A GEOLOGICAL RECONNAISSANCE OF THE CHINAMORA BATHOLITH NEAR SALISBURY, RHODESIA

by
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ABSTRACT

The Chinamora batholith consists of a series of granitic rock types which are arranged in roughly concentric zones. The core of the batholith is a coarse-grained, often porphyroblastic, granite which is skirted by rocks which range from granodiorite to tonalite in composition. Tonalite is prevalent in the southern quadrants, except where the central granite is intrusive and transgresses the schist belt. Coarse-grained granodiorite, including areas of tonalite, skirts the northwestern quadrant and a medium-grained granodiorite skirts the northeastern quadrant. In this quadrant there is a transition zone up to 3 km wide, between the central granite and the medium-grained granodiorite. Large xenoliths of tonalite occur amidst the granite in the central portion of the batholith.

It is probable that the batholith was originally a mantled gneiss dome mainly composed of tonalite, which was modified subsequently by the addition of potassium to form granodiorite, and in turn to form a granite core.

Three samples of granite were dated by the potassium-argon method and their ages were reported to be 1 429 m.y., 1 376 m.y., and 874 m.y. respectively. These dates are much younger than the age of the Chinamora batholith which was probably emplaced at 2 900 m.y. or earlier, and they are taken to indicate continued thermal activity which terminated in the late Precambrian.

Aerial photographs on a scale of 1:80 000 indicate numerous strongly foliated zones which form a complex system of synforms and antiforms upon which is superimposed a rectangular grid of deeply incised lineations. These features appear to be transgressed by the granite and are taken as additional evidence of potassium metasomatism in the core of the batholith. These structures are believed to result from the rotation of the direction of pressure in a clockwise direction, starting in the north-northeast and terminating in the south-southwest.

The complex structure and the presence of large xenoliths in the central portion are taken to indicate that the present erosion surface is close to the roof of the batholith.

No evidence was obtained to indicate a genetic relationship between the granite and the mineral deposits which surround it due, possibly, to a lack of analytical data.

The presence of a transgressive phase of the granite on the southern flank of the batholith may account for the lack of gold mineralization in that vicinity.

In conclusion it is believed that the results of this work justify the reconnaissance approach which was used.

CONTENTS

I. INTRODUCTION

The Chinamora batholith is situated about 15 km to the north of Salisbury in Rhodesia. It is an elliptically shaped mass of granitic rocks 1 488 sq km in extent which measures about 40 km from north to south and about 50 km from east to west.

The batholith is Archaean in age and is almost completely surrounded by the Salisbury, Mazoe, Bindura and Shamva schist belts. There is a gap of approximately 20 km in the east where the granitic rocks of the Chinamora merge with those of the Mrewa batholith.

The schist belts are well mineralized and numerous mines and mineral prospects are situated close to the contact with the batholith. Gold is ubiquitous and several old mines occur in the western portion of the batholith itself; nickel-copper deposits are being mined in the north, pyrite deposits in the northwest and pegmatite deposits are exploited on a small scale in the southwest and south (Figure 1).

The Chinamora area is well suited to the reconnaissance type of investigation for several reasons, some of which are related to its geological significance and others to its accessibility. Geologically it is of special interest for it approaches and perhaps typifies a gregarious batholith of Archaean age, as described by A. M. Macgregor (1951) (Figure 2). In addition, it appeared from the results of a previous study by Viewing (1968) that the occurrence of the pegmatite deposits on the south flank of the Chinamora batholith was anomalous. Briefly, this work indicated that pegmatite deposits of commercial importance occur in the vicinity of granites which are relatively rich in potassium. The chemical analyses available at the time indicated that granites of this type were concentrated along the northern and southern flanks of the craton, parallel with the Zambezi and Limpopo metamorphic belts.

However, the only granitic rocks to have been analysed from the Chinamora region were grano-

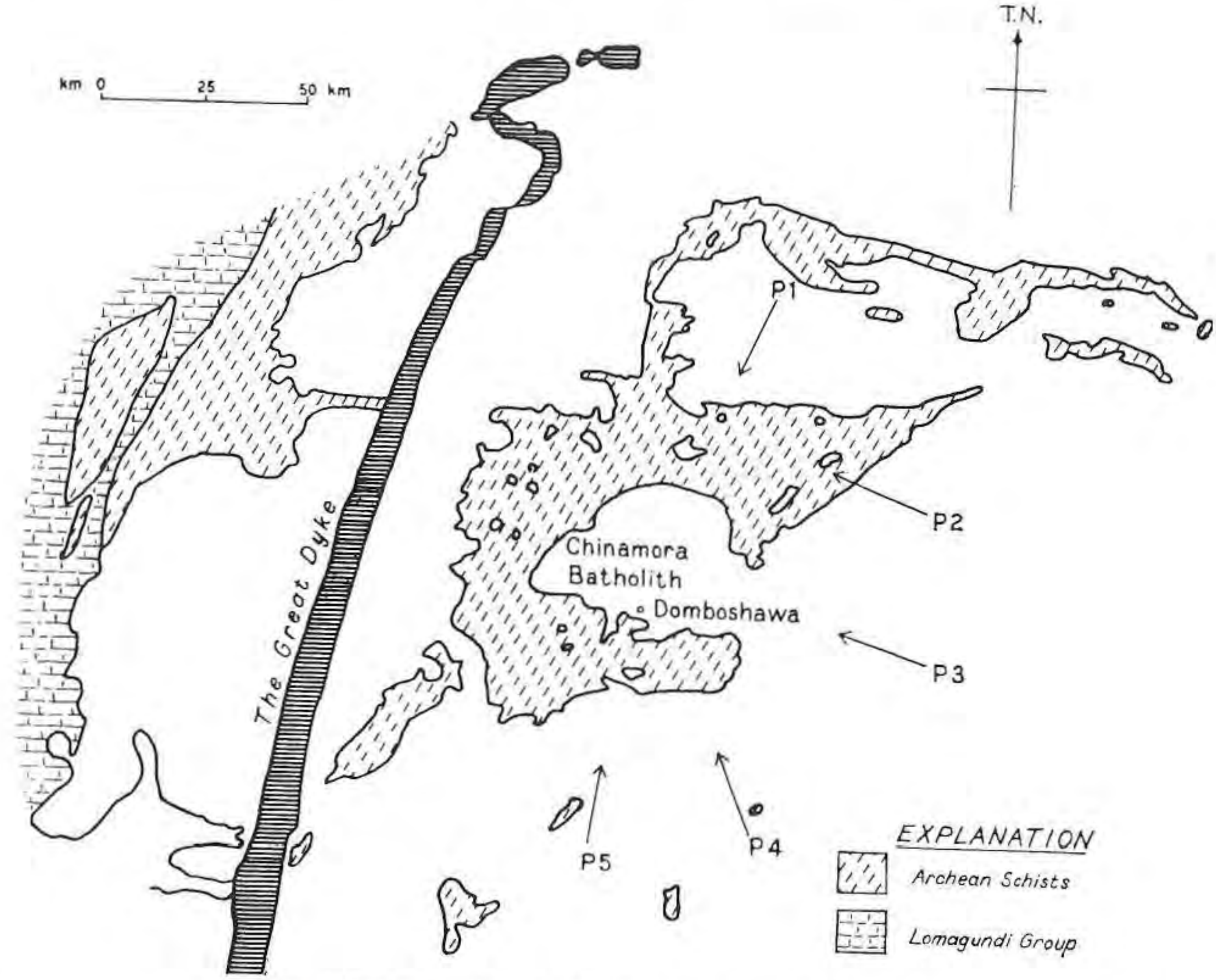

Figure 1. Regional setting of the Chinamora batholith, Rhodesia.

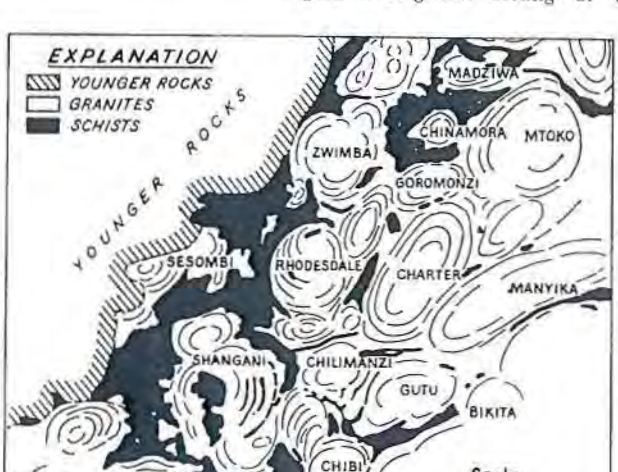

Figure 2. Rhodesian Archaean structure explained by gregarious batholiths (from A. M. Macgregor, 1951).

diorites from small stocks within the schist belts, and none had been analysed from the batholith itself. Subsequently a series of four samples was collected at intervals of about 4,8 km apart along a road traverse from the southern margin of the batholith towards the central area. The chemical analyses of these samples indicate the granites to be uniformly rich in potassium, from 4,33 per cent to 5,93 per cent, and amongst the richest to have been reported from Rhodesia (Viewing, 1969).

In addition to the features of geological interest, the Chinamora rocks are relatively well exposed as compared with other batholiths which form the margins of the Archaean schist belts. The schist belts which surround this area are served by excellent motor roads and the batholith itself, except in the most rugged areas, is traversed by a network of all-weather unmetalled roads and tracks.

Some 300 samples of granitic rocks were collected at random from 275 sites on a network of road traverses, a sample density of 1 per 5,45 sq km or 2,01 sq miles. The samples were classified according to grain size, foliation and whether they were porphyroblastic, or potassic, or sodic.

II. PREVIOUS WORK

There is no previous separate and coherent geological study of the Chinamora batholith, but there are several short accounts of portions of its fringe, particularly in the south, southwest and western quadrants. These accounts form parts of certain bulletins of the Geological Survey of Rhodesia and are supplemented by a report by Robertson (1964) (Figure 3).

The southern flank of the batholith was mapped in conjunction with the major portion of the Salisbury gold belt by H. B. Maufe (1920). He was

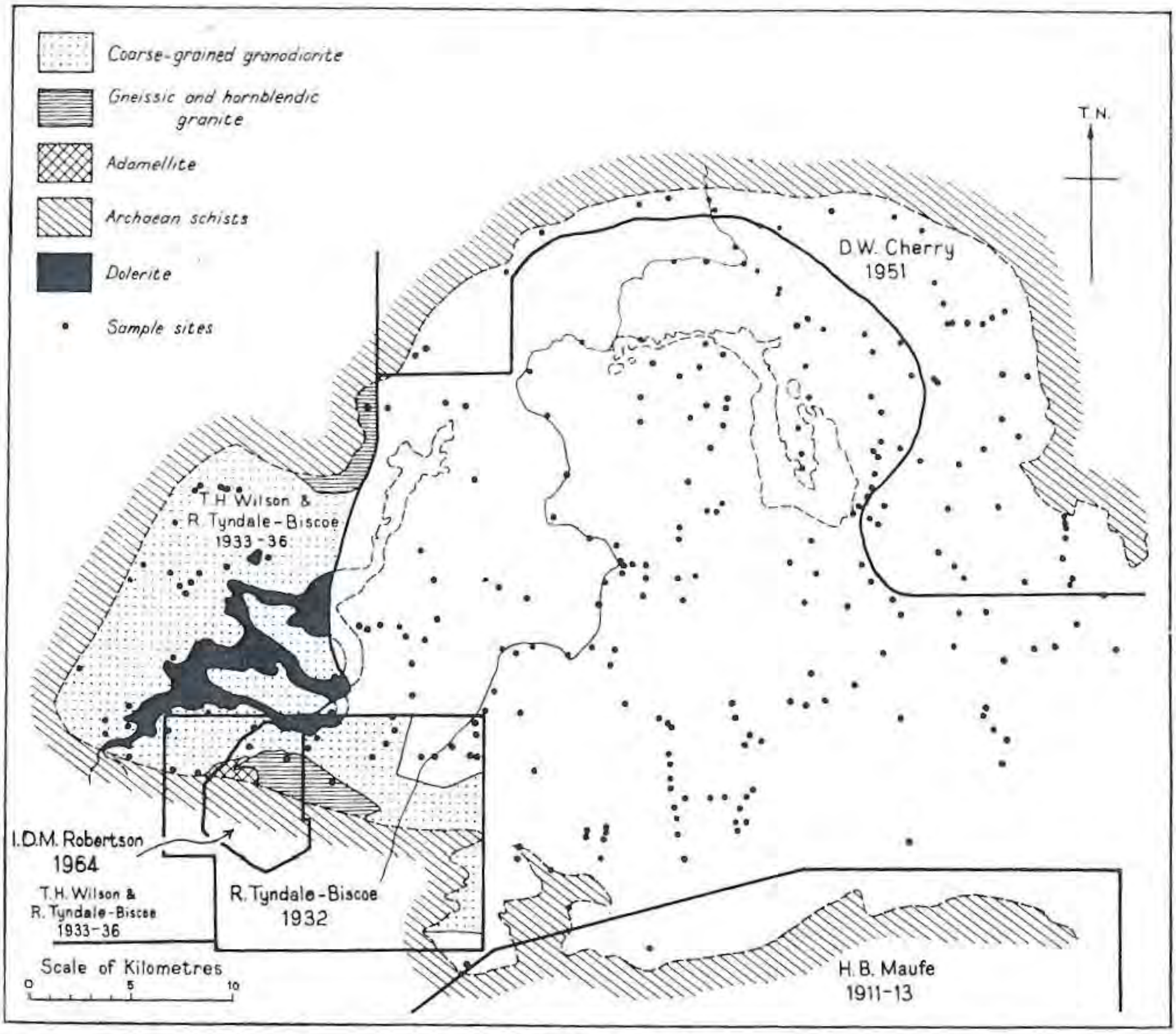

Figure 3. Previous work.

convinced that the granite is intrusive into the basement schists of the gold belt and took as evidence the degree of contact metamorphism, the incorporation of lumps and slivers of the recrystallised greenstone, and the *lit par lit* penetration of the greenstone by stringers and knots of granite a few yards from the contact. These observations relate to the granite on the southern side of the Salisbury gold belt, some distance from the Chinamora outcrops, but Maufe believed that all the granites in this area were intrusive and that the Chinamora is a separate batholith which coalesces with the Mrewa batholith to the east.

Maufe's mapping along the flank of the Chinamora batholith was extended to the west by R. Tyndale-Biscoe (1932) who recognised three different types of granite. The most extensive of these is a coarse-grained, massive, sodic granite whose texture varies to gneissic, and in the eastern portion of the area mapped has a marginal phase of gneissic and hornblendic, potassic granite. This is intruded by a medium and fine-grained massive granite which is younger, and which separates the coarse-grained massive granite from the schists in the western part of the area mapped.

Tyndale-Biscoe supported Maufe's view that the granite is intrusive and took as evidence its cross-cutting relationship with the strike of the schists, and the abundant inclusions of greenstone, greywacke and conglomerate in the granite. In addition he described the occurrence of gold in five groups of claims, in which the mineralization occurs in vein quartz in granite or associated with inclusions of schistose rocks in the granite.

The western portion of the Chinamora batholith was described by Ferguson and Wilson (1937). Their map is in part contiguous with Tyndale-Biscoe's and it is possible to distinguish the granites which they described. The main granite of both areas is the coarse-grained, grey, massive, biotite granite, but in Ferguson and Wilson's area the marginal phase is a coarse-grained, microcline-rich, biotite granite, with pink and granular varieties.

The gneissic and hornblendic granite, which forms a marginal phase to the main granite in Tyndale-Biscoe's area, occurs to the north of the microcline granite. It is greyish coloured, granular and characterised by a green amphibole and a little biotite. Ferguson and Wilson reported a granitic breccia in which the main granite contains inclusions of a "granite" which is particularly rich in amphiboles. They noted that inclusions of quartz and micaceous schist are common along the contact with the Chinamora batholith.

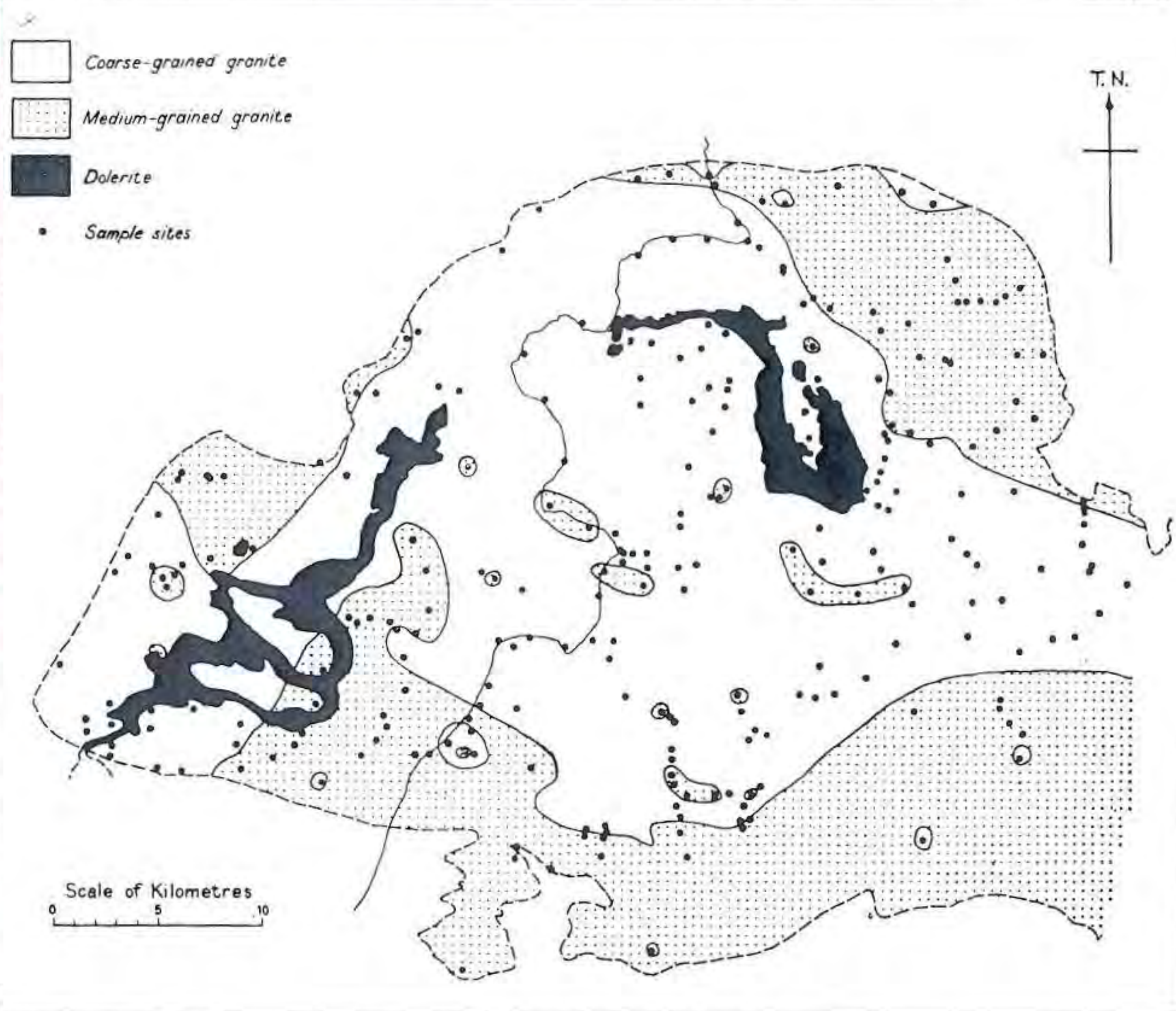

Figure 4. Coarse- and medium-grained rocks.

A portion of the area mapped by Tyndale-Biscoe was reinvestigated by I. D. M. Robertson (1964). He named the main granite described by Tyndale-Biscoe as "The Gneissic Granite" and reported it to vary from fine- to coarse-grained, and in texture from even-grained to porphyritic. Characteristically this rock is rich in magnetite, has a gneissic texture, and the plagioclase is crushed and partly replaced by microcline. The marginal phase of the main granite he described as hornblendic gneiss and the contact between it and the main granite appears gradational. It is intrusive into the rocks of the schist belt, and consists mainly of plagioclase, quartz, biotite and hornblende, with minor amounts of microcline, epidote and sphene. It contains numerous pegmatites, some of which contain lithium, tantalum, tin and beryllium. Robertson described both the main granite and its marginal, gneissic phase, as syntectonic and distinguished between these and the "Elpidha granite" which he classified as post-tectonic. This is a quartz-microcline-plagioclase adamellite, of medium grain size, and from these features and from its intrusive nature it is assumed to be the medium- and fine-grained massive granite described by Tyndale-Biscoe.

Robertson mapped some fifty pegmatites which strike west-northwest to east-southeast, parallel to the trend of the cleavage throughout the area. The lithium content of the pegmatites increases towards the southwest and he favoured a source in the Elpidha granite.

The age of most of the pegmatites is inferred from a determination on monazite from the Jack tin claims in the western part of the batholith. An age of 2 650±10 million years was accepted by Holmes (1954), and its validity was accepted in subsequent studies by Ahrens (1955) and by Vail (1968).

Other work in the Chinamora area was done by Cherry (1951), in which most of the northern margin of the granite was mapped, but not described, and by Debnam and Webb (1960). This later work was concerned in part with the geochemical dispersion of beryllium from the Mistress Mine. In addition there are reports by the staff of the Geological Survey who have visited the mines in the area from time to time, and reports by members of the United Kingdom Atomic Energy Board on the beryllium potential of the pegmatite deposits.

III. RESULTS OF THE RECONNAISSANCE

The fieldwork was restricted to sampling only and no systematic record was kept of structural features or descriptions of hand specimens which would be considered necessary in a more detailed investigation.

A feature of the Chinamora granites is that each hand specimen appears in some respects to be different from each other. This characteristic is a signifi-

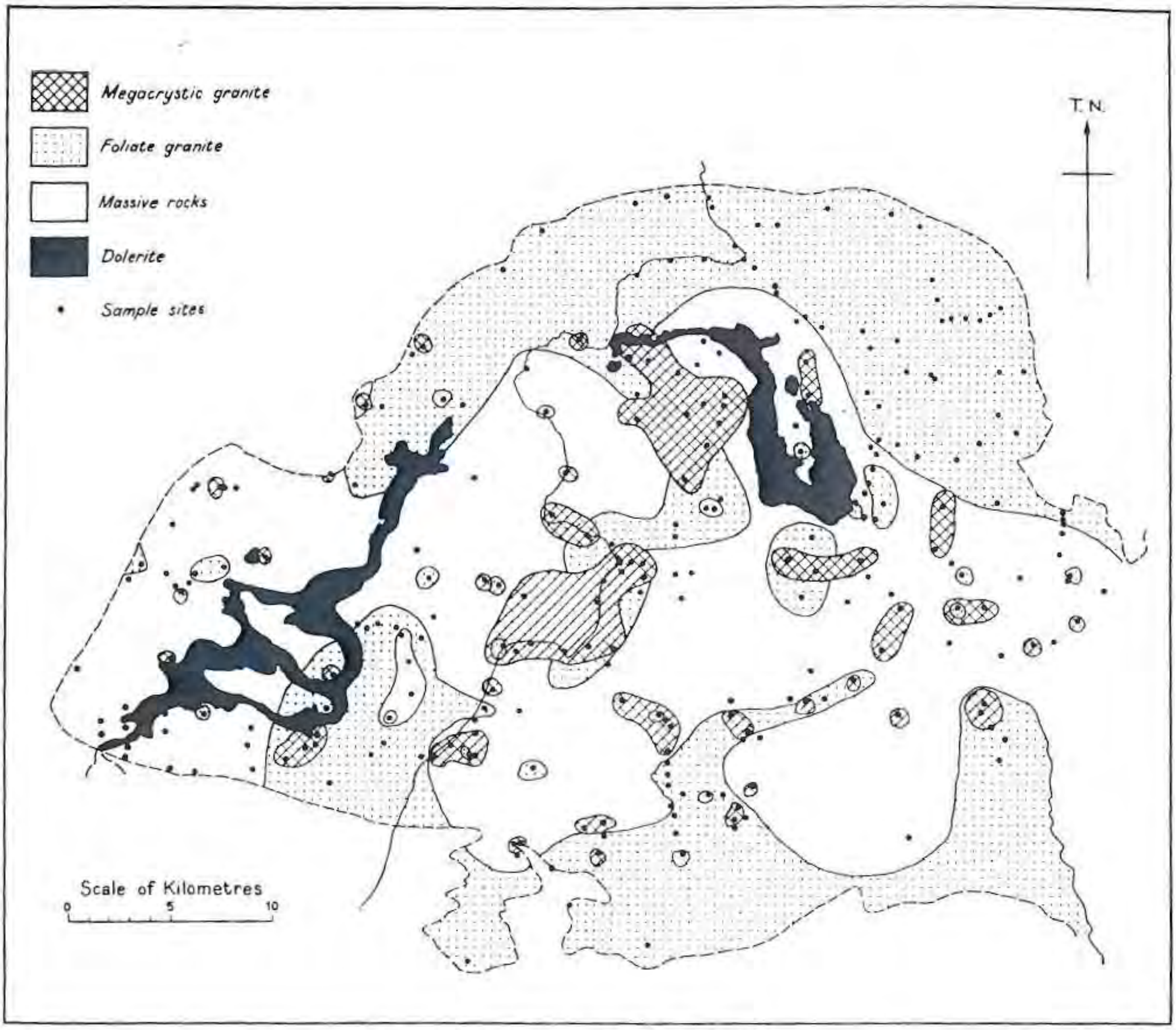

Figure 5. Foliated and megacrystic rocks.

cant problem in sorting some 300 samples into significant groups. Accordingly, the specimens were sorted into groups on a simple system of classification, mainly in order to avoid the selection of potentially insignificant groups. The classification which was used distinguished between:

(1) coarse and medium or fine-grained rocks,
(2) foliated and massive texture,
(3) porphyritic or porphyroblastic (megacrystic) and even-grained rocks,
(4) potassium-rich and sodium-rich rocks.

A. Physical Features of the Rock Samples

Medium- and fine-grained granites are widespread in the northeastern and southwestern quadrants of the Chinamora batholith but, in general, the central area is coarse-grained. This phase extends to the central parts of the northern boundary, and to the eastern and western boundaries also (Figure 4). The boundary between the medium- and fine-grained granite, and the coarse-grained granite is best exposed in the southern portion of the batholith. In one traverse of samples the boundary is gradational over a relatively short distance of 0,3 km.

The foliated granites are distributed mainly around the periphery of the batholith and are particularly prominent in the northeastern and southwestern quadrants. The central part of the batholith contains a tongue of foliated granite which almost links the northern margin with the southwestern margin. In general, the remainder of the batholith is massive in texture although containing several relatively small areas of foliated granite. Massive granite forms the margin of the batholith in the eastern and western extremities (Figure 5).

The distribution of the megacrystic rocks conforms to a loose pattern in which they are not characteristically associated with either foliated or massive rocks; however, there are associations on a regional scale. For example, the foliated granite of the northeastern boundary is characteristically non-megacrystic, whereas the belt of foliated granites which extends from the northern boundary, through the centre of the batholith to the southwestern boundary, is almost characterised by the presence of megacrysts (Figure 5).

The distribution of the potash-rich feldspars, as compared with the soda-rich feldspars, was determined by the visual estimation of polished and stained chips. The chips were about 30 mm square, polished, etched and stained according to the method recommended by Van Der Plas (1966). By this method the potash-rich feldspars are stained bright yellow, whereas the soda-rich varieties, quartz, biotite and hornblende are unaffected. The stained chips

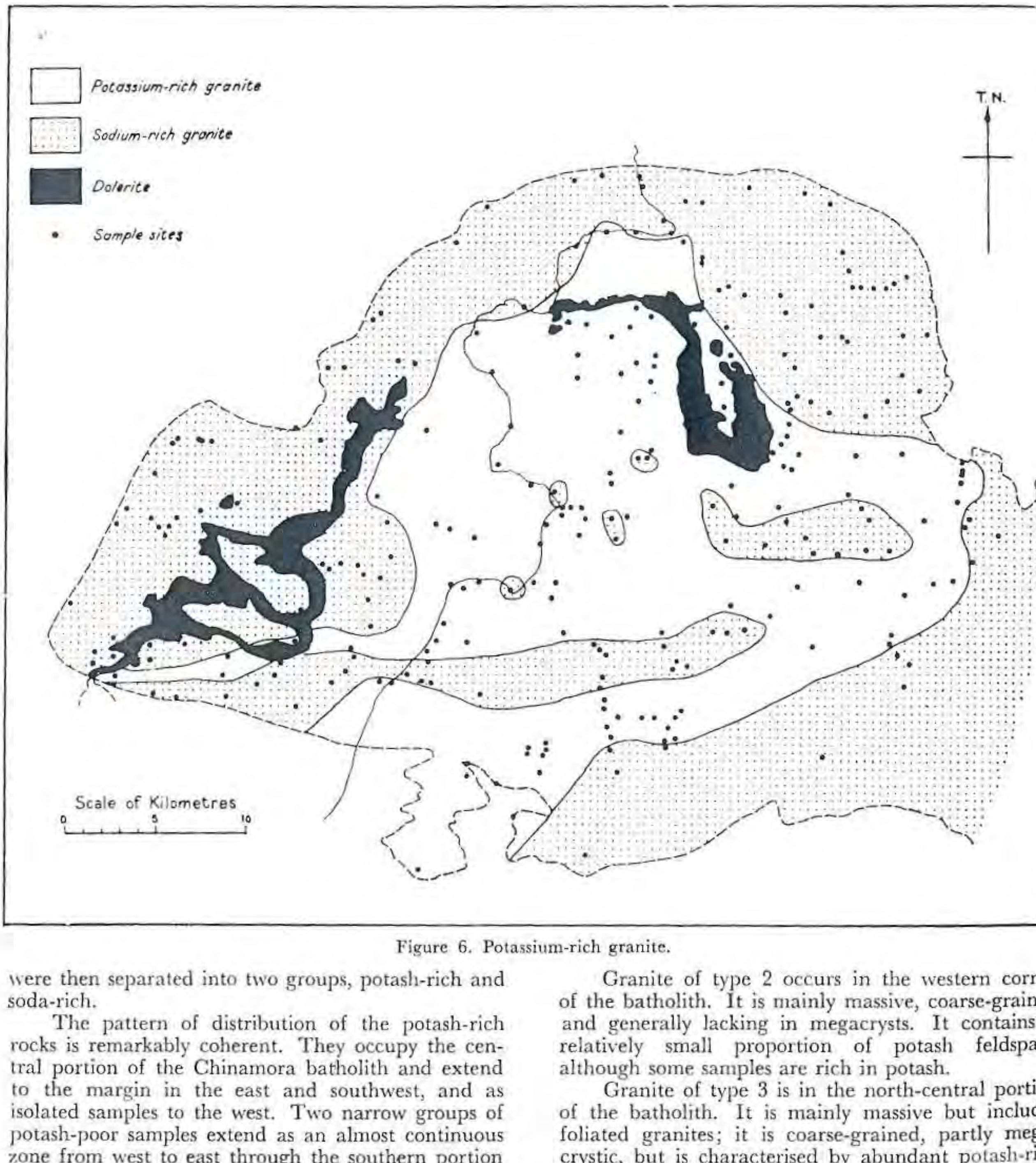

Figure 6. Potassium-rich granite.

were then separated into two groups, potash-rich and soda-rich.

The pattern of distribution of the potash-rich rocks is remarkably coherent. They occupy the central portion of the Chinamora batholith and extend to the margin in the east and southwest, and as isolated samples to the west. Two narrow groups of potash-poor samples extend as an almost continuous zone from west to east through the southern portion of the batholith (Figure 6).

B. Summary of Granitic Types

It is clear that there is wide variation in the degree of resolution of the distribution patterns which are presented, and it follows that those patterns with poor resolution may be insignificant. However, within the possible inconsistencies of the distribution patterns there are six which appear to be significant — four of these are pronounced and appear to have coherent distributions whereas two are relatively unpronounced. For ease of reference these patterns are given type numbers.

Granite of type 1 is situated in the northeastern portion of the batholith. Characteristically it is foliated, medium- to fine-grained, lacking in megacrysts and contains a relatively small proportion of potash feldspars, although some of the samples are rich in potash.

Granite of type 2 occurs in the western corner of the batholith. It is mainly massive, coarse-grained and generally lacking in megacrysts. It contains a relatively small proportion of potash feldspars, although some samples are rich in potash.

Granite of type 3 is in the north-central portion of the batholith. It is mainly massive but includes foliated granites; it is coarse-grained, partly megacrystic, but is characterised by abundant potash-rich feldspars.

Granite types 4 and 5 are marginal phases to type 3. Granite of type 6 was not recognised from the distribution patterns, but from its characteristic appearance as a relatively dark, foliated and coarse-grained rock, with a very small proportion of potash feldspars. This granite is not megacrystic and is somewhat similar to granite of type 2.

IV. CHARACTERISTICS OF THE DISTRIBUTION PATTERNS

The descriptions of several features of the granitic rocks of the Chinamora batholith indicate that there are significant variations in the compositions of these rocks, which from the patterns of distribution appear to be coherent on a regional scale.

The validity of these patterns was established by the chemical analysis of 46 samples of granitic rocks for the elements Na, K, Ca, Rb, Pb, Cu, Ni and Li.

TABLE I
SUMMARY OF ANALYTICAL RESULTS

		K_2O %	Na_2O %	$\frac{K_2O}{Na_2O}$	CaO %	Rb ppm	Pb ppm	Li ppm	Sr ppm	Cu ppm	Ni ppm	Number of Samples
Standard deviation		0,11	0,11		0,11	6	12	3,5	3	1,3	2,5	
Type 1	high	3,3	4,0	1,06	1,0	96	60	55	85	2	17	
	low	3,0	3,1	0,75	0,7	88	37	36	50	ND	11	3
	mean	3,1	3,68	0,86	0,87	91	48	44	65	1	13	
Type 2	high	4,0	4,3	1,14	1,8	120	74	35	135	12	25	
	low	2,8	3,5	0,92	0,4	54	37	3	5	3	12	7
	mean	3,66	4,0	0,65	0,95	95	51	18	70	7	16	
Type 3	high	6,1	3,8	1,61	0,8	212	90	39	70	2	15	
	low	4,9	3,2	1,36	0,6	154	57	23	25	ND	10	8
	mean	5,30	3,50	1,51	0,70	190	66	25	55	1	12	
Type 6	high	3,1	5,9	0,52	3,2	172	67	92	380	>50	100	
	low	0,24	3,2	0,08	1,1	74	20	6	45	2	21	9
	mean	2,07	4,27	0,48	2,17	74	42	27	196	19	54	

Of these samples, 36 were taken from the granitic rocks types 1 to 6, and the remainder were from traverses across boundaries between these granitic types. Thin sections from each were examined and finally, the relative ages of 3 samples of the granitic rocks were determined by the K-Ar method of analysis.

A. Geochemistry

Twenty-seven samples were analysed to establish whether there are significant differences in the chemistry of the four main phases of granite rocks and to discover whether the boundaries between them are gradational or distinct.

The analytical results are summarised in Table I and in Figure 7, according to Harpum's (1963) classification. The data indicate that granites of types 1 and 2 are remarkably similar in composition and it appears that texture is their only distinguishing feature. Granite of type 3 is distinctly different in composition and is characterised by a significant increase in the content of K, Rb and Pb, and a decrease in the content of Ca, Cu and Ni.

Granite of type 6 has a wide range of composition but characteristically is rich in Na, Ca and Cu, and is poor in K.

Other granites, for example types 4 and 5, are marginal phases. Type 4, the analysis of which is not given, was found to be similar to type 3, but contains significantly less Rb. Type 5 is a marginal phase between types 1 and 3 and the results confirm the gradual reduction in the content of K and Rb across this zone (Table II).

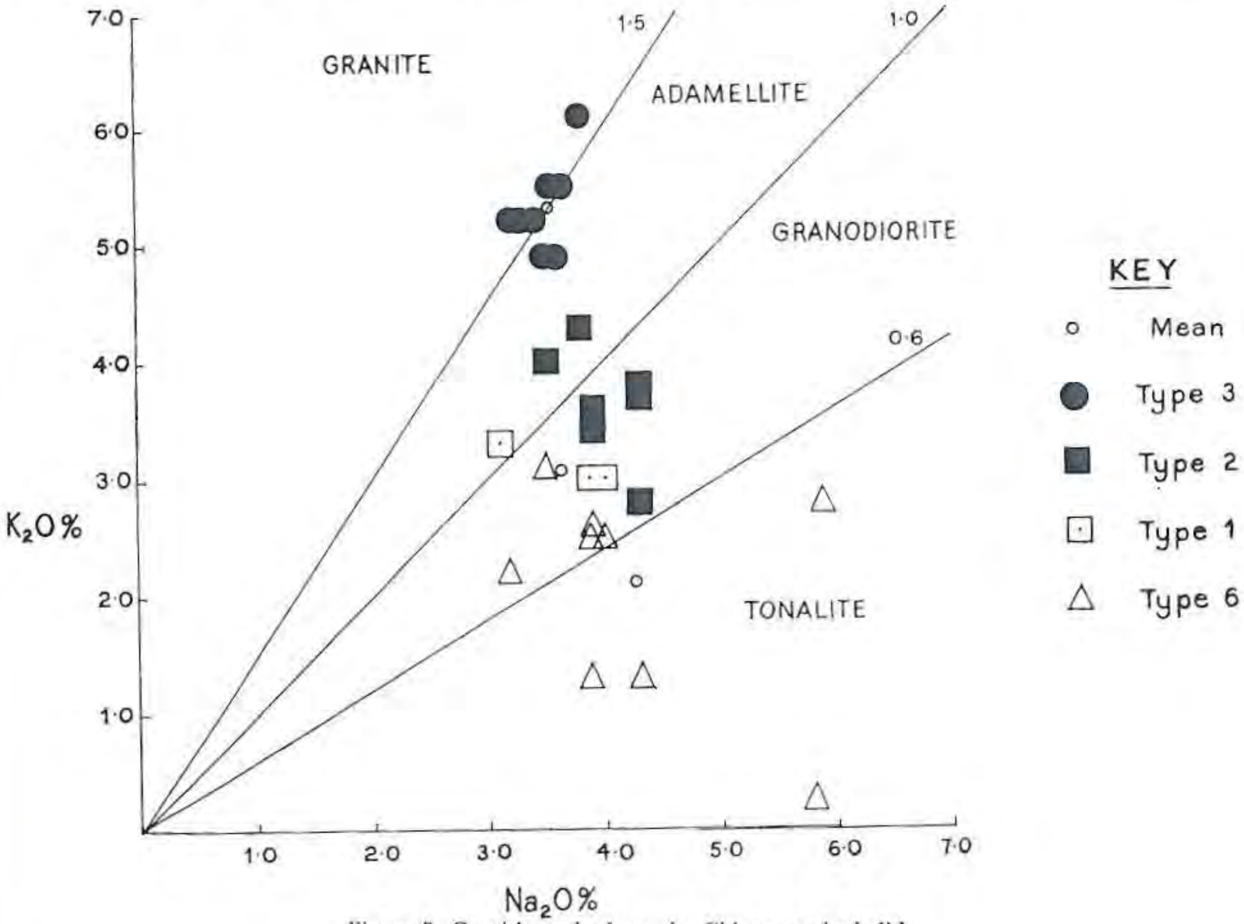

Figure 7. Granitic rocks from the Chinamora batholith.

TABLE II
TRAVERSE FROM GRANITE OF TYPE 3 TO GRANITE OF TYPE 1; NORTHEAST SECTOR, FROM SOUTHWEST TO NORTHEAST; DISTANCE 11 KM.

	K_2O %	Na_2O %	K_2O / Na_2O	CaO %	Rb ppm	Pb ppm
Standard deviation	0,11	0,11		0,11	6	12
Sample No.						
182	5,5	3,6	1,53	0,6	212	70
181	3,8	3,0	1,27	0,7	104	50
195	3,6	3,4	1,06	1,1	100	56
267	3,0	4,0	0,75	1,4	90	60
203	3,3	3,1	1,06	1,0	96	49
201	3,0	3,9	0,77	1,3	88	37

Chemical analyses of a series of five samples from the southern boundary of the Chinamora batholith near Domboshawa, indicate a gradational boundary from granite of type 3 to granite type 1 and to granite type 6.

B. Petrology

Thin sections of several samples from each of the granites were examined under the polarising microscope.

Granite type 1 is characteristically medium-grained and equigranular. It consists of fairly coarse-grained quartz, clear or slightly sericitised plagioclase, and fresh microcline with small amounts of biotite. The microcline is mainly interstitial but there are a few large megacrysts. The microcline is the youngest of the feldspars and the quartz is gently strained. Characteristically the plagioclase is fresh and unsericitised, and this feature is taken to indicate that the rock is recrystallised — *a medium-grained granodiorite.*

Granite type 2 is coarse-grained and its plagioclase, which is strongly sericitised, varies from euhedral to anhedral in texture. The plagioclase also contains discrete muscovite and some epidote. The quartz is coarse-grained. Biotite forms characteristic aggregates of small flakes, a feature which is also exhibited by epidote and some of the chlorite. Microcline forms large ragged crystals with strained twinning, and these contain inclusions of plagioclase, quartz and biotite — *a coarse-grained granodiorite.*

Granite type 3 contains large microcline crystals with numerous inclusions. The plagioclase grains are irregular and sericitised. The quartz forms a coarse-grained and sutured mosaic which is both cracked and strained. Biotite occurs as discrete flakes. The texture is interlocking but the inclusions of sericitised plagioclase in the microcline indicate the relatively late development of the potash feldspar — *a coarse-grained adamellite.*

Certain of the granites from the fringe of the batholith and from xenolithic remnants in the central portion have broad similarities, and these are typified by the gneiss at the Mistress Mine, called type 6.

Granite type 6 consists of large, oriented, strongly sericitised plagioclase set in a matrix of a fine-grained mosaic of quartz. There are scattered flakes of biotite and granular epidote aggregates, and crystals of green hornblende are scattered through the slide. Microcline is rare and is confined to the groundmass — *a gneissic hornblende biotite tonalite.*

C. Geochronology

Three samples of granitic rocks were analysed by Drs. Miller and Fitch of the University of Cambridge, using the K-Ar method. The samples were taken from the geographical centre of the batholith, and from points approximately equidistant from the centre and the north boundary, and from the centre and the south boundary, respectively. The samples analysed were relatively fresh as compared with the rocks at other sample sites in the vicinity.

The results of the analyses are 874±35 m.y., 1 376±41 m.y., and 1 429±42 m.y. respectively. These ages are substantially younger than the date of 2 650±10 m.y. reported by Holmes (1954) from a pegmatite within the Chinamora granite (Table III).

V. PHOTOGEOLOGICAL OBSERVATIONS

The photogeological interpretation was made following the reconnaissance sampling and the interpretation of that data. The reason for this unusual approach was to ensure that the rock sampling programme was random and not influenced by observations and interpretations which could provide a bias.

TABLE III
RESULTS OF CONVENTIONAL K-Ar DETERMINATIONS FROM THREE GRANITIC ROCKS IN THE CHINAMORA BATHOLITH, RHODESIA (MILLER & FITCH, 1971)

Reference	Rock	Method K-Ar	K_2O%	Atmospheric contamination	v/m	Apparent age & error in m.y.	Interpretation
10946	I.M.R.9/241	chloritised biotite 50/100	4,1 4,1 4,1	4,85 4,98 4,97	$1,41x10^{-2}$ $1,57x10^{-2}$ $1,55x10^{-2}$	828±34 902±36 893±36 av 874±35	Minimum age for crystallization and close maximum age for subsequent stress/metasomatism (completely chloritised "biotite").
10944	I.M.R.9/97	biotite 50/100	5,05 5,05 5,05	4,02 4,40 3,58	$3,39x10^{-1}$ $3,40x10^{-1}$ $3,38x10^{-1}$	1 377±41 1 377±41 1 375±41 av 1 376±41	Minimum age for intrusion and a maximum age for subsequent alteration (partly altered and strained biotite).
10945	I.M.R.9/217	biotite 50/100	6,85 6,85 6,85	4,58 3,40 3,52	$4,75x10^{-1}$ $4,75x10^{-1}$ $4,75x10^{-1}$	1 469±42 1 409±42 1 409±42	Minimum age for crystallization and maximum age for stress and alteration (partially altered biotite).

* v/m=volume of radiogenic argon-40 $(mm)^3$ N.T.P. per weight of sample (g).

The photographs used were black and white prints scale 1:80 000 (1965).

The most significant feature of the photogeological interpretation of the Chinamora area is the simple, roughly circular, form of the contact between the granite and the schistose rocks. This apparently simple form includes a group of linear features which are superimposed upon a complex system of basin or dome and syncline or anticline structures. Variations in the tone of the photographs distinguish areas of granitic rocks, and soils where no outcrops exist, from areas of dolerite. These are situated mainly in the western and north-central portions of the batholith. In addition certain variations of tone amongst the granites emphasize two belts of intensely contorted granites, one on the northern fringe of the batholith, and the other extending from the central portion to the east and south.

In general, the strike of the schistose rocks is parallel to the margin of the Chinamora batholith and there is little evidence of the nature of the contact between these rocks. It is only in relatively short sections of the contact that the strike of the schists is truncated by the granite, and these are close to Salisbury in the south, near the Iron Duke Mine in the northwest, and near the Lion's Head mountain in the east.

The boundary between the schists and the Chinamora granite is displaced and influenced by a series of faults which strike north-northeast to south-southwest parallel to the Great Dyke of Rhodesia (Figure 1). The faults are transverse and the most prominent of these has a dextral throw of about 1 km. In the central part of the batholith a dolerite dyke occupies the main fault fissure at a slight change of strike towards the north, and also occupies a short extension of the main fracture.

Two other prominent groups of lineations occur which strike at 90° west-northwest and 45° north-n-rthwest to the direction of the transverse faults. These lineations are believed to be second order features related to the development of the transverse faults. The west-northwest lineations are prominent near the Mazoe Dam in the western part of the Chinamora region, whereas the north-northwest, diagonal lineations are prominent in the central part of the batholith.

Other linears indicate the distribution of a complex series of fold structures which consist of basins or domes, some of which extend into closed synclines. The axes of these structures lie on a grid-like pattern whose intercepts are spaced at intervals of 5,7 km apart. The fold patterns are repetitive, but their axes are oriented in different directions. For example, the strikes of the most common fold axes are north-northeast and west-northwest, both parallel and normal to the direction of the transverse faults; whereas the strikes of the less common axes are north-northwest and east-northeast, parallel and normal to the diagonal fractures which are related to the development of the transverse faults. The pattern is not simple, however, for the syncline or anticline in the southern part of the batholith has a long axis which strikes east-northeast, whereas the syncline in the central portion has a long axis which strikes north-northwest.

In each case the outlines of the different fold structures appear to merge, and in the southern portion of the batholith a basin or dome extends into two synclines or anticlines whose long axes strike north-northwest and east-northeast respectively.

A. Interpretation

From the descriptions of the shear and fold patterns it is evident that these structures result from reciprocal pressures which were directed from the north-northeast, east-northeast, east-southeast and south-southwest respectively. The multiple fold structures are so complex that they are likely to have formed during the cooling and crystallization phase in the development of the Chinamora batholith. The structures related to the rectangular grid are the most commonly developed, whereas those related to the diagonals are less common, and from this pattern it is believed that the dominant pressure directions were north-northeast and east-southeast, and their reciprocals. These pressure directions could account for the major structure of the batholith and its present roughly circular boundary with the schistose rocks of the surrounding gold belts.

The diagonal direction accounts for folded structures which are relatively less persistent, and it is assumed that the pressures responsible were of lesser significance.

The dominant pattern of lineaments lies on the same rectangular grid as the fold structures, north-northeast and east-southeast and their reciprocals. In addition, the diagonal lineaments follow the directions of one of the less frequent fold axes, the south-southeast direction and its reciprocal. It is clear that two of the north-northeast lineaments indicate the trace of faults, both of which have a dextral throw of 1 km. These faults are 30 km apart, and between them there are other lineaments which appear to lie on a grid whose intercepts are about 5 km apart, and in places 2,5 km apart. This grid has a remarkably similar distribution to the grid pattern of the dominant fold structures and it is conceivable that here the linears indicate the trace of the axial cleavages which may be expected.

However, the north-northwest lineations indicate dextral transverse faults; and the lineations directed at right angles east-southeast, and diagonally, south-southeast, are likely to result from the same stress field.

The somewhat similar distribution pattern of these two groups of lineaments, related to folding and to faulting respectively, cannot be separated, and it is unlikely that their coincidence is fortuitous. It is reasonable to assume, however, that certain of the more prominent of the lineations indicate planes of weakness in the granite in which joints related to the transverse faulting are superimposed on cleavage directions.

It is assumed that the transverse faults and the joint patterns, east-southeast and south-southeast which are related to them, developed at a late stage as compared with the fold structures, and the granite is assumed to have been massive and crystalline.

The development of the structural patterns which have been described and discussed is believed to be the result of a gradual rotation of pressure which was directed first from the north-northeast (P1), and rotated clockwise through east-northeast (P2), east-southeast (P3), south-southeast (P4), to its reciprocal, south-southwest (P5). Renewed activity from the south-southwest (P5) at a relatively late stage resulted in transverse faults and the joint patterns related to them (Figure 8).

It is assumed that the clockwise rotation of the direction of pressure is related to a stable block of the craton west of the Chinamora batholith, con-

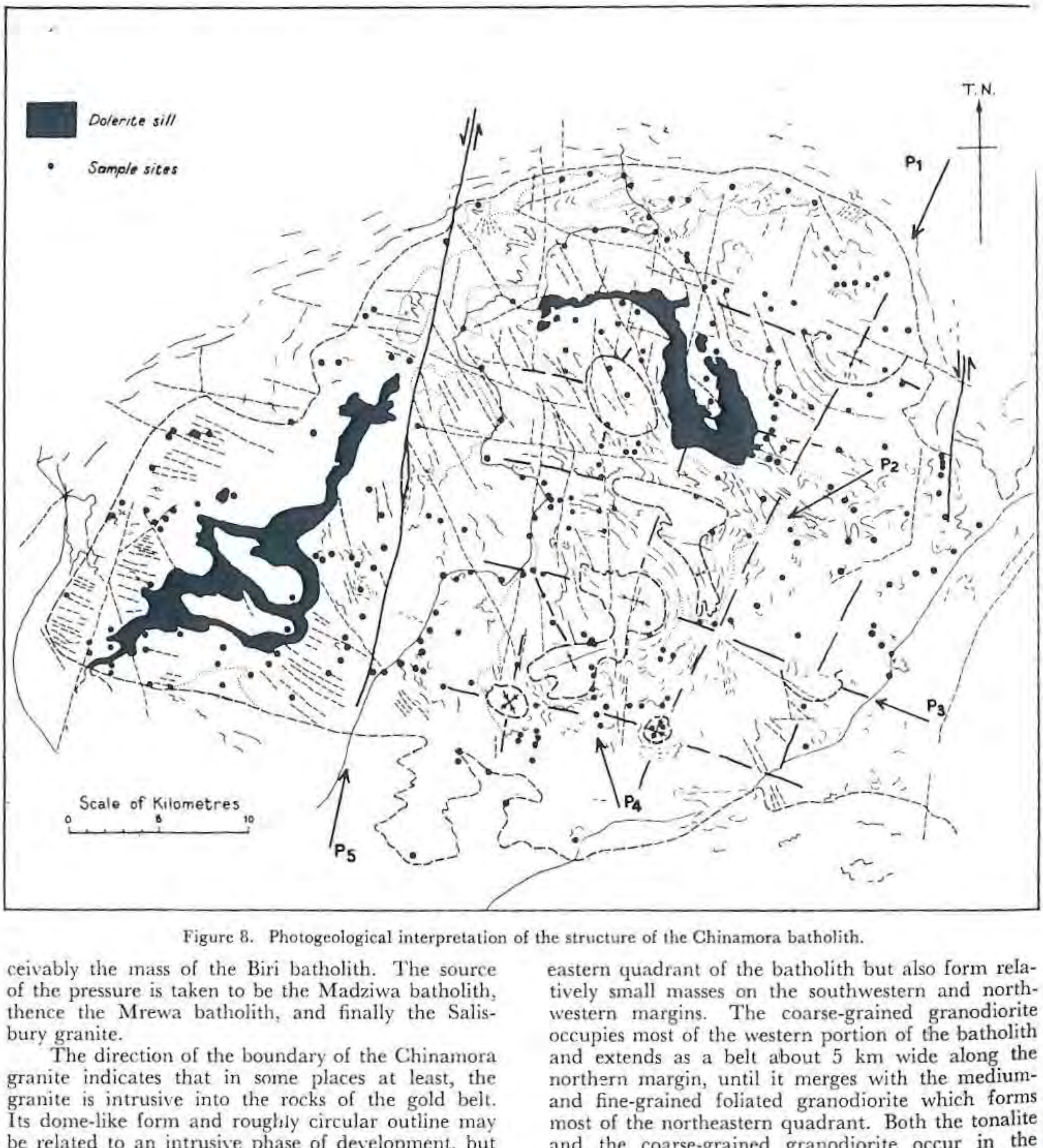

Figure 8. Photogeological interpretation of the structure of the Chinamora batholith.

ceivably the mass of the Biri batholith. The source of the pressure is taken to be the Madziwa batholith, thence the Mrewa batholith, and finally the Salisbury granite.

The direction of the boundary of the Chinamora granite indicates that in some places at least, the granite is intrusive into the rocks of the gold belt. Its dome-like form and roughly circular outline may be related to an intrusive phase of development, but could equally result from the principal directions of folding north-northeast (P1) and east-southeast (P3) respectively.

VI. DISCUSSION

The results of the chemical analyses and the examination of the thin sections of the granitic types have established that a variety of different rocks occur within the margin of the batholith and that these rocks have a coherent pattern of distribution on a regional scale.

On both petrological and petrochemical classifications these rocks range in composition from tonalite to granite, and these terms are used in the geological interpretation of the batholith (Figure 9). The marginal phases of the batholith consist of gneissic mesocratic hornblende tonalite or gneissic biotite tonalite, and coarse- and medium-grained granodiorite. The tonalites occur mainly in the southeastern quadrant of the batholith but also form relatively small masses on the southwestern and northwestern margins. The coarse-grained granodiorite occupies most of the western portion of the batholith and extends as a belt about 5 km wide along the northern margin, until it merges with the medium- and fine-grained foliated granodiorite which forms most of the northeastern quadrant. Both the tonalite and the coarse-grained granodiorite occur in the central portion of the batholith, the granodiorite forming elongated masses which strike from west to east in the central and southern portions. The tonalite masses occur in the central portion and are relatively small in size.

The central portion of the batholith consists mainly of coarse-grained granite and adamellite which in some areas are characterised by megacrysts and are foliated. These rocks are believed to result from the alteration of granodiorite on a regional scale, due to the effects of potassium metasomatism. In the northeastern quadrant of the batholith the boundary of the granite-adamellite is gradational into foliated and medium-grained granodiorite over a distance of about 11 km (Table II). The chemical analyses of six samples over this distance indicate a gradual increase in the contents of K, Rb and Pb towards the centre and, conversely, an increase of Ca

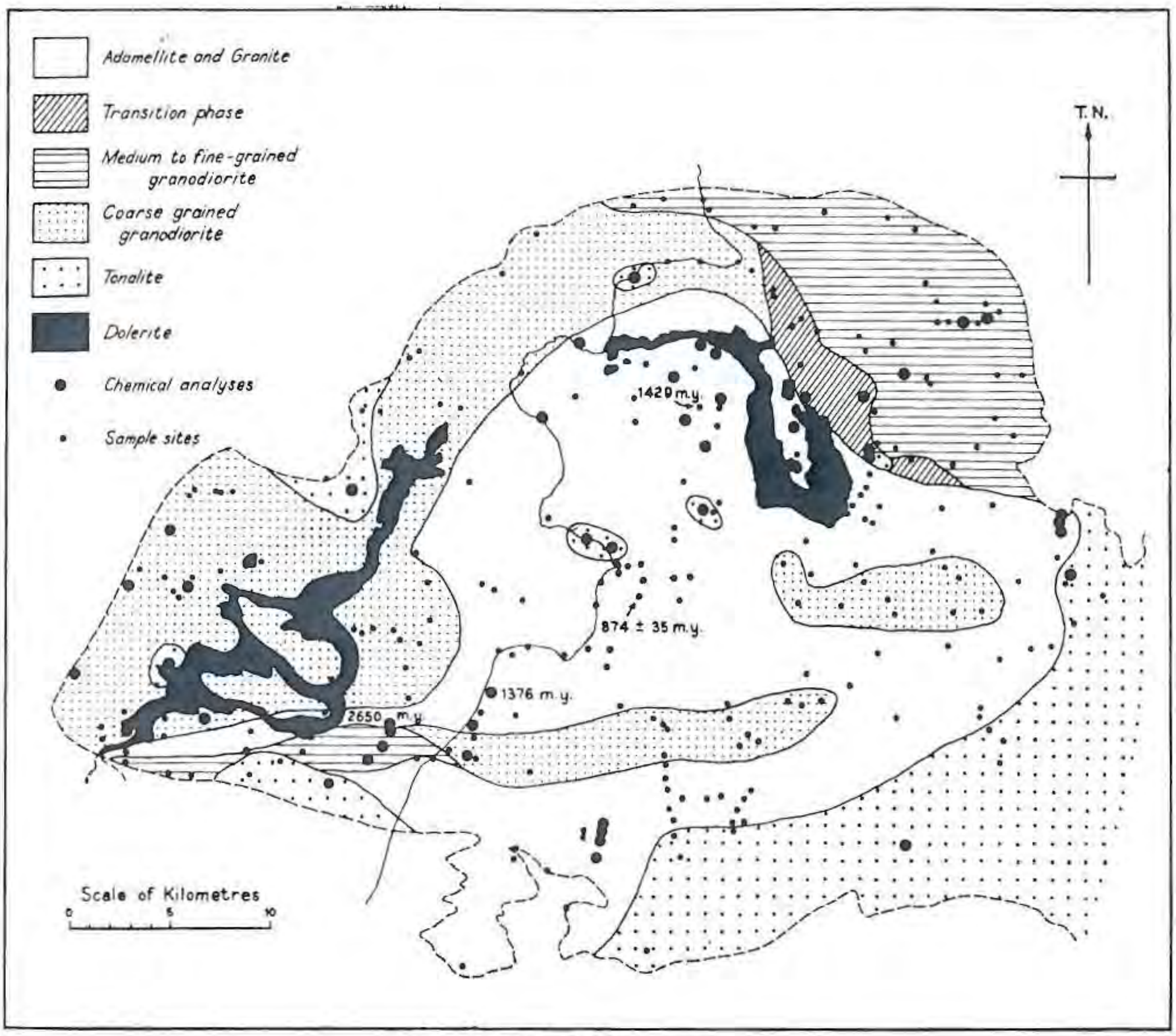

Figure 9. Geological interpretation.

towards the periphery. This is taken as clear evidence of a transformation of the chemical composition of the granodiorite to become adamellite and granite. It is significant also that the medium-grained foliated granodiorite is characterised by fresh plagioclase which is believed to have been recrystallised.

The contact between the granitic rocks and the rocks of the schist belt is not exposed and its nature is unknown, except where it can be inferred from field relationships on a major scale. For example, the granite and adamellite in one section of the southern fringe of the batholith have a distinctly cross-cutting relationship with the rocks of the schist belt, and the granite in this area is probably intrusive. A similar situation occurs at the extremity of the Shamva schist belt in the eastern portion of the batholith. Elsewhere, however, the strike of the contact is regular and conforms to a deformed dome, elongated in the east to west direction. This dome appears to result from a cross fold structure on a regional scale which involves the rocks of the schist belt and the primitive crust upon which these were deposited. The general form and field relations of the Chinamora batholith correspond therefore to those of a mantled gneiss dome as accepted for the Archaean in Rhodesia by Macgregor (1951), and as discussed by Watson (1967).

In the Chinamora region the primitive crust could be represented by the leucocratic and mesocratic tonalites, the composition of which may well be influenced by the assimilation of ancient sediments from different origins. There is no evidence that the composition of the tonalites was altered by the addition of potassium to form granodiorite, but from their distribution patterns it appears unlikely that the granodiorites were intrusive. However, there is evidence that the composition of the granodiorite has altered to that of adamellite and granite by metasomatism. It is possible therefore that metasomatism mainly by potassium may have gradually modified the original composition of the batholith to its present character, except where granite rich in potash has intruded and cuts across the strike of the rocks of the schist belt.

The geochronology of the Chinamora granite offers support for this concept. The oldest date of 2 650±10 m.y. was obtained from a crystal of monazite from the Jack tin claims situated in the southwestern part of the batholith. The pegmatites are characterised by lithium minerals, are intrusive into coarse-grained granodiorite and tonalite, and are obviously younger than both of these rocks. Three other dates were obtained from K-Ar analyses on biotite. These indicate a range in age from 874±35 m.y. to 1 376±41 m.y. to 1 429±42 m.y., and in each case these indicate a minimum age for crystallization and the maximum age for the last effects of this and metasomatism.

Two of these ages, 1 376±41 m.y. and 1 429±42 m.y., were obtained from rocks rich in potassium, and these are taken to represent the completion of the potassium metasomatism in their respective areas. The third age determination of 874±35 m.y. was obtained from a rock which is relatively poor in potassium. This rock was taken from a leucocratic xenolithic remnant in the geographical centre of the batholith, where it is surrounded by granite and adamellite. Although relatively poor in potassium, the biotite is almost completely altered to chlorite, and it is believed that the age of 874±35 m.y. relates to the completion of this alteration and to the completion of the potassium metasomatism which altered the composition of the surrounding rocks to granite and adamellite.

This range of dates, from pre-2 650±10 m.y. to 874±35 m.y. within one batholith, covers a relatively wide range as compared with other ages which have been reported from granites elsewhere in the Rhodesian craton and those in the Barberton region of Swaziland, as summarised by Bliss and Stidolph (1969), Vail and Dodson (1969) and by Viljoen and Viljoen (1969). The youngest granites to be recorded previously from the Rhodesian craton are of about 1 800 m.y., whereas the younger plutons of the Swaziland Archaean range from 2 500 to 2 650 m.y..

The ages of the younger granites appear to be in the same range as those dates which are reported from the Limpopo Mobile Belt which borders the southern margin of the Rhodesian craton. The data from the Chinamora area indicate that the granitic rocks in this batholith were undergoing metasomatism during and long after the period of geological activity in the Limpopo Belt. It is unlikely that the granite and adamellite of the Chinamora region are unique in this respect and it is probable that other batholiths and granitic areas of the Rhodesian craton will be found to be characterised by potassium metasomatism which persisted until the late Precambrian.

The minor structures within the batholith which are revealed by study of the aerial photographs provide a complex pattern of folds and fractures. The fold patterns reflect, presumably, the contortion of granitic and schistose rocks which formed the roof of the batholith. Further, the mesocratic tonalitic xenoliths in the central portion of the batholith may be taken as remnants of the ancient roof of the batholith.

A comparison of the distribution of the fold structures (Figure 8) with the distribution of the coarse-grained granodiorite in the central portion of the batholith (Figure 9) indicates a correlation between the most prominent of the fold structures and these rocks. The fold structures are less prominent in the north central area of the batholith which is characterised by the megacrystic granite and adamellite and where, presumably, the effects of potassium metasomatism were particularly strong. It is clear therefore, that the effects of the metasomatism are younger than the period of stress which resulted in the folded patterns of lineations.

VII. CONCLUSIONS

1. The Chinamora batholith represents a mantled gneiss dome which has a complex composition and geochronology. It is characterised mainly by the effects of potassium metasomatism and also by a relatively young intrusive phase of granite-adamellite. The metasomatism overrides and partly obscures the foliated structure of the batholith which is evident from the aerial photographs.
2. It is probable that the granite rocks of the Chinamora batholith developed almost progressively from the Archaean to the late Precambrian, when activity ceased. The evidence indicates the existence of thermal activity long after the craton became stable, throughout the period of development and stabilization of the Limpopo Mobile Belt, and extending almost to the period of the metamorphism which affects the Zambezi Belt. It is unlikely that the Chinamora batholith is unique in this respect, and other areas of granitic rocks first developed during the Archaean may be similarly affected.
3. The results of the chemical analyses of 15 per cent of the granitic samples are not adequate to determine whether a genetic relationship exists between any phases of the batholith and the distribution of the mineral deposits which occur within the granitic rocks and in the Archaean schists which surround them.
4. In conclusion it is believed that the reconnaissance technique which was devised for this study was successful, for results of geological significance were obtained and important problems were identified which justify further research.

VIII. RECOMMENDATIONS FOR FURTHER RESEARCH

There is clear evidence of the effects of potassium metasomatism in the Chinamora granite but the source of this is unknown. It is possible, but believed to be unlikely, that this phase of activity is of the same age as the intrusive granite-adamellite which transects the strike of the Archaean schists near Domboshawa on the southern margin of the batholith. The geochronology and geochemistry of this association require clarification. Similarly, it is possible that the granodiorites result from potassium metasomatism of mesocratic and leucocratic tonalites and are the result of a separate intrusive phase.

The aerial photography indicates that the granitic rocks which form the batholith are strongly folded according to a complex structural pattern. In addition, it appears that the boundaries of the different granitic rocks often traverse the structural pattern. There is a clear need to investigate the significance of the structures in relation to the petrology and geochemistry by mapping and sampling areas of critical interest in the field.

The Chinamora area includes and is surrounded by numerous mineral deposits of different types and which contain a variety of valuable metals. Certain of these deposits, for example those of nickel, copper and iron sulphide, are almost certainly unrelated genetically to the granitic rocks, but others, for example lithium and tin, are probably derived from the granites. Geochemical mapping on the present reconnaissance scale may reflect primary dispersion patterns of the rare metals which could be related to particular granitic phases and to the distributions of mineral deposits. In this connection the relationship between the structural patterns of the gold deposits in the schist belts which encircle the batholith and those which occur within it, are of economic significance and, in the Arcturus district, of current importance. Conversely certain portions of the schist belts, for example close to Domboshawa, appear to be devoid of mineral deposits, a feature which could be ascribed to an increase in the temperature and pressure of the and the maximum age for the last effects of this and metasomatism.

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On a regional scale it is important to clarify the geological significance of the tonalite and its leucocratic and mesocratic varieties which occur in the Chinamora batholith and which may well also occur in the adjacent masses of granitic rocks which form the batholiths of Raffingora, Zwimba, Salisbury and Mrewa-Mtoko. One area of critical interest is the eastern margin of the Chinamora granite, adjacent to the Mtoko-Mrewa batholith, but this may prove to be unsuitable due to a lack of outcrops.

The petrology and geochemistry of the tonalites and the granodiorites in this region should be compared with the characteristics of the granitic stocks which intrude the axial zones of the schist belts. Are these stocks domical remnants of the floors of the schist belts or are they relatively young intrusions somewhat similar to the granite and adamellite of the batholith?

IX. ACKNOWLEDGEMENTS

This work forms a part of the programme of research in the regional geochemistry of Archaean granites at the Institute of Mining Research. The authors gratefully acknowledge the assistance of Mr. E. W. Fowler, who is responsible for the chemical analyses, Mr. P. A. Snowden in collecting 130 of a total of some 300 samples and of Mr. R. G. Jack in different phases of the sample preparation. Finally the authors acknowledge the benefit of discussions with their colleagues and in particular with Mr. A. E. Phaup, a former Director of the Geological Survey of Rhodesia.

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DISCUSSION

DR. SAGGERSON: I would like to thank Dr. Viewing for his interesting information concerning the geochemical distribution of Na and K in the Chinamora batholith and surrounding greenstone belts. From a study of the distribution of metamorphic facies within the greenstone belts of Rhodesia it is clear that the distribution of Na corresponds with that of the greenschist facies and of K with that of the amphibolite facies. Is it possible, therefore, that the K-rich phase of the batholith has resulted from the higher temperatures achieved within the rocks of the amphibolite facies, permitting movement into higher tectonic levels where tonalites were the more stable granitic phase in association with the rocks of the greenschist facies?

DR. VIEWING: This might be so, but we made no study of the metamorphic grades of the rocks surrounding the Chinamora batholith.

MR. DUNCAN: You made no mention of any possible relationship between the chemical elements in this batholith and the mineralization of the surrounding belts; can you make any?

DR. VIEWING: Yes. I believe that it is possible but unlikely, that base metal mineralizations are genetically related to granites although I accept this concept for the pegmatite elements. It was for this reason that we determined copper, nickel and lithium in each of the samples that were analysed. These were only about 50 of the total of 275. We did find in one case, a copper content of greater than 50 ppm on the northern fringe of the batholith where some of the schist belt rocks are rich in nickel and copper. However, we do not really have enough analytical data from this batholith at present to show whether there is any significant concentration pattern relating to the distribution of the minor elements. We have analysed chromium and titanium, hoping that with nickel they could be used to discriminate between portions of the tonalite, or of the granodiorite, which could be ascribed to large-scale incorporation of mafic as distinct from ultramafic rocks into these rocks.
It is of interest that gold deposits on the southern margin of the batholith do not occur in the vicinity of the transgressive potassic phase of the Chinamora, but they do occur in the schists which flank the tonalites to the east and to the west. Dr. J. Watson mentioned a somewhat similar situation in the Canadian Shield in which the gold deposits occur in areas of relatively low-grade metamorphism, whereas gold deposits are rare in areas of relatively high-grade metamorphism.
We had hoped to discover a pattern of concentration of lithium in the vicinity of the lithium-bearing pegmatites but the few results we have cannot be taken to indicate this possibility. Dr. Grubb was speaking

of the distribution of the lithium minerals in the pegmatite mine which occurs on the southern fringe of the Chinamora batholith, and I believe that I mentioned in my introduction the regional correlation between potassic granites and pegmatites in Rhodesia.

PROFESSOR FYFE: Are there any clues at all, derived from the contact metamorphic rocks, as to what the depth of emplacement may have been?

DR. VIEWING: The only metamorphic rock that I have seen, on the northern fringe, was a quartz-muscovite-garnet schist. I have no idea as to the depth of emplacement.

PROFESSOR FYFE: Are there any calcareous rocks?

DR. VIEWING: There are strongly calcareous tonalites, and some of these contain up to 6½ per cent lime. However, I don't think there are any in the marginal schist belts. The northern fringe is composed characteristically of metasediments and a leucocratic tonalite extends to the western fringe. In the southern fringe you find the mafic greenstones, and presumably they contain about 4 per cent lime.

MR. SNOWDON: On the northern margin there are some contacts with limestones which have been quarried.

MR. MILLMORE: Limestone has been found in the schist belt in association with the ironstones there. It is crystallised limestone and has been almost mined out.

MR. WOLSTEN-CROFT: Nothing has been said about the structural relationships or about the enclosing rocks. It seems to me on the northern margins, in at least the northern and western arcs, that the rocks are tightly folded and overturned and dip about 70° outwards from the batholith. This seems to indicate a forceful sort of emplacement.

DR. VIEWING: I would like to follow that up by referring to the paper by Messrs. Gewald and Pirajno which was presented recently. This concerns the orientation of certain fracture patterns in the Madziwa batholith, which were orientated on a northwest and northeast grid. The Chinamora batholith lies to the south of the Madziwa batholith and if you extend this fracture pattern, I think it will continue to the Chinamora pattern which has a north and east direction. The northerly direction is parallel to the transverse fault system, and to the west one of these includes a dolerite dyke in the middle of the fault zone. This is exactly the same situation Dr. A. Roberts was discussing for us from the Inyati mine.