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HOLOCENE CLIMATE OF NAMIBIA: A REVIEW BASED ON GEOARCHIVES

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ABSTRACT The Holocene palaeoclimates in Namibia are reviewed by discussing different palaeoclimate geoarchives. The available evidence suggests little climatic fluctuations during the Holocene. There is evidence of more humidity compared to today during the early Holocene. Short dry episodes occurred around 8 ^{14}C-ka BP and around 5–3 ^{14}C-ka BP. Since 1000 years the northern Benguela Current sea surface temperatures show a decline and since ca. 500 years Namibia experienced in the Namib Desert and adjacent areas more arid conditions than before. Extreme flash floods occurred more frequently during the Little Ice Age, probably correlating to variations of sun spot activity.

Key Words: Holocene; Geoarchives; Palaeoclimate; Namibia.

INTRODUCTION

When the future greenhouse warming was first identified (see Oeschger, 2000), scientists informed about the potential impacts and implications of such change for selected aspects of the environment. It was tempting to turn to the past for analogues in the future. Yet, the isotopically inferred temperature record from Central Greenland and Antarctica (Fisher & Koerner, 2003) is not a template for all aspects of Holocene climate everywhere (Oldfield, 2003). If we accept that the climate past is the key for the climate future, we have to discuss the Holocene climate with its regional and short-term fluctuations for the geographic region under concern. So far there are some studies about climate change in southern Africa in the 20th century (Gerstengarbe & Werner, 2004; Mendelsohn *et al.* 2002; Heine, 1998a) and about scenarios for the future (Hulme, 1996; Hadley Centre, 2001) showing that climate change may not be uniform in southern Africa. Unfortunately, evidence of Holocene climate changes for Namibia is sparse, geographically scattered and often poorly dated. Here, I present a short review of the Holocene climatic history of Namibia based on a palaeoclimatic interpretation of geoarchives and archaeological findings.

RESEARCH AREA AND METHODS

Namibia is a large country, covering an area of about 823,680 km^2 and spanning some 1,320 km between ca. 17° and 29°S and roughly 12° and 25°E. Its coastline of approximately 1,570 km separates the land from the Atlantic Ocean. The general topographic pattern reflects three prominent elements: a narrow coastal plain (Namib Desert, 0–500/1000 m asl.), an eroded escarpment reaching altitudes of 1000/1500–2000 m asl., and an extensive interior plateau (Kalahari Basin, 1000–1500 m asl.). The Brandberg granite pluton rises to 2579 m asl. Most climatic features result from Namibia's position (Fig. 1). It is exposed to air movements driven by the Intertropical Convergence Zone, the Subtropical High Pressure Zone, and the Temperate Zone. The relative positions of the systems determine Namibia's rainfall. The cold Benguela Current is responsible for little rain, lower temperatures, stronger winds, frequent fogs, higher humidity,

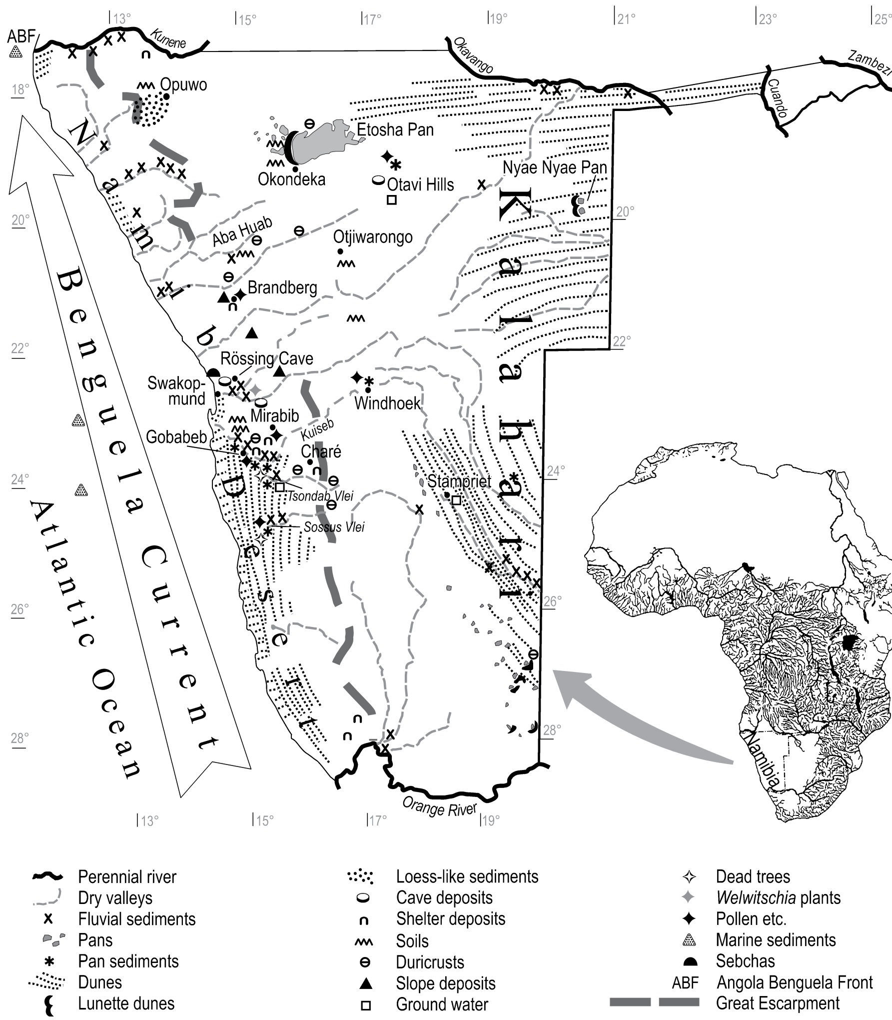

Fig. 1. Location map and localities of georarchives in Namibia and pattern of perennial rivers in Africa (inset map).

less radiation and no frost along the Atlantic coast. Thermo-topographic airflows over the central Namib are found to have a regional significance frequently equalling or exceeding that of the general circulation (Lindesay & Tyson, 1990). The mean annual rainfall of less than 20 mm.a^{-1} in the Namib Desert makes this region one of the driest in the world. To the northeast rainfall reaches >600 mm.a^{-1}. In the west (Namib Desert), dominant soils are arenosols, gypsisols, leptosols together with dune sands, gravel and rock outcrops. In the escarpment areas and mountains mainly leptosols and regosols are found, on calcareous rocks calcisols are common. In the Kalahari basin arenosols, and in the northwestern areas cambisols are widespread. Soils along the margins and valleys of larger river courses are fluvisols and in pans solonchaks and solonetzes are found (Mendelsohn *et al.*, 2002).

Holocene geoarchives that preserve one or more types of decipherable record of past environmental conditions and that can be used for palaeoclimatic reconstructions are the following: (a) dunes of the Namib Desert and the Kalahari region as well as the Etosha area, and desert loess, (b) fluvial deposits such as fluvial gravel, sand, silt and clay, slack water deposits, organic mud, from perennial rivers (Kunene, Okavango, Zambezi and Orange River) and from episodic and ephemeral rivers, (c) pan and lake sediments, (d) cave deposits (sinter, speleothems, sand), (e) soils, (f) slope deposits (debris), (g) groundwater, (h) trees (living and dead), (i) molluscs, ostracods, (j) pollen and hyrax dung, (k) marine sediments, and (l) sebhka deposits. In some cases a single archive will contain several possible proxies that can be translated into validated paleoenvironmental information (Oldfield, 2003).

Archaeological sites, documentary and instrumental records provide further palaeoclimatic information.

The current emphasis on climate reconstruction has led to an incredible diversity of proxy climate signatures (Oldfield, 2003). Most palaeoclimatic reconstructions from proxy records do not consider the fact that proxy records may represent either a general trend (within millennia: pedogenesis, vegetation changes etc.), a short phase (within several years, decades or centuries: lake-level fluctuations, lacustrine sedimentation, lunette dune formation etc.) or extreme climatic events (within days, weeks or months: flash-floods, debris flows etc.) The records from Namibia reflect the relative paucity of evidence in that part of the world (e.g. Street-Perrott & Perrott, 1993; Jones *et al.*, 2001; Heine, 2002), and in most cases these refer to precipitation. The need for chronological control on all records of Holocene climate change in Namibia has to be emphasized. Only by chronological control a high time resolution is achieved and permits close comparison between archives and sites. Hence, miscorrelations and misinterpretations are avoided.

A large variety of methods is applied by the different authors mentioned in this review. I refer to the original literature for detailed methodological information.

GEOARCHIVES

I. Dunes and Desert Loess

Extensive systems of stabilized, degraded or fossil aeolian landforms (dunes) are located in various areas of Namibia. In the Namib Desert complex linear dunes (Lancaster, 1989) and in the southwestern, northwestern and northern Kalahari simple linear dunes are the dominant form, whereas near pans and the coast other dune types, such as lunettes and barchans, are found. According to optical luminescence dates, middle and later Holocene linear dune reactivation occurred in the southwestern Kalahari from about 26 to 8 ka BP and around 4 ka BP (Thomas *et al.*, 1997, 1998; Eitel & Blümel, 1998; Stokes *et al.*, 1997a, 1997b; Heine, 2002). Lunette dune formation in the western Kalahari (Nyae Nyae pans, Heine, 1995) shows higher wind velocity ca. 8 ka BP and in the southwestern Kalahari aeolian activity occurred frequently throughout the past 18 ka, indicating that the factors controlling lunette sedimentation were markedly different from those determining linear dune mobilization (Lawson & Thomas, 2002). At the same time the final deposition of linear dune sand occurred in the southwestern Kalahari (Blümel *et al.*, 1998; Eitel, Blümel *et al.*, 2002; Thomas & Shaw, 2002). Investigations of the valley fills of the southwestern Kalahari (Heine, 1981, 1990) show dune building around 4.5–3.5 ^{14}C-ka BP and after AD 1850 due to invading cattle breeders. More arid conditions and/or higher wind velocity is documented in the Kuiseb valley near Gobabeb by encroaching dune sand into the valley about 300–400 years ago (Mizuno & Kotaro, 2003).

In northern Namibia (SW of Opuwo), loess-like sediments accumulated during the Middle/Younger Holocene (?) and during the last 3000 years (Brunotte & Sander, 2000).

New analyses of data sets of luminescence ages for the southwest Kalahari suggests that different aeolian forms (linear dunes, lunettes, sand sheets) have been active over different time scales in the past, have different sensitivities to environmental changes and have different time scales over which they record and preserve the palaeoenvironmental record (Bateman *et al.*, 2003). The same is the case in the Etosha Pan area (Heine, 1995). Palaeoenvironmental reconstruction must consider this.

II. Fluvial Deposits

Considerable effort has been invested into process-orientated studies of the nature and impact of flash floods. Palaeoflood and slackwater deposits (for description see Baker, 1987, 2003: 308; Saint-Laurent, 2004) that are to be found in many valleys have been used as archives for palaeohydrological and palaeoclimatic reconstructions (e.g. Baker, 2003; Heine, 2004a, 2004b; Eitel *et al.*, 2001, 2005). Earlier publications on fluvial forms and sediments in valleys — now interpreted as slackwater deposits and corresponding floodouts (Heine, 2004a, 2004b) — had been described as archives documenting more arid climatic conditions in the catchment than today (Vogel & Rust, 1987, 1990; Blümel *et al.*, 2000; Eitel *et al.*, 2001, 2005; Hüser *et al.*, 1998). There is evidence that during the early Holocene and since about 2000 years slackwater deposits were accumulated, with a period of more frequent flash-floods during the Little Ice Age (Heine, 1998c, 2004a).

In the southwest Kalahari, coarse fluvial gravels, erosion processes, stone pavements and dune sands blown into the valleys indicate a dry phase about 4 ^{14}C-ka BP (Heine, 1982).

The so-called Gobabeb Gravel, non-calcified gravels found at numerous localities in Namibia (Martin, 1950), are dated to the Pleistocene/Holocene transition period and are interpreted as sediments of larger rivers (Ward, 1987). For the Namib Desert, Lancaster (2002) reports a period of increased river discharge centred on 12–8 ^{14}C-ka BP.

III. Pan, Lake and Swamp Sediments

Anoxic lake and swamp deposits which preserve fossil pollen, are very scarce in Namibia. Palynological studies attempted on pan sediments from Sossus Vlei (van Zinderen Bakker & Müller, 1987) and speleothems from the Rössing Cave (pers. communication, L. Scott) provide no data on Holocene environmental changes. For the central highland, Scott *et al.* (1991) find wetter conditions ca. >7–6 ^{14}C-ka BP and drier climates after ca. 3.5 ^{14}C-ka BP. Gypsiferous (Mees, 1999) and calcareous deposits (Mees, 2002) of southwestern Kalahari pans are not dated with respect to climate change.

Calcareous lacustrine deposits are found in interdune areas of the Namib Sand Sea (Lancaster & Teller, 1988; Teller *et al.*, 1990). They do not provide any sound information about the Holocene climatic history because of poor dating (Heine, 1995).

IV. Cave Deposits (sinter, speleothems, sand) and Shelters

Investigation of Namib cave speleothems indicate that there was no sinter formation during the Holocene (Heine, 1998b; Heine & Geyh, 1984).

From stalagmite deposition in northern Namibia, Brook *et al.* (1999) conclude that the mid-Holocene was not substantially wetter than now, but that in the early and late Holocene significantly dry periods occurred according to lowering of the groundwater table.

From shelters in the Namib Desert Scott (1996), Sandelowski (1977) and Brain & Brain (1977) provided evidence for increasing aridity during the Holocene since about 5 ^{14}C-ka BP and since ca. 500 years, respectively. In the Kaokoland, archaeobotanical and archaeozoological data do not confirm any climatic variation (Albrecht *et al.*, 2001).

V. Soils and Duricrusts

Periods of pedogenesis indicate changing climate conditions (Heine, 1995). Marked climate changes did not occur during the last glacial cycle in the extremely arid central Namib (Heine & Walter, 1996; Lancaster, 2002). Several episodes of fluvial silt sedimentation and weak pedogenesis occurred in the basin of the Aba-Huab catchment (Eitel & Zöller, 1996) and appear to correlate with late glacial (LGM, Antarctic Cold Reversal) and Holocene (8.2 ka event) climatic phases (Heine, 2002). The archaeological site of Mirabib and Charé indicate more arid conditions during the last ca. 500 years in the eastern central Namib (Heine, 1995).

In the Etosha area, the formation of the Okondeka I-Soil (Buch *et al.*, 1992) comprises only the early half of the Holocene. TL-ages indicate dune sand movement since the Middle Holocene. In the Otjiwarongo area vertisol — kastanozem — calcisol soil associations, developed in fine-grained mid-Holocene sediments (Eitel, Eberle *et al.*, 2002), document weak environmental changes.

Duricrusts such as calcretes and silcretes have been investigated by many authors (e.g. Blümel, 1979, 1981; Eitel, 1994). Because the beginning, the duration and the termination of soil and duricrust development cannot be dated accurately, time-resolution is poor (Heine, 1995, 2002; Lancaster, 2002), correlation of phases of pedogenesis is impossible and palaeoclimatic conclusions are often contrary to the real climatic history.

VI. Slope Deposits (Debris)

Holocene colluvia such as slope deposits and debris flow sediments, are widespread in Namibia. Apart from investigations together with prehistoric research (e.g. Richter, 1991), Namibian slope deposits of Holocene age are not analyzed and dated, although systematic investigations could yield detailed information about environmental changes during the Holocene (see Völkel 1995). The stratigraphies from different archaeological sites of the Namib Desert and adjacent areas show coarse and fine debris strata of early Holocene age at the base and silt/sand sediments (partly with organic material) in the upper parts of middle to late Holocene age (Richter, 1991).

VII. Groundwater and Spring Tufas

Noble gas, isotopic composition and chemistry of the Stampriet groundwater have provided data about late Quaternary climatic conditions, yet do not show significant Holocene temperature changes (Stute & Talma, 1998).

A lowering of the groundwater table in the Otavi hills in northern Namibia is documented by speleothem formation around 8 ka (Brook *et al.*, 1999).

Spring and waterfall tufas are common in the Namib Desert. These deposits have not been investigated as palaeoclimatic archives. Increased groundwater flow in the Namib Desert occurred ca. 12–8 ^{14}C-ka BP (Lancaster, 2002).

VIII. Trees and Plants (Living and Dead)

In some places of the Namib Sand Sea, dead *Acacia erioloba* trees, still standing and now devoid of groundwater, died out around AD 1400 in the Sossus Vlei area (Vogel, 1989, 2003). Dead trees of the Tsondab Vlei may have grown during a brief warm and wet 17th century period, but died out around AD 1700 (Vogel, 2003). Moving dune sand covered trees in the Kuiseb valley 300–400 years ago (Mizuno & Kotaro, 2003).

The distribution of *Welwitschia mirabilis* shows that in the central Namib no young plants occur, whereas in the northern Namib old and young specimens are widely found. The *Welwitschia* plants of the central Namib could only have grown when soil moisture was sufficient over many years so that the plants were able to produce taproots from the surface to the deep lying groundwater table or moist strata. In the central Namib, on the gravel plains east of Swakopmund, the distribution of *Welwitschia* plants in terms of pattern and age suggests that the last period with favourable conditions for seed germination and the establishment of plant communities, occurred during the Little Ice Age.

IX. Molluscs, Ostracods, Diatoms

Mollusc, ostracod and diatom data and interpretation in terms of palaeoclimatic reconstruction with sufficiently high time resolution were not presented from Namibia. Many ^{14}C-ages of molluscs from many places all over the country have been published, but it is not clear whether the inferred timing of periods of climate change is certain, given their reliance on ^{14}C dates on carbonate material (Heine, 1995).

X. Pollen, Owl Pellets and Hyrax Dung

Local arid conditions prevent the formation and preservation of lake or swamp deposits with reducing conditions that could preserve fossil plant material like pollen (van Zinderen Bakker & Muller, 1987). Pollen from Holocene hyrax dung samples compare well with modern assemblages but marked variations of grass, succulent and woody elements, call for investigations of secondary variations in Holocene vegetation and climate (Scott *et al.*, 2004). The climate reconstructed by pollen from hyrax middens of the Kuiseb valley show warm and moderately dry conditions between ca. 970 and 930 years BP, and relatively cool, wet conditions between ca. 700 and 620 years BP (Scott, 1996). Micromammalian evidence for drier climate in the central Namib points to ca. 5200 ^{14}C years BP and the last 500 years (Brain & Brain, 1977; Avery, 1993).

XI. Marine Sediments

Off the Namibian coast at about 23°S and 12°E alkenone-derived past sea-surface temperatures show for the Holocene little time resolution and temperature variation (Kirst *et al.*, 1999; Rimbu *et al.*, 2004). An early Holocene arid period from 11 to 9.8 ka BP was associated with weakened upwelling and warmer sea surface temperatures (Shi *et al.*, 2000). Dupont *et al.* (2004) give alkenone-derived sea surface temperatures (SSTs) for the Benguela Current near the Kunene mouth that show a sharp decline in SSTs (>1°C) to modern values in the past 1000 years. Pollen (Shi *et al.*, 1998, 2000), organic components (Diester-Haass *et al.*, 1988), dust and clay minerals from marine deposits indicate that the Holocene conditions along the Namib Desert coast and the interior underwent but little changes.

XII. Sebhka Deposits

Sebhka deposits within the coastal plain of Namibia have not been used as palaeoclimatic archives. A complex interaction between fluvial, aeolian and pedogenic processes is postulated between the Namib playas and sebkhas by Eckardt *et al.* (2001).

PALAEOHYDROLOGY

Evidence from fluvial sediments, pollen, soils, pan deposits and dunes indicates several phases of increased humidity and surface runoff in Namibia. Namib pan deposits show that there were no marked hydrologic changes in the arid western areas during the late Pleistocene and Holocene (Teller *et al.*, 1990; Lancaster, 2002). In the Etosha area, also only but weak precipitation fluctuations are represented by late Quaternary dune and soil development (Buch *et al.*, 1992; Heine, 1992, 1995, 2002). On the other hand, in the southwestern Kalahari, aeolian processes, fluvial activity and pedogenesis document dry *and* wet phases about 19 to 13 ^{14}C-ka BP (Heine, 1981, 1982). This can be concluded from valley deposits that contain fluvial silt and clay deposits with a rich mollusc fauna intercalated with aeolian dune sand. Although of pre-Holocene age, the example from the southwestern Kalahari shows that only the synthesis of proxy records yield a reliable palaeoclimatic reconstruction (Heine, 1981). In the southwestern Kalahari fluvial sedimentation was caused by low to moderate river discharge during years with higher above normal precipitation (summer *and* winter rains, see also Lee-Thorp & Beaumont, 1995), whereas in the Namib valleys higher precipitation with low to moderate discharge may result in incision of valley floor deposits. Slackwater deposits and floodouts reflect extreme flash floods of only a very short duration (one to several days; see Jacobson *et al.*, 1995: 118–119). Yet, during an exceptionally humid rainy season, flash floods and slackwater/floodout deposition may occur repeatedly (e.g. during the 1933/34 rainy season in Namibia), when sediment-loaded floodwaters are diverted from the main flow to quieter areas where the load settles, forming several horizontal layers of silts and fine sands. Where sediment-loaded flash floods leave the narrow mountain valleys, the floods can spread and form floodouts where the sediment load settles as result of reduced carrying capacity (Scheidegger, 1991). Slackwater deposits and floodouts, therefore, do represent but extreme flood events regardless of the climate and the geographical region of Namibia. Slackwater deposits and floodouts do not document any changes of the general climate of a certain Holocene period *a priori*.

CLIMATE RECONSTRUCTION AND CONCLUSIONS

The major features affecting precipitation are the situation of the southern boundary of the Intertropical Convergence Zone and the upwelling system off the west coast of Namibia which has some unusual distinguishing patterns (Tyson *et al.*, 2003). It consists of a number of distinct upwelling cells. A sudden collapse of the Angola-Benguela front (ABF) allows a flow of warm water along the coast to cause the Benguela Niños and may cause precipitation in the northern Namib Desert (see Shannon *et al.*, 1986; Krapf *et al.*, 2003).

There is no record of Holocene temperature changes from Namibia. Alkenone-derived SSTs show a decline in temperatures ca. 1000 years ago near the Kunene mouth (Dupont *et al.*, 2004).

Although there have certainly been wetter and drier phases, Namibia's climate has been rather similar to what it is today for the Holocene (Fig. 2). Proxy records for early Holocene precipitation changes stem from cave speleothem, spring tufas and deposits of shelters documenting more humidity roughly between 12 and 8 ^{14}C-ka BP. On the other hand, dune mobilization occurred in the western and southwestern Kalahari. Grain size analyses of lunette dunes show higher wind velocities during a phase around 8 ka BP (Heine, 1995). Some fluctuations in humidity are dated between 5 and 3 ^{14}C-ka BP (only in southern Namibia?). For the last ca. 500 years, more aridity has been observed in the central Namib Desert and adjacent areas. Lunette dunes are less climatically discriminating than linear dunes in terms of the conditions which lead to their development (Lawson & Thomas, 2002).

Slackwater deposits and floodouts cannot be used as palaeoclimatic archives; yet, they document flash-flood conditions caused by extreme precipitation events in the early Holocene and during the last 1000 years, with a concentration of floods in northern Namibia during the Little Ice Age.

The terrestrial proxy climate signatures from the Namibian mainland do not present any information about temperature fluctuations during the Holocene. Only from marine archives a SST decline of >1°C off northwest Namibia is reported.

The proxy data of the palaeoenvironmental archives are extremely heterogeneous and show that the environments react with different sensibility to weak climatic fluctuations (see also Cohen & Tyson, 1995).

The period of the Little Ice Age seems to be an exceptional case. Only during the Little Ice Age apparently more frequent and heavier precipitation events occurred, which produced bigger flash-floods than today in the northern

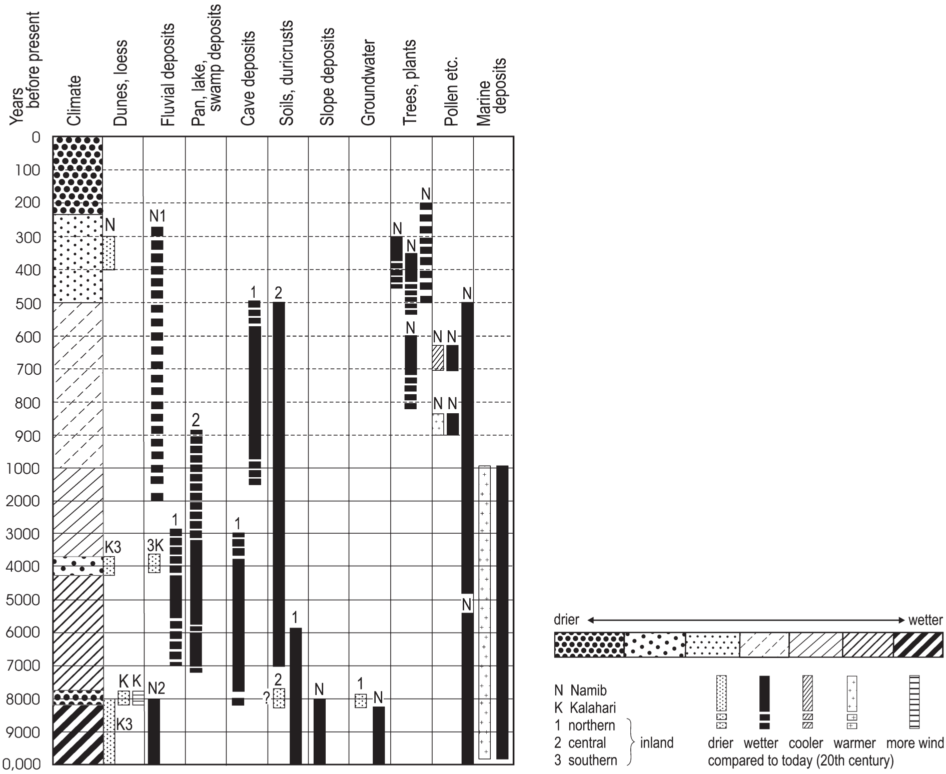

Fig. 2. Summary of dated evidence from different geoarchives for periods of increased and decreased moisture, phases with intensification of wind velocity, lowering of ground water table, soil formation phases etc. in Namibia.

Namib valleys. It should be emphasised that climatic phases during which in Namibia slackwater deposits and floodouts were accumulated experienced a cooler and drier than normal climate in southern Africa (Heine, 2004a). These floods presumably were caused by small shifts of the Tropical Temperate Troughs (TTTs) over southern Africa and in the southwestern Indian Ocean corresponding to periods of reduced solar activity (Heine, 2004a). Recent studies of solar variability (Solanki *et al.*, 2004) and Holocene climate (Kromer *et. al.*, 2004) call for a re-evaluation of the influence of solar activity variations on climate (Foukal *et al.*, 2004; von Storch *et al.*, 2004).

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REFERENCES

Albrecht, M., H. Berke, B. Eichhorn, T. Frank, R. Kuper, S. Prill, R. Vogelsang & S. Wenzel 2001. Oruwanje 95/1: a late Holocene stratigraphy in northwestern Namibia. *Cimbebasia*, 17: 1-22.

Avery, D.M. 1993. Last Interglacial and Holocene altithermal environments in South Africa and Namibia: micromammalian evidence. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 101: 221-228.

Baker, V.R. 1987. Palaeoflood hydrology and extraordinary flood events. *Journal of Hydrology*, 96: 79-99.

——— 2003. Palaeofloods and Extended Discharge Records. In (K.J. Gregory & G. Benito, *eds*.) *Palaeohydrology, Understanding Global Change*, pp. 307-323. Wiley, Chichester.

Bateman, M.D., D.S.G. Thomas & A.K. Singhvi 2003. Extending the aridity record of the Southwest Kalahari: current problems and future perspectives. *Quaternary International*, 111: 37-49.

Blümel, W.D. 1979. Zur Struktur, Reliefgebundenheit und Genese südwestafrikanischer und südostspanischer Kalkkrusten. *Zeitschrift für Geomorphologie, N.F. Supplement Band*, 33: 154-167.

——— 1981. Pedologische und geomorphologische Aspekte der Kalkkrustenbildung in Südwestafrika und Südostspanien. *Karlsruher Geographische Hefte*, 10: 1-128.

Blümel, W.D., B. Eitel & A. Lang 1998. Dunes in southeastern Namibia: evidence for Holocene environmental changes in the southwestern Kalahari based on thermoluminescence data. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 138: 139-149.

Blümel, W.D., K. Hüser & B. Eitel 2000. Landschaftsveränderungen in der Namib. *Geographische Rundschau*, 52(9): 17-23.

Brain, C.K. & V. Brain 1977. Microfaunal remains from Mirabib: some evidence of palaeoecological changes in the Namib. *Madoqua*, 10: 285-293.

Brook, G.A., E. Marais & J.B. Cowart 1999. Evidence of wetter and drier conditions in Namibia from tufas and submerged speleothems. *Cimbebasia*, 15: 29-39.

Brunotte, E. & H. Sander 2000. Loess accumulation and soil formation in Kaokoland (Northern Namibia) as indicators of Quaternary climatic change. *Global and Planetary Change*, 26: 67-75.

Buch, M.W., D. Rose & L. Zöller 1992. A TL-calibrated pedostratigraphy of the western lunette dunes of Etosha Pan/northern Namibia: Palaeoenvironmental implications for the last 140 ka. *Palaeoecology of Africa*, 23: 129-147.

Cohen, A.L. & P.D. Tyson 1995. Sea-surface temperature fluctuations during the Holocene off the south coast of Africa: implications for terrestrial climate and rainfall. *The Holocene*, 5: 304-312.

Diester-Haass, L., K. Heine, P. Rothe & H. Schrader 1988. Late Quaternary history of continental climate and the Benguela Current off South West Africa. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 65: 81-91.

Dupont, L.M., J.-H. Kim, R.R. Schneider & N. Shi 2004. Southwest African climate independent of Atlantic sea surface temperatures during the Younger Dryas. *Quaternary Research*, 61: 318-324.

Eckardt, F., N. Drake, A.S. Goudie, K.White & H. Viles 2001. The role of playas in pedogenic gypsum crust formation in the central Namib Desert: a theoretical model. *Earth Surface*

Processes and Landforms, 26: 1177-1193.
Eitel, B. 1994. Kalkreiche Decksedimente und Kalkkrustengenerationen in Namibia: Zur Frage der Herkunft und Mobilisierung des Calciumcarbonats. *Stuttgarter Geographische Studien*, 123: 1-193.
Eitel, B. & W.-D. Blümel 1998. Pans and dunes in the southwestern Kalahari (Namibia): Geomorphology and evidence for Quaternary paleoclimates. *Zeitschrift für Geomorphologie, N.F. Supplement Band*, 111: 73-95.
Eitel, B., W.D. Blümel, K. Hüser & B. Mauz 2001. Dust and loessic alluvial deposits in Northwestern Namibia (Damaraland, Kaokoveld): sedimentology and palaeoclimatic evidence based on luminescence data. *Quaternary International*, 76/77: 57-65.
Eitel, B., W.D. Blümel & K. Hüser 2002. Environmental transitions between 22 ka and 8 ka in monsoonally influenced Namibia – A preliminary chronology. *Zeitschrift für Geomorphologie, N.F. Supplement Band*, 126: 31-57.
Eitel, B., J. Eberle & R. Kuhn 2002. Holocene environmental change in the Otjiwarongo thornbush savanna (Northern Namibia): evidence from soils and sediments. *Catena*, 47: 43-62.
Eitel, B., A. Kadereit, W.D. Blümel, K. Hüser & B. Kromer 2005. The Amspoort Silts, northern Namib desert (Namibia): formation, age and palaeoclimatic evidence of river-end deposits. *Geomorphology*, 64: 299-314.
Eitel, B. & L. Zöller 1996. Soils and sediments in the basin of Dieprivier-Uitskot (Khorixas District, Namibia): Age, geomorphic and sedimentological investigation, paleoclimatic interpretation. *Palaeoecology of Africa*, 24: 159-172.
Fisher, D.A. & R.M. Koerner 2003. Holocene ice-core climate history – a multi-variable approach. In (A. Mackay, R. Batterby, J. Birks & F. Oldfield, *eds*.) *Global Change in the Holocene*, pp. 281-293. Arnold, London.
Foukal, P., G. North & T. Wigley 2004. A Stellar View on Solar Variations and Climate. *Science*, 306: 68-69.
Gerstengarbe, F.-W. & P.C. Werner 2004. Klimaentwicklung im südlichen Afrika. *Geographische Rundschau*, 56: 18-24.
Hadley Centre 2001. *Hadley Centre regional climate modelling system*. Meteorological Office, London.
Heine, K. 1981. Aride und pluviale Bedingungen während der letzten Kaltzeit in der Südwest-Kalahari (südliches Afrika). *Zeitschrift für Geomorphologie, N.F. Supplement Band*, 38: 1-37.
——— 1982. The main stages of the late Quaternary evolution of the Kalahari region, southern Africa. *Palaeoecology of Africa*, 15: 53-76.
——— 1990. Some observations concerning the age of the dunes in the western Kalahari and palaeoclimatic implications. *Palaeoecology of Africa*, 21: 161-178.
——— 1992. On the ages of humid Late Quaternary phases in southern African arid areas. *Palaeoecology of Africa*, 23:149-164.
——— 1995. Paläoklimatische Informationen aus südwestafrikanischen Böden und Oberflächenformen: Methodische Überlegungen. *Geomethodica*, 20: 27-74.
——— 1998a. Klimawandel und Desertifikation im südlichen Afrika – ein Blick in die Zukunft. *Geographische Rundschau*, 50: 245-250.
——— 1998b. Late Quaternary climate changes in the Central Namib Desert, Namibia. In (A.S. Alsharhan, K.W. Glennie, G.L. Whittle & C.G.St.C. Kendall, eds.) *Quaternary Deserts and Climatic Change*, pp. 293-304, Balkema, Rotterdam.
——— 1998c. Climate change over the past 135,000 years in the Namib Desert (Namibia) derived from proxy data. *Palaeoecology of Africa*, 25: 171-198.
——— 2002. Sahara and Namib/Kalahari during the late Quaternary – inter-hemispheric

contrasts and comparisons. *Zeitschrift für Geomorphologie, Suppl.-Band*, 126: 1-29.
——— 2004a. Flood reconstructions in the Namib Desert, Namibia and Little Ice Age Climatic Implications: Evidence from Slackwater Deposits and Desert Soil Sequences. *Journal Geological Society of India*, 64: 535-547.
——— 2004b. Little Ice Age climatic fluctuations in the Namib Desert, Namibia, and adjacent areas: evidence of exceptionally large floods from slack water deposits and desert soil sequences. In (W. Smykatz-Kloss & P. Felix-Henningsen, *eds*.) *Palaeoecology of Quaternary Drylands, Lecture Notes of Earth Sciences*, 102: 137-165, Springer, Berlin — Heidelberg.
Heine, K. & M.A. Geyh 1984. Radiocarbon dating of speleothems from the Rössing Cave, Namib Desert, and palaeoclimatic implications. In (J.C. Vogel, ed.) *Late Cainozoic Palaeoclimates of the Southern Hemisphere*, pp. 465-470. Balkema, Rotterdam.
Heine, K. & R. Walter 1996. Die Gipskrustenböden der zentralen Namib (Namibia) und ihr paläoklimatischer Aussagewert. *Petermanns Geographische Mitteilungen*, 140: 237-253.
Hulme, M. 1996. *Climate Change in Southern Africa: an exploration of some potential impacts and implications in the SADC regio*n. Climatic Research Unit, University of East Anglia, Norwich, UK, and WWF International, Gland, Switzerland.
Hüser, K., W.D. Blümel & B. Eitel 1998. Geomorphologische Untersuchungen an Rivierterrassen im Mündungsbereich des Uniab (Skelettküste/NW-Namibia). *Zentralblatt für Geologie und Paläontologie, Teil I*, 1997 (1-2): 1-21.
Jacobson, P.J., K.M. Jacobson & M.K. Seely 1995. *Ephemeral Rivers and Their Catchments. Sustaining People and Development in Western Namibia*. Desert Research Foundation of Namibia (DRFN), Windhoek.
Jones, P.D., T.J. Osborn & K.R. Briffa 2001. The evolution of climate over the last millennium. *Science*, 292: 662-667.
Kirst,G.J., R.R. Schneider, P.J. Müller, I. von Storch & G. Wefer 1999. Late Quaternary Temperature Variability in the Benguela Current System Derived from Alkenones. *Quaternary Research*, 52: 92-103.
Krapf, C.B.E., H. Stollhofen & I.G. Stanistreet 2003. Contrasting styles of ephemeral river systems and their interaction with dunes of the Skeleton Coast erg (Namibia). *Quaternary International*, 104: 41-52.
Kromer, B., M. Claussen, N. Latuske, M. Lüken, M. Remmele & G. Schleser 2004. Solar Variability and Holocene Climate: Evidence from Radiocarbon, Tree-Ring Proxies and Climate System Modeling. *PAGES News*, 12(2): 13-15.
Lancaster, N. 1989. *The Namib Sand Sea. Dune forms, processes and sediments.* Balkema, Rotterdam.
——— 2002. How dry was dry? – Late Pleistocene palaeoclimates in the Namib Desert. *Quaternary Science Reviews*, 21: 769-782.
Lancaster, N. & J.T. Teller 1988. Interdune deposits of the Namib Sand Sea. *Sedimentary Geology*, 55: 91-107.
Lawson, M.P. & D.S.G. Thomas 2002. Late Quaternary lunette dune sedimentation in the southwestern Kalahari desert, South Africa: luminescence based chronologies of aeolian activity. *Quaternary Science Reviews*, 21: 825-836.
Lee-Thorp, J.A. & P.B. Beaumont 1995. Vegetation and Seasonality Shifts during the Late Qauternary Deduced from $^{13}C/^{12}C$ Ratios of Grazers at Equus Cave, South Africa. *Quaternary Research*, 43: 426-432.
Lindesay, J.A. & P.D. Tyson 1990. Climate and Near-surface Airflow Over the Central Namib. In (M.K. Seely, *ed.*) *Namib ecology: 25 years of Namib research*: 27-37, Transvaal Museum Monograph No. 7, Transvaal Museum, Pretoria.
Martin, H. 1950. Südwestafrika. *Geologische Rundschau*, 38: 6-14.

Mees, F. 1999. Distribution patterns of gypsum and kalistronite in a dry lake basin of the southwestern Kalahari (Omongwa Pan, Namibia). *Earth Surfaces and Landforms*, 24: 731-744.

——— The nature of calcareous deposits along pan margins in eastern central Namibia. *Earth Surface Processes and Landforms*, 27: 719-735.

Mendelsohn, J., A.Jarvis, C. Roberts & T. Robertson 2002. *Atlas of Namibia. A Portrait of the Land and its People.* Ministry of Environment and Tourism, Windhoek, D. Philip Publishers, Cape Town.

Mizuno, K. & K. Yamagata 2003. Vegetational Succession and Plant Utilization in Relation to Environ mental Change along the Kuiseb River in the Namib Desert. *Title in Japanese*, 35-50.

Oeschger, H. 2000. Perspectives on Global Change Science: isotopes in the Earth System, past and present. In (K. Alverson, F. Oldfield & R.S. Bradley, *eds*.) *Past global changes and their significance for the future, Quaternary Science Reviews* 19: 37-44.

Oldfield, F. 2003. Introduction: The Holocene, a special time. In (A. Mackay, R. Batterby, J. Birks & F. Oldfield, *eds*.) *Global Change in the Holocene*, pp. 1-9. Arnold, London.

Richter, J. 1991. Studien zur Urgeschichte Namibias. Holozäne Stratigraphien im Umkreis des Brandbergs. *Africa Praehistorica*, 3: 1-345.

Rimbu, N., G. Lohmann, S.J. Lorenz & J.H. Kim 2004. Holocene climate variability as derived from alkenone sea surface temperature and coupled ocean-atmosphere model experiments. *Climate Dynamics*, 23: 215-227.

Saint-Laurent, D. 2004. Palaeoflood hydrology: an emerging science. *Progress in Physical Geography*, 28(4): 531-543.

Sandelowski, B.H. 1977. Mirabib: an archaeological study in the Namib. *Madoqua*, 10: 221-283.

Scheidegger, A.E. 1991. *Theoretical Geomorphology*. Springer, Berlin etc.

Scott, L. 1996. Palynology of hyrax middens: 2000 years of palaeo-environmental history in Namibia. *Quaternary International*, 33: 73-79.

Scott, L., B. Cooremans, J.S. de Wet & J.C. Vogel 1991. Holocene environmental changes in Namibia inferred from pollen analysis of swamp and lake deposits. *The Holocene*, 1: 8-13.

Scott, L., E. Marais & G.A. Brook 2004. Fossil hyrax dung and evidence of Late Pleistocene and Holocene vegetation types in the Namib Desert. *Journal of Quaternary Science*, 19: 829-832.

Shannon, L.V., A.J. Boyd, G.B. Brundrit & J. Taunton-Clark 1986. On the existence of an El Nino-type phenomenon in the Benguela System. *Journal of Marine Research*, 44: 295-520.

Shi, N., L.M. Dupont, H.-J. Beug & R. Schneider 1998. Vegetation and climate changes during the last 21,000 years in SW Africa based on a marine pollen record. *Vegetation History and Archaeobotany*, 7: 127-140.

Shi, N., L.M. Dupont, H.-J. Beug & R. Schneider 2000. Correlation between vegetation in southwestern Africa and oceanic upwelling in the past 21,000 years. *Quaternary Research*, 54: 72-80.

Solanki, S.K., I.G. Usoskin, B. Kromer, M. Schüssler & J. Beer 2004. Unusual activity of the Sun during recent decades compared to the previous 11,000 years. *Nature*, 431: 1084-1087.

Stokes, S., D.S.G. Thomas & R. Washington 1997a. Multiple episodes of aridity in southern Africa since the Last Interglacial Period. *Nature,* 388: 154-158.

Stokes, S., D.S.G. Thomas & P.A. Shaw 1997b. New chronological evidence for the nature and timing of linear dune development in the Southwest Kalahari Desert. *Geomorpholo-*

gy, 20: 81-93.

Street-Perrott, F.A. & R.A. Perrott 1993. Holocene Vegetation, Lake Levels, and Climate of Africa. In (H.E. Wright,Jr., J.E. Kutzbach, T. Webb III, W.F. Ruddiman, F.A. Street-Perrott & P.J. Bartlein, *eds*.) *Global Climates since the LGM*, pp. 318-356. University of Minnesota Press, Minneapolis.

Stute, M. & A.S. Talma 1998. Glacial temperatures and moisture transport regimes reconstructed from noble gas and $\delta^{18}O$, Stampriet aquifer, Namibia. In (IAEA, ed.) *Isotope techniques in the Study of Environmental Change, Proceedings of the Symposium of the International Atomic Energy Agency, Vienna*, pp. 307-328, International Atomic Energy Agency, Wien.

Teller, J.T., N. Rutter & N. Lancaster 1990. Sedimentology and paleohydrology of late Quaternary lake deposits in the northern Namib Sand Sea, Namibia. *Quaternary Science Reviews*, 9: 343-364.

Thomas, D.S.G. & P.A. Shaw 2002. Late Quaternary environmental change in central southern Africa: new data, synthesis, issues and prospects. *Quaternary Science Reviews*, 21: 783-797.

Thomas, D.S.G., S. Stokes & P.A. Shaw 1997. Holocene aeolian activity in the southwestern Kalahari Desert, southern Africa: Significance and relationships to Late-Pleistocene dune-building events. *The Holocene*, 7: 271-279.

Thomas, D.S.G., S. Stokes & P.W. O'Connor 1998. Late Quaternary aridity in the southwestern Kalahari Desert: New contributions from OSL dating of aeolian deposits, northern Cape Province, South Africa. In (A. Alsharhan, K.W. Glennie, G.L. Winttle & C.G.St.C. Kendall, *eds*.) *Quaternary Deserts and Climate Change*, pp. 213-224. Balkema, Rotterdam.

Tyson, P., E. Odada, R. Schulze & C. Vogel 2003. Regional-Global Change Linkages: Southern Africa. In (P. Tyson, R. Fuchs, C. Fu, L. Lebel, A.P. Mitra, E. Odada, J. Perry, W. Steffen & H. Virji, *eds*.) *Global-Regional Linkages in the Earth System*, pp. 3-73. Springer, Berlin.

Van Zinderen Bakker, E.M. & M. Müller 1987. Pollen Studies in the Namib Desert. *Pollen and Spores*, 29: 185-206.

Vogel, J.C. 1989. Evidence of past climatic change in the Namib Desert. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 70: 355-366.

——— 2003. The age of dead trees at Sossusvlei and Tsondabvlei, Namib Desert, Namibia. *Cimbebasia*, 18: 247-251.

Vogel, J.C. & U. Rust 1987. Environmental changes in the Kaokoland Namib Desert during the present millennium. *Madoqua*, 15: 5-16.

Vogel, J.C. & U. Rust 1990. Ein in der Kleinen Eiszeit (Little Ice Age) begrabener Wald in der nördlichen Namib. — *Berliner Geographische Studien*, 30: 15-34.

Völkel, J. 1995. Periglaziale Deckschichten und Böden im Bayerischen Wald und seinen Randgebieten als geogene Grundlagen landschaftsökologischer Forschung im Bereich naturnaher Waldstandorte. *Zeitschrift für Geomorphologie, Supplement-Band*, 96: 1-301.

Von Storch, H., E. Zorita, J.M. Jones, Y. Dimitriev, F. González-Rouco & S.F.B. Tett 2004. Reconstructing Past Climate from Noisy Data. *Science*, 306: 679-682.

Ward, J.D. 1987. The Cenozoic succession in the Kuiseb Valley, central Namib Desert. *Geological Survey of South West Africa, Memoir* 9: 1-124.

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