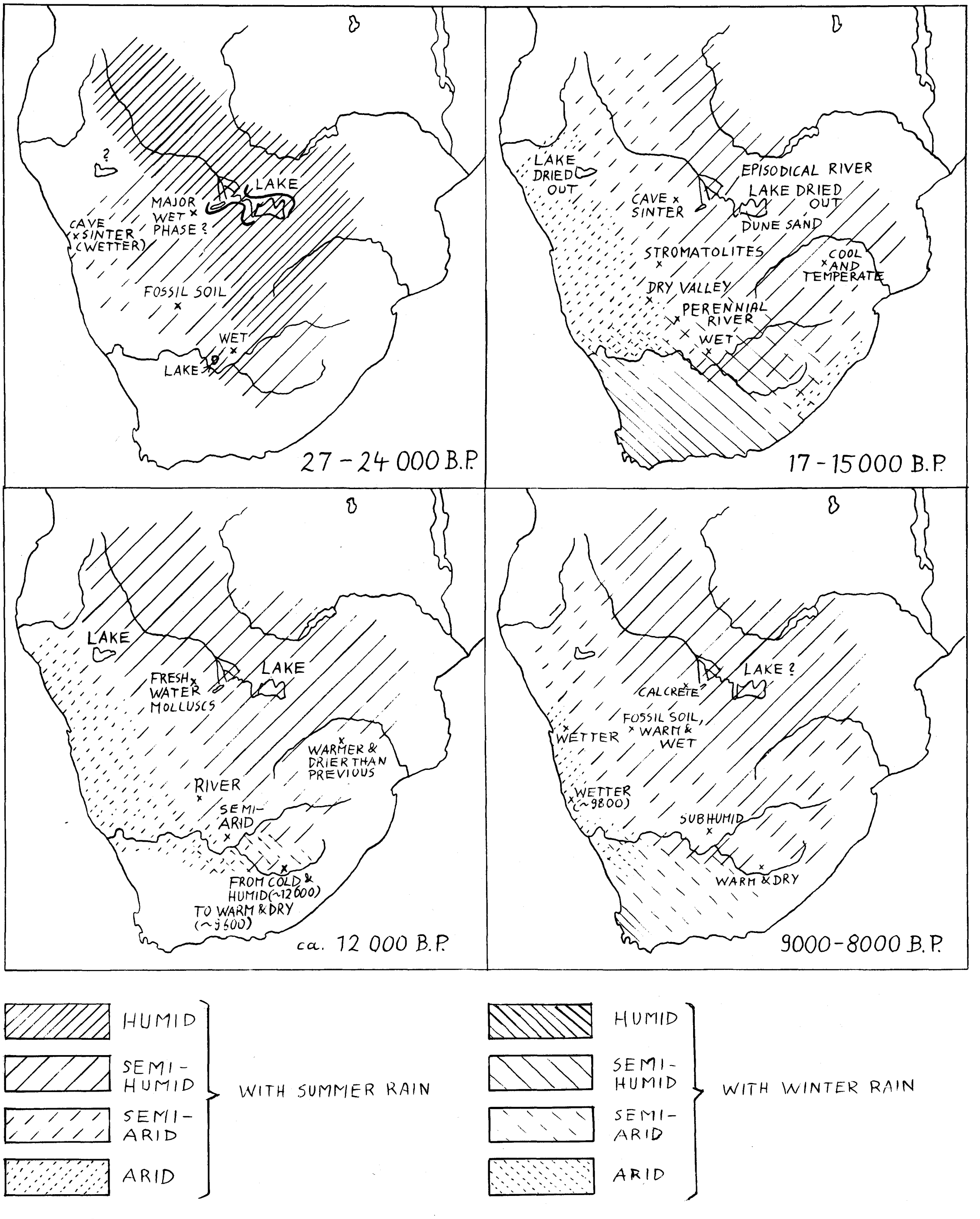

Fig. 2: Maps showing hypothetical climatic regions in the Kalahari for the periods 26 000 - 24 000 B.P., 17 000 - 15 000 B.P., ca. 12 000 B.P., and 9000 - 8000 B.P., based on palaeoclimatic interpretations of ^{14}C dated deposits, molluscs, cave sinters, etc. See text.

result of the surface runoff which is favoured along the 920 m shoreline by the absence of aeolian cover sands; the less dissected 945 (946) m shoreline is often located next to dune sand areas where little or no surface discharge occurs (that means less erosion).

(4) Further evidence for a pluvial period around 12 000 B.P. in the Kalahari region north of about 20°S is indicated by lacustrine sediments in the Etosha Pan; the radiocarbon dates of a readily traceable layer of lacustrine chalk are: 13 680±175 (Hv 9494) and 12 720±165 (Hv 9492); molluscs of a fossil shore (mostly *Xerocerastus* sp.) are dated to 10 670±465 (Hv 9493). These determinations are in certain agreement with the dates of the younger Makgadikgadi pluvial phase. In the Kwihabe valley calcrete CIV sometimes contains fresh water mollusc shells (COOKE 1975, 433); COOKE & VERHAGEN (1977) date the calcrete CIII or CIV to 9800 - 11 000 B.P.; perhaps the calcrete CIV with fresh water molluscs represents my younger pluvial phase (ca. 12 000 - 9000 B.P.).

(5) COOKE comments that my radiocarbon dates are 'a very welcome contribution to the work that is at present in progress, but the dates would have been better presented as such, and not used to support what are at this stage unjustified general statements'. I interpreted my radiocarbon dates very simply: Fresh water molluscs and lacustrine chalk = wet phase; lacustrine sediments = lake; aeolian sand = arid phase (everywhere in arid environments aeolian sand transport and accumulation is observed together with certain fluvial processes that provide the sand for wind deflation); fluvial laminated deposits (sand, silt, clay) without molluscs, but often with a certain percentage of aeolian sand = episodical discharge (in an arid to semiarid environment); fluvial deposits with fresh water molluscs = runoff, either periodical or perennial (depends on the molluscs); calcrete = semihumid to humid phase (yet the calcrete may be interpreted in another way, see COOKE 1975); fossil soil with an A-horizon rich in organic matter = humid phase, if found in an area where today desert and semidesert soils are developing; cave sinters = semiarid to semihumid conditions (the growth rates of the Kwihabe cave sinters appear to be rapid and indicate favourable conditions of water availability and temperature from 14 000 to 17 000 B.P. (COOKE 1975, 441) or from 13 000 to 16 000 B.P. (GREY & COOKE 1977, 131); the occurrence of cave sinters in the Namib (dated to about 26 500 B.P.) shows that considerable rates of solution are also possible in a more or less arid environment). Up to now my chronology is based on 44 radiocarbon dates, and furthermore on the palaeoecological interpretation of the molluscs, indicating fresh water and - in some cases - perennial flow of fresh water. The combination of these palaeoenvironmental facts with the absolute ^{14}C dates supported by sedimentological data have encouraged me to make some remarks about the Late Quaternary climatic development in southern Africa.

Table 1 shows a proposed correlation of the different observations from the Kalahari region during the Late Quaternary. Figure 2 shows a palaeoclimatic interpretation of the deposits, molluscs, cave sinters, etc. that are dated by ^{14}C. It seems that the major wet phase occurs between > 30 000 and 19 000 B.P., because of relative warm temperatures (interstadial) and a southward displacement of the summer rain belt (as a result of a meridional circulation pattern); at the same time the Namib receives some precipitation, possibly because of a weak Benguela current. The last glacial maximum (ca. 19 000 to 12 000 B.P.) is characterized by extreme arid conditions in the Namib and arid conditions in Southwest Africa (caused by a strong Benguela current, see CLIMAP Project Members 1976) on the one hand and semiarid to semihumid conditions in the Kalahari on the other hand; in the southern region of the Kalahari the summer and winter rain areas overlap, resulting in wet conditions for this area (perennial river in the Molopo valley). About 12 000 B.P. the temperatures become warmer, the summer rains are intensified, penetrating now further westward (Etosha Pan), whereas the south Kalahari becomes much more arid, because of reduced winter rainfall. About 9000 - 8000 B.P. the Benguela current is weak (climatic optimum of the southern hemisphere), so that the summer rains episodically can penetrate into the Namib desert; yet extreme pluvial conditions are not observed in the Kalahari, probably because of a zonal circulation pattern (in contrast to the extraordinary wet phase between about 30 000 and 19 000 B.P., a period with a meridional circulation pattern). Table 1 and figure 2 combine all observations from the Kalahari region, thus leading to a complex palaeoclimatic reconstruction of the interior of southern Africa.

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