5. GENERAL GEOLOGY OF THE YOUNGER FORMATIONS

In the area of study surficial deposits cover large low-lying areas such as the Gawib River Valley, Gawib Flats, Tumas River Valley and certain areas of Dorstrivier. Basement rocks are exposed as mountains, inselbergs and in canyons through this cover. The surficial deposits consist mainly of siliceous clastic material that has been cemented with calcite and/or gypsum. The nature of the clastics is variable. Particles are both rounded and angular, with sizes as small as 2 µm in clays to boulders of several metres in diameter.

The terminology adopted was an attempt to incorporate into the definitions some of the features mentioned above.

Duricrust

A general term for a rock formed in semi-arid and arid climates by the accumulation, in clastic materials, of minerals that have been precipitated from waters carrying dissolved ions in solutions. The nature of the precipitate can be calcium carbonate, calcium sulphate, silicon, ? aluminium, etc.

Calcrete

A duricrust containing calcium carbonate (calcite) cement.

Gypcrete

A duricrust containing calcium sulphate (gypsum) cement.

Six varieties of calcrete have been reported from Southern Africa (Netterberg, 1971, p. 2-6), viz. calcified soil, powder calcrete, nodular calcrete, honeycomb calcrete, hardpan calcrete and boulder calcrete. The classification is basically genetic, each type representing a stage in the development of calcrete (<u>ibid</u>., p. 8, Table 1). The sequence is essentially a time-based function according to which the calcium carbonate content increases with age.

Only three of the six calcrete varieties are represented at the Langer Heinrich, viz the calcified soil, the hardpan calcrete and boulder calcrete. For the purpose of this discussion, however, the term calcified soil is replaced by a synonymous term, calcified breccia-conglomerate. According to the Glossary of Geology (1972, p. 91), breccia-conglomerate is defined as 'a sedimentary rock consisting of both angular and rounded particles' and this describes more precisely the nature of the clastic host material being dealt with in this study.

According to Netterberg (1971, p. 2-6), calcified breccia-conglomerate represents the youngest variety of calcrete which in places is not well cemented, having calcium carbonate values between 10 and 50 per cent. Hardpan calcrete is an older and better developed calcified breccia-conglomerate, and has a higher calcium carbonate content. It forms a sheet-like layer over less consolidated and developed calcrete. Boulder calcrete is a disintegrated and weathered variety of hardpan calcrete.

Four stages have been recognized in the formation of calcrete horizons (Gile <u>et al</u>, 1966, p. 354) as follows:

Stage	Carbonate Morphology
1	Thin discontinuous pebble coatings.
2	Continuous pebble coatings.
3	Many interpebble fillings forming a plugged zone.
4	Laminated zone overlying plugged zone.

Discontinuous segregations form in the initial stages of calcium carbonate accumulations. As calcium carbonate precipitation proceeds, the zone becomes more continuous until the plugged stage, termed the k-horizon, is reached. Finally a laminated zone, having a high $CaCO_3$ content, forms upon the k-horizon.

Gypcrete can be classified in a similar manner as calcretes, and those represented are powder gypcrete, vuggy gypcrete and consolidated gypcrete. Powder gypcrete is a surface accumulation and is the youngest in the stages of development. Beneath the ground surface vuggy gypcrete forms, and consists of a zone of small interlocking desert roses. The oldest form is the consolidated gypcrete, which is similar to the hardpan calcrete in appearance.

The gypcretes of the Namib Desert are very extensive and form a veneer over most of the calcretes in the area being investigated. It appears that towards the coast the ratio between the gypsum and calcite contents of the duricrusts increases as shown in Fig. 2. The vertical scale gives the relative percentage of each component. At Swakopmund, and this may apply to the whole of the Namib Desert along the coast, the duricrusts consist mostly of gypcrete, but at the Langer Heinrich the gypsum veneer is very thin and the calcite prodominates.

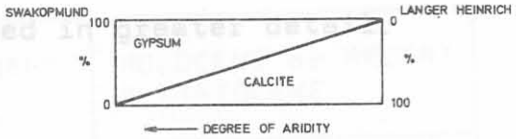
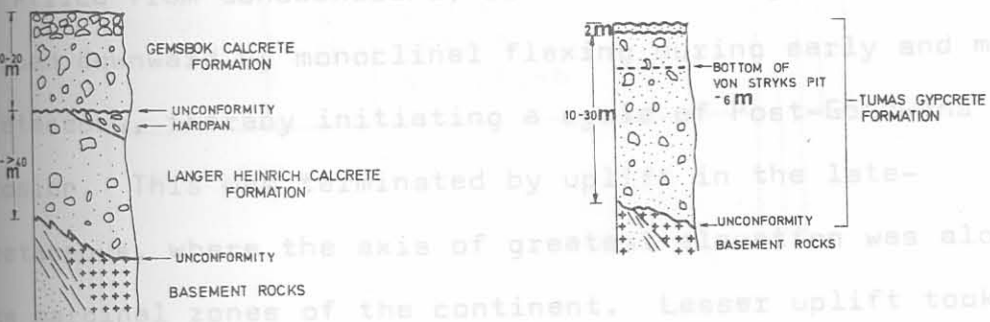


Fig. 2: A schematic relationship between gypsum and calcium contents of the duricrusts in the Namib Desert with respect to the degree of aridity.

Schematic profiles through the superficial duricrust deposits to the basement rocks are given in Fig. 3.



(a) (b)

Fig. 3: Schematic profiles through the superficial duricrust deposits to the basement rocks at
(a) The Langer Heinrich area;
(b) Von Stryks pit in the bed of the Tumas River. The pit is only approximately 6 m deep and the geology below this point is only inferred. Information from seismic data tends to confirm this. (See Fig. 7).

5.1 Geomorphology

Before describing the geology of the duricrust deposits, it is necessary to consider briefly the geomorphological sequence of events that culminated in the formation of the present-day landscape of the Namib Desert. Greater emphasis is placed on the Gawib River and environs, as that area was mapped in greater detail.

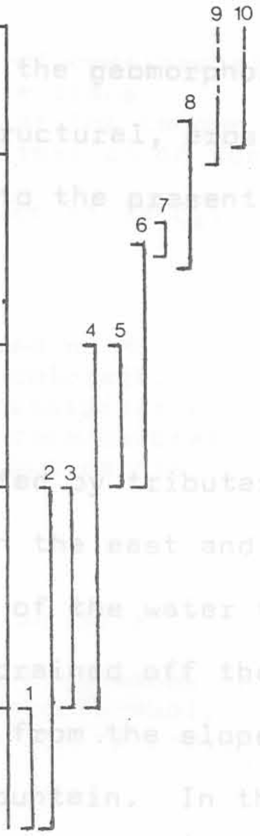
5.1.1 Palaegeomorphology

The Namib Plain and the sediments comprising it are the consequence of successive erosion cycles (King, 1963; Dixey, 1955, p. 5-15; Gevers, 1942, p. 63; Truswell, 1971, p. 139-142) and the sequence of events is given in chronological order in Table 3. Following the separation of Africa from Gondwanaland, continental margins were warped downward by monoclinal flexing during early and mid-Cretaceous, thereby initiating a cycle of Post-Gondwana erosion. This was terminated by uplift in the late-Cretaceous, where the axis of greatest elevation was along the marginal zones of the continent. Lesser uplift took place on the outward and inward flanks of the axis. A new erosion cycle began, lasting between early Senonian and late-Oligocene and culminating in the African erosion surface. During this time humid conditions prevailed.

By the end of the Miocene, epeirogenic uplift brought about erosion of the African surface to produce the widely distributed Post-African landscape. Final uplift in the late Pliocene and early Quarternary tilted the margins outward. It is thought that this period of uplift was of a multicyclic nature. Erosion eventually produced the Quarternary surface. A feature of this last uplift was doming along a central axis, making the Namib Plain slightly convex.

TABLE 3: CHRONOLOGICAL DEVELOPMENT OF THE NAMIB DESERT

CAINOZOIC	QUARTERNARY		HOLOCENE or RECENT PLEISTOCENE
	TERTIARY		PLIOCENE MIOCENE OLIGOCENE EOCENE
MESOZOIC	CRETACEOUS	UPPER	DANIAN SENONIAN
		LOWER	TURONIAN CENONANIAN ALBIAN APTION NEOCOMIAN
	JURASSIC		



1. Gondwana erosion surface
2. Fragmentation of Gondwanaland - continental drift
3. Downwarping, marine transgression
4. Post-Gondwana erosion surface
5. Uplift
6. African erosion surface, humid climate, formation of initial Gawib and Tumas River Valleys.
7. Uplift
8. Post-African erosion surface - desert climate, Langer Heinrich calcrete and Tumas gypcrete formations developed.
9. Multi-cyclic uplifts
10. Quarternary erosion surface, Gemsbok calcrete formation developed, Swakop and Khan River canyons formed

The gouging out of the pre-alluvial Gawib River Valley between the Langer Heinrich Mountain and the Schieferberge is probably of Post-Gondwana and African erosion surface age. This was therefore the palaeotopo=

graphic base upon which the sediments, as found today, were deposited.

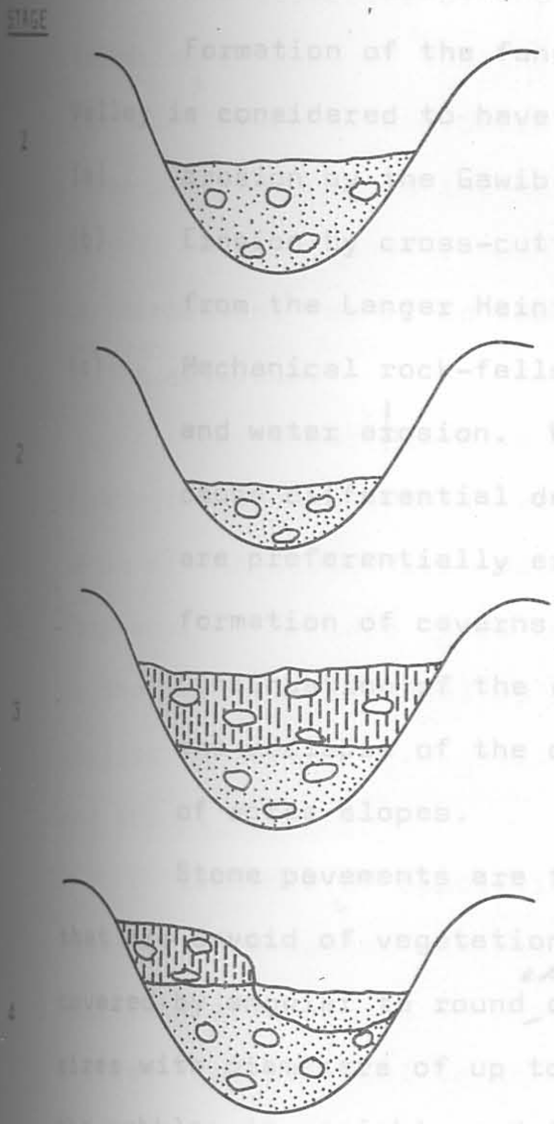
Fig. 4 illustrates diagrammatically the geomorphological development of the Gawib River Valley. Structural, erosional and sedimentary features can be traced up to the present time.

5.1.2 Modern geomorphology

The Gawib River drainage system is fed by tributaries originating between the Tinkas watershed in the east and the Gawib watershed in the west (Map 1). Most of the water that has flowed through the Gawib River Valley drained off the Tinkas watershed, deriving the bulk of its volume from the slopes of the Augawibberge and the Langer Heinrich Mountain. In the west, the Gawib watershed feeds water into streams running off the Schieferberge.

Mountainous terrain surrounds the Gawib River Valley. The Langer Heinrich Mountain to the north has an altitude of 1 052 m. The Schieferberge to the south are less impressive, attaining heights of 820 m. The mountains are in a youthful stage of erosion, characterized by steep - sided valleys and gullies.

Fanglomerates are characteristic of desert environ= ments (King, 1963). In the Gawib River Valley a remnant terrace of the Gemsbok calcrete formation has been preserved in an enclave of the more competent quartzites of the Etusis Formation (Plate 6). Normally fanglomerates in deserts advance outward from the mountain fronts, but in this



1. Deposition of continental breccia on African surface.
2. Initiation of the Langer Heinrich calcrete formation in desert conditions.
3. Precipitation of $CaCO_3$.

1. Uplift at end of Miocene.
2. Erosion of calcrete.
3. Continued precipitation of $CaCO_3$.
4. Langer Heinrich calcrete formation completed, but partially eroded.

1. Multicyclic uplifts in the Pleisto=cene
2. Development of Gemsbok calcrete formation unconformably on the Langer Heinrich calcrete formation.

1. Continued Pleistocene uplift.
2. Present Gawib River channel formed, filled with Recent alluvium.
3. This was contemporaneous with erosion of Khan and Swakop River canyons.

▨ **LANGER HEINRICH CALCRETE FORMATION**

▥ **GEMSBOK CALCRETE FORMATION**

Fig. 4: Geomorphological development of the sediments in the Gawib River valley

case it is purely an erosional type. Mabbutt (1952, p. 345) describes similar terraces in the Ugab River Valley.

Formation of the fanglomerate in the Gawib River Valley is considered to have taken place by three processes:

(a) Erosion by the Gawib River when in flood.

(b) Erosion by cross-cutting tributaries originating from the Langer Heinrich Mountain.

(c) Mechanical rock-falls due to undercutting by wind and water erosion. Wind erosion has a tendency to cause differential deflation where the softer parts are preferentially eroded. The result is the formation of caverns and overhangs (Plate 7). Continuation of the deflationary processes causes the collapse of the overhangs and the development of scree slopes.

Stone pavements are found on the Gawib Flats in areas that are devoid of vegetation. They are surfaces which are covered by angular to rounded quartz pebbles of different sizes with diameters of up to 50 mm. The packing density of the pebbles is variable and it was observed that those areas with high packing densities contain pebbles that are rounder (Plate 8). This suggests that the denser the packing and the rounder the pebbles, the longer the stone pavement has been exposed to deflationary processes.

Stone pavements are formed after the removal of finer material by wind and/or water action, leaving a pebble residue on the surface. Loose boulders lying on top of the Gemsbok calcrete formation have been subjected to negligible cementing due to this phenomenon.

5.2 Langer Heinrich Calcrete Formation

The calcretes of the Langer Heinrich calcrete formation consist of the three types mentioned earlier. Calcified breccia-conglomerate forms the bulk of the formation and only in the north-east does a remnant hardpan calcrete unit remain (Map 1). Boulder calcrete is unimportant for it consists of loose boulders scattered in the alluvium.

The Langer Heinrich calcrete formation is a desert fluviatile sediment which was deposited and cemented in wadis of the Gawib River during the dry middle to late Tertiary. (The term '_Wadi_' as applied in this context is the same as that used by Glennie (1970, p. 29), which implies 'a form of fluviatile transport which is sporadic and abrupt').

Evidence of deposition by water is shown in Plate 9. The larger and flatter pebbles of schist and quartzite are aligned in a westerly direction, suggesting a river flow parallel to the Gawib River today. Microscopic examination of orientated hand samples, taken from several localities along the Gawib River, showed no visual lineation of the smaller sand particles.

The calcified breccia-conglomerate is generally medium to coarse-grained with grain sizes between 0,5 and 45 mm. The distribution of grain size in the outcrops is not uniform, for in parts it is finer grained that in others. Grain sizes between 0,5 mm and 15 mm with an average of 2-3 mm constitute the finer-grained material.

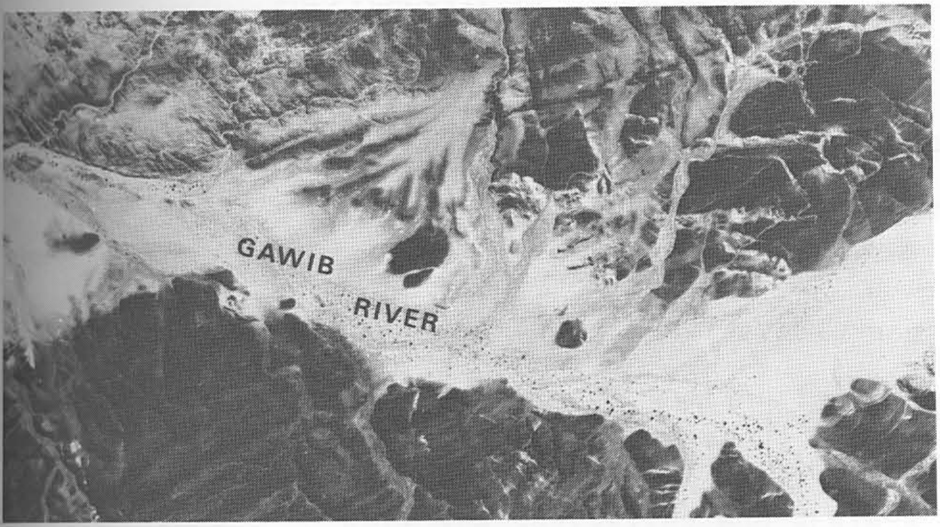


PLATE 6 Aerial photograph showing the fanglomerate of the Gemsbok calcrete formation in the Gawib River Valley.

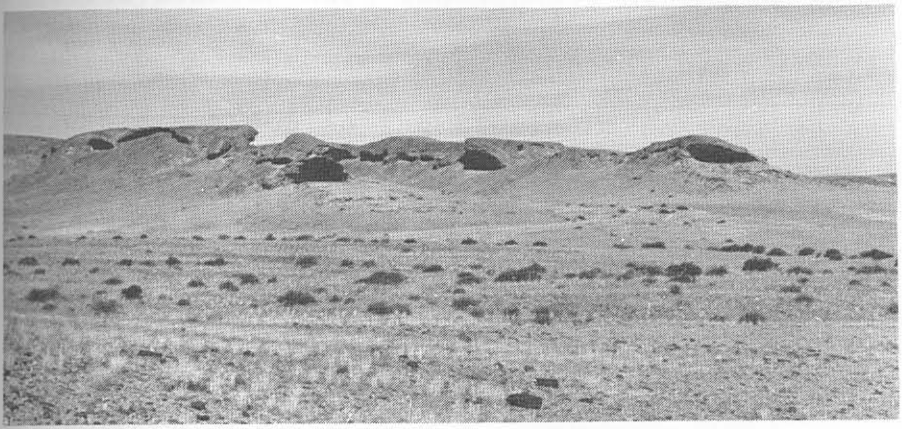


PLATE 7 Caverns and overhangs in the Gemsbok calcrete formation formed by deflationary processes.

PLATE 8 Stone pavement on the Gawib Flats composed of angular to rounded quartz pebbles.

The pebbles are predominantly quartzite with lesser amounts of granite, quartz (sometimes smokey), feldspar and schist.

Rounding in the grains varies considerably and is dependent largely on their composition and fabric. Those pebbles which show bedding planes and schistosity are the least rounded, for example, the quartzites and schists of the Etusis and Tinkas Formations respectively. Quartz, granite and pegmatite pebbles have the highest degree of rounding. Most of the rounded pebbles have probably been derived from the conglomerate bands in the Etusis Formation, as water and river action is too sporadic to be of any significance. Glennie (1970, p. 33) points out that roundness is not a guaranteed criterion for indicating distance from source.

The mineralogical components of the calcified breccia-conglomerate are mainly calcite, quartz and feldspar, minor biotite and carnotite, with accessory clay such as montmorillonite and attapulgite. Dolomite is absent, which agrees with the statement of Mackenzie and Bricker (1971, p. 241) that dolomite cements do not form in younger sediments. Microscopical and X-ray diffraction analyses of heavy mineral concentrates in several samples show the presence of diopside, hornblende, biotite, ore, garnet, tourmaline, sphene, zircon, apatite as allogenic minerals as well as carnotite. This assemblage seems to be fairly general and indicates a provenance of pegmatites, Bloedkoppie Granite, schists and granofels of the Tinkas Formation, and the quartzites of the Etusis Formation. Carnotite is a mineral which was precipitated from solution and is therefore authigenic.

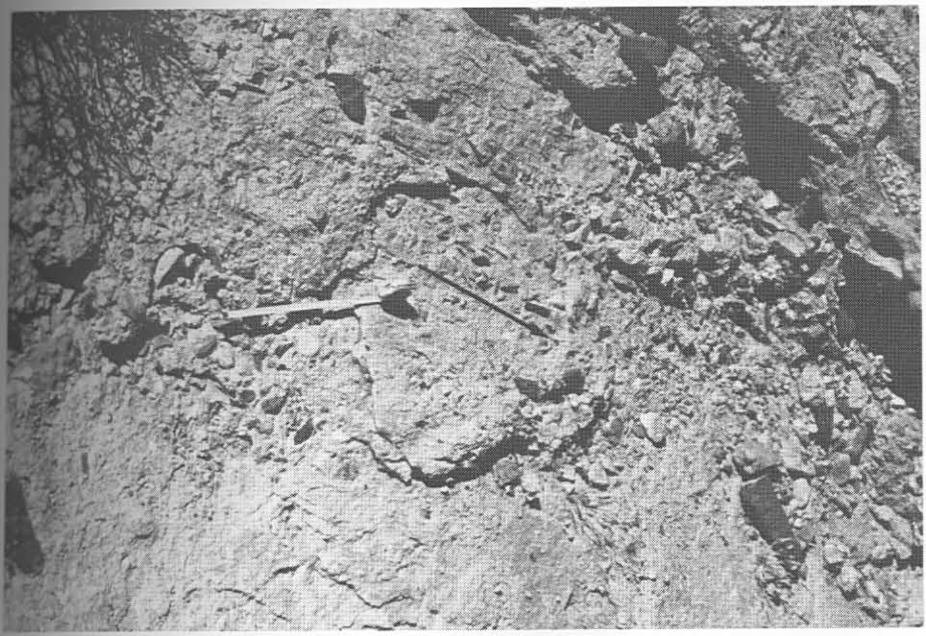


PLATE 9 Flatter pebbles of schist in the Langer Heinrich calcrete formation orientated in the direction of waterflow as shown by the arrow.

Montmorillonite and attapulgite represent weathering products. Attapulgite is found in those calcretes which have a slight greenish colouration, and predominates locally towards the west where the Gawib River turns northward. Montmorillonite is widely distributed and is found in the normal greyish calcrete.

Calcite and gypsum accumulation in the detrital material shows peculiar characteristics. The growth of crystals from solutions results in the detrital fragments being pushed apart. A stage is eventually reached where the grains are pushed apart to such an extent that they are no longer in contact with one another and 'float' in a sea of calcite or gypsum. The result is that there is an expansion of the sediment as a whole. If this expansion is large enough in a horizontal direction, pseudo-anticlines and synclines may develop (Goudie, 1973, p. 61). Plate 10 shows that there are no two detrital grains in contact. With an increase in age of the calcrete, the distance between the grains becomes larger. Plate 11 is particularly interesting, and demonstrates how the 'pages of a biotite book' have been separated by calcite precipitating between them. Goudie (1970, p. 42) reports that pressures resulting from crystal growth may reach approximately 5 000 kPa. Such pressures are sufficient to shatter rock fragments of which the tensile strength lies between 2 000 and 20 000 kPa.

Certain parts of the Langer Heinrich calcrete formation have a lower degree of calcification than others and Plate 12 illustrates such an example. The black areas are pore spaces, and the degree of separation of the grains is not as large as that illustrated in Plate 10. Typically, the pores are located mainly along surfaces of the detrital grains and cut across calcite crystals to a lesser extent. Calcrete with this open structure may be considered to be the main acquifers which afford passageways to potentially mineralizing solutions.

A second generation of calcite precipitation has resulted in the filling of the pore spaces. Plate 13 shows rims of younger calcite surrounding the rock fragments. Within the calcite matrix, and also contributing to the cement, is carnotite (black crystals in Plate 13) which has a good platy morphology. In other cases carnotite exhibited no external crystal structure and it appeared as a generally amorphous mass.

In thin section, carnotite is almost opaque, having a dark green colour, whereas in polished section it is a translucent yellow.

Plates 14(a) to (c) and 15(a) to (c) are electron photomicrographs of carnotite mineralization in calcrete. Within the lower part of Plate 14(a) amorphous carnotite is concentrated, the presence of which is confirmed by the electron scatter photographs of uranium and vanadium in Plates 14(b) and (c) respectively. Carnotite with a platy structure is exhibited in Plates 15(a) and (b), the latter of which is an enlargement (x 3) of the former. Note the corresponding distribution of carnotite and uranium in Plates 15(a) and (c).

Carnotite is thought to have precipitated in the calcrete at about the same time as the second generation

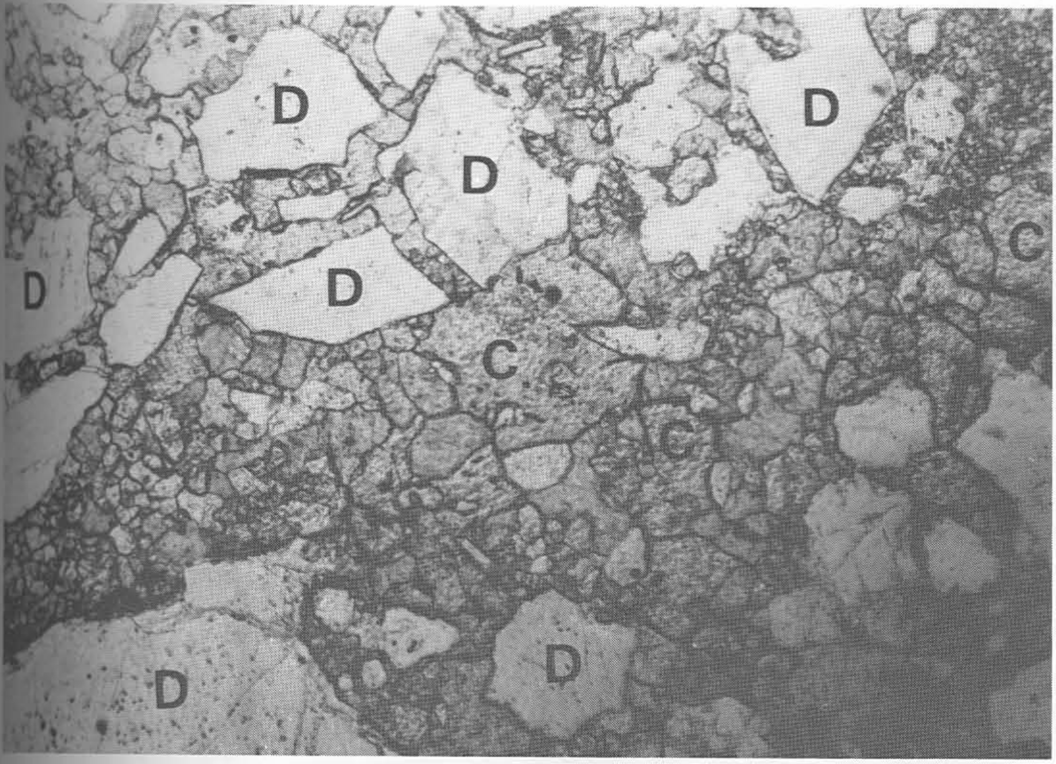


PLATE 10 Photomicrograph showing the pushing apart of detrital grains by calcite. D = detrital grains, C = calcite. Magnification x 50.

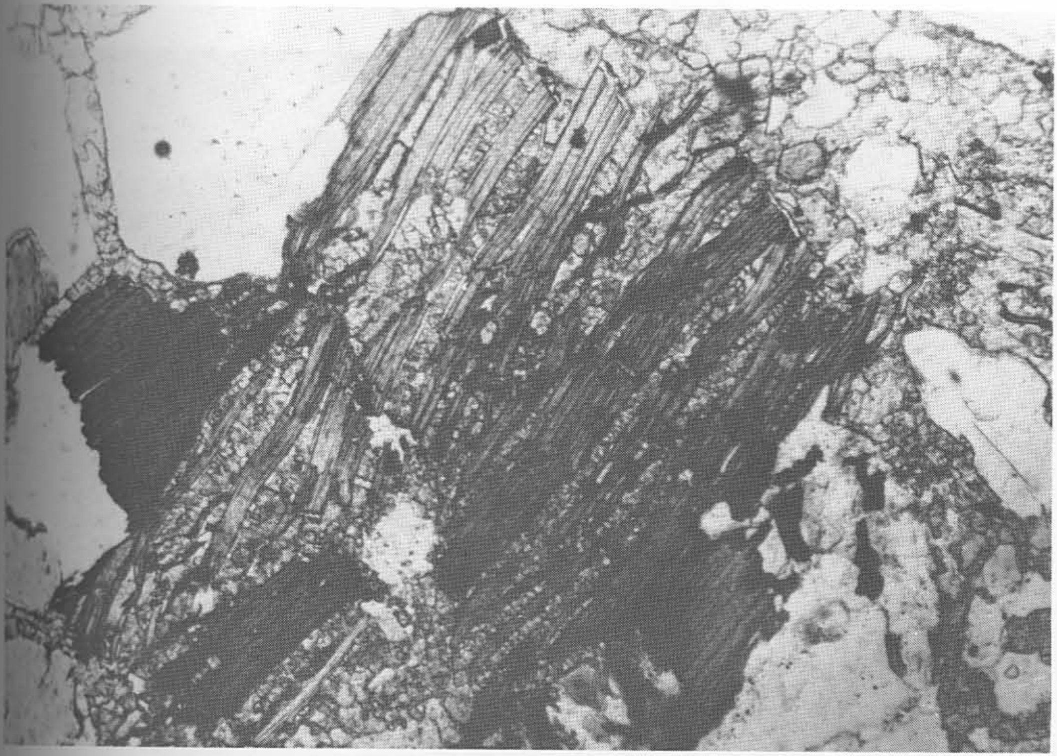


PLATE 11 Photomicrograph showing how the pages of a biotite 'book' have been separated by the precipitation of calcite between them. Magnification x 50.

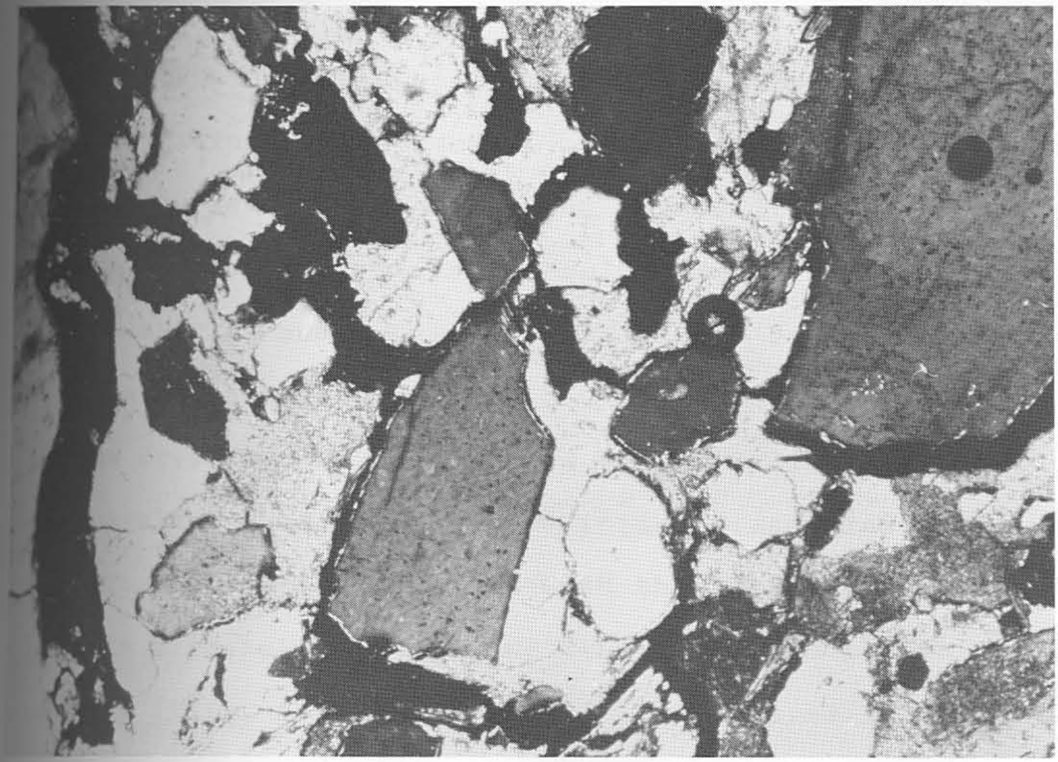


PLATE 12 Photomicrograph illustrating a low degree of calcification. The black areas are pore spaces which frequently surround the detrital grains. Separation of grains by calcite precipitation is less extensive. Crossed nicols. Magnification x 50.

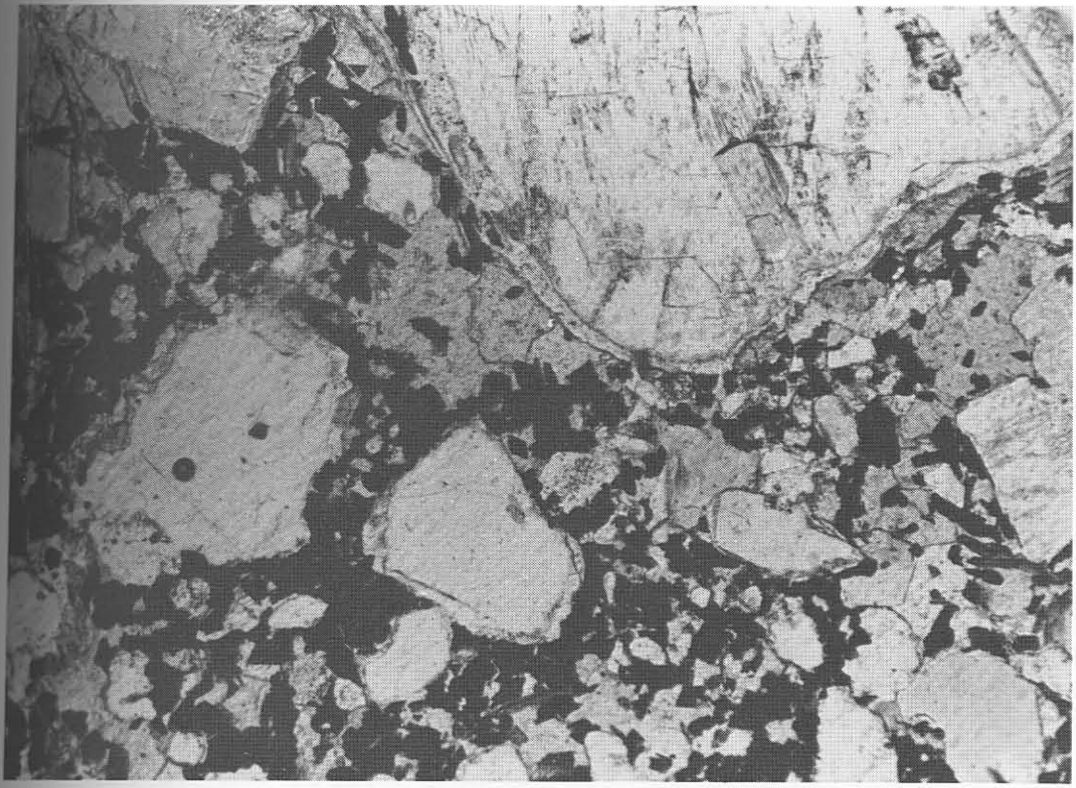


PLATE 13 Photomicrograph showing rims of second generation calcite surrounding detrital grains. The black areas are carnotite crystals in a lighter calcite matrix. Magnification x 50.

calcite. Characteristically, carnotite surrounds the detrital grains in the same way as the second generation calcite and is to a lesser extent crystallized as inclusions in single calcite crystals. Should it occur within the calcite matrix, some distance away from a detrital grain, it is often found on or close to boundaries of interlocking calcite crystals, which provided a more limited passageway to mineralizing solutions. The intimate association between rock fragments and carnotite, with the latter having crystallized in original pore spaces, is illustrated in Plate 16. Langford (1974, p. 519) noted similar features in the Yeelerrie uranium deposit of Western Australia.

Therefore it is concluded that there are at least two ages of calcite precipitation, with the first taking place on a much larger scale than the second. The latter had the tendency to seal up the pore spaces, and an examination of Plates 13 and 16 show that there is almost no visible pore space remaining. A notable feature of the uranium mineralization is that it is monomineralic, having only carnotite present.

The hardpan capping of the Langer Heinrich calcrete formation lies stratigraphically above the calcified breccia-conglomerate, but is no longer found in contact with it. Plate 17 shows the hardpan calcrete overlying the Bloedkoppie Granite. Remnant boulders, i.e. boulder calcrete, are found scattered on the Bloedkoppie Flats. This suggests that the hardpan calcrete at one stage covered at least an area to the east of the region mapped.

PLATE 14(a) Electron photomicrograph of amorphous carnotite in calcrete. Magnification x 1 000.

PLATE 14(b) Electron scatter photomicrograph of uranium of the same area in Plate 14(a).

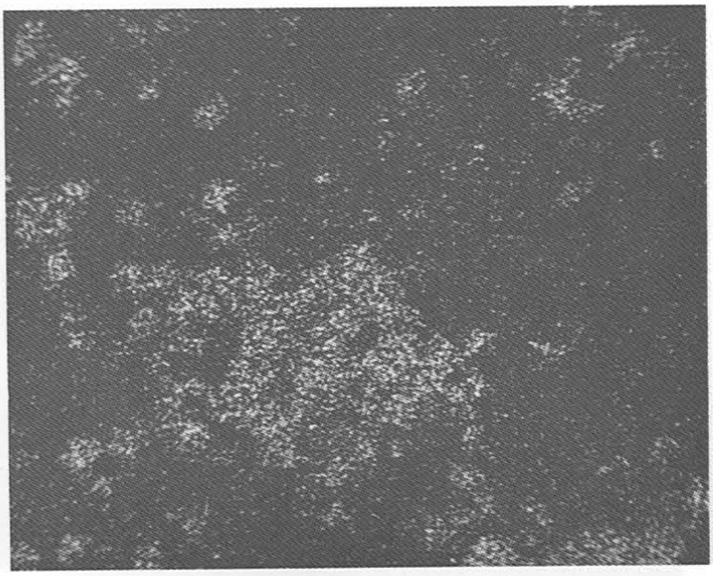


PLATE 14(c) Electron scatter photomicrograph of vanadium of the same area in Plate 14(a).

PLATE 15(a) Electron photomicrograph of platy carnotite in calcrete. Magnification x 1 000.

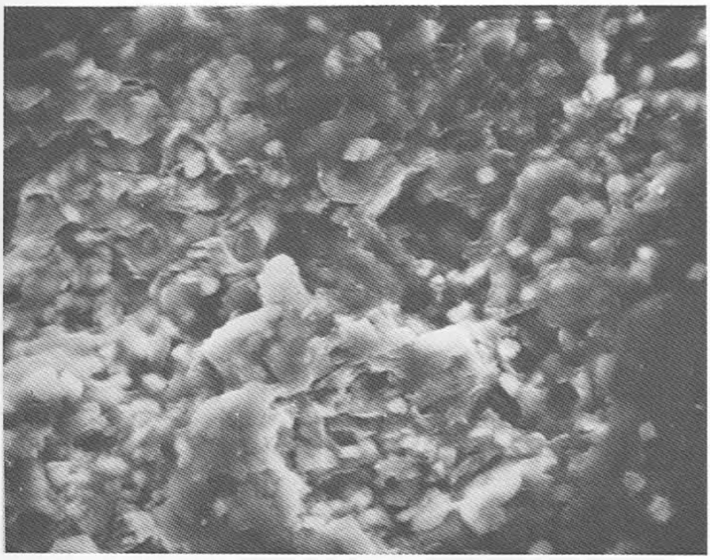


PLATE 15(b) Electron photomicrograph of platy carnotite in calcrete. Magnification x 3 000.

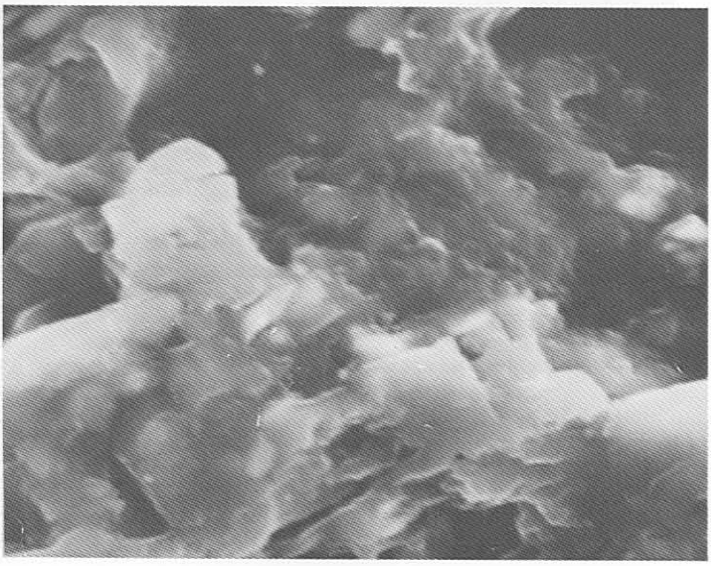
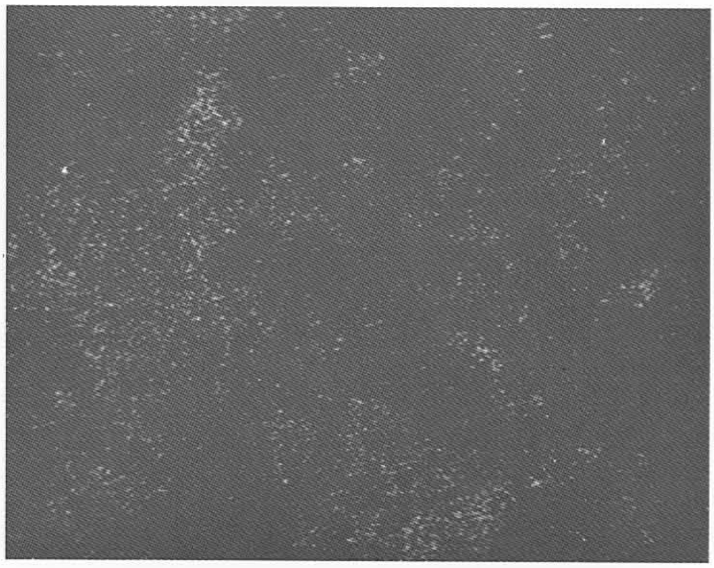


PLATE 15(c) Electron scatter photomicrograph of uranium of the same area in Plate 15(a).



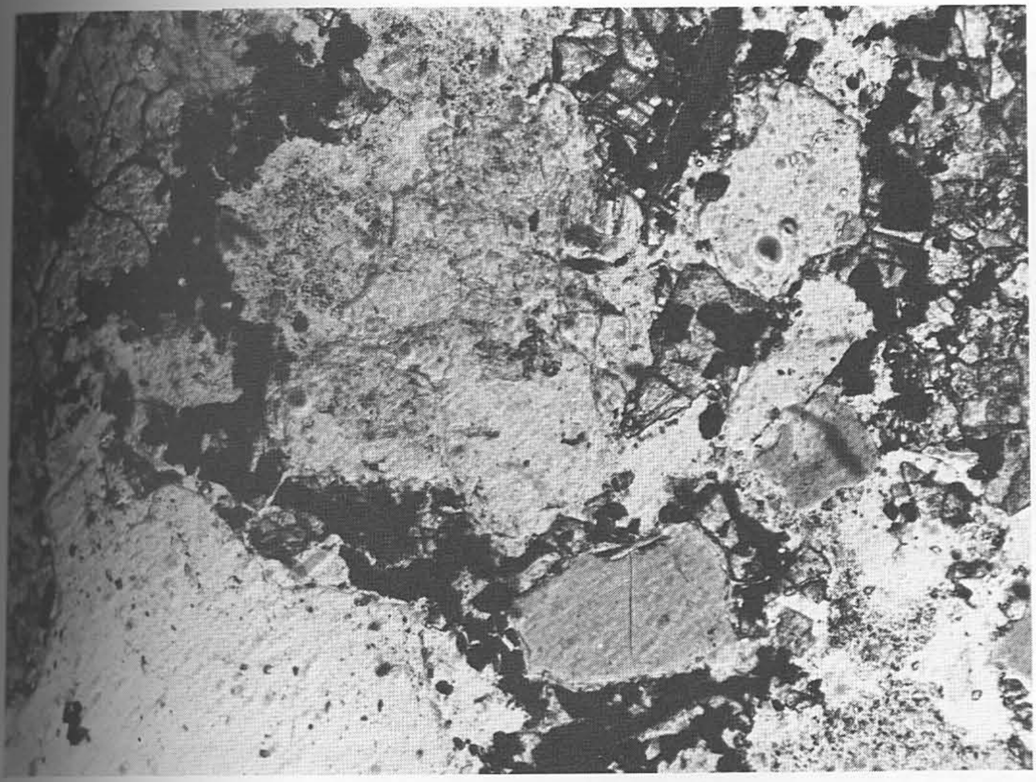


PLATE 16 Photomicrograph showing the crystallization of carnotite (black areas) around detrital fragments.

PLATE 17 Hardpan calcrete overlying Bloedkoppie Granite.

PLATE 18 Photomicrograph of the hardpan calcrete. Detrital grains are set in a semi-opaque, ferrugenous calcite matrix. Transparent, second generation calcite has filled pore spaces and formed rims round the larger grains. Crossed nicols. Magnification x 50.

Away from the Bloedkoppie Flats and westward into the Gawib River Valley the harcpan calcrete is not found at the contact between the Langer Heinrich calcrete and Gemsbok calcrete formations. This may be an erosional feature, since it was removed prior to the deposition of the latter.

In outcrop, the hardpan calcrete is also a breccia-conglomerate, having pebbles as large as 200 mm but generally averaging 20-30 mm in diameter. The matrix is a semi-opaque, fine-grained, brown-coloured ferrugenous calcite. (The presence of iron in the calcite was confirmed by qualitative electron probe analysis). Compared with the calcified breccia-conglomerate, the detrital grains in the hardpan calcrete have a higher degree of separation, which suggests a greater $CaCO_3$ content. This is substantiated by a higher CaO content in the analysis (Table 28). Larger grains have a higher degree of roundness than the smaller sand particles (Plate 18).

Fractures and original pore spaces have been filled with a second generation calcite which is not opaque. This implies that the conditions for the precipitation of the two types of calcite were dissimilar, for the latter phase contained no iron. It will be remembered that in the calcareous breccia-conglomerate two similar phases of calcite precipitation took place, the last one concurrent with the carnotite mineralization. Therefore this may provide evidence that the conditions under which the cogenetic carnotite and second generation calcite formed were at variance with those of the primary epigenetic calcite.

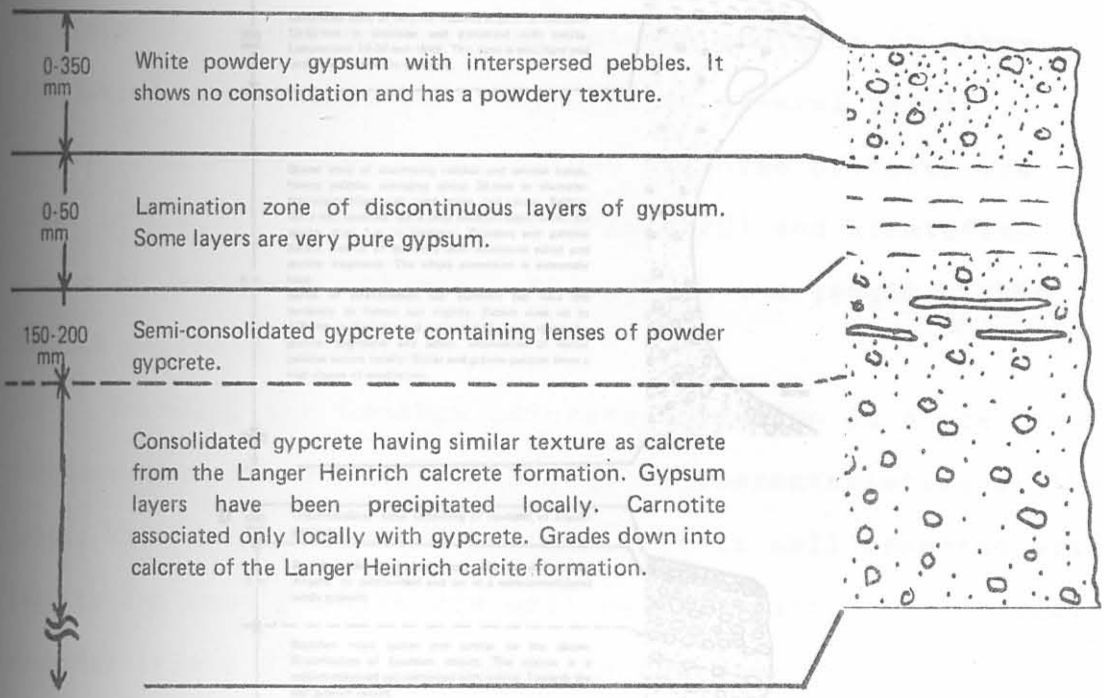
No uranium mineralization was found in the hardpan, but boulder calcrete lying in the alluvium of the Bloedkoppie Flats contained uranium in places (Table 28, sample LH-24). Gypcrete accumulations at the Langer Heinrich are included in this section because they are found to be mainly associated with the sediments of the Langer Heinrich calcrete formation. Information about the gypcrete was obtained from one cutting in the Gawib River bed. Fig. 5 is a diagrammatic sketch of the profile which was only about 1 m deep. Gypsum does, however, extend to greater depths. Sample HJ1-1, from borehole HJ-1 which is in the same vicinity as the profile in Fig. 5, has a sulphate content of 12 per cent at a depth of 0,5 m (Table 27). The sulphate tends to decrease with depth and reaches an average background value of between 0,01 and 0,02 per cent.

5.3 Gemsbok Calcrete Formation

In the Gawib River Valley the Gemsbok calcrete formation is preserved in enclaves of the harder basement of the Etusis and Tinkas Formations. Further west it forms the surface of the Gawib Flats.

The Gemsbok calcrete formation rests unconformably on the Langer Heinrich calcrete formation (Fig. 4(a)). Exposures of the contact are not very clear due to overlying scree and alluvium. Northwest of the area mapped, very distinct contacts were found in a stream channel.

Profiles through the Gemsbok calcrete formation are seen in terraces in the erosional fanglomerates. A typical view through the formation, but not to the base, is illustrated



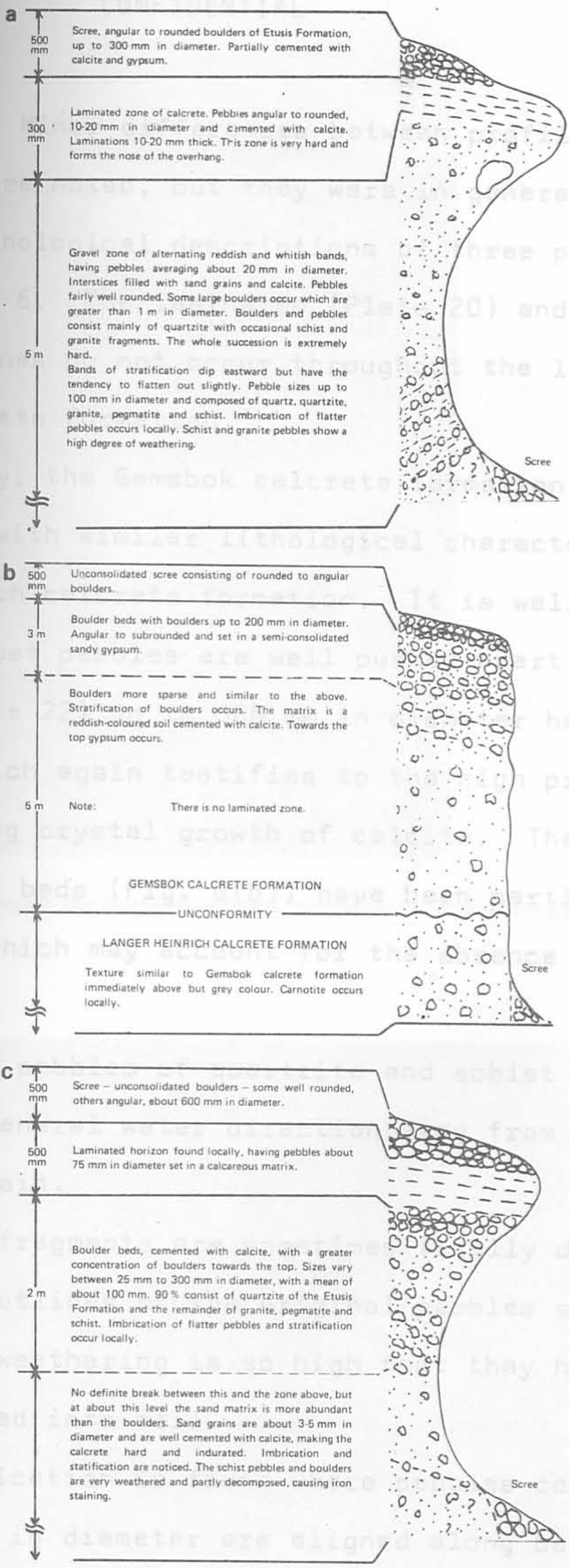
White powdery gypsum with interspersed pebbles. It shows no consolidation and has a powdery texture.

Lamination zone of discontinuous layers of gypsum. Some layers are very pure gypsum.

Semi-consolidated gypcrete containing lenses of powder gypcrete.

Consolidated gypcrete having similar texture as calcrete from the Langer Heinrich calcrete formation. Gypsum layers have been precipitated locally. Carnotite associated only locally with gypcrete. Grades down into calcrete of the Langer Heinrich calcite formation.

Fig. 5 A profile of gypsum accumulation in the Langer Heinrich calcrete formation which outcrops in the bed of the Gawib River.



Scree, angular to rounded boulders of Etusis Formation, up to 300 mm in diameter. Partially cemented with calcite and gypsum.

Laminated zone of calcrete. Pebbles angular to rounded, 10-20 mm in diameter and cemented with calcite. Laminations 10-20 mm thick. This zone is very hard and forms the nose of the overhang.

Gravel zone of alternating reddish and whitish bands, having pebbles averaging about 20 mm in diameter. Interstices filled with sand grains and calcite. Pebbles fairly well rounded. Some large boulders occur which are greater than 1 m in diameter. Boulders and pebbles consist mainly of quartzite with occasional schist and granite fragments. The whole succession is extremely hard.

Bands of stratification dip eastward but have the tendency to flatten out slightly. Pebble sizes up to 100 mm in diameter and composed of quartz, quartzite, granite, pegmatite and schist. Imbrication of flatter pebbles occurs locally. Schist and granite pebbles show a high degree of weathering.

Unconsolidated scree consisting of rounded to angular boulders.

Boulder beds with boulders up to 200 mm in diameter. Angular to subrounded and set in a semi-consolidated sandy gypsum.

Boulders more sparse and similar to the above. Stratification of boulders occurs. The matrix is a reddish-coloured soil cemented with calcite. Towards the top gypsum occurs.

Note: There is no laminated zone.

GEMSBOK CALCRETE FORMATION

UNCONFORMITY

LANGER HEINRICH CALCRETE FORMATION

Texture similar to Gemsbok calcrete formation immediately above but grey colour. Carnotite occurs locally.

Scree – unconsolidated boulders – some well rounded, others angular, about 600 mm in diameter.

Laminated horizon found locally, having pebbles about 75 mm in diameter set in a calcareous matrix.

Boulder beds, cemented with calcite, with a greater concentration of boulders towards the top. Sizes vary between 25 mm to 300 mm in diameter, with a mean of about 100 mm. 90 % consist of quartzite of the Etusis Formation and the remainder of granite, pegmatite and schist. Imbrication of flatter pebbles and stratification occur locally.

No definite break between this and the zone above, but at about this level the sand matrix is more abundant than the boulders. Sand grains are about 3-5 mm in diameter and are well cemented with calcite, making the calcrete hard and indurated. Imbrication and statification are noticed. The schist pebbles and boulders are very weathered and partly decomposed, causing iron staining.

Fig. 6 Lithological descriptions of profiles through the Gemsbok calcrete formation. For the site localities refer to Map 1.
(a) Profile 1 : Gemsbok calcrete formation in the west. vest.
(b) Profile 2 : Gemsbok and Langer Heinrich calcrete formations near the original prospecting campsite.
(c) Profile 3 : Gemsbok calcrete formation in central part of the erosional fanglomerate.

in Plate 19. Minor differences between profiles in other localities were noted, but they were in general fairly uniform. Lithological descriptions of three profiles are given in Fig. 6. The laminated (Plate 20) and stratified (Plate 21) zones do not occur throughout the length of the Gemsbok calcrete formation.

Broadly, the Gemsbok calcrete formation is a breccia-conglomerate with similar lithological characteristics as the Langer Heinrich calcrete formation. It is well cemented with calcite and most pebbles are well pushed apart. Even larger boulders (Plate 22) up to 300 mm in diameter have been separated, which again testifies to the high pressures involved during crystal growth of calcite. The upper layers of the boulder beds (Fig. 6(b)) have been partially cemented with gypsum, which may account for the absence of a laminated layer.

Flatter pebbles of quartzite and schist are imbricated, indicating a general water direction away from the Langer Heinrich Mountain.

Schist fragments are sometimes totally decomposed and only remnant outlines of the original pebbles still remain. The degree of weathering is so high that they have almost been transformed into soil.

Stratification is found where pebbles commonly as large as 70 mm in diameter are aligned along bedding planes. In the case for the stratification presented in Plate 21, the beds dip towards the east. This is roughly perpendicular to the direction of the stream channel. Glennie (1970,

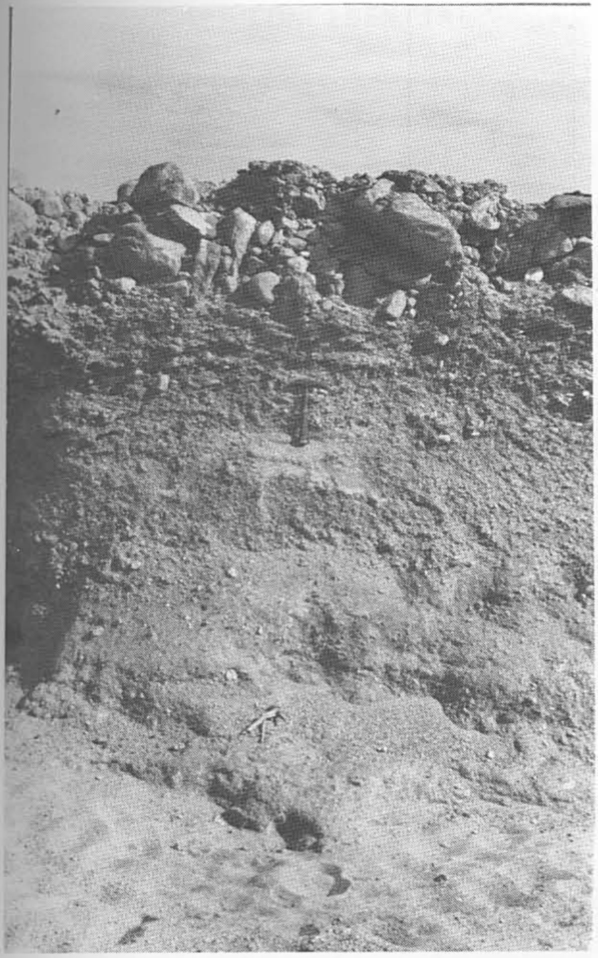


PLATE 19 A cross-sectional view through the Gemsbok calcrete formation in the western part of the area.

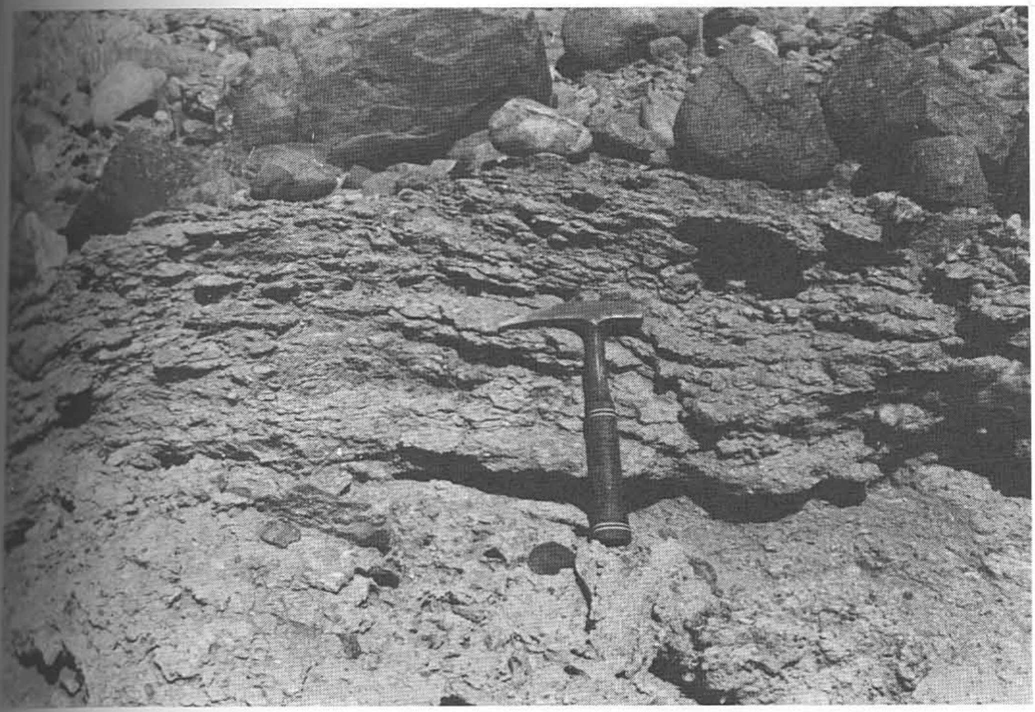
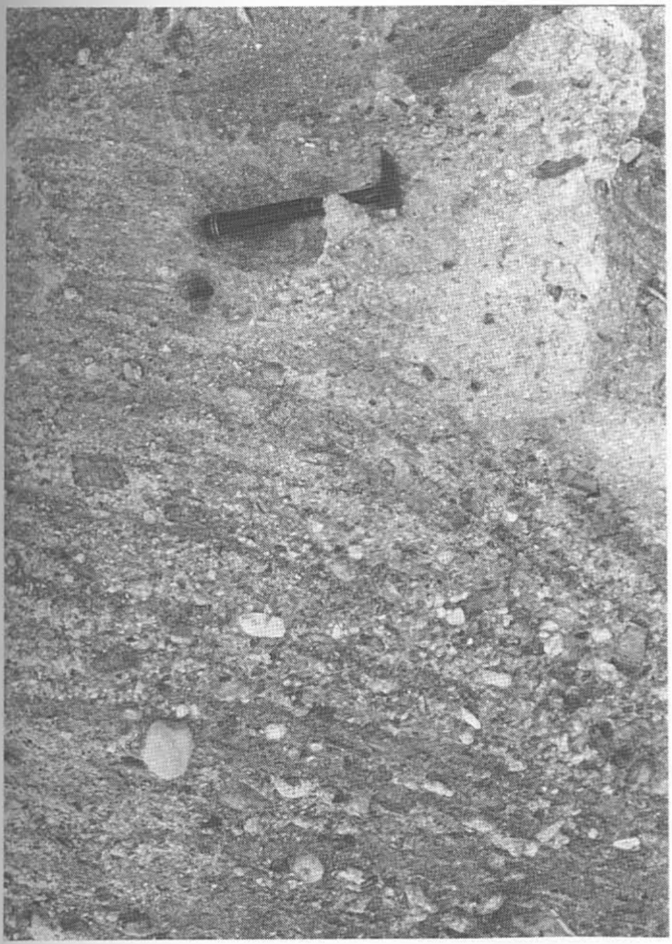


PLATE 20 Laminated zone of calcrete in the Gemsbok calcrete formation.



LATE 21 Stratified zone in the Gemsbok calcrete formation.

LATE 22 Large boulders (up to 300 mm in diameter) have been pushed apart by calcite crystallization.

p. 30) mentions that the type of sedimentation is related to the velocity of the stream, and that at lower stream velocities ripples may form at right angles to the direction of flow. At higher velocities the ripples become larger and are arranged in the same direction as above. For the example shown in Plate 21 the velocity must have been fairly high to have formed the large ripples, several metres in wavelength, and to have carried the heavy load of pebbles. Furthermore, a slurry with a low water-to-sediment ratio is capable of supporting pebbles of greater size. (ibid., p. 29).

Mabbutt (1952) describes a terrace in the Ugab River Valley, which may be correlated with the Gemsbok calcrete formation, and dates it as lower to middle Pleistocene on the basis of artifacts. Archaeologically this corresponds to the Chelles-Acheul age, between 45 000 and 500 000 years. (Netterberg, 1969(a), p. 89).

5.4 Tumas Gypcrete Formation

The Tumas gypcrete formation consists of the gypcretes in the Tumas River Valley.

Lithologically the rocks are similar in appearance to the calcretes of the Langer Heinrich and Gemsbok calcrete formations, but in this case the cement is composed mostly of gypsum in the upper layers.

The three basic types of gypsum are the powder, vuggy and consolidated varieties. The powder gypcrete appears to be mainly a surface accumulation commonly associated with vuggy gypcrete which occurs just below the surface and attains a maximum depth of about 2 m. Vuggy gypcrete derives its name from the cavernous structure it develops, which has the appearance of microcaves due to the crystallization of interlocking desert roses. Both powder and vuggy gypcrete are fairly pure as they contain very little detrital material. Carnotite has crystallized in patches and is not uniformly distributed; it therefore appears to be epigenetic with respect to the gypsum.

The consolidated gypcrete lies below the vuggy gypsum, and the best exposures are seen in Von Stryks pit. It is an indurated, well cemented and hard breccia-conglomerate. There is no evidence of desert roses, the disappearance of which is a consolidation effect. Sporadic carnotite mineralization is found towards the top of the consolidated gypcrete, but lower down in Von Stryks pit it vanishes.

Pebbles are both angular and rounded. The latter type were probably derived from thick conglomerate bands of the Etusis Formation nearby. The largest pebbles found were 200 mm but usually they were only about 10 mm in diameter. The 'pushing apart' effect of the gypsum was noticeable.

Fig. 7 is a preliminary interpretation of a seismic profile down the 15° 00' line of longitude. The inter=pretation is tentative and subject to revision, but has never=theless yielded a considerable amount of useful data.

Four basic seismic velocities were detected and interpreted as follows:

570- Unconsolidated sand and gravel, probably including alluvium and powder, and vuggy gypcrete.

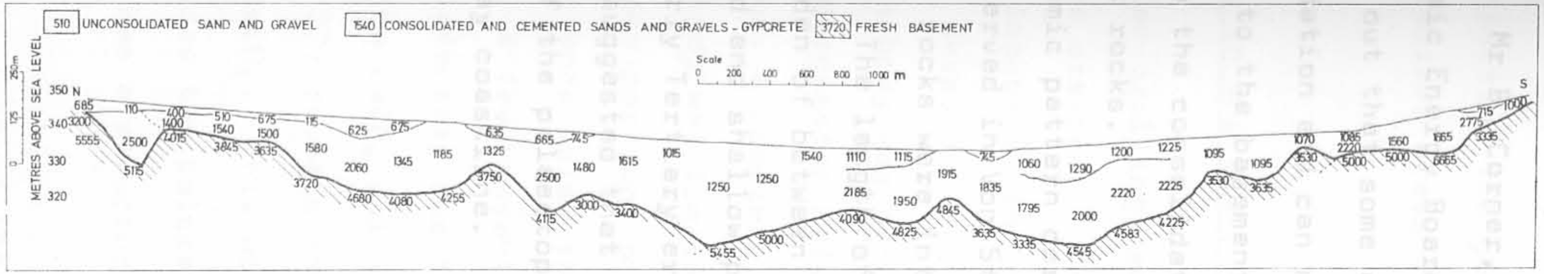


Fig. 7: A seismic profile down the 15° line of longitude. (Courtesy, Anglo American Prospecting Co. Ltd.)

1540 - Cemented sands and gravels - consolidated gypcrete.

2500 - This velocity has not been interpreted successively as yet. Mr B. Corner, of the Geology Division of the Atomic Energy Board (personal communication), pointed out that some calcretes have a high degree of consolidation and can maintain seismic velocities similar to the basement rocks. By analogy this may apply to the consolidated gypcrete.

3720 - Basement rocks.

The seismic pattern derived seems to correspond with the facts as observed in Von Stryks pit, with the exception that no basement rocks were intersected in the latter due to its shallowness. The length of the profile is 8 km, with a gypcrete overburden of between 5 and 30 m thick. This indicates a broad and shallow pre-alluvium topography which is typical of early Tertiary erosion surfaces (Mabbutt, 1952, p. 359). It is suggested that this profile may be fairly representative of the palaeotopography from the Gawib Flats to the present-day coastline.