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Late Quaternary climate changes in the Central Namib Desert, Namibia

Klaus Heine 1998
Department of Geography, University, Regensburg, Germany

ABSTRACT: The hyper-arid central Namib Desert represents a flat gravel plain (Namib Unconformity Surface) that rises from the coast in the west to about 1000 m a.s.l. in the east. In the south the Kuiseb River gorge separates the plains with inselbergs from the Namib erg. The aridity along the Namib coast is caused by the cold Benguela Current, which has persisted since Tertiary times. Little is known about late Quaternary climate changes in the central Namib Desert. Here we refer to investigations on Kuiseb River sediment sequences (Homeb Silt Formation), gypsum soils of the Namib Unconformity Surface, and speleothems of Namib caves to discuss their paleoclimatic evidence. According to geomorphologic, sedimentologic, paleopedologic evidence and information of speleothem growth in combination with ^{14}C, U/Th, and TL age determinations, the central Namib Desert experienced an arid climate during the late Quaternary. No evidence was found that the major late Quaternary climate changes affected the central Namib area. We conclude that the cold Benguela Current was stable off the central Namib coast, thus producing the conditions for the aridity throughout the late Quaternary. U/Th dates point to some fluctuations in available moisture during and before the isotope stage 5.

1 INTRODUCTION

The occurrence of coastal deserts along the western shore of most continents has attracted the attention of scientists for a long time. These deserts are of different natures; some are hyper-arid while others are semi-arid. In recent years the age and origin of these deserts and their Quaternary climatic changes have been the focus of much research of an interdisciplinary nature. The Namib Desert of Southwestern Africa (Fig. 1) is about 1400 km long and between 40 and 120 km wide. It is characterized by a climate that has been more or less arid for approximately 40 million years. Marine pollen assemblages in cores off the coast document arid climatic conditions along the coast ever since Pliocene times. Whether more humid phases occurred in the Namib desert and surrounding areas during the late Quaternary has been discussed recently by different authors (Heine 1992, 1995, Rust 1989, 1994, Teller et al. 1990, Geyh 1995). An analysis of the paleoclimatic information from landforms, palesols, sediments, and speleothems in southwestern Africa shows that only few data concerning the climatic history are useful (Heine 1995). Many problems hamper the geochronological and paleoclimatical interpretation of the ^{14}C, U/Th, and TL dates (Geyh 1995). By comparison, the climatic development during the Holocene is rather well established. But for the Upper Pleistocene, no exact information can be given because of difficulties with the absolute age determinations. no paleoclimatic information can be obtained for the time before 40 ka BP based on ^{14}C dates, and before 100 ka BP based on TL dates. All paleoclimatic data obtained in recent years from calcretes, fossil horizons, speleothem etc. point to a relatively arid climate in the central Namib Desert, at least since the last glacial maximum, this part of the Namib Desert was not affected by more than normal rainfall. Fluctuations in precipitation are superimposed, but these fluctuations did not lead to a decisive change of the general climatic regime.

Here we show that in the hyper-arid Namib Desert, in the area between the Kuiseb and Swakop valleys as well as in the area of the Rössing Mountains and the Tinkas Flats, late Quaternary fluctuations in precipitation did not affect the desert environment.

2 THE STUDY AREA

The hyper-arid central Namib Desert borders on the cold Atlantic Ocean to the west and a dissected plateau slope beneath the Escarpment (which has an average altitude of 1500 m, rising to 2300 m in places) some 160 to 180 km to the east (Lindesay & Tyson 1990) (Fig. 1).

The Swakop and Kuiseb River valleys are deeply incised into bedrock. The latter separates the relatively flat gravel plains with inselbergs (Rössing mountains) to the north from the coast-parallel linear dunes of the sand sea to the south. The plain of the central Namib Desert rises from sea level to about 1000 m a.s.l. at the foot of the Great Escarpment. This plain is called the Namib Unconformity Surface.

WARD, Viv
D R F N
NAMIBIA

WEIK, Mr Jörg
G T Z
P. O Box
AMMAN 11118
JORDAN
Telephone (Work): 092625359726
Fax: 096265156457
E-Mail: jweik@go.com.jo

WEISS, Mr Eckehard
G T Z
P O Box 5180
ESCHBORN 65726
GERMANY
Telephone (Work): 09496196791912
E-Mail: eckehard.weiss@gtz.de

WERNER, Wolfgang
D R F N
NAMIBIA

WILCKE, Mrs Angelika
Entwicklung And Laendlicher Raum/Agriculture And Rural
Eschborner Landstrasse 122
FRANKFURT 60489
GERMANY
Telephone (Work): 09496924788465
Fax: 09496924788481
E-Mail: A.Wilcke@DLG-Frankfurt.de

WOEHL, Dr Helmut
D R F N
GERMANY

WOLF, Katherine
D R F N
NAMIBIA
E-Mail: katherinew@drfn.org.na

ZEHTABIAN, Dr Gholam Reza
Associate Professor
University Of Tehran
P O Box 14185/354
Natural Resources College Of Tehran University
KARAJ 31585/4314
IRAN
Telephone (Work): 0998261222044
Fax: 0998261222765
E-Mail: ghzehtab@chamran.ut.ac.ir

ZVINGADZA, Mr Sherpard
Zero Regional Environment Organization
P O Box 5338
HARARE
ZIMBABWE
Telephone (Work): 09263791333
Fax: 09263791333
E-Mail: zero@mweb.co.zw

It was formed by long continued erosion across the Precambrian rocks, thus separating the metamorphic bedrock from all younger deposits (Ollier 1977).

The mean annual rainfall of less than 20 mm/year along the coastal belt makes the Namib Desert one of the driest areas in the world according to common definitions of a desert (Fig. 2). Rainfall increases from the coast towards the interior changing to a summer rainfall zone on its eastern edge. The combination of cool air masses under the influence of the cold Benguela Current, together with the high pressure conditions in the subtropics is mainly responsible for the scanty rainfall. Apart from rainfall, precipitating fog is the second source of moisture that sustains life in the Namib. Rainfall over the central Namib Desert occurs mainly in the form of convective summer storms (Sharon 1981) from which maximum precipitation is received over the Excarpment to the east, while fog precipitation is the dominant moisture source over the western parts of the desert adjacent to and inland from the coast (Lancaster et al. 1984, Lindesay & Tyson 1990).

3 PALEOCLIMATIC INFORMATION FROM CENTRAL NAMIB SITES

3.1 *The Homeb Silts*

The Kuiseb drainage system rises in the Khomas Highlands to cross the central Namib Desert and reach the coast near Walvis Bay. Near Homeb, in the rock-walled canyon of the Kuiseb, some relics of alluvial terraces are preserved (Fig. 3). The Cenozoic deposits of the Kuiseb valley have been documented by Ward (1987) and Ward & Corbett (1990). The sediments form isolated outcrops hanging from the rock walls of tributary valleys. The maximum thickness is more than 25 m. The most elevated sediments are some 45 m above the present river bed. Vogel (1982) dates the Homeb Silt Formation to some 20,000 years BP. The Homeb Silt Formation consists of eroded remnants of fine-grained alluvium deposited as flash-flood sediments that were colonized by successive generations of opportunistic arthropods (Smith et al. 1993). The stacked flood units each comprise a massive tabular siltstone bed overlain by a thinner interval of rapidly alternating sandstone and siltstone with claystone veneers. These flood units are interpreted as having accumulated under semi-arid climatic conditions by episodic back-flooding of the Kuiseb River into embayments and tributary mouths (Smith et al. 1993). Soon after deposition, as the floodwaters subsided, the sediment was colonized by burrowing, sediment-ingesting organisms, mostly arthropods, that produced a Taenidium ichnofacies. After the floodwaters had drained, the exposed sediment was colonized by grasses and burrowed by terrestrial arthropods, probably ants and termites, resulting in an overprint of Termitichnus ichnofacies with associated pelletal chambers (Smith et al. 1993). Thirteen horizons of rhizocretions and root tubules occur toward the top of the succession and indicate a gradual reduction in the frequency of flooding. These immature calcic paleosols suggest that the climate in the central Namib Desert was semi-arid ca. 20,000 years ago, being wetter and more seasonal than the hyper-arid conditions that prevail today (Smith et al. 1993).

Although there seems to be little doubt about the observations by Smith et al. (1993) that the Homeb Silt Formation proves semi-arid climatic conditions, some fundamental questions arise. Previous workers have offered several other explanations of the characteristic Homeb sediments (e.g. Scholz 1972, Rust & Wieneke 1980, Marker & Muller 1978, Vogel 1982, Ollier 1977). They were variously interpreted as river end-point accumulations, flood deposits of an aggrading river, or sediments deposited behind a dune dam. Hövermann (1978) postulates a fluvial origin of the silts, and Heine (1987) describes as their mode of origin flash-flood fluvial sediments that were deposited beside the main channel flow in overbank areas (mainly in tributary valleys). Thus, the Homeb Silt Formation represents not only the climatic regime of the central Namib Desert, but also the climatic conditions in the upper reaches of the Kuiseb (interior plateau, Great Escarpment, eastern Namib).

The age of the Homeb Silt accumuluation is dated by ^{14}C as 23-19 ka BP (Vogel 1982) and by TL as about 18.3 +/- 3.4 and 17.4 +/- 3.8 ka BP (Eitel 1994). Although the age determinations differ within a couple of thousand years, the time of accumulation is centered around 20,000 year BP, and thus is roughly synchronous with the last glacial maximum (LGM).

3.2 *Soils of the central Namib Desert*

According to Scholz (1972), raw mineral soils, calcrete and gypcrete soils, are the most important soil types of the gravel plains of the central Namib Desert. In the vicinity of Gobabeb, north of the Kuiseb, most of the soils have a light brown to ochre color, and are shallow, with a subsurface horizon which may consist of calcrete, gypcrete, or salt.

A detailed investigation of the desert soils with respect to the meso- and microrelief north of the Namib Research Station of Gobabeb (Walter 1994) yields the distinction of different phases with characteristic pedogenic processes. A schematic soil profile of the central Namib gravel plain is shown in Figure 4.

From top to bottom, the following soil horizons are developed: (1) layer of 2-3 cm of eolian material, with a desert pavement (quartz, rock fragments, feldspar, remnants of calcrete, etc. sandy-gravel), composed of a layer of angular to subrounded gravels one or two stones thick sitting on a mantle of finer stone-free silty sand; (2) gypsum crust; in the upper part characterized by thin, discontinuous gypsum coatings on the undersides of the stones (stage I after the classification of Reheis 1987) and by abundant gypsum pendents under stones and

PAXTON, Ms Midori
U N D P
WINDHOEK
NAMIBIA
Telephone (Work): 09264612046232
Fax: 09264612046203
E-Mail: midori.paxton@undp.org

PELLANT, Mr Mike
Bureau Of Land Management
1687 S. Vinnell Way
Boise
IDAHO 83709
USA
Telephone (Work): 0912083733823
Fax: 0912083733805
E-Mail: mike_pellant@blm.gov

PENNY, Ms Roben
D R F N
Woodbine
Essex Road
KALK BAY
Telephone (Work): 7881285
E-Mail: robenpen@jaywalk.com

PHILANDER, Angy
D R F N

PRINZ, Aubrey
D R F N
NAMIBIA

RAJI, Dr B. A.
Ahmadu Bello University
Department Of Soil Science
Faculty Of Agriculture/Institute For Agricultural Research
P.M.B. 1044
ZARIA 0023469
NIGERIA
Telephone (Work): 0923469551607
E-Mail: cndciar@inet-global.com

RETHMAN, Dr Norman
University Of Pretoria
Department Of Plant Production And Soil Sciences
PRETORIA 0002
Telephone (Work): 0124203225
Fax: 0124204120
E-Mail: nrethman@postino.up.ac.za

ROGGE, Jo
D R F N
NAMIBIA

SAIDE, Mr Eusebio
Coterra
Rua Henrique De Sousa
No 45.
MAPUTO
MOZAMBIQUE
Telephone (Work): ~~092581308866~~ 092581313741
Fax: ~~092581308866~~ 092581313741
E-Mail: ~~eusibio2001@yahoo.com~~
eusebios2001@yahoo.com.br

SALOMO, Mr C A
D R F N

SASS, Ms M
D R F N

SCHLYTER, Dr Peter
Stockholm University
Se-10691
STOCKHOLM
SWEDEN
Telephone (Work): 094686747822
E-Mail: peter.schlyter@natueo.su.se

SECK, Dr Emmanuel
Endatm
B P 3370, 54 Rue Carnot Dakar
DAKAR
SENEGAL
Telephone (Work): 092218222496
Fax: 092218217495
E-Mail: energy2@enda.sn

SEELY, Dr Mary
D R F N
P O BOX 20232
WINDHOEK
NAMIBIA
Telephone (Work): 0926461229855
Fax: 0926461230172
E-Mail: mseely@drfn.org.na

SHIKONGO, Mr Sem
No Info At This Stage
NAMIBIA

SHOKO, Mr Mzondiwa
P O Box Cy385
Causeway
HARARA
ZIMBABWE
Telephone (Work): 092634705671
Fax: 092634793123
E-Mail: zpn143@mweb.co.zw

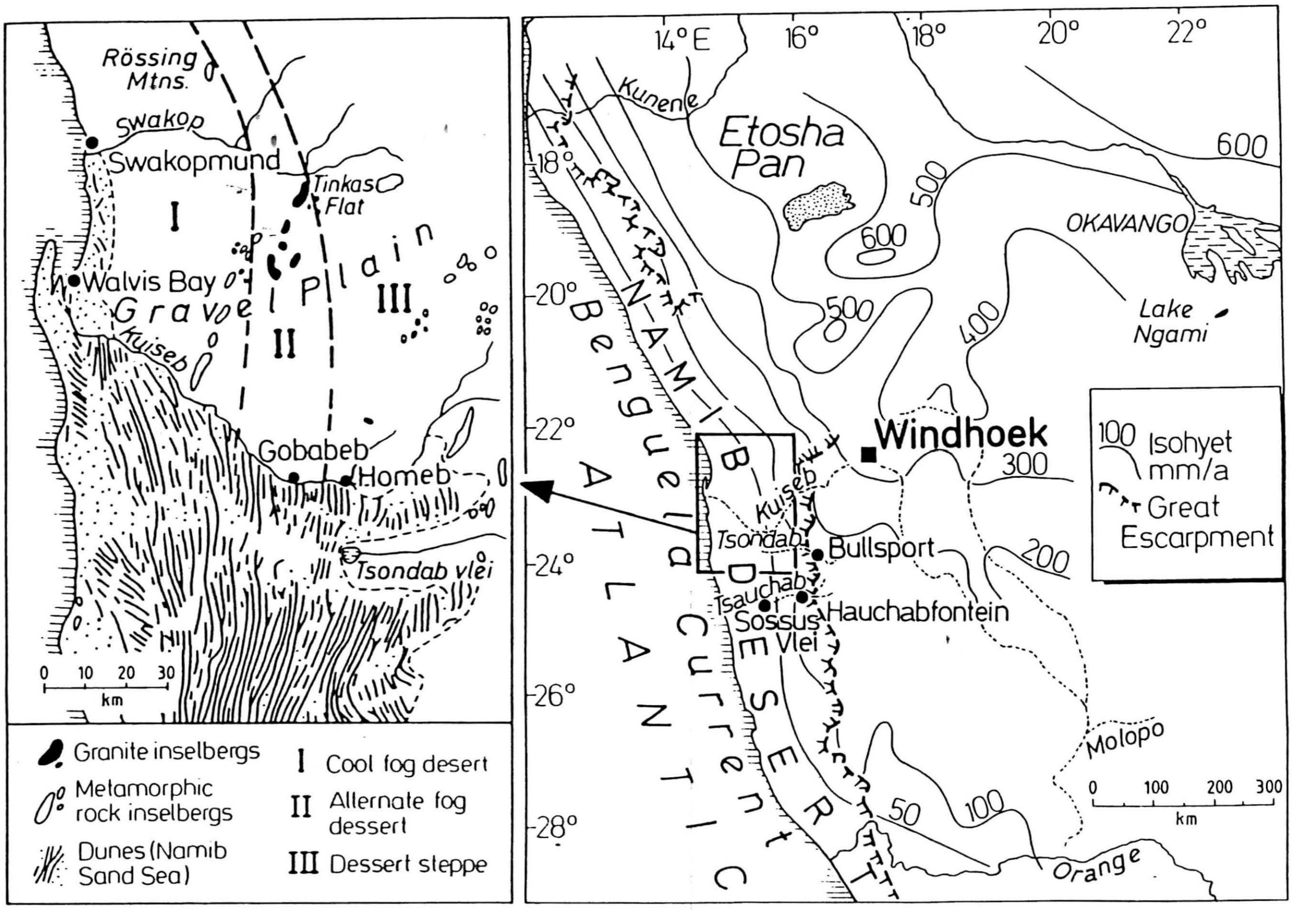

Figure 1. Location map. Climatic zones (after Besler 1972).

gypsum crystals scattered through the matrix (stage II after Reheis 1987); in the lower part a gypcrete developed, consisting of a continuous gypsum-plugged matrix, with stones and smaller debris floating in the gypsum matrix (stage IV after Reheis 1987); (3) crust mixed from cemented gypsum and calcrete with decomposed bedrock; (4) horizon rich in $CaCO_3$ or decomposed bedrock with fresh gypsum minerals formed by crystallization from descending soil water; (5) bedrock or calcrete.

In the central Namib Desert the pedogenic gypcretes result from downward movement of gypsum. Gypcretes are found between the coast and the inland limit of the influence of frequent fogs. The importance of fog carrying dissolved salts is emphasized by many authors (Scholz 1972, Scholz & Beckmann 1971, Walter 1994). The development of very thin gypsum crusts only a few millimeters thick takes a period of at least 10,000 years, as is documented by stage I-gypcretes on dated alluvial terraces in the Kuiseb valley near Homeb. On the Namib Unconformity Surface, the gypsiferous soils are found nearly everywhere. Gypcretes occur even along slopes and in drainage channels beneath a loose sandy layer of a few to ca. 20 cm depth; they document an inactive relief of the Namib Unconformity Surface with regard to geomorphodynamic processes. Active lowering of the surface by erosion and denudation has not been observed. Therefore, major fluctuations in humidity (rainfall) cannot have occurred during the late Quaternary. If they had occurred, they would have removed the gypcretes that are observed even in the drainage channels.

3.3 *Speleothems of the 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 some meters to several decameters. The caves show sinter growth. The speleothem formation depends on local precipitation since surface and/or groundwater influx is excluded in the dolomite ridges (Heine & Geyh 1984). The caves themselves must have developed 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 shows that these conditions could have prevailed before the Late Miocene/Early Pliocene calcrete formation on the Namib Unconformity Surface (Besler et al. 1994).

NZABONIMPA, Abdallah
Channel Africa Radio
P O Box 91313
AUCKLAND PARK
Telephone (Work): 0117144198
Fax: 0117142424
E-Mail: nzabonimpaa@sabc.co.za

O' FARRELL, Mr Patrick
University Of Cape Town
24 The Avenue
WOODSTOCK 7925
Telephone (Work): 4483675
E-Mail: ofarrell@nbict.nbi.ac.za

ODADA, Ms Catherine
U N D P
WINDHOEK
NAMIBIA
Telephone (Work): 09264612046232
Fax: 09264612046203
E-Mail: catherine.odada@undp.org

OETTLE, Noel
E M G
P O Box 13378
Mowbray
CAPE TOWN 8001
Telephone (Work): 4882881
E-Mail: dryland@global.co.za

OGUNLOLU, Mr Olufemi Adebayo
F R S C Kwara
P O Box 2068
Sapon
ABEOKUTA OGUN 110221
NIGERIA
Telephone (Work): 0923208023076889
E-Mail: femog2001@yahoo.com

OKPARA, Mrs C. N.
Nigerian Concerned Group For Environment, Popuation And
57 Njiribeako Street
P O Box 3122
OWERRI
NIGERIA
Fax: 09234012610310
E-Mail: n_cogep_d@usa.net

OKPARA, Prof Enoch
Nigerian Environmental Study / Action Team
1 Oluokun Street
Off Awolowo Avenue
U I P O Box 22025
IBADAN
NIGERIA
E-Mail: nestnig@nest.org.ng

OLIVER, Mrs Ian
Karoo Desert N B G
P O Box 152
WORCESTER
Telephone (Work): 0233470785
Fax: 0233428719
E-Mail: karroid@intekom.ca.za

ORLALE, Mr Martin
Practical Skills Training Institute
P.O. Box 57729
NAIROBI 00100
KENYA
Telephone (Work): 09254272772360
E-Mail: pinstitute@pinfosol.com

OUESSAR, Mr Mohamed
Researcher
Institut Des Régions Arides (IRA)
Ira, Route De Jorf Km22.5
MÉDENINE 4119
TUNISIA
Telephone (Work): 0926165633005
Fax: 0921675633006
E-Mail: Ouessar.Mohamed@ira.rnrt.tn

OYEBODE-ADESINA, Mr Adewale
Timmey Nig.Ltd
P O Box 28241
IBADAN 200003
NIGERIA
Telephone (Work): 09232716548
Fax: 09232413988
E-Mail: shinedude2@yahoo.com

PALMER, Anthony
A R C - Range And Forest Institute
P.O. Box 101
GRAHAMSTOWN 6140
Telephone (Work): 0466222638
Fax: 0466222638
E-Mail: t.palmer@ru.ac.za

PANDO-MORENO, Ms Marisela
Lecturer
Universidad Autonoma De Nuevo Leon
P O Box 41
LINARES 67700
MEXICO
Telephone (Work): 095282124895
Fax: 095282124251
E-Mail: mpando55@hotmail.com

PAUDYAL, Prof Dhanpati
Inshured
10 New Ban Pb6218
KATHMANDU 6218
NEPAL
Telephone (Work): 099771487376
Fax: 099771487376
E-Mail: inshured@hotmail.com

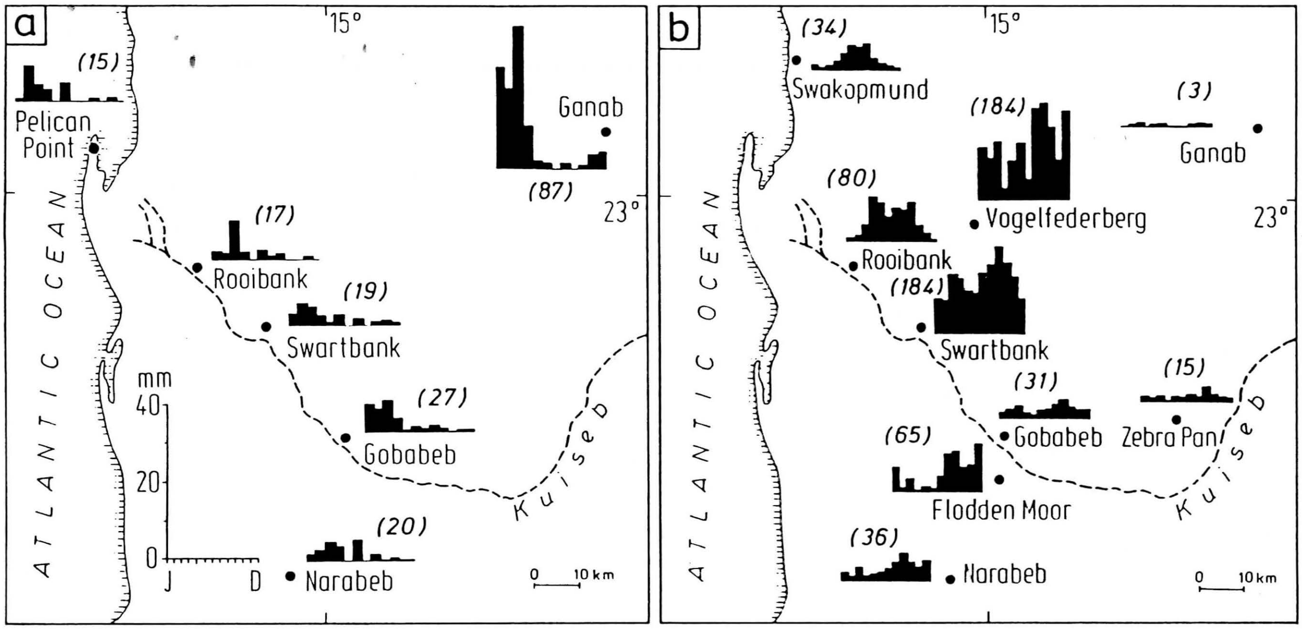

Figure 2. a) Mean monthly and mean annual rainfall in mm for longer term stations. b) Mean monthly and mean annual fog precipitation in mm (after Lancaster et al. 1984).

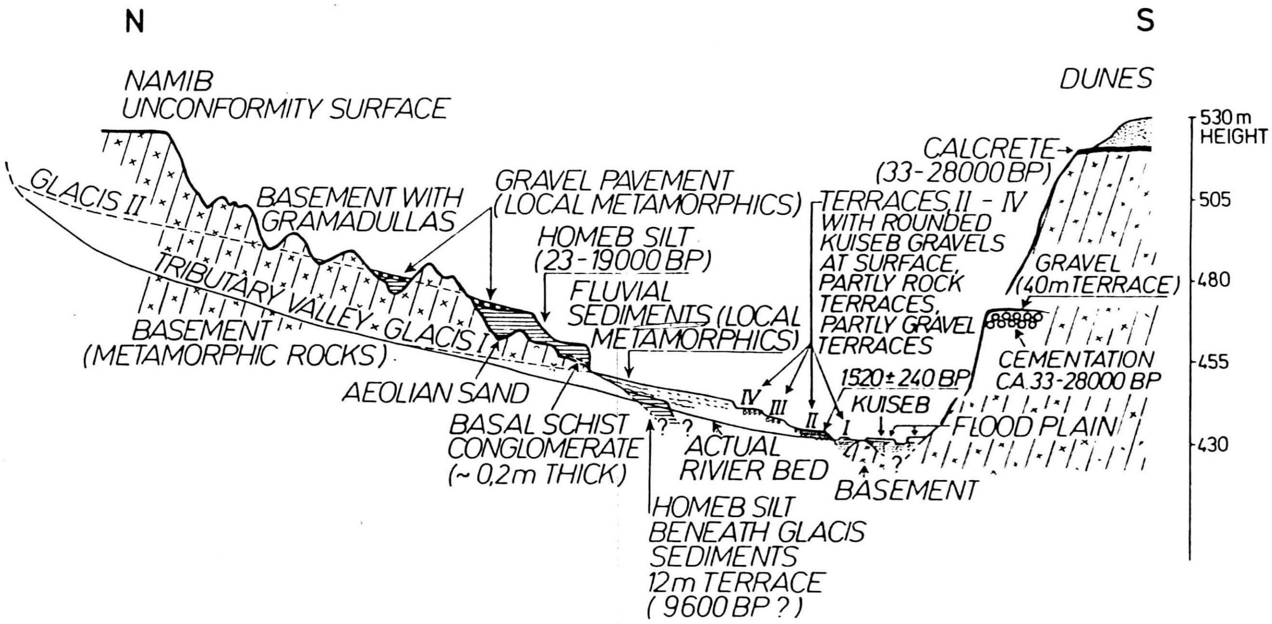

Figure 3. Schematic cross-section of the Kuiseb River valley near Homeb. The ages are ^{14}C dates (adopted from Vogel 1982).

Several flowstones, stalagmites, stalagtites, drip curtains, cave popcorn, and other speleothem were radiocarbon-dated (Heine & Geyh 1984, Heine 1991, 1992, Geyh 1995). The resulting ages are all greater than 25 ka BP. Compact speleothems were even older than 35 ka BP. According to the radiocarbon dates no sinter growth occurred after 25 ka BP. (Figs 5, 6).

Additionally, several sinter samples from the Rössing and Tinkas Caves were dated by U/Th. The results differ considerably from the radiocarbon dates (Figs 5, 6). Furthermore, some TL age determinations from sands that were blown into the Rössing Cave yield minimum ages of > 64.3 +/- 5.2 and > 87.5 +/- 6.5 ka BP (Fig. 5).

An interpretation of the ^{14}C, U/Th, and TL ages

MUSONDA, Mr Thomson C
No Info At This Stage
LUSAKA
ZAMBIA

MUTAMBA, Mr Emmanuel
Team Director
Green Living Movement
P O Box 38254
LUSAKA 10101
ZAMBIA
Telephone (Work): 0926096760966
E-Mail: emutamba@yahoo.com

MUWAYA, Mr Stephen
M A A I F
P O Box 102
ENTEBBE
UGANDA
Telephone (Work): 0925641343696
Fax: 0925641321255
E-Mail: ccdnap@infocom.co.ug

MWANZA, Regina
P O Box 50266
LUSAKA
ZAMBIA
CELL NO 097824772

NAKALE, Tufikifa
D R F N
NAMIBIA

NANGOMA, Everhart
No Info At This Stage
BLANTYRE
MALAWI
Telephone (Work): 09266621348
Fax: 09266621022
E-Mail: umoyo@malawi.net

NANTANGA, Komeini
D R F N
NAMIBIA

NAWASEB, Gabes
D R F N
NAMIBIA

NDITEZEUA, Mina
D R F N
NAMIBIA

NDJITEZEUA, Asser
Khoadi Llhôas Conservatory
P. O Box 119
KAMANJAB
NAMIBIA
Telephone (Work): 0926467333017
Fax: 0926467333020

NDLELA, Elmon
Brot Für Die Welt / UNCCD Support Programme
A C A T
Eastern Cape
E-Mail: des2002@gliese.de

NJEAZAEH, Mr Jerome Akaning
Associated Country Women Of The World (Acww)
P. O. Box 446
BUEA 0144
CAMEROON
Telephone (Work): 092377523264
Fax: 092377523264
E-Mail: nnangela@yahoo.com

NOMTSHONGWANA, Mr Ngcali
D E A T
JOHANNESBURG

NTANDO, Mr Simanga
Yonge Nawe
Covetry Cresent
Jenden Building Office 13
MBABANE
SWAZILAND
Telephone (Work): 092684041394
Fax: 092684047710
E-Mail: btmakama@yongenawe.rg.sz

NUPPENAU, Prof Ernst-August
Justus-Liebig-University
Institut Fuer Agrarpolitik
Senckenbergstrasse 3
GIESSEN 35390
GERMANY
Telephone (Work): 09496419937022
Fax: 09496419937029
E-Mail: Ernst-August.Nuppenau@agrar.uni-giessen.

NYIKA, Walter Mugove
Zimbabwe Institute Of Permaculture - S C O P E
P O Box CY301
Causeway
HARARE
ZIMBABWE
Telephone (Work): 092634333812
Fax: 092634333811
E-Mail: scope@africaonline.co.zw

NYIKAYARAMBA, Mr Charles Marcos
Department Of Natural Resources
P O Box 585
MUTARE
ZIMBABWE
Telephone (Work): 092632062509
Fax: 092632067098

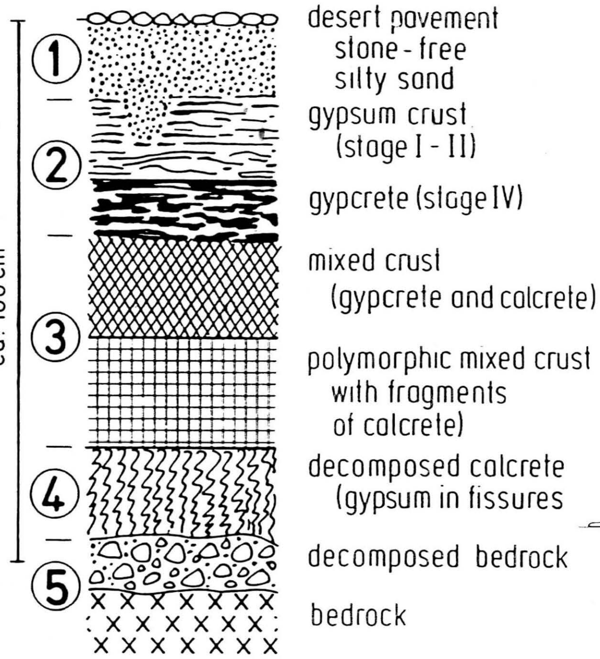

Figure 4. Schematic gypcrete profile of the central Namib Desert. For explanation see text.

from the caves of the central Namib is difficult because of methodological problems (Heine 1992, Holmgren et al. 1994, Geyh 1995). The radiocarbon dates are very old and therefore probably rejuvenated by contamination. In no case do they correspond to the U/Th dates and the TL dates. We conclude that very old speleothem (older than the last glacial epoch) were moistened by dropping water that resulted in fog precipitation or in occasionally rainfall in the central Namib Desert. Recrystallization of calcite was possible. All photomicrographs (Plates 1-3) of speleothems show very thin calcite layers on top of the sinter material. In the lower layers, bigger, mosaic and elongated crystals can be observed. Diagenetically altered layers and iron- and manganese-rich horizons are common in the outer parts of the speleothems. They document hiatuses in the development of the sinter. Sharp boundaries indicate periods of dry conditions when the environment was not conducive to speleothem growth and some dissolution of underlying layers took place. The vague layer boundaries mark erosion-free stoppages in sinter formation. Beneath the sinter surfaces the layers are very thin, thus indicating a slower growth with many interruptions.

The results of the age determinations indicate on the one hand that speleothems were not formed during the late Quaternary apart from the very thin layers that may document minimal moisture fluctuations. Sinter growth cannot be detected during the period after ca. 20,000 years BP. On the other hand, the U/Th analyses of some speleothems yield characteristic Eem (stage 5) and, probably, stage 7 ages (Heine 1992, Geyh 1995). The speleothems with these ages consist of very thin layers. Therefore, we conclude that during the late Quaternary in particular, and during the Quaternary in general, calcite precipitation was confined to the formation of extremely thin layers. This documents a prolonged period of extreme aridity in the central Namib Desert, starting in the Miocene. No phases with major shifts to more humid conditions can be postulated.

The discrepancies between the ^{14}C and U/Th ages

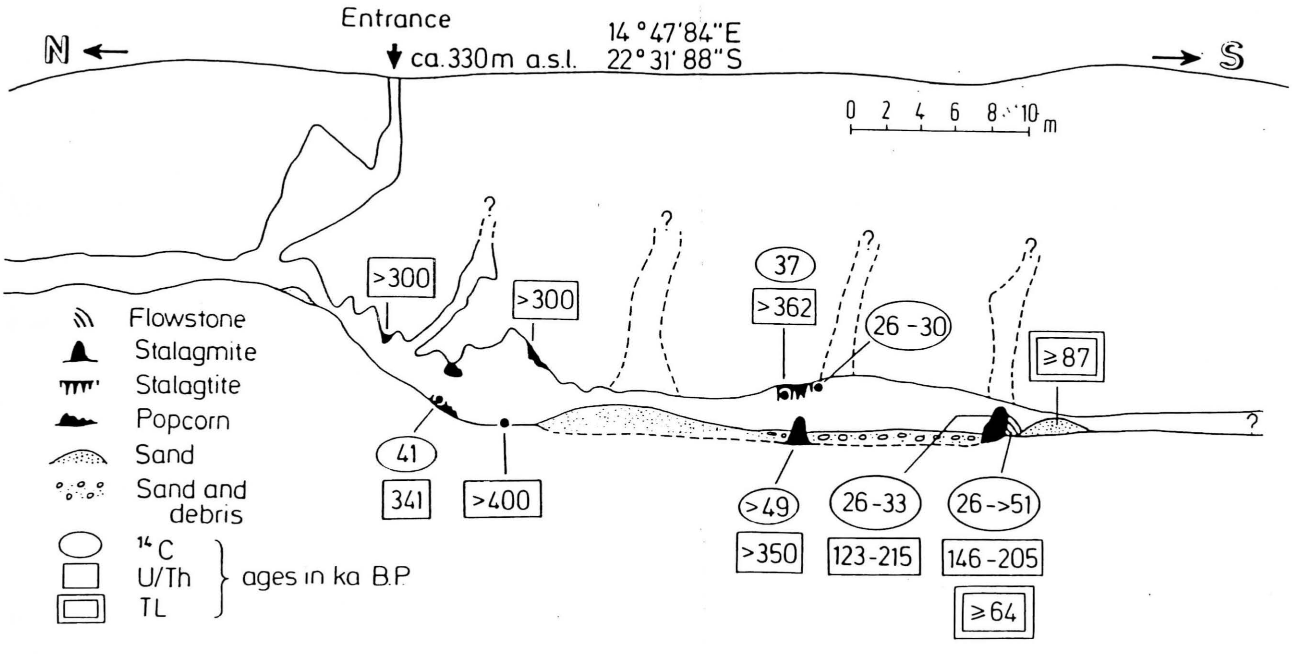

Figure 5. Rössing Cave, Namib Desert, showing the position of the dated samples. 24 ^{14}C dates and 16 U/Th dates of speleothems show the problems of dating (see Heine 1992, 1995, Geyh 1995).

MANSUR, Prof Shaban
TRIPOLI
LIBYA

MCCLURE, Mr Beaumont
Bureau Of Land Management
222 N. Central Avenue
Phoenix
ARIZONA 85004
USA
Telephone (Work): 091602419430
Fax: 091602417998
E-Mail: beau_mcclure@blm.gov

MHLANGA, Rose M
No Info At This Stage
ZAMBIA

MITCHELL, Dr David
Wolverhampton University
School Of Applied Sciences
WOLVERHAMPTON WV11SB
UK
Telephone (Work): 091441902322173
Fax: 091441902322680
E-Mail: d.mitchell@wlv.ac.uk

MITEMBE, William
No Info At This Stage
LILONGWE
MALAWI
Telephone (Work): 09265771000
Fax: 09265784268
E-Mail: sadcfstu@malawi.net

MODISAOTSILE, Mr Modisaotsile K C
Ministry Of Agriculture
Private Bag 003
GABORONE
BOTSWANA
Telephone (Work): 0926735510
Fax: 09267307057
E-Mail: mmodisoatsile@gov.bw

MOLAPO, Mr Jobo
Director
S A D C Elms
MASERU
SWAZILAND

MONTOIRO, Mr Marcos
Associate External Relations Officer
U N C C D Secretariat
Martin Luther King Street 8
BONN
GERMANY
Telephone (Work): 09492288152806
Fax: 09492288152899
E-Mail: mmontoiro@unccd.int

MOORE, Mr Franklin
U S A I D
WASHINGTON
USA
Telephone (Work): 092027121863
E-Mail: fmoore@usaid.gov

MOSER, Petra
D R F N
NAMIBIA

MOUAT, Dr David
Division Of Earth And Ecosystem Sciences
Desert Research Institute
2215 Raggio Parkway
RENO NEVADA 89512
USA
Telephone (Work): 097756737042
Fax: 097756747557
E-Mail: dmouat@dri.edu

MSANGI, Prof Josephine
Professor And Head Of Department
University Of Namibia
Private Bag 13301
WINDHOEK 264
NAMIBIA
Telephone (Work): 0926412063383
Fax: 0926412063424
E-Mail: jpmsangi@unam.na

MTHETHWA, Mr Doctor
No Info At This Stage

MUGUTI, Mr Edward Chege
Trace(K) Network
P.O. Box 525
EMBU 254(0)161
KENYA
Telephone (Work): 0925416120120
Fax: 0925416130165
E-Mail: chegeh@yahoo.co.uk

MUKUTE, Mutizwa
Brot Für Die Welt / U N C C D Support Programme
PELUM
ZIMBABWE
E-Mail: des2002@gliese.de

MULINDWA, Miss Aisha
Rwanda Desert Awareness Organisation
B.P. 6215
KIGALI 250
RWANDA
Telephone (Work): 0925074506
Fax: 09250570188
E-Mail: aishamulinda@yahoo.com

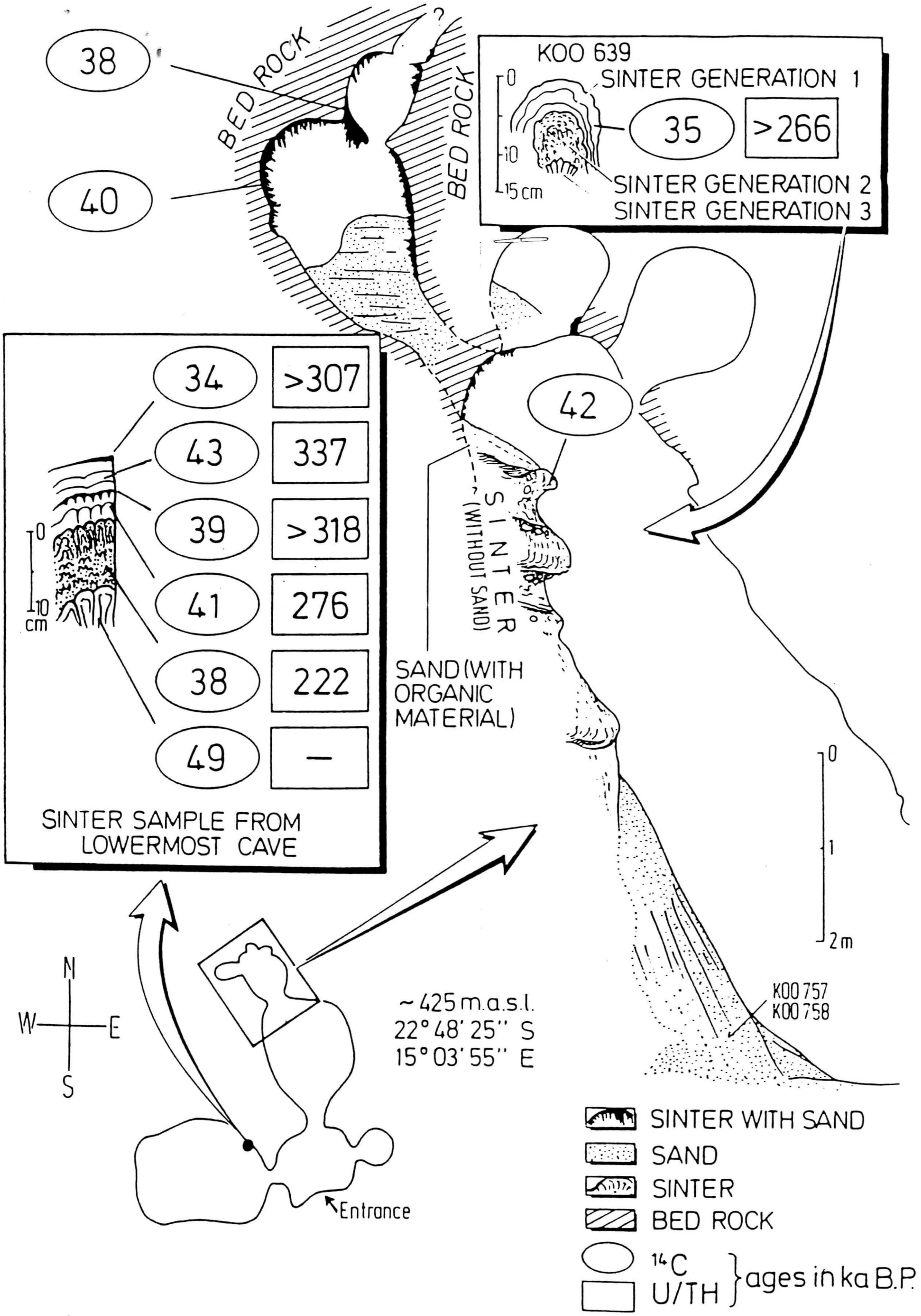

Figure 6. Tinkas Cave, Namib Desert, showing the position of the dated samples (10 ^{14}C dates, 7 U/Th dates). Bottom, plan of the different cave chambers. Top, stratigraphic section through the cave sediments. The speleothems show very thin calcite layers on top (sinter generation 1); in lower layers bigger, mosaic and elongated crystals can be observed (sinter generation 2 and 3).

KELLNER, Prof Klaus
Potchefstroom University For C H E
School Of Environmental Sciences And Development
POTCHEFSTROOM 2520
Telephone (Work): 0182992510
Fax: 0182992370
E-Mail: plbkk@puknet.puk.ac.za

KHUMALO, Mr Luyanda T.
No Info At This Stage
MBABANE
SWAZILAND
Telephone (Work): 092684043858
Fax: 092684044700
E-Mail: lups@realnet.co.sz

KIHAULE, Mr Joseph
No Info At This Stage
DAR ES SALAAM
TANZANIA

KLINTENBERG, Patrik
D R F N
NAMIBIA

KOELLE, Ms Bettina
Social Geographer
Indigo Development Change
P O Box 350
NIEUWOUDTVILLE 8180
Telephone (Work): 0272181148
Fax: 0272181148
E-Mail: bettina@indigo-dc.org

KOMATI, Justine
D R F N
NAMIBIA

KOOTJIE, Albertus
D R F N
NAMIBIA

KRUGER, Bertus
D R F N
NAMIBIA

KRÜGER, Prof Gert
Potchefstroom University For C H E
School Of Environmental Sciences And Development
POTCHEFSTROOM 2520
Telephone (Work): 0182992520
Fax: 0182992503
E-Mail: plbghik@puknet.puk.ac.za

LANCASTER, Ms Judith
Division Of Earth And Ecosystem Sciences
Desert Research Institute
2215 Raggio Parkway
RENO NEVADA 89512
USA
Telephone (Work): 097756737300
Fax: 097756747557
E-Mail: judith@dri.edu

LERATA, Mr Thabiso
Ministry Of Environmental, Gender And Youth Affairs (E M P R
MASERU
LESOTHO
Telephone (Work): 09266314763
Fax: 09266310506
E-Mail: natenv@ilesotho.com

LUNGU, Bazak Zakeyo
Brot Für Die Welt / U N C C D Support Programme
ZAMBIA
E-Mail: des2002@gliese.de

MACHARIA, Mr Peter
Senior Research Officer
Kenya Agricultural Research Institute / Kenya Soil Survey
P.O. Box 14733
NAIROBI
KENYA
Telephone (Work): 092542440903
Fax: 092542443376
E-Mail: kss@iconnect.co.ke

MAJUVA, Rosaldina A C
No Info At This Stage
DAR ES SALAAM
TANZANIA
Telephone (Work): 0925522218005
Fax: 0925522182240
E-Mail: jet@africaonline.co.tz

MANDAKH, Miss Nyamtseren
Institute Of Geoecology Mongolian Academy Of Sciences
Ulaanbaatar.Bruun Selbe - 13.
ULAANBAATAR
MONGOLIA
Telephone (Work): 0997697411326620
E-Mail: maaggi@yahoo.com

MANGANDA, Ernest
Focal Point
CONGO
E-Mail: Une adresse@yahoo.fr gratuite et en

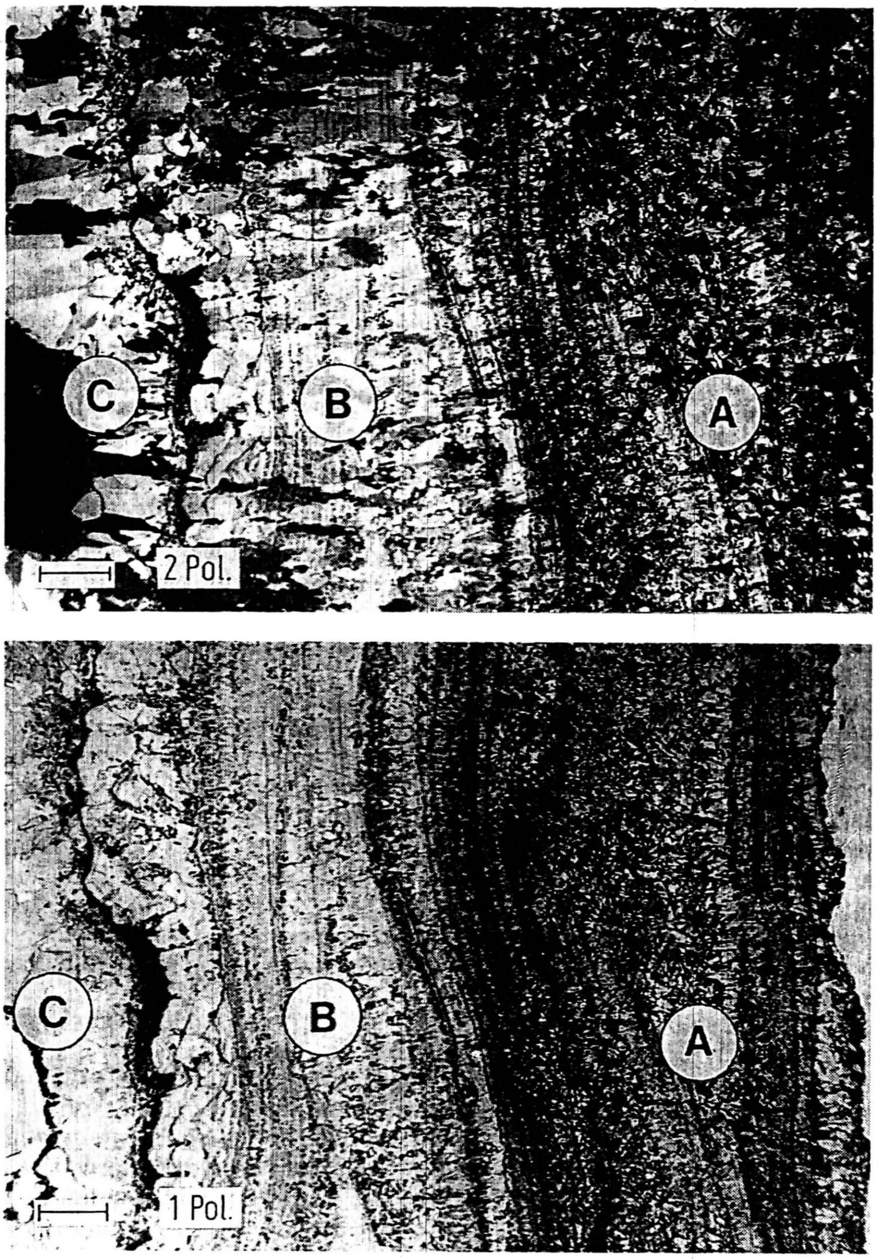

Figure 7. Photomicrograph of Namib speleothem, Rössing Cave. Main stalagmite (see Heine & Geyh 1984). Characteristic rhythmically deposited calcite layers. Extremely thin layers in the outer part (A). Elongated big crystals in the inner part (C). Diagenetically altered layers and iron- and manganese-rich horizons as boundaries between the sets of layers. The hiatuses document weathering horizons during periods of dry climate. Bar = 1 mm. In the Namib cave speleothems, growth layers always occur as thin layers in the outer part and thick layers in the inner part. The outer layers (A) yield a U/Th age of ca. 123 ka BP, the layers (B) a U/Th age of ca. 215 ka BP. Radiocarbon ages of the outer layers are ca. 26 to 33 ka BP.

can be explained by the limited growth of the sinter formations, since the samples for radiocarbon dating were collected from pieces of sinter that comprises several small calcite layers. AMS ^{14}C and mass spectrometry U-series age determinations have not yet been processed from the Namib speleothems.These tasks are in progress.

4 DISCUSSION AND PALEOCLIMATIC IMPLICATIONS

Paleoclimatic information from southwest African soils and landforms are discussed by Heine (1995). Based on ^{14}C, U/Th and TL ages, partly contradictory paleoclimatic concepts have been developed (Heine 1991, 1992, 1995, Geyh 1995). The paleoclimatologic information on the available dates from the central Namib Desert is not yet

GUSTAFSSON, Sigi
D R F N
NAMIBIA

GUSTAVO, Margareth
D R F N
NAMIBIA
Telephone (Work): 0926461229855
Fax: 0926461230172
E-Mail: margarethg@drfn.org.na

HASSANE, Mr Moussa
Researcher In Forestry Agroforestry
P O Box 429
INRAN
NIGER
Telephone (Work): 09227740916

HAYWARD, Ntsiki

HENDRICKS, Howard
South African National Parks
P O Box 110040
Hadison Park
KIMBERLEY 8306
Telephone (Work): 0538325488
Fax: 0538334543
E-Mail: howardl@parks.sa.za

HESSELMAN, Mr H

HOFFMAN, Prof Timm
Institute For Plant Conservation
U C T
RONDEBOSCH
Telephone (Work): 6502440
Fax: 6504046
E-Mail: thoffman@botzoo.uct.ac.za

HUONGO, Mr Abias
J E A
ANGOLA
Telephone (Work): 0924423969547
E-Mail: jea@angola.com

JAFARI, Dr Mohammad
Associate Professor
University Of Tehran
P O Box 14185/354
Natural Resources College Of Tehran University
KARAJ 37585-4314
IRAN
Telephone (Work): 09982612223044
Fax: 09982261227765
E-Mail: mjafari@chamran.ut.ac.ir

JAIN, Dr Kalpana
23, Jhiniret Ki Gali
UDAIPUR 313001
INDIA
Telephone (Work): 0991294525593
Fax: 0991294529922
E-Mail: ncjain@bppl.net.in

JONAS, Miss Zuziwe
University Of Cape Town
47 Fumana Street Harare
Khayelitsha
CAPE TOWN 8000
E-Mail: zjonas@botzoo

KALENGA, Mrs Lahja
D R F N
P. O. Box 175
Oshakati
OSHAKATI 9000
NAMIBIA
Telephone (Work): 0926465221854

KALENTA,
D R F N
NAMIBIA

KALLIPA, Mrs Wandile
Channel Africa Radio
P O Box 91313
AUCKLAND PARK
Telephone (Work): 0117143759
Fax: 0117144959
E-Mail: kallipaw@channelafrica.org

KANOUTE, Mr Salif
S T P / C I G Q E
B P 2357
BAMAKO
MALI
Telephone (Work): 09223231074
Fax: 09223235867

KARIMPOOR REIHAN, Dr Majid
Tehran University
Iran Desert Research Center
TEHRAN 31585
IRAN
Telephone (Work): 0998218958448
Fax: 0998218965287
E-Mail: karimpoor@chamran.ut.ac.ir

KASUSYA, Mr Pius
Resource Projects Kenya
P O Box 59411
NAIROBI
KENYA
Telephone (Work): 092542890595
Fax: 092542890592
E-Mail: iagi.rp@africaonline.co.ke

definite because of the methods used and the unsuitability of the dated material (Geyh 1995). Nevertheless, a critical evaluation of the Homeb Silt Formation, the Namib gypcretes, and the Namib speleothems can contribute to a better understanding of the late Quaternary climatic history of the central Namib Desert.

The Homeb Silts, for the first time, provide evidence for moister conditions in the central Namib Desert. Without any doubt, the description of Smith et al. (1993) document a more humid environment than today for the period of the accumulation of the Homeb Silt Formation, namely the last glacial maximum. Unfortunately, the ^{14}C and TL ages of the Homeb Silts can give only a vague criterion for the true time of sedimentation, at some time or other around the LGM. Since there is no other evidence for a markedly wetter phase in the central Namib around 20,000 years BP, we cannot exclude that the moist environmental conditions at Homeb, documented by the ichnofacies and the horizons of rhizocretions and root tubules in the sediment sequence, reflect influences from the upper reaches of the Kuiseb river system. Mineralogical characteristics of the Homeb Silts show that these sediments originated in the Khomas Highland (far in the east) (Eitel 1994). Reconstructing the central Namib paleoclimate by referring to the Homeb Silt Formation, therefore, should not be considered as a reliable method. Investigations on paleosols in Sossus Vlei, Hauchabfontein, and Bullsport (Heine 1993) indicate that late Quaternary humid phases cannot be traced in the central Namib Desert, but become more and more accentuated towards Northeast and East (Namibian Highland) where more humid phases compared with todays climatic conditions occurred > 25 to 19 ka BP and about 10 to 8.5 ka BP (Heine 1993).

These conclusions are corroborated by investigations of late Quaternary lake deposits in the northern Namib Sand Sea south of the Kuiseb valley (Teller et al. 1990). Teller et al. (1990) believe that the region remained hyper-arid throughout the late Quaternary, and ponding and sedimentation in vleis and interdune valleys were related to small increases in runoff and groundwater recharge from the East. The age of ponding may be oldest in the west (30-25 ka BP, west of Gobabeb) and youngest to the east (17.5 to 11.1 ka BP, north of Tsondab Vlei).

Until now there have been no further detailed investigations of the Namib Desert soils. Therefore, there is nothing with which to compare the results of Walter (1994). Little is known about the origin of the central Namib gypcretes. Together with Dixon (1994a, b), we recognize the Namib Desert gypsum soils as "true gypsum" or "croûte de nappe" that occur as slightly cemented gypsum crystals up to 1 mm in length commonly developed beneath non-gypsiferous sediment or as desert rose crust consisting of interlocking lenticular gypsum crystals ranging in size from a few millimeters to 20 cm. The paleoclimatic interpretation of pedogenic gypcretes is difficult, since relatively little work has been undertaken on the downward movement of gypsum, the source of gypsum (which is generally regarded as aeolian), the time which is necessary to develop a certain abundance of gypsum in characteristic soil layers, and the climatic conditions necessary for gypcrete formation. Furthermore, only little is known of the relationship between climatic parameters, time, amount of aeolian input of salts, gypsum, etc. on the one hand and the occurrence, morphology, and mineralogy of gypcretes on the other hand. From our investigations of gypcretes (Walter 1994, Heine & Walter 1996), we conclude that in the central Namib Desert there is no evidence for humid phases during the late Quaternary.

Clastic cave sediments and speleothems are providing important new information about past climates in arid and semi-arid southern Africa (Brook 1995, Brook et al. 1990, Burney et al. 1994, Holmgren et al. 1994, Holmgren et al. 1995, Heine 1991, 1992, Heine & Geyh 1984, Geyh 1995). Unfortunately, no investigations were carried out in the Namib caves apart from the work by Heine (1992), Heine & Geyh (1984), and Geyh (1995). For the interior of southern Africa, despite the dating problems (see Heine 1991, Holmgreen et al. 1994, Geyh 1995), some conclusions can be reached concerning the nature of late Quaternary changes or the timing of climatic fluctuations. Based on speleothem investigations, the Namibian highlands and the Kalahari Basin (Botswana) experienced wetter conditions in late glacial times (ca. 25-12 ka BP) and more arid conditions in the early Holocene (10-7 ka BP). In the western parts of semi-arid southern Africa (Etosha area to the Tsauchab valley), the opposite was the case during the early Holocene (Heine 1995) when conditions became more humid. However, the U/Th dates from speleothems show that the last period with extensive sinter growth occurred during isotope stage 7 (Brook et al. 1990, Heine 1992) and not during the late Quaternary.

Although studies of the paleoclimate signal contained within speleothem growth are few, some implications can be reported: (1) Speleothem growth rates were highest in pre-Quaternary times in the Namib caves. (2) Only extremely small growth rates occurred during the Quaternary in the Namib caves, and after ca. 125 ka BP no speleothem growth was observed. (3) In the arid to semi-arid interior of southern Africa, speleothem growth rates decreased after isotope stage 7 as well. (4) Climatic fluctuations are documented by speleothem formation during different late Quaternary periods. (5) During and before isotope stage 7, conditions for speleothem growth were more favorable than during later phases with sinter development. This applies to the Namib caves as well as to the interior caves. (6) Since isotope stage 7, the range of moisture fluctuations seems to have decreased. At the same time, the magnitude of climatic changes decreases from East to West. As a result, the central Namib Desert did not experience fluctuations in precipitation during the late Quaternary, whereas the interior of southern Africa was effected by late glacial changes in precipitation. (7) The early Holocene of the Namib Desert seems to be out of phase with regard to the humidity

DIALLO, Mr Hama Arba
BURKINA FASO

ELFADL, Dr Mohamed
Forestry Research Centre
P.O. Box 7089
Soba
KHARTOUM
SUDAN
Telephone (Work): 0924911787136
E-Mail: mohamed.elfadl@helsinki.fi

EL GAMRI, Tarig
Researcher
Environment And Natural Resources Research Institute
P O Box 6096
People Hall
KHARTOUM
SUDAN
Telephone (Work): 0924911475153
Fax: 0924911463416
E-Mail: tarig_ncr@yahoo.com

ESLER, Dr Karen
University Of Stellenbosch
Private Bag X1
Matieland
STELLENBOSCH 7603
Telephone (Work): 8083063
Fax: 8083607
E-Mail: kje@sun.ac.za

ESMAEIL ZADEH, Mr Hamid
Tehran University
Faculty Of Natural Resources
KARAJ 31585
IRAN
Telephone (Work): 09982662232721
Fax: 09982612227765
E-Mail: hesmaely@yahoo.com

FITTER, Dr Joern
G T Z Office
P O Box 8016
WINDHOEK 061
NAMIBIA
Telephone (Work): 096461222447
Fax: 094661222427
E-Mail: fitter@iafrica.com.na

FOX, Dr Dennis
Associate Professor
C N R S
U M R Espace 6012 Cnrs
98 Blvd Ed Herriot
NICE 06800
FRANCE
Telephone (Work): 0933493375380
Fax: 0933493375430
E-Mail: fox@unice.fr

GABES, Arnold
D R F N
NAMIBIA

GAMATHAM, Helen
D R F N
NAMIBIA

GASEB, Nickey
D R F N
NAMIBIA

GAUR, Dr Mahesh
Head, Department Of Geography
S B K Government College
10/35 Chopasni Housing Board
JODHPUR 342000
INDIA
Telephone (Work): 0991291754406
Fax: 0991291438691
E-Mail: iemsd@satyam.net.in

GEORGE, Kevin
F O N S A G
GABORONE
BOTSWANA
Telephone (Work): 09267307506
E-Mail: fonsag@global.bw

GLIESE, Jürgen
Brot Für Die Welt / U N C C D Support Programme
Schifferstr 33a
FRANKFURT D-60594
GERMANY
Telephone (Work): 09496961993706
Fax: 09496961993707
E-Mail: des2002@gliese.de

GOAGOSEB, Gabriel
D R F N
NAMIBIA

GOUWS, Ms Sarah
Landscape Committee
D R F N
Postal Agency
PAULSHOEK 8221
Telephone (Work): 0275411055
Fax: 0276521356

GURUNG, Mr Kumar
Inshured
10 New Ban Pb6218
KATHMANDU 6218
NEPAL
Telephone (Work): 099771487376
Fax: 099771487376
E-Mail: inshured@hotmail.com

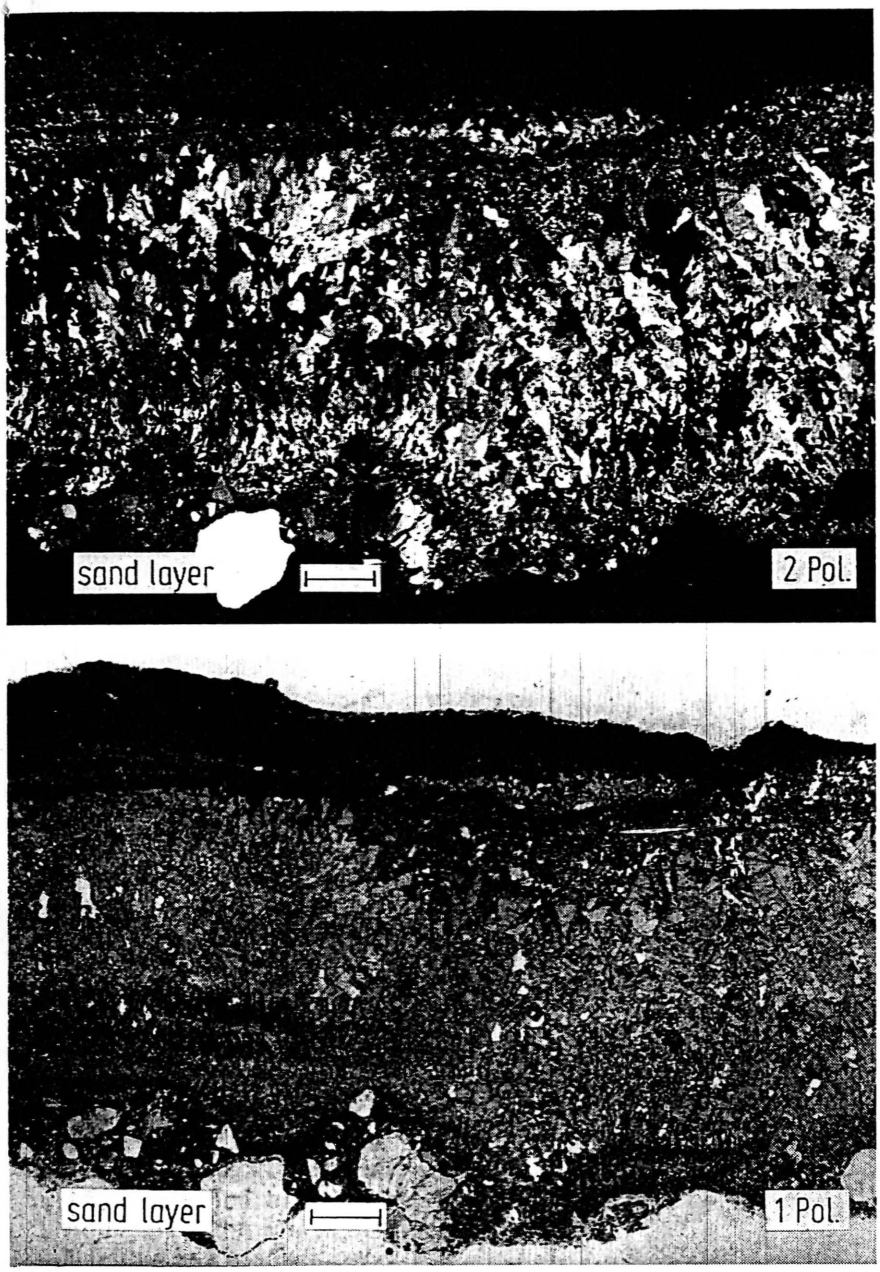

Figure 8. Photomicrograph of Namib speleothem, Rössing Cave, flowstone intercalated with aeolian sand (see Heine & Geyh 1984, Heine 1992). A U/Th age of ca. 185 ka BP was processed from the calcite layers. A set of several of such flowstone layers and sand layers documents alternating deposition of sinter and aeolian sand. This record indicates changes in available moisture during a period dated around 146 to 205 ka BP (see Fig. 5). Bar = 1 mm.

fluctuations in the interior of southwestern Africa.

Thus, the late Quaternary climatic development of the central Namib Desert reflects the situation of the surface oceanography in the South Atlantic Ocean, which is characterized by a cyclonic gyre circulation including the northwest-directed Benguela Current, the eastward South Equatorial Counter Current, and the Angola Current which flows southward along the Angola Margin. During the late Quaternary, the surface oceanography off southwestern Africa (central Namib area) was more or less stable. Geochronological evidence suggests a prolonged period of aridity during the late Quaternary that was influenced by neither the large climatic changes nor the fast and abrupt climate variability recorded in Greenland ice cores (Broecker 1994, Zahn 1994, Bond 1995) or in long terrestrial sediment sequences (e.g. Hooghiemstra 1989). The part of the global ocean circulation that influences the Benguela Current off the central Namib coast may not have been altered during the late Quaternary. Sudden (recurring) changes in the operation of the Benguela Current did not occur.

CLEMENTS, Mrs Amanda
U.S. Bureau Of Land Management
B L M Uncompohgre Field Office
2505 South Townsend Avenue
MONTROSE 81401
USA
Telephone (Work): 0919702405306
Fax: 0919705405367
E-Mail: amandaclements@montrose.net.

CLOETE, Mr Eric
D R F N
P O Box 553
SPRINGBOK 8240
Telephone (Work): 0277122011
Fax: 0277122174
E-Mail: eric@intekom.co.za

CLOETE, Helen
D R F N

CLOETE, Mr Mervin
Landscape Commitee
Postal Agency
PAULSHOEK 8221
NAMIBIA
Telephone (Work): 0275411055
Fax: 0276521356

COIRINI, Prof Ruben Omar
Universidad Nacional De Cordoba
San Juan 669 "20 De Junio"
CORDOBA 5003
ARGENTINA
Telephone (Work): 09543514842399
Fax: 095453514334118
E-Mail: mam@agro.uncor.edu

CONRADIE, Mr Wayne
Rare Image
Suite 1
Private Bag X335
CAPE TOWN 8000
E-Mail: wphoto99

CORJEUS, Mr John
D R F N
Postal Agency
PAULSHOEK 8221
Telephone (Work): 0275411055
Fax: 0276521356

DALL, Moizelle
D R F N
NAMIBIA

DARKOH, M B K
University Of Botswana
Department Of Environmental Science
University Of Botswana
PrivateBag 0022
GABARONE
BOTSWANA
Telephone (Work): 092673552526
Fax: 09267318265
E-Mail: darkohmb@mopipi.ub.bw

DA SILVA BAIXO, Mr Eduardo Jorge
No Info At This Stage
MOPUTO
MOZAMBIQUE
Telephone (Work): 092581465843
Fax: 092581465849
E-Mail: lhilario@teledata.mz

DAUSAB, Rudolf
D R F N
NAMIBIA

DAVIS, George
D R F N

DEFANG, Mr Pius
Associated Country Women Of The World (Acww)
P. O. Box 446
BUEA 0144
CAMEROON
Telephone (Work): 092377523264
Fax: 092373322366
E-Mail: nnangela@yahoo.com

DE KLERK, Mr Johannes Nicolaas
Project Manager / Bush Encrouchment
Ministry Of Environment And Tourism
P O BOX 5846
Ausspannplatz
WINDHOEK 26409
NAMIBIA
Telephone (Work): 0926461249015
Fax: 0926461240339
E-Mail: ndk@dea.met.gov.na

DELEGATE 6,
Brot Für Die Welt / U N C C D Support Programme
ZIMBABWE
E-Mail: des2002@gliese.de

DEMBELE, Mr Moussa
S T P - C I G Q E / Malie
Bp 2357
BAMAKO
MALI
Telephone (Work): 09223231074
Fax: 09223235867
E-Mail: stp@cefib.com

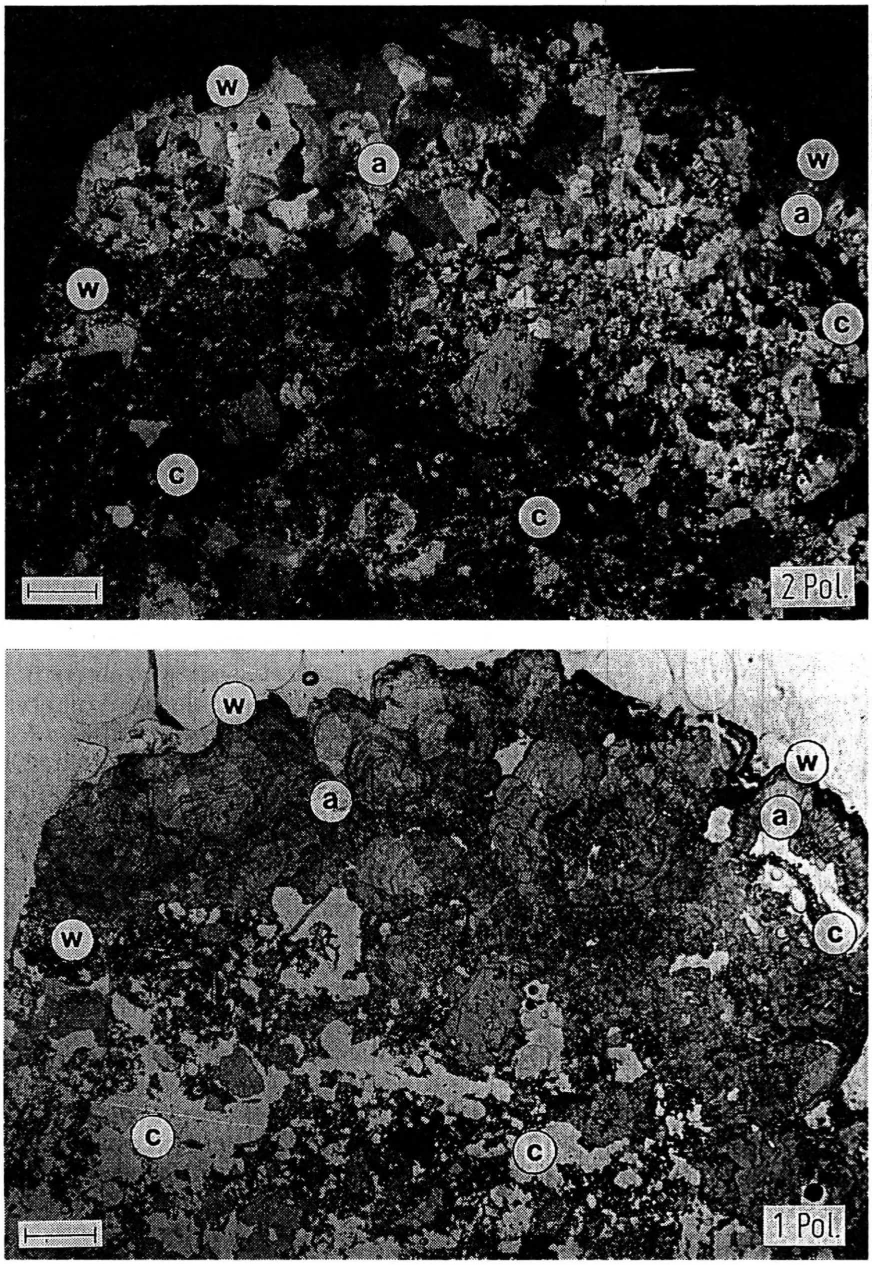

Figure 9. Photomicrograph of Namib speleothem, Tinkas Cave, "sinter-with-sand" stalagtite (see Heine 199 and Fig. 6). Cross-section with canals (c) and growth rings (a). A weathering horizon (w) developed on the surface and along the canals. The weathering crust consists of $CaCO_3$, blown-in minerals (quartz, mica etc.) and colloidal SiO_2 with iron. The weathering horizon documents that there was no speleothem formation during the late Quaternary. U/Th ages from speleothems are older than ca. 220 ka BP. Bar = 1 mm.

5 CONCLUSIONS

In the hyper-arid central Namib Desert, in the area north of the Namib Sand Sea, flash-flood sediments of the Kuiseb River, gypcretes of the Namib Unconformity Surface, and speleothems of caves have been found to be an excellent repository of paleoclimatic data for terrestrial environments. In particular, the very presence of speleothem relics indicate more moisture at the time of formation. Both, ^{14}C and U/Th age determinations were used to date the speleothems and, hence, the climatic conditions.

The U/Th dates, as well as TL dates from cave dune sands, show that chronostratigraphies based on ^{14}C dates have to be revised. Radiocarbon ages of speleothems seem not to reflect the time of the speleothem growth, but the time of contamination of a finite age with no realistic reference to any more humid period. The last significant pre-Holocene pluvial phase with speleothem growth in the central Namib Desert probably occurred during oxygen isotope stage 7 (ca. 200-220 ka BP). It seems likely that climate in the arid parts of southwestern Africa experienced a more humid phase around and after

ANDERSON, Ms Pippin
University Of Cape Town
24 The Avenue
WOODSTOCK 7925
Telephone (Work): 4483675
E-Mail: panderson@botzoo.uct.za

ARIBEB, Karl
D R F N
NAMIBIA

ARIF, Mr Tanveer
PAKISTAN

AZARNIVAND, Mr Hossein
University Of Tehran
P O Box 14185/354
Natural Resources College Of Tehran University
KARAJ 37585-4314
IRAN
Telephone (Work): 09982612230497
Fax: 09982261227765
E-Mail: hazar@chamran.ut.ac.ir

BADCOCK, Ms Jacqui
Resident Representative
U N D P
NAMIBIA
E-Mail: jacqui.badcock@undp.org

BANK, Maria
D R F N
NAMIBIA

BARAC, Miss Anuschka
Student
Potchefstroom University
School Of Environmental Sciences And Development
Potchefstroom
POTCHEFSTROOM 2520
Telephone (Work): 0182992499
Fax: 0182992503
E-Mail: plbasb@puknet.puk.ac.za

BETHUNE, Ms Shirley
National Co-Ordinator NAPCOD
Directorate Environmental Affairs
Private Bag 13306
WINDHOEK
NAMIBIA
Telephone (Work): 0926461294015
Fax: 0926461240339
E-Mail: bethune@dea.mel.gov.na

BEUKES, Adolf
D R F N
NAMIBIA

BIELEK, Dr Pavol
Director Of Institute
Soil Science And Conservation Research Institution
Gagarinova 10
BRATISLAVA 82713
SLOVAK REPUBLIC
Telephone (Work): 09421743420866
Fax: 09421743295487
E-Mail: bielek@vupu.sk

BOOIS, Salomon
D R F N
NAMIBIA

BORJIGDKHAN, Mr Adiyasuren
U N C C D Focal Point Of Mongolia Environmental Education And
P O Box 752
ULAANBAATAR
MONGOLIA
Telephone (Work): 0997611312458
Fax: 0997611312320
E-Mail: adyasurents@usa.net

BOTES, Andre
D R F N
NAMIBIA

BOTO, Mrs I.
C T A
Posbus 380
WAGENINGEN 6700AJ
NETHERLANDS
Telephone (Work): 0931317467157
Fax: 0931317460067
E-Mail: boto@cta.nl

BRAHIMI, Mr Youssef
PARIS
FRANCE

BRAND, Miss Nellie
D R F N
P O Box 20232
WINDHOEK
NAMIBIA
Telephone (Work): 0926461229855
Fax: 0926461230172

CHIKWENYA, Musampa
P O Box 450061
MPIKA
ZAMBIA
Telephone (Work): 092604370387
E-Mail: zaw@zamnet.co.zm

200 ka BP. As the TL chronostratigraphies of paleodunes of the Etosha area in northern Namibia together with paleosol evidence show no indication of a significantly more humid phase after 120 ka BP (Heine 1992), the results from the central Namib Desert prove continued aridity along the Namibian coast between Walvis Bay and Swakopmund.

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ABISOYE, Dr V.
Tropical Forest Network
P.O. Box 38471
Dugbe
IBADAN 20001
NIGERIA
Telephone (Work): 09234712628
Fax: 092348109051
E-Mail: tfnnigeria95@yahoo.co.uk

ABRAHAMS, Miss Natasha
Student
University Of Western Cape
Botany Department
Private Bag X17
BELLVILLE 7535
Telephone (Work): 9593783
Fax: 9592266
E-Mail: nabrahams@uwc.ac.za

ADESANYA, Mr Adekunle
Alaaka Community Development Association
P O Box 27040
Agodi Post Office
IBADAN 200003
NIGERIA
Telephone (Work): 0923422410842
Fax: 0923422318400
E-Mail: prince2002t@onebox.com

ADEYEMI, Prince
Alaaka Community Development Association
P O Box 27040
Agodi Post Office
IBADAN 200003
NIGERIA
Telephone (Work): 0923422410842
Fax: 0923422318400
E-Mail: prince2002t@onebox.com

ADISA-BALOGUN, Mrs I. A.
Tropical Forest Network
P.O. Box 38471
Dugbe
IBADAN 20001
NIGERIA
Telephone (Work): 09234712628
Fax: 092348109051
E-Mail: tfnnigeria95@yahoo.co.uk

AHMADI, Dr Hassan
University Of Tehran / Iran Desert Research Center
P O Box 14185/354
TEHRAN 37585-4314
IRAN
Telephone (Work): 09982612223044
Fax: 09982612227765
E-Mail: ghzehtab@chamran.ut.ac.ir

AJARU, Mr Ali Alias
Mili Mil Paresh
Kuja
Amuria Country
KATAKWI DISTRIK
UGANDA
Telephone (Work): 092564132004
Fax: 0925641321010
E-Mail: smuwaya@yahoo.com

ALEX, Mr Lwakuba
M A A I F
P O Box 102
ENTEBBE
UGANDA
Telephone (Work): 0925641320004
Fax: 0925641321010
E-Mail: smuwaya@yahoo.com

ALLSOPP, Dr Nickey
University Of The Western Cape / Botany Department
ARC - Range & Forage Department
Private Bag X17
BELLVILLE 7535
Telephone (Work): 9593373
Fax: 9591376
E-Mail: nallsopp@uwc.ac.za

ALOJO, Mr Lawrence
Alaaka Community Development Association
P O Box 27040
Agodi Post Office
IBADAN 200003
NIGERIA
Telephone (Work): 0923422410842
Fax: 0923422318400
E-Mail: prince2002t@onebox.com

AMAAMBO, Otillie
D R F N
P O Box 1228
Ondangwa
OSHANA REGION
NAMIBIA
Telephone (Work): 0926465221854

AMOS, Mr D.G.
Tropical Forest Network
P.O. Box 38471
Dugbe
IBADAN 20001
NIGERIA
Telephone (Work): 09234712628
Fax: 092348109051
E-Mail: tfnnigeria95@yahoo.co.uk

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WARD, Viv
D R F N
NAMIBIA

WEIK, Mr Jörg
G T Z
P. O Box
AMMAN 11118
JORDAN
Telephone (Work): 092625359726
Fax: 096265156457
E-Mail: jweik@go.com.jo

WEISS, Mr Eckehard
G T Z
P O Box 5180
ESCHBORN 65726
GERMANY
Telephone (Work): 09496196791912
E-Mail: eckehard.weiss@gtz.de

WERNER, Wolfgang
D R F N
NAMIBIA

WILCKE, Mrs Angelika
Entwicklung And Laendlicher Raum/Agriculture And Rural
Eschborner Landstrasse 122
FRANKFURT 60489
GERMANY
Telephone (Work): 09496924788465
Fax: 09496924788481
E-Mail: A.Wilcke@DLG-Frankfurt.de

WOEHL, Dr Helmut
D R F N
GERMANY

WOLF, Katherine
D R F N
NAMIBIA
E-Mail: katherinew@drfn.org.na

ZEHTABIAN, Dr Gholam Reza
Associate Professor
University Of Tehran
P O Box 14185/354
Natural Resources College Of Tehran University
KARAJ 31585/4314
IRAN
Telephone (Work): 0998261222044
Fax: 0998261222765
E-Mail: ghzehtab@chamran.ut.ac.ir

ZVINGADZA, Mr Sherpard
Zero Regional Environment Organization
P O Box 5338
HARARE
ZIMBABWE
Telephone (Work): 09263791333
Fax: 09263791333
E-Mail: zero@mweb.co.zw