The soils of the central Namib Desert with special consideration of the soils in the vicinity of Gobabeb

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ABSTRACT

In this study the most important soils of the central Namib are discussed after a brief preliminary discussion of the climate. Precipitation consists of rain and fog, resulting in sparse vegetation, and succulents in sheltered places. Grass appears only after sufficent rain has fallen.

Geologically the region is made up of metamorphic schists, marble and granite. In the peneplains these formations are covered by calcrete and gypcrete.

The surface of the central Namib consists of a large peneplain with occasional inselberge, larger periodical stream valleys occurring only rarely. Mechanical weathering supersedes chemical weathering in the process of the breaking up of rocks, but nevertheless the latter should not be underestimated.

Raw mineral soils, calcrete and gypcrete soils are the most important soil types. In the vicinity of Gobabeb, south of the Kuiseb, the "ergs" or sand desert soils are also found. Most of the soils have a light brown to ochre brown colour, and are shallow, with an underground horizon which may consist of calcrete, gypcrete or salt. This concerns recent soils only. A buried red-brown fossil soil is found near Gobabeb, indicative of past climatic changes.

INTRODUCTION

The general aspects of desert soils have previously been treated by Mortensen (1930), Kubiena (1953) and Mohr and Van Baren (1954). Durand (1959) studied the soils of the Sahara. The soils of the Namib desert, however, have not yet been investigated in detail.

Earlier, Scholz (1963) recorded and described the principal soil types of the central Namib Desert along an east-west profile, the results of which investigation are summarized in the first part of this paper. The second part deals with the soils found in an area covering approximately 200 km² in the vicinity of the Desert Research Station Gobabeb. Aerial photographs were used as a base for mapping.

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CLIMATE

The Namib Desert is the only true desert in southern Africa. It is a foggy desert and extends 1,300 miles along the coast of the Atlantic Ocean, from the Olifants River in South Africa to Mocamedes in Angola. There is some moderation in the hot desert climate on account of the fog along the coast (Koch, 1962).

The aridity of the Namib Desert region is caused by the cold Benguela Current which reduces the temperature of the westerly winds with the result that they absorb very little moisture. On reaching the land they warm up and consequently the relative humidity of the air decreases with the formation of fog.

The moisture-laden air, which brings precipitation to the hinterland of South West Africa from the east, warms up adiabatically as it drops over the escarpment into the Namib Desert. As a result precipitation decreases rapidly towards the Atlantic coast. In the east the desert has no definite boundary because rainfall and vegetation increase gradually towards the interior.

Only that area which receives less than 100 mm of annual rainfall is considered a desert. For a large portion of the Namib in S.W.A. the 100 mm isohyet coincides approximately with the edge of the Great Escarpment. Gobabeb is situated within the region having an annual rainfall of less than 50 mm.

Another component of the precipitation in the Namib Desert is fog, which extends about 70 miles inland. Goudie (1968) makes the following statement concerning fog:

At Gobabeb itself fog was present on an average of 102 days for the years 1964—1967 inclusive. However, the fog precipitated only on an average of 60 days in the year and produced a precipitation of 31 mm per annum, a figure slightly greater than the rainfall itself. Daily quantities are small, though 6,5 mm have been recorded in one day at Gobabeb. The salt content of the fog is remarkably high. Four analyses of fog water from Walvis Bay, Rooibank (2) and Gobabeb showed Total Dissolved Solids at 180°C of 9860, 1290, 795 and 1175 ppm respectively.

Thus the fog brings a significant quantity of moisture and salts into the desert. These factors are of great ecological and pedological importance.

VEGETATION

In the Namib Desert only some algae and lichens are able to absorb the water directly in the form of dew (Walter, 1936). Prominent lichens are *Parmelia hottentotta, Parmelia namaensis* and *Caloplaca elegantissima.* Among the algae, the so-called "window-algae" (Vogel, 1955) are to be found underneath the translucent quartz and marble pieces. These blue-green algae are important for the fixation of nitrogen in the soil.

In addition to the lichens, the succulent plants make use of the water that condenses on the rocks and accumulates in the stone crevices. Therefore the succulents predominate on the slopes of the inselberge or on pegmatite dykes. The following genera commonly occur: *Hoodia, Lithops, Sarcocaulon, Euphorbia* and *Aloe.*

In the plains the vegetation is confined to erosion channels filled by infrequent downpours. Here the halophytic *Zygophyllum stapfii, Zygophyllum simplex* and *Aizoon dinterii* predominate. With regard to moisture the *Arthraerua leubnitziae* and *Euphorbia cervicornis* are less fastidious. In the wide riverbeds of the Swakop and Kuiseb, *Tamarix, Lycium* and *Salsola* grow near the coast. Towards the interior, however, these rivers are lined by dense fringes of *Acacia giraffae, Ac. albida, Euclea pseudebenus* and *Salvadora persica.* The Narras plant *(Acanthosicyos horrida)* is widespread in the Kuiseb valley (Giess, 1962). East of the fog boundary, some 50 miles from the coast, the soil is less salty and a large variety of *Aristida* grasses thrive when sufficent rain has fallen. The halophile *Mesembrianthemum* is also dependent on sufficient rain. A gymnosperm noteworthy on account of its rarity is the *Welwitschia mirabilis,* which is confined to a few localities.

GEOLOGY

The mica schists of the Khomas Series of the precambrian Damara System underlie most of the central Namib Desert. They are formed partly of pure mica schist and partly of micaceous sandstones and quartzites which are mostly strongly folded and traversed by quartz veins. Various types of marble are also interbedded in the mica schists.

Some precambrian granites have intruded into the crystalline basement complex. The grey to reddish Salem granite is the most prevalent.

During the upper Triassic and lower Jurassic period basaltic lavas were poured out onto the surface in South West Africa. They were afterwards mainly eroded from the central Namib Desert and today only the feeder dykes are preserved. These basaltic dykes belong to the Karroo System (Du Toit, 1956).

The crystalline basement is commonly covered by Cretaceous to Pleistocene calcrete, gravel, sand and gypsum crusts (Gevers, 1936) constituting the substrates for the soils of the desert.

GEOMORPHOLOGY

1. General Geomorphology

The central Namib creates the impression of a vast plain, dissected by larger and smaller stream valleys. It is also called the "Namib-Platform" (Logan, 1961), and rises steadily eastwards from the coast to attain an elevation of about 1000 metres at the foot of the Great Escarpment. The monotony of the scenery is interrupted by a number of inselberge protruding from the level tract of country. Because of their size and resistance to weathering these mountains are not yet peneplained.

The plains are traversed by small furrows and erosion gullies, which sooner or later dwindle away in the sand because the periodical water run-off is insufficient to create a continuous drainage system. The scree and alluvials carried along are deposited as detrital fans after a short distance. Thus the valleys are choked and rare sheet floods level the landscape by a similar process.

The larger rivers like the Swakop and the Kuiseb, which derive their floods from the heavier inland rainfall, have cut deep channels into the crystalline subsurface. They must have formed during the pluvials of the Pleistocene when more water descended from a higher gradient thereby supplying the necessary potential for these incisions (Martin, 1961). Consequently the desert surface in the surroundings of these river valleys is no longer a plain but is hilly or sometimes even mountainous.

2. Geomorphological types

Extensive plains covered by coarse and blocky detritus, also called "Hammada" (Meckelein, 1959) and well-known from the Sahara, do not occur in this area. Inselberge, consisting of homogeneous rocks like dolerite, indurated shale and quartz pegmatites, develop Hammada-like surfaces on their slopes (Figs. 1 and 2).

Although the "Hammada" desert is wanting, the "Serir" (Arab.) is very common. It is also a kind of stony desert on the surface of which rounded gravel and grit cover the soil where there are no rock outcrops (Fig. 3). A "Serir" desert is thought to originate by deflation.

Aeolian sand gathering in dunes and known from the Sahara as "Ergs" covers the Namib platform south of the Kuiseb, and also occurs along a narrow strip along the coast between the towns of Walvis

Bay and Swakopmund (Figs. 4 and 5). The dune landscape south of the Kuiseb consists of more or less parallel ridges and valleys running in a north-south direction.

WEATHERING

1. Mechanical weathering

As in all desert areas, mechanical weathering plays a vital role in the Namib desert. The effect of sand blasting is observed on rock outcrops (Fig. 6). The harder rocks like diabase, quartz and quartzite are ground and polished during this process. The quartz gravels found south of the Kuiseb valley at Gobabeb yield fine examples of polished stones that look as if they have been covered by a varnish.

The rocks are mainly broken down by insolation. A repeated process of strong heating in the sun followed by cooling down after sudden rainshowers brings about tensions in the rock leading to cracks (Figs. 7 and 8) and causing exfoliation and desquamation (Brinkmann, 1961). Fine examples of this kind of disintegration are seen on granite (Figs. 9 and 10).

2. Chemical weathering

Besides mechanical weathering, the effect of chemical weathering is observed on rock outcrops in the form of holes and caves, a cavernous weathering commonly found near the coast (Figs. 11 and 12). Here the mist, enriched by salts from sea spray, is the main solvent. Hydrogen sulphide erupted from the sea reacts with the moisture of fogs to form sulphurous acid (H_2SO_3). The combination of acid, salts and high temperatures increases the solvent power (Scholz, 1963). This may be an explanation of the extensive cavernous weathering in the Namib. A good example of this is the granite hill at Rooikop, about ten miles east of Walvis Bay.

Another kind of chemical weathering is the so-called "shadow weathering" (Schattenverwitterung) described by Knetsch (1960) from Egypt. This term refers to the decomposition observed on the shady side of the rocks, which remains moist for longer periods. Caves are formed by this process and the rocks may weather in the shape of mushrooms or even bells (Fig. 13). Clay minerals present in soils show that here too, in spite of scanty moisture, chemical weathering occurs.

SOILS

1. The Syrosems

Where solid rock is exposed, it is mainly broken down by mechanical weathering. Rock fragments and exfoliation chips gather around the outcrops, where they undergo further processes of weathering. The first stage, therefore, is a coarse disintegrate lacking soil. This is the typical "Syrosem". The degree of chemical decomposition then increases with distance from the place of origin. The Syrosem is followed by the zone of ochre-brown, calcareous soils which are again succeeded by the ochre-brown limestone soils (Fig. 14).

2. The ochre-brown limestone soils

2. i. On the origin of the surface limestone (calcrete)

As previously mentioned, surface limestone, also known and described as calcrete (Logan, 1961; Martin, 1964) is very widespread in the Namib. It probably formed during a pluvial period when a minimum of ground water was available. It is likely therefore, that the calcrete in the Namib is predominately fossil. Similar relations are also reported from the Sahara (Durand, 1953, Wilbert, 1962). Kaiser (1926) and Knetsch (1937) point out the importance of the subsurface for the origin of crusts. A permeable surface layer should have an underlying denser layer that prevents ground water seepage. The ground water dissolves the calcium carbonate from the bedrock and the subsoil, rises to the surface through capillary action and deposits the dissolved $CaCO_3$ on evaporation. Apparently, however, crusts could also form in deep soils. The author has observed that at first single $CaCO_3$ concretions are formed which gradually grow togther to form a more or less solid crust. Martin (pers. comm.) maintains that the crusts of the Namib have originated in the soil but have later been uncovered by erosion.

Surface limestone may apparently form in two distinct ways, either below or on top of the surface. The structure of numerous limestone crusts was observed and it was found that they become more compact from the bottom to the top. From 3 to 6 feet below the surface the crusts still consist of loosely cemented concretions, whereas nearer to the surface they change into a solid crust. The processes creating this type of crust are thought to occur entirely within the soil.

In the uppermost 1 or 2 cm the compact surface limestone commonly reveals a layered structure (Fig. 15). This uppermost part, which morphologically clearly differs from the lower one, must have formed at the surface on the evaporation of rain water saturated with calcium hydrocarbonate. Thus calcium carbonate was precipitated in very fine sinter layers, this no longer being a pedological process. Similar crusts were observed to coat the walls of animal burrows.

2. ii. The soils on surface limestone

The soils that developed on calcrete are denoted here as "limestone soils" for the sake of brevity. Usually they are ochre-brown or grey coloured, enriched in scree, and they show a calcic horizon. They are mostly covered with a layer of limestone and quartz detritus as a result of deflation. Thus a desert pavement is formed. The limestone soils have pH values between 7,4 and 8,3 (in KC1). The cation exchange capacity on account of their low percentage of clay seldom reaches 10 mequ/100 gm soil. About 0,5% organic matter is contained in these soils. The percentage of detitus in these soils may amount to as much as 90% by volume.

3. The gypsum crust soils

3. i. On the origin of the gypsum crusts (gypcrete)

Some 50 miles from the coast gypsum begins to occur in the soil and the proportion of gypsum steadily increases towards the coast. Near the coast the gypsum has developed into solid crusts. Martin (1964) thinks that the origin of the gypsum is linked with hydrogen sulphate eruptions from the sea. Surface limestone also occurs near the coastline and the reaction of hydrogen sulphate with the $CaCO_3$ of these crusts formed gypsum. The author's investigations fully support Martin's theory. It is indeed true that gypsum occurs for the first time near the fog-border, about 50 miles from the coast. Close to the coast, where fog precipitation is highest, the largest amount of gypsum is to be found in the soils (Scholz, 1963).

3. ii. The soils on gypsum crusts

Proceeding from east to west there is a gradual transition from limestone to gypsum soils until pure gypsum soils occur about 15 miles from the coast. Like the limestone soils, the gypsum soils generally have an ochre-brown colour. The gypsum horizon lies at the bottom of the profile and beneath any existing calcic horizon if one exists. However, the gypsum soils contain less detritus because the gypsum crusts are softer and are more easily decomposed than limestone crusts. The pH values lie between 7,6 and 8,3 (in KC1).

4. The soils in the area of Gobabeb

An area of about 180 sq. km was surveyed in the surroundings of Gobabeb in order to trace the zonal distribution of soils which characterize the Namib. This area is particularly suited for that purpose because it covers a variety of geomorphological units. Gobabeb itself is situated on the banks of the Kuiseb River. The river bed, the vast sea of sand dunes extending to the south and the slightly undulating plains to the north form very different pedological units.

4. i. The soils of the dune area south of the Kuiseb

I. The "Ergs", or the soils of the dunes (S.U. 1)[1]

Soil cannot form on the dunes because the sand is constantly in motion, especially near the surface (Fig. 17). Nevertheless, the foggy climate is responsible for chemical weathering such as the dissolution of the iron minerals and the feldspars. The particle size distribution of two samples of dune sand is give in Table 2, Numbers 15 and 16. The presence of silt and clay may also be indicative of chemical weathering. It may be expected that chemical weathering is intensified in depth. This is also testified by Kaiser (1926) who studied some dunes in the southern part of the Namib. Unfortunately it proved impossible to excavate into the loose sand in order to determine the extent of the process of decomposition.

The dunes are inhabited by a large number of animals, particularly beetles, which generally appear on the surface at dusk or during the night (Koch, 1961). These animals introduce into the sand organic material blown in from the grassy hinterland in the north and east. On sheltered spots in the dunes, paddings of this material are found which may accumulate to more than a foot thick.

The specific gravity of mineral grains in the sand of the dunes varies. Concentration of heavy grains is observed particularly on the luff sides of the dunes because the lighter quartz grains are transported first. The flank of the dunes therefore has different colours depending on the dominant minerals in the sand, i.e. dark in the case of magnetite and reddish in the case of garnet (Fig. 18). On the whole, the sands of the dunes have a brownish colour, lighter near the coast and a reddish brown colour predominating towards the interior. This is due to a thin ironhydroxide coating around the mineral grains. Table 1 lists the minerals occurring most abundantly in dune sands near Gobabeb.

Aristida namaquensis and *Acanthosicyos horrida* grow on some dunes along the banks of the Kuiseb where they draw moisture from the subsurface flow of the river through capillary action (Fig. 19).

[1]) Surveying Unit on soil map

Table 1. Mineralogical composition of some dune sands

Sample locality	Main constituents	Secondary constituents
south of Kuiseb at Sout-River (light dune sand)	feldspar and quartz, strongly weathered	monazite, much ore and opaque grains, staurolite, chlorite
same locality (dark dune sand)	garnet, monazite, opaque ore minerals, feldspar	chlorite, zircon, epidote, staurolite, tourmaline, ilmenite

4. i.

II. The soils on the plains between the dune ridges (S.U. 3,4,5)

S.U. 4: There is no soil formation on the fossil dune sands which lie partly open in the plains and which have consolidated to a loose sandstone. These fossil dunes are capped by a terrace of reddish limestone crust and gravel.

The profile is as follows:

0 - about 20 cm:	a reddish-grey, dense limestone crust, containing large pebbles in its upper portions and covered with quartz gravel. It has partly disintegrated into slabs. The surface of the crust is attacked by wind abrasion.
20 - 200 cm and more:	a fossil, red dune sand cemented mainly by gypsum and studded with single white limestone concretions.

The reddish-grey crust (0 - 20 cm) contains 41,5% $CaCO_3$ and the next 10 cm below 46%. $CaCO_3$ has precipitated in this sandstone below the crust in the following different forms:—

1. Mere precipitation or coatings around grains, which are partly cemented.
2. Hemispherical to spherical hollow concretions with an opening pointing upwards. These may reach a diameter of up to 8 cm and are filled with material similar to that in which they occur (Fig. 20A).
3. Cylindrical shaped concretions, similar to the European "Loesskindl". They may attain the size of a finger (Fig. 22).

S.U. 3: On the slopes of the sandstone terraces, which are covered by gravel and detritus derived from the upper terrace, no soil has developed (Table 2, No. 9). Where the top of the sandstone actually forms the surface over large areas (e.g. in the western dune valley on the soil map) it is traversed by vertical joints, 5 to 10 cm in width, dividing the surface into polygons with a diameter up to 20 metres. The fissures have been filled with aeolian sand. To date the author has no explanation for the origin of these polygons.

S.U. 5: On the lower terrace a true desert soil, a limestone soil, has developed above the metamorphic schists. The profile of Gobabeb V (Table 2, No. 5) is a typical example of this and may be described as follows:

0 - 8 cm:	brown to dark brown gritty sand, strongly blended with dune sand, covered by a dense layer of quartz, feldspar grit and scattered stone. The soil has a granular structure and is traversed by a loose network of roots.
8 - 30 cm:	yellowish-grey, sandy gravel containing a large number of $CaCO_3$ concretions, partly growing together to form a solid crust also containing gypsum. Some roots occur.
30 - 40 cm:	micaceous granite in the process of weathering. Coatings and fillings of $CaCO_3$ occur on fissures and cracks.

Similar profiles are Gobabeb VI and Gobabeb XI (see Table 2, No. 6 and 10).

4. i.

III. Young soils with calcium carbonate concretions (S.U. 2)

Hemispherical calcium carbonate concretions found in fossil dune sands have already been mentioned. Recent structures very similar to these were observed in the westernmost dune valley in the surveyed area. Near its northern entrance and some 300 metres distant from the southern Kuiseb river bank, this valley is traversed by a barrier of aeolin sands impeding the run-off of rain water after occasional downpours. $CaCO_3$ contained in this water is precipitated in the sand. As a result limestone concretions with a peculiar form originate. They may resemble a hen's egg and contain partly cemented sand (Fig. 21) or occasionally may be very similar to the hemispherical concretions mentioned above (Fig. 20B), while others may have an irregular spiky surface (Fig. 23).

These structures are presumably of organic origin, possibly from algae which lived in stagnant water and set free CO_2. Because the water was saturated with $Ca(HCO_3)_2$, the calcium carbonate precipitated directly on the surface of the organisms preserving their forms.

4. ii. The soils of the slightly undulating plains north of the Kuiseb

I. General

On the slightly undulating plains north of the Kuiseb river two principal soil types can be distinguished:

1. The Syrosems or raw mineral soils, also known as "Regs" from North Africa
2. The soils with limestone or gypsum crusts.

Generally the soils of this area, like all zonal desert soils, have a light grey to ochre-brown colour (Finck, 1963). The decomposition of iron minerals is incomplete on account of the weak humidification of desert soils. The occurrence of reddish colours at intervals is due mainly to a higher NaC1 content of the soil, activating the solving of iron (Mortensen, 1930).

Because these desert soils cannot be compared with those of more humid climates, some authors exclude them from soils altogether. However, French and American pedologists (Durand, 1953; Aubert, 1960; Kellogg, 1960) treat them as well defined soils.

4. ii.

II. The Syrosems and the weakly developed soils with crusts (S.U. 6)

The Syrosem, which consists of mechanically weathered material with no or little chemical decomposition, covers unweathered rock close to the surface. In the surveyed area the Syrosems occur predominantly near the banks of the Kuiseb river where the surface is strongly eroded.

The broad, shallow valleys further away from the Kuiseb are covered with calcareous soils with a gypsum horizon at the bottom of the profile. In these positions the soils are sheltered from severe denudation. They are mainly shallow soils consisting of the weathered residue of the underlying rocks.

Many variations depending on the age of the soil can be observed between these two extremes. As the distance of transportation of detritus from the site of origin increases, chemical weathering becomes more important. Similarly the proportion of aeolian sand increases and limestone and gypsum crusts become more prominent (see Fig. 14). The profile Gobabeb I (Table 2, No. 1) is an example of such a weakly developed and shallow calcareous soil with a gypsum horizon, derived from granitic Syrosem material.

4. ii.

III. The salty gypsum soils (S.U. 7)

West of the confluence of the Sout- and Kuiseb Rivers, parallel to the course of the latter, there is a shallow depression about 2½ km long, with its surface above the Kuiseb river bed. In this area a soil rich in sodium chlorite has developed with NaCl forming a solid crust in the subsurface. Here, in the profile Gobabeb IX (Table 2, No. 8), distinct silifications are observed directly on top of the rock surface. No similar phenomenon has ever been found elsewhere in this area. It remains uncertain whether the high alkalinity of the soil is responsible for the peculiar silification. Except for the salt crust this soil otherwise resembles the gypsum soils of the surrounding area.

4. ii.

IV. The calcareous gypsum soils (S.U. 8 and 9)

S.U. 8: In the weakly dissected area north of Gobabeb the flat hill crests are formed by pegmatite dykes, whereas the softer mica schist underlies the valleys. The soil thickness increases from the ridges towards the valleys. The level slopes flanking the ridges are covered by coarse grained pegmatite detritus mixed with inblown sand. The profile Gobabeb XVI lies on one of these ridges (see also Table 2, No. 14). Here and there the gypsum crust, which had originally formed the surface, can still be observed. Further down the slope the soils become thicker, reaching a maximum thickness of about 30 cm at the foot of the hills. The following is a description of such a profile:

(Gobabeb II, Table 2, No. 2).

0— 7 cm:	ochre-brown, mostly $CaCO_3$-free aeolian fine sand mixed with grit. The grains are loose and some roots occur. The soil is covered with a layer of quartz-grit.
7—13 cm:	brownish-yellow, calcareous, weakly gritty and loamy fine sand with subangular structure and fine pores. The horizon is traversed by single roots.
13—40 cm:	greyish-white, partly soft and partly compact gypsum crust, which is occasionally calcareous.
40—50 cm+:	greyish mica schist in the process of decomposition, partly encrusted with gypsum along cracks and fissures.

Green coatings of blue-green algae are found below the surface layer of quartz pebbles.

The soil of the valleys resembles the above-mentioned example except for a thicker top soil, which is the result of colluvial accumulation (profile Gobabeb III, Table 2, No. 3). The vegetation is limited to some halophytes and single lichens which cover the rock surfaces. Grass grows only after sufficient rainfalls.

S.U. 9: Older soils can be observed in the area north of the Sout River, which is not so strongly eroded. As a result, the development of the gypsum crust is more intensive. It can be observed throughout the profile forming a solid crust at the surface.

4. ii.

V. The buried, fossil reddish-brown soils (S.U. 10)

The eastern portion of the surveyed area, some 6 to 8 km east of the Kuiseb River, is not yet strongly dissected. The old peneplain still exists and a weathered gypsum crust occurs at the surface. The gypsum soils found in this area strongly resemble those described above. However, there is one important difference, a reddish-brown soil occurring below the gypsum crust. In a thin section this soil resembles the brown loams described by Kubiena (1953), formed in alternating moist and warm climates. Similar conditions may have prevailed in the Namib during the Pleistocene (Korn and Martin, 1937).

Gobabeb IV (Table 2, No. 4) is a profile of such a soil:

0 — 3 cm:	ochre-brown, gritty sand with granular structure, covered by a loose layer of quartz grit.
3 — 7 cm:	as above, but containing $CaCO_3$.
7 — 30 cm:	brownish-yellow, somewhat loamy sand, rich in $CaCO_3$, with subangular structure and a loose network of roots.
30 — 40 cm:	yellowish-white, very coherent gypsum crust free of $CaCO_3$.
40 — 80 cm:	reddish-brown clay, partly soft and partly cemented by gypsum.
80 — 120 cm:	reddish-brown clay-gypsum crust with scattered white specks.

The reddish-brown soils mentioned above extend far beyond the surveyed area. They are important because they indicate that the present Namib desert may have experienced a more moist climate in the past, a hypothesis confirmed by a gossan cap covering a dunite dyke south of the Kuiseb River consisting of a brown, extremely hard rock, rich in iron (Correns, 1939).

This gossan cap could have originated under a warmer and moister climate (Mückenhausen, pers. comm.).

While this manuscript was in preparation, Dr. C. Koch, director of the Namib Desert Research Station, Gobabeb, kindly drew the author's attention to the fact that similarly buried red soils were also found between Walvis Bay and Rooibank during road construction.

4. ii.

VI. The soils of the smaller desert valleys (S.U. 13 and 14)

S.U. 14: The almost flat surface of the desert is nevertheless traversed by a network of erosion channels and smaller rivers which occasionally reach a width of 100 metres. The Sout-River, which joins the Kuiseb River 3 km downriver from Gobabeb, is a typical example. It contains a relatively badly sorted load derived from desert detritus and eroded soils in the drainage area. No soil has developed in this young alluvium.

S.U. 13: In some of the smaller rivers a weak underground drainage occasionally emerges where the rock sub-outcrop is near the surface. Here the water evaporates on the surface and forms a dry, salty crust (Fig. 24) rich in NaCl, whereas the undersurface remains moist, resulting in salty swamps. In the Sahara a similar feature is called by the Arabic name "Sebka" (Meckelein, 1959). The dirty, brownish surface is extremely irregular and rough and has broken up to a polygonal pattern (Fig. 25). The edges of the polygons are lined by dense white salt flowers. They are bent up because of the swelling up of the salt-clay complex, forming many cavities below the crust. Beneath the crust, which may be up to 20 cm in thickness, there occurs loamy soil saturated with salt water (Gobabeb VIII, Table 2, No. 7). Algae are found coating the moist clods even in this adverse environment. These "Sebkas" are very limited in occurence and extent as they depend on shallow salty ground water.

4. iii. The soils of the Kuiseb Valley

I. General

In the Namib Desert only a few riverbeds are comparable in size to the Kuiseb and extend to the coast. Others, like the Tsondab and Tsauchab, are eventually blocked up by the desert detritus and end in pans amidst the sand dunes. The Kuiseb River, when in flood, is one of the rivers which may reach the sea. As it flows fairly regularly in the rainy seasons, it carries a well-sorted load. At Gobabeb, gravel is practically absent and the river carries light-coloured, slightly micaceous sand. A few undemanding grasses may grow in sheltered places on these sandy deposits after a flood.

In his unpublished report "The source of drinking water at Gobabeb", Stengel investigated the ground water conditions of the Kuiseb near Gobabeb. The following abstract contains some facts taken from his report which are of geomorphological and pedological importance:

> The Kuiseb is blocked at certain depths by granite rock, forming a groundwater sill with an immense storage basin of ground water. In such places the water level is only a few feet below riverbed level.
>
> The flowing water in the sand bed of the river is of varying quality. Brackish and fresh water will be found to occur in close proximity to each other. As a rule, fresh water will occur in the upper layers and in greater quantity on the southern side of the river, whereas brackish and salty water will occur in the deeper layers and in greater quantity on the northern side of the river. The salt and brackish water is derived from the mist and the weathering of the rocks. The mist, which is brackish due to the proximity of the coast, comes in from the Atlantic, mainly in winter, and covers the area during the early hours of the day, precipitating its brackish moisture on the top soil over the whole area. The brack is washed down by the rains into the river bed where it forms lenses and pockets in the immediate vicinity of the fresh ground water which originates from the infiltration of the fresh flood water. In addition evaporation takes place from the ground water, turning the fresh water, which always contains some salt in solution, into brackish water. The water quality ranges approximately from 300—1000 parts per million total dissolved solids.

4. iii.

II. The recent silt terraces (S.U. 11)

Elevated marginal silt terraces are drowned during higher floods. The current being retarded near the banks, silt and clay particles are readily deposited to form flood-loam high level terraces which may occasionally be eroded during excessive floods. After a flood the terraces are covered with wet muds which develop a system of cracks on drying. These polygons may be 1 metre in diameter (Fig. 26). On the flood-loam terraces grow species of *Acacia giraffae, Ac. albida, Euclea pseudebenus* and the shrubs *Salvadora persica* and *Acanthosicyos horrida.* Here the trees find security from most floods and the subsoil carries moisture all the year round. Here and there in favourable places small waterholes occur after a flood. Organic matter deposited in these depressions is overgrown by liverworts. There is a distinct smell of gasses produced by bacteria when organic matter is decomposing. These soils resemble Sapropels, but they occur only locally and are mentioned for the sake of completeness.

4. iii.

III. The fossil silt terraces (S.U. 12)

Fossil flood-loams occur along both banks of the Kuiseb as remnants of higher level terraces up to 15 metres above the present river bed. There is only one explanation for them. The river must at times have been blocked by dune sand causing the water to dam up and deposit these sediments high above the usual flood level. Partly these flood-loams contain gypsum (Gobabeb XII, Table 2, No. 11); partly they may be rich in NaC1, e.g. a flood-loam remnant 200 metres north of Gobabeb (Profile Gobabeb XIII, Table 2, No. 12). The composition of fossil flood-loams possibly reflects the influence of different provenance areas, drowned by different floods.

The fossil loams have a dirty brownish colour in the field. They are mainly soft, but occasionally they may be so compact and indurated that it is difficult to chip them with a hammer (Fig. 27). One km east of Gobabeb, at the confluence of a tributary with the Kuiseb, an interesting profile can be observed (Gobabeb XIV, Table 2, No. 13). Below some 20 cm of weathering detritus derived from gypsum soils and rocks in the vicinity, a 50 cm thick flood-loam horizon is found. This flood-loam covers loose dune sands which have a lighter colour than the dune sands south of the Kuiseb. This sand in turn rests on solid mica schist. The flood-loams, therefore, must have been deposited at a time when aeolian sands covered larger areas north of the Kuiseb than they do today. This proves that the river must have been blocked by high dunes at some time in the past. The dunes have since been eroded by wind and water.

Outside the surveyed area, some 15 km east of Gobabeb, large remnants of grey, well layered and partly calcified flood-loams with 17,1% $CaCO_3$ are found in an inlet of the Kuiseb River. They form a terrace about 15 to 20 metres above the present river bed. It remains unknown whether these flood-loams formed contemporaneously with those of the surveyed area. They are, however, petrologically different.

Some of the material of the flood-loams was carried out by SW winds and deposited in the plains north of the Kuiseb. This could explain the loess-like horizon, free of grit, which occurs in the soils of that area. The finer fractions of both materials are somewhat similar. More evidence would come from a mineralogical analysis.

REFERENCES

Aubert, G., 1960. Les sols de la zone aride. Colloque general sur les problémes de la zone aride. Paris, 11-18.

Brinkmann, R., 1961. Abriß der Geologie. I. Bd., Ferd. Enke Verl., Stuttgart.

Correns, C. W., 1939. in Barth, Correns, Eskola: Die Entstehung der Gesteine. Verl. Julius Springer, Berlin.

Durand, J. H., 1953. Étude géologique, hydrogéologique éet pédologique des croûtes en Algérie. Direction de l'hydraulique et de èquipment rural. Birmanreis, Algier.

Du Toit, A. L., 1956. Geology of South Africa. Oliver and Boyd, Edinburgh and London.

Finck, A., 1926. Tropische Böden. Verl. Paul Parey, Hamburg und Berlin.

Gevers, T. W., 1936. The morphology of western Damaraland and the adjoining Namib Desert of South West Africa. S. Afr. Geogr. J. **19:** 61—79.

Giess, W., 1962. Some notes on the vegetation of the Namib Desert. Sci. Pap. Namib. Des. Res. Stn., **3:** 1—35.

Goudie, A.S., 1968. The geomorphology of the Namib Desert near Gobabeb, S.W.A. Unpublished report.

Kaiser, E., 1926. Die Diamantenwüste Südwestafrikas 2 Bde, Berlin.

Kellogg, C. E., 1960. Soil classification, a comprehensive system. 7th Approximation, U.S. Dept. of Agriculture, Washington.

Knetsch, G., 1937. Beiträge zur Kenntnis von Krustenbildungen. Zeitsch. Dtsch. Geol. Ges., **89:** (4).

Knetsch, G., 1960. Über aride Verwitterung unter besonderer Berücksichtigung natürlicher und künstlicher Wände in Ägypten. Zeitschr. Geomorph., Suppl. Bd. 1, Berlin-Nikolsee.

Koch, C., 1961. Some aspects of abundant life in the vegetationless sand of the Namib Desert dunes. Sci. Pap. Namib Des. Res. Stn., **1:** 1—34.

Koch, C., 1962. The Tenebrionidae of Southern Africa. Sci. Pap. Namib Des. Res. Stn., **5:** 61—106.

Korn, H. und Martin, H., 1937. Die jüngere geologische und klimatische Geschichte Südwestafrikas. Zentralbl. Min., **11:** 456—473.

Kubiena, W. L., 1953. Bestimmungsbuch und Systematik der Böden Europas. Enke, Stuttgart.

Logan, R. F., 1961. The Central Namib Desert, South West Africa. Nat. Ac. Sci.-Nat. Res. Council, Washington, D. C.

Martin, H., 1961. Abriß der geologischen Geschichte Südwestafrikas. J. SWA-Wiss. Ges., XV.

Martin, H., 1964. A suggested theory for the origin and a brief description of some gypsum deposites of South West Africa. Trans. Geol. Soc. S. Afr.

Meckelein, W., 1959. Forschungen in der zentralen Sahara. Westermann Verl.

Mohr, E.C.J. and van Baren, F. A. 1954. Tropical soils. Van Hoeve, The Hague.

Mortensen, H., 1930. Die Wüstenböden. In „Handbuch der Bodenlehre", Bd. 3, Berlin, Springer Verl.

Scholz, H., 1963. Studien über die Bodenbildung zwischen Rehoboth und Walvis-Bay. Diss., Bonn.

Stengel, W.H., 1968. The source of drinking water at Gobabeb. Unpublished report.

Vogel, S., 1955. Niedere „Fensterpflanzen" in der südafrikanischen Wüste. Beitr. Biol. Pflanzen, Bd. 31.

Walter, H., 1936. Die ökologischen Verhältnisse in der Namibnebelwüste (Südwestafrika). Jb. wiss. Botanik, Bd. 84.

Wilbert, J., 1962. Croûtes en encroutements calcaires au Maroc. Al Awamia, No. 3, Rabat.

DIE GRONDSOORTE VAN DIE SENTRALE NAMIB-WOESTYN MET BESONDERE VERWYSING NA DIÉ IN DIE OMGEWING VAN GOBABEB

Die klimaat, plantegroei, geologie en die geomorfologie van die sentrale deel van die Namib-woestyn word kortliks beskrywe. Die belangrikste grondsoorte van die gebied word behandel. In besonder word 'n beskrywing van diè grondsoorte in die omgewing van Gobabeb gegee. Hier is ongeveer 180 vierkante kilometer pedologies opgeneem. Die hoof grondsoorte bestaan uit chemies min verweerde minerale-, kalk- en gips-uitgangsmateriaal, meestal van ligte bruin kleure.

Profile No.	Depth (cm.)	Particle size distribution (mm.) in % of soil						pH in KCL	Organic matter %	Cation exch. cap. meq./100 gm. soil	Base sat. %	$CaCO_3$ %	H_2O sol. salts %	conductivity (mmho cm^{-1})	in water-extract mgm. /100 gm. soil	
		0,002	0,002 -0,006	0,006 -0,02	0,02 -0,06	0,06 -0,2	0,2 -2,0								Na_2O	CaO
No. 1	0-15	0,9	0,8	0,6	7,5	69,8	20,4	8,0	0,4	9,6	96,3		0,07	0,16	4,1	1,7
Gobabeb I	15-22	13,3	5,3	1,1	5,5	40,3	34,5	8,4	0,3	13,7	98,6	24,3	0,9	2,73	94,5	15,7
No. 2	0- 7	2,0	1,4	2,2	9,2	67,2	18,0	8,0	0,1	9,9	98,7		0,2	6,5	11,6	26,9
Gobabeb II	7-13	14,4	5,1	3,4	10,5	53,2	13,4	8,0	0,2	15,6	97,9	20,5	0,5	1,6	45,0	4,5
	13-40	2,6	0,4	4,1	15,0	26,6	51,3	7,9	0,3	6,4	95,1		3,0	6,6	145,5	19,8
No. 3	0-15	1,1	0,9	1,5	7,3	60,5	28,7	8,2	0,04	8,2	97,3			0,2	3,3	1,1
Gobabeb III	15-25	4,5	0,9	1,5	4,2	34,2	54,7	8,1	0,1	9,0	96,9	9,9		1,9	38,8	119,0
No. 4	0- 3	1,2	0,6	0,6	8,4	71,6	17,6	7,8	0,1	4,4	89,6					
Gobabeb IV	3- 7	1,0	0,6	4,3	7,4	67,8	18,9	8,1	0,04	7,3	93,4	3,4				
	7-30	7,1	2,7	0,9	7,2	54,1	28,0	8,0	0,1	8,8	94,7	21,6				
	30-40											8,3	0,7			
	40-80	2,5	0,2	1,2	6,4	19,8	69,9	7,8		5,9	94,6		0,1			
No. 5	0- 8	0,6	0,0	0,8	9,2	64,2	25,2	8,1	0,1	12,4	97,0		0,04	0,08	1,1	3,4
Gobabeb V	8-30											50,0				
No. 6	0- 7	0,5	0,0	1,4	7,9	69,5	20,7	8,1	0,03	4,0	88,4		0,04	0,07	1,1	3,4
Gobabeb VI	7-55	2,9	1,0	1,3	4,9	39,3	50,6	8,4	0,2	7,7	95,8	41,5	0,3	0,85	22,1	7,9
No. 7	0-15	2,3	0,0	0,4	2,6	81,0	13,7	8,5		7,3	97,4		1,3	3,7	10,5	135,6
Gobabeb VIII	15-30	2,9	0,3	1,4	4,6	42,8	48,0	8,7								
No. 8	0- 5	1,1	1,5	1,6	4,8	55,8	35,2	8,1				10,1			117,5	
Gobabeb IX	5-15	8,6	6,0	3,1	5,8	40,8	35,7	8,1								
	15-40	4,6	0,7	1,0	6,5	70,1	17,1	7,6								
No. 9 Gobabeb X	0-50 +	0,3	0,2	0,9	1,8	20,1	76,7	7,7				0,7			5,5	396
No. 10	0-15	1,6	0,2	1,1	16,0	59,7	21,4	7,4				0,5				
Gobabeb XI	15-30	6,7	6,1	16,0	6,6	28,2	36,4	8,7				16,6				
	30-80 +	2,2	1,0	0,7	1,3	43,9	50,9	8,6				1,3				
No. 11 Gobabeb XII	0-50	7,2	6,2	22,4	31,7	22,2	10,3	8,0							3,0	
No. 12 Gobabeb XIII	0-50	3,9	1,3	10,5	67,2	16,5	0,6	7,3	1,6						62,5	
No. 13	0-20	1,8	0,2	0,4	1,0	40,0	56,6	7,5								
	30-50	1,4	0,2	0,4	6,3	35,8	55,9	7,5								
Gobabeb XIV	60-110	0,2	0,3	0,3	0,1	51,5	47,6	7,4								
No. 14	0-10	14,7	11,1	8,5	8,0	45,6	12,1	7,7	0,1			14,6				
Gobabeb XVI	10-20	0,4	0,6	1,6	9,0	31,6	56,8	7,6								
No. 15 Gobabeb XVII	0-10	0,0	0,8	0,3	0,1	29,8	69,0	7,3								
No. 16 Gobabeb XVIII	0-10	0,1	0,0	0,4	0,0	49,2	50,3	7,6								

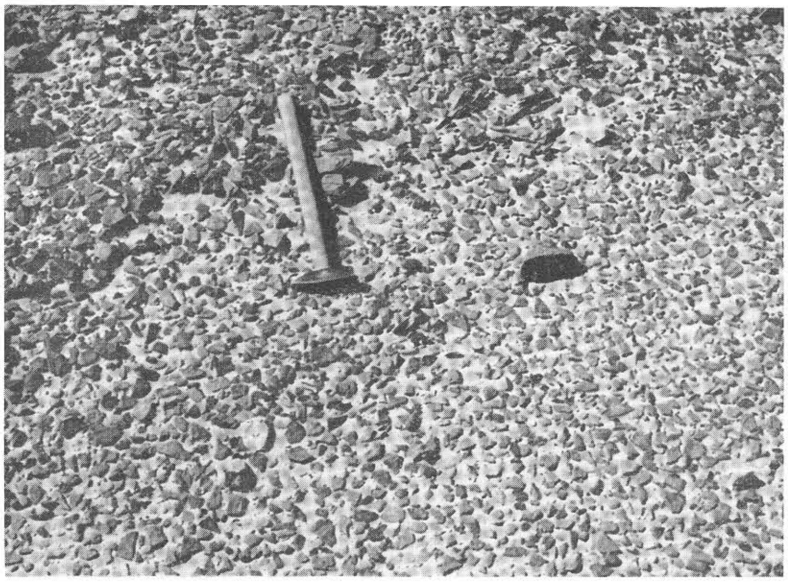


Figure 1. Soil surface in Namib Desert covered by coarse detritus near outcrop of indurated shale.

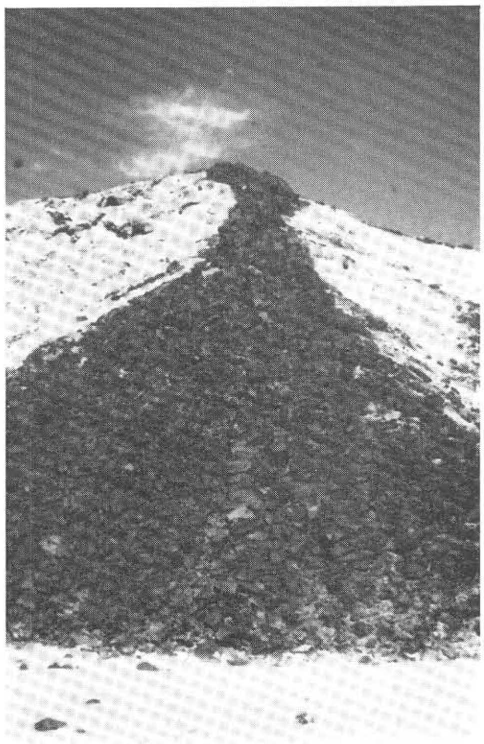


Figure 2. Fan of blocky detritus developed by physical weathering of a dolerite dyke.

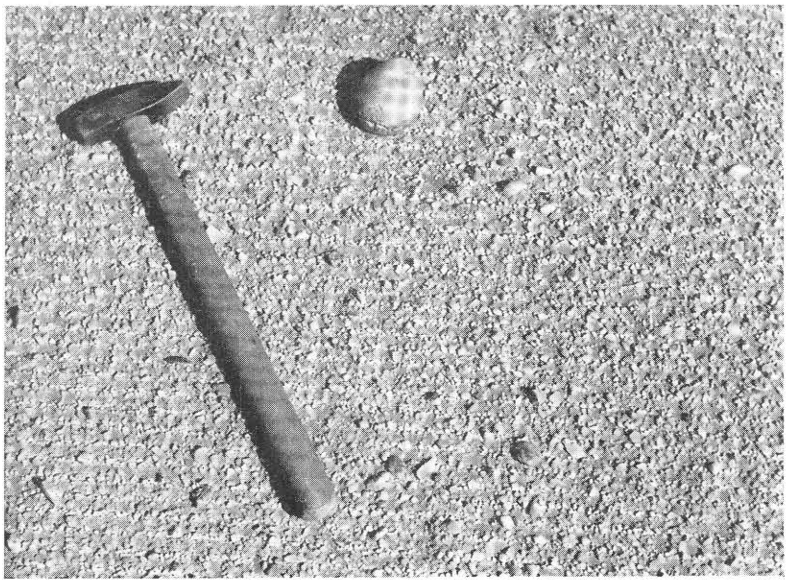


Figure 3. Soil surface in Namib Desert covered by rounded gravel and grit. This type of stony desert is also call- "Serir".

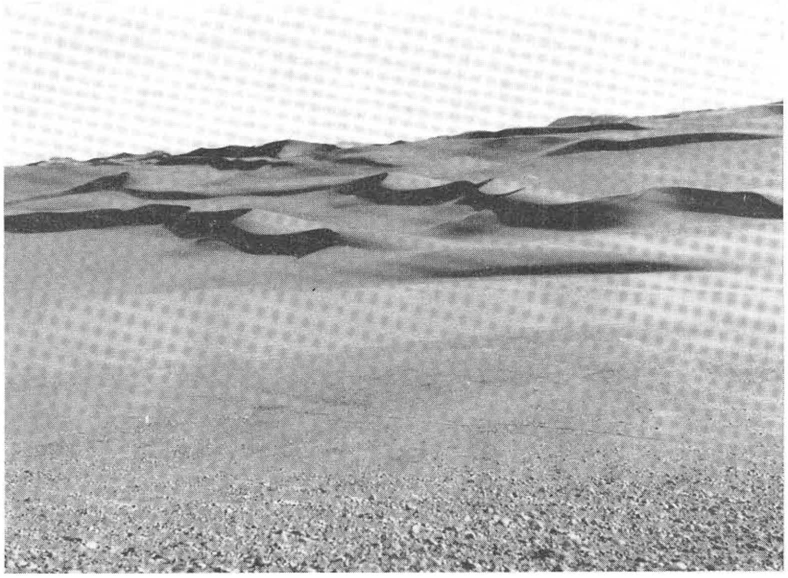


Figure 4. Shifting sand dunes south of Gobabeb in more or less parallel ridges.

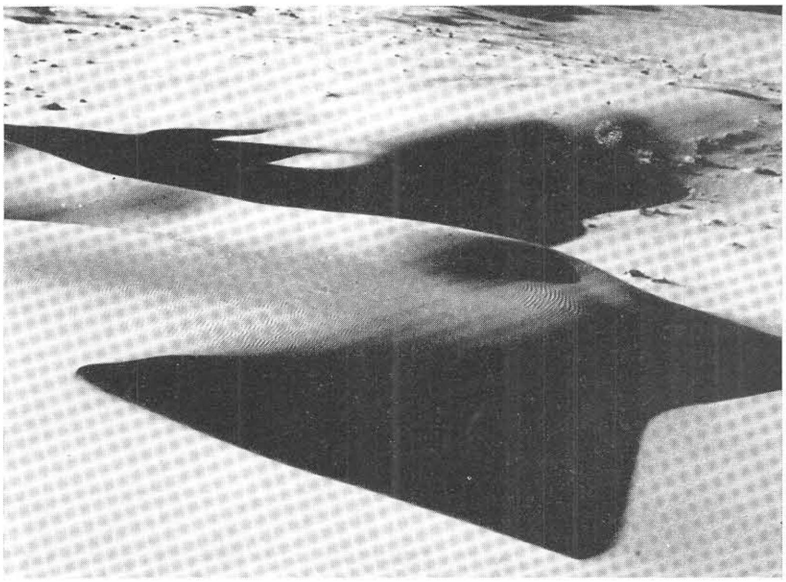


Figure 5. Barchans south of the Kuiseb River.

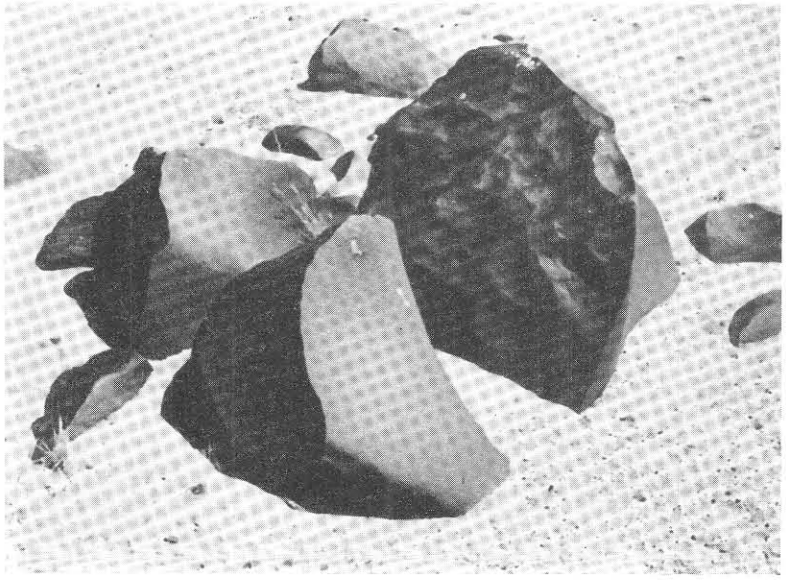


Figure 6. Weathered dolerite block with sand blasted surfaces.

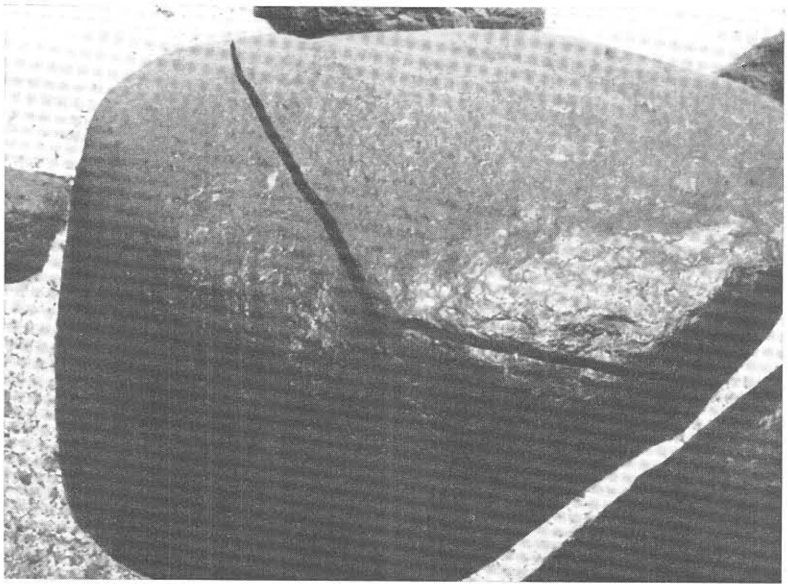


Figure 7. Dolerite block cracked by temperature change.

Figure 8. Broken down granite boulder due to insolation.

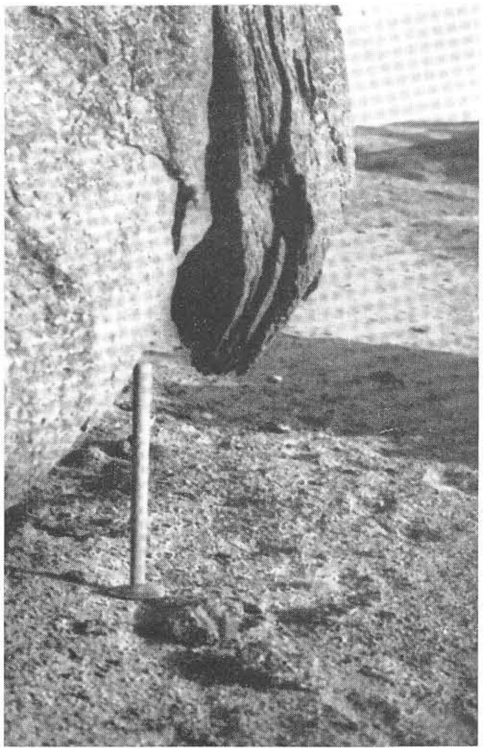


Figure 9. Exfoliation of granite due to physical weathering.

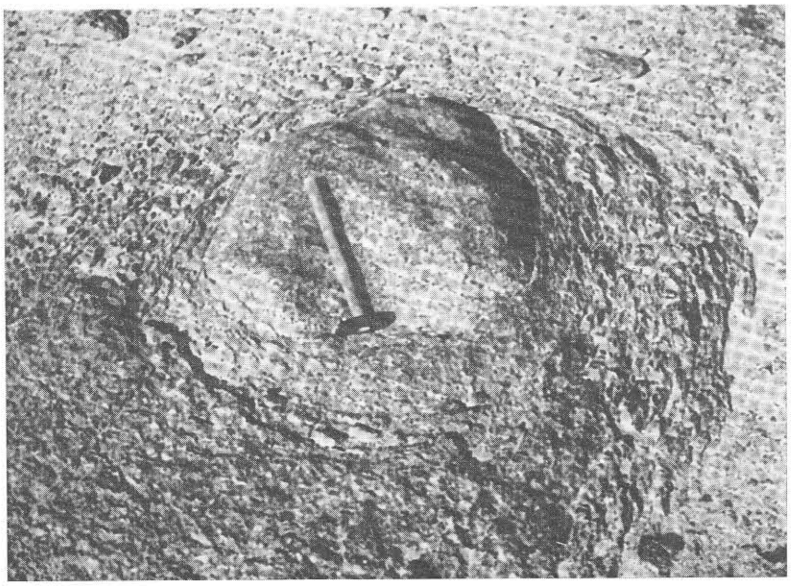


Figure 10. Desquamation of granite due to physical weathering.

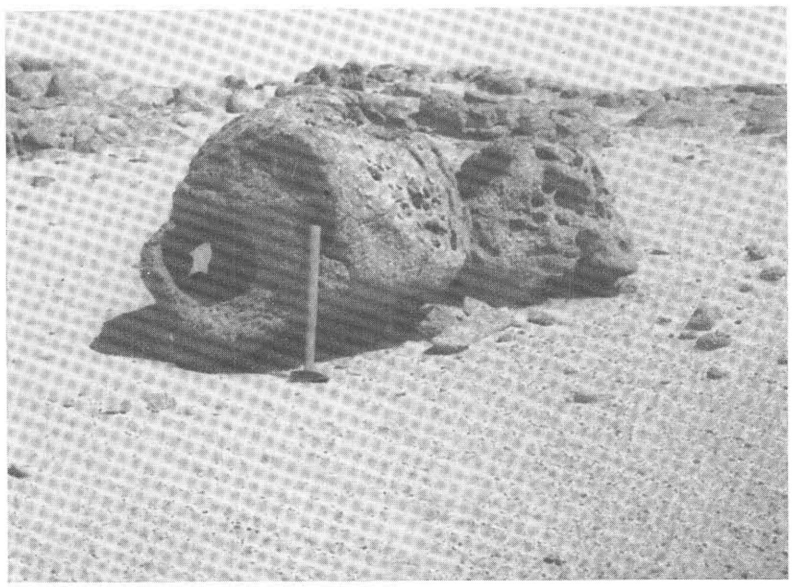


Figure 11. Cavernous weathering due to dissolution brought about by salty mist.

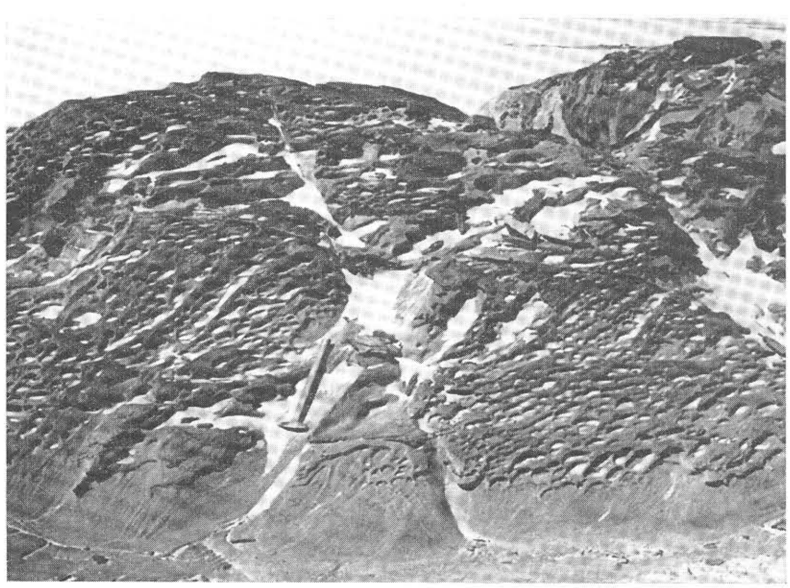


Figure 12. Cavernous weathering on mica shist.

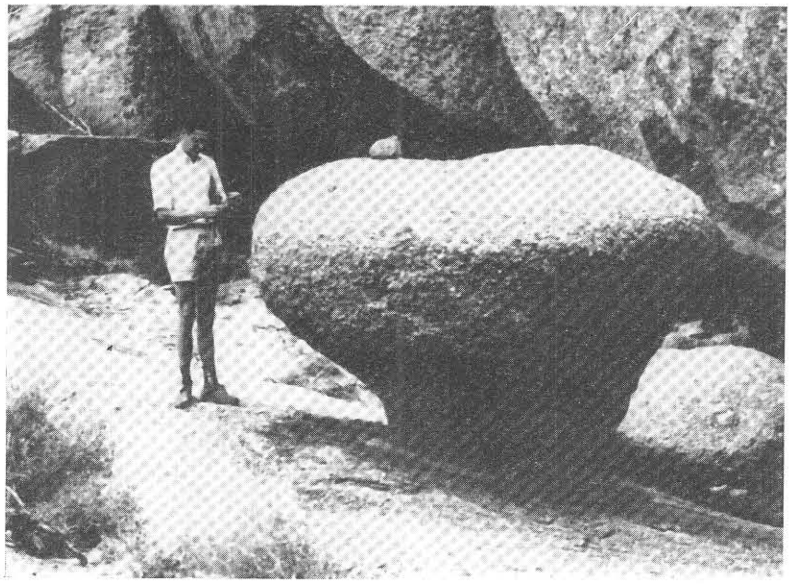


Figure 13. Chemical weathering of granite. Here the rock is decomposed from beneath and from the shady side where it remains moist for longer periods.

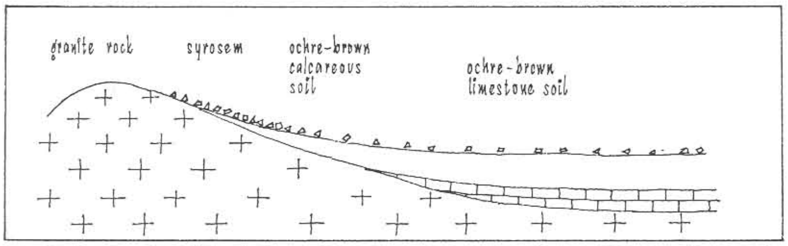


Figure 14. Development of soils on granite in the Namib Desert (schematically).

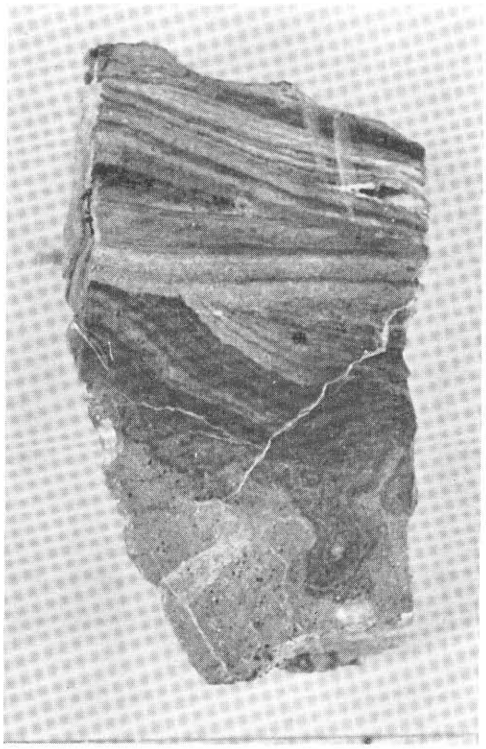
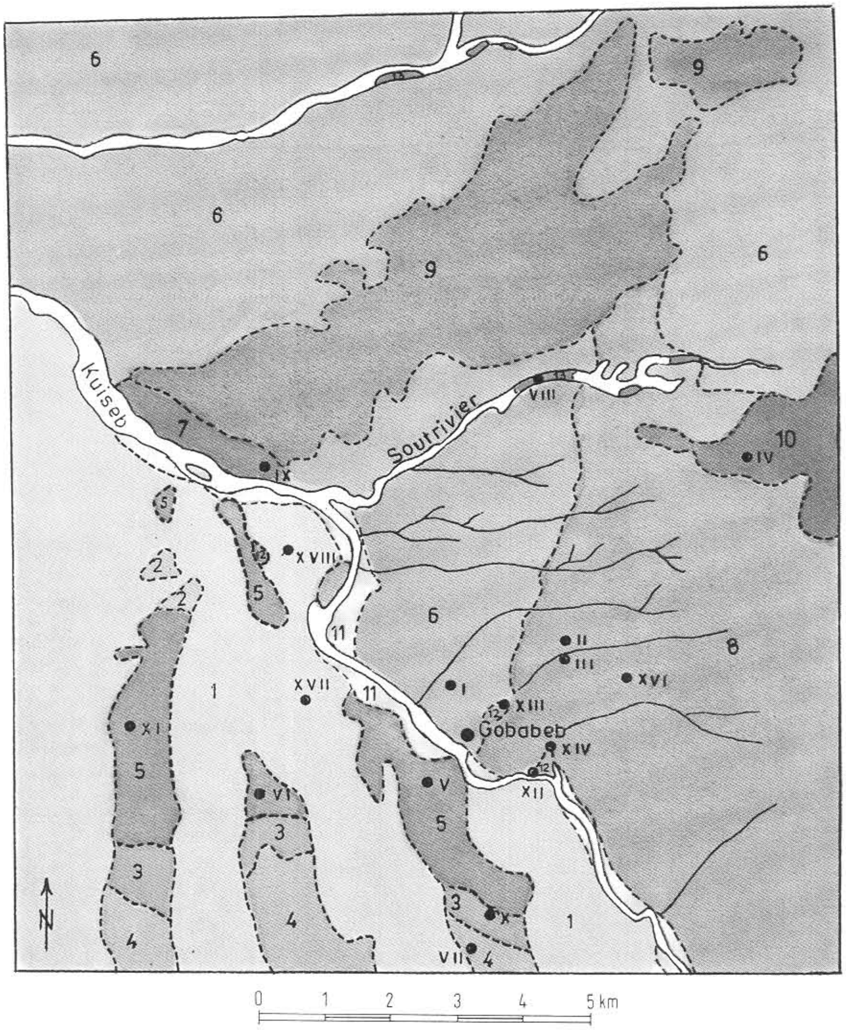


Figure 15. Frequently the uppermost one to five cm of calcrete reveal a layered structure.

Figure 16. Soils in the vicinity of Gobabeb.



A. Soils of the dune area

1 Vegetationless sands forming dunes which are still in motion. The sands consist mainly of quartz and feldspar grains.

2 Young soils with calcium carbonate concretions and crusts in depression of dune valley.

3 Fossil, cemented red-brown aeolic sands, partly eroded, containing gypsum and single calcium carbonate concretions.

4 Cemented red-brown aeolic sands with surface crust of calcium carbonate and gravel blanket.

5 Ochre brown limestone soil and calcareous gypsum soil above granite with a blanket of grit and a large proportion of aeolic sands in the upper horizon.

B. Soils with crusts in the plains

6 Shallow, ochre brown calcareous soil with a slight gypsum crust above granite and with a grit blanket; also Syrosem of granite.

7 Ochre brown salt containing gypsum soil on granite and with a grit blanket.

8 Ochre brown calcareous gypsum soil on metamorphic schists, with a grit blanket; also shallow gypsum soil on pegmatites, rich in detritus.

9 Ochre brown calcareous soil on granite, with grit blanket and with gypcrete at surface.

10 Ochre brown, partly calcareous gypsum soil with grit blanket and buried red-brown soil.

C. Soils of the valleys

11 Young brown flood-loam rich in mica bordering the Kuiseb river bed and overgrown with trees.

12 Fossil dark brown remains of flood-loam on high level terraces, mostly incrusted by salts.

13 Dirty brown, salt containing soil of various rivers, with a polygon crack pattern on the surface formed by underground water.

14 Riverbeds, partly choked with eroded desert detritus, partly with light coloured quartz sands.

● Research Station Gobabeb

● Site of profile.

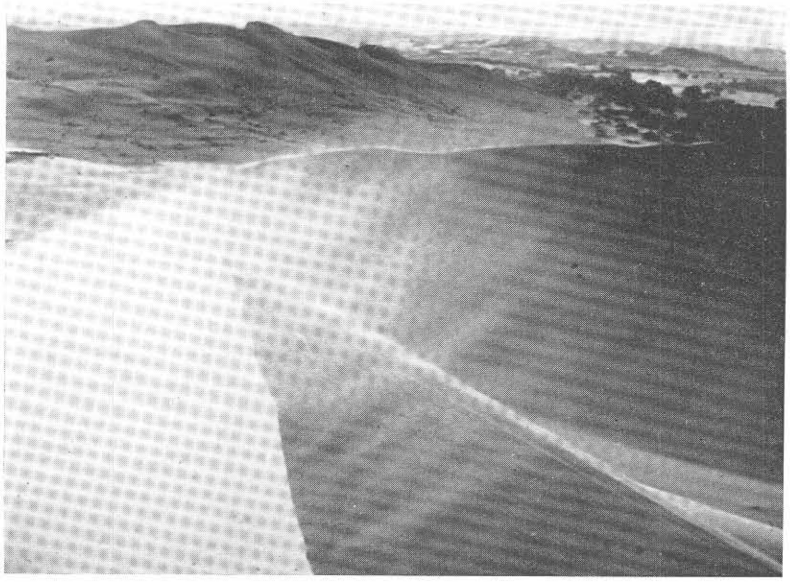


Figure 17. Especially near the surface of the dunes the sand is constantly in motion.

Figure 18. The flanks of the dunes may have different colours depending on the dominant mineral, i.e. dark in the case of opaque minerals, brown in the case of lighter minerals.

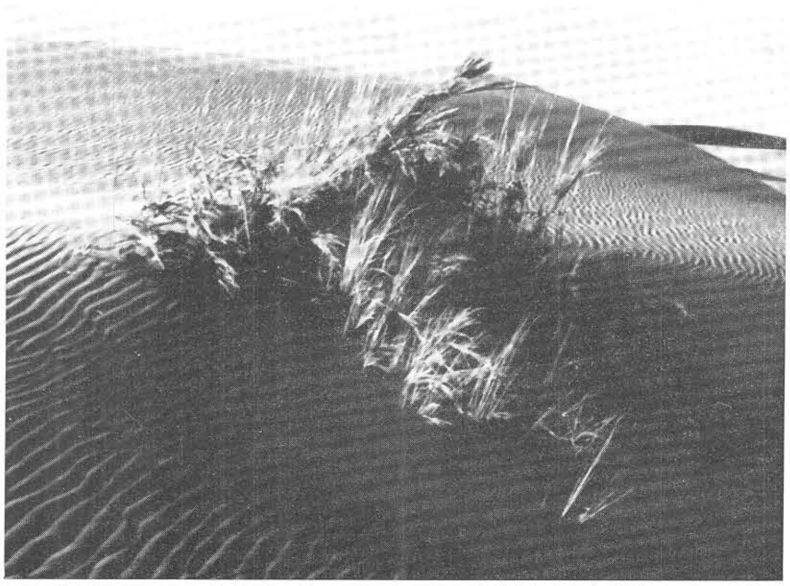


Figure 19. Isolated patches of vegetation occur on the dunes along the banks of the Kuiseb River.

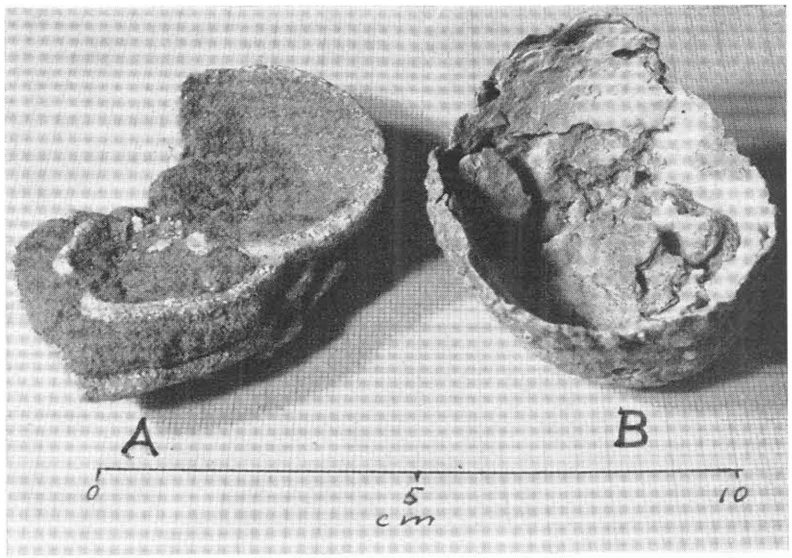


Figure 20. (A) Hemispherical calcium carbonate concretions embedded in fossil cemented dune sands. (B) Hemispherical calcium carbonate concretions out of recent loose sands of a pan-like dune valley.

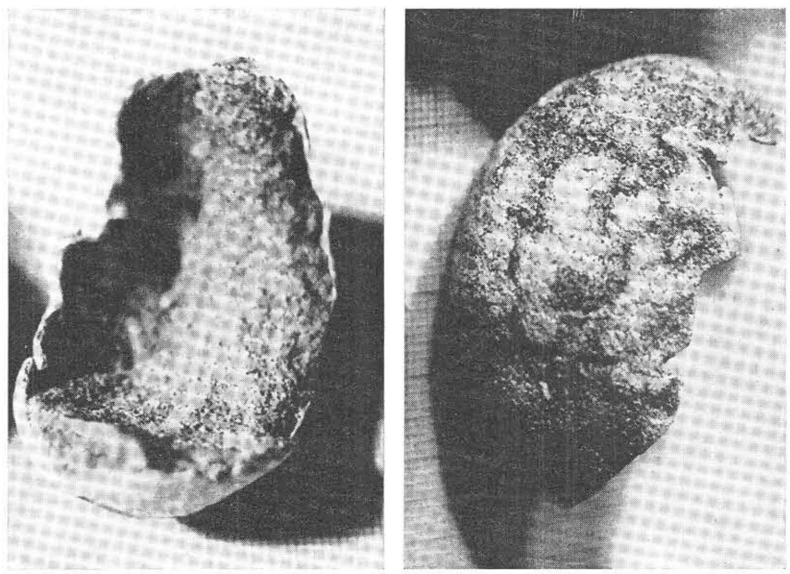


Figure 21. Partly destroyed calcium carbonate concretion shown in two different views, resembling a hen's egg, is filled with partly-cemented sand.

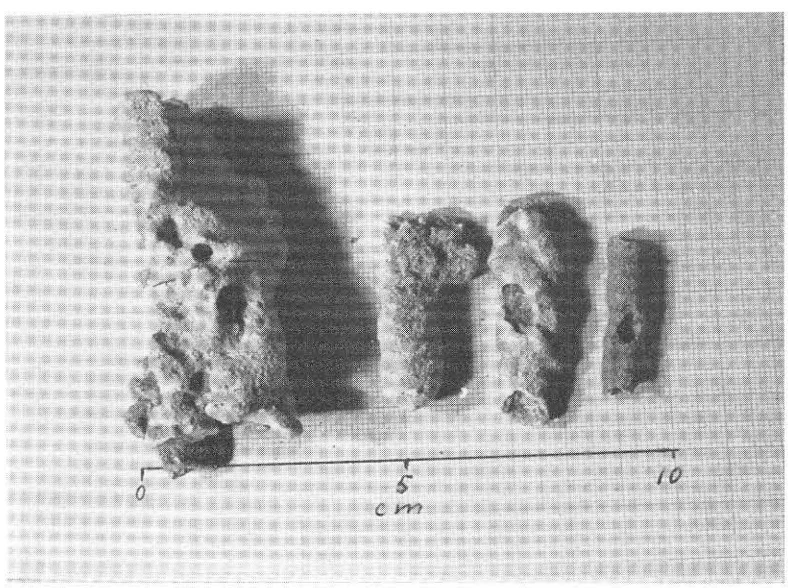


Figure 22. Cylindrical shaped calcium carbonate concretions out of fossil dune sands.

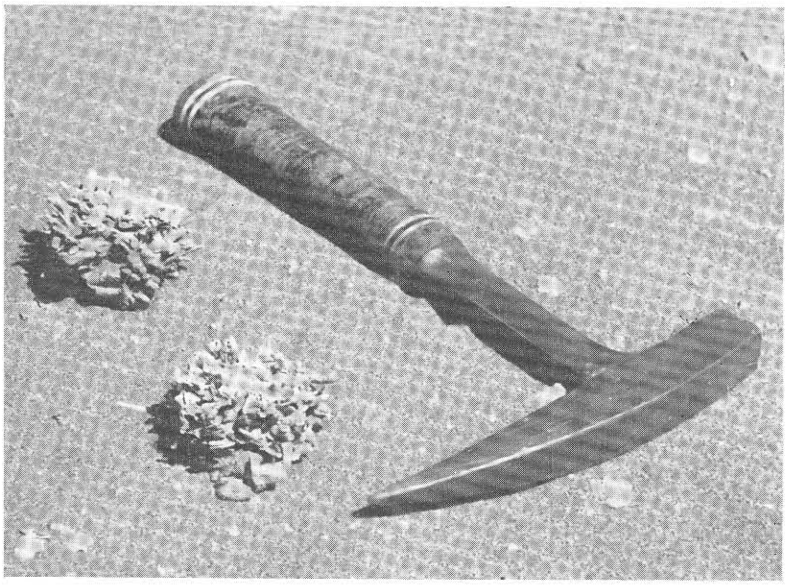


Figure 23. Calcium carbonate concretions with irregular, spiky surface found in loose sands of a pan-like dune valley.

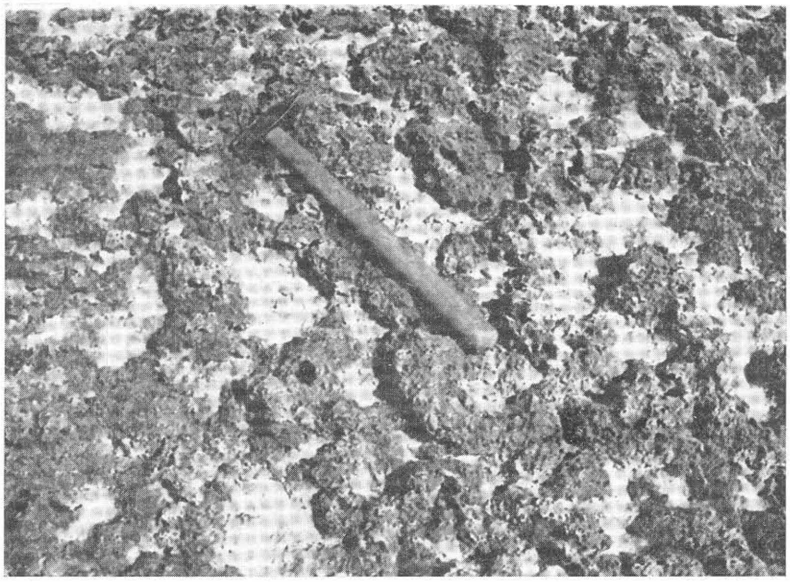


Figure 24. In the salty swamps of some tributaries of the Kuiseb River in the Namib Desert water evaporates on the surface and forms a dry, salty crust.

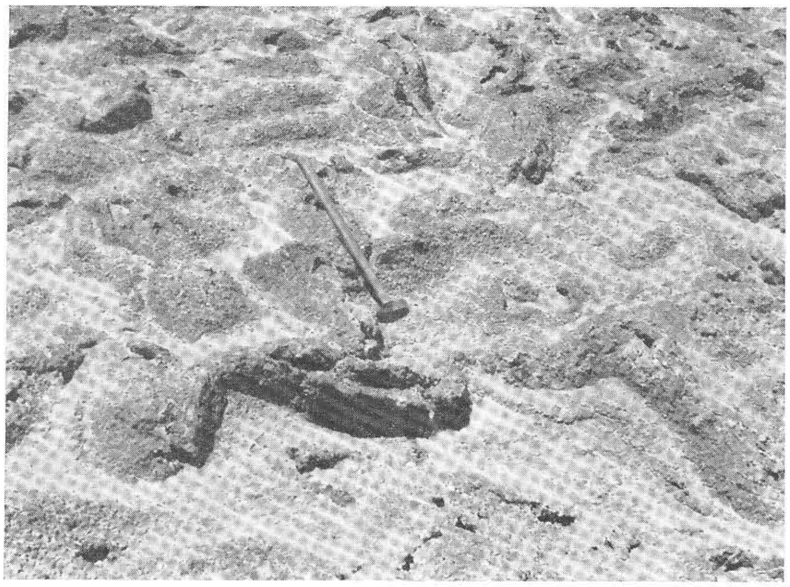


Figure 25. The surface of the salty swamps of Sout River near Gobabeb is extremely irregular and rough and has broken up to a polygonal pattern.

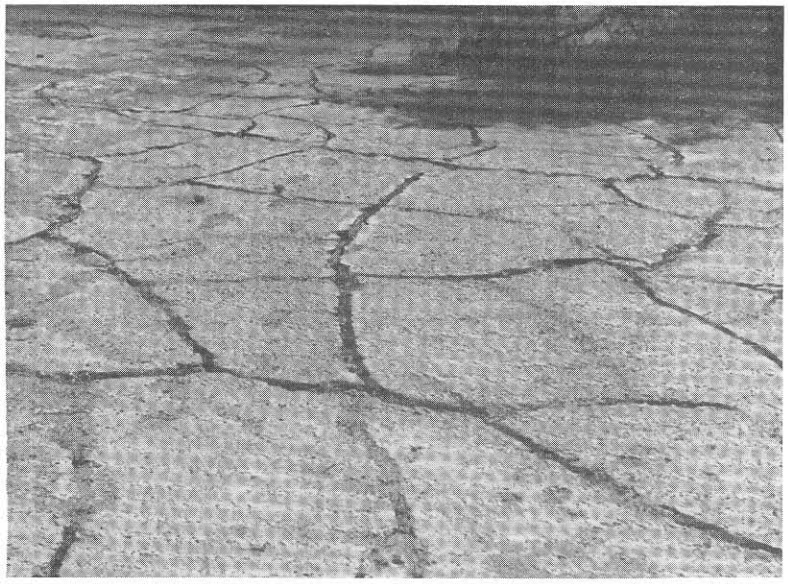


Figure 26. After flood of the Kuiseb River the higher levelled terraces are covered with silt which develop a system of mud cracks on drying.

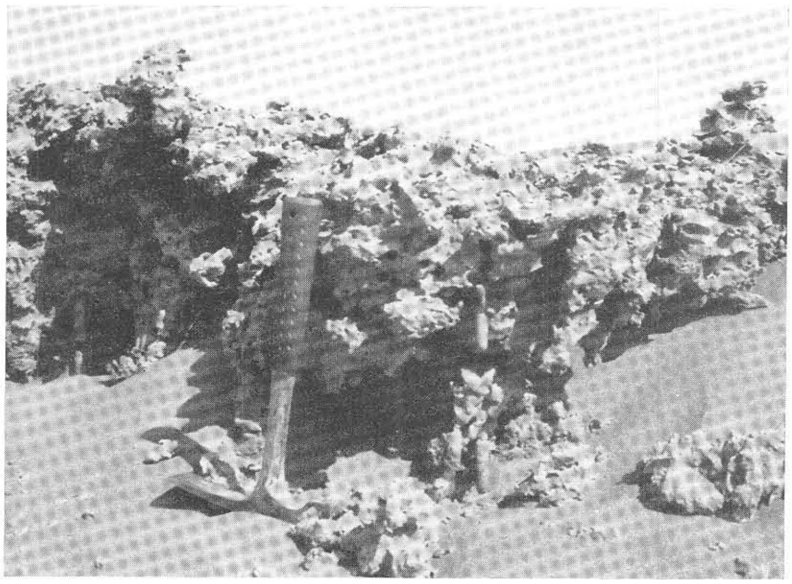


Figure 27. Some fossil loams are compact and indurated especially on the surface.