VEGETATION POLYGONS IN THE CENTRAL NAMIB DESERT NEAR GOBABEB

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Vegetation polygons

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Abstract

In the vicinity of Gobabeb, both North and South of the Kuiseb, well developed vegetation polygons have been noted. Previous workers have concentrated their efforts on the patterned ground features in the interdunal valleys South of the Kuiseb. Two other zones of patterned ground development are described and it is proposed that all three types are genetically similar. Desiccation of gypsum-rich sediments seems to have produced the polygonal networks.

Contents

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 millimetres compared with the earlier long term mean quoted by Schulze (1969) of less than 30 millimetres. 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 interdunal valleys South of the Kuiseb, 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 kilometres South-east of Walvis Bay, as well as the interdunal patterned ground, (see figure 1).

Figure 1.

Granite Plains

The undulating plains to the North of the Kuiseb River are composed of Proterozoic Damaran System metamorphic rocks with intrusions of Post-Damaran (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 five and twenty centimetres wide with the central areas of the polygons being two to five metres 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 many cases, however, the vegetation polygons are found in areas with lithosols over one metre deep. This suggests that bedrock structure is not a significant factor. The vegetation grows in cracks filled with sandy material. This sand is a mixture of rounded, iron oxide stained quartz grains, derived from the dunes to the South, and angular quartz fragments from the weathered granite bedrock. The sand covers the bulk of the plains near Gobabeb to a depth of five to twenty centimetres but extends to more than twenty centimetres in the cracks. In the areas with vegetation polygons the sand overlies a silty-clay horizon about five to ten centimetres thick. This in turn overlies coarse granite fragments which are frequently partially consolidated by calcium carbonate and/or gypsum (see 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 inpenetrable 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 has a calcium carbonate content of less than three percent by weight, while the gypsum content is less than 0.5%. This compares with a sequence through the weathered granite horizon showing high calcium carbonate levels at the top but decreasing with depth while the percentage gypsum increases down-profile (see table 1).

Table 1. Calcium carbonate and gypsum concentrations in a soil profile from the granite plains North of Gobabeb.

Depth	$CaCO_3$ %.	$CaSO_4.2H_2O$ %.
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 evidently the result of leaching of the minerals from surface deposits and precipitation of the less soluble calcium carbonate above the gypsum (Krupkin, 1963; Page, 1972). It is possible that volume changes occur when these minerals undergo desiccation. This will be dealt with in the context of the patterned ground associated with gypsum crusts.

Vegetation polygons on gypsum crusts

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 metre in diameter which are associated with large columnar structures in the gypsum crust extending up to two metres 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 two and six metres 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 one to two percent gypsum and two to three percent calcium carbonate. The rest of the surface is composed of powdery material containing thirty to forty percent calcium carbonate and forty to fifty percent gypsum. Occasionally this surface is masked by a layer of sand and pebbles usually less than five centimetres thick. The fissures are five to ten centimetres wide and up to sixty centimetres deep. They have walls composed of slightly indurated material with a gypsum content of over 65% and a calcium carbonate content less than 5% (see 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.

Figure 2 (full page)

These large polygons have never been examined in detail. The clay content of the soil is generally very low, less than five percent 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 metres 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 ($CaSO_4.\frac{1}{2}H_2O$). Under conditions of low Relative Humidity dehydration can occur when temperatures reach 30°C. It may be necessary to invoke processes of chemical dehydration to explain the columnar structures of some crusts, yet evidence from Tunisia (Page, 1972) suggested that these crusts are subsurface in origin and hence have been subjected to different processes than the crusts exhibiting large scale polygonation. It would seem most valid to invoke desiccation of the gypsum-rich sediment to explain the fissures since the dimensional ratios are in keeping with those of salt lake polygons.

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

Vegetation polygons in interdunal valleys

A number of different forms of patterned ground have been described bordering the Kuiseb, South of Gobabeb. All the types form random orthogonal nets and rarely achieve pentagonal or hexagonal patterns (see plate 2). Goudie (1972) identified three different forms; polygons with raised edges up to 40 centimetres high and surface diameters up to 20 metres; those with raised central portions; and those with depressions marking the edges (see 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 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 seems arbitrary and the intermediate type is not explained.

The patterned ground is located in dry river channels dissecting the calcrete capped 42 metre terrace of the Kuiseb described by Goudie (1972). The channels incise the calcium carbonate cemented dune sand which underlies the bulk of the Namib dune field. They appear to represent overflow channels of the Kuiseb. The formation of these channels may be contemporaneous with the infilling of the Kuiseb's main channel with silt deposits further upstream at Ossewater and Homeb. These have been described by Goudie (1972), Wieneke and Rust (1973), Rust and Wieneke (1974), Ollier (1977), Marker (1977), and Marker and Mueller (1978). The channels are now locally overlain by longitudinal dunes. It is evident that the character of the fissures forming the patterned ground is dependent on their position on the sides of these dry channels (see figure 3).

The larger polygons, up to 20 metres in diameter with cracks 20 to 30 centimetres wide, are found immediately downslope from the pebbly calcrete caprock of the 42 metre terrace. Here the polygon surface is composed of a lag of pisolitic calcrete overlying the cemented dune sand, while the fissures are infilled 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 (see figure 2C). Near the floors of the dry channels, which may be up to 20 metres deep and 200 metres wide, there is no longer a nodular calcrete lag and the cemented dune sand is exposed. This material is bedded sub-horizontally and is relatively resistant to plant root penetration, although there is available moisture within 20 centimetres of the surface. In this area the polygons are only four to eight metres in diameter and the sand filled cracks are less than ten centimetres across. Here the Stipagrostis gonatostachys roots in the cracks which, being narrower than at the top of the slope, are not as well drained (see 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 ten to twenty centimetres 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 (see figure 2E).

Figures 3 and 4 (full page)

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 derived from the caprock. This indurated material is less prone to weathering and erosion than the sandstone and so forms a ridge (see 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 relict features developed on the old land surface their density would decrease with depth. 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 down slope from the calcrete cap. At the lowest points where the sandstone is exposed it contains between two and five percent calcium carbonate by weight, while at 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 interdunal valleys are gypso-calcareous. Analyses of the sandstones and calcretes associated with the patterned ground reveal gypsum contents less than one percent by weight, though in certain localities one to two centimetre 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 interdunal 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 reducing the calcium carbonate content of the sandstone surface (see 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 interdunal valleys South of Homeb, 30 kilometres 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.

Summary

The vegetation polygons located on the plains North of the Kuiseb, those on gypsum crusts between Rooibank and Swartbank, and those in the interdunal 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 interdunal 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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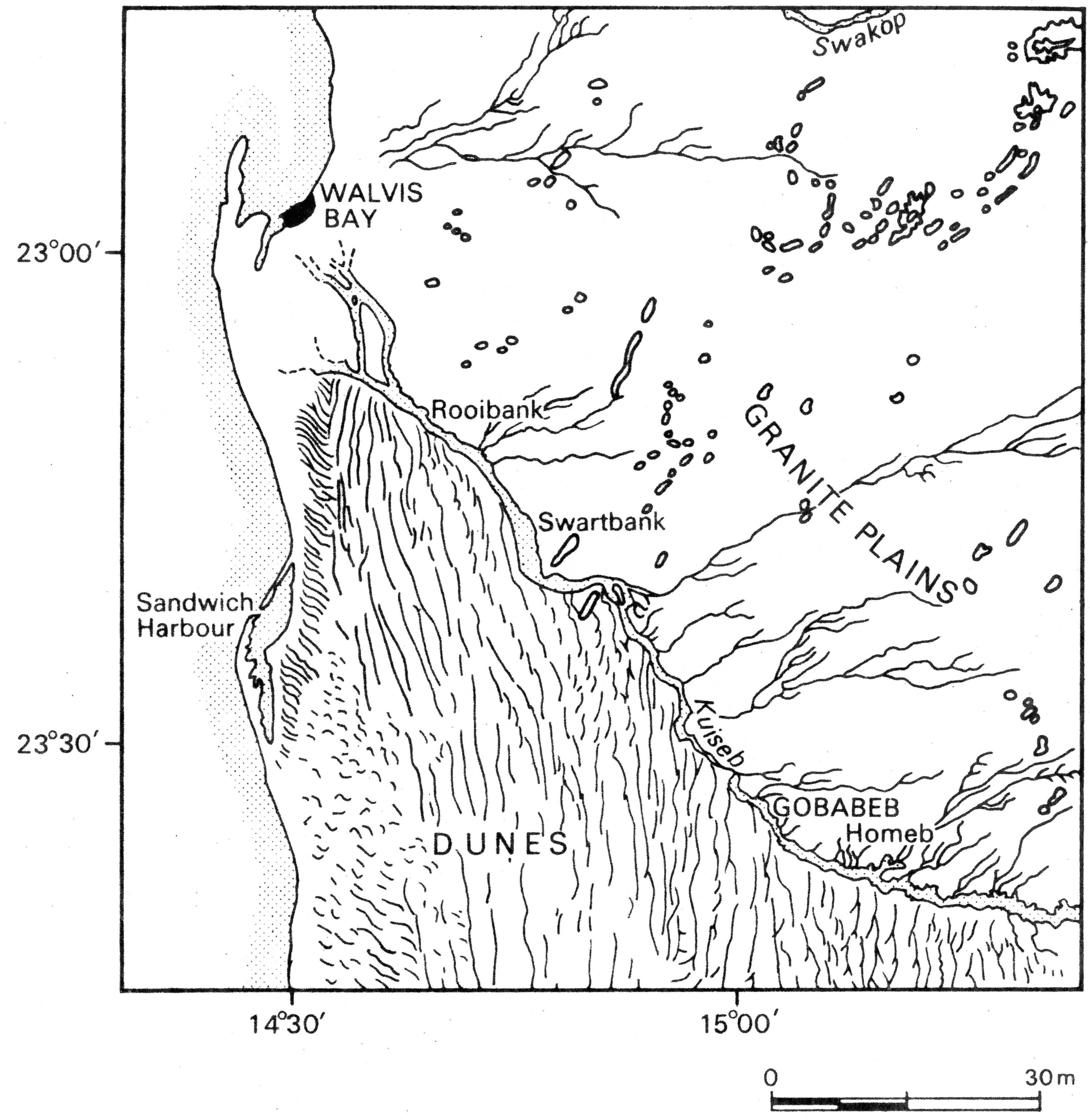
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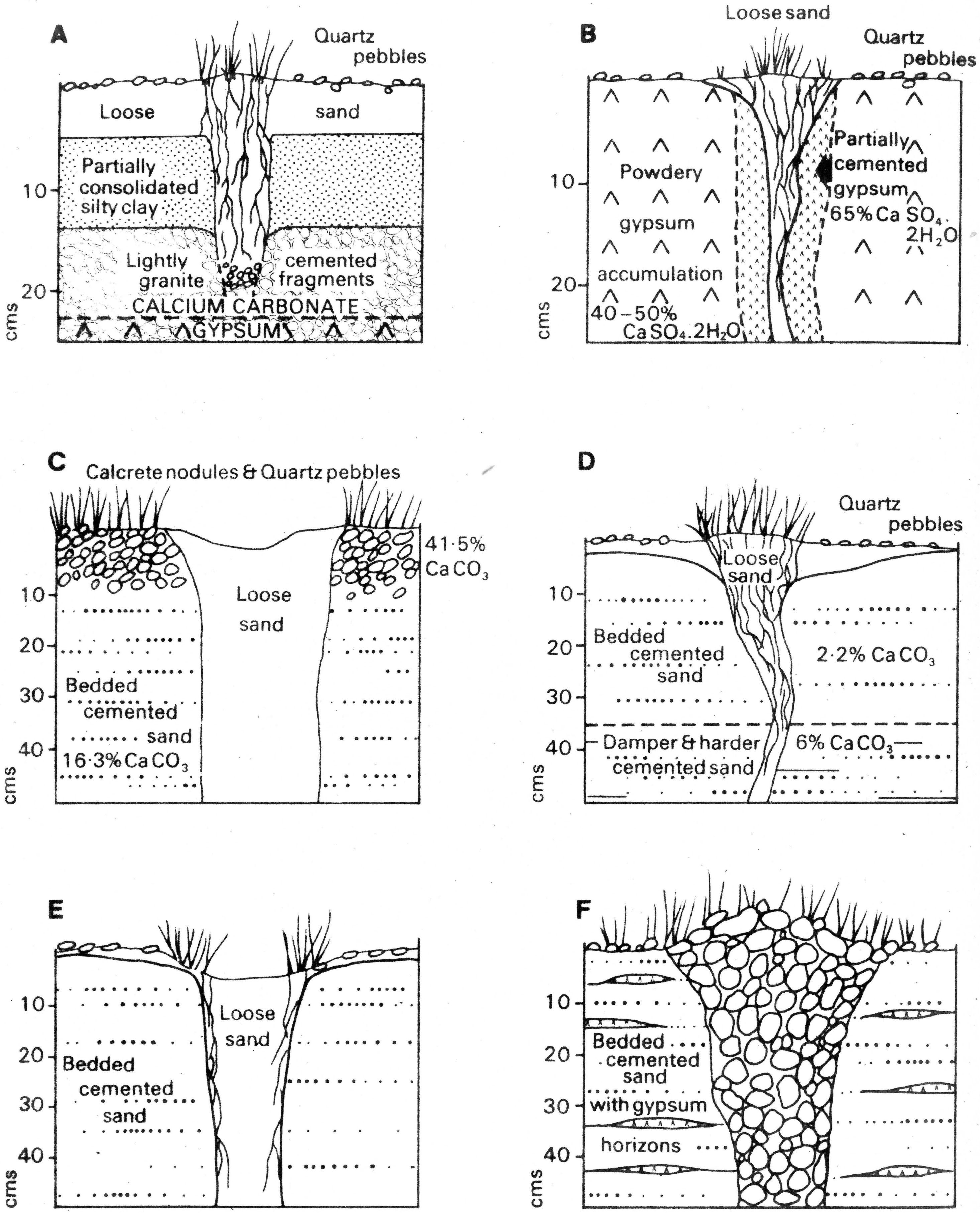
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Quartz pebbles
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Partially consolidated silty clay
Lightly cemented granite fragments
CALCIUM CARBONATE
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10
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Quartz pebbles
Powdery gypsum accumulation
40 – 50% $CaSO_4.2H_2O$
Partially cemented gypsum
65% $CaSO_4.2H_2O$
10
20
cms
C
Calcrete nodules & Quartz pebbles
41·5% $CaCO_3$
Loose sand
Bedded cemented sand
16·3% $CaCO_3$
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D
Quartz pebbles
Loose sand
Bedded cemented sand
2·2% $CaCO_3$
Damper & harder cemented sand
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Loose sand
Bedded cemented sand
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Bedded cemented sand with gypsum horizons
10
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cms

Fig 2

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Fig. 2. Soil profies.

A. Granite plains North of Gobabeb.

B. Gypsum crust area near Swartbankberg.

C. Interdunal area. Vegetation free polygon edges.

D. Interdunal area. Vegetation along fissures.

E. Interdunal area. Intermediate zone between C and D.

F. Interdunal area. Polygons with raised edges.

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Fig. 3. Diagramatic section showing the transition of vegetation characteristics in the interdunal valleys.

Fig. 4. Vegetation polygons, interdunal valley South of Gobabeb. Stipagrostis gonatostachys growing in the fissures.

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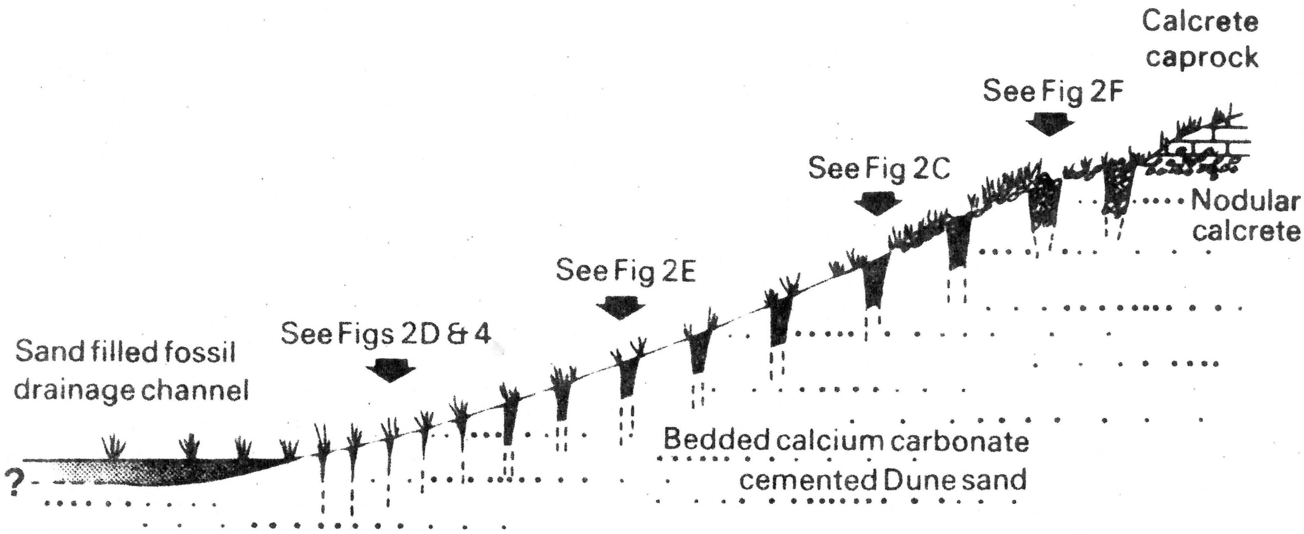
Plate 1. The edge of a vegetation polygon on a gypsum crust near Swartbankberg.

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

Plate 3. Fissured sandstone in the interdunal valley South of Gobabeb.

Plate 4. Interdunal vegetation polygons South of Gobabeb.


Calcrete
caprock
See Fig 2F
See Fig 2C
Nodular
calcrete
See Fig 2E
See Figs 2D & 4
Sand filled fossil
drainage channel
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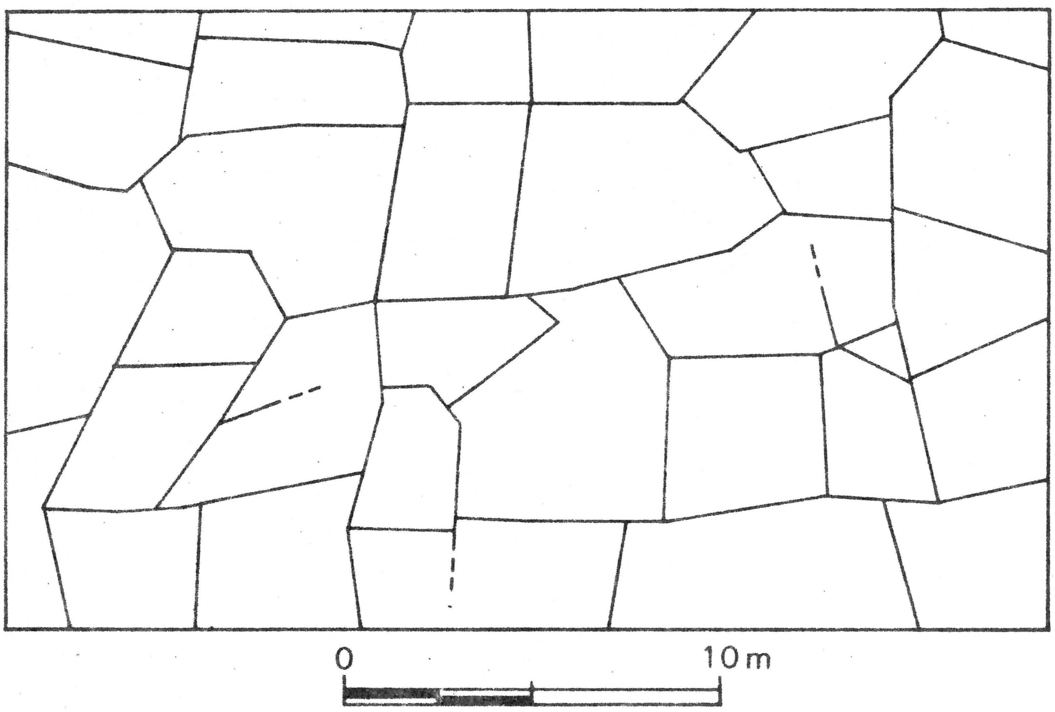
Bedded calcium carbonate
cemented Dune sand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