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THE PETROLOGY of the GOODHOUSE - PELLA AREA, NAMAQUALAND, SOUTH AFRICA.

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R É S U M É.

An area of 570 sq. miles between Goodhouse and Pella in Namaqualand, S.A. is mapped on a scale 1:100,000. It comprises three intrusive granites which carry a profusion of sedimentary xenoliths of the Kheis Series. Mineralogical and petrographical data are amplified by volumetric analyses, which together with other available modal percentages are represented graphically. Seven new chemical analyses are appended and data pertaining to assimilation, granitisation, foliation and correlation are discussed.

Six new analyses of the younger Cape granites renders possible the construction of reliable variation diagrams, and a relationship is deduced between the quantity of normative corundum and the potash-soda ratio.

The compositions of the granites of South Africa are discussed in the light of normative variation diagrams of the trilinear co-ordinates, and a rigid chemical distinction seems applicable to some of these provinces.

CONTENTS.

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x. The granites only are here described; the petrology of the sedimentary xenoliths will form the subject of a later paper.

1. INTRODUCTION

(a) Location and Extent of Area:

The area mapped comprises a rectangular tract of country bounded by the Orange River in the north (at Goodhouse lat. S. 28°56', long. E. 18°13'): by a roughly parallel line 10 to 15 miles south of the Orange River in the south: by the boundary of the Goodhouse farm in the west: and by the farm boundary of the Pella Mission (long. E.19°9', lat. S.29°1') in the east.

The terraine covers approximately 570 sq. miles. The distance from Cape Town to Goodhouse is 429 miles, and from Goodhouse to Pella 80 miles.

(b) Climatic Conditions and Vegetation :

The average annual rainfall over the entire area is less than 5 inches, and the precipitation is equally contributed by summer thunder storms, and the drizzling "mist rains" of the winter months, April to September. The mean maximum and mean minimum temperatures, in °F, for January, the hottest month, and July, the coldest month, are respectively 102°, 71° and 73°, 44° as averaged at Goodhouse over 15 years.[x] The mean maximum of 102° is the highest recorded by the meteorological stations in the Union.

The vegetation comprises typical desert shrub and desert grass, which increase in abundance towards the east and outside the bare canyon of the Orange River. Apart from the Orange River which is normally a perennial stream, there are tiny permanent springs at Dabenoris and Klein Pella, as well as a number of bore holes which yield small quantities of brackish water. The agricultural enterprises are limited to two citrus plantations at Goodhouse and Abbasas, which are irrigated from the Orange River,

x. Official Year Book of the Union of South Africa, etc.

and to some small scale dryland farming on Klein Pella and the Pella Mission.

(c) Geological Surveying :

For the western part of the area a base map (scale 1: 75,000) was prepared from an excellent hand plotted triangulation net (scale 1: 50,000) which is accessible at the Offices of the Surveyor General, Cape Town. In the west (Pella, Kanbreek and Klein Pella) the working map comprised a chart (1"= 800 Cape roods) which was plotted and kindly supplied by Land Surveyor, J.H.C. Krapohl, who is responsible for the original observations. With the exception of the Orange River, and some of its sand drowned tributaries, these maps contain no topographical detail, and it is to be regretted that the original co-ordinates are no longer procurable.

The procedure of mapping resolved itself into (1) the taking of long range shots on prominent land marks, depicted by flags, by means of a Zeiss telescopic alidade from the stone beacons which have survived destruction, (2) the determination of positions from a minimum of three known points by the tracing paper method, and (3) the gradual elaboration of the work from the points thus located until the whole area was covered. The outcome of these efforts is embodied in the accompanying geological map on the scale 1: 100,000 or 1"= 1.58 miles. The magnetic declinations, in April 1936 were, according to the sheets issued by the Irrigation Department, 22°15' W. (Pella) and 22° 35' W. (Goodhouse), but the many local disturbances, and the long sights, are not conducive to the application of prismatic compass methods.

A small store exists at Pella but the field geologist has to cope with the difficulty of carrying potrol, water and provisions throughout the better part of the 570 sq. miles, and he is also inconvenienced by the strenuous traverses on foot through the mountainous belt which fringes the Orange River.

Over the partly sand-covered stretches further south the conditions are more amenable by virtue of a network of interconnected tracks which lend easy access to the exposures.

(d) Previous Work :

There is no need to review the early literature on the geology of northernNamaqualand, the relevant aspects of which have been ably summarised in the recent papers by Prof. Gevers [6], Dr. van Biljon[20], and Mrs. Mathias[15]. Prof. Gevers' memoir on the Pegmatite Area[6] is primarily an economic study, but it also contains a comprehensive résumé of the field relationships of the Kheis xenoliths, the post-Kheis intrusives, and the later sedimentary series between the Steinkopf - Goodhouse - Vioolsdrift triangle. The geological map, issued with this bulletin, is a glowing tribute to the skilful field investigations conducted over an inhospitable terraine; it bears a greater multiplicity of rock types than those encountered in the Goodhouse-Pella area, with which it is continuous in the east.

Mrs. Mathias' paper, "A Comparative Study of the Namaqualand Granites" is a quantitative microscopic investigation of the granites collected along the road from Garies to Vioolsdrift. The many modal analyses and the chemical data in the communication are extensively utilised to arrive at the graphical representations figures in the present thesis.

The genesis of a metamorphosed aluminous sediment on South Pella was described by the writer elsewhere. [x]

(e) Acknowledgments :

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x. Coetzee, C.B. - Sillimanite-Corundum Rock. A metamorphosed "Bauxite" in Namaqualand. Trans. Royal Soc. S.A., Vol. XXVIII, 1940.

dissertation, and for the subsequent loan of specimens.

The National Research Board, of the Department of Union Education, for a liberal grant to defray the cost of 13 chemical analyses.

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II. LABORATORY METHODS.

The plagioclase feldspars were determined from the N_g and N_p indices, in sodium light, by testing a minimum of 15 fragments in either case, and standardising the immersion media on a Leitz-Jelley Micro-Refractometer after every measurement, in order to control the temperature fluctuations. In many instances the results were tested on the Universal Stage by plotting the optical and morphological vectors and evaluating the feldspar by Reinhard's projections: the agreement was invariably excellent. Optic axial angles were determined by the Federow mothod, or in the case of small angles by Mallard's method.

The modes were assessed on a six spindle Leitz-Schumann Integrating Stage by traversing separately for the dominant constituents and the total accessories. The proportions of the minerals in the latter were then attained from areal measurement by means of a cross grated ocular, or by a count of the relative numbers of the grains in the heavy residue.

(a) The Accuracy of the Micrometric Data :

Since many of the conclusions in this paper are based on volumetric analyses, it is desirable to check the accuracy of the measurements. According to Larsen and Miller[13], micrometric analyses have an accuracy of 2% when the total length of the traverse equals 200 times the length of the largest grain. The quartzes and the feldspars in many of the granites have average maximum lengths of 4mm, but since the rocks generally have a linear inequigranularity in which the uniformity of the distribution of the individual constituents is not too good, it was deemed necessary to traverse from 1200 to 1600 mm. in different cases to attain this accuracy. From the spatial arrangements of the minerals in the medium-grained rocks it is evident too that greater precision is ensured by traverses in which the lateral intervals are relatively broad, e.g. 1·5 mm, although the number of sections required for the analysis is then necessarily increased.

TABLE A.

	(1)	(2)	(3)
SiO_2	78·12	78·8	0·7
Al_2O_3	11·16	11·5	0·3
Fe_2O_3	·49	·4	0·1
FeO	·97	·5	0·5
MgO	·43	·2	0·2
CaO	1·36	1·2	0·2
Na_2O	2·25	2·6	0·3
K_2O	4·51	4·8	0·3
MnO	Trace	...	...
P_2O_5	·05	·04	0·01
TiO_2	·22	·22	0·1
H_2O +	·26	...	...
H_2O −	·05	...	...
Totals	99·87	100·14	0·5

Norm.

Q	= 43·50
or	= 26·69
ab+an	= 26·06
femic	= 3·55

Mode.

Quartz	= 42·8
Microcline	= 28·1
$Ab_{82}An_{18}$	= 27·3
Rest	= 1·8

The Geselskapbank granite is well suitable as a means of testing the precision of the method in the light of a chemical analysis since (i) the granularity is representative of the younger granites, (ii) the feldspars are not intensively altered, and (iii) the percentage of accessories, the compositions of which are not so well known from their optical constants, is small. In the columns of Table A, (1) is the actual analysis by W.H. Herdsman, (2) is the composition as calculated from the mode, and (3) represents the ensuing errors. These are never of great magnitude: for Na_2O, K_2O and CaO they are well below 0·5: and when the analysis (1) is recalculated water-free, the silica error becomes 0·5, which is indeed small when it is recalled that the limits of analytical error for SiO_2 allowed by Groves[8] are ∓ 0·20.

The agreement between the norm and the mode is excellent, on account of the small amounts of K_2O, Na_2O and CaO derived from the mafic minerals, but calculated as or, ab and an in the norm.

(b) Microphotographs:

Microphotographs were taken by (1) the "Panphot" Universal Camera Microscope, and in the case of low magnifications by (2) a new Projection Method. In the latter case light is transmitted through the section by a small projector, and the image is photographed on a screen by a miniature camera. Polarised light may be effectively producedby the addition of polaroid glasses to the lens system, but since the author is not alone responsible for the perfection of this method, the details which are essential to ensure refinement will not be discussed.

III. GENERAL GEOLOGY.

(a) Physiography:

West of the Aughrabies Falls the Orange River flows in a deep gorge whose margins are dissected into innumerable ridges and conical peaks to produce the extremely rugged mountainous tract. (Photograph 1). The area under discussion is about equally apportioned between the latter, and part of the transitional slope from the river to the Bushmanland peneplain, the edge of which, some 20 miles south of Goodhouse, lies at an elevation of 2700 ft. above the level of the river. South of the mountainous tract the slope comprises an "inselberge" region: (Photograph 2)., conspicuous koppies of domed granite, black amphibolites, and white quartzites projecting above the sea of rock debris and wind blown sand.

According to Gevers[6] the Bushmanland peneplain was formed during the Cretaceous-Eocene, with dessication commencing in the Eocene-Oligocene. The man incision of the peneplain to form the Orange River gorge, as well as the evolution of the Aughrabies falls are correlated with a continental uplift in the late Tertiary.

The low angle depression about the Pella River is a filled-in valley which enters the Orange River at grade, but with the exception of the sand drowned Goodhouse valley (photograph 3), the precipitous marginal ravines are scoured clear of much overload, and they generally have a small breadth - height ratio, which points to the concentrated precipitation that accompanies cloud bursts in an arid region.

(b) Outlines of Field Geology :

The major portion of the area comprises three post-Kheis intrusive granites, viz (1) An Older Granodiorite grading into quartz-monzonite and "biotite-granite". These types are of a grey colour, weather into rounded boulders of the woolsack type, and are generally non-gneissose except along the contact with (2) the pinkish coarsely foliated Younger Granite-Gneiss, of the Namaqualand Massif, whose weathering is accompanied by the production of platy slabs. The precise nature of the contact is not clear: on Koisabes and Hom it is sand covered, whereas on Abbasas the alleged contact presents a confusing mixture of granitic rocks whose mutual relations are further obscured by an abundance of pegmatites. The normal rocks grades into a porphyritic (rapakivi) type, which forms patchy exposures along a line extending roughly between the water holes of Abbasas and Kabis. The third intrusive is (3) an Aplogranite, which is probably a leuco acid differentiate of the younger granite, in which it occurs as veined gneisses, interconnected dykes, and to the east as larger continuous bodies.

There is a profusion of anastomising pegmatite veins of the marginal type throughout the entire area, and the larger more or less continuous bodies, have been sketched on the geological map. The pegmatites have two dominant strikes, N.W. - S.E; N.E. - S.W. and their emplacement was related by Gevers[6] to the intrusion of the younger Namaqualand granite. Except for some tourmaline, red garnet and muscovite they are invariably barren, but it is believed that more intense mineralisation has occurred in the exterior pegmatites on northern Kabis and Houniams, where quantities of scheelite have been recovered from the quartz veins associated with the pegmatites.

The pre-granitic rocks include the following metamorphics from the Kheis Series.

1. Recrystallised Quartzites, which are probably to be correlated with the Kaaien beds, cap and partly build the highest mountains of the area, e.g. the peak of Abbakop, the dissected range on Guadom-Dabenoris, (photograph 4) the table mountains of Wortel and Pella. These occurences are amplified by a series of low quartzite koppies, e.g. on the southern parts of Hom and Klein Pella, and by comparatively thin quartzite bands parallel to which the granite-gneiss has often been soaked by aplitic emanations (Hoogoor and Hartebeest River). The quartzites may attain a vertical thickness of about 400 ft. and they are evidently the erosional relicts of a former peneplain as reflected by the fact that the higher peaks have somewhat corresponding altitudes, e.g. the following heights are available from the trigonometrical beacons: 3051' Abbakop, 3487' Dabenoris, 3785' Wortel, 3076' Hoogoor, 3602' Groot Rozyn, and 3940' Pella.

2. Biotite Gneisses. Much of the biotite gneiss follows the tectonic plan of the Kaaien quartzites, with reference to which, in such cases, it exhibits a conformable relationship, and the basal periphery of these darkish rocks to the white quartzite mountains, always forms a conspicuous feature in the

field. Where the biotite gneiss attains good lateral development, as is the case north of the Pella Mission, it presents a zone of intense migmatisation, and the injected components include both the younger granite and the later pegmatites.

(3) Amphibolites. The area contains a wealth of amphibolites the sedimentary derivation of which is confirmed both by field observations, and by mineralogical and chemical data, although the multitude of pitch black koppies superficially simulate the appearance of basic and ultra basic intrusions. Mechanical injection of the amphibolites is exceptional, and positive examples were observed on Koenabib and Wortel only. In most cases, there exists a knife sharp contact between the metamorphosed sediments and the granite.

IV. THE PETROGRAPHY AND MINERALOGY OF THE GRANITES.

A. THE BASEMENT GRANITES.

(a) The Granodiorites :

The texture of this group is hypidiomorphic granular, but due to the dominance of plagioclase over potash feldspar in a ratio which generally exceeds 2 : 1, the resemblance is dioritic rather than granitic. The sequence of crystallisation was normal except for some irregularities about the borders of the mafic minerals, in consequence of an overlap in the separation of the leucocrates and the melanocrates; otherwise the bulk of the plagioclase preceded quartz, which in turn was followed by much interstitial microcline.

Evidence of mechanical deformation follows from the wavy extinction in many quartz crystals, but the stresses were inadequate to effect a bending of the plagioclase twin lamellae (Microphotograph 1).

Quartz. The average percentage calculated from 15 modes is 27, and the extreme values are 14 and 43. The average longer diameters range from ·4 mm. to 1·4 mm.

TABLE 1. Modes of the Basement Granites.

	1.	2.	3.	4.	5.	6.	7.
Quartz	25·4	43·1	26·3	14·4	33·1	28·5	26·4
Potash feldspar	12·9	12·3	14·9	22·6	16·1	15·8	17·0
Andesine	48·1	31·7	39·4	41·2	35·7	39·2	39·1
Apatite	+	+	+	·5	+	+	+
Biotite	10·2	9·9	–	12·3	11·3	11·2	12·2
Hornblende	+	+	+	·7	–	+	1·4
Zircon	+	+	+	+	+	+	+
Titanite	+	+	+	·9	·4	+	·6
Orthite	–	–	+	+	+	+	+
Iron Ore	1·0	1·1	1·4	1·9	1·0	1·3	·1
Epidote	1·7	1·3	3·8	5·0	1·9	2·7	2·8
Chlorite	+	+	12·2	+	+	+	
Rest	·7	·6	2·0	·5	–	1·3	
% An in Plag.	39	34	39	38	44	40	34
Total % Ab.	29·3	20·9	24·0	25·5	21·8	23·5	25·8
K.feldspar:Ab.	·4	·6	·6	·9	·7	·7	·7
S.G.	2·75	2·71	2·75	...	...	...	...

1-3, Goodhouse; 4, Henkries; 5, Uranoop river.
6, Average (Coetzee); 7, Average (Mathias[16])

Microcline. The Basement granites differ from normal granodiorites in so far as orthoclase is almost entirely proxied by microcline, whereas this is commonly the case only in types relatively rich in K_2O. The volumetric amounts vary between 12 and 23 %, and the average crystal length is about ·9 mm.

Plagioclase. The composition is almost exclusively limited to andesine since in 13 out of 15 cases the anorthite values range between 33% and 45%. The crystals are mainly twinned on the Carlsbad, Albite and Pericline Laws, and fairish examples of continuous zoning are occasionally encountered. In one instance the core gave $2V_z = 78^\circ$ and the mantle $2V_z = 83^\circ$ which corresponds to 56% and 43% of anorthite respectively. In the mode plagioclase varies from 32% to 49%, and the average length of the crystals is about 1·4 mm. The alteration products, kaolin, secondary mica and epidote acquire some regularity when they are confined to the central or the marginal zones of the andesines. Granophyric intergrowths of quartz and andesine, and microcline and acid plagioclase (microcline - perthite) are sometimes observed.

Biotite. Biotite which has an average of 12% is the most abundant of the ferromagnesians, with which it tends to be grouped in open clusters. It is highly pleochroic in tones of X = straw - yellow, Y=Z = dark brown, and its optical properties are very uniform as illustrated by the fact that in five cases Nm varied from 1·631 to 1·635 only. During the decomposition of the biotite to chlorite, the former passes through a green mica stage, which retains the high refringence of the biotite, while Nm is not more than ·003 less than the corresponding index of the brown original.

Amphibole. The optical properties of three amphoboles are listed below, but inspite of the variation here observed it is a noteworthy feature that the bulk of the bornblendes from the Goodhouse areaare of the high refractive index type; in fact when these data are linked with those obtained by Mathias[15], it is found that in 9 cases out of 10 the hornblendes have identical optical properties. As a rule the amphibole does not alter directly to epidote, but it is first converted into biotite and/or chlorite, and the extent of this altecation is such that epidote has a persistent value of some 2% in the mode.

	Goodhouse.	Goodhouse.	Henkries.
N_p	1·670	1·671	1·667
N_m	1·685	1·685	...
N_g	1·693	1·693	1·684
$N_g - N_p$	·023	·021	·017
$2V_x$	79°	82°	...
$Z \wedge c$	20°	22°	18°
X	deep straw-yellow	deep straw-yellow	greenish-yellow
Y	yellowish-green	yellowish-green	pale green
Z	bluish-green	bluish-green	green

Epidote. Pistacite occurs as granular aggregates or columnar cystals, elongated parallel to the ortho axis and ·3 mm in length. The mineral is of secondary origin and can be entirely accounted for by the decomposition of the ferromagnesian silicates. Variations in colour and pleochroism are linked with differences in the optical constants as illustrated below.

	Goodhouse (a)	Goodhouse (b)
N_p	1·733	1·730
N_m	1·762	1·753
N_g	1·772	1·765
$2V_x$	71°	76°
X	colourless	colourless
Y	yellowish-green	greenish-yellow
Z	yellowish-green	greenish-yellow
$HCa_2Fe_3Si_3O_{13}$	32%	25%

Titanite. Sphene is the most plentiful accessory, iron ore excepted, and it is frequently possible to distinguish between primary titanite, which occurs as honey coloured acute rhombs ·3 mm in length, and secondary titanite arising from the decomposition of biotite. This latter variety has a dull gray colour and granular appearance.

Orthite. Orthite is generally found as cores surrounded by mantles of epidote. The largest crystal observed had diameters ·9 mm x ·5 mm, with an epidote fringe ·03 mm in thickness. The following data were determined on two Goodhouse granites:

$$N_p = 1{\cdot}700,\quad N_g = 1{\cdot}720 \quad \mp \cdot 007 \qquad\qquad N_p = 1{\cdot}710,\quad N_g = 1{\cdot}730 \quad \mp \cdot 007$$

$$2V_x = 60^\circ \mp 5^\circ \qquad\qquad 2V_x = 65^\circ \mp 5^\circ$$

X = deep brown

Y=Z=dark reddish brown.

The interfacial angles of an obtuse rhomb were, $(001)\wedge(101) = 65^\circ$ and $(00\bar{1})\wedge(101) = 116^\circ$.

Between crossed Nicols the mineral is often zoned, and it is always altered and heterogeneous in different degrees, so that the optical properties are not only variable, but could not even be determined with great precision in the comparatively good crystals measured above.

The additional accessories include colourless zircon and magnetic iron ore.

(b) The Biotite-granites.

The biotite-granites have a poorly developed gneissose texture, produced by the alignment of the longer axes of the biotite crystals, but there is no well marked continuity between the mica trails. The fabric is seriate and all intermediate sizes can be recorded between the average lengths of the larger crystals (quartz = 1·2 mm, microcline = 2·5 mm, andesine = 1·6 mm), and the average lengths of the smaller crystals (quartz = ·2 mm, microcline = ·3 mm, andesine = ·2 mm.).

TABLE II. Modes of the Biotite-granites.

	1.	2.	3.	4.	5.
Quartz	38·9	38·3	40·8	34·4	38·1
Potash feldspar	31·8	25·8	31·0	35·1	30·9
Andesine	23·6	24·9	21·2	23·0	23·2
Apatite	+	+	+	+	+
Muscovite	+	+	+	+	+
Biotite	4·9	9·6	6·1	6·8	6·8
Zircon	+	+	+	+	+
Titanite	+	+	+	+	+
Orthite	+	+	—	+	+
Iron Ore	·1	·1	·7	·5	·4
Epidote	·3	1·1	+	·1	·4
Chlorite	+	+	+	+	+
Rest	·4	·2	·2	·1	·2
% An in Plag.	45	45	37	35	41
Total % Ab.	13·0	13·7	13·4	15.0	13·8
K.feldspar: Ab.	2·4	1·9	2·3	2·3	2·2
S.G.	2·66	2·69	2·65	2·68	2·67

1,2,3, Goodhouse: 4, Hom: 5, Average.

Felsic Minerals. The volumetric analyses show good uniformity in the percentages of quartz, microcline and plagioclase. The former occurs to the exclusion of orthoclase, and the latter forms a basic andesine with anorthite ranging from 35% to 45% . In contrast to the limpid microcline, the soda-lime feldspar is well kaolinised and poorly twinned.

Biotite. Biotite has an elongation index of 2·7 which agrees well with the figures given by Truemann for gneissose granites, viz: 2·5. The pleochroism is the same as in the granodiorites, but the refractive indices are slightly higher e.g. the following values were obtained from various localities : $N_m = 1{\cdot}635$, 1·636, 1·638, 1·639.

Muscovite. Primary muscovite (N_m=1·610, $2V_x=37^{\circ}$) is always present in very small quantity, and the figures indicate a mica with about 40% of the phengite molecule.

Secondary sphene and pistacite are regelated to the trains of biotite, and the epidote frequently occurs as fibrous lobate masses wedged between the cleavages of the mica.

B. THE YOUNGER NAMAQUALAND GRANITE-GNEISS.

(a) The Porphyritic Type.

The porphyritic texture of the coarse grained types is controlled by insets of microcline 20mm x 10mm in size. The phenocrysts have inclusions of microcline and plagioclase, and are bordered by a fringe of oligoclase granules ($2V_x = 85^{\circ}$), in consequence of which the microcline simulates the texture of the orthoclases in the rapakivi granites. (Microphotograph 2).

In the medium-grained types a glomero-porphytitic texture is developed in which there occur in addition to the microcline insets (a) 9mm long lenticular aggregates of altered oligoclases with individual lengths of ·7mm (b) clusters of fresh microclines and (c) elongated groups of quartz crystals 3·5mm in diameter. The porphyritic aspect is enhanced by blades of ripidolite and accessory minerals which enfold the porphyritic components described above. The constants of the chlorite are :

$N_m = 1{\cdot}620$	X = pale yellow
$2V_x = 7^{\circ}$	Y=Z=deep green.

The polarisation colours are abnormal in tints of blue, purple and brown.

(b) The Normal Gneissose Type.

The fabric is gneissose, inequigranular, andmedium grained but the absolute grain size is such that the gneissic character is not so apparent on a microscopic scale (Microphotograph 3).

TABLE III. Modes of the Younger Granite-gneiss.

	1.	2.	3.	4.	5.	6.	7.	8.
Quartz	34·5	42·2	34·2	42·8	32·5	33·5	36·6	31·9
Potash feldspar	28·9	24·0	31·1	28·1	40·7	29·2	30·3	30·7
Oligoclase	28·7	24·8	27·1	27·3	23·6	30·4	27·0	27·5
Apatite	+	+	+	+	+	+	+	+
Biotite	3·3	5·5	4·7		2·4	5·2	3·3	7·3
Hornblende	2·3	+	+	+	—	—	·4	·3
Zircon	+	+	+	+	+	+	+	+
Titanite	1·4	1·5	1·7	+	+	+	·8	·3
Orthite	+	+	—	+	—	+	+	...
Iron Ore	·6	1·5	·8	+	+	+	·5	1·8
Epidote	·1	+	+	+	+	+	+	·1
Chlorite	+	+	—	+	+	—	+	...
Rest	·2	·5	·4	1·8	·8	1·7	·9	...
% An in Plag.	28	30	27	22	28	29	27	30
Total % Ab.	20·7	17·4	19·6	22·4	17·0	21·6	19·7	19·3
K.feldspar: Ab.	1·4	1·4	1·6	1·3	2·4	1·4	1·5	1·5
S.G.	2·69	2·67	2·67	...	...	...	...	...

1,2,3,6, Pella; 4, Geselskapbank; 5, Springbok;
7, Average (Coetzee): 8, Average (M. Mathias[15]).

Felsic Minerals. A review of all the available planimetric analyses, the new ones of which are listed in Table III, indicates that the percentages of the leucocrates are highly variative, viz. quartz 21% - 53% ; potash feldspar 24% - 41% ; and plagioclase 18% - 38% . This tendency is also conformed to by the basicity of the plagioclase (An = 10% - 43%) and the general microscopic characters of the felsic minerals. The granularity is not uniform as illustrated by the figures below:

	Quartz.	Plagioclase.	Microcline
Av. of max. lengths, mm.	4·1	3·8	4·0
Av. lengths, mm.	1·0	1·0	1·0

The effects of cataclasis are preserved in some sections by thin mortar rims about the quartz crystals, but otherwise strain phenomena are not in evidence. Intergrowths of microcline-perthite, antiperthite and myrmekite are relatively more abundant than in the older granites, and pellets of feldspar or pools of quartz form inclusions on an extensive scale. The potash feldspar which is represented by microcline only, is always perthitic and in an extreme case (Niegramoep) 200 albite blebs were counted to an area of ·25 sq.mm. This extensive exsolution of soda appears to be concomitant with the high degree of saussuritisation observed in the plagioclase.

Biotite. The N_m values of the biotites from six localities are : 1·634 (Pella), 1·634 (Pella), 1·638 (Dabenoris), 1·630 (Klein Pella), 1·637 (Geselskapbank) and 1·645 (Springbok). In contrast to the generalisation by Mathias[15] viz., that sagenite webs of rutile are characteristic of the younger granite-gneiss, no rutile needles were observed in the biotites from the Pella area. The biotite from the Springbok granite, however, does include rutile, and has a refractive index appreciably higher than those of the rutile-free micas. The pleochroism is X = straw-yellow, Y=Z = deep brown, and the mineral shows the usual alteration to green chlorite, which is accompanied by the liberation of iron ore.

Amphibole. Green hornblende is present in about 75% of the sections. The pleochroism is always from yellowish-green to deep green, but the intensities of the shades vary in different cases, and this observation is obviously related to the different values ascertained for the refractive indices. The conclusion is, therefore, warranted that the hornblendes from the Namaqualand granite-gneiss, show a far greater range in composition than those from the older granites. Sieve texture, embayment, and degredation to biotite, chlorite and epidote are common features.

	Pella.	Pella.	Geselskap-bank.	Koenabib.	Range determined by M. Mathias
N_p	1·672	1·671	1·667	1·666	1·655 - 1·662
N_g	1·695	1·694	1·684	1·685	1·678 - 1·690

Titanite. In the Pella granites titanite occurs as beautiful acute rhombs 2·3mm x ·8mm in size, with inclusions of allanite, iron ore, biotite, epidote and quartz.

$2V_z = 36^{o} \mp 3^{o}$ (sodium light) X = Y = pale yellowish brown Z = deep orange brown.

Orthite. Allanite is present in some cases only, althought it attains good development in a granite from Geselskapbank, and in another from Pella in which a large anhedron 2·4 mm in length was observed.

Zircon. Brown zircons are the dominant type, and the index of elongation, 2·4 to 2·9, conforms to the normal values for igneous rocks. An abnormality in this respect occurs in a granite from Springbok, in which the elongation ratio is 1·7 only, but the full implication of this will be discussed later. The other accessories comprise purple fluorite, apatite, magnetite and ilmenite.

C. THE APLOGRANITES.

The texture is typically allotriomorphic granular, which is attributable to the fact that the crystal boundaries of the leucocrates were largely determined by mutual interference. (Microphotograph 4).

Felsic Minerals. The volumetric data in Table IV show excellent agreement between the percentages of the leucocrates. Microcline which is the only potash feldspar, differs from the microcline of the granite-gneiss, by the scarcity of the intergrown albite lamellae. The latter correspond to $Ab_{93}An_7$ ($2V_z$=81°), and many veinlets are oriented parallel to (100) of the microcline host ($2V_x$=80°). Acid oligoclase ranges from $Ab_{90}An_{10}$ to $Ab_{80}An_{20}$, and in this respect the aplogranites differ from the aplites of the alaskite type where the plagioclase is referred to $Ab_{100-90}An_{0-10}$[x]. The grain sizes which are cited below indicates that

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the granularity of the aplogranites lies on the border which separates the medium grained and fine grained rocks, if Tyrrell's figure of 1 mm. is accepted as such.

	Spring-puts.	Pella.	Guadom.	Hoogoor.
Lengths in mm.				
Av. lengths of larger quartzes	1·9	·7	·7	2·3
Av. lengths of larger oligoclases	1·2	·6	·6	1·3
Lengths of largest microclines.	3·4	...	...	3·6
Av. lengths of microclines.	·8	·6	·5	·9

<u>Biotite</u>. A high refractive index biotite was determined in the heavy residues of the aplogranites from Pella, Guadom and Hoogoor. The optical constants are :

$N_m = 1{\cdot}703 \mp {\cdot}005$ $2V_x = 10^\circ$ (Mallard)

X = yellowish brown Y=Z=deep reddish brown.

Winchell[23] refers the high indices of such unusual biotites to ferric iron and/or titanium, for example a biotite with 16·48% Fe_2O_3 and 24·06% FeO has N_g=1·697, N_p=1·616, $N_g - N_p$ = 0·081. The chloritisation of the biotite has proceeded to such a degree that the mica constitutes only 0·1% by weight of the rock, and enough material for a chemical analysis could unfortunately not be isolated. The biotite and chlorite frequently enclose acicular crystals of a colourless anisotropic mineral with low relief, strong birefringence, and parallel extinction. The needles are ·06 mm x ·004 mm. in size, and their arrangement as often as not produces asterism.

Apart from the normal accessories of the aplogranites viz. secondary muscovite, zircon, apatite and magnetite, the following minerals were determined in the specimen from Hoogoor: <u>Pyrochlore?</u> variety microlite as dark brown isotropic grains which are decomposed on prolonged digestion with conc. H_2SO_4, N = 1·91 ∓ ·02. Purple <u>fluorite</u> and <u>epidote</u> (N_p = 1·732, N_g=1·778) are associated with chlorite. Green <u>hornblende</u> (N_p = 1·665 , N_g = 1·685) and dark brown <u>titanite</u> (N_m=1·92 ∓ ·02, $2V_z$=35°) are rare constituents.

TABLE IV . Modes of the Aplogranites.

	1.	2.	3.	4.	5.	6.
Quartz.	40·5	40·2	40·3	39·7	40·3	36·3
Potash feldspar	34·6	38·0	37·2	36·4	36·6	35·8
Oligoclase	22·3	18·5	21·0	21·2	20·8	25·1
Apatite	+	+	+	+	+	+
Muscovite	—	+	+	+	+	+
Biotite	+	+	+	—	+	1·5
Hornblende.	—	—	—	+	—	—
Zircon	+	+	+	+	+	+
Titanite	+	+	+	+	+	—
Iron Ore	·6	·5	·2	·7	·5	1·3
Chlorite	1·9	2·7	1·2	1·0	1·7	—
Epidote	—	—	—	+	—	—
Rest	·1	·1	·1	·2	·1	—
% An in Plag.	19	10	18	20	17	16
Total % Ab.	18·1	16·7	17·2	17·0	17·3	21·2
K.feldspar: Ab.	1·9	2·3	2·2	2·1	2·1	1·7
S.G..	2·62	2·62	2·61	2·62	2·62	2·70

1, Springputs; 2, Pella; 3, Guadom; 4, Hoogoor;
5, Average; 6, Aggenys granite[15].

V. THE PETROLOGY AND AFFINITIES OF THE GRANITES.

A. THE OLDER BASEMENT GRANITES.

(a) Nomenclature and Mineralogical Variation.

The collective term "Basement Granite" is here adopted in conformity with the suggestion raised by Gevers[5], and embraces the older group of ancient granitic intrusives which pinch out against the Orange river in the western part of the Goodhouse - Pella area. On the geological map of the Pegmatite Area[6], the group was described as "Biotite and biotite-hornblende granite, grading into granodiorite, quartz-diorite, etc. in part gneissose", and subsequently Mathias[15] referred to these as "Old Granites". In Fig. 1 the felsic minerals, whose modal percentages are recalculated to a 100, are plotted in a triangular diagram with quartz, potash feldspar, and plagioclase at the corners, which is the scheme

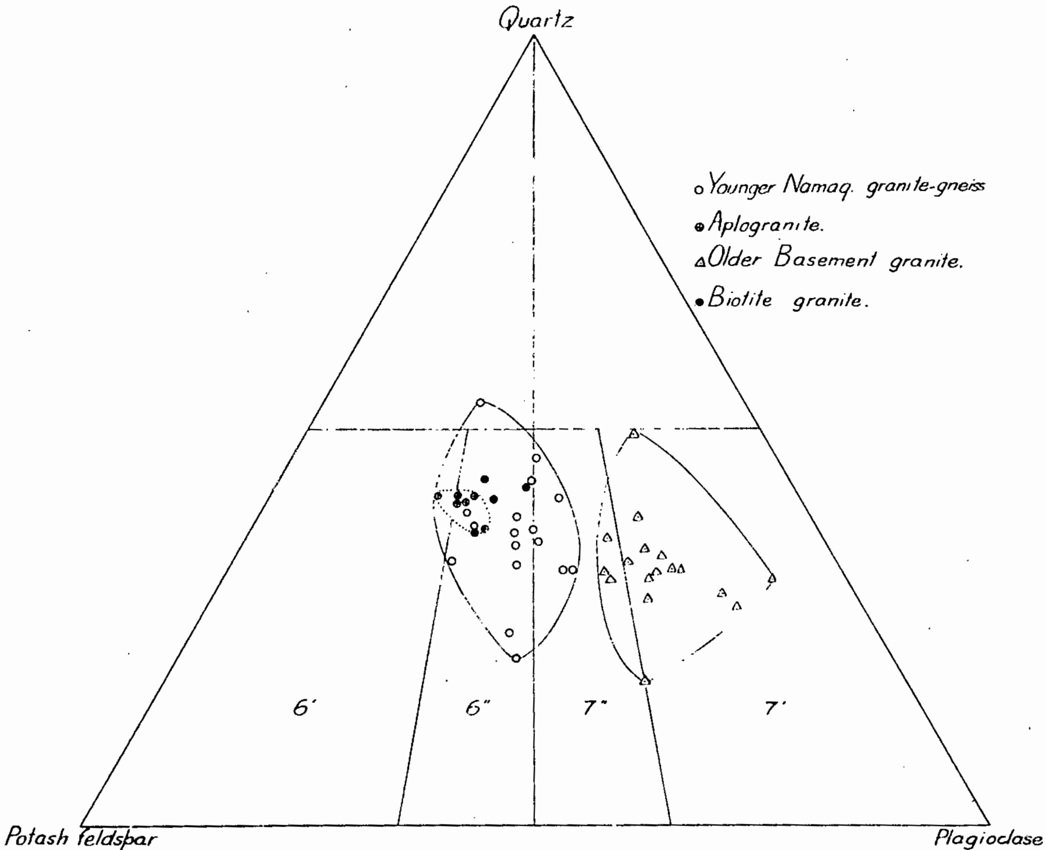

Fig. 1. Modal Variations of the Felsic Minerals in the Namaqualand Granites.

utilised by Johannsen[11] (Vol.1), in his quantitative mineralogical classification of granitic rocks. In terms of this system the "main" Basement granites, cover the upper and central portions of the monzotonalites, and transgress well into the adamellites.

If Holmes' definition[10] of a granodiorite is strictly applied, i.e. that the ratio of orthoclase to plagioclase falls between one-third and one-seventh, then the majority of the old granites enclosed by the continuous line in Fig.1, must be referred to as "quartz monzonites", and this condition generally attains in the Goodhouse-Pella area. Similarly if 5% is the maximum amount of potash feldspar allowed in a quartz-diorite[11] (Vol.II), then this group is not represented in the area or among the old granites analysed by Mathias[15].

(b) Chemical Analyses.

Three new chemical analyses of the older granites, together with other relevant analyses, and norms are listed below.

TABLE V. Chemical Analyses of the Older Granites.

	(1)	(2)	(3)	(4)	(5)	(6)	(7).
SiO_2	60.57	65.42	66.80	72.93	64.66	77.05	70.01
Al_2O_3	18.03	16.28	16.07	14.04	16.25	10.68	14.20
Fe_2O_3	2.72	1.77	1.52	.78	1.29	1.10	.42
FeO	1.95	2.84	2.04	1.39	2.68	1.71	3.24
MgO	1.79	1.86	1.74	.66	1.23	.34	.55
CaO	5.12	4.78	3.52	2.23	3.08	.93	2.06
Na_2O	2.95	2.19	2.75	2.01	3.33	2.52	3.14
K_2O	4.46	2.79	4.02	4.96	4.39	4.30	4.45
MnO	.08	.06	.05	.04	.07	.03	.06
P_2O_5	.27	.15	.06	.09	.45	.29	.20
TiO_2	.89	.58	.70	.18	1.26	.28	.48
H_2O +	.85	1.16	.73	.58	.83	.39	.63
H_2O −	.14	.10	.12	.19	.03	.03	.02
CO_2	...	...	...	...	.26	.22	.15
S	...	...	...	...	.05	.02	.02
Totals	99.82	99.98	100.12	100.08	99.86	99.96 x	99.74 △

x Includes ZrO_2 = .02, BaO = .05

△ Includes BaO = .11

Norms.

	(1)	(2)	(3)	(4)	(5)	(6)	(7).
Q	13·74	28·02	25·0	36·12	21·30	44·2	27·9
or	26·69	16·68	23·9	29·47	26·13	25·6	26·1
ab	24·63	18·34	23·1	16·77	27·77	21·0	26·7
an	22·52	23·07	16·7	10·29	10·84	1·4	8·9
c	...	1·22	1·1	1·53	2·14	1·4	·9
di (wo	·35	...	...	...	...	...	...
di (en	·30	...	...	...	...	...	...
di (fs	...	...	...	...	...	...	...
hy (en	4·20	4·60	4·3	1·70	3·10	·8	1·4
hy (fs	...	2·77	1·4	1·72	1·85	1·7	4·9
mt	3·94	2·55	2·1	1·16	1·86	1·6	·7
il	1·67	1·22	1·4	·30	2·43	·6	·9
cc	...	...	...	....	·60	·5	·3
ap	·67	·34	·3	·20	1·01	·7	·3
zr	...	...	...	...	py ·24	·2	...
H_2O	·99	1·26	·8	·77	·86	·4	·7
Totals	99·70	100·07	100·1	100·03	100·13	100·1	99·7

(1) Granodiorite, Henkries Valley, Namaqualand, Anal. C.B. Coetzee, (new analysis .)

(2) Granodiorite, Goodhouse, Namaqualand, Anal.W.H. Herdsman, (new analysis).

(3) Old Granite, Jackalswater, Namaqualand, Anal. M.Mathias[15],

(4) Biotite-granite, Hom, Namaqualand, Anal. W.H. Herdsman, (new analysis .)

(5) Granodiorite, Parys-Vredefort, Anal. J. Willemse[21].

(6) Old granite-gneiss, Hlatikulu, Swaziland, Anal.T. Kameda[7].

(7) Old granite, west of Hillcrest, Camperdown, Natal, Anal. R.B. Ellestad[7].

Sympathetic variations exist between alumina, lime, ferric oxide, and manganous oxide with reference to the silica percentage, but the other oxides occupy aberrant positions. Soda is decidedly low and in (2) it actually falls outside the range which has been compiled by Johannsen for 140 granodiorites i.e. 2·40% - 6·95% . In (1) and (3) this tendency is offset by a highish potash and in (2) by a highish lime. The values of CaO are in no way incompatible with the average figures[3] for quartz-diorites (CaO = 5·45%), granodiorites ($CaO=4\cdot47\%$) and quartz-monzonites ($CaO=3\cdot54\%$).

(c) Assimilation.

From the comparison of analysis (3) with the analyses of the old granites from Swaziland and Natal, i.e. (6) and (7) above, Mathias[19] concluded: "This bears out the contention that the old granite of Namaqualand has, in places, assimilated aluminous sediments and hornblende schists or amphibolites". The comparison is hardly fair as a means of establishing the thesis of basification of the old granite magma since (3) is a quartz-monzonite, (6) is an aplitic granite and (7) is a normal granite. There is no evidence to indicate that the magmas of the old granites from South Africa were of a granitic composition only, and that the granodioritic varieties are consequently contaminated types which acquired normal igneous characters as a result of assimilative processes. In this connection Willemse[21] writes: " The tendency to the 'residual-magma-differentiation' is noticed as clearly in the Basement granitic rocks from Southern Africa as in rock assemblages with a greater variation in rock types", and it will be noticed that a much more amenable comparison may be struck between the old granites, (2) and (3), from Namaqualand, and the granodiorites from Parys (6).

One factor which may be suggestive of the modification of the granodioritic magma by lime is the basicity of the plagioclase, which has cumulative values between Ab_{67-55} An_{33-45}, whereas the basement granites of the Vredefort region[21] have peak values at $Ab_{80-75}An_{20-25}$. But this disparity acquires much less significance if the basicity of the plagioclase in a representative set of granodiorites is considered e.g. in Johannsen's book[11] (Vol.II) the relative numbers of granodiorites carrying oligoclase (Ab_{90-70} An_{10-30}) and andesine (Ab_{70-50} An_{30-50}), which latter is the category of the Namaqualand rocks, are 71 and 45 respectively. The high anorthite content may consequently be nothing more but a consanguineous property which distinguishes the petrographic province in general.

The habit of the hornblende as a criterion of assimilation may now be examined, and in this connection the sieve textures and embayments which often obtain in the mineral, may place it as a residual constituent, which was incorporated into the "granites" by the mechanical disintegration of amphibolites. As previously shown, the most pronounced feature of the hornblendes in the "granites" is the uniformity of their optical constants, whereas the hornblendes of the amphibolites in the area to the east of the basement granites are extremely variable with respect to these constants. If the magma of the older granites had pierced a similar set of amphibolites in the west, and acquired the amphibole as a result of this passage, then a similar variation in the granitic hornblendes would be anticipated, but this expectation is indeed contrary to fact. The hornblende may therefore be regarded as a normal pyrogenetic mineral, and its occasional absence may be adequately explained by conversion to biotite, chlorite and epidote, the more so because these alterations are always observed to a greater or lesser extent. In the Kapaonik granodiorite, Wilson[22] has actually recorded the progressive reconstitution, as exemplified by the <u>variation</u> in the N_g index, of metamorphic amphiboles launched into the igneous mass as xenocrysts.

(d) The Biotite-granite.

The precise relation of the biotite-granite to the granodiorite and quartz-monzonite cannot be established in the field by virtue of their profound megascopic similarities. From the modal variation diagrams (Figs. 1,2,3) and from Table II it appears that the biotite granites form a closed group which is mineralogically sharply demarcated from the granodiorites. The basicity of the plagioclase, $Ab_{65-55}An_{35-45}$, is also quite anomalous for a granite with 72·9% SiO_2 and it is therefore reasonable to question the origin of this type as a normal crystallisation product which is genetically related to the granodiorites. The chemical analysis of the biotite-granite may be almost exactly duplicated by mixing one part of the granodiorite (analysis (2) Table V), with three parts of aplogranite (analysis (7) Table VII), and there is consequently some ground for regarding the biotite-granite as an interaction product between aplogranite magma and granodiorite. The supposed genesis may be likened to the origin of the "main" granodiorites of the Kapaonik batholith which arose (Wilson[22]) by the mechanical mixture of aplitic magma with marginal contaminated types of monzonitic composition. The analysis of the biotite-granite (a) and the hypothetical composition of the "mixed rock" are cited in Table VI.

TABLE VI. Analysis of the biotite-granite and the composition of "mixed rock."

	(a)	(b)
SiO_2	72·93	73·32
Al_2O_3	14·04	13·84
Fe_2O_3	·78	·90
FeO	1·39	1·35
MgO	·66	·68
CaO	2·23	2·35
Na_2O	2·01	2·08
K_2O	4·96	4·62
MnO	·04	·02
P_2O_5	·09	·05
TiO_2	·18	·30
H_2O+	·58	·63
H_2O-	·19	·03
Totals	100·08	100·17

Norms.

	(a)	(b)
Q	36·12	36·84
or	29·47	27·24
ab	16·77	17·82
an	10·29	10·68
c	1·53	1·02
hy en	1·70	1·70
hy fs	1·72	1·19
mt	1·16	1·39
il	·30	·61
ap.	·20	·13
H_2O	·77	·66
T otals	100·03	100·28

B. THE YOUNGER NAMAQUALAND GRANITE-GNEISS AND THE APLOGRANITE.

(a) Modal Relationships.

The area occupied by the granite-gneiss in the triangular diagram, Fig.1, indicates a considerable amount of mineralogical variation between the felsic minerals, but the points are amassed in that part of the granite field which is adamellitic in character. The tendency towards a quartz-monzonitic composition is disclosed by the migration of a few points into the granodioritic region.

It will be observed that the delimitation of the fields of the older and younger granites in Fig.1 forms a very satisfactory basis of distinction between these intrusives, and a similar quantitative separation is effected in Fig. 2, where the modal percentages of potash feldspar and total albite are plotted as abscissae and ordinates respectively. The only disturbing factor in these schemes is the biotite granites, which tra nsgress the field of the younger granites,

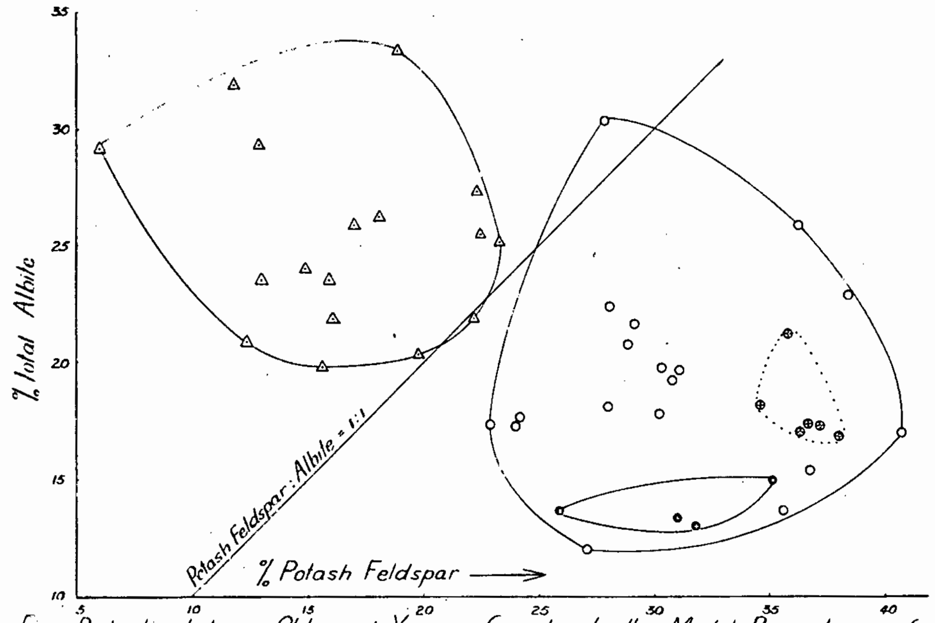

Fig. 2. Distinction between Older and Younger Granites by the Modal Percentages of Albite and Potash Feldspar.

○ Younger Namaq. granite - gneiss.
△ Older Basement granite.
⊕ Aplogranite
• Biotite granite.

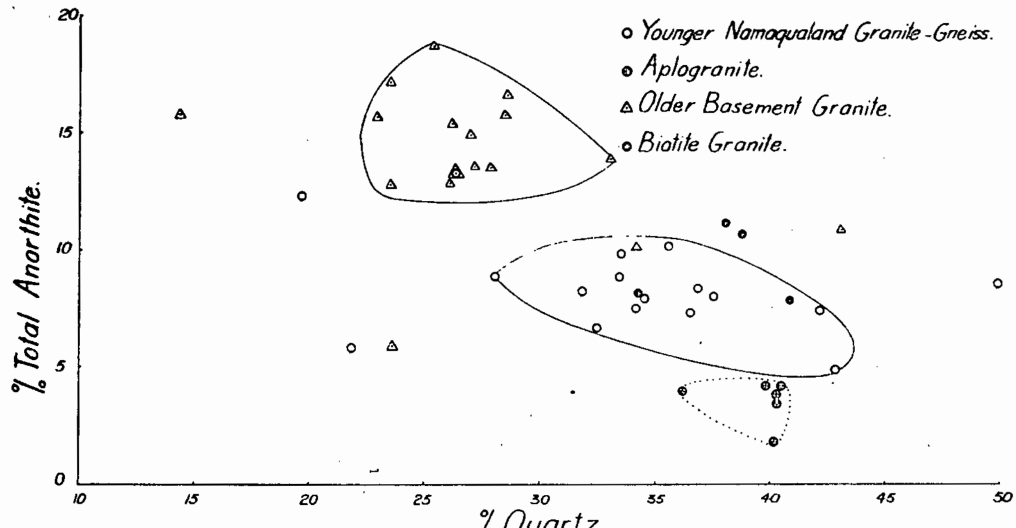

Fig.3. The relative basicities of the granites as exemplified by the anorthite-quartz ratio.

although in the second diagram the points are always confined to the bottom part of this area, by virtue of their low soda percentage. The overlap of the aplogranites is of little consequence since textural features are sufficiently divergent to distinguish this suite from the granite-gneiss.

In Fig. 3 an attempt was made to evaluate the basicity of the granites by plotting the calculated amount of modal anorthite against modal quartz. The fields are only drawn through those areas where the points are scattered most densely, but it is evident that the aplogranites fall clear of the granite-gneiss, not so much as a result of the smaller percentage of the plagioclase than as a consequence of its greater acidity.

(b) <u>Chemical Analyses.</u>

The available analyses of the younger Namaqualand granites and the aplogranites are adduced in Table VII.

TABLE VII. <u>Analyses of the Younger Namaqualand Granites and Aplogranites.</u>

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8).
SiO_2	71·78	72·46	78·12	71·26	72·86	72·09	77·27	76·22
Al_2O_3	14·26	13·25	11·16	13·73	13·82	13·77	12·62	11·56
Fe_2O_3	·97	1·59	·49	1·56	1·02	1·28	·47	·66
FeO	1·68	1·24	·97	1·09	1·07	1·27	·61	1·05
MgO	·70	·39	·43	·43	·52	·51	·09	·44
CaO	2.57	1·61	1·36	1·80	1·90	1·97	1·14	1·26
Na_2O	2·81	3·60	2·25	3·59	2·49	3·12	2·03	3·18
K_2O	4·46	4·97	4·51	4·99	5·66	5·02	5·54	5·16
MnO	Trace	·02	Trace	Trace	·02	·01	Nil	Trace
P_2O_5	·09	·09	·05	·56?	Trace	·09	Trace	Trace
TiO_2	·43	·36	·22	·30	·14	·41	·16	·18
H_2O	·26	·40	·26	·62	·33	·40	·36	·27
H_2O	·18	·09	·05	·18	·07	·13	Nil	·10
Totals	100·19	100·07	99·87	100·11	99·90	100·07	100·29	100·08

<u>Note</u>: The author is inclined to question the determination of P_2O_5 in analysis (4).

Norms.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Q	31·68	29·10	43·50	28·20	31·56	30·06	41·88	35·40
or	26·13	29·47	26·69	29·47	33·36	29·47	32·80	38·02
ab	23·58	30·39	19·39	30·39	20·96	26·20	16·77	26·72
an	11·95	5·28	6·67	5·28	9·45	8·90	5·56	2·50
c	·51	...	·10	·41	·10	...	1·33	...
di (wo	...	·81	...	...	...	...	...	1·51
di (en	...	·60	...	...	...	...	...	·75
di (fs	...	·13	...	...	...	...	...	·72
hy (en	1·80	·40	1·10	1·10	1·30	1·30	·20	·35
hy (fs	1·58	·13	1·06	·26	1·19	·66	·26	·33
mt	1·39	2·32	·70	2·09	1·39	1·86	·70	·93
il	·76	·76	·46	·61	·15	·76	·46	·30
ap	·24	·34	·13	1·34	...	·34	...	...
H_2O	·44	·49	·31	·80	·40	·53	·36	·37
Totals	100·06	100·22	100·11	99·95	99·86	100·08	100·32	99·99

(1) Younger granite , Pella, Anal. W.H. Herdsman (new analysis).

(2) Younger granite, Springbok, Anal. C.B. Coetzee (new analysis.)

(3) Younger granite, Geselskapbank, Anal. W.H. Herdsman (new analysis).

(4) Younger granite, 28 miles north of Garies, Anal. M. Mathias[15].

(5) Younger granite, 16 miles west of Springbok, Anal. W.H. Herdsman.[15]

(6) Average of 4 younger granites i.e. (1), (2), (4), (5).

(7) Aplogranite, North Springbots, Anal. W.H. Herdsman (new analysis).

(8) Aplogranite, Aggenys, Anal. W.H. Herdsman [15].

The analysed rocks all correspond to normal potash-soda granites with K_2O: $Na_2O = 1·38 - 2·72$. The compositions of the aplogranites (7) and (8) conform to acid differentiates of the granite-gneiss from which they differ in regard to higher percentages of SiO_2 and lower percentages of Al_2O_3, CaO, Fe_2O_3, FeO and MgO. The serial character of the suite as exemplified by the variation of the other oxides with respect to the silica percentage, or the proportion of the salic minerals, is not very evident from variation diagrams.

(c) An Example of Granitisation in the Springbok Granite.

Smithson[18] describes a very convincing method to distinguish sedimentary zircons from igneous zircons by plotting length versus

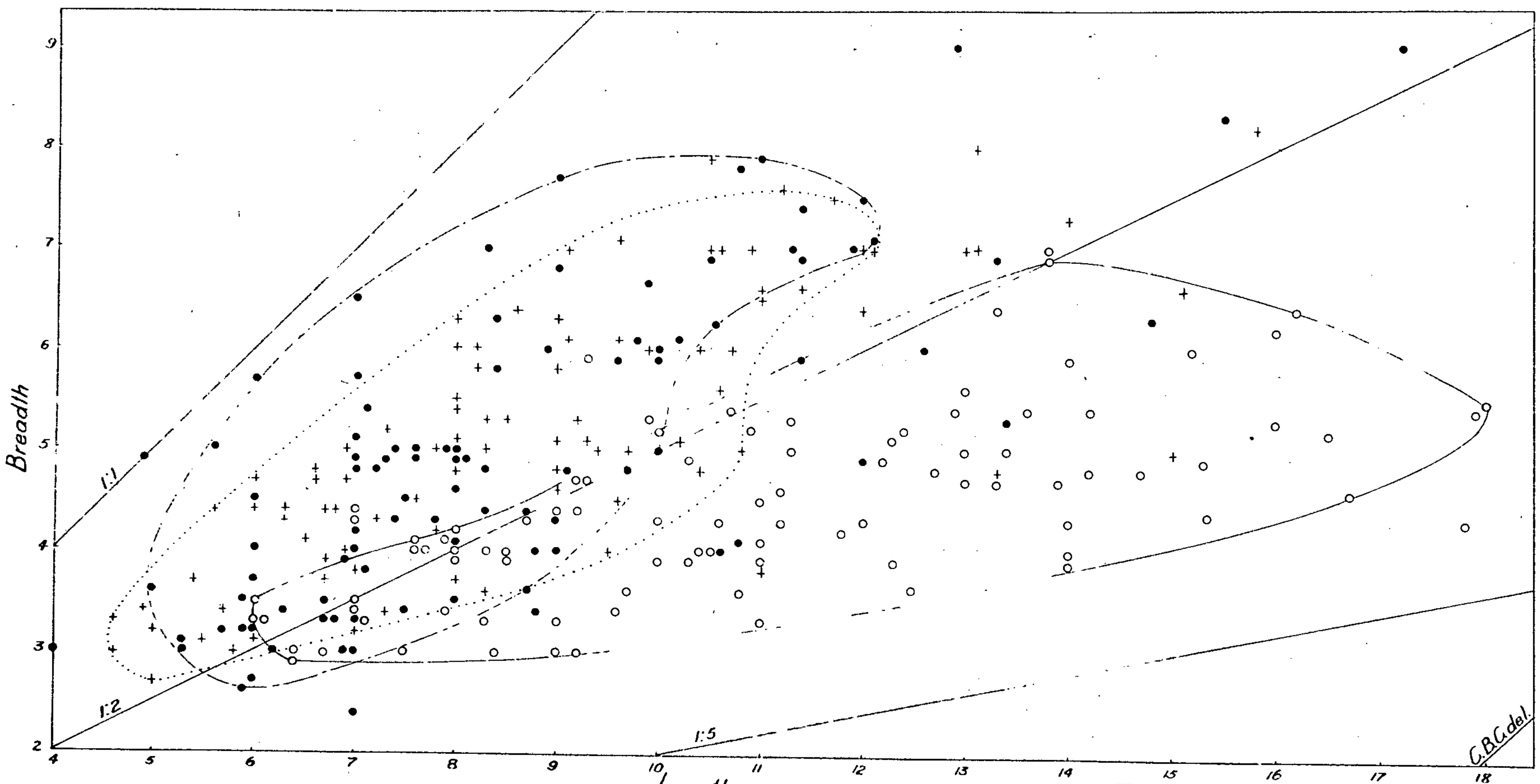

Fig. 4. Length : Breadth Diagram for Zircons. One Unit of Length = .0158 mm.

● — · — T.M.S. Rondebosch.
+ ········ Granite, Springbok.
○ ——— Granite, Pella.

breadth, and drawing certain ratio lines in the diagram viz. breadth : length = 1: 1, 1: 2, 1: 5. Igneous zircons then flood the area between the 1: 5 and 1: 2 lines, and sedimentary zircons the area between the 1: 1 and 1: 2 lines, although there is always some transgression of sedimentary zircons beyond the latter line into the igneous field.

The dispositions of the curves are naturally dependent on the accepted belief that detrital zircons are rounded during the process of transportation, as a result of which there occurs an appreciable diminution in the length : breadth ratio, and the validity of this assumption was recently excellently illustrated by the experiments of Thiel[19].

The heavy concentrate from a specimen of Springbok granite contained abundant rounded zircons, and when these were plotted in the way described above, the resulting field closely simulates that which was obtained by Smithson for sedimentary zircons. The contour is moreover entirely similar to that procured for a sedimentary rock, the Table Mountain sandstone from Rondebosch, but quite dissimilar to the field of the normal igneous zircons from the Pella granite. These relationships are illustrated in Fig. 4, and Table VIII contains additional evidence to emphasise the detrital character of the Springbok zircons.

If we discard the improbability that the zircons from the Springbok granite were uniformly rounded by magmatic resorption, then since the chemical analysis (2) and the petrofabric features of the granite are entirely comparable with those of a normal igneous rock, it seems permissible to relate the origin of this particular specimen to the granitisation of a sedimentary xenolith.

TABLE VIII. Comparison of the zircons from T.M.S., Springbok granite, and Pella granite.

	Granite, Springbok	Sandstone, Rondebosch.	Granite, Pella.
Av. elongation index of 50 zircons	1·73	1·92	2·44
Av. size of 20 zircons in mm.	·14 x ·08	·13 x ·07	·16 x ·07
Greatest observed elongation index	3·0	3·0	5·0
Percentage zircons definitely rounded	70	75	5.

The rock can moreover not be regarded as a granitoid gneiss i.e. a metamorphosed sediment with the accidental composition of an igneous rock, since the specimen contains part of a biotite-rich relict, from which the granite was presumable evolved by processes such as are invoked by MacGregor and Wilson[14].

(d) The Geselskapbank Analysis.

This analysis (3) is anomalous with respect to the silica percentage, which lies not only well above the figures for the other analyses of the younger granites, but which also surpasses those of the aplogranites. The latter condition again is irregular if the aplogranites are regarded as acid differentiates of the granite-gneiss, since in that case the percentage of SiO_2 in the granite would not be expected to exceed the value of the aplogranite. Two alternatives are suggested as possible explanations viz: (1) that the granite is a pegmatitic facies, which may be doubted on the ground that the plagioclase is oligoclase and not albite, and (2) that the granite magma was modified by the assimilation of highly siliceous matter. In the latter case a fair agreement would be expected if 6·03% SiO_2 is added to the average analysis of the younger granite (in order that it may attain the same silica percentage as the Geselskapbank rock), and if the other oxides of the average granite are then reduced proportionately. From a comparison of the analyses (b) and (c) it would appear that the second possibility is by no means excluded.

TABLE IX. Comparative Data on the Geselskapbank Granite.

	(a)	(b)	(c)
SiO_2	72·09	78·12	78·12
Al_2O_3	13·77	10·80	11·16
Fe_2O_3	1·28	1·00	·49
FeO	1·27	·99	·97
MgO	·51	·49	·43
CaO	1·97	1·44	1·36
Na_2O	3·12	2·44	2·25
K_2O	5·02	3·95	4·51
MnO	·01	·01	Trace
P_2O_5	·09	·07	·05
TiO_2	·41	·32	·22
H_2O	·40	·31	·26
H_2O	·13	·10	·05
Totals	100·07	100·04	99·87

(a) Average of 4 younger granites: (1), (2), (4), (5).

(b) Theoretical composition of "mixed rock" produced by adding 6·02% SiO_2 to analysis (a), and recasting the other oxides proportionately.

(c) Younger granite, Geselskapbank, Anal. W.H. Herdsman.

(e) The Problem of Petrographic Distinction between the Granites.

Krauskopf's résumé[12] of the literature on the correlation of, or distinction between intrusives by way of the heavy minerals, either as different species, the assemblages of the suites, or the peculiar varieties of each, shows a nearly uniform consensus of opinion to emphasise the severe limitations of the validity of this scheme. This conclusion applies well to the granites from the Goodhouse-Pella area e.g. the titanium in the younger granite is often lodged completely in the large titanites to the exclusion of the development of sagenite webs in the biotite, and of crystals of rutile and ilmenite. Consequently the latter three components, whose presence is regarded by Mathias[15] as distinguishing features of the younger granites, may in some cases lose their significance entirely, and, finally, the random distribution of allanite, not only in the granites, but also in the para-gneisses, deprives this mineral of all correlative value.

The abundance ratios of the felsic minerals (Figs. 1 and 2) are highly informative (a point appreciated also by Krauskopf[12]), but it cannot be foreseen to what extent the fields will be affected by the normal biotite granite, which according to Gevers[1] comprises a major quantitative unit in the older granites to the south and west of the present area.

(f) Foliation in the Granite.

There is some evidence to indicate that the foliation in the granite of the Namaqualand Massif was developed as a primary flow structure during the syntectonic intrusion of the batholith at great depth. The longer axes of the interconnected dykes of aplogranite are arranged parallel to the strike of the foliation in the younger granites, and the leucocratic rock often simulates the character of a veined gneiss produced by the impregnation of the younger granite with aplitic magma parallel to the foliation planes of the former. The gneissose structure must consequently have been developed to a significant extent at the time of the intrusion of the aplogranite, and from the grain size of the latter, it would appear that the emplacement of the acid phase occurred when the granite of the batholith was still at a relatively high temperature, but it is realised that chilled margins may in general fail to develop under conditions of deep seated plutonic intrusion.

Finally, if foliation were impressed on the younger granites by orographic movements subsequent to the complete consolidation of the batholith, more signs of deformation and recrystallisation would be expected in the texture of these rocks. The gneissose character of the older granite, which seems to be only developed along the contact zone with the younger granite, may indicate that the latter was emplaced under considerable mechanical pressure. On the assumption that the intrusives were subjected to the same deforming forces the more profound structural modification of the younger granite may be attributed to a smaller relative rigidity (or incomplete consolidation) than obtained in the older granite

(g) Correlation.

From the mineralogical and chemical resemblances, Mathias[15] correlated the younger Namaqualand granite-gneiss with the younger Cape granites, as represented by the members of the Paarl and the Cape Peninsula. This view was questioned by Gevers[5], since the younger Cape granites are intrusive into the Malmesbury Series, whereas the Namaqualand granites are not intrusive into the Nama beds on the Steinkopf and Neintnababeep plateaux, but as was pointed out by the same author "the stratigraphic correlation of the various supposed members of the Nama group of sediments is still rather insecure, owing to the intermittent nature of the outcrops and great differences in the degree of folding and metamorphism."

VI. REMARKS ON THE CHEMICAL VARIATION IN THE GRANITES* OF SOUTH AFRICA.

A. THE YOUNGER CAPE GRANITES.

Although a fair number of chemical analyses are available

* The term "South Africa" is used to embrace both the Union and the Rhodesias.

of the Basement granites in the Transvaal and Rhodesia, and of the Bushveld granites, the group of the so called younger Cape granites have been rather neglected in this respect, and prior to the recent work of van Biljon[20] (1940) and Mathias[15] (1941), only one analysis of this group was recorded by Grout[7]. In order to bridge this gap, and to place the subsequent comparisons on a more reliable basis, six new analyses of the Cape granites are incorporated in this paper.

(a) Mineralogical data.

On account of the impossibility to distinguish the decomposed feldspars in some of the analysed rocks, modal determinations were not attempted, and the ascertained mineralogical data are summarised in Table X.

TABLE X. Mineralogical data on the younger Cape granites.

	(4)	(5)	(7)	(8)	(9)	(11)	(3)	(6)
% An in Plag.	25	30	10	11	27	11	28	27
Indices) Np of) Nm Biotite) Ng	1·597 1... 1·650	... 1·667 ...	... 1·635 ...	... 1·649 ...	1·600 ... 1·652	... 1·650 ...	... 1·649 ...	... 1·649 ...
Muscovite	+	—	—	—	+	+	+	—
Amphibole	—	—	—	—	—	—	—	+
Apatite) Zircon) Iron Ore)	+	+	+	+	+	+	+	+
Titanite	—	—	—	+	+	—	—	—
Xenotime	+	—	—	—	—	—	—	—
Monazite	—	—	—	—	—	—	—	+
Epidote	—	+	+	+	+	—	—	+
Tourmaline.	+	—	—	—	—	—	+	—

Note: The numbers in brackets refer to the localities at the end of Table XI. A plus sign denotes present and a minus sign denotes absent.

Muscovite, amphibole, titanite, xenotime and tourmaline occur as localised accessories. The Darling specimen contains accessory monazite; the largest crystal measures ·40 mm. x ·28 mm. (microphotograph 5), and the mineral may be of pneumatolytic origin since the granite was sampled in the proximity of a pegmatite. The optical constants of the monazite are: -

$Np = 1{\cdot}783$
$Nm = 1{\cdot}784 \mp {\cdot}003$
$Ng = 1{\cdot}838$

Pleochroism X = light yellow; Y = dark yellow; Z = greenish yellow.

$Ng - Np = {\cdot}055$

$2V_z = 11^\circ$ (Mallard) Absorption $Y > X = Z$.

The commonest biotites have Nm 1·650, but dark micas with comparatively high and low indices were observed in the Paternoster and Robertson specimens, where Nm = 1·667 and 1·635 respectively. The plagioclase shows a fair range in composition, $Ab_{90-70}An_{10-30}$, but it is always represented by the oligoclase division.

Difficulty was experienced in the choice of the Cape Peninsula granite which was entirely free from signs of contamination, and it would appear that the distribution of micaceous and pinitic aggregates, which probably owe their origin to assimilated material, is so prevalent and uniform as to suggest a wholesale digestion of incorporated xenoliths. The quantity of these foreign segregation in the Landudno granite was however decidedly low, and the clots were composed of the following constitutents (Microphotograph 6) :

(i) Biotite. X = pale yellow, Y=Z = deep reddish brown. Nm=1·649, $2V_x = 14^\circ$.

(ii) Muscovite. Nm.=1·593, $2V_x = 49^\circ$.

(iii) Chlorite. X = yellow, Y = Z = pale green. Nm = 1·62 ∓ ·01

(iv) Scaly Mica. Colourless and greenish.

(v) A few grains of blue tourmaline.

(b) Chemical Analyses.

The general trend of the variation as shown in Fig. 5 may be stated in the following terms: with an increase in the SiO_2 percentage, the percentages of Al_2O_3, Na_2O, K_2O and Fe_2O_3 decrease to a minimum value between 70·6 and 72·6 per cent of silica, beyond which there occurs a definite increase in the values of these oxides. CaO, MgO and FeO initially increase with the silica percentage, but the slope of the curves is reversed over approximately the same interval as in the case of the first set.

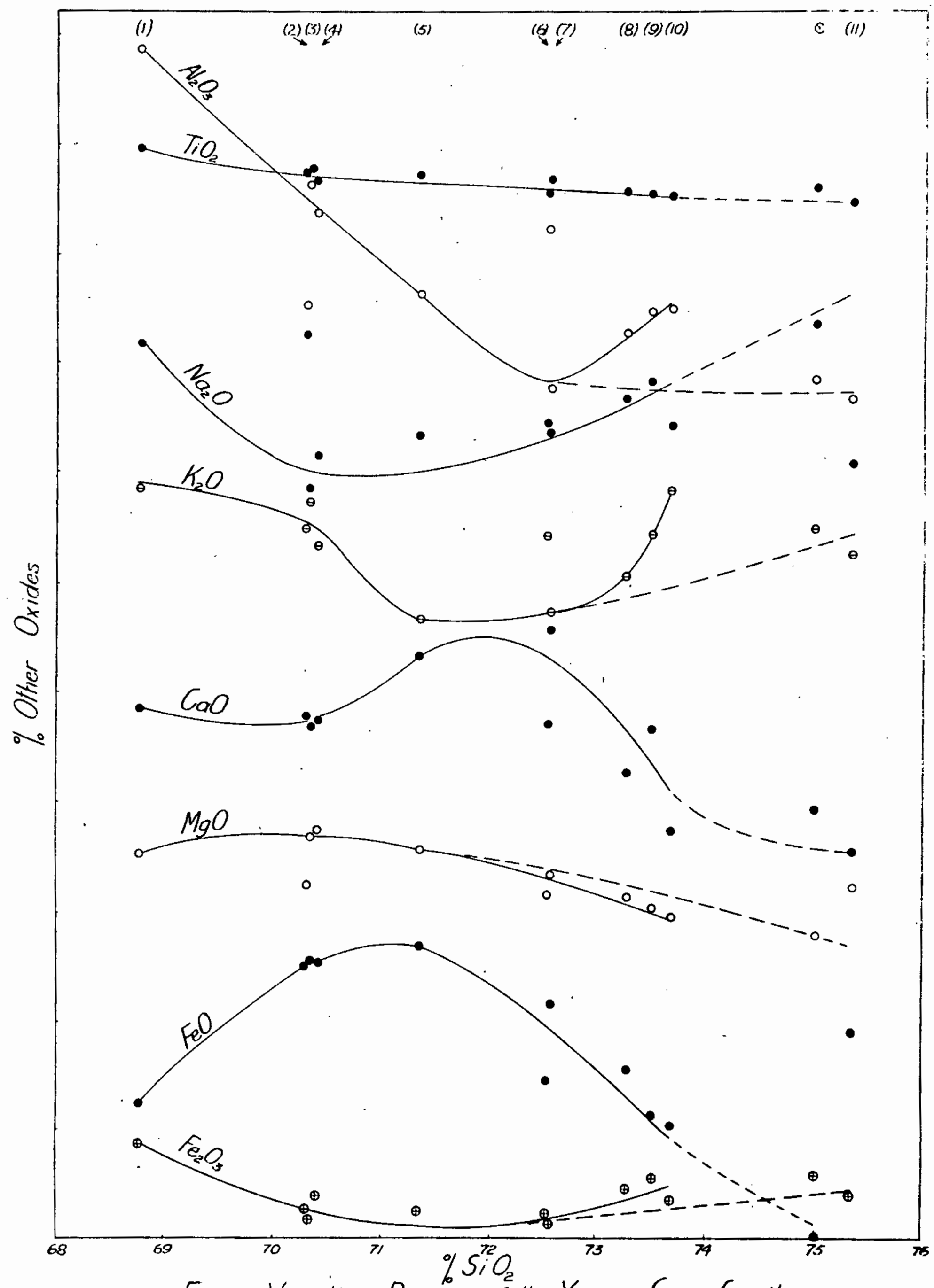

Fig. 5. Variation Diagram of the Younger Cape Granites.

⊗ Av. of 15 granite aplites (Washington, Osann).

TABLE XI. Chemical Analyses of the Younger Cape Granites.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
SiO_2	68·76	70·31	70·32	70·36	71·34	72·54	72·56	73·28	73·50	73·66	75·32
Al_2O_3	16·16	13·83	14·93	14·68	13·92	14·52	13·08	13·57	13·78	13·80	12·49
Fe_2O_3	·89	·27	·17	·39	·23	·21	·14	·44	·54	·34	·39
FeO	1·63	2·91	2·92	2·92	3·09	1·86	2·56	1·95	1·51	1·42	2·30
MgO	1·02	·74	1·19	1·24	1·06	·67	·83	·62	·52	·46	·72
CaO	2·04	1·99	1·88	1·92	2·52	1·90	2·78	1·46	1·86	·94	·75
Na_2O	3·39	3·48	2·06	2·35	2·54	2·68	2·58	2·89	3·02	2·62	2·28
K_2O	5·17	4·80	5·04	4·64	3·98	4·73	4·01	4·36	4·73	5·13	4·54
MnO	·06	...	...	·03	...	...	...	...	·04	·04	...
P_2O_5	·13	·24	·06	...	·11	...	·12	·07	...	·22	·09
TiO_2	·68	·45	·46	·38	·41	·26	·38	·26	·25	·22	·18
H_2O+ }	} ·25	} ·92	·56	·74	·64	·63	·92	1·02	·22	·73	·79
H_2O- }			·14	·18	·06	·12	·14	·13	·16	·04	...
CO_2	S ·03	·05	...	...	...	...	...	...	...	·07	...
Totals	100·21	99·99	99·73	99·83	99·90	100·12	100·10	100·05	100·13	99·72x	99·85

x Includes ZrO_2 = ·02, BaO = ·01

Norms.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Q	23·16	25·05	31·86	31·08	32·64	32·70	33·84	34·92	32·52	36·24	40·86
or	30·58	28·36	29·47	27·24	23·91	27·80	23·91	25·58	27·80	30·02	26·69
ab	28·82	29·34	17·29	19·91	20·96	22·53	21·48	24·63	25·15	22·01	19·39
an	9·17	7·78	8·62	9·45	11·68	9·45	12·23	6·39	9·17	3·06	2·78
c	1·63	...	2·96	2·35	1·12	1·53	...	1·63	·41	2·86	2·86
di (wo	...	(	...	...	...	...	·23	...	...	...	...
di (en	...	(1·31	...	...	...	...	·10	...	...	...	...
di (fs	...	(	...	...	...	...	·13	...	...	...	...
hy (en	(3·66	(5·40	3·00	3·10	2·60	1·70	2·00	1·50	1·30	1·20	1·80
hy (fs	(	(	4·36	4·36	4·88	2·77	3·83	2·64	2·11	1·98	3·43
mt	1·39	·46	·23	·70	·23	·23	·23	·70	·70	·46	·70
il	1·37	·91	·91	·76	·76	·61	·76	·61	·46	·46	·46
ap	·34	·34	·34	...	·34	...	·34	·34	...	·34	·34
H_2O	·25	·92	·70	·92	·70	·75	1·06	1·15	·38	·77	·79
Totals	100·37	99·87	99·74	99·87	99·82	100·07	100·14	100·09	100·00	99·60x	100·10

x Includes calcite = ·20

(1) Average of 6 Kuboos granites[20].

(2) Average of 6 coarsely porphyritic Nama granites, C.P.[17]

(3) Granite, Landudno Drive, Cape Peninsula (new analysis).

(4) Granite, quarry below Cableway, Cape Peninsula.[15]

(5) Porphyritic granite, Paternoster (new analysis).

(6) Granite, Darling (new analysis).

(7) Granite, Robertson (new analysis).

(8) Fine grained granite, Malmesbury (new analysis) .

(9) Granite, Paarl.[15]

(10) Granite, George, Anal. F.F. Grout.[7]

(11) Granite, Schapenberg, Somerset West (new analysis).

<u>Note</u>: Analyses (3) - (9) and (11) by T.H. Herdsman.

The only points to fit in loosely with this scheme are the Na_2O in analysis (2), the Al_2O_3 in analyses (2) and (6) and the K_2O in (6). The wandering of the soda positions is to be anticipated since Na_2O in the younger Cape granites varies within relatively wide limits, for example in the Kuboos batholith[20] the variation in the molecular proportions of this oxide is 4 times greater than in the case of the "main" Dartmoor granites.[2]

Analyses (3), (4), (10) and (11) bear noteworthy excesses of corundum in the norm viz. 2·96, 2·35, 2·86 and 2·86 respectively, although the figures still fall within the "safety limits" of normative corundum for igneous rocks as determined by Bastin[1]. When the molecular proportions of K_2O and Na_2O in these rocks are plotted as ordinates and abscissae (Fig.6) the majority of the points are distributed in a field which is approximately bisected by the 1 : 1 ratio line, but the positions of the four analyses with the excess of corundum fall in a separate field in which the ratio of K_2O : $Na_2O = 1·3$. These factors i.e. the excess of corundum and the higher potash : soda ratio are corroborative evidence of the assimilation of aluminous-potassic material, which in turn conforms to the composition of the Malmesbury shales. It is of interest to observe that these four analyses are all from centres (Cape Peninsula, George and Schapenberg) where the granite was immensely active in its behaviour towards the intruded Malmesbury Series.

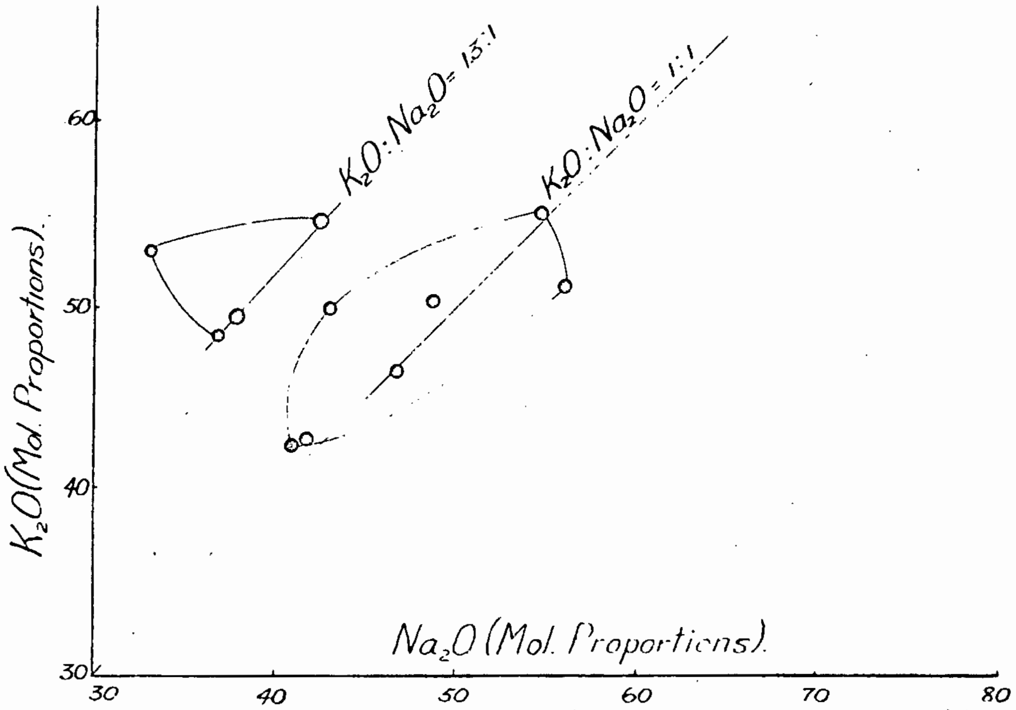

Fig. 6. Ratio of the Molecular Proportions of K_2O and Na_2O in the Younger Cape Granites.

The relations of the Schapenberg granite (11), whose composition is entirely at variance with the normal variation curves of the other granites, require some further comment. From a comparison with the average analysis of 15 granite-aplites (Osann, Washington), it would appear that the rock is in aplitic variant, which is related to the "normal" granite by the broken lines in Fig. 5. In this representation, however, the MgO, and especially the Na_2O and FeO of the Schapenberg granite occupy truly anomalous positions, which may be referred to contamination by sedimentary matter. Indeed, if the composition of the latter approached that of the average shale, as given by Clarke, the tendency would be towards a low soda, a high magnesia, and a high total iron, which are exactly the conditions that obtain in the Schapenberg analysis. This conclusion is furthermore confirmed by the thin sections, in which the biotite tends to be grouped in open clusters.

B. NORMATIVE VARIATIONS IN THE GRANITES OF SOUTH AFRICA.

(a) Representation in Triangular Diagrams.

The mutual relations of the "Old Granites" of South Africa have been discussed by Willemse[21] in the light of variation diagrams based on Niggli values, and attention was drawn to the fact that quite a number of the South African "granites" are chemically and mineralogically far closer to the quartz-diorites and granodiorites. In the following paragraphs the granitic rocks of South Africa are examined by way of their normative variations, which are plotted by trilinear co-ordinates in Figs. 7 and 8. The petrographic provinces which are considered and the sources of the analyses are summarised below:

Petrographic Province.	Sources of Analyses.	No. of Analyses.
(1) Younger Cape Granites:		
Kuboos	Van Biljon[20]	11
S.W. Cape	Analyses Pg.35 above	10
(2) Younger Bushveld Granites.	Compilation by Hall[9]	9
The felsites and the Magnet Heights granite are excluded.		
(3) Older Granite, Transvaal.	Compilation by Willemse[21]	14
(4) Older Granite, S. Rhodesia.	Compilation by Hall[9].	32.
(5) Older Granite, Namaqualand.	Analyses pg. 22 above	3
(6) Younger Granite, Namaqualand.	Analyses pg. 27 above	7.
Other "Old Granites" taken from Grout[7] include: Broken Hill (N. Rhodesia); Hlatikulu (Swaziland) Camperdown (Natal); Port Shepstone (Natal).		

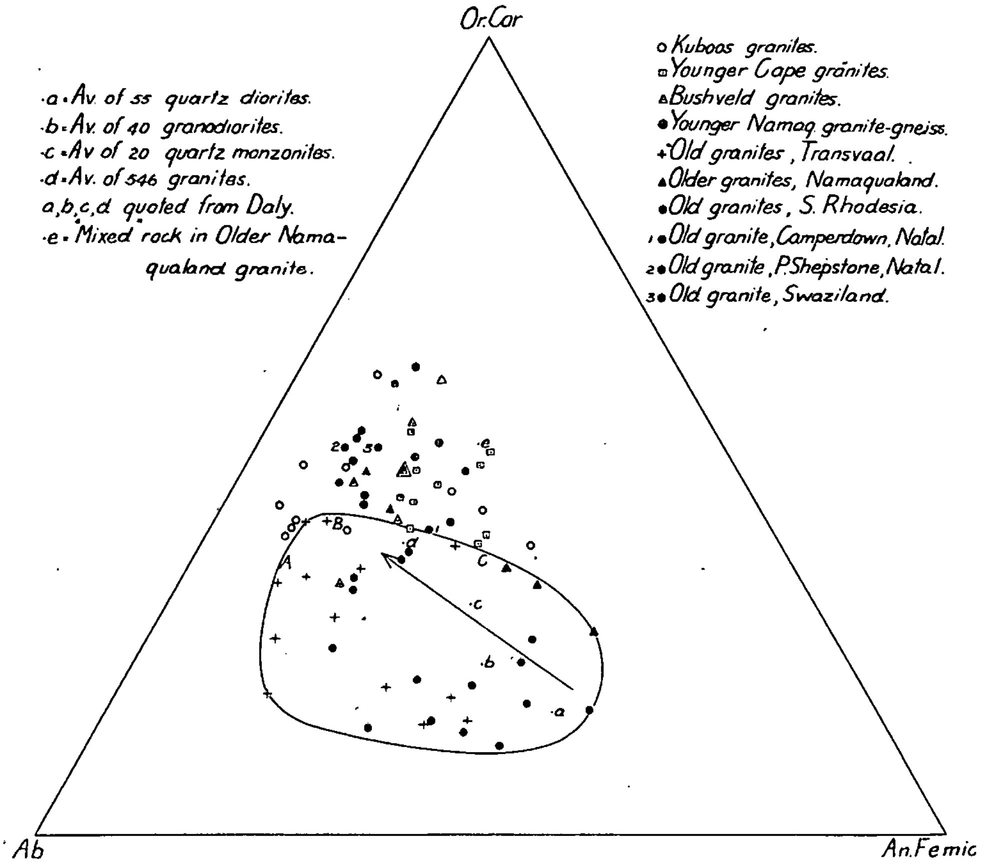

Fig. 8. Norm Compositions of the Granites of South Africa.

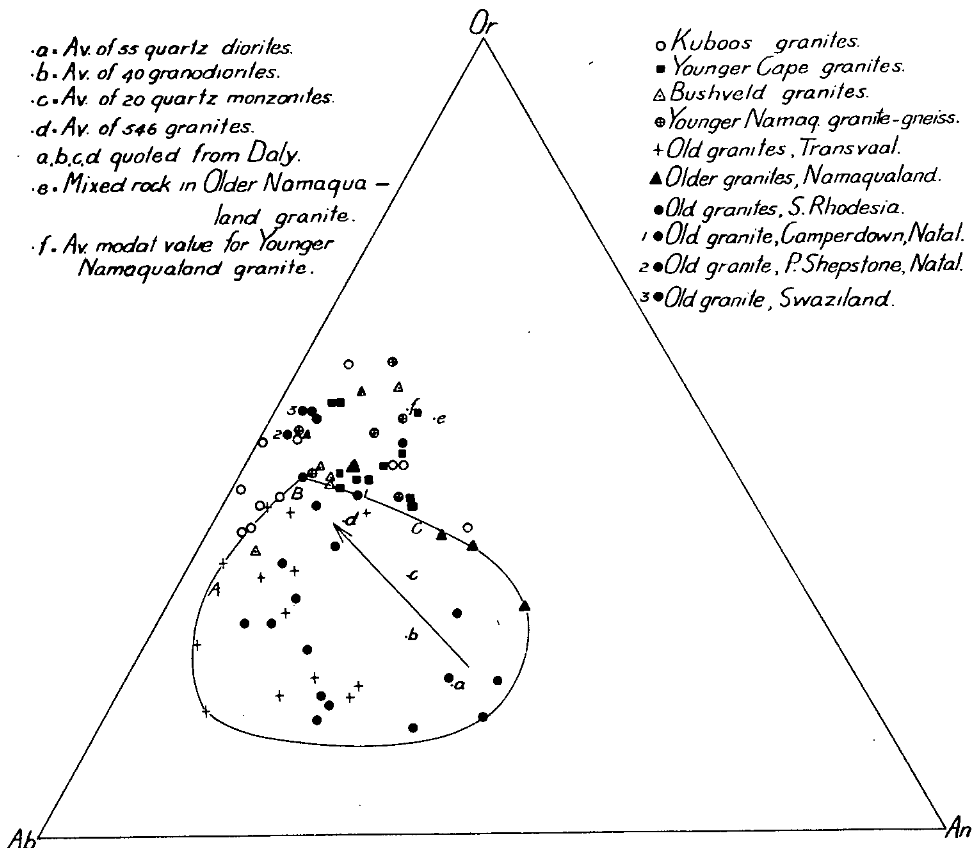

Fig. 7. Norm Compositions of the Granites of South Africa.

(b) Discussion of the Diagrams.

In the triangular diagrams the old granites of the Transvaal may be completely separated by a smooth curve, ABC, from the younger granites of Kuboos, the S.W. Cape, and the Bushveld. The only exception is one of the latter which lies inside the old granite field. The close relationship in chemical features between the Kuboos, Cape and Bushveld granites, as pointed out by van Biljon,[20] is especially evident between the latter two groups which differ in general from the Kuboos rocks by a higher normative anorthite.

As far as the available data go it appears that the highly potassic variants (which are generally characteristic of the younger granites), are not represented among the old granites of the Transvaal, and in order to balance this condition the latter points exhibit a tendency to flow towards the albite pole. This observation agrees with a remark by Daly[3] on the granodiorite clan viz: "The abundant so-called 'quartz-monzonites,' intimately associated with the granodiorites, are partly granodiorites, and for the rest granites with soda dominating potash." For the Transvaal granites, also, the trend of the variation from the quartz-dioritic towards the granitic end lies well to the west of the direction a,b,c,d, which points represent the average composition of the Quartz-diorites, granodiorites, quartz-monzonites and granites as computed by Daly.[3]

The old granites from S. Rhodesia have a wider range in normative composition than those of the Transvaal, and the points migrate over the boundary towards the orthoclase pole, but if the analyses are representative of the quantitative distribution of the different types, it is evident that the majority of the old granites from S. Rhodesia conform chemically to those of the Transvaal.

If the younger Namaqualand granite is considered part of the Basement Granite Complex, it is noteworthy that all the analyses of the former lie above the boundary line, which is also the case for the old granites from Port Shepstone (Natal), Camperdown (Natal), and Hlatikulu (Swaziland). Judging from the 10 available chemical analyses, it is consequently apparent that there is a convergence in the chemical composition of the older granite batholiths to the south-west and south-east of the Transvaal granites. It may therefore be suggested that this difference in chemical composition is related to two main periods of granitic intrusion: one in the Transvaal and another in Namaqualand - Natal - Swaziland. This hypothesis finds some confirmation in the fact that the older Namaqualand granite (which is chemically rather allied to the Transvaal type), has definitely preceded the younger Namaqualand granite , which, as stated above, is nearer in composition to the granites of Swaziland and Natal. On these grounds the wider range in the old granites of S. Rhodesia may be referred to the presence of either phase of igneous activity.

The numerical data in Table XII illustrate the adequacy of the boundary ABC in affording (1) an unobscured chemical distinction between the older granites (Transvaal, Namaqualand), and the younger granites (Cape, Kuboos, Bushveld) and (2) a distinction between the older granite (Transvaal, Namaqualand) and the younger Namaqualand granite (plus the older granites from Natal and Swaziland.)

TABLE XII.

	Younger Cape, Kuboos and Bushveld granites.	Old granites, Transvaal and Namaqualand.	Old granites S. Rhodesia.	Column 4.
No. of Analyses	30	16	32	13
No. outside Tvl. field.	29	0	6	13
No. inside Tvl. field.	1	16	26	0

Note: Column 4 contains the younger Namaqualand granites, and the old granites from Swaziland and Natal. Some of the Rhodesian rocks were not plotted in the diagrams since their positions could be ascertained by inspection.

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List of Photographs and Microphotographs.

(a) Photographs.

1. The mountanous tract along the Orange River. Illustrates the dip of the foliation flanes to the north in the younger granite on Zandfontein. The Orange River is hidden by the ridges and the furthest conical peaks are inselberge in South West Africa.

2. The sand-covered transitory slope towards the Orange River comprises an inselberge region. The highest peak in the back ground bears the Groot Rozyn trigonometrical beacon, and to its right lies the Wortel quartzite table mountain.

3. The sand-covered Goodhouse valley. The cap of dark basic rocks on the two highest peaks, the western one of which is Vuurdood, is clearly recognisable.

4. The quartzite hills of Garganab and Dabenoris. The veld in the foreground testifies to the luxurious desert vegetation which follows abundant rain.

(b) Microphotographs.

1. Granodiorite, Goodhouse. Altered plagioclase, quartz and ferromagnesians. Polarised light, (x 10).

2. Porphyritic facies of the younger granite, Abbasas. Phenocrysts of colourless microcline mantled by turbid oligoclase simulating the rapakivi texture. Ordinary light, (x 4).

3. Younger granite, Geselskapbank. Quartz (with pellets of plagioclase), microcline and zonal oligoclase. Polarised light, (x 10).

4. Aplogranite, Springputs. Allotriomorphic granular texture with dentated margins between quartz, microcline and turbid oligoclase. Polarised light, (x 9).

5. Crystal of monazite in the younger Cape granite (Darling) surrounded by biotite, altered oligoclase and colourless quartz and microcline. Ordinary light, (x 71).

6. Younger Cape granite, Landudno Drive. The patch of micaceous material, presumably developed from assimilated shale, is marked by a white line. Zonal oligoclase, quartz, perthitic microcline and reddish biotite with pleochroic haloes. Polarised light, (x 9).

-Photographs-

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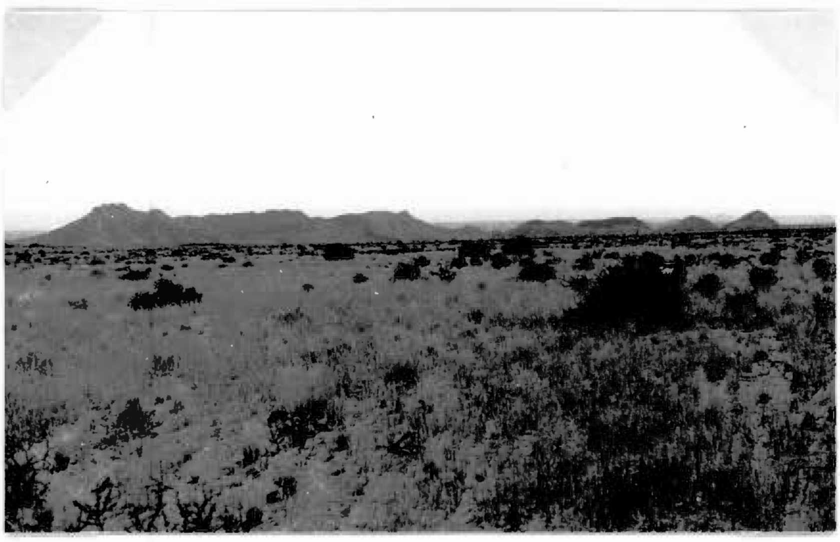

– Microphotographs –

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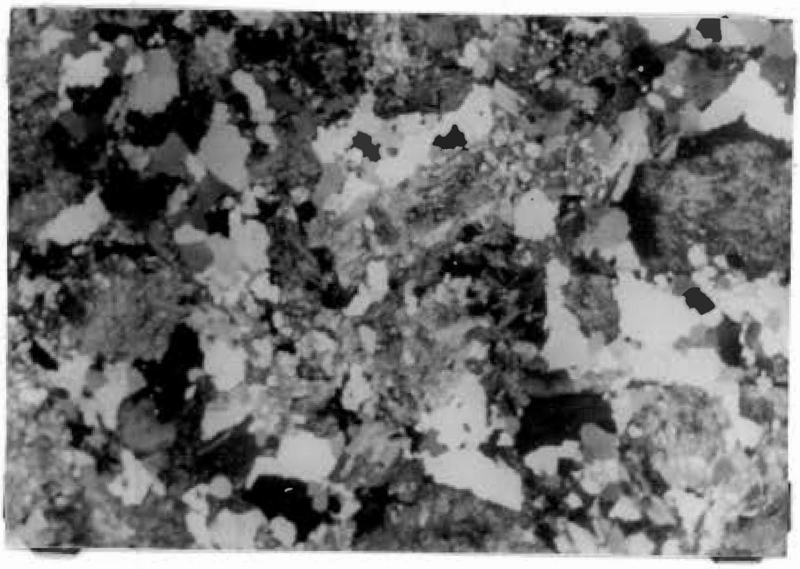

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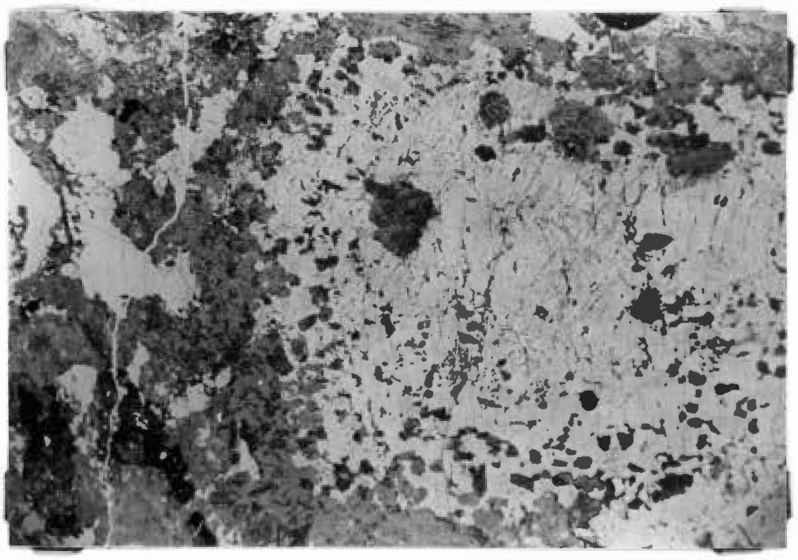

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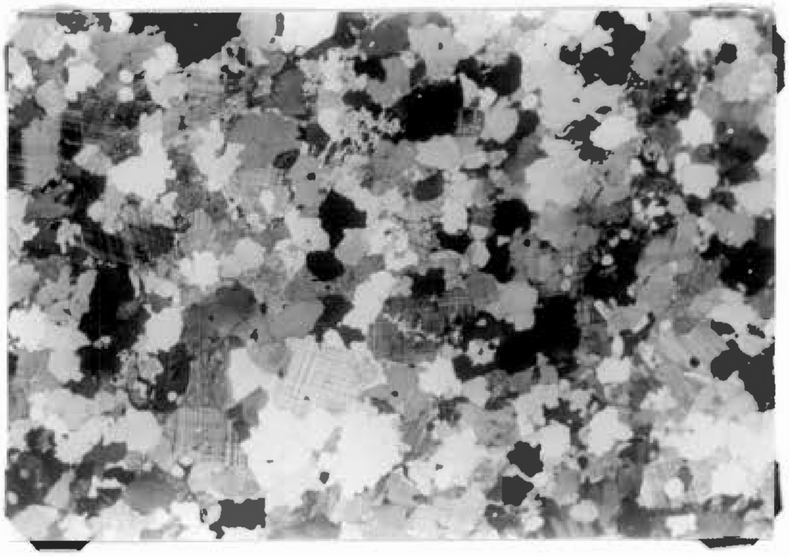

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