# Vegetation polygons in the central Namib Desert near Gobabeb

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CONTENTS



ABSTRACT

In the vicinity of Gobabeb, both north and south of the Kuiseb River, well developed vegetation polygons have been noted. Previous workers have concentrated their efforts on the patterned ground features in the interdune valleys south of the Kuiseb. Two other areas of patterned ground development are described and it is proposed that all three types are genetically similar. Desiccation of gypsum rich sediments in the soil horizons and/or the partially weathered bedrock horizon appears to have produced the polygonal fissure networks.

## 1 INTRODUCTION

During the summer of 1977 – 1978 precipitation in the central Namib Desert was two or three times the long term average. Gobabeb received about 100 mm compared with the earlier long term mean quoted by Schulze (1969) of less than 30 mm. As a result of this the vegetation cover was considerably more extensive than usual, revealing well developed polygonal patterns. These features are the product of large scale soil structures which, although noted by other workers (Goudie, 1972; Ollier and Seely, 1977), have never been fully investigated. Previous studies have concentrated on the patterned ground found in the interdune valleys south of the Kuiseb River, near Gobabeb. This examination will attempt to describe and interpret three distinct types of vegetation polygons, those found on the granite plains near Gobabeb, those associated with gypsum crusts in the vicinity of Swartbankberg, 40 km south-east of Walvis Bay, as well as the interdune patterned ground (Fig. 1).

## 2 GRANITE/GRAVEL PLAINS

The undulating plains to the north of the Kuiseb River are composed of Proterozoic Damara System metamorphic rocks with intrusions of Post-Damara (Khomas and Hakos) Salem Granites. In the vicinity of Gobabeb mica schists with intrusive granite and associated feldspar pegmatite predominate (Martin, 1965). The surface materials in the area are shallow lithosols derived from the weathering of the bedrock though there are also areas of fossil reddish-brown soils and gypsum and gypso-calcareous crusts (Scholz, 1963, 1968 and 1972).

The vegetation polygons in this area are rarely well developed. They consist of lines of grasses which define a net pattern. The lines are generally between 5 and 20 cm wide with the central areas of the polygons being 2 to 5 m in diameter. There are other forms of vegetation patterning in this area, for example, lines of plant growth directly associated with widened joints in the granite bedrock and also rings of vegetation around partially buried granite core boulders which have been weathered by desquamation (Scholz, 1972).

It is possible that the net patterns are also the product of preferential growth of vegetation along joint lines in the bedrock. In most cases, however, the vegetation polygons are found in areas with lithosols over 1 m deep. Though the plant root systems may tap groundwater and soil moisture from great depths in arid zones, here they do not utilise the bedrock joints in exposed rock masses or beneath shallow soil cover as much as they do the polygonal fissure systems on the deeper soils and lithosols. These systems appear to be independant of the larger bedrock networks identifiable on the outcrops. The vegetation grows in cracks filled with sandy material. This sand is a mixture of rounded, iron oxide stained quartz grains and angular quartz fragments. The polished surfaces and roundness of the former are characteristic of desert dune sand while the iron staining is the same as that on sand grains from the dunes south of the Kuiseb River. Apparently these grains represent Namib dune sand which has been blown across the river. The angular quartz grains show no signs of abrasion or weathering and are probably of recent derivation from the weathering of local bedrock. The sand covers the bulk of the plains near Gobabeb to a depth of 5 to 20 cm but extends to more than 20 cm in the cracks. In the areas with vegetation polygons the sand overlies a silty-clay horizon about 5 to 15 cm thick. This in turn overlies coarse granite fragments which are frequently partially consolidated by calcium carbonate and/or gypsum (figure 2A). Evidently the vegetation grows in the cracks because the roots have easy access to soil moisture below the clay horizon which is relatively impenetrable to the root systems.

The cracks may originate in two ways. Firstly, they may be the result of volume changes in the clay layer caused by wetting and drying cycles. Scholz (1973) stated that attapulgite and halloysite are the main clay minerals associated with the granites but locally montmorillonite may predominate (Rust, 1970). The large volume changes that occur when montmorillonite undergoes wetting and drying could account for the large scale crack patterns (Ollier, 1966). Alternatively the cracking may be related to the materials cementing the granite debris beneath the clay layer. The clay horizon from 5 to 20 cm below the surface has a calcium carbonate content of less than 3 % by weight, while the gypsum content is less than 0,5 %. This compares with a sequence through the underlying weathered granite lithosol showing high calcium carbonate levels at the top but decreasing with depth while the percentage gypsum increases down-profile (table 1).

TABLE 1: Calcium carbonate and gypsum concentrations in a granite lithosol profile from the granite plains north of Gobabeb.

| Depth | $CaCO_3$%. | $CaSO_4\ 2H_20$%. |
|---|---|---|
| 20 cm | 67.14 | 1.12 |
| 30 cm | 5.12 | 50.41 |
| 40 cm | trace | 63,21 |
| 50 cm | 17.07 | 54.35 |

Similar profiles have been described by Scholz (1972) and are probably the result of leaching of the minerals from surface deposits and precipitation of the less soluble calcium carbonate above the gypsum. This *per descensum* model of soluble salt accumulation has been described by Page (1972) in relation to Tunisian gypsum crusts, while Krupkin (1963) and Yaalon (1964) have examined the mechanisms experimentally and theoretically. Soluble salts deposited at the surface are leached through the soil horizons by rain-water.

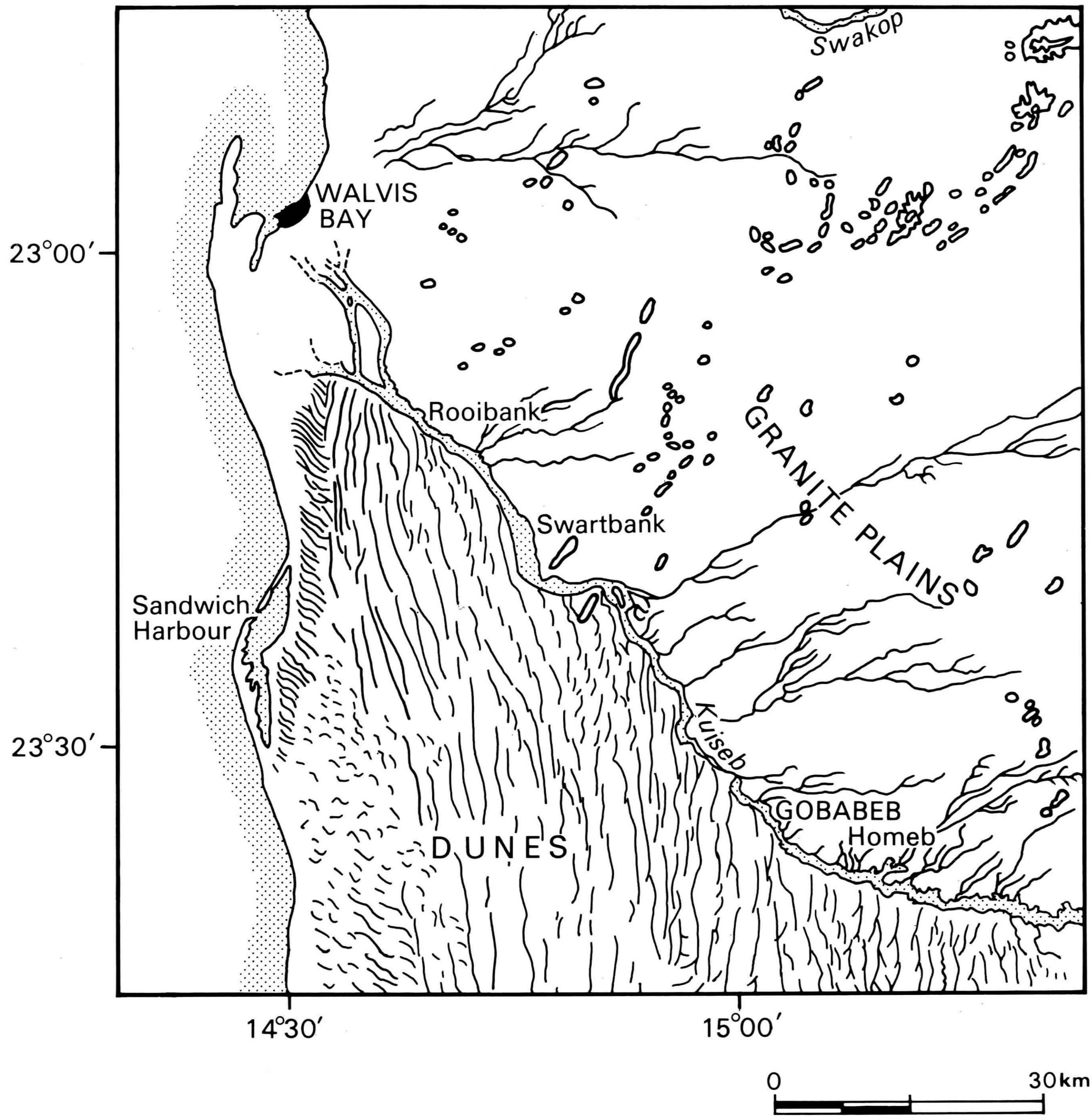


FIGURE 1: The Central Namib Desert near Gobabeb; major dune crests are marked to the south of the Kuiseb River and to the north high ground is encircled.

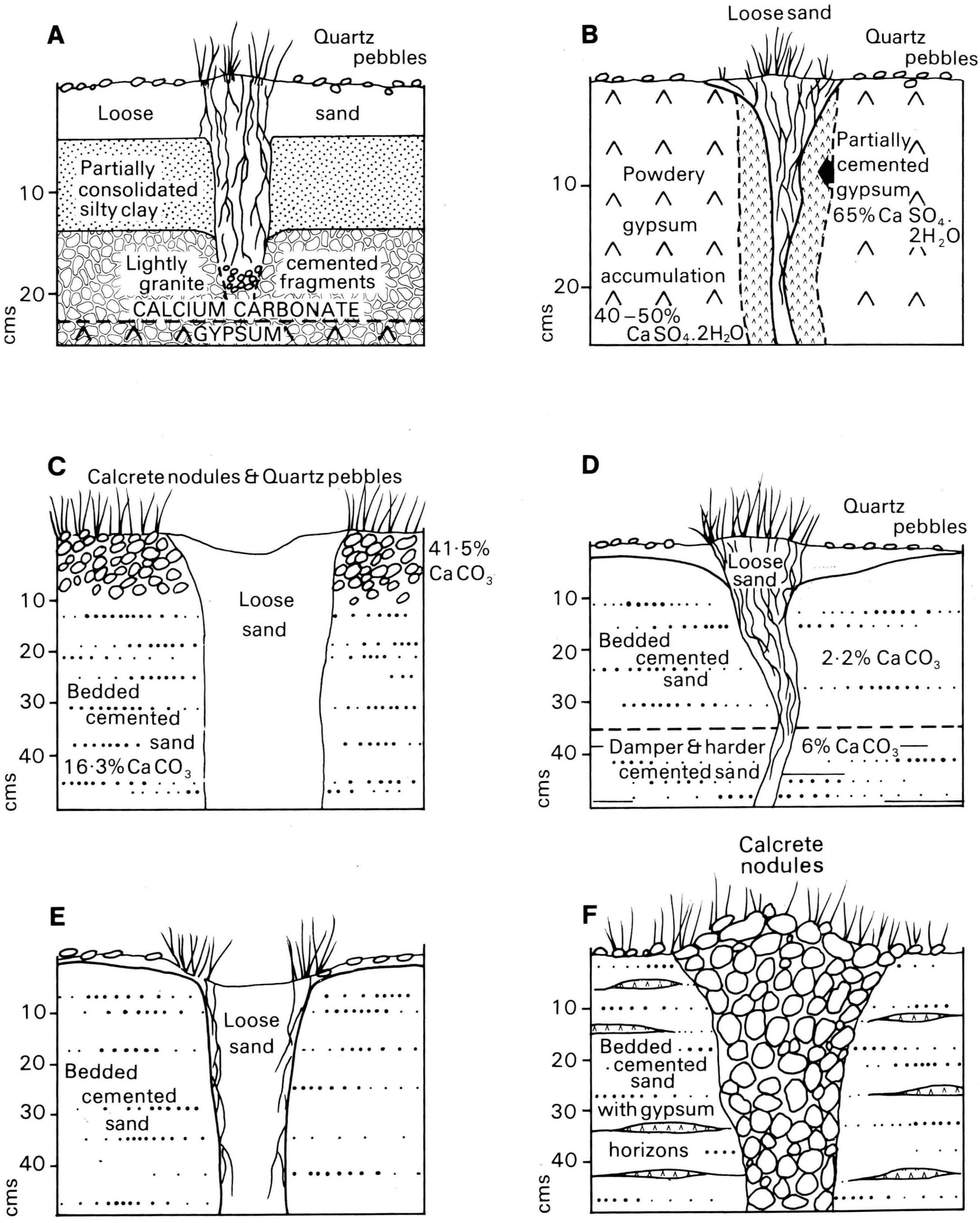


FIGURE 2: Soil profiles across polygon edges: a) Granite/gravel plains north of Gobabeb; b) Gypsum crust area near Swartbankberg; c) Interdune area. Vegetation-free polygon edges; d) Interdune area. Vegetation along fissures; e) Interdune area. Intermediate zone between c and d; f) Interdune area. Polygons with raised edges.

In dry soils the water will replace the soil moisture lost by evaporation during antecedent dry conditions. The salts are precipitated as this soil moisture evaporates during the following dry period. As long as the amount of rain-water available at any one wet phase is insufficient to replace the soil moisture deficit, the salts will not be flushed out of the soil zone. Over a period of several wetting and evaporating cycles the most soluble salts will accumulate at the greatest depth and the least soluble salts nearest the surface. In table 1 the dominance of gypsum beneath a calcium carbonate rich horizon can be explained by the greater solubility in water of calcium sulphate than calcium carbonate, provided the pH does not fall below about 5. The salts required to form these accumulations were probably deposited at the surface as fog moisture evaporated. Walter (1936 and 1937) and Boss (1941) have shown that Namib fogs are capable of depositing up to 100 $g/m^2$ of soluble salts annually, with an average of 20 $g/m^2$.

It is possible that volume changes occur when these soluble mineral accumulations in the soil undergo desiccation. This will be dealt with in the context of the patterned ground associated with gypsum crusts.

## 3 VEGETATION POLYGONS ON GYPSUM CRUSTS

A number of workers (Kaiser, 1929; Kaiser and Neumaier, 1932; Martin, 1963; Scholz, 1963; Besler, 1972; Wieneke and Rust 1973 and 1975; Rust and Wieneke, 1976) have referred to the gypsum crusts of the central Namib Desert but few have described the geomorphic locations, structures or possible origins. There are examples of the three main genetic forms of gypsum crust (Watson, 1979) in the Namib Desert. These are evaporitic crusts, *croûtes de nappe* and surface gypsum crusts. The last of these predominate in South West Africa. They are located on hill tops as well as over large areas of the gravel plains where they underlie a lag of pebbles on the surface. These characteristics suggest that the gypsum crusts are pedogenic features of illuvial origin, their exposure at the surface being the result of deflation of the fine fraction of the original overburden.

Patterned ground associated with gypsum crusts has been described by a number of workers in north Africa (Coque, 1955 and 1962; Butzer and Hansen, 1968; Page, 1972; Vieillefon, 1976) and by Besler (1972) in the central Namib. There are essentially two forms. The first consists of small polygons 0,25 to 1 m in diameter which are associated with large columnar structures in the gypsum crust extending up to 2 m below the surface. This form is rare in the Namib. The second form is found in the central Namib between Rooibank and Swartbankberg. The polygons are between 2 and 6 m in diameter, their edges being defined by lines of grass growth while the rest of the surface is devoid of vegetation. As in the case of the vegetation polygons on the granite plains the grasses grow in sand filled cracks. The quartz sand has 1 % to 2 % gypsum and 2 % to 3 % calcium carbonate. The rest of the surface is composed of powdery material containing 30 % to 40 % calcium carbonate and 40 % to 50 % gypsum. Occasionally this surface is masked by a layer of sand and pebbles usually less than 5 cm thick. The fissures are 5 cm to 10 cm wide and up to 60 cm deep. They have walls composed of slightly indurated material with a gypsum content of over 65 % and a calcium carbonate content of less than 5 % (figure 2B and plate 1). Evidently the continual movement of moisture down the cracks has resulted in solution and reprecipitation of gypsum on the fissure walls.

These large polygons have never been examined in detail. The clay content of the soil is generally very low, less than 5 % by weight, so volume changes resulting from desiccation effects on clays (Ollier, 1966) would not play a significant role. Large polygonal features have been reported from salt lakes in the western United States (Lang, 1943; Willden and Mabey, 1961; Christiansen, 1963; Neal and Motts, 1967). These are formed by saline water movement and desiccation causing tensional stresses on the rigid salt crust. Tucker (1978) suggested that the columnar structure of some gypsum crusts might be explained by similar desiccation stresses. However, the large ratio of depth to surface diameter of the columns is not in keeping with the salt lake polygons which are up to 300 m in diameter but have fissures the depths of which are generally a tenth of the surface diameter. Alternatively, the volume decrease may be the result of mineralogical changes in the gypsum. Chatterji and Jeffery (1963) and Hunt, Robinson *et al* (1966) have shown that there is a 5 % volume change when gypsum ($CaSO_4.2H_2O$) dehydrates to hemihydrate ($CaSO_4.½H_2O$). Under conditions of low relative humidity dehydration can occur when temperatures reach 30°C. The volume reduction of dehydration to anhydrite ($\gamma$- or $\beta$-$CaSO_4$) would be even greater but the high temperatures required to dehydrate solid phase calcium sulphate probably occur naturally only several hundred metres beneath the earth's surface. It may be necessary to invoke chemical dehydration to explain the columnar structures of some crusts, yet evidence from Tunisia (Page, 1972) suggests that these structures are confined to pedogenic crusts consisting of over 85 % gypsum. It would appear that the development of the structures is closely related to the processes involved in the subsurface accumulation of gypsum by almost total chemical replacement and/or physical displacement of pre-existing materials. The large scale polygonation of the central Namib gypsum crusts seems to be the product of volumetric contraction resulting in fissuring of a semi-cohesive surface layer, the cohesion is caused by gypsum cementation. Volumetric contraction may be attributed to progressive drying of the gypsum crust from the surface downwards. In effect the polygonation is caused by essentially the same processes as those that occur on some

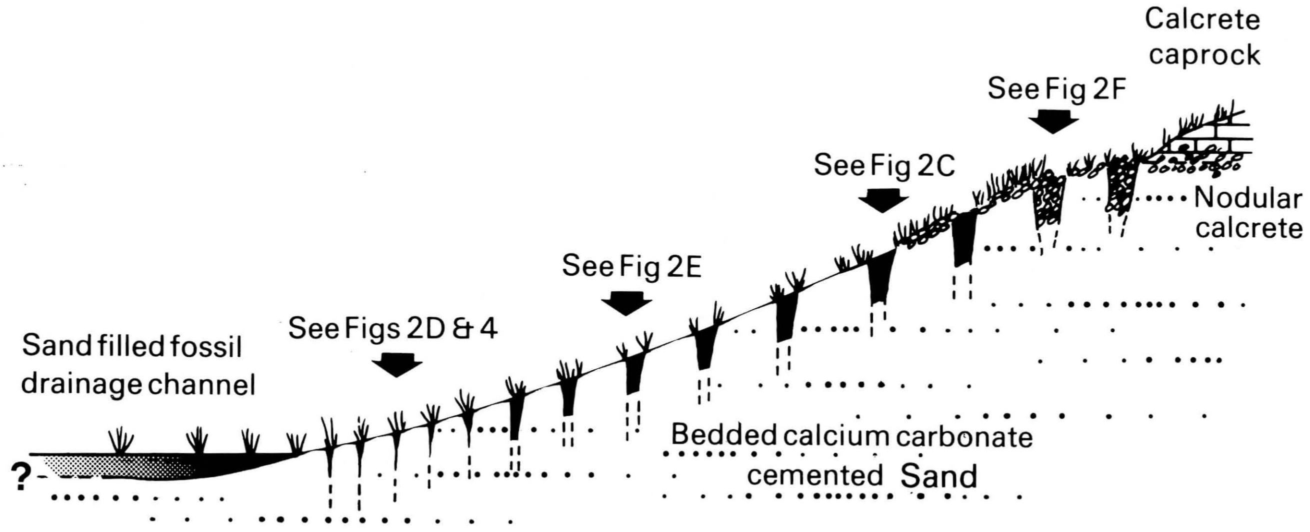


FIGURE 3: Diagrammatic section showing the transition of vegetation characteristics in the interdune valleys.

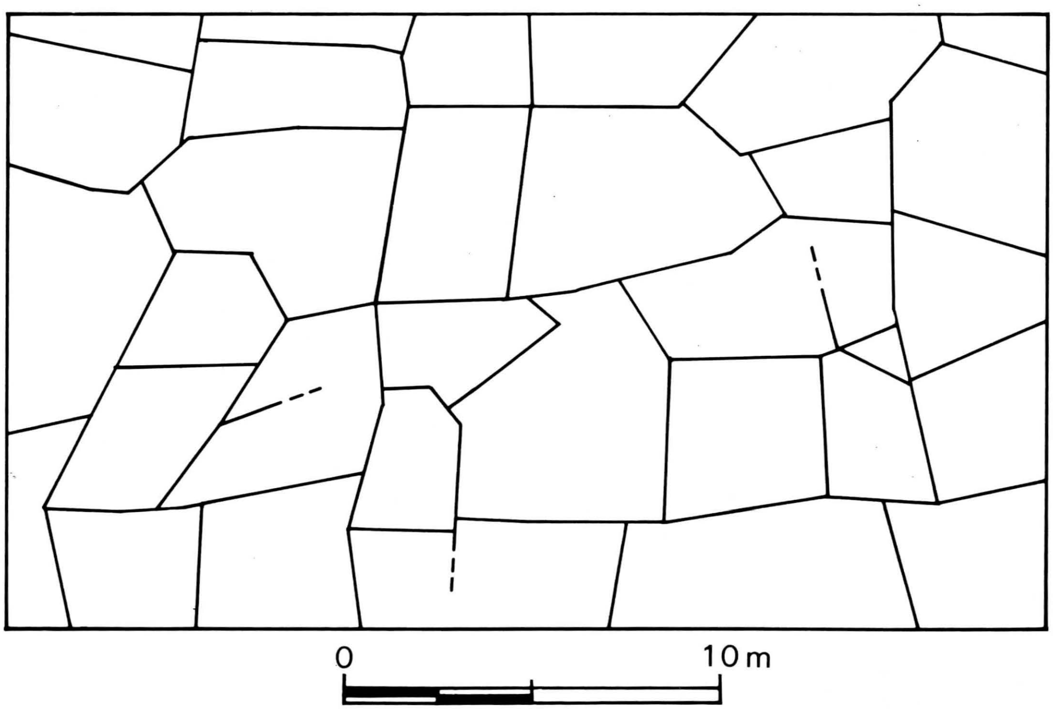


FIGURE 4: Vegetation polygon pattern defined by *Stipagrostis gonatostachys* growing in the fissures, interdune valley south of Gobabeb. Surveyed approximately with tape measure and compass, east is to the top of the diagram.

salt lakes. Furthermore, the ratio of fissure depth to polygon diameter is in keeping with that of salt crust desiccation structures, that is 1:10.

Once the cracks have developed they are maintained through the processes of infilling with wind-blown sand and moisture seepage through this permeable medium.

## 4 VEGETATION POLYGONS IN INTERDUNE VALLEYS

A number of different forms of patterned ground have been described bordering the Kuiseb River, south of Gobabeb. All the types form random orthogonal nets and rarely achieve pentagonal or hexagonal patterns (plate 2). Goudie (1972) identified three different forms; polygons with raised edges up to 40 cm high and surface diameters up to 20 m; those with raised central portions; and those with depressions marking the edges (plate 3). Ollier and Seely (1977) classified the features according to different vegetational characteristics; those having vegetation along the cracks and a bare surface; those with grasses on the surface and edges free of vegetation; and an intermediate form with complete grass cover but dominant growth along the polygon edges. They interpreted the differences in terms of the characteristics of the surface materials. The polygons with edges defined by vegetation are located on exposures of calcium carbonate cemented dune sand. The grasses root preferentially in the cracks where moisture is available. In the areas where there is what Ollier and Seely (1977) tentatively term an 'alluvial' fill the fissures are too well drained for plant growth but the surface of the polygon can support growth. The subdivision between these two forms cannot easily incorporate the intermediate type which is not explained.

The patterned ground is located on the sides of dry river valleys dissecting the calcrete capped 42 m terrace of the Kuiseb River described by Goudie (1972). The channels incise the calcium carbonate cemented sand which underlies the bulk of the Namib dune field. They appear to represent overflow channels or distributaries of the Kuiseb. The origin of these channels, which may be identified in many areas along the south bank of the Kuiseb River between Homeb and Gobabeb, has not been adequately explained by any of the workers who have examined the geomorphology of the river recently (Wieneke and Rust, 1973; Rust and Wieneke, 1974; Ollier, 1977; Marker, 1977; and Marker and Mueller, 1979). The channels are now overlain locally by longitudinal dunes. It will be shown that the character of the fissures forming the patterned ground is dependent on their position on the sides of these dry channels (figure 3).

The larger polygons, up to 20 m in diameter with cracks 20 to 30 m wide, are found immediately downslope from the pebbly calcrete caprock of the 42 m terrace. Here the polygon surface is composed of a lag of pisolitic calcrete overlying the cemented sand, while the fissures are filled in with loose wind-blown sand. Here the grasses, predominantly *Stipagrostis gonatostachys*, can obtain moisture by rooting in the nodular debris but not in the well drained sand in the cracks (figure 2C). Near the floors of the dry valleys, which may be up to 20 m deep and 200 m wide, there is no longer a nodular calcrete lag and the cemented sand is exposed. This material is bedded sub-horizontally and is relatively resistant to plant root penetration, although there is available moisture within 20 cm of the surface. In this area the polygons are only 4 to 8 m in diameter and the sand filled cracks are less than 10 cm across. Here the *Stipagrostis gonatostachys* roots in the cracks which, being narrower than at the top of the slope, are not as well drained (figure 2D, figure 4 and plate 4). Though the density of the network changes the topology remains the same. Between these two extremes is a zone in the middle of the slope where the bedded sandstone again precludes plant growth but the cracks are 10 to 20 cm wide and moderately well drained. Here the grasses grow at the edges of the cracks but not in the centre, thereby utilising optimal conditions of rooting potential and moisture availability at the side of the sandstone block (figure 2E).

The patterned ground with raised edges described by Goudie (1972) is relatively uncommon compared with the aforementioned forms. It occurs at the highest parts of the valley sides and appears to represent fissures in the sandstone which have been filled with purer calcrete nodules derived from the caprock. This indurated material is less prone to weathering and erosion than the sandstone and so forms a ridge (figure 2F).

This phenomenon suggests that the cracks in the sandstone predate the development of the pebbly calcrete caprock. Yet the increase in the density of fissures down-slope indicates that other factors are involved. If they are relic features developed on the old land surface their density would decrease with depth. Hence, the cracks are not relic joint systems in the sandstone. The raised edges have probably developed as differential erosion has exposed the nodular calcrete which found its way into the fissures after the sandstone was exposed. It is feasible that the density of the crack network is a function of the amount of moisture in the material when it was first exposed by fluvial erosion. The sandstone lower down the slope would have been moister than that upslope and hence volume reductions caused by desiccation would have been greater producing the denser network. This is also a feature of patterned ground on salt lakes. The deeper the water table is in any locality the larger are the polygons and the widths and depths of the fissures (Neal and Motts, 1967).

The soluble mineral content of the surface materials also appears to play a significant role. There is a marked decrease in the calcium carbonate concentration downslope from the calcrete cap. At the lowest points where the sandstone is exposed it contains between 2 % and 5 % calcium carbonate by weight, while at

PLATE 1: The edge of a vegetation polygon on a gypsum crust near Swartbankberg.

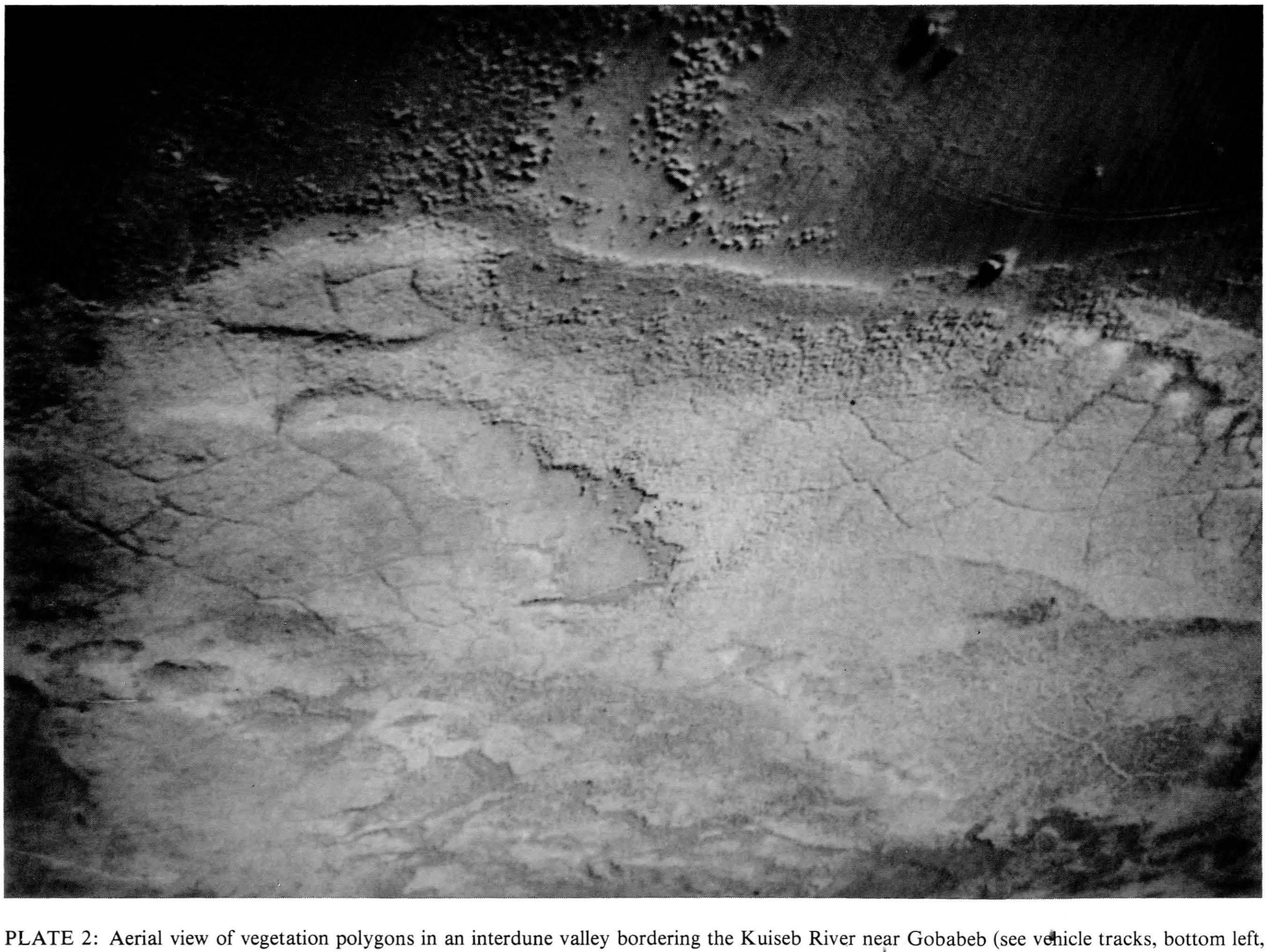

PLATE 2: Aerial view of vegetation polygons in an interdune valley bordering the Kuiseb River near Gobabeb (see vehicle tracks, bottom left, for scale).

PLATE 3: Fissured sandstone in the interdune valley south of Gobabeb.

PLATE 4: Interdune vegetation polygons south of Gobabeb.

the highest levels the figure reaches between 20 % and 40 %. The calcrete caprock contains in the region of 60 % to 70 % calcium carbonate and no fissuring is evident. It is possible that the high calcium carbonate concentrations consolidate the sandstone and inhibit fissuring. Both Goudie (1972) and Scholz (1972) pointed out that the soils of the interdune valleys are gypsocalcareous. Analyses of the sandstones and calcretes associated with the patterned ground reveal gypsum contents less than 1 % by weight, though in certain localities 1 to 2 cm thick bands of material with up to 60 % gypsum are found in the bedded sandstone. The increase in gypsum content with depth below calcrete horizons noted on the granite plains north of the Kuiseb is also likely to occur in the interdune valleys. In the latter area, however, the greater permeability of the surface materials will result in the evacuation of the more soluble gypsum to greater depths. This leaching process is also currently reducing the calcium carbonate content of the sandstone surface (figure 2D). Hence the patterned ground may be a product of high gypsum contents at the time of exposure of the sandstone and its desiccation. This interpretation is supported by evidence from identical fossil river channels found in the interdune valleys south of Homeb, 15 km further inland. Here the climate is too wet and/or the area too distant from the coast for gypsum soils to have developed and the vegetation polygons are absent. The only patterned ground in this area consists of sand filled sink-holes in the calcrete caprock. Despite the higher rainfall here the sand is still too permeable to enable plant growth.

## 5 SUMMARY

The vegetation polygons located on the plains north of the Kuiseb River, those on gypsum crusts between Rooibank and Swartbank, and those in the interdune valleys near Gobabeb are all structurally similar. That is, in terms of the topology of the fissure intersections, they are random orthogonal features. On the granite plains the stratigraphy is essentially the same as that described by Ollier (1966) at Coober Pedy in Australia. He attributed the patterned ground formation to volume changes in the montmorillonite layer, not the underlying gypsum. In the Central Namib the fissures extend below the clay horizon and hence the gypsum would seem to play an important role. At Swartbank the patterned ground occurs on materials with very low clay fractions but high gypsum concentrations. In the interdune valleys clays are virtually absent and gypsum horizons are found only locally. Here the bulk of the gypsum has been leached to greater depths since the exposure of the sandstone beds. It is suggested that the main factor in the production of the patterned ground in the central Namib Desert is desiccation of gypsum rich sediments. Variations in gypsum and calcium carbonate concentrations and moisture availability account for different fissure dimensions and network densities.

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