CONTRIBUTIONS TO THE PETROLOGY OF NAMAQUALAND

Department of Geology

by

Norma MATHIAS.

PH.D. Thesis, December 1940.

ABSTRACT.

The farm Aggenys and part of the adjoining farm Zuurwater have been geologically surveyed for the first time. The geology and mineralogy of the rocks in this area are described. Detailed mineralogical data of the old granite and granite-gneiss of Namaqualand, and the Paarl and Cape Peninsula granites are recorded. The old granite is correlated with the basement granite of South Africa. It frequently shows the effects of either metasomatism or contamination by Kheis sediments. The Namaqualand granite-gneiss is correlated with the Cape granite and exhibits a more acid marginal phase on the farm Aggenys. A comparative study is made of the ancient Namaqualand quartzites and the Kasien quartzites, but insufficient evidence is available for definite correlation.

CONTENTS.

INTRODUCTION.

Many geologists and prospectors have been attracted to Namaqualand since the first discovery of copper in 1685, but, with some notable exceptions, their interest has been mainly concerned with the economic resources of the country.

The present research was made primarily in an endeavour to add to the mineralogical knowledge of the Namaqualand rocks. A representative area was accordingly selected for detailed description and this was then used as a basis for a wider comparative study embracing the granites and quartzites from various known formations outside Namaqualand.

After visiting many parts of Namaqualand on six separate occasions the writer selected the farm Aggenys and part of the adjoining farm Zuurwater for detailed description and mapping. Besides the representative character of the rocks on these two farms, Zuurwater has the additional advantage of containing an extremely interesting and unique deposit of iron ore associated with barite, which had not hitherto been described.

An account is given in the following pages of the geology and mineralogy of the area surveyed, i.e. Aggenys and part of Zuurwater. A comparative study of the granites of Namaqualand, excluding the Kuboos batholith, is dealt with in a further chapter with the object of:- (a) giving exact mineralogical data of the two main granite masses; (b) observing distinguishing features of these granites; (c) affording a comparison and possibly a means of correlation, between the Namaqualand granites and the Cape Peninsula and Paarl facies of the Cape granite.

Quartzites from various places in Namaqualand and from the Kheis and Nama systems have been examined with a view to establishing a positive correlation with some known sedimentary series. Dr. Gevers 3 has tentatively correlated the Namaqualand quartzites with the Kaaien series but as this assumption was apparently based on field resemblances only, it was hoped that more detailed study would furnish definite proof of their identity.

LOCATION AND EXTENT OF AREA.

Zuurwater is situated in the North-eastern portion of Namaqualand (approximate latitude 29°15′ South and longitude 18°50′ East). It is about 75 miles North-east of Springbok, 24 miles South of the Orange river and 25 miles from Pella mission station. The direction from Pofadder is 79° west of South and from Pella mission station 58° West of South. The main road from Springbok to Pofadder passes through the farm Aggenys.

The area from which the collection of granite specimens was made extends from seven miles south of Vioolsdrift on the Orange river to two miles south of Garies. It is bounded on the east by the farm Aggenys and on the west by the range of Nama beds running just west of Steinkopf. The approximate positions from which each series of specimens was collected are marked on the accompanying sketch map of Namaqualand. This map has been compiled from the topographical maps of the Union, Dr. A.L. du Toit's geological map of South Africa and Dr. Gevers map accompanying Memoir 31 of the Geological Survey publications, and shows the main geological features of Namaqualand, but the scale does not permit the inclusion of relatively small outcrops such as the quartzites of the Een Riet hills, etc. The western boundary of the old granite is not at present known, and the contact marked on the sketch map is purely arbitrary. For information regarding the eastern limits of the old granite I am indebted to Mr. C.B. Coetzee who has mapped this area.

Outside the Namaqualand area granites for comparison were collected at Paarl and the Cape Peninsula and quartzites at Upington and Marydale.

TOPOGRAPHY.

The farms Aggenys and Zuurwater belong to a region of semi-desert. The scenery is typical 'Inselberge' projecting from a floor of red sand, dunes, and grass-covered sandy flats, flanked on the North by a flat-topped mountain ridge. The 'Inselberge' consist of Koppies and hills, nearly all of which are capped by hard resistant beds of greyish quartzite.

A view of Aggenys taken from the the eastern boundary.

The northern mountain range of quartzites forms a water-shed between northward drainage to the Orange river and the southern inland drainage. The stream beds of Aggenys and Zuurwater are normally quite dry and to a large extent filled with sand and detritus. Only after exceptionally heavy rains do they fill and eventually lose themselves in small inland vleis.

Summer thunderstorm rainfall is typical of this area with only an occasional short shower or mist in the winter. There are no exact figures available for the total rainfall, but this probably does not exceed 5 inches per year. The climate is thus related to that of Pella, Pofadder, Kenhardt and Upington. Springbok and the southern part of Namaqualand, on the other hand, have winter rains. The prevailing wind is South and South-West in summer varying with East to South-East. In winter the wind blows mainly from the North-West.

The general land surface is approximately 3000 feet above sea level, and forms part of the Namaqualand peneplain. There is also evidence of a previous peneplanation in this area. The flat table-topped quartzite mountains extending intermittently from Aggenys to the Orange river and east-south-east along Tafel Berg have approximately the same height, and this is evidently not due to horizontal bedding as all these quartzites dip at angles between 20° and 40° in a north-easterly direction.

PREVIOUS WORK AND LITERATURE.

No previous geological work has been done in the area of Zuurwater and Aggenys. At the base of the hill, Swartkop, in Zuurwater (see map) an abandoned well and prospecting trench were found. These lie a few yards away from the beds containing iron ore and disclose traces of copper-bearing minerals, so that the prospecting may have been for either copper or iron.

Mr. Burger, the owner of the farms, mentioned that gold had once been found in the vicinity but that later search had failed to reveal its exact locality. None of the samples of sand or quartzite have yielded gold in recognisable quantity and it is presumed that, if this statement has foundation, the gold must be further afield or that chalcopyrite, or pyrite has been mistaken for gold.

No geological survey maps have as yet been made of this area and on the map of South Africa compiled by Dr. du Toit, it is all marked as old granite. In view of this lack of data it became necessary to try to establish a correlation between the geology of Aggenys and Zuurwater, and the parts of Namaqualand already surveyed by Dr. Rogers and Dr. Gevers.

The relevant literature on the granites of Namaqualand is as follows:-

Andrew Wyley 20, in 1857, was the first to comment upon the granite of Namaqualand and to recognise that it is intrusive into the ancient schists of the area. Dunn 2 also appears to have observed this relationship.

It was not, however, until 1911, when Dr. Rogers surveyed a portion of Namaqualand, that a precise and accurate account of the younger granite-gneiss was available 11. Briefly Dr. Rogers describes it as a biotite-gneiss which is frequently porphyritic, the phenocrysts consisting of orthoclase or perthite, and the other constituents being microcline, microperthite, oligoclase, biotite, apatite, magnetite, zircon, and occasionally epidote, sphene and garnet.

Dr. Gevers 3 was the first to report the presence of an older granite north of Jackalswater and to distinguish it from the Namaqualand granite-gneiss already described by Dr. Rogers. In referring to this old granite Dr. Gevers states "the mineralogical composition of this widely distributed granite varies. Its bulk represents a typical biotite granite with microcline and orthoclase by far predominating over acid plagioclase and with little or no hornblende. While the biotite granite predominates there appear to be all gradations through quartz monzonites to granodiorite and quartz dioritic types".

Dr. Gevers describes the typical Namaqualand granite as a biotite-gneiss, and he distinguishes it from the old granite by the absence of hornblende and the fact that the Namaqualand granite does not grade into dioritic varieties.

He attributes the high biotite content of certain areas, e.g. Eenkokor, to the assimilation of biotite schists and other argillaceous rocks of the Kheis system, and refers to "the frequent presence of abundant sillimanite and occasionally of corundum, as further strengthening this view".

The quartzites of Namaqualand, as mentioned by Dr. Gevers, were formerly thought to be of igneous origin and "Merensky in 1928 first pointed out their probable sedimentary origin, and suggested that they represent xenoliths of recrystallised quartzites".3 Dr. Gevers supports this view of Merensky's and adds valuable evidence. (See Memoir 31 of the Geological Survey publications, pages 26 and 27). No mineralogical work on these quartzites, however, has yet been recorded.

METHODS OF RESEARCH.

(a) In the Field.

Two secondary trigonometrical beacons have been erected on the high quartzite ranges to the west and north-west of the farm houses on Aggenys, but as these had not been surveyed, and as the more northerly one was only visible from parts of the flat-topped quartzite mountains in the north, it was decided that the best means of mapping would be by the method of triangulation. The base line was measured from the eastern farm house to the farm beacon on a small hill beside the road to Namies. Measurement was made by means of a range finder and checked by successive speedometer readings in the car. From these base points shots were taken with the plane table and alidade to the other farm beacons and all prominent hills. The scale adopted for the map was 1 : 50,000.

Compass readings were quite unreliable owing to the large quantity of magnetite in the district and the map was subsequently oriented from the divisional maps of Namaqualand.

Owing to the long distances covered, the Namaqualand granite-gneisses were collected at intervals of approximately 15 miles, from 2 miles south of Garies to 15 miles south of Steinkopf. Field observations were, however, made as continuous as the nature of the country permitted.

LABORATORY METHODS.

All refractive indices were determined by the immersion method, using oriented crystal fragments, sodium light, and the Leitz-Jelly refractometer. Indices above 1.78 were determined by the method advocated by Dr. E.S. Larsen 7 using piperine and iodide melts. All modes were calculated from the volume percentage obtained by the Dollar integrating stage, and the distance traversed was between 150 and 200 times the length of the largest grain in the rock. The mode of the Cape granite was arrived at by first determining the proportion of phenocrysts to ground-mass macroscopically.

The values of 2 V were obtained by using the Universal stage. The specific gravities were determined by the Walker steelyard balance. Each granite was crushed and the heavy residue separated. Any minerals present in the heavy residue but not in the sections are recorded amongst the accessories.

Large quantities of quartzite from each locality were first broken into small chips and then quartered. A fairly large sample was retained for panning so that the heavy residue extracted would not be too small. 120 mesh was found to be the most suitable for crushing. Separation was effected by centrifuging the crush in bromoform, except in the case of the relatively coarse sands for which the funnel method of separation was found to give excellent results.

The magnetite content was determined by crushing a separate portion in a porcelain mortar and extracting by means of a hand magnet. The heavy residue of the quartzites was further separated into moderately magnetic and non-magnetic crops by use of the electro-magnet.

Great care was used to avoid any possible contamination, and the usual sieves were replaced by squares of muslin, having the same mesh, which were discarded after each separation.

In the chemical analyses of the alkalis the indirect method (titration with silver nitrate) was used.

GENERAL GEOLOGY OF AGGENYS AND PART OF ZUURWATER.

Ancient sediments are represented by recrystallised quartzites, schists, amphibolites and sheared conglomerates. They have all been metamorphosed by an intrusive aplo-granite.

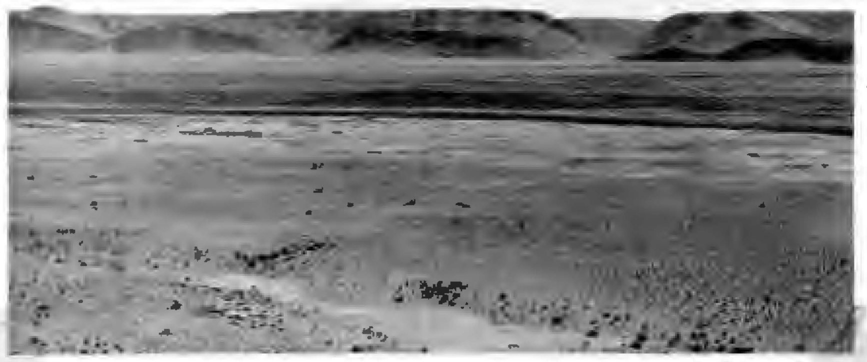
The Granite, Quartz Veins and Pegmatites.

The granite is a fine-grained aplitic variety, predominantly grey in colour, but with pink orthoclase and microperthite. It builds several isolated koppies rising from the sandy floor, but is principally intrusive into the schists on the southern side of the mountainous quartzite range in the north, and the hills to the south and south-west of this range. The contact with the schists is somewhat obscured by their similarity when weathered, and in many cases it is difficult to say exactly where the granite ends and the schists begin. There is no doubt, however, about the intrusive nature of the contact as the granite sends tongues into the overlying schists at varying levels and quartz vein and pegmatite offshoots from the granite penetrate the bedding of the sedimentary formations. Most of the granite is considerably weathered but fresh specimens were collected from an excavation for a well between the two farm houses on Aggenys. It is highly probable that the bedrock underlying the sand, which covers the greater part of the area, is of granite.

Small quartz veins and stringers are numerous, but have not been marked on the map as the scale does not warrant their inclusion. All the important pegmatites appear on the map. The pegmatite which occurs in the granite koppie on the northern boundary of Zuurwater contains amazonstone, but the others are barren of any minerals of economic worth. It is occasionally possible to trace the transition from granite through pegmatite to quartz vein.

Conglomerate.

A local development of sheared conglomerate occurs between the schists and quartzites, and near an outcrop of amphibolite east of the farm houses along the main quartzite range. It is of very limited extent, the outcrop being only 30 feet in length by 4 feet in thickness. The pebbles are composed



The northern quartzite mountain ranges on Aggenys.

of quartz and have an average size of approximately 4" x 1". They have been subjected to directional pressure which has caused them to assume elongated and ellipsoidal forms. The matrix is composed of fine-grained quartzitic material containing abundant magnetite. The pebbles show much more clearly on weathered surfaces, owing to the fact that the matrix is coated with a thin film of black iron ore - mostly magnetite.

The finding of this conglomerate is of special interest as only one other occurrence of conglomerate, that on the farm Namiep 8, has been recorded at the base of the ancient quartzites and schists of Namaqualand.

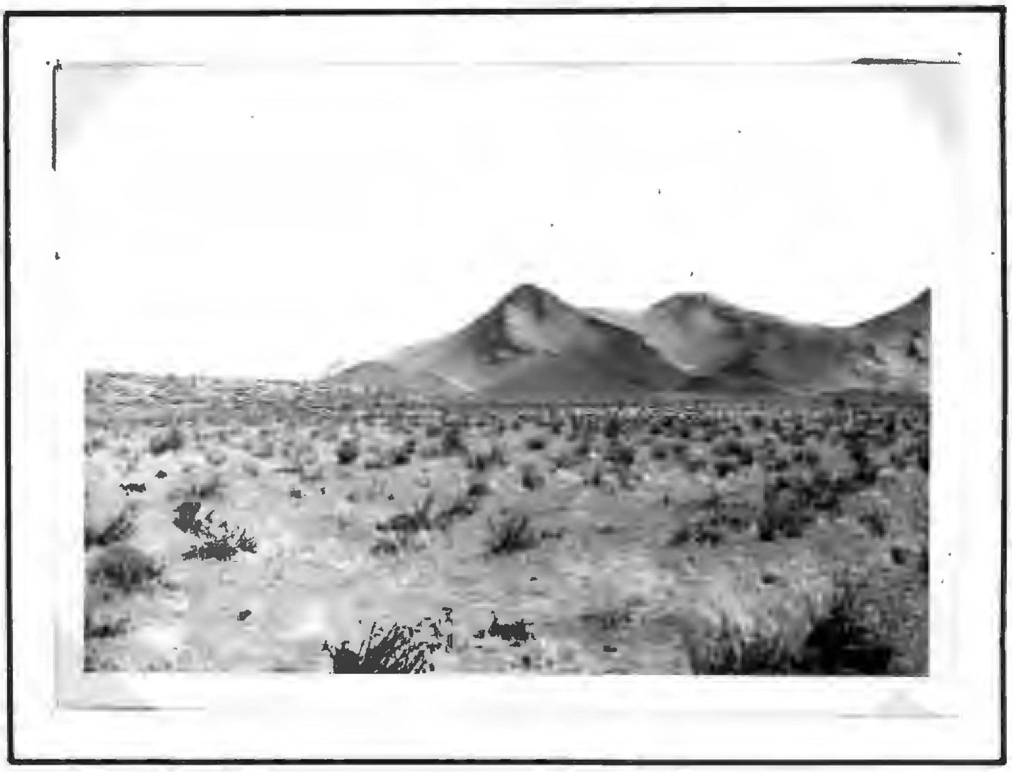
Schists.

Quartz-muscovite schists underlie and are inealoated with the quartzites. Owing to the comparative ease with which they weather, the schists generally occupy the valleys between quartzite ranges and the lower slopes of the hills. They are nearly all highly weathered and disintegrate on handling. The outcrops are coloured brown or red by iron oxides.

Progressive leaching and weathering of the iron ores can be seen in some of the finer grained schists. In these the inner layer is white and the iron completely leached out, the middle layer is stained red by haematite and the outer layer stained brown by limonite. The schists vary considerably in the relative coarseness of their grain. The grain size invariably decreases away from the granite contact, so that the metamorphic action of the granite must be, at any rate partially, responsible for the recrystallisation of the schists in its vicinity.

Quartzites.

The quartzites form a hard, resistant capping to the 'Inselbergs' which characterise this area, and in the north build flat-topped mountain ranges extending from east of Aggenys to some 5350 yards beyond the boundary with Zuurwater. They are a conspicuous landmark, visible from nearly 20 miles to the south. This main range of quartzites is divided by interbedded schists into two main portions:- (a) the high flat-topped mountains, and (b) a belt of hills intersected by river beds immediately to the south. The quartzites dip at angles between



Swartkop

The bedded iron ore at the base of Swartkop.

22° and 40°, the general direction of dip being north-north-east.

The majority of the quartzite is either grey, bluish grey, or white. It is of the 'sugar-candy' type and grades at its lower contact by increase in muscovite content into quartz-muscovite schist. Pale pink and rose quartzite occurs in irregular patches at approximately 50' and 200' above the plateau level in the main quartzite range and slightly below the magnetite-barite deposit on the hills Z_2 and Z_3, also near the summit of the hills Z_1, Z_2, Z_3, and Z_4. Green quartzite is a conspicuous feature on the northern side of the hill Z_2. It varies in colour from almost emerald green to pale green. A dark quartzite, mottled pink and black occurs on the same hill. The pink mineral is quartz, while the dark colour is due to abundant inclusions of magnetite.

<u>Iron Ore Deposit associated with Barite.</u>

<u>Field characters of the magnetite deposit.</u>

The iron ore extends in an easterly direction for approximately 3 miles from Swartkop. It occurs in the quartzite along a range of hills, Z_2 - Z_5, and also in the basal quartzites of the main range.

(a) <u>Swartkop and the hills to the East.</u>

With the exception of Swartkop, which is roughly circular in plan, the hills are elongated, East to West, in conformity with the strike of the sediments. The ore is interbedded with the quartzites and occurs at approximately the same horizon from Swartkop to Z_5. The width of the ore bed varies from 4 feet to 10 feet.

Swartkop, so named on account of its black appearance, is an outstanding landmark, and it seems, at first sight, to be composed entirely of iron ore. In point of fact the iron ore is of limited extent, and the surface features are due to fallen boulders and fragments which litter the hillside. The main concentration of ore is in a bed 8 feet thick intercalated with the quartzites and dipping at 35° in a North-easterly direction. It is composed of massive magnetite and haematite with only a slight admixture of quartz. An old working and a well are

The iron ore deposit on the hill Z 3.

Crystals of magnetite and martite protruding from a matrix of quartz and barite.

situated about 30 yards West of the main ore body. A pegmatite cuts the quartzite at this point; it carries spessartite, biotite, muscovite, chalcopyrite, pyrite, azurite, and malachite, besides magnetite and haematite.

The other portion of the deposit cuts across the bedding of the quartzites, from the top of Swartkop East-south-east to the base. It occurs as an impregnation of the quartzite and carries a far greater percentage of silica than the bedded ore. The dry river-bed North-east of Swartkop and the sandy flats for some distance from the base are littered with boulders of magnetite. The rock here shows a very fine polished surface due to sand-blasting.

On the northern side of the hill Z_2 the magnetite bed reappears, and here, as well as along Z_3, it carries white and pale pink barite as the chief gangue mineral. The width of the bed is approximately 6 feet, and the magnetite attains a striking crystal development. Perfect octahedra of magnetite and pseudomorphs in martite varying in size from 2.4 centimeters to a few millimeters, project from a surface of coarsely granular barite and remnantry quartz.

At Z_4 the magnetite horizon occurs on the southern slopes of the hill. There is no visible barite here, and the ore has again become massive. The magnetite bed continues along the top of the hill Z_5, the ore gradually becoming more disseminated: at the eastern end of the hill it forms veinlets branching through a bed of quartzite 6 feet thick.

No further outcrop of magnetite was found east of Z_5.

(b) Iron ore of the main range.

Magnetite and haematite occur in the belt of hills immediately to the south of the main range of quartzites, and extend in the form of a bedded deposit for approximately 2 miles. The ore is massive and has suffered extensive surface weathering to haematite. The thickness varies between 6 ft. and 12 ft. No macroscopic barite was found.

Amphibolites.

There are two varieties of rocks consisting mainly of amphibole on Aggenys

The bedded amphibolite. D. 3.

and Zuurwater. The first variety D.3. occurs on a hill just outside the western boundary of Aggenys and approximately ½ mile west of the road to Springbok. It lies near the base of the quartzites, with which it is interbedded, and about 50 yards from the granite contact. In hand specimen it is a dark holocrystalline medium-grained rock consisting mainly of crystals of hornblende having an imperfect schistose arrangement, and subsidiary amounts of felspar.

The second variety D.4 occurs as dykes transgressing the bedding of the schists and quartzites to the north and north-east of the farm-houses. It is a dark fine-grained rock with no trace of schistosity and in hand specimen resembles a hornfels.

The former is evidently a metamorphosed sediment and the latter an altered igneous rock.

Surface Sand.

Wind-blown sand covers much of the ground on both farms. In the south and west it forms extensive dunes, but as these are constantly moving, they have not been mapped. The sand is stained reddish-orange by iron oxides and the grains are nearly all sub-angular, not rounded as would be the case with true desert sands. Thirteen samples were taken from a depth of approximately one foot, at intervals of 1 mile from the farm houses southward in the direction of Springbok.

MINERALOGY OF THE AGGENYS GRANITE.

Quartz.

The size of the quartz grains varies from 2.2mm x 1.24mm to .001mm. The average size is approximately .4mm x .3mm. About 50% of the grains are strained. The majority of the quartz crystallised prior to microcline but later than the other minerals. Small amounts of dust-like inclusions are to be seen in the quartz either in trails or irregularly distributed. They appear to be composed of apatite, iron ore, liquid and glass. Granophyric texture occurs in several places.

Potash felspar.

Both orthoclase and microcline are present in the sections and are microperthitic. The orthoclase predominates. The largest crystal of potash felspar measures 3.14mm. x 1.24mm. and the average size is approximately .9mm. x .6mm. The orthoclase rarely shows Carlsbad twinning. Microcline shows the typical 'cross hatching' caused by the combined Albite and Pericline twinning. The refractive indices of the orthoclase are:

$$z = 1.526$$
$$y = 1.522$$
$$x = 1.519$$

The potash felspars are quite fresh and the slight cloudy effect seen in some of the crystals is due to the decomposition of the albite inclusions. Microcline was the last mineral to crystallise and occurs interstitially.

Plagioclase felspar.

The average size of the oligoclase is .6mm. x .4mm. The largest crystal measures 1.6mm. x 1.98mm. The oligoclase all shows a fair degree of decomposition with the formation of Kaolin, quartz, and muscovite. It is twinned according to the Albite law and contains inclusions of quartz, biotite, magnetite and muscovite.

$$\text{Refractive indices} \begin{cases} z = 1.545 \\ y = 1.540 \\ x = 1.536 \end{cases}$$

This indicates a composition of $Ab_{84}An_{16}$. A maximum extinction of 5° in the symmetrical zone confirms this result.

Biotite.

Most of the biotite has undergone alteration, the first stage of which is a simple colour change to green without any change in the optical properties. Later the biotite alters completely to chlorite. In rare cases the biotite and the secondary chlorite are characterised by the presence of sagenite webs of rutile. The maximum length of the rutile needles is .15mm. and the average length .02mm. Inclusions in the biotite comprise apatite, magnetite, and zircon. Zircons are surrounded by well-marked pleochroic halos.

Refractive indices	z = 1.643 x = 1.601	Pleochroism	z = dark brown x = pale straw yellow

Accessories

Muscovite occurs in small quantity. It is included in quartz, orthoclase and plagioclase felspar. Prismatic sections show good basal cleavage and give straight extinction. A basal section with low interference colours gave a good biaxial negative interference figure.

Refractive indices $\begin{cases} z = 1.603 \\ y = 1.595 \\ x = 1.564 \end{cases}$ $2V_x = 42^\circ$

Apatite is plentiful. Fairly large subhedral prisms varying in size from .14mm. x .09mm. to .06mm. x .05mm. are present as well as thin prisms with an average size of .13mm. x .03mm. and an elongation ratio of 1:4. Apatite is enclosed by all the other minerals in the sections except muscovite and zircon.

Zircon crystals occur abundantly; the largest measures .21mm. x .11mm. The colour varies from brown to colourless. The average elongation of the crystals is 1:2.

Iron ore is present in moderate amount. Magnetite is the main ore, but a little ilmenite showing partial alteration to leucoxene also occurs.

PETROLOGY OF THE AGGENYS GRANITE.

An analysis of this granite was made by Mr. F. Hardman, and this together with the norm, mode and specific gravity are given below.

Analysis		Norm			Mode	
SiO_2	76.22	Quartz		35.40	Quartz	36.3
Al_2O_3	11.56	Orthoclase		30.02	Potash felspar	35.8
Fe_2O_3	.66	Albite		26.72	Plagioclase felspar	25.1
FeO	1.05	Anorthite		2.50	Biotite	1.5
MgO	.44	Diopside	$CaSiO_3$	1.51		
CaO	1.26		$MgSiO_3$	.75	Iron ore	1.3
Na_2O	3.18		$FeSiO_3$	.72		100.0
K_2O	5.16	Hypersthene	$MgSiO_3$	.35		
MnO	trace		$FeSiO_3$	.33		
P_2O_5	trace	Magnetite		.93	Specific gravity = 2.70	
TiO_2	.18	Ilmenite		.30		
H_2O+	.27	Water		.37		
				99.99		
H_2O-	.10					
	100.08					

There is excellent agreement between the analysis, the norm and the mode, and these do not present any unusual features.

The correlation of the Aggenys granite with the Namaqualand granite-gneiss will be dealt with later.

PETROGRAPHY OF THE IRON ORE DEPOSIT.

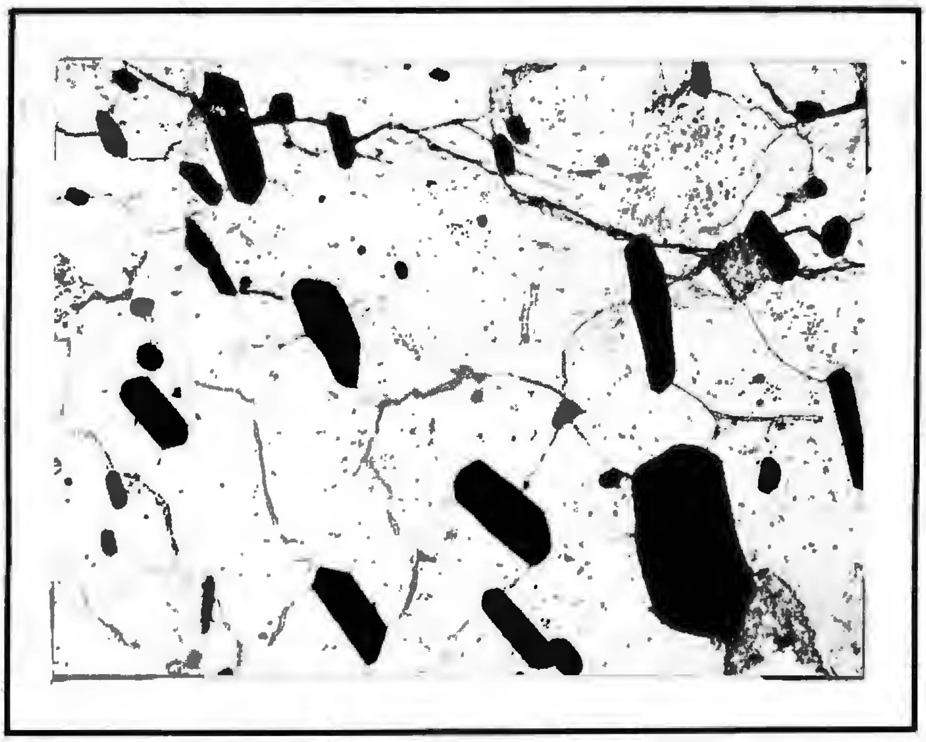
(a) Swartkop

The iron ore here appears massive in hand specimen and consists principally of magnetite which is often coated with the red oxide, haematite.

Magnetite.

The thin section shows crystals and crystalline aggregates of magnetite which have in part been replaced by pseudomorphs of haematite, i.e. martite. These are set in a ground-mass of quartz.

The proportion of iron ore to quartz varies in the main bed from approximately 75% to 50%. The quartzite above and below also carries a gradually diminishing quantity of magnetite.



Photomicrograph of the magnetite - barite rock from the hill Z2 showing the elongation of the magnetite crystals along planes of weakness between quartz grains.

Ordinary light x 32.

Many of the smaller magnetite crystals are elongated along the vertical axis. This is due, evidently, to the conditions of growth as the elongation invariably occurs along cracks in the quartz or boundaries between quartz grains.

Some crystals have been entirely replaced to form martite, and are then distinguishable by their reddish-brown colour in reflected light. Martite has frequently formed around the edges of crystal aggregates of magnetite. The size of the magnetite crystals varies from 1.15mm. to 0.053mm.; the average size is 0.23mm.

Quartz forms a mosaic of interlocking grains, most of which show strain phenomena. The average size of the quartz grains is approximately 0.33mm. The grains vary greatly in size and shape. The largest grain in the section measured 1.24mm., and the smallest 0.01mm.

An unusual feature is the abnormal amount of dustlike inclusions, which are probably iron ore. Occasional small prisms of apatite are also enclosed by the quartz: these show good relief, and a few give uniaxial negative figures in convergent light.

Barite is a minor constituent: it occurs as small colourless allotriomorphic grains which are moulded on the magnetite. They measure between 0.14mm. and 0.03mm.

An analysis was made of the iron content, and samples were taken from the base, the centre, and the top of the ore bed.

	Base	Centre	Top
FeO	0.17	10.24	9.32
Fe_2O_3	76.11	50.66	48.88

The metallic iron content calculated from these figures is as follows:-

Base,	53.36
Centre,	43.39
Top,	41.43

Photomicrograph showing the interstitial nature of the barite.

Ordinary light x 32.

Analysis.

SiO_2	41.34
FeO	.87
Fe_2O_3	37.98
TiO_2	.15
BaO	11.86
SO_3	6.18
MnO	Nil, or traces
P_2O_5	" " "
ZrO	" " "
CuO	Nil
	98.38

I estimated the water content from a sample taken from the same locality, and found it to be 0.95%. This brings the total to 99.33%.

The composition of the rock corresponding to this analysis is:-

Quartz	41.34
Barite	18.06
Ilmenite	.285
Magnetite	2.49
Haematite	30.60
Limonite	6.58
	99.35

(e) Eastern end of the deposit on Z_5.

The hand specimen shows quartzite veined by magnetite.

The section reveals clear evidence of dynamic metamorphism. The quartzite has been subjected to great shearing stress, which has caused the quartz to become elongated in a direction at right-angles to the stress.

A certain amount of granulation has taken place, and the average size of the grains is small, approximately 0.16mm. in length and 0.04mm. in breadth.

Between crossed Nicols nearly all the quartz shows undulose extinction, and the section appears to have a schistose texture.

The magnetite is not nearly so well crystallised as in other parts of the deposit and here forms irregular veinlets replacing the quartz along the planes of schistosity.

Martite occurs in minor amount.

Barite was not found either in the section or in the heavy residue.

Garnet. The manganese garnet, spessartite, occurs plentifully in the quartzite. It is mostly colourless in thin section, but some of the larger grains have a faint yellowish-brown tinge.

The largest garnet measured 0.18mm. x 0.11mm., and the smallest 0.016mm. x 0.015mm.

The average size = 0.04mm. x 0.03mm.

The refractive index was determined by immersion in a piperine and iodide melt: RI = 1.80 (±.01). In the sodium carbonate bead the powder gave a strong manganese reaction.

Zircon and biotite occur as minor constituents in the quartzite.

(d) Main range ore.

The ore here is similar to that described at Swartkop, except that no barite was found.

Origin of the Deposit.

In considering the question of the origin of the magnetite-barite rock the following features should be taken into account:-

(a) The fact that barite is confined to the ore horizon.

(b) The occurrence of copper ores in association with the iron at Swartkop.

(c) The nature of the contact with the quartzites, which shows a gradual diminution of iron content.

(d) The fact that the magnetite transgresses the bedding of the quartzites at Swartkop.

(e) The veining of the quartzite by magnetite at the eastern end of the outcrop.

These features have led me to postulate an epigenetic origin for both the magnetite and barite. I believe the iron ore to be a metasomatic replacement deposit introduced into the quartzites from an igneous source at a time when the quartzites were deeply buried beneath younger sediments.

The source of the iron was presumably the granite batholith of southern Namaqualand.

An aplitic facies of this is intrusive into the schists and quartzites of the area under consideration.

Barite is usually formed at a lower temperature than magnetite, and according to the microscopic evidence the barite was introduced subsequent to the magnetite.

Barite probably thus represents a later phase of hydrothermal emanation from the same source.

Alternative theory.

The hypothesis might be advanced that the bedded nature of the deposit suggests a sedimentary origin, and that the barite alone is epigenetic.

If this were so, one would expect to find the deposit thinning out towards the end of the outcrop. Actually, it does not do this, but breaks up into bifurcating veins and stringers which seam the quartzite bed. The transgressive nature of the magnetite at Swartkop and the occurrence of copper ores in association with the iron, likewise point to an igneous origin for the magnetite.

A microscopic examination of thin sections from the ore bed proves that the magnetite is of later formation than the quartz.

In the case of a metamorphosed ferruginous sandstone, magnetite, being high in the crystalloblastic series, would speedily have assumed crystal form and the quartz would be found filling the interstices between magnetite crystals.

Instead of this one finds that the development of magnetite has been guided by planes of weakness between the quartz grains and cracks in the quartz itself.

The possibility of barite being residual seems very remote. Barium sulphate is relatively very insoluble in ground-waters.

W.A. Tarr 16 quotes Clarke as giving 0.05% barium content in sandstones and shales.

It is difficult to see why descending solutions, even supposing they could concentrate sufficient $BaSO_4$, should deposit their content within a quartzite bed, and not have penetrated to a point where they came into contact with some less pervious formation.

Economic aspects.

A rough estimate of the available tonnage of iron ore shows that approximately 46,000 tons are exposed at the surface. This does not allow for the persistence of the ore bed in depth.

The grade of the ores is slightly less than that of the iron ore from the Lake Superior region which contain approximately 50% to 60% of iron.

At Zuurwater the deposit averages 42% metallic iron. This is well within the minimum tenor for iron ore quoted by W. Lindgren 9 (i.e. 30%), but the deposit cannot be considered an economic proposition on account of its inaccessibility and small reserves. It is situated 62 miles from the nearest railway station at O'okiep and 118 miles from Port Nolloth which is the nearest seaport.

MINERALOGY OF THE AMPHIBOLITES.

A. Amphibolite of sedimentary origin. D.3.

Sieve texture is characteristic of the rock and is shown by nearly all the crystals of amphibole, of which over 50% of the rock is composed. The other minerals present are plagioclase felspar, quartz, magnetite, biotite, apatite and zircon.

Quartz.

Irregular interstitial grains of quartz occur between the other minerals and as inclusions in the amphibole crystals. The average grain size is approximately .1mm.

Plagioclase felspar.

The plagioclase has the same mode of occurrence as the quartz. A number of the plagioclase grains are untwinned, but can easily be identified by their refractive indices, which are considerably above those of quartz. Albite and Carlsbad Twinning are common, while crystals twinned according to the Manebach and Baveno laws occur rarely. The average size of the plagioclase crystals is approximately .25mm. x .15mm., and the maximum size .56mm. x .33mm.

$$\text{Refractive Indices} \begin{cases} z = 1.575 \\ y = 1.570 \\ x = 1.565 \end{cases} \qquad 2V_x = 86^\circ.$$

The refractive indices together with the maximum extinction in the symmetrical zone i.e. 42°, and the extinction angle on the face [010], i.e. -30°, agree with a composition of $Ab_{25}An_{75}$ i.e. Bytownite.

Amphibole.

The monoclinic amphibole is the most abundant constituent of the rock and forms by far the largest crystals. These have average dimensions of approximately 1.5mm. x .35mm. and maximum dimensions of 4.13mm. x 1.82mm. All the large amphibole crystals show "sieve" texture and the included minerals are bytownite, quartz, magnetite and a little apatite. Twinning parallel to the orthopinacoid (100), is fairly common. Some amphibole crystals are colourless or nearly so, and in others the colourless variety occurs together with the normal green coloured amphibole in one crystal. The refractive indices and the extinction angles are the same for both colourless and green crystals and it is therefore concluded that the former is a bleached variety of the latter.

Refractive Indices $\begin{cases} z = 1.668 \\ y = 1.660 \\ x = 1.648 \end{cases}$ $Z \wedge C = 20^\circ$ $2V_z = 72^\circ$.

Pleochroism. $\begin{cases} z = \text{greenish blue} \\ y = \text{green} \\ x = \text{straw yellow.} \end{cases}$

Biotite.

Flakes of biotite, partially altered to chlorite occur rarely. They are pleochroic from yellowy brown to pale straw yellow. The biotite is uniaxial.

Refractive Indices $z = y = 1.640$
$x = 1.600$.

Accessory Minerals.

Magnetite is by far the most abundant accessory mineral. It occurs as small crystals and irregular grains scattered throughout the rock. The maximum size is .2mm. x .1mm. and the average size .05mm. x .05mm. Prisms of apatite have an average length of .08mm. and are moderately abundant. Zircon crystals are very small i.e. .03mm. and less and are colourless. They are of rare occurrence.

B. Amphibole of Igneous origin. (D4).

The rock is composed essentially of amphibole and plagioclase felspar. The structure approaches decussate but is not typical.

Plagioclase felspar

ranges in size from minute grains in the groundmass to laths 1mm. x .15mm. The average size is approximately .12mm. x .07mm. The ratio of length to breadth is approximately 2:1 in the medium sized laths and ranges up to 10:1 in some of the larger crystals. Both Carlsbad and Albite Twinning are very common. Pericline Twinning occurs rarely. Minute dust-like inclusions are fairly abundant in the felspars.

Refractive Indices $\begin{cases} z = 1.571 \\ y = 1.567 \\ x = 1.564 \end{cases}$ $2V_z = 86.5°$.

These values indicate an anorthite content of 70%, i.e. basic labradorite and this result is verified by the extinction angles measured on combined Carlsbad-Albite twins.

Amphibole.

The amphibole is pale green in colour. Twinning is not very common but does occur parallel to the face (100). The average length of the crystals is approximately ·12mm. and the average breadth approximately .06mm.

Refractive Indices $\begin{cases} z = 1.660 \\ y = 1.652 \\ x = 1.641 \end{cases}$ $Z \wedge C = 19°$, $2V_z = 67°$.

Pleochroism $\begin{cases} z = \text{bluish green} \\ y = \text{yellowish green} \\ x = \text{straw yellow.} \end{cases}$

Accessory Minerals.

Zoisite is fairly plentiful in the groundmass and is conspicuous on account of its ultra-blue interference colours.

Refractive Indices $\begin{cases} z = 1.706 \\ y = 1.704 \\ x = 1.700 \end{cases}$

Apatite occurs in minor amount. Its presence was verified by the ammonium molybdate test. Clinozoisite was found in the heavy residue separated by methylene iodide.

$$\text{Refractive Indices}\quad \begin{cases} z = 1.728 \\ y = 1.720 \\ x = 1.714 \end{cases}$$

Epidote also occurs in this crop together with pyrite and zircon.

PETROLOGY OF THE AMPHIBOLITES.

A). D3.

The field occurrence, 'sieve' texture and mineral assemblage all indicate that the rock is a dynamo-thermal metamorphic product of a calcareous sediment e.g. a marl.

The amphibole has properties intermediate between pargasite and hornblende, but as the optical sign is positive it probably corresponds more nearly to pargasite. This variety of amphibole is generally found in contact zones, and the near vicinity of the granite contact suggests that the intrusive granite was the source of the metamorphic action.

The mode and specific gravity are given below:-

Mode.

Amphibole	51.5
Bytownite	29.9
Quartz	11.4
Magnetite	6.9
Biotite	.3
	100.0.

specific gravity = 3.0.

B). (D.4).

The mode and the specific gravity of the rock are as follows:-

<u>Mode</u>

Amphibole	63.8
Plagioclase	36.2
	100.0

Specific gravity = 2.9

The field occurrence of the amphibolite, i.e. in dyke form cutting across the bedding of the quartzites and schists, precludes the possibility of its being of sedimentary origin, and it is in all probability a metamorphosed dolerite dyke.

The amphibole is intermediate in composition and optical properties between pargasite and hornblende, but is nearer the pargasite end of the series. The amphibole was separated and a chemical analysis made. This is given below, together with two comparable analyses.

	Amphibole D.A.	Hornblende in diorite (A).	Pargasite in metamorphic rock (B).
SiO_2	48.60	49.16	49.33
Al_2O_3	12.28	11.28	12.72
Fe_2O_3	.94	.02	1.72
FeO	10.96	14.48	4.63
MgO	12.55	12.01	17.44
CaO	11.80	10.57	9.91
Na_2O	1.25	.58	2.25
K_2O	.69	1.12	.63
TiO_2	.26	.18	-
Ignition	.54	.98	.29
MnO	not determined	.14	-
Cr_2O_3	" "	.09	-
F	" "	-	[illegible]
	99.87	100.79	99.13.

Analyses A and B were taken from tables of analyses in 'Rock Minerals' by J.P. Iddings 6 pp. 351 and 352.

B. Matrix.

The matrix consists of a fine-grained granular mosaic of quartz, basic plagioclase felspar, epidote, zoisite, orthite, magnetite, hornblende, biotite, apatite, sphene and ilmenite.

Quartz.

Grains of quartz are more abundant than any other mineral and represent approximately 70% of the matrix. They have an average size of .1mm. and are nearly all strained.

Plagioclase felspar.

After quartz, plagioclase felspar is the most abundant mineral in the sections. It is perfectly fresh and is frequently twinned according to the Carlsbad and Albite laws and occasionally according to the Manebach and Baveno laws. Some crystals, however, are untwinned, but these can be readily distinguished from quartz on account of their higher refractive indices. The Albite twin lamellae are occasionally bent. The plagioclase never shows good crystal form but occurs as irregular grains the majority of which have rounded or embayed outlines. The maximum size is 1.24mm. x .91mm. and the average size is approximately .25mm. x .15mm. Many of the larger plagioclase grains show 'sieve' texture, the inclusions consisting mostly of quartz. Any of the other minerals present in the rock may also be included in plagioclase.

$$\text{Refractive Indices} \begin{cases} z = 1.580 \\ y = 1.575 \\ x = 1.569 \end{cases}$$

These values, together with the extinction angles measured on combined Carlsbad Albite twins, indicate that the felspar is a Bytownite having a composition of $Ab_{21}An_{79}$.

Hornblende.

Green hornblende occurs as ragged and embayed crystals the larger of which occasionally show 'sieve' texture. It is a fairly abundant accessory constitutent and has a maximum size of 1.66mm. x .5mm. Hornblende includes quartz, apatite, magnetite, sphene, orthite, and epidote.

Refractive Indices
$z = 1.683$
$y = 1.675$
$x = 1.661$

$Z \wedge C = 16°$.

Pleochroism
z = bluish green
y = yellowish green
x = straw yellow.

Sphene.

is another plentiful accessory. It occurs as diamond-shaped crystals and aggregates of irregular grains frequently associated with iron ore and apatite. Sphene may be included in any other minerals except those of the epidote group. It occasionally encloses iron ore. The maximum size attained by crystals of sphene is .4mm. x .25mm. and the average size is approximately .1mm. x .05mm.

Epidote Group.

(a) Pistacite or common epidote occurs as scattered grains and crystals throughout the groundmass and occasionally along cracks in the pebbles. It has an average size of approximately .08mm. x .08mm. and is faintly pleochroic from lemon yellow to colourless. Twinning is occasionally seen.

Refractive Indices
$z = 1.770$
$y = 1.760$
$x = 1.731$.

(b) Orthite is of slightly less frequent occurrence in the rock than epidote. It forms orange-brown crystals and grains which are commonly zoned and which have an average size of approximately .05mm. x .05mm. The orthite is distinctly pleochroic in shades of brown and yellow. It occasionally surrounds a core of epidote, from which it can be distinguished by its cheaper colour, lower refractive indices and bi-refringence. No exact refractive indices could be obtained as the orientation of the grains was uncertain, but the two values measured were:- $n_1 = 1.733$ and $n_2 = 1.748$. These values correspond most nearly to the altered orthite given by Larsen 7. which has a mean refractive index of 1.74.

(c) Zoisite occurs in minor amount. The largest crystals measure only .08mm. x .05mm. The crystals are colourless and show the characteristic ultra-blue interference colours.

Refractive Indices	z = 1.702 x = 1.695.

Apatite is moderately abundant and occurs most plentifully in the vicinity of magnetite, sphene and hornblende. It forms crystals having a maximum size of .16mm. x .12mm. and an average size of approximately .05mm. x .05mm.

Biotite occurs in minor amount in the heavy residue, but does not appear in the sections.

Refractive Indices	z = 1.640 x = 1.600
Pleochroism	z = dark brown x = straw yellow

Iron Ores.

Magnetite is by far the most abundant iron ore. Ilmenite occurs in small amount in the heavy residue. Magnetite occurs as ragged grains and corroded crystals which attain a maximum size of 1.32mm. x 1.07mm. It is very plentiful in the matrix. Approximately 40% of the heavy residue is composed of magnetite.

Zircon is relatively scarce. The crystals are nearly all colourless. The lengths and breadths of over 100 zircons in the heavy residue were measured and the results plotted. This diagram is included for comparative purposes with other similar length: breadth diagrams for the zircons of various known sedimentary formations and is to be found on page 75.

THE PETROLOGY OF THE SHEARED CONGLOMERATE.

Judging by the texture and mineral assemblage, the rock was originally a conglomerate with a marly matrix, which has since been metamorphosed under stress. The quartz pebbles have been elongated, cracked and in places granulated, while the matrix has been completely recrystallised. Calcic minerals predominate, i.e. sphene, hornblende, bytownite, apatite and the epidote group. The general lack of crystal form, together with the prevalence of 'sieve' texture and corrosive effects indicate marked metamorphic action and recrystallisation under stress. The length: breadth diagram of the zircons with its broad base on the 1:1 bounding line provides corroborative evidence that the rock is of sedimentary origin.

MINERALOGY OF THE SCHISTS.

Quartz.

All the larger grains and many of the smaller grains show undulose extinction, while much of the quartz is elongated at right angles to the direction of stress. This is evidently due to local solution at points of maximum pressure and recrystallisation of material where the pressure was least. Inclusions in the quartz consist of apatite, magnetite and zircon. The average size of the quartz grains is approximately 1mm. x 1.65mm. in the coarse schist and .5mm. x .15mm. in the finer schist.

Muscovite.

Nearly all flakes of muscovite show parallel orientation, and in a few cases bending. The large prismatic crystals have an average size in the coarse schist of 2mm. x .4mm. and .5mm. x .2mm. in the fine schist.

$$\text{Refractive Indices} \begin{cases} z = 1.602 \\ y = 1.597 \\ x = 1.564 \end{cases} \qquad 2V_x = 40^\circ.$$

and gaseous inclusions. In the quartzites associated with the magnetite-barite deposit there is an abnormal amount of minute inclusions of iron ore.

Muscovite.

The white mica, muscovite, is present in all the quartzites, but varies considerably both in size and quantity. It is most abundant in the basal quartzites, which are generally either white or pale yellowish green in colour. Muscovite frequently shows undulose extinction.

Refractive Indices $\begin{cases} z = 1.602 \\ y = 1.596 \\ x = 1.564. \end{cases}$ $2V_x = 42°.$

Biotite.

Prismatic sections and cleavage flakes of strongly pleochroic biotite occur only in the quartzite associated with the iron ore deposit. They vary in size from 1.32mm. to .06mm. and have an average size of .41mm. The colour is either brown or green, and the latter variety is probably an alteration phase intermediate between the brown mica and chlorite. It has similar optical properties to the brown biotite.

Refractive Indices $\begin{cases} z = e = 1.600 \\ x = w = 1.571. \end{cases}$

The chlorite, which has been formed at the expense of the biotite has the following refractive indices:-

z = 1.598. y = 1.587. x = 1.586.

Barite.

This mineral occurs fairly plentifully in the dark quartzite (A.Q.6). It is interstitial to the other minerals, and has a somewhat glassy appearance and an abundance of inclusions. The refractive indices and other properties are similar to those given for the barite of the iron ore deposit. (See page 16)

Iron Ores.

Magnetite occurs abundantly only in the dark quartzite (A.Q.6). It forms crystals, crystal aggregates and irregular grains scattered throughout the quartz and along the contacts between quartz grains. The maximum size is .36mm. x .3mm. and the average size is approximately .08mm. x .08mm. Haematite, limonite and more rarely pyrite occur in subsidiary amount in all the quartzites and increase in quantity in the vicinity of the ore deposit.

Accessory Minerals.

(a) Spessartite is abundant in the quartzites associated with the magnetite-barite deposit but does not occur in any others. The grains range in size from .03mm. x .04mm. to .75mm. x .58mm.

(b) Anatase occurs in the form of perfect tetragonal crystals and as rounded and irregular grains. The majority of the anatase is opaque but a few grains are blue. They appear in the non-magnetic crop of the heavy residues.

(c) Apatite is rare. It occurs mostly as egg-shaped grains and as small crystals enclosed by quartz.

(d) Rutile. Orange to foxy red crystals of rutile are fairly abundant in the heavy residues. The majority are faintly pleochroic.

(e) Tourmaline is a very rare constituent. It is pleochroic from pale blue to indigo and from pink to blue. The grains are irregular in shape and only occur in the heavy residues.

(f) Chalcopyrite occurs in the quartzites from Swartkop where it is moderately abundant.

(g) Zircon crystals are mostly colourless and clear, but may be crowded with inclusions. A few yellowish and pink crystals occur. The majority are fairly well rounded. A length: breadth diagram of the zircons is included with those from other quartzites in the chapter on the comparative study of the quartzites.

(h) Epidote occurs sporadically as small irregular grains associated with haematite in the quartzite on the hill Z_2. The epidote is bright yellowish green in colour and is distinctly pleochroic. The average diameter of the grains is approximately .05mm.

$$\text{Refractive Indices} \begin{cases} z = 1.769 \\ y = 1.753 \\ x = 1.730. \end{cases}$$

(i) Pleonaste (?). A few grains of a grass-green mineral occur in the heavy residues. It shows complete isotropism, is non-magnetic and contains no inclusions.

(j) Blue mineral. Two grains of this mineral occur in the section of the dark quartzite (A Q 6) from the hill Z_2. It has a vivid colour similar to Stephen's blue ink and is pleochroic from blue to colourless. The direction of maximum absorbtion is parallel to that of the slow ray Z. Two refractive indices were measured.

$z = 1.678.$ x or $y = 1.652.$

The interference figure was indistinct but appeared to be either uniaxial positive, or biaxial with a small optic axial angle. The mineral is possibly either blue tourmaline or a copper aluminium silicate.

MINERALOGY OF THE AGGENYS SANDS.

Thirteen samples of sand were examined and separated into light and heavy crops. The relative proportions of heavy minerals present were estimated approximately by counting grains from representative samples taken by means of the micro-splitter. The light crops were boiled with dilute HCl to remove the coating of iron oxides from the grains. The sands were all separated into three groups: a) grains too large to pass through the 60 mesh sieve, b) grains passing 60 mesh, but not 90 mesh, and c) grains passing 90 mesh. The light crops are invariably composed of quartz, microcline and microcline microperthite, muscovite and plagioclase which is much decomposed.

Quartz.

The great majority of the quartz grains are sub-angular. They generally contain abundant inclusions, consisting mainly of apatite, iron ore and zircon. Biotite and tourmaline are also present as inclusions in the quartz of the three sands collected nearest the farm houses, i.e. S_1, S_2 and S_3. The ratio of quartz to felspar averages approximately 3:1.

Felspar.

Microcline, the majority of which is microperthitic constitutes about 98% of the felspar present. 'Grid-iron' structure is characteristic and the grains are only slightly decomposed. The perthitic inclusions are generally very fine vein-like bodies. Orthoclase and plagioclase felspar are invariably much decomposed, and generally can only be distinguished by the 'Becke line' Test, and in certain cases even this cannot be applied. Albite twin lamellae can rarely be distinguished but in the sand S16 a few grains were found sufficiently fresh for the determination of their refractive indices. One grain in this sand showed anti-perthitic structure.

Refractive Indices
$$\begin{cases} z = 1.553 \\ y = 1.549. \\ x = 1.547 \end{cases}$$

These values correspond to an acid andesine having an anorthite content of 33%.

Muscovite.

The white mica is generally present in both the light and heavy crops. It occurs as basal flakes and gives a good biaxial negative figure in convergent light.

The contents of the heavy residues are set out below in tabular form.

MINERAL	S.1	S.3	S.5	S.7	S.9	S.10	S.11	S.12	S.13	S.14	S.15	S.16	S.17
Magnetite	M	A	M	A	A	M	M	M	M	A	A	A	A
Haematite and Limonite	R	R	M	R	R	M	A	A	A	M	M	M	R
Ilmenite	R	M	M	A	M	M	R	M	R	R	M	M	M
Chromite													R
Biotite	M	R	R		R	R	R	R	R	R	R	vR	R
Muscovite	M	M	M	M	M	M	R	R	M	M	M	R	M
Hornblende	M	R	R	R	R	M	R	M	M	M	M	M	M
Garnet	M	M	M	M	M	M	M	M	M	R	R	R	R
Sphene								R	R	R	R	vR	
Epidote	R	R	R	R	R	R	R	R	R	R	R	R	R
Zoisite								R					
Piedmontite					vR		vR	vR			vR		
Monazite										vR			
Tourmaline	R	M	R	R	R	R			R				
Sillimanite	R	R	R	R	R	R	R	R					
Apatite			vR		vR		vR	R					
Rutile	R	R	R	R	R	R	R	R	R	R	R	vR	R
Zircon	R	R	R	R	R	R	R	R	R	R	R	R	M
Staurolite							vR						

A = abundant > 25%

M = moderately abundant 10 - 25%

R = rare 1 - 10%

vR = very rare < 1%

The sands were collected at one mile intervals in a south-south-west direction from the farm-houses at Aggenys. The following tables give the actual distances from the houses:-

S 1	at the farm houses
S 3	1 mile from the houses
S 5	2 miles from the houses
S 7	3 miles from the houses
S 9	4 miles from the houses
S 10	5 miles from the houses
S 11	6 miles from the houses
S 12	7 miles from the houses
S 13	8 miles from the houses
S 14	9 miles from the houses
S 15	10 miles from the houses
S 16	11 miles from the houses
S 17	12 miles from the houses.

The mineral content of the sands is what one would expect to find from the weathering, under semi-arid conditions, of the surrounding rocks. The occasional appearance of apatite in the heavy residues is probably due to its recent release from enclosing quartz grains which acted as a protective covering, while the constant occurrence of garnet (almandine) points to the weathering of contact rocks, probably schists.

A COMPARATIVE STUDY OF THE NAMAQUALAND GRANITES AND THE CAPE GRANITE.

Field Characters of the Namaqualand Granites.

A. Younger Granite-gneiss.

The field characters of these granites and gneisses vary considerably and no means of field identification was found practicable. No sharp contact was discernible between the typical granites and the gneisses, and the relationship between the two types appears to be gradational. The author agrees with Dr. Gevers in his view that the high biotite content of certain varieties is due to the assimilation by the granite magma of ancient sediments. The biotite content of the granites collected varies from 1.53% to 13.84% and averages 7.34%.

Inselberge of granite at Geselskapbank.

Dome weathering of the Namaqualand granite-gneiss.

The Old granite in the contact zone near Jackalswater showing the platy weathering.

The granite-gneiss is normally grey in colour, but there are exceptions, notably on or near the farm Geselskapbank where a pinkish colour is given to the rock by the potash felspar. The texture is typically phanerocrystalline, medium to fine grained, and the fabric granitoid or gneissic. Porphyritic varieties occur, e.g. G8 and G15, but this texture is the exception rather than the rule, and the phenocrysts are not very abundant.

Care was taken in the collection of the granites to choose localities as far as possible from any visible source of contamination such as the presence of remnantry sediments, traces of which abound all over Namaqualand.

Dr. Rogers, Dr. du Toit 12 and Dr. Gevers 3 all record the presence of sillimanite in the Namaqualand granites and gneisses, and corundum is known to occur in the granite near Steinkopf. Neither of these minerals has been recorded in the present collection of samples.

Dome weathering and exfoliation are well displayed by the Namaqualand granite, and the outstanding scenic feature of the area occupied by the younger granite is the magnificent smooth dome of the granite mountains.

The older granite is typically grano-dioritic in composition, although in hand-specimens it appears to be a normal granite. Its texture and fabric are similar to the Namaqualand granite except that the sheared gneissic varieties appear to be confined to the belt of contact with the younger granite just south of Jackalswater. Hornblende occurs in specimens in six out of the ten localities. It is possible that the hornblende present in these samples is due to the assimilation of ancient basic country rocks. The hornblende occurs either as porphyroblasts or in corroded crystals and is sporadically distributed throughout the rock. Sieve texture is characteristic. This granite normally weathers into round boulders.

MINERALOGY OF THE NAMAQUALAND GRANITE-GNEISS.

Quartz.

The majority of the quartz grains in the younger granites are strained and show undulose extinction. G12 and G15 are exceptions in this respect.

These rocks have apparently been largely recrystallised and the quartz forms a mosaic with the other minerals of interlocking grains which are relatively free from inclusions. The crystallisation period of quartz invariably extends from just before the final crystallisation of biotite to just after that of the potash felspar microcline. Trails of minute inclusions of iron ore, small crystals of apatite, and liquid and gaseous inclusions are commonly present and vary only in quantity. The quartz of G12 contains fine acicular inclusions of an opaque mineral which is presumably iron ore. The grain size varies from a maximum of 4.10mm. x 3.46mm. and an average of 1mm. x 1mm. in the medium grained granites to a maximum of 2.62mm. x 2.53mm. and an average of .6mm. x .3mm. in the fine grained granites. Granophyric intergrowths between quartz and plagioclase felspar occur in seven out of the ten granites.

Potash felspar orthoclase.

The monoclinic felspar orthoclase is present in only three samples, G7, G5, and G12. In G7 it is the dominant potash felspar, but in G5 and G12 it occurs in minor quantities and in the latter chiefly in the form of phenocrysts which have a maximum size of 23mm. x 1[illegible]mm. The average size of the orthoclase crystals is 1mm. x .9mm.

$$\text{Refractive Indices}\begin{cases} z = 1.526 \\ y = 1.524 \\ x = 1.519 \end{cases} \qquad 2V_x = 70^\circ$$

The orthoclase is microperthitic. The perthite is in the form of small vein-like bodies which have an average length of .01mm. Orthoclase crystallised after biotite and the accessory minerals, and before microcline. The crystals are fresh and show only rare twinning according to the Carlsbad law.

Microcline.

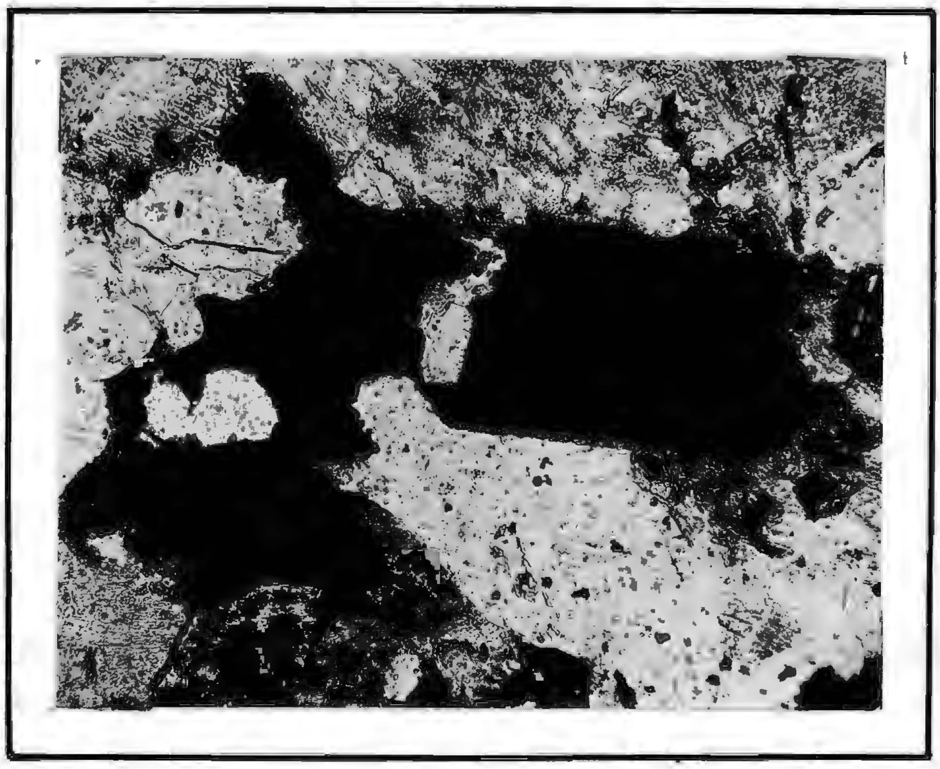
Microcline microperthite is the characteristic felspar. It is invariably fresh and any slight cloudiness appears due, on examination, to the decomposition of the perthitic intergrowths. These vary in abundance and size and are composed of acid plagioclase having an anorthite content ranging from 5% to 12%.

They occur most commonly in the form of veinlets oriented parallel to [100] but irregular blebs are also present. The average length is .01mm. and the maximum dimensions .13mm. x .03mm. Microcline occurs interstitially and appears strained in only one instance, i.e. G6. Crystals show the typical 'cross-hatching' due to Albite and Pericline twinning and attain a maximum size in G3 of 4.63mm. x 3.46mm. The average size is approximately .80mm. x .50mm.

$$\text{Refractive Indices}\begin{cases} z = 1.526 \\ y = 1.524 \\ x = 1.518 \end{cases} \qquad 2V_x = 80^\circ$$

<u>Plagioclase felspar.</u>

The composition of the plagioclase felspar varies from $Ab_{90}An_{10}$ in G7, to $Ab_{57}An_{43}$ in G5. It always shows some degree of decomposition with the formation of Kaolin, muscovite and quartz, or saussurite in the case of the more basic felspars. The range of crystallisation of the plagioclase extends over much the same period as that of quartz, the bulk of the plagioclase, however, crystallising before the majority of the quartz. The size of the crystals varies with the grain size of the rock. It attains a maximum in G5 of 4.13mm. x 2.48mm. while the average size is approximately 1mm. x .7mm. Microcline antiperthite occurs in the granites, G5, G6, and G15. The size of the microcline intergrowths is much larger than that of the normal perthite and reaches a maximum of 1mm. x 1mm. and has an average length of .32mm. The microcline exhibits the typical 'cross-hatching'. In G15 the plagioclase phenocrysts are composed of microcline antiperthite. Plagioclase crystals are typically twinned according to the Albite law, and less frequently according to the Carlsbad and Pericline laws. The composition of the felspars was determined by measuring the refractive indices and was checked by means of the maximum extinction angle in the symmetrical zone, or the extinction angles of combined Carlsbad-Albite twins, the latter method being preferred. The complete list of the refractive indices and the corresponding compositions is given below



Photomicrograph of biotite in the Granite-gneiss showing 'sagenite webs' of rutile.

Ordinary light x 100.

Refractive Indices

Rock	Z	Y	X	Anorthite content
G4	1.545	1.541	1.536	17.5%
G5	1.558	1.555	1.550	43%
G6	1.554	1.548	1.546	33%
G7	1.540	1.536	1.531	10%
G8	1.554	1.550	1.547	35%
G13	1.553	1.550	1.547	35%
G12	1.553	1.550	1.547	35%
G11	1.548	1.546	1.541	25%
G3	1.550	1.546	1.543	27%
G15	1.555	1.551	1.547	37%

Biotite.

Prismatic grains and allotriomorphic basal flakes of strongly pleochroic biotite mica are present in all the younger granites. The percentage of the biotite in the rocks varies from approximately 13.84 to 1.53. The size of the prisms reaches a maximum of 1.82mm. x .74mm. and the average dimensions are .5mm. x .3mm. Acicular inclusions of an opaque mineral in the form of sagenite webs are characteristic of the biotite of all but two of the Namaqualand granites, G11 and G15. The inclusions have a maximum length of .15mm. and an average length of .02mm. They are probably minute needles of rutile, and they occur most abundantly in G6 in which the biotite has an exceptionally dark colour owing to their presence. Much of the biotite has altered to green chlorite and this secondary chlorite also contains the sagenite webs. The mean refractive index of the chlorite is 1.62. In the two instances where sagenite webs are absent sphene has developed along the cleavage planes of the biotite and around the clusters of mica. Inclusions in the biotite comprise apatite, zircon, quartz, and plagioclase. Occasionally epidote is to be seen partially replacing biotite. The refractive indices and the pleochroism are given below

Refractive Indices

Rock	z	x	Pleochroism z	Pleochroism x
G4	1.640	1.596		
G5	1.642	1.600		
G6	1.630	1.590		
G7	1.643	1.601		
G8	1.643	1.600	dark	straw
G13	1.642	1.600	brown	yellow
G12	1.643	1.601		
G11	1.646	1.599		
G3	1.650	1.602		
G15	1.646	1.599		

Hornblende.

The monoclinic amphibole occurs in four out of the ten granites examined and its distribution in these is very sporadic. Many sections of the rocks G11, G6, G3, and G15 contain no hornblende, while in other sections it is relatively plentiful. G11 contains corroded hornblende crystals with a maximum size of 2.48mm. x 1.16mm. and an average size of .7mm. x .50mm. Inclusions are abundant and comprise a variety of minerals, apatite, magnetite, quartz, biotite, oligoclase and sphene. In the recrystallised rock G15 hornblende occurs as small irregular grains having a maximum size of .08mm. x .08mm. Hornblende appears to be of a remnantry character in this rock and apparently has been largely replaced by biotite. In G3 hornblende is represented by large porphyroblastic crystals measuring up to 25mm. in length.

Pleochroism:
- z = dark bluish green
- y = yellowish green
- x = greenish yellow

Refractive Indices

	G11	G15	G3
z	1.678	1.681	1.679
y	1.671	1.671	1.671
x	1.660	1.662	1.660

$Z \wedge C = 16°$

In G6 the hornblende was only noticed in the heavy residue in which it occurs in minor amount. Its properties are quite different from the previous hornblendes and are therefore given separately below.

Refractive Indices $\begin{cases} z = 1.690 \\ y = 1.677 \\ x = 1.655 \end{cases}$ Pleochroism $\begin{cases} z = \text{brownish green} \\ y = \text{brown} \\ x = \text{light yellow} \end{cases}$

$$Z \wedge C = 23^{\circ}.$$

Sphene.

Minor amounts of secondary sphene occur in six granites. It is formed from the alteration of ilmenite in the granites G11, and G4. In G15 and G11 it has developed along cleavage planes in the biotite, while in G13, G8 and G3 its origin is doubtful as it only appears as small grains in the heavy residue. The pleochroism is from colourless to honey-brown. Wedge-shaped crystals and crystal aggregates are characterised by irregular cracks, and incomplete extinction between crossed Nicols. The mean refractive index obtained by the immersion of crystals in a piperine and iodide melt is 1.96.

Epidote.

Pleochroic yellowy green grains of epidote occur in minor amount in all the granites except G13, G6, and G15. Epidote replaces biotite and is an alteration product of plagioclase felspar.

Refractive Indices $\begin{cases} z = 1.768 \\ y = 1.750 \\ x = 1.729 \end{cases}$

Accessory minerals.

(a) Apatite. Crystals of apatite vary in size from less than .001mm. to .42mm. x .35mm. The average size is .08mm. x .05mm. Apatite is generally a fairly abundant accessory and may be included in any of the other minerals except zircon. Crystals frequently contain very minute opaque inclusions, presumably iron ore, and occasionally thin prisms of a colourless highly refractive mineral which is probably zircon.

(b) Iron ore. Magnetite occurs in all the granites and in the principal iron ore. It is present in varying amount and occurs as crystals and crystal aggregates with average dimensions of .70mm. x .50mm. Ilmenite occurs in minor amount in all the granites except G5, G6, and G3. It is frequently surrounded by rims of secondary leucoxene.

(c) Zircon. All the granites except G4 and G13 have average numbers of zircon crystals. In G4 and G13 zircons are rare. The colour of the crystals appears to be largely determined by the inclusions of iron ore and ranges from colourless to brown and opaque. G15 and G4 contain only colourless zircons and in G11 the majority are colourless. In all the other granites yellow and brown crystals predominate. The inclusions are frequently zonally arranged. The average elongation ratio is 1:2. The crystals are all of the normal type, i.e. prisms terminated by small pyramid faces and are either idiomorphic or slightly rounded.

(d) Rutile. Small foxy-red prisms of rutile appear as a very rare constituent in the heavy residues of G3, G4, G5, G6, and G11. Two orangy-brown rutiles also occur in G11.

(e) Fluorite. A few grains of purple fluorite occur in G4.

(f) Muscovite. Primary muscovite occurs in the rock G7.

$$\text{Refractive Indices} \begin{cases} z = 1.603 \\ y = 1.595 \\ x = 1.564. \end{cases} \qquad 2V_x = 42^\circ$$

PETROLOGY OF THE NAMAQUALAND GRANITE-GNEISS.

Analyses of the granites G7 and G12 have been made, the former by the author and the latter by Mr. F. Herdsman. The results together with the norms, modes and analyses of comparable rocks are given below.

	G7	G12	A	B	C	D
SiO_2	71.26	72.86	71.12	73.66	70.31	70.18
Al_2O_3	13.73	13.82	13.60	13.80	13.83	14.47
Fe_2O_3	1.56	1.02	1.69	.34	.27	1.57
FeO	1.09	1.07	.65	1.42	2.91	1.78
MgO	.43	.52	.69	.46	.74	.88
CaO	1.80	1.90	.97	.94	1.99	1.99
Na_2O	3.59	2.49	3.70	2.62	3.48	3.48
K_2O	4.99	5.66	5.78	5.13	4.80	4.11
MnO	trace	.02	.03	.04		.12
P_2O_5	.56	trace	.15	.22	.24	.19
TiO_2	.30	.14	.46	.22	.45	.39
H_2O+	.62	.33	.64	.73	.92	.84
H_2O-	.18	.07		.04		
CO_2				.07	.05	
ZrO_2				.02		
BaO				.01		
	100.11	99.90	99.95	99.72	99.99	100.00

G7. Namaqualand granite from 28 miles north of Garies. (Analyst, M. Mathias)

G12. Namaqualand granite from sixteen miles west of Springbok. (Analyst, F. Herdsman)

A. Porphyritic granite from Kuboos mountain, Northern Namaqualand 17 (Analyst, C.J. Liebenberg)

B. Young (?) granite-gneiss from George, Cape Province 4. (Analyst, F.F. Grout)

C. Average of six coarsely porphyritic Nama granites from Namaqualand 13 (Analyst, D.L. Scholtz)

D. Average of 546 granites of world-wide distribution 1.

Norms

	G7	G12	A	B	C	D
Quartz	28.20	31.56	24.60	36.24	25.08	28.26
Orthoclase	29.47	33.36	34.47	30.02	28.36	24.46
Albite	30.39	20.96	31.44	22.01	29.34	29.34
Anorthite	5.28	9.45	3.06	3.06	7.78	9.17
Corundum	.41	.10		2.86		.92
Diopside $CaSiO_3$			.46		.58	
Diopside $MgSiO_3$			1.70		.18	
Diopside $FeSiO_3$					.43	
Hypersthene $MgSiO_3$	1.10	1.30		1.20	1.62	2.20
Hypersthene $FeSiO_3$	.26	1.19		1.98	3.96	1.45
Magnetite	2.09	1.39	1.16	.46	.46	2.32
Ilmenite	.61	.15	.76	.46	.76	.76
Haematite			.96			
Apatite	1.34		.34	.34	.34	.34
Calcite				.20		
Water	.80	.40	.64	.77	.92	.84
	99.95	99.86	99.59	99.60	99.81	100.06

Modes

	G4	G5	G6	G7	G8	G13	G12	G11	G3	G15
Quartz	21.9	26.4	28.1	29.4	19.7	33.6	36.9	37.6	49.9	35.6
Potash felspar	36.2	24.2	30.2	27.9	38.4	28.0	36.7	35.6	27.1	22.9
Plagioclase felspar	31.6	30.9	26.8	33.7	34.9	27.9	23.7	21.6	16.5	27.5
Biotite	6.8	13.8	11.5	6.3	6.0	8.3	1.5	2.3	5.1	11.7
Hornblende								2.7		
Epidote	1.5									
Sphene								.3		
Iron ore	2.0	3.8	3.4	1.1	1.0	2.2	1.2		1.3	2.2
Muscovite		.8		1.6						
Total	100.0	99.9	100.0	100.0	100.0	100.0	100.0	100.1	99.9	99.9
Specific gravity	2.69	2.66	2.71	2.70	2.69	2.61	2.56	2.80	2.69	2.69
Anorthite content of the plagioclase felspar	17.5%	43%	33%	10%	35%	35%	35%	37%	27%	37%

The granites are normal potash granites and their analyses correspond closely to that of the average analysis given by Daly 1. As is to be expected, these analyses are very similar to the average analyses of the six Nama granites (G), while they differ from the George and Kuboos granites in having a higher percentage of CaO. The titanium content of the Namaqualand granite-gneisses cannot be accounted for by the very small amount of ilmenite present in the thin sections, and it is therefore suggested that the analyses provide additional proof that the sagenite inclusions in the biotite are composed of rutile. In all other respects there is good agreement between the analyses, the modes, and the norms.

The modes do not present any unusual features except in the case of G3 in which the percentage of quartz is abnormally high. It is suggested that this may be due to the assimilation by the granite magma of Kaaien quartzites, outcrops of which occur not far from the place where the granite was collected.

Sphene is only present in appreciable amount in the recrystallised granites G11 and G15 in which there are no sagenite webs in the biotite. It occurs around and near biotite clusters and along cleavage planes in the biotite. Both these granites contain hornblende. It is therefore probable that the biotite has released its originally absorbed titania and that this titania has reacted with hornblende to produce sphene, whereas in the less disturbed granites the titania has crystallised out within the biotite host to form minute needles of rutile.

From the sporadic field occurrence and the mineralogical characters of the hornblende there appears to be a strong presumption that it is a remnantry mineral derived from pre-existing basic rocks. The granites which contain hornblende also contain either sphene or rutile, other than the rutile present in the biotite, or both sphene and rutile. This relationship is illustrated in the following table.

Rock	Hornblende	Sphene	Rutile
G3	*	*	*
G6	*		*
G11	*	*	*
G15	*	*	

MINERALOGY OF THE OLD GRANITES

Quartz.

In all the granites except OG6, the majority of the quartz grains are strained. The quartz in OG6 has been recrystallised and now forms a mosaic of interlocking grains which contain very few inclusions. Similar quartz mosaics have developed in parts of the rock OG8. The grain size of the quartz attains a maximum in OG7 of 2.97mm. x 2.07mm. and the average size ranges from .2mm. x .2mm. in OG6 to 1mm. x 1mm. inOG3. Quartz commenced crystallising early in the history of the granites, i.e. before the later portion of the biotite, muscovite and sphene, and continued until after all the other minerals except microcline. Small amounts of minute inclusions are invariably present in the quartz and comprise apatite, iron ore, and bubbles containing liquid and gas. Granophyric intergrowths with plagioclase felspar occur in all the granites except OG5, OG6, and OG8.

Potash felspar.

(a) Orthoclase. OG6 is the only granite which contains an appreciable amount of orthoclase felspar. The orthoclase occurs in minor quantity, i.e. less than 10% of the total potash felspar present. The crystals have a maximum size of 1.3mm. x 1mm. and show Carlsbad twinning.

$$\text{Refractive Indices} \begin{cases} z = 1.526 \\ y = 1.524 \\ x = 1.519 \end{cases} \qquad 2V_x = 72^{\circ}$$

(b) <u>Microcline</u>. Microcline, showing the typical 'cross-hatching' and microperthitic intergrowths, is invariably the dominant potash felspar. The maximum grain size is 6mm. x 4.5mm. (OG10) and the average is approximately .5mm. x .3mm. It is typically fresh and occurs interstitially. Carlsbad twinning is fairly common. The refractive indices of the larger perthites show them to be composed of acid oligoclase having an anorthite content of 10%. They occur principally in the form of veinlets, most of which are oriented parallel to [100], but small globular and irregular bodies are also present. The maximum dimensions of the perthites are .16mm. x .01mm. and the average length is approximately .01mm.

$$\text{Refractive Indices} \begin{cases} z = 1.526 \\ y = 1.523 \\ x = 1.518 \end{cases} \qquad 2V_x = 80^\circ$$

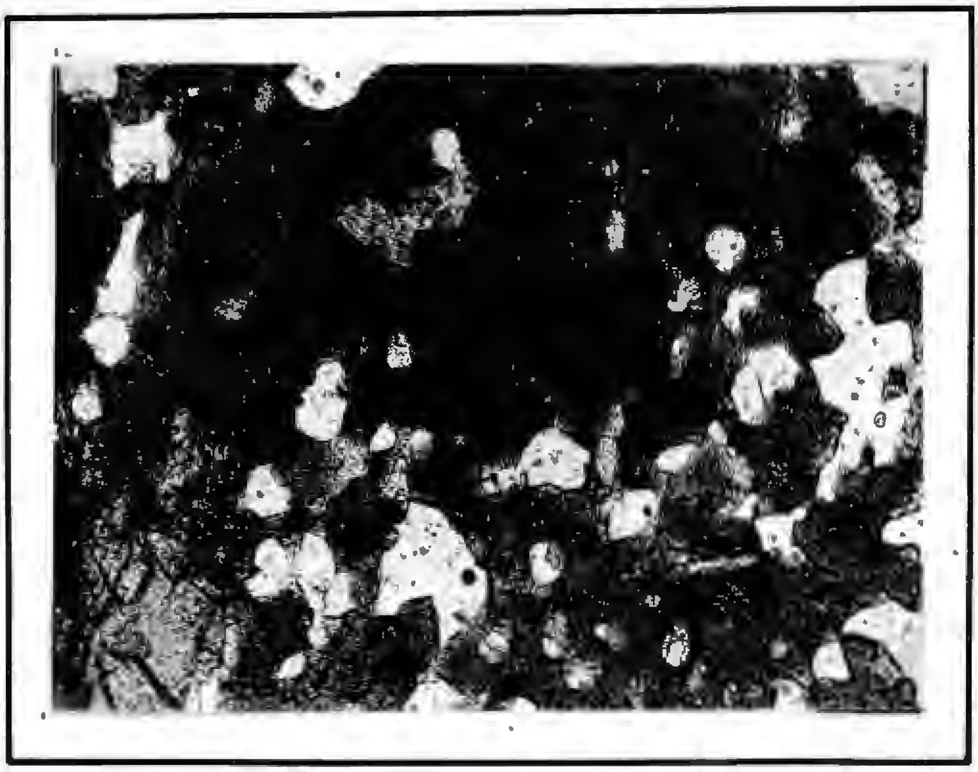
<u>Plagioclase felspar</u>.

The amount of plagioclase felspar in all the old granites exceeds that of the potash felspar. The average ratio of the plagioclase to potash felspar is approximately 2:1. Acid andesine is the most typical felspar in these sections. The composition, however, ranges from oligoclase ($Ab_{85}An_{15}$) to andesine ($Ab_{55}An_{45}$). Saussuritisation of the felspars is common, and epidote is a conspicuous product of this alteration. The period of crystallisation of plagioclase felspar is normal. It commenced about the same time as quartz and ended before the majority of the microcline. The crystals twin according to the Albite, Carlsbad, and Pericline laws, and have a maximum size of 3.31mm. x 2.56mm. and an average size of .80mm. x .70mm. The andesine of OG7 forms antiperthitic intergrowths with microcline. Granophyric intergrowths with quartz have already been referred to. The compositions of the felspars have been determined by measuring their refractive indices and were checked by means of the extinction angles on combined Carlsbad-Albite twins or the maximum extinction angles in the symmetrical zone.

Rock	Refractive Indices			Anorthite Content
	z	y	x	
OG1	1.559	1.555	1.552	45%
OG2	1.550	1.546	1.543	27%
OG3	1.554	1.550	1.546	35%
OG4	1.553	1.548	1.546	33%
OG5	1.558	1.553	1.550	43%
OG6	1.544	1.539	1.535	15%
OG7	1.554	1.550	1.547	35%
OG8	1.556	1.552	1.548	38%
OG9	1.553	1.549	1.546	35%
OG10	1.554	1.550	1.547	35%.

Biotite.

Strongly pleochroic biotite occurs in clusters or as scattered flakes throughout the granites. In OG6, OG5, OG10 and parts of OG7 the biotite is oriented at right angles to directions of stress and the rock has assumed a gneissic texture. Prismatic crystals of biotite have a maximum size of 3.30mm. x 1.66mm. and the average size is approximately .4mm. x .2mm. Decomposition to chlorite occurs in minor amount. The chlorite is pleochroic from green to straw yellow and has a mean refractive index of 1.618. Sericite is secondary after biotite in OG1 and OG2. Its refractive indices are: z = 1.612, y = 1.606, x = 1.576. Replacement of biotite by crystals and crystalline aggregates of epidote is of frequent occurrence. Inclusions in the biotite comprise apatite, sphene, magnetite, zircon, and more rarely quartz and plagioclase felspar. The refractive indices and pleochroism of the biotite are given below.



Photomicrograph of a crystal of hornblende in the Old granite showing sieve texture.

Ordinary light x 100.

Rock	Refractive Indices		Pleochroism
	z	x	
OG1	1.632	1.590	
OG2	1.630	1.591	
OG3	1.630	1.590	
OG4	1.630	1.590	z = dark brown
OG5	1.638	1.590	x = straw yellow
OG6	1.631	1.592	
OG7	1.635	1.590	
OG8	1.632	1.590	
OG9	1.632	1.590	
OG10	1.635	1.598	

Hornblende.

The occurrence of hornblende is invariably sporadic. It is present in all but three of the specimens collected, i.e. OG2, OG6, and OG10. The crystals are generally comparatively large and measure up to 5mm. x 4.13mm. In all the sections some of the hornblende presents a corroded appearance and is embayed by quartz and occasionally plagioclase. Sieve texture is fairly common. Inclusions comprise quartz, plagioclase felspar, sphene and apatite. Biotite and epidote have occasionally developed at the expense of the hornblende. Prismatic cleavage and twinning parallel to [100] are seen in some of the crystals. The refractive indices and pleochroism are shown in the table below.

Rock	Refractive Indices			Pleochroism
	z	y	x	
OG1	1.693	1.680	1.669	
OG3	1.693	1.680	1.669	
OG4	1.693	1.680	1.669	z = bluish green
OG5	1.693	1.680	1.669	
OG7	1.693	1.680	1.669	y = yellowish green
OG8	1.694	1.680	1.670	
OG9	1.693	1.680	1.668	x = deep straw yellow

$X \wedge C = 22^{\circ}$ $2V_{x} = 80^{\circ}$

Epidote.

Epidote occurs as crystals and crystalline aggregates generally associated with or replacing biotite. It frequently contains a core composed of a brown slightly pleochroic mineral which is probably orthite. The refractive indices of the orthite vary from similar values to those of epidote, to considerably below, i.e. from approximately 1.77 to approximately 1.62. Exact values could not be obtained owing to the small size and lack of crystal outline. Orthite occurs in all the sections of old granites. It has a maximum size of .25mm. x .13mm. The largest epidote crystal measures .83mm. x .58mm. and the average size is approximately .02mm. x .02mm. Orthopinacoidal sections of epidote show basal cleavage and give straight extinction. Twinning is rare.

Refractive Indices	z = 1.768	Pleochroism	z = colourless
	y = 1.750		y = yellowish green
	x = 1.729		x = colourless

The optical character is negative. $2V_x = 72°$.

Accessory minerals.

Sphene. Crystals and crystalline aggregates of sphene occur in all the old granites and in the majority of specimens sphene constitutes the most abundant accessory. Wedge-shaped crystals attain maximum dimensions of 2.97mm. x 1.48mm. The average size is approximately .2mm. x .1mm. The crystals are frequently characterised by irregular cracks and show high interference colours and incomplete extinction between crossed Nicols. Sphene is pleochroic from colourless to honey brown and has a mean refractive index of 1.98. Inclusions in sphene are not common but are sometimes present and comprise apatite, quartz, iron ore, and biotite. Secondary sphene has occasionally formed along the cleavage planes in biotite.

Apatite. Prisms of apatite occur in moderate amount in the old granites. The maximum dimensions are .5mm. x .16mm. and the average size is approximately .08mm. x .08mm. The crystals are fairly free from inclusions which are mainly composed of iron ore and zircon.

Iron ore. The characteristic iron ore is magnetite which occurs as crystals and crystalline aggregates in varying quantity. The average grain size is approximately .05mm. x .05mm. Ilmenite and pyrite occur in minor amount in OG7.

Zircon. Clear colourless zircons predominate. Pink varieties occur in OG2, OG6, OG8, and OG10, while a very small minority in OG1 and OG3 are coloured pale yellow or orangy brown. Approximately 50% of the crystals are idiomorphic. The others are rounded in varying degrees. The zircon crystals in OG3 and OG4 show modified terminal faces. Inclusions in the zircons are not numerous but where present they may show a zonal arrangement. The average elongation ratio is 1:2.

Tourmaline. The brown and blue varieties of tourmaline occur in minor amount in the heavy residue of OG8.

Refractive indices of brown tourmaline	Z = w = 1.659 X = e = 1.625	Pleochroism	Z = deep brown X = light brownish yellow
Refractive indices of blue tourmaline	Z = w = 1.657 X = e = 1.637	Pleochroism	Z = dark blue X = pale brown with bluish tinge

Fluorite. A few grains of fluorite appear in the sections and heavy residue of OG8. The fluorite is colourless with patches of violet.

PETROLOGY OF THE OLD GRANITES

A chemical analysis of the granite OG1 was made by the author. The results of this are given below together with two other analyses of old granites from other parts of South Africa, and two average analyses of granodiorites and quartz monzonites for comparison. The norms and modes are also tabulated below. There is excellent agreement between the analysis, norm and mode of OG1.

	OG1	OG(X)	OG(Z)	A	B
SiO_2	66.80	77.05	70.01	65.01	66.64
Al_2O_3	16.07	10.68	14.20	15.94	15.57
Fe_2O_3	1.52	1.10	.42	1.74	1.91
FeO	2.04	1.71	3.24	2.65	1.94
MgO	1.74	.34	.55	1.91	1.41
CaO	3.52	.93	2.06	4.42	3.50
Na_2O	2.75	2.52	3.14	3.70	3.41
K_2O	4.02	4.30	4.45	2.75	3.72
MnO	.05	.03	.06	.07	.06
P_2O_5	.06	.29	.20	.20	.19
TiO_2	.70	.28	.48	.57	.50
H_2O+	.73	.39	.63	1.04	1.15
H_2O-	.12	.03	.02		
CO_2		.22	.15		
ZrO_2		.02	-		
S		.02	.02		
BaO		.05	.11		
	100.12	99.96	99.74	100.00	100.00

OG1 = Old granite from near Jackalswater, Namaqualand. (Analyst, M. Mathias)

OG(X) = Old granite gneiss from Hlatikulu, Swaziland[4]. (Analyst, T. Kamada).

OG(Z) = Old granite from west of Hillcrest, Camperdown, Natal[4]. (Analyst, (R. B. Ellestad).

A = Average of forty granodiorites[1].

B = Average of twenty quartzmonzonites[1].

Norms

		OG1	OGX	OGZ	A	B
Quartz		25.0	44.2	27.9	20.3	23.7
Orthoclase		23.9	25.6	26.1	16.1	21.7
Albite		23.1	21.0	26.7	31.4	28.8
Anorthite		16.7	1.4	8.9	18.6	14.7
Corundum		1.1	1.4	.9		.6
Diopside	$CaSiO_3$				1.0	
	$MgSiO_3$				.6	
	$FeSiO_3$				.5	
Hyper-sthene	$MgSiO_3$	4.3	.8	1.4	4.2	3.5
	$FeSiO_3$	1.4	1.7	4.9	2.3	1.3
Magnetite		2.1	1.6	.7	2.5	2.8
Ilmenite		1.4	.6	.9	1.1	.9
Calcite			.5	.3		
Apatite		.3	.7	.3	.3	1.0
Zircon			.2			
Water		.8	.4	.7	1.0	1.1
		100.1	100.1	99.7	99.9	100.1

The following tables give the modes of the old granites:-

Modes.

	OG1	OG2	OG3	OG4	OG5	OG6	OG7	OG8	OG9	OG10
Quartz	28.6	34.3	23.5	26.1	27.0	23.6	23.5	27.3	22.9	27.9
Microcline	19.6	22.3	11.7	18.1	15.6	18.8	13.0	22.2	5.9	23.3
Plagioclase	37.0	37.4	49.0	39.2	34.5	39.2	36.2	35.4	44.7	38.6
Biotite	10.1	6.0	11.5	13.2	15.9	10.6	19.1	11.6	16.0	8.3
Hornblende					2.7		4.7		6.2	
Epidote	1.9		2.9	1.8	4.3	6.9	2.3	2.9	4.3	.6
Sphene			1.4	1.6		.9	1.2	.6		.6
Iron ore										.7
Muscovite	2.7									
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

It will be seen from a comparison of the analyses and norms that the old granite of Namaqualand differs from the Swaziland and Natal old granites in having a smaller proportion of silica, and a greater proportion of alumina, magnesia, and lime. This bears out the contention that the old granite of Namaqualand has, in places, assimilated aluminous sediments and hornblende schists or amphibolites. In regard to this a comparison between the analysis of the old granite of Namaqualand and the average analyses of granodiorites and quartz monzonites quoted by Daly[1] shows that whereas the composition of the old granite most nearly approaches that of the monzonites, it differs from the latter in the proportions of alkalis present. The old granite contains less Na_2O and more K_2O than the quartz monzonites and this same ratio is borne out in the other analyses of old granites. The calculated analysis of OG1, derived from the mode, gives the following percentages of alkalis: Na_2O = 2.33 and K_2O = 4.25.

The absorption of CaO by the granite magma, which, according to Nockolds[10] produces more basic rocks in every case, thus accounts for the exceptional basicity of the plagioclase felspar. Willemse[18] gives an average anorthite content of 20% in the old granites of the Vredefort region whereas the anorthite content of the plagioclase in OG1 is 45%.

The occurrence of corroded hornblende crystals in samples collected from seven localities and the prevalence of sieve texture in the hornblende further strengthens the view that the granite magma has been contaminated by the almost complete assimilation or metasomatism of hornblende-bearing rocks. It is interesting to note here the statement made by J. Willemse[18] that "the old granite in South Africa is characterised by the absence of any hornblende".

The presence of cores of orthite in a large proportion of the epidote crystals points to the latter being an allogenic or primary rather than a secondary product and, in the former case, as being derived in all probability from the same source as the hornblende. The allogenic origin of a proportion of the epidote and orthite is supported by the fact that epidote occurs in much greater proportion in the old granites than normal.

The modes do not show any features inconsistent with a granitic magma which has suffered partial contamination. The felspars in OG9 show great alteration and it is quite possible that the ratio of approximately 6% of potash felspar to 45% of plagioclase felspar is not accurate. Sphene is invariably an important accessory while rutile has not been recorded.

In conclusion, it is the author's opinion that the old granite of Namaqualand is genetically related to the basement or old granite of South Africa and that the differences are best accounted for by assuming that the Namaqualand rock has, in places, assimilated or metasomatised older rocks such as hornblende schists and shales or mudstones.

MINERALOGY OF THE PAARL GRANITE

Quartz.

The majority of the quartz grains are strained. They have an average size of 1.5mm. x 1.3mm. and a maximum size of 3.64mm. x 2.64mm. The crystallisation period is normal for granites.

Potash felspar.

The potash felspar is microcline which is microperthitic. The average size of the interstitial microcline is 1.6mm. x 1.2mm. while the largest crystal measures 3.31mm. x 4.10mm. The perthitic intergrowths measure up to .21mm. x .18mm. and are composed of albite.

$$\text{Refractive Indices}\begin{cases} \alpha = 1.526 \\ \gamma = 1.524 \\ \alpha = 1.519 \end{cases}$$

Plagioclase felspar.

Crystals of oligoclase measure up to 2.31mm. x 1.65mm. and have an average size of 1.2mm. x .7mm. The oligoclase occasionally shows intergrowths of microcline antiperthite.

Refractive Indices $\begin{cases} z = 1.550 \\ y = 1.546 \\ x = 1.543 \end{cases}$

Extinction angles on combined Carlsbad-Albite twins are 4° and 3° and these indicate an anorthite content of 24% while the refractive indices agree with a value of $Ab_{73}An_{27}$. The oligoclase is fairly fresh and not infrequently zoned. Extinction angles on sections showing combined Albite and Pericline twinning indicate an anorthite content of 32% for the core and 24% for the margins.

Biotite.

Strongly pleochroic biotite flakes have a maximum prismatic size of 1.32mm. x 1.15mm. and an average size of .80mm. x .40mm. A slight amount of alteration to chlorite has taken place, principally along the cleavage planes. Occasionally epidote replaces biotite. Sagenite webs of rutile were observed in a few basal sections. Inclusions in the biotite comprise apatite, zircon, magnetite, quartz and oligoclase.

Refractive Indices $\begin{cases} z = 1.652 \\ x = 1.600 \end{cases}$ Pleochroism $\begin{cases} z = \text{dark brown} \\ x = \text{straw yellow} \end{cases}$

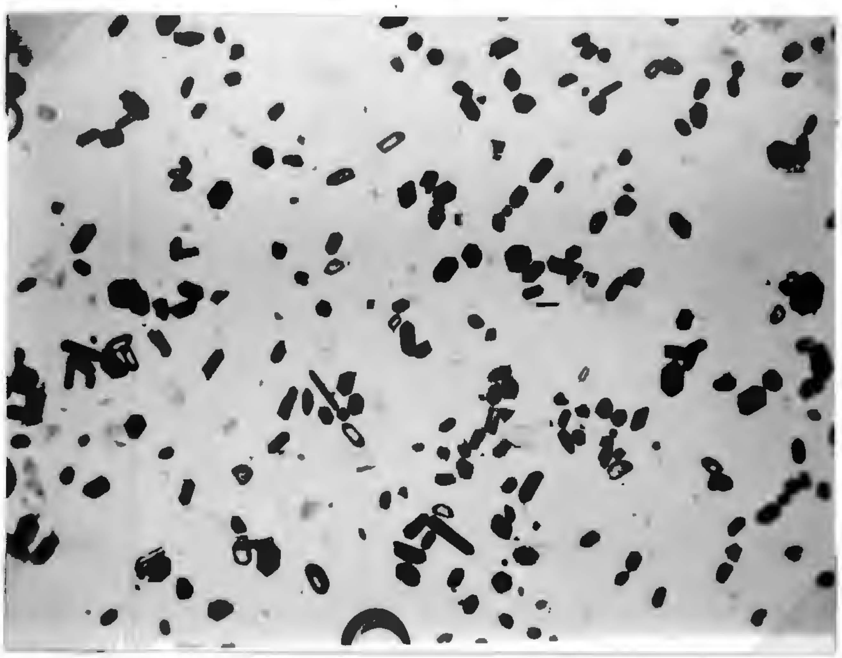
Accessories

Sphene occurs as pleochroic crystals measuring up to 1.15mm. x .83mm. It includes apatite, iron ore and oligoclase and is marked by irregular cracks. The pleochroism is from colourless to honey brown and the mean refractive index is 1.98.

Muscovite occurs in small quantity as a primary constituent. It is principally included in quartz. The majority of the muscovite is secondary after plagioclase felspar.

Apatite is not abundant. It forms small crystals with a maximum size of .08mm. x .08mm. and an average size of .05mm. x .05mm.

Magnetite is scarce. Crystals and crystal aggregates together with a little ilmenite occur in association with the other accessories and have average



Photomicrograph of the zircons in the heavy residue from the Paarl granite.

Ordinary light x 32.

THE CAPE PENINSULA GRANITE

Samples of the granite were collected from a quarry on the lower slopes of Table Mountain below the cable-way.

MINERALOGY

Quartz.

The majority of the grains are strained and the average dimensions are approximately 1.3mm. x 1.2mm. A little quartz had crystallised before some of the biotite and the crystallisation period for quartz extends until after the commencement or that of microcline. An average amount of dust-like and minute glass and liquid inclusions occur.

Potash felspar.

The phenocrysts are composed of orthoclase microperthite. The perthitic intergrowths are very abundant and form long stringers in the mineral. The orthoclase in the groundmass is also microperthitic and microcline microperthite occurs in smaller quantity. Potash felspar contains inclusions of all the other minerals in the rock.

Refractive Indices of orthoclase: $z = 1.526$, $y = 1.524$, $x = 1.518$ $2V_x = 70^\circ$

Plagioclase felspar. The plagioclase felspar is fairly fresh but shows a slight amount of alteration to Kaolin, saussurite, muscovite and calcite. Some crystals show straight phenomena, i.e. undulose extinction and a slight bending of the twin lamellae. The maximum size of the plagioclase crystals is 6.94mm. x 4.15mm. and the average dimensions are 1.90mm. x 1.30mm. Antiperthite is occasionally seen but much commoner is an intergrowth between plagioclase which is noticeable by the slight difference in the extinction positions. No appreciable difference in the refractive indices was found on testing by the immersion method. Albite twin lamellae can be seen traversing both plagioclases without interruption. Plagioclase felspar includes biotite, quartz, muscovite, magnetite, apatite, and zircon. Extinction angles on combined Carlsbad-Albite twins indicate an anorthite content of 25% and this is confirmed by the refractive indices.

$$\text{Refractive Indices}\begin{cases} z = 1.551 \\ y = 1.546 \\ x = 1.543 \end{cases}$$

__Biotite.__

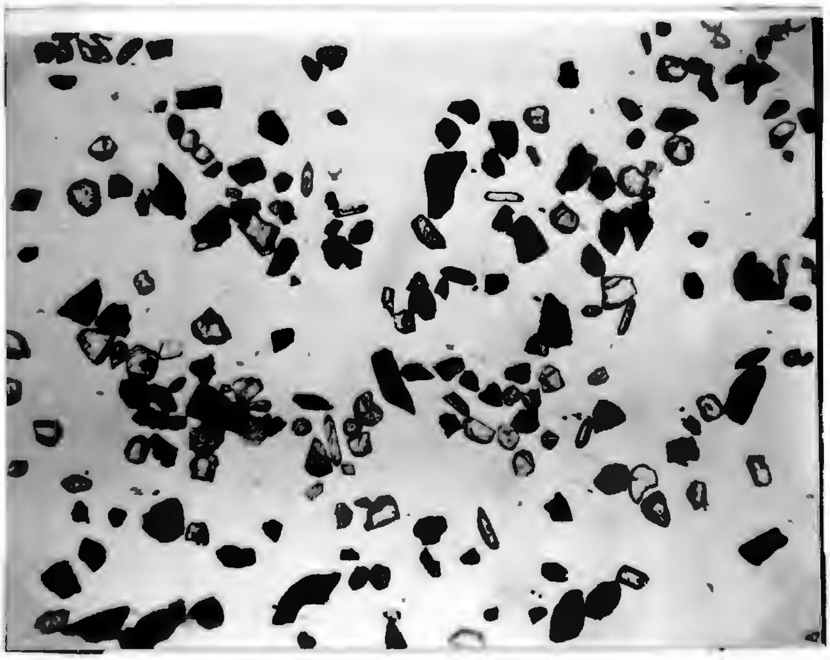
By artificial light the biotite appears much redder than in previous granites. The maximum prismatic size is 6.94mm. x 4.15mm. and the average size is 1.6mm. x 1.2mm. Intense pleochroic halos surround zircon inclusions. Other inclusions are of apatite, quartz and magnetite. Alteration to chlorite and sericite occurs occasionally. Sagenite webs in the biotite were noticed in two instances.

$$\text{Refractive Indices}\begin{cases} z = 1.650 \\ x = 1.597 \end{cases} \quad \text{Pleochroism}\begin{cases} z = \text{deep reddish brown} \\ x = \text{pale straw yellow} \end{cases}$$

__Accessories__

Primary muscovite occurs in minor quantity. It has an average size of .5mm. x .16mm. and a maximum size of 2.15mm. x 1.15mm.

Apatite is a plentiful accessory. It builds prisms having an average size of .13mm. x .08mm. It is commonly included in biotite. Magnetite is fairly abundant. The maximum dimensions of a single crystal are .99mm. x .5mm. Tourmaline occurs in three different varieties, brown, blue and green. A number of the tourmaline prisms have a patchy distribution of blue and brown colour.



Photomicrograph of the zircons in the heavy residue from the Cape Peninsula granite.

Ordinary light x 32.

Refractive Indices of brown tourmaline: z = w = 1.648; x = e = 1.628. Pleochroism: z = dark brown; x = colourless

Refractive Indices of blue tourmaline: z = w = 1.649; x = e = 1.624. Pleochroism: z = blue; x = colourless

Refractive Indices of green tourmaline: z = w = 1.662; x = e = 1.647. Pleochroism: z = dark slightly bluish green; x = light yellowish green.

Zircon crystals are mainly colourless but pinkish brown and yellowish brown crystals are fairly common. Modified terminations occur but are not so characteristic of the zircons of the Peninsula granite as of the Paarl granite. The average elongation ratio is 1:3. Lemon yellow xenotime crystals occur less frequently than zircons. They have the typical well developed pyramid faces and small prism faces.

PETROLOGY OF THE CAPE GRANITE

The analysis, the norm and the mode of the Cape granite are given below. The analyst was Mr. F. Herdsman. Excellent agreement is shown between them.

Analysis

SiO_2	70.36
Al_2O_3	14.68
Fe_2O_3	.39
FeO	2.92
MgO	1.24
CaO	1.92
Na_2O	2.35
K_2O	4.64
MnO	.03
P_2O_5	trace
TiO_2	.38
H_2O+	.74
H_2O-	.18
	99.83

Norm

Quartz	31.08
Orthoclase	27.24
Albite	19.91
Anorthite	9.45
Hypersthene $MgSiO_3$ / $FeSiO_3$	3.10 / 4.36
Corundum	2.35
Magnetite	.70
Ilmenite	.76
Water	.92
	99.87

Mode

Quartz	31.4
Potash felspar	28.4
Plagioclase felspar	28.3
Biotite	9.4
Muscovite	2.5
	99.9

Specific gravity = 2.70

The Cape Peninsula granite is normal in character. It differs from the Namaqualand granite-gneiss and the Paarl granite in the coarseness of its texture and in the presence of abundant phenocrysts of orthoclase microperthite. Nearly all the phenocrysts show Carlsbad twinning. The maximum size of the phenocrysts is 60mm. x 40mm. and the average size is 35mm. x 20mm. Quartz occasionally attains fairly large dimensions, the maximum grain measured being 13mm. x 13mm. The granite does not vary greatly in field characters although there are occasional concentrations of mafic minerals forming large or small clots principally composed of biotite.

Mr. F. Smithson's new statistical method of studying the zircons from different formations has been adopted, and length : breadth diagrams of the zircons in the Namaqualand granite-gneiss, the old granite, and the Cape and Paarl granites are shown opposite, together with the length : breadth diagrams given by Smithson 15. In each case between 150 and 200 zircons were measured, the results plotted, and the points enclosed by a smooth outline. The method of measurement employed was that of traversing one or more heavy residue slides. The readings were taken on a micrometer ocular and these were subsequently converted into millimetres.

The outlines in red are a copy of the diagrams given by Smithson. The sandstone near York is the Bunter sandstone from Bilborough, near York, and the lower Estuarine sandstone is from near Brandsby, Yorkshire. The coloured dots on the other diagrams represent the points of coincidence of two or more readings as follows:-

Red = 6 or more

Green = 3 to 5

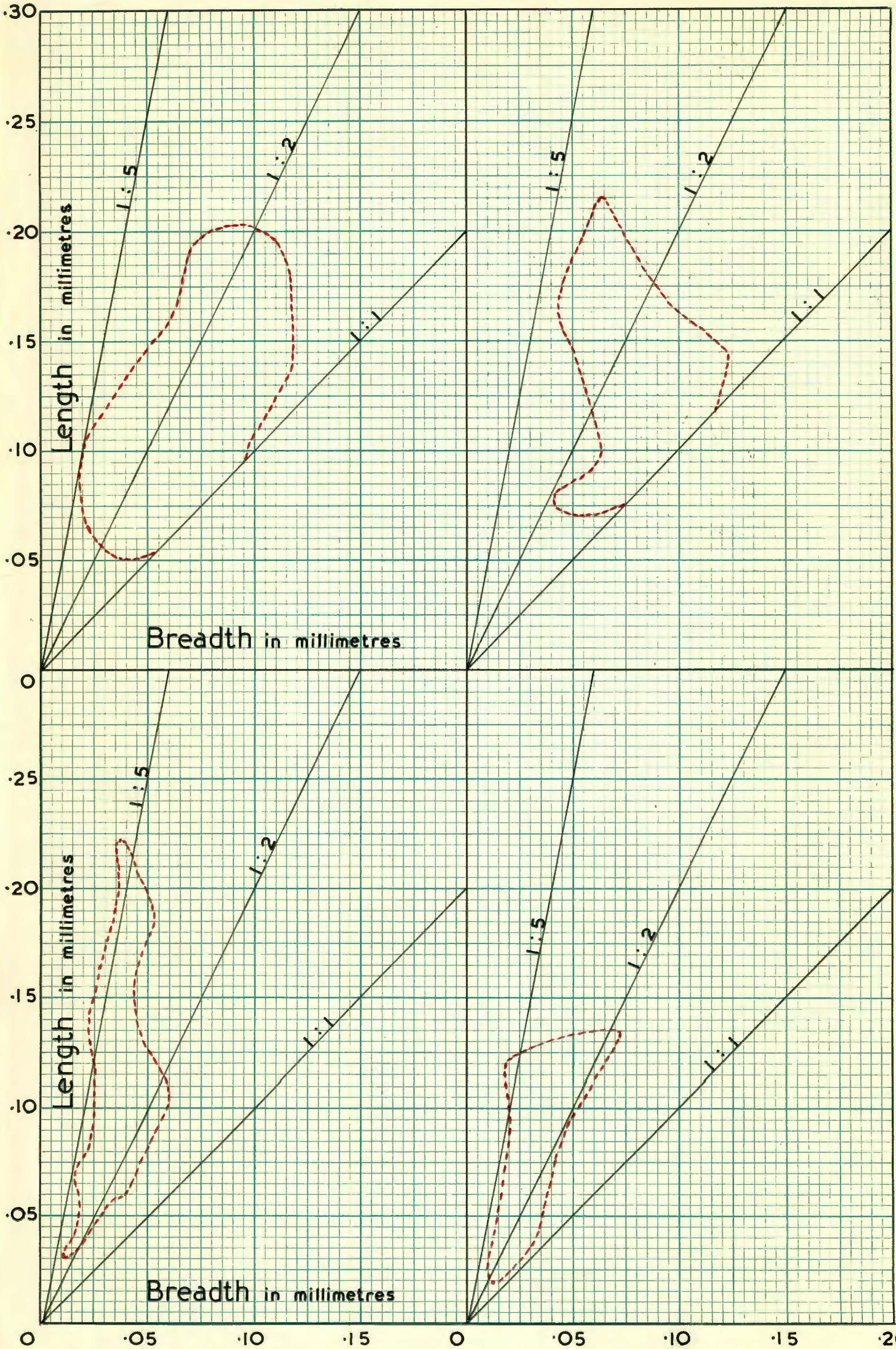
Yellow = 2.

A comparison of these diagrams shows that although the outlines vary considerably in shape and size, those of zircons from igneous rocks invariably overlap the 1 : 5 ratio line and do not rest with a broad base on the 1 : 1 line, i. e. the igneous zircons tend to have a greater elongation ratio than detrital zircons. This conclusion is what one would expect in view of the fact that

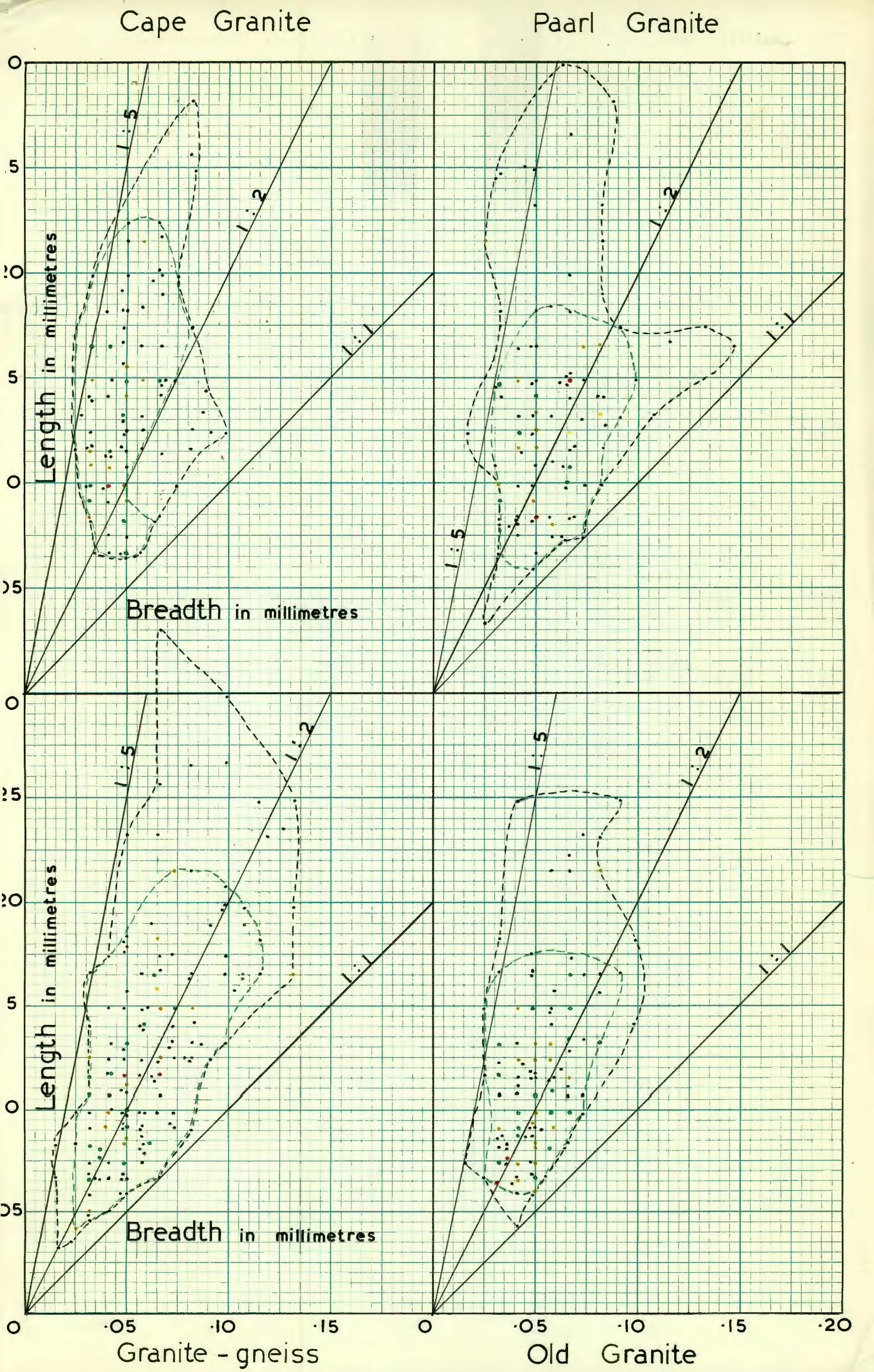
Length : Breadth Diagrams

of Zircons.

Sandstone near York   Estuarine Sandstone



Rhode Island Granite   Leinster Granite



Cape Granite
Paarl Granite
Length in millimetres
Breadth in millimetres
Length in millimetres
Breadth in millimetres
1:5
1:2
1:1
0
·05
·10
·15
·20
·25
Granite - gneiss
Old Granite

the mechanical abrasion, that a tetragonal crystal would normally suffer during the process of transportation and sedimentation, tends to round the crystal and reduce the length of the prism. Zircons from igneous rocks, on the other hand, retain to a great extent their original idiomorphic contours. These results compare favourably with those of Smithson, but it is to be regretted that Smithson did not include the points representing the actual sizes of the zircons encountered in the four diagrams reproduced.

The outlines of the diagrams in black were drawn so as to include all the points. If, however, the outlying points are disregarded, the outlines tend to become flattened but do not lose greatly in width. This can be seen from the second outline in green. Different facies of the same granite, e.g. Cape and Paarl, show dissimilar outlines both in green and black, and it is therefore concluded that this method cannot be used for correlation.

CONCLUSIONS

The foregoing data are briefly summarised below. The old and young Namaqualand granites are contrasted, and evidence is given for the correlation of the young Namaqualand granite-gneiss with the Cape granite, as represented by the Cape Peninsula and Paarl granites. The granite at Aggenys is seen to be an acid marginal phase of the Namaqualand granite-gneiss.

The major differences between the old and young Namaqualand granites are tabulated below.

Old granite	Young granite-gneiss
(a) Chemical criteria indicate that the granite has suffered contamination or metasomatism, but is otherwise similar to the basement granite of South Africa.	(a) Chemical criteria show the granite to be a normal alkali granite.
(b) Gneissic structure is only present along the contact zone.	(b) Gneissic structure is common throughout the batholith.
(c) The average anorthite content of the plagioclase felspar is 34.1%, i.e. an acid andesine.	(c) The average anorthite content of the plagioclase felspar is 29.7%, i.e. a basic oligoclase.
(d) The ratio of potash felspar to plagioclase felspar is approximately 1 : 2.	(d) The ratio of potash felspar to plagioclase felspar is approximately 1 : 1.
(e) Sphene is invariably an important accessory.	(e) Sphene is only present in appreciable amount in those granites G11 and G13 which do not contain rutile inclusions in the biotite.
(f) The biotite contains no sagenite webs.	(f) Sagenite webs of rutile are characteristic of the biotite.
(g) Rutile is absent.	(g) Rutile is invariably present.
(h) Epidote is abundant and frequently contains intergrowths of orthite.	(h) Epidote is scarce and does not include orthite.
(i) Perthitic intergrowths are not very abundant.	(i) Perthitic intergrowths are abundant.
(j) Ilmenite is very scarce.	(j) Ilmenite occurs in the majority of specimens.
(k) The majority of the zircons are colourless. Pink varieties are common and inclusions are not abundant.	(k) The majority of the zircons are yellowy brown. No pink varieties occur, and inclusions are abundant.

Analyses and modes of the two granites are given below.

	Old granite	Young granite-gneiss	
	OG1	G7	G12
SiO_2	66.80	71.26	72.86
Al_2O_3	16.07	13.73	13.82
Fe_2O_3	1.52	1.56	1.02
FeO	2.04	1.09	1.07
MgO	1.74	.43	.52
CaO	3.52	1.80	1.90
Na_2O	2.75	3.59	2.49
K_2O	4.02	4.99	5.66
MnO	.05	trace	.02
P_2O_5	.06	.56	trace
TiO_2	.70	.30	.14
H_2O+	.73	.62	.33
H_2O-	.18	.18	.07
	100.12	100.11	99.90

The following are the average modes of the old granite and granite-gneiss respectively.

Modes

	Old granite	Granite-gneiss
Quartz	26.4	31.9
Potash felspar	17.0	30.7
Plagioclase felspar	39.1	27.5
Biotite	12.2	7.3
Hornblende	1.4	.3
Epidote	2.8	.1
Sphene	.6	.3
Muscovite	.3	.2
Iron ore	.1	1.8
	99.9	100.1

Data for the correlation of the Namaqualand granite-gneiss with the Aggenys, Paarl and Cape Peninsula granites, is given in the following table.

	Namaqualand granite-gneiss	Aggenys granite	Paarl granite	Cape Peninsula granite
Chemical composition	Normal alkali-granite	Normal alkali-granite	Normal alkali-granite	Normal alkali-granite
Texture	Granitic and gneissic medium-to fine-grained	Fine-grained granitic	Medium-grained granitic	Coarse-grained porphyritic
Approximate ratio of potash felspar to plagioclase felspar	1 : 1	1 : 1	1 : 1	1 : 1
Anorthite content of plagioclase felspar	average = 29.7%	16%	27%	28%
'Sagenite webs' of rutile in the biotite	Abundant	Present, but rare	Present, but rare	Present, but rare
Ilmenite	Occurs in the majority of samples	Present	Present	Present
Zircons	Majority are yellowish brown. Inclusions are abundant.	Majority are yellowish brown Inclusions are abundant.	Majority are yellowish brown Inclusions are abundant.	Majority are colourless; yellowish brown varieties are common. Inclusions are not abundant.
Epidote	Rare	Rare	Rare	Absent.

The chemical analyses and modes are given below. The mode of the Namaqualand granite-gneiss is the average of the ten modes previously quoted.

	Namaqualand granite-gneiss G7	Namaqualand granite-gneiss G12	Aggenys granite	Paarl granite	Cape Peninsula granite
SiO_2	71.26	72.86	76.22	73.50	70.36
Al_2O_3	13.73	13.82	11.56	13.78	14.68
Fe_2O_3	1.56	1.02	.66	.54	.39
FeO	1.09	1.07	1.05	1.51	2.92
MgO	.43	.52	.44	.52	1.24
CaO	1.80	1.90	1.26	1.86	1.92
Na_2O	3.59	2.49	3.18	3.02	2.35
K_2O	4.99	5.66	5.16	4.73	4.64
MnO	trace	.02	trace	.04	.03
P_2O_5	.56	trace	trace	trace	trace
TiO_2	.30	.14	.18	.25	.38
H_2O+	.62	.33	.27	.22	.74
H_2O-	.18	.07	.10	.16	.18
	100.11	99.90	100.08	100.13	99.83

Modes

	Namaqualand granite-gneiss	Aggenys granite	Paarl granite	Cape Peninsula granite
Quartz	31.9	36.3	38.5	31.3
Potash felspar	30.7	35.8	24.0	28.4
Plagioclase felspar	27.5	25.1	31.5	28.3
Biotite	7.3	1.5	5.7	9.4
Hornblende	.3			
Epidote	.1			
Sphene	.3		.3	
Muscovite	.2			2.5
Iron ore	1.8	1.3		
	100.1	100.0	100.0	99.9
Specific gravity	2.7	2.7	2.7	2.7

Part of the Een Riet hills. The mountains bordering the Orange river are visible in the distance.

These granites show a marked similarity to each other in all significant aspects. The Cape Peninsula and Paarl granites have already been correlated as belonging to the same age of intrusion, and the chief differences between the four granite masses, i.e. in texture and anorthite content of the plagioclase felspars, also exist between the Cape Peninsula and the Paarl granites. The Aggenys granite is evidently a slightly more acid marginal phase of the Namaqualand granite-gneiss, while the latter can be correlated, with reasonable certainty, with the group of Cape granites to which the Paarl and Cape Peninsula granites belong.

A COMPARATIVE STUDY OF THE NAMAQUALAND AND KAAIEN QUARTZITES.

The ancient quartzites of Namaqualand can be distinguished from the Nama quartzites in the field by observing the nature of the contact of the sediments with the granite. The Nama quartzites are definitely younger than the granites and the contact is either unconformable or faulted. The ancient quartzites, on the other hand, are older than the granites and the contact is intrusive.

It has been suggested that the ancient quartzites belong to the Kheis System and the Kaaien Series (3) so that the following mineralogical descriptions have been confined to these two groups.

A.(1) Ancient Quartzites from the Een Riet hills.

These are 'sugar candy' quartzites varying in colour from pure white to mauve. Weathered surfaces show a thin film of limonite, or, more rarely, haematite. Muscovite is invariably present and occurs either as scattered flakes or in clusters with individual flakes measuring up to 5mm. in diameter. Magnetite is a fairly common macroscopic constituent in some specimens.

Mineralogy.

Quartz.

The grains of quartz are strained and have an average diameter of approximately 6.6mm. Inclusions are fairly plentiful, and consist chiefly of trails of iron ore, apatite, liquid and gas. Zircon and chlorite are of less frequent occurrence, while muscovite and magnetite form larger inclusions.

Muscovite.

Flakes of muscovite occur between and enclosed by quartz grains. The muscovite frequently has a ragged appearance and is embayed by quartz and in such cases contains numerous inclusions of quartz forming 'sieve' texture.

$$\text{Refractive Indices} \begin{cases} z = 1.602 \\ y = 1.596 \\ x = 1.564. \end{cases} \qquad 2V_x = 40^{\circ}.$$

Magnetite.

It occurs as crystals, granular aggregates and trails of minute inclusions in the quartz. It is frequently associated with muscovite.

Accessory minerals occurring in the heavy residue.

(a) Limonite and haematite grains are abundant.

(b) Rutile crystals are pale yellow to orange yellow in colour and show marked vertical striations and striations oblique to the prism edge due to polysynthetic twinning parallel to the face (101). Geniculate twinning parallel to (101) occurs fairly frequently. Pleochroism is only noticeable in a few crystals and is weak. A few foxy red rutiles occur and some of these have a patchy distribution of colour.

(c) Anatase occurs as opaque crystals and irregular yellow and blue grains.

(d) Sillimanite is a very rare constituent.

(e) Zircon crystals are mostly colourless and fairly well rounded. The average elongation ratio of 100 crystals is 1 : 1.61. Purple zircons occur next in frequency to the colourless crystals. They are the colour of alexandrite in artificial light. Yellowish to reddish iron-stained zircons are comparatively rare. Nearly all the zircons contain inclusions and occasionally these show a zonal arrangement.

(f) Biotite and chlorite are of very rare occurrence.

Muscovite.

Flakes of the white mica occur most abundantly in the basal quartzites, which grade into quartz-muscovite schists.

$$\text{Refractive Indices} \begin{cases} z = 1.603 \\ y = 1.596 \\ x = 1.564. \end{cases} \qquad 2V_x = 40^\circ.$$

Magnetite.

Crystals and irregular grains of magnetite measure up to approximately .4mm. x .2mm. Magnetite is not plentiful.

Accessory Minerals in the heavy residue.

(a) Mag-haematite forms an abundant moderately magnetic crop.

(b) Apatite occurs rarely as rounded grains.

(c) Garnet of the pink almandine variety is fairly abundant.

(d) Rutile crystals are very rare. They are slightly pleochroic and vary in colour from yellowish orange to reddish orange.

(e) Zircon crystals are generally crowded with inclusions. Clear and colourless zircons are in the minority.

(f) Chlorite is of rare occurrence. It frequently contains sagenite webs of rutile.

(g) Anatase occurs mostly in the form of opaque crystals and rounded grains. It is rather rare.

B.(2) Kaaien Quartzite from Upington.

In hand specimen the Upington quartzite is predominantly mauvish in colour due to the dissemination of haematite. No schists were seen underlying the quartzite.

Mineralogy.

Quartz.

The quartz grains are very irregular in shape.and show pronounced undulose extinction. Minute dust-like inclusions are exceptionally abundant and mostly

A.(2) Ancient Quartzites collected from the farm Geselskapbank.

The quartzites are somewhat similar in appearance to the Een Riet specimens but white varieties are not so abundant and the prevalent colour is mauvish and brown. The texture is the 'sugar-candy' type.

Mineralogy.

Quartz.

Large strained grains of quartz have a maximum size of 10mm. x 7.77mm. and an average size of approximately 3mm. x 2.5mm. There is not a great abundance of minute inclusions, but, where present, these are scattered irregularly or occur in thin traits in the quartz. They consist of zircon, apatite, biotite, iron ore and liquid containing bubbles of gas which show 'Brownian' movement. Larger inclusions comprise biotite, muscovite, magnetite and zircon, and in the quartzite from the hills immediately to the south-east of the farms garnet and anatase are plentiful.

Garnet.

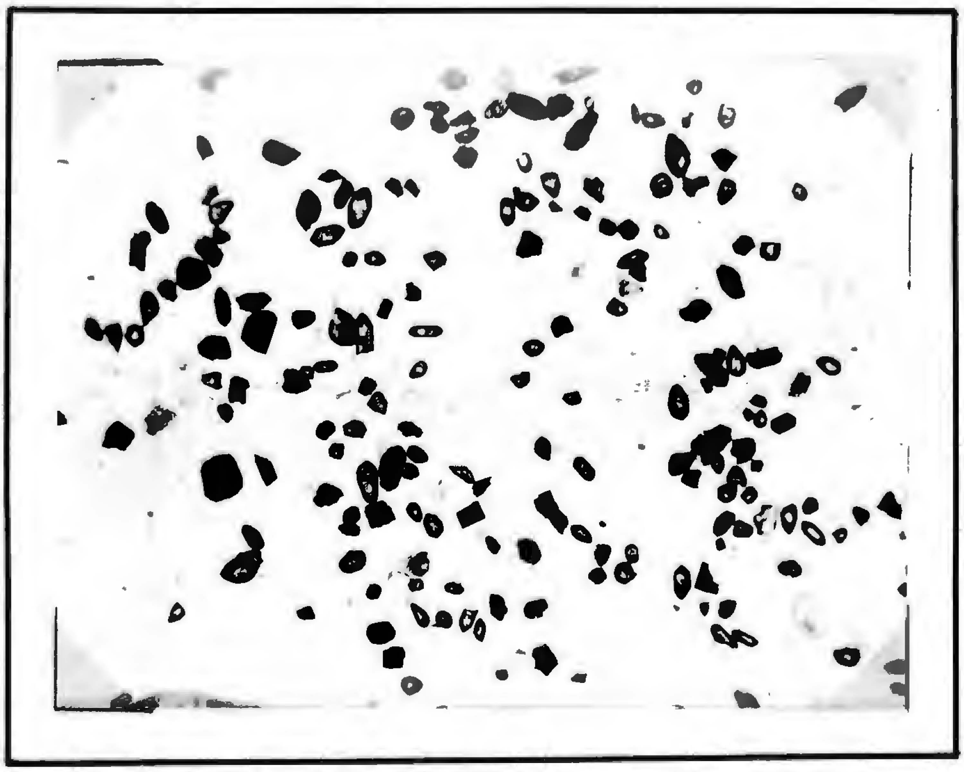
Crystals and irregular grains of pink Almandine occur plentifully in the lower horizons of the quartzite. The largest crystal measures .54mm. x .5mm. and the average size is approximately .1mm. x .08mm. Garnets occur mainly at the junctions between quartz grains, but are also included by quartz.

Biotite.

A minor amount of biotite occurs in the basal quartzites. Prismatic grains have an average length of approximately .1mm. and breadth of .03mm.

Muscovite.

Flakes of muscovite also occur in minor amount but have a larger grain size and a wider distribution than the biotite. The maximum size is .36mm. x .33mm.



Photomicrograph of the zircons in the non-magnetic heavy residue of the Geselskapbank quartzite.

Ordinary light. x 32.

Anatase.

Opaque crystals of anatase have an average diameter of approximately .05mm. They are associated with almandine. Other varieties are indigo-blue, pale blue, bluish-green and yellow in colour. The transparent anatases are mostly either irregular or rounded and probably represent detrital grains, while the opaque euhedra are probably of authigenic origin and have been formed from other titaniferous minerals. Prismatic crystal forms are most common, but tabular basal sections occur which give a uniaxial negative figure in convergent light.

Accessory minerals occurring in the heavy residue.

(a) Apatite prisms and grains measuring up to .2mm. x .15mm. are moderately abundant.

(b) Rutile crystals occur which are distinctly pleochroic from orange to foxy red.

(c) Zircons are mostly some shade of yellow or brown and contain many inclusions. Colourless crystals are also fairly abundant and pink crystals slightly less so. Some zircons show a zonal arrangement of their inclusions.

(d) Iron ores and (e) biotite are scarce. The biotite grains generally show 'sagenite' inclusions.

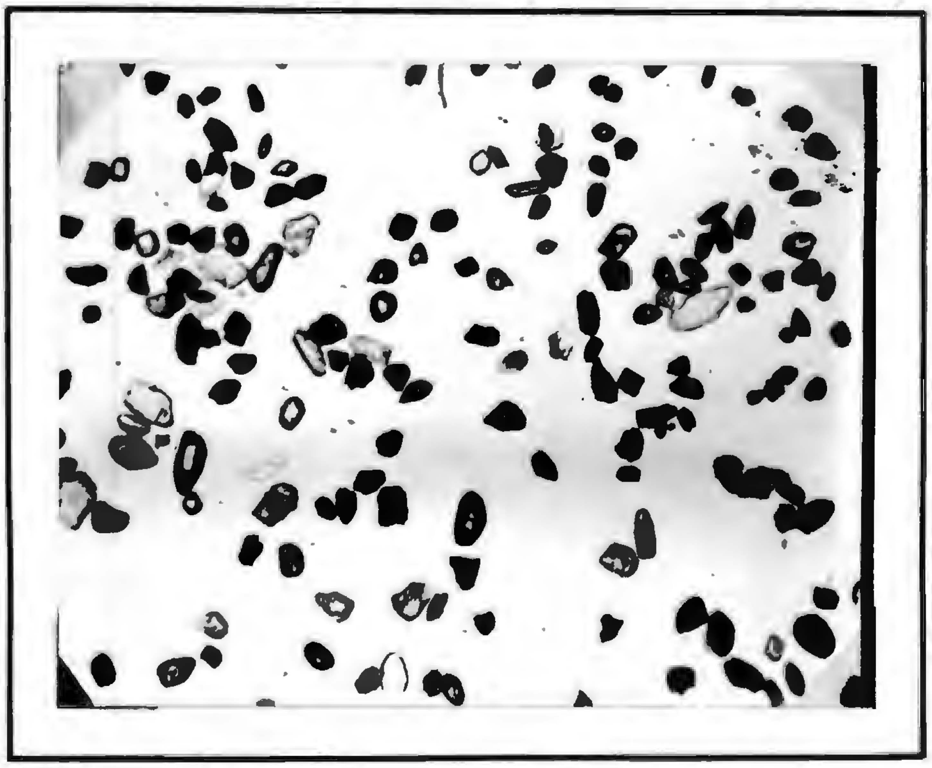
B.(1). Kaaien Quartzites from the hills west of Marydale.

The Kaaien quartzite in this region is mostly white and of moderately coarse grain, but grey-green finer grained varieties and reddish and brown quartzites also occur. At one place in these hills the quartzites grade into fine-grained quartz-muscovite schists at their lower contact.

Mineralogy.

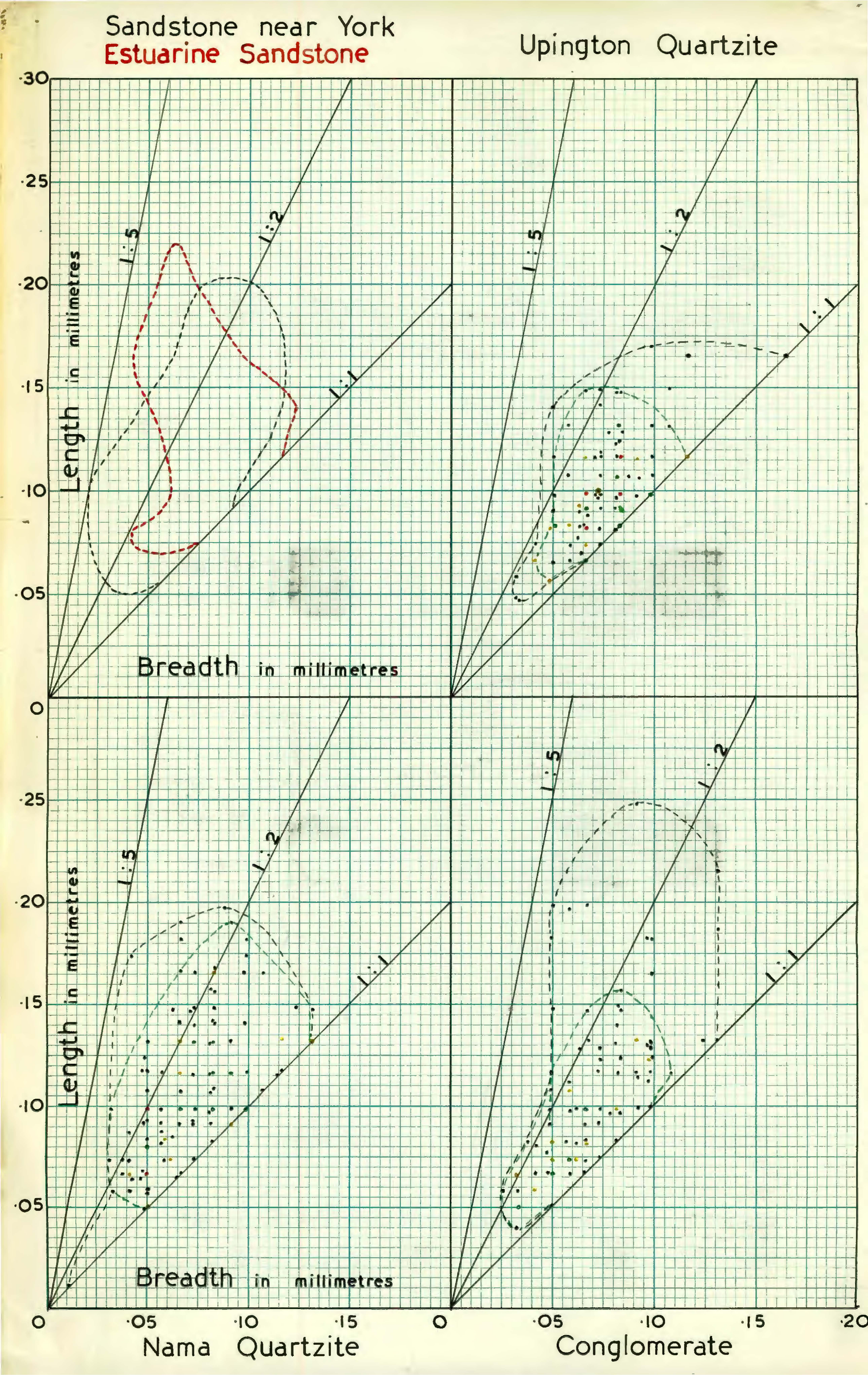
Quartz.

The average grain size of the quartz is approximately .3mm. x .25mm. The quartz is strained and contains the usual minute inclusions. Muscovite, magnetite and chlorite are also included by the quartz.

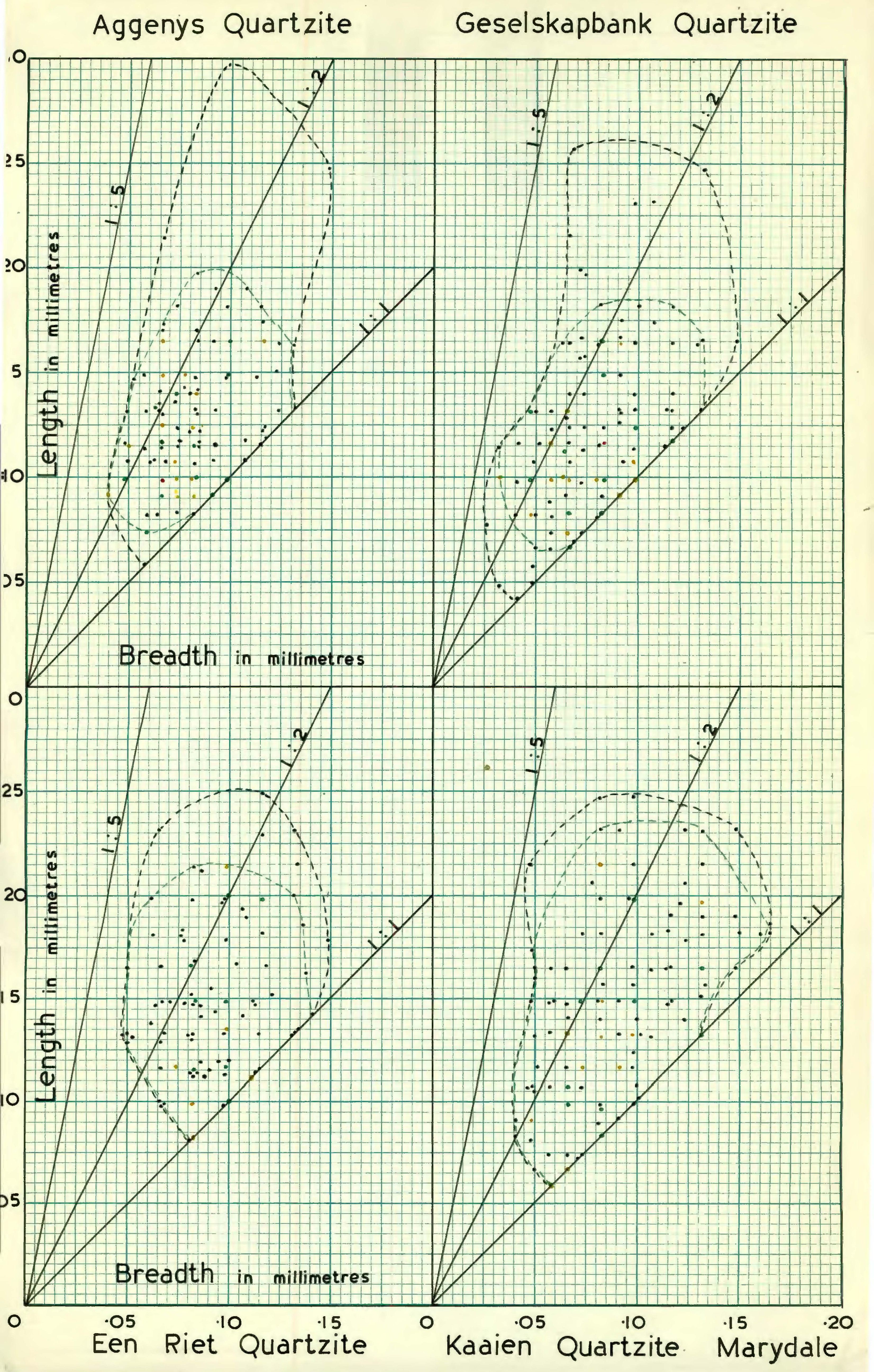


Photomicrograph of the zircons in the non magnetic heavy residue of the Kaaien quartzite at Marydale.

Ordinary light x 32.



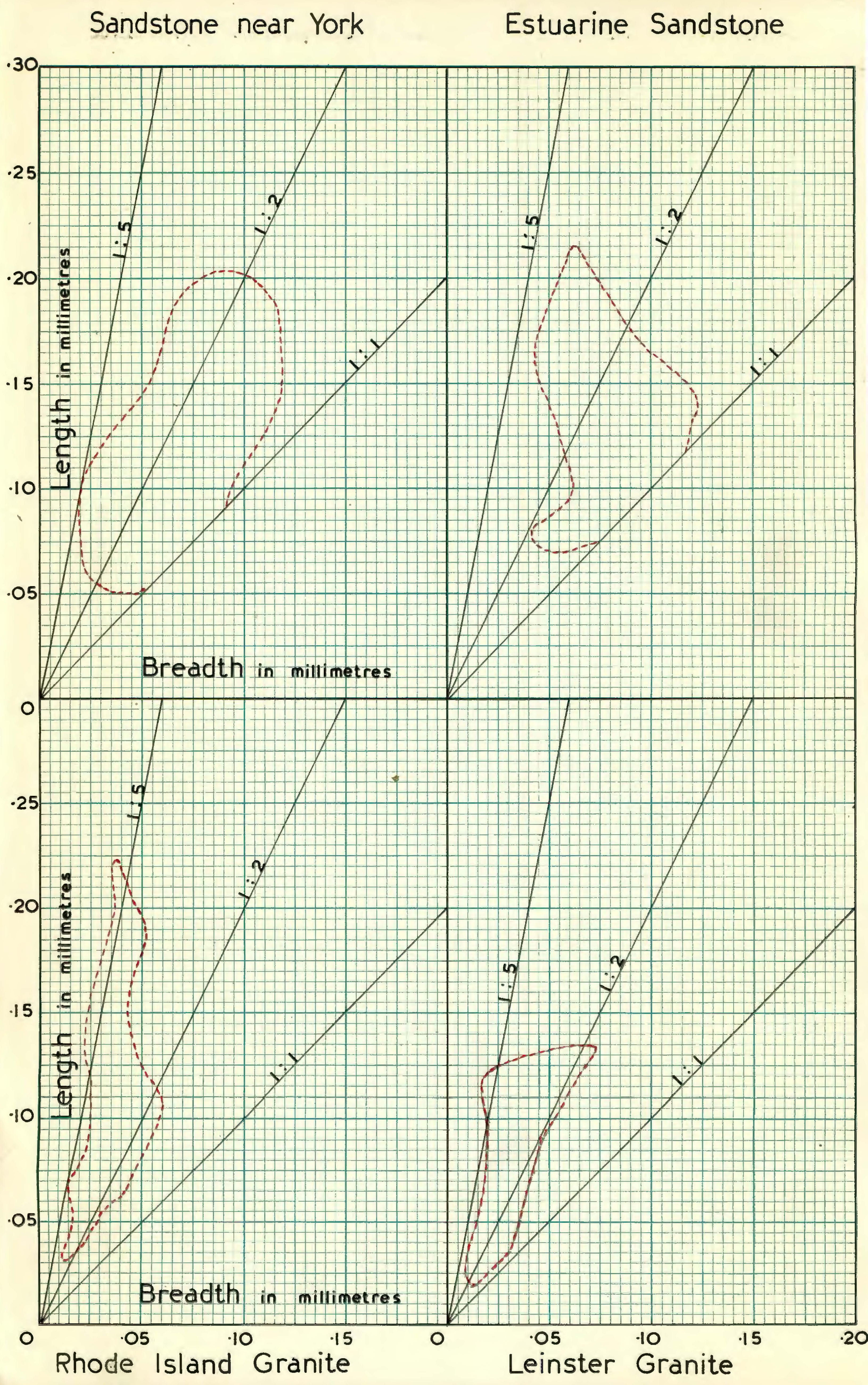
Sandstone near York
Estuarine Sandstone
Upington Quartzite
Nama Quartzite
Conglomerate
Length in millimetres
Breadth in millimetres
1:5
1:2
1:1
·30
·25
·20
·15
·10
·05
0
·05
·10
·15
·20



Aggenys Quartzite
Geselskapbank Quartzite
Length in millimetres
Breadth in millimetres
1:5
1:2
1:1
·05
·10
·15
·20
25
20
15
10
0
Een Riet Quartzite
Kaaien Quartzite
Marydale

Length : Breadth Diagrams

of Zircons.


Sandstone near York
Estuarine Sandstone
Rhode Island Granite
Leinster Granite
Length in millimetres
Breadth in millimetres
1:5
1:2
1:1
·30
·25
·20
·15
·10
·05
0
·05
·10
·15
·20

consist of iron ore.

Magnetite.

Irregular grains and small crystals of magnetite have an average diameter of approximately .03mm. It is a moderately abundant accessory.

Accessory Minerals in the heavy residue.

(a) Composite grains of magnetite, haematite and limonite are very abundant.

(b) Muscovite flakes are next in abundance in the heavy crop.

(c) Anatase, in the form of opaque euhedra and irregular blue grains, is comparatively rare.

(d) Zircon crystals are nearly all well rounded and the majority have a yellowish or brownish colour. A few zircons are colourless and one or two relatively large individuals are purple.

(e) Clorite is a rare constituent.

Length : breadth diagrams, similar to those of the granites, were prepared from a measurement of the zircons of the quartzites and the sheared conglomerate. F. Smithson's diagrams are again reproduced for comparison. The red dots signify the coincidence of six or more zircon measurements, the green from three to five, and the yellow two.

The characteristic broad base on the 1 : 1 ratio line and the fact that the outlines do not overlap the 1 : 5 line give additional proof that the quartzites and the sheared conglomerate are of sedimentary origin. This result is in accordance with the theoretical calculations based on Stoke's law and referred to by Smithson[15].

As in the length : breadth diagrams of the granites, a green outline has been drawn so as to omit the outlying zircons, and in these a certain similarity can be seen between all the outlines of zircons from the Namaqualand quartzites. The two Kaaien quartzites, however, from Upington and Marydale respectively, show considerable difference in their green outlines, and it is again concluded that the method is unreliable for establishing correlations.

Conclusions.

The Namaqualand quartzites are typically glassy, highly recrystallised and have a 'sugar candy' texture. They differ in this respect from the Kaaien quartzite which is more normal in appearance and has a finer grain. The Namaqualand quartzites generally grade into quartz-muscovite schists, while this is not often the case with the Kaaien quartzites.

The following tables show the heavy mineral assemblages:-

MINERAL	ANCIENT QUARTZITE (Aggenys)	ANCIENT QUARTZITE (Een Riet)	ANCIENT QUARTZITE (Gesels-kapbank)	KAAIEN QUARTZITE (Marydale)	KAAIEN QUARTZITE (Upington)
Magnetite	*	*	*	*	*
Haematite and Limonite	*	*	*	*	*
Pyrite	* rare				
Chalcopyrite	* rare				
Muscovite	*	*	*	*	*
Biotite	* rare	* rare	*		
Chlorite	* rare	* rare		* rare	* rare
Anatase	*	*	*	*	*
Garnet	*		*	*	
Barite	*				
Tourmaline	* rare				
Sillimanite		* rare			
Apatite	* rare		*	* rare	
Epidote	*				
Rutile	*	*	*	* rare	
Zircon	*	*	*	*	*

The consistent occurrence of anatase in all these quartzites is noteworthy but no special importance can be attached. Anatase has also been recorded in the banket 21 and in the Molteno beds 14. The heavy minerals do not provide sufficient basis for a definite correlation of the Namaqualand quartzites with the Kaaien series, and the intense recrystallisation which the former have undergone rather points to their being an older quartzitic member of the Kheis System, which may be of local occurrence in Namaqualand. It is still possible, however, that further work on these groups of quartzites will bring to light conclusive evidence for their inclusion with the Kaaien series.

ACKNOWLEDGEMENTS.

I should like to express my indebtedness to Dr. F. Walker, Professor of Mineralogy and Geology at the University of Cape Town, for his guidance and invaluable assistance in every branch of my work. I am also indebted to Mr. A.R.E. Walker, Senior Lecturer in Geology, for advice and for the loan of slides. In addition my thanks are due to the following: Professor W. J. Talbot, for the loan of mapping instruments, Dr. W. Pugh, for affording me facilities for chemical analysis, and Major J. G. W. Leipoldt for directing my attention to the iron ore deposit, for the collection of sand samples, and for his unfailing kindness to me in the field.

BIBLIOGRAPHY.

1. Daly R. A. "Igneous Rocks and the Depths of the Earth". McGraw-Hill 1933.
2. Dunn E. J. "Report on the Country Traversed by the Gold Prospecting Expedition in Namaqualand". Cape Town G.21. 1872.
3. Gevers T. W. "The Pegmatite Area South of the Orange River in Namaqualand". Geological Survey of S.A., Memoir 31, 1937.
4. Grout F. F. "The Composition of some African Granitoid Rocks". Journal of Geology, vol. 43, 1935.
5. Holmes A. "Petrographic Methods and Calculations". Murby, 1921.
6. Iddings J. P. "Rock Minerals". Wiley, 1911.
7. Larsen E. S. and Berman H. "The Microscopic Determination of the Nonopaque Minerals". U.S. Geol. Survey Bulletin, 848, 1934.
8. Leipoldt S. Unpublished paper, 1932.
9. Lindgren W. "Mineral Deposits". New York, 1928.

10. Nockolds S. R. "Some Theoretical Aspects of Contamination in Acid Magmas". Journal of Geology 1933.

11. Rogers A. W. "Report on the Geological Survey of Parts of the District of Van Rhynsdorp and Namaqualand". Annual Report of the Geological Commission C.R.G. 1911.

12. Rogers A. W. and du Toit A. L. "Report on the Geology of Parts of Kenhardt, Prieska, Victoria West and Carnavon, Annual Report of the Geological Commission 1910.

13. Scholtz D. L. Unpublished Paper on Western Province Granites.

14. Schwarz E. H. L. "Diamonds from the Molteno Beds". Transactions of the Geological Society of S.A., 1916.

15. Smithson F. "Statistical Methods in Sedimentary Petrology" Part II. Geological Magazine 1939.

16. Tarr W. A. "Barite Deposits of Missouri". Economic Geology, vol. xiv, 1919.

17. Van Biljoen S. "The Kuboos Batholith, Namaqualand, South Africa". Transactions of the Geological Society of S.A. vol. 42, 1939.

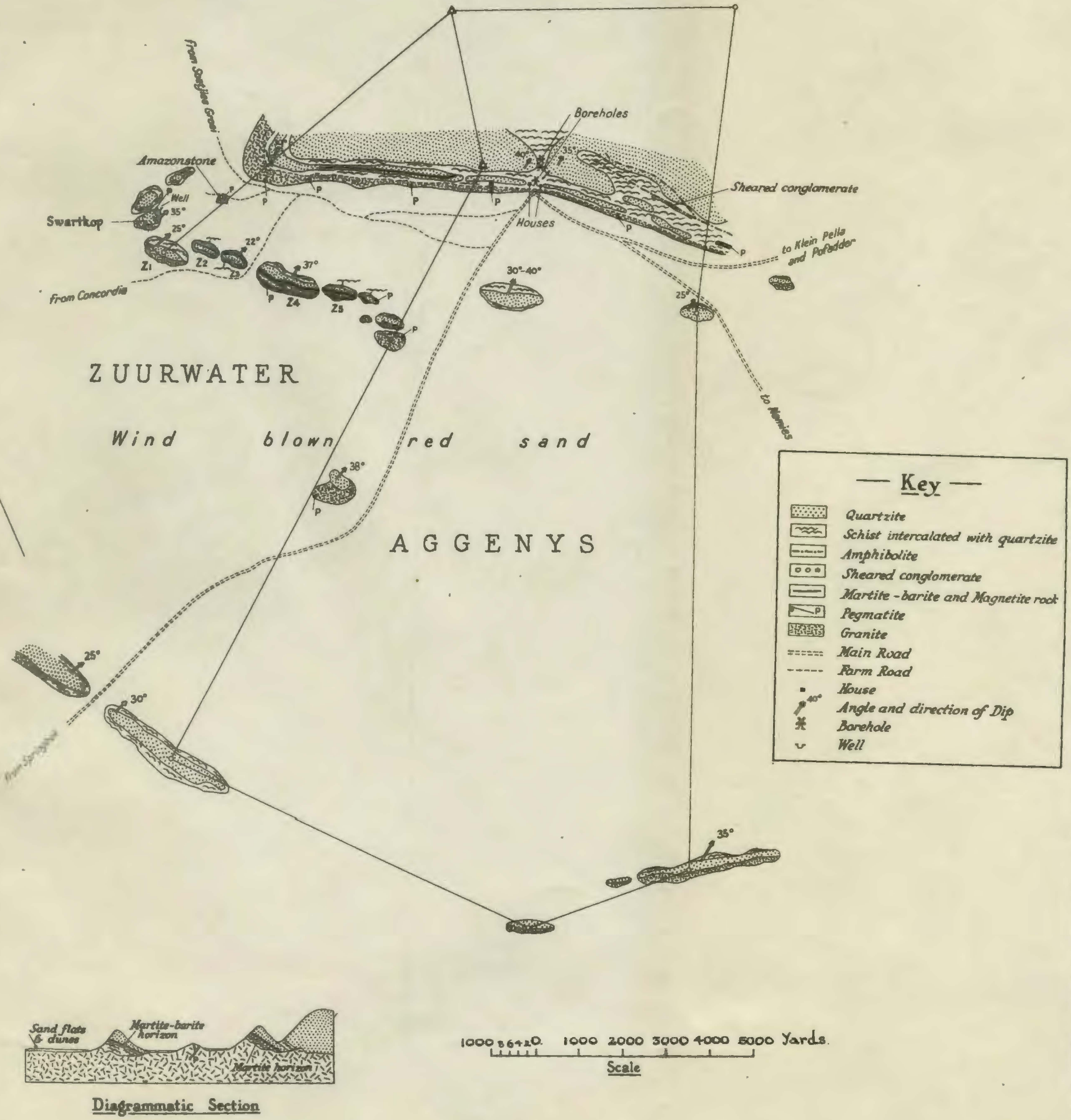
18. Willemse J. "On the Old Granite of the Vredefort Region and some of its Associated Rocks". Transactions of the Geological Society of S.A., 1938.

19. Winchell "Elements of Optical Mineralogy, Part II.

20. Wyley A. "Report upon the Mineral and Geological Structure of South Namaqualand and the Adjoining Mineral Districts. Cape Town G36, 1857.

21. Young R. B. "The Banket". Gurney and Jackson, 1917.

Sketch Map of the Farm Aggenys and Part of Zuurwater



SKETCH MAP OF NAMAQUALAND