SOUTH WEST AFRICA
SUIDWES-AFRIKA

No. 4

South West Africa Series

The Khoabendus Formation in the Area Northwest of Kamanjab and in the Southeastern Kaokoveld, South West Africa

by

H. R. Porada

Met 'n opsomming in Afrikaans onder die opskrif:

DIE FORMASIE KHOABENDUS IN DIE GEBIED NOORDWES VAN KAMANJAB EN IN DIE SUIDOOSTELIKE KAOKOVELD, SUIDWES-AFRIKA

REPUBLIC OF SOUTH AFRICA, DEPARTMENT OF MINES

GEOLOGICAL SURVEY

REPUBLIEK VAN SUID-AFRIKA, DEPARTEMENT VAN MYNWESE

GEOLOGIESE OPNAME

Price — R0,40 — Prys

Overseas — R0,50 — Oorsee

Post-free — Posvry

Printed by and obtainable from the Government Printer, Private Bag X85, Pretoria
Gedruk deur en verkrybaar van die Staatsdrukker, Privaatsak X85, Pretoria

1974

ISBN 0 621 01650 0

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GEOLOGICAL SURVEY
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THE KHOABENDUS FORMATION IN THE AREA NORTHWEST OF KAMANJAB AND IN THE SOUTHEASTERN KAOKOVELD, SOUTH WEST AFRICA

ABSTRACT

Reconnaissance mapping during the winter season of 1970 in Area 1914 A and portions of Area 1914 B revealed that the Khoabendus Formation is much more widespread in the north-western Kamanjab Inlier than is shown on the Geological Map of South West Africa (1963). Many occurrences of granite and gneiss formerly correlated with the Basement Complex proved to belong to the Khoabendus Formation.

The outlines of the Khoabendus stratigraphy are presented. The lower part of the formation (West End Member) is made up of acid to intermediate lava (rhyodacite, dacite and rocks transitional to andesite) with associated pyroclastic rocks. This basal succession is overlain by a sequence of green andesitic tuff and flows of pyroxene andesite and hornblende andesite. Intruded into the volcanic rocks of the West End Member are bodies of adamellite and granodiorite porphyries which form sills and small apophysal bodies which were emplaced either towards the end of the volcanic period or post-date it.

The upper part of the Khoabendus Formation (Otjovazandu Member) has as its basal part a variety of volcanic and sedimentary rocks which were emplaced contemporaneously. The most characteristic rock-type included in the Otjovazandu Member is a white glassy orthoquartzite of terrestrial origin. It is overlain by massive rhyolite and felsite or by fine clastic sediments which were deposited in basins invaded by the sea. The member is capped by a succession of calcareous rocks precipitated after the final marine incursion in the area.

The Khoabendus Formation was invaded by two types of pre-Damara granite which have been named Kaross granite and Kamdescha granite. Through the intrusion of the Kaross granite, extensive portions of rhyolitic lava of the Otjovazandu Member were transformed into granitic rocks. The Kamdescha granite is coarse and porphyritic and was emplaced towards the end of the Khoabendus epoch.

The major structures in the area trend north-east or north and are of Khoabendus age. Structures of Damara age are superimposed on these and strike both north-west and north.

The metamorphism displayed by the Khoabendus rocks is low and does not exceed the greenschist facies.

The Khoabendus Formation may be correlated with the Opdam, Doornpoort, Nagatis and Sinclair Formations of the central and southwestern part of South West Africa.

I. INTRODUCTION

A. LOCATION

The Khoabendus Formation is exposed to the west, north and north-east of Kamanjab and to the north and north-west of Fransfontein. In this paper only the north-western part of the outcrop area of Khoabendus rocks is considered, comprising Area 1914 A and the south-western portion of Area 1914 B, altogether 3 000 km^2 in size (fold. 1).

B. PHYSIOGRAPHY

The eastern portion of the area is characterized by several prominent ridges of white Khoabendus quartzite running in south-easterly and northeasterly directions and rising up to 250 m above the surroundings. They divide an otherwise flat landscape into a number of interconnected open plains with an average elevation of 1 250 m above sea-level.

Towards the west the plains become more dissected by rivers draining westwards, the terrain becoming more rugged. In the westernmost portion of the area north-trending valleys, some of them possibly established in pre-Karoo times, are predominant. Their average elevation is 850 to 900 m, whereas the mountains framing them rise to 1 250 m.

C. PREVIOUS WORK

The name “Khoabendus Formation” was proposed by Stahl (1926, p. 146) for a succession of porphyries, mafic rocks, quartzites, schists and carbonates which occupies a considerable area in the northern part of the Kamanjab Inlier to the north and north-west of Fransfontein. According to him the Khoabendus Formation rests unconformably on highly metamorphic gneiss and granite of the Basement. However, he later (1940, p. 61) admitted that at the actual contact an unconformity is almost unrecognisable due to deep folding of the Khoabendus succession into the underlying rocks and that a clear-cut separation of the Khoabendus Formation from the Basement rocks is therefore not possible.

Stahl (1926, p. 147) correlated the Khoabendus Formation with the lower part (Kunjas Series) of the “Konkipformation” which was defined by Range (1912) as a succession of tuffs, amygdaloidal lavas, porphyries and conglomerates occurring in the catchment area of the Konkiep River near Helmeringhausen.

Martin (1965, p. 21) tentatively proposed the correlation of the Khoabendus Formation with the Skumok and Doornpoort Formations because of “......... comparable thicknesses of felsic quartz porphyries and feldspar porphyries”. Accordingly the Khoabendus and Skumok Formations are indicated with the same colour and hatching on the Geological Map of South West Africa (1963).

II. PRESENT INVESTIGATION

During the winter of 1970, Area 1914 A and those portions of Area 1914 B which are occupied by rocks of Khoabendus age were mapped by the author with a view to elucidating the stratigraphy of the Formation in its type area. Mapping was carried out on aerial photographs to a scale of 1:36 000.

A. GEOLOGICAL SETTING

The geological formations mapped are given below, together with brief descriptions of rocks in the areas other than those of the Khoabendus Formation.

1. Basement Complex

Granitic and granodioritic rocks, probably representing the Basement in the area, were found on De Ville 638, Swartskamp 640, West End 642, Tevrede 643, Khoabendus 645 and Kaross 237, altogether covering an area of approximately 50 km^2. In general they are almost unfoliated. Locally, however, gneissic structure with a north-trending foliation and shear-zones striking in the same direction are de-

Stratigraphic Column

Damara System	Upper Otavi Series		Cherty dolomite, limestone Biohermal dolomite Itabirite, tilloid
	Lower Otavi Series		Dolomite, shale
Nosib Formation			Feldspathic quartzite, grit Conglomerate
	Unconformity		
Khoabendus Formation	Otjovazandu Member	(Upper part max. thick-ness ca. 1 500 m)	Limestone, dolomite, marble (200 m) Cherty iron ore (50 m) Shale, siltstone (500 m) Rhyolite, felsite, tuff, andesite (450 m) White quartzite, conglome-rate (350 m)
		(Lower part max. thick-ness ca. 2 000 m)	Rholite, felsite; quart-zite Quartz porphyry, granite
	West End Member		Andesitic tuff and lava (150 m) Acid to intermediate lava and intrusives (500 m ?) Pyroclastic rocks (400 m)
	Unconformity		
Basement Complex			Granite, granodiorite
Intrusive Rocks	Kamdescha granite		Coarse porphyritic granite
	Felsite dyke		
	Kaross granite		Porphyritic granite, partly recon-stituted acid volcanic rocks

veloped. South-west of Otjovazandu these rocks are unconformably overlain by acid lavas of the Khoabendus Formation, while on Swartskamp 640 and De Ville 638 they grade through a palaeo-weathered zone into pyroclastic rocks belonging to the Khoabendus Formation. On. Kaross 237, however, they are intruded by a granite of Khoabendus age. The possibility that some of the rocks mapped as Basement may in fact be reconstituted Khoabendus rocks cannot be excluded.

2. Nosib Formation

In the northern and south-western parts of the area the Khoabendus Formation is unconformably overlain by a coarse boulder-conglomerate of Nosib age with blocks up to 1 m in diameter. At the very base the subangular blocks consist almost without exception of the rocks occurring directly below. Upwards the conglomerate is less coarse, better sorted and polymictic, containing boulders from different levels of the underlying Khoabendus Formation. The conglomerate is overlain by a reddish or grey feldspathic quartzite with pebbles in layers and lenses or scattered throughout the rock. Good outcrops displaying the succession of the Nosib Formation, which may locally exceed 1 000 m in thickness, are found near Kowares and along the Hoanib River west of Kamdescha 624.

3. Damara System

Rocks of both the Lower and Upper Otavi Series of the Damara System are found in the south-western part and along the western boundary of the area. In the northern part of the outcrop area only the Lower Otavi sequence, comprising light-grey shale, siltstone and intercalated light-coloured cherty dolomite is developed. It overlies the Nosib Formation paraconformably. Towards the south the lowermost members either fade out in a transgressive overlap (Martin, 1965; Guj, 1970) or were eroded before the onset of the deposition of the Upper Otavi succession, which otherwise follows discordantly on the Lower Otavi Sequence. In the south, therefore, only the Upper Otavi Series or part of it is developed. Where the complete succession is found, it starts with a reddish-brown feldspathic quartzite which is followed by tilloid with lenses of itabirite (Tillite Substage). The overlying succession begins with a dark biohermal and stromatolitic dolomite upon which rests a marker horizon of pale-pink dolomite. The top of the succession consists of several hundred metres of thinly bedded grey cherty dolomite.

III. KHOABENDUS FORMATION

The Khoabendus Formation consists of a variety of acid to intermediate effusive and intrusive igneous rocks accompanied by tuffs and pyroclasts, and a series of clastic and calcareous sediments.

During the course of the investigation it proved practicable to subdivide the Khoabendus Formation into two members, viz. the West End Member and the Otjovazandu Member and to distinguish two associated granites differing in age of intrusion.

A. WEST END MEMBER

The West End Member comprises a suite of various acid to intermediate volcanic rocks and associated intrusives. It includes pyroclastic rocks, tuffs and lava flows. The member normally starts with a thick succession of pyroclasts with thin intercalated lava bands. The average grain-size of the pyroclastic rocks decreases towards the top, whereas in the same direction the proportion of lava increases. The uppermost part of the West I End Member is made up of fine-grained green tuff, tuffaceous quartzite and intermediate lava.

1. Distribution and Field Relations

The fact that rocks of the West End Member crop out in the central and western parts of the area is due to a deeper level of erosion and probably also to the original extent of the deposits. The main outcrops lie within a zone approximately 20 km wide which stretches north-south from Kowares to Kamdescha 624, covering about 550 km^2. While the lower pyroclastic portion of the member is exposed in wide flat outcrops building a rolling landscape, the upper more tuffaceous part either crops out in long narrow bands following the overlying sedimentary-volcanic succession of the Otjovazandu Member, or occasionally also covers areas larger in extent, e.g. west of Otjovazandu.

The relationship with the surrounding rocks is as follows:

(i) The base of the West End Member is exposed at a few localities only. On De Ville 638 pyroclastic rocks of the lower portion of the member overlie granitic rocks of the Basement Complex. The contact is indistinct due to palaeo-weathering and a debris zone in the uppermost portions of the Basement succession.

(ii) Wherever exposed, the contact of the West End Member with the overlying igneous and sedimentary rocks of the Otjovazandu Member is conformable. Locally, however, a transition from West End Member rocks to those of the Otjovazandu Member is developed through a zone of repeated interbedding of intermediate and acid volcanic rocks (western part of the area, west of Kamdescha 624).

(iii) On De Ville 638, Kamdescha 624, northwest of the Kowares waterhole and in the western part of the area, rocks of the West End Member have been intruded by a coarse porphyritic granite (Kamdescha granite).

(iv) At several localities west and south of Kowares the West End Member succession has been intruded by a fine to medium-grained granite which has been tentatively correlated with the acid volcanic rocks of the Otjovazandu Member.

(v) West of Kamdescha 624 and in the area around Kowares rocks of the West End Member are unconformably overlain by a coarse conglomerate and quartzite of the Nosib Formation.

Field evidence readily allows a twofold subdivision of the West End Member into a lower mainly pyroclastic and effusive succession, and an upper tuffaceous part including flows of intermediate lava.

The upper part is rather uniform in appearance due to a general green colour and fine grain-size of the rocks. However, because of this uniformity it very often proved difficult to distinguish lava flows from interbedded tuff deposits. The exact succession therefore remains uncertain, and on the accompanying map these rock-types have not been separated. The thickness of the succession varies widely, which is not unusual for volcanic beds. It may reach 100 m and more on Tevrede 643 and in the large outcrop area farther west, or may be entirely absent, e.g. on Marenphil 641 and west of De Ville 638.

The lower part of the West End Member comprises a great variety of acid to intermediate rocks, grey to black in colour, occurring underneath the green tuff and lava. Pyroclastic rocks, locally with intercalations) intermediate lava 10 to 15 m thick, are the most widespread, occurring almost ubiquitously between Kowares and Kamdescha 624. They are not easily recognised everywhere in the field, but angular fragments of feldspar which stand out on weathered surfaces reveal the pyroclastic origin of the rocks, e.g. west of Otjovazandu and on Marenphil 641.

It is very difficult to estimate the thickness of these beds as the complete succession is exposed at only a few localities and it is not known whether repetition took place due to folding; owing to their explosive origin, considerable variations in thickness are to be expected.

West of Otjovazandu the thickness is estimated to be of the order of 10 to 30 m, while it may reach several hundreds of metres on West End 642 and west of Marenphil 641. In addition to pyroclastic rocks, effusive rocks become more abundant to the west of Kamdescha 624 and Kowares. Towards the west the pyroclastic rocks seem to die out or to interfinger with acid and intermediate lava. However, as it is not known which part of the succession is exposed at that locality, the change in rock facies may not be lateral but vertical, i.e. the pyroclastic rocks may also grade into lava flows towards the top.

Both lateral and vertical changes in rock facies probably take place in the western part of the area and, due to strong volcanic activity, manifold transitions and gradations from one rock-type to another are developed. More puzzling, however, is the fact that at a few localities effusive and intrusive rocks are found close together and that seemingly effusive rocks in places display intrusive relationships; fine-grained acid lava locally grades into coarse-grained rocks exhibiting textures typical of intrusive rocks. Some of these phenomena can be explained by the occurrence of sills and sub-volcanic intrusions of acid to intermediate rocks which affected the freshly deposited lavas and tuffs, while others may well reflect the usual physical variations in lava flows.

Near the northwestern corner of the outcrop area of Khoabendus rocks, light-coloured cross-bedded brittle quartzite is invaded by a medium-grained equigranular greenish-grey rock of granodioritic composition which at other occurrences has a gradational relationship to lava flows. This intrusive rock may occur below, above or within the quartzite and locally contains rounded xenoliths of the intruded rock and of intermediate lava and green tuff. An interpretation that these are sills is possible, but that it is a discordant intrusion seems more likely. The intrusion is regarded as closely related to the West End Member volcanism but post-dating the main volcanic events, since the granodioritic rock contains inclusions of green tuff which everywhere else has been found overlying the pyroclastic and effusive products of this volcanism. The intrusion could even have occurred considerably later if the intruded and included quartzite is correlated with those of the Otjovazandu Member. A certain continuation of the West End Member volcanism until after the outpouring of the first acid lava of the Otjovazandu Member is indicated in numerous outcrops by the interbedding of rocks of both Members, forming a transitional contact.

The whole suite of acid to intermediate, and to a lesser extent basic, igneous rocks is regarded as representing a single phase of volcanic activity with the rocks originating from a common magmatic course, but erupted and extruded from different localities over a considerable span of time. There must have been several centres of eruption to cover more than 1 500 km^2 with volcanic products, but their positions are not known. For the upper tuffaceous portion of the West End Member, one of the centres was presumably located on Tevrede 643 west of Otjovazandu, where large amounts of green lava and tuff of andesitic composition are still preserved.

2. Description of Rock-types

The more important rock-types included in the West End Member are pyroclastic rocks, various acid to intermediate lavas and intrusive rocks, green tuff and associated andesite.

(a) Pyroclastics

The general term “pyroclastics” is used for this group of rocks, because their actual mode of emplacement, which may well differ from place to place and within the stratigraphic succession, could not be determined. The term is thus applied to all detrital volcanic material explosively or aerially ejected from volcanic vents.

Pyroclastic rocks are frequently found at the base of the West End Member and may occupy a considerable thickness of its lower part. They are distinguished from interbedded and overlying lava flows by their fragmental nature, which is recognisable in hand-specimen.

Pyroclastic rocks are fairly widespread in the central part of the area mapped. They were first identified on West End 642 and Marenphil 641, where they are fairly fresh and only moderately sheared, whereas in many other areas strong alteration and severe shearing have obscured their pyroclastic nature and made them resemble a gneiss, e.g. around Kowares. They usually occur in flat outcrops from which more silicified portions may stand out as steep ledges 2 to 3 m high. The unsheared rock is greyish in colour and on the weathered surface exhibits irregularly-shaped fragments of feldspar, quartz and occasionally of ground-mass, whereas the fresh surface gives the impression of being a lava with a dark dense ground-mass and a few insets of quartz. In the lower portion of the succession the fragments, mainly feldspar, may measure up to 20 mm across, but higher up the average diameter ranges from 2 to 6 mm. In some layers the poorly sorted fragments are so densely packed that locally the rock may consist almost entirely of them, whereas at other localities more ground-mass can be recognised. At a few places graded bedding was observed in layers with thicknesses of about 20 cm.

In most of the outcrops the rocks are more or less strongly sheared and exhibit a greenish-grey or even green colour due to advanced saussuritisation of the feldspars and the formation of epidote and (or) chlorite. The feldspars and other detrital inclusions are rounded, or completely flattened, occasionally giving a distinct parallel structure to the rock. Where the shearing and flattening is less advanced, a speckled appearance is common.

Under the microscope all samples proved to be strongly altered. The original texture is rather obscured by a large number of newly crystallized minerals such as epidote, sericite, chlorite, biotite, albite, sphene and iron ore. However, angular crystal and lithic fragments set in a holocrystalline fine-grained matrix of mainly quartz and feldspar are recognisable.

Among the insets both alkali feldspar and plagioclase occur frequently, being represented either in more or less equal quantities or with the plagioclase dominating. The alkali feldspar is quite often a perthite with the sodium component arranged in patches (patch or vein perthite) or in minute strings (string or film perthite). Inclusions of clear plagioclase surrounded by rims of albite are not uncommon.

Plagioclase is usually much more weathered than the alkali feldspar and often only aggregates of sericite and epidote (clinozoisite), with the original plagioclase dimly discernible, remain. Some of the aggregates are surrounded by seams of clear albite, which points to their original nature. The composition of only a few plagioclase crystals could be determined; they proved to be albite to albite-oligoclase (An_{10-12}).

Fragments of quartz are less frequent than those of feldspar. They are usually small and poorly sorted but display their fragmental nature very distinctly; many of them are corroded.

Lithic fragments are difficult to recognise. Some aggregates consisting mainly of sericite and very fine-grained quartz and those which are not surrounded by albite rims might probably have been volcanic rock fragments originally.

The groundmass is either coarse and holocrystalline, comprising a mosaic of grains of quartz, alkali feldspar and plagioclase, or else fine and felted with abundant sericite and epidote and locally considerable amounts of chlorite and (or) biotite concentrated in patches or rims, and some larger grains or sphene and patches of calcite. Zircon is present as an accessory.

Judging from the proportions of quartz, perthite and albite, the composition of the rocks described above is rhyolitic to rhyodacitic.

(b) Lavas and Associated Rocks

The lavas and closely related rocks are distinguished from the pyroclastics by the absence of a fragmental rock structure and by being generally finer-grained, and from intrusive rocks by not displaying intrusive relationships. Lavas are found interbedded with pyroclastics as well as overlying them. The main outcrops are situated near the centre of the area, about 2 to 10 km northwest of beacon 39 and covering some 75 km^2, but lava flows may also be encountered elsewhere covered by the lower portion of the West End Member.

In the field and in hand-specimens a clear-cut distinction between pyroclastics and lavas on the one hand and between lavas and intrusives on the other is generally not possible; on the accompanying map lavas are therefore specifically marked only where they could be identified. Generally a sharp contact is not easily recognised between the above-mentioned rock-types, but a gradual transition is developed, with the rocks getting finer and locally losing most of their insets towards the lava. However, the lava is not everywhere fine-grained and without phenocrysts; considerable variations are developed and its appearance may range from fine without insets to medium or even coarse-grained with quartz and (or) feldspar phenocrysts.

The colour of the rocks is grey to dark grey with or without a greenish tinge. All specimens from which thin sections were prepared could not be exactly identified. That they are presumably rhyodacitic to dacitic in composition is suggested by the presence of quartz phenocrysts together with insets of alkali feldspar and plagioclase, as well as hornblende and biotite. Types transitional to andesite, i.e. without quartz phenocrysts and with minor alkali feldspar, are met with occasionally.

The quartz phenocrysts are quite often strongly corroded and range from 0,5 mm to more than 6 mm across. Alkali feldspar is present as insets of microcline-perthite and rarely of microcline and probably of orthoclase, which displays a patchy extinction. Plagioclase is the dominant feldspar; large phenocrysts and smaller laths are randomly distributed throughout the rock. They are all strongly altered to sericite or saussurite and frequently only patches of fine-grained felty white mica are left to indicate the former existence of plagioclase. Albite rims bordering the plagioclase are common, especially when the latter is in contact with alkali feldspar. These may have formed through the breakdown of calcic or intermediate plagioclase to saussurite and albite or by exsolution of the sodium component from alkali feldspar and perthite. Occasionally twinned plagioclase is dimly visible through the network of its own alteration products and proved to be an albite up to An_{10}. This albite is, however, regarded as pseudomorphic after the original more calcic plagioclase.

Biotite and green hornblende, with one or the other dominating in different rocks, are strongly altered to chlorite and epidote; sagenite is common in the altered biotite. Sphene is a rather abundant accessory and occurs in the form of irregular grains, of which some are of considerable size.

The ground-mass, consisting mainly of quartz, feldspar and alteration products, is always holocrystalline and may vary from fine-grained and felted, to coarse-grained and microgranitic to almost granitic in texture. Likewise the ratio of ground-mass to phenocrysts may vary considerably. Whereas in certain layers only a few phenocrysts are set in a uniform fine-grained matrix, at other places phenocrysts may be so numerous that almost no ground-mass is visible. Normally there is a distinct difference in grain-size between the smallest phenocrysts and the particles of the ground-mass; certain rocks, however, possess a seriate texture, i.e. a complete range in size of grains between ground-mass and phenocrysts.

Not all rocks described under this heading can be strictly classified as lavas. Because of their coarse matrix, some of them should rather be termed porphyritic micro-adamellite and micro-granodiorite or, using a different terminology, quartz-feldspar porphyry and dacite porphyry. These terms are usually applied to intrusive rocks, whereas those described above do not bear any intrusive relations to the surrounding rocks. However, some of the medium-grained varieties may well form sills or apophysal bodies which originated from the same magmatic source and intruded the freshly ejected lavas penecontemporaneously. The contacts would not be recognisable due to increased recrystallisation of the ground-mass of the invaded rock near the intrusion. On the other hand, they may also represent the lower portions of thick lava sheets in which cooling was slower than close to the open air, resulting in a coarser ground-mass.

(c) Intrusive Rocks

These rocks have been found to be intrusive into, and to include rounded xenoliths of, rhyodacitic lava, green tuff and quartzite and may somewhat post-date the West End Member.

The exact relation between the lava and the intrusive rocks is still unknown as the actual contacts are recognised with difficulty due to transitions. The possibility that magmatic stoping played a role during the emplacement of the intrusives is not excluded.

The rocks examined microscopically have a porphyritic texture almost without exception and fall in the quartz monzonite (adamellite) - granodiorite range; locally a quartz diorite has developed. Plagioclase and alkali feldspar occur in approximately equal quantities in most samples, but the plagioclase may also predominate in some and the alkali feldspar may be absent altogether. The plagioclase, which is represented by albite pseudomorphs after intermediate to calcic plagioclase, usually forms large euhedral phenocrysts, whereas the alkali feldspar (microcline-perthite) is present as allotriomorphic crystals which frequently contain inclusions of quartz.

The plagioclase is always strongly saussuritised and (or) sericitised but original zoning of the crystals may still be recognised. Albite rims are common where plagioclase borders on alkali feldspar.

Mafic constituents, which in some rocks amount to almost 50 per cent by volume, are green hornblende and biotite. Both are usually found in the same rock, either forming phenocrysts or being located in interstices between plagioclase crystals. The proportion of hornblende to biotite may, however, vary considerably. As a rule, hornblende predominates where plagioclase is the prevailing feldspar, whereas biotite is dominant where both feldspars occur in approximately equal quantities. The biotite is green and generally well preserved, whereas the hornblende is generally strongly altered to a mixture of epidote, chlorite and magnetite.

(d) Andesitic Tuff and Lava

Wherever rocks described under this heading are found, they overlie the rhyodacitic to dacitic lavas. Their distribution is shown on the accompanying map. Individual layers of tuff and lava are, however, not differentiated as they frequently interfinger and distinction between them is usually difficult in the field. On the other hand, they are easily distinguished from the other rocks included in the West End Member by their green colour, fine grain-size and greater susceptibility to shearing; the shearing is responsible for the serrated appearance which is a typical feature of the outcrops found in the country underlain by these volcanics.

Some of the tuffs are well-stratified and locally cross-bedded, e.g. 5 km west of Otjovazandu. Individual layers varying in thickness from 1 to 10 mm may be finer or coarser grained and may also differ considerably in composition. Crystals of green hornblende set in a very fine-grained silicified matrix are concentrated in some bands, whereas in others they may be rare, and angular fragments of quartz measuring up to 0,1 mm across are dispersed throughout the ground-mass instead. Feldspar is uncommon and, due to strong alteration, hardly recognisable. Some indistinct patches which are richer in sericite and epidote than the surrounding matrix, may point to the original presence of plagioclase. They may, however, also represent inclusions of altered rock fragments.

The most widespread type of tuff is unstratified and contains small angular fragments of quartz together with larger ones of hornblende and possibly feldspar in a fine-grained matrix of sericite, epidote, quartz, albite, chlorite and calcite; the matrix may be silicified locally.

It is presumed that some-of the tuffs described above are mixed with sedimentary material.

The lava associated with the tuff is andesitic to dacitic in composition. The most common type is a pyroxene andesite with phenocrysts of hypersthene or diopside and a little plagioclase, set in an originally pilo-taxitic ground-mass of plagioclase microlites, pyroxene laths and interstitial cryptofelsite. The ground-mass is altered to a dense network of sericite, uralite and chlorite with numerous grains of epidote, quartz, magnetite and a little albite. The hypersthene is transformed to bastite and the diopside to uralite, while relics of the original minerals are rarely seen.

In another type of andesite which has been found to be rich in calcite, green hornblende occurs as phenocrysts accompanied by a few grains of olivine.

B. OTJOVAZANDU MEMBER

The Otjovazandu Member is a sequence of igneous and sedimentary rocks including felsite, rhyolite, quartz porphyry, andesite, subordinate basalt, granite, conglomerate, quartzite, slate, siltstone, carbonates and iron ore. During the early stages of the development of this member, outflow of volcanics and deposition of clastic sediments took place contemporaneously at many localities. After cessation of volcanic activity, sedimentation of finer clastics and carbonates continued. Towards the top of the member andesitic and basic lavas are found locally.

This sequence has been called Otjovazandu Member because to the north of Otjovazandu a major part of the succession is typically developed, although the contemporaneous development of sediments and volcanics in the lower part of the succession is not exposed there.

1. Distribution and Field Relations

These rocks occupy more than 1 500 km^2 of the area, mainly in the eastern part. The upper sedimentary part is preserved only in long narrow synclines and synclinoria, the more important of which are situated around Voorspoed 629 and Blyerus 628, between Otjovazandu and Kamdescha 624, and in an area about 17 km west of De Ville 638 and Kamdescha 624. Between these areas this upper part has been eroded or was not deposited so that only the lower volcanic part is present.

The field relations of the Otjovazandu Member to the surrounding rocks are as follows:

(i) The Otjovazandu Member, with acid volcanics or clastic sediments at its base, overlies the West End Member conformably. In the western part of the area lava of the West End Member may be interbedded with the acid volcanics of the Otjovazandu Member at the contact.

(ii) Quartz porphyry of the Otjovazandu Member unconformably overlies granitic rocks of the Basement Complex along a sharp contact which is well exposed some 4 km south-west of Otjovazandu.

(iii) Granitic rocks which are closely related to the quartz porphyry of the Otjovazandu Member intrude granite and granodiorite of the Basement Complex in the north-western portion of Kaross 237.

(iv) In the north-western and south-western parts of the area rocks of the Otjovazandu Member are unconformably overlain by conglomerate and quartzite of the Nosib Formation.

During field-work it proved advantageous to use a prominent white glassy quartzite, called the "Khoabendusquarzit" by Stahl (1926), as a marker horizon. Due to its resistance to weathering it forms prominent ridges over long distances.

To simplify the description, it was deemed useful to subdivide the member into two parts, a lower one comprising the rocks which underlie the quartzite marker and an upper part starting with the quartzite. The Kaross granite, which is closely related to rocks of the lower part, is described separately.

2. Lower Part

The lower part of the member is developed only in the south-eastern part of the area and is characterized by the contemporaneous deposition of volcanic and sedimentary rocks, while at the same time the outflow of andesitic lava of the West End Member had not everywhere ceased. As a result, interbedding and the irregular distribution of the contemporaneous rocks can be observed wherever this part of the Otjovazandu Member is developed.

Typical sections are exposed at a few localities on Blyerus 628 and Voorspoed 629. In the latter occurrence quartzite is interbedded with acid lava and occasionally accompanied by tuff and flows of andesite. Individual layers are not persistent along strike; the quartzite especially may vary considerably in thickness and may even die out or interfinger with volcanic rocks.

The quartzite is dirty-grey in colour but reddish in places due to finely dispersed hematite. It is irregularly bedded and exhibits cross-bedding which is accentuated by thin layers rich in magnetite. At some places the quartzite grades into grit or even pebbly quartzite, or it may contain volcanic ejectamenta and become a tuffaceous quartzite.

Acid volcanics predominate in the lower part of the Otjovazandu Member. The microscope has shown them to be rhyolite and felsite, depending upon the presence or absence of flow-banding. Corroded phenocrysts and chips of quartz, potash feldspar and albite-oligoclase are always present in the fine-grained holocrystalline matrix in which very often a banding, marked by alternating coarser and finer layers, is recognisable. Lenticles consisting of somewhat coarser grained quartz or quartz-feldspar mosaics are frequently developed within the banded fine-grained sericitisedgroundmass of the rhyolite; they are arranged parallel to the banding, which is mostly straight or slightly undulating.

Due to the straight banding, the rhyolite in places has a platy appearance which is locally accentuated by shearing. The felsite, on the other hand, is more massive and occurs in irregular blocks which are scattered over the outcrop area. The ground-mass of the felsite is uniformly fine-grained and is not distinctly banded.

The rhyolite and felsite are interbedded and interfinger at some localities. No regular distribution, either along strike or within the succession, could be traced with any certainty. On Weissbrunn 192, Louwsville 633 and Die Vlakte 634 felsite seems to form the uppermost portion of the succession, whereas rhyolite and quartz-feldspar porphyry form the lower part. In this area no interbedded quartzite is present.

It could not be proved microscopically that any of the rocks are ignimbrites; the presence of crystal fragments and sporadic lithic fragments, as well as the straight banding, may indicate an ignimbritic origin for the rhyolites. Such an interpretation is further suggested by the vast areal extent of the rocks, which amounts to some 750 to 800 km^2.

The total thickness of the lower part of the Otjovazandu Member varies considerably, which is typical of volcanic successions. A rough estimate shows it to be in the range 1 500 to 2 000 m.

3. Upper Part

Because of local contemporaneous volcanic activity and sedimentation and deposition in separate basins, the sequence is characterized by considerable variations in thickness and facies. Typical schematic stratigraphic columns indicate that the succession can be conveniently subdivided into a lower volcanic-sedimentary and an upper carbonate part (fig. 1). The base of the carbonate rocks has been taken as a datum level, although its value as a chronostratigraphic marker is limited. However, its position marks a distinct general change in conditions of deposition which has affected large parts of the area within a comparatively short span of time. Below the carbonate rocks variable thicknesses of classic sediments and volcanic rocks accumulated. A maximum thickness of about 750 m is found at Gelbingen 630 and Kaross 237, whilst north of Otjovazandu the total thickness of the clastic and volcanic rocks amounts to only 250 m.

The distribution of acid volcanic rocks within the sediments is irregular. In some places the rhyolite occurs as a single layer up to 300 m thick, whereas in others it is found as layers 25 to 30 m thick, interbedded with sediments. The tuff associated with it either interfingers or is intermingled with the surrounding rocks. In the eastern part of the area volcanic and sedimentary rocks are intermingled to a lesser extent than to the west of Kamdescha 624, where almost the whole succession consists of interbedded volcanic and sedimentary rocks.

The more important rock-types or groups of rocks included in the upper part of the Otjovazandu Mem-

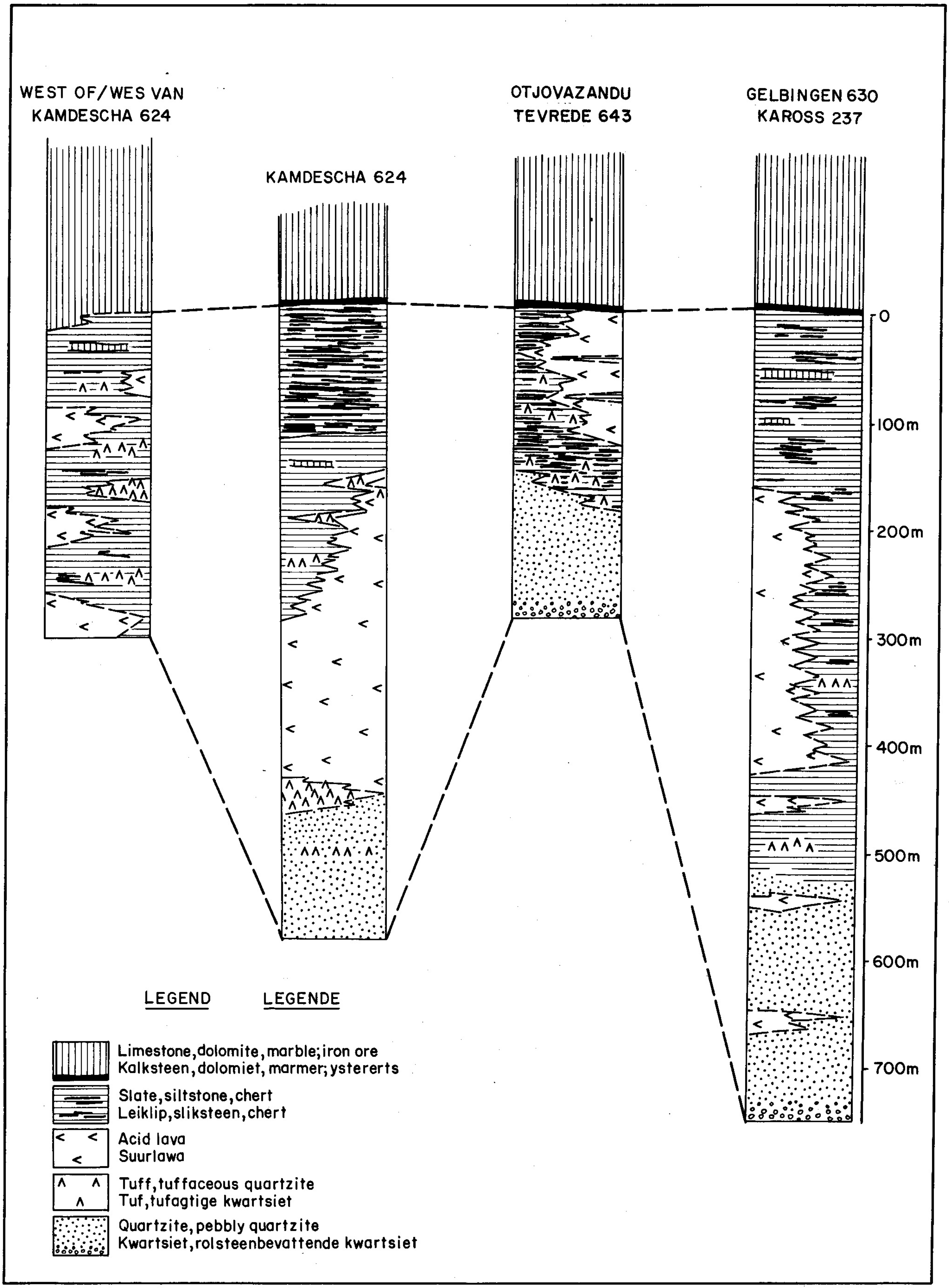

FIG. 1.—Section across the type area of the upper part of Otjovazandu Member of the Khoabendus Formation

Snit oor die tipegebied van die boonste gedeelte van die Otjovazandudeel van die Formasie Khoabendus ber are briefly described below according to their stratigraphic order.

(a) White Quartzite (“Khoabendusquarzit”)

This quartzite, which varies in thickness between 100 and 500 m, has been taken as the base of the upper part of the Otjovazandu Member. Resistant to weathering, it forms high ridges which can be followed over long distances, facilitating the unravelling of many of the complicated structures.

A red pebbly quartzite at the base is exposed at many localities on Gelbingen 630, Voorspoed 629, Blyerus 628 and Kaross 237 and can be traced as far as 15 km north-west of Otjovazandu. It is an important marker which proved to be very useful in the identification of the “Khoabendusquarzit” and in the elucidation of the structure, especially on Voorspoed 629 where the intricate structure of the synclinorium could hardly be unravelled without this bed. The rock consists of well-rounded pebbles and cobbles, up to 20 cm in diameter, of white to light-grey quartzite and a few of green felsite set in a reddish quartzitic or gritty matrix which in places is rich in feldspar detritus or iron oxides. The matrix is locally schistose. Some layers are conglomeratic with the pebbles densely packed, whereas others are almost free of pebbles, being reddish grit or quartzite. Locally, as for example in the southern portion of Arendsnes 627, the pebbly quartzite grades into a thick boulder-conglomerate containing subrounded blocks of grey quartzite up to 1 m in diameter.

Towards its top the pebbly quartzite gradually becomes lighter in colour, poorer in pebbles and harder, and finally becomes a white hard glassy quartzite which only very occasionally contains pebbles. In its lower part the quartzite includes thin layers and lenses of grit, consisting of well-rounded quartz grains 2 to 3 mm in diameter which are bluish opalescent and closely resemble the quartz phenocrysts of the underlying rhyolite and felsite.

Locally these gritty layers may increase considerably in number and thickness and constitute almost the whole rock.

Higher in the succession the quartzite is usually very fine-grained and pure and only rarely includes thin layers of sericite and talc. At some localities cross-bedding and ripple-marks are found, whereas at others bedding may not be recognisable in the massive rock. The purity is indicative of the high maturity of the quartzite, which should therefore be classified as an ortho-quartzite (Pettijohn, 1957, p. 295).

On Voorspoed 629 and adjoining farms layers of chlorite-actinolite schist, which probably represent altered andesitic to mafic rocks, occasionally accompany the quartzite. It cannot be stated with certainty whether they are flows or sills since the contacts are obliterated by shearing.

On Kamdescha 624 and farther to the north-west the white quartzite is often found interbedded with tuff and acid lava. Locally tuff and quartzite grade into each other, forming a zone of tuffaceous quartzite which is easily distinguishable from pure quartzite by its more greyish colour, distinct stratification and rough surface, the last being due to the numerous quartz, feldspar and lithic fragments included in the rock.

About 4 km north of Otjovazandu a minor occurrence of gold and silver is found within the quartzite, but the grade of .the ore is low and the deposit is of no economic value.

In the north-western portion of Kamdescha 624, on Weissbrunn 192 and at a few other localities, lenses of hematite ore are present in the quartzite; they are, however, of poor quality and of no economic value.

(b) Acid Volcanic Rocks

As previously mentioned, the white quartzite on Kamdescha 624 and farther to the north-west usually contains intercalations of tuff and acid lava with the latter either occurring in thin layers or as major bands. Towards the top of this succession an increase in volcanic rocks may usually be observed, while clastic sedimentary rocks gradually diminish.

In the eastern part of the area and to the north and north-west of Otjovazandu the basal quartzite usually does not contain any volcanic rocks, but is almost everywhere overlain by rhyolite and felsite along a sharp contact. On Voorspoed 629 south of the main road to Kamanjab and on Die Vlakte 634, where the actual contact is clearly exposed, a zone up to 2 m thick contains highly contorted and irregularly shaped lumps of a quartzite-felsite mixture which gives the impression of a lava which has flowed over sand.

Above this first flow or series of flows, which is locally up to 300 m thick, interbeds of quartzite, tuff and lava occur. Fine exposures of these are found on Robyn 647, Ermo 646 and north and north-west of Otjovazandu.

Quartzitic debris covers the outcrops of the acid volcanic rocks in many places and loose blocks, mainly of felsite, are scattered over the surface.

The acid lavas are rhyolitic and felsitic, smaller than those below and above the quartzite. This lava is, however, to a greater extent felsitic in appearance, i.e. without evidence of flow-banding and containing fewer phenocrysts. Where flow-structures are present they are very contorted, suggesting a highly viscous lava that flowed only for short distances.

It should be mentioned that there is some doubt about the true nature of certain felsites, which do not contain any phenocrysts but which consist entirely of a highly siliceous microcrystalline to cryptocrystalline mass. The possibility should not be excluded that they may be either very fine-grained devitrified and (or) silicified rhyolitic ash or even silicified shale, with the silica originating from associated acid volcanic rocks.

(c) Upper Sedimentary Sequence

Under this heading a variety of sedimentary rocks overlying the quartzite and lavas and underlying the carbonate rocks are described. They are irregularly distributed in the area and may be very thick at some localities whilst at others they may be absent. The succession may differ so much from place to place that each occurrence displays individual characteristics, although the rock-types included in the different occurrences are essentially the same everywhere. They were probably deposited in basins flooded during occasional marine ingressions. Some of these basins subsequently may have become separated from the open sea and remained filled with water after marine regression, whereas others may have dried up and again became part of the land area. During subsequent ingressions the low-lying areas might have been flooded again, starting a new cycle of marine deposition.

A fairly complete succession is exposed about 3 km north-east of the homestead on Kaross 237. From the base upwards the following tightly folded thin layers occur: purple siltstone, black and purple dolomite, red gritty quartzite, purple and grey chert, grey and black shale, grey and purple dolomite, black chert, grey shale, grey pebbly quartzite. On top of these follows a less differentiated sequence of schist with interbedded quartzite and occasional intercalated layers of chlorite-actinolite schist, which probably represent sheared and altered andesite. A thin band of cherty iron ore occurs at an indefinite level within the lower part of the succession.

At certain localities some of these rocks are missing, while others are more prominent or modified, e.g. the chert may be oölitic instead of being bedded, and instead of only one layer of iron ore, two may be developed locally. In some places, e.g. on Gelbingen 630, two prominent layers of hard white quartzite, which at other localities are hardly recognisable, are found near the base of the succession. On Die Vlakte 634 and on Gelbingen 630 the uppermost part of the sequence consists of a red ferruginous gritty quartzite about 300 m thick.

On Marenphil 641 and West End 642 the sedimentary succession is somewhat different, comprising mainly greenish-grey schist, brittle iron-stained quartzite and a thin hematite horizon which overlies the "Khoabendusqarzit" directly. In parts the quartzite and schist contain some tuffaceous material, while towards the top the schist gradually becomes calcareous.

On Kamdescha 624 and in a single outcrop 4 km north-west of Otjovazandu the succession is represented by black slate or schist including a few layers of purple dolomite and a layer of hematite and siderite approximately 2 m thick. On Kamdescha 624 the slate grades laterally westwards into tuffaceous siltstone or even tuff, which is thinly layered and locally interbedded with limestone.

The exposures at Marenphil 641 and Kamdescha 624 clearly indicate a connection in time between volcanic activity mainly on land areas and marine deposition in invaded basins, by the occurrence of tuff and tuffaceous beds within a shaly and calcareous sequence. They furthermore reflect a gradual deepening of the flooded areas by the increase in carbonate rocks towards the top of the succession.

The maximum thickness of the upper sedimentary sequence is estimated to be in the range 400 to 500 m, with an average thickness of 150 to 200 m.

(d) Iron Ore

Layers and lenses of iron ore are found at various horizons within the Otjovazandu Member. None of them is of any economic value. The occurrence of a few hematite lenses in the "Khoabendusquarzit" has been mentioned.

In the lower part of the member minor concentrations of hematite are also found within the quartzite which is interbedded with the rhyolitic rocks. One or two thin layers of hematite and siderite are present in the upper sedimentary sequence.

Only one relatively persistent band of iron ore up to 50 m thick was met with, being at the base of the carbonate rocks near the top of the member. It is exposed about 4 km north of Otjovazandu, close to the main road to Ohopoho and can be traced to Kamdescha 624 over a distance of more than 40 km. It is generally highly siliceous and in many places grades into a ferruginous quartzite or chert which itself grades into the overlying carbonate rocks. The main iron minerals are siderite and hematite.

(e) Carbonate Rocks

The main outcrops of carbonate rocks are situated in a narrow zone stretching from Kamdescha 624 to north of Otjovazandu, while minor occurrences are exposed on Gelbingen 630, about 2 km north-east and 4 km east of the homestead. North of Otjovazandu they form a very broad outcrop due to broad open folding.

The lowermost impure limestone and dolomite are interbedded with chert, schist, sandstone and discontinuous layers of tuff. Higher up in the succession pink limestone and grey dolomite with a few interbeds of chert predominate. Generally the dolomite and limestone are thinly bedded but locally more massive types are present, especially in the uppermost portion.

The limestone and dolomite are virtually unmetamorphosed except for the westernmost occurrences, where recrystallisation gave rise to white marble. Although the rock is highly siliceous no other minerals were formed. The more important deposits of marble, with minor intercalations of quartzite, purple slate, sandy schist and chlorite-actinolite schist (sheared andesite), attain maximum thicknesses of almost 200 m and are situated about 20 km north-west of Kamdescha 624 on both sides of the road to Sesfontein. Along the southern boundary of the outcrop the marble is unconformably overlain by rocks of the Nosib Formation.

(f) Intermediate and Basic Rocks

Intermediate to basic flows and possibly also sills are found at several levels within the Otjovazandu Member. Those situated immediately below and within the “Khoabendusquarzit” are exposed mainly in the area between Arendsnes 627 and Weissbrunn 192. They have been transformed into chlorite-actinolite schist by strong shearing and it is not known whether they were flows or sills.

Immediately south-east of Otjovazandu hypersthene andesite forms an extensive outcrop. The exact stratigraphic position of this lava is unknown because it is not in direct contact with any sedimentary rocks of the Otjovazandu Member. It is, however, younger than the adjoining quartz-feldspar porphyry, as the latter is intruded by numerous intermediate to basic dykes related to this andesite.

Smaller occurrences of lava are exposed on Rasthof 631, in the northern corner of Louwsville 633 and on Die Vlakte 634. The rocks are either andesitic or basaltic in composition and are strongly altered, as indicated by the presence of epidote, chlorite, calcite and uralite. The lava is situated mainly above the carbonate rocks at the top of the Otjovazandu Member and was probably ejected under submarine conditions.

Diabase dykes are found on Louwsville 634 and Kamanjab Nord 212.

C. Kaross Granite

On Blyerus 628 the rhyolite of the Lower Otjovazandu Member is underlain by quartz porphyry and quartz-feldspar porphyry which grade into porphyritic granite. The contact which is exposed next to the main road to Kamanjab is not clear and unequivocal and rather gives the impression of being a transitional one. A similar transition is developed on Kaross 237, after which the granite is named.

The relationship of the Kaross granite to the surrounding rocks is somewhat confusing and contradictory:

(i) It seems to underlie the “Khoabendusquarzit” on Arendsnes 627; the contact is either obliterated by a fault-zone or covered by quartzite debris.

(ii) On Marenphil 641 and Swartskamp 640 a finer-grained variety of the granite overlies quartzite which is either red, glassy and recrystallised (Marenphil 641), or considerably feldspathised (Swartskamp 640).

(iii) In the southwestern corner of Tevrede 643 fine-grained red granite overlies brittle granitic rocks of the Basement Complex along an irregular distinct contact.

(iv) In the northwestern corner of Kaross 237 the same granite seems to intrude Basement rocks.

(v) On Swartskamp the granite is cut by a dyke of felsite.

(vi) Finally, as mentioned above, a transition from granite to quartz porphyry and rhyolite can be observed at several localities.

The granite is usually red to greenish-red and varies from fine to coarse-grained. Texturally, variations from microgranite through "normal granite" to porphyritic granite are found. The most striking feature, which is encountered almost ubiquitously within the granite, is the presence of insets of shining round bluish opalescent quartz ranging in diameter from 1 to 6 mm. They are rather abundant in the porphyritic granite in some areas (e.g. Arendsnes 627, Wildeck 626), but in others they are rare and small (e.g. Swartskamp 640); this also holds for feldspar insets, which may measure up to 15 mm across locally.

These phenocrysts, which are often corroded, are always conspicuous in thin section, even when the ground-mass is very coarse. The latter consists of quartz, potash feldspar and plagioclase accompanied by muscovite, biotite, calcite and iron ore. The quartz is present either in the form of subhedral rounded grains or extremely allotriomorphic filling of interstices. Alkali feldspar is represented by microcline and perthite which are occasionally replaced by albite along the margins; the plagioclase is albite-oligoclase and quite often poikiloblastic, containing numerous inclusions of quartz, albite and muscovite. The ground-mass varies considerably in grain-size and texture. It is either fine-grained and equigranular with a low degree of grain-interlocking, resembling the texture of a quartzitic or fine-grained sandstone and displaying a seriate texture with a complete range in grain-size between ground-mass and phenocrysts, or may be medium to coarse-grained and highly interlocked, in appearance like a recrystallised originally finer-grained matrix. Occasionally it displays a granophyric texture.

It is presumed that the granite largely represents transformed acid volcanic rocks. The reconstitution of these rocks was most probably caused by a post-volcanic granitic intrusion. Both the volcanic rocks and granite are believed to belong to the same phase of magmatic activity and to have a common magma source, of which they merely represent the effusive and intrusive or hypabyssal facies respectively.

Because of the extensive reconstitution of the volcanic rocks, their contact with the granite is transitional. As similar transitions are also found between less transformed and more transformed volcanic rocks, the proportions of actual lava and "real" granite cannot be determined in the outcrop area. On the other hand, magmatic activity cannot be questioned, as is proved by the intrusion of the Basement rocks* by the Kaross granite, and by the existence of numerous aplitic and felsitic dykes.

A major hiatus between the extrusion of acid volcanics and the emplacement of the intrusives is unlikely; most probably the intrusion occurred after deposition of the "Khoabendusquarzit" and together with the

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* It is possible that the granitic rocks regarded as Basement may to a certain extent represent reconstituted acid to intermediate volcanics belonging to the West End Member. This holds especially for some occurrences on De Ville 638, Swartskamp 640 and Kaross 237.

subsequently reviving volcanic activity.

D. KAMDESCHA GRANITE

The Kamdescha granite is very coarse and porphyritic and intrudes both members of the Khoabendus Formation. It forms three major outcrops, namely on portions of Kamdescha 624 and De Ville 638, immediately west of the Okanamuhona waterhole near the northern boundary of the area, and in the western portion of the area.

On Kamdescha 624 and De Ville 638 it intrudes rocks of the Basement Complex, the West End Member and quartzite and rhyolite of the Otjovazandu Member. The contact with the rhyolite is transitional, probably due to chilling within the granite and partial assimilation and reconstitution of the rhyolite. Where intruding the quartzite, the granite has a fine-grained chill-zone at the contact and the quartzite is glassy and splintery. The quartzite which forms the base of a small closed syncline 5 km long and up to 1 km wide on Kamdescha 624, virtually floats in the granite. Andesitic tuff of the West End Member is found locally as rounded xenoliths within the granite, while at other places it is baked along the contact and more splintery than usual. Altogether, however, the effect of the intrusion on the country-rocks here is insignificant.

In the western portion, however, the effect of the granite on the surrounding rocks of Khoabendus age is more marked. At many places an increase in grain-size of the invaded rock can be observed, while the granite has a fine grained chill-zone 3 to 5 m thick. A contact displaying these features is found some 15 km east of the western boundary of the area and about 4 km north of the southern road to Sesfontein. There the rhyodacitic and dacitic lava is transformed into rocks resembling intrusives and cut by numerous granitic and aplitic dykes.

Where the granite intrudes the acid lava, the contact is generally transitional due to partial reconstitution of the latter, whereas andesitic tuff appears to be less affected; except for induration and an increase in grain-size, no apparent changes are noted. Very often, however; xenoliths of green andesitic tuff are found in the granite.

The marble along the contact shows a considerable increase in grainsize and a high content of silica.

Numerous aplitic dykes and quartz veins are found in a zone about 10 km wide around the granite; they are presumably genetically related to the intrusion.

West of Okanamuhona the granite intrudes rocks of the West End Member and is unconformably overlain by quartzite of the Nosib Formation.

The Kamdescha granite everywhere is very coarse-grained and distinctly porphyritic with phenocrysts of alkali feldspar up to 4 cm in length. Plagioclase (albite-oligoclase) insets are less abundant and strongly saussuritised or sericitised. They usually occur in smaller subhedral crystals up to 1 cm across, while quartz fills the interstices and usually stands out on the weathered surface as irregular patches. The phenocrysts of alkali feldspar are perthite and microcline perthite and are often surrounded by rims of saussuritised plagioclase (rapakivi texture). The groundmass, which forms a small proportion by volume of the rock, consists of quartz, or quartz and feldspar, with biotite as the only mafic constituent.

IV. DEPOSITIONAL ENVIRONMENT

The rocks of the West End Member most probably formed in a terrestrial environment. Part of the andesitic tuff in the uppermost part of the succession might have been deposited under marine conditions.

The rocks of the Otjovazandu Member reflect distinct changes in depositional environment. Very typical of this member is the association of orthoquartzite and carbonate rocks. It is presumed that the lower part of the member, which includes quartzite and volcanic rocks, formed on a very low-lying land-surface which was occasionally flooded by sea. After subsequent withdrawals of the sea, basins separated from the open sea might have been left at various localities, and black shale, siltstone and possibly also chert were deposited.

The absence of shale in the quartzite suggests that the land areas were deserts from which the clay fraction was removed by wind, leaving only a sand-dune complex which was invaded and redistributed by the sea. The acid volcanics were ejected only on land areas and contributed to the frequent changes in the landscape. Ignimbrites would have spread on land surfaces only, while tuff was probably also deposited in an aqueous environment.

Acid volcanic activity and deposition of sand ceased at the time of final ingression by the sea. Iron ore was precipitated along the shore-line, while in the shallow sea carbonate rocks and, in deeper portions, shales accompanied by local flows of andesitic and basic lava were deposited.

V. STRUCTURE

Only the more important structural features will be dealt with. Two major structural patterns, the one superimposed on the other and attributed to different geological epochs, are displayed. In the eastern portion the trends of the main structures are delineated by the “Khoabendusquarzit”, which clearly marks the synclines and synclinoria which generally strike north-east. In the central and western parts of the area they turn to a more northerly direction. These structures are pre-Damara in age and are attributed to the Khoabendus epoch.

Two major synclinoria are preserved in the central and eastern portions, the one situated between Arendsnes 627 and Gelbingen 630, and the other between Kamdescha 624 and Otjovazandu. In the north-east, along the boundary of the area, the synclinoria are connected by a common limb trending south-east. This direction coincides with the general structural trend of the Damara rocks exposed nearby. In many localities it is superimposed upon the “Khoabendus direction”, being manifested as a crenulation of schistosity planes or as a second schistosity in shale, siltstone or fine grained tuff of the Khoabendus Formation, and is attributed to the Damara Orogeny. On Kamdescha 624 and south of it major folds are themselves folded along north-west-striking axes of Damara age.

There are numerous faults, many of them dip-faults with considerable throws locally. They can be best observed along the limbs of the synclinonoria in the eastern portion of the area. Strike-faults are rare or inconspicuous; a major one which caused a horizontal displacement of more than 1 000 m is present on Gelbingen 630.

VI. METAMORPHISM

The grade of regional metamorphism observed is low and nowhere exceeds the greenschist facies. In the eastern and central portions the rocks are virtually unmetamorphosed; limestone and dolomite are not even fully recrystallized. Farther west a slight increase in metamorphism is noted; the limestone is largely recrystallized to white marble and some biotite has developed randomly in certain tuffs and slates. In the marble the calcite-quartz association is still gone beyond the greenschist tern exposed only

10 km west that the metamorphism is of stable and the metamorphism has therefore not facies. The carbonate rocks of the Damara System of the marble are not affected, indicating pre-Damara age.

VII. CORRELATION

With no age determinations available, correlation of the Khoabendus rocks with other distant formations is somewhat speculative, as it can be based only on similarities in stratigraphic position, lithology, succession and thickness.

Formations comparable in these aspects with the Khoabendus are the Opdam and Doornpoort Formations in the central part of South West Africa and, farther south, the Nagatis and Sinclair Formations near Helmeringhausen (Von Brunn, 1969). Geochronological determinations made on rocks of these formations gave ages ranging between 1 100 and 1 290 My.

A special problem is presented by the Kaross and Kamdescha granites, both of which are closely associated with the Khoabendus Formation. They are most probably identical with some varieties of the Fransfontein granite, which therefore may not be as uniform as indicated on the Geological Map of South West Africa (1963), but which probably consists of various granites, volcanic rocks, transformed lavas and sedimentary rocks of different ages, including Basement Complex and Khoabendus rocks. Similar inferences are drawn by Guj, who found the Fransfontein granite to intrude the Khoabendus porphyries at several localities north and north-west of Fransfontein.

The question thus arises, what to call "Fransfontein granite". Three samples of Fransfontein granite (specimens 1, 2 and 9 of Clifford et al., 1969) collected close to Khoabendus rocks gave whole-rock rubidium-strontium ages of 1 100 to 1 300 My. Although Clifford et al. (1969) regard this age as "discordant" and adulterated by a post-crystallisation migration of radiogenic Sr, it is surprising to find it coinciding with the age expected for the Khoabendus Formation and the included granites.

The author therefore recommends that the term "Fransfontein granite" be applied only to those granites in the Kamanjab Inlier for which an age of approximately 1 650 My has been proved.

BIBLIOGRAPHY

CLIFFORD, T.N., NICOLAYSEN, L.O. and BURGER, A.J., 1962. Petrology and age of the pre-Otavi basement granite at Franzfontein, northern South West Africa: J. Petrol., 3, p. 244-279.

CLIFFORD, T.N., ROOKE, J.M. and ALLSOPP, H.L., 1969. Petrochemistry and age of the Franzfontein granitic rocks of northern South West Africa: Geochim. Cosmochim. Acta, 33, p. 973-986.

REPUBLIC OF SOUTH AFRICA, DEPT. OF MINES, 1963. Geological map of South West Africa, Scale 1:1 000 000: Geol. Surv. S. Afr., Government : Printer, Pretoria.

GUJ, P., 1970. The Damara mobile belt in the south-western Kaokoveld, South West Africa: Bull. precambr. Res. Unit, Univ. Cape Town, 8.

MARTIN, H., 1965. The Precambrian geology of South West Africa and Namaqualand: Precambr. Res. Unit, Uni v. Cape Town.

RANGE, P., 1912. Geologie des deutschen Namalandes, Deutsch-Südwestafrika: Beitr. geol. Erf. dtsch. Schutzgeb., 2.

STAHL, A., 1926. Geologische Grundzüge des nördlichen Südwestafrika und Erzlagerstätten des Otavi-Berglandes: Z. prakt. Geol., 34, p. 145-160.

_________1940. Die Otaviformation des Etoschabogens (Südwestafrika): Beitr. geol. Erf. dtsch. Schutzgeb., 22, p. 1-66.

VON BRUNN, V., 1969. Igneous rocks of the Nagatis and Sinclair Formations north-east of LUderitz, South West Africa: Bull. precambr. Res. Unit, Univ. Cape Town, 7.

DIE FORMASIE KHOABENDUS IN DIE GEBIED NOORDWES VAN KAMANJAB EN IN DIE SUIDOOSTELIKE KAOKOVELD, SUIDWES-AFRIKA

OPSOMMING IN AFRIKAANS

Verkenningskartering gedurende die winterseisoen van 1970 in Gebied 1914 A en gedeeltes van Gebied 1914 B het getoon dat die Formasie Khoabendus 'n baie groter deel in die noordwestelike Kamanjab-venster dek as wat op die Geologiese Kaart van Suidwes-Afrika (1963) aangetoon word. Baie voorkomstes van graniet en gneis wat voorheen gekorreleer is met die Fundamentele Kompleks, is bewys as behorende tot die Formasie Khoabendus.

Die geologiese opeenvolging van gesteentes in hierdie gebied word in die onderstaande stratigrafiese kolom uiteengesit.

Sisteem Damara	Serie Bo-Otavi		Chertagtige dolomiet, kalksteen Biohermale dolomiet Itabiriet, tilloïed
	Serie Laer Otavi		Dolomiet, skalie
Formasie Nosib			Feldspatiese kwartsiet, grint, konglomeraat
		Diskordansie	
Formasie Khoabendus	Lid Otjovazandu	(Boonste deel maks. dikte ± 1 500 m)	Kalksteen, dolomiet, marmer (200 m) Chertagtige ystererts (50 m) Skalie, sliksteen (500 m) Rioliet, felsiet, tuf, andesiet (450 m) Wit kwartsiet, konglomeraat (350 m)
		(Laer deel maks. dikte ± 2 000 m)	Rioliet, felsiet; kwartsiet kwartsporfier, graniet
	Lid West End		Andesitiese tuf en lawa (150 m)

Lid West End (Verv.)		Suur tot intermediêre lawa en intrusies (500 m?) Piroklastiese gesteentes (400 m)
	Diskordansie	
	Fundamentele Kompleks	Graniet, granodioriet
	Kamdeschagraniet	Growwe porfiritiese graniet
Intrusiewe Gesteentes	Felsiet-gang	
	Karossgraniet	Porfiritiese graniet, gedeeltelik omvormde suur vulkaniese gesteentes

Die laer gedeelte van die Formasie Khoabendus (Lid West End) bestaan uit suur tot intermediêre lawa (riodasiet, dasiet en oorgangsgesteentes tot andesiet) met geassosieerde piroklastiese gesteentes. Hierdie basale suksessie word oorlê deur ‘n opeenvolging van groen andesitiese tuf en vloeiinge van pirokseen-andesiet en hornblende-andesiet. Intrusief in die vulkaniese gesteentes van die Lid West End kom liggame van adamelliet- en granodiorietporfiere voor in die vorm van plate en klein apofise liggame wat df aan die end van die vulkaniese periode ingeplaas is òf daarna.

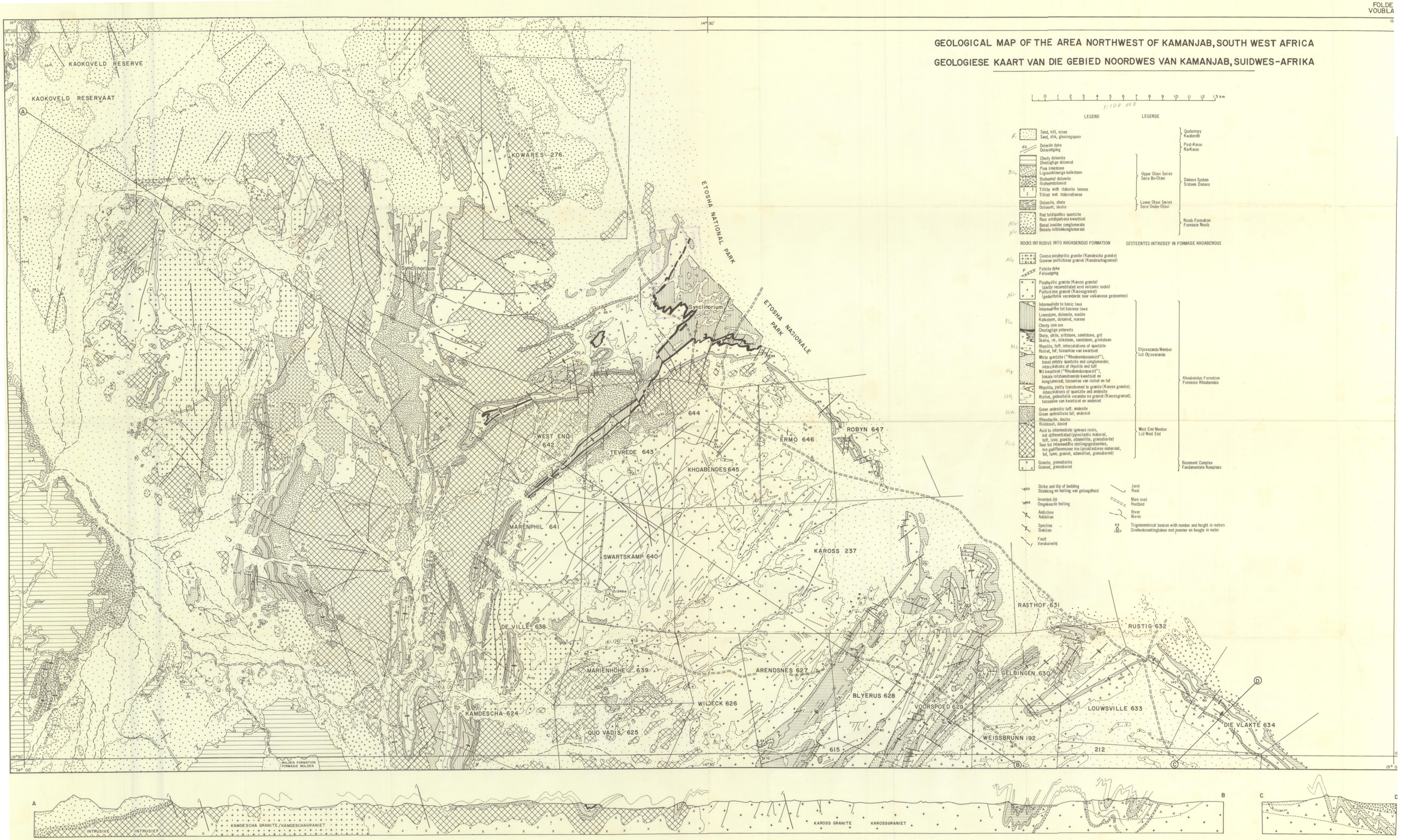
Die boonste deel van die Formasie Khoabendus (Lid Otjovazandu) het as basale deel ‘n verskeidenheid van vulkaniese en sedimentêre gesteentes wat gelyktydig ingeplaas is. Die mees karakteristieke gesteentetipe van die Lid Otjovazandu is ‘n wit glasagtige ortokwartsiet van land-oorsprong. Dit word oorlê deur massiewe rioliete en felsiete of deur fyn-klastiese sedimente wat in komme wat deur die see oorstroom is, afgeset is. Hierdie lid word bedek deur ‘n opeenvolging van kalkhoudende gesteentes wat ná die finale marine-inname van die gebied gepresipiteer het.

Die Formasie Khoabendus is deur twee tipes voor-Damara graniet ingedring met name Kaross- en Kamdeschagraniet. Deur die indringing van die Kaross-graniet, is uitgebreide dele van riolitiese lawa van die Lid Otjovazandu verander na granitiese rotse. Die Kamdeschagraniet is grof en porfirities en het teen die end van die Khoabendustydperk ingedring.

Die hoofstrukture in die gebied strek noordoos of noord en is van Khoabendusouderdom. Strukture van Damara-ouderdom is hierop gesuperponeer en strek beide noordwes en noord.

Die metamorfose wat deur die Khoabendusgesteentes vertoon word, is van lae graad en oorskrei nie die groenskisfasies nie.

Die Formasie Khoabendus kan met die Formasies Opdam, Doornpoort, Nagatis en Sinclair van die sentrale en suidwestelike dele van Suidwes-Afrika gekorreleer word.


FOLDE
VOUBLA
GEOLOGICAL MAP OF THE AREA NORTHWEST OF KAMANJAB, SOUTH WEST AFRICA
GEOLOGIESE KAART VAN DIE GEBIED NOORDWES VAN KAMANJAB, SUIDWES-AFRIKA
1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 km
1:100 000
LEGEND
LEGENDE
Sand, silt, scree
Sand, slik, glooiingspuin
Quaternary
Kwaternêr
Dolerite dyke
Dolerietgang
Post-Karoo
Na-Karoo
Cherty dolomite
Chertagtige dolomiet
Pink limestone
Ligrooskleurige kalksteen
Biohermal dolomite
Biohermdolomiet
Tillite with itabirite lenses
Tilliet met itabirietlense
Upper Otavi Series
Serie Bo-Otavi
Dolomite, shale
Dolomiet, skalie
Lower Otavi Series
Serie Onder-Otavi
Damara System
Sisteem Damara
Red feldspathic quartzite
Rooi veldspatiese kwartsiet
Basal boulder conglomerate
Basale rolblokkonglomeraat
Nosib Formation
Formasie Nosib
ROCKS INTRUSIVE INTO KHOABENDUS FORMATION
GESTEENTES INTRUSIEF IN FORMASIE KHOABENDUS
Coarse porphyritic granite (Kamdescha granite)
Growwe porfiritiese graniet (Kamdeschagraniet)
Felsite dyke
Felsietgang
Porphyritic granite (Kaross granite)
(partly reconstituted acid volcanic rocks)
Porfiritiese graniet (Karossgraniet)
(gedeeltelik veranderde suur vulkaniese gesteentes)
Intermediate to basic lava
Intermediêre tot basiese lawa
Limestone, dolomite, marble
Kalksteen, dolomiet, marmer
Cherty iron ore
Chertagtige ystererts
Shale, slate, siltstone, sandstone, grit
Skalie, lei, sliksteen, sandsteen, grintsteen
Rhyolite, tuff; intercalations of quartzite
Rioliet, tuf; tussenlae van kwartsiet
White quartzite ("Khoabendusquarzit"),
basal pebbly quartzite and conglomerate;
intercalations of rhyolite and tuff
Wit kwartsiet ("Khoabendusquarzit"),
basale rolsteendraende kwartsiet en
konglomeraat; tussenlae van rioliet en tuf
Rhyolite, partly transformed to granite (Kaross granite);
intercalations of quartzite and andesite
Rioliet, gedeeltelik verander na graniet (Karossgraniet);
tussenlae van kwartsiet en andesiet
Otjovazandu Member
Lid Otjovazandu
Green andesitic tuff; andesite
Groen andesitiese tuf; andesiet
Rhyodacite, dacite
Riodasiet, dasiet
Acid to intermediate igneous rocks,
not differentiated (pyroclastic material,
tuff, lava; granite, adamellite, granodiorite)
Suur tot intermediêre stollingsgesteentes,
nie gedifferensieer nie (piroklastiese materiaal,
tuf, lawa; graniet, adamelliet, granodioriet)
West End Member
Lid West End
Khoabendus Formation
Formasie Khoabendus
Granite, granodiorite
Graniet, granodioriet
Basement Complex
Fundamentele Kompleks
Strike and dip of bedding
Strekking en helling van gelaagdheid
Inverted dip
Omgekeerde helling
Anticline
Antiklien
Syncline
Sinklien
Fault
Verskuiwing
Joint
Naat
Main road
Hoofpad
River
Rivier
Trigonometrical beacon with number and height in metres
Driehoeksmetingbaken met nommer en hoogte in meter
KAOKOVELD RESERVE
KAOKOVELD RESERVAAT
KOWARES 276
ETOSHA NATIONAL PARK
ETOSHA NASIONALE PARK
Synclinorium
Synclinorium
WEST END 642
TEVREDE 643
644
ERMO 646
ROBYN 647
KHOABENDES 645
MARENPHIL 641
SWARTSKAMP 640
KAROSS 237
RASTHOF 631
RUSTIG 632
DE VILLE 638
MARIENHÖHE 639
ARENDSNES 627
GELBINGEN 630
BLYERUS 628
WILDECK 626
VOORSPOED 629
LOUWSVILLE 633
DIE VLAKTE 634
KAMDESCHA 624
QUO VADIS 625
WEISSBRUNN 192
615
212
MULDEN FORMATION
FORMASIE MULDEN
14° 00'
14° 30'
15° 00'
A
B
C
D
INTRUSIVE INTRUSIEF
KAMDESCHA GRANITE / KAMDESCHAGRANIET
KAROSS GRANITE KAROSSGRANIET