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On the ages of humid Late Quaternary phases in southern African arid areas (Namibia, Botswana)

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ABSTRACT

Oxygen isotope stages 6 and/or 7 were the last significantly more humid phases relative to today in the Namib and Kalahari Deserts. That it has been more humid at that time is shown by $^{230}Th/^{234}U$ dates of speleothem from the Namib and the Kalahari. $^{230}Th/^{234}U$ dates obtained from calcretes and lacustrine chalk from the southwestern and central Kalahari, as well as TL dates obtained from dune sands from the Etosha area support the cave evidence. At the same time there is evidence for late Quaternary variations in precipitation. Hereby the eastern regions (Botswana) experienced higher variations than the western regions (Namib Desert). These variations could not yet be closely dated.

INTRODUCTION

Climate in the coastal areas of Namibia has been more or less arid for approximately 40 million years. During the Upper Oligocene and Lower Miocene the Antarctic polar front became established, and the Late Cenozoic system of oceanic currents developed together with the Antarctic ice build-up. The south Atlantic high pressure cell and the cold upwelling waters have controlled climate along the southwest African coast at least since the Mio/Pliocene times. According to van Zinderen Bakker (1984) marine pollen assemblages document arid climatic conditions along the Namib coast ever since Pliocene times. The question whether more humid phases occurred in the Namib Desert and surrounding areas during the Late Quaternary has been discussed recently (Heine 1988, Rust 1989, Teller et al. 1990). Paleoecological interpretation of sediments and landforms together with numerous ^{14}C dates from calcretes, fossil soil horizons, speleothem etc. show that climatic variations did occur during the Late Quaternary. During oxygen isotope stage 3 climate was supposedly more humid than today (Heine 1988).

Sinter deposits formed in limestone caves have been found to be an excellent repository of palaeoclimatic data for terrestrial environments (Gascoyne 1992). In the Namib Desert the very presence of a relict speleothem indicates more moisture at the time of formation. Both ^{14}C and uranium-series methods can be used to date the speleothem and, hence, the age of these climatic conditions (Gascoyone 1992). A detailed description of the uranium-series dating methods can be found in Gascoyne et al. (1978) and Li et al. (1989).

THE NAMIB DESERT

Speleothem

In the arid central Namib Desert, in the area of the Rössing Mountains and the Tinkas Flats, caves have developed in dolomites (Fig. 1). As these dolomitic ridges are more resistant to denudation, they surmount the Namib Unconformity Surface by several decameters. The caves show sinter growth. The speleothem depends on local precipitation since surface and/or ground water influx is excluded in the ridges. The caves themselves must have formed under a comparatively humid climatic regime. Furthermore, the base level and therefore the Namib Unconformity Surface must have been at a higher elevation than today. The geomorphic evidence concerning the formation and development of the Namib Unconformity Surface show that these conditions could have prevailed before the Late Miocene/Early Pliocene calcrete formation on the Namib Unconformity Surface in the Kuiseb area (see Rust & Summerfield 1990, Spönemann & Brunotte 1989).

Several stalagmites, stalagtites, flowstones, and other speleothem were dated by the radiocarbon method (Heine & Geyh 1984, Heine 1991). The resulting ages are all larger than 25 ka BP. Compact speleothem were even older than 35 ka BP. According to the ^{14}C dates, no speleothem have formed since 25 ka BP. Table 1 and Figures 2 and 3 show the ^{14}C dates.

A number of speleothem samples from the Rössing and Tinkas Caves were dated additionally by $^{230}Th/^{234}U$ (Figs 2 and 3, Table 2). The results differ considerably from the ^{14}C dates. While the $^{230}Th/^{234}U$ dates from the Tinkas Cave do not provide evidence for significantly more humid phases during the Quaternary, the youngest flowstone from the Rössing Cave could have been formed during oxygen isotope stage 6. Samples K00 613 and K00 616 are from flowstones intercalated with eolian sands. Sample K00 616 has been retrieved from a lower part of the same section. The resulting $^{230}Th/^{234}U$ dates are stratigraphically reasonable, although their standard deviations overlap. The sinter has been

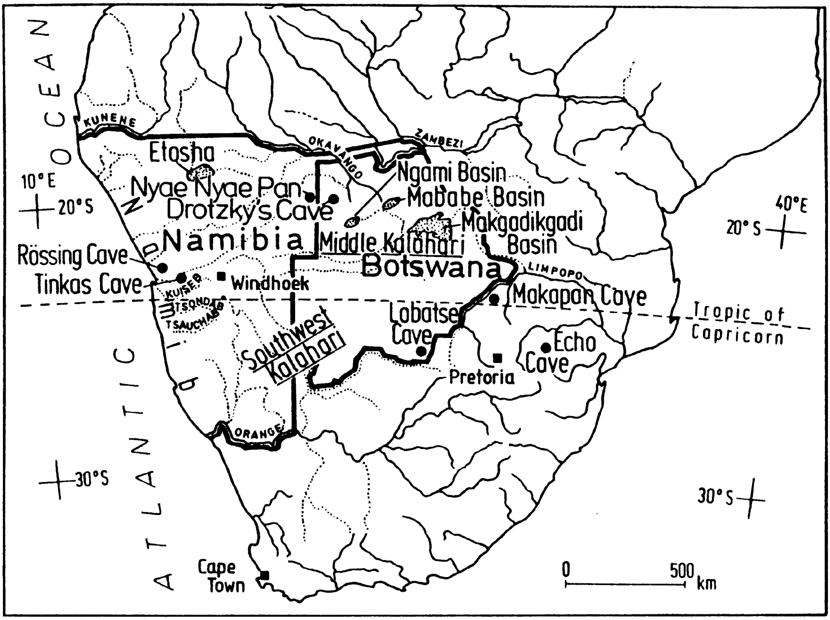

Figure 1. Location of research sites in southern Africa.

percolated by dripping water containing younger bicarbonates long after sedimentation, as shown by the ^{14}C date of sample K00 613 (26.8 ka BP) from the top of the flowstone. Besides irregular rainfall, fog precipitation in this region may result in wetting the speleothem frequently. Therefore, U mobilization resulting in 'open system' conditions cannot be excluded which would explain too large ^{230}Th/^{234}U ages.

The thermoluminescence analyses from sands that were blown into the Rössing Cave (Table 3) of the samples K00 760 and 763 imply that it seems impossible to date the eolian cave sands by the TL method, because their natural TL is almost in saturation. Therefore, the TL dates can only be interpreted as minimum ages and do not contradict the ^{230}Th/^{234}U dates. However, they show even within the 2σ standard deviation significantly higher ages than the formerly obtained ^{14}C dates.

There are indications from these comparatively high age of the Namib sinter that the speleothem development did not occur during the Late Quaternary and the central Namib Desert has been arid or hyperarid throughout the Late Quaternary.

Table 1. Radiocarbon dates from speleothems of the Namib Desert.

Lab.no. Hv	Sample K00	Material	$\delta^{13}C$ [‰]	Conventional ^{14}C age (years before 1950)	^{14}C value (pmc)
08364	77/49	L	−2.5	24,330±270	4.8±0.2
08380	77/48	C	+0.1	13,275±110	19.2±0.3
09489	162	Ks	−2.0	26,530±920	3.7±0.4
09909	162	Ks	−4.5	29,680+1480/−1250	2.5±0.4
09910	162a	Ks	−5.7	26,680±540	3.6±0.2
11634	610	Ks	−5.4	26,630±500	3.6±0.2
11635	613	Ks	−7.9	26,780±360	3.6±0.2
11636	612	Ks	−3.6	29,830±660	2.4±0.2
11637	616	Ks	−4.0	33,590+1315/−1070	1.4±0.2
11638	619	Ks	−5.0	36,950+1130/−945	1.0±0.1
11639	621	Ks	−6.8	37,025+1910/−1430	1.0±0.2
11640	622	Ks	−5.3	41,530+1330/−1140	0.6±0.1
12704	626	Ks	−5.2	34,050+2850/−2100	1.4±0.4
12705	625	Ks	−1.5	30,360+1750/−1440	2.3±0.4
12871	636	oM	−20.1	–	107.8±0.7
12872	639-1	Ks	+1.6	35,000+3300/−2330	1.3±0.4
12873	646-1	Ks	+0.9	34,000+2740/−2040	1.5±0.4
12874	646-2	Ks	−1.9	43,450+3490/−2420	0.4±0.2
12875	646-3	Ks	−0.5	38,650+1730/−1420	0.8±0.2
12876	646-4	Ks	−0.2	40,550+2540/−1930	0.6±0.2
12877	646-5	Ks	+0.9	38,400+1790/−1460	0.8±0.2
12878	646-6	Ks	+1.7	48,950+3730/−2540	0.2±0.1
12879	642	Ks	+1.3	39,590+2060/−1640	0.7±0.2
12880	645	Ks	−0.3	37,680+4470/−2860	0.9±0.4
12881	637-1	Ks	+2.5	42,210+2670/−2000	0.5±0.1
15928	768-1	Ks	−5.9	>49,000	0.3±0.1
15929	768-2	Ks	−6.5	47,750+4370/−2810	0.3±0.1
15930	768-3	Ks	−5.5	>49,940	0.4±0.1
15931	768-4	Ks	−3.8	>48,640	0.2±0.1
15962	794	M	–	980±115	88.5±1.3
15963	822	M	−1.9	3,520±100	64.6±0.8
16107	103	C	+0.4	30,990±490	2.1±0.1
(09884	103	C	–	8,245± 75	35.8±0.3)

Ks = speleothem; L = lacustrine chalk; M = mollusc; oM = organic material; C = calcrete.

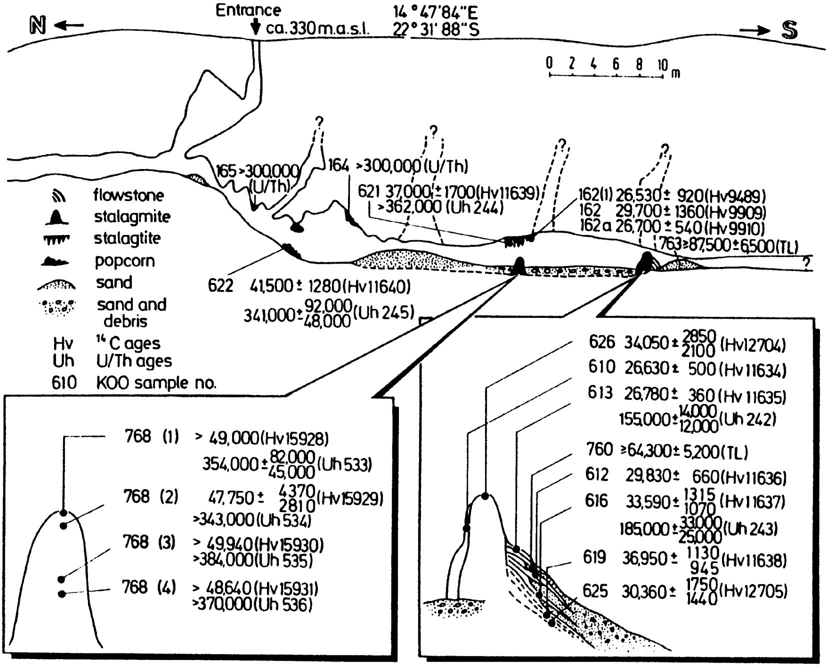

Figure 2. Rössing Cave, Namib Desert, showing the positions of the dated samples.

Other evidence

In the Kuiseb valley on the northern margin of the great Namib sand sea, calcareous cementation of gravel terraces ('40 m terrace') together with pedogenic calcretes have been ^{14}C dated 32-28 ka BP old (Vogel 1982). The geomorphologic situation (erosion of the compact conglomerates within only 5000 years before the sedimentation of the 23-19 ka BP old Homeb Silts) and the stratigraphic position of the '40 m terrace' indicate an Early Pleistocene to Pliocene age (Ward 1988). The occurrence of ESA (Early Stone Age) artefacts on the terrace surface, as well as the current hypotheses concerning the formation of calcretes several metres thick (Marion 1989), indicate a significantly higher age for the formation of the '40 m terrace' as well as the calcareous cementation. A humid phase during stage 3 postulated from the ^{14}C dates of the '40 m terrace' calcretes is questioned.

The Tsauchab and Tsondab valleys originate in the area of the escarpment. They run westward into the sand sea and end in pans. Sedimentation in the pans alternated between fluvial-lacustrine silts and clays, and dune sands. ^{14}C dates of the calcareous sediments indicate lake formation 40-20 ka BP (Vogel & Visser

Table 2. Results of U-series dating (speleothems, calcretes, lacustrine chalk). Estimated ages according to geomorphological, sedimentological and stratigraphical observations are shown in right column.

Lab. no Uh-Hv-	Sample K00	^{238}U (ppm)	^{232}Th (ppm)	^{234}U / ^{248}U	^{230}Th / ^{232}Th	^{230}Th / ^{234}U	$^{230}Th/^{234}U$ age (ka BP) fo = 0	$^{230}Th/^{234}U$ age (ka BP) corr., fo = 1.0	Estimated age
213	639	0.651	0.072	1.023	28.44	1.006	>266		>1 Ma
12872		±0.015	±0.011	±0.022	±4.23	±0.040			
214	646-1	2.033	0.223	1.032	43.12	1.508	>307		1 Ma
12873		±0.035	±0.009	±0.011	±1.67	±0.029			
215	646-2	2.665	0.014	1.004	575.52	0.956	337	337	>1 Ma
12874		±0.050	±0.014	±0.011	±575.5	0.024	−51+104	−51+104	>1 Ma
216	646-3	5.558	0.051	1.005	337.63	1.013	>318		>1 Ma
12875		±0.104	±0.007	±0.008	48.67	±0.025			
217	646-4	7.869	0.316	0.999	69.79	0.922	278	276	>1 Ma
12876		±0.117	±0.021	±0.005	4.19	±0.026	−33+48	−32+47	
218	646-5	2.727	0.168	1.001	43.17	0.873	224	222	>1 Ma
12877		±0.043	±0.004	±0.007	0.97	±0.013	−11+13	−11+13	
242	613	2.054	0.201	1.128	27.53	0.783	158	155	155 ka
11635		±0.064	±0.008	±0.018	±1.08	±0.028	−12+14	−12+14	
243	616	2.490	1.090	1.136	6.82	0.863	199	185	185 ka
11637		±0.049	±0.069	±0.010	±0.23	±0.050	−28+38	−25+33	
244	621	1.534	0.001	1.004	3706.4	1.015	>362		>1 Ma
11639		±0.025	±0.001	±0.008	±3706	±0.015			
245	622	0.590	0.194	1.067	9.70	0.981	351	341	>1 Ma
11640		±0.001	±0.006	±0.015	±0.29	−52+107	−48+92		
533	768-1	1.111	1.030	276.9	0.971	354	354		>350 ka
15928		±0.020	±0.001	±0.016	±31.0	±0.016	−45+83	−45+82	
534	768-2	1.287	0.004	1.016	849.5	1.004	>343		>350 ka
15929		±0.024	±0.001	±0.016	±247.9	±0.017			

535	768-3	2.323	0.016	1.001	443.1	1.009	>384		>350 ka
15930		±0.034	±0.001	±0.008	±40.3	±0.012			
536	768-4	1.782	0.001	1.017	4542.2	0.989	>370		>350 ka
15931		±0.028	±0.001	±0.012	±####.#	±0.014			
777	77/48	0.820	0.346	1.399	4.7	0.467	65.9	55.2	13-15 ka
8380		±0.012	±0.059	±0.017	±0.8	±0.028	±5.5	±5.8	
778	77/49	1.836	2.428	1.204	2.1	0.754	143	98	50-100 ka
8364		±0.029	±0.035	±0.013	±0.0	±0.011	±4.5	±5.3	
546	103	2.419	2.312	1.951	5.4	0.875	172	157	157 ka
16107		±0.075	±0.041	±0.047	±0.1	±0.024	−10+11	−9+10	

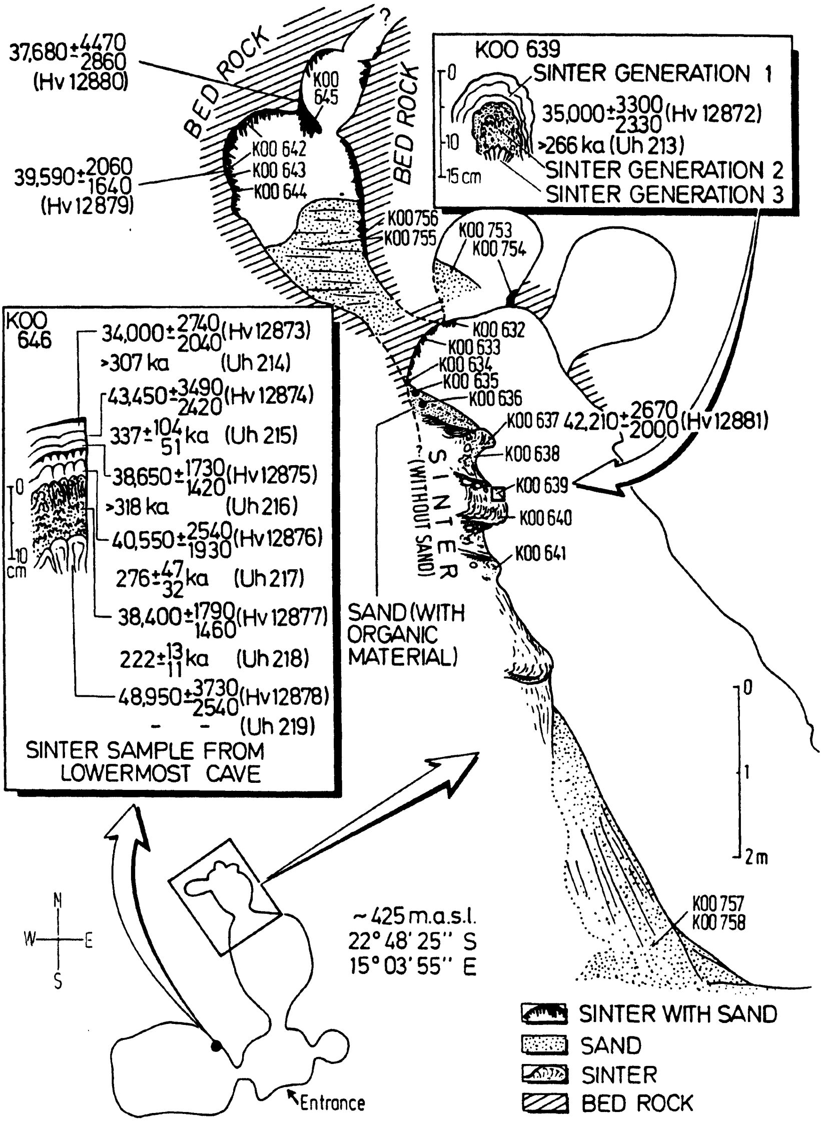

Figure 3. Tinkas Cave, Namib Desert. Bottom, plan map of the different cave chambers. Top, stratigraphic section through the cave sediments.

Table 3. Thermoluminescence results from eolian sand (Etosha dunes, Kalahari dunes, Namib cave sand).

Sample K00	ED (Gy)	U (ppm)	Th (ppm)	K (%)	TL age (ka BP)	Remarks
831	48.3±8.6	0.21	0.7	0.37	80.8±7.1	Etosha dune sand
837	42.9±3.4	0.61	1.27	0.92	34.3±2.6	Etosha dune sand
837		1.62±0.13	1.55±0.39		28.5±2.4	Etosha dune sand
859	5.24±0.43	0.99	0.71	0.21	8.27±0.83	Nyae Nyae Pan/Kalahari dune sand
763	ca. 340	1.5	6.6	3.36	≥87.5±6.5	Rössing cave sand
760	285+38/−32	2.9	12.9	2.98	≥64.3±5.2	Rössing cave sand

1981, Teller et al. 1988, 1990). In contrast to these dates, the position of the massive longitudinal dunes on top of some of the dated sections, the pronounced stabilisation and the red colour of the fossil dune sands between the clay/silt layers, the denudation of the sediments in the interdune corridors, the occurrence of desert pavements with in situ artefacts from the ESA and MSA (Middle Stone Age), the paleontological evidence (*Elephas recki*, 400-700 ka BP) together with two $^{230}\text{Th}/^{234}\text{U}$ dates (210±15 and 260±25 ka BP, Selby et al. 1979) from lake bed carbonates show the high age of the fluvial-lacustrine silts and clays.

THE KALAHARI

Makgadikgadi Basin, Ngami Basin, Mababe Basin

In the region of the Okavango Delta, of Lake Ngami, and of the Mababe and Makgadikgadi pans, paleolake sediments, calcretes, molluscs, stromatolites, etc., as well as fossil shorelines, dune systems, and river terraces indicate that climatic variations occurred in the past (Fig. 4). Interpretation of the evidence for Late Quaternary climatic change is not yet free from contradictions: Cooke & Verhagen (1977) assume a more humid climate as shown by speleothem for the period 29-45 ka BP, and Heine (1987) also postulates a more humid climate at the end of stage 3 from lake sediments, whereas Shaw et al. (1988) and Thomas & Shaw (1991) suggest a number of substantial hygric alternations between 45 ka BP and 20 ka BP.

The interval 17-12 ka BP after the Last Glacial Maximum (LGM) has been

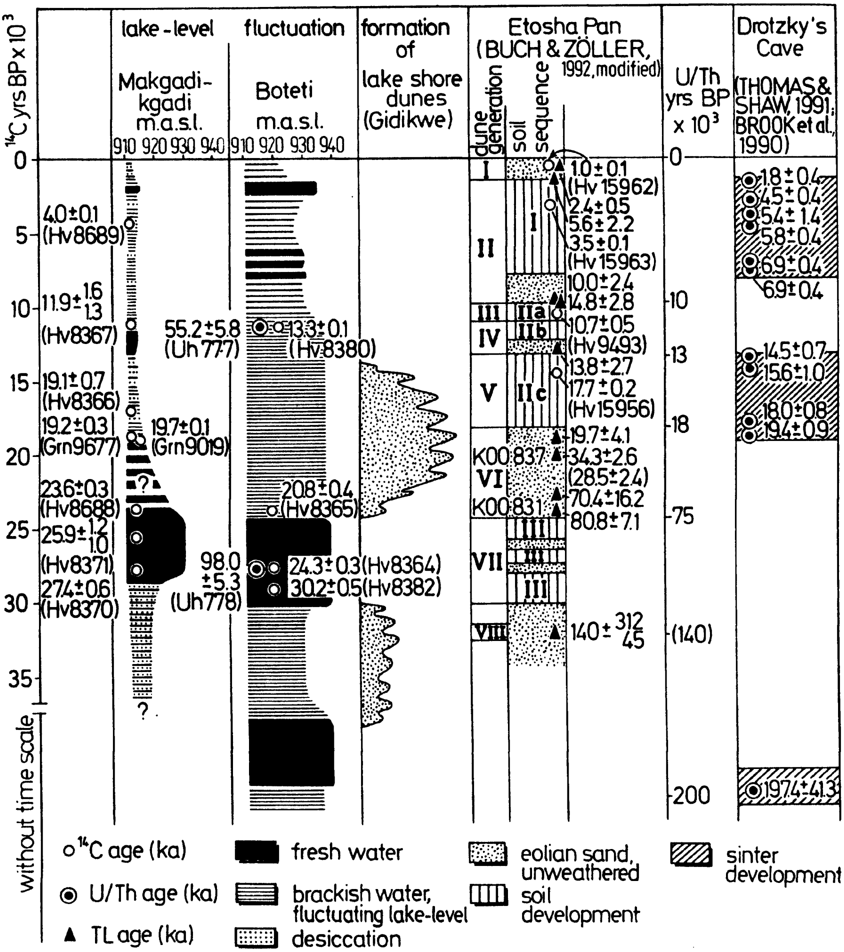

Figure 4. Late Quaternary lake-level fluctuations, dune formation, soil development and sinter growth from selected areas of the Kalahari region.

suggested both semi-arid (Heine 1987) and semi-humid/humid (Thomas & Shaw 1991). Nothing is known about the climate of the area before 45 ka BP, since ^{14}C dating reaches only this far back.

One mid-Pleistocene and 10 Late Pleistocene to Holocene samples of speleothems from Drotzky's Cave have been dated by $^{230}Th/^{234}U$ (Brook et al. 1990, Thomas & Shaw 1991). The age sequence of the lake sediments and of the other paleoclimatic evidence from the Makgadikgadi Basin in all cases remain doubtful (Heine 1991), since the lake-level fluctuations have been reconstructed from ^{14}C dates from calcretes, marls, and molluscs (Heine 1978, 1987), and from calcretes (Thomas & Shaw 1991) that were collected from different sites in the pans and surroundings. Therefore a sequence near the Boteti (Fig. 4) that is of great importance for the interpretation of the former lake-level fluctuations of Lake Makgadikgadi has been dated again by ^{230}Th/^{234}U (Table 2). The ^{230}Th/^{234}U dates are significantly higher than the ^{14}C dates. The ^{230}Th/^{234}U activity ratios of samples 77/48 and 77/49 are typical for carbonates from fresh and salt water lakes. The difference between 'detritus'-corrected and uncorrected ages, calculated with a plausible correction factor of 1, is significantly large, therefore, maximum ages for the samples are given. Since ^{14}C dates from carbonates of about 13 ka BP can only be a few millenia too small, but ^{230}Th/^{234}U dates can easily be many millenia too large due to leaching of U by groundwater, it is probably that the true age of sample 77/48 is closer to 13 ka BP than to 55 ka. The geomorphologic-sedimentologic situation of sample 77/49 (Heine 1987) as well as the archaeologic evidence (Helgren 1984) suggests an age of larger than stage 3.

Southwest Kalahari

Dating problems of calcretes by ^{14}C also occur in the southwestern Kalahari, as shown by ^{230}Th/^{234}U dates. A sequence of several calcretes is overlain by dune sands (Heine 1990). The youngest calcrete (sample K00 103) has been 23914C-dated at 8 and 31 ka BP, its ^{230}Th/^{234}U date is 157 ka BP (Tables 1 and 2).

Etosha area

The shores of the Etosha Pan in northern Namibia are accompanied in many places by fossil terraces. An especially pronounced terrace level at about 12 m is covered by massive calcrete deposits, which have been ^{14}C dated at 32-28 ka BP (Rust 1985). However, the geomorphologic-pedologic evidence suggests a significantly higher age of the calcretes and the terrace (Heine 1991). On the western shore of the Etosha Pan, the shore terrace is covered by dune ridges. A section through these dunes shows a differentiated sequence of paleosoils (Fig. 4, Buch & Zöller 1992). At least three phases of soil development are recognisable. Thermoluminescence dates (Table 3 and Buch & Zöller 1992) show that the sand accumulated between about 75 and about 25 ka BP (Fig. 4). Oxygen isotope stage 3 coincided with a period of sand accumulation rather than soil development.

DISCUSSION AND CONCLUSION

A synopsis of all ^{14}C dates from Namibia and Botswana (Fig. 5) shows that there are only three pre-Holocene ^{14}C dates from samples that are not from inorganic sediments: (1) wood from the Homeb Silts in the Kuiseb valley (Vogel 1982); (2) material from a fossil Ah soil horizon from the southwestern Kalahari (Heine 1982); and (3) peat from the Makgadikgadi Pan (Thomas & Shaw 1991). Paleoclimatic interpretation of the ^{14}C dates from the Namib Desert shows that the region remained arid to hyperarid throughout the Late Quaternary. Ponding and sedimentation were related to small increases in runoff and groundwater recharge (see also Teller et al. 1990). In the southwestern Kalahari, there is proof for a somewhat more humid phase compared to today during the late stage 3 (see Heine 1990). The same more humid phase seems to have occurred in the Okavango/Makgadikgadi area, but the ^{14}C dates from this region remain questionable, since all but one are from material containing $CaCO_3$ (calcrete, molluscs, etc.).

The $^{230}Th/^{234}U$ dates from speleothem and calcretes, as well as the TL dates from dune sands show that the chronostratigraphies based on ^{14}C dates have to be altered. The last significant pre-Holocene pluvial phase with speleothem formation in the Namib caves probably occurred during stage 6 and/or 7. $^{230}Th/^{234}U$ dates from other areas in southern Africa support this view (Brook et al. 1990): Drotzky's Cave (Botswana): 197 ± 41.3 ka BP; Lobatse 2 Cave (Botswana): about 197 ka BP; Echo Cave (Transvaal): 197.1 ± 17.6 ka BP and 198.8 ± 21.4 ka BP; Makapan Cave (Transvaal): 202.0 ± 39.0 ka BP. It seems likely that climate in the arid and semi-arid parts of southern Africa experienced a more humid phase around and after 200 ka BP (Brook et al. 1990). As the TL chronostratigraphies of the paleodunes of the Etosha area (Buch & Zöller 1992) together with the paleosoil evidence do not show any indication of a significantly more humid phase after 140 ka BP, the existing observations from the Namib and Kalahari Deserts are interpreted as follows: About 200 ka BP (and during stage 6 ?) there was more available moisture over much of Botswana and the Transvaal of South Africa; pluvial conditions prevailed that were significantly more humid than any following humid phase apart from Holocene periods of comparatively humid climate. The intensity of the humid phases was extremely small in the Namib Desert, it increased eastward. In the central Kalahari Desert, the extremely humid phase is characterised by flooding of the cave and extensive re-solution of speleothem at one or several times during the period between 197 ka BP and before 45 ka BP (Brook et al. 1990). Apart from this the Namib Desert probably experienced a minor increase in humidity only at the end of stage 3 and during the early stage 2. This did not result in significant speleothem formation. In contrast to this, the central Kalahari Desert (Okavango Delta, Makgadikgadi Pans) shows evidence for numerous hygric variations, some rather pronounced. Opinions on the chronostratigraphy of these variations still differ due to problems with ^{14}C dating of the deposits (e.g. Heine 1982, 1990, Thomas & Shaw 1991).

Similar observations come from the northern African arid areas (Causse et al.

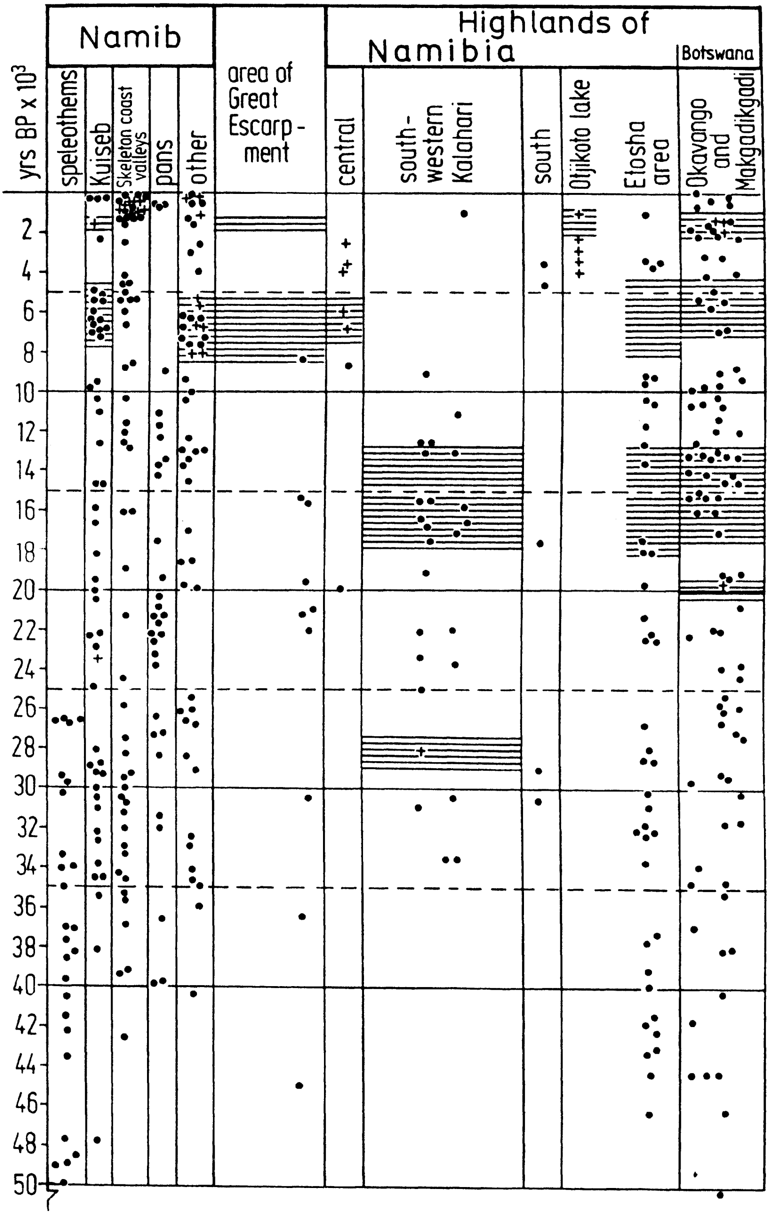

Figure 5. Radiocarbon dates from Namibia and Botswana (for references see Heine 1991 and Scott et al. 1991). Dots represent inorganic material, crosses represent organic material. The horizontal-ruled pattern shows 'humid phases' (= humidity greater than today) according to reliable radiocarbon dates.

1989, Fontes & Gasse 1989, Fontes et al. 1991). In some caves in the Australian Nullarbor Desert, stratigraphic relationships indicate that there were at least three phases of calcium carbonate deposition. Most samples have ages in excess of ca. 400 ka BP; one sample of a gypsum speleothem has as finite age of ca. 185 ka BP, and some small halite speleothems formed during the Holocene (Goede et al. 1990). The geochronological evidence presented from the Namib, the Kalahari, and southern Australia suggests a prolonged period of aridity during the Late Quaternary in the deserts of the southern hemisphere.

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