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Some observations concerning the age of the dunes in the western Kalahari and palaeoclimatic implications

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ABSTRACT

The forms and sediments described below represent fluvial as well as aeolian processes in the southwestern Kalahari during the Last Glacial Maximum (LGM). The phases of intensive dune formation appear to have been restricted to glacial periods. Only the youngest dune complexes could be dated (LGM and Holocene).

INTRODUCTION

Some of the most striking geomorphological evidence of late Quaternary climatic change in southern Africa is the presence of extensive systems of fixed sand dunes in areas where contemporary climates are not conductive to sand movement (Thomas 1984). This leads to two deductions regarding differences between the present climate of the western Kalahari and the climate at the time of dune formation: Firstly, in the area of fixed dunes the climate must have been drier than it is today to allow aeolian processes to operate, and secondly, winds may have been different from today in strength and prevailing direction during periods of aeolian activity (see Thomas 1984, Lancaster 1981).

In 1978 and in 1981 I first proposed several arid periods when aeolian processes may have operated. Lancaster (1981) proposes several arid periods while referring to dates published by myself, but without mentioning the source. More recently Lancaster (1987) put forward palaeoclimatic reconstructions which do not take into account my detailed description (Heine 1981) of the late Quaternary evolution of dunes, pans and valleys.

Dating periods of dune formation in the southwestern Kalahari adds to the information needed about late Quaternary climates of southern Africa in order to establish the Quaternary climatic history of the subcontinent.

The study area is situated between 18 and 24°S and 19 and 22°E (Fig. 1). This report deals with observations in the southwestern and western Kalahari.

The fieldwork comprised an analysis of the shape of dunes, pans as well as river valleys and their terraces, an analysis of sediments and soils including duricrusts, and the gathering of samples for further laboratory investigations. In the laboratory sedimentological investigations were carried out concerning grain size parameters, light and heavy minerals, clay minerals, soil texture (thin sections), palaeontological determinations of mollusca, radiocarbon age determinations etc. Moreover, the interpretation of satellite imagery and aerial photography yield further insight into dune morphology and dune dynamics.

RESULTS

Dune types

In any dunefield the interaction through time between synoptic wind-flow,

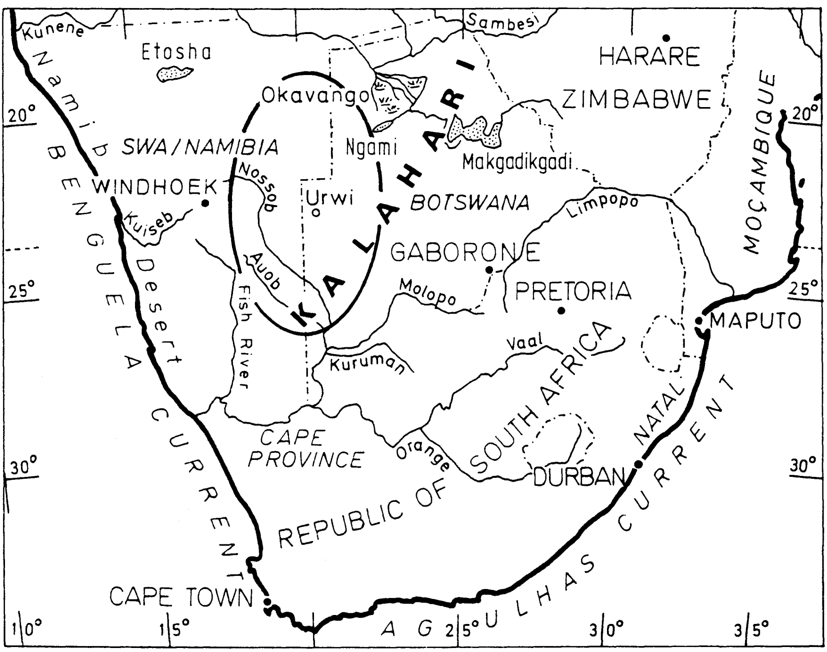

Figure 1. Southern Africa. Location of study area is shown by circle.

aerodynamic modifications over bedforms, sediment grain size, volume of sand in the dunefield, vegetation cover, and topography is likely to affect the size and distribution of bedforms (Thomas 1988a). Whilst identifiable relationships between these parameters are likely, they will evidently be more complex in the southwestern Kalahari, since the parameters have to be retraced to different stages of late Quaternary dune formation. Attempts to explain the patterns of the southwestern Kalahari dunes and the potential sand transport by modern winds (Lancaster 1980, Thomas 1988a, b, Fryberger 1979) must be rejected.

Most of the southwestern Kalahari is covered by dunes. The dunes can be distinguished into several types according to their patterns (Fig. 2): (A) reticulate, (B) parallel-dendritic, (C) dendritic to clustered dendritic, (D) clustered dendritic, (E) parallel, (F) sheets of reticulate and linguoid dunes, and (G) sand sheets, clustered dendritic. The distribution of the dune types in the southwestern Kalahari is shown in Figure 3.

In Namibia north of 25°S the dunes are of linear form. In the south there are areas of compound or dendritic linear dunes and also of sand sheets with clustered dendritic patterns. Reticulate dunes occur in the area of the Nossob and Auob confluence. Parabolic dunes and linguoid shaped forms are characteristic for densely vegetated areas in Botswana and between the Auob and Nossob River valleys. I have reported earlier on the geomorphological role of vegetation in the dune systems of the Kalahari (Heine 1981, see also Thomas 1988b).

Dune initiation occurred in various ways in the southwestern Kalahari (see also Lancaster 1988). Pans, valleys and pediments are source areas of sand. Reworking and mobilisation of interdune sediments is responsible for dune formation, too (Heine 1981, Lancaster 1988).

In the southwestern Kalahari an analysis of the relationship between dune forms on the one hand and palaeowind directions on the other hand suggests that the dune patterns were caused by two differing wind systems. In the north of the area investigated northwest and northerly winds are responsible for sand movement and dune formation whereas in the south the dune forms are due to west winds. A transition area with both wind directions can be reconstructed between 25°30'S and 29°S. Westwinds occur in connection with winter circulation patterns over Southern Africa; northwest winds are common under modern October conditions (Lancaster 1988), but also in drought years. In conclusion one can say that the crossing dune patterns are a product of infrequent, strong, north to northwest winds on the one hand and strong west winds on the other hand (Heine 1981, see also Wilkinson 1988).

Ages of the dunes

There is geomorphologic evidence that the linear dune systems are of differ-

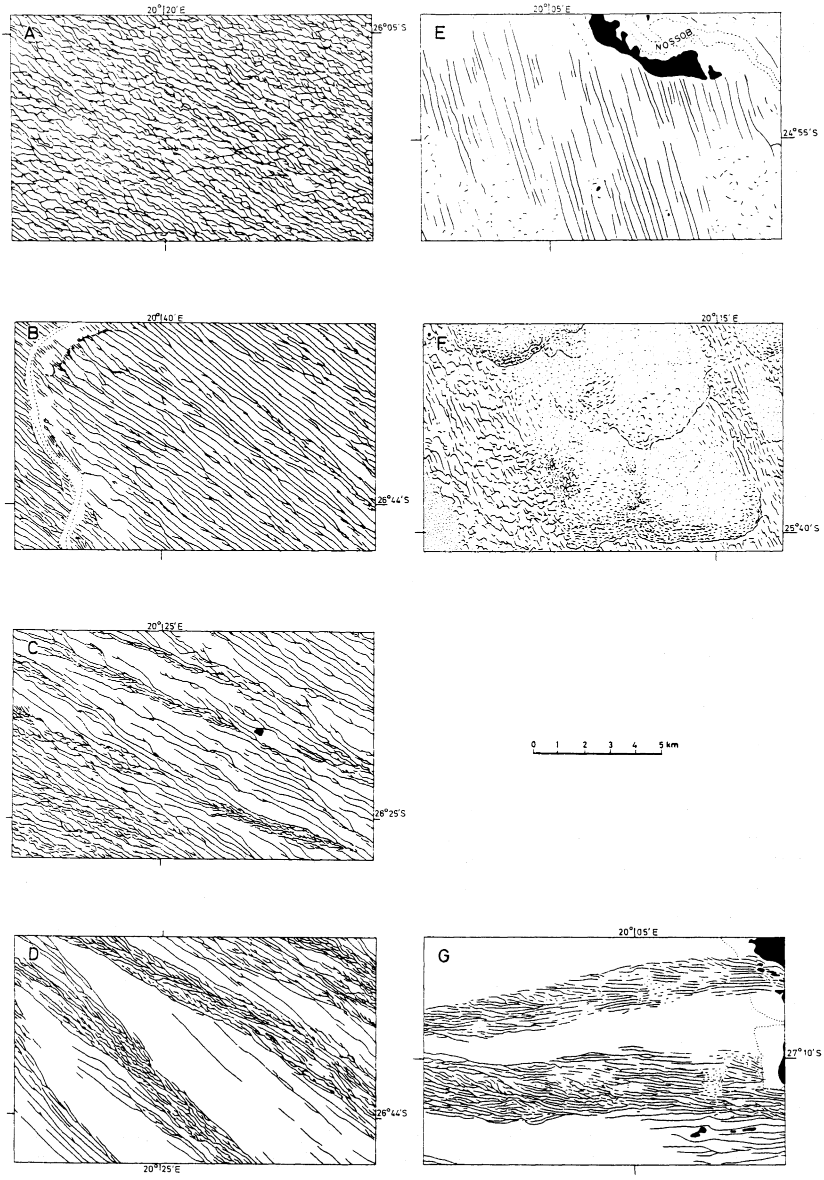

Figure 2. Dune types of the southwestern Kalahari. A. reticulate, B. parallel-dendritic, C. dendritic to clustered dendritic, D. clustered dendritic, E. parallel, F. sheets of reticulate and linguoid dunes, and G. sand sheets, clustered dendritic.

ent ages with regard to their first shapings. Two sets of lunette dunes from the large pans within the linear dune fields seem to be the youngest aeolian forms.

Until now it has not been possible to date the dunes of the Kalahari by physical or chemical methods although by thermoluminescence dating reliable results may be obtained (Readhead 1988). Some ostrich egg shells and mollusca I found in dune sand, gave no radiocarbon age because the samples were too small. Only by relative age determination can we establish a chronostratigraphy of the late Quaternary dune formation (Heine 1978, 1981, 1982, 1983).

In the southwestern Kalahari cross sections of linear dunes document several phases of sand accumulation and remobilisation (Fig. 4). At least four dune complexes can be distinguished. All linear dune complexes show the typical cross stratification described by McKee (1979) which is attributed to the formation of linear dunes in bimodal wind regimes created by the dune itself, rather than by atmospheric conditions (Thomas 1988c).

Dune complex IVb is the most recent accumulation which was remobilized after cattle breeders intruded from the Cape some 200 years ago. It can be found as small dunes on top of the older dune systems and as little dunes in and near the valleys. The dune complex IVb forming the crests of the linear dunes consists of remobilized older dune sand. Near the valleys and pans the dune complex IVb is characterized by relatively small grain size diameters, a yellowish brown colour (7.5 YR-10 YR), a high percentage of clay pellets ($\geq$ 10%), seeds, and vegetational fragments; little stone fragments are often included. The content of $CaCO_3$ is high and may range between 10 and 20%. The clay mineral assemblages show all those components that are found in the recent pan and valley sediments.

There is no doubt that dune complex IVb is a result of overgrazing since about 200 years. Dating of a buried *Acacia* sp. root yielded a ^{14}C age of 180 ± 70 (Hv 9886), thus supporting the field and laboratory observations.

During the Holocene, between ca. 5 and 3 ka climatic conditions prevailed that favoured aeolian processes and dune formation all over the southwestern Kalahari. All sections of the Auob valley (Fig. 5) north of 25°30'S, exposed in several pits, contained aeolian sand between two clearly recognizable zones of fluvial and sheetwash sediments. The maximum of the arid phase occurred around 4 ka (Heine 1982) and is also well documented for the southern Kalahari by other authors (Avery 1981, Van Zinderen Bakker 1982, Beaumont et al. 1984, Deacon & Lancaster 1988, Heaton et al. 1983). South of 25°30'S and west of the Nossob valley aeolian processes were active not only during the Holocene arid phase (5-3 ka), but presumably during the whole Holocene little sand movement occurred.

Dune complex III is – apart from the remobilized complexes IVa + b – the youngest dune formation of the late Quaternary. The main components of complex III are quartz grains of which more than 2/3 are red coloured by

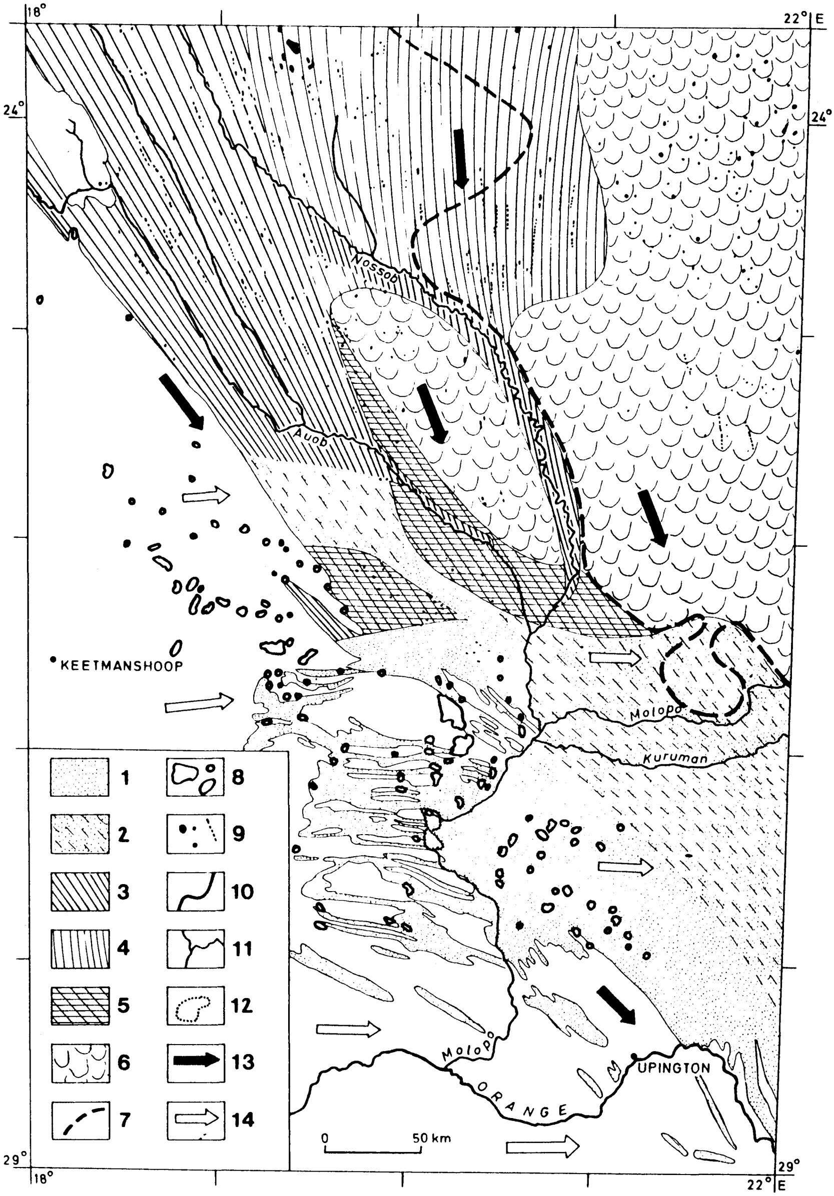

Figure 3. Distribution of dune types. 1 – sand sheets, dendritic and clustered dendritic, 2 – linear dunes, dendritic, 3 – linear dunes, parallel, 4 – linear dunes, older fossil forms with strings of pans marking old drainage lines, 5 – linear dunes, reticulate, 6 – mainly

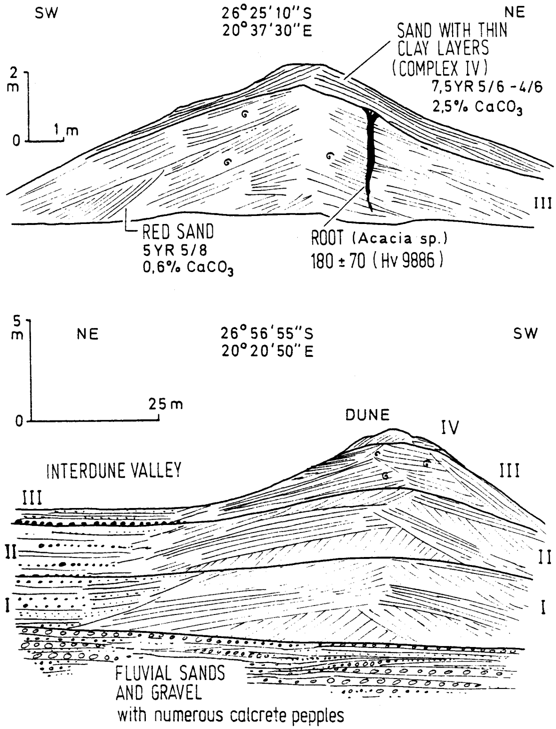

Figure 4. Cross sections of linear dunes. Nossob valley (above) and northeast rim of Koppieskraal pan (below). The interdune sediments interfinger with the dune sands documenting simultaneous accumulation by aeolian and sheet wash processes.

iron-oxide and -hydroxide (5YR 5/8). The sand fractions contain up to 10% of opaque rounded grains. Compared with dune complex IV characteristics, the median grain-size increases, sorting improves, and the grain size distribution is less skewed and more normalized. Clay pellets are absent, and coarse grains are rare.

As reddish yellow dunes (7.5 YR 6/6) complex III is found even in the main valleys of the Nossob south of the Nossob/Auob confluence and of the

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(elongate) linguoid dunes, partly with reticulate pattern; the forms are older in the Northeast than between the Nossob and Auob, 7 – eastern limit of red sand dunefield, 8 – pans, calcrete-rimmed, big size, 9 – pans with small parabolic dunes on their lee side, presumably late Quaternary, 10 – perennial river, 11 – dry valley, partly with seasonal or episodic runoff, 12 – late Quaternary lake of the lower Molopo, covered by dunes, 13 – reconstructed main wind regimes during the LGM summer/spring, 14 – reconstructed main wind regimes during LGM winter (after Heine 1981).

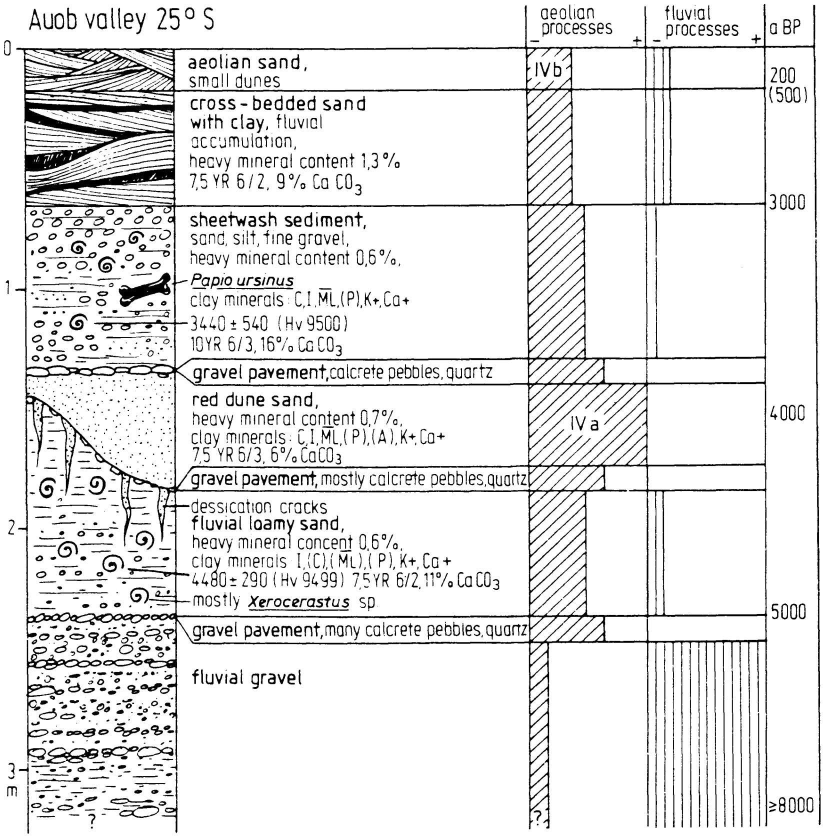

Figure 5. Cross section of Holocene deposits in the Auob valley south of Gochas (SWA/Namibia) and palaeo-geomorphodynamic interpretation. Abbreviations of clay minerals: C – chlorite; $\overline{\text{ML}}$ – mixed layer 14-18 Å; P – palygorskite; K – kaolinite; Q – quartz; FeO – Fe oxides; ( ) – secondary mineral; I – illite; $\underline{\text{ML}}$ – mixed layer 10-14 Å; S – sepiolite; A – analcime; F – feldspar; Ca – calcite, dolomite; + – traces.

Molopo south of Koopan Suid, documenting that after the formation of dune complex III the valleys must have been inactive, whilst valley sections without complex III dunes indicate fluvial activity after the period of formation of dune complex III (Fig. 6).

According to the stratigraphy of the fluvial valley sediments the formation of dune complex III took place after ca. 19 ka and prior to ca. 12 ka. The fluvial sediments have been dated by radiocarbon age determinations (Figs 6 and 7).

The fluvial sediments of the valleys with radiocarbon ages of over 19 ka appear to be not significantly influenced by aeolian remobilisation and redeposited sand grains. Only very few grains are of aeolian origin. During the accumulation of these sediments wind activity must have been suppressed and sand movement was virtually impossible because of conditions favouring soil development, a dense vegetation cover and a high groundwater level. These environmental conditions are documented by mollusca found in the fluvial sediments.

Furthermore, clay mineral assemblages of the fluvial sediments dated 20 ka account for relatively humid climate, too (see Table 1). The fossil soil of an age of about 28 ka – i.e. prior to the dune complex III-formation – represents palaeoenvironmental conditions that favoured a dense vegetation cover, and prevented aeolian sand movement as well as the formation of the clay mineral palygorskite. Palygorskite is an excellent indicator of arid or semiarid conditions (Velde 1977, Singer 1979/80, 1984, Watts 1980). Consequently the mobilisation of aeolian sand of dune complex III only started after the moist phase.

During the period 20 ka to 30 ka lacustrine fresh water sediments in the Ngami and Makgadikgadi pans indicate humid conditions, too. These sediments are completely free of aeolian sand grains (Heine 1987). Prior to 23 ka, a lacustrine phase is documented in the Etosha pan and intensive lunette development occurred thereafter. The climates of most of the Kalahari before the Last Glacial Maximum (LGM) were considerably more humid than they were after 20 ka (Heine 1978, Deacon & Lancaster 1988).

In the lower Molopo valley, fluvial sediments of LGM age (ca. 20-12 ka) are not covered by dunes of the complex III. The mollusca of these sediments document fresh water conditions in perennial and seasonal rivers. Grain size analyses indicate that aeolian sand transport and fluvial processes occurred simultaneously. This means that dune sand was blown into the valley. It was then transported downvalley by fluvial processes. During dry seasons wind remobilized the sand grains, so that river valleys were important localities of dune initiation. According to the sedimentological features of the fluvial accumulations of LGM age, there is no doubt that the LGM was a period of dune formation and that this last major period of dune activity began after 19-20 ka and continued for several thousand years thereafter.

Figure 8 shows a sequence of late Quaternary dunes, soils, lake levels and river sediments of the southwestern Kalahari compared with sequences from Etosha, Ngami/Makgadikgadi and the lower Orange River area.

Palaeoenvironmental reconstruction of the LGM

Figure 9 presents a palaeoenvironmental reconstruction of the LGM summer and winter conditions in the southwestern Kalahari. During the LGM summer (Fig. 9B), and possibly for most of the year, the relative strength of anticyclonic circulation patterns was greater than today and appears to be

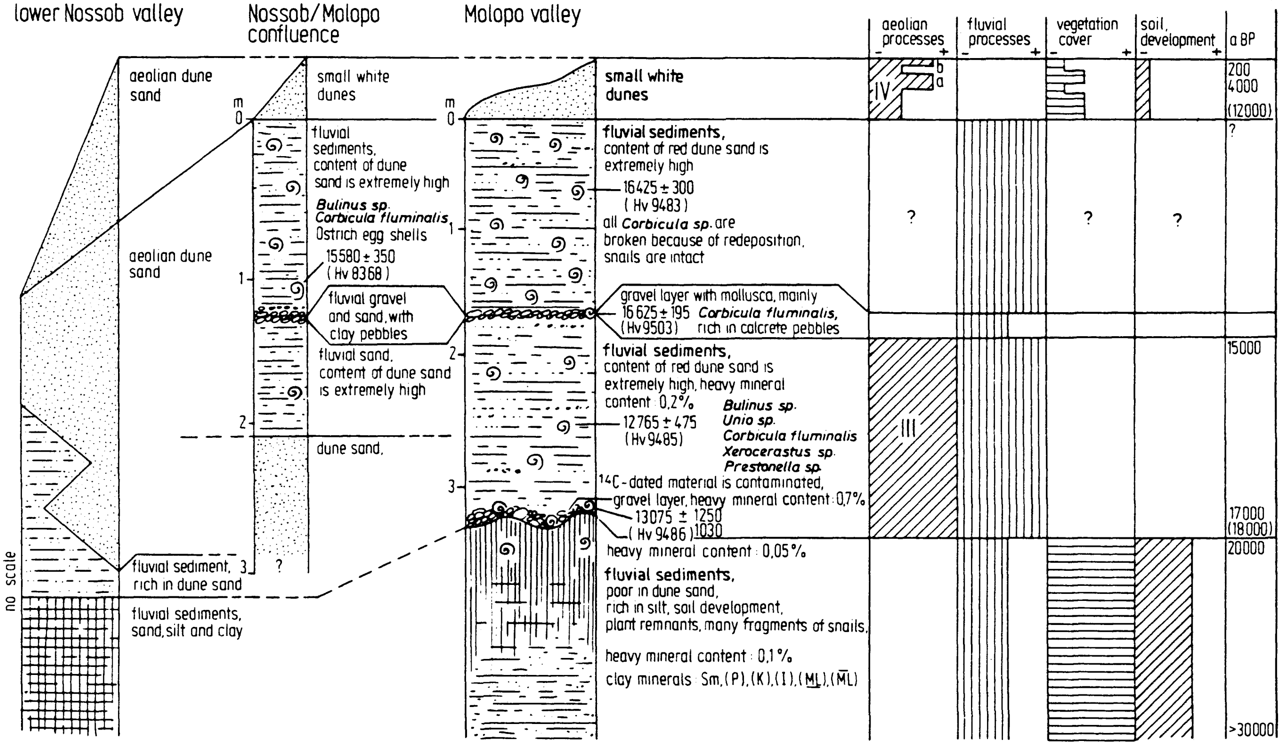

Figure 6. Cross sections of the Nossob and Molopo valley sediments near the Nossob/Molopo confluence and palaeo-geomorphodynamic interpretation. Abbreviations of clay minerals see Figure 5.

Table 1. Clay mineral assemblages of selected samples from the southwestern Kalahari.

Locality	Chlorite	Illite	10-14 Å mixed layer	14-18 Å mixed layer	Smectite	Kaolinite	Palygorskite	Sepiolite	Quartz	Feldspar	Fe-oxides	Calcite	Dolomite	Analcime
Fossil soil, ca. 28 ka 26°30'E	-	20	20	30	30	-	-	-	-	-	-	-	-	-
Nossob valley, > 20 ka 26°15'S, 20°40'E	-	60	-	tr	20	20	-	tr	+	+	-	-	-	-
Molopo valley, > 16 ka 26°S, 21°E	-	5	5	5	65	5	15	-	-	-	-	-	-	-
Auob valley, Holocene 25°S, 19°E	10	10	-	5	45	tr	30	tr	-	+	-	-	-	-
Auob valley, Holocene 25°30'S, 19°20'E	SM	PM		+		(+)	SM	0	-	-	+	SM	-	-
Auob valley, Holocene 25°10'S, 19°E	SM	PM		SM		+	SM	0	-	-	-	+	+	-
Auob valley, Holocene 25°S, 19°E aeolian sand and dust	PM	PM		PM		+	SM	0	-	-	-	+	+	+
Auob valley, Holocene 25°S, 19°E sheet wash sediment	PM	PM		PM		+	SM	0	-	-	-	+	+	-
Koopan Noord Pan, Holocene, 26°50'S, 20°35'E pan sediment	-	PM		-		-	-	-	-	-	+	+	+	SM

PM – main components, SM – secondary components, tr – traces, + – present.

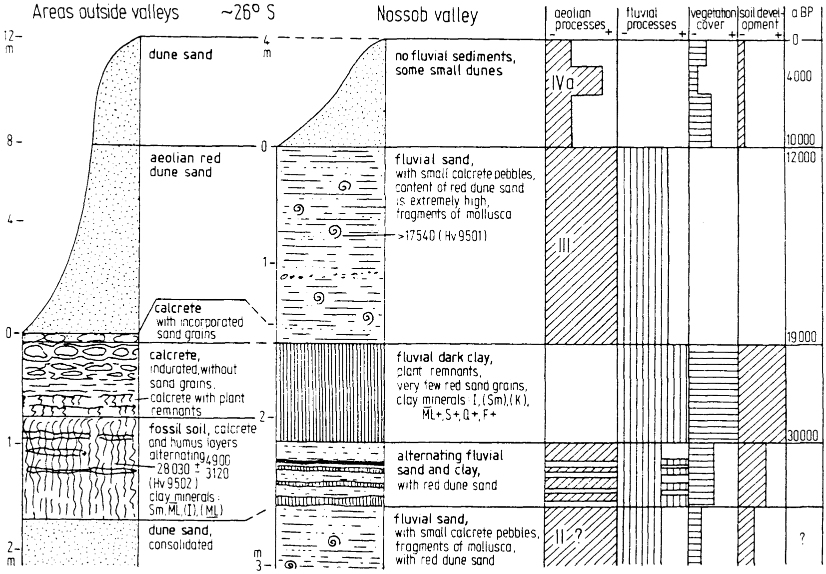

Figure 7. Cross sections of the Nossob valley about 26°S and adjacent dune field and palaeo-geomorphodynamic interpretation. Abbreviations of clay minerals see Figure 5.

responsible for wind directions from northwest or north, parallel to the longitudinal dunes, throughout the region.

During the LGM winter (Fig. 9C), west winds may have influenced the southwestern Kalahari, but only south of circa 25°30'S. The dune patterns very clearly show the influence of two different wind regimes on the dune formation.

The reconstruction of climatic-geomorphological provinces of the LGM is shown in Figure 9D. Compared with Holocene climates, the LGM was much more windy right through the region. The western areas of Namibia were arid; in the south the cyclonic winter rains led to semiarid conditions. For the lower Molopo valley a perennial river was made out by palaeontological findings. Tropical summer rains and cyclonic winter rains overlapped in this area. Therefore, the evidence from the south-western Kalahari indicates comparatively moist conditions. This is not in contrast with southern Cape data as Cockcroft et al. (1987) presume (see also Tyson 1986).

Old dune complexes

Comparatively old dune complexes are documented by cross sections of

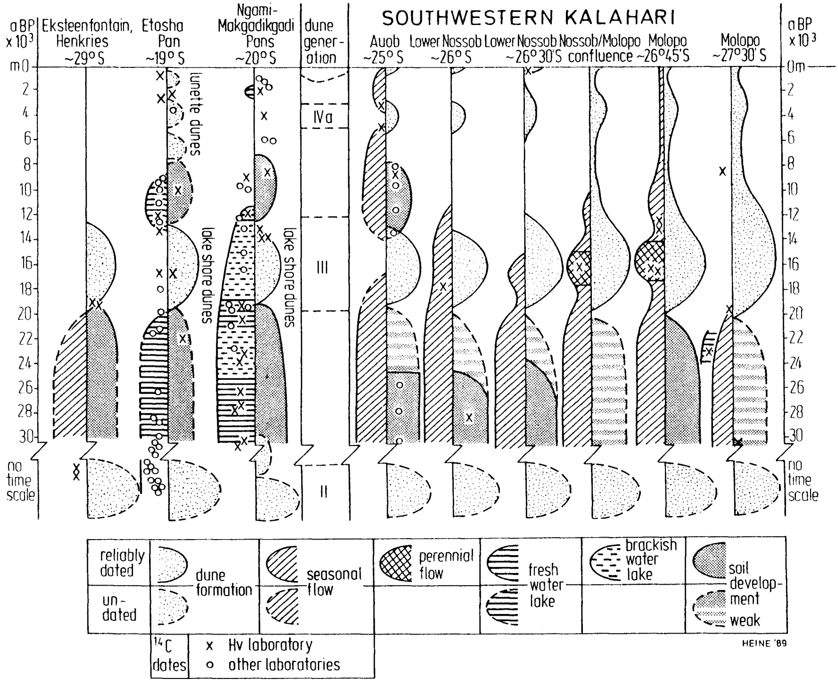

Figure 8. Sequence of late Quaternary dunes, soils, lake levels and river sediments of the southwestern Kalahari compared with sequences from Etosha (SWA/Namibia), Ngami/Makgadikgadi (Botswana) and the lower Orange River area (RSA).

linear dunes in the southwestern Kalahari. At least two dune complexes older than complex III occur (Fig. 4). According to the soil development of dune complexes II and I as well as to geomorphological and sedimentological investigations the dune formation started in the early Quaternary or even in late Tertiary times (Fig. 10). The oldest dune complexes do not appear on the river terraces of the Auob, Nossob and Molopo nor are they situated over calcrete horizons. Aeolian dust is considered to be the major source of ions for calcrete formations, which first occurred together with the early dune formation in Namibia.

Recent surface dune forms of the southwestern Kalahari indicating a distinct windy period with several predominant wind directions, only show the directions in which Kalahari sand was redistributed in late Quaternary times and do not reveal the directions of original derivation. From the study of dune sands and of satellite imagery it may be concluded that during the late Qua-

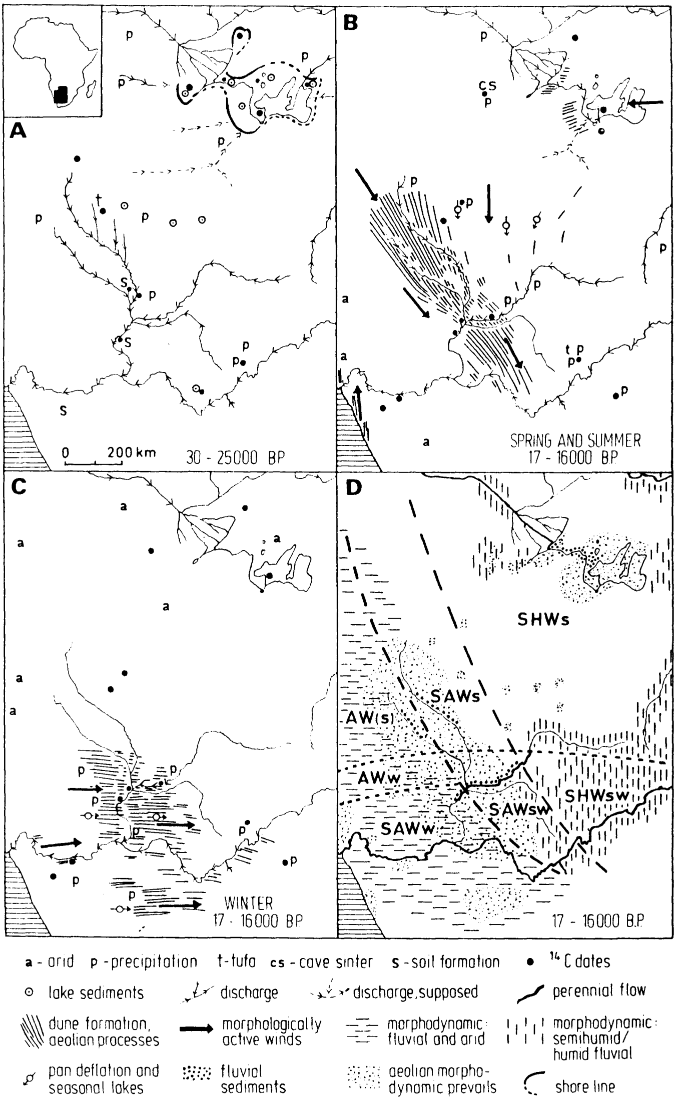

Figure 9. Palaeogeographical maps of the southwestern Kalahari. A. 30 – 25 ka, B. LGM summer/spring, C. LGM winter. Abbreviations of climatic areas: SHWs – semi-humid, windy, summer rainfall, SAWs – semi-arid, windy, summer rainfall, SAWsw – semi-arid, windy summer and winter rainfall, SHWsw – semi-humid, windy, summer and winter rainfall, SAWw – semi-arid, windy, winter rainfall, AWw – arid, windy, winter rainfall, AW(s) – arid, windy (summer rainfall).

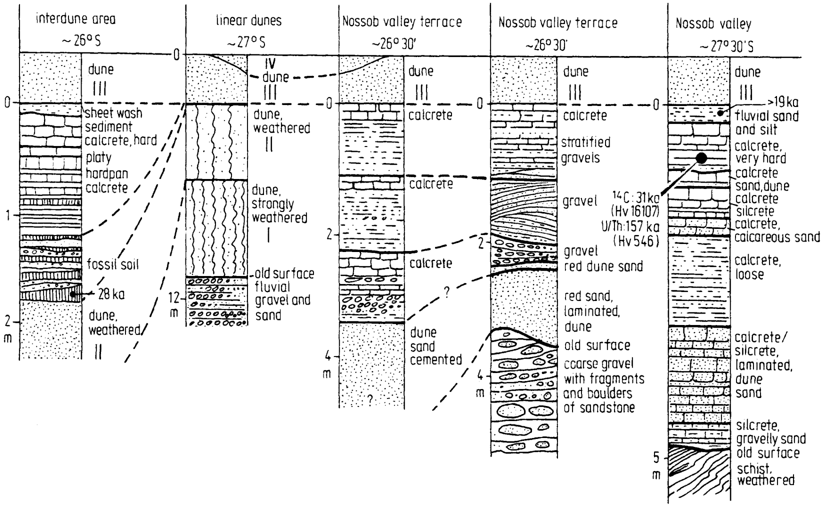

Figure 10. Some sections documenting several dune formation phases in the southwestern Kalahari.

ternary the main features of the dune systems were not altered in general and that only slight modifications occurred. The eastern limit of reddish sand dunes in the southwestern Kalahari indicate that there was no mixing of different sand provinces by long distance aeolian transport (Mallick et al. 1981) (Fig. 3).

The dune sands appear to be of local derivation (Baillieul 1975, Mallick et al. 1981) and their first development dates back into the early Quaternary or late Tertiary. Therefore the geomorphology of the dune systems reflects a long climatic history during which dune ridges were being formed and again degraded for several times. The latest sand movements and thereby induced forms have to be considered seperately from older testimonies of aeolian processes and forms. The question whether the main dune formation was synchronous or diachronous in different regions of the Kalahari sands cannot be answered yet.

The $^{230}Th/^{234}U$ method (see Netterberg 1978) has been applied to a calcrete underlying the dune complex III. The $^{230}Th/^{234}U$ date is 140-157 ± 10 ka indicating that the radiocarbon age (30 990 ± 490, Hv 16 107) of the same calcrete does not refer to the calcrete formation age, but to a later moist phase which is responsible for the young ^{14}C age. The red dune sand in the long record of at least six calcrete complexes demonstrate the old age of the beginning of dune sand movement in the southwestern Kalahari (Fig. 10).

CONCLUSIONS

The sediments described above represent fluvial as well as aeolian processes in the southwestern Kalahari during the LGM. The phases of intensive dune formation appear to have been restricted to glacial periods. The presence of several dune complexes and fossil dune sands in long records of Quaternary age give evidence that the dune formation dates back to the Early Quaternary and that dune building phases were interrupted by periods of soil formation and dune stabilisation. Only the youngest dune complexes could be dated (LGM and Holocene).

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