CARBONATE-BEARING ERUPTIVES BETWEEN THE GREAT KARAS MOUNTAINS AND THE BREMEN IGNEOUS COMPLEX, SOUTH WEST AFRICA

BY

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ABSTRACT

Minor carbonate-bearing bodies of igneous origin are widely distributed in the Karasberg district, South West Africa. The area in which they occur consists of granites and gneisses of the Namaqualand Metamorphic Complex overlain by relatively flat strata of the Nama and Karoo Groups and intruded by plutonic and hypabyssal rocks of various ages. The latter include a single post-Karoo carbonatite.

The largest concentration of carbonate-bearing eruptives is on the farm Garub 266 in the Great Karas Mountains, but they extend approximately 100 km westwards as far as the Bremen Alkaline Complex. The Karas Mountains are now believed to be the result of a series of thrust-faults which may perhaps be associated with the intrusion of plutonic complexes of the Kuboos-Tatasberg-Bremen-Haruchas lineament, to which the Garub eruptives may also be related.

The Garub-type pipes, dykes and sills are composed of alkaline-ultrabasic carbonate-bearing breccia, lamprophyric carbonate rock and tuffisite. They intrude rocks of the Namaqualand Metamorphic Complex and the Kuibis, Schwarzrand and lower Fish River Formations of the Nama Group, and are considered to be subvolcanic.

The bodies contain between 10 and 20 per cent CO_2 and about 25 per cent SiO_2 and are obviously not typical carbonatite. Biotite, pyroxene, amphibole and ilmenite form both phenocrysts and fine-grained crystals in a groundmass of ankerite. Minute ankeritised lath-shaped crystals (either melilite or feldspar originally), are almost invariably present in the lamprophyric carbonate rock. Interstitial quartz and feldspar occur sporadically, whereas inclusions of wall-rock, where present, are usually abraded and rounded. Fenitisation has been observed at two localities, where quartz and feldspar in the wall-rock have been replaced by soda amphibole.

Fluidisation appears to provide a satisfactory mechanism for the emplacement of these bodies. Strong evidence in favour of this interpretation are the intrusive contacts, abraded and rounded inclusions, non-dilational veins in the wall-rock, accretionary pisolites, upward and downward movement of inclusions in the bodies, carbonated inclusions and matrices and the absence of contact or pyrometamorphic effects.

Chemically the carbonate rocks bear similarities to kimberlite and olivine-melilitite, but are most akin to alnoite. Carbonatite, olivine-melilitite, kimberlite, alnoite, damkjernite and the Garub rocks are all considered to have the same magmatic affinities. It is tentatively suggested that the Garub suite is genetically related to an unexposed alkaline complex of the Fen type, and that the composition of the carbonate-bearing rocks approaches that of the parent magma of the plutonic complexes along the Kuboos lineament.

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1 INTRODUCTION

1.1 GENERAL

A peculiar suite of carbonate-bearing eruptive rocks occurs along a narrow strip of 30 x 100 km in the Karasburg district of southern South West Africa (Fig. 1, Folder 1). The small township of Grünau (Lat. 27°14', Long. 18°23'), is situated in the central part whereas Karasburg lies some 20 km to the south-east of the area. The carbonate-bearing bodies investigated in detail are situated to the east and north-east of the main road linking Karasburg, Grünau and Keetmanshoop. A small fluorite deposit occurs in association with one of the bodies on Garub 266, which is regarded as the type locality of the suite.

It seems likely that the Garub suite belongs to the NE-trending Swartbank-Kuboos-Tatasberg-Bremen-Haruchas line of complexes (Fig.2). A structural relationship might exist due to emplacement along a common zone of weakness. This is parallel to the Cape Cross line of post-Karoo age in northern South West Africa (Martin, Mathias and Simpson,1960) and the same trend appears to be well established in Angola (Lapido-Loureiro, 1973), but considerable doubt may be expressed about the validity of a lineament between Phalaborwa and Vanrhynsdorp (Garson and Smith, 1958; Lapido-Loureiro, 1973), due to long distances and big differences in age between individual complexes. Cornelissen and Verwoerd (1975), made an alternative suggestion namely that the Garub suite is part of an alkaline petrographic province marking a Cretaceous upwarp parallel to the west coast of southern Africa, but this is ruled out by the much greater age of the Garub carbonate-bearing rocks.

The Garub bodies take the form of small pipes, sills, dykes and irregular intrusions. Their shape, high carbonate

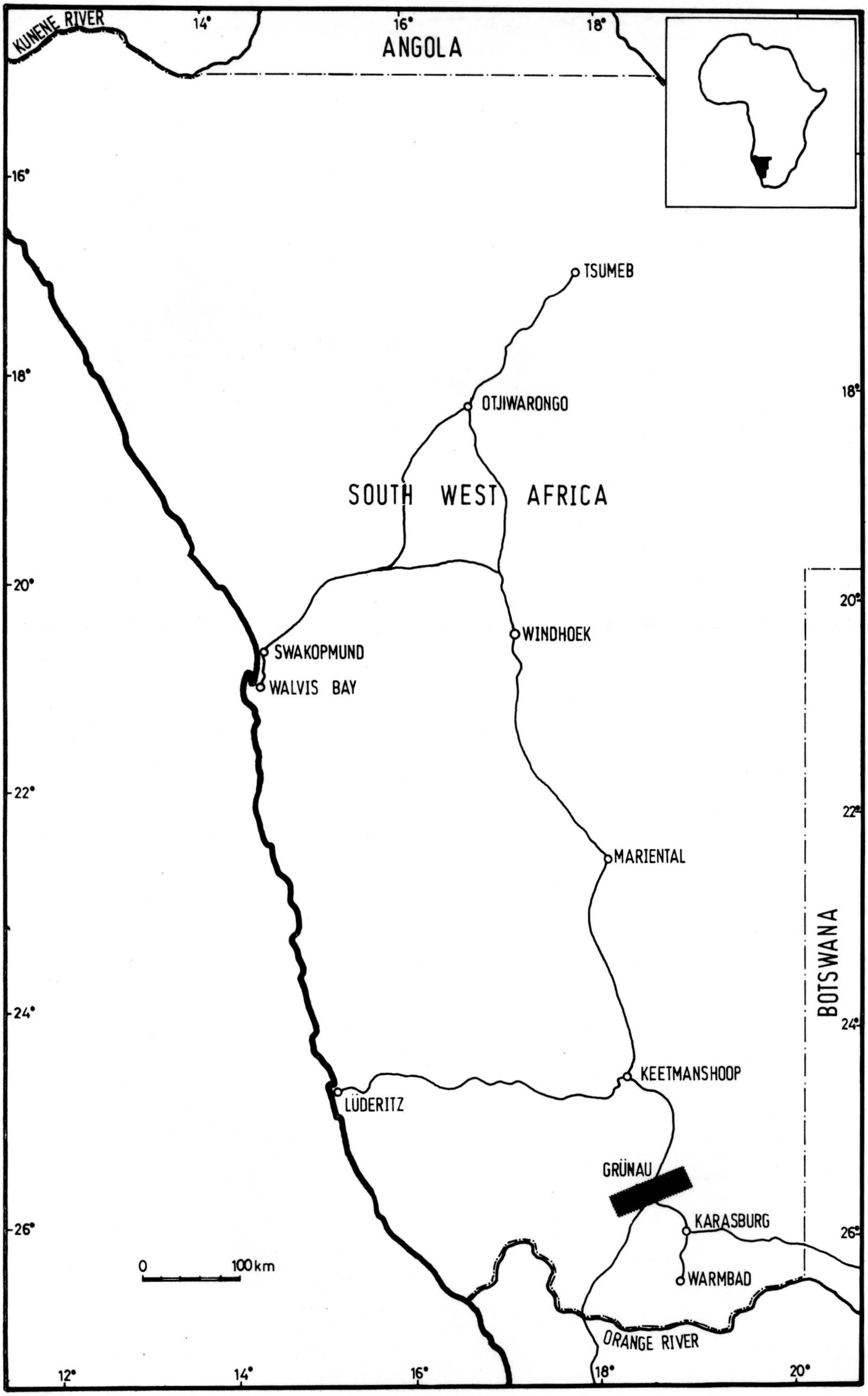


FIG. 1 — Locality map of the area studied.

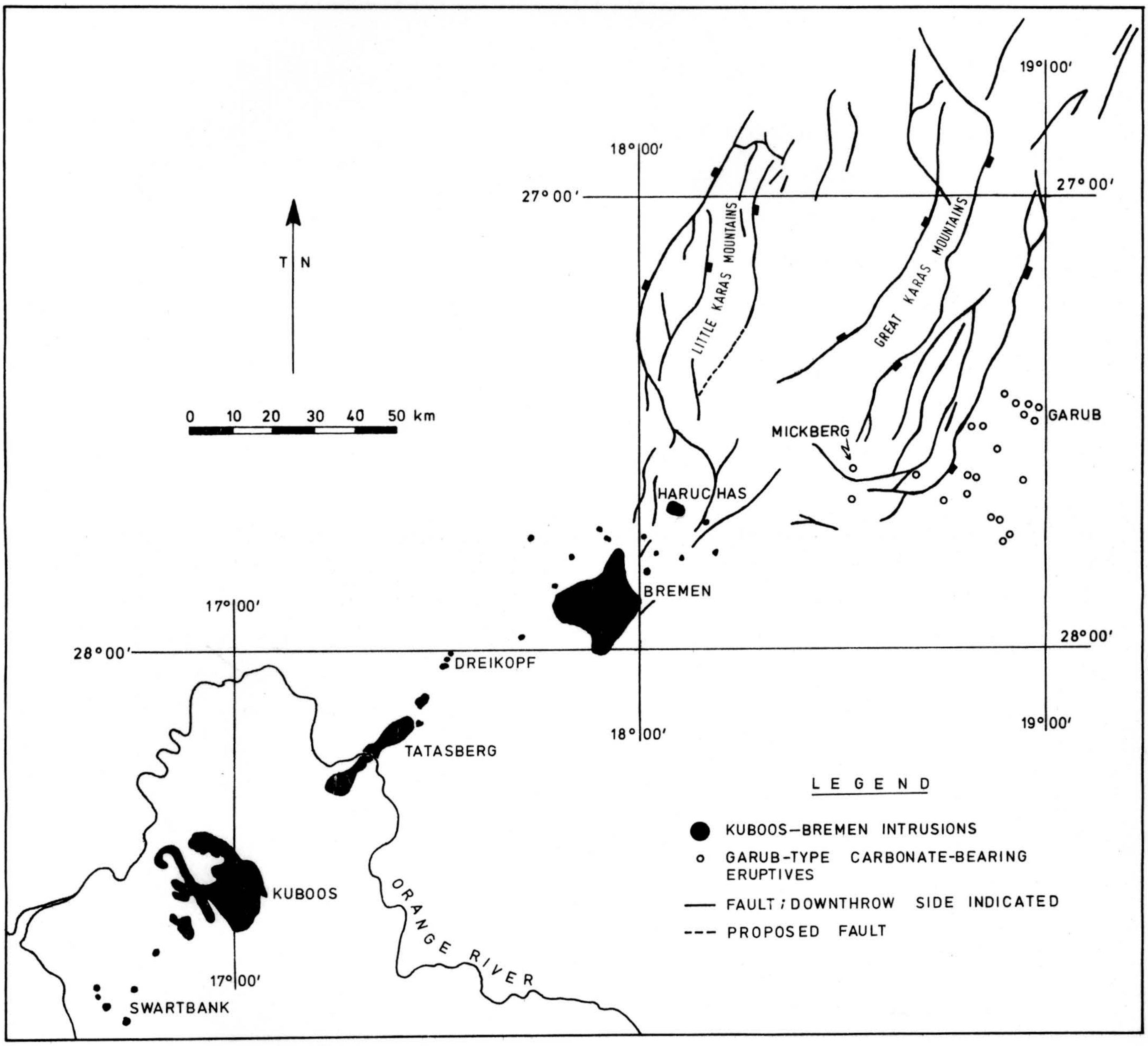


FIG. 2 — Map to illustrate the geographic relationship of the Garub-type eruptives with the Swartbank-Kuboos-Tatasberg-Bremen-Haruchas lineament and the Karas Mountains.

content and the presence of pseudomorphic, pisolitic and brecciated textures invite comparison with South African carbonatite, kimberlite and olivine-melilitite deposits. The following problems require attention:

1. What are the magmatic affinities of these rocks?
2. Is there a petrogenetic relationship with the Kuboos-Bremen line of complexes or is this association merely structural?
3. Is the high carbonate content original or due to subsequent carbonatisation?
4. What mode of emplacement can explain their textural and structural peculiarities?

1.2 PREVIOUS WORK

Previous descriptions of the Garub suite of rocks are scanty. They were probably discovered by J.T. Wessels who mapped the Karas Mountain area together with C.M. Schwellnus during the field seasons of 1937 through 1939. On the legend of their unpublished map, the carbonate rocks are called "sills and diatremes of carbonatite". This map was not accompanied by a geological description. In unpublished Geological Survey reports, De Kock (1942) and Schwellnus (1942) discussed the economic possibilities of the Garub fluorspar mine. Kent at al., (1943), described the history, location and extent of the Garub deposit and the grade and type of ore. They called the eruptives "injection breccias of post-Dwyka age".

Verwoerd (1957), made the first real attempt at unravelling the general geology, petrology, mineralisation, origin and mode of emplacement of these "carbonate-bearing eruptives". He concluded that they are "in neither form nor composition similar to known occurrences of carbonatite" and that a more detailed petrographic study should be made.

In his handbook on the carbonatites of South Africa and South West Africa(1967), the same author classifies them as carbonatites of doubtful status, and suggested that they may be ancient peperites.

1.3 PRESENT INVESTIGATION

The field work was carried out as part of a programme of regional mapping during 1971 through 1973 by the Geological Survey of South Africa. The general survey was done on aerial photographs on a scale of 1:60 000, and this was augmented by detailed plane-table mapping of some of the more important and diversified occurrences.

Petrographic work was carried out on representative specimens. Minerals were identified by optical methods and where necessary confirmed by x-ray diffraction, while chemical analyses of rocks were made by means of x-ray fluorescence spectrometry at the University of Stellenbosch. Electron microprobe analyses with a JEOL instrument were kindly conducted by the Geological Survey Laboratory in Pretoria on four carefully selected minerals.

2 GEOLOGICAL SETTING

The stratigraphic and structural setting of the Garub suite is shown schematically in Fig. 3B and the various rock-types are briefly described below.

2.1 THE NAMAQUALAND METAMORPHIC COMPLEX

Gneisses, granites and other metamorphic rocks occupy the Garub 266 and Ariams 27 inliers, as well as the rugged mountainous areas on Genadendal 264 and Liebenrust 300 and a vast, mainly sand covered plain and hills to the north and east of Grünau township (Folder 1). These rocks have been correlated with the 1 000 My old Namaqualand Metamorphic Complex **(Beukes, 1973; Blignault, 1974).**

On Garub 266 a mesocratic, medium-grained, often porphyroblastic biotite-garnet-sillimanite granite-gneiss predominates. Xenoliths of quartzite and garnetiferous quartzite, which are usually elongated parallel to the well developed foliation, frequently occur. Subsidiary rock types are garnet-biotite-orthopyroxene gneiss, charnockite, garnet-sillimanite-spinel granulite and diablastic granulite, (Verwoerd, 1957).

To the north, east and west of Grünau township a succession of leucocratic gneiss, schistose biotite and amphibole gneiss, biotite-garnet gneiss and amphibolite is found. The biotite-garnet gneiss is locally porphyroblastic and is especially well developed in the Hom River on Geis 67. Irregular bands of garnet-sillimanite-cordierite gneiss are encountered as a series of rough, dark coloured ridges on Mickberg 262. Elongated xenoliths of quartzite are present in most of the above-mentioned rock-types.

On Genadendal 264 metasediments of the Namaqualand

Metamorphic Complex are intruded by poorly foliated biotite granite, containing subordinate garnet and sillimanite as well as quartzitic xenoliths.

A porphyritic granite is intrusive into metasediments of the Namaqualand Metamorphic Complex and is best developed on Grabwasser 261, where it forms a mountainous terrain. The rock is leucocratic and generally contains K-feldspar megacrysts. Both the above-mentioned granites are believed to be of syntectonic origin.

The metasediments of the Namaqualand Metamorphic Complex in the area represent both amphibolite facies and granulite facies of regional metamorphism and are generally above the "quartz + muscovite out" isograd (Beukes, 1973; Blignault, 1974).

2.2 PRE-NAMA PLUTONIC AND HYPABYSSAL ROCKS

An intrusive complex of stocks, plugs and ring-dykes occurs on Bremen 4 and surrounding farms to the NE of Tatasberg on the Swartbank-Kuboos-Tatasberg line of intrusives. Two phases of intrusion have been postulated, one pre-Nama and one post-Nama. Syenite, alaskitic granite, quartz syenite, bostonite, granite porphyry and spessartite were generated during the first cycle, dated at 913 $\pm$ 13 My by Rb-Sr measurements (Allsopp et al., in press). The bulk of the complex consists of granite and syenite. The latter contains perthite, hornblende, plagioclase, biotite and accessories, while the granite consists of quartz, perthite, plagioclase, biotite and accessory minerals. The main mass is cut by numerous dykes of granite porphyry, spessartite and bostonite. (Middlemost, 1967).

Pre-Nama dolerite dykes, probably a continuation of the well-known Richtersveld dyke swarm, intrude the Namaqualand Metamorphic Complex in a roughly north-north-easterly direction. On Garub 266 a few of these dykes are cut by carbonate-bearing eruptives. The dolerite dykes generally are 3-5 metres wide and hundreds of metres long, although a few thin (10-30 cm wide) veins, controlled by joints, also occur.

The composition and texture of the dykes vary. Subhedral grains of andesine-labradorite are generally embedded in a mesostasis of ferro-augite and pigeonite, displaying the typical ophitic texture. Saussuritisation of the plagioclase, chloritisation and alteration of pyroxene to amphibole (actinolite?) are common. Accessory minerals are biotite and pyrite.

2.3 THE NAMA GROUP

Nearly horizontal strata of the Nama Group cover the north-eastern part of the area and the prominent flat-topped hills of the Great Karas Mountains. However, the succession is thinner than in the vicinity of Bethanie and Maltahöhe (Germs, 1972). Subdivision is as follows:

3. Fish River Formation.
2. Schwarzrand Formation.
1. Kuibis Formation.

All three formations are developed in the area. On Garub 266 however, the Kuibis Formation is absent; the Schwarzrand Formation thus directly overlies rocks of the Namaqualand Metamorphic Complex.

2.3.1 The Kuibis Formation

Lithostratigraphically the Kuibis Formation can be subdivided into a lower feldspathic and an upper non-feldspathic, quartzitic part. The basal part commences with light coloured feldspathic grit, attaining a thickness of 10 to 15 m in the central Great Karas Mountains, 12 m on Geis 67 and 36 m on Weltevrede 302. The grit is interlayered with several layers or lenses of conglomerate, 5 to 30 cm thick. Pebbles are well rounded but badly sorted, and are larger and more polymictic than to the west of the Klein Karas Mountains. The poor sorting and immaturity of the grit suggest rapid deposition.

The basal part is conformably overlain by coarse-grained quartzitic sandstone which becomes finer-grained to the top and grades into hard, light-coloured and grey, massive quartzite, interlayered with 4 to 6 m of red, black, grey and blue shale. The composition of the quartzitic sandstone and quartzite is subarkosic to quartz arenitic respectively. The maturity of the upper quartzitic layers compared with the basal feldspathic grit layers, implies deposition farther away from the coast, and obviously lower energy conditions and slower deposition (Germs 1972).

Cross-bedding and parting lineation are the main primary structures.

2.3.2 The Schwarzrand Formation

The Schwarzrand Formation conformably overlies the Kuibis Formation and consists of a monotonous succession of greyish-green quartzite, sandstone, sandy shale, siltstone and various layers of brown and yellow weathering dolomitic limestone. The greyish-green quartzite at the base varies from sublitharenitic to litharenitic, while the overlying sandstones are lithic arkoses and litharenites (Germs, 1972).

A prominent layer of dolomitic limestone occurs 13 to 15 m below the upper contact of the succession. On Tafelkop (Vredenhof 301) a black limestone band, 2 to 3 m thick, locally underlies the prominent upper limestone band.

The thickness of the Schwarzrand Formation is difficult to ascertain. It is nowhere bounded by both Kuibis and Fish River Formations. Schwellnus (1941) mentions a maximum thickness of 154 m in the vicinity of the Great Karas Mountains. On Garub 266 a thickness of 80 m is reached.

The Schwarzrand sediments generally lie horizontally or are very nearly horizontal. Where monoclinal folding or faulting is encountered, however, the dip may change to almost vertical. On Groenrivier 265 and Ariams 27, the Schwarzrand Formation was deposited on inselbergs of the Namaqualand Metamorphic Complex, causing the sediments to dip radially outwards — a feature which is believed to be the result of compaction and expulsion of water during consolidation.

Alternation of sandstone, shale and limestone layers implies a rhythmic change in energy and depositional conditions. Cross-bedding, parting lineation and slump structures are the main primary structures encountered.

2.3.3 The Fish River Formation

The Fish River Formation conformably overlies the Schwarzrand Formation and is poorly preserved in the area. The succession usually commences with thickly bedded brown and red quartzite followed by sandstone, argillaceous sandstone and quartzite that can be classified as sublitharenites, lithic arkoses and litharenites (Germs, 1972).

Although in places the succession is only a few metres thick, it attains a maximum of 68 m on Duurdrift Nord 26. On Ariams 27 and Stinkdorn 28, patches of Fish River sediments are coloured, baked and elevated by the intrusion of dolerite sills of Karoo age.

Cross-bedding, ripple-marks, impressions of raindrops and slump structures are the main primary structures. Paleocurrent directions and sedimentary structures indicate deposition under shallow marine conditions in a marginal trough, with provenance areas predominantly to the north, but also to the west and south (Germs, 1972).

2.4 POST-NAMA PLUTONIC AND HYPABYSSAL ROCKS

The second phase of the Bremen Igneous Complex is post-Nama, with an age of 515-565 My according to the Rb-Sr whole rock isochron method and 550 My by the U-Pb method on zircon. (Allsopp et al., in press). Large masses of greyish-red, yellow and grey syenite and ferrosyenite were emplaced during this phase. These rocks are cut by numerous bostonite, microgranite and trachyte dykes, striking roughly north-south. Near the homestead on Bremen 4, deformation of limestone of the Kuibis Formation was caused by the intrusion of granular and porphyritic syenite.

On Haruchas 10 a small pear-shaped intrusive complex, covering an area of 2,5 km^2, occurs. The complex comprises a syenite zone around a core of foyaite. The latter mainly consists of perthite, albite-oligoclase, nepheline, biotite and aegirine, while the syenite is devoid of nepheline and contains subordinate quartz (G. Genis, personal communication). The complex is cut by a swarm of greenish-grey bostonite dykes striking roughly north-south. The Haruchas Complex is not in contact with Nama or Karoo sediments, but is believed to be the same age as the younger phase of the Bremen Complex.

A post-Nama dolerite dyke, approximately 13 km long, occurs on Uitkomst 25. The dyke has the normal width of 2 to 3 m and strikes roughly east-west in contrast with the north-easterly trend of the pre-Nama dolerite dyke swarm elsewhere in the area. It was emplaced in sandy shale and sandstone of the Schwarzrand Formation, and is cut by a younger brown, often pisolitic carbonate-bearing dyke of the Garub type. Microscopically, the dyke consists of labradorite and pigeonite with an ophitic texture. Sphene and ore are accessories while serpentine is a secondary mineral.

The Garub suite which forms the main subject of this investigation belongs in this age group.

2.5 THE KAROO GROUP

Only the Dwyka Formation of the Karoo Group is preserved in the area, and it unconformably overlies pre-Karoo rocks. The tillite at the base is mainly of the "blue-weathering" type (Haughton and Frommurze, 1936), and is believed to have been deposited by ice-sheets from the ancient Griqualand-West highlands. Glacial striae strike roughly east-west. Thicknesses vary from 1 to 8 m on Nanzes 22 and Amas 46 respectively. Due to the glacio-marine origin of this tillite, several bands occur at different stratigraphic horizons, interlayered with green and black shale, dropstone shale, dropstone mudstone and brown sandy limestone. In contrast with the type of tillite in the western part of the Karasburg Karoo basin, this "blue-weathering" type generally contains smaller erratics of granite, gneiss, jasper, chert, quartz-feldspar porphyry, quartzite and amygdaloidal lava. Above the tillite is a layer of mudstone, 10 to 50 cm thick, followed by green shale, the lower part of which contains dropstones of up to 1 m in diameter. These dropstone mudstone and dropstone shales were deposited by ice-sheets in shallow water. In contact with and in the vicinity of dolerite sheets, the tillite, mudstone and shale were baked to hornstone or lydianite.

2.6 INTRUSIONS OF KAROO AGE

Dolerite sheets and dykes probably represent the last phase of the Karoo period in this part of the country. Large areas in the Karasburg Karoo basin are overlain by sheets of dolerite. Rocks of different ages were elevated to higher topographic and stratigraphic levels during intrusion. On Ariams 27 and Stinkdorn 28 the Fish River Formation of the Nama Group was affected, whereas on Geis 67 and Kanus 94 the Kuibis Formation of the Nama Group was elevated. On Spes Bona 21, Obub 47 and Nanzes 22, dolerite sheets intruded at the base of the Dwyka tillite.

Petrologically, the dolerite is of the usual tholeiitic type with a variable texture. Saussuritised labradorite is ophitically and subophitically intergrown with pigeonite and augite. Feldspar microlites, apatite and ore are common accessories, while chlorite is a secondary mineral. Thin dykes are generally aphanitic.

2.7 POST-KAROO CARBONATITE

An oval-shaped pipe and two sinuous dykes of carbonatite were encountered on Grünau 16 by G. Genis during a regional survey of the area in 1972. The pipe has a longest diameter of about 30 m and consists of weathered carbonatite crammed with angular and rounded fragments of shale, quartzite, limestone, gneiss and dolerite. The groundmass comprises virtually nothing but finely crystalline calcite and pulverised material while apatite and Fe-hydrates are subordinate. The dykes emanate from the pipe and extend for distances of 120 m to the south-west and 150 m to the north-east respectively. The pipe and dykes are intrusive in tillite, boulder shale and limestone of the Dwyka Formation. Emplacement was apparently controlled by a shear zone in the Karoo and older sediments.

This occurrence shows a close resemblance with the satellite breccia bodies and dykes around Brukkaros mountain near Keetmanshoop. The satellite bodies also consist of carbonatite (beforsite) full of fragments of shale, quartzite, schist, gneiss and granite , in places very finely comminuted. (Verwoerd, 1967; Janse,1969). Brukkaros and the carbonatite on Grünau 16 are possibly related to the Late Cretaceous period of carbonatite volcanism, alkali plutonic activity and kimberlite eruptions.

3 GEOLOGICAL STRUCTURE OF THE KARAS MOUNTAINS

The first detailed description of the Karas Mountains was given by Waibel (1925), who interpreted them as uplifted blocks bounded by single-limbed monoclinal flexures and drags, and described the whole structure as a "Mono-anticline". He commented upon the development of faults from flexures through intensified deformation, especially in the central portions of the Karas Mountains and gave a post-Karoo age to the tectonic events. Schwellnus (1941), considered the Karas Mountains to be a series of horsts and intervening graben due to tensional fracturing (Fig. 3A). Holmes (1965), copied a schematic section through the Karas Mountains from Schwellnus (op. cit.,p.21), and used it to demonstrate typical horst and graben structures in areas of tectonic tension. Münch (1971-72), described a series of synclines and anticlines, single-limbed flexures which pass into fractures with the development of drags and upthrusts, and overturned strata in the northern parts of the Karas Mountains. He concluded that these structures are evidence for lateral compression and simultaneous vertical uplift, with stresses operating from the west and north-west.

Field evidence in the central and southern Great Karas Mountains similarly points towards compressive forces during deformation. Overfolded Nama strata and the dips of fault planes, which range from 30° to about 75° where observed, indicate that the major faults are not normal but upthrust and overthrust faults (Fig. 3B). This has been confirmed by boreholes on Dassiefontein 87 in the central Great Karas Mountains. Thrust fault planes are usually obscured, but it seems as if their angles of dip tend to decrease towards the flanks of the Karas Mountains. Flexures or monoclinally folded Nama strata may in places mask thrust-faults in the basement rocks. The same feature is described by De Sitter (1956), in the High Atlas Mountains of Marocco.

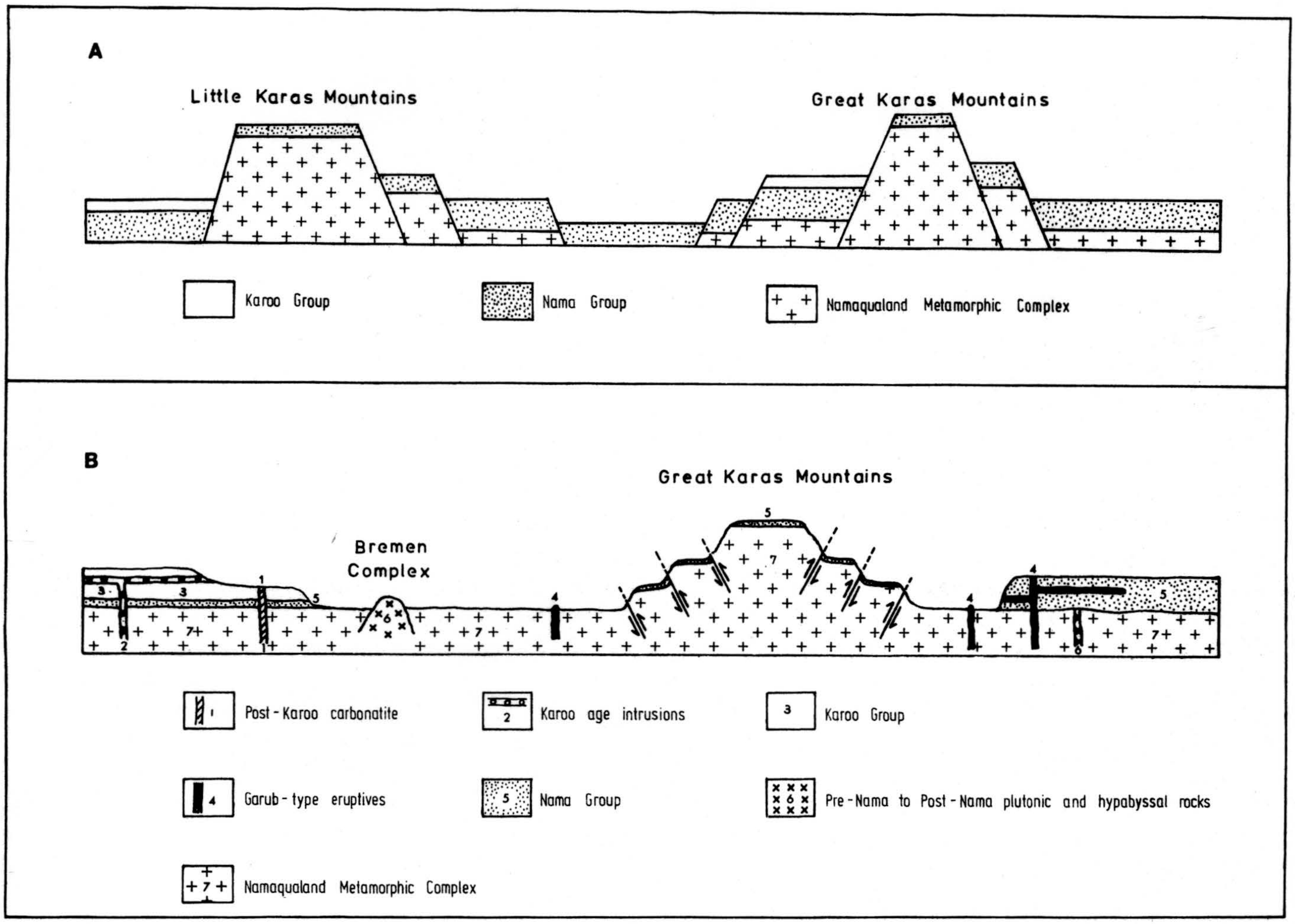


FIG. 3A — Previous diagrammatic section through the Karas Mountains showing horsts and graben — the result of normal faulting (After Schwellnus, 1941).

FIG. 3B — Alternative diagrammatic section through the Great Karas Mountains showing thrust faults and the stratigraphic relationship of rock types in the vicinity.

The Karas Mountain faults are peculiarly localised and their arcuate trends (cf. Fig.2) afford no comparison with the elongated shape of larger rift valleys in central Africa and the Rhine valley (Cloos, 1936; De Sitter, 1956; Sowerbutts, 1972), which are in fact elongated, subsided strips resulting from tension. On the other hand the arcuate trends correspond to those of thrust-faults in some parts of the Wasatch Mountains in Utah (Eardley, 1953). Furthermore, the higher elevation of the Nama sediments in the Karas Mountains as compared with the low-lying, undisturbed Nama sediments which extend for many kilometres to east, north and west, is difficult to explain by means of the tension concept.

A genetic relationship between the Karas Mountains and the Kuboos-Tatasberg-Bremen-Haruchas line of complexes is problematic, although they are conspicuously linked geographically. The pre-Karoo complexes are situated in line with the post-Karoo Karas Mountain faults (Fig. 2), which obviously denote a common zone of weakness in the crust. An unexposed plutonic mass of pre-Karoo age, possibly related to the Kuboos-Haruchas Complexes, could have given rise to reverse faults in pre-Karoo times, in a way analogous to the formation of cone sheet fractures. Post-Karoo rejuvenation of these faults would then have to be assumed. The strain-ellipsoid requires that maximum compressive stress for the formation of thrust-faults be horizontal. One can therefore assume that lateral compressive forces must have been active largely in post-Karoo times.

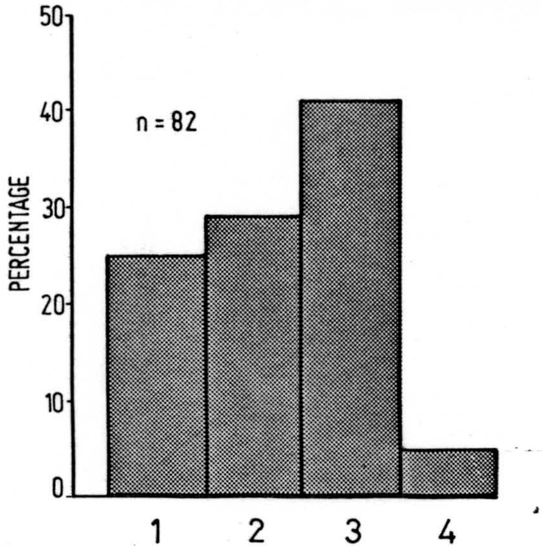
During the downwarping of the Kalahari the most active deformation would be expected to occur in the centre of the basin. It is therefore doubtful whether this had any effect on the development of the Karas Mountains, because the latter are situated on the periphery of the basin.

4 DESCRIPTION OF THE IGNEOUS CARBONATE-BEARING ROCKS

4.1 THE GARUB SUITE

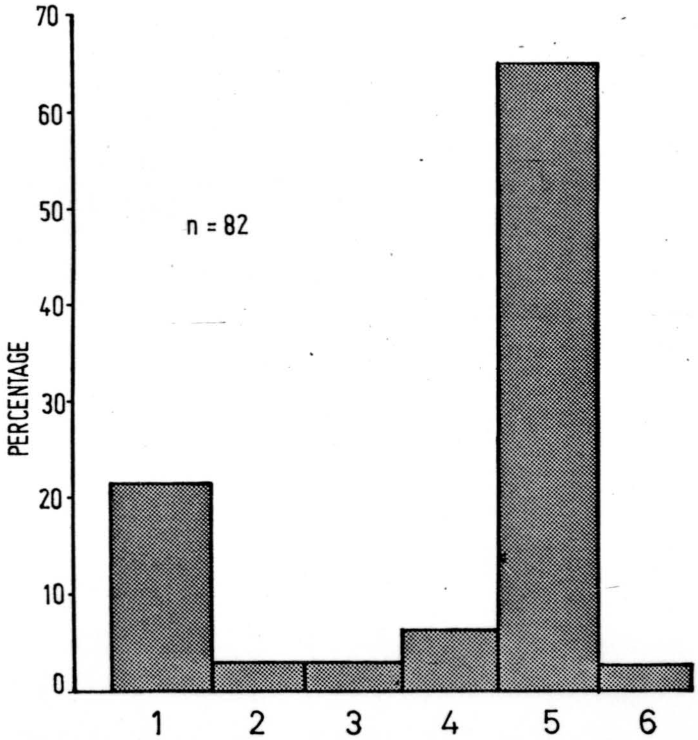
The Garub-type eruptives are easily recognised in the field by their typical brown weathered crust. More than eighty bodies were investigated. Individual localities are numbered on Folder 1 and referred to in the text accordingly. Sketch maps of some of the more important bodies are shown on Folder 2. They may be classified by shape into (1) volcanic necks or pipes, (2) sills, and (3) dykes and veins. Because pipes are usually surrounded by one or more sills or dykes, it is not unexpected that only about 25 per cent of all occurrences assume a pipe-like shape. Dykes and veins amount to 29 per cent and sills and sheets to 41 per cent of the total, whereas the shape of 5 per cent of the smaller occurrences are uncertain (Fig. 4).

Emplacement favoured certain stratigraphic horizons. Because the sedimentary cover has been removed by erosion in many places, about 21,6 per cent are at present encountered in basement rocks (Fig. 5). Although the basement-Kuibis and basement-Schwarzrand contacts would seem to be favourable planes, they were not utilised to any great extent; one or two of the larger sills were emplaced along this unconformity. Only 2,5 per cent of the bodies are found in the Kuibis Formation. About 65 per cent of all occurrences were intruded into the Schwarzrand Formation mainly as fairly inconspicuous sills, following well-developed bedding planes as well as the upper or lower contacts of prominent limestone bands. Because very little of the Fish River Formation is preserved in the area, it is not surprising that only 2,4 per cent occur in this upper division of the Nama Group.



(1) Pipes,(2) Dykes and veins,(3) Sills,(4) Uncertain.

FIG. 4 — Subdivision of Garub-type eruptives according to shape.



(1) Basement rocks, (2) Basement-Kuibis unconformity,
(3) Kuibis Formation, (4) Basement-Schwarzrand unconformity,
(5) Schwarzrand Formation, (6) Fish River Formation

FIG. 5 — Histogram showing the location of Garub-type eruptives at different stratigraphic horizons.

Most of the vents and some of the dykes are filled with coarse breccia, while parts of dykes and most of the sills consist of relatively homogeneous carbonate-bearing material with fewer fragments. The origin of this rock type is problematic but where the texture is predominantly clastic it is described as an intrusive tuff or tuffisite.

4.1.1 Field Relations

4.1.1.1 **Pipes**

The pipe-like bodies are oval, circular or pear-shaped in plan. They are much smaller than the majority of carbonatite and kimberlite pipes. Their diameters vary from 30 to 180 m, and many of them occur as small, easily recognisable conical hills, one to several metres high. The prominent plug on Mickberg 262 is exceptional, with a total height of 97 m and a longer diameter of 450 m. A few occurrences like the one on Weltevrede 302 merely form undulating topography.

The pipes occur at all stratigraphic levels, although only one body has been observed in rocks of the Fish River Formation (No.1). The contents of the vents do not differ significantly in accordance with stratigraphic position.

Many vents in shale of the Schwarzrand Formation are partly surrounded by up to eight superimposed sheets (Verwoerd, 1957), whereas at a few places on Garub 266, Vredenhof 301 and Uitkomst 25, pipe-like bodies gradually change into dykes and veins. On Garub 266, Verwoerd (1957) also mentions a dyke-like connection (No. 35) between a vent and several sheets. To the east of the main road on Uitkomst 25 a pear-shaped vent occurs in sediments of the Schwarzrand Formation. This vent is linked to a northeast striking dyke which, in turn, is apparently connected with a transgressive sill.

Only at two places could the attitudes of the pipes be recognised viz. at localities 56 and 60 where the contacts dip to the south and north-east respectively. On Bismarck-Aue 23 a well was dug in vent breccia and the dip appeared to remain vertical down to a depth of 23 m.

At several localities (8, 26, 63) the rising fluids were obstructed in the vents by overlying Nama quartzite, causing an irregular network of veins to intrude along numerous cracks and joints. About 250 m north of the homestead on Groenrivier 265, a small dome of quartzite was pushed through overlying sandy Schwarzrand shale by the intrusion. Carbonate-bearing material is exposed only on the western side of the hill where it has an irregular outcrop underneath the radially dipping quartzite. Perhaps the scarcity of carbonate-bearing bodies in the Fish River Formation may be ascribed to the same barrier effect.

4.1.1.2 Dykes and veins

Dykes generally occur as conspicuous brown and dark-brown ridges, 2 to 5 m wide and 100 to 500 m long, whereas a few of the larger ones attain heights of 10 to 15 m. About 2 km north-west of the homestead on Nanzes 22, a dyke is found which is much longer than all the others. It has a width of 2 to 3 m and a length of 2 km and hardly protrudes above the general surface. Most of the dykes are fairly straight, but some are irregular or arcuate.

The majority of dykes are surrounded by rocks of the Namaqualand Metamorphic Complex. A few, however, occur in sandstone and shale of the Schwarzrand Formation , whilst one dyke-like body is found in quartzite of the Fish River Formation on Garub 266 (No.40). Where dykes occur in the Schwarzrand Formation, the strata are bent upwards for a distance of 10 to 40 cm from the contact.

Internal structure could be recognised in a few of the dykes. Numbers 21 and 23 have cores of a homogeneous blue-green biotite-chlorite rock, etched out by weathering and surrounded by more prominent brown carbonate-bearing breccia. The dykes on Nanzes 22 and Groenrivier 265 have conspicuous aphanitic chill-zones.

Contact effects on the wall-rock, due to dyke intrusion, are not common. The lamprophyric dyke no. 5 near the old fluorite mine has a zone of thin carbonate-bearing veins in the hanging-wall, as well as off-shoots parallel to the main dyke (Fig.6). The gneiss is fairly weathered and crumbly, and in places bounded by a bleached zone.

A great many dykes are randomly orientated, sinuous in shape and probably not structurally controlled. Dyke 21, however, lies in line with three vents. A probable continuation of this dyke is revealed as a zig-zag grassy strip in a northern direction. This dyke and a few other straight ones striking in the same direction, are apparently controlled by joints in the wall rock. Dyke 5 strikes east-west and dips 40° to the south. Emplacement was controlled by foliation in the gneiss.

The relationship of dykes with vents and sills is of interest. Dyke 4 terminates in a pipe having smaller dimensions than the dyke itself. On Uitkomst 25 the size of the dyke exceeds that of the associated pipe and sill.

Thin veins of fine-grained yellowish carbonate-bearing rock are commonly associated with dykes and pipes e.g. between intrusives 8 and 9, 47 and 48, in the vicinity of pipe 64(a) as well as approximately 25 m to the east of dyke 75. On Tafelkop (Haochanas 24), several such veins, 2 to 8 mm wide, are found in argillaceous sandstone of the Schwarzrand Formation, about 3 m from the outer contact of pipe 65(a). Emplacement seems to have been in pre-existing cracks or joints in the sandstone. Lamination can be followed vaguely through the veins (Fig.22). The vein material is more homogeneous than that of the vents, dykes and sills, and is usually devoid of phenocrysts and pisolites.

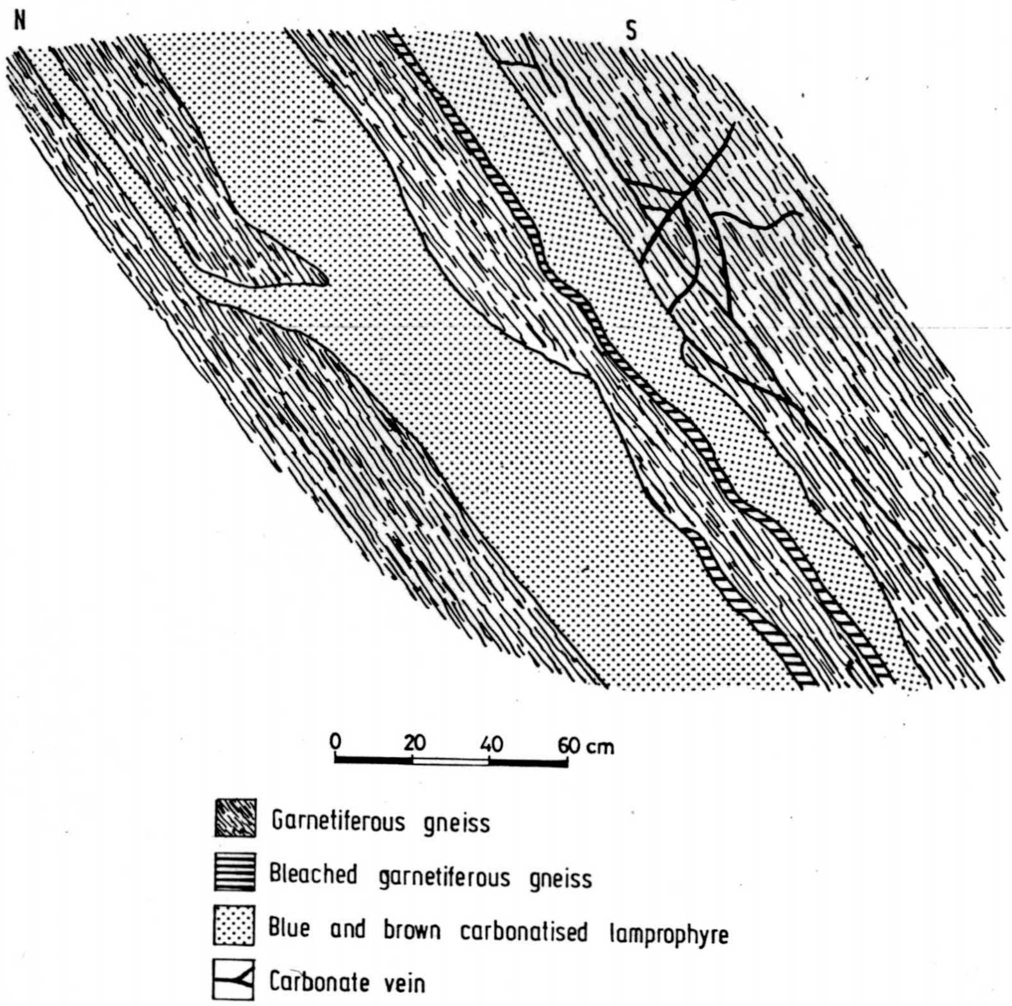


FIG. 6 — Emplacement of the lamprophyric dyke associated with pipe 5 was controlled by foliation in the gneiss. The main dyke shows several parallel offshoots and a series of thin carbonate veins in the hanging-wall. The bleached zones in the gneiss could be a contact effect.

4.1.1.3 Sills

Although not as conspicuous as the pipes and dykes, most sills are easily recognised due to their mode of weathering and typical dark-brown colour which contrast with the surrounding rocks. In some places no pipe or dyke-like conduit could be recognised, but most sills are intimately associated with a pipe or feeder-dyke (cf. Folder 2).

The sills were emplaced mainly along the well-developed bedding planes of the Nama Group, (Plate 3C), and in particular above or below any of the prominent limestone bands of the Schwarzrand Formation. Part of sill 2 displays a conformable contact with the Schwarzrand limestone but is easily distinguished by its irregular texture and ferruginous composition. Several sills cut transgressively through the limestone bands (2, 46, 64, 78).

Sills may vary in thickness from a few centimetres to 5 m as is the case with 34, and often exhibits a selvage on both top and bottom. Sill 64 has been obstructed by limestone of the Schwarzrand Formation; the contact is sharp, and although a fine grained chill-zone could be distinguished in the intrusion, no alteration effect due to contact metamorphism could be recognised in the sedimentary limestone. A transgressive sill (46), dipping south-east and passing into an arcuate dyke to the north-east, cuts twice across a limestone horizon. At one locality the sill elevated the limestone by about 6 m, causing the latter to fold and fracture.

The thickness of a particular sill seldom remains constant; 61 for example varies from 15 cm at the thin end to about 2 m in the central part of the body, whereas 71 thickens from 23 cm to 1,5 m, resulting in a distinctly lenticular shape.

In exceptional cases only one sill is associated with a pipe-like body and in others no obvious feeder can be recognised. Very often numerous sills are found to emanate from a single vent e.g. sills 42, 43, 44, 45, 46 and the series numbered 78 which are superimposed with vertical intervals of up to 6 m. Sills 34 and 38, although not visible as such on surface, are probably linked below the Nama cover (Folder 2). Should that be the case, this sill would cover an area of about 2,6 km^2 which is much larger than any other sill in the area (Verwoerd, 1957). Sill 31 intersects a dolerite dyke, and is partially obstructed by it.

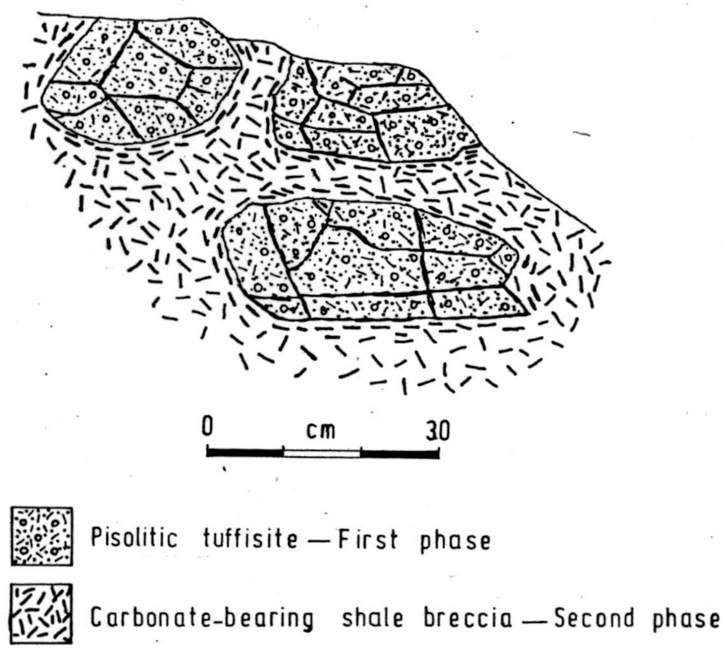


FIG. 7 — Rounded inclusions of first phase pisolitic tuffisite in second phase carbonate-bearing shale breccia. Shale fragments are oriented parallel with outlines of tuffisite inclusions (Sill 66a).

An outcrop at the southern end of sill 27 is of interest. This typical blue-green biotite-rich sill is underlain by a 1 m thick layer of reddish-brown, massive, splintery tuff-like rock in which layering and fragments of feldspar and quartz are clearly visible. The tuffaceous sediments contain coarser, gritty layers and would seem to indicate contemporaneous volcanism. However, this occurrence appears to be exceptional and no further evidence of volcanic activity during sedimentation of the Nama has been found anywhere else in the area.

The majority of sills consist of thinner subordinate, tabular units. This feature could either be ascribed to horizontal jointing or to different pulsations of the sill-forming process. Sill 66(a) undoubtedly shows at least two stages of emplacement. Rounded and subrounded inclusions of relatively homogeneous, pisolitic carbonate-bearing tuffisite representing the first phase are embedded in a younger phase of heterogeneous, carbonate-bearing shale-breccia. The latter appears to be massive and free of cracks and joints, whereas abrasion and fracturing due to emplacement of the second phase are clearly visible in the inclusions (Fig. 7). The alignment of elongated shale fragments around the inclusions is conspicuous and demonstrates the relatively fluid condition of the second phase.

4.1.2 Petrology

Although all the rocks of the Garub suite are similar with respect to matrix, phenocrysts and clasts, several different petrological types could be distinguished. These differences are primarily based on microscopic characteristics, but are also visible in hand specimens. Transitions from one type to the next are common. In a few cases where different petrological types are in contact, age relationships could be established.

4.1.2.1 Carbonate-bearing breccia

Most pipes (7,49,69), as well as a few dykes and sills consist of **bluish-green** and brown ferruginous, carbonate-bearing breccia. It grades from a true breccia consisting of virtually nothing but fragmentary material to a more homogeneous carbonate rock containing fewer fragments. The rough surface and irregular mottled appearance makes this rock conspicuous in the field.

The groundmass commonly consists of medium-grained ankerite and subordinate calcite and ferroan calcite, Fe-hydrates, chlorite and subordinate biotite. Fragments of micropegmatite, quartz and feldspar are often partly replaced by ankerite, giving rise to a moth-eaten texture. Rounded insets of biotite are often surrounded by later "chess-board" albite. The relationship between chloritisation and ankeritisation is sometimes clearly shown. Radial aggregates of penninite and a second chlorite showing anomalous brownish-yellow interference colours, are in some cases partly replaced by ankerite with an opaque rim. A few subhedral grains of serpentine, showing faint "hourglass" structure, are also present.

Fragments in these breccias are of a great variety in type, shape and size, and appear to be controlled by the wall-rock and the size of the breccia body. In vents with the normal 40-60 m diameter, blocks rarely exceed one metre in diameter, while fragments of 1-5cm in diameter are more abundant. They consist of granite, gneiss, schist, shale, quartzite and occasionally dolerite and amphibolite. Those of sedimentary origin are often found in vents entirely surrounded by gneiss, "proving that fragments were not only carried upwards in the diatreme, but also downwards from a pre-existing cover" (Verwoerd, 1957). Bodies 1 and 40, partly emplaced in Fish River quartzite, contain angular inclusions of the same rock. Dyke 62 penetrates the

Schwarzrand Formation and is crowded with shale and micaceous shale derived from that Formation.

The southern extremity of dyke 4 ends in a pipe which contains a variety of angular and well-rounded clasts of sedimentary, plutonic and metamorphic origin. At one specific locality the larger ones appear to be well rounded while the smaller ones are angular. Zoning of the size and shape of the clasts seemed likely and this was investigated in some detail. The size, roundness and sphericity of 507 large clasts were measured and their positions plotted in order to compare these geometrical properties quantitatively for different localities in the pipe. Only the central 670 m^2 of the pipe could be taken into account because the contacts are covered by débris, but the unexposed rim is probably narrow.

The nominal diameter (size) of clasts is calculated from measurements of the long and short axes and by using the formula as proposed by Pye and Pye (1943):

$$d_n = \sqrt{d_l d_s}$$

where d_n is the nominal diameter;
d_l is the long diameter and
d_s is the short diameter.

The results are shown in Fig.8

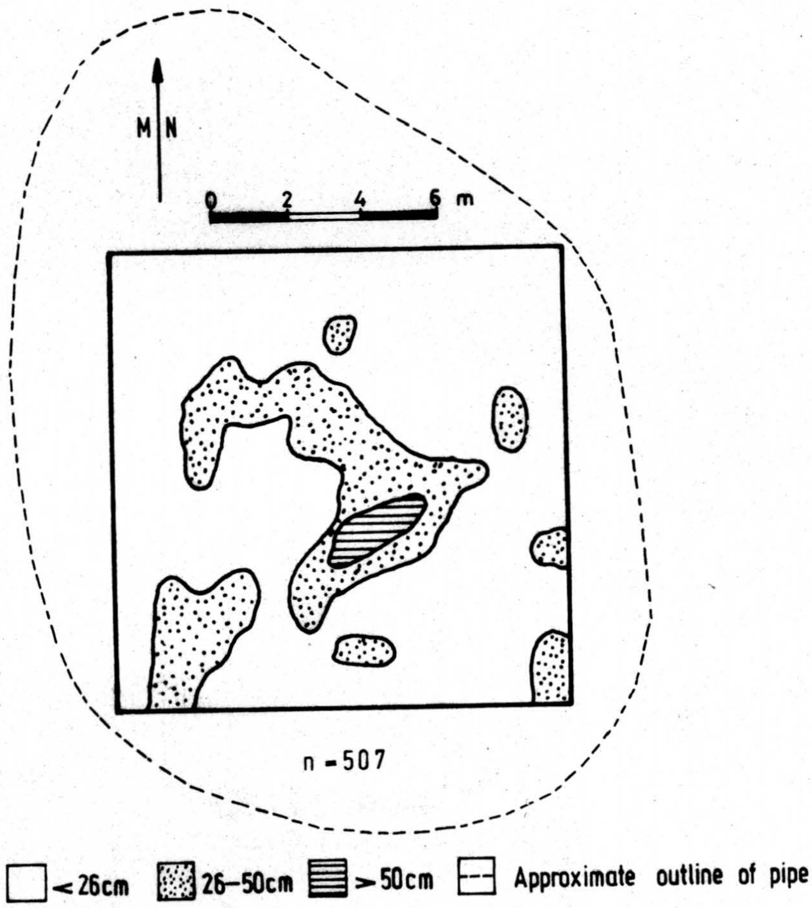


FIG. 8 — Diagram showing the nominal diameter (size) of clasts in the central part of pipe 4.

The same 507 clasts were classified by inspection in different roundness grades as proposed by Pettijohn (1957) for pebbles and sand grains. A rather irregular pattern was obtained as shown in Fig. 9.

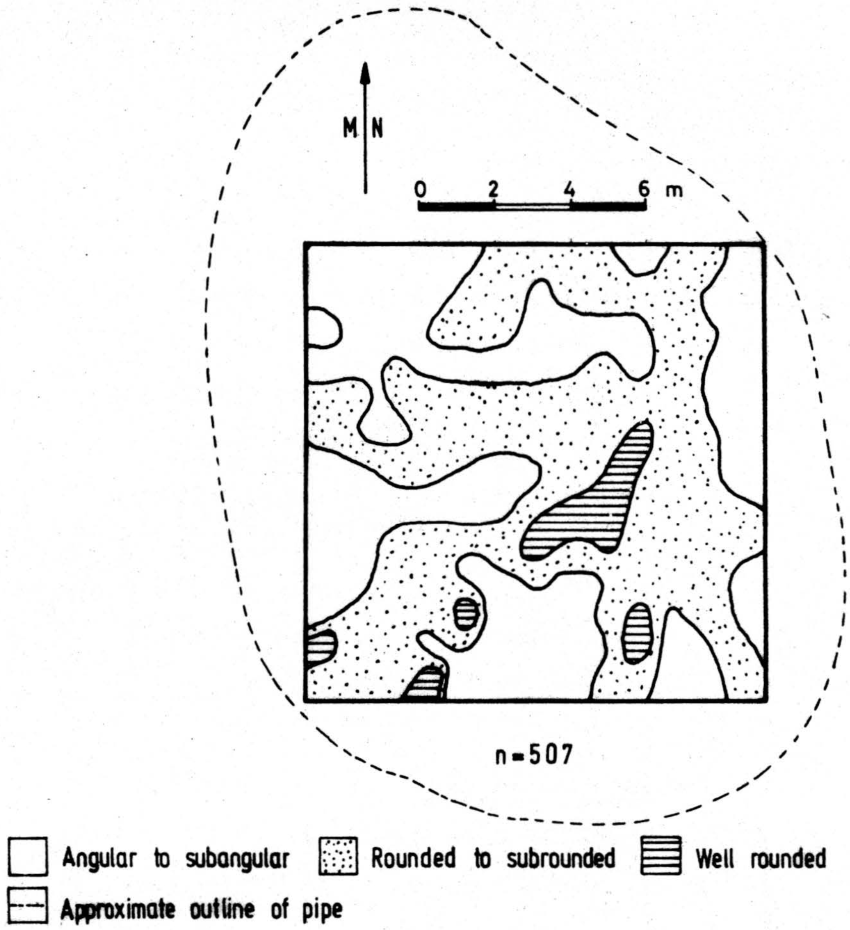


FIG. 9 — Diagram showing the roundness of clasts in the central part of pipe 4.

Sectional sphericity of clasts was determined by measuring the long and short diameters and then using the circumscribed and inscribed circles. The formula used is that of Riley (1941):

$$\phi = \sqrt{\frac{d_i}{d_c}}$$

where ϕ is the sphericity;

d_i is the diameter of the largest inscribed circle and

d_c is the diameter of the smallest circumscribed circle.

A very irregular pattern was obtained as shown in Fig.10.

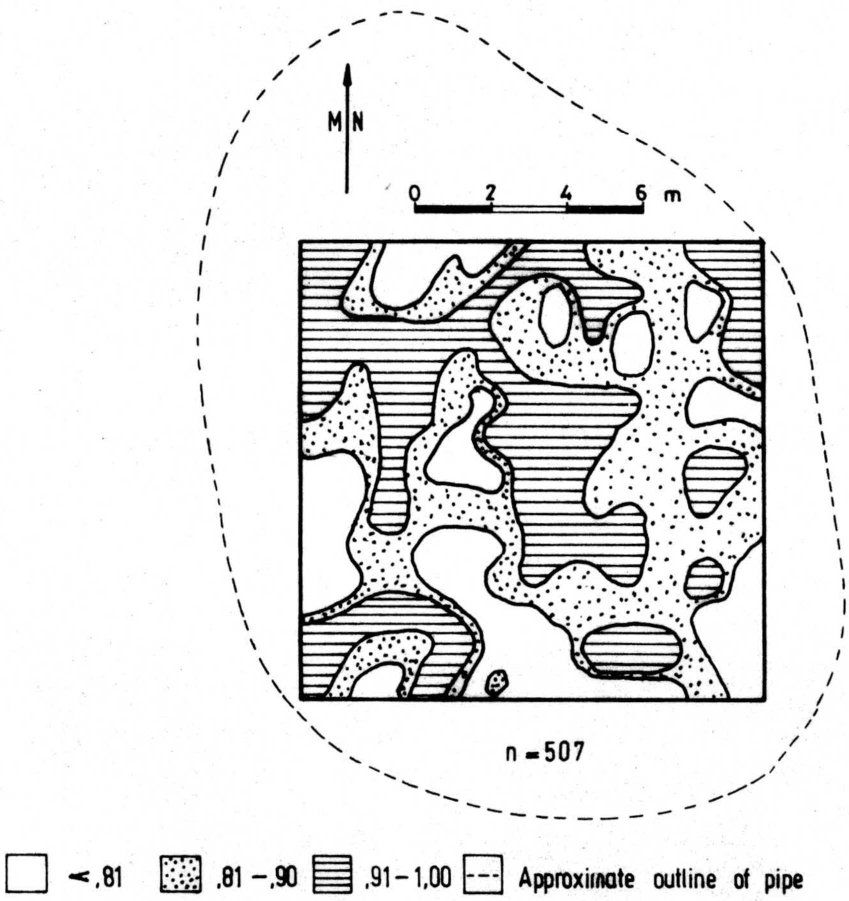


FIG. 10 — Diagram showing the sectional sphericity of clasts in the central part of pipe 4.

The following conclusions could be drawn from these figures:

1. Although pipe 4 is one of the most typical, no convincing evidence of regular zoning exists between different classes of size, roundness and sphericity.

2. Nevertheless, in the centre of the pipe the highest grades of the different geometrical parameters are encountered.

3. Roundness is independent of shape (i.e. sphericity), being concerned with the sharpness of edges and corners of fragments (Pettijohn,1957). Because a large proportion of the clasts in the pipe consists of stratified sedimentary rocks, a better zoning of roundness than of sphericity could be expected, and was indeed obtained.

4. Clasts of diverse texture, structure and composition would obviously react differently on abrasion and corrosion in a vent. This could explain the irregularity of figures 8, 9 and 10 to some extent.

These features might throw light on the mode of emplacement of the breccia bodies, and will be discussed later on.

4.1.2.2 Lamprophyric carbonate rock

Many sills, parts of dykes and parts of pipes consist of a greenish-grey medium-grained rock containing phenocrysts of biotite, ilmenite and often amphibole and pyroxene. The biotite phenocrysts vary in diameter from 1-5 mm and often occur as small books, while phenocrysts of pyroxene and amphibole reach diameters up to 3 cm. Irregular blobs of pyrite up to 6 mm in diameter are also scattered through the rock. What makes this dark, splintery rock interesting under the microscope, however, are the ubiquitous lath-shaped crystals in the groundmass. These are invariably ankeritised. Usually this rock type also contains fragmentary material as do the carbonate-bearing breccias.

The best and apparently least-altered example of this rock is found in the east-west striking dyke associated with pipe 5 (Fig. 11). The matrix largely consists of fine-grained ankerite, but a "ghost structure" of lath-shaped crystals is also present (Plate 5B). Although these laths have been replaced by carbonate they are easily distinguished due to their homogeneous extinction (Verwoerd, 1957). They vary in length from 0,1 to 0,5 mm and are randomly orientated in the groundmass. In the vicinity of phenocrysts of biotite, amphibole or pyroxene, however, these laths are orientated in the form of trachitoid flow-layers around the first-mentioned. Lamellar aggregates and plates of green and brown biotite are often bent and fractured, while crystals with tabular (001) habit and pseudohexagonal outlines are common. Alteration of amphibole to biotite is also seen. Part of the groundmass is made up of penninite, showing anomalous "Berlin blue" interference colours, while a few inclusions are altered to a fine, unidentifiable aggregate. Small carbonatised inclusions were seen to be partly enclosed by spherulitic chalcedony showing typical extinction crosses under crossed nicols (Plate 7A). A single, rounded grain of colourless garnet was identified, showing a kelephytic rim of fine opaques and ankerite.

Mineralogically the rock corresponds to the lamprophyres, i.e. igneous rocks characterised by a high percentage of mafic minerals(especially biotite, hornblende and pyroxene), which forms the phenocrysts, and a fine-grained groundmass with the same mafic minerals in addition to feldspars or felspathoids (A.G.I. Glossary, 1972). It is tempting to interpret the lath-shaped crystals as carbonatised melilite, in which case the Garub lamprophyre would

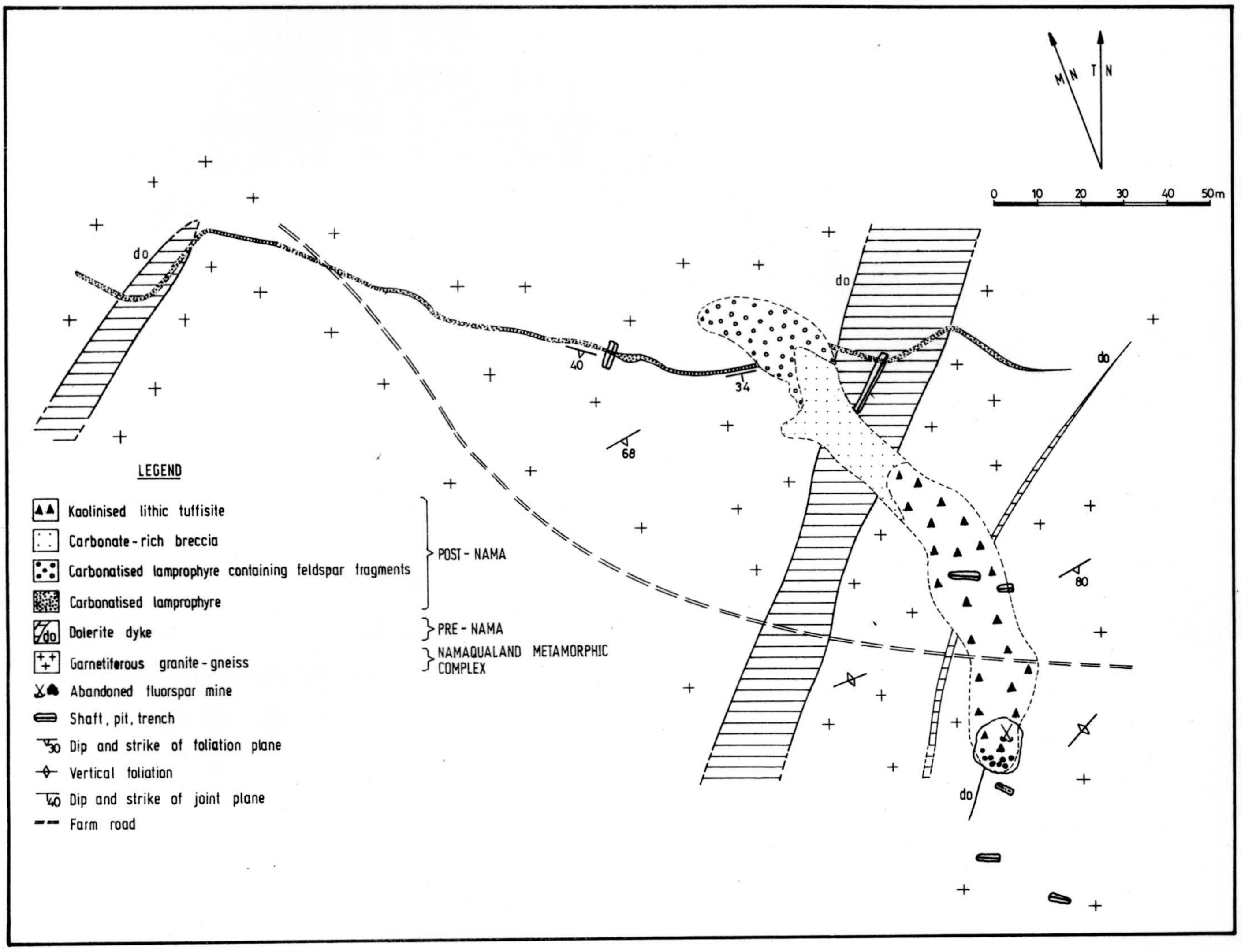


FIG. 11 — Geological map of pipe 5, Garub 266.

be classified as alnöite. The chemical data support this suggestion (cf. Petrochemistry). However some of the laths could also have been feldspar cleavage fragments from the gneissic wall-rock before they were carbonatised. The northern part of pipe 5 consists of ferruginous carbonatised lamprophyre (?) with numerous tiny tabular fragments of feldspar (Plate 5A), whereas dykes 6 and 48 display fragmentation of the feldspar in the gneiss on a macroscopic scale (Plate 4C).

A specimen from sill 70 contains biotite surrounded by a thin layer of dust in which irregular grains of ore occur. The biotite grains are crowded with small rutile needles concentrated along the cleavage.

Specimens from sill 52 show "rounded, apparently corroded inclusions of brick-red and light-green material set in a fine-grained greenish matrix "(Verwoerd, 1957). The green blobs consist of carbonate and chlorite bordered by an accummulation of ore, and they show vague cracks similar to the cleavage pattern of pyroxene. Other only partly carbonatised and chloritised phenocrysts of augite, up to 8 mm in diameter, are colourless to pale green in thin section and often zoned. Small partly replaced phenocrysts of zoned hornblende (Plate 6A), and a light brown orthorombic amphibole with large 2V and feeble pleochroism were also identified. The replacement by ankerite and chlorite give the pyroxenes and amphiboles a moth-eaten appearance.

The well-rounded brick-red blobs consist of an irregular network of opaque material bordered by Fe-hydrates causing the red colour. The carbonate-filled interstices are stained by iron-hydrates. Verwoerd (1957) tentatively concluded that these red blobs could be the remnants of altered and resorbed phenocrysts of olivine. Small euhedral grains of magnetite are abundant in all occurrences, while serpentine, apatite and leucoxene are common accessories.

4.1.2.3 Homogeneous tuffisite (?)

Some sills (the best example being sill 61 on Garub 266) dykes and cores of pipes (e.g.1,21,23) consist of a greyish-green homogeneous carbonate-bearing rock, called alvikite and at other localities biotite-glimmerite by Verwoerd (1957). This rock is fine to medium-grained and minerals constituting the groundmass are usually not macroscopically identifiable. It is soft but tough, and is mostly covered by a weathered rim of brown and dark-brown iron-rich material. Although this rock-type is mostly free of inclusions, sill 61 contains fragments of Schwarzrand shale scattered through the otherwise homogeneous matrix. Thin whitish veinlets of calcite are common in almost all occurrences. The 2 km long dyke no. 73 on Nanzes 22 is exceptional. It is cut by many 17 mm wide veinlets of chrysotile partly replaced by calcite. It also contains phenocrysts of ilmenite, 1-4 mm in diameter and minute blobs of pyrite.

Under the microscope this rock is found to consist of biotite, chlorite and ankerite. The groundmass originally consisted primarily of minerals showing good cleavage in places (biotite?) and fibrous elsewhere, but is now completely ankeritised. It differs from the lamprophyric carbonate rock in the relative scarcity of phenocrysts (xenocrysts ?) and lath-like pseudomorphs.

A sample taken at the northern end of sill 34 contains insets of zoned, light green augite up to 3 cm in diameter. Elongated crystals of biotite are orientated parallel to the edge of the augite. Other well-rounded inclusions are carbonatised whilst the groundmass is crammed with euhedral and anhedral grains of ore (ilmenite, magnetite, pyrite). A concentration thereof is encountered around the carbonatised insets (Plate 6B). Apatite and serpentine are accessories. Several samples show original euhedral crystals now replaced by penninite. The latter, in turn, is partly replaced by calcite, and displays a moth-eaten texture.

Crystals of biotite are also chloritised and ankeritised, especially along cleavage directions, where streaks of hematite are concentrated. Ankerite replacing the groundmass and xenocrysts (?) is often relatively coarse-grained and twinned, whereas anhedral ankerite and calcite occur interstitially.

A specimen from sill 52 contains large partly ankeritised augites and smaller serpentinised insets which are often also somewhat carbonatised. Accumulations of grains of ore around carbonatised insets, accentuate original crystal boundaries. The marginal zone of dyke 73 contains minute veinlets of younger calcite cutting through grains of ankerite, magnetite and flamboyant radial aggregates of penninite. Veinlets of chrysotile are also present.

On Groenrivier 265 the northern part of dyke 64 has a coarse central zone and a fine-grained marginal zone. The groundmass of both zones consists of twinned ankerite, biotite, serpentine, and minute carbonatised lath-shaped crystals. The carbonatisation of these laths is characterised by a concentration of ore. Apatite is an accessory mineral.

The southern extremity of sill 27 consists of a medium-grained equigranular rock containing ankerite and calcite, biotite, penninite, serpentine, hematite, magnetite and apatite. Verwoerd (1957) also identified substantial amounts of a light yellow andradite garnet in a rock from this locality. Macroscopically similar material is found as a ring-dyke cutting across breccia pipe 58. It is fine-grained and consists of ankerite as well as apatite, magnetite and later interstitial chalcedony with sutured contacts due to partial replacement by ankerite.

The origin of this rock type is problematic but in many respects it appears to be transitional between the lamprophyre and pisolitic tuffisite.

4.1.2.4 Pisolitic tuffisite

Many occurrences of dykes, pipes and sills consist in part of brown and greenish-grey pisolitic material. Typical examples occur on Liebenrust 300 where sills of brown-weathering, pisolitic rock were emplaced in grit of the Kuibis Formation (Plate 3C). The spheroidal, often concentric pisolites vary from 5 mm to about 10 mm in diameter. They are frequently associated with rounded and angular fragments, and are easily distinguished from the groundmass. The ease of weathering of some pisolites may cause a rock surface to be irregular and pitted, whereas in other cases the groundmass weathers more easily, giving the rock a nodular appearance.

Sill 66 consists of greenish-grey, ankeritic shale breccia and contains numerous inclusions of an older pisolitic phase (Fig. 7). The pisolites vary from 1 mm to 6 mm in diameter and occur together with fragments of shale of the Schwarzrand Formation. Most pisolites have cores which are easily recognised. They sometimes consist of prismatic crystals and radiating fibrous aggregates of zeolite accompanied by penninite but are more often replaced by coarse-grained ankerite or an intricate network of ferruginous veins. Within the pisolites the ankeritised cores are surrounded by numerous small, irregular blobs of ore, concentric layers of fine opaque dust, magnetite grains, iron hydrates, crystals of ankerite and ankeritised laths orientated parallel to the core boundaries. Interstices are filled with ferric hydrates, ankerite, calcite and ferroan calcite.

The groundmass and the pisolites of the sills on Liebenrust 300 are largely ferruginised, thus obscuring petrographic details. Some pisolites show no definite core at all but only appear as lighter coloured spheroids in a darker groundmass. Other pisolites, however, contain cores of a partly altered pale-coloured, lath-like biaxial mineral showing parallel extinction, length slow character and low birefringence. X-ray diffraction revealed the pattern of an amphibole (anthophyllite ?). Pisolites centered by irregular gneiss fragments are also present but not common.

The pisolitic material from the two pipes on Tafelkop (Haochanas 24) is rather different from that of the other occurrences. Macroscopically the pisolites appear in the form of dark-coloured spheroids, 1 to 14 mm in diameter, embedded in a hard, splintery groundmass of carbonate, fragmental material and dust (Plate 4A). Ninety five per cent of the rock consists of ankerite, while spherulites of feldspar, magnetite and chlorite with colourless fluorite filling cleavage cracks are subordinate (Plate 6C). All cores of pisolites have been replaced by ankerite; the original outlines are indicated, however, by the concentration of dust and ore grains.

Pisolites are nowhere closely packed, but "float" in the groundmass, although in some cases two or more are coupled. Neither are they squeezed into oblong shapes. With regard to their origin, it seems that accretion in a wet environment of different layers of dust around xenocrysts and accidental inclusions from the wall rock caused many of them to form. However, the eastern part of dyke 6 contains pisolites which are **definitely** not accretionary lapilli. These "orbicular" pisolites (Plate 4B) have cores of coarse-grained ankerite surrounded by fine-grained ankerite and practically no dust. Original outlines of the now ankeritised cores are accentuated by an accumulation of opaque material, while some cores are chloritised and only partly ankeritised. These pisolites probably originated by chemical reaction between mafic xenocrysts and the surrounding carbonate-bearing fluid.

4.1.2.5 Gneiss breccia

On Weltevrede 302 an irregular pipe-like body (80) consists mainly of grey and brown breccia with variable carbonate content (Fig. 12). The mottled appearance of the breccia is due to the buff colour of the fragments which are mostly embedded in a brown ferruginous groundmass. The latter varies from small pulverised fragments to brown, mostly opaque Fe-hydrates. In places the fragments are so small and tightly packed that the rock appears tuffaceous. On closer examination it was found that the following rock types could be distinguished although transitions occur:

a. Light grey brecciated gneiss comprising only crushed and pulverised gneiss and no carbonate;

b. Greyish gneiss breccia, consisting mainly of closely packed gneiss fragments, subordinate ferruginous material and dust-filled interstices;

c. Brownish carbonate-bearing breccia, made of loosely packed fragments in a brown ferruginous groundmass of dust with subordinate ankerite; and

d. Brown carbonate-rich breccia consisting predominantly of a brown ferruginous groundmass of dust, Fe-hydrates and ankerite with fewer fragments.

The latter two rock types are similar to the carbonate-bearing breccia described under 4.1.2.1. Although the colour varies from light grey to brown and dark brown, it is often difficult to decide which of the four above-mentioned rock types one is dealing with. The fragments are angular to well rounded and consist of micropegmatite, gneiss, quartz, dull perthite and microcline. Small, rounded grains of zircon are accessories, and are probably derived from the gneiss.

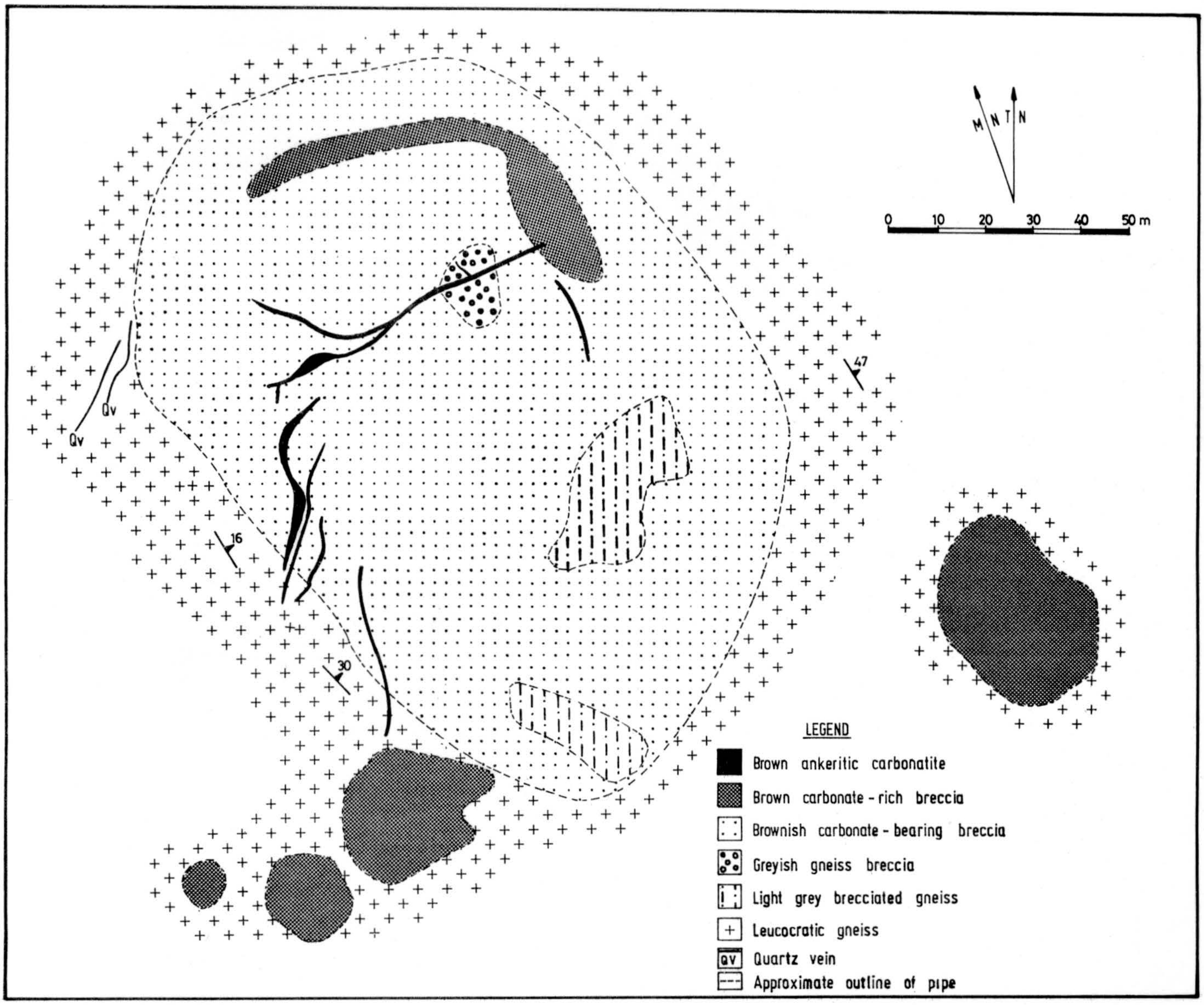


FIG. 12 — Geological map of pipe 80, Weltevrede 302.

The Weltevrede pipe is traversed by irregular dykes of brown ankeritic carbonatite and in this respect resembles the Mickberg plug nearby rather than the Garub suite.

4.1.2.6 Kaolinised lithic tuffisite

On Garub 266 the southern part of inclined pipe no.5 comprises buff-coloured, fine to medium-grained tuffaceous rock in which angular to subangular fragments of quartz, altered feldspar and micropegmatite are recognisable as well as larger clasts of kaolinised gneiss (Fig.11). The groundmass consists entirely of grains derived from the surrounding gneiss (Plate 5C). The quartz shows undulatory extinction, no recrystallisation and frequently contains minute, unidentifiable microlites. No traces of desilication or carbonatisation were encountered. Although most of the feldspars are kaolinised beyond further identification, plagioclase, microcline and microcline-perthite could be recognised in some instances. Accessories are zircon, well rounded tourmaline and irregular grains of hematite.

Except for the kaolinisation which appears to be genetically related with the fluorspar deposit, this rock-type resembles the relatively carbonate-free gneiss breccia on Weltevrede 302 to some extent.

4.2 THE MICKBERG PLUG

On Mickberg 262 carbonate rocks occur in garnet gneiss of the Namaqualand Metamorphic Complex in the form of several adjacent irregular outcrops. Together they probably constitute a near-vertical plug. The body differs from the breccia pipes on Garub 266 in topographic expression, dimensions and rock types and deserves a separate description. It is mainly composed of impure carbonatite, post-dates the Nama Group and has some petrographic features in common with the Garub suite. A genetic connection is not certain, however.

4.2.1 Field relations

The plug is elongated in a north-north-easterly direction and consists of two joined hills attaining a maximum height of about 100 m above the surrounding plain and a longer diameter of about 450 m (Fig. 13 and Plate 1A). On the south-western side where large domes of gneiss occur, the slope is rather steep. The hills consist mainly of gneiss that is brecciated in places, whilst outcrops of dark-brown ankeritic carbonatite crammed with inclusions are irregular and patchy. There are no clear-cut contacts between brecciated and undisturbed gneiss. Thin stringers and dykes of brown carbonatite are in sharp contact with disoriented blocks of gneiss (Plate 1B). On the northern slope of the larger hill a dyke of younger light-coloured, crystalline carbonatite 1 to 3 m wide, cuts through brown carbonatite and through a large included block of Kuibis grit. No internal structure or evidence of zoning have been found. North of the hill top the carbonatite is bluish due to the presence of soda-amphibole.

Inclusions of gneiss, and grit and quartzite of the Kuibis Formation are embedded in the carbonatite. They are well-rounded to angular (Plate 2B) and vary from several mm up to 6 m in diameter. The xenoliths of sedimentary origin lie at levels much lower than their original stratigraphic position. As a result of fenitisation, some fragments of Kuibis quartzite are light-blue in colour.

No obvious structural control exists in the area. The nearest major fault associated with the Great Karas Mountains is about 1 km eastward. The sporadic brecciation of the wall-rock is believed to be a local effect of the intrusion.

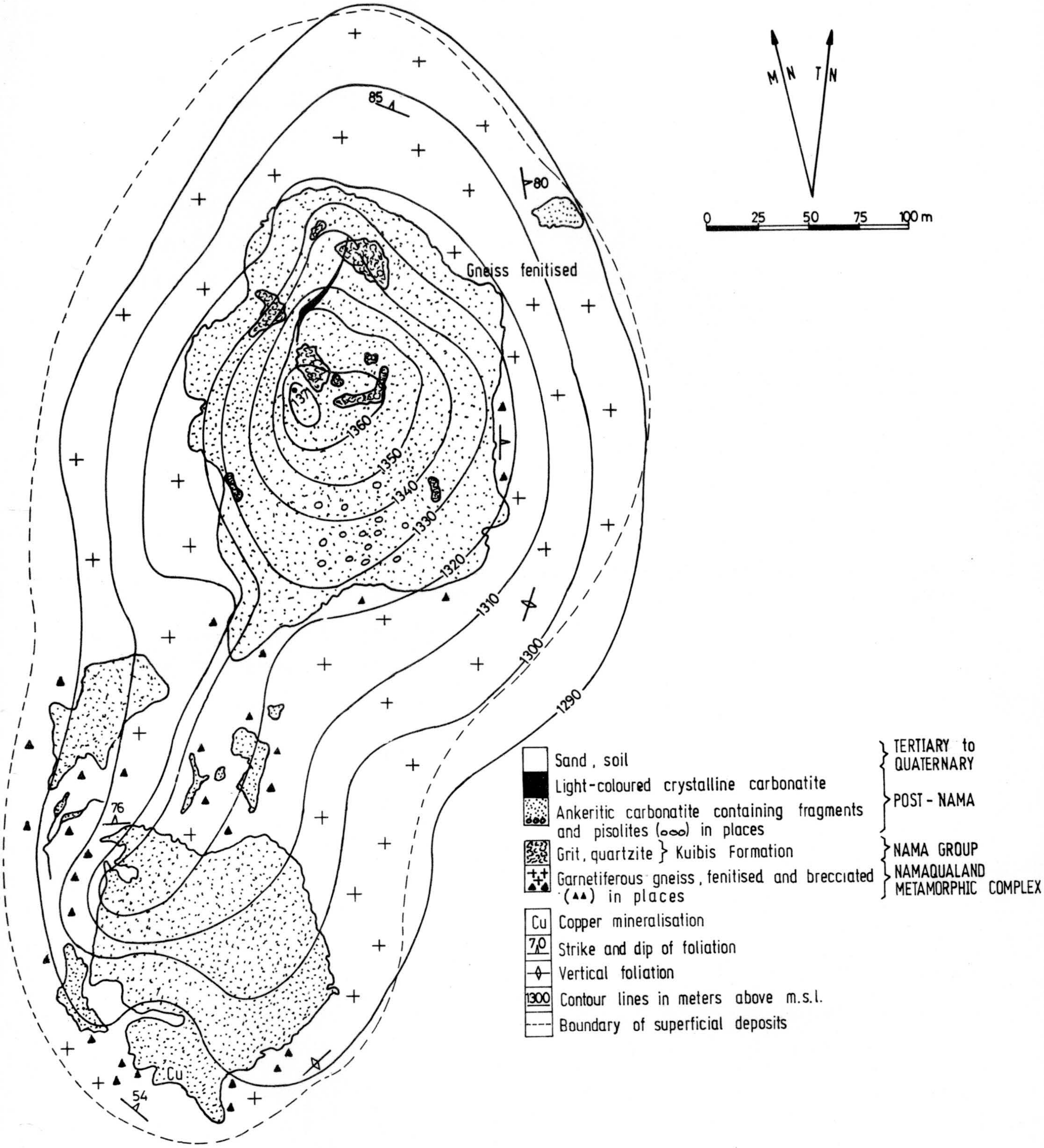


FIG. 13 — Geological map of plug 82, Mickberg 262.

4.2.2 Petrology

The principal rock type is dark-brown carbonatite containing numerous fragments of varying dimensions (Plate 1C). Under the microscope the main constituents were found to be euhedral ankerite in a groundmass of anhedral ankerite grains considerably contaminated with Fe-hydrates. Interstices are filled by subordinate calcite and ferroan calcite. Euhedral and well-rounded grains of apatite, magnetite and biotite are also present, while serpentine and chlorite with ultra-blue interference colours are secondary. The mineralogical composition of the rock therefore corresponds to beforsite. The smaller inclusions are microcline-perthite, microcline, pericline-twinned plagioclase, micropegmatite and quartzite. Most of the fragments are carbonatised to some extent whilst many grains of feldspar are saussuritised beyond further identification. In some areas the impure carbonatite has a typical blue colour due to the replacement of quartz and feldspar by soda-amphibole.

The light-brown inclusion-free carbonatite dyke consists of medium-grained ankerite occurring as rhombohedral crystals and spherulites. Zircon is a subordinate mineral. Rather small fragments of microcline, microcline-perthite and quartzite are present, but are largely carbonatised.

On the southern side of the large hill the carbonatite contains spherical inclusions up to 15 cm in diameter (Plate 2C). Most of these structures are nucleated by foreign material such as granite, gneiss, quartzite and schist. Nuclei vary from 1 to 7 cm in diameter, and are usually fairly weathered. The nuclei are surrounded by faint, concentric shells made up of fine-grained ankerite, dust, small angular and well-rounded fragments of quartz and saussuritized feldspar and subordinate apatite. The spherical inclusions are sometimes embedded in a brownish medium-grained, silica-rich matrix. Under the microscope this facies of the carbonatite is seen to consist of equidimensional grains of quartz, microcline and albite, displaying a mosaic texture. The quartz shows enlargement of grains and undulatory extinction whilst the feldspars are slightly saussuritised. Only very few grains are carbonatised. Zircon and ore are accessory minerals.

4.3 MINERALOGICAL COMPOSITION

The mineralogical composition of the Garub-type carbonate rocks and their associates is summarised in Table 1.

Staining tests as proposed by Dickson (1965), using Alizarin red S and potassium ferricyanide, indicate the presence of three different carbonates, viz. ankerite, ferroan calcite and calcite. Ankerite is the most abundant carbonate mineral and is the major constituent of all the carbonate-bearing rocks described. The calcite and ferroan calcite commonly occur as irregular interstitial matter amongst coarse euhedral ankerite grains which were probably the first to have crystallised. Veinlets of calcite cutting across ankerite and ferroan calcite are also found.

Phenocrysts of kaersutitic hornblende, showing large 2V, negative optical character, pale brown to brownish-green pleochroism and an extinction angle of 12-15° were encountered in some of the carbonate-bearing rocks. An electron microprobe analysis of the amphibole revealed relatively high Ti and Mg contents. Optical zoning is common and varies from shades of green in the core and brown at the rim (Plate 6A). This zoning also reflects chemical variation (Table 2), with rims being lower in Fe, Al and Na and higher in Mg, Ca and Ti compared to cores. Another light-brown orthorhombic amphibole with large 2V, length-slow character and feeble pleochroism (anthophyllite ?), was also observed. A soda amphibole containing Si, Mg, Fe, Al, Ca and Na and tentatively identified as crossite (Verwoerd 1957), has anomalous reddish extinction colours, maximum absorption parallel to the elongation, length-slow character and refractive indices of about 1,66.

Reddish-brown biotite phenocrysts are present in most of the carbonate rocks, and are pleochroic from pale yellow to reddish-brown, with lighter coloured outer zones, whilst some biotite grains have pale green rims of chlorite. Many grains of biotite contain tiny needles of rutile grouped in a triangular pattern in which the needles intersect at an angle of 6o°.

Rounded and well-rounded grains of green augite (Ca_{43} Mg_{37} Fe_{20}) (Table 2), occur in the lamprophyric rocks. Pleochroism in the coloured varieties is weak and varies from pale brown to pale green. The 2V is large and the extinction angle is 32^{o}.

No unaltered grains of olivine could be identified. However, some irregular, ferruginous aggregates may be altered olivine.

Carbonatised lath-shaped pseudomorphs are almost invariably present in the carbonate-bearing rocks and could be original melilite or feldspar.

Large irregular grains and tiny acicular crystals of apatite and well rounded grains of zircon are primary subordinate minerals in the carbonate-bearing rocks, although the latter mineral may have been derived from the gneissic wall-rock. Small, fairly abraded grains of tourmaline were observed only in the lithic tuffisite, and were almost certainly derived from the wall-rock.

Light yellow garnet was found in carbonate-bearing tuffisite from sill 27. The mineral, with a unit cell length of 12,09 $\pm$,02 Å and refractive index of 1,81 has been identified as andradite with subordinate grossularite (Verwoerd 1957). A single grain of colourless garnet was identified in a specimen from the dyke associated with pipe 5. Analysis of the garnet (Table 2) indicates that it

Rock type	Ankerite	Ferroan calcite	Calcite	Biotite	Augite	Other amphiboles	Soda amphibole	Apatite	Lath-shaped pseudomorphs	Ilmenite	Leucoxene	Magnetite	Hematite	Pyrite	Garnet	Zircon	Tourmaline	K-feldspar	Plagioclase	Quartz and chalcedony	Fluorite	Talc	Zeolite	Chlorite	Serpentine
Carbonate-bearing breccia	X	0	0	+			0	0	+	0	0			0		0		+	+	+				0	0
Mickberg carbonatite	X	0	0	0	+		0	0						0		0		+	+	+			0	0	0
Gneiss breccia	+		0					0		0	0					0		+	+	+					
Lamprophyric carbonate rock	X	0	0	X	+	+		0	+	0	0	0		0	0	0		0	0	0			0	+	+
Homogeneous tuffisite (?)	X	+	0	+				0	0	0	0	0	0	0	0									+	0
Pisolitic tuffisite	X	0	0	+		0		0	+	0	0			0				0	0	0	0	0	0	+	0
Kaolinised lithic tuffisite													0			0	0	X	X	X	X				

TABLE 1 — MINERALOGICAL COMPOSITION OF THE GARUB-TYPE ERUPTIVES AND ASSOCIATED ROCKS

X Major constituent + Minor constituent 0 Accessory constituent

TABLE 2 — ELECTRON MICROPROBE ANALYSES OF MINERALS FROM THE LAMPROPHYRIC CARBONATE DYKE ASSOCIATED WITH PIPE 5, GARUB 266

	Amphibole core	Amphibole rim	Garnet[d]	Magnetite[e]	Clinopyroxene[f]
SiO_2	40,99	41,20	38,69	-	52,79
Al_2O_3	11,86	8,03	20,68	2,72	1,59
TiO_2	2,26	3,50	-	12,31	0,44
MgO	13,35	16,30	7,81	2,05	13,03
FeO[b]	14,13	10,42	30,77	75,99	8,87
MnO	0,05	0,10	0,16	0,54	0,36
Cr_2O_3	-	-	0,64	0,15	0,14
NiO	-	-	-	0,30	0,21
CaO	10,15	12,25	1,88	0,09	21,02
Na_2O	4,09	3,02	-	-	0,03
K_2O	1,96	2,28	-	-	-
Total	98,84[a]	97,10[a]	100,63	94,15	99,58

Structural Formulae

	23[c]	23[c]	24[c]	32[c]	6[c]
Si	6,114	6,227	6,027	-	1,940
Al	2,068	1,431	3,798	1,127	0,070
Ti	0,254	0,394	-	3,259	0,012
Mg	2,968	3,665	1,813	1,075	0,723
Fe	1,763	1,317	4,009	22,736	0,276
Mn	0,006	0,006	0,084	0,148	0,101
Cr	-	-	0,020	0,042	0,004
Ni	-	-	-	0,085	0,006
Ca	1,622	1,971	0,314	0,043	0,839
Na	1,183	0,885	-	-	0,079
K	0,373	0,430	-	-	0,002

(a) Total excludes volatiles;
(b) Total iron as FeO;
(c) Number of oxygens on which the structural formula is based;
(d) Alm_{64} $Spess_{0,3}$ Pyr_{31} $Gross_{3,4}$ $Uvar_{1,3}$ (Calculated after Rickwood, 1968)

(e) Mt_{67} $Ulvo_{33}$

(f) Ca_{43} Mg_{37} Fe_{20}

Analyst R.C. Wallace , **Geological Survey Laboratory.**

is rich in the pyrope and almandine molecules (Alm_{64} $Spess_{0,3}$ Pyr_{31} $Gross_{3,4}$ $Uvar_{1,3}$). This grain was probably derived from the high grade gneissic wall-rock.

Irregular blobs of ilmenite, often altered to leucoxene, pyrite and rectangular grains of magnetite are present in most of the carbonate-bearing rocks. Microprobe analysis indicates that the magnetite (Mt_{67} $Ulvo_{33}$) is rich in titanium (Table 2).

Quartz, plagioclase and alkali-feldspars occur as "accidental" fragments derived from the wall-rock. However, in a few cases late quartz, chalcedony and plagioclase have been found as interstitial matter among ankerite grains.

A zeolite with weak birefringence and length slow character occurs as radiating, fibrous aggregates in some carbonate rocks.

Chlorite and serpentine occur as probable late primary minerals and secondary alteration products. In some instances the chlorite shows the anomalous "Berlin Blue" interference colours typical of penninite. Thin veins of fibrous, colourless to pale green chrysotile were observed at two localities. The fibres are 3-5 mm long and are aligned across the veins.

Except for massive purple, green and white fluorite associated with pipe 5, this mineral was only observed in a specimen from one other locality (Pipe 68). The fluorite is colourless and occur as a late-crystallising mineral along cleavage in chlorite. The fluorite, in turn, is penetrated by cracks filled by talc.

4.4 FENITISATION EFFECTS

Fenitisation of the wall-rock was observed at only a few localities. However, the result of the fenitisation process is not always macroscopically evident, so that changes which are only recognisable under the microscope may have occurred elsewhere.

The best example of fenitisation was encountered at dyke 48. The latter consists of two parts separated by a mass of sheared, brecciated and recrystallised gneiss. According to Verwoerd (1957) the shear planes dip 45° eastwards while rounded blocks of brecciated gneiss are enveloped by flow layers containing inclusions of recrystallised feldspar. The brecciation is associated with fenitisation — the development of spectacular blue amphibole and large porphyroblasts of pinkish microcline. Fenitisation also occurs elsewhere along the dyke-wall-rock contact. The outer limits of fenitisation, however, are not sharply defined but gradational.

Microscopic examination showed that the rock consists of abundant quartz partly replaced by blue amphibole. The latter forms rosettes of fine needles, usually penetrating the quartz from the periphery, thus leaving the centres of most quartz grains clear and unaffected (Plate 7B). The amphibole with its anomalous reddish extinction colours, was tentatively identified by Verwoerd (1957), as the soda variety crossite. Tufts of crossite are often totally surrounded by microcline perthite, both replacing quartz. Grains of quartz are partly replaced by microcline-perthite and "chess-board" albite. Spherulites of either feldspar or zeolite are also partly replaced by crossite and to a lesser extent carbonatised. Rounded grains of fairly turbid feldspar are in some cases fenitised and surrounded by rims of Fe-hydrates and a fine aggregate of chlorite. Several strongly pleochroic grains of brown biotite are apparently unaffected. Apatite and zircon are accessories.

A specimen from the same brecciated mass at dyke 48 that appeared to be blueish limestone and effervesces with cold, dilute hydrochloric acid, was found to consist of 40 per cent fine-grained quartz and 50 per cent fine-grained calcite. The quartz is to a large extent replaced by crossite. Zircon and chlorite are accessory minerals in the "limestone". The origin of this block is not evident, but it could represent carbonatised and fenitised fine-grained Nama quartzite.

The northern part of the larger hill on Mickberg 262 consists of dark-bluish carbonatite contaminated by gneiss. The quartz is again replaced by crossite and feldspar. Turbid homogeneous K-feldspar often changes to microcline-perthite and albite/oligoclase. Enlargement of microcline-perthite grains by later crystallisation is conspicuous, whilst ankeritisation is common.

A few xenoliths of Kuibis grit, several metres in diameter and embedded in the Mickberg carbonatite, are also found to be fenitised. The interlocking grains of quartz, showing undulatory extinction, are partly replaced by tufts of crossite and a mosaic of microcline-perthite and albite/oligoclase (An_{10}). The crossite fibres vary in length from 0,05 to 0,2 mm. In separate grains of quartz and feldspar the fibres are straight and needle-like, while in interstices they are bent and grouped in bands. The grains of new microcline-perthite and albite/oligoclase show an increase in grain size, while the rest of the feldspar remains cloudy.

The following generalisations appear to be applicable to the fenitisation process associated with the Garub suite and the Mickberg plug:

1. The silicic and arkosic (metamorphic and sedimentary) country rocks were subjected to sodic metasomatism by some, but not all the carbonate-bearing eruptives.

2. Quartz was the first mineral to be replaced by soda-amphibole (crossite).

3. Crossite replaced the quartz and feldspar grains along cracks and grain boundaries whereas centres of grains were often left clear and unaffected. This substantiates previous opinions that the fenitisation process must be the result of circulating fluids and not of ionic migration.

4. Biotite, as a mafic mineral,was virtually unaffected.

5. Original, relatively homogeneous feldspars became turbid.

6. Large amounts of albite/oligoclase and microcline-perthite were formed. In hand specimen porphyroblasts of pinkish microcline-perthite are conspicuous.

7. The feldspars increased in grain size during fenitisation. This feature is accentuated by rims of impurities and irregular extinction.

8. Ankerite is fairly abundant in some of the fenitised rocks and may reach approximately 50 per cent, while apatite is invariably present but subsidiary. The occurrence of carbonate minerals in fenitised rocks originally not containing significant carbonate, proves that the fenitisation was closely related to the introduction of the carbonates and the emplacement of the carbonate-bearing eruptives.

4.5 AGE

Intrusions of the Garub suite have been emplaced into the Kuibis, Schwarzrand and lower Fish River Formations. On Grünau 16 a carbonatite dyke cuts through the Dwyka Formation of the Karoo Group, but is probably not related to the Garub eruptives. No evidence that the latter ever penetrated post-Nama rocks has been found. Some occurrences like the Mickberg plug, are not in contact with sedimentary rocks but contain Nama inclusions so that they may be considered as post-Nama or as post-Karoo.

Rb-Sr-isotopic age measurements were carried out on a specimen from a "pyroclastic sill associated with a carbonatitic diatreme" from Garub 266 and gave an age of 506 ± 8 My, which is isochronous with the "Pan-African" orogenic event (Allsopp et al., in press). If the age of between 550 and 700 My for the Nama Group is correct (Op cit.), the Garub eruptives therefore post-date the Nama and more specifically the lower Fish River Formation. The igneous activity of the Garub suite is typically non-orogenic and appears to have been restricted to the craton during the "Pan-African" event.

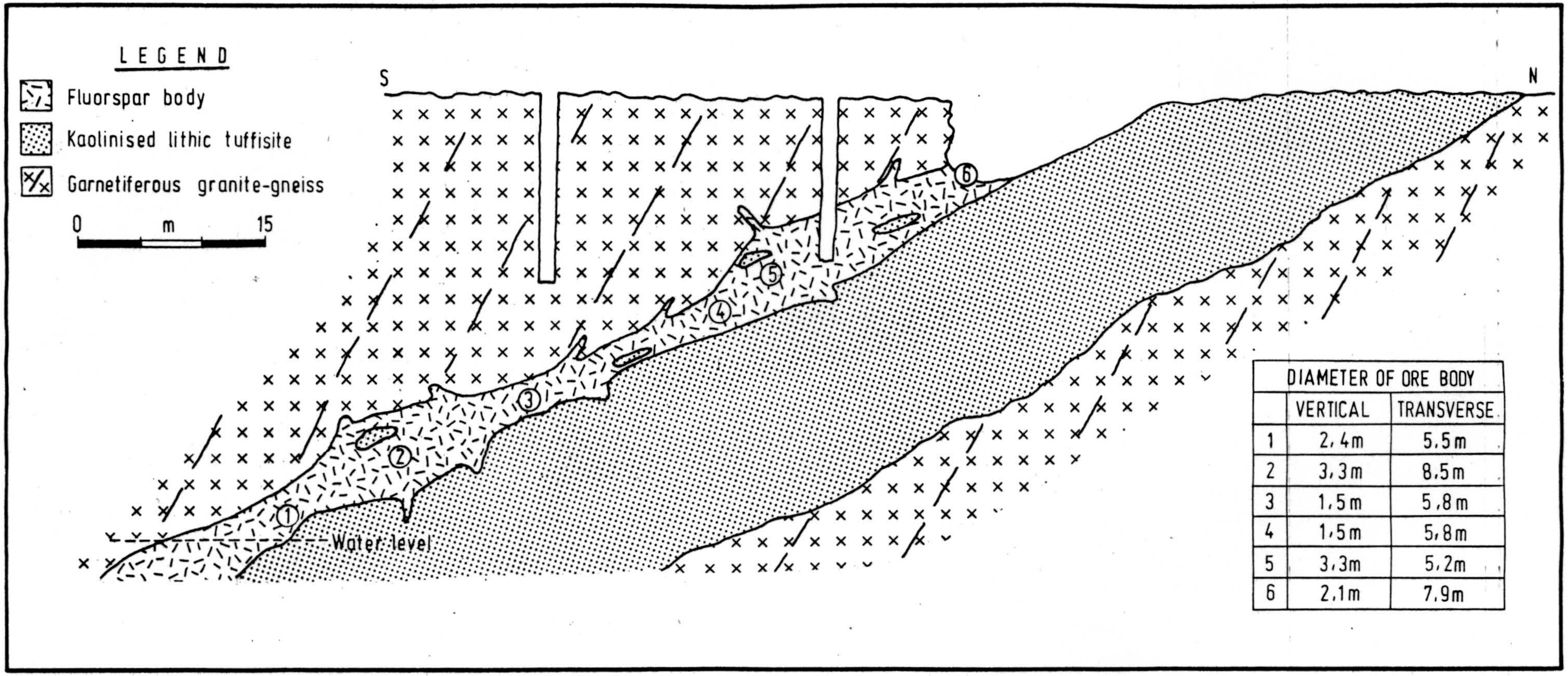
5 ECONOMIC GEOLOGY

5.1. THE GARUB MINE

The only mineralisation that has thus far been of economic value is at pipe 5 on Garub 266 (Fig. 11). The small abandoned mine has had a varied history. The outcrop is reported to have consisted of a copper-stained gossan which was discovered around 1913 (Schwellnus,1942). Exploitation only commenced in 1922, when it was worked as a lead mine. This first attempt was not very successful and the mine lay unworked until 1928, when a certain Mr. Maxim recommenced operations, this time for lead and fluorspar. Maxim found the lead pockets to be few and far between; in fact, it is stated that consignments at the coast were dumped into the sea at Luderitz and Cape Town (De Kock,1942).

In 1932 the mine was reopened for fluorspar by T.G. Gericke. Operations were suspended, however, on account of the high transport costs which left too small a profit margin on the then selling price of £2-15-0 f.o.b. Cape Town. Up to 1939 the deposit was worked by Fluorite & Minerals, but has lain unproductive since that time (Schwellnus, 1942).

The inclined pipe of kaolinised lithic tuffisite was emplaced in fairly fresh and unsheared granite-gneiss and associated metamorphic rocks, as described under "GEOLOGICAL SETTING". The pipe is elongated in outline and exhibits constrictions and swellings along its length. The ore body varies in diameter from almost 2 to 8 m and is situated along the upper contact of the pipe (Fig.14). Tuffisite is sporadically included in the ore body. Fragments of country rock in the tuffisite are often well-rounded. The granite-gneiss locally shows signs of disturbance that could be the result of the intrusive force of the tuffisite. The mineralising fluids may have been



DIAMETER OF ORE BODY		
	VERTICAL	TRANSVERSE
1	2,4m	5,5m
2	3,3m	8,5m
3	1,5m	5,8m
4	1,5m	5,8m
5	3,3m	5,2m
6	2,1m	7,9m

FIG. 14 — Diagrammatic section through pipe 5, showing the Garub fluorspar body and its relationship to the kaolinised lithic tuffisite (Modified after Schwellnus, 1942).

responsible for the kaolinisation because this effect was not observed at any of the other occurrences.

Mining has been carried out down to water level at a depth of 49 m (160 ft.) along the inclined shaft. All ore has been recovered to this depth, except for a few pockets in the sides of the stope where the body was lenticular in shape. It is not known to what depth the ore body continues.

Because the ore body was surrounded by veinlets and tongues of fluorspar in the wall-rock, a few smaller prospecting pits have been dug in the vicinity — apparently without favourable results.

Fluorspar of a very high grade was the predominant mineral in the deposit. It was generally compact and massive, and of at least 99,8 per cent purity (Schwellnus, 1942). Total production during the period 1924 to 1939 amounted to approximately 1800 tons. According to de Kock (1942) zones of purple, green and white fluorite alternated from the margins of the ore body towards the centre. In addition to fluorspar, a little galena is still present in the upper portion of the mine, but absent near water level (De Kock, 1942). Associated subordinate minerals are barite, calcite, chalcopyrite, bornite, chalcocite, covellite, cerussite, malachite, azurite and chrysocolla. On some euhedral crystals of quartz there is a yellowish-green brittle coating, identified by Verwoerd (1957), as the copper-vanadium mineral mottramite.

Several specimens were collected from the mine dumps for microscopic investigation. Unfortunately they could not be related to the depth of occurrence. Galena was the first opaque mineral to crystallise and appears massive but is occasionally severely cracked. Covellite, showing diagnostic grey to blue bireflection and extreme grey to flame-red anisotropism, displays a colloform banded texture around the galena. Rhythmic bands of covellite alternate with chalcopyrite, chalcocite and gangue material (Plate 7C). Under high magnification, minute exsolution "pips" of bornite can be observed in the chalcocite. The banded textures imply the filling of interstices and not replacement. Large grains of chalcopyrite are generally severely cracked. These cracks are filled by chalcocite, apparently due to a process of supergene enrichment. In a few polished sections replacement of galena by needle-like grains of chalcocite and chalcopyrite along three crystallographic directions is conspicuous. The proposed crystallisation sequence is as follows: gangue material, galena, covellite, chalcopyrite, chalcocite, bornite.

The abundant colloform textures and the mineral assemblage imply that crystallisation temperature was moderate to low.

5.2 OTHER OCCURRENCES

Mineralisation is also associated with dyke 79 on Weltevrede 302. The dyke, 1-2 m wide, follows a zig-zag direction along strike of the foliation and consists of carbonate-rich breccia. The southern extremity of the dyke locally consists of coarse-grained, buff and dark-brown ferroan calcite and calcite associated with sulphide mineralisation. Small uneconomic amounts of galena, chalcopyrite, malachite and chrysocolla occur sporadically.

The southern part of vent 82 on Mickberg 262 shows insignificant amounts of malachite and chrysocolla.

It is not considered likely that mineralisation of economic importance will be found in association with these comparatively small breccia bodies, but the Garub deposit should at least be drilled to test its continuity in depth.

6 PETROCHEMISTRY

Eight representative samples of fresh Garub-type carbonate-bearing tuffisite, lamprophyric carbonate rock and associated fenitised rocks were analysed by x-ray fluorescence spectrometry in the Geochemistry Laboratory of the University of Stellenbosch. Three conventional analyses of similar rocks collected by Verwoerd in 1956 were obtained from the literature (Visser, 1964) and one analysis was kindly provided by Dr. A. Kröner of the University of Cape Town. The results are given in Table 3. Total iron is given as Fe_2O_3 in the Table, but recalculated to FeO on the diagrams (Figs. 15 - 18).

6.1 MAJOR ELEMENTS

The relatively low Si, Al and high Ca, Mg, Fe, Ti and CO_2 contents of the Garub suite are conspicuous (Table 3). This reflects their carbonate-rich and ultrabasic character. The high iron content is probably due to the large amount of ankerite and the abundance of magnetite and ilmenite, whilst the latter two minerals in the carbonate rocks are also responsible for the high values for titanium (cf. Table 2).

In an attempt to solve the problem of origin of the Garub-suite, interelement ratios of these rocks are first compared with those of similar rocks viz. South African olivine-melilitites, kimberlites, African alnöites and damkjernites (Figs. 15 - 19). Secondly, the possibility that they are chemically related to syenite, bostonite, camptonite, kersantite and spessartite of the Kuboos Igneous Complex is investigated by means of variation diagrams (Figs. 21, 22).

<u>Al_2O_3 / MgO / FeO (total iron).</u> There is a fairly close correspondence between the Al_2O_3, MgO and FeO con-

TABLE 3 - CHEMICAL COMPOSITION OF GARUB-TYPE CARBONATE-BEARING AND ASSOCIATED FENITISED ROCKS

Sample No.	CP1	CP2	CP3	CP4	CP5	CP6	1047	1048	1049	DG	CP7	CP8
SiO_2	25,75	26,06	27,86	33,77	27,93	25,31	27,00	24,36	23,95	29,43	56,66	67,15
Al_2O_3	5,84	4,87	5,68	6,33	6,60	5,91	5,78	5,45	5,98	7,56	14,24	14,41
Fe_2O_3	14,07	14,02	13,47	11,13	14,24	15,24	12,17	16,75	14,15	13,96	4,16	3,91
MgO	7,61	11,19	10,31	8,67	9,37	10,09	7,75	10,23	12,05	5,77	1,72	1,15
CaO	21,01	16,76	16,98	15,86	17,07	20,15	17,09	15,50	14,62	18,18	7,07	1,77
Na_2O	1,19	2,11	1,76	1,29	1,46	1,15	0,30	0,25	0,18	0,00	8,66	9,52
K_2O	0,12	1,26	1,09	1,87	1,29	0,37	3,28	2,48	0,58	0,24	0,46	0,24
TiO_2	3,80	4,75	4,12	2,58	4,20	4,19	3,10	4,00	3,53	4,61	0,65	0,55
P_2O_5	1,27	1,12	1,19	0,77	1,54	1,53	1,25	1,19	1,18	1,15	0,26	0,25
MnO	0,32	0,22	0,21	0,19	0,23	0,24	0,14	0,22	0,31	0,27	0,08	0,04
BaO	0,07	0,14	0,09	0,22	0,16	0,32	0,01	0,05	0,01		-	-
SrO	0,14	0,17	0,21	0,14	0,16	0,25	0,12	0,06	0,04		0,13	0,02
CO_2	14,62	15,86	13,46	15,07	11,81	10,10	20,46	18,22	21,69	12,14	-	-
H_2O^+							1,36	1,36	2,70	5,51		
H_2O^-	0,38	0,48	0,57	0,58	0,39	0,69	0,18	0,16	0,24	1,07	0,41	0,22
L.o.i.*	3,73	0,89	2,18	1,76	2,69	4,03					4,72	0,49
TOTAL	99,92	99,90	99,18	100,25	99,14	99,57	99,99	100,28	101,21	99,89	99,22	99,72
Trace elements, ppm												
Nb	158	202	188	126	197	248						
Zr	352	322	302	287	383	517						
Y	26	29	30	25	34	42						
Rb	4	35	41	85	37	10						

* Loss on ignition at 850°C; FeO recalculated to Fe_2O_3
Analyses 1047-1049 from Visser.(1964).
DG analysed in the Dept. of Geochemistry, University of Cape Town (Allsopp et al., in press).
CP1-CP8 analysed by C.P. Schreuder, at the University of Stellenbosch by XRF.

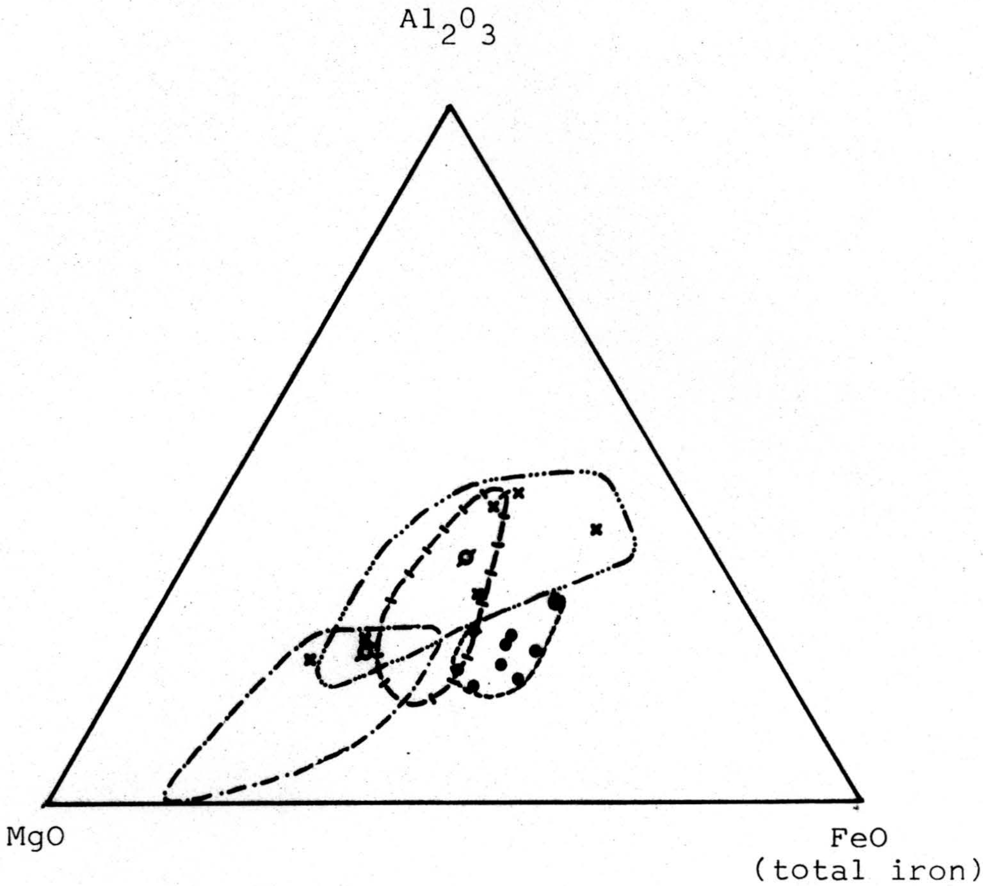
Sample localities

CP1 Tuffisite dyke 73, Nanzes 22
CP2 Lamprophyric carbonate dyke associated with pipe 5, Garub 266
CP3 Tuffisite dyke 52, Garub 266
CP4 Lamprophyric carbonate sill 65, Mooirivier (Ariams 27)
CP5 Lamprophyric carbonate sill 34, Garub 266
CP6 Tuffisite core of pipe 1, Stinkdorn 28

1047 Pyroclastic rock, carbonatised, pisolitic, Garub 266
1048 Pyroclastic rock, carbonatised, Garub 266
1049 Pyroclastic rock, carbonatised, Garub 266

DG Lamprophyric carbonate sill, Garub 266

CP7 Fenitised biotite-garnet gneiss associated with lamprophyric dyke 48, Garub 266
CP8 Fenitised inclusion of Kuibis grit in carbonatite plug 82, Mickberg 262



—·—·— South African kimberlites (Cornelissen and Verwoerd, 1975).

···—···— Bushmanland kimberlites (Cornelissen and Verwoerd, 1975).

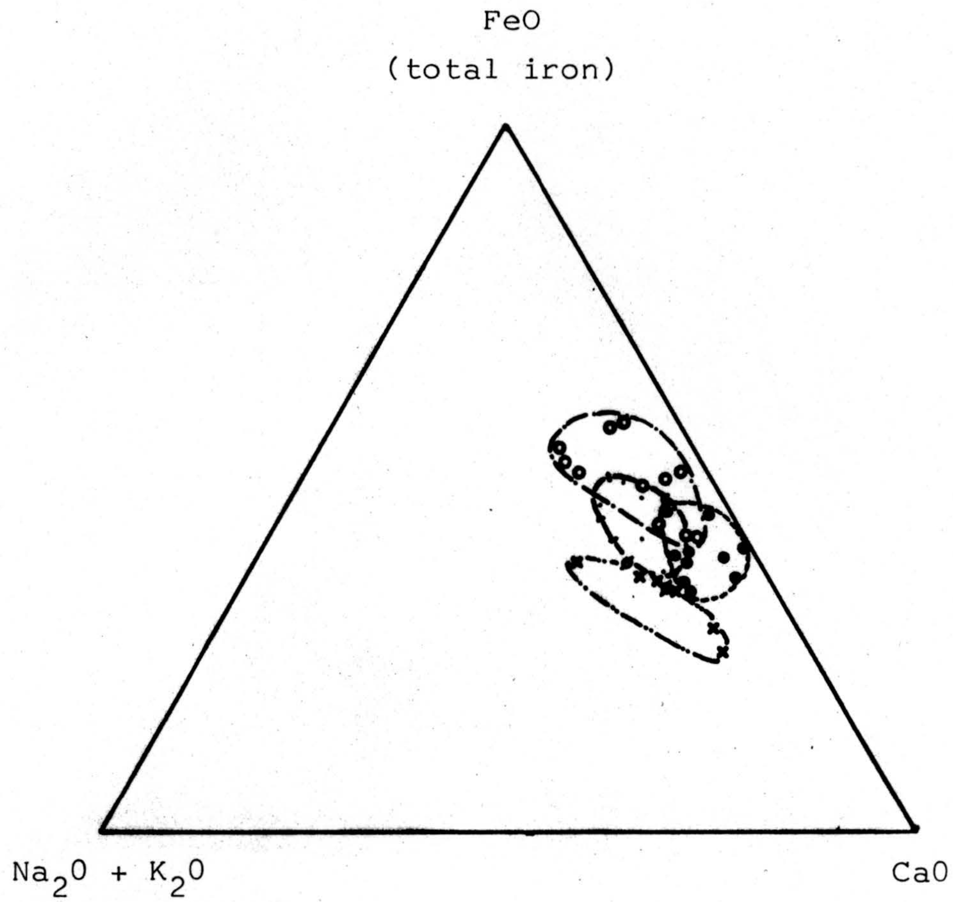
–ı–ı–ı South African olivine-melilitites (Cornelissen and Verwoerd, 1975).

ø Damkjernite (Brögger, 1921).

× African alnöite (Visser, 1964; Garson, 1962).

•------- Garub-type carbonate rocks.

FIG. 15 — Al_2O_3 - MgO - FeO diagram.



o-·—·—·— South African kimberlites (Frick, 1970).

·-ı—ı—ı— South African olivine-melilitites (Taljaard, 1937).

x—·—·—· African alnöites (Visser, 1964; Garson, 1962).

ø Damkjernite (Brögger, 1921).

•-------- Garub-type carbonate rocks.

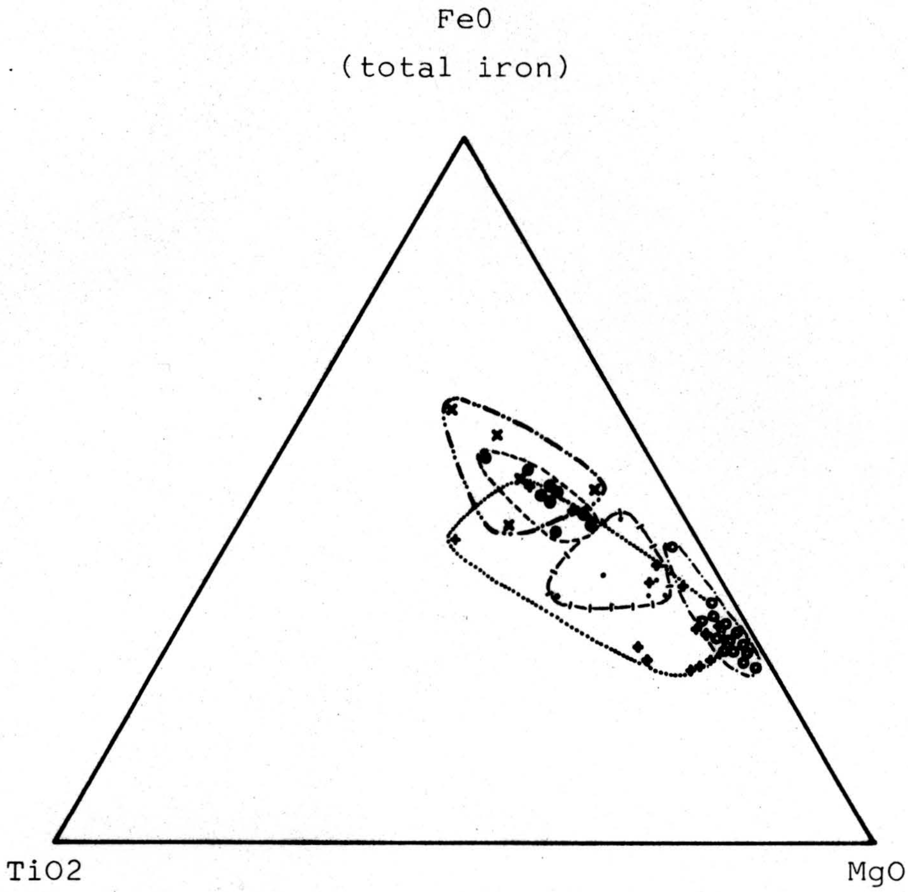
FIG. 16 — FeO - alkali - CaO diagram.

tents of the Garub carbonate-bearing eruptives, South African kimberlites, Bushmanland kimberlites, South African olivine-melilitites and some African alnoites (Fig. 15). The areas of olivine-melilitite and the Garub eruptives slightly overlap, although the MgO/FeO ratios of South African kimberlites and olivine-melilitites are in general larger than those of the Garub eruptives. The Garub rocks are decidedly more iron-rich than the others.

<u>FeO / Na_2O + K_2O / CaO</u>. Fig.16 again shows the similarity between the FeO / Na_2O + K_2O / CaO ratios of South African kimberlites, South African olivine-melilitites, African alnöites, damkjernites and the Garub-type eruptives. In general the latter appear to be intermediate between the alnöites and kimberlites. The Garub rocks are less alkalic than some of the olivine-melilitites, the alnöites and the damkjernites. The CaO / FeO ratio of the Garub eruptives is greater than that of South African kimberlites, a phenomenon that can possibly be related to their carbonate content.

<u>FeO / TiO_2 / MgO</u>. In Fig. 17 the Garub rocks coincide almost entirely with the African alnöite field and are clearly separated from the South African olivine-melilitites and South African kimberlites. The large area of the kimberlites from outside South Africa overlaps with most of the others but it is doubtful whether all so-called kimberlitic rocks from outside South Africa are in fact kimberlites (Verwoerd, 1970 p.54). The similar FeO / MgO ratios of the alnöites and Garub rocks proves that the position of the latter on this diagram is not a peculiarity due to their ankerite content.

<u>Alkali index /Mafic index</u>. In Fig. 18 a clear distinction can be seen between the Garub carbonate rocks and alnöites on the one hand and the kimberlites and olivine-



+ ········ Kimberlites from outside South Africa (Frick, 1970).

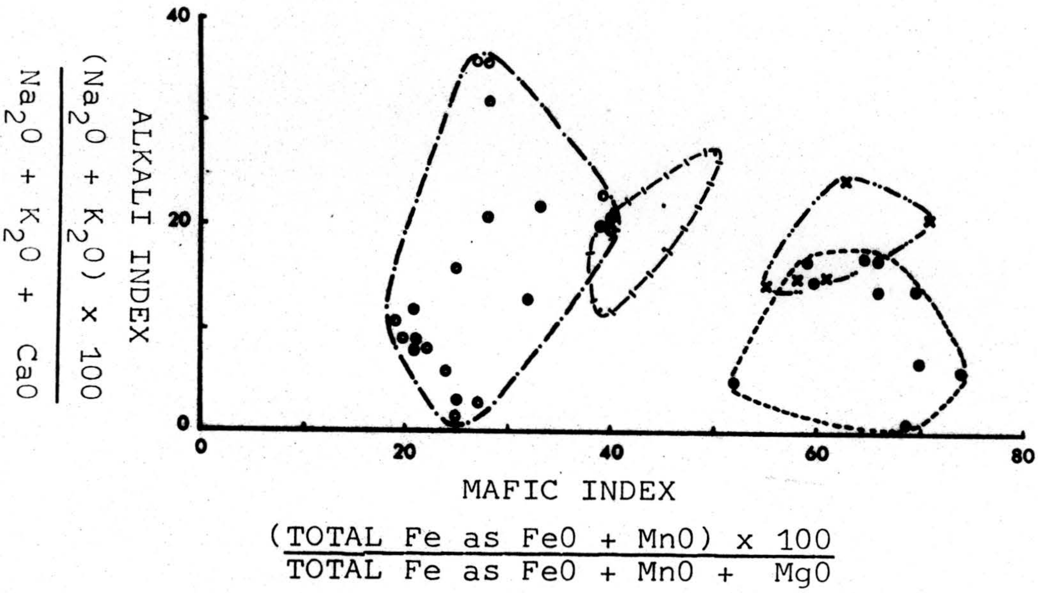
o— · — · — South African kimberlites (Frick, 1970).

·I—I—I—I South African olivine-melilitites (Taljaard, 1937).

×··—··— African alnöites (Visser, 1964; Garson, 1962).

●------ Garub-type carbonate rocks

FIG. 17 — FeO - TiO_2 - MgO diagram.



o-·-·-·- South African kimberlites (Frick, 1970).

·I—I—I—I—I South African olivine-melilitites (Taljaard, 1937).

x-·-·-·- African alnöites (Visser, 1964; Garson, 1962).

●-------- Garub-type carbonate rocks.

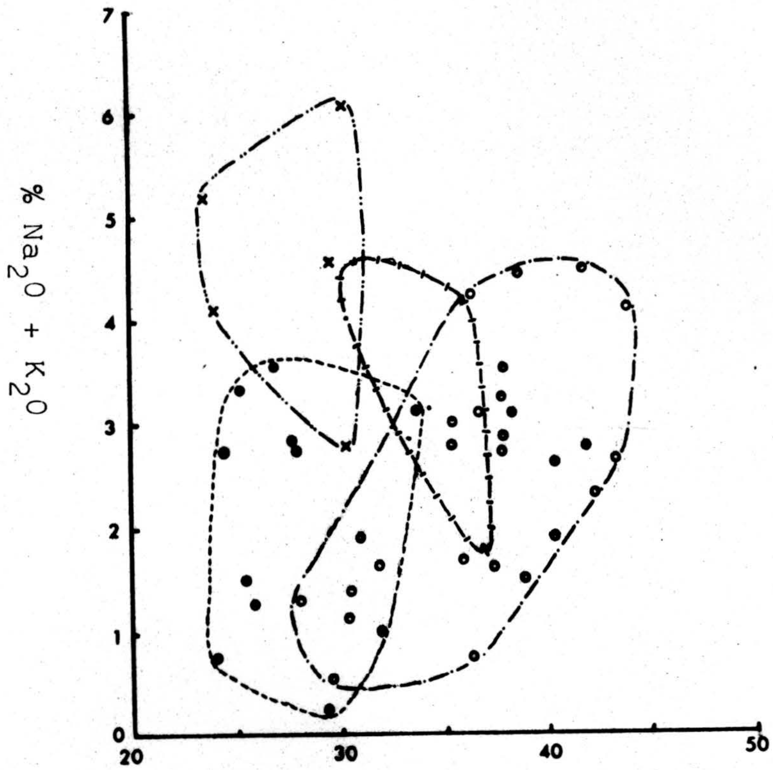
FIG. 18 — Diagram showing the relationship between the mafic and alkali indices in various ultrabasic rocks and the Garub carbonate rocks.

melilitites on the other hand. The Garub carbonate rocks are somewhat less alkalic than the majority of alnoites and olivine-melilitites, but have a much higher mafic index than kimberlites and olivine-melilitites. The indices of the Garub rocks correspond better with those of the alnöites than with any of the other rock types.

$Na_2O + K_2O$ / SiO_2. The $Na_2O + K_2O$ and SiO_2 contents of the Garub carbonate rocks, alnöites, olivine-melilitites and South African kimberlites are all rather low due to their ultrabasic character. The Garub rocks have a similar silica content but are lower in alkalis than the alnöites (Fig. 19).

Variation Diagrams. Fig. 20 shows reasonably clear differentiation trends when plotting the different element ratios of the Garub carbonate rocks and the syenite, spessartite, bostonite, camptonite and kersantite from the Kuboos Igneous Complex on one diagram. Very much the same trends were obtained by Nockolds and Allen (1953) and Ferguson (1973), on similar rock assemblages elsewhere (Fig.20). It would have been interesting to see if rocks of the Tatasberg, Bremen and Haruchas Complexes would plot on the same lines as the Kuboos and Garub rocks. Unfortunately no analyses of these complexes are available. Compared to the Kuboos rocks, the Garub carbonate rocks are enriched in Ca, Fe and Mg and are relatively impoverished in Na and K. This figure provides strong evidence that the Garub eruptives are not only structurally but also chemically related to the Kuboos Complex.

Fig. 21 shows the Si, Ca, Mg, Ti and Na + K values of the same Garub and Kuboos rocks plotted against the differentiation index $[(^1/_3 \text{ Si} + \text{K}) - (\text{Ca} + \text{Mg})]$ of Larsen (1938), as modified by Nockolds and Allen (1953). The serial relationship between the different rock types is again illustrated. It is clear that the Garub carbonate rocks are relatively impoverished in silica and the alkalis but



% SiO_2

o-·—·— South African kimberlites (Frick, 1970).

·-ı—ı—ı South African olivine-melilitites (Taljaard, 1937).

x—··—·· African alnöites (Visser, 1964; Garson, 1962).

•------- Garub-type carbonate rocks.

FIG. 19 — Alkali - silica diagram.

enriched in Ca, Fe, Mg and Ti compared to the Kuboos rocks. The regular change in interelement ratios shown in Figs.20 and 21 suggests that the Garub carbonate rocks and Kuboos silicate rocks may have been derived from a common parent magma, perhaps not very different in composition from the silicate phase of the Garub rocks.

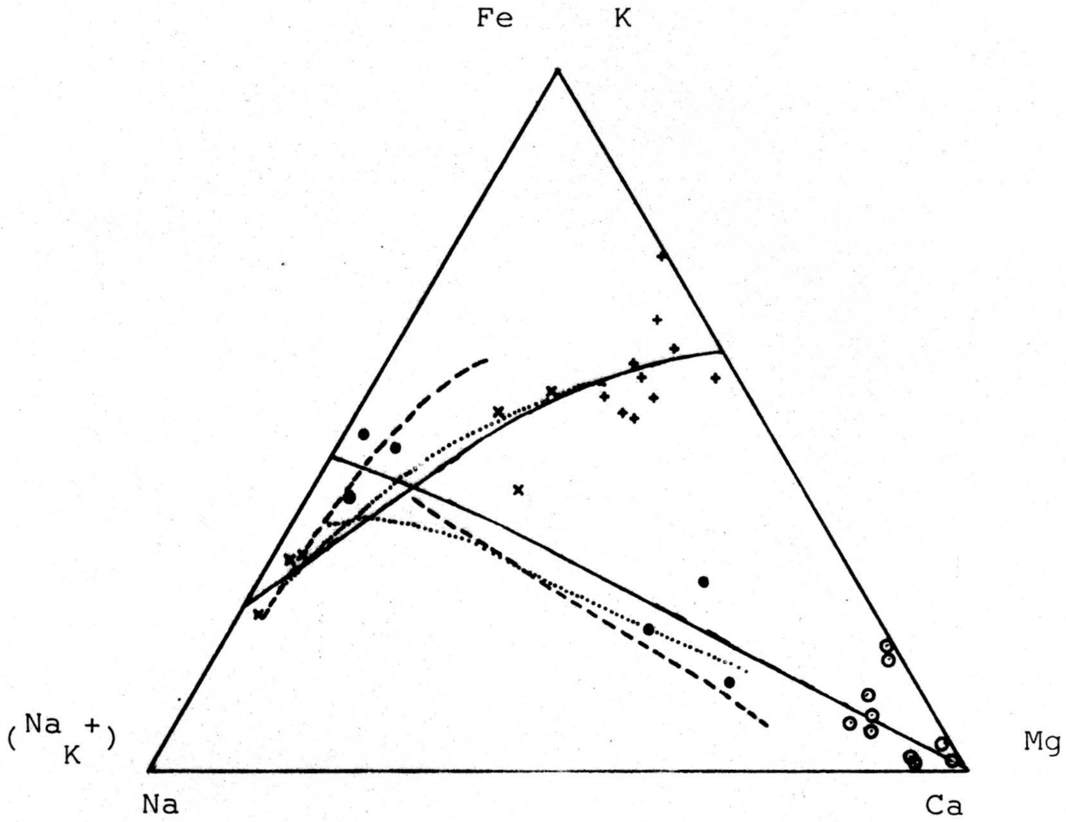
6.2 TRACE ELEMENTS

Some trace elements of the Garub suite as determined by XRF are shown in Table 3 and the calculated mean values are compared with those of other rock types in Table 4. In the Garub eruptives barium is considerably lower than most of the values given for carbonatite and olivine-melilitite, corresponds to the values for alnöite and syenite, but is higher than in kimberlite. The mean strontium values show large variations among the different rock types. The Garub rocks contain more strontium than kimberlite and syenite but much less than carbonatite. The relatively low values for Nb, Zr and Y of the Garub rocks correspond to those of kimberlite and (as far as known) of olivine-melilitite. The mean rubidium content of the Garub carbonate rocks is comparable to that of olivine-melilitite and distinctly less than in kimberlite and syenite. Unfortunately little or no data is available for alnöite.

The Garub suite is not particularly enriched in any of the rare elements determined and does not show obvious geochemical affinities with either carbonatite or kimberlite.

6.3 SUMMARY

From the major element chemistry it is clear that, apart from their high carbonate content, the Garub eruptives belong to the same family of rock types as kimberlite, olivine-melilitite, alnöite and damkjernite, and the resemblance between the Garub rocks and the alnöites is greatest.

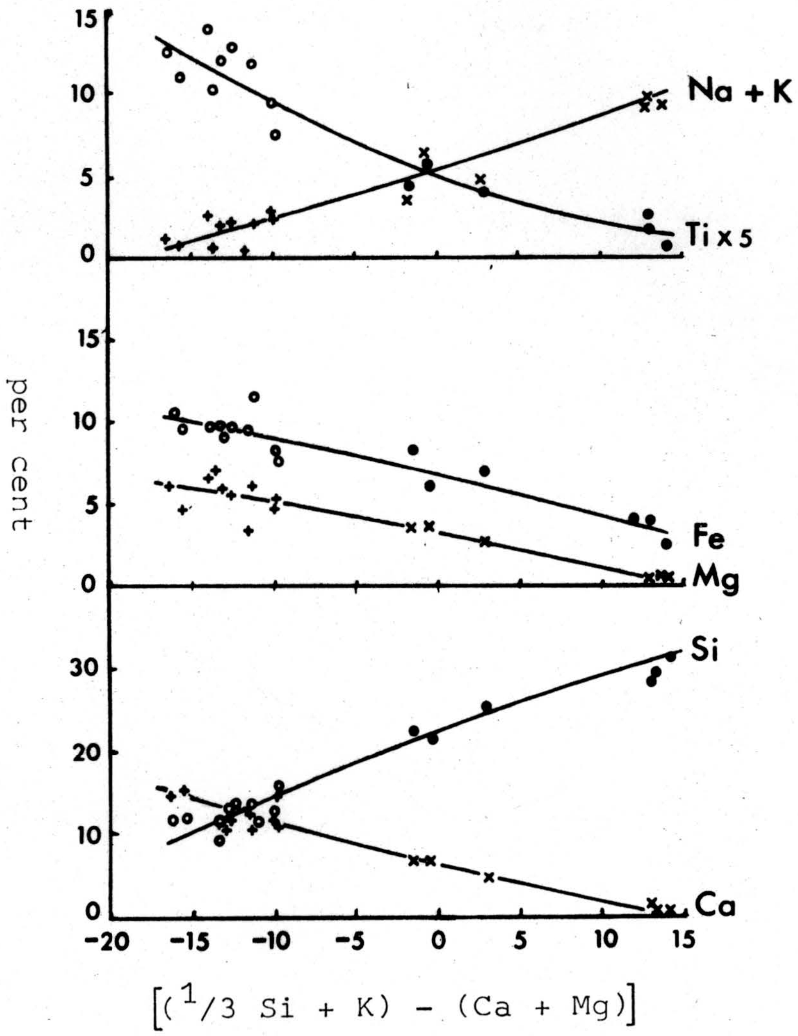


K, Na and Ca: ∘—— Garub rocks, •—— Kuboos rocks
Fe, (Na + K) and Mg: +—— Garub rocks, ×——Kuboos rocks.

.... Polynesian alkali basalt - phonolite series (Nockolds and Allen, 1953).

------- Pilanesberg magmatic province (Ferguson, 1973).

FIG. 20 —— Variation diagram of Kuboos alkali and basic rocks (Van Biljon, 1939) and Garub-type carbonate rocks, compared with Polynesian and Pilanesberg alkaline provinces.



o,+ Garub rocks ●,x Kuboos rocks

FIG. 21 — Variation diagram showing Kuboos and Garub rocks plotted against differentiation index.

The regular change in interelement ratios between the Garub rocks and various syenites and lamprophyres of the Kuboos Complex, which belongs to the same age group, points towards a possible genetic relationship.

TABLE 4 — MEAN TRACE ELEMENT CONTENT OF THE GARUB CARBONATE-BEARING ERUPTIVES AND OTHER ROCK TYPES.

Rock type	Trace element					
	Ba	Sr	Nb	Zr	Y	Rb
Garub carbonate rock	1666	1783	186	360	31	35
Carbonatite	1875[g]	4735[g]	1690[e]	83[e]	95[h]	
	4030[f]	7525[f]			38[h]	
	2330[e]	3380[e]			49[h]	
	3799[h]				35[h]	
Kimberlite	847[h]	467[d]	239[d]	446[d]	44[d]	171[h]
	741[d]					
Alnöite	1890[h]					
Olivine-melilitite	6100[h]				40[h]	18[h]
					20[h]	
Syenite	2753[h]	700[b]	35[c]	500[c]	20[c]	136[h]
	1600[a]	600[a]				100[c]
		200[h]				

a Rankama and Sahama, 1950
b Goldschmidt, 1954
c Turekian and Wedepohl, 1961
d Dawson, 1962
e Gold, 1963
f Gold, 1964
g Verwoerd, 1967
h Wedepohl, 1972

7 ORIGIN AND MODE OF EMPLACEMENT

7.1 MODE OF EMPLACEMENT

The first process that will be considered is fluidisation, which implies the mixing of gas and loose, fine-grained solid material, so that the whole flows like a liquid (A.G.I. Glossary, 1972).

Reynolds (1954), listed three features characteristic of gas-emplaced bodies:

1. Intense brecciation, with the admixture of blocks in the central zone and non-dilational or replacement veins in the margins of the bodies.
2. Abrasion and rounding of particles.
3. A deep penetration into cracks and fissures or pre-existing spaces.

All these features are commonly encountered on Garub 266 and in the vicinity. On Tafelkop (Haochanas 24), thin veinlets of tuffisitic carbonate rock of non-dilational type have penetrated the Schwarzrand sandstone to about 5 m from the main body (Fig. 22). The emplacement of these veinlets seems to have occurred by chemical or permissive mechanical replacement and not by forcing open of pre-existing fissures and crevices.

Coe (1966) enumerated several other characteristics of fluidised bodies, most of which are applicable to the Garub suite:

1. Many of the bodies are pipes and dykes showing vertical or very steep contacts.
2. Inclusions of country rock occur above as well as below their true stratigraphic horizon.
3. The inclusions show signs of attrition, and the matrix itself also contains comminuted material.

4. Matrices and inclusions are carbonated.

5. High mobility is shown by deep penetration of thin veins into the wall-rock. At dyke 75 carbonate veins are found up to 25 m from the dyke.

6. Pyrometamorphic effects are negligible, but hydrothermal alteration is common. Leached zones of gneiss in contact with the Garub carbonate bodies and alteration rims in inclusions are considered to be due to hydrothermal alteration, and not the result of contact or pyrometamorphism. Absence of talc, tremolite and diopside from the siliceous dolomitic limestone bands of the Schwarzrand Formation, which are often in direct contact with Garub carbonate-bearing sills, excludes high temperature at the time of intrusion.

The existence of accretionary lapilli or pisolites in parts of numerous Garub-type pipes, dykes and even sills, provide additional evidence for gas-solid streaming (Farmin, 1934). Furthermore, thin slabs or "screens" of wall-rock in carbonate dykes (Plate 3A), could only be preserved during a relatively passive process of emplacement similar to fluidisation. These would not have survived forceful magmatic intrusion (Dawson, 1962).

The Garub eruptives may be compared with several occurrences in other parts of the world. They are in some respects similar to the shallow intrusions of carbonatite in the Rufunsa province, Zambia (**Bailey,** 1966). The composite sill-like Kaluwe intrusion consists of fragmental sövite and agglomerate containing carbonatite and quartz fragments, martite, apatite, vermiculite and pyrochlore. The bodies are believed to have been emplaced in a fluidised condition as a liquid-solid or dense gas-solid system rich in CO_2. However, emplacement was controlled near the surface by a synclinal structure pitching towards a major fault which served as conduit. No similar structural control is associated with the Garub eruptives.

The Swabian tuffisite pipes are composed of blocks and tuff derived from the wall-rock. Evidence suggests that gas, charged with melilite basalt lapilli surged upwards through fractures. Fragments derived from the wall-rock rendered great erosive power to the gas streams which effected a widening of fractures. Massive blocks of wall-rock became detached and were engulfed in the gas-tuff stream and, as in the case of the Garub bodies, often came to rest at a lower level than their true stratigraphic horizon (Cloos, H., 1941).

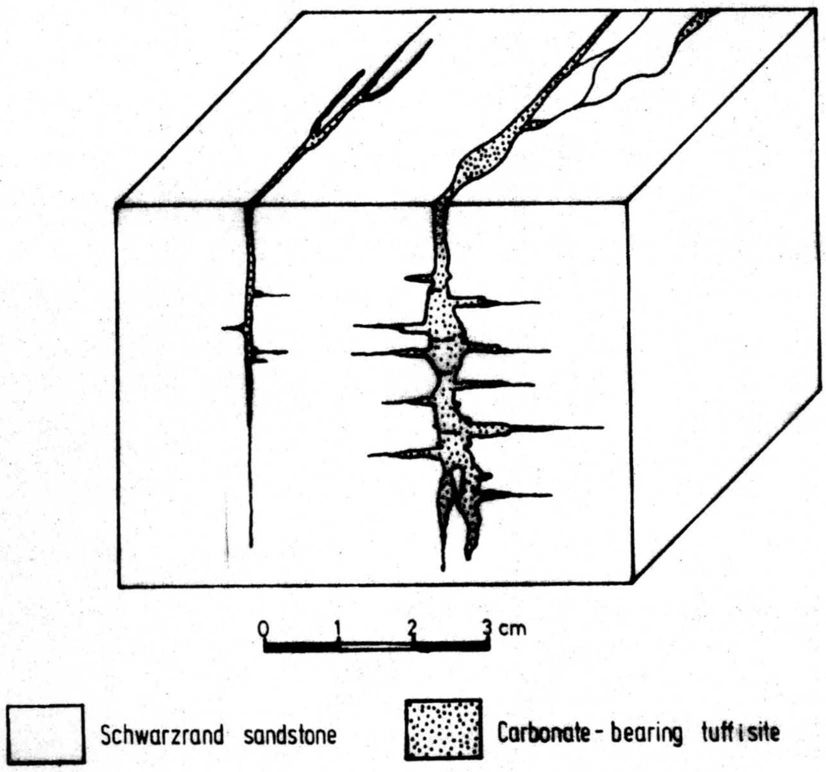


FIG. 22 — Block diagram showing non-dilational veinlets of carbonate-bearing tuffisite in Schwarzrand sandstone. Pipe 68 on Tafelkop (Haochanas 24).

Intrusive pipes and dykes of West Cork, Ireland, similar to the Garub bodies display sharp contacts with the country rock. Mechanical abrasion of inclusions in the tuff pipes and dykes is conspicuous. The bodies are believed to have originated by a process of fluidisation. Because of their high carbonate content, they have been compared with carbonatites that are believed to be high level developments of kimberlite (Coe, 1966).

Breccias of Sudbury, Ontario, are composed of rounded and subrounded wall-rock fragments embedded in a comminuted but recrystallised matrix, also partly derived from the wall-rock. As in the case of some of the Garub-type bodies, small fractures filled by comminuted material provide evidence for high mobility. The bodies were emplaced by the process of fluidisation, and chemical reaction between fragments and fluidising gases is indicated by an increase in soda in the fragments (Fairbairn and Robson, 1942).

Other intrusions that are believed to have originated by gas streaming are the pseudotachylyte veins in the Vredefort area (Shand, 1916; Bisschoff, 1962), the plug-like masses of granophyre in Slieve Gullion, Northern Ireland (Reynolds, 1951 b), kimberlite dykes in Lesotho (Dawson, 1962), plugs and dykes of ignimbrite in the Hot Creak Range, Nevada (Cook, 1968), and the Bull Domingo Breccia body in Colorado (Peters, 1953).

Although they exhibit numerous features which may be ascribed to fluidisation, the Garub carbonate rocks do show some characteristics typical of other carbonatitic rocks. <u>Metacarbonatite</u>, as used by Verwoerd (1967), refers to an originally igneous rock that shows secondary carbonatisation. Such rock types occur at Goudini Kop in the Transvaal, and are characterised by carbonatised pseudomorphs after pyroxene, biotite and other rock forming minerals. Pisolitic structures also occur. Due to the highly altered state of the metacarbonatites, it is difficult to determine their original nature (Verwoerd, 1967). The term metacarbonatite could also be applied to some of the Garub-type carbonate rocks. The latter contain minerals that have been affected by secondary carbonatisation in the conduits, but the presence of primary carbonates in the groundmass shows that carbonate minerals are essential and original constituents of the rocks themselves.

Features typical of magmatic carbonatite, such as a holocrystalline non-fragmental igneous texture and fenitisation of the country rock are not characteristics of the Garub suite. The groundmass is often tuffaceous and fenitisation was only encountered at a few localities. The Garub carbonate rocks also contain interstitial quartz and feldspar and laths of what may have been melilite, none of which are typical carbonatite minerals. The Garub carbonate rocks may have carbonatitic affinities, but are certainly not carbonatite sensu stricto.

Certain modes of emplacement that have been proposed can be ruled out with a reasonable degree of confidence. According to Verwoerd (1967, p.247) "some features of the Garub rocks suggest that they may be ancient peperites". The latter are formed in lacustrine or marine environments as a result of extrusion into shallow water or intrusion into wet, unconsolidated sediments (Wentworth and Williams, 1932; Carozzi, 1960). The presence of large and small, often glassy nodules of quenched lava in a calcareous and argillaceous matrix is typical. Glassy granules, often containing calcite-filled cavities, also occur. Volcanic bombs, 7 to 10 cm in diameter and consisting of a core of sedimentary or igneous rock surrounded by vitreous, non-scoriaceous lava, are usually found in the central portions of peperite bodies. Around the center of emission, peripheral peperites occur which are usually devoid of glassy nodules and volcanic bombs. In these, glassy volcanic granules set in an interstitial matrix of finely granular calcite and clay minerals can make up as much as 45 per cent of the total volume. None of these features is present in the Garub carbonate bodies and not even devitrified structures were found in their matrices. A mode of emplacement similar to that of peperites therefore seems unlikely.

From the above it should be clear that a mechanism of emplacement by fluidisation is strongly favoured in the case of the Garub suite. The following sequence of events is envisaged. During ascent of the carbonate-bearing magma that eventually gave rise to the eruptives, a gas phase would have been released when total pressure fell below the vapour-pressure curve of the melt (Fyfe, 1970, p. 208), and also during rapid crystallization when nearing the surface (Coe, 1966). The gas, charged with lapilli and fragments of various sizes, penetrated fractures and cracks. Detached fragments and larger inclusions from the wall-rock enhanced the erosive power of the gas-solid mixture. Only a large difference in pressure will have enabled movement of this mixture to occur, and it must have been able to escape to the surface (Cloos, 1941). Turbulence in the conduits resulted in the rounding and sorting of blocks and fragments and the formation of accretionary pisolites. Energy conditions would have been higher in the central parts of conduits. The Garub-type vents which contain breccia could possibly be the result of relatively forceful explosion, whereas some of the conduits containing more homogeneous tuffisitic material could have originated by less violent "drilling" of a fluidised system, fluidisation not forming part of the explosion process (Reynolds, discussion in Coe, 1966).

Considering the large amounts of carbonate and hydrous minerals present in the Garub rocks, the partial pressure of CO_2 and H_2O must have been high. The temperature during emplacement must have been low, because no metamorphic effect could be observed in the wall-rocks.

It is tempting to consider the tuffisite sills as older than the breccia bodies because brecciation phenomena associated with the sills are minimal. These sills could possibly have been emplaced at a stage when pressure was not high enough to effect penetration of the cover rocks, and intrusion into bedding planes and unconformities took place. Subsequent pressure build-up then led to explosive rupture of the roof, brecciation of wall-rock and inclusion of fragments of the latter in the rising igneous material. In some breccia pipes and dykes (1, 18, 23), the central homogeneous portions which are devoid of inclusions, are thought to represent the final central channel of the conduit up which the gas-streaming continued, even after material had started to descend in the outer parts of the same vent (Coe, 1966).

Although some pipes and dykes of the Garub type are possibly extrusive, fluidisation still played a major rôle. In contrast with this mode of emplacement, small carbonatitic volcanoes in Tanzania (Dawson, 1964) and diatremes in the Hopi and Navajo reservations in Arizona(Shoemaker et al., 1962), originated by violent explosion followed by accumulation of ash and sedimentary infilling of craters.

7.2 MAGMATIC AFFINITIES

According to the mineralogical and geochemical data presented above, the volcanic and intrusive rocks of the Garub suite are not carbonatised basaltic rocks but rather show ultrabasic affinities. A genetic connection between carbonatite, kimberlite, olivine-melilitite and other alkaline-ultrabasic rocks is widely accepted, although the exact relationships between these rock types are still obscure. Possible relationships with each of these will now be discussed.

CARBONATITE: Geologically and geochemically the Garub carbonate-bearing eruptives cannot be classified as typical carbonatite. The presence of partly carbonatised mafic minerals and lath-shaped pseudomorphs also points to a different magmatic association. However, the high CO_2 content of the rocks is undoubtedly of primary magmatic origin and this points towards a possible relationship with carbonatite.

The plug on Mickberg 262 consists of beforsitic carbonatite and probably belongs to the same age group as the Garub suite. No lath-shaped pseudomorphs were found in the groundmass, while ankerite, biotite, apatite and magnetite occur as primary constituents. These are typical carbonatite "indicator" minerals according to Verwoerd (1967). Soda-fenitisation, a feature commonly associated with carbonatite, is also fairly extensive at the Mickberg body.

OLIVINE-MELILITITE (Melilite basalt): Apart from their carbonate content, the Garub rocks are reasonably close to South African olivine-melilitites in composition. The former could perhaps be interpreted as olivine-melilitites which were altered by Ca and Fe-rich fluids. However, the evidence for the former presence of olivine is meagre and perovskite, a characteristic accessory of olivine-melilitite appears to be absent. Verwoerd (1957) interpreted certain ferruginous aggregates in lamprophyric carbonate sill No. 52 as possible altered and resorbed phenocrysts of olivine. The silica set free in such an alteration process could well be the interstitial quartz and chalcedony which occur in the groundmass. Olivine-melilitites are nowhere known to be associated with a tuffisite facies and are regular magmatic rocks in contradistinction to the Garub suite.

KIMBERLITE: The Garub carbonate-bearing rocks do not resemble kimberlite in thin sections or in hand specimens. Mineralogically they are devoid of olivine, although possible pseudomorphs are found as described above. Of the typical kimberlite "indicator minerals", (chrome-diopside, pyrope-garnet and magnesium-rich ilmenite), only ilmenite is present but its Mg and Cr contents are not known. The almandine-pyrope garnet observed at one locality, was probably derived from the garnet gneiss wall-rock. Verwoerd (1970, p. 51) describes kimberlite as "an ultrabasic but problematic rock type, recognised more often than not by the presence of characteristic xenoliths (garnet peridotite, pyroxenite and eclogite)". None of these deep-seated inclusions was observed in the Garub eruptives. In addition, amphibole is a common constituent of the Garub rocks, but is not typical of kimberlite.

Geochemically the kimberlites are more magnesium-rich than the Garub carbonate-bearing rocks. However, indications are that low magnesia kimberlites do occur, in which case they appear to be devoid of ilmenite or chrome diopside (Cornelissen and Verwoerd, 1975). The kimberlite matrix contains more K_2O than Na_2O as a result of its biotite content. This also applies to some of the samples of Garub carbonate rocks that have been analysed.

The Garub suite is geochemically and mineralogically different from kimberlite, sensu stricto, though they may have affinities with so-called "central complex" kimberlites.

ALNOITE AND DAMKJERNITE: Alnöite and damkjernite are lamprophyres allied to olivine-melilitite and kimberlite but with important mineralogical differences. Alnöite consists of biotite, diopsidic augite, olivine, melilite, barkevikitic amphibole, magnetite, apatite and carbonate (Von Eckermann, 1948c; Garson, 1962). Nepheline and garnet are often present but are not essential. Damkjernite from the type locality at Fen in Norway is closely related to alnöite and differs only in containing no melilite (Saether, 1958). Mineralogically and geochemically the Garub carbonate-bearing rocks correspond quite well to alnöite, although they are not identical. They contain phenocrysts of biotite, augite, kaersutitic amphibole, magnetite and apatite in a groundmass of carbonate and, at two localities, garnet. Pseudomorphs that could possibly be altered melilite and olivine occur, but nepheline was not observed.

A structure found in some alnöites of the Monteregian Province in Quebec (Philpotts, 1974), consists of spherical bodies of alnöite in a groundmass of carbonate and it was speculated whether these structures could be the result of immiscibility between a carbonate magma and an alkali-rich silicate magma (op cit., p. 297). Apart from the accretionary pisolites so common in the Garub carbonate-bearing rocks, the latter also contain spherical structures filled by radiating feldspar that could be the result of immiscibility between a carbonate and a silicate facies.

Geochemically the Garub carbonate-bearing rocks are closer to alnöite than damkjernite. The FeO/MgO and FeO/CaO ratios are much the same for alnöite and the Garub rocks, and the CO_2 and TiO_2 content is relatively high in both cases. The alkali content is slightly higher in alnöite.

Alnöite and damkjernite are typical associates of carbonatite-bearing alkaline provinces. These are briefly reviewed below for purposes of comparison with the Kuboos-Bremen-Garub igneous province.

In the Maimecha-Kotui region in northern Siberia carbonatites and alnöites are associated with other alkaline ultrabasic rocks and alkaline basaltoids (without feldspar). These rock types are considered to be genetically related and emplacement was tectonically controlled by zones of deep-seated faults (Egorov, 1970). In the north-eastern United States so-called kimberlite dykes grade into alnöite along their length (Martens, 1924) and similar relationships have been described by Von Eckermann at Alnö island, Sweden, where minor intrusions of alnöite are associated with carbonatite, carbonatitic kimberlite and melilite basalt around a central sövite plug. Fenitisation of the country rock is widespread. These rock types are genetically related and it is postulated that metasomatic interchange of material between the gneissic wall-rock and a dolomitic magma rich in fluorine and potash gave rise to the different rock types (Von Eckermann, 1963a).

The ring complex at Fen in Norway, consists of a variety of peralkaline rocks, viz. carbonatite, transitional rocks, fenite, kimberlite and damkjernite. Of special interest are the numerous satellitic vents, dykes and diatremes composed of granitic and damkjernitic breccia around the central complex. It is possible that the different rock types are of magmatic origin but that metasomatism, immiscibility and fluidisation contributed to the petrological diversity (Barth and Ramberg, 1966).

In Africa a period of kimberlite magmatism appears to have followed the final break-up of Gondwanaland during Cretaceous time. South African and Lesothan kimberlites are relatively minor bodies and emplacement was probably controlled by deep-seated fractures. Rounded bodies produced by fluidisation are common inclusions in many kimberlites, and most of the pipes have a brecciated structure with incorporation of foreign fragments. They are not related to any other alkaline or ultrabasic rocks, either in time or place (Verwoerd, 1970), although a genetic relationship between kimberlite and carbonatite has been suggested by several authors (Seather, 1958; Garson, 1962; Wyllie, 1967; Dawson, 1971).

A cluster of relatively small diatremes of glassy limburgite tuff, breccia, agglomerate and kimberlite occur in the Hopi and Navajo Indian reservations in Arizona.

The kimberlite diatremes are considered to represent the initial stages of intrusion and show features which are attributed to rapid unmixing of gas from magma during ascent through the crust along many separate fissures. Explosive activity was followed by collapse of the wall-rock, sedimentary infilling of the craters and eventually by upwelling of lava (Shoemaker et al., 1962)

Minor plugs, dykes and sills of monchiquite, camptonite and alnöite in the Monteregian Province, Quebec, are associated with carbonatite and alkaline rocks (Philpotts, 1974). Similar associations occur at the Magnet Cove Complex, Arkansas (Erickson and Blade, 1963), the Kaiserstuhl area in Germany, (Wimmenauer, 1966), the Gardar Province, Greenland (Upton, 1974), the Chilwa Province in southern Malawi (Garson, 1966), the Jacupiranga Alkaline Complex in Brazil (Melcher, 1966) and the Shawa and Dorowa Complexes in Rhodesia (Johnson, 1966).

7.3 POSSIBLE ALKALINE ASSOCIATES OF THE GARUB CARBONATE-BEARING ROCKS

On Garub 266 and in the near vicinity there are no outcrops of alkaline igneous rocks but their existence in depth is not excluded. It seems to be a general rule that large plutons do not crop out in the vicinity of fluidised intrusions, but in many cases their presence in depth has been postulated(Coe, 1959). The Garub carbonate-bearing rocks and the Kuboos-Tatasberg-Bremen-Haruchas series of alkaline rocks, are roughly coincident in time, are situated along a common lineament and show serial chemical relationships as illustrated by the trends in Figs. 20-21. This provides strong evidence for a genetic relationship. The granites, syenites and nepheline syenites could either be the result of magmatic differentiation or of the silication of a Mg-rich carbonatitic liquid. At Alnö the nepheline syenite surrounding the central sövite is not interpreted as the differentiate of a primary sub-alkaline or alkaline magma, but as the product of the silication of a very basic carbonatitic magmatic liquid rich in volatiles (Von Eckermann, 1948c), and this appears to be the kind of rock exposed at Garub. During the ascent of such a parental magma, some changes could be expected, viz. one or all of the following: crystal fractionation, exsolution, contamination, assimilation and ionic diffusion. With much volatile activity in a melt it is unnecessary to invoke special crystal fractionation mechanisms or partial melting to relate nephelinite to melilitite (Bailey, 1974).

7.4 CONCLUSION

The minor carbonate-bearing bodies on Garub 266 and vicinity are not unique, but probable equivalents are found in many places over the world in association with alkaline complexes. The Garub bodies are especially similar to the minor intrusions of alnöite at Alnö island, Sweden and the damkjernites of Fen, Norway. Contrary to these localities, however, the Garub bodies are not associated with exposed central plutons of alkaline rocks.

Emplacement probably occurred as a result of gas-streaming which caused fragmentation and incorporation of wall-rock in the gas-tuff stream. Sill-like bodies intruded as carbonate-rich tuffisite under relatively passive conditions. The breccias could have formed as a result of explosion near surface when confining pressures became too high.

Petrologically and mineralogically the Garub-type rocks belong to the same alkaline-ultrabasic rock series as kimberlite, olivine-melilitite and alnöite but show the closest correspondence to the latter. They are relatively enriched in CO_2 but no particular enrichment of trace elements could be demonstrated. It is tentatively suggested that the composition of the Garub eruptives approaches that of the parent magma from which the alkaline rocks of the Kuboos lineament were derived.

ACKNOWLEDGEMENTS

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REFERENCES

ALLSOPP, H.L., KÖSTLIN, E.O., WELKE, H., BURGER, A.J., KRÖNER, A. and BLIGNAULT, H.J., in press. Geochronological aspects of late Precambrian early Paleozoic igneous activity in the Richtersveld and southern South West Africa. Trans. geol. Soc. S. Afr.

AMERICAN GEOLOGICAL INSTITUTE, 1972. Glossary of geology: Kingsport Press, Kingsport, Tennessee.

BAILEY, D.K., 1966. Carbonatite volcanoes and shallow intrusions in Zambia, in Tuttle, O.F. and Gittins, J. (eds.), Carbonatites: Interscience Publishers, New York.

__________, 1974. Nephelinites and ijolites, in Sörensen, H. (ed.). The alkaline rocks: John Wiley & Sons, London.

BARTH, T.F.W. and RAMBERG, I.B., 1966. The Fen Circular Complex, in Tuttle, O.F. and Gittins, J. (Eds.), Carbonatites: Interscience Publishers, New York.

BEUKES, G.J., 1973. 'n Geologiese ondersoek van die gebied suid van Warmbad, Suidwes-Afrika, met spesiale verwysing na die metamorf-magmatiese assosiasies van die voor-Kambriese gesteentes: D.Sc. thesis, Univ. O.F.S., Bloemfontein. (Unpubl.).

BISSCHOFF, A.A., 1962. The pseudotachylite of the Vredefort Dome: Trans. geol. Soc. S. Afr., 65, 207 - 255.

BLIGNAULT, H.J. 1974. The tectonic zonation of part of the Namaqua Province in the lower Fish River/Narubis cross-section: Annu. Rep. P.R.U., Univ. Cape Town, 10-11, 43-45.

BRÖGGER, W.C., 1921. Die Eruptivgesteine des Kristianiagebietes. IV. Das Fengebiet in Telemark, Norwegen: Norsk. Vidensk. Selsk. Skr. 1, Math. Nat. Kl., 2(9).

CAROZZI, A.V., 1960. Microscopic sedimentary petrography: John Wiley & Sons, New York.

CLOOS, H., 1936. Einführung in die Geologie: Borntraeger, Berlin.

_______, 1941. Bau und Tätigkeit von Tuffschloten. Untersuchungen an dem Schwäbischen Vulkan: Geol. Rdsh., 32, 709 - 800.

COE, K., 1959. Intrusion breccia of Dunmore, Co. Donegal: Geol. Mag., 96, 172 - 173

——— , 1966. Intrusive tuffs of West Cork, Ireland: Quart. J. geol. Soc. Lond., 122, 1-28.

COOK, H.E., 1968. Ignimbrite flows, plugs and dykes in the southern part of the Hot Creek Range, Nye County, Nevada: Mem. geol. Soc. Amer., 116, 107-152.

CORNELISSEN, A.K. and VERWOERD, W.J., 1975. The Bushmanland kimberlites and related rocks: Phys. Chem. Earth, 9, 71-80.

DAWSON, J.B., 1962. Basutoland kimberlites: Bull. geol. Soc. Am., 73, 545-560.

——— , 1964. Carbonate tuff cones in northern Tanganyika: Geol. Mag., 101, 129-137.

——— , 1971. Advances in kimberlite geology: Earth Sci. Rev., 7, 187-214.

DE KOCK, W.P., 1942. The Garub fluorspar mine: Rep. geol. Surv. S. Afr. (Unpubl.).

DE SITTER, L.U., 1956. Structural geology (1st ed.): McGraw Hill, London.

DICKSON, J.A.D., 1965. A modified staining technique for carbonates in thin section: Nature, 205 (4971), 587.

EARDLEY, A.J., 1953. Structure and physiography of the southern Wasatch Mountains: Pap. Mich. Acad. Sci., 19, 377-400.

EGOROV, L.S., 1970. Carbonatites and ultrabasic-alkaline rocks of the Maimecha-Kotui region, N. Siberia: Lithos, 3, 341-359.

ERICKSON, R.L. and BLADE, L.V., 1963. Geochemistry and petrology of the alkalic igneous complex at Magnet Cove, Arkansas: U.S. Geol. Surv., Prof. Paper 425.

FAIRBAIRN, H.W. and ROBSON, G.M., 1942. Breccia at Sudbury, Ontario: J. Geol., 50, 1-33.

FARMIN, R., 1934. "Pebble dykes" at Tintic, Utah: Econ. Geol., 29(4).

FERGUSON, H., 1973. The Pilanesberg alkaline province, Southern Africa: Trans. geol. Soc. S.A., 76(3), 249-270.

FRICK, C., 1970. The mineralogy and petrology of kimberlite and its related inclusions, with special reference to Premier mine: D.Sc. thesis, Univ. Pretoria, (Unpubl.).

FYFE, W.S., 1970. Some thoughts on granitic magmas, in Newall, G. and Rast, N. (eds.), Mechanism of igneous intrusion: J. geol. Soc. Liverpool, Spec. Issue no. 2.

GARSON, M.S., 1962. The Tundula carbonatite ring-complex in southern Nyassaland: Mem. geol. Surv. Mal., 2.

————————, 1966. Carbonatites in Malawi, in Tuttle, O.F. and Gittins, J. (eds.), Carbonatites: John Wiley & Sons, New York.

———————— and SMITH, W.C., 1958. Chilwa island: Mem. geol. Surv. Nyasald, 1.

GERMS, G.J.B., 1972. The stratigraphy and paleontology of the lower Nama Group, South West Africa: Bull. P.R.U., Univ. Cape Town, 12.

GOLD, D.P., 1963. Average chemical composition of carbonatites: Econ. Geol., 58 (6), 988-991.

————————, 1964. The average and typical chemical composition of carbonatites: Int. miner. Ass., New Delhi meeting. (Preprint).

GOLDSCHMIDT, V.M., 1954. Geochemistry: Clarendon Press, Oxford.

HAUGHTON, S.H. and FROMMURZE, H.F., 1936. The geology of the Warmbad district, South West Africa: Mem. S.W.A. Dep. Min., 2.

HOLMES, A., 1965. Principles of physical geology: Thomas Nelson Ltd., London.

JANSE, A.J.A., 1969. Gross Brukkaros, a probable carbonatite volcano in the Nama plateau of Southwest Africa: Bull. geol. Soc. Amer., 80, 573-586.

JOHNSON, R.L., 1966. The Shawa and Dorowa carbonatite complexes, Rhodesia, in Tuttle, O.F. and Gittins, J. (eds.), Carbonatites: John Wiley & Sons, New York.

KENT, L.E., RUSSEL, H.D. and VAN ROOYEN, D.P., 1943. Fluorspar in the Union of South Africa and South West Africa: Bull. Dep. Min. S. Afr., 14.

LAPIDO-LOUREIRO, F.E. De V., 1973. Carbonatitos de Angola: Mem. e Trabalhos do Instituto de Investigacao Cientifica de Angola, 11.

LARSEN, E.S., 1938. Some new variation diagrams: J. Geol., 46, 505-520.

MARTENS, J.H.C., 1924. Igneous rocks of Ithaca, New York and vicinity: Bull. geol. Soc. Amer., 35, 305-320.

MARTIN, H., MATHIAS, M. and SIMPSON, E.S.W., 1960. The Damaraland sub-volcanic ring complexes in South West Africa: Rep. 21st int. geol. Congr., Norden, 13, 156-174.

MELCHER, G.C., 1966. The carbonatites of Jacupiranga, Sao Paulo, Brazil, in Tuttle, O.F. and Gittins, J. (eds.), Carbonatites: John Wiley & Sons, New York.

MIDDLEMOST, E., 1967. Petrology of the Bremen granite syenite complex, South West Africa: Trans. geol. Soc. S. Afr., 70, 117-134.

MÜNCH, H.G., 1971-72. The tectonics of the northern part of the Klein Karas and Groot Karas Mountains, South West Africa: Ann. geol. Surv. S. Afr., 9 (2), 107-109.

NOCKOLDS, S.R. and ALLEN, R., 1953. The geochemistry of some igneous rock series: Geochim. et cosmoch. Acta, 3 & 4.

PETERS, W.C., 1953. The Bull-Domingo breccia in south-central Colorado: Econ. Geol., 48, 598-599.

PETTIJOHN, F.J., 1957. Sedimentary rocks (2nd ed.): Harper and Bros., New York.

PHILLPOTTS, A.R., 1974. The Monteregian province, in Sorenson, H. (ed.), The alkaline rocks: John Wiley & Sons, London.

PYE, W.D. and PYE, M.H., 1943. Sphericity determination of pebbles and sand grains: J. sediment. Pet., 13, 85-104.

RANKAMA, K. and SAHAMA, Th. G., 1950. Geochemistry: Univ. Chicago Press, Chicago.

REYNOLDS, D.L., 1951b. The geology of Slieve Gullion, Foughill and Carrickcaruan: an actualistic interpretation of a Tertiary gabbro-granophyre complex: Trans. roy. Soc. Edinb., 62(1), 85-143.

―――――――――――――, 1954. Fluidization as a geological process and its bearing on the problem of intrusive granites: Amer. J. Sci., 252, 577-614.

RICKWOOD, P.C., 1968. On recasting analyses of garnets into end-member molecules: Cont. Mineral. and Petrol., 18, 175-198.

RILEY, N.A., 1941. Projection sphericity: J. sediment. Pet., 11, 94-97.

SAETHER, E., 1958. The alkaline rock province of the Fen area in southern Norway: Norsk. Vidensk., Selsk. Skr. 1957, 1-150.

SCHWELLNUS, C.M., 1941. The Nama tillite in the Klein Kharas Mountains, S.W.A.: Trans. geol. Soc. S. Afr., 44, 19-34.

―――――――――――――, 1942. The Garub mine, Keetmanshoop District, S.W.A.: Rep. geol. Surv. S. Afr. (Unpubl.).

SHAND, S.J., 1916. The pseudotachylyte of Parys, Orange Free State, and its relation to "trap-shotten gneiss" and "flinty crush-rock": Quart. J. geol. Soc. Lond., 72, 198-221.

SHOEMAKER, E.M., ROACH, C.H. and BYERS, F.M., 1962. Diatremes and uranium deposits in the Hopi Buttes, Arizona: Volume Honor A.F. Buddington, geol. Soc. Amer., 327-355.

SOWERBUTTS, W.C.T., 1972. Rifting in eastern Africa and the fragmentation of Gondwanaland: Nature, 235 (5339), 435-437.

TALJAARD, M.S., 1937. South African melilite basalts and their relations: Trans. geol. Soc. S. Afr., 39, 281-316.

TUREKIAN, K.K. and WEDEPOHL, K.H., 1961. Distribution of the elements in some major units of the earth's crust: Bull. geol. Soc. Amer., 72, 175-192.

UPTON, B.G.J., 1974. The alkaline province of south-west Greenland, in Sorenson, H. (ed.), The alkaline rocks: John Wiley & Sons, London.

VAN BILJON, S., 1939. The Kuboos batholith in Namaqualand, South Africa: Trans. geol. Soc. S. Afr., 42, 123-219

VERWOERD, W.J., 1957. Carbonate-bearing eruptives on Garub 266 in the Great Karasberge, S.W.A.: Rep. geol. Surv. S. Afr. (Unpubl.).

____________, 1967. The carbonatites of South Africa and South West Africa: Handbook geol. Surv. S. Afr., 6.

____________, 1970. Economic geology and genesis of kimberlites: a review: Anais XXIV congr. Bras. Geol., Brasilia, 51-70.

VISSER, J.N.J., 1964. Analysis of rocks, minerals and ores: Handbook geol. Surv. S.A., 5.

VON ECKERMANN, H., 1948c. The genesis of the Alnö alkaline rocks: Int. geol. Congr., 18th Sess., Pt. 3, 94-101.

____________, 1963a. Contributions to the knowledge of the alkaline dykes of the Alnö region: Arkiv. f. Mineral. Geol., 3, 397-402.

WAIBEL, L., 1925. Gebirgsbau und Oberflächengestalt der Karrasberge in Südwest-Afrika: Mitt. dt. Schutzgeb., 33, 2-38 and 81-114.

WEDEPOHL, K.H., 1972. Handbook of geochemistry, II/2-3: Springer Verlag, Berlin.

WENTWORTH, C.K. and WILLIAMS, H., 1932. The classification and terminology of the pyroclastic rocks: Nat. Research Council, Rept. Comm. Sedimentation, Bull., 89, 19-53.

WIMMENAUER, W., 1966. The eruptive rocks and carbonatites of the Kaiserstuhl, Germany, in Tuttle, O.F. and Gittins, J. (eds.), Carbonatites: John Wiley & Sons, New York.

WYLLIE, P.J., 1967. Kimberlites, in Wyllie, P.J. (ed.), Ultramafic and related rocks: John Wiley & Sons, New York.

PLATE 1

A. The Mickberg carbonatite plug (82) viewed from the north-east. Mickberg 262.

B. Sharp contact between carbonatite containing angular inclusions and garnet gneiss. Note the bleached (fenitised ?) zone on the contact. Mickberg 262.

C. Ankeritic carbonatite containing inclusions of quartzite (1), hornblende gneiss (2), red garnet gneiss (3), pyroxene (4), and apatite (5). Mickberg 262.

PLATE 1

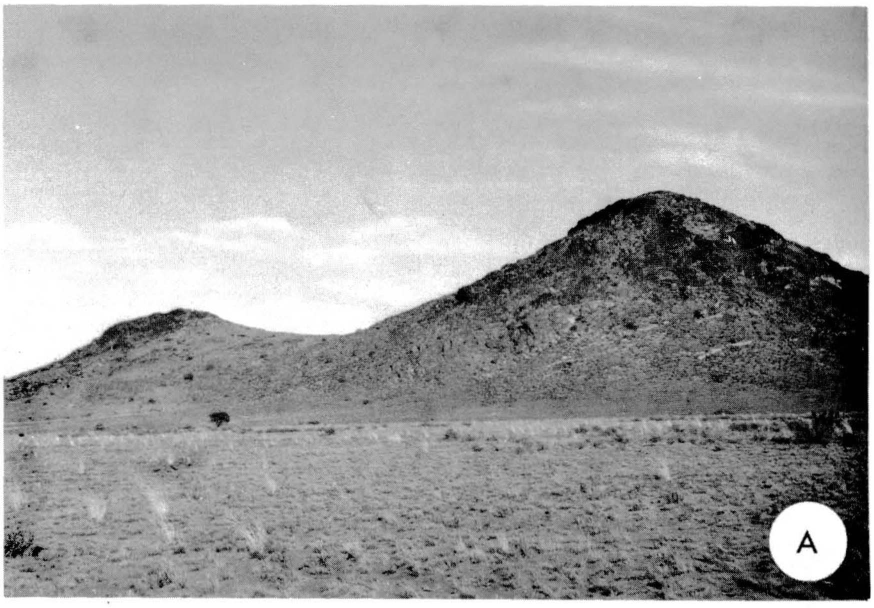


PLATE 2

A. Rounded inclusion of gneiss in carbonatite showing peripheral fenitisation (?). Mickberg 262.

B. Angular and well-rounded inclusions of quartzite, sandy shale and various types of gneiss in carbonatite matrix. Mickberg 262.

C. Spherical structures consisting of nuclei of gneiss surrounded by concentric layers of carbonatite, dust and carbonatised fragments. Mickberg 262.

PLATE 2

PLATE 3

A. Lamprophyric carbonate dyke cutting through granite-gneiss. Note the screen of granite-gneiss in centre of dyke and the rounded inclusion of granite. West of prospecting pit on east-west striking dyke associated with pipe 5, Garub 266.

B. Pisolitic tuffisite dykes and veins in garnet gneiss wall-rock along western contact of dyke 23, Garub 266.

C. Slightly transgressive sill of pisolitic tuffisite in basal grit of the Kuibis Formation. South-west of shed, Liebenrust 300.

PLATE 3

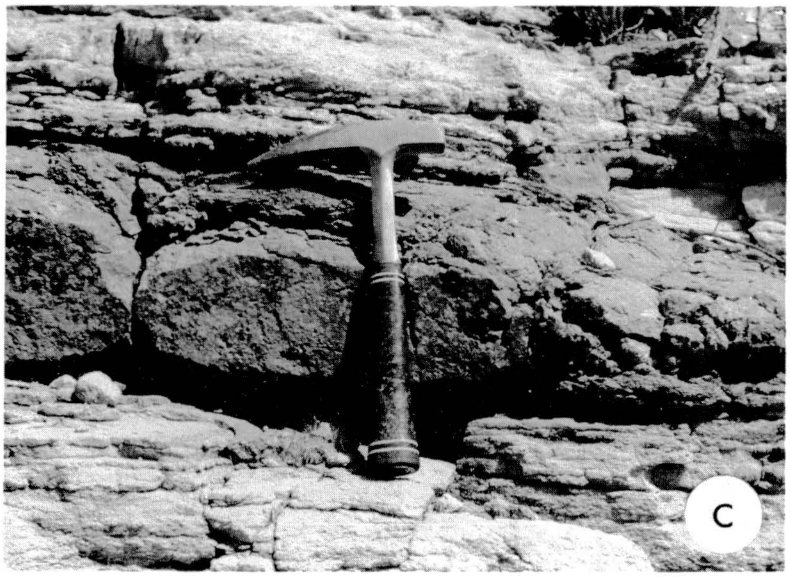


PLATE 4

A. Accretionary lapilli or pisolites composed of nuclei of wall-rock gneiss and feldspar rimmed by ankerite, small fragments and dust. Pipe 68 Tafelkop (Haochanas 24).

B. Spherical structures of the orbicular type showing rims of fine-grained ankerite around cores of coarse-grained ankerite and chlorite. These orbicular pisolites are often coupled and slightly elongated, and apparently formed as a result of chemical interaction between a mafic inclusion and the ankeritic matrix. Dyke 6, Garub 266.

C. Tabular inclusions of quartz and feldspar in ankeritic groundmass, formed by fragmentation of the wall-rock gneiss along closely spaced joints and cleavage cracks. Dyke 48, Garub 266.

PLATE 4

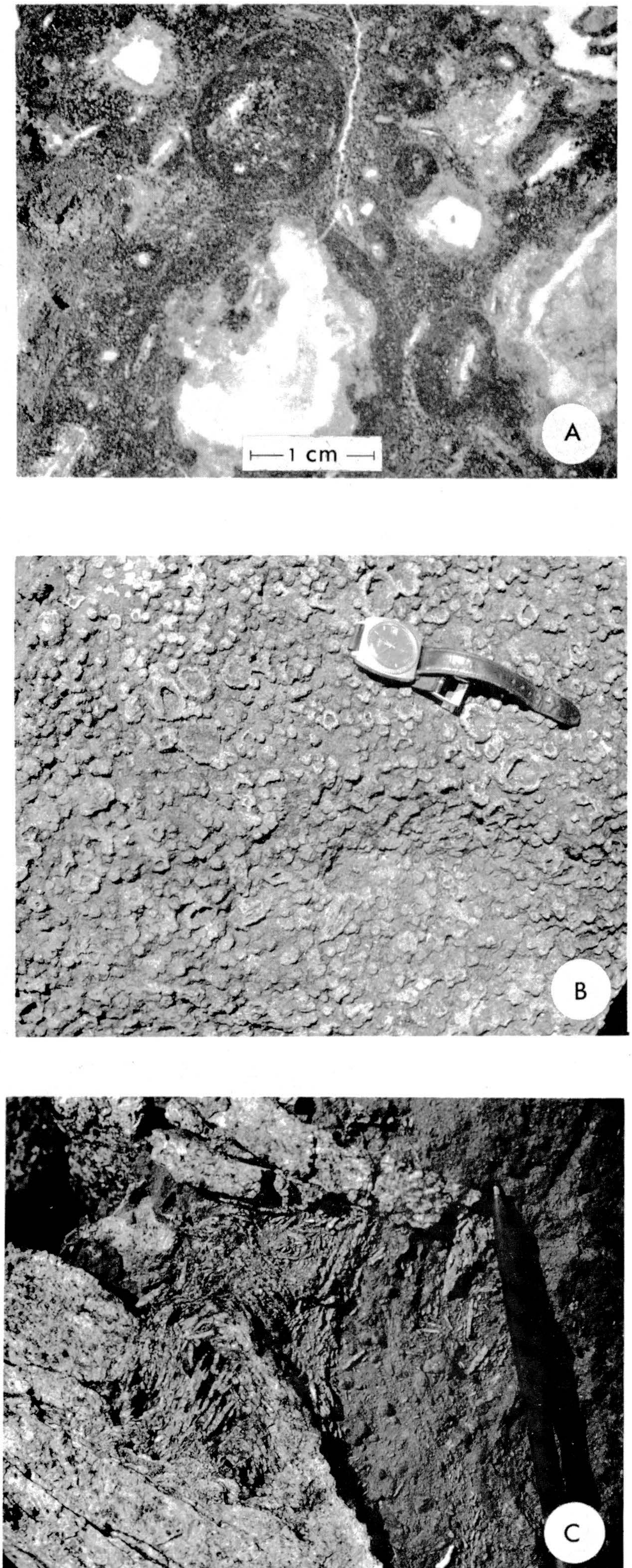


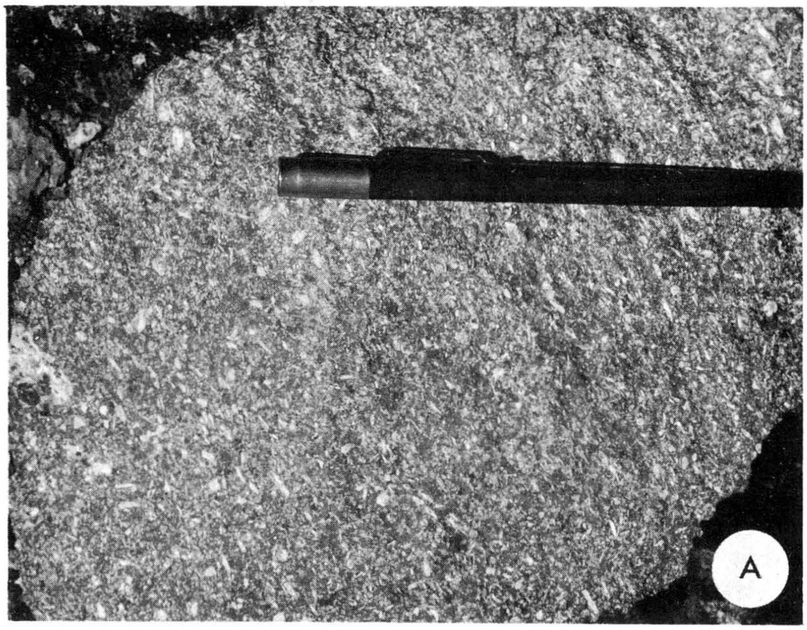
PLATE 5

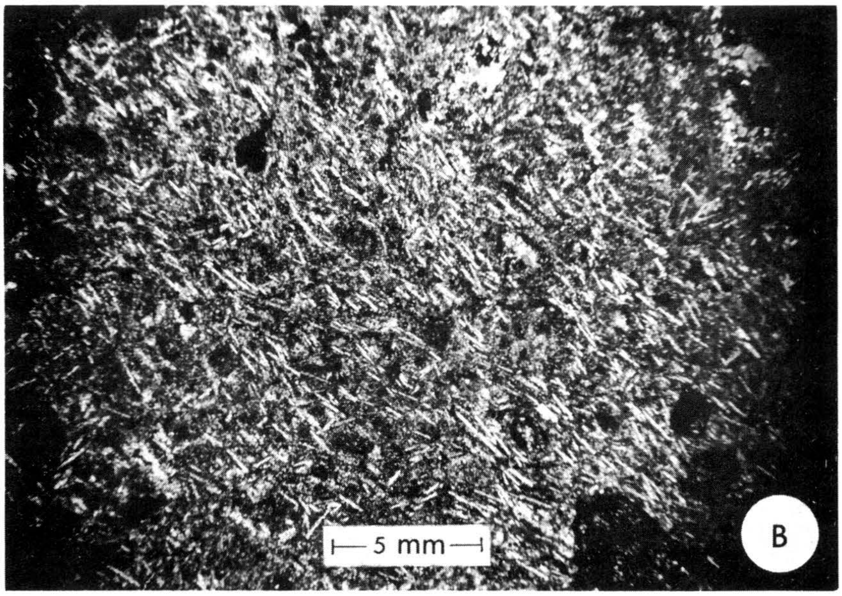
A. Freshly broken surface showing slightly kaolinised lamellar fragments of feldspar in ankeritic groundmass. Northern part of pipe 5, Garub 266.

B. Photomicrograph of ankeritised lath-shaped pseudomorphs (after melilite ?) in a microcrystalline groundmass. East-west striking dyke associated with pipe 5, Garub 266. Crossed nicols.

C. Photomicrograph of kaolinised lithic tuffisite displaying mosaic texture of angular grains of quartz and feldspar, and secondary quartz vein running diagonally over plate. Southern part of pipe 5, Garub 266. Crossed nicols.

PLATE 5





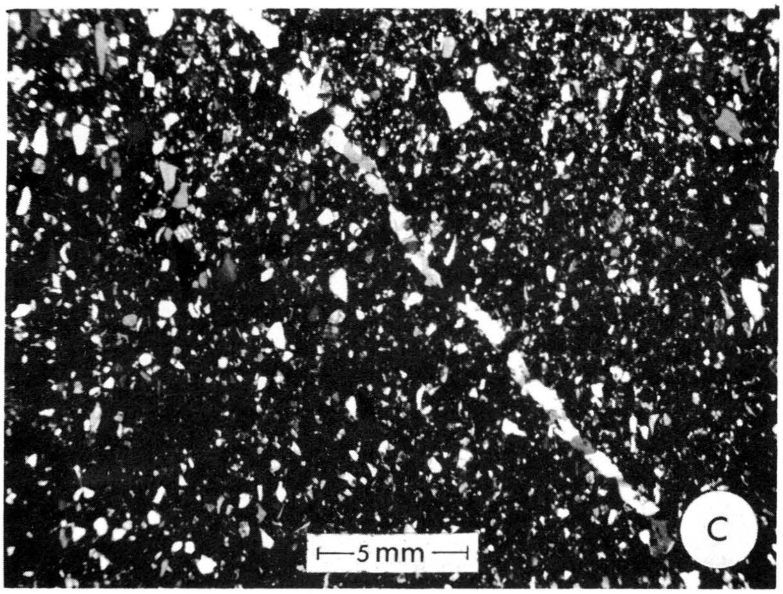


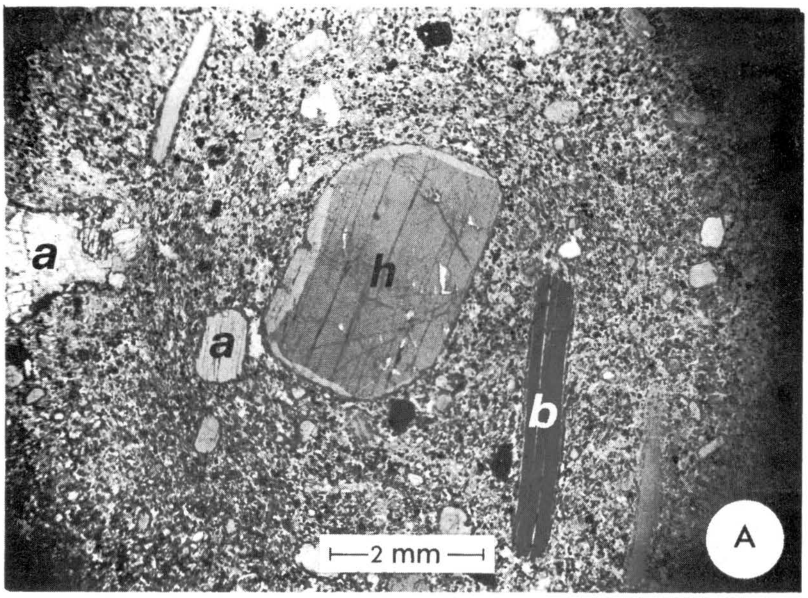
PLATE 6

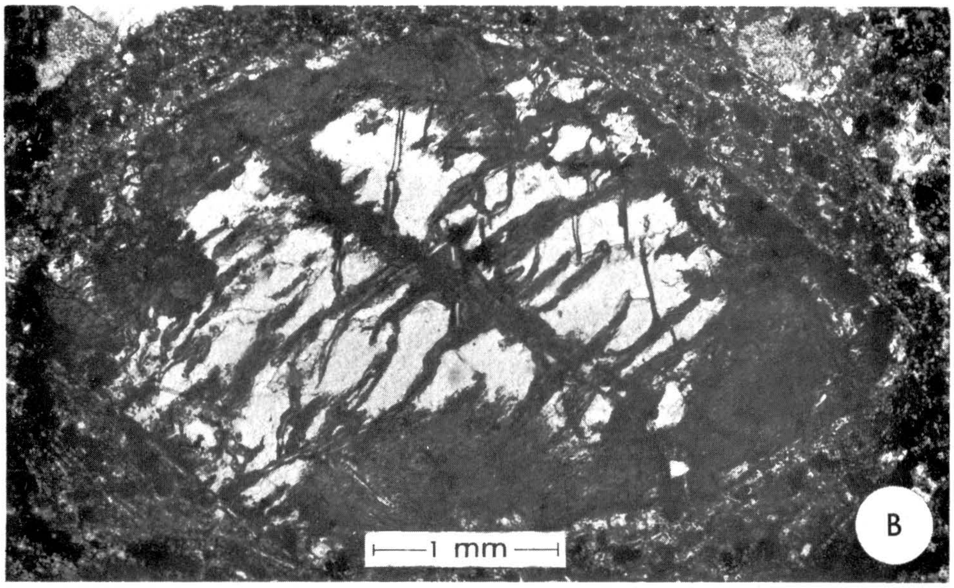
A. Photomicrograph of lamprophyric carbonate rock with phenocrysts of zoned hornblende (h), augite (a) and biotite (b). Dyke associated with pipe 5, Garub 266. Crossed nicols.

B. Photomicrograph of partly ankeritised xenocryst of augite in homogeneous tuffisite (?). Note concentration of ore around periphery. Sill 70, Bismarck-Aue 23. Crossed nicols.

C. Photomicrograph of chlorite (c), pseudomorphic after mica, with fluorite (f) along cleavage. The fluorite is penetrated by veinlets of talc. Tafelkop (Haochanas 24). Crossed nicols.

PLATE 6





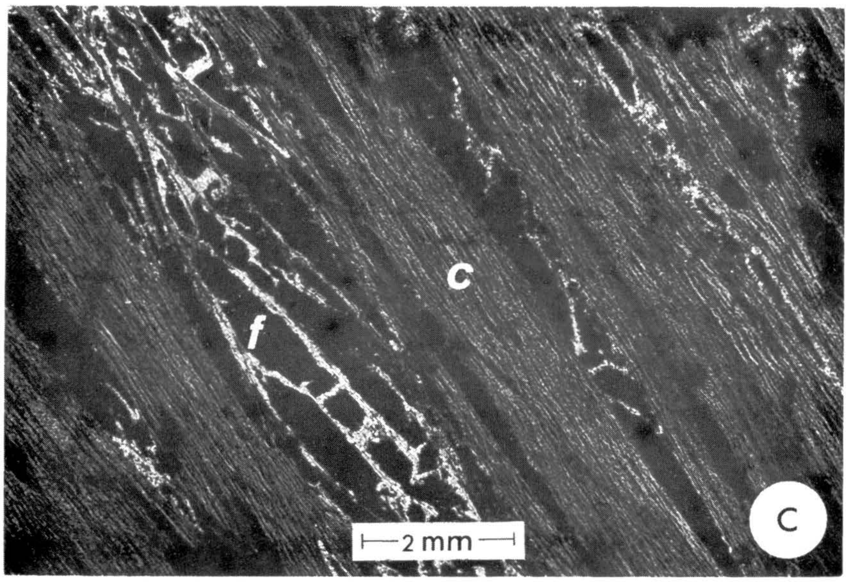


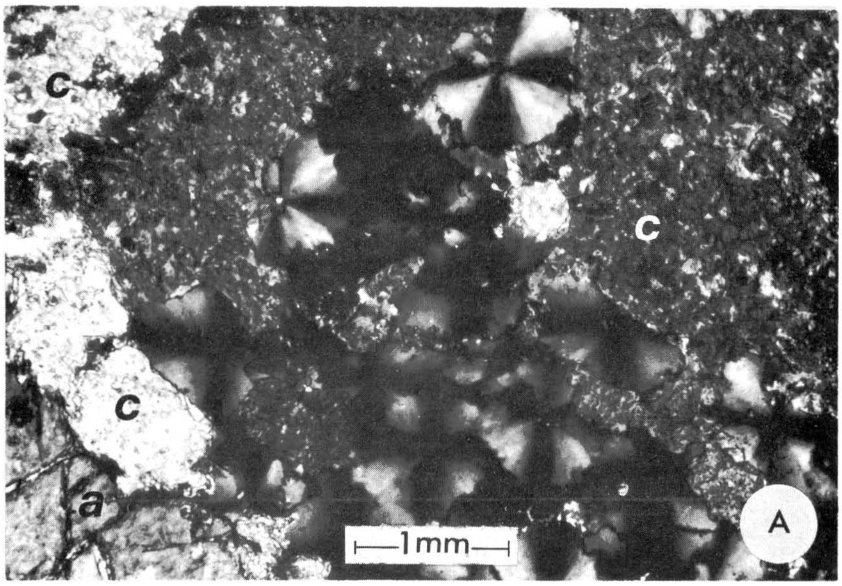
PLATE 7

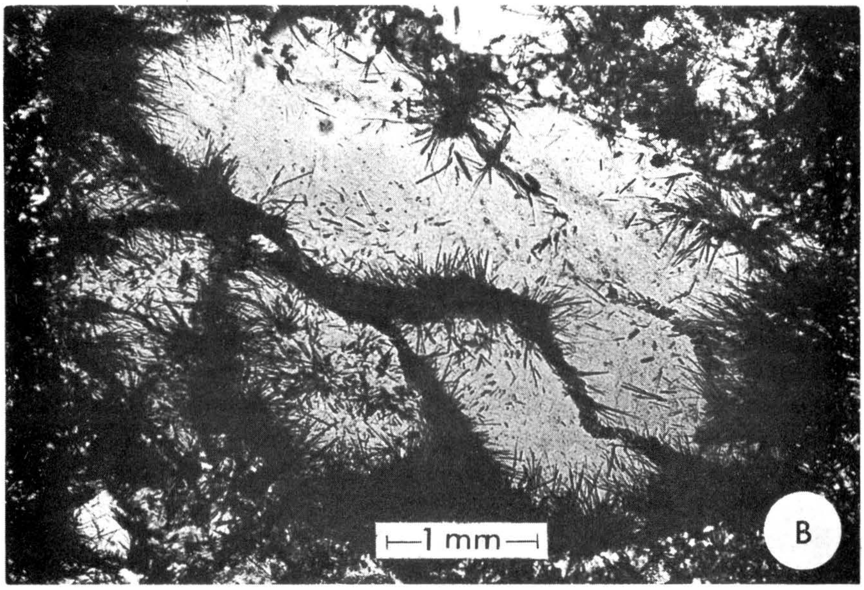
A. Photomicrograph of low temperature quartz (spherulitic chalcedony) and augite (a) in coarse-grained ankerite (c). Dyke associated with pipe 5, Garub 266. Crossed nicols.

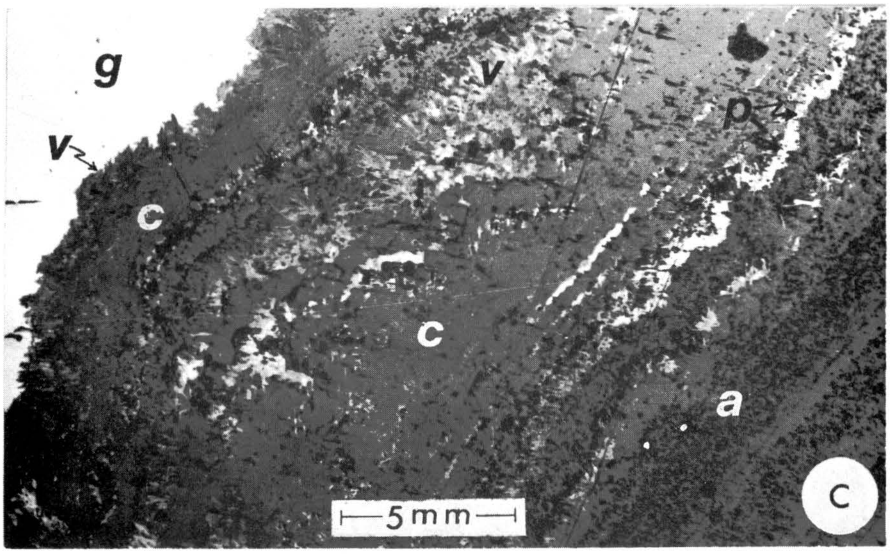
B. Photomicrograph of needles of soda amphibole replacing quartz from the periphery and along cracks. Fenitised wall-rock gneiss in contact with dyke 48, Garub 266. Crossed nicols.

C. Photomicrograph of colloform texture shown by rhythmic banding of galena (g), covellite (v), chalcocite (c), chalcopyrite (p) and gangue material (a). Fluorspar mine, Garub 266. Ordinary reflected light.

PLATE 7







APPENDIX ON TERMINOLOGY

Numerous classifications of pyroclastic rocks have been proposed and many terms have been loosely and often wrongly applied. The field of alloclastic rocks, however, (i.e. rocks formed by volcanic processes beneath the surface) has been neglected. It is therefore advisable to explain some of the terms that have been used. Unless stated otherwise, the terms are based on those of the A.G.I. Glossaries of Geology (1960, 1972).

ACCIDENTALS: Enclosed grains or fragments having no genetic connection with the rocks in which they occur.

ACCRETIONARY LAPILLI: Volcanic pellets, commonly exhibiting concentric structures, owing to accretion around a nucleus.

BRECCIA: A coarse-grained clastic rock composed of large (greater than sand size, or 2 mm in diameter), angular, and broken rock fragments that are cemented together in a finer-grained matrix (which may or may not be similar to the larger fragments) and that can be of any composition, origin, or mode of accumulation.

FRAGMENT: A piece of rock that has been detached or broken from a pre-existing mass; e.g. a clast produced by volcanic, dynamic, or weathering processes.

LAPILLI: Pyroclastics that may be either essential, accessory or accidental in origin, of a size range that has been variously defined within the limits of 1-64 mm diameter.

LITHIC: Said of fragments of previously formed rocks, also referring to a rock containing such fragments.

PISOLITE: A spherical or subspherical (accretionary) body over 2 mm in diameter (Pettijohn, 1949).

PISOLITIC TUFF: Tuff composed of accretionary lapilli or pisolites.

TUFFISITE: Intrusive tuff.

VENT: The channel or conduit through which volcanic materials pass.

VOLCANIC: Used in a broad sense meaning "volcanically formed" (Fisher, 1961).

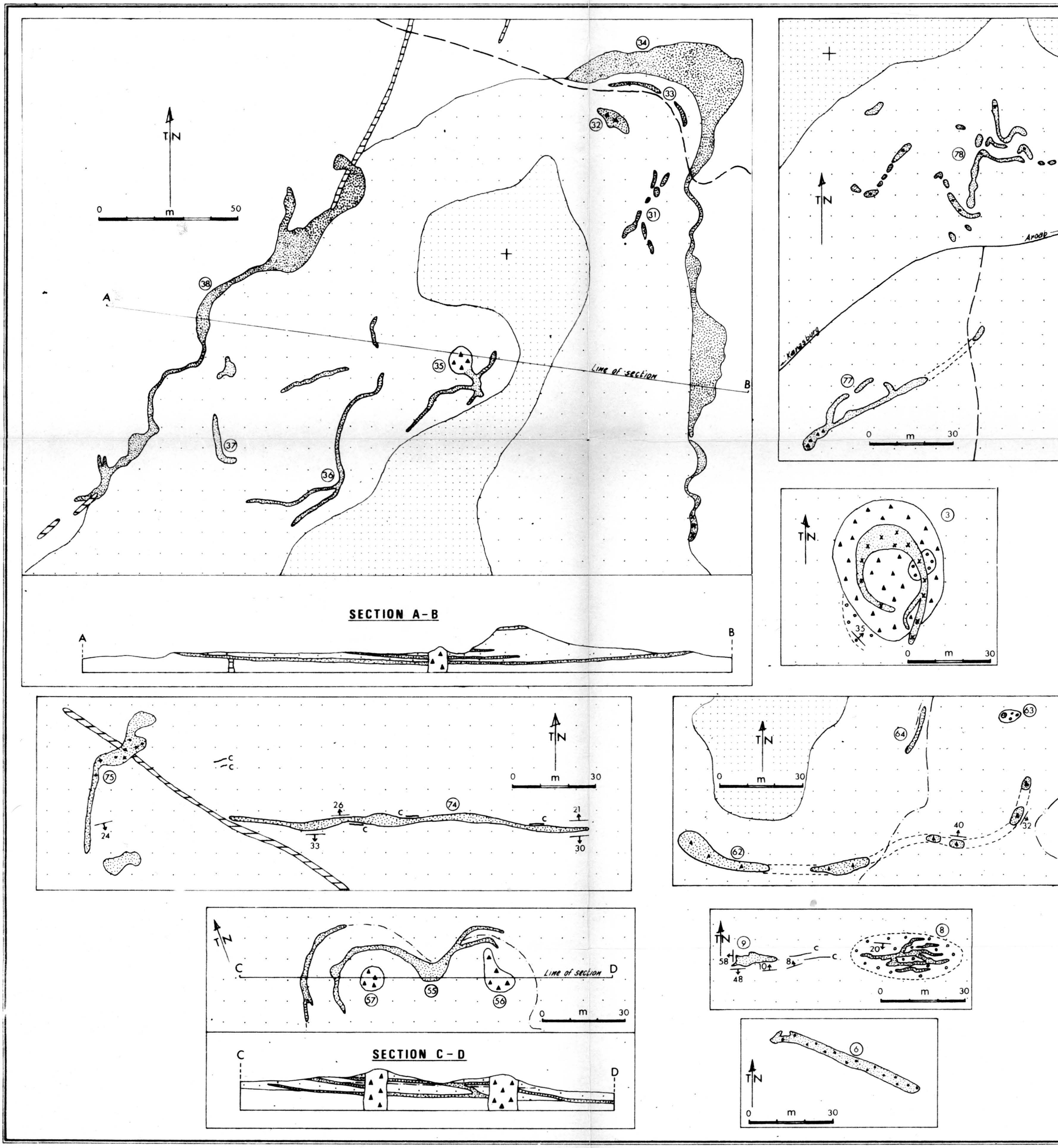
REFERENCES

AMERICAN GEOLOGICAL INSTITUTE, 1960. Glossary of geology and related sciences (2nd ed.): Washington,D.C.

AMERICAN GEOLOGICAL INSTITUTE,1972. Glossary of Geology: Washington, D.C.

FISHER, R.V., 1961. Proposed classification of volcaniclastic sediments and rocks : Bull. geol. Soc. Amer., 72, 1409-1914.

PETTIJOHN, F.J.,1949. Sedimentary rocks (1st ed.): Harper & Bros., New York.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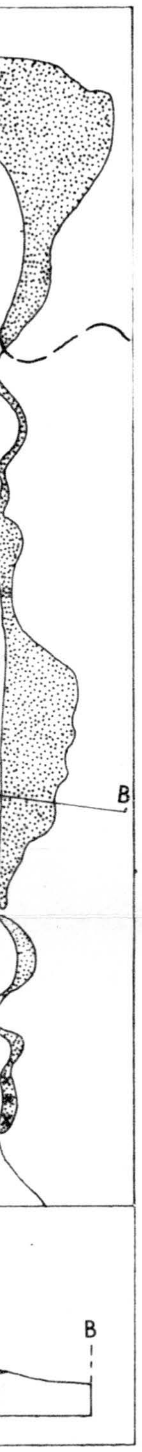
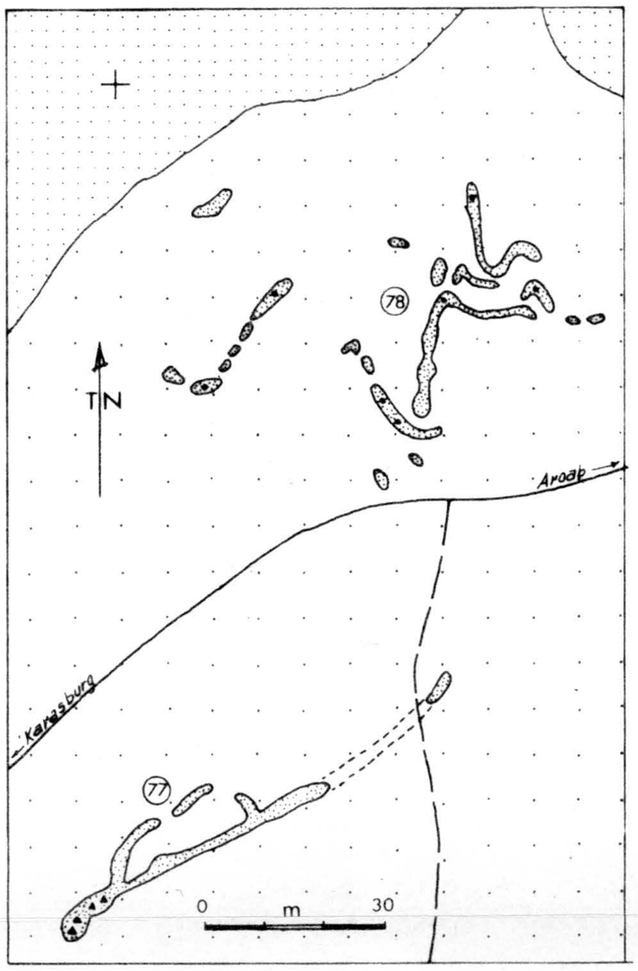
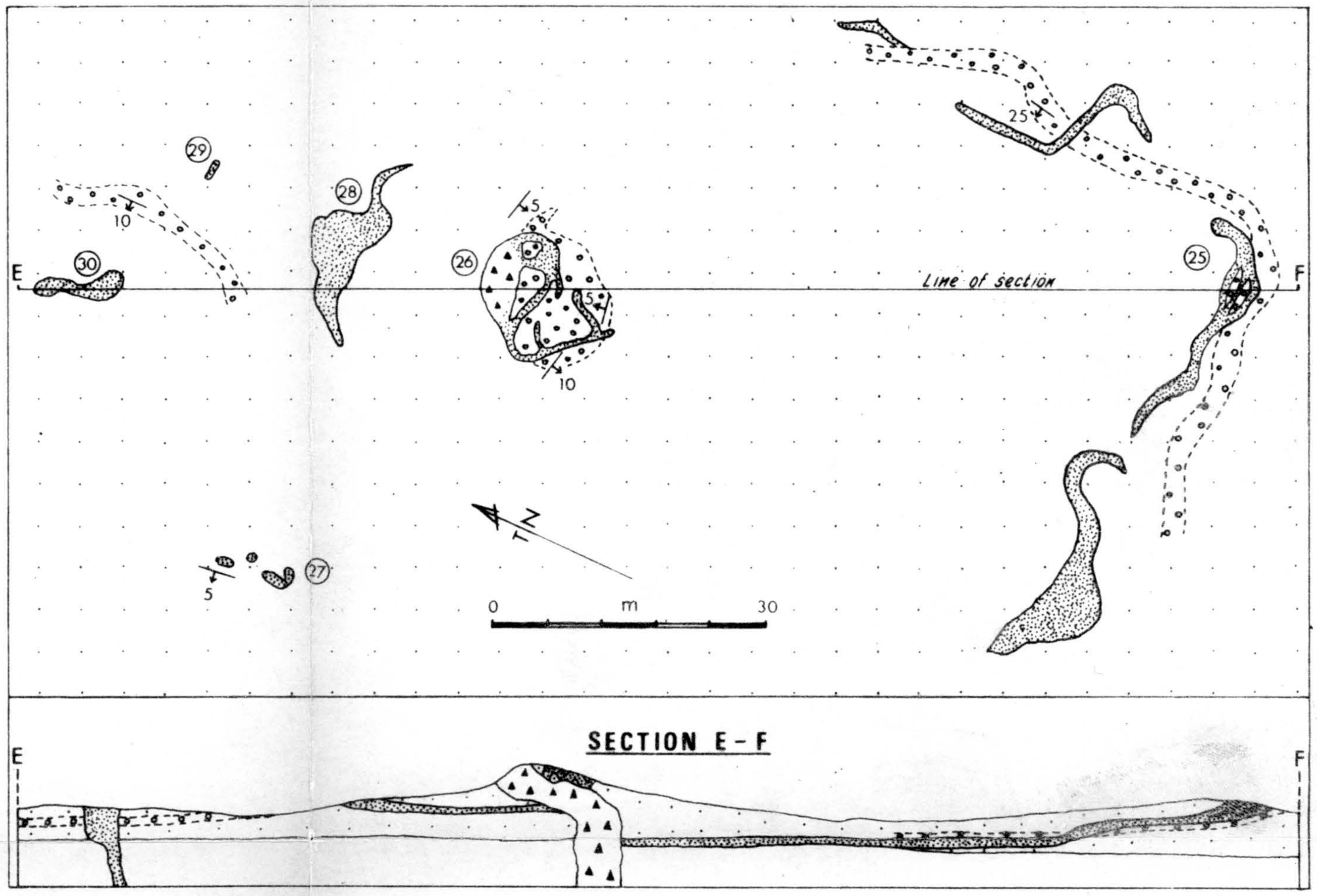
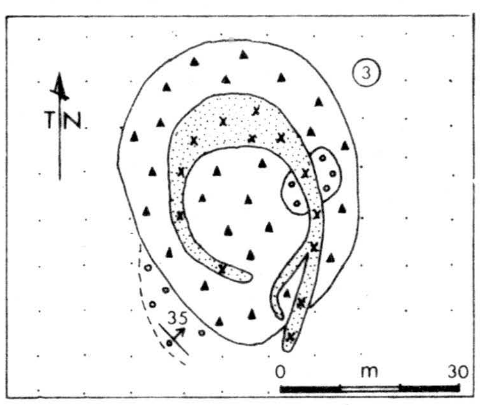
FOLDER 2

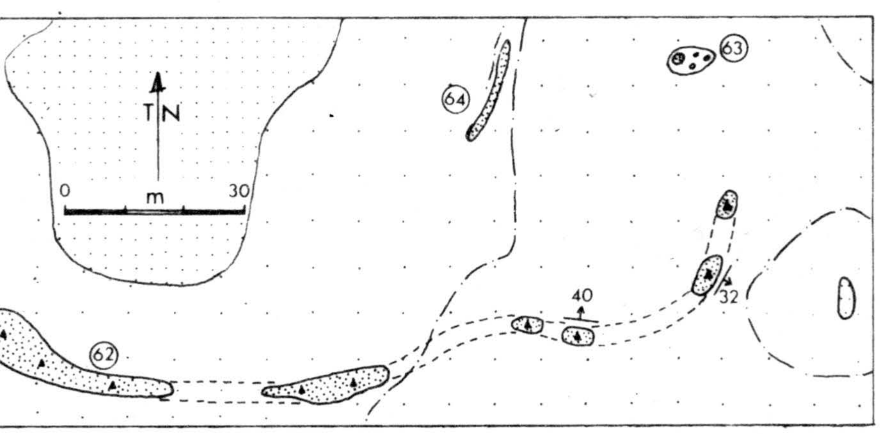


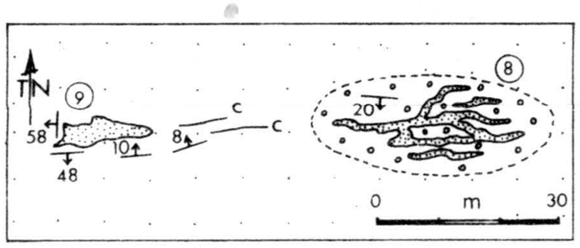


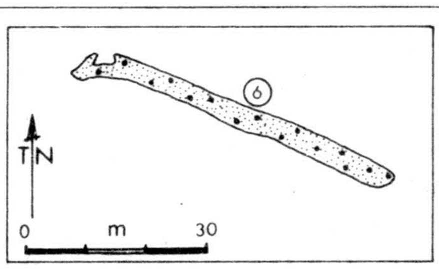


SKETCH MAPS OF SOME CARBONATE-BEARING BODIES ON GARUB 266 AND SURROUNDINGS









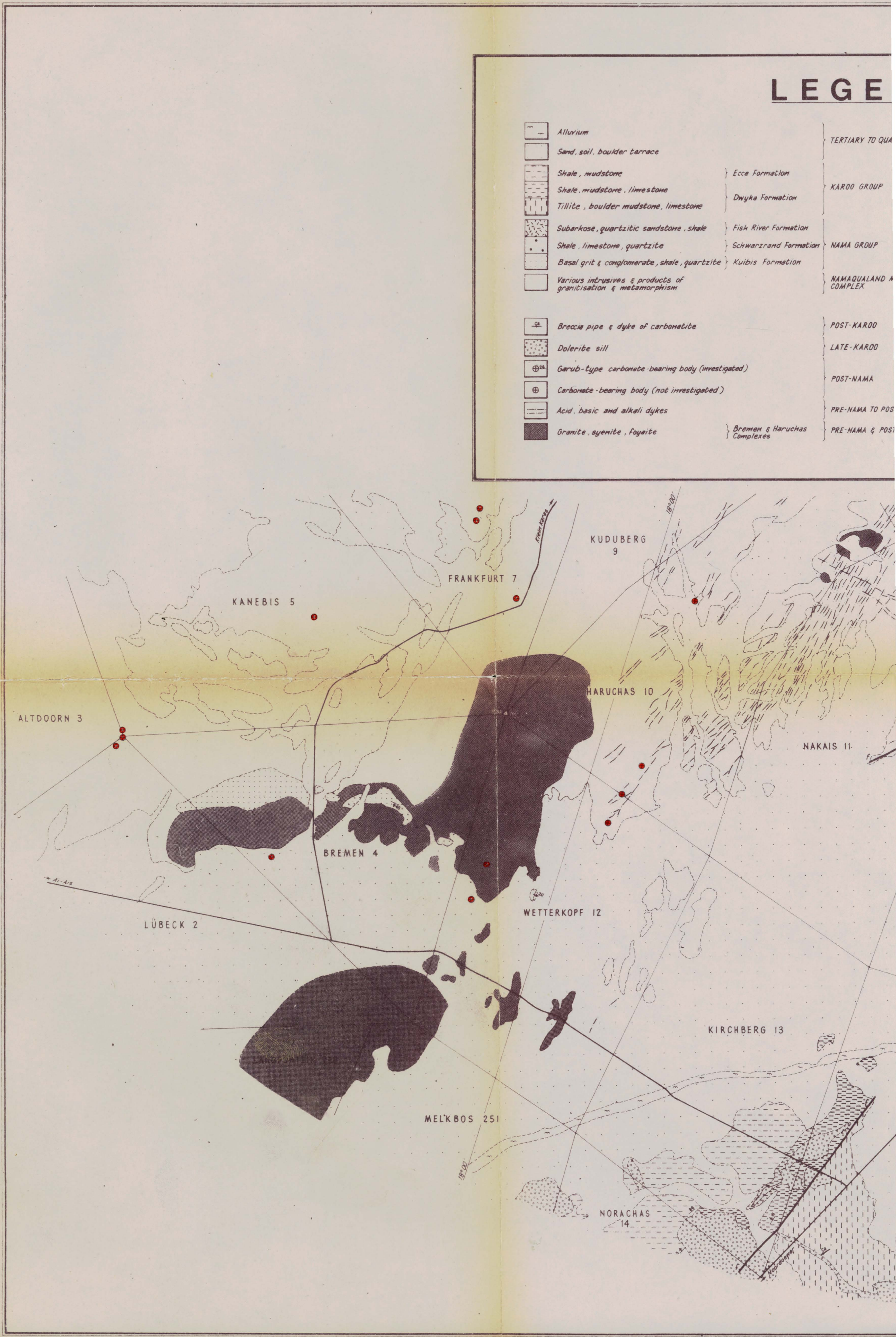
LEGEND

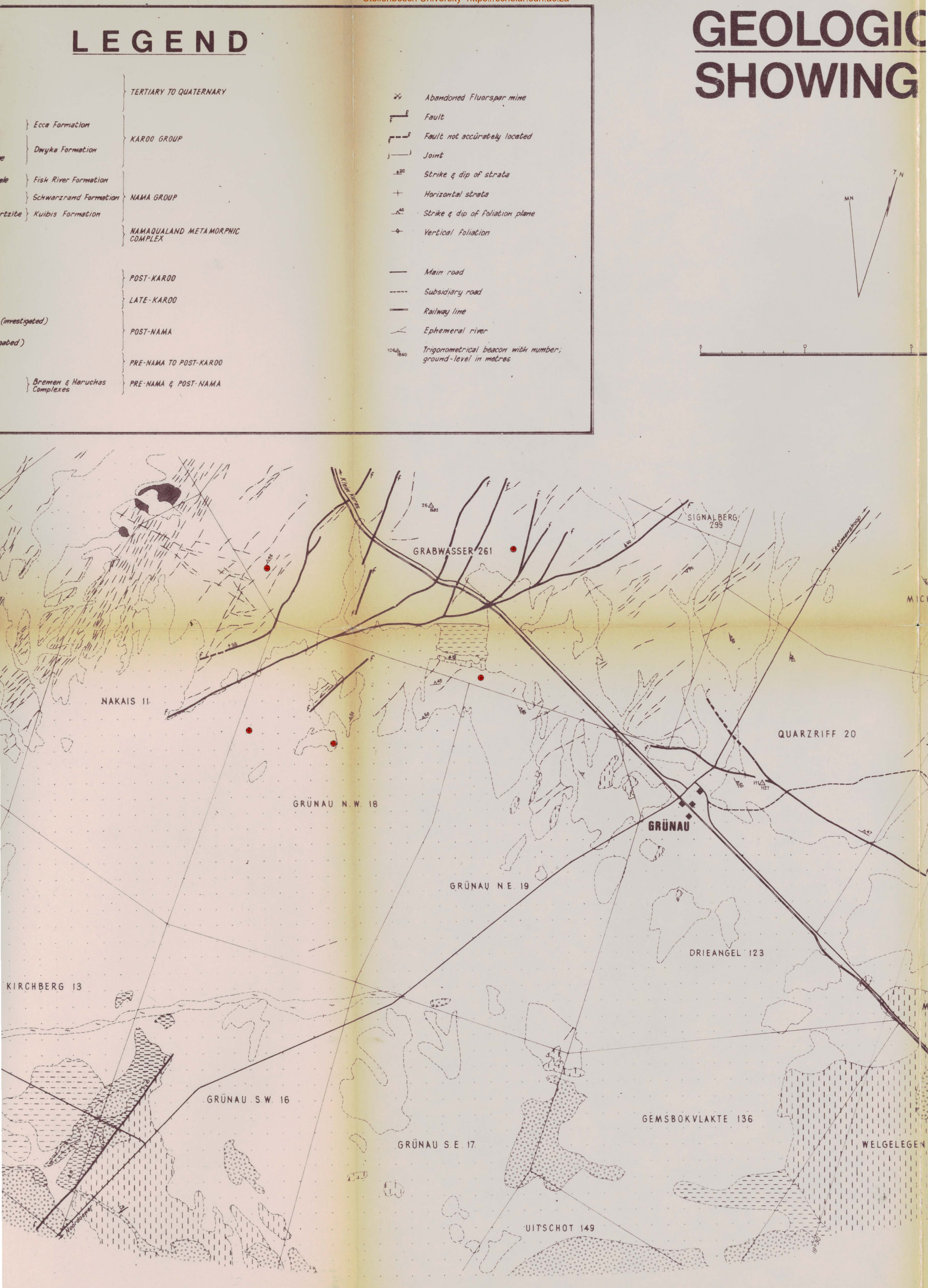
▲	Carbonate-bearing breccia		POST-NAMA
	Sills, dykes and veins (c) of lamprophyric carbonate rock, pisolitic (··) in places		POST-NAMA
x	Carbonate-bearing tuffisite		POST-NAMA
	Brown and reddish quartzitic sandstone and quartzite	Fish River Formation	NAMA GROUP
	Greenish-grey sandy shale with subordinate bands of quartzite (∘∘) & limestone (— —)	Schwarzrand Formation	NAMA GROUP
	Dolerite dyke		PRE-NAMA TO POST NAMA
	Biotite granite-gneiss with accessory garnet and sillimanite		NAMAQUALAND METAMORPHIC COMPLEX

- 56 — Strike & dip of strata
- + — Horizontal strata
- Main road
- Farm road
- A B — Line of section
- (6) — Reference number of body

(PARTLY AFTER VERWOERD, 1957)

FOLDER 2


LEGE
Alluvium
Sand, soil, boulder terrace
TERTIARY TO QUA
Shale, mudstone
Ecca Formation
Shale, mudstone, limestone
Tillite, boulder mudstone, limestone
Dwyka Formation
KAROO GROUP
Subarkose, quartzitic sandstone, shale
Fish River Formation
Shale, limestone, quartzite
Schwarzrand Formation
NAMA GROUP
Basal grit & conglomerate, shale, quartzite
Kuibis Formation
Various intrusives & products of granitisation & metamorphism
NAMAQUALAND
COMPLEX
Breccia pipe & dyke of carbonatite
POST-KAROO
Dolerite sill
LATE-KAROO
Garub-type carbonate-bearing body (investigated)
Carbonate-bearing body (not investigated)
POST-NAMA
Acid, basic and alkali dykes
PRE-NAMA TO POS
Granite, syenite, Foyaite
Bremen & Haruchas Complexes
PRE-NAMA & POS
KUDUBERG 9
FRANKFURT 7
KANEBIS 5
HARUCHAS 10
ALTDOORN 3
NAKAIS 11
BREMEN 4
WETTERKOPF 12
LÜBECK 2
KIRCHBERG 13
MELKBOS 251
NORACHAS 14
18°00'
Ai-Ais
Kleinn Karas


GEOLOGIC
SHOWING
LEGEND
TERTIARY TO QUATERNARY
Ecca Formation
Dwyka Formation
KAROO GROUP
Fish River Formation
Schwarzrand Formation
NAMA GROUP
Kuibis Formation
NAMAQUALAND METAMORPHIC COMPLEX
POST-KAROO
LATE-KAROO
(investigated)
POST-NAMA
PRE-NAMA TO POST-KAROO
Bremen & Haruchas Complexes
PRE-NAMA & POST-NAMA
Abandoned Fluorspar mine
Fault
Fault not accurately located
Joint
Strike & dip of strata
Horizontal strata
Strike & dip of foliation plane
Vertical foliation
Main road
Subsidiary road
Railway line
Ephemeral river
Trigonometrical beacon with number; ground-level in metres
MN
TN
GRABWASSER 261
SIGNALBERG 299
NAKAIS 11
QUARZRIFF 20
GRÜNAU N.W. 18
GRÜNAU
GRÜNAU N.E. 19
DRIEANGEL 123
KIRCHBERG 13
GRÜNAU S.W. 16
GEMSBOKVLAKTE 136
GRÜNAU S.E. 17
WELGELEGEN
UITSCHOT 149

FOLDER 1

AL MAP OF AREA AROUND GRÜNAU, S.
THE DISTRIBUTION OF CARBONATE-BE
BODIES

...ND GRÜNAU, S.W.A., ... CARBONATE-BEARING

MAPPED BY C.P.SCHREUDER AND G. GENIS