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LANDFORM DEVELOPMENT ALONG THE MIDDLE COURSE OF THE KUISEB RIVER IN THE NAMIB DESERT, NAMIBIA

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ABSTRACT The hyperarid to arid Namib Desert extends along the west coast of southern Africa. The Kuiseb River is one of the major ephemeral rivers originating in the interior highland, and crosses the Namib Desert. Fluvial terraces are well developed along the middle reaches of the Kuiseb River near Gobabeb, and are classified into four surfaces: upper (H), middle 1 (M1), middle 2 (M2), and lower (L). Layers of calcrete are founded on the M1 and M2 surfaces, and gypcrete layers are founded on the H surface. Dead tree matter, buried by dune sand on the L surface, dates to 300±60 years BP and 550±50 years BP. The calcareous crusts on the M1 surface date to 5,300±60 years BP and 6,450±50 years BP, and those of the M2 surface date to 22,070±260 years BP. The presence of calcrete suggests that the ground water level was higher when the M1 and M2 surfaces were formed than it is at the present time. Tree size distribution on the L surface demonstrates that the L surface was also formed during a relatively wet period. It may be concluded, therefore, that these fluvial terraces record the humid periods of ca 22 ka, 5–6.5 ka, and 300–600 years BP in the catchment area of the Kuiseb River. The presence of a water-soluble gypsum crust on the H surface suggests that the paleohydrologic environment of these terrace-forming periods probably involved increased rainfall in the interior highland east of the desert.

Key Words: Namib Desert; Kuiseb River; Ephemeral River; Fluvial Terrace; Calcrete, Dendrochronology; Paleohydrology.

INTRODUCTION

The Namib Desert stretches along the Atlantic coast of southern Africa, measuring about 1,400 km in length and varying between 40 and 120 km in width. The Namib Desert is one of the driest deserts in the world. The cold Benguela current that flows northward along the coast of Namibia strongly influences the extremely dry climate of the Namib Desert. The whole area of the Namib Desert receives less than 200 mm precipitation per year.

Previous studies have shown that marked environmental changes occurred in the African continent during the Quaternary age. However, current understanding of paleoenvironmental change in southern Africa remains insufficient, and the area understudied, as compared to parts of northern Africa centered on the Sahara Desert. Paleoenvironment evidence in dry regions is rarely well-preserved.

Ephemeral rivers are the areas of particular interest in which the paleoenvironmental record of the desert has been well preserved. The fluvial sequences in the Namib Desert indicate alternating periods of aggradation and degradation throughout the Quaternary (Heine, 1998; Lancaster, 2002). Late Pleistocene and Holocene fluvial deposits indicate periods of fluvial aggradations at approximately 19–23 ka, 10–12 ka, 3–5 ka, 0.9–1.2 ka BP, and 300 years ago (Lancaster, 2002).

The Kuiseb River is the most thoroughly studied river in the Namib Desert. The deposits and terraces of the Kuiseb River have been studied by a series of researchers (Rust & Wieneke, 1974, 1980; Marker, 1977; Marker & Muller, 1978; Vogel, 1982; Ward, 1987; Heine, 1985). The Homeb Silt deposit, which has been interpreted as a slack water deposit (Heine & Heine, 2002), occurs in the Kuiseb Valley upstream of Gobabeb. Radiocarbon dates from the Homeb Silt range between 23 and 19 ka BP. The Gobabeb Gravel deposits overlying the Homeb Silt date to 9.6 ka BP, indicating a period of Holocene aggradation (Vogel, 1982). The depositional environment and origin of these deposits have been discussed elsewhere, it remains unclear, however, whether such aggradations indicate a humid period or a dry period.

The aim of this study was to investigate the paleohydrological environmental history of the Kuiseb River. The landforms of the middle course of the Kuiseb River at Gobabeb are classified, and the soil profiles of each geomorphic surface are used to estimate the paleoenvironmental conditions. The ages of fluvial terraces are dated, using radiocarbon dating and dendrochronology.

Desertification has become the most important environmental problem facing Namibia. The descent of the groundwater level and the accompanying decline of riparian vegetation along the Kuiseb River have been reported in recent years (Mizuno & Yamagata, 2003). The processes of the area's paleoenvironmental changes should be very helpful in evaluating the present environmental problem.

RESEARCH AREA

The Kuiseb River is one of the major rivers rising in the interior highland and crossing the Namib Desert (Fig. 1). It is an ephemeral river, flowing only after sufficient rain has fallen in the catchment area. This river marks the border between the sand desert to the south and the rock desert to the north, as the temporal floods tend to wash out the dune sand advancing from the south (Fig. 2 & 3). The underflow water of the Kuiseb River creates a narrow oasis along the river. Due to these conditions, several types of environments adjoin the narrow riverside area.

Most previous studies have investigated the Kuiseb Canyon in the upper river basin. This study investigates the area around Gobabeb, along the middle reach of the Kuiseb River, about 60 km inland from the Atlantic coast. The study area lies at the mouth of the canyon, where the fluvial terraces and present flood plain are well developed (Fig. 2 & 3). Under these geomorphic conditions, the riparian forest should be strongly affected by the fluctuation of the

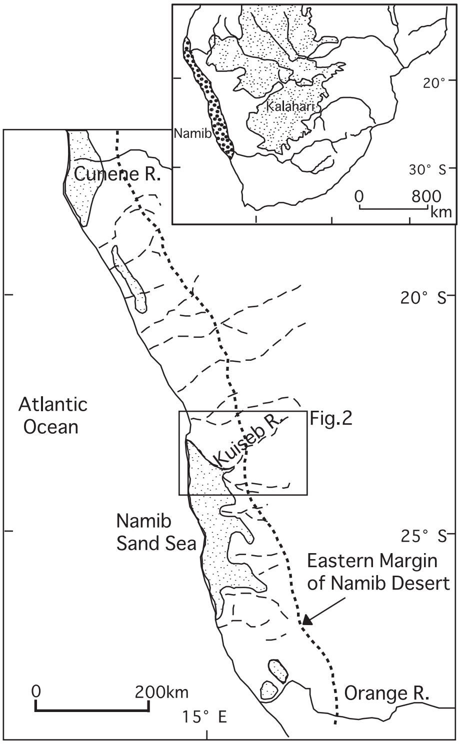

Fig. 1. The Namib Desert, showing major drainages, dune areas (dotted area), and location of study area (quadrangle area). Shaded area of Kalahari in the inserted map shows the distribution of the Kalahari Sand. (adapted from Thomas and Show, 1991)

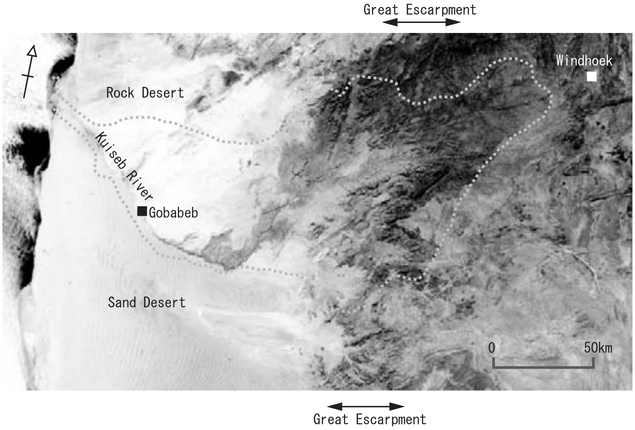

Fig. 2. CORONA satellite photograph of the Kuiseb River marking the boundary between sand desert and rock desert. (Imagery supplied by USGS; 1963/08/29)

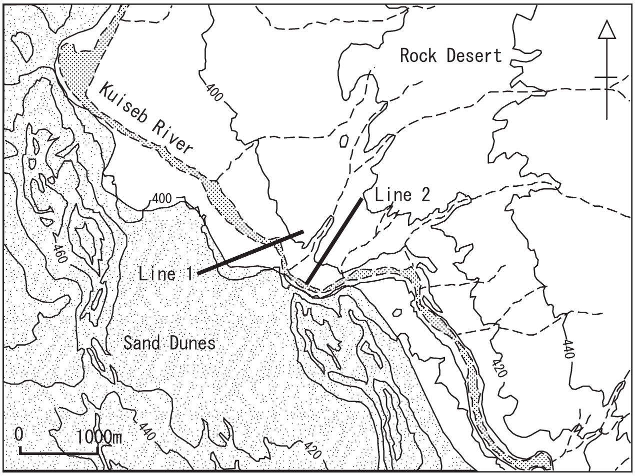

Fig. 3. Topographic map of the study area. Lines indicated are survey lines.

ground water level, making the locality particularly suitable for studying landform development and environmental change.

TERRACE SURFACE AND DEPOSITS

Two survey lines were set across the Kuiseb River valley, from which two topographic profiles were drawn. Similarly, soil profiles along the survey lines were observed at points along each geomorphic surface.

The topographic profile of line 1 is illustrated in Fig. 4. The three terraces are classified as Lower (L), Middle 1 (M1), and Higher (H). Although this region receives only 27 mm of annual precipitation, the underflow water of the Kuiseb River nurtures a riparian forest that is developed primarily on the present floodplain and L surface. In contrast, there is almost no vegetation on the M1 and H surfaces. Small sand dunes are formed on the boundary between the terrace L and M1 surfaces, while large-scale linear sand dunes develop on the H surface. Because river-borne gravel deposits are recognized on the H surface, this surface is considered to be a fluvial surface.

On the other hand four terraces are recognized in the topographic profile of line 2 (Fig. 4). Of those terraces, three correlate with the L, M1, and H surfaces, based on the relative height of the terraces from the present riverbed, and on the characteristics of the soil profiles. With the new classification of the Middle 2 (M2) surface, a total of four terrace surfaces are identified in the study area, of which three (L, M1 & M2) develop only around this region. The H surface appears to continue through to the Great Escarpment and on to the Atlantic coast.

The columnar sections of surficial deposits on each terrace are shown in figure 5. Deposits on the L, M1, and M2 surfaces are mainly composed of

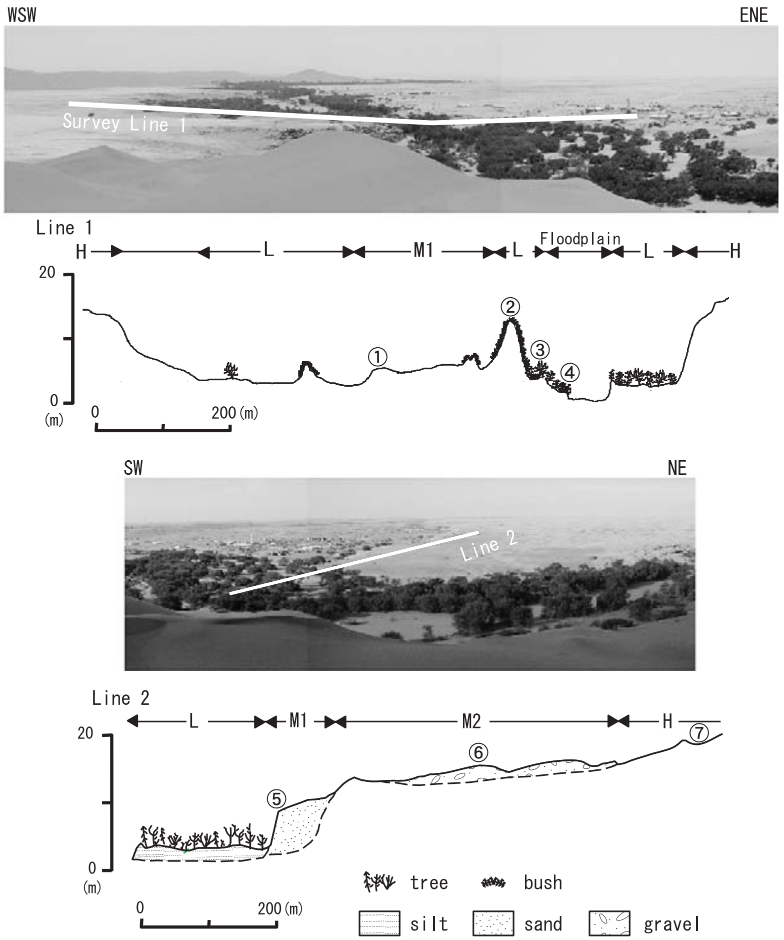

Fig. 4. Panorama views of the study area with the survey line and topographic profiles along the survey lines showing the distribution of the vegetation and locality of geological sections.

sandy deposits, and include stratified silt layers in some places. On the M2 surface, a gravel layer containing pebbles of about 2–4 cm in diameter occurs at the top of the deposit (Fig. 5–6). The most part of the H surface is exposed rock, but as some partial gravel deposits are recognized here, it is confirmed as a fluvial surface.

The difference in height between the present floodplain and the L surface is less than 1 m, but thick litter deposits are recognizable only on the L surface (Fig. 5). This supports the conclusion that the L surface is older than the present floodplain.

Duricrusts have clearly formed on the M1 and H surfaces, and are somewhat developed on the M2 surface. However, no duricrust is present on the L surface or the present floodplain. Figure 6 shows the duricrust on the M1 and H surfaces; the color and shape of the two duricrusts differ markedly from each

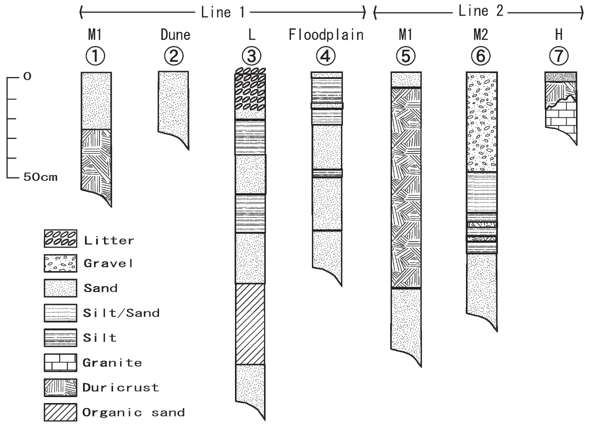

Fig. 5. Soil profile along survey line 1 (①–④) and line 2 (⑤–⑦). The localities are shown in Fig. 4.

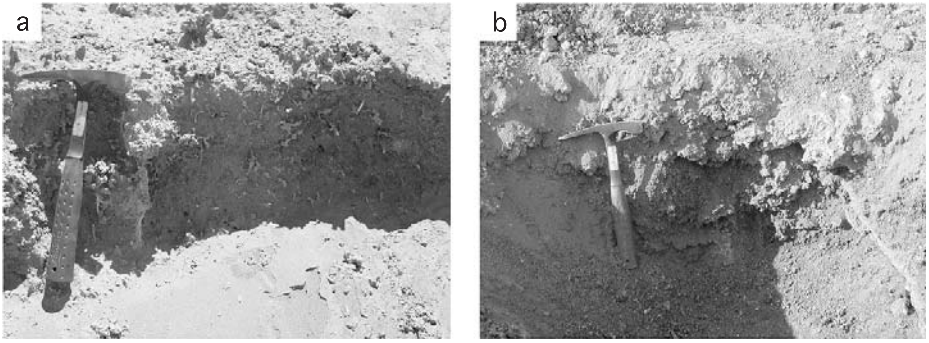

Fig. 6. Duricrust on the M1 and H surfaces.
(a) Duricrust on the M1 surface, (b) Duricrust on the H surface.

other.

In order to determine the mineral composition of duricrust, x-ray diffraction analysis was performed on the orientated samples of the clay fraction, which was separated from crushed samples by centrifuge. Figure 7 illustrates the x-ray diffraction patterns of the deposits. The diffraction patterns clearly show that the deposits on the M1 surface contain calcite, while the deposits on the H surface contain gypsum. The deposit on the M2 surface also contains a small amount of calcite. Therefore, the duricrust formed on the M1 surface is identified as calcrete, and the duricrust on the H surface is identified as gypcrete. The deposits on the present floodplain contain no calcite or gypsum, but do contain clay minerals such as illite and chlorite, derived from the process of rock weathering.

The absence of calcrete on the present riverbed suggests that the M1 and M2 surfaces were formed under different conditions from those that pertain to the present time. Calcrete formed near the surface by the accumulation of calcium

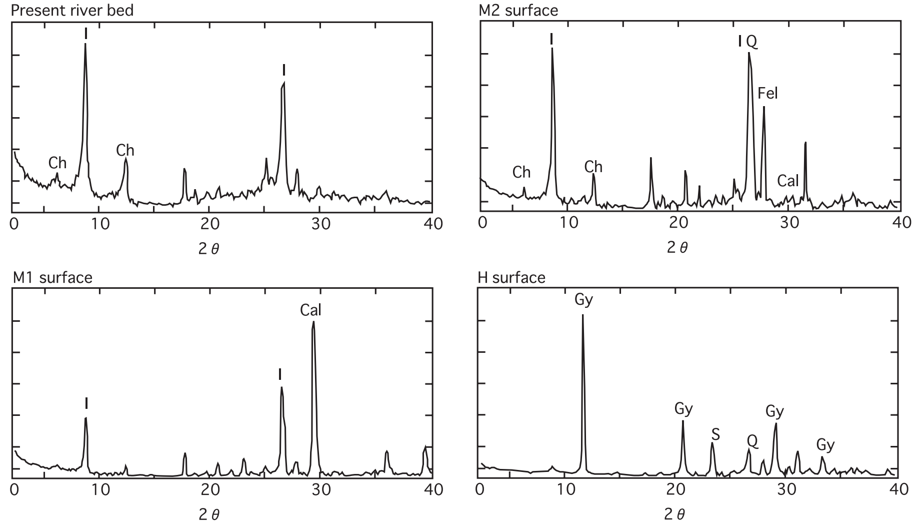

Fig. 7. X-ray diffraction pattern for terrace deposits.
Ch: Chlorite, I: Illite, Gy: Gypsum, S: Sulphate, Q: Quartz, Fel: Feldspar, Cal: Calcite.

carbonate, deposited by capillary rise and evaporation. Because water must be present in the soil to evaporate, the groundwater level was assumed to have been at a higher level than at present.

Although the M1 surface currently supports no vegetation, the calcrete on the M1 surface appears to have precipitated around the roots of plants (Fig. 6). This suggests that the M1 surface was originally covered with vegetation, which covered an area much larger than the present riparian forest.

AGES OF THE TERRACES

Calcrete contains carbonate, which allows the use of radiocarbon dating. However, this method may not yield an accurate date for the material owing to contamination of the sample by younger carbonate. On the other hand, this means that the radiocarbon dating of calcrete generally yields the youngest possible age. The calcrete formed on the fluvial terraces in the study area is thought to have formed within a short period of time. When the river floor terraced, the surfaces were separated from the underflow water of the Kuiseb River, causing calcrete formation to cease. The fact that the calcretes on the M1 and M2 surfaces formed weakly around the roots of plants supports the theory that they formed over a brief period of time (Fig. 6a). It is therefore concluded that the age of the calcrete yields the substantially accurate age of the terraces.

Radiocarbon dating of the calcrete was performed to determine the age of the terraces, and the ages obtained are shown in Table 1. Conventional radiocarbon ages of 5,300±60 years BP and 6,450±50 years BP were obtained for the

Table 1. Radiocarbon dates of samples (conventional ^{14}C age).

Surface	Material	^{14}C data (years BP)	Laboratory code number
L	Wood	300±60	Beta-165889
M1	Calcrete	5,300±60	Beta-164939
M1	Calcrete	6,450±50	Beta-176921
M2	Calcrete	22,070±260	Beta-176922

calcrete on the M1 surface, and an age of 22,070±260 years BP was obtained for the M2 deposit.

The dead trees buried by sand dunes on the L surface were dated to 300±60 years BP and 550±50 years BP. Samples for dating were taken from the surface of the tree trunk, and the age of the L surface was determined to be about 300 to 600 years old. Dendrochronological techniques were also used to fix the age of the L surface. Several large-diameter trees were cored, and their ages were calculated to range from about 300 to 600 years old.

The base diameter distribution of the trees on the L surface was measured (Fig. 8). Under ordinary circumstances, the distribution pattern should show that younger trees are more numerous. But the results indicate a marked deviation at a diameter of 20–30 cm (Fig. 8). In fact, young trees and seedlings are not evident in the forest, suggesting that the riparian forest formed during the past humid period of about 300–600 years ago, and that the forest has terminated the regeneration since the L surface terraced.

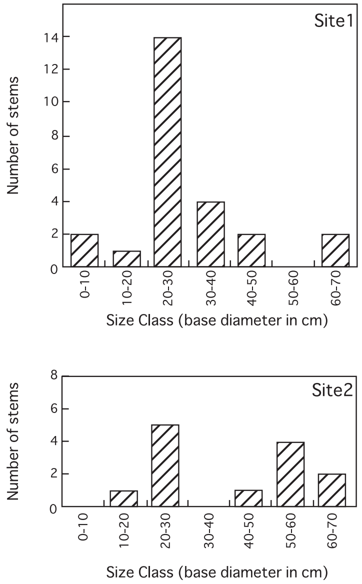

Fig. 8. Size distribution of riparian forest trees on the L surface.

PALEOENVIRONMENTAL AND PALEOHYDROLOGIC CHANGES IN THE MIDDLE COURSE OF THE KUISEB RIVER

Paleoenvironmental changes along the middle course of the Kuiseb River can be reconstructed on the aforementioned results as follows: The M2 surface formed ca. 22 ka of the last glacial maximum. This period was likely to have been more humid than the present, leading to a considerably higher rate of sediment generation, resulting in the formation of a relatively high depositional surface. A drier period probably followed this period, followed in turn by a more humid period at about 5–6.5 ka. The depositional surface (M1) formed in the valley and was covered by vegetation during this period. Simultaneously, the calcrete precipitated on the surface via the capillary rise of the shallow groundwater. During the subsequent drier period, this vegetation retreated. About six hundred years ago, the climate once again became more humid, and the present riparian forest was established. The most recent aridification began about 300 years ago, and led to the decline of the riparian forest and an increase in dune formation.

It is problematical whether this evidence indicates an increase in precipitation in the Namib Desert. The gypsum in the Namib Desert was probably formed by the deposition of atmospheric sulphate derived from the Atlantic Ocean (Eckardt & Spiro, 1999). The presence of a water-soluble gypsum crust on the H surface suggests that a significant increase in rainfall did not occur during the late Quaternary period. Therefore, the paleohydrologic environment of the terrace-forming periods probably involved increased rainfall in the interior highland east of the desert, rather than in the desert itself (Heine, 1998).

The previous chronology of the environmental change in southern Africa is shown in Fig. 9. The data from basin, lake, pan, and river in the inland Kalahari Desert record a humid period of 20–25 ka, during the last glacial age, a date that is in common with the records present in the Kuiseb River (Fig. 9-a). However, evidence of humid periods between 10–20 ka and around 40 ka does not appear in the Kuiseb River. Holocene environmental change has been examined in the Namib and Kalahari deserts, and within a marine core taken from off the coast of the Namib Desert (Fig. 9-b). The humid period of around 6 ka was recognized as a distinct humid event in the Kalahari Desert, but the humid period of 2 ka and 4 ka recorded in the Kalahari Desert is not evident at the Kuiseb River. In addition, evidence of humidification during the Little Ice Age has not been obtained from the Kalahari Desert. Therefore, it seems that there were some humid periods, identifiable not only in the Kalahari Desert, but also in the Namib Desert. This leads to the conclusion that the three humid periods identified in this study (ca. 22 ka, 5–6.5 ka, and 300–600 years BP)

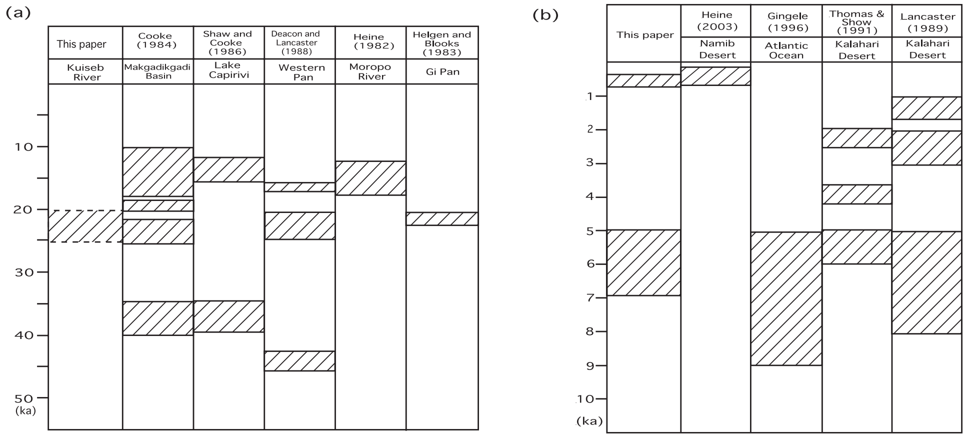

Fig. 9. Chronology of environmental change in southern Africa proposed by various authors.
(a): The humid period of the Last Glacial Age in the Namib and Kalahari Deserts, (b): The Holocene climatic change in southern Africa.

were intensive enough to influence the Namib Desert.

SUMMARY

1. The four terraces L, M1, M2, and H were classified in the vicinity of Gobabeb along the middle course of the Kuiseb River.
2. The ages of the terraces were estimated by radiocarbon dating of calcretes and dead trees on these surfaces, and through dendrochronological data of the riparian forest on the L surface as follows: L surface: 300–600 years BP; M1 surface: 5–6.5 ka M2 surface: ca. 22 ka.
3. The formation of calcrete on the M1 and M2 surfaces and the establishment of the riparian forest on the L surface suggest that the terrace-forming periods were more humid than at present.
4. The presence of water-soluble gypsum on the H surface demonstrates that humidification did not occur in the Namib Desert, but in inland along the upper stream of the Kuiseb River.

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REFERENCES

Cooke, H.J. 1984. The evidence from northern Botswana of climatic change. In (J. Vogel, *ed.*) *Late Cenozoic Palaeoclimates of the Southern Hemisphere,* pp. 265-278. Balkema, Rotterdam.

Deacon, J. & N. Lancaster 1988. *Late Quaternary Palaeoenvironments of Southern Africa*, Oxford Science Publications, New York.

Eckardt, F.D. & B. Spiro 1999. The origin of sulphur in gypsum and dissolved sulphate in the Central Namib Desert, Namibia. *Sedimentary Geology*, 123: 255-273.

Gingele, F.X. 1996. Holocene climatic optimum in Southwest Africa: evidence from the marine clay mineral record. *Palaeogeography*, *Palaeoclimatology*, *Palaeoecology*, 122: 77-87.

Heine, K. 1982. The main stages of late Quaternary evolution of the Kalahari region, southern Africa. *Palaeoecology of Africa*, 15: 53-76.

——— 1985. Late Quaternary development of the Kuiseb river valley and adjacent areas, central Namib Desert, South West Africa/Namibia, and palaeoclimatic implications. *Zeitschrift für Gletscherkunde und Glazialgeologie*, 21: 151-157.

——— 1987. Jungquartäre fluviale Geomorphodynamik in der Namib, *Süd-westafrika/ Namibia. Zeitschrift für Geomorphologie Supplmentband*, 66: 113-134.

——— 1998. Climate change over the past 135,000 years in the Namib Desert (Namibia) derived from proxy data. *Palaeoecology of Africa*, 25: 171-198.

——— 2003. 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 (Smykatz-Kloss, W. & P. Felix-Henningsen, *eds*.), *Palaeoecology of Quaternary Drylands*, (Lecture Notes of Earth Sciences, Band 102). pp. 137-165, Berlin - Heidelberg.

Heine, K. & J.T. Heine 2002. A paleohydrologic re-interpretation of the Homeb Silts, Kuiseb River, central Namib Desert (Namibia) and paleoclimatic implications. *Catena*, 48: 107-130.

Helgren, D.M. & A.S. Brooks 1983. Geoarchaeology at Gi, a middle stone age and later stone age site in the Northwest Kalahari. *Journal of Archaeological Science*, 10: 181-197.

Lancaster, N. 1989. *The Namib Sand Sea: Dune Forms, Process, and Sediments*. A. A. Balkema, Rotteldam.

——— 2002. How dry was dry? — Late Pleistocene palaeoclimates in the Namib Desert. *Quaternary Science Reviews*, 21: 762-782.

Marker, M.E., 1977. A long-return geomorphic event in the Namib Desert, South West Africa. *Area*, 9: 209-213.

Marker, M.E. & D. Muller 1978. Relict vlei silts of the Kuiseb River valley, South West Africa. *Madoqua* II, 2: 151-162.

Mizuno, K. & K. Yamagata 2003. Vegetational succession and plant utilization in relation to environmental change along the Kuiseb River in Namib Desert (in Japanese). *Asian and African Area Studies*, 3: 35-50.

Rust, U. & F. Wieneke 1974. Studies on gramadulla formation in the middle part of the Kuiseb River, South West Africa. *Madoqua*, 3: 5-15.

Rust, U. & F. Wieneke 1980. A reinvestigation of some aspects of the evolution of the Kuiseb River valley upstream of Gobabeb, South West Africa. *Madoqua*, 12: 163-173.

Shaw, P.A. & H.J. Cooke 1986. Geomorphic evidence for the late Quaternary palaeoclimates of the middle Kalahari of northern Botswana. *Catena*, 13: 349-359.

Thomas, D.S.G. & P.A. Shaw 1991. *The Kalahari Environment*. Cambridge University Press, Cambridge.

Vogel, J.C. 1982. The age of the Kuiseb River silt terrace at Homeb. *Palaeoecology of Africa*, 15: 211-216.

Ward, J.D. 1987. The Cenozoic succession in the Kuiseb Valley, Central Namib Desert. *Geological Survey of Namibia, Memoir,* 9: 124.

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