THE GEOLOGY OF THE BINDURA GRANITE COMPLEX IN SOUTHERN RHODESIA

by

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Thesis for The Degree of Master of Science.
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C O N T E N T S   O F   T H E S I S .

P A R T   O N E .

<u>SEDIMENTARY ROCKS. Continued.</u>

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THE BINDURA GRANITE COMPLEX.

INTRODUCTION.

The investigation of the Bindura Granite Stock is one of several geological projects set aside by the Rhodesian Geological Survey, for the specific purpose of academic research. It was considered to be of particular interest for University post-graduate work, principally because of the large area of tourmaline-bearing rocks that occur there.

Mr. R.M. Tyndale-Biscoe suggested this area to me as being suitable for a thesis in December 1958, and during this and the following two months most of the geological mapping and field-work was carried out. It was geologically mapped using a base map compiled from air photographs and from the Air Survey Company's 1 : 5000 topographical maps of Bindura.

The remainder of the year, except for a short period in July when Bindura was revisited, was spent at Rhodes University, where the time was devoted to mineralogical and petrological work. One hundred and forty rock slides were made and studied, and six full and several partial chemical analyses were carried out.

The object of this investigation was to examine the variations in the granite and the relation between the granite and the surrounding metamorphosed sedimentary rocks of the Shamvaian System (Primitive). Although this object may not have been fully achieved, it has been possible to show that a wide variety of rocks is present in the area, and a few suggestions as to their origin have been made.

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A C K N O W L E D G E M E N T S.

The writer wishes to express his sincere gratitude to Professor E. D. Mountain, Mr. A. Ruddock and Mr. H. V. Eales of Rhodes University for their supervising of the work at different times. Particular thanks are due to Mr. Eales for the taking of the photomicrographs.

The writer is extremely grateful to Mr. R. Tyndale-Biscoe, Dr. F. Amm and Mr. J. G. Stagman of the Rhodesian Geological Survey for their useful suggestions and criticisms during the early stages of the work.

To the above people and to numerous mining and farming people of the Bindura District who have not been specifically named, the writer is greatly indebted, as without their cooperation the presentation of this thesis would not have been possible.

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PREVIOUS GEOLOGICAL WORK.

Previous work in this area seems to have been restricted to Mr. R. Tyndale-Biscoe's Bulletin (Bull. No 22.) of the Central Part of the Mazoe Valley Gold Belt, and to various reports of the mining companies.

Except for the work carried out at the Phoenix Prince Mine, (originally the Prince of Wales) on the Phoenix Prince Diorite, little detailed mapping and petrology seems to have been done. The Bindura Stock is shown up very accurately as far as geological boundaries between igneous and sedimentary rock types are concerned on Tyndale-Biscoe's map, and the main dolerite dykes are also plotted in. However, the smaller dykes and the variations in the igneous rocks themselves are not given.

The rocks named " banded ironstone " near that marked Bindura Granite on the Geological Survey's map are, in fact, the tourmaline-quartz rocks of the complex. This point was later noted by Tyndale-Biscoe himself, and was the chief reason why he considered further work necessary on the stock.

Two analyses of the Bindura Granite have been carried out for the Rhodesian Geological Survey by E. Golding. (Survey Numbers, 219, 503.)

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G E O G R A P H I C A L   F E A T U R E S .

AREA AND POSITION.

Bindura is a small town situated roughly forty miles north-east of Salisbury. The geographical boundaries enclosing the area involved in this thesis, are taken from the Air Survey Company's topographical map of the central part of the Mazoe Valley and are as follows :-

17°	15'	10"	South -	17°	18'	58"	South.
31°	16'	53"	East -	31°	21'	53"	East.

These latitude and longitude readings enclose an area of some twenty - five square miles, but detailed mapping was restricted to rather less than twenty square miles.

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TOPOGRAPHY AND DRAINAGE.

Erosion cycles have highly dissected this region and produced a very mature landscape. No distinctive remnant plains remain in existence today, apparently due to gradual rejuvenation of streams which are continually cutting back their headwaters.

The Mazoe River meandering eastwards in a wide strike valley, provides the main drainage system to the area as a whole. It only just touches the thesis area in the north-western portion, and makes a wide sweep round it to the north. The main mass of the complex is drained by numerous unnamed tributaries of the Mazoe which fan out from the highest land into the curve afforded by the trunk stream.

There are conspicuous and rapid changes in altitude from the Mazoe River flood Plain at 3400 feet, to heights of 3652', 3685', 3965', 4162 feet etc.. Generally the high elevations are surrounded by several lesser summits, and between these groups of kopjes the land is flatter and covered by a great depth of soil. Consequently while the boulder strewn hills give valuable geological data, the lower lying land withholds, sometimes completely, the vital information it contains. There are four main clusters of hills; in the northern, the western, the north-east flank, and in the extreme south-east of the complex.

The highest point near Bindura is found on the eastern end of the ridge near the town, where the land

TOPOGRAPHY AND DRAINAGE: Continued.

rises from 3600 feet to 4165 feet in a distance of a quarter of a mile, on the hill known to the Survey as Bindura 25. Some six-tenths of the land on the map lies over 3500 feet. Topography is related to Geology in two ways.

(a) The granite mass appears more resistant to erosion than the sediments and forms a dome-like feature protruding out of the Shamvaian System.

(b) Local lines of hills are produced by the larger dolerite dykes.

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HUMAN HABITATION.

The town of Bindura with a European population of 400 in 1956, is a mining and agricultural centre in the fertile Mazoe Valley.

Although this part of Rhodesia was opened up by the Europeans because of the mining, it has like other goldbelts turned largely towards farming and the land around Bindura is now split up into large cattle and maize farms.

Of the twenty gold mines that have in the past been associated with this granite stock, only the three largest remain producing today. They are the Botha-Promoter, the Phoenix Prince and the R.A.N. Mines, and it seems very likely that one of them will close down in the near future.

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GEOLOGY

SUMMARY OUTLINE OF THE GEOLOGY OF THE BINDURA COMPLEX.

Dr. A.M. Macgregor in his Anniversary Address as President of the South African Geological Society (1950), had this to say about the Bindura Granite.

"   Sited approximately along the synclinal axis of the Mazoe gold belt are five stocks or cupolas all of which have the character of grey tonalite, although as shown in the plot there are minor differences in composition. The important Bindura granite, which is represented by three analyses is more potassic than the others. Five more stocks of similar character occur in the Jumbo gold belt between central Mazoe and Salisbury. Gold deposits are associated with most of the stocks, and scheelite is produced in some of them as a by product or on its own account."

"   The grey tonalite stocks are on the average less potassic, but the Bindura stock has less soda. In composition it resembles the Motopo granites. "

(Of the three analyses given, Survey Numbers 503, 219 and No. 232, the last is in fact of the Phoenix Prince Diorite.)

The Archaean sediments of the Shamvaian System have, at Bindura, been subjected to a series of igneous intrusions. Partly because time restricted further work, final proof on the origin of many rocks cannot be given, so assumptions have been made, and a sequence of events is drawn up on this basis.

The amphibolite rocks are considered to have been derived from an original gabbroidal sill-like or lopolithic body, intrusive into the Shamvaian System.

A granite magma is then believed to have stoped its way from below, incorporating in itself varying amounts of sedimentary material before intruding the gabbro and sediments, splitting the gabbro as it did so into two portions.

SUMMARY OUTLINE OF THE GEOLOGY
OF THE BINDURA COMPLEX. Continued.

The tourmaline rocks were then formed by pneumatolytic action from the residual liquor, after solidification of the main granite mass.

Dolerite dykes of later age cut through all the earlier rocks.

The rocks of the Bindura Granite Complex can be divided into seven distinct groups as follows:-

(a) Granite.

(b) Relict Country Rocks in the Granite.

(c) Tourmaline - Bearing Rocks including Aplites.

(d) Amphibolite.

(e) Phoenix Prince Diorite.

(f) Dolerite.

(g) Sedimentary Rocks of Archaean Age.

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G R A N I T E .

GENERAL STATEMENT.

Granite is a very wide term in general use by most geologists to include all coarse - grained intrusive rocks that are holocrystalline, granitoid and composed essentially of quartz and alkali felspar, with or without ferromagnesian minerals and containing various accessory minerals. (Following H.H. Read.)

In a strict petrological classification such as that of E. Wm. Heinrich, the definition of granite is given as a rock with less plagioclase than orthoclase. (except Na. granites.)

E. Wm Heinrich. " 1956. p29."

" Granite is plutonic and hypabyssal, holocrystalline, phaneritic containing,

Quartz	10 - 40 %
Potash Felspar.	30 - 60 %
Sodic Plagioclase.	0 - 35 %
Mafics (biotite, hornblende.)	35 - 10 % "

With increasing plagioclase at the expense of the potash felspar, and to a lesser extent quartz, the rock grades into granodiorite and then tonalite.

Heinrich.

" Granodiorite.		Tonalite.
20 - 40 %	Potash Felspar.	Accessory.
25 - 45 %	Sodic Plagioclase.	50 - 80 %
35 - 10 %	Quartz.	35 - 10 %
30 - 10 %	Mafics (biot., hornbl.)	35 - 10 % "

Frank F. Grout in his book " Petrography and Petrology " (p.86.) states that a granodiorite is a quartz diorite with 10 - 30 % orthoclase.

Johannsen (Vol. 1. p. 144) restricts the term tonalite to a rock with less than 5 % potash felspar.

Chemically granites have a silica content of over 70 % according to Tyrrell (1952. p. 122.), while the average silica content for a granodiorite is 66 %. (The average of thirty-seven rocks.)

Both chemically and mineralogically the Bindura granite rocks do not fall within the strict classification of a granite. However, following MacGregor (1951) who explains,

> " I use the word granite in a wide sense to include tonalite and granodiorite, ... "

the term granite is used here in the same broad sense, although from chemical and mineralogical evidence, and in view of the various authors consulted above, the Bindura rocks should strictly be called granodiorites.

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FIELD CHARACTERS AND OCCURRENCE.

Granite forms the bulk of the complex and covers six-tenths of the surface area of intrusive rocks surrounded by Primitive System Schists. In the field it may form conspicuous hills, as for example the high elevations just north of Bindura itself and those near the Botha-Promoter Mines. The granite kopjes are usually covered by boulders, and hence show little granite actually in place, although in some parts large exposures of bare granite do occur. While this is most typical granite also underlies large areas of low-lying vlei land hidden by an over-burden of up to thirty feet of weathered granite, and perhaps six feet of soil or alluvium.

While the outcrops of granite allow a large number of fresh or fairly fresh specimens to be obtained evenly through-out the area, the soil unfortunately veils the important contacts between the granite and adjacent rock types.

A structural map of the granite showing foliations such as parallel growth of felspar or biotite, or fracturing other than surface jointing could not be produced by standard observations. Petrofabric analyses would be essential to work of this nature. No macroscopic alignments of felspars are apparent, and in general there are too few quarries, cuttings or natural rock exposures to show the character of the granite in a vertical direction for any distance.

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MINERALOGY AND PETROLOGY.

The minerals occurring in the Bindura Granite are divided into three separate groups:

(a) PRIMARY.

1. ESSENTIAL MINERALS.
Those minerals which influence greatly the character of the rock, and whose presence is necessary for naming it.

2. ACCESSORY MINERALS.
The minerals found in small amounts and not significant in classifying a rock.

(b) SECONDARY MINERALS.

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TEXTURES OF THE GRANITE.

All the specimens are holocrystalline. The mafic constituents and some of the felspars are subhedral to euhedral, while quartz and the remaining felspars are anhedral.

A few of the rocks are equigranular but most commonly the texture is porphyritic, with microcline and oligoclase phenocrysts (and sometimes hornblende) occurring in a granular groundmass of quartz and felspar. The phenocrysts are up to 5 mm. in length. The groundmass of some rocks is composed almost entirely of a mosaic, in which the texture resembles that of a quartzite.

Graphic intergrowth of felspar and quartz is not common, but occasionally myrmekite structures are present.

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ESSENTIAL MINERALS.

(a) QUARTZ.

Of quartz in granites Johannsen (1939, Vol.II. p.31.) says,

" In normal granites quartz was the last mineral to crystallise, consequently it usually fills the interstices between the other constituents. Since its borders are then impressed upon it by the adjacent minerals it is xenomorphic sometimes in granular aggregates. "

Quartz comprises from 14 - 36 %. of the Bindura Granite, the average being 26%. It does occur as large irregular crystals up to 4 mm. across, but is present more commonly as a fine granular aggregate of crystals; where the average diameter of grains is 0.25 mm. The effect of this marked granular habit of the quartz is to produce a rock texture that is porphyritic, with large felspar and hornblende prisms in a groundmass of finer-grained quartz.

In some slides tiny veinlets of quartz, possibly due to late stage hydrothermal veining cut through the felspar, and in one particular rock section microcline seems to have been replaced by quartz. Evidence for this is the presence of unconnected microcline remnants extinguishing together in a large quartz crystal. Because of the fine-grained nature of most of the quartz, inclusions in it of other minerals are not as common a feature as the inclusion of quartz by biotite and felspar.

(b) FELSPAR.

On weathered surfaces of the Bindura Granite phenocrysts of white to pink felspar standing out in relief are very prominent. The largest measured 24 mm., but more generally they average 5 - 6 mm.

There are two felspars present between them making up 60 % of the rock. They are microcline and a soda - rich plagioclase. Perthitic intergrowth of the two minerals is not characteristic, and only in one or two slides is there a suggestion of this. The development of wholly untwinned or of partially twinned felspar is typical of the Bindura Granite. This makes it tedious to determine the felspars and to distinguish one type from another. E. Wm. Heinrich (1955 p.8.) suggests the use of concentrated sodium coboltinitrite as a staining technique to distinguish between potash and plagioclase felspars. Unfortunately this particular reagent could not be obtained in South Africa while the work was being carried out.

The most abundant felspar is oligoclase with an anorthite content varying from 16 to 22 %. It occurs as large stocky prismatic crystals up to 5 mm. across. Albite twinning is fairly common round the margins of crystals, but this quickly fades out and the central parts are untwinned and often cloudy. Sometimes the whole crystal is a large Carlsbad twin with fine albite twinning round the rim.

Numerous inclusions of apatite, and sometimes biotite and hornblende occur. Micaceous alteration products are very characteristic and emphasise the zoning of crystals, which is due to slight differences in composition.

Determination of the exact composition of this felspar

/ was carried

was carried out by four main methods.

(a) Universal Stage. Although the plagioclase forms large crystals the narrow rim of fine twinning made work of this nature restricted. Using the Fedorov method of determination (standard diagrams relating the orientation of the optic vectors of the plagioclase to composition), twelve results from six slides show an oligoclase felspar with 20 % An.

(b) In all thin sections maximum symmetrical extinction angles on albite twins are below twelve degrees, confirming the plagioclase to be oligoclase.

(c) Accurate refractive index determinations on crushed fragments of plagioclase from twelve typical specimens all give a maximum refractive index of 1.548 for γ, revealing that no felspar contains more than 22 % An.

(d) The composition of the plagioclase as determined by calculation from the two chemical analyses of granites, gives 23.84 % An. in the first case and 26.86 % An. in the other. The slight discrepancy in composition may be accounted for by the fact that the lime rather than soda is likely to occur in minerals not calculated in the norm, e.g. epidote, amphibole, zoisite and scheelite. Biotite is the exception to this.

The potash felspar microcline, is easy to recognise if cross-hatched twinning is present. More often than not this twinning is absent, and then it is extremely difficult to distinguish it from other felspars. The extinction angle on 001, Carlsbad Twin, of fifteen degrees distinguishes this felspar from orthoclase, but leads to confusion with single twins of plagioclase. Some microcline grid twinning is present

/ in every

in every section of granite. The potash content in the analysis gives proof of the presence of substantial quantities of this mineral.

(c) FERROMAGNESIAN MINERALS.

The two important ferromagnesian minerals are biotite and hornblende, with the former in greater abundance. Together or individually these minerals occur in quantities of up to 20 % of the rock, but seldom more than this, and with an average of 12 % for twenty-one specimens. Neither of the two minerals is restricted to particular parts of the granite intrusion.

Generally both minerals have well defined crystal outlines and frequently lie in contact with each other, the cleavages of the two minerals then being sensibly parallel. Both minerals are strongly pleochroic, the hornblende green and the biotite a brown colour. Bright green biotite is sometimes present and in one slide (48) it seems to be replacing common brown biotite.

Inclusions of apatite, sphene, epidote and quartz occur in both minerals, and in the biotite pleochroic halos are common. In the hornblende twinning on (100) is not at all uncommon. Usually it is simple, but sometimes it is repeated and resembles an albite twin. The 2V of hornblende measured on the universal stage varied from 75 to 78 degrees. The biotite is almost uniaxial.

Chlorite is another ferromagnesian mineral which is present and is sometimes the only coloured mineral in the rock. However it is secondary and is presumably produced by the hydrothermal alteration of pre-existing aluminous mafic minerals.

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ACCESSORY MINERALS.

A large number of minerals form a small but not insignificant portion of most granites, and that at Bindura is no exception. Their combined total seldom reaches anything like 5 %.

APATITE is the most characteristic of all accessory minerals and it occurs to a greater or lesser extent in nearly all the sections made of the granite. It is present as colourless needles or lath shaped crystals with hexagonal basal sections. The largest crystals are seldom more than 2 m.m. long. Apatite occurs as inclusions in quartz and felspar, but in biotite and hornblende in particular, and frequently lies in contact with the latter two minerals.

SPHENE is another extremely common mineral occurring as rectangular or diamond-shaped crystals, or else as small aggregates of crystals. Twinning on 010 is sometimes observed and this mineral, particularly the darker varieties, is very pleochroic. It is associated closely with the ferromagnesian minerals.

THE IRON ORES magnetite and pyrite are both very widely distributed, with magnetite in greater abundance. Perfect crystal form of both minerals is common. Frequently pyrite is enclosed by a rim of Limonite.

TOURMALINE may be found as scattered globules (0.15 mm. diameter) or as acicular crystals, throughout the granite mass, and is

/ found with another

found with another ferromagnesian mineral in close association. It is a rare mineral and of forty slides of granite it is present in only eight. Tourmaline veins of any abundance are not found anywhere in the granite except along the extreme eastern margin of the granite near the main belt of tourmalinisation.

Although individual grains have not been observed, gold does occur in parts of the granite, probably introduced hydrothermally. It has been mined, along with scheelite, in the main western cluster of granite kopjes, where there are lenses of highly pyritic granite dipping south-westwards at an angle of thirty degrees.

Several unusual corona or reaction rim structures are present which may have some significance. Two of them in sequence from centre to rim are as follows:

(a) Magnetite, quartz, biotite.

(b) apatite, chlorite, sphene, quartz.

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SECONDARY MINERALS.

Chlorite is one of the most common alteration products. It is present in fair amounts in several of the rocks but is never primary and is produced by the alteration of the existing biotite and hornblende. It sometimes occurs as small veinlets which tend to follow the boundaries between the quartz and felspar, but seldom cuts through them, although small

/ needles may

needles may penetrate as offshoots from the veinlets for short distances.

Epidote and zoisite are common minerals which are derived as hydrothermal alteration products of felspar and amphibole. Sericite is very common, being derived from the alkali felspars, and often emphasising the zoning present in them.

Limonite or iron staining seals up cracks or micro-jointing between any of the other constituents and may be largely a surface phenomenon. Haematite is sometimes present and is either primary or else formed from magnetite.

Calcite is present in small amounts in part of the eastern granite, in particular near the contact with the Shamvaian System where it occurs as secondary veinlets.

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The diagram below is based on modes of twenty-two specimens of the Bindura granite from widely distributed points in the complex. This diagram seems to suggest an interesting variation in the ratio of total felspar to the mafic minerals, as the quartz content decreases. In rocks of high quartz content the ratio of felspar to the mafic minerals is 5.3 : 1, but as the quartz content drops to fifteen percent, so the ratio of the former minerals changes to 3.25 : 1. This may be due to one of two things:

(a) The possibility that as the granite became more acid, the content of the mafic minerals decreased, showing a tendency towards a silica and alkaline residual liquor.

(b) The effects of contamination by sedimentary material.

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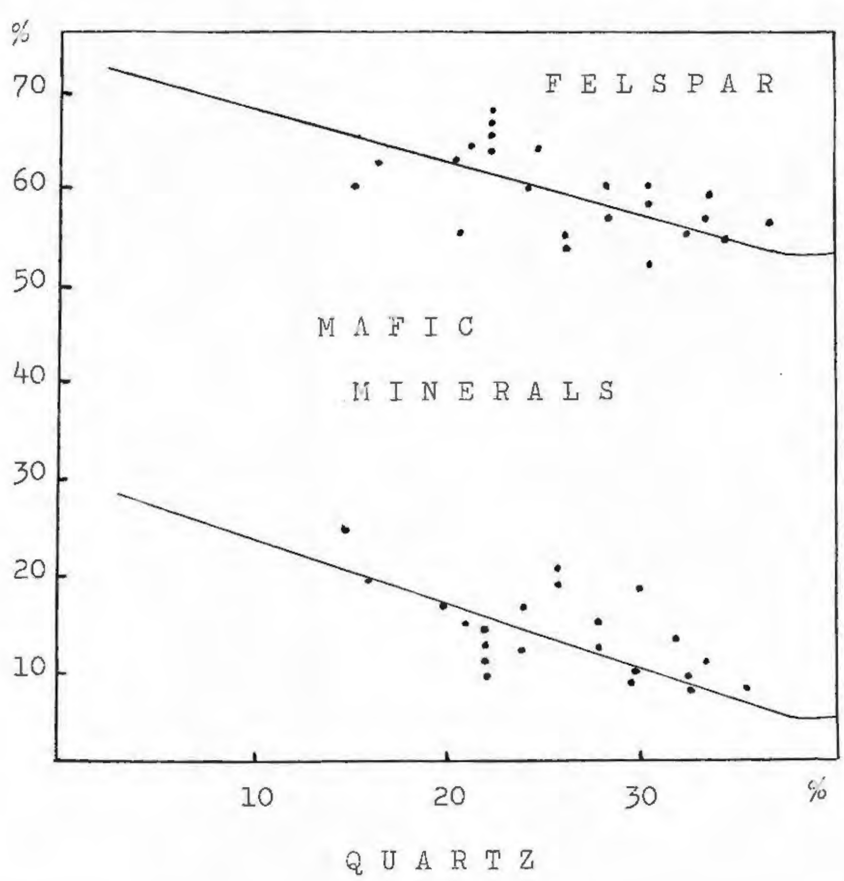
(Quartz is plotted against (a) Total Felspar.
(b) Mafic minerals.)

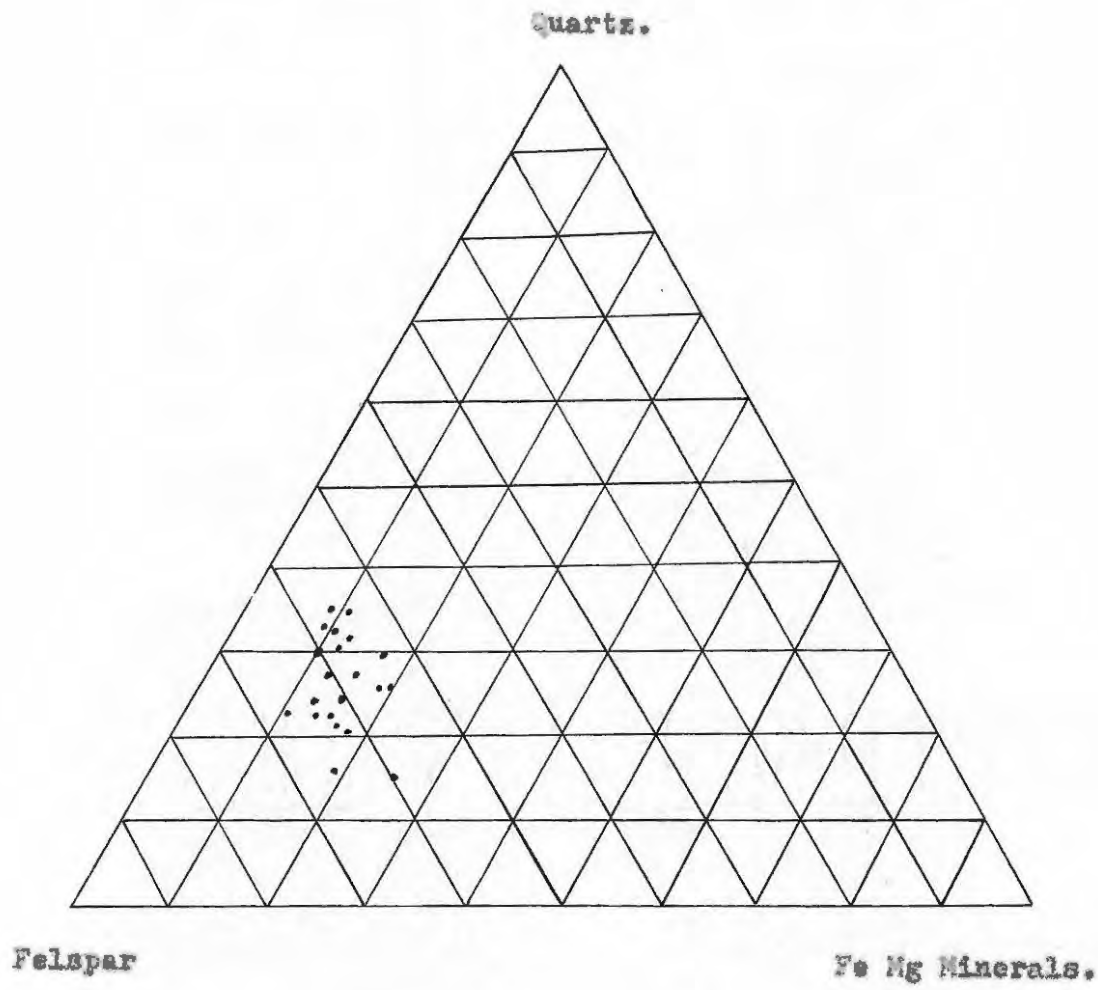


MODES OF TWENTY TWO GRANITES OF THE COMPLEX.

	No 5 BKI	No 4 BKI	No 1 BKI	No 92a	No102	No 4	No 82	No 2 BKI	No 49	No 36	No 97	No 59	No 68	No 92	No 3 BKI	No 48	No 5	No 2a BKI	No 51	No 62	No 70	No 37b	AVERAGE.
QUARTZ.	36	34	33	33	32	30	30	30	28	28	26	26	24	24	22	22	22	22	21	20	16	15	26
FELSPAR.	56	55	57	59	55	52	59	60	57	60	54	55	64	60	64	66	66	68	64	63	65	60	59
BIOTITE.	8	11	5	8		3	8	10		12	20	6	9	16	14	5	8	10	15	17	3	13	9
HORNBLENDE			5			15	3					13	3	:		7	4				16	12	4
APATITE	:	:	:	:		:	:	:	:	:		:	:	:	:		:	:		:	:	:	
SPHENE	:	:		:			:	:	2			:	:	:	:	:	:	:		:		:	
MAGNETITE	:	:		:		:	:	:			:	:	:		:	:	:	:			:	:	
TOURMALINE					:						:												
CALCITE											:												
ZOISITE											:												
MUSCOVITE										:	:												
PYRITE					:				5	:	:												
CHLORITE					13				8														
EPIDOTE										:													

MODES DETERMINED BY DOLLAR INTEGRATING STAGE.

MODES OF TWENTY TWO GRANITES PLOTTED ON A TRIANGULAR DIAGRAM.



The photomicrographs show the varying size of crystals, and as the above results were obtained using Dr. Dollar's Integrating Stage, these modes can only be approximations, although each is the average of several slides.

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CHEMICAL COMPOSITION OF THE GRANITES.

The chemical compositions of three granites from the Bindura Complex are listed below. No 5 is of a granite from the main Bindura Ridge between the Police camp and the water tower tanks. No 115b. is from the northern granite. The third analysis, carried out by E. Golding, is of a sample from the bore-hole core of the Hay Mine on the 150 - foot level.

The second page of analyses shows granites of similar composition to the Bindura Granite. Two are taken from Vol. 1, " Chemical Analysis of Igneous Rocks", H.S. Washington. (U.S.G.S. Professional paper No. 99.) Analyses Nos., 257 and 250. Both rocks are catalogued as 1 (2), 4, 2, 3. in the C.I.P.W. Classification. The Kisian Granodiorite from Kenya is also listed. (E.P. Saggerson. Kenya Report No. 21. p. 66.)

The compositions of the rocks show them to be granodiorites. (Johannsen Vol. 11. Tables 171. No. 27, and table 174, Nos. 27, 53.)

The composition of the felspars calculated in the norms show the ratio of plagioclase to microcline. The alkalis of mafic minerals have not been excluded from the total, so this is only a rough generalisation.

Analysis of;	Plagioclase.	Potash Felspar.
115 b	53.76 %	19.46 %
No. 5.	45.42 %	26.69 %
Hay Mine Core.	40.69 %	14.46 %

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CHEMICAL ANALYSES OF THE BINDURA GRANITES.

	No. 5.	No. 115 b	May Mine.
SiO_2	65.18 %	64.56 %	68.86 %
Al_2O_3	18.14	16.45	13.20
Fe_2O_3	0.93	1.14	0.48
FeO	2.59	2.57	2.98
MgO	2.07	2.46	1.38
CaO	2.18	3.56	5.26
Na_2O	4.11	4.65	3.02
K_2O	4.47	3.31	2.47
TiO_2	0.34	0.40	0.36
H_2O+	0.25	0.42	0.49
H_2O-	0.15	0.20	0.17
P_2O_5		0.18	0.50
MnO		0.04	
	100.41 %	99.94 %	99.17 %
Quartz	14.76 %	12.96 %	30.00 %
Orthoclase	26.69	19.46	14.46
Albite	34.58	39.30	25.68
Anorthite	10.84	14.46	15.01
Hypersthene	8.63	8.50	5.57
Magnetite	1.39	1.62	0.70
Ilmenite	0.61	0.61	0.76
Corundum	2.35		
Apatite		0.34	1.34
Diopside		2.04	4.86
	99.85 %	99.91 %	98.38 %
SG.	2.675	2.67	2.71.
Analyst.	D.J. Bowen	D.J. Bowen	E. Golding.

CHEMICAL ANALYSES OF SIMILAR GRANITES.

	No 257	No 250	Kisian Granodiorite
SiO_2	64.25 %	63.86 %	65.47 %
Al_2O_3	18.38	17.87	15.66
Fe_2O_3	2.92	1.24	1.54
FeO	2.07	2.88	2.07
MgO	1.46	0.99	1.90
CaO	2.64	3.33	3.46
Na_2O	3.00	4.10	4.31
K_2O	4.27	3.56	4.52
TiO_2		0.02	0.35
P_2O_5		0.65	0.14
H_2O +	1.63	0.84	0.60
H_2O -		0.17	0.60
	100.62 %	99.51 %	100.62 %
S. G.	2.70		

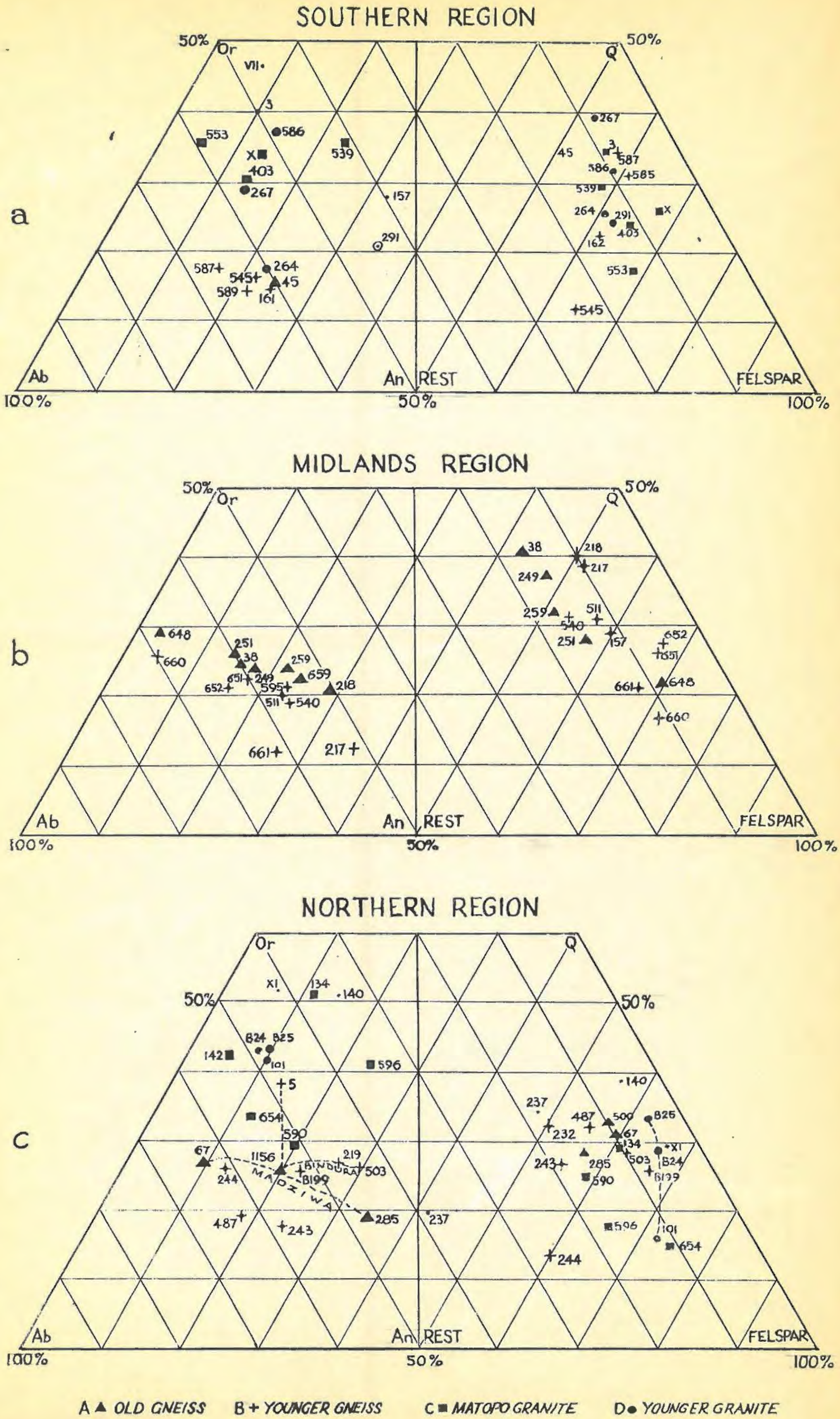
R. Reinisch	U. S. Survey Lab.	W. Horne.
Granite	Granite	Granodiorite.
Kohlhaustrasse Lausitz	Steinauer Operwald	Kisumu.
Saxony	Hesse.	Kenya.

In the above analyses certain minor constituents have been omitted.

DIAGRAMS FROM DR. A.M. MACGREGOR'S ANNIVERSARY ADDRESS TO THE GEOLOGICAL SOCIETY OF SOUTH AFRICA, COMPARING SOUTHERN RHODESIAN GRANITES.

FOUR ANALYSES OF THE BINDURA GRANITE ARE PLOTTED.

NUMBERS:- 5, 115B, 219 and 503. (Northern Region) .


SOUTHERN REGION
a
50% Or
Q 50%
Ab 100%
An REST 50%
FELSPAR 100%
MIDLANDS REGION
b
50% Or
Q 50%
Ab 100%
An REST 50%
FELSPAR 100%
NORTHERN REGION
c
Or
Q
50%
50%
BINDURA
MADZIWA
Ab 100%
An REST 50%
FELSPAR 100%
A ▲ OLD GNEISS
B + YOUNGER GNEISS
C ■ MATOPO GRANITE
D ● YOUNGER GRANITE

JOHANNSEN CLASSIFICATION OF IGNEOUS ROCKS.

The norms of the three granites if plotted as mineral compositions in the Johannsen rock classification clearly show the rocks to be granodiorites.

A mineral classification is used with chemical analyses as in the Johannsen Scheme the ferromagnesian minerals in themselves are not considered to be important.

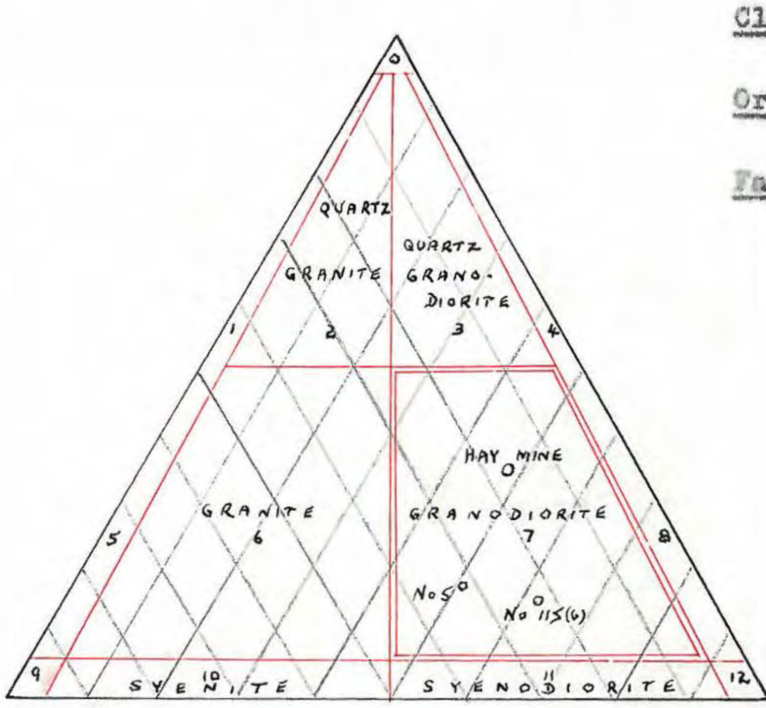
The fact that the potash, lime and soda may well occur in minerals other than the felspars has not been overlooked, but it appears from the plotting of the three " norms", that the discrepancy of these oxides being in part in hornblende or biotite is insufficient to affect the name.

Quartz.

<u>Class 2.</u>

<u>Order 2.</u>

<u>Family 7.</u>



Orthoclase Plagioclase.

Quartz, Orthoclase and Plagioclase reduced to 100 from Norm (100 %).

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(Johannsen Volume One. Page 143, 144, etc.)

RELICT COUNTRY ROCKS IN THE GRANITE.

GENERAL STATEMENT.

The origin of granite provides a subject of great controversy amongst petrologists. Today it is well realised that granites can be formed in several ways, when H.H. Read says " There are granites and granites ", and Frank F. Grout writes, (1948 p 451),

> " Clearly granite may originate in two or more ways, and the emphasis is put on different processes by different geologists. In outline the different origins are,
>
> (a) From cooling of a granitic magma.
>
> (b) By replacement of other rocks.
>
> (c) Possibly some mixture or interaction between (a) and (b). "

Evidence that a granite has been formed by the incorporation in a magma of sedimentary material is provided by,

(a) Relict sedimentary rocks and structures in the granite.

(b) The presence of resistant, detrital sedimentary or metamorphic minerals in the granite itself. (R.H. Rahns. B.G.S.A. No 28 1948 p 94.)

(c) The relationships that the granite bears to the surrounding rocks.

The intrusive nature of the Bindura granite is very evident in the R.A.H. mine (east side of complex) where the granite - schist contact is very sharp, though highly irregular. Small offshoots of granite five or six feet long penetrate the surrounding quartzitic rocks, but no metamorphic effects from the presence of the granite are perceptible.

In the Bindura granite there appears to be unquestionable evidence of relict sedimentary rocks. Because the granite is undoubtedly intrusive, the most logical explanation of the features to be described is therefore, that the original granite magma stoped upwards and assimilated into itself sedimentary material before further intruding the Shamvaian System.

FIELD CHARACTERS AND OCCURRENCE.

There appear to be three different occurrences of sedimentary rocks recognisable in the granite.

(a) Present throughout the Bindura granite are numerous bands of quartzitic material, trending without exception in an east- westerly direction:- this direction also being the strike of the nearby Shamvaian System. The width of the quartzitic bands varies from two to fifty feet, and in length from ten yards to well over a mile and a half, while the dip is nearly always vertical.

The largest band stands out as a distinct " vein - like " feature in the granite striking E. 15° N. and with a vertical dip. Numerous smaller veins appear to be of a similar type, as does the " dyke " rock of the R.A.N. mine. The possibility that the rocks may be aplitic or even rheomorphic in nature has not been overlooked, but this is regarded as highly unlikely.

(b) In the hills south-west of the large quartz mass in the northern part of the intrusion, there is a granitic rock of two components, both with the same mineral composition. The bulk of the rock is a fine grained granite through which run stringers and lenses of a coarser material. The origin of

/ this rock provides

this rock provides an interesting but so far unsolved problem. It is suggested though, that this patch of rock was an original sediment, which became drenched in the granite magma, but did not become entirely fluid, and remains as a partly assimilated xenolithic feature in the granite.

(c) A mixed zone of granite, quartzite and mica-schist is present in the north-east part of the complex. The sedimentary series form beds of rock alternating with the granite in bands up to thirty feet wide. It is assumed that here lit-par-lit injection of granite magma into the sediments has taken place, producing a zone of migmatites.

MINERALOGY AND PETROLOGY.

QUARTZITIC BANDS IN THE GRANITE.

Microscopic examination of these rocks suggests the name porphyroid as the most suitable term for them. Large crystals of plagioclase and quartz are set in a fine grained groundmass of quartz, sericite, felspar and biotite. A porphyroblastic texture is dominant and the groundmass is similar to a recrystallized sandstone. The meta-crysts up to four millimetres across, frequently show augen structures. G.E. Goodspeed (1959 p 248) commenting on this point in granite rocks writes

> " Another indication that crystallization took place in an essentially solid medium is where earlier minerals seem to have been pushed aside by later ones. For example in some granitic rocks ragged shred-like flakes of biotite surround large plagioclase crystals somewhat similar to the way they enclose garnet porphyroblasts in a metamorphic rock. "

Universal stage measurements show the felspar to be oligoclase with 13 - 16 % Anorthite, which is slightly more sodic than the felspars in the granite. The oligoclase crystals do not have straight edges against quartz grains, as one expects, following the normal order of crystallisation, but in fact recrystallised quartz lies in embayments in the sides of the felspar. Most felspars show various stages of alteration due to sericitization or kaolinization. In some slides the oligoclase encloses large plates of sericite, which are split up by micro-faulting.

Some of the slides show a strong foliation of quartz and sericite, similar in appearance to medium - grained argillaceous sediments. Although the dominant foliation is undoubtedly due to metamorphism, it may be parallel to an original bedding. The larger quartz grains are not rounded, but they may be detrital, as similar quartz crystals are present in the quartzites outside the granite.

Nearly all the minerals present in the granite are also found in this rock. They include apatite, epidote, hornblende, sphene, magnetite, microcline, mispickel, sericite, plag ioclase, tourmaline and pyrite. In most specimens quartz and mica are far more abundant than in most of the granite rocks. Quartz is present to the extent of forty percent in some specimens, while sericite, hornblende and biotite may make up a similar amount. Felspar is not as abundant as in the granites and generally forms well under forty percent of the rock. One section contains small amounts of a pale red garnet (Almandine?).

Fifty grams of rock from each of three specimens were crushed up and concentrates collected. The concentrate included the " heavies " of the above list of minerals together with occasional grains of zircon: and were similar to pannings from sedimentary rocks outside the granite. Neither group of concentrates revealed any substantial rounding of grains due to abrasion.

THE PARTLY ASSIMILATED XENOLITHIC ROCK.

The fine and coarse portions of this rock are practically identical as far as mineral composition is concerned. It is a felspar rich rock composed of 62% soda-rich oligoclase, 20% quartz and 16% biotite. Both green and brown biotite occur in different slides, and magnetite epidote, microcline, sphene, apatite and tourmaline form the accessorites. In some sections the rock texture resembles a granophyre, but more commonly it is similar to the granites, though the finer portion of the rock is often variolitic.

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CHEMICAL COMPOSITION OF THE QUARTZITIC ROCKS IN THE GRANITE.

An analysis of a sample from the largest quartzitic band reveals a rock similar at first glance to a granite which, except for the high alkalies, is not so very different from the surrounding sediments.

The rock analysed contains very high alkalies, but has a very low lime and magnesian content in comparison with both the granite and quartzites analysed.

The analysis would appear to suggest that, if the rock had been an original sediment, then the reason why it did not " flux " properly with the granite magma was because it lacked essential lime and magnesia, present originally as carbonates.

Most of the rocks of this type, judging from thin section slides, contain a higher percentage of silica than the one analysed.

No. 115 a.		Norm.	
SiO_2	68.78 %	Quartz	21.30 %
Al_2O_3	16.47	Orthoclase	19.46
Fe_2O_3	1.03	Albite	44.54
FeO	2.12	Anorthite	5.84
MgO	0.36	Enstatite	0.90
CaO	1.34	Ferrosilite	2.64
Na_2O	5.30	Magnetite	1.39
K_2O	3.33	Ilmenite	0.61
TiO_2	0.32	Corundum	2.14
H_2O +	0.80	Apatite	0.34
H2O -	0.22	Water	1.02
	100.17 %		100.18 %

S.G. 2.60 Oligoclase 11.61 % An. Analyst. D. Bowen.

TOURMALINE BEARING ROCKS INCLUDING APLITES

GENERAL STATEMENT.

In general, tourmaline - bearing rocks are derived by pneumatolytic action following the consolidation of the main magma mass, and the phases of pegmatite and aplite veining. Tyrrell (1953 p.325) writes,

> " Three main types of pneumatolysis are connected with the intrusion of granitic magma; tourmalinisation, greisening, and kaolinisation. Tourmalinisation is due to the combined action of water, boron, and fluorine, which are concentrated in the residual liquors towards the end of the crystallisation period of the granite. They may attack the already solidified parts of the igneous mass, and the felspars are partially replaced by tourmaline, with the formation of tourmaline - granite. With more intense activity the felspars are completely destroyed, and the rock is then converted into an aggregate of quartz and tourmaline, which is termed schorl-rock. "

FIELD CHARACTERS AND OCCURRENCE.

Tourmaline bearing rocks occur in a zone roughly three miles long by one wide, on the eastern edge of the Bindura Granite. This zone follows the surface margin of the granite but does not extend into the granite itself to any recognisable extent. The tourmaline rocks are extremely well developed and form one of the striking features of this intrusion. They can be subdivided into three groups;

(a) Rocks containing small veinlets of tourmaline all less than four inches wide.

(b) Tourmaline bearing hydrothermal quartz veins and aplites,

(c) Tourmaline quartz rocks derived from an original sedimentary rock type.

- - - - - -

MINERALOGY AND PETROLOGY.

(a) Rocks containing small tourmaline veins.

In an area of approximately three square miles, small veins up to four inches wide, of tourmaline with associated pyrite or magnetite, are extremely common. The veins are most characteristic of the aplites and amphibolites (described in later section), but also occur in the granites and mica-schists or quartzites. The term Luxullianite can be used to describe the tourmalinised granite.

This belt of tourmalinisation follows the trend of the granite rocks, and in this area there is considerable parallelism of individual veinlets. The distance apart of individual veins varies, but they commonly form clusters sometimes only a few inches apart.

A less dominant continuation of this belt of tourmalinisation to the northern part of the granite seems likely, as some quartz containing tourmaline is present there.

(b) Tourmaline-bearing Hydrothermal Quartz Veins and Aplites.
Aplites are produced by crystallisation of late stage material from granite magmas.

Although aplite veins, varying in width from one to twenty feet are common in the Bindura Granite, no pegmatite veins have yet been discovered.

Aplites and hydrothermal quartz veins are more common in the eastern portion of the granite where they are associated with the tourmalinisation. They are not found at all in the west granite, but are occasionally present in the central parts, and here contain no tourmaline.

This presents the problem of determining if the tourmaline is pre or post vein in age. It seems most likely, however, that the tourmalinisation of the rocks took place at much the same time as the veins were intruded and the two phases are in fact overlapping.

Some of the largest aplite veins, twenty feet wide, are found striking parallel to the roof pendant of mica-schists in the amphibolites. Here exposures in the stream reveal the glistening white aplite veins containing in them smaller blue - black veinlets of tourmaline and vein quartz up to ten inches wide.

Microscope slides of typical aplite specimens at Bindura reveal a rock composed of nearly equal proportions of quartz, and an albite-oligoclase felspar with less than eighteen percent anorthite. Microcline may be present but no grid twinning is apparent. The rock is fine grained (0.05mm.) and has a very sutured texture. In the aplites and quartz veins in the east portion of the granite, veinlets of tourmaline and pyrite (or magnetite) two inches wide, cut through the rock striking parallel to the main vein. The tourmaline often forms radiating fans or sunbursts.

S. Maske. (Stellenbosch Annals Vol. 33 p. 33), also notes the close association of iron with tourmaline in hydrothermal veins.

(c) Tourmaline - Quartz Rock.

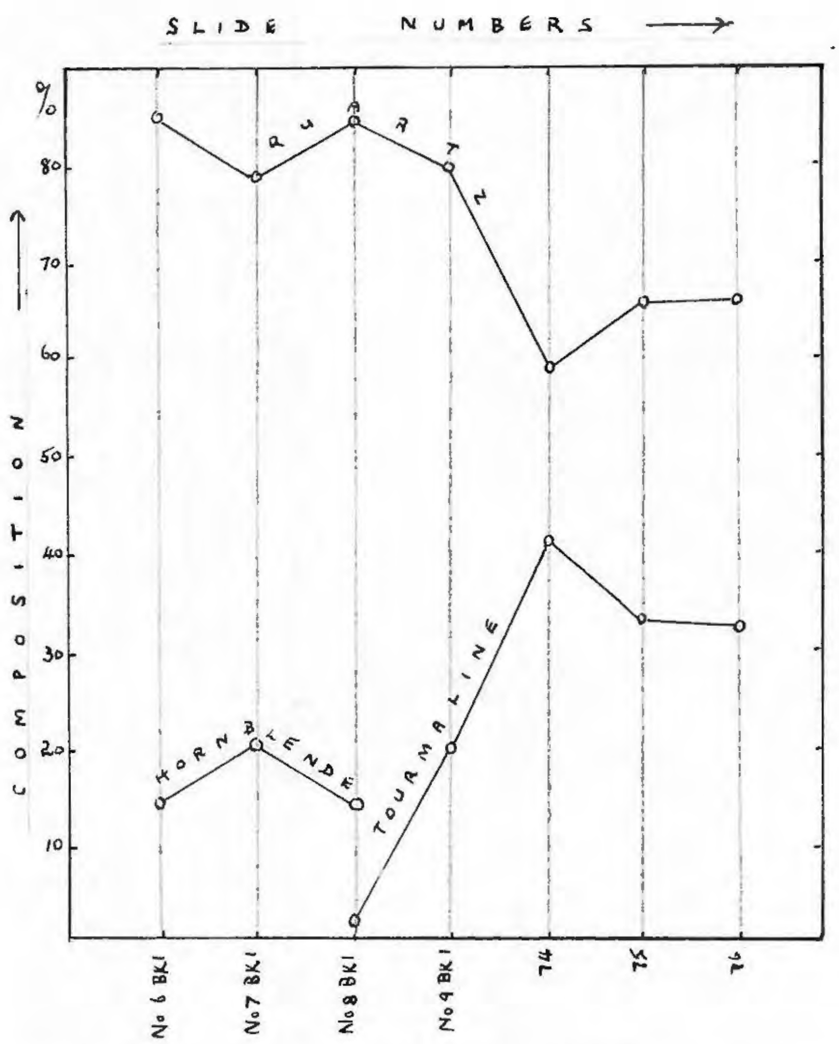
The complete alteration of a metamorphosed sedimentary rock, to a rock composed only of quartz and tourmaline is seen on the eastern side of the hill just north of the R.A.N. mine, in a circular mass of rocks roughly five hundred yards in diameter. Individual specimens vary in texture and grain size tremendously, and Johannsen's description (1939 p. 22. Vol. 2) of Tourmalite is most apt.

> " For rocks consisting only of tourmaline and quartz I suggested, in 1919 the name Tourmalite.
>
> Tourmalite is generally a mottled, black and white coarse to fine granular, in some cases schistose rock, which consists of white to gray quartz, and brown to black tourmaline. R. Freiesleben divided these rocks into granular schistose and dense varieties. In the first the tourmaline as well as the quartz is granular, and both are recognisable megascopically. Occasionally the tourmaline is in radial aggregates as tourmaline suns. The second variety is schistose from parallel arrangement of tourmaline. The third variety is so dense and the two minerals so intimately intergrown that they cannot be recognised megascopically and the rock is a uniform gray colour. "

The term schorlite (as a rock name) is synonymous with, and is possibly a better word to use than tourmalite. The Bindura schorlites are often fine-grained and are dark blue-black in colour. Although small crystals of tourmaline up to ten millimetres long are occasionally found, development of large tourmaline crystals is unusual.

Under the microscope schorlite resembles a recrystallised quartzite, one third of which consists of the mineral tourmaline. In six slides of fine grained rocks, Dollar stage determinations show a variation in the quartz content from fifty-nine to seventy-eight percent, the remainder of the sections being tourmaline. Crystals do occur up to one millimetre across, but most of the rock is finer grained than this. Accessory minerals, less than one percent of the rock, include oligoclase, epidote, sphene and hornblende, but most rocks do not have any accessories.

The metamorphosed sediments surrounding the schorlite are quartz hornblende rocks. The hornblende has presumably been derived metamorphically from the original clay and silt fractions of the sandstone. Slides made from specimens taken at fifty yard intervals, illustrate the interesting variation in the rocks down the east slope of the hill north of the R.A.N. mine, from the sedimentary rock to the middle of the schorlite.



The close association of hornblende and tourmaline is also characteristic of the tourmaline veins in the amphibolites and seems to suggest that the tourmaline has been formed from amphibole where sufficient boron was available to convert it.

A M P H I B O L I T E.

GENERAL STATEMENT.

Numerous other authors agree in general with C.M. Rice's definition that,

> " Amphibolite is a granulose or glomeroblastic rock consisting essentially of amphibole and plagioclase, and containing quartz, epidote or garnet. "

It is, however, a very flexible definition, and no one writer seems prepared to lay down the minimum amount of amphibole that is needed to call a rock by this name.

The term amphibolite is used below to include a wide range of rocks consisting essentially of two minerals, amphibole and plagioclase.

FIELD CHARACTERS AND OCCURRENCE.

Although the amphibolites form a suite of rocks present principally in the eastern section of the complex, they also occur between the Phoenix Prince Diorite and the granite on the south-west side. In the field the actual relationships the amphibolites bear to the granite are very difficult to perceive, as the contact between them is not exposed anywhere. Outcrops of amphibolite are not nearly as conspicuous as are those of the granite, chiefly because with one exception they form low-lying land. The main eastward flowing stream in the area does, however, provide valuable outcrops and this rock can be seen practically throughout its course. Where the river has worn a clean surface, the outcrops have a characteristic blue-green colour.

Numerous veins of hydrothermal quartz and aplite cut through the amphibolites in the eastern section. Here the rocks are in the main belt of tourmalinisation, and small veins of tourmaline and magnetite or pyrite are an extremely common feature. The width of these veins varies from one millimetre up to twenty centimetres.

MINERALOGY AND PETROLOGY.

The amphibolites have a well defined sutured texture, which is most apparent between adjoining felspar crystals.

The minerals present include hornblende, actinolite, plagioclase, quartz, biotite, sphene, apatite, magnetite, pyrite, tourmaline and microcline. Modes of ten specimens are listed below.

Slide No	104	107	30	118	45	1	28	14a	P4	26	
Amphibole	83	48	45	42	42	36	27	26	25	23	%
Plagioclase	17	52	32	57	45	64	65	46	50	55	
Quartz			14		10		6	28	8	19	
Biotite					3				12	3	
Apatite	✓	✓	✓	1		✓	2	✓	✓	✓	
Sphene						✓	✓	✓	✓	✓	
Magnetite	✓	✓	✓			✓			✓	✓	
Pyrite						✓		✓	✓		
Sericite										✓	
Tourmaline			9				✓				
Microcline.			✓								

Hornblende and plagioclase make up the bulk of most rocks but in more than half of them quartz is an important mineral.

/ The accessory minerals

The accessory minerals, except for those in pneumatolytic veins, form an extremely small portion of some rocks and are not found in others at all. They are not nearly as common or as abundant as in the granites.

The hornblende varies in colour from a very pale blue-green to a bright green. It occurs as lath-shaped crystals up to one and a half millimetres across, but is present more commonly as a fine crystalline mesh of amphibole. The 2 V of this mineral is large - seventy-eight degrees. This value, near the limits of the Universal Stage made results difficult to determine accurately.

Both plagioclase and a potash felspar occur, but the latter is present in insignificant amounts. The felspars are largely untwinned. The Universal Stage reveals that some of the felspar at least is labradorite with an Anorthite content of 52 - 54 %. Refractive index determinations on crushed fragments of finely twinned plagioclase show a less calcic felspar of 35 - 40 % Anorthite to be more common. There is probably an extremely wide range of plagioclase in the field.

Tourmaline is an extremely common mineral in the amphibolites, being present in pneumatolytic veins. There is usually a concentration of amphibole in zones on either side of the tourmaline vein, and of the same thickness as the vein. Some of the veins are very small and can be seen only with the microscope.

CHEMICAL COMPOSITION OF THE AMPHIBOLITES.

One complete analysis and one partial one were carried out on two specimens of amphibolites. The two analyses are remarkably similar in some respects, although the two rocks in handspecimen are very different in appearance. One is a very light coloured rock while the other is much " greener " . A tourmaline vein in No 118 introduced some boron which because it was not determined has caused a discrepancy of total in the analysis.

The high orthoclase content in the norm is undoubtedly incorrect, as most of the potash really belongs to the amphibole which is not represented.

The third analysis is of the Sweet Valley Uralitised Gabbro, part of the intrusive complex found fourteen miles to the west of Bindura.

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CHEMICAL ANALYSES.

	No. 28.	No. 118.
SiO_2	53.54 %	49.22 %
Al_2O_3	21.58	24.33
Fe_2O_3	0.96	1.42
FeO	3.11	5.88
MgO	2.24	2.54
CaO	10.92	10.53
Na_2O	2.55	2.03
K_2O	2.25	0.49
P_2O_5	0.66	
TiO_2	0.77	0.19
MnO	0.04	
H_2O	0.63	1.40
H_2O	0.36	0.32
	99.61 %	98.35 %
B_2O_3		n.d
S.G.	2.739	2.748
Analyst.	D.J. Bowen	D.J.Bowen.

NORM OF NO. 28.

Quartz	5.70 %	Diopside	7.02 %
Orthoclase	13.34	Hypersthene	5.64
Albite	21.48	Apatite	1.68
Anorthite	40.87	Magnetite	1.39
		Ilmenite	1.52
	81.39 %		17.25 %

ANALYSIS OF THE SWEET VALLEY GABBRO FOR COMPARISON WITH THE AMPHIBOLITES.

(ESSENTIAL CONSTITUENTS LISTED.)

SiO_2	47.20 %
Al_2O_3	20.20
Fe_2O_3	0.49
FeO	8.55
MgO	3.96
CaO	11.44
Na_2O	1.79
K_2O	1.03
H_2O	2.26
H_2O	0.19
TiO_2	0.44
MnO	0.08
	97.73 %

Analyst. E. Golding.

(G. S. Bulletin of Southern Rhodesia No. 29. 1936. p. 24)

ORIGIN OF THE AMPHIBOLITES.

The origin of the amphibolite provides a very interesting problem. A rock occurring fourteen miles to the west of Bindura is called the Sweet Valley Gabbro by the Rhodesian Geological Survey. (R.G.S.B. No 22 p.58). This " uralitized gabbro" similar,and in some cases identical to the Bindura amphibolites (mineralogically and chemically), is cut by an intrusive granite stock. The granite cuts the Sweet Valley Gabbro into two sections, one on each of the north-east and south-west sides of the stock. The structure of the gabbro as suggested by Tyndale-Biscoe (p58) is probably sill-like.

> " .... Either it is a differentiate of the magma from which the granite of the stock originated, and was intruded a short time before or after the granite, or it is a sill which was intruded at a much later date than the granite. The evidence is very meagre. "

Although some of the Bindura amphibolites are identical with the Sweet Valley Gabbro, many do not resemble it very closely. Those that do not, contain more quartz, apatite, sphene, microcline and pyrite, are very much lighter in colour and indeed look " granitic ".

The amphibolites appear to have been derived from some earlier basic rock which was intrusive into the Shamvaian System. A roof-pendant of steeply dipping mica-schists is remnant in the middle of the amphibolites, bearing testimony to the intrusive nature and ortho origin of the rocks. Evidence from outcrops in the river appear to suggest a nearly horizontal igneous lamination in the rock, which is almost like bedding. This intrusion was probably sill like, in contrast to the steeply dipping neighbouring sediments.

/ The granite.

ORIGIN OF THE AMPHIBOLITES. Continued.

The granite intrusion is presumably responsible for the alteration of the gabbro or some such similar rock into the amphibolite. Numerous aplite and quartz veins as well as the tourmalinisation, date the age of the amphibolites in the eastern section. The great variety of the " amphibolites" is presumably produced by various stages of contamination, by material from the granite. The presence of microcline, large quantities of quartz, pyrite, sphene, apatite and tourmaline, supports this view.

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P H O E N I X   P R I N C E   D I O R I T E.

GENERAL STATEMENT.

The Phoenix Prince Gold Mine (previously called the Prince of Wales) is situated about a mile west of the Bindura Railway Station, in the middle of a mass of rock known as the Phoenix Prince Diorite.

FIELD CHARACTERS AND OCCURRENCE.

In the field there are very few natural exposures of this rock and it is only where there are mine quarries, that this rock is observable. These quarries reveal that the rock near the surface has a strong igneous or metamorphic foliation and banding, dipping to the south at eighty-five degrees. Quartz veins up to six inches wide lie parallel to and form a dominant feature of the alignments.

MINERALOGY AND PETROLOGY.

R. M. Tyndale-Biscoe described this heavily mineralized rock in his report on the central Mazoe Valley, and conclusively proved this rock to be a diorite. His description (p.49) reads,

> " The typical country rock is a medium to coarse-grained holocrystalline rock of a dark grey colour. To the unaided eye it consists apparently of about equal proportions of grey felspar and of black hornblende and biotite together.
>
> The microscope shows these to be the chief constituents. The hornblende and biotite are in roughly equal proportions and commonly intergrown. Crystal outlines are rare. Most of the felspar is a medium to basic oligoclase, generally turbid from alteration. Quartz is very scarce and may be regarded as an accessory mineral. Other accessory minerals are apatite and sphene, both fairly abundant and a little ilmenite. Calcite occurs as a product of alteration, derived probably from felspar, while much of the sphene is evidently derived from biotite by alteration. "

MINERALOGY AND PETROLOGY. Continued.

Quartz is not as rare a mineral as the above description suggests and makes up as much as ten percent of this diorite. (Excluding the veins of quartz). In thin section there is a sub-parallel orientation of biotite and quartz stringers, which is parallel to the large scale banding of the rock, observable in the quarries.

Tyndale-Biscoe notes the important changes that take place from the footwall to the hanging wall (i.e. from north to south) stating that, (p.50)

> " An examination of microscope slides at first suggests that in those parts of the mass which constitute reef the hornblende becomes converted to biotite, ... "

Just north of the main Phoenix Prince mine dumps a typical amphibolite, identical to some of those on the north-east part of the complex outcrops. It consists of two minerals, hornblende and a basic andesine. (44 % An.). This rock changes gradually into the pyritized Phoenix Prince Diorite. The actual mineralogical changes that take place can best be seen with the photomicrographs, but they include,

(a) Presence of increasing amounts of quartz.

(b) Replacement of hornblende by biotite.

(c) Introduction of sulphides and gold.

(d) Introduction of microcline, apatite and sphene.

(e) The alteration of the Ca rich plagioclase into oligoclase.

As long ago as 1938 the granite-amphibolite-diorite relationship came to the fore with a visit by B. Lightfoot to the mine. He wrote of the occasion,

> " The object of the visit was to see a tongue of granite which has cut the diorite on the 7th. level. "

The relationship the granite bears to the diorite and the amphibolite as a whole, is summed up by a former manager of the Phoenix Prince Mine, A. Haworth. He writes in his mine report of July 1941.

> " It will be seen that the granite penetrates but a short distance into the schist and the suggestion is that the granite has already penetrated an area of pre-existing diorite.
>
> It is true that there are large fragments of schist within the diorite, but these schist fragments have sharp outlines and the assimilation of the schist by the diorite was a slow process, and no large volume of rock could have been formed in this way. The diorite has a relatively uniform composition over a very large volume of the rock and must be regarded as a separate igneous product. Moreover the contact between the diorite and granite is generally well defined and there is clear evidence that the granite, on solidification was chilled against the diorite showing that the latter was in a solid state when the granite intrusion took place. "

> " The granite gave rise to the fracturing of the diorite and the schist (<u>to the south of the diorite.</u>)and it was from the granite that the quartz reefs and their gold originated. "

A. Haworth in a letter to Major Lightfoot on 28th. January, 1944 says,

> " We have quartz veins coming out of fissures in the granite- small fissures with gold <u>in</u> the granite and in short we have the whole book of words on ore deposits in one place or another. "

The diorite it seems in view of the evidence as it stands at the moment, must have been derived from an original gabbro or some other similar basic rock. The alteration of the gabbro and mineralization of it was brought about by the intrusion of the granite, and by solutions or emanations from it.

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CHEMICAL COMPOSITION OF THE DIORITE.

Five analyses of the Phoenix Prince Mine diorite were carried out for the Rhodesian Geological Survey by E. Golding.

An interesting graph is constructed if the various oxides of the diorite are plotted, along with those of the Sweet Valley Gabbro and the two amphibolites of the Bindura complex.

This graph illustrates the similarities in composition between the amphibole - plagioclase rocks, and the gradual change in value of alumina and lime at the expense of silica from the footwall to the hanging wall of the diorite. This variation suggests that the diorite is really the altered gabbro. The FeO, MgO and alkalis do not change substantially so it appears these oxides were also introduced from the granite.

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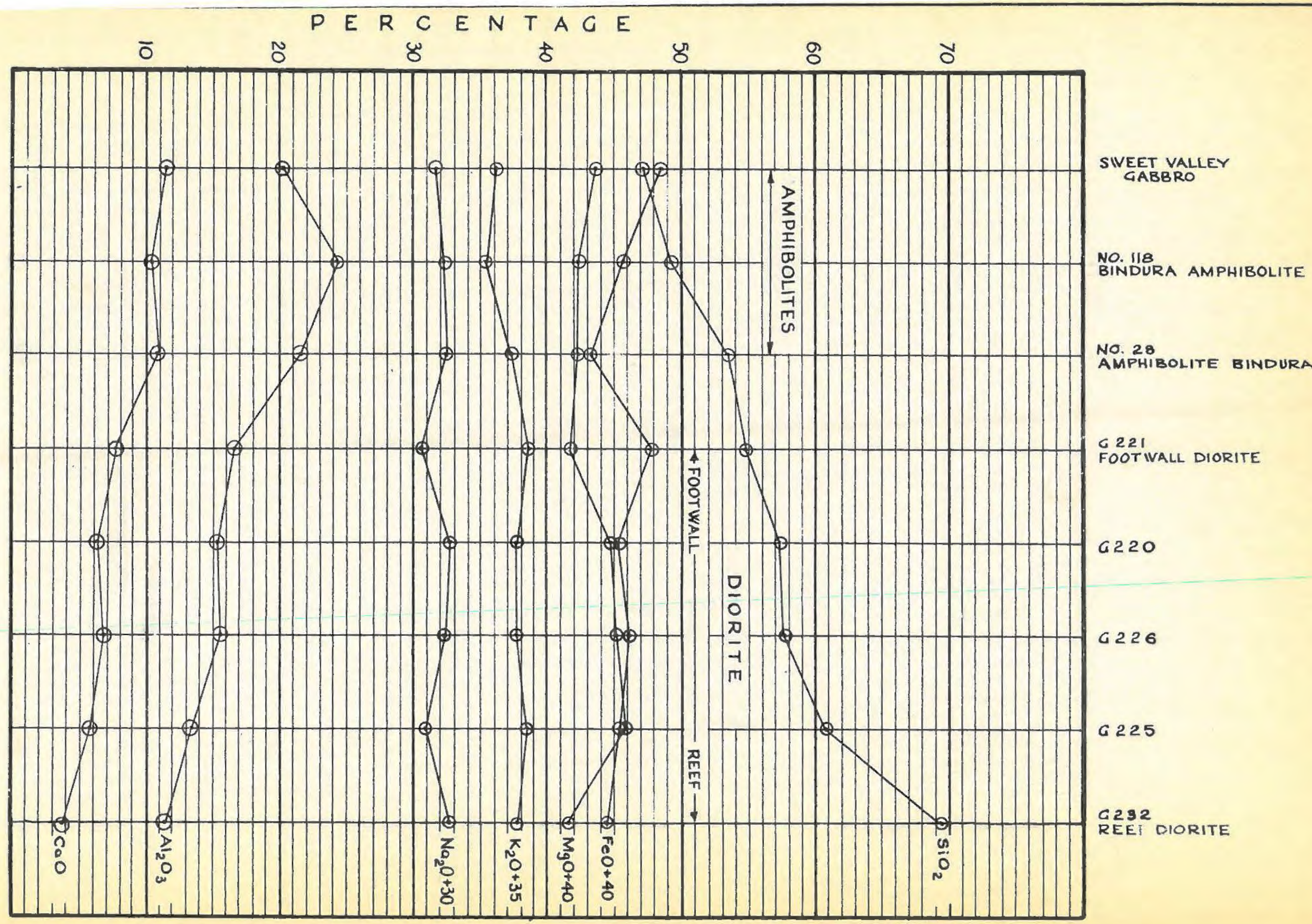
PERCENTAGE
10
20
30
40
50
60
70
SWEET VALLEY GABBRO
NO. 118 BINDURA AMPHIBOLITE
NO. 28 AMPHIBOLITE BINDURA
G 221 FOOTWALL DIORITE
G220
G226
G225
G232 REEF DIORITE
AMPHIBOLITES
FOOTWALL
DIORITE
REEF
CaO
Al2O3
Na2O+30
K2O+35
MgO+40
FeO+40
SiO2

ANALYSES OF THE PRINCE OF WALES DIORITE.

PAGE NO 54. BULLETIN NO. 22.

	G220	G 226	G 221	G 225	G 233
SiO_2	57.36 %	57.61 %	54.90 %	60.85 %	69.14 %
Al_2O_3	16.28	15.60	16.80	13.26	11.65
Fe_2O_3	0.32	0.27	0.36	0.75	0.64
FeO	5.47	6.10	7.96	5.49	4.39
MgO	4.99	5.23	2.72	5.77	1.95
CaO	6.33	6.59	7.68	5.96	3.79
Na_2O	2.76	2.41	0.56	0.81	2.85
K_2O	2.82	2.88	3.46	3.35	2.58
H_2O+	0.59	0.65	0.36	0.57	0.36
H_2O-	0.11	0.03	0.16	0.03	0.07
TiO_2	0.95	0.75	0.88	0.75	0.77
	97.98 %	98.12 %	95.84 %	97.59 %	98.19 %
Analyst.	E. Golding.	do.	do.	do.	do.

NORMS.

Quartz	9.00 %	9.60 %	19.68 %	21.36 %	32.10 %
Orthoclase	16.68	17.24	20.57	20.02	15.01
Albite	23.06	20.44	4.72	6.81	24.10
Anorthite	23.91	23.07	21.41	22.52	11.41
Corundum			4.28		
Diopside	0.89	1.83		0.69	2.29
Hypersthene	20.12	22.10	18.55	21.33	8.79
Magnetite	0.46	0.46	0.46	1.16	0.93
Ilmenite	1.82	1.37	1.67	1.37	1.37
Apatite	2.02	1.01	1.01	1.01	
	97.96 %	97.12 %	92.35 %	96.27 %	96.00 %

In the above analyses certain minor constituents have been omitted.

D O L E R I T E.

GENERAL STATEMENT.

The only rocks intrusive into the granite, and the youngest igneous rocks in the area, take the form of dykes of dolerite. These vary tremendously in size but their strike is confined to north-south or east - west.

FIELD CHARACTERS AND OCCURRENCE.

There are two large dykes of dolerite, here called the main North and the main South Dykes. Both of these strike east - west, and each can be traced through practically the whole width of the area. They stand out in the landscape and in places form a conspicuous chain of hills.

The northern dyke appears to die out suddenly in the extreme west, while the southern dyke thins out gradually to the east and is finally lost to sight on the big hill north of the R.A.H. mine. The width of both these dykes in particular the northern one is considerable. In its widest place the latter dyke is over two hundred yards wide, while the southern one is not much less.

The southern dyke thins out until it is only two or three feet wide, and where it narrows it splits up into two portions with a mass of granite between the two arms. Where the dyke thins out there is a sharp well defined contact between granite and dolerite. Sometimes small masses of granite have been caught up in the dolerite. They are up to six inches across. Where the dyke thins out the rock loses its ophitic texture, becomes highly altered, fine grained and resembles the smaller dykes in the area. It appears that

/ the grain size.

FIELD CHARACTERS AND OCCURRENCE. Continued.

the grain size depends directly on the size of the intrusion.

In addition to the two dykes already described, a great number of smaller dykes occur in the area, some of them only two feet across and traceable for a hundred yards or less.

MINERALOGY.

The dolerite of the two main dykes is a coarse-grained rock made up of an ophitic intergrowth of pyroxene and plagioclase, with iron ores. Because there are crystals of quartz scattered sparsely through the rock it can be called a quartz dolerite.

Plagioclase and pyroxene each make up 46% of the rock and the iron ores 6 - 9 %. The plagioclase laths which have a length/breadth ratio of three, are twinned on the normal felspar laws. They ophitically penetrate the slightly larger square sectioned pyroxene crystals.

The composition of the plagioclase as determined by the universal stage varies from 56 to 64% Anorthite, with 62% Anorthite being most typical. There is some alteration of the labradorite to saussurite.

Two pyroxenes are present: pigeonite and augite. Pigeonite is by far the most abundant pyroxene, and although not a common feature it sometimes forms the core to a composite pyroxene crystal. Both pyroxenes have been altered to the variety of hornblende known as uralite. This mineral may make up to eight percent of the total rock.

Olivine, as is expected from the presence of quartz is not a common mineral, although scattered crystals do occur

/ particularly in the

MINERALOGY. Continued.

particularly in the largest north south dyke. The two iron ores are magnetite and ilmenite, although pyrite is sometimes present. Opaque grey white leucoxene is very common as an alteration product of the ilmenite, with which it forms skeleton crystals.

The smaller dykes are very much finer grained rocks, which have been highly altered. Pyroxene has been almost completely changed to uralite and labradorite to saussurite. J.W. Wiles uses the term meta-dolerite to describe such rocks.

> " 'Meta' is a prefix here used to indicate a dolerite in which the alterations are saussuritization and uralitization. "

The word epidiorite could also be used in this connection.

CHEMICAL COMPOSITION.

An analysis of a coarse grained dolerite from the centre of the northern dyke is listed below.

No. 35.

SiO_2	47.59 %	Quartz	
Al_2O_3	16.86	Albite	14.15 %
Fe_2O_3	3.65	Anorthite	37.25
FeO	11.45	Orthoclase	2.78
MgO	5.72	Diopside	15.92
CaO	11.48	Hypersthene	21.68
Na_2O	1.70	Olivine	1.10
K_2O	0.	Magnetite	5.34
TiO_2	0.85	Ilmenite	1.52
H_2O +	0.54	Water	0.80
H_2O -	0.26		
	100.50 %		100 .54 %

S.G. 3.03.

Analyst. D.J. Bowen.

S E D I M E N T A R Y   R O C K S.

GENERAL STATEMENT.

The igneous rocks of the complex are surrounded by sedimentary rocks of the Shamvaian System. The sediments, all of which have been substantially metamorphosed, constitute what must have been a wide assemblage of original sub-aqueous and possibly aeolian deposits.

The altered rocks now include various schists, quartzites and conglomerates. (All Primitive System Rocks.)

FIELD CHARACTERS AND OCCURRENCE.

There is a large mass of coarse-pebbled conglomerate bordering part of the western granite. Although this rock forms several conspicuous ridges, its relationships with the granite or other sediments are difficult to determine. It is present only on the one side of the granite though its strike suggests that it could be present on the east side as well.

The most common rock is a schistose quartzite or a quartz sericite schist. Except in river beds or quarries the strikes and dips are difficult to determine, but around the granite stock, nearly all beds strike east-west and dip vertically.

The only clear contact showing the intrusive nature of the granite is in the R.A.N. mine. There is no schistosity or lineation parallel to the margins of the granite.

MINERALOGY AND PETROLOGY.

The conglomerate is coarse - grained with large pebbles, boulders

/ and rock fragments.

and rock fragments up to one foot across in it. The pebbles include granite, quartzite, vein quartz, chalcedony and schale, set in a fine grained matrix of quartz, hornblende and biotite. The matrix of the rock is similar to the quartzitic rocks elsewhere around the complex, and it appears that the hornblende and mica minerals are due to a recrystallization of the clay and silt fractions of the unaltered sediments.

Bronson Stringham's description of rocks at Bingham, Utah, could well apply to the rocks at Bindura.

> " Quite evidently the greenish colours in the rock are due to different concentrations of chlorite, green biotite and actinolite. The green stringers that traverse the quartzite may be explained on the basis that the original interstitial impure substances, lime magnesia; alumina and iron were mobile enough during the formation of these minerals to migrate through channels and form veinlets or group themselves in patches. "

The average mineral composition of three micaceous quartzites is quartz 66 %, sericite 25 % and biotite 8 %. Magnetite, pyrite, hornblende, tourmaline (authigenic), zoisite and sometimes calcite form the bulk of the accessory minerals. In one slide zoisite appears next to pyrite and magnetite.

Commonly the ferromagnesian minerals occur in small stringers and veinlets, parallel to one another and forming the schistosity to the rock.

Molybdenite is found in quartz-calcite veins in the sediments to the south of Bindura.

Heavy mineral separation fails to reveal any significant rounding (by sub-aqueous or aeolian weathering) of mineral grains, and concentrates are similar to those obtained from the quartzitic bands in the granite.

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CHEMICAL COMPOSITION OF THE QUARTZITE.

One analysis of a mica - schist No 43. is shown along with three other analyses of the Shamva Grit Series.

	No. 43	G 350	G353	G 360
SiO_2	66.53 %	74.01 %	63.31 %	62.75 %
Al_2O_3	14.65	8.63	15.95	14.93
Fe_2O_3	1.49	0.27	0.23	0.20
FeO	2.51	6.06	5.95	7.84
MgO	2.72	2.67	3.86	3.99
CaO	5.74	2.55	4.51	3.89
Na_2O	1.11	0.97	1.94	1.20
K_2O	2.52	1.51	1.87	1.62
H_2O+	0.77	0.46	0.81	1.68
H_2O-	0.20	0.17	0.14	0.07
TiO_2	0.33	0.40	0.64	0.58
CO_2	1.45	0.81		
MnO	0.06	0.12	0.10	0.16
	100.08 %	98.63 %	99.51 %	98.91 %
Analyst	Bowen	Golding	Golding	Golding.

NORM OF NUMBER 43.

Quartz	36.54 %	Hypersthene	9.70 %
Orthoclase	15.01	Magnetite	2.09
Albite	9.43	Ilmenite	0.61
Anorthite	19.46	Calcite	3.30
		Corundum	2.96
		Water	0.97

TOTAL. 100.07 %

ORIGIN AND HISTORY OF THE ROCKS.

Undoubtedly one of the most interesting problems concerns the origin of the many different rock types of the complex.

Structurally the Shamvaian System rocks of the Mazoe Valley have been folded into a syncline, and petrographically they consist of conglomerates, quartzites and mica-schists. All these rocks, which have been subsequently altered by metamorphism, are presumably of an original sub-aqueous environment. The sedimentary rocks have been subjected to a series of igneous intrusions throughout the valley length. Five granite stocks and their associated rocks are found along the axis of this syncline. Two of them, the Bindura and the Glendale Granites, are remarkably similar in several respects, particularly in shape and size.

On the Plymouth and Sweet Valley farms some fourteen miles to the west of Bindura, a granite stock is intrusive into a mass of gabbro (The Sweet Valley Gabbro). The Glendale Stock, as it is named, appears to have forced its way up through the gabbro near its central part, and in doing so split the earlier basic intrusion into two portions, one on the north-east flank of the granite, the other on the south-west. Dolerite dykes of later age cut through both granite and gabbro.

The following is a suggested summary of events, (excluding the periods of folding and uplift) of the Bindura Stock as indicated by the work carried out in this thesis.

/ (a) The Laying down

(a) The laying down of the Shamvaian System under conditions of varying aqueous environment.

(b) The sediments were intruded by a sill-like or lopolithic body of gabbro.

(c) A primary granite magma then stoped its way upwards beneath the site of the previous intrusion incorporating sedimentary material in itself. The sedimentary rocks were perhaps wholly or partly assimilated, and a hybrid or compound magma intruded the gabbro and sediments, splitting the gabbro into two portions. The effect of the granite intrusion (the addition of material and by metamorphic effects) was to change the gabbro into an amphibolite , Mineralized solutions or emanations from the granite changed part of the south-western gabbro into the Phoenix Prince Diorite.

(d) Numerous aplite veins were intruded into the granite and amphibolite, followed almost simultaneously by a phase of pneumatolytic tourmalinization, which produced the large belt of tourmaline bearing rocks on the north - east side of the complex.

(e) Hydrothermal veins of quartz were intruded into the granite and the surrounding rocks, completing this cycle of events.

(f) The introduction of the dolerite dykes followed at some later stage.

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It is difficult to decide when the high degree of metamorphism took place in the surrounding sediments, but it seems probable that this had occurred before the intrusion of the granite. The main reasons for this conclusion are that similar metamorphic rocks occur throughout the Mazoe Valley, there is no increase in the metamorphism towards the granite boundaries, and neither does the granite itself show any recognisable metamorphic effects.

With regard to tourmalinisation, the Bindura Area provides most of the conditions necessary for the process described by Alfred Harker.

He writes : - (1932 p 118)

> " The most widespread type of pneumatolysis associated with granitic intrusions is due to boric emanations and takes the form especially of tourmalinization ....
>
> Tourmalinization may indeed be found at a considerable distance from a granite-contact, but only in the proximity to tourmaline-quartz veins, which mark the channels of supply. The change commonly begins with the formation of little crystals of tourmaline enclosed in those aluminous silicates which furnish most of the material. Biotite is first attacked, then cordiorite and andalusite, and finally felspar if present.
>
> Ultimately all the silicates are destroyed, and the final product of boric pneumatolysis in a slate, as in a granite, is a tourmaline-quartz rock. Here, however, it may be named a tourmaline - quartz - schist. "

Many other writers substantially agree with this description. There is not the same unanimity of opinion as far as the origin of amphibolites is concerned.

Amphibolites of a supposedly similar type to those at Bindura have been described by several people.

J.A. Richardson writing on amphibolites in Malaya came to the conclusion they had been derived by a granitic intrusion.

/ " It is possible

" It is possible, therefore, that the conditions of compression, hypothetical FeO, CaO MgO migration, and any superimposed conditions of heating and base migration from the Main Range Granite in the vicinity may have combined to produce the amphibole schist series. "

Turner and Verhoogen conclude though, that regional metamorphism is of the utmost importance in producing amphibolites as can also be contact metamorphism.

" The amphibolite facies embraces the range of temperature and pressure for which the assemblage hornblende-plagioclase is stable. The amphibolite facies correspond to medium and high grades of regional metamorphism, and medium grades of contact metamorphism. "

An interesting case is provided by T.A. Dodge's work. He described amphibole rocks similar to those occurring at Bindura. Of these he writes, (p.581, 569)

" .... a zone of sills of gabbrose or doleritic character were injected into the district.

Continued folding and differential stress changed these intrusives into amphibolites.

The felspar is chiefly oligoclase although both albite and andesine are also found.

The quartz in the amphibolite is identical in appearance with the felspar, ... "

No explanation is given, however, of the abundance of quartz, and of how the plagioclase became so sodic, i.e. a change from labradorite to albite or oligoclase.

The real question appears to be whether the amphibolite has been formed by regional metamorphism, and the granitic material present injected into the already altered " gabbro ", or whether the granite intrusion itself was responsible for the alteration of the basic rock.

At Bindura the structural relationships as well as the petrography indicate an ortho-origin for the amphibolite. It seems most probable that this rock was formed by the contact effects together with addition of material, from the granite.

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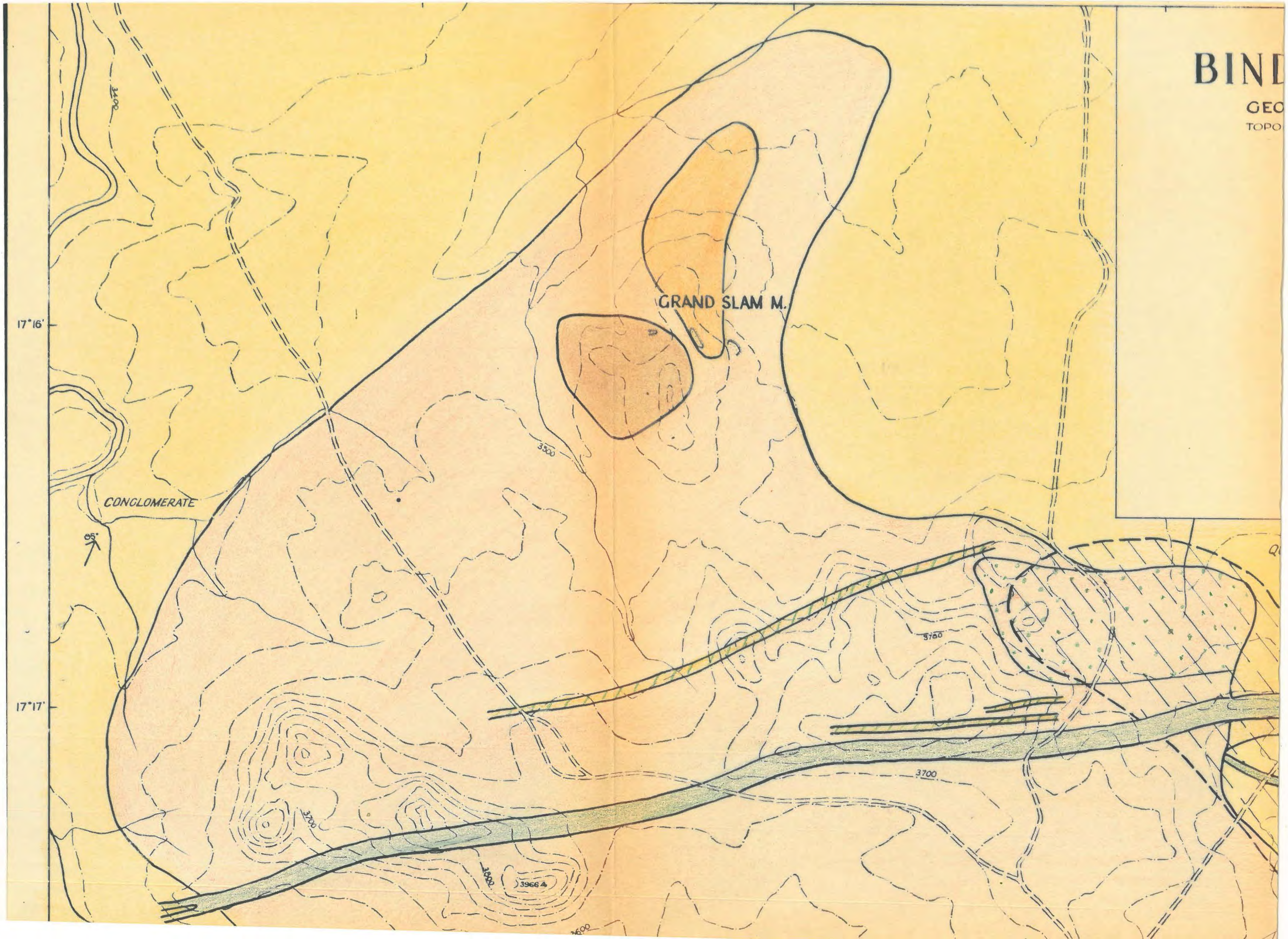
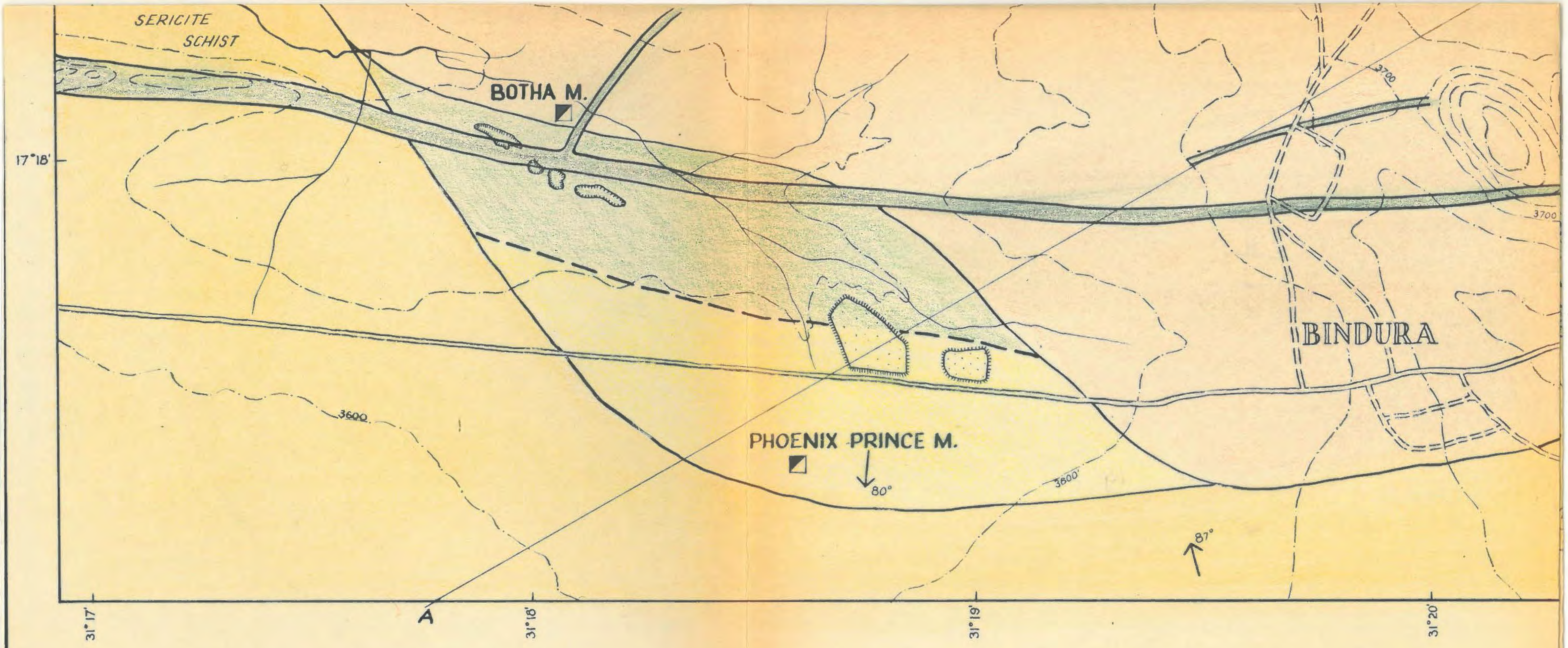
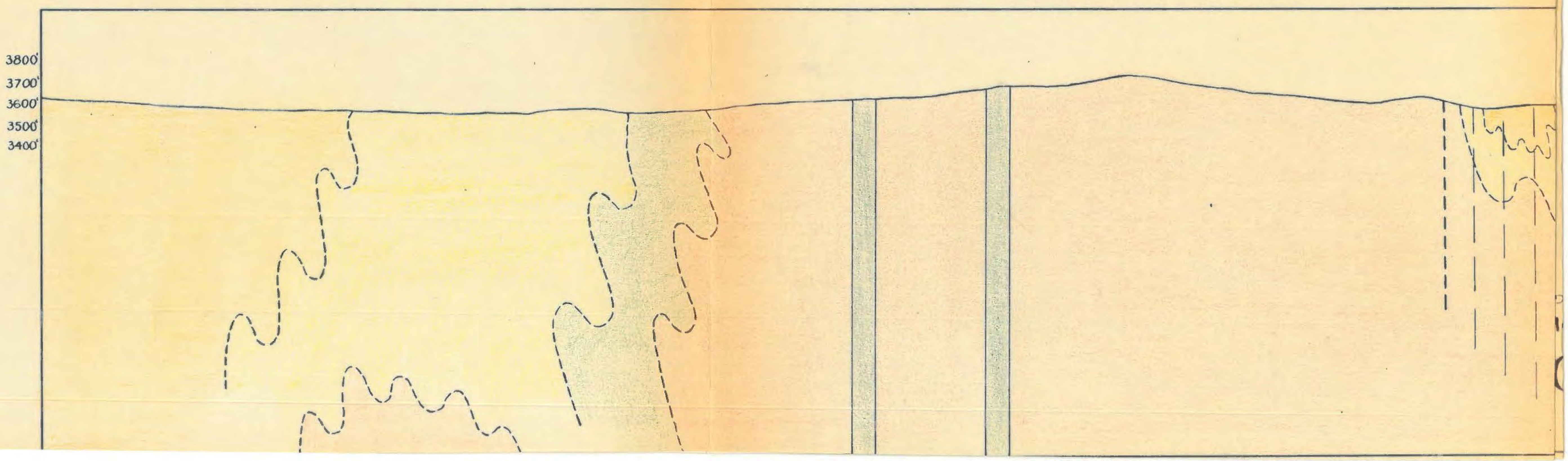
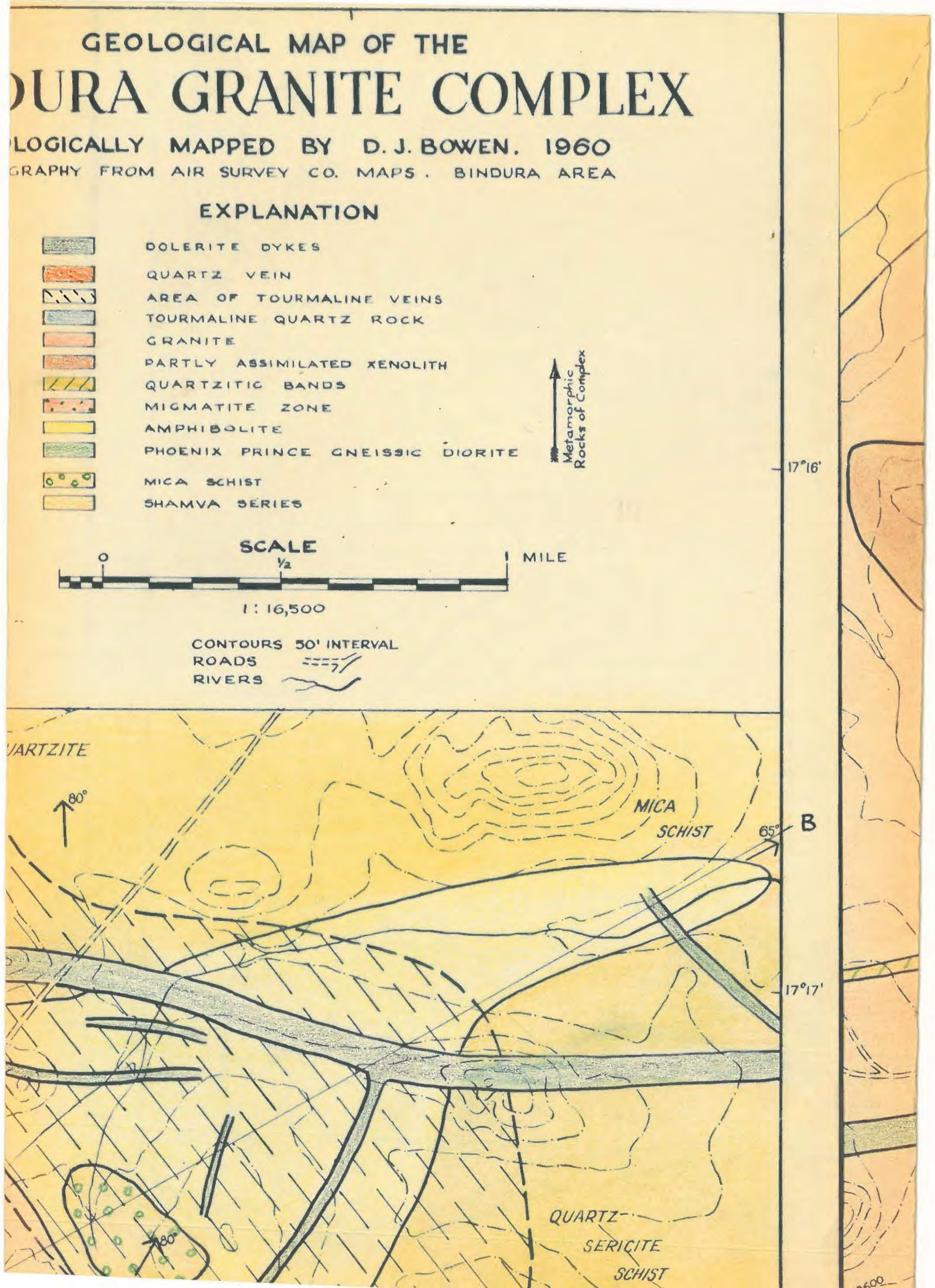


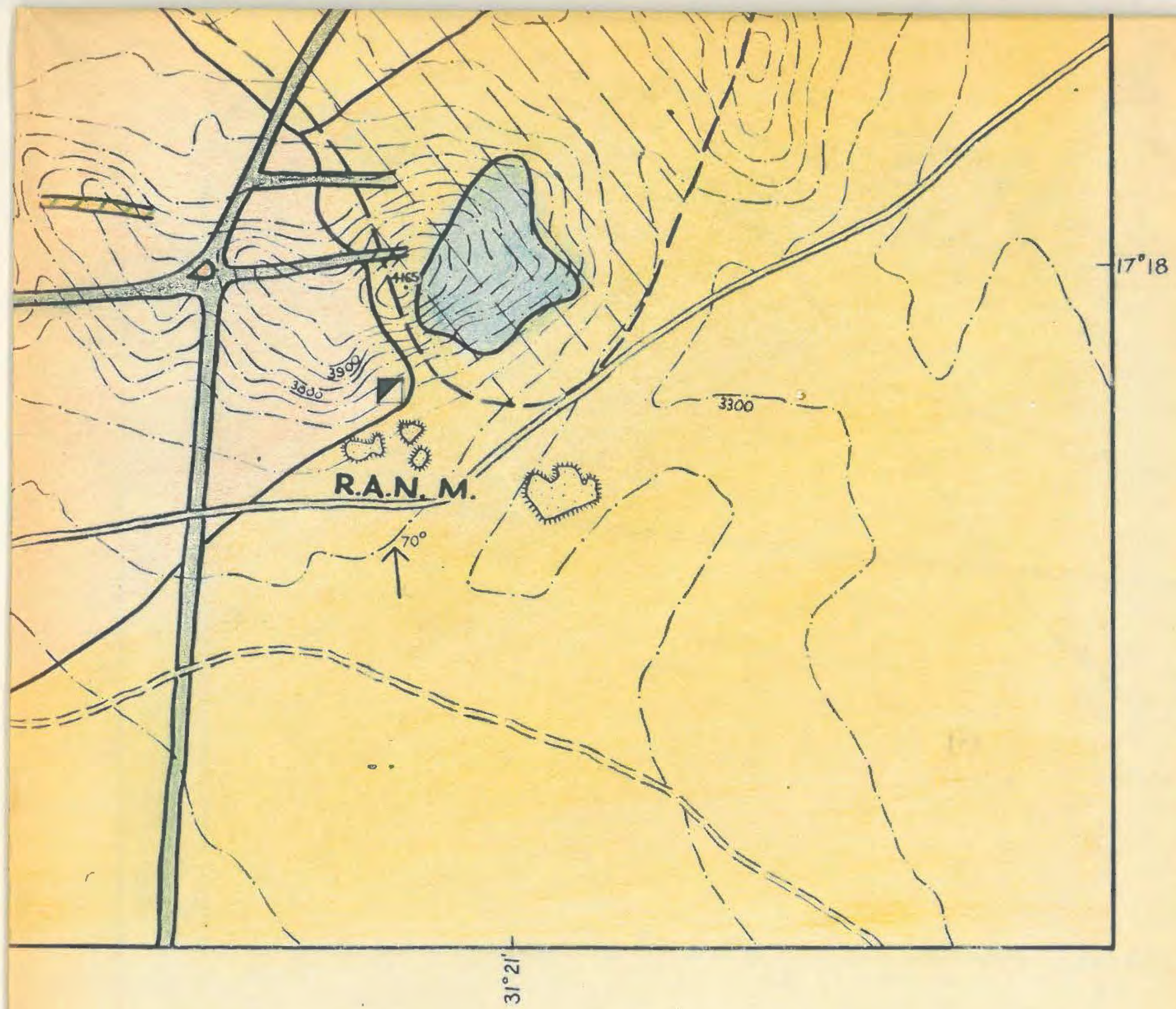
GRAND SLAM M.
CONGLOMERATE
17°16'
17°17'
3500
3700
3700
3966



SECTION A-B
VERTICAL SCALE 1"=800'




GEOLOGICAL MAP OF THE
)URA GRANITE COMPLEX
·LOGICALLY MAPPED BY D. J. BOWEN. 1960
GRAPHY FROM AIR SURVEY CO. MAPS. BINDURA AREA
EXPLANATION
DOLERITE DYKES
QUARTZ VEIN
AREA OF TOURMALINE VEINS
TOURMALINE QUARTZ ROCK
GRANITE
PARTLY ASSIMILATED XENOLITH
QUARTZITIC BANDS
MIGMATITE ZONE
AMPHIBOLITE
PHOENIX PRINCE GNEISSIC DIORITE
MICA SCHIST
SHAMVA SERIES
Metamorphic Rocks of Complex
SCALE
0
½
1 MILE
1 : 16,500
CONTOURS 50' INTERVAL
ROADS
RIVERS
17°16'
17°17'
UARTZITE
80°
MICA
SCHIST
65°
B
QUARTZ-
SERICITE
SCHIST
80°



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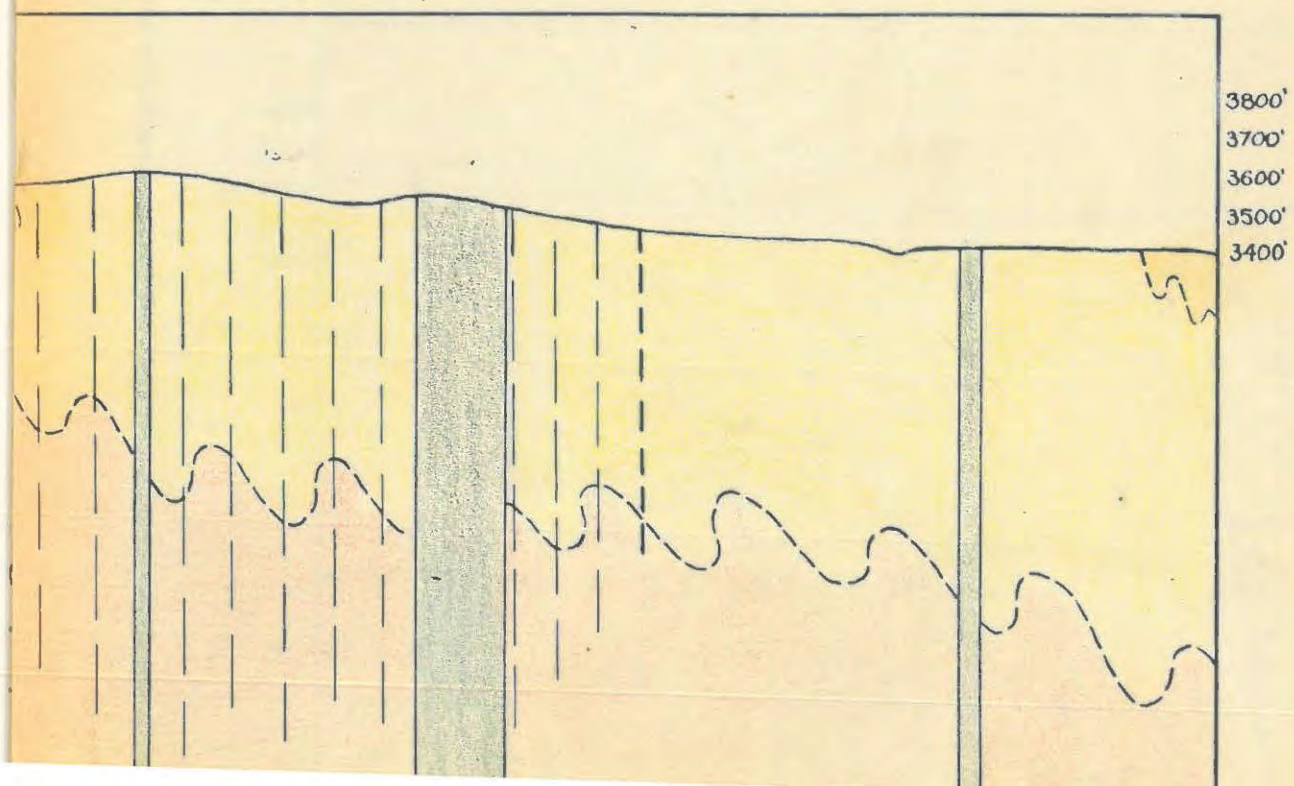

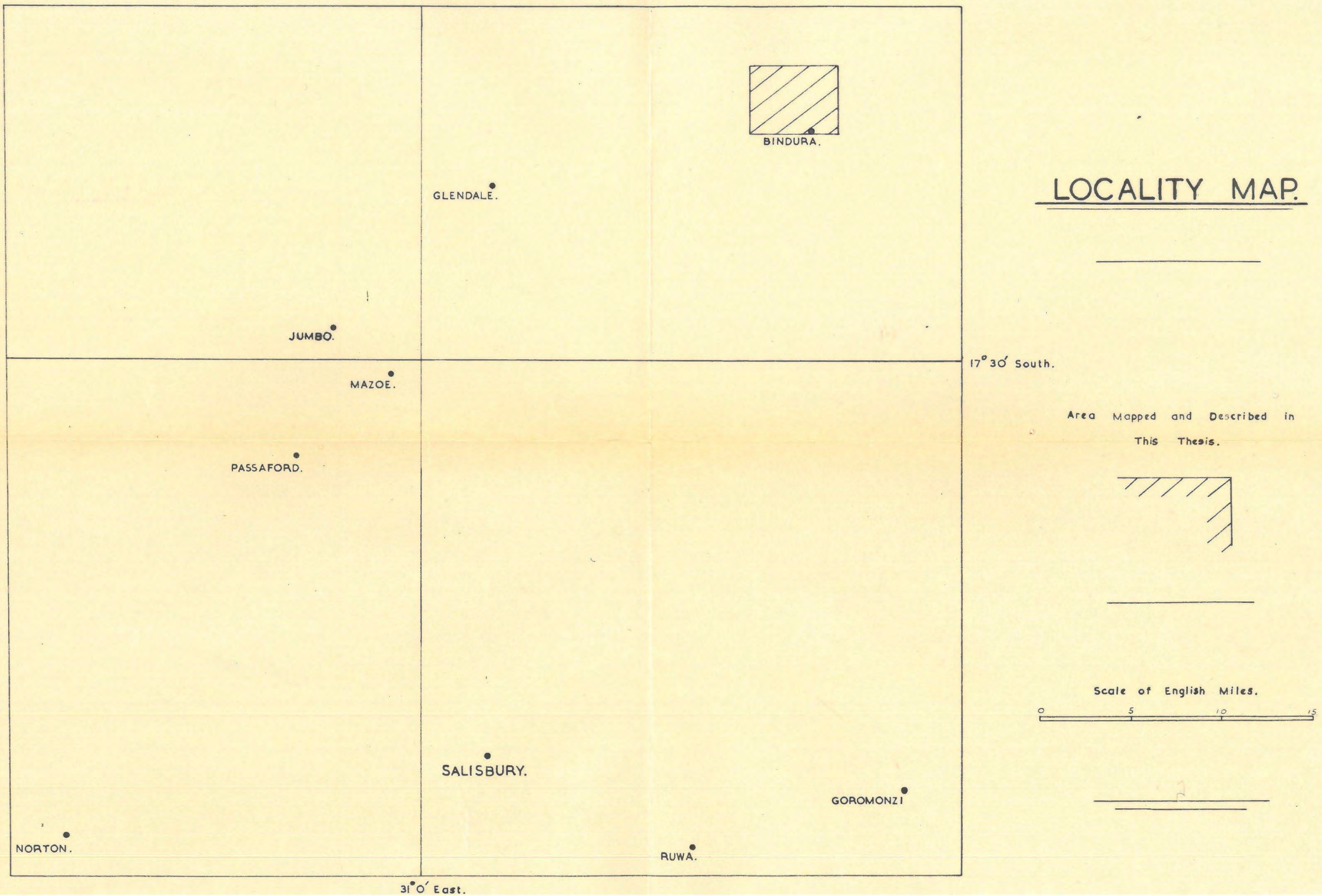

LOCALITY MAP.
BINDURA.
GLENDALE.
JUMBO.
MAZOE.
PASSAFORD.
SALISBURY.
GOROMONZI
NORTON.
RUWA.
17° 30′ South.
31° 0′ East.
Area Mapped and Described in This Thesis.
Scale of English Miles.
0
5
10
15