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,

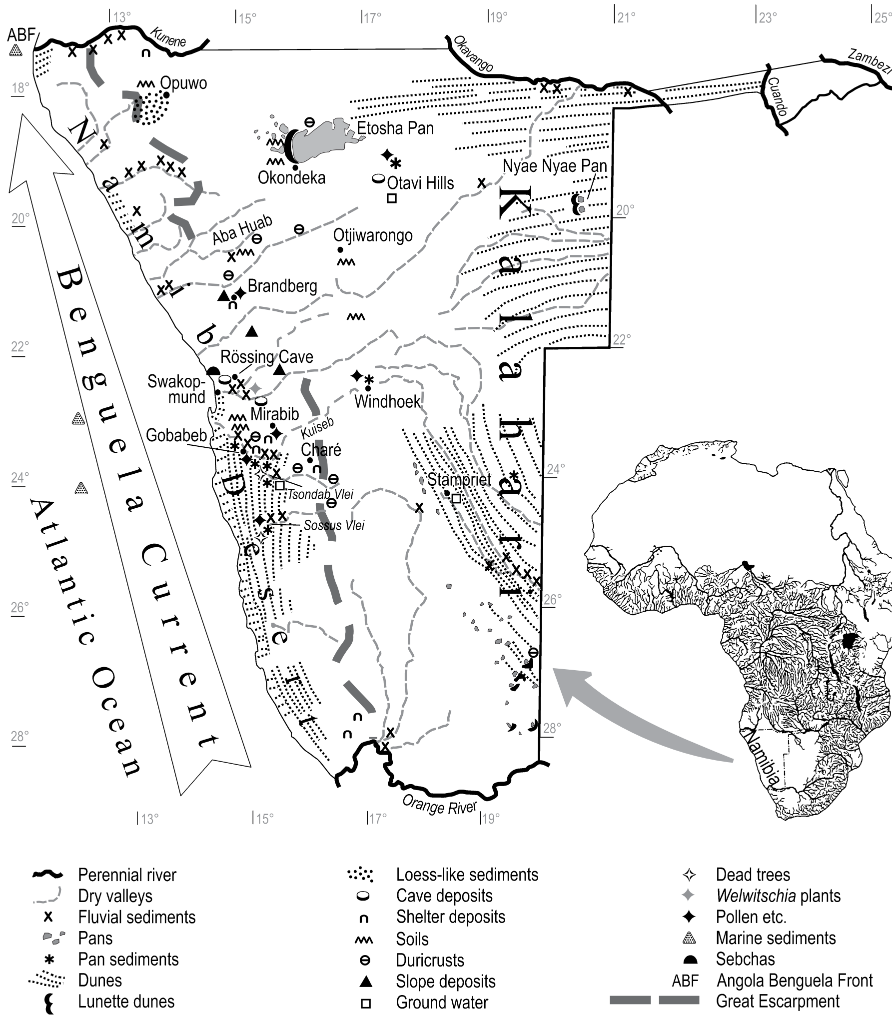

Fig. 1. Location map and localities of georarchives in Namibia and pattern of perennial rivers in Africa (inset map).

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

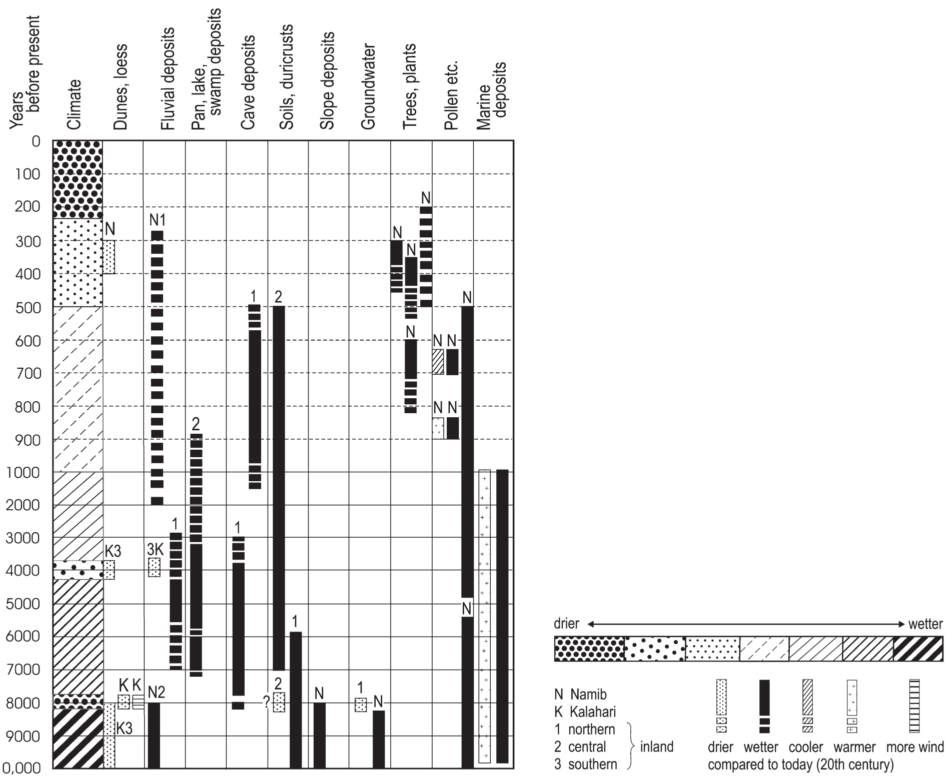

Fig. 2. Summary of dated evidence from different geoarchives for periods of increased and decreased moisture, phases with intensification of wind velocity, lowering of ground water table, soil formation phases etc. in Namibia.

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).

ACKNOWLEDGEMENTS I am grateful to K. Mizuno (University of Kyoto, Japan) who invited me for palaeoecological research in Namibia (Project No. 13371013, Ministry of Education, Science, Sports and Culture, Japanese Government), to the Ministry of Environment and Tourism (MET) of Namibia for providing research permits, and to the Desert Research Foundation of Namibia (DRFN, J. Henschel) for the cooperation. I thank the DEUTSCHE FORSCHUNGSGEMEINSCHAFT (DFG) for continuous financial

support for research in southern Africa.

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——— Accepted *January 22, 2005*

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