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PALEOCLIMATIC INFERENCES FROM THE GEOMORPHOLOGY OF THE CENTRAL NAMIB DESERT, SOUTH WEST AFRICA/NAMIBIA.

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Abstract. The Tumas River valley occupies the 40 km-wide zone between the larger drainages of the Kuiseb and Swakop Rivers. All three rivers flow west across the Namib Plain - here 120 km wide - to the Atlantic. The Tumas is autochthonous to the Namib Desert whereas the latter rise inland on the better watered plateau: the Tumas valley is correspondingly shallow and is impounded behind a coastal dune cordon, the other two being characterised by 200m-deep canyons by which floods regularly reach the coast. The Namib sand sea immediately to the south of the Kuiseb has breached the canyon on two occasions and may have invaded the Tumas valley.

Evidence of a succession of climatic environments occurs in the Tumas valley: reworked eolian sands, boulder-sized to fine-grained sheet-flood alluvia, suites of dated terraces, both near the coast and 50 - 70 km inland, and several phases of soil development usually armoring the inland terraces. A drilling program has provided information on the subsurface geology. Tentative correlations between the study area sequence and both coastal and inland sequences to the east, suggest that the documented climatic fluctuations may have been regional rather than local.

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PALEOCLIMATIC INFERENCES FROM THE GEOMORPHOLOGY OF THE CENTRAL NAMIB DESERT, SOUTH WEST AFRICA/NAMIBIA

1. Introduction

The Tumas River valley drains a 30 - 40 km-wide stretch of the central Namib Desert (approx. 4,000 km^2) inland of the coastal towns of Walvis Bay and Swakopmund (23^0S) in South West Africa/Namibia. This perennially dry river rises 100 km from the coast below the Great Escarpment at an altitude of 1,000m - that is, it rises within the west coast desert environment where the precipitation is 150mm p.a. and traces a braided course westwards across the Namib Plain, which becomes progressively more arid (50mm is a rough average for the coastal yearly precipitation: Goudie 1972). At present the Tumas is prevented from reaching the sea by a narrow cordon of dunes (1 - 2 km) at the coast behind which its floodwaters are ponded in a depression, or "vlei".

How often the Tumas floods is not known, but only one flood has occurred in a local wadi at the Gobabeb Research Station (30 km to the south of the Tumas) since the Station was founded 18 years ago (Marker 1977). By contrast the allochthonous Kuiseb and Swakop Rivers rise well inland on the better watered plateau (250 - 350mm p.a.) and they flow almost every year.

The valleys are thus geomorphically very different. The Tumas is a wide shallow valley, its braided course being four to seven kilometers in overall width, with terraces 20 - 30m above the present talweg. The Kuiseb and Swakop Rivers are characterised by canyons cut 200m deep into the Namib Plain (Fig. 1).

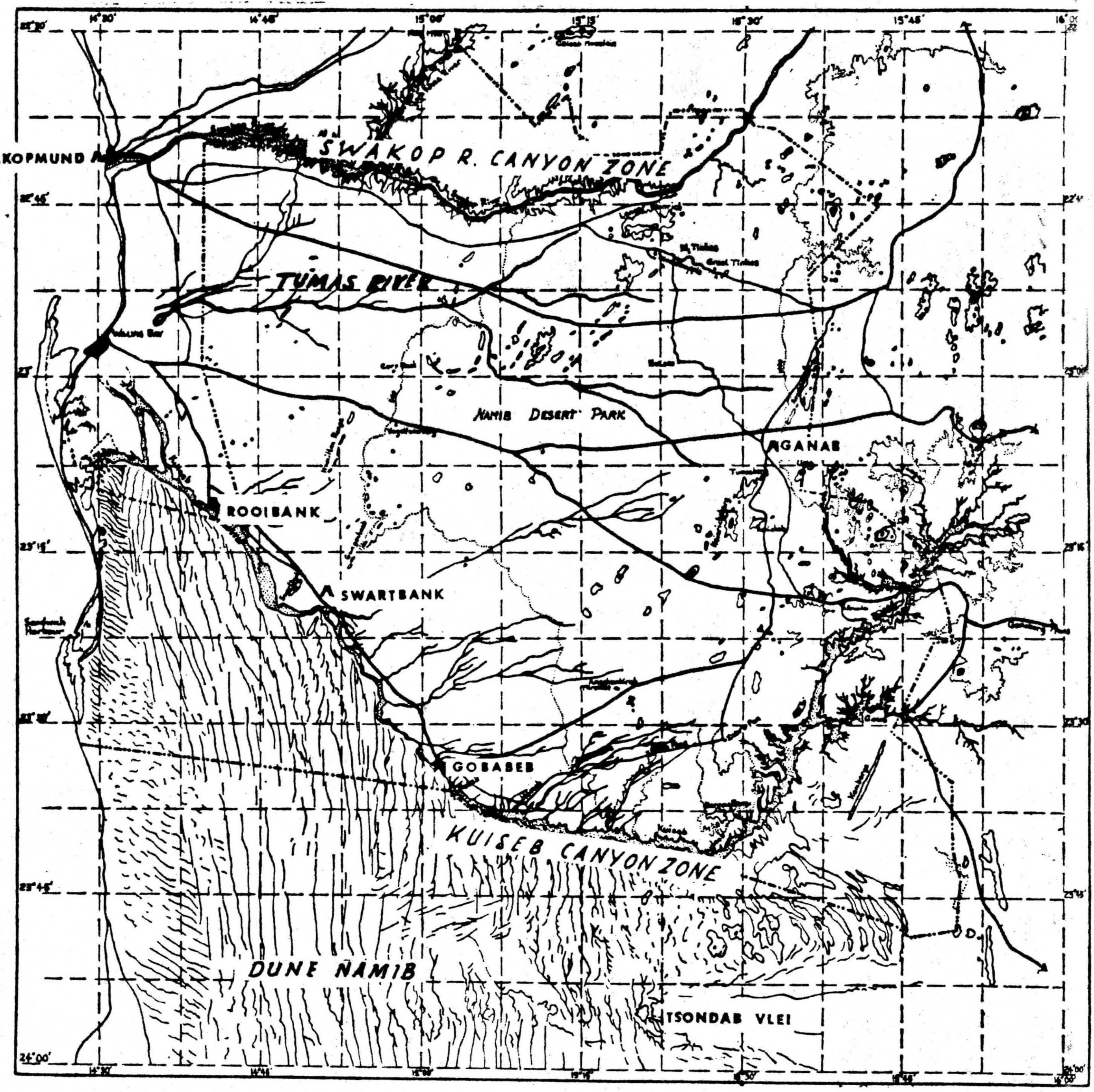

Fig. 1 : The Central Namib Desert (after Seely and Stuart 1976)

South of the Kuiseb River lies the extensive Dune Namib (34,000 km^2; Barnard 1973), a sand sea with some of the highest dunes in the world (300m; Barnard 1973)which stretches southwards along the coast for 500 km with a breadth of up to 100 km. The Kuiseb R. floods effectively prevent the northward-migrating dunes from overrunning the stony desert plains of the Tumas basin and beyond. However,the floods have only actually reached the sea fifteen times during the period 1837 - 1963 (Stengel 1964), thereby allowing the dunes to migrate across the Kuiseb delta and accumulate as the coastal dune cordon which stretches north 25 km to the Swakop R. mouth. Floods in the latter river effectively prevent this smaller dune mass from crossing.

The purpose of this paper is to outline some Pleistocene environments by presenting the preliminary findings of a geomorphic study and a drilling program carried out in the middle course of the Tumas basin (15 - 75 km inland from the coast); and to interpret the findings in relation to various recent studies of the Pleistocene history of the Namib, both on the coast, and to the east at the foot of the escarpment.

Though fragmentary, there is much evidence which points to climatic fluctuations in the Namib during the Quaternary and earlier. Moister conditions than exist today are suggested by several reports of fossil soils. Calcretes occur near the coast in a climate considered too arid for their present formation (Goudie 1972). "Buried, fossil, reddish-brown soils" immediately north of the Kuiseb near the Gobabeb Research Station are described by Scholz (1972), who reports that they are fairly widespread.

A paleosol is reported by Selby (1976) buried within the calcreted basal sands of the Dune Namib, and Scholz (1976) mentions reports of buried soils near the coast at Walvis Bay and Rooikop.

Calcareous cave deposits in the Erongo Mts, taken to imply moister conditions in the past, are reported by Martin and Mason (1954) and also by Wilkinson (1976) for the Swakop canyon zone. Korn and Martin (1955) interpret a Middle Stone Age "pluvial" for the Naukluft Mts. in the south.

Geomorphological and sedimentological analyses at several points along the coast, from Walvis Bay 60 km northwards, have documented three moister periods (with local gully incision and fan development), each followed by drier phases of active sand movement or gypsum crust development (e.g. Wieneke and Rust 1973, 1976). These fluctuations relate to Last Glacial times. High sea levels are correlated with drier fluctuations by means of the prominent terraces in the lower Swakop R. (e.g. Rust and Wieneke 1976).

Hydroclimatic changes and zonal atmospheric circulation changes have been suggested as causes for climatic fluctuations on the arid Namib coast. The upwelling of cold water along the coast slackens off during summer at present as atmospheric circulation weakens. Similarly, long term changes in circulation intensity may have affected sea surface temperatures during the Quaternary (Tankard 1975). Tankard (1975) argues for a west coast hydroclimate a full 10°C warmer in the "pre-glacial Pleistocene", but his analyses of open coast marine fauna show that there was no temperature change in the Benguella Current in the Last Glacial (Tankard 1975, p.13).

Valentine (1955) has argued for a general warming of oceanic waters in the Last Interglacial which may have had a marked effect on the Namib environment.

On a wider scale Zinderen Bakker (1967) has suggested that a northerly shift of the South Atlantic High during Interglacials would probably have affected most of the interior of the African subcontinent even bringing the southern parts of the Namib within the range of the storm tracks of the circumpolar westerlies. Zinderen Bakker and Butzer (1972) mention an alternate hypothesis suggested by J.Bjerknes: world climatic belts may have shifted southwards as a result of the growth of continental glaciers in the northern hemisphere thereby bringing southern Africa entirely within the summer rainfall belt. Because of the strong local effect of the Benguella Current it is difficult to know how much the Namib could have been influenced by such zonal atmospheric shifts.

2. Pleistocene Events in the middle Tumas R.basin.

Several deep boreholes have shown that the sediments in the study area are more than 100m thick. It is not known at what level the Pleistocene succession begins. The percussion drill method used for the main drilling program produces a pulverised and often contaminated "core", depending on the degree of consolidation of the subsurface beds[1]. The Red Sand member is the earliest well-documented deposit in the study area and very probably

1. Drill lines transverse to the valley, were surveyed at kilometer intervals, and 2 km intervals nearthe extremities of the study area. Drill line length varied in accordance with the 5 - 7 km width of the sediment body, along the length of which the Tumas R. flows. Boreholes were drilled 250m apart along each drill line (except on bedrock outcrops) to an average depth of 25m , some holes penetrating to 50m.

Pleistocene in age.

2.1. Red Sand Member

Red-brown to pale pink cemented sands are exposed at the surface over much of the western 26 km of the study area and in two major north-bank tributaries of the Tumas, either where the gypsum crust has been removed, or in vertical section where the river has developed 1-4m high terraces, and in several test pits. Borehole data suggests that this member continues eastward another 10 km at least. It is thus a widespread unit (36 km in length and probably more) restricted to the Tumas valley bottom and its tributaries.

Sections constructed from the drill information indicate that this unit is irregular in shape and thickness, with many pinch-outs. Nevertheless it does increase downstream from average thicknesses of 10 -15m in the east to 15 - 20m in the west, with a maximum thickness of 37m in the westernmost drill line. The upper contact is on average 1 - 4m below the surface. It is a continuous body in the western 35 km of the study area.

The sands are dominantly of blown-sand size fractions, with occasional stony inclusions. Eolian bedding structure is entirely absent in the various exposures. Borehole data suggests that white to gray coarse sand lenses and pebble-to boulder-grade beds are intercalated with the red sands.

The red sands therefore seem to be reworked eolian sand deposited

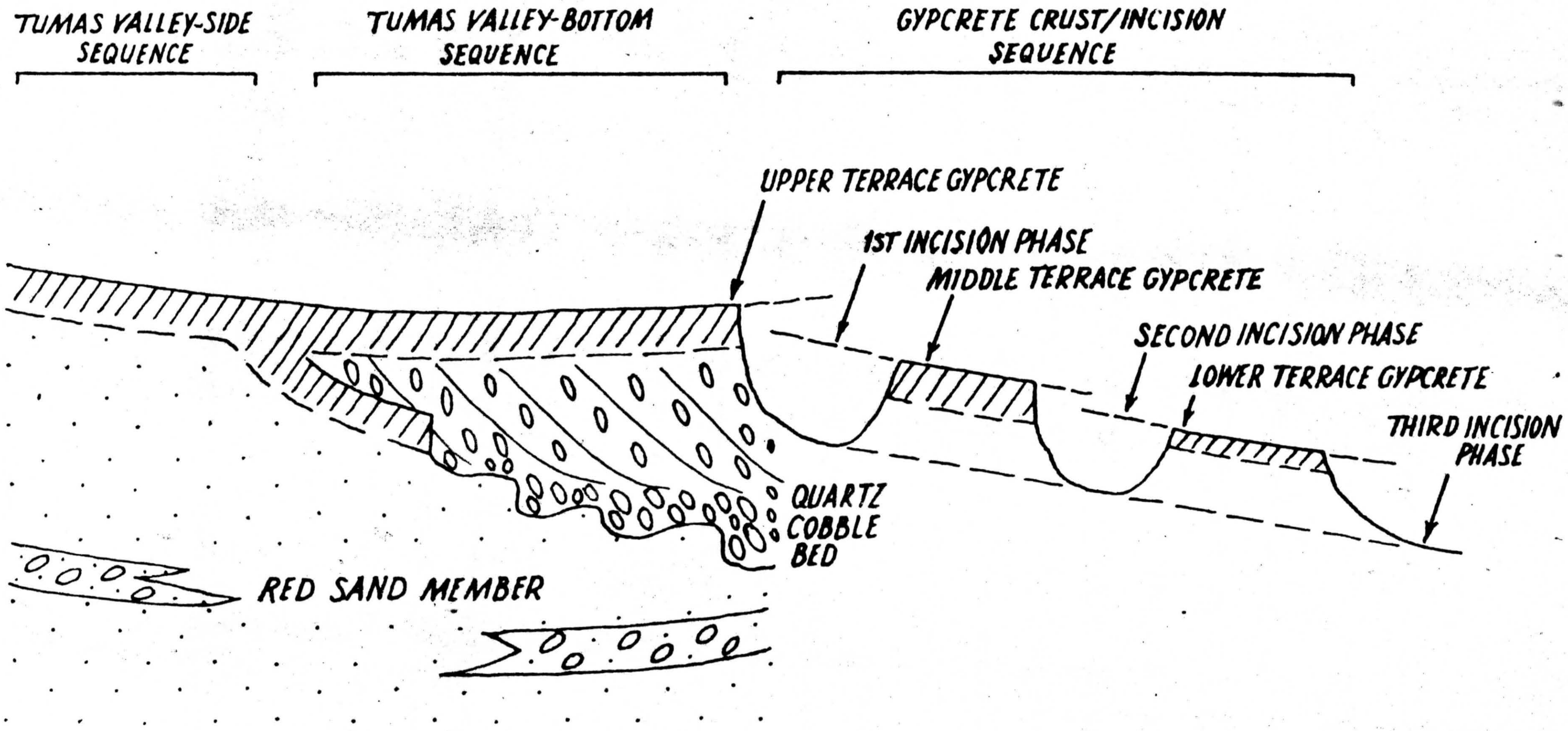

Figure 2 : Pleistocene events of the middle Tumas River basin.

by floodwater. Surrounding pediments were presumably denuded of eolian sand by both wind and water action.

2.2 Gypsum Crusts.

Gypsum crusts, or gypcretes, are confined to a 50 - 60 km-wide strip along the Namib coast which is affected by fogbanks from the Atlantic. These blow in on average 102 days per year, mainly in winter (Goudie 1972). The fogs seem to supply the calcium sulphate which is the main constituent of the gypcretes (Martin 1963).

A hard, porcellanous gypcrete has developed directly on the Red Sand member in areas set well away from the present Tumas bed, and it has developed on the ubiquitous cobble bed (2.3 below) which occupies the central part of the Tumas (Upper Terrace - Fig.2).

Two subsequent gypcrete crusts are documented, armoring the younger terraces in the valley (Middle and Lower Terraces - Fig.2). Crusts vary in thickness with age: the oldest is approximately 1m thick, dense and very hard; the Middle Terrace gypcrete is 50 - 60cm thick with well developed pressure structure features which disrupt the bedding patterns of the host deposit and reduce compaction; the youngest, Lower Terrace gypcrete is usually 10 - 20cm thick, which forms a friable "puffy" surface and displays incipient small pressure structures (wavelengths and amplitudes less than 0.5m).

2.3. Quartz Cobble Bed.

This bed is ubiquitous in the central parts of the Tumas valley and comprises a 1 - 2m thick deposit of wind-faceted quartz material which displays increasing coarse sand matrix and gypcreting upwards, and definite Red Sand components in the lower part. Where structure has not been entirely disrupted by gypsum accumulation, foreset beds seem crudely developed. The lower contact is highly irregular with clasts of the underlying indurated Red Sand included in the Cobble bed. This deposit seems to represent a sheetflood deposit of surface lag material which disrupted the gypcreted Red Sand surface beneath.

2.4. Incision Phases.

Thirty kilometers upstream of the western boundary of the study area, incision into the Upper Terrace gypcrete is first observed. As incision increases downstream this thick, indurated crust becomes a prominent sky-line feature up to 20m above talweg level. However, 15 km from the western boundary little of the Upper Terrace remains as a result of this first incision phase, with the Middle Terrace gypcrete developing across wide areas.

Two subsequent phases of incision can be documented: the earlier resulted in destruction of the outer margins of the Middle Terrace and its replacement by the Lower Terrace and associated gypcrete cap. The youngest phase of incision has cut into the Lower Terrace and up most of the tributaries, excavating the younger, least developed inner margins of the two younger gypcretes (Fig.2).

A drainage reorientation is documented 20 - 25 km from the western

TABLE 1

Pleistocene Events in the Middle Tumas Valley

STAGE	EVENT
1	Sand Sheet Influx (inferred)
2	Fluvial reworking of the sand sheet (Red Sand)
3	Gypcrete
4	Quartz Cobble Bed
5	Gypcrete: Upper Terrace
6	Incision (Drainage re-orientation)
7	Gypcrete: Middle Terrace
8	Incision
9	Gypcrete: Lower Terrace
10	Incision
11	Modern (incipient gypsum)

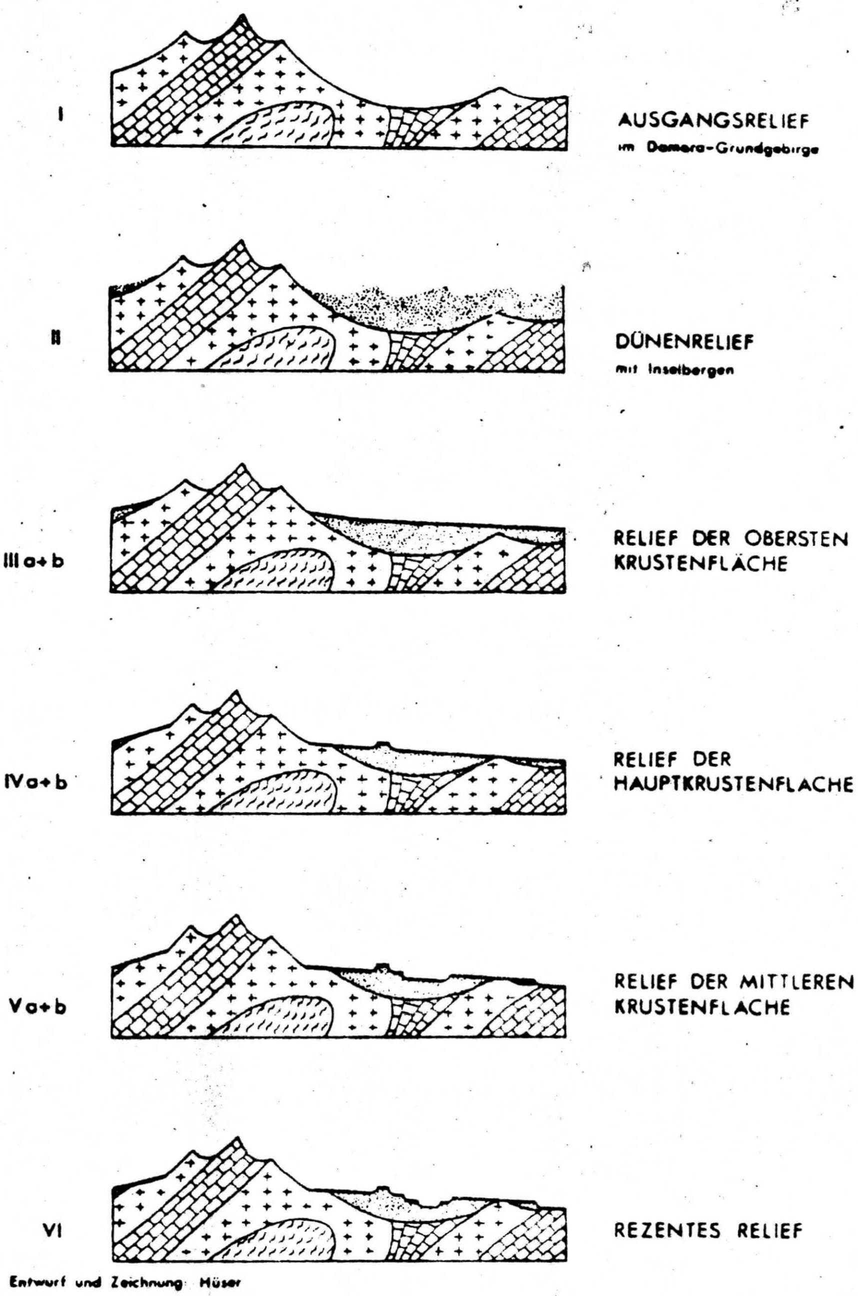

Fig.3 : Geomorphic events east of the Dune Namib (after Hueser 1976)

boundary of the study area: the Upper Terrace gypcrete has preserved shallow valley slopes which indicate that the Tumas flowed approximately one kilometer south of its present position in "Upper Terrace" times. By contrast, the Middle Terrace is everywhere integrated with the present drainage configuration.

The events documented from the study area are presented chronologically in Table 1. The influx and modification of a sand sheet in the Tumas basin is discussed below (Stages 1 and 2 - Table 1), as is the alternation of geomorphic phases of soil formation and incision (Stages 3 - 11 - Table 1).

3. Discussion.

3.1. Possible Regional Correlations.

Recent work by Hueser (1976) suggests that the sequence outlined in Table 1 above may be regionally applicable. The major elements are all present in his study area 120 km south-east of the Tumas basin on the eastern edge of the Dune Namib: an active dune sheet advances into the area; fluvial processes modify the upper surface which accords with rock-cut pediments; a calcrete crust develops on this surface, and apparently rhythmic phases of incision and calcrete development on the new surfaces ensue. Three calcrete crusts of decreasing age result, each followed by a phase of river incision (Fig.3). This essentially follows the sequence outlined for the Tumas (Table 1) from Stage 1 to Stage 11. Hueser even reports drainage reorientations subsequent to the formation of the oldest calcrete crust.

The Tumas valley-side sequence (see Fig.2) parallels Hueser's (1976) most closely - i.e. excluding the more localised quartz cobble bed (Stage 4, Table 1), and assuming the Stage 3 and 5 gypcretes relate to a single phase of geomorphic stability.

A cursory investigation of the Tumas vlei area revealed an unexpected correlation with the inland sequence: a cemented, gritty, mottled red and gray sandy substrate is overlain by a 1 - 2m cobble bed and brown laminated silts. A gypsum crust has indurated the upper meter of the cobble bed. The Tumas has since incised these deposits, to give a sequence reminiscent of Stages 2 - 6 in the study area (Table 1) 45 km upstream.

These possible correlations are relevant to considerations of regional climatic fluctuations and to the problem of dating the terrestrial events by correlation with the marine.

3.2. Past Extent of the Sand Sea.

It seems important to weigh the evidence of a possible advance of the Dune Namib sands into the Tumas basin, in the same way that it migrated inland towards the escarpment (Hueser 1976).

The dune sands have indeed been mobile in the past. There is evidence that the dunes have crossed the Swakop R. mouth as far as Mile 4, just as they cross the Kuiseb delta today (Wieneke and Rust 1976). It is further argued that the mouths of the Kuiseb, Tumas and Swakop have all been blocked at some stage during the Pleistocene by the extension of the dune sands northward along the coast.

Biological evidence suggests that the smaller dune-covered area on the northern coastal strip of South West Africa/Namibia (north of 21°S) has been connected to the major sand mass of the Dune Namib (at present south of 23°S), certainly at some stage in the Tertiary (Zinderen Bakker 1975).

Scholz (1972) has argued that the thick (more than 10m), horizontally-bedded silts in the Kuiseb canyon 70 km from the coast must represent a damming of the Kuiseb by advancing dunes. An older, cemented cobble deposit also exists in the lower levels of the canyon, and it too may indicate that the dunes breached the river well inland. It is thus not unreasonable to suggest that the dune sea may have crossed the Kuiseb on a front far wider than the present coastal dune cordon width. Given time and favourable conditions, dunes would experience no impediment to to their migration into the Tumas basin.

Color shifts in the Red Sand member reflect those in the Dune Namib, further suggesting a possible connection between the two. The Red Sands are reported to be a darker brownish red in the eastern third of the study area (P.Woodhouse, pers. com.) than further downstream according to borehole samples. Besler (1976) has documented a similar difference in the Dune Namib, yellower sands occurring near the coast and redder sands with increasing distance inland.

3.3. Climatic Implications.

Red Sand Member. With decreasing runoff from the plateau and

and escarpment zones, the Kuiseb would be unable to maintain its course to the sea. In this sense desiccation inland would act as the trigger for a wholesale advance of the sand sheet.

Besler (1976) however, has argued that wind systems may have been more vigorous in the past, based on her analyses of dune types and orientations. She implies that even without a reduction in runoff a more mobile sand mass might cross the Kuiseb.

Hueser (1976) suggests that the easterly extension of the Dune Namib towards the escarpment relates to an extremely arid "interpluvial" phase. Increasing aridity on a regional scale would seem to be the best explanation at present for the advance of the dunes eastwards and northwards beyond their present limits, if it is indeed true that the Red Sands of the Tumas are reworked eolian deposits.

Fluvial reworking appears to have affected most or all of the Red Sand Member , as evidenced by the many lenses of coarse sand, pebbles and cobbles intersected within or at the same level as this member. The borehole data also suggest there may have been two,more important episodes of Red Sand deposition in the western 8 km of the study area separated by a gypsiferous gray-white sand unit. The lower contacts of these strata are suggestive of fluvial paleochannels.

Hueser (1976) claims that a radical shift of climate to moister conditions must be invoked to explain the the fluvial leveling of the dunes in his study area to the east of the Dune Namib. Fluvial reworking in the of the Red Sands in the tributaries of the Tumas near the coast suggests moister conditions over a wider area, if indeed the phases of reworking were coincident.

Gypsum Crusts, Calcretes and Incision Phases. The calcrete caps reported by Hueser (1976) lie in an area with a rainfall of ca.150mm p.a. Goudie (1973), while noting that calcretes in the Namib seem to have "no definite dry limit", nevertheless does suggest that 100 - 200mm of yearly rainfall is a general "dry limit" for calcrete development. A small precipitation increment and/or evaporation reduction therefore, might raise the soil moisture to well within the 100/200mm to 500mm annual precipitation range which characterises so many calcrete environments (500mm is significant "in many parts of the world"as a maximum rainfall cutoff point, although calcretes occur in northern Namibia in present environments of 850mm yearly rainfall - Goudie 1973,p.96 and Table 32). Hueser (1976) envisages a rainfall of 450 - 750mm p.a. for the development of the calcretes east of the dune field, and this seems a reasonable range.

The same cannot be said for the Tumas crusts however. Hueser (1976) has suggested that the three inland calcrete caps are related to the three "moist active"phases of the Wieneke and Rust model. However, by this model the three Tumas crusts are assigned to "dry stable" morphogenetic phases. Further detailed analyses will help elucidate this problem. At present the Tumas crusts are enigmatic in terms of environmental reconstructions, especially in the light of the rapid climatic gradient which exists between the coast and the escarpment. What is certain is that the crusts represent a period of geomorphic stability by contrast with the incision phases.

Incision phases, first dissectional and subsequently denudational relate more plausibly to explanations of climatically induced geomorphic change than of sea level controls, since the Tumas has been insulated from such effects probably for the last 30 000 years by the coastal dune barrier (Wieneke and Rust 1976). The suggestion that the inland calcretes relate to the three "moist active" phases at the coast (Hueser 1976),implies that postive geomorphic balances predominated on the inner margins of the Namib with simultaneous linear dissection nearer the coast in the middle Tumas drainage, by the model of Wieneke and Rust (1976).

Certainly a greater discharge than present seems required for the removal of Tumas sediments during cutting phases. Little more can be said with the limited amount of analysis thus far conducted.

3.4. Preliminary Absolute Chronology.

The following is an attempt to provide a temporal perspective for the events under discussion, with the explicit realization that the geological and geomorphological correlations of inland and coastal sequences with the Tumas are highly tentative as yet.

If the inland calcretes do infact correlate with the "moist active" phases documented at the coast (Wieneke and Rust 1976), as Hueser (1976) suggests (p.76), then the oldest calcrete crust predates a marine transgression which has been dated at ca. 36,000 BP (Wieneke and Rust 1976). Similarly the intermediate calcrete crust predates a transgression dated with greater confidence at ca. 26,000 BP (Wieneke and Rust 1976). This implies similar ages for the two higher Tumas sequence gypcretes.

The same conclusion arises if the correlation between the middle Tumas terraces and the Tumas vlei sequence is valid. The latter appears, on altimetric grounds, to be older than the first marine transgression - and its associated platform - mentioned above. Therefore the Upper Terrace gypcrete phase, assuming correlation with the gypcreted surface capping the vlei sequence, also predates ca.36,000 BP.

Two U/Th dates of 400,000 BP have been obtained on uraniferous precipitates in the Red Sands, above present talweg level (P.Levinson, pers.com.). The precipitation phase must post-date the emplacement of this unit, suggesting that Stages 1 and 2 (Table 1) are older than this determination.

4. Conclusion.

Locally there is evidence of phases of aridification and humidification along the Central Namib coast, on the Namib Plain (Tumas study area), and inland near the escarpment. It is tentatively suggested that portions of the study area sequence can be correlated with portions of the other two. This implies that proposed climatic causative factors were of regional rather than local importance.

The suggested sand sheet influx, and its subsequent reworking argue for a very arid period and a subsequent moister-than-present period. Both events occurred prior to 400,000 BP, although more determinations than the two available will have to be acquired to secure this date.

Climatic inferences from the gypcrete/incision phases are less easy to ascertain. Preliminary correlations imply Last Glacial dates for these events.

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