4. THE GEOLOGY OF THE BASEMENT ROCKS

Only the Langer Heinrich region was mapped in detail (Map 1) and the description of the basement rocks is there= fore confined to those found in that area.

Stratigraphically, with respect to the rocks in the Khan/Swakop area of the Damara orogen, the lithological sequence is incomplete, for the Khan, Rössing, Karibib and Witpoort Formations are absent. Consequently the Chuos and Tinkas Formations follow unconformably on the Etusis and Chuos Formations respectively. No limestone typical of the Karibib Formation is developed. Jacob (1974, p. 14, Fig. 1) schematically shows the relationship between the Karibib and Tinkas Formations within the area he mapped. Eastwards, the limestone disappears gradually to give way almost exclusively to the schists of the Tinkas Formation, except for localized development of thin limestone bands. Smith (1965, p. 22) reported similar findings in an area to the north.

4.1 Etusis Formation (Ns_1Q)

The Etusis Formation incorporates most of the Langer Heinrich Mountain and two small outcrops in the east.

The rocks are 'psephitic and psammitic' in character (Jacob, 1974, p. 10) and are composed of feldspathic quartzites and oligomictic conglomerate bands. The thicknesses of the latter are mostly between 100 mm and

200 mm, but do occur as thick as 15 m.

The pebbles are generally well rounded and are composed mainly of quartz with lesser amounts of granite, pegmatite and amphibolite. Metamorphism has not affected the rocks to any significant degree, but the pebbles in the conglomerate do show some elongation. Bedding planes are still easily recognizable, especially where the conglomerates are found.

The quartzites are composed of quartz, microcline and plagioclase with smaller amounts of biotite and muscovite. Magnetite and zircon are the main accessory minerals. The matrix of the conglomerate is similar to the quartzite, but has a greater proportion of magnetite and zircon (ibid., p. 93).

4.2 Chuos Formation (D_2G)

The Chuos Formation is developed only at the foot of the western slopes of the Langer Heinrich Mountain. It is a rock type of uncertain origin and has been variously described as a tillite, tilloid or diamictite. No evidence has been found to regard the Chuos Formation as being definitely of glacial origin (ibid., p. 17).

The rock is essentially schistose, having a cleavage direction parallel to the overlying schists of the Tinkas Formation. Metamorphism has elongated the pebbles parallel to the schistosity, giving the diamictite the appearance of an 'augen gneiss'. Quartz, quartzite and granite are the main constituents of the pebbles. Occasionally secretion quartz veins are found.

Mineralogically, the matrix is composed of quartz, plagioclase, microcline, biotite and muscovite.

4.3 <u>Tinkas Formation</u> (D_4S)

The Tinkas Formation covers the largest area in the region mapped. It forms the prominent Schieferberge in the south and the Augawibberge in the south-east.

The most striking feature of these rocks is their banded appearance due to alternating fine-grained pelitic schists and calc-granofels bands. The thicknesses of the bands vary, with the latter not exceeding about 1 m. On outcrop, the calc-granofels is more resistant to weathering and stands out as a low narrow ridge.

Calc-granofels bands are 'massive and non-foliated' except where gneissic structures have developed in tight folds (<u>ibid</u>., p. 65). In hand-specimen, the rocks are melanocratic, sometimes greenish, fine-grained and extremely hard. Texturally they are either porphyroblastic or <u>seriate</u> ? (<u>ibid</u>., p. 67). Quartz, plagioclase and diopside are generally the major constituents. Other minerals such as microcline, hornblende, garnet, calcite and scapolite are also present to a greater or lesser extent. The granofels bands must surely also belong to this facies

The mineralogical assemblages of the pelitic schists belong to the amphibolite facies and correspond to the medium and high grades of metamorphism. Within the area mapped, the schists fall in the medium grade, as <u>separation of the grades is found further to the north</u>, ? at the 'beginning of anetexis in gneisses' isograd (ibid., pp. 92 and 129).

The rocks are fine-grained with lepidoblastic texture and are composed of quartz, plagioclase, biotite, K-feldspar and cordierite. Minor minerals such as muscovite, sillimanite, andalusite and garnet are commonly found. (ibid., p. 93, Table 17). Biotite is responsible for the lepidoblastic texture.

4.4 Salem Granite (Gn_2)

The Salem granite is located to the north-east of the area. Good exposures, although very weathered, are found in the Tinkas River.

It is a porphyritic biotite granite, medium to coarse grained, and has a composition varying between granodiorite and granite (ibid., p. 144, Fig. 54). Mineralogically, the Salem Granite contains quartz, microcline, plagioclase and biotite. Phenocrysts consist of microcline perthite.

Stratigraphically the Salem Granite occurs above the Etusis Formation in the zone normally occupied by the Tinkas Formation.

4.5 Bloedkoppie Granite (G_1)

The Bloedkoppie Granite is the main granite found in the area, and is situated south-east of the Langer Heinrich Mountain. Its most striking physical feature is the prominent whale-back dome, called the Blutkuppe by the early German pioneers. Smaller granite outcrops are found sporadically in the Bloedkoppie Flats which extend eastwards (Plate 1).

Intrusive features of the Bloedkoppie Granite are shown by cross-cutting relationships to the Tinkas Formation. Low intrusion temperatures are indicated, for there has been little alteration of the country rock, although in some localities migmatization and partial granitization over distances of a few tens of millimetres can be seen. Xenoliths are well represented and those of the Tinkas Formation are orientated towards the north-east. This indicates that the Bloedkoppie Granite was implaced during the period of regional deformation of the Damara Orogen and is therefore probably late-syntectonic in age. There is a notable difference between the xenoliths of the Tinkas and Etusis Formations, for the latter show a greater degree of alteration, whereas the former are hardly affected except for the smaller rafts.

The north-east orientation of xenoliths is parallel to younger aplitic intrusions and fracture patterns, along which deep weathering has produced gorges in the Bloedkoppie itself. In a north-westerly direction a second fracture pattern has developed containing coarse-grained secretion pegmatites. These pegmatites are pinkish in colour, with biotite and tourmaline crystals orientated at right angles to the contacts (Plate 2). Both fracture patterns cross each other at angles varying between 30° and 70°.

The Bloedkoppie Granite is very similar to the Salem Leucogranite, but is slightly more potassic (Jacob, 1974, p. 145). It is a medium-grained, but locally coarse-grained, leucogranite with quartz, microcline, plagioclase and biotite as the main constituents. Accessory minerals such as zircon, apatite, allanite and ore are present. In places, the quartz grains are slightly smokey. Grain sizes of the feldspars vary locally up to 25 mm in longitudinal section. Texturally the rock is hypidiomorphic granular and has graphic intergrowths.

It was virtually impossible to obtain a fresh sample from the Bloedkoppie Granite pluton. Large sections of the granite were so weathered that individual grains had almost no coherence. Even the freshest pieces of granite had iron rims around biotite flakes, indicating that iron was gradually being released from the crystal structure as a result of weathering. Plate 3 illustrates typical weathering in the feldspars.

Unusual weathering features are developed on the Bloedkoppie Granite, and three basic types emerge. The first is exfoliation on both large and small scales, the former being more conspicuous on the Bloedkoppie dome, where large granite slabs cling to the steep slopes. Secondly, there is a type of weathering that results in a spongy texture and is referred to as alveoles (Plate 4). Thirdly, the development of large caverns (Plate 5) termed tafoni are to be found. Both alveoles and tafoni as found in other deserts of the world have been described by previous authors, but they occur most frequently in the foggy coastal type to which the Namib Desert belongs (Cooke and Warren, 1973, p. 58).

The shapes of the alveoles vary, but all have an essentially rounded entrance and the direction of penetration

PLATE 1 Bloedkoppie Granite dome viewed across the Bloedkoppie Flats from the Augawibberge, with the Langer Heinrich Mountain in the background to the north. Granite outcrops in the middle foreground.

PLATE 2 Secretion pegmatite in the Bloedkoppie Granite with biotite crystallizing along and normal to the contacts.

of the hole is randomly orientated. No preferential siting of alveoles in the granite face is apparent, for they are not necessarily located towards the direction of the prevailing winds. Holes, in places, have completely eaten through the granite. The entrance sizes vary between 30 to 50 mm in diameter, and the holes penetrate up to 300 mm into the rock.

On a much larger scale, tafoni have developed on the north-facing slope of the Bloedkoppie. The size of these varies between 2 to 10 m in height and 4 to 20 m in length, with a depth penetration of as much as 10 m. All have arch-shaped entrances, with some flatter than others. Inner surfaces are concave and irregular (Plate 5). The origin of both alveoles and tafoni is puzzling, particularly with regard to the former. Granular disintegration, unevenly distributed on the rock surface, seems to be the most plausible explanation for the formation of the alveoles. Loci of disintegration bear no obvious relationship to a wind direction that could carry sand particles or nuclei of moisture.

Onshore fogs commonly penetrate inland as far as the Langer Heinrich (about 100 km from Swakopmund) and the dissolved salts they bear act as chemical etching agents. Penetration into the granite is by mechanical means and chemical reaction in microcracks along intergranular boundaries at the point of weakness. No evidence of salt crusts is found in the alveoles, but these may have been removed by rainfall.

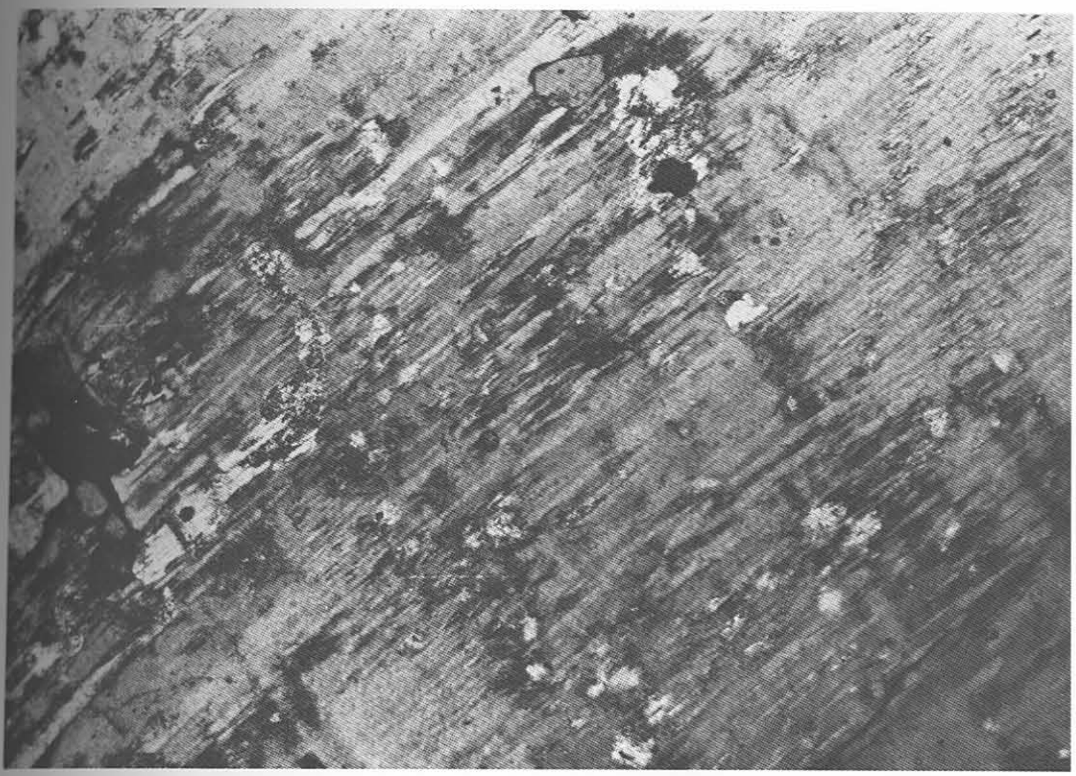

PLATE 3 Photomicrograph showing weathering effects in the feldspars. Crossed nicols. Magnification x 50.

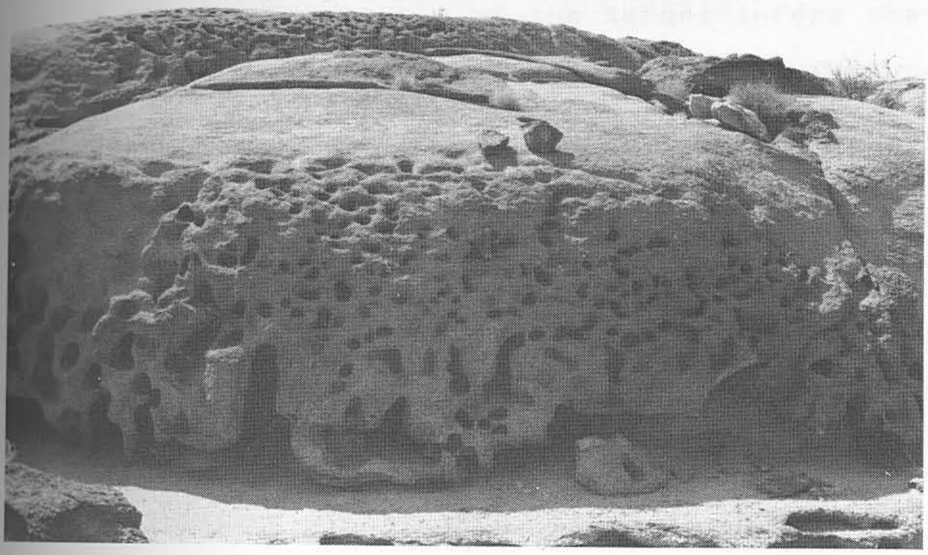

PLATE 4 Alveoles in the Bloedkoppie Granite.

PLATE 5 Tafoni on the north-facing slope of the Bloedkoppie dome. Dimensions are approximately 10 m high, 10 m deep and 30 m wide.

A directional aspect of the tafoni infers that a weakness at a point in the granite was brought about and aggravated by environmental factors such as differential temperatures and corrosive solutions. A north-facing slope in the southern hemisphere accumulates a greater amount of heat during the day than do southern slopes. This may have been sufficient to form a crack in the granite and thereby initiate a tafoni.

Examination of the inner faces of the tafoni shows that flaking and disintegration are taking place simultaneously, producing a constantly crumbling surface. Salt precipitation between the flakes is common. This indicates that the flaking is caused by initial chemical reaction, probably hydration of feldspars, followed by differential volumetric expansion of crystallizing salts.

X-ray diffraction analysis reveals that the chief constituents of the salt crust are sodium chloride and some other hydrated salt (probably a hygroscopic type) of which identification was not possible. A partial chemical analysis of the salt crust is given in Table 2.

Neither alveoles nor tafoni were found in the quartzites and schists of the Etusis and Tinkas Formations or the Gawib Granite, but they are locally developed in the Salem Granite. This observation therefore implies a textural and possibly a compositional control of the respective rock types, thereby inhibiting or promoting the formation of alveoles or tafoni.

TABLE 2: PARTIAL CHEMICAL ANALYSIS OF THE SALT CRUST ACCUMULATING IN A TAFONI ON THE BLOEDKOPPIE

Cation	%	Anion	%
Ca	1,8	Cl^-	52,6
Mg	1,0	SO_4^{2-}	2,9
Na	24,1	NO_3^-	0,13
K	0,04	CO_3^{2-}	0,58

4.6 Gawib Granite (G_3)

The Gawib Granite is situated in the south-western corner of the area. Structurally, it forms a pluton, with intrusive and cross-cutting relationships to the Tinkas Formations. It appears to be a composite intrusion of which the outer gneissic margin is older than the locally porphyritic interior. No large prominences are present as in the case of the Bloedkoppie Granite, but the Gawib Granite consists of rounded onion-foliated boulders of up to 2 m in diameter. The colour of weathered surfaces is an earthy brown.

The gneissic margins are granodioritic, but towards the centre the composition becomes more granitic (Jacob, 1974, p. 147).

Quartz, plagioclase, microcline, biotite and hornblende are the chief constituents, with epidote and sphene the main accessory minerals. Compared with the Bloedkoppie Granite the amount of microcline is much less, whereas the plagioclase and biotite contents are considerably greater.

4.7 Horebis Granite (G_5)

The Horebis Granite in outcrop is small and developed as a stock on the extreme west of the area. Contacts with other rock types are covered by sediments of the Gemsbok calcrete formation, but contact with the Gawib Granite is inferred, for in one locality they are separated by only one metre of soil.

It has an unusual spotted appearance due to the clusters, 10 to 30 mm in diameter, of black tourmaline. Both red and white varieties are found. Texturally, it is aplitic and composed of quartz and microcline with minor plagioclase.

4.8 Pegmatites

Pegmatites cover most of those types described by Jacob (1974, p. 154). The oldest type are the syntectonic homogeneous varieties developed in the regional foliation planes. The bulk of pegmatites, however, belong to the heterogeneous class, consisting of zoned and layered types, the latter being the more abundant of the two.