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PRELIMINARY REPORT ON THE STRATIGRAPHY OF THE DAMARA SEQUENCE AND THE GEOLOGY AND GEOCHEMISTRY OF DAMARAN GRANITES IN AN AREA BETWEEN WALVIS BAY AND KARIBIB

by

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ABSTRACT

The rocks investigated in the present study occur within the Central Zone of the Damara Orogen in the area between Walvis Bay and Karibib. This country is underlain by the Abbabis Metamorphic Complex and the Damara Sequence. The former comprises a reddish augengneiss, metabasalt, calc-silicate rocks, quartzite and schist, whereas the latter is represented by metamorphosed sedimentary rocks of the Nosib and Swakop Groups. In this area, both groups have a conformable relationship.

The successions have been repeatedly deformed and display a variety of fabrics. The F_1 phase is documented by a schistosity that was overgrown by cordierite. It was co-axially deformed during F_2 resulting in the principal regional schistosity s_2. During F_3, pre-existing structures were deformed, but only locally a new fabric was created. The major megascopic structures are NE-trending folds. At a few places, the effects of thrusting are apparent.

In the course of the Damara Orogeny, the Damara succession as well as its Abbabis basement were intruded on a large scale by various magmas ranging from gabbroic to syenitic and granitic. It is the principal aim of the present study to unravel the relationships between the various intrusive rocks, to find out their protoliths and their position in the structural and metamorphic evolution of the Damara Orogen. The intrusions occurred between 750 m.y. (age of a diorite on Palmental 86) and about 456 m.y. (age of the Rössing alaskite). According to the time of their emplacement (pre-, syn- or post-tectonic), the intrusive rocks also display a fabric.

A number of intrusions are described, of which the Salem Granite has the widest distribution.

Petrogenetic studies indicate that the opinion of former investigators, who considered the Salem Granite a melting product of the Kuiseb schist, cannot be maintained, but that certain varieties of it must have been derived from other protoliths. It was established that the various members of the suite are not consanguineous.

Many of the intrusive masses have been investigated geochemically; modal analyses, Rb-Ba-Sr diagrams, the Si/total alkali ratios, SiO_2-element diagrams, a modified Larsen index-element diagram and triangular variation diagrams are discussed.

UITTREKSEL

Die gesteentes wat in hierdie studie ondersoek word, kom in die Sentrale Sone van die Damara Orogeen in die gebied tussen Walvisbaai en Karibib voor. Hierdie gebied word deur die Metamorfe Kompleks Abbabis en die Opeenvolging Damara onderle. Eersgenoemde bevat 'n rooierige augengneis, metabasalt, kalksilikaatgesteentes, kwartsiet en skis, terwyl laasgenoemde deur metasedimente en lawas van die Groepe Nosib en Swakop verteenwoordig word. In hierdie gebied het die twee groepe 'n konforme verhouding.

Die opeenvolgings is herhaaldelik vervorm en vertoon verskeie maaksels. Die F_1-fase word deur 'n skisteusheid gedokumenteer wat na sy aanvang deur kordiëriet oorgroei is. Dit is gedurende F_2 ko-aksiaal vervorm waartydens die vernaamste regionale skisteusheid s_2 ontstaan het. Gedurende F_3 is bestaande strukture vervorm, maar 'n nuwe maaksel het slegs plaaslik ontstaan. Die vernaamste megaskopiese strukture is NO-strekkende plooie. Op 'n paar plekke kan die effekte van verskuiwing waargeneem word.

In die verloop van die Damara-Orogenie is die Damara asook die Abbabisgesteentes op 'n groot skaal deur verskeie magmas ingedring wat van gabbroïes tot sïenities en granities varieer. Die hoofdoele van hierdie studie is om die verhoudings tussen die verskeie intrusiewe gesteentes te ontrafel en om hul protoliete asook hul posisie in die strukturele en metamorfe ontwikkeling van die Damara-orogeen te bepaal. Die intrusies het tussen 750 m.y. (ouderdom van 'n dioriet op Palmental 86) en ongeveer 456 m.y. (ouderdom van die Rössingalaskiet) plaasgevind. Afhanklik van die tyd van hul inplasing (voor-, sin- of na-tektonies) vertoon ook die intrusiewe gesteentes 'n maaksel.

'n Aantal intrusies word beskryf; hiervan het die Salem-graniet die wydste verspreiding.

Petrogenetiese studies dui aan dat die menings van vroeëre navorsers, wie die Salemgraniet algemeen as 'n smeltingsproduk van die Kuisebskis beskou het, nie gehandhaaf kan word nie, maar dat sekere variëteite daarvan van andere protoliete afkomstig moet wees. Daar is vasgestel dat die onderskeie lede van die suite

nie stamverwant is nie.

Baie van die intrusiewe massas is geochemies ondersoek; modale analises, Rb-Ba-Sr-diagramme, die Si/totale alkali verhoudings, SiO_2/element diagramme, 'n gemodifiseerde Larsen indekselement diagram en driehoekige variasiediagramme word bespreek.

1. INTRODUCTION

The Damara Orogenic Belt forms part of the late Precambrian to early Palaeozoic Pan African orogenic system (Kennedy 1964). It consists of three branches, of which the main one, situated between the Congo and Kalahari cratons, extends in a north-easterly direction whereas the northern and southern ones parallel the coast and continue into Angola and South Africa respectively.

This study is carried out in the "Central Zone" of the intracratonic branch, roughly between Walvis Bay and Karibib some 140 km further inland.

Recent seismic investigations (Baier 1982) indicate that in this area the continental crust is about 40-45 km thick.

The Okahandja Lineament, an ENE to NE trending zone of mainly vertical differential movement, separates the Central from the Southern Zone of the Damara Orogen.

At several localities basement rocks of the Abbabis Metamorphic Complex of pre-Damaran age are exposed. They comprise augengneisses, metasediments and metavolcanics which are between 1 700-2 000 m.y. old (Jacob *et al.* 1978).

The Damara Sequence was deposited between about 900-720 m.y. (Hawkesworth *et al.* 1981) upon a floor of Abbabis Metamorphic Complex rocks and its estimated total thickness has been some 10-14 km. The Damara Sequence begins with feldspathic quartzites, meta-arkoses and locally developed conglomerates, marbles and schists of the Etusis Formation. Together with the calc-silicate rocks and subordinate quartzites and schists of the Khan Formation, these constitute the Nosib Group. This succession is overlain by the Swakop Group, including the Rössing Formation (dolomitic marble, quartzite, calc-silicate, conglomerate), Chuos Formation (mixtite, meta-arkose, marble), Oberwasser Formation (calc-silicate, marble, phyllite), Kubas Formation (conglomerate, amphibole schist, calc-silicate, marble), Karibib Formation (mainly calcitic marble) and the Kuiseb Formation (mainly schist).

The rocks of the Abbabis Metamorphic Complex and the Damara Sequence were intruded by large masses of plutonic rocks. Apart from granites and granodiorites, which are most abundant, there are tonalites, quartz monzonites, quartz monzodiorites and quartz diorites. The earliest plutonic rocks intruding Damara metasediments have been dated at approximately 750 m.y. (Kröner 1980), whereas the youngest ones have an age of about 460 m.y. (Haack *et al.* 1983). The Otjimbingwe Alkali Complex consists of alkali-feldspar syenite, quartz syenite and aplite and is of Damaran age.

In the Central Zone, three major deformation phases occurred concomitantly with a long-lasting period of igneous activity. On a regional scale, NE-SW trending dome structures are the most conspicuous tectonic features.

The western part of the Central Zone is characterised by a high grade of metamorphism, and anatexis has occurred at some localities. A typical mineral association in schist is: cordierite + K-feldspar + biotite + quartz + plagioclase ± almandine; this indicates PIT conditions of about 2,5 kbar and 660°C (Hoffer 1977, Puhan 1979). The temperature decreased to about 640°C in an easterly direction and around Usakos a typical mineral assemblage in schist is K-feldspar + biotite + quartz + plagioclase ± sillimanite ± muscovite (Hoffer 1977, Puhan 1979).

During late Jurassic and early Cretaceous time Basement and Damara rocks were intruded by dykes and sills of dolerite and dacite and, near Henties Bay, by an alkali complex.

The combination of stratigraphic, petrologic and structural data has led to the development of two models for the evolution of the Damara Orogen. The intracratonic aulacogen model (Martin and Porada 1977) stands against a subduction model (Barnes and Sawyer 1980, Downing and Coward 1981).

The aim of the present investigations is to shed more light on the genesis of some of the plutonic rocks in the area between Walvis Bay and Karibib. The attention is focused on petrogenesis, geochemistry, intrusive relationships and geochronology of rocks belonging to, or associated with, the Salem Granite.

Detailed geological mapping has been carried out and samples for petrological, geochemical and geochronological studies were collected.

2. STRATIGRAPHY

Detailed descriptions of the stratigraphy were compiled by Gevers (1931), Smith (1965), Jacob (1974) and Bunting (1977). In the present chapter some additional information gathered during mapping in 1981 is given.

A review of the stratigraphy in the area is presented on Table 1.

2.1 Abbabis Metamorphic Complex

The most widespread and conspicuous rock-type of the Complex is a grey, pink or buff-coloured quartzofeldspathic augengneiss which also appears to be the lowest stratigraphic unit. Many weathered rocks display a reddish tint.

The following section through a stratigraphically higher level of the complex was established on the south-eastern limb of an isoclinal fold on Ubib 76.

E of Henties Bay	Sukses 90	Navachob 58
Kuiseb Fm	Kuiseb Fm	Kuiseb Fm
Karibib Fm	Karibib Fm	Karibib Fm
Oberwasser Fm	Oberwasser Fm	Kubas Fm
	Etusis Fm	Etusis Fm
		Abbabls M C
Kubas 77	Neu Schwaben 73	Otjimbingwe 104
Kuiseb Fm	Kuiseb Fm	Kuiseb Fm
		Tinkas M
Karibib Fm	Karibib Fm	Karibib Fm
Kubas Fm		
Chuos Fm		
Etusis Fm	Etusis Fm	Etusis Fm
	Abbabis M C	Abbabis M C
Rössing Mtn	Rössing Mine area	Horebis Mtn
Kuiseb Fm	Kuiseb Fm	Kuiseb Fm
		Tinkas M
Karibib Fm	Karibib Fm	Karibib Fm
Chuos Fm	Chuos Fm	Chuos Fm
Rössing Fm	Rössing Fm	
Khan Fm	Khan Fm	
	Etusis Fm	Etusis Fm
	Abbabis M C	Abbabis M C

Table 1: Stratigraphic sequence in different parts of the Walvis Bay - Karibib area.

top - metabasalt, consisting of a dark-green epidote-rich calc-silicate rock with irregular quartz veins. Amygdales are filled with epidote, but some have a quartz core. Thickness over 200 m
- fine crystalline calc-silicate rock (40 m)
- meta-arkose (30 m)
- scapolite-bearing calc-silicate rock (few metres) with intercalated thin layers (some cm) of grossular-bearing marble

bottom - coarsely crystalline, grey quartzite (10 m)

The highest stratigraphic unit of the Abbabis Metamorphic Complex consists of a cordierite-garnet-sillimanite-hornblende schist forming the syncline of the Klein Chuosberge on Tsawisis Suid 95.

2.2 Damara Sequence

The Nosib and the Swakop Group occur in the present area.

2.2.1 Nosib Group

This group of rocks has been subdivided into the Etusis and Khan Formations.

The former occurs in a broad zone, situated between Okahandja Lineament in the south-east of the present area and a line Walvis Bay - Usakos in the north-west.

The occurrence of the Khan Formation overlaps with that of the Etusis Formation in a zone of about 25 km wide south-east of the Walvis Bay - Usakos line. In a north-westerly direction, the Khan Formation extends for a further 20 km, whereas in a south-westerly direction the Etusis Formation extends about 30 km beyond the Khan Formation.

Etusis Formation

At the NE-trending anticlinal structure building the Kuduberg between Neu Schwaben 73 and Gamikaub 78 muscovite-bearing feldspathic quartzites with interbeds of sillimanite schist rest on pre-Damara augengneiss. The contact between the Etusis Formation and pre-Damara rocks is often strongly weathered. No basal conglomerate has been found here in the Etusis Formation.

In a domal structure, where Audawib West 81, Toanib Sued 117 and Otjimbingwe 104 meet, pink-red feldspathic quartzite of the Etusis Formation, locally including sillimanite-rich augen, is in direct contact with rocks of the Karibib and Kuiseb Formation.

Locally the quartzites are alternating with more pelitic layers. On Navachab 58, the Etusis Formation consists of feldspathic quartzites with one interbed of immature quartzite and, near to the top of the formation, a 2 m thick pebbly horizon. A conglomerate (channel-fill) on Etusis 75 belongs to the Etusis Formation and not the Chuos Formation as indicated by Smith (1965) (H. Martin, pers. comm. 1982).

Khan Formation

In the area south of Usakos and Karibib, no Khan Formation rocks are present. This also holds for the vicinity of the Tachub beacon (where Ubib 76, Etusis 75 and Kubas 77 meet), where, contrary to what is indicated on the existing geological map (Smith 1965), Chuos mixtite is in direct contact with Etusis quartzites.

2.2.2 Swakop Group

In this area there is a conformable relation between the Nosib and Swakop Groups. The lowest stratigraphic unit of this group is the Rössing Formation, followed by the Chuos, Oberwasser, Kubas, Karibib and Kuiseb Formations.

Rössing Formation

The occurrence of this formation is restricted to a triangular area defined by Swakopmund - Eureka 99 and a point some 40 km east of Walvis Bay.

The north-western part of this area (Swakopmund - Rössing Mountain - Eureka 99) is mainly underlain by dolomitic marbles characterised by the presence of partly serpentinised forsterite and, locally, of chondrodite. In the south-west a more diversified succession of marble, quartzite, calc-silicate, conglomerate and schist defines the Rössing Formation.

Chuos Formation

The terrain of Chuos mixitite in the north-western direction coincides with, but in the south-eastern direction goes beyond, that of the Rössing Formation up to the Langer Heinrich and the Chuos Mountains. The two supposed occurrences of this formation on Navachab 58, indicated by Smith (1965), actually belong to the Kubas Formation as described below. Likewise, a channel-fill conglomerate exposed on Etusis 75, which Smith (1965) believed to be Chuos age, actually belongs to the Etusis Formation (H. Martin, pers. comm. 1982).

Near the Tachub beacon (where Ubib 76, Etusis 75 and Kubas 77 meet) occurs a 30-40 m thick mixtite layer interfingered with typical Etusis Formation feldspathic quartzites (Fig. 1).

There seems to be a facies change in the Chuos Formation which must occur across the line Swakopmund-Usakos. On the north-western side of this line, the formation mainly consists of pebbly schist with subordinate meta-arkoses and marbles. The widely scattered pebbles in this mixtite measure up to 10 cm and mainly consist of quartzite and vein-quartz. These rock types can not be related to any exposed stratigraphic units in this area.

The more south-western occurrence of the Chuos Formation consists of a larger variety of rock types, and the density of pebbles and boulders is much higher. Boulders up to 80 cm and angular fragments of vein-quartz, quartzite, schist, calc-silicate, granite, pegmatite and aplite have been found. Some granite boulders were derived from the Abbabis Metamorphic Complex.

Oberwasser Formation

In Area 2114 D (north-east of Henties Bay) a very consistent calc-silicate unit below the Karibib Formation has been named the Oberwasser Formation (Botha 1978). Similar rocks in the same stratigraphic position occur in the area between Henties Bay and the Arandis Tin Mine, further eastwards on Sukses 90, on and west of Navachab 58, and continue in a northerly direction up to Uis. These calc-silicate rocks do not resemble the rocks of the Khan, Rössing or Chuos Formations in the Rössing Mountain - Khan Mine area.

Because these rocks, occurring directly below the Karibib Formation, form a well mappable unit within the area, extending from just east of Henties Bay inland up to Navachab 58 and northwards up to Uis, they can be considered as a formation at a stratigraphic level directly below the Karibib Formation.

Locally there are marble horizons within the calc-silicate succession and it has therefore been suggested (H. Martin, J. Klein, pers. comm. 1980), that this marble represents the Rössing Formation and that schists and calc-silicates above this marble are equivalents of the Chuos Formation mixtites whereas the calc-silicates below the marble are equivalents of the Khan Formation. In the area just north of Sukses 90, however, marbles intercalated in calc-silicates could be followed laterally into the marble succession of the Karibib Formation (N. Watson, pers. comm. 1980).

It seems therefore more likely that the marble horizons intercalated in the calc-silicate rocks of the Oberwasser Formation indicate that the deposition of pure limestone began locally in Oberwasser time already and that it was only during the following Karibib time that it became predominant. A similar distribution of sedimentary facies recurred when, as portion of the Tinkas Member and the Kuiseb Formation, limestones of the Karibib time were still deposited locally while in other areas shale and marl accumulated which later became Tinkas calc-silicate and schist and Kuiseb schist.

Kubas Formation

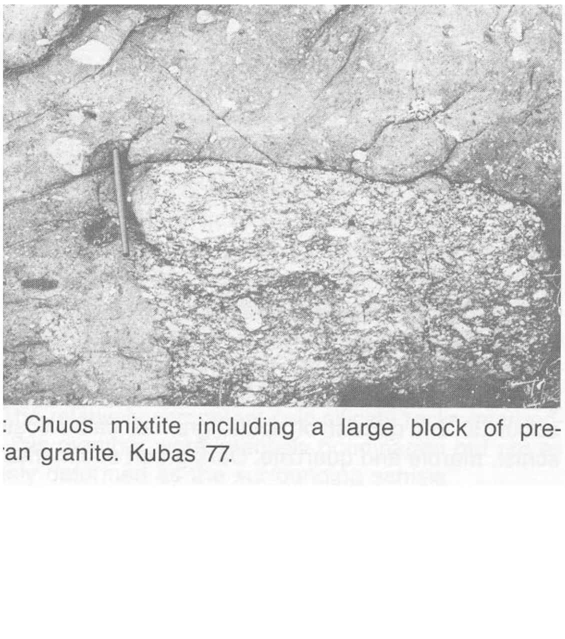
On Habis 71, Navachab 58 and Okatjimukuju 55 occur conglomeratic rocks with a calc-silicate matrix in a stratigraphic position between the Abbabis Metamorphic Complex and Karibib Formation. Pebbles and boulders up to about 30 cm consist of aplite, granite, calc-silicate rock, schist, marble and quartzite. Dark green sedimentary calc-silicate layers are present and locally imbrication structures have developed.

On Navachab 58 the following sequence is present:

Karibib Formation (W) -	layered white and grey marble
	dark grey phyllites and amphibole schist (80 m)
	phyllite (50 m)
	marble (60 m)
Kubas Formation -	phyllite (45 m)
	amphibole schist (50 m), locally with calc-silicate and granite pebbles in a layered calc-silicate matrix
	phyllite (80 m)
Etusis Formation -	meta-arkose and feldspathic quartzite

whereas at Tachub beacon on Kubas 77, the following rocks have been found in a N to S section:

Kuiseb Formation -	biotite schist
	white and grey marble (up to



: Chuos mixtite including a large block of pre-
'an granite. Kubas 77.

80 m) brecciated marble (1-2 m)
spotted hornblende-bearing calc-silicate rock with few very subordinate layers or lenses containing granite debris. Joints are filled with epidote
marble (1 m)
grey, very fine-crystalline mica

Kubas Formation - schist with calc-silicate seams including small hornblende blasts (50 m)
breccia or pebbly rock with blocks up to 80 cm (4-5 m) calc-silicate rock with epidote-filled joints (10 m)
marble (2 m)
pebbly or brecciated rock (10 m) calc-silicate rock with epidote in joints (10-15 m)

Chuos Formation - mixtite (30-40 m), interfingered with Etusis Formation rocks; no sedimentary layering

Etusis Formation - feldspathic quartzite and meta-arkose, at few localities calc-silicate lenses.
Joints filled with epidote

From the above, it is clear that in the area between Kubas 77 and Okatjimukuju 55 there is a stratigraphic unit between the Chuos and Karibib Formation consisting of conglomerate, calc-silicate rock, amphibole schist, phyllite and marble. The conglomerates have in contrast to the Chuos Formation mixtites a sedimentary layering and locally display sedimentary structures such as imbricated position of pebbles.

A good section through this stratigraphic unit occurs near the Tachub beacon on Kubas 77, hence the name Kubas Formation.

Karibib Formation

Calcitic marbles of this formation are widespread in the north-west of the present area, passing into more dolomitic ones towards the Okahandja Lineament. They are characterised by very local occurrence of chondrodite and serpentinised forsterite.

Karibib marbles interfinger upwards with the Kuiseb Formation or its Tinkas Member and downwards with the Oberwasser and, sporadically, the Khan Formation.

Kuiseb Formation

Schists belonging to this formation are widespread. The main types are a biotite-quartz and a less pelitic, more feldspathic schist. Garnet, cordierite and microcline are usually present as well. Muscovite is also quite abundant in the area south of Usakos and Karibib as a late mineral, which has overgrown the pre-existing planar fabric of the schist. Calc-silicate intercalations, locally boudinaged, do occur.

On the southern side of the complex tectonic structure formed by Karibib marble on Neu Schwaben 73 (northern part of Audawib West 81 on old maps), Kuiseb Formation schists are in contact with a porphyritic Salem granite. Near the contact the schist contains K-feldspar porphyroblasts, an indication of contact metamorphism due to granite intrusion.

As described more extensively later in section 4.5, Kuiseb Formation schists at many localities occur together with Salem granite. Virtually all of this granite has intruded the schist but not the underlying Karibib marble from which it is usually separated by a likewise unintruded seam of mica schist. Examples of this can be found on Navachab 58, Etusis 75, Okongava Ost 72, Kubas 77 and Gamikaub West 115.

Tinkas Member: Along the north-western side of the Okahandja Lineament the Kuiseb Formation, besides the thick mica schists making up for most of this unit, also comprises a sequence of alternating thinly-bedded calc-silicate rocks, para-amphibolite, marble and mica-quartz schists. The latter are of the same type as the ones following higher up in the sequence. On the eastern side of the Vredelus dome (on Vredelus 112) these rocks occupy a stratigraphic position above the Karibib Formation but below the bulk of the Kuiseb schists, and thus constitute the Tinkas Member of the Kuiseb Formation as defined by Jacob (1974). In the area along the Swakop River south of Usakos and Karibib, the Tinkas Member occurs at the Erekere Mountain (Otjimbingwe 104) and around the Potberg (Tsaobismund 85).

3. ANALYSIS OF THE STRUCTURAL AND METAMORPHIC HISTORY OF THE METASEDIMENTARY ROCKS

3.1 Micro- and Mesoscopic Structures

3.1.1 Deformation of Schist

From thin section and field observations it was found that the porphyroblastic cordierites of the Tinkas and Kuiseb schists possess a more or less planar internal fabric s_1. It is caused by the planar arrangement of included biotite flakes, quartz, feldspar and, locally, sillimanite crystals. This is the first tectonic planar fabric s_1 in the rock and originated during the first phase of deformation, F_1. The same, although generally coarser crystalline, major rock-forming minerals also from the external fabric s_6 outside the cordierite crystals.

S_2 is the main regional schistosity, which came into being only after the interkinematic (F_1 - F_2) growth of cordierite, and the re-alignment of the major rock forming minerals. It is classified as an s_2 schistosity. In most cases it is still continuous with s_1, but bends around the cordierites whereas the s_1 often has been rotated with the cordierites during F_2. A prolonged period of cordierite growth during F_2 can be deducted from the occurrence of cordierite tails in pressure shadows of such rotated crystals. Garnet occurs less abundantly in the area south of Usakos and Karibib; it was probably formed at the same time as the cordierites. Sillimanite, where it occurs in cordierite, must have crystallised before its host. Aggregated sillimanite (fibrolite) was deformed by F_2 into augen arranged in the main (s_2) schistosity plane. It has an undulatory extinction and is folded together with the main schistosity. Two generations of muscovite occur. The very early crystals (pre-F_1) are undulatory and some of them were partly replaced by K-feldspar and sillimanite. Later crystals have overgrown the main, folded fabric of biotite, quartz and feldspar and do not show a preferred orientation or undulatory extinction. The main schistosity (s_2) is not deflected around these muscovites and this indicates their postkinematic (post-F_3) crystallisation. Fig. 2 illustrates the paragenetic sequence of the metamorphic minerals.

The third deformation phase F_3, which has been ubiquitously active, as can be deduced from the deformation of the F_2 schistosity and structures, led only locally to the development of a schistosity plane s_3, mainly in schists of the Tinkas Member. The s_3 schistosity planes developed as fracture planes or crenulation cleavage planes in schists, resulting in a tectonic layering parallel to the F_3 axial plane (Fig. 3). Away from the Tinkas belt and the Okahandja Lineament, the small scale F_3 deformation is less conspicuous. The relatively competent calc-silicate rocks interbedded in this member were intensely boudinaged but not as intricately deformed as the surrounding schists.

3.1.2 Deformation of Marble

On Navachab 58 the Karibib Formation consists of a succession of light- and dark-grey layers between less than one cm and more than one metre thick. Several horizons or lenses in the marble sequence are brecciated. In such cases the dark-grey layers are broken up and the pieces float in a light-grey matrix. These brecciated

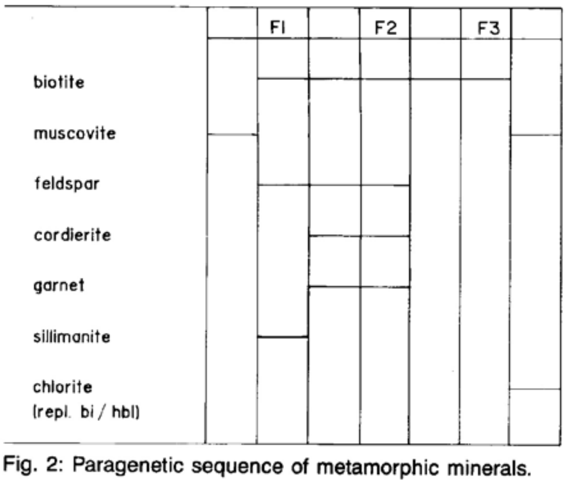


Fig. 2: Paragenetic sequence of metamorphic minerals.

Fig. 3: F_3 fracture cleavage in cordierite-bearing layers of the Tinkas Member. At bank of Swakop River, some 20 km west of Otjimbingwe.

zones are always parallel to the sedimentary layering and might have originated during the consolidation of the calcareous sediments. This type of fracturing has been found at several localities.

The deformation of the marbles can be studied in the field only once well defined calc-silicate or schist layers are present. Many small-scale F_1 folds in calc-silicate layers embedded in marble have a typical “flame” appearance. Due to the plasticity of the marble, the F_1 folds remained undeformed during subsequent folding. On mesoscopic scale there are indications that NE-trending F_2 and F_3 structures are coaxial.

The succession of calc-silicate and marble layers does not necessarily represent a simple sedimentary sequence. It has been found that thin spurs of calc-silicate material out of one layer cross the intermediate marble layer and disappear into the next calc-silicate layer. These spurs are often associated with the “flame-like” folds as mentioned before and the present layering in the marbles is partly of tectonic origin and a result of the first phase of deformation.

3.2 Megascopic Structures

The main structures formed by rocks of the Abbabis Metamorphic Complex and the Damara Sequence are longstretched north-eastward trending folds, due to the coaxiality of the F_2 and F_3 phases of deformation (see 3.1.2). Non-coaxial interference structures such as exposed at the Rössing Mountain and the Karub Gorge, or the Nose Structure (Smith 1965), are F_1/F_2 interference folds.

3.3 Thrusting

On Goas 79, augengneiss of the Abbabis Metamorphic Complex has been found intercalated in Karibib Formation marbles. It was brought into this position by thrusting oblique to the Basement-Damara contact.

The southern part of this Basement occurrence is in contact with schists of the Kuiseb Formation. Further to the north-east, however, there is a wedge of porphyritic Salem granite between the schists and the basement. The schist contains feldspar porphyroblasts, and in both the granite and the schist the large feldspar crystals were rotated and sheared. This granite-Basement contact is probably also abnormal and a result of thrusting.

A strongly sheared contact between feldspathic quartzites of the Etusis Formation and overlying marbles of the Karibib Formation has been found on Neu Schwaben 73. The contact rock is a blasto-mylonitic schist, about 10 m thick. Quartz-feldspar augen are embedded in a recrystallised biotite-quartz-feldspar matrix. The calcite crystals in the marble show only weak deformation, indicating a recrystallisation after the thrusting.

4. PLUTONIC ROCKS

4.1 General Remarks

Previous investigations by Gevers (1931), Smith (1965), Jacob (1974) and Bunting (1977) have shown that in the area between Karibib and Walvis Bay rocks of the Damara Sequence and the Abbabis Metamorphic Complex have repeatedly been intruded by large masses of plutonic rocks in the course of their structural and metamorphic evolution. The earliest plutonic rocks are of pre-Damaran age and intruded the older succession comprised in the Abbabis Metamorphic Complex.

At the onset of Damaran intrusive activity in the present area, “diorites”, now exposed on Palmental 86, intruded ± 750 m.y. ago (Kröner 1980), whereas the age of the youngest intrusives, the Rössing alaskites, is ± 460 m.y. (Hawkesworth *et al.* 1981).

There are five major groups of plutonic rocks:

(i) red inhomogenous syntectonic granites, occurring with Nosib or Basement rocks, or occupying the stratigraphic position of these. They are confined to the western part of the Central Zone where the degree of metamorphism was higher than in the eastern part;

(ii) red and grey homogenous syntectonic granites, not confined to a certain stratigraphic level; these occur throughout the Central Zone;

(iii) the Salem granite, a group of fine-to coarse-crystalline, porphyritic, grey (locally reddish) granites. The group comprises pre-, syn- and post-tectonic members. Apart from a few exceptions, these rocks occur mainly together with the Kuiseb Formation;

(iv) the post-tectonic granites of which the Donkerhuk Granite along the Okahandja Lineament is the most important one. Other intrusives of this group are the Gawib, Achas, Bloedkoppie and Kubas granites;

(v) alaskites or leucogranites, the youngest intrusive, do not form discrete plutonic bodies, but occur largely as sheets (Downing *et al.* 1981) at various stratigraphic levels. They are syn- or posttectonic and mainly intruded into the higher metamorphic western part of the Central Zone.

4.2 Aim of Present Investigations

The present investigations try to unravel the relationship between different plutonic rocks, their possible protoliths and their place in the structural and metamorphic evolution of the Damara Orogenic Belt. Research is mainly focussed on the Salem granite but to be able to define the group in geochemical and geochronological terms, it is necessary to investigate other granites as well. Samples for geochemical research have been taken in the area south of Karibib and Usakos.

4.3 Description of Major Plutonic Rocks

4.3.1 Habis Granite

Gevers (1931) named this grey-brown porphyritic granite after the farm Habis 71 where it occurs within the domain of the Abbabis Metamorphic Complex. It is a coarse-crystalline biotite granite with K-feldspar phenocrysts, which only locally define a slight foliation. Xenoliths of biotite or hornblende schist and of hornblende-rich rock are present. The planar fabric in the rock is mainly defined by biotites of the matrix. In places the granite has a gneissic appearance with broken or flattened phenocrysts. This basement granite also occurs above the Karibib Formation and it is believed that this is due to thrusting oblique to the contact of basement and Damara rocks. Blocks and boulders of this granite have been found in channel-fill metasediments of the Etusis Formation on the farm Etusis 75 (Martin, pers. comm.), attesting to its pre-Damara age.

4.3.2 Metagabbros

At many localities a coarse crystalline dark green-black and relatively homogeneous hornblende-rich rock is present, consisting almost entirely of hornblende crystals with a varying amount of interstitial plagioclase and quartz. Some varieties include quartz porphyroblasts. Gabbros contain xenoliths of calc-silicate, marble and schist. Small plug- or dyke-like bodies are present, in most cases together with hornblende granodiorite or hornblende-quartz diorite. The contacts of the metagabbros with surrounding plutonic or metasedimentary rocks are sharp. On Neikhoes 74 and Etusis 75 dykes and plugs of metagabbro form a pattern resembling a ringdyke with a diameter of about 4 km.

At one of the localities on Otjimbingwe 104, metagabbro occurs in a hornblende-quartz diorite. On the cuspate margins of the metagabbro, small basic pegmatitic veins have grown, consisting of hornblende crystals a few cm long in a plagioclase matrix with accessory sphene and calcite. This gabbro probably

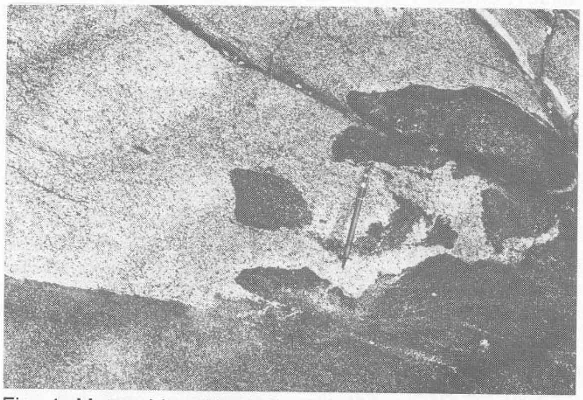


Fig. 4: Metagabbro (dark), intruded by hornblende-quartz diorite. Audawib River, Otjimbingwe 104.

intruded after the granodiorite and quartz diorite had intruded the metasediments, because it occurs within these intrusives and contains xenoliths of the Damara metasediments. It has been suggested (B.J.V. Botha, pers. comm.) that this is an example of "magma mixing" in which a more basic and hotter magma intruded a more felsic one (Fig. 4).

4.3.3 Otjimbingwe Alkali Complex

Two occurrences of Damaran syenitic and associated plutonic rocks are present in the Otjimbingwe 104 area. The western one forms part of the Erekere Mountain between the Audawib and Swakop Rivers and measures about 10 by 1,5 km, whereas the second body occurs about 12 km further E and is described by G. de Kock (this volume).

Several rock-types occur, viz:

(i) a foliated, dark-grey, porphyritic hornblende-alkali-feldspar syenite or quartz syenite, the main component of the complex. The rock is holocrystalline and has a hypidiomorphic texture. The main rock-forming minerals are microcline and plagioclase, green hornblende, biotite and colourless pyroxene (augite). Accessories such as sphene, apatite and opaque ore minerals are present. The K-feldspar phenocrysts reach a length of up to 10 cm, the hornblende crystals up to 0.5 cm. The pyroxene often occurs in the centre of hornblende crystals, attesting to the origin of the hornblende by replacement of the pyroxene;

(ii) a foliated very light-grey hornblende-alkali feldspar or quartz syenite, devoid of K-feldspar phenocrysts, forming an oval body within the main syenite. It contains xenoliths of a dark-green hornblende-rich rock;

(iii) a relatively fine-crystalline, light-grey biotite granite;

(iv) a hornblende-rich rock, occurring as xenoliths in most of the other rock-types. It also contains grey K-feldspar phenocrysts, but they are somewhat smaller than the ones in the host rock;

(v) pink feldspar-rich or feldspar-only veins which intruded most rocks of the complex. A coarse crystalline rock with magnetite seems to be the main type, but finer crystalline veins without this mineral are also present;

(vi) hornblende rocks, forming veins only a few mm thick, which cut across the foliation of other members of the complex. Light-green hornblende crystals have overgrown the contact between the syenite and the feldspar-rich veins.

4.3.4 Hornblende-bearing Plutonic Rocks

Several isolated bodies of hornblende-bearing plutonic rocks are present in the area south of Usakos arid Karibib.

The modal composition of the one on Goas 79 (Goas granite, Gevers 1931) varies between that of tonalite and granodiorite. The pluton on Okongava Ost 72 consists of granodiorite, quartz monzonite and quartz diorite. Quartz monzonite occurs on Navachab 58 and is probably part of the Okongava body. The medium-crystalline hornblende-bearing rocks may contain biotite and some garnet, and have sharp contacts to metasedimentary rocks of the Kuiseb and Karibib Formations and the Tinkas Member. At the edge of plutons, xenoliths of the metasediments can be present, whereas xenoliths of dark green-black hornblende-biotite-feldspar rocks are common throughout all the plutons.

On Navachab 58 quartz monzonite has been found above Karibib Formation marble and below it, together with Abbabis Metamorphic Complex rocks. A plug of dark hornblende-quartz diorite (?) together with some white sugary marble occurs in Basement augengneisses on Habis 71. The diorite intruding the gneiss has possibly brought this piece of Karibib (?) marble along.

The hornblende-bearing plutonic rocks were intruded by lighter-coloured biotite granites and several types of pegmatite. On Goas 79, foliated tonalites were intruded by the porphyritic Salem Granite and on Navachab 58 some quartz syenite dykes intruded quartz monzonites.

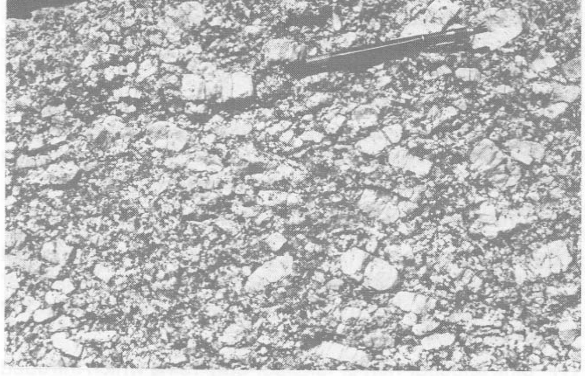


Fig. 5: Weathered surface of porphyritic Salem granite. Neu Schwaben 73.

4.3.5 Salem Porphyritic Granite

The name Salem Granite was introduced by Gürich in 1891 for the well known grey porphyritic biotite granite exposed on and near Salem 102 at the Swakop River. It is a coarse-crystalline quartz-biotite granite with K-feldspar phenocrysts of up to 3 em (at one place up to 7 cm) (Fig. 5). Schist xenoliths are common along its contacts with metasedimentary rocks. At the Swakop River on Tsaobismund 85, a large inclusion (60 x 30 m) of Karibib Formation (?) marble has been found. On Neu Schwaben 73 lenses or veins of the granite occur, parallel to the regional schistosity in neighbouring schists. Contact metamorphism led to the growth of K-feldspar porphyroblasts in the schist within a few metres of the contact with the main granite, and some porphyroblasts have overgrown the schist - granite contact (Fig. 6).

On Neikhoes 74 secondary muscovite occurs in schist up to 100 m away from granite-schist contacts.

In the area immediately south of Karibib and Usakos there is no regionally developed foliation in the porphyritic Salem granite, but elsewhere in the Walvis Bay - Karibib area this may be present. Occasionally a primary foliation (planar flow structure) is present in the form of biotite-enriched schlieren in which the biotite has a planar orientation.

4.3.6 Plutonic Rocks on Neikhoes 74 and Etusis 75

Plutonic rocks at these localities are quite different from the other occurrences. Whereas elsewhere.there is little variability of rock types in a certain area, here many different types of plutonic rock occur, as well as migmatites. This complex rock mass is surrounded by schist of the Kuiseb Formation; in areas where these were cut off by the intrusive rocks, Karibib Formation marbles fringe the complex.

Most of the area is underlain by granodiorites and tonalites (chapter 4.3.4), whereas dykes and plugs of gabbro form a pattern resembling a ringdyke. Hornblende-quartz diorite, porphyritic Salem Granite and fringing Kuiseb Formation schist were intruded by a biotite granite that is characterised by roundish quartz phenocrysts which locally are elongated in a foliation plane.

A leucocratic two-mica granodiorite is intrusive; into the rocks mentioned.

4.3.7 Naibberg Granite

This buff-coloured, fine to medium crystalline, foliated and in places garnetiferous biotite granite is present at several localities. It contains widely scattered, up to 1 cm long K-feldspar phenocrysts not all of which are orientated in the foliation plane. Muscovite is present as a secondary mineral and has overgrown the foliation.

On Ukuib West 116 this granite intruded the porphyritic Salem Granite. Along their contact both granites have the same foliation. On Otjimbingwe 104 the Naibberg Granite intruded the hornblende-quartz monzonite and was itself intruded by Donkerhuk Granite (G.S. de Kock, pers. comm.).

4.3.8 Kubas Granite

A large portion of Ubib 76 and Kubas 77 is underlain by a porphyritic, leucocratic biotite granite, which has K-feldspar phenocrysts right up to the contact with the metasedimentary rocks. Whereas, with the exception of the Habis granite, all intrusive rocks described in section 4.3 occur in the same stratigraphic position as the Kuiseb Formation, the Kubas Granite is not restricted to any certain stratigraphic level and is in contact with the Abbabis Metamorphic Complex and the Etusis, Chuos, Kubas, Karibib and Kuiseb Formations (Fig. 7).

At the contact, the schistosity planes as well as pegmatite veins in Basement rocks are cut off by the granite. Pegmatite veins emanating from the granite intruded the country rock and remained unfoliated. At the contact with the Etusis Formation the granite has a foliation parallel to it and the Etusis feldspathic quartzites

Fig. 6: Porphyroblasts of K-feldspar developed in a xenolith of mica schist (top) included in coarsely porphyritic Salem granite (bottom). Otjimbingwe 104.

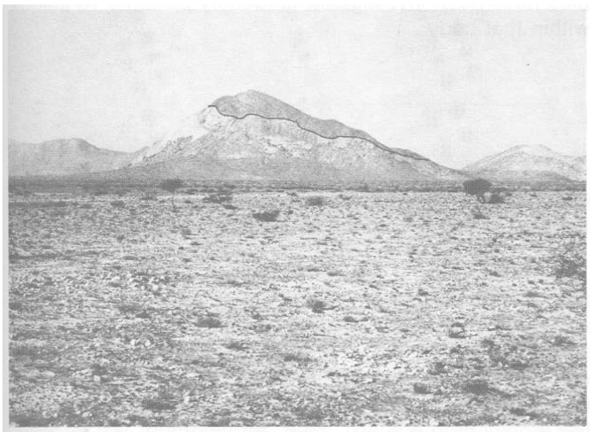


Fig. 7: Kubas Granite (lower portion of hill) overlain by feldspathic quartzite of the Etusis Formation. Contact as indicated by black line. Ubib 76.

are slightly brecciated and have a tectonically disrupted sedimentary layering.

The porphyritic leucogranite was locally intruded by a reddish brown weathered leucogranite.

4.3.9 Donkerhuk Granite

The Donkerhuk Granite on Otjimbingwe 104, north of the Swakop River, is a medium crystalline, light-grey biotite-muscovite granite which locally contains K-feldspar phenocrysts up to 3 cm long. As is the case with the likewise post-tectonic Gawib Granite (south-west of the present area), an early granodiorite phase of this granite mass is also present. The contact with schists of the Tinkas Member or Kuiseb Formation is sharp. As is the Tinkas Member, the Donkerhuk Granite too is confined to a well defined belt, which also bounds the domain of the Tinkas Formation in the SE, along the Okahandja Lineament. Near the contact with the Tinkas Member the phenocrysts are idiomorphic or slightly elongated; pressure shadows were filled by quartz and feldspar. A foliation bends around these phenocrysts.

Garnet and sillimanite occur sporadically in the rocks and segregations of biotite were formed at many places.

The Donkerhuk Granite intruded the Naibberg Granite (see 4.3.7).

4.4 Some Structural Features of the Plutonic Rocks

At many places along the contact of plutonic bodies and metasedimentary rocks, a foliation parallel to this contact is developed. This phenomenon is too local to be of interest for a structural analysis, because it is not obvious whether this foliation developed due to intrusion or as a result of later, regional tectonic stress.

Most of the plutonic bodies display a penetrative foliation only locally, and in many cases a lineation is more prominent but again not uniform in orientation. It has been found that sheetlike granite bodies are easier subject to the development of a penetrative structural foliation than are the plug- or stock-like bodies. In porphyritic granites this is indicated by the mechanically rotated K-feldspar phenocrysts.

In the area investigated only the porphyritic Kubas Granite on Kubas 77 and Ubib 76 cuts distinctly across the schistosity of surrounding metasedimentary rocks (Fig. 8). Except for a locally developed foliation parallel to the margin, this granite does not display any other penetrative foliation and is therefore of post-tectonic (post-F_3) age.

A body with a very strong foliation is the eastern extension of the western syenite body on Otjimbingwe 104 which intruded the Tinkas Member and is merely an about 1 m thick sheet of buff-coloured alkali-feldspar syenite, speckled with green hornblende. K-feldspar phenocrysts, up to one cm long, form augen or schlieren and many have pressure shadow tails filled by later feldspar. The foliation cuts through the hornblende crystals and is not flattened around them. In general there is a foliation of biotite, hornblende and K-feldspar phenocrysts which is parallel to the regional F2 schistosity in the host Tinkas Member schists. The syenite has a pre- or syn-F_2 age.

Fig. 8: Kubas Granite (bottom) cutting across schistosity and quartz-feldspar veins in schist of Abbabis Complex. Ubib 76.

The porphyritic Salem Granite as well as the hornblende-bearing plutonic rocks are locally intensively interfingered with Kuiseb Formation or Tinkas Member schists. The intrusion has always followed the main schistosity s_2 in the country rock and the plutonic rocks have developed a foliation plane parallel s_2. Locally these rocks are involved in F_3 folds and are therefore of a pre-F_3 age (Fig. 9). The schist xenoliths in the porphyritic Salem Granite locally contain small cordierite crystals with a planar internal fabric of F_1 age. The planar biotite-quartz-feldspar fabric in the groundmass was deflected around these porphyroblasts and is of F_2 age. These inherited and well preserved fabrics indicate a post-F_2 age of the Salem intrusion. It can therefore be concluded that this granite on the farm Goas 79 has

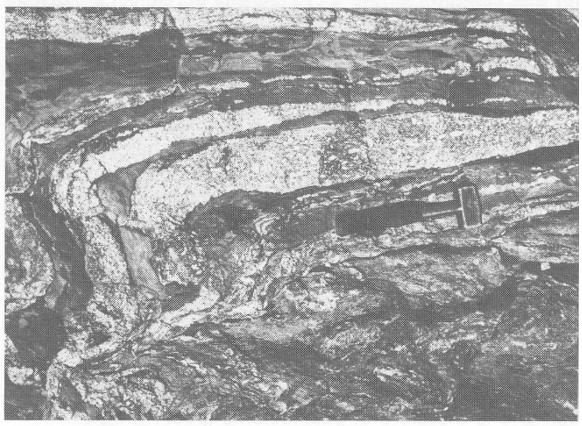


Fig. 9: Schist of the Kuiseb Formation (dark) injected by tongues of porphyritic Salem Granite (light); the granite-intruded succession was subsequently folded during F_3. Toanib 80.

intruded between the F_2 and F_3 phases of regional deformation.

4.5 Petrogenesis of Salem Granite

During more than 90 years the Salem Granite in the Central Zone has repeatedly been subjected to petrologic research (Gürich 1891, Gevers 1931, Smith 1965, Miller 1973, Jacob 1974, Bunting 1977). Most of these investigators were of the opinion that several of the intrusives found in the metasedimentary rocks belong to one magmatic suite, viz. the Salem Suite of which the ages of the members vary between 750 m.y. (Kröner 1980) and 459 my (Haack *et al*. 1982). It was therefore assumed that the Salem Suite attests to about 290 m.y. of igneous activity. There has, however, been quite a controversy about the petrogenesis of the Salem granites.

Some authors were of the opinion that the Salem magma was generated by partial melting of Kuiseb Formation schists, in which stratigraphic horizon the rocks belonging to the Suite almost always occur (Smith 1965, Miller 1973, Jacob 1974). In the present area the initial $^{87}Sr/^{86}Sr$ ratio of the Salem rocks is relatively high (between 0.72 - 0.74) and $d^{18}0$ and Sr isotope data show that they might well have been derived from Damaran metasediments (Haack *et al*. 1982). It was found, however, that in the northern part of the Central Zone the initial $^{87}Sr/^{86}Sr$ ratio of the Salem rocks is lower than the one in the Kuiseb Formation schists and therefore in this area the schists cannot have been the protolith of the Salem rocks. The same conclusion was drawn from a combination of $d^{18}0$ and Sr isotope data (Haack *et al.* 1982). Nd- and Sr-isotope work (Hawkesworth *et al.* 1981) has revealed that various rocks, which supposedly belong to the Salem Suite, were actually derived from different protoliths. "Diorites" originated probably in the upper mantle, whereas "granites" have a crustal origin.

Also relatively low temperatures of metamorphism of between 660-710°C (at 2.5-3 kbar) resulting from melting experiments and the study of metamorphic assemblages (Hoffmann 1976, Hoffer 1977) indicate that the Salem rocks in the Central area were not generated by partial melting of any underlying metasedimentary rocks.

The results of these investigations make it clear that no consanguinity within the Salem Suite exists.

4.6 Geochemistry of the Plutonic Rocks

4.6.1 Modal Analyses

Volumetric analyses have been carried out on 75 plutonic rock samples (Fig. 10). From some bodies up to seven samples have been investigated to identify possible variations within that body.

The five plots in the alkali-feldspar corner of Fig. 10 represent samples from the syenite body on Otjimbingwe 104. The two quartz syenites are veins intruded into the hornblende-quartz monzonite on Navachab 58. The Habis Granite of the Abbabis Metamorphic Complex, the porphyritic Salem Granite, the Naibberg Granite, the Kubas Granite and the Donkerhuk Granite all plot in the granite field. The plutonic rocks containing hornblende plot in the granodiorite, tonalite, quartz monzonite, quartz monzodiorite and quartz diorite fields. A xenolith in hornblende tonalite on Goas 79 revealed a dioritic composition.

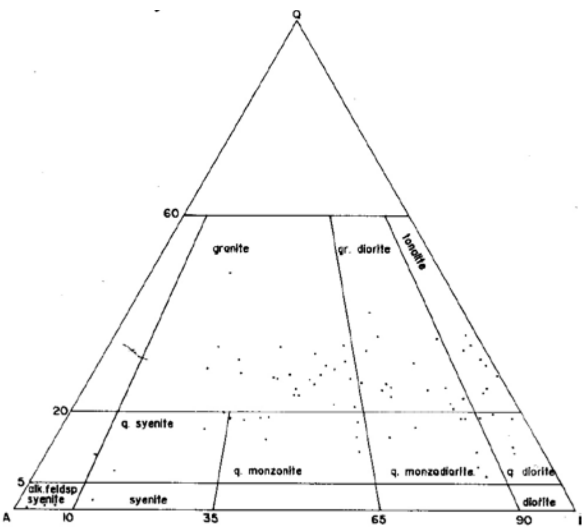


Fig. 10: Modal analyses of 75 plutonic rocks of I)amara age.

4.6.2 Rb, Ba, Sr Diagram

Not all rocks on which modal analyses have been carried out, have also been analysed geochemically.

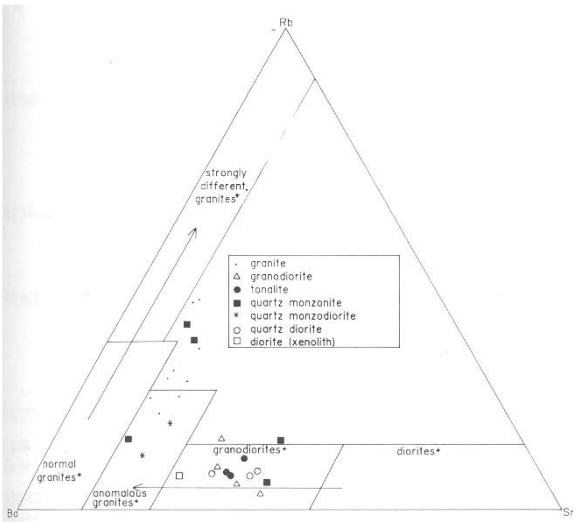


Fig. 11: Ternary relationship between Ba, Sr and Rb of various plutonic rocks of Damara age. Differentiation trend (arrows) after El-Bouseily *et al*. (1975).

The relationship between Rb, Ba and Sr is represented on a ternary diagram (Fig. 11) which according to El-Bouseily *et al.* (1975), can be used to trace differentiation trends in a series of plutonic rocks. As can be seen from the figure, the various plutonic rocks do not fall into the "prescribed" fields, and the plots actually do not indicate any trend. It seems that there are two groups of rock, the one comprising the granitic and quartz monzodioritic varieties, the other one the hornblende-bearing ones. The quartz monzodioritic rocks of the first group comprise the two migmatitic porphyritic Salem rocks with lots of garnet and cordierite in the leucosome which occur at Wlotzkasbaken.

The one quartz monzonite in the "anomalous granite" field is a weathered porphyritic Salem rock. Of the other two quartz monzonites, one belongs to the group of late intrusives, and on.e is a xenolith in a late granite. The hornblende-bearing rocks of the second group fall in, or near to, the "granodiorite" field. The one granodiorite with low Rb content is a late intrusive rock (post-dating the porphyritic Salem Granite) found on Neikhoes 74.

On separate Hb-Sr (Fig. 12) and Rb-Ba (Fig. 13) diagrams the trends in the distribution of points are the same. The diorite xenolith in the tonalite on Goas 79 plots near to the quartz monzodiorites. It contains less Sr than its host rock, indicating that there is no magmatic relationship between the two rock types.

4.6.3 Silica - Total Alkalies

A plot of SiO_2 against total alkalies (Na_2O+K_2O) is presented in Fig. 14. The two parameters seem to be related to each other (no statistical test has been carried out), since with a higher SiO_2 content the alkali content also increases.

The granites and quartz monzonites contain between 7.5 and 10.5 weight-percent Na_2O+K_2O whereas this percentage in the other plutonic rocks is only between 3 and 8. The difference must be ascribed to the higher alkali feldspar content of the granites and quartz monzonites compared to the higher plagioclase and biotite + hornblende content (see Fig. 15) of the other types of rock.

The trend in points, representing rocks with a different SiO_2 value, does not correspond with a trend in magmatic rock types, so it seems that there is no chemical evolution-trend. What is evident, however, is a general tendency towards grouping together of the granites on the one hand and the remaining rock types on the other hand. The three quartz monzonites, which in most

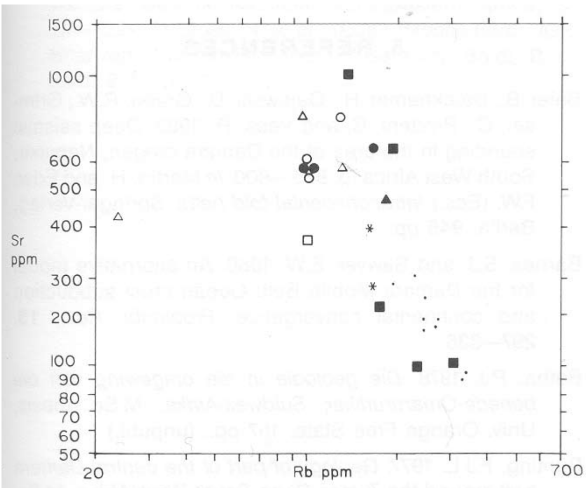


Fig. 12: Rb-Sr diagram of Damaran plutonic rocks. (Symbols as in Fig. 11).

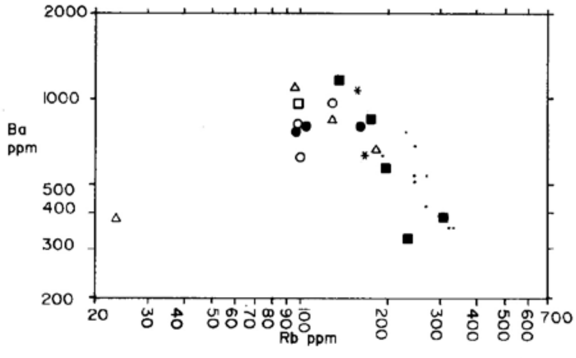


Fig. 13: Rb-Ba diagram of Damaran plutonic rocks. (Symbols as in Fig. 11).

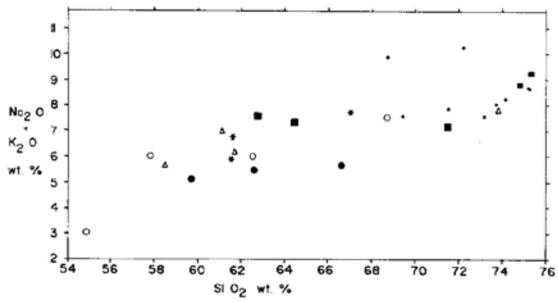


Fig. 14: SiO_2 - total alkalies diagram of Damaran plutonic rocks (Symbols as in Fig. 11).

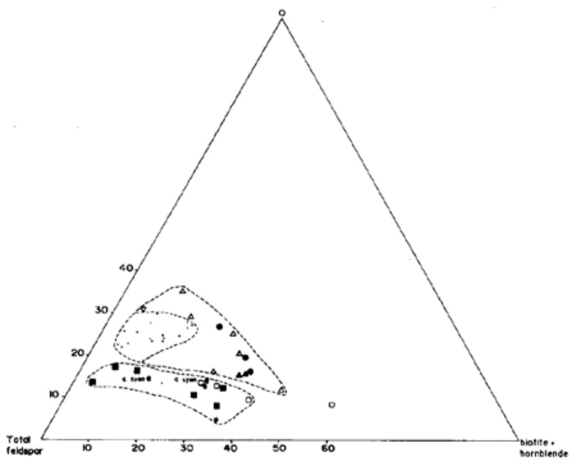


Fig. 15: Ternary relationship between total feldspar - biotite + hornblende - quartz of Damaran plutonic rocks. (Symbols as in Fig. 11).

diagrams plot together with the granites, are actually relatively late plutonic rocks, as are the granites. The same holds for the one granodiorite. There seems to be no chemical or time related evolution tendency between the plotted rock types. There are, however, intergroup relationships which can be derived from different plots.

4.6.4 SiO_2 - Element Diagrams

The elements K, Rb, Sr, Zr, V, Co, Y and Nb have been

plotted against SiO_2.

K_2O plots follow about the same trend as the total alkalies. Those of Rb behave similarly; the element is enriched towards the SiO_2 end of the diagram.

Sr and V show an opposing trend, as do Ba, Y and Co, but the data points are somewhat more scattered. Plots of Zr and Nb against SiO_2 give relatively horizontal trend-lines.

In most instances the granites and non-granites have different trends. The quartz diorites and tonalites in all diagrams display a well defined trend which may coincide with that of the granites (e.g. V, Nb, Rb), it can just have a different angle (e.g. Zr, Co), or the angle can be opposing (part of the Se curve).

4.6.5 Modified Larsen Index (MLI) - Element Diagrams

To identify the variation of some trace elements with the major elements use has been made of the Modified Larsen Index (Nockolds and Allen, 1953).

It was found that there is a gap in MLI values between the early plutonic rocks (MLI 4.2-8.8) and the later ones (MLI 11.4-15.9). Analyses of more samples are awaited to see whether this is accidental or whether there is a compositional gap. The spread of data points and the tendencies in the SiO_2-element diagrams and the MLI-element diagrams are about the same. The group of early plutonic rocks with an MLI of between 4.2 and 8.8 corresponds to the group of non-granites of the SiO_2-element diagrams. The group of younger rocks (MLI between 11.4 and 15.9) corresponds likewise to the group of granitic rocks of the SiO_2-element diagrams.

In the cases of Rb and Zr the data points in the group with the lower MLI values determine a trend more distinctly, in other cases (Sr, V) it is the group with the higher MLI values. Trends of the two groups can have the same, a different or an opposing angle. The same was found in plots of SiO_2 against different elements (4.6.4).

4.6.6 Triangular Variation Diagrams

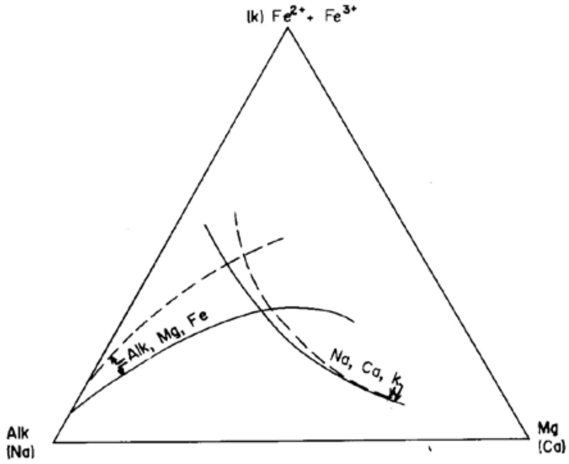


Fig. 16: Ternary trends as indicated. Solid lines: Damaran plutonic rocks; dashed lines: Southern California batholith (Nockolds and Allen, 1953).

Na+K, Mg, Fe^{2+} +Fe^{3+} and Na, Ca, K plots (Fig. 16) have been compared with similar plots which Nockolds and Allen (1953) established on tonalites, granodiorites and some leucocratic rocks of the Southern California batholith. Both curves for the Damaran plutonic rocks lie below the ones of Nockolds and Allen, indicating that in general the Damaran rocks are richer in Na and Mg and contain less K and Fe. In both curves the Damaran granites cluster around the trend-line, the other plutonic rocks show quite a spread along the line but the plots do not coincide with the granite cluster.

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