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EOLIAN, FLUVIAL AND PAN (PLAYA) FACIES OF THE TERTIARY TSONDAB SANDSTONE FORMATION IN THE CENTRAL NAMIB DESERT, NAMIBIA

J.D. WARD

Geological Survey of South West Africa/Namibia, P.O. Box 2168, Windhoek 9000 (Namibia)

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ABSTRACT

Ward, J.D., 1988. Eolian, fluvial and pan (playa) facies of the Tertiary Tsondab Sandstone Formation in the central Namib Desert, Namibia. In: P. Hesp and S.G. Fryberger (Editors), Eolian Sediments. Sediment. Geol., 55: 143–162.

The Pliocene to Recent sand sea in the central part of the 2000 km long Namib Desert is underlain widely by sediments comprising the Tsondab Sandstone Formation (TSF) of Early to Middle Tertiary age. This formation is the earliest record of terrestrial sedimentation in the central Namib Desert and formerly was thought to consist of only eolian dune and sand sheet deposits of a desert origin.

However, recent field investigations indicate that the TSF also includes deposits of ephemeral watercourses and pans (playas). These fluvial and playa sediments are associated intimately with the eolian dune and sand sheet deposits, as is likewise the case in the present, extreme-arid Namib Desert. Sedimentary structures and trace fossils in the TSF eolianites resemble those found in the modern sand sea. Furthermore, these eolianites were deposited under a dominant southerly and a subordinate easterly quadrant wind regime which is similar to the present-day circulation pattern in the Namib.

Since the cold Benguela Current was established only in the Late Tertiary, the TSF represents a major, ancestral arid phase in the Namib tract that was controlled by an early anticyclonic wind regime and a geographic location on the rainshadow side of southern Africa.

INTRODUCTION

The extreme-arid Namib Desert, lying between about 14° and 33°S, contains the largest active dunefield in southern Africa. This eolian deposit, covering some 34,000 km^2 between about 23° and 28°S, is known as the main Namib Sand Sea and stratigraphically comprises the Sossus Sand Formation (Barnard, 1973; SACS, 1980; Fig. 1). This sand sea, which apparently dates from the Late Pliocene (Korn and Martin, 1957), is underlain widely by red-brown arenites of the Early to Middle Tertiary Tsondab Sandstone Formation (TSF, Fig. 1). This formation, up to 220 m thick, provides the first record of terrestrial sedimentation in the central Namib Desert.

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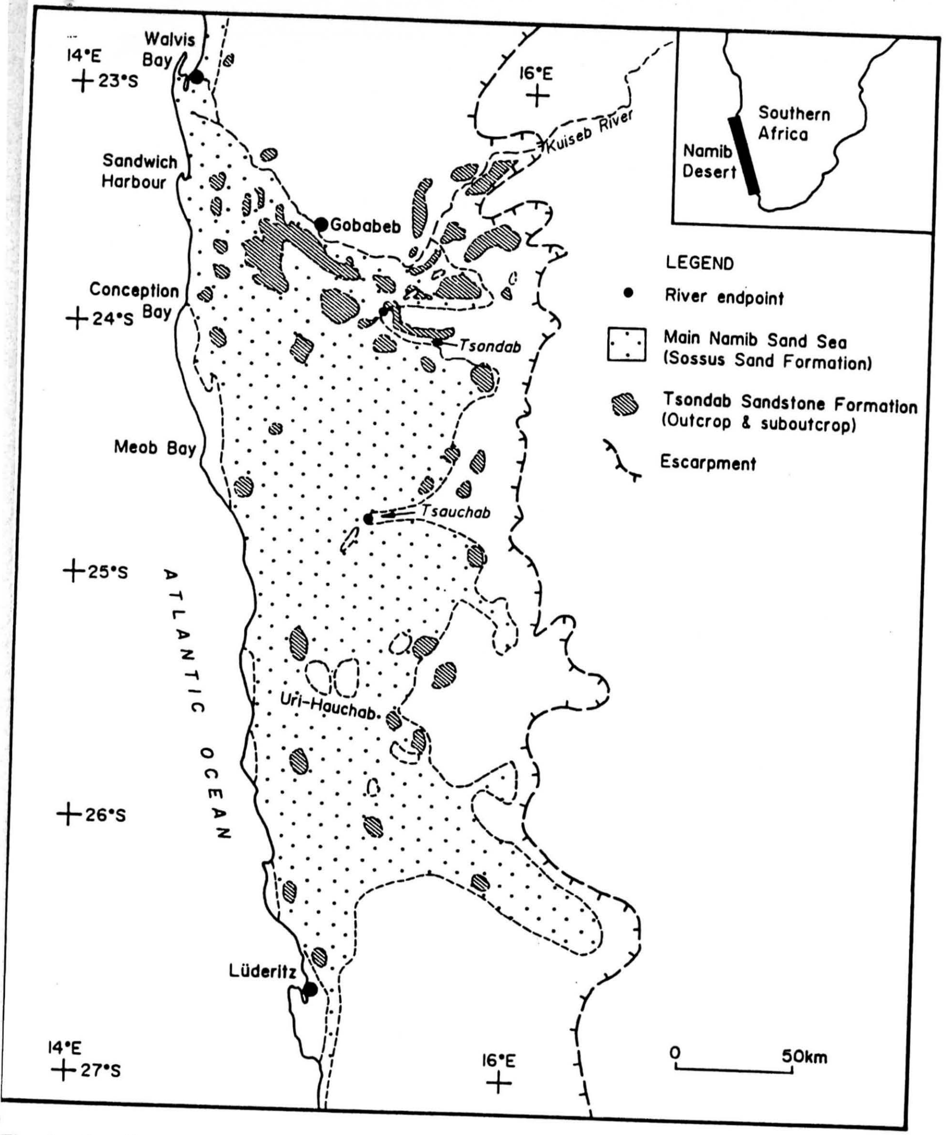

Fig. 1. The distribution of the main Namib Sand Sea (Sossus Sand Formation) and the Tsondab Sandstone Formation (partly after Besler and Marker, 1979).

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Previous workers, including Martin (1950), Barnard (1973), Selby (1976), Besler (1977, 1980), Marker (1977), Ollier (1977), Besler and Marker (1979), SACS (1980) and Ward et al. (1983), identified the TSF as eolian dune and sand-sheet deposits which accumulated under desert conditions. These authors (in particular, Besler and Marker, 1979) reported on the distribution and the composition of the TSF. However, only an eolian facies was recognized, and the stratigraphic context and

lateral facies relationship of carbonate-cemented arenites, described as "valley-fill sandstones", was not elucidated.

Subsequent mapping of Cenozoic deposits in the central Namib, notably in the Kuiseb Valley (Ward, 1984a,b) show that fluvial and pan (playa) deposits are also associated with the eolian sediments that dominate the TSF. This paper presents an interpretation, based on an appreciation of modern sedimentary environments in the Namib, of the eolian, fluvial and pan facies of the TSF.

FACIES DESCRIPTION AND INTERPRETATION

The distribution of the TSF in relation to the main Namib Sand Sea is shown in Fig. 1 and its distribution within the Kuiseb catchment in the desert region is depicted in Fig. 2. Simplified reference sections for the eolian, fluvial (proximal and distal) and pan facies are also incorporated in Fig. 2. Table 1 summarizes the salient sedimentological features and probable paleoenvironments of these three facies which are discussed briefly below in relation to modern Namib environments.

Eolian facies

The "typical" Tsondab Sandstone is a moderately- to well-sorted, reddish-brown, quartzose arenite that is mostly consolidated but, in places, is patchily cemented by carbonate (Ollier, 1977; Besler and Marker, 1979). Medium- to large-scale, horizontally- and cross-stratified beds are evident in most exposures (Fig. 3), although outcrops along the eastern edge of the Namib commonly appear massive and well-jointed. The cross-stratified deposits have been interpreted as paleodunes and the horizontally disposed beds as sand sheets that accumulated under desert conditions (Besler and Marker, 1979; SACS, 1980). Thus, a dune/interdune setting, as observed in the modern sand sea (Fig. 4), provides a useful analogue for the eolian facies of the TSF.

The predominant northeast–northwest azimuths of the cross-bedded strata in the eolian facies indicate deposition under a prevailing southerly quadrant wind regime, which is similar to the present regional circulation pattern (Ward et al., 1983). A low-frequency, but high-velocity, easterly quadrant wind prevails during the winter months in the modern Namib, and the effects of a similar paleowind are implied by the southwesterly orientation of cross-stratified beds in some exposures of TSF eolianite.

All major dune types are found in the main Namib Sand Sea (McKee, 1982) and their distribution has been well documented by, among others, Barnard (1973), Besler (1980) and Lancaster (1983). Basically, crescentic dunes occupy a coast-parallel belt up to about 25 km from the Atlantic Ocean, linear dunes a north–south zone between about 25–110 km inland, and star and reticulate dune types are found along the eastern margin of the sand sea that, in places, is up to 140 km from the

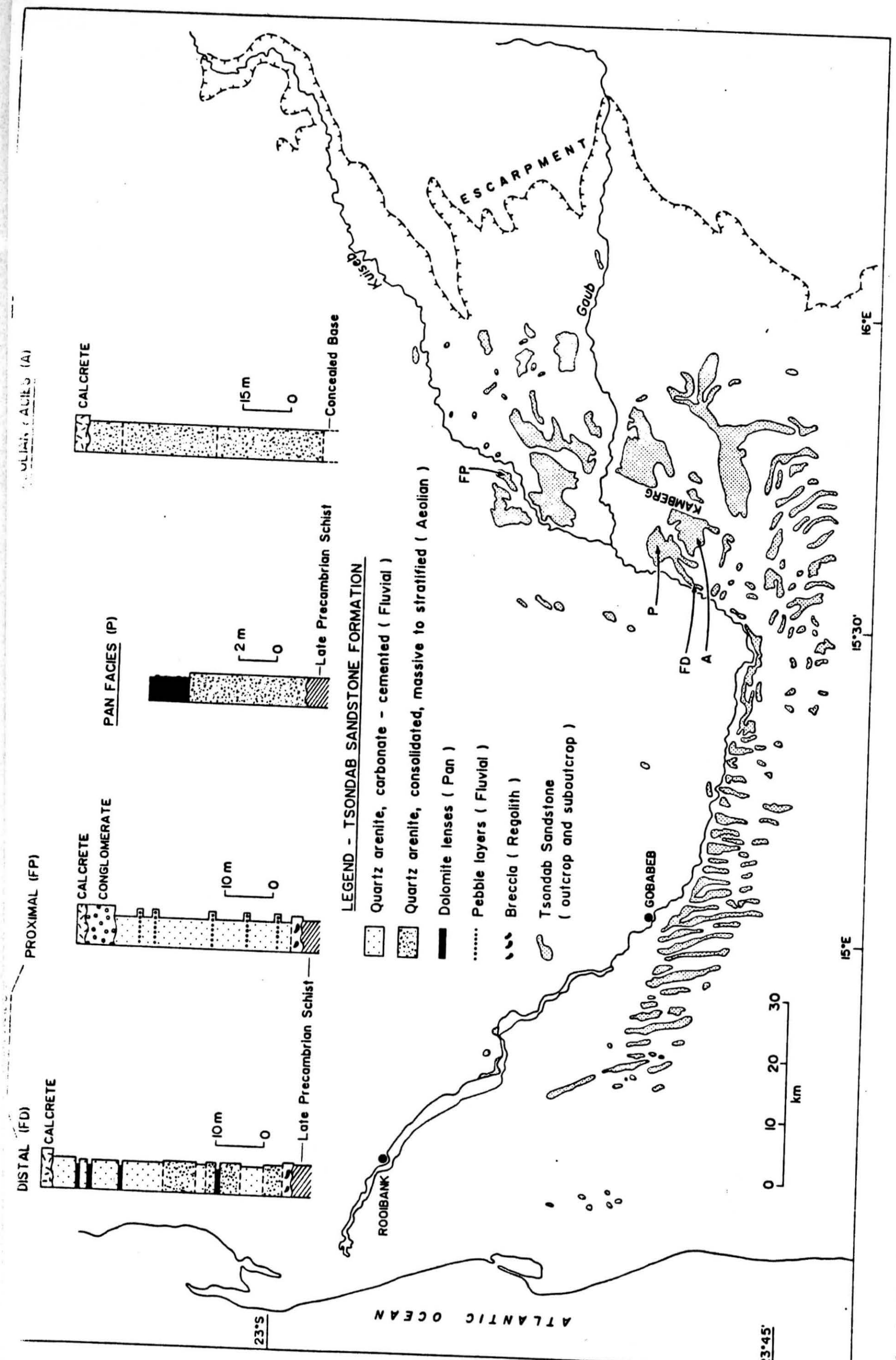


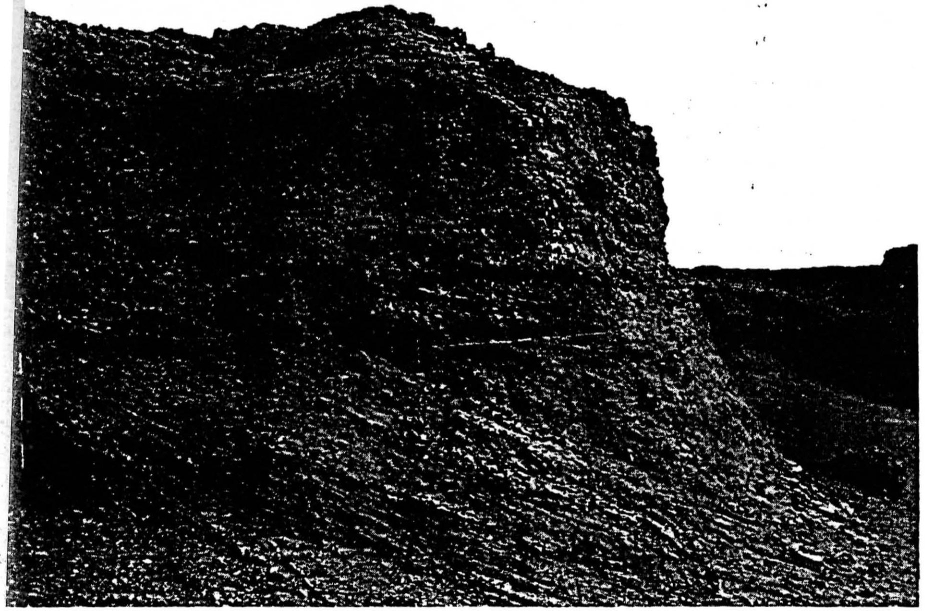
Fig. 2. The distribution of the Tsondab Sandstone Formation (outcrop and suboutcrop) in the Kuiseb Valley, central Namib Desert. Simplified reference sections for the eolian, fluvial (proximal and distal) and pan facies included.

TABLE 1

Salient features of the eolian, fluvial and pan facies of the Tsondab Sandstone Formation

Facies	Lithology and notes	Interpretation
Eolian	Quartz arenite; well- to moderately-well sorted; reddish-brown.	Desert dunes.
	Consolidated, uncemented to patchily cemented by carbonate.	Sand sheets, probably interdunal areas.
	Known maximum thickness 220 m.	Predominant southerly quadrant wind regime.
	Massive to horizontally- or cross-stratified; large-scale, steeply dipping cross-beds commonly orientated NE to NW.	
	Biogenic structures include termite-like passages, chambers and hives and mole-like burrowing trackways.	
	Tsondab Sandstone sensu SACS (1980).	
Fluvial	Quartz arenite, minor but conspicuous mica flakes and sand-sized garnets; poorly to moderately well sorted.	Ephemeral watercourses, mainly sandy, terminating amongst dunes of the ancestral sand sea.
	Whitish, greyish, reddish-brown, diagenetic mottling and pedotubules common.	
	Cemented by carbonate (varying calcite: dolomite).	Broad, shallow valleys, up to 12 km wide near base of escarpment.
	Known maximum thickness 50 m.	
	Apparently massive to horizontally layered.	
	Proximal arenites contain pebble layers.	
	Distal arenites interbedded with uncemented, red-brown arenites (eolian facies) and thin dolomite lenses (pan facies).	
Pan	Carbonate, mainly dolomite; greyish, whitish.	Endpoints of ephemeral watercourses.
	Commonly well-indurated and exposed today as positive relief.	
	Maximum thickness 3 m.	Local, temporary lakes/pans following short-lived periods of higher rainfall in the desert.
	Massive to horizontally stratified.	
	Gypsum crystal casts, eolian-sand-filled desiccation cracks, invertebrate trackways and burrows, vegetation casts.	Pans formed adjacent to watercourses by high groundwater levels.
	Associated with dune arenites, distal fluvial facies and bedrock erosion surface.	

coast. Because the paleowind wind regime under which the TSF eolian deposits accumulated resembled the present circulation pattern, the distribution of dune types in the ancient erg is predicted to be similar to that in the modern Namib Sand Sea.



g. 3. Horizontally and cross-stratified beds of Tsondab sandstone, Elim area. Ranging rod intervals 25 m.

Fig. 4. Interdune and dune setting in the Namib Sand Sea, south of Rooibank. Linear dune approximately 120 m high.

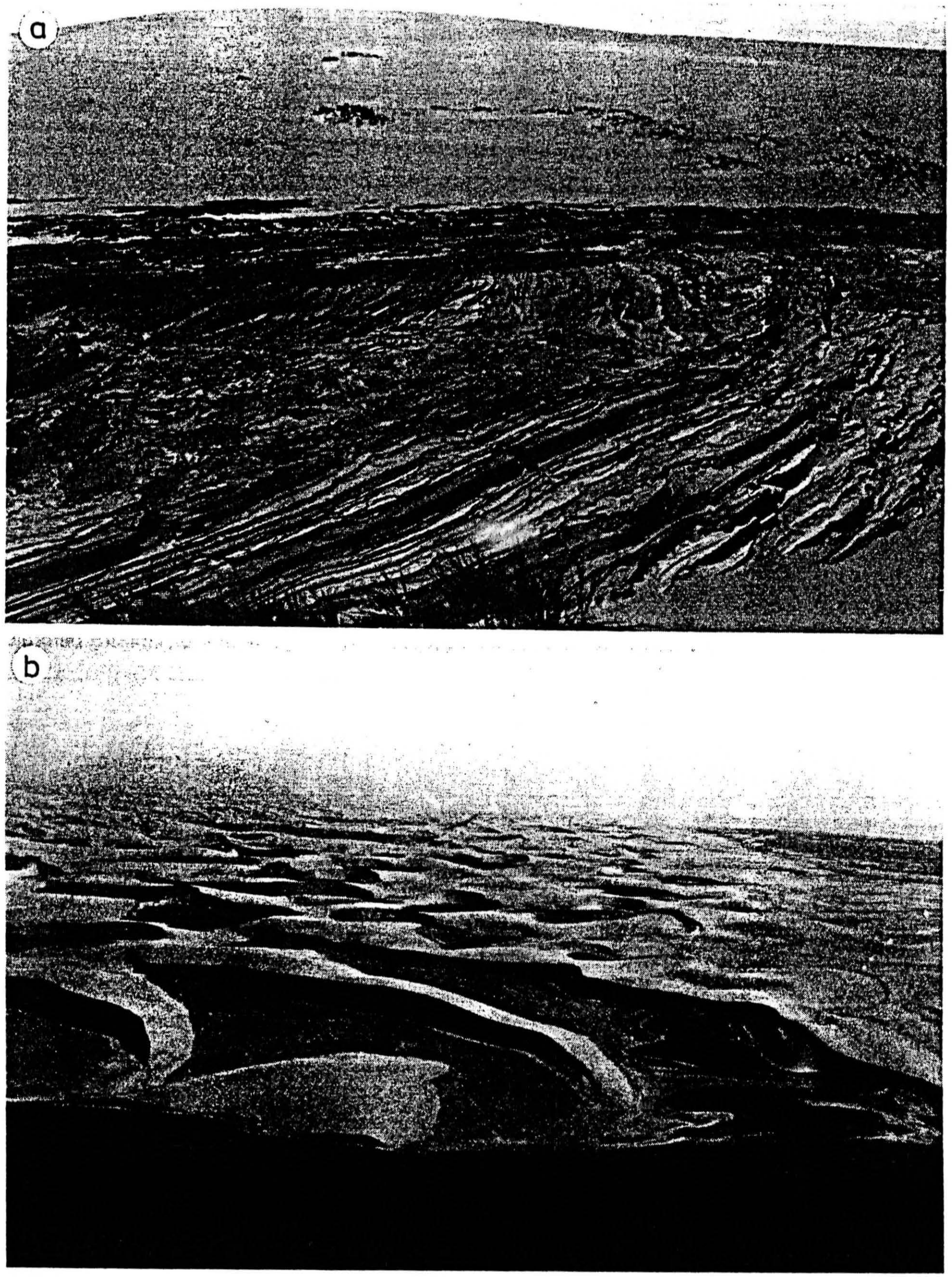
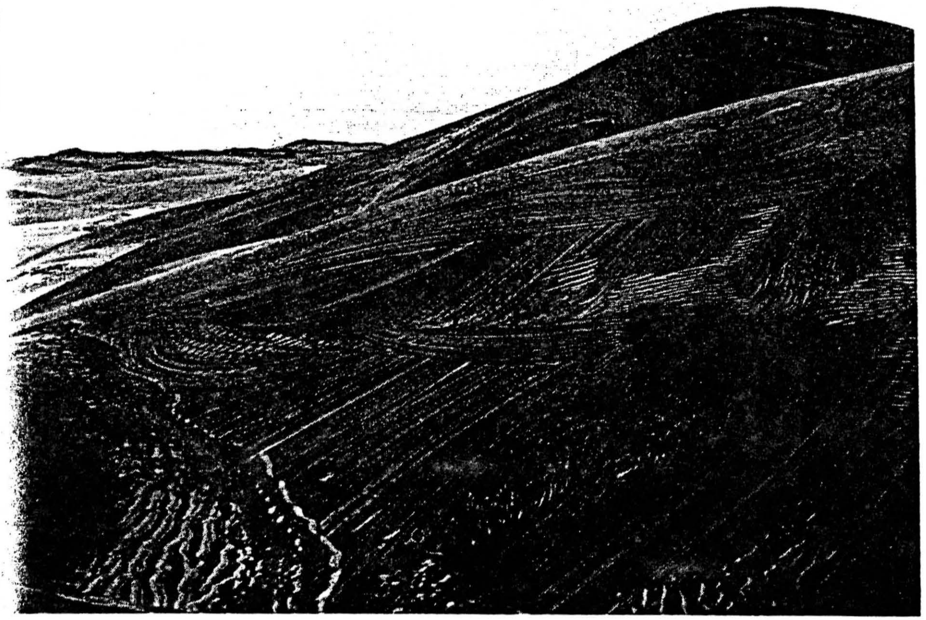


Fig. 5. (a) Large-scale, arcuate cross-stratification in Tsondab sandstone near Meob Bay. Person for scale. (b) Oblique aerial view of barchanoid ridge and simple transverse dunes, 7–10 m high, on the southeastern side of Sandwich Harbour.

6. Oblique aerial view of a large, complex linear dune, approximately 140 m high, fronting onto the ıseb River near Swartbank.



7. Intricate internal stratification near the crest of a linear dune south of Rooibank. Geological mmer (left, centre) for scale.

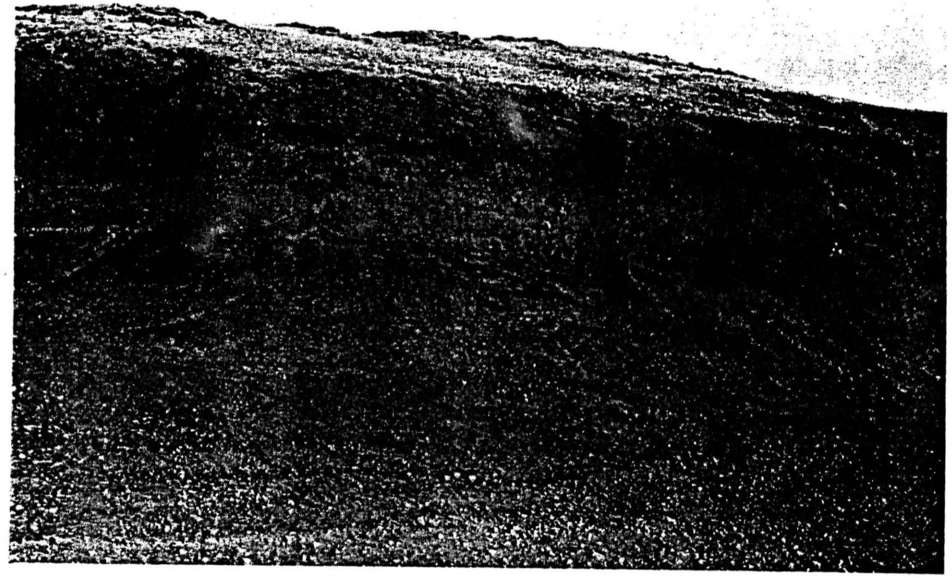


Fig. 8. Bi-directional orientation of large-scale cross-stratification in Tsondab sandstone, Elim area. Ranging rod (right, centre) 1.5 m high.

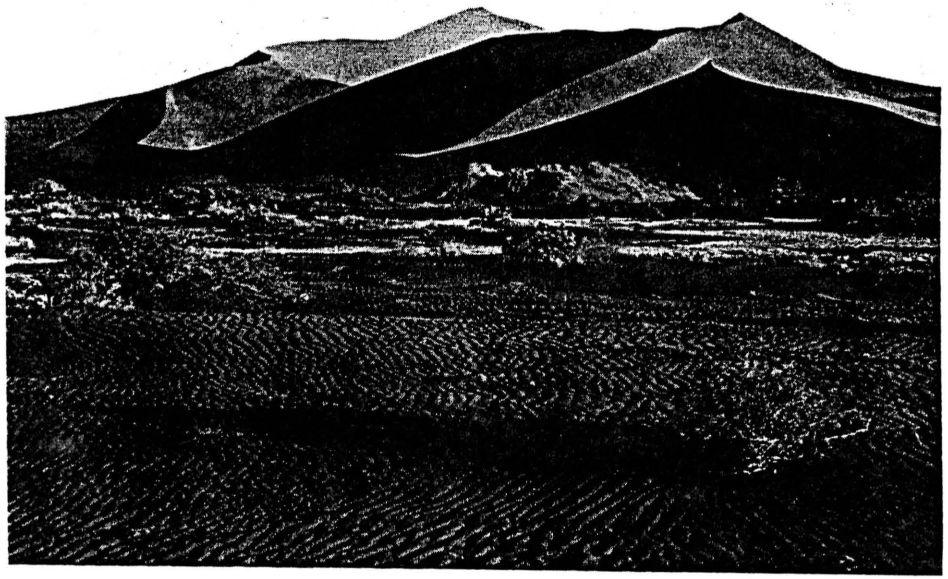


Fig. 9. Medium-sized and extremely large star dunes on the southern side of the Tsauchab Valley. The large dune on the skyline is approximately 220 m high.

It is significant, therefore, that TSF eolianites exposed in the coastal belt between leob and Conception Bays (Figs. 1 and 5a) exhibit large-scale, arcuate cross-strati-cation with a prominent northerly dip. The unimodal character of these bedforms, ıeir location in the coastal zone and a comparison with modern crescentic dunes ᵎig. 5b) strongly suggests a barchanoid ridge or simple transverse dune origin for ıese eolianites.

The current sand sea is dominated by large, complex linear dunes which trend pproximately north–south and incorporate barchanoid, transverse, reversing and tar dune elements (Fig. 6; McKee, 1982). Consequently, the internal structure of hese dunes is highly variable and intricate, as was evident after rare rain events e.g., January 1976, April 1979, October 1981) had dampened the dunes and emporarily enhanced the stratification (Fig. 7). Therefore, linear dunes have not yet ɔeen recognized in eolianites of the TSF, which supports Rubin and Hunter's (1985) concept that this dune type has been overlooked in the geologic record.

At some localities on the eastern edge of the main Namib Sand Sea, exposures of TSF display internal stratification on both a medium and extremely large scale (Fig. 8). These structures are interpreted as portions of star dunes that today are found in approximately the same vicinity (Fig. 9).

Certain trace fossils in the TSF eolianites could be matched convincingly with structures made by contemporary organisms inhabiting the modern sand sea. In

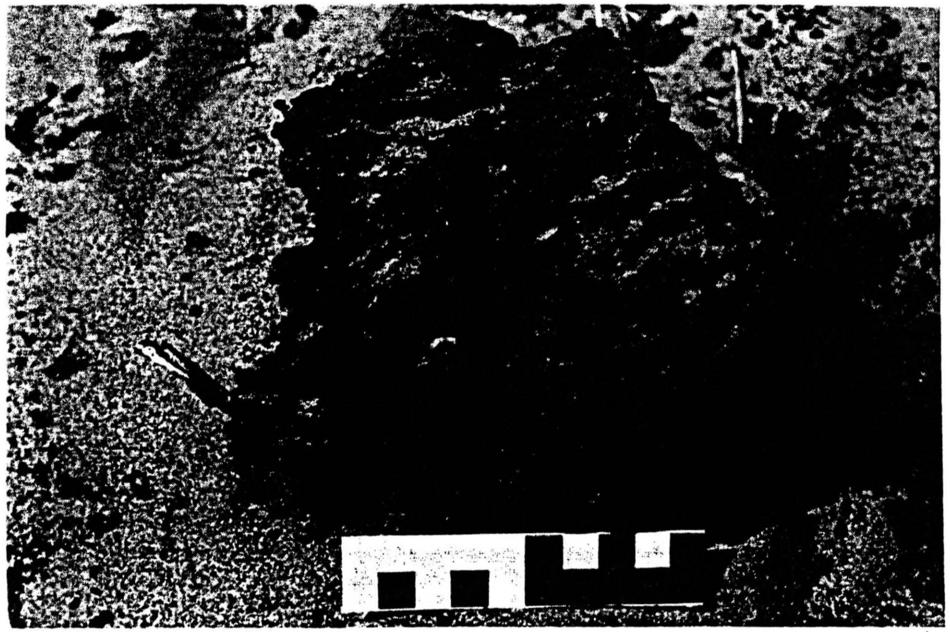


Fig. 10. A modern *Psammotermes* sp. chamber in unconsolidated dune sand south of Homeb. Bar scale 10 cm long.

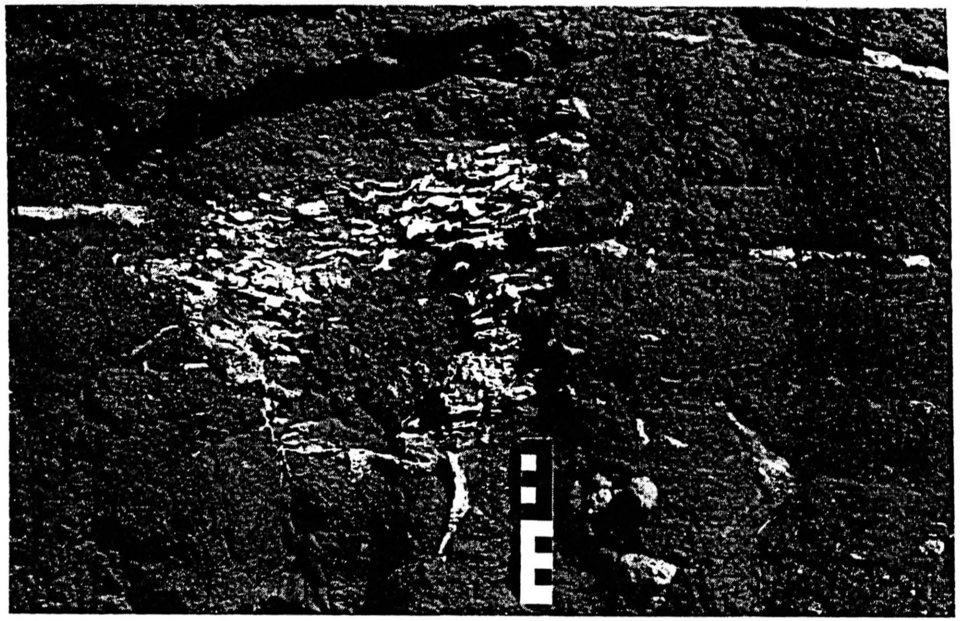


Fig. 11. Partly calcified, fossil termite chamber in Tsondab sandstone, Kamberg area. Bar scale 10 cm long.

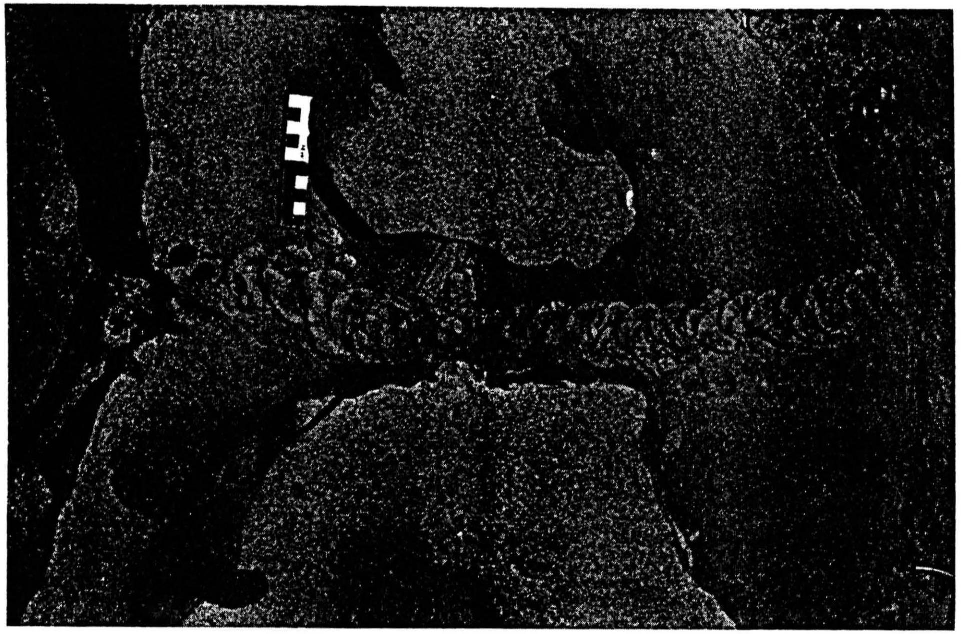
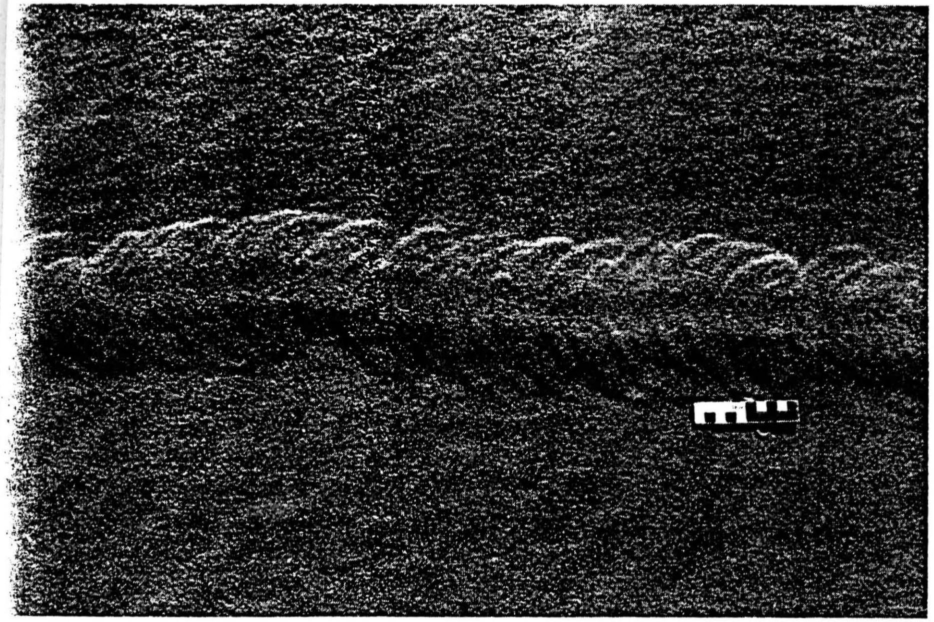
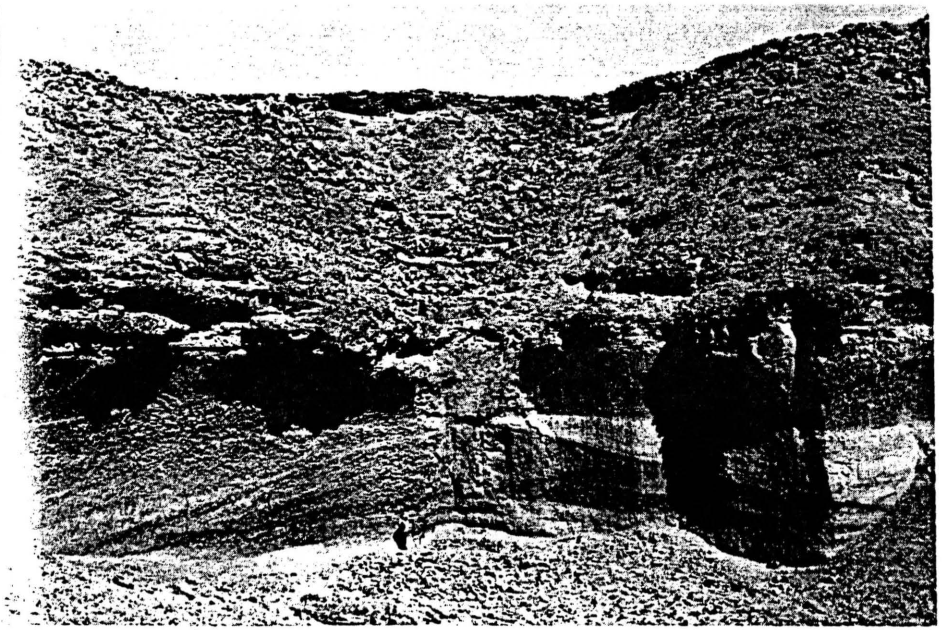


Fig. 12. Burrow-like trace in Tsondab sandstone near Meob Bay. Bar scale 10 cm long.



.. 13. A golden mole burrowing track across the surface of a linear dune, south of Homeb, Bar scale 10 ; long.



4. Greyish, fluvial arenite bed wedging laterally into red-brown eolianite, Tsondab Sandstone ..rr.ation, Kamberg Cliff. Person for scale.

particular, the passageways, hives and chambers of both the harvester termite, *Hodotermes* sp., and the sand-dwelling termite, *Psammotermes* sp. (Fig. 10), closely resemble the calcified pedotubules and globular structures commonly found scattered through the Tsondab eolianites (Fig. 11; McKee, 1982). Back-filled, burrow-like traces cutting across eolian stratification in the TSF (Fig. 12) resemble trackways left by the golden mole, *Eremitalpa* sp., that today is endemic to the Namib Desert (Fig. 13).

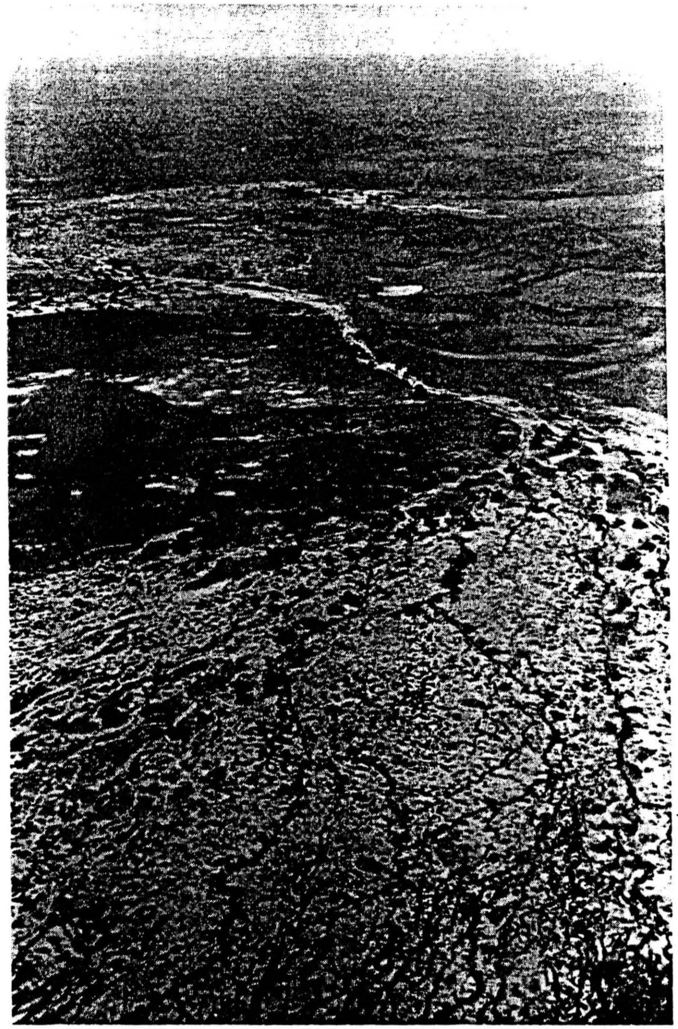


Fig. 15. Oblique aerial view of the lowermost reach and endpoint of the Tsauchab River. Pale-coloured, sandy silts deposited during the 1985/86 rainy season.

As mentioned earlier, the stratigraphic context of "valley fill sandstones" in the ɔntral Namib had previously been in doubt. However, a crucial exposure in the .amberg Cliff shows these fluvially derived, greyish arenites wedging into, and ıterbedded with, eolian sediments typical of the TSF (Fig. 14; Ward, 1984a, b).

The ephemeral Tsauchab River, which today terminates in several pans amongst igh star dunes of the Namib Sand Sea, provides a modern analogue for the ıterdigitating eolian–fluvial relationship noted in the TSF. This watercourse flooded ɔ its endpoint for the first time in a decade during the 1985/86 rainy season (Fig. 5). Calcareous silts were deposited on the floodplain and over small red dunes that ad encroached upon the Tsauchab River during the previous dry years. Thus, olian dunes were capped by fluvial deposits (Fig. 16) and incorporated into the nodern sedimentary succession of the Tsauchab Valley. This process accounts for he field relationship between eolian and fluvial arenites observed in the TSF xposure at the Kamberg Cliff (Fig. 17). In addition, this comparison lends support or the ephemeral nature of the watercourses associated with the ancient sand sea luring Tsondab times.

A proximal to distal change is evident in the fluvial facies of the TSF exposed in

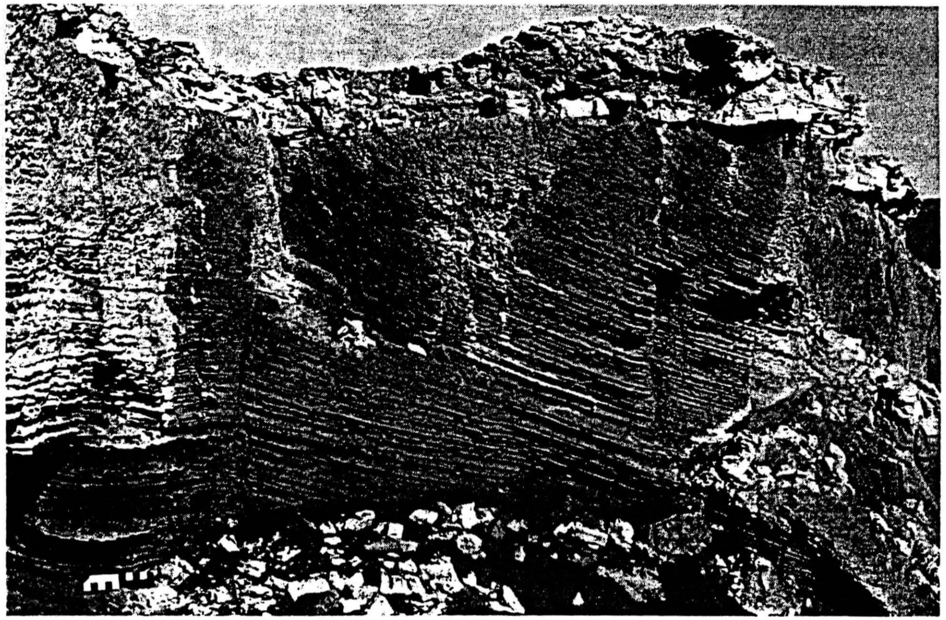


Fig. 16. Reddish dune sand, displaying aeolian cross-stratification, capped by calcareous silts deposited by the contemporary Tsauchab River near its endpoint. Bar scale 10 cm long.

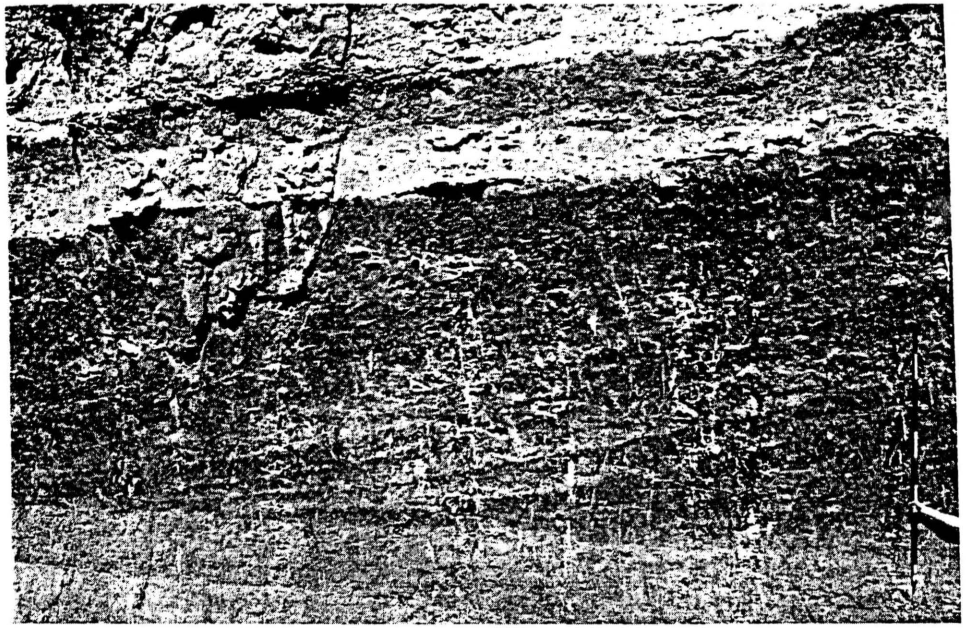


Fig. 17. Cross-stratified eolianite capped by calcite-cemented, silty fluvial arenite, Tsondab Sandstone Formation, Kamberg Cliff, Ranging rod 2 m long.

Fig. 18. Oblique aerial view of the terminal pans amongst +200 m high star dunes at the endpoint of the Tsauchab River, 1985/86 rainy season. Pans approximately 500 m long.

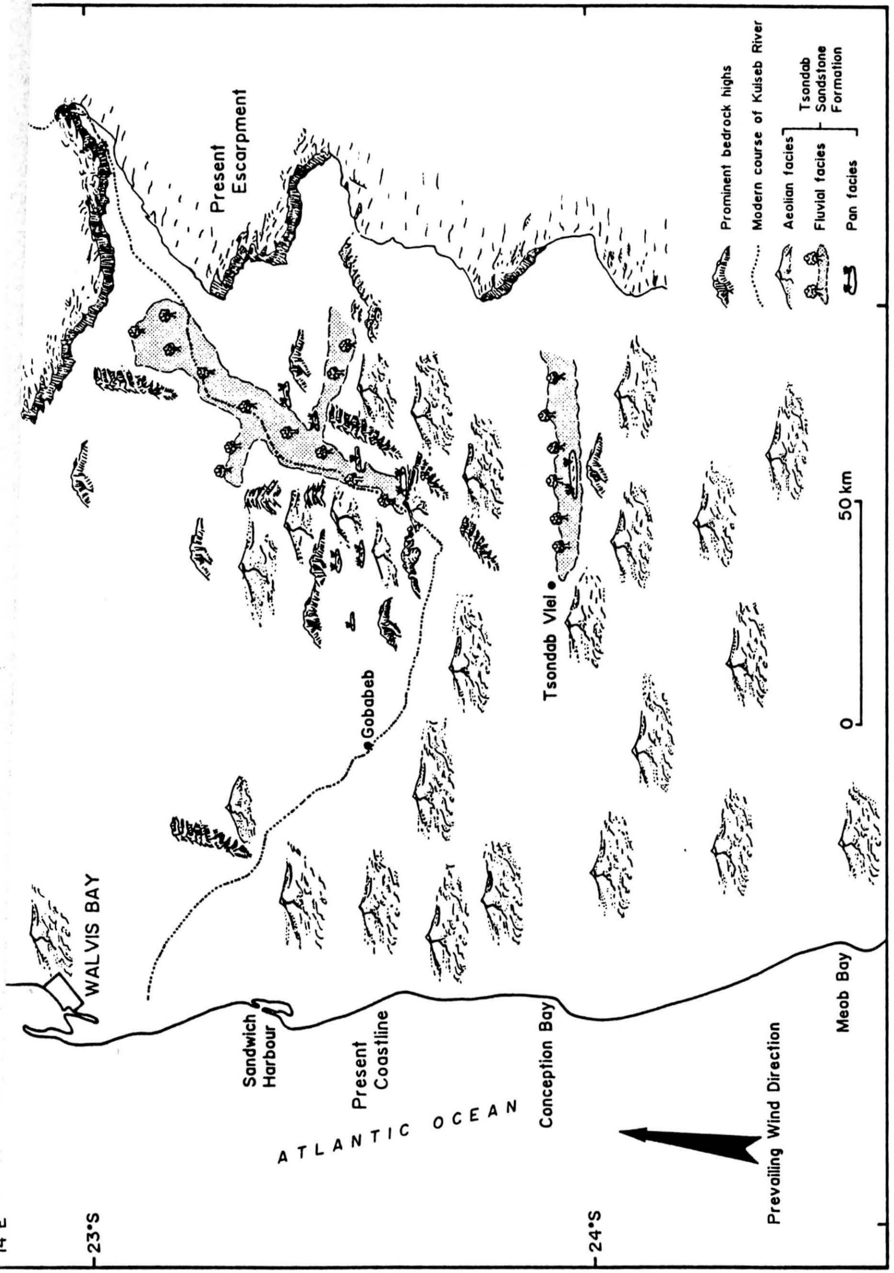


Fig. 20. Simplified reconstruction of probable paleoenvironments in the central Namib Desert during Tsondab times.

influences the southerly wind regime, and the location of this long, narrow tract of land on the southwestern, rainshadow side of southern Africa.

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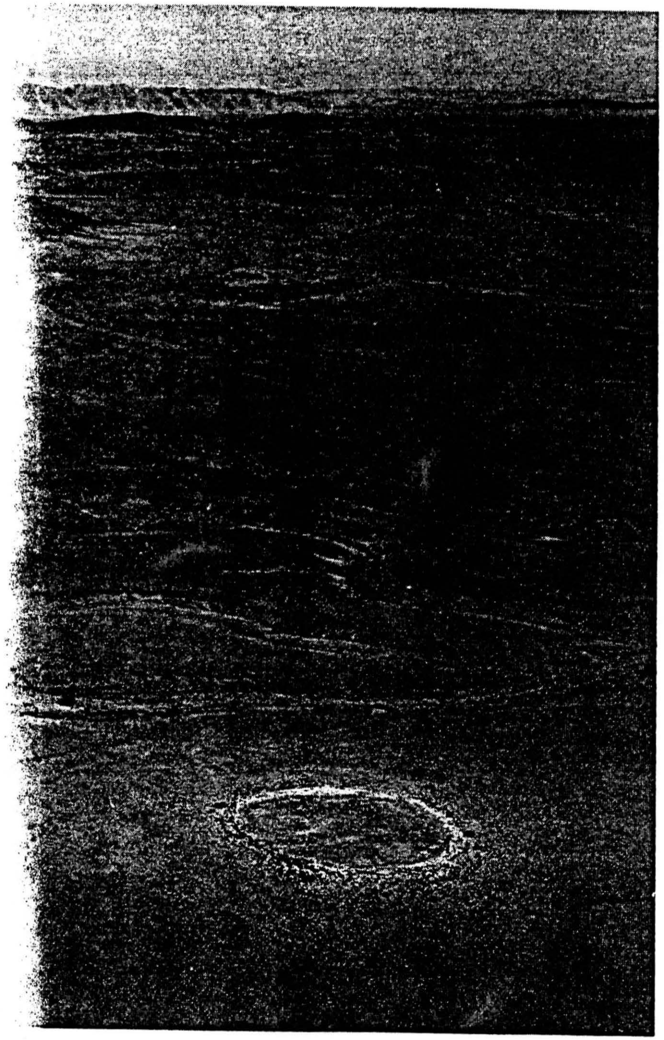
the Kuiseb Valley (reference sections, FP and FD, Fig. 2). Although predominantly arenaceous, the deposits closer to the Great Escarpment contain scattered pebble layers whereas farther downslope, thin discontinuous dolomite lenses are interbe-dded with the fluvial and eolian sediments. These dolomite lenses are interpreted as originally calcareous sediment settled from suspension in pans demarcating the endpoint of the proto-Kuiseb drainage. The terminal pans that persist for some months after flooding in the ephemeral rivers today, e.g., the Tsauchab (Fig. 18), provide a persuasive analogue for this interpretation.



. 19. Oblique aerial view of an almost circular carbonate body, approximately 67 m diameter, capping ndab sandstone near the Kamberg.

Pan (Playa) facies

Although pan deposits are associated with the distal fluvial facies of the TSF, as described above, discrete carbonate (mainly dolomite) bodies form lenses in, or caps on, the eolianite (Fig. 19). The distinct carbonate composition, presence of gypsum crystal casts, algal structures, plant imprints, invertebrate trackways and burrows and desiccation cracks filled with eolian sand indicate a pan paleoenvironment (Martin, 1957; Ward, 1984a,b).

This carbonate/arenite association, which led to the recognition of the Zebra Pan Carbonate Member of the TSF (Ward, 1984a,b), is well known in other ancient eolian sandstone successions where thin, locally restricted limestone and dolomite bodies have been interpreted as paleoplayas (Walker and Middleton, 1977). The Zebra Pan carbonates appear to have been deposited in several different environments; (1) pans formed in interdunal and bedrock depressions during limited periods of higher rainfall in the ancestral desert; (2) terminal pans of ephemeral watercourses; and (3) temporary water bodies formed amongst dunes adjacent to the ephemeral watercourses. High groundwater levels in the ancient rivers, related either to wetter periods in the desert or increased run-off from the escarpment (catchment area), would have forced the water table to the surface in low-lying depressions flanking the shallow valleys, as it does today in the Kuiseb Valley at Bubuses and Matoab.

CONCLUSIONS AND IMPLICATIONS

From an appreciation of lateral facies relationships between the main Namib Sand Sea and associated watercourses and pans, the Tertiary Tsondab Sandstone Formation (TSF) consists not only of eolian deposits but also fluvial and pan (playa) sediments. Therefore, the previous spatial and stratigraphic limits of this formation have been expanded considerably and allow for a paleoenvironmental reconstruction of the central Namib Desert during the Early to Middle Tertiary (Fig. 20). In addition, the magnitude of this Tertiary arid phase is emphasized by: (1) - the relatively thick TSF sequence compared to the modern sand sea; (2) - the distribution of TSF eolianites east of the present limits of the sand sea; and (3) - the ancestral drainage systems of the central Namib, notably the Kuiseb and Tsondab Rivers, which did not persist through to the Atlantic Ocean.

Although not well-dated, an understanding of the stratigraphic context of the TSF allows for comment on the aridity in the Namib tract. The cold-water Benguela Current System, which is considered a major contributor to the current extreme-arid climate of the Namib Desert (Van Zinderen Bakker, 1975), dates from the Late Miocene (Siesser, 1978, 1980). The TSF probably pre-dates the Late Miocene (Ward et al., 1983), which suggests that Cenozoic aridity in the Namib Desert has been controlled primarily by the South Atlantic anticyclonic circulation system, which