Evidence of wetter and drier conditions in Namibia from tufas and submerged speleothems

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Twelve submerged speleothems were recovered from 5 flooded caves in the Otavi Mountain Land, Grootfontein District, Namibia. Thirteen uranium-series ages based on these speleothems suggest more arid conditions in Namibia at several times during the last 130 ka B.P. The significance of this information is reviewed in the context of previous palaeoenvironmental information from Namibia, as well as additional ages derived from the Blässkranz tufa deposit in the Naukluft Mountains.

INTRODUCTION

Namibia is an arid country with large areas of hyperarid desert. Not surprisingly, therefore, palaeoenvironmental research has focused on past wetter climates and much less on periods of greater aridity. Heine (1999) suggests that during the late Quaternary, periods of increased rainfall were more pronounced further inland at greater distance from the coast, so that in the Kalahari area these increases were quite significant. Heine contends that during the last 125 ka B.P. the hyperarid coastal zone of the Namib Desert remained arid at all times, only experiencing variations in precipitation that are typical of a desert region. Vogel (1989) holds a slightly different view. He admits that much of the evidence for increased wetness in the Namib Desert is derived from river valleys which drain the uplands, so that it may be argued that this reflects rainfall conditions above the escarpment. Vogel is, however, of the view that there is no reason to assume that in the late Quaternary the general atmospheric circulation changed fundamentally, so that precipitation changes inland should also be reflected in the desert.

There has been an increased interest in the drier periods of the past since the development of thermoluminescence/optically stimulated luminescence (TL/OSL) dating, which has made it possible to determine when currently inactive dunes were formed (e.g. Heine 1992; Stokes *et al.* 1997a, 1997b; Thomas *et al.* 1997). Namibia, however, offers another, rather unusual way of determining when the climate was more arid. In the Otavi Mountains, east of the Namib Desert, there are cenotes and flooded caves that preserve submerged stalagmites and stalactites (speleothems). As speleothems form in air-filled caves and not under water, they bear witness to times when ground water levels in the dolomite aquifer of the region were considerably lower than they are today. In August and September, 1992, with the assistance of the Namibian Underwater Federation and South African Spelaeological Association cave diving and caving groups, samples of submerged speleothem material were recovered from five flooded caves. These samples have provided information concerning more arid conditions in Namibia dating back to the last interglacial.

Spring and waterfall tufas, and cave speleothems, are two of the most reliable indicators of increased wetness in arid and semiarid environments (e.g. Beaumont & Vogel 1993; Brook *et al.* 1990, 1996, 1997; Butzer *et al.* 1978; Hennig *et al.* 1983; Marker 1972). This paper presents new data on tufa deposition in the Namib Desert indicating wetter conditions in the past, and age data for submerged speleothems from the Otavi Mountain region indicating drier conditions.

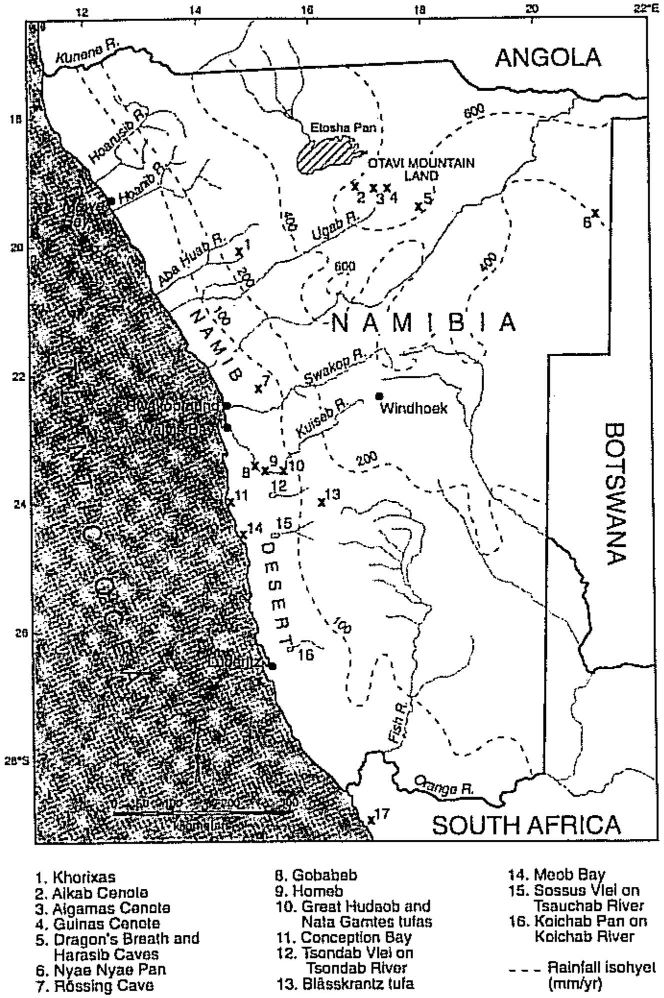

Figure 1. Location of palaeoenvironmental sites discussed in the text.

These ages, together with already published data for Namibia, are then examined alongside information from other parts of the Southern African summer rainfall zone to see whether climate changes in Namibia paralleled those in adjacent areas of Botswana and South Africa. Finally, the information is examined to determine if the Namib Desert itself underwent significant environmental changes over the last 40 ka or so.

TIMESCALE USED IN THIS STUDY

Evidence of environmental change in Southern Africa has been dated by a variety of methods principal amongst which are radiocarbon, TL/OSL, and U-series. As previously mentioned by Brook *et al.* (1996, 1997), these ages can not be compared directly. This is due to the fact that there have been variations in atmospheric CO_2 over time, such that radiocarbon ages are consistently younger than TL/OSL and U-series ages through the effective time range of the radiocarbon method (Bard *et al.* 1990; Vogel 1983). Based on data in Bard *et al.* (1990), Brook *et al.* (1996) used the equation: ^{14}C age (yr B.P.) = 53 + 0.85 U-series age (yr B.P.), to convert ^{14}C ages to the U-series/TL/OSL timescale up to ^{14}C ages of 35 ka B.P. As Vogel (1983) suggests that a plateau is reached in the difference between U-series and ^{14}C ages above about 35 ka B.P., ages from 35-45 ka B.P. were corrected simply by adding 6 ka B.P. to the age. As the vast majority of evidence on environmental change in Namibia has been dated by the ^{14}C method, all ages used in this study (to 45 ka B.P. on the ^{14}C timescale and 51 ka B.P. on the U-series and TL/OSL timescale) were converted to the ^{14}C timescale. U-series ages greater than 51 ka were not corrected in any way.

THE FLOODED CAVES AND THEIR SPELEOTHEMS

The Otavi Mountain Land (OML), about 80 km southeast of the Etosha Pan, is part of the Damara Orogen where sediments were deposited 920-650 million years ago. Deposition of the Damara sequence began with the Nosib Group including various clastic sediments and lavas deposited on the Basement Complex. Dolomite and limestone units belonging to the Otavi Group cover the Nosib. The lower part of this Group is the Abenab Sub-Group made up of, from the base, the Berg Aukas, Gauss and Auros Formations. Resting unconformably on the Abenab is the Tsumeb Sub-Group. At the base of the Tsumeb are the Chuos Formation mixtite and other glacial sediments overlain by the Maieberg, Elandshoek and Hüttenberg Formations. The Mulden Group, consisting of clastic sediments such as shale, phyllite and sandstone, unconformably overlies the Otavi carbonate sequence. The OML is highly mineralized with economic deposits of copper, lead, zinc, silver, germanium, and vanadium (Miller & Grote 1988; Andreas Palfi pers. comm. 1990).

Submerged speleothems in growth position were collected from five caves in the Otavi Mountain region (Figure 1). Three of the caves, Aikab, Aigamas and Guinas, have collapsed roofs and are extensively open to the surface making them cenotes. The remaining two, Harasib and Dragon's Breath, have relatively small entrances but large underground water bodies. Precipitation in the region varies from 600-700 mm/yr.

Cross sections of four of the flooded caves from which we obtained speleothems are shown in Figure 2. Aikab is situated beneath the plain near the southeastern border of Etosha National Park. It is a doline or sinkhole, which leads to a large underground water body. The cenote is developed in the massive dolomite of the Elandshoek formation of the Tsumeb Subgroup. Harasib and Dragon's Breath caves are also developed in this formation. Aikab was reportedly used as a water source by the Heikum San and in later years by farmers on the neighboring farm Lynplaas. The underground cavity is roughly circular in plan, being 120 x 100 m in extent and up to 63 m deep. Water marks on the walls, as much as 15 m above the level in 1992, as well as historical accounts, attests to past higher water levels in the cave. Guinas Lake is 145 x 70 m in extent and about 120 m deep. The lake is completely open to the surface and is used for irrigation by local farmers. Divers explored the cave to a depth of about 60 m, but found submerged speleothems only to 11 m below the surface. The water surface in Aigamas cenote is about 81 m below ground surface. The lake is 115 m long and about 20 m wide with depths exceeding 40 m. Harasib Cave was first explored in the early 1900s. The vertical distance to water is about 100 m and the lake in the cave is 135 x 35 m in extent and more than 70 m deep. Dragon's Breath Cave was discovered in 1986. It is entered via a 1.5 m wide fissure, which leads down 40 m via a series of vertical pitches. There is a final drop of 20 m into an underground lake 260 m by 180 m in surface dimensions and more than 90 m deep.

Thirteen U-series ages have been obtained for twelve submerged speleothems from the five flooded caves (Table 1). Divers recovered the speleothems from depths ranging from 3-40. The speleothems varied from 20-25 cm long and 7-12 cm in diameter, and ranges in U-series age from 7.5 ± 0.3 to 129.9 ± 6.9 ka B.P. There are two distinct groupings in the ages. Four fall in the interval 9.1-6.4 radiocarbon ka B.P. and three in the range 26.2-24.1 ka B.P. This suggests that in northeastern Namibia the early Holocene was drier than now with ground water levels at some locations at least 13 m lower than they are today. The grouping of ages at 26.2-24.1 ka B.P. tells of drier conditions a few thousand years before the peak of the last glacial maximum with ground water levels at least 13.5 m below present at some sites. Speleothems from Harasib, dating to 8.5 ± 0.5 ka B.P. and 28.7 ± 1.4 ka B.P., and recovered from 13 m and 13.5 m, respectively, suggest that ground water levels may have

Table 1. Ages and depths of submerged cave speleothems, Otavi Mountain Land, Namibia.

Cave	Sample ID		$^{230}Th/^{232}Th$ Ratio	U-Series Age (ka B.P.)[1]	Equivalent Radiocarbon Age (ka B.P.)[2]	Depth below water level (m)
Aikab	Ak	92-4	>1000	7.5 ± .3	6.4	3
Harasib	H	92-4	143	8.5 ± .5	7.3	13
Dragon's Breath	DB	92-2	>1000	8.8 ± .5	7.5	5
Aikab	Ak	92-1	62	10.6 ± .4	9.1	13
Guinas Meer	G	92-4	100	13.5 ± .3	11.5	9
Guinas Meer	G	92-4	>1000	15.4 ± .8	13.1	9
Guinas Meer	G	92-5	250	28.3 ± 14	24.1	11
Harasib	H	92-1	250	28.7 ±1.4	24.4	13.5
Guinas Meer	G	92-3	>1000	30.8 ± 2.0	26.2	5
Guinas Meer	G	92-4	40	61.4 ± 3.6		9
Harasib	H	92-6	>1000	107.6±6.6		16
Aigamas	Ag (outside)	92-3	250	112.0±5.3		40
Aigamas	Ag (inside)	92-3	>1000	129.9±6.9		40

[1] Ages were determined in the Department of Geology, Florida State University, U.S.A.
[2] Radiocarbon ages were determined from U-series ages using the equation: ^{14}C age (yr B.P.) = 54 + 0.85 U-series age, up to U-series ages of 41 ka B.P. Ages of 41-51 ka B.P. were converted to ^{14}C ages by subtracting 6 ka.

been similar during both intervals. However, given that temperatures were almost certainly higher during the early Holocene, meaning higher evapotranspiration rates, this suggests less precipitation 26.2-24.1 ka B.P. than during the early Holocene. Radiocarbon ages of 11.5 and 13.1 ka B.P. for two submerged speleothems, and a U-series age of 61.4 ka B.P. for another, suggest that these times were also characterized by much lower ground water tables than the present.

It is perhaps not coincidental that six of the thirteen dates indicate dry periods, with low ground water levels, during known warm periods of the past when evaporative water losses were likely to be high. As pointed out earlier, four ages date to the early Holocene when global temperatures may have been about 1 °C warmer than now (Jouzel *et al.* 1987). The U-series age of 129.9 ± 6.9 ka B.P., for a speleothem from Aigamas, indicates that it was forming during deep sea isotope substage 5e when global temperature may have averaged 2 °C warmer than today (Jouzel *et al.* 1987) and, as a result, sea levels were about 8 m higher. A second U-series age for this speleothem of 112.0 ± 5.3 ka B.P., and an age of 107.6 ± 6.6 ka B.P. for a stalactite from

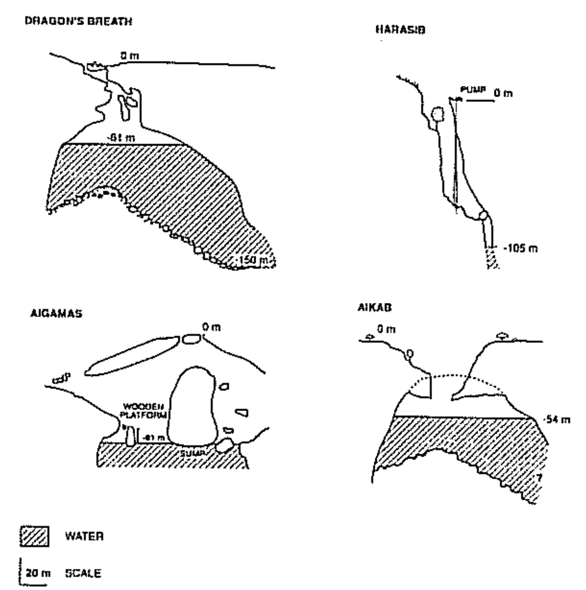

Figure 2. Cross-sections of the flooded caves in the Otavi Mountain Land, from which submerged speleothems were recovered.

Harasib, suggest that conditions were also drier during isotope substage 5d. The two speleothems dating to deep-sea isotope stage 5 were recovered from greater depths than the other formations studied (40 m and 16 m respectively). It is, therefore, perhaps not unreasonable to suggest that, in terms of available moisture, isotope substages 5e and 5d were drier than the early Holocene, and may have been among the driest intervals of the last 130 ka. As mentioned above, however, low groundwater tables at times of lower mean annual temperature, and therefore lower evapotranspiration, such as was probably the case in the interval 26.2-24.1 ka B.P., may record lower levels of precipitation than during warm, dry intervals, when evapotranspiration contributed significantly to water table declines.

THE BLÄSSKRANTZ TUFA

This waterfall tufa, located in the Namib-Naukluft Park, Namibia, where precipitation is less than 50 mm/yr, is approximately 50 m high and 200 m wide. Three samples of tufa were taken for radiocarbon dating from different locations on the front face of the deposit. An attempt was made to select samples that might be of different age. The samples proved to be 20.4 ± 0.2, 15.1 ± 0.2, and 11.0 ± 0.1 ka old (Table 2). These ages indicate active tufa deposition prior to and following the peak of the last glacial maximum. Many more samples will be needed to document the long history of deposition of this huge tufa deposit.

Table 2. Radiocarbon ages for the Blässkrantz tufa deposit, Namib Desert.

Sample I.D.	Laboratory Number	Age
B1	UGA6379	15,068±120
B2	UGA6380	20,379±151
B3	UGA6381	10,971±76

SUBMERGED SPELEOTHEM AND TUFA AGE DATA IN A REGIONAL CONTEXT

The speleothem and tufa age data discussed above are compared in Figure 3 with other ages for wetter and drier conditions in Namibia, and in the rest of the Southern African summer rainfall zone. Evidence of dry conditions in Figure 3a includes eight TL ages for dunes at Etosha Pan and one for a dune at Nyae Nyae Pan (Buck *et al.* 1992; Heine 1992) and 29 ages for fluvial silt deposits in valleys of rivers draining westwards from highland areas to the east. These silt deposits are considered to be evidence of past drier climates as they were probably deposited under conditions of low stream discharge and competence. This data set includes 8 ages for the Homeb silts and 6 for the Natab silts in the Kuiseb Valley; 7 for Young Terrace sediments in the Hoanib (1) and Hoarusib (6) valleys; and 2 for the fan at the mouth of the Hoarusib River (Vogel 1982, 1989; Vogel & Visser 1981). Also included are 6 TL ages on fluvial sediments at Dieprivier - Uitskot on a tributary of the Aba Huab River (Eitel & Zöller, 1996). Evidence of wetter conditions in Figure 3a includes 4 ages for tufa deposits at Great Hudaob and Nata Gamtes in the Kuiseb Valley (Vogel 1989), and ages for peat or organic-rich sediments at Windhoek and Kannikwa (Beaumont 1986; Scott *et al.* 1991). Also included is the age of a fluvial silt deposit at the Hoanib Oasis, seaward of the dune barrier across the Hoanib Valley, which, according to Vogel (1989), documents a stage when the river was more competent than it is today. Thirty-two dates relate to interdune pond and lacustrine deposits, including several for calcified reed stalks. Twelve dates are from Vogel and Visser (1981), including 3 for the Tsondab lower valley, west of the present endpoint at Tsondab Vlei, 6 from interdune depressions south of Gobabeb on the Kuiseb River, 1 from a site southeast of Meob Bay, and 2 from a site near Conception Bay. Eleven dates are from Vogel (1989: 366) including 8 for calcified reedbeds at 7 different locations and 3 for

interdune calcretes at 3 locations. The remaining 9 dates are for deposits in West Pan, Salty Pan, Namib IV Pan and Bone Pan and in pans at Narabeb (Teller *et al.* 1990; Teller & Lancaster, 1986). Finally, Figure 3a also includes 25 ages for calcretes and stromatolites. Three of these ages are for carbonate cementing the Oswater conglomerates, which in the past filled much of the Kuiseb River gorge between Gobabeb and Homeb, and 2 for inter-dune calcretes on the upland surface south of the Kuiseb (Vogel 1982, 1989; Vogel & Visser 1981). The remaining 20 ages are for pedogenic and evaporative calcretes and stromatolites in the Etosha Pan area, which Rust (1984) interprets as evidence of geomorphic stability and increased moisture.

Figure 3b is a simpler diagram in that it includes only what we consider to be very reliable data on former wet and dry periods in the Southern African summer rainfall zone outside of Namibia. Speleothem and tufa ages are used to examine past periods of increased wetness. These ages are reliable and both tufa and cave speleothem deposition is recognized as being an excellent indicator of increased moisture availability. These data have been discussed previously in Brook *et al.* (1996, 1997), and sources are given in those references. The 39 OSL ages for dunes in the Kalahari Desert, which are indicative of former drier climatic intervals during the past 40 ka B.P., were obtained from Stokes *et al.* (1997a, 1997b) and Thomas *et al.* (1997).

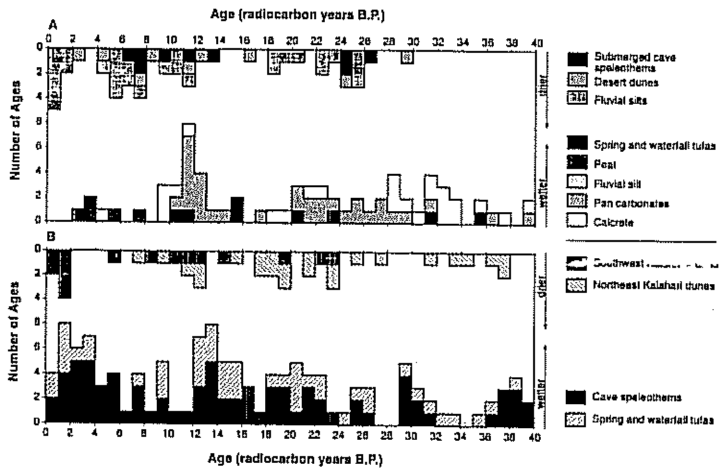

Figure 3. Histograms of ages for wetter and drier climates during the last 40 ka B.P. in Namibia (a), and in the summer rainfall zone in South Africa and Botswana (b).

Many of the dates included in Figure 3 are for freshwater carbonates, including speleothems, tufas, pan carbonates and calcretes. Vogel (1982) has discussed the sources of uncertainty with regard to radiocarbon ages for deposits of this kind. He notes that because most shallow groundwaters contain only 85% modern carbon a correction of -1.6 ka should be applied to conventional ages for such deposits. As this assumption is widely accepted in the case of cave speleothems, all radiocarbon determinations of the ages of these deposits were corrected by assuming 85% modern carbon. However, in the case of waterfall and spring tufas, Butzer *et al.* (1978) and Beaumont & Vogel (1990) found that tufa deposits along the Gaap Escarpment are deposited with 100% modern carbon and so applied no corrections to ages of older deposits. In the case of calcite crusts in fluvial silts, pan carbonates (including reed and root casts), and pedogenic and evaporative calcretes, Vogel (1982, 1989) recommends a correction of -1.0 ka to the conventional radiocarbon age. As such a correction is not universally accepted (e.g. it was not used by Teller *et al.* 1990, to correct the ages of pan carbonate deposits in the northern Namib Sand Sea), it was not applied to any of the ages used in Figure 3. If freshwater carbonates are contaminated by older, dead carbon, their ages will be too old probably by about 1.6 ka. If, on the other hand, these deposits are contaminated by younger carbon, their ages may be too young and in some cases significantly too young.

In our view, some of the deposits considered in Figure 3 may be dated more reliably than others and so can provide better data on wet and dry periods of the past. For example, we consider ages on submerged cave speleothems to be the most reliable source of data on past arid conditions, followed closely by TL/OSL dates on desert dunes. In our view, the ages of periods of fluvial silt accumulation are a less reliable indicator of aridity (e.g. *vide* comments in Heine 1999). In the case of past wetter conditions, cave speleothems, spring and waterfall tufas, and peats, probably provide the most reliable information, followed by pan carbonates, fluvial silt deposits, and pedogenic and evaporative calcretes. Figure 3 must, therefore, be examined critically in terms of the variable reliability of the ages used in its construction.

Based on the frequency of ages indicating wet and dry conditions, it is clear from Figure 3, that the record for Namibia closely parallels that for the rest of the Southern African summer rainfall zone. The Namibian evidence suggests wet intervals at 40-35, 34-28, ca. 25.5, 24-20, 16-10, and 5-2 ka B.P. while the evidence from the rest of the summer rainfall region indicates wetness at 40-36, 32-29, 27-25, 23-18, 16-12, and 4-1 ka B.P. Drier conditions are indicated in Namibia at ca. 29.5, 27-22, 21-16, ca. 13.5, 12-9, 8-4, and 0-2 ka B.P., and in the rest of the summer rainfall region at 38-31, 28-25, 24-21, 20-17, 16-14, 13-7, ca. 5.5, and 2-0 ka B.P. (Figure 3). The records of environmental change are not identical but given the uncertainty in some of the age determinations, both in regard to corrections for possible contamination, and to interpretation of the sediments in terms of environmental conditions, the records are in remarkable agreement.

DISCUSSION

As was pointed out above, Namibia was affected by the same changes in environmental conditions that affected the rest of the summer rainfall zone of Southern Africa. Unlike other areas, however, there is less evidence from Namibia for a significant increase in moisture during the mid Holocene from about 6 ka to as late as 1 ka B.P. So far, only peat and organic-rich deposits seem to indicate that this period was somewhat wetter. On the other hand, the submerged speleothem, desert dune and fluvial silt evidence seems to indicate significant dry periods in the early and late Holocene. There seems to be no doubt, overall, that the mid-Holocene was somewhat wetter but there is no evidence thus far to indicate that it was substantially wetter than now. Teller *et al.* (1990) essentially made the same observation. They note that since the establishment of the end point of the Tsondab River at its present location, perhaps 10 ka B.P., it appears that river flooding and groundwater recharge have not been enough to cause ponding at any of the inter-dune sites in the southern sand sea. They point out that this is consistent with the lack of radiocarbon dated evidence for wetter conditions in the Namib after 11 ka B.P. (Vogel 1989).

Very little of the evidence in Figure 3a relates directly to conditions in the Namib Desert region proper. Apart from the three ages for the Blässkrantz tufa (of 20.4, 15.1 and 11.0 ka B.P.), the only other irrefutable evidence of wet periods is presented by Vogel (1989). He reports that at Great Hudaob, 55 km upstream of Gobabeb, there is a tufa deposit on the south bank of the Kuiseb Canyon, which formed, from seepage draining out of a small side gully. Vogel reports radiocarbon ages of 35.0 ± 0.9, 31.1 ± 0.7, and 10.9 ± 0.1 ka B.P. for the deposit and argues that it clearly documents more humid conditions locally. He also notes that 10 km downstream, at Nata Gamtes, another small tufa tongue emerges from the north bank of the canyon. A sample of this tufa gave an age of 15.8 ± 0.1 ka B.P. Together, these ages for tufas within the Namib Desert proper suggest locally wet conditions at about 35-31, 20.5, and 16-11 ka B.P. These periods of tufa deposition correspond well with distinct wet periods evidenced in Figure 3b. This suggests that during the last 40 ka B.P. the Namib Desert was affected by the same climatic changes which affected other areas of the summer rainfall zone and that it did not remain as dry as present as suggested for the 50 km wide coastal zone by Heine (1999). Vogel 1989 is also of the opinion that the Namib Desert was further affected by climate changes during the late Quaternary. He notes that cut-and-fill sequences in the main stream valleys, which cross the desert from east to west, are often paralleled in the side valleys which carry only local runoff. Vogel thus believes that the ages for fluvial silt deposits in Figure 3 are an indication of conditions in the Namib Desert as well as in the uplands to the east.

Possibly some of the best evidence for wetter periods in the Namib Desert will eventually come from caves (e.g. Heine 1992, 1999). However, caution will be needed in interpreting these data. In 1984, Heine & Geyh reported 10 radiocarbon ages in good stratigraphic order for speleothem material from Rössing Cave in the Namib Desert. They argued on the basis of these for a period of more humid climate from 41.5 to 26.5 ka B.P. Heine (1992) lists 17 radiocarbon ages of less than 40 ka B.P. for speleothems from the hyperarid Namib Desert. These ages range from 39.6 to 26.5 ka B.P. and fall into groups at about 40-37, 35-30 and 26.5 ka B.P. Coincidentally, these age groupings correspond extremely well with wet periods evident in Figure 3b at 40-36, 32-29, and 27-25 ka B.P. However, Heine (1992, 1999) now considers these ages to be suspect, as similar materials dated by the U-series method have given substantially older ages. He suggests that the speleothems are actually much older than the range of the radiocarbon method, but give finite ages because they have been contaminated by small amounts of modern carbon. This explanation is not easy to accept, given the apparent reliability of radiocarbon ages for speleothems from many other caves around the world. We shall have to wait for more U-series dates before the full truth is known. It is to be hoped that the close proximity of rich uranium deposits, being exploited at the Rössing Uranium Mine, is not affecting the reliability of U-series dating of Rössing Cave speleothems.

In summary, U-series ages for submerged speleothems in the Otavi Mountain area have provided valuable information on periods of greater aridity in Namibia to 130 ka B.P. What is more, they have revealed that during these periods ground water table elevations declined in many areas by more than 15 m and in some by as much as 40 m. Namibia must have been dry indeed at these times. Clear evidence of increased aridity during periods when global temperatures were warmer than now, such as during deep sea isotope substage 5e, and during the early-mid Holocene hypsithermal, suggest that global warming may well bring greater dryness to an already arid and semiarid country.

Our new ages for the submerged speleothems in the Otavi Mountains, and for tufa deposits at Blässkrantz in the Namib Desert, have added to a growing body of data on late Quaternary climate change in Namibia and in the summer rainfall zone of Southern Africa in general. When these data are taken together, it is clear that the entire summer rainfall zone acted in unison in regard to climate change. Furthermore, it is apparent that even the hyperarid Namib Desert was affected, although the changes there may have been less marked than in better-watered areas to the east. Holocene climate change in Namibia does not appear to have been as marked as in other parts of the summer rainfall zone, but as more information comes to hand this observation may also be subject to change.

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interdune calcretes at 3 locations. The remaining 9 dates arë for deposits in West Pan, Salty Pan, Namib IV Pan and Bone Pan and in pans at Narabeb (Teller *et al.* 1990; Teller & Lancaster, 1986). Finally, Figure 3a also includes 25 ages for calcretes and stromatolites. Three of these ages are for carbonate cementing the Oswater conglomerates, which in the past filled much of the Kuiseb River gorge between Gobabeb and Homeb, and 2 for inter-dune calcretes on the upland surface south of the Kuiseb (Vogel 1982, 1989; Vogel & Visser 1981). The remaining 20 ages are for pedogenic and evaporative calcretes and stromatolites in the Etosha Pan area, which Rust (1984) interprets as evidence of geomorphic stability and increased moisture.

Figure 3b is a simpler diagram in that it includes only what we consider to be very reliable data on former wet and dry periods in the Southern African summer rainfall zone outside of Namibia. Speleothem and tufa ages are used to examine past periods of increased wetness. These ages are reliable and both tufa and cave speleothem deposition is recognized as being an excellent indicator of increased moisture availability. These data have been discussed previously in Brook *et al.* (1996, 1997), and sources are given in those references. The 39 OSL ages for dunes in the Kalahari Desert, which are indicative of former drier climatic intervals during the past 40 ka B.P., were obtained from Stokes *et al.* (1997a, 1997b) and Thomas *et al.* (1997).

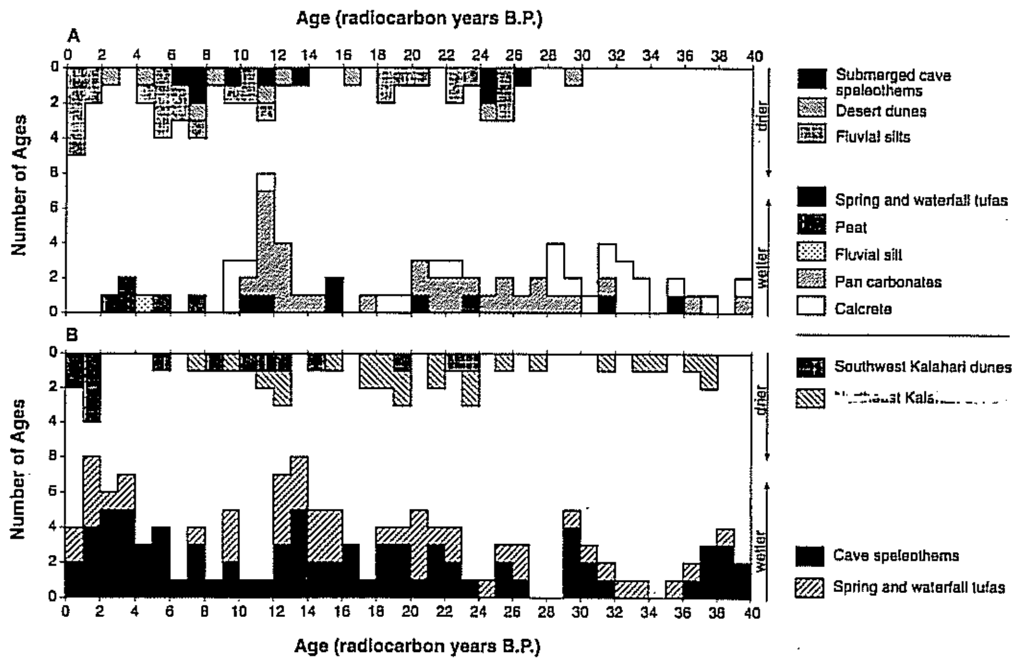

Figure 3. Histograms of ages for wetter and drier climates during the last 40 ka B.P. in Namibia (a), and in the summer rainfall zone in South Africa and Botswana (b).