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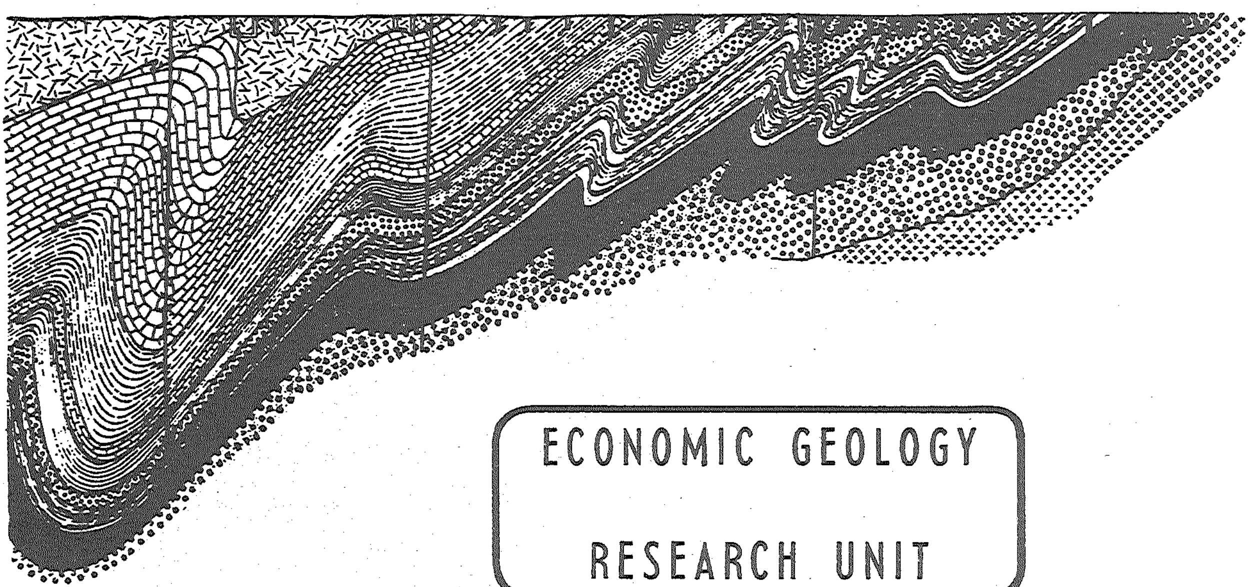

ECONOMIC GEOLOGY

RESEARCH UNIT

INFORMATION CIRCULAR No. 23

THE TECTONICS OF THE MAIN GOLD-PRODUCING AREA OF THE BARBERTON MOUNTAIN LAND

C. ROERING

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by

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INFORMATION CIRCULAR No. 23

MAY, 1965

INFORMATION CIRCULAR No. 23
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THE TECTONICS OF THE MAIN GOLD-PRODUCING AREA OF THE BARBERTON MOUNTAIN LAND

ABSTRACT

An attempt has been made to synthesize all recent structural geological data from the major gold-producing area of the Barberton Mountain Land. At least six phases of deformation have been active.

The Main Phase of deformation, present over the whole area, was responsible for the east-northeast fold trend, the formation of the regional strike faults, and the overturning of the folds to the north-northwest. The force producing these folds, which came from the south-southeast, was operative, to a greater or lesser degree, throughout the entire structural history of the area. The Main Phase folding was superimposed on early structures of a possibly previous orogeny about which very little is known. Later phases of folding which started to act during the period of the Main Phase stress gave rise to tectonic complexities. Incipient arcuation of the supra-crustal rocks north of the Saddleback and Barbrook Faults caused slight deformation of the Main Phase folds in the Eureka and Ulundi Synclines. Consequently, Main Phase cleavages and folds were superimposed on these slightly distorted larger folds. The Shebang Fold was superimposed on the westward extension of the Eureka Syncline. The angular difference between the original fold orientation and the superimposed cleavages and folds is small, indicating a small amount of rotation only prior to the effects of superimposition. In the Saddleback and Lily Synclines the cleavage is geometrically compatible with the fold shapes. The former fold, occurring south of the Barbrook and Saddleback Faults, was not subjected to the same inflection as the rocks to the north, and thus does not reveal superimposition of cleavage. The Lily Syncline lies adjacent to the Nelspruit Granite, the intrusion of the homogenous phase of which was essentially synchronous with the Main Phase deformation, and was therefore in a more plastic state than the Eureka and Ulundi Synclines.

Two significant cross-fold trends of post-Main Phase age have been recognized. The first was produced by forces acting almost horizontally and in an east-west direction, at right angles to the regional trend. Strong folds were formed in the Montrose locality, while in the Eureka Syncline and its continuation to the west of Barberton conjugate folds and faults were developed. Subsequently, there was another period of pronounced cross-folding which is evident only in the area north of the Barbrook and Saddleback Faults. This folding was responsible for the northwest-trending Consort Folds, and the arcuation of the Eureka and Ulundi Synclines. The cause of the folding was either the emplacement of the Kaap Valley Granite, or the northeastward movement of an already consolidated Kaap Valley Granite pluton towards the Nelspruit Granite. Continued pressure from the south-southeast resulted in east-northeast folds being superimposed on the arcuate Ulundi Syncline, and was responsible for forcing the Eureka Syncline northwestwards between the two granite blocks onto the northwest-trending Jamestown schist belt. Complex folding and faulting resulted in the area northwest of the Eureka Syncline. A vertical stress was responsible for the widespread regional development of folds with flat axial planes in the area lying to the north of, and including, the Eureka Syncline. South of Barberton, folds indicating a similar stress have been found locally, but these are genetically related to the large strike faults.

The entire sequence of deformation is post-Moodies in age, and can be related to the emplacement of granites having an age of about 3,000 million years. These granites also deform and metamorphose the Pongola System in southern Swaziland. The following possibilities are offered for the origin of these granites :

(i) they are related to the Swaziland orogenic cycle of which the Pongola System is the epeirogenic basin equivalent;

(ii) they are related to the Swaziland orogenic cycle and are intrusive into the unrelated Pongola System which must, therefore, be older;

(iii) they are related to the Pongola orogenic cycle and are intrusive into the unrelated Swaziland System which, in this case, is the older;

(iv) they are not related to any orogenic cycle, but to some fundamental process in the mantle which resulted in the accumulation of granite in the earth's crust during the 3000 million year epoch.

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THE TECTONICS OF THE MAIN GOLD-PRODUCING AREA OF THE BARBERTON MOUNTAIN LAND

INTRODUCTION

The Barberton Mountain Land is believed to represent the remnants of a classic Archean geosyncline, as developed in South Africa. The rocks composing it are considered to be among the oldest known in the world. It acts as host to gold deposits of considerable economic importance. The importance of structure in the localization and development of these deposits has long been appreciated, but in recent years new approaches to structural mapping have indicated the necessity of reappraising the tectonic history of the Mountain Land. This paper is a first attempt at a synthesis of the results of the reappraisal which was initiated in 1961 by J. G. Ramsay of the Imperial College of Science and Technology, London, and was subsequently continued by a number of investigators from Eastern Transvaal Consolidated Mines Limited, Barberton Mines Limited, and the Economic Geology Research Unit of the University of the Witwatersrand.

On the conclusion of the first systematic and comprehensive study of the geology of the Barberton Mountain Land, Hall (1918) concluded that the complex structure of the area could be attributed to the intrusion of the various granites. Van Eeden (1941), from a detailed structural investigation of the Sheba Hills area, deduced that the forces which produced the folds in the Mountain Land were from the south-southeast. Over-folding to the north-northwest took place, and the folds were oriented at right angles to the major force, i.e. the axial plane trace direction was roughly east-northeast. The deformation of the supra-crustal rocks and the intrusion, or formation, of the Nelspruit Granite were believed to be synchronous events. Only one period of deformation was thought to have affected the Mountain Land. Complications in the fold pattern were caused by the presence of the already crystallized Kaap Valley pluton which acted as a solid buttress in the vicinity of which changes in the orientation of the folds occurred, e.g. the Eureka Syncline.

Hearn (1943) envisaged the folding as having been caused by the compression of the supra-crustal rocks between the Nelspruit Granite in the north and the Swaziland Granite in the south. After consolidation of these granites, later tectonism, caused by the emplacement of the Kaap Valley Granite, resulted in the bending of the strata in the Sheba Hills area. Hunter (1961) suggested the following sequence of events for the Precambrian of Swaziland :

(i) geosynclinal phases : deposition of Swaziland System

(ii) initial magmatic phase : Jamestown Complex

(iii) regional metamorphism

(iv) main orogenic pulsation : migmatization and granitization

(v) inter-tectonic sedimentation and volcanism : Insuzi and Mozaan Series

(vi) second orogenic phase : widespread intrusion of G.4 Granite

(vii) post-orogenic phase : G.5 Granite plutons

To the data gathered by the above investigators has been added the very appreciable amount of information collected by the Geological Survey (Visser et al, 1956), Ramsay (1963), Herget (1963), Anhaeusser (1964), Viljoen (1964), van Vuuren (1964), Poole (1964), Cooke (1965), and the author. The conclusions reached from the synthesis of this information form the topic of this paper, in the preparation of which the author has received suggestions and criticisms from Mr. D. A. Pretorius, Mr. E. J. Poole, and Dr. J. F. Truswell.

GENERAL GEOLOGY

A. STRATIGRAPHIC SUCCESSION

The most detailed and exhaustive account of the rock-types occurring in the Barberton Mountain Land is that of Visser et al (1956). The following descriptions represent a summary of this work, to which have been added some data gathered during the last few years. The generalized stratigraphic column used in this paper is as follows :

Intrusive Rocks :	Nelspruit Granite, Kaap Valley Granite, Mpageni Granite	
Swaziland System	Jamestown Complex	basic rocks serpentinites
	Moodies Series	containing a molasse facies
	Fig Tree Series	containing a flysch facies
	Onverwacht Series	including the Oorschot Series and certain rocks previously ascribed to the Jamestown Complex
Basement :	migmatites and gneisses of "Nelspruit Granite"	

(a) Basement

Very little is known about the basement on which the Swaziland System was deposited, but it is considered that the Nelspruit Granite (composed largely of migmatites and gneisses) represents a basement which became partially reactivated and intrusive into the Swaziland System at a later stage (Ramsay, 1963; Viljoen, 1964).

(b) Onverwacht Series

At present considerable disagreement exists as to which rocks actually belong to this group. The South African Geological Survey identified a pre-Fig Tree volcanic sequence - the Onverwacht Series - which it divided into a lower, basic phase, and an upper, acid phase (Visser, 1956). Gribnitz et al (1961) were of the opinion that the Onverwacht Series consists of basic rocks intrusive into an older Oorschot Series which is made up of arenaceous and calcareous sediments, banded cherts, and banded ironstones. The Onverwacht Series was thought to contain extrusive basic rocks as well. Recent work by Anhaeusser (1964), Viljoen (1964), and Herget (1963) has shown that certain rocks, previously correlated with the Jamestown Complex and resembling members of the Oorschot Series, are, in fact, pre-Fig Tree in age, and are thus metamorphosed members of the Onverwacht Series. However, other Jamestown rocks, mainly serpentinites, are intrusive into the Moodies Series. It is not known whether they were derived from the pre-Fig Tree sequence (ultrabasic lava flows or intrusions) and migrated to higher levels during deformation.

In Swaziland, rocks very similar to those described by the above three investigators as belonging to the Onverwacht Series are thought to be members of the Jamestown Complex (Urie, 1961). This Complex is considered to be essentially a highly metamorphosed ultrabasic intrusive of the Alpine-type, which was emplaced at an early stage of the post-Moodies orogeny. The intrusion was accompanied by a certain amount of selective assimilation of the Lower Fig Tree sequence.

The controversy is treated in detail by Anhaeusser and Viljoen (1965). They conclude that the reconstituted Onverwacht Series, forming the basal assemblage of the Swaziland System, actually consists of basic and acid lavas (the original Onverwacht Series), clastic and non-clastic sediments (formerly the Oorschot Series), and ultrabasic intrusives and/or extrusives (part of the original Jamestown Complex). This assemblage is virtually identical to that belonging to the initial magmatic phase of a typical geosyncline.

(c) Fig Tree Series

The Fig Tree Series is made up of a considerable thickness of sediments, and, locally, near the top, of lavas. The sediments consist of greywackes (Visser et al, 1956; Ramsay, 1963), subgreywackes (Herget, 1963), grits, shales, banded cherts, banded jaspers, and banded ironstones, as well as subordinate conglomerates. The greywackes commonly reveal graded-bedding, the individual units being of variable thickness. Kuenen (1963) recognized numerous sedimentary structures indicating that the greywackes were formed by turbidity currents. Flute-casts, load-casts, and possible slide-marks have been identified by van Vuuren (1964) in the greywackes of the Ulundi Syncline. Herget (1963) observed flute-casts and convolute-bedding in the Montrose area.

These features strongly suggest that the greywackes were deposited in deep water by turbidity currents, and that these rocks are similar to typical flysch sediments. The presence of banded cherts, jaspers, and ironstones indicates that quieter periods occurred in which chemical precipitation took place in the depository.

Problematic volcanic rocks have been described from the upper part of the Fig Tree Series. Ramsay (1963) suggested that the 'lavas' are, in fact, greywacke slump breccias, but Anhaeusser (1964) and Viljoen (1964) considered them to be of volcanic origin, and to represent crystallized tuffs, tuffaceous greywackes, or volcanic tuffs.

(d) Moodies Series

The Moodies Series is composed predominantly of psammitic and psephitic sediments. According to Visser et al (1956), the Moodies sediments overlie older rocks with a definite unconformity at certain localities. The dominant rock-types are boulder beds, conglomerates, quartzo-felspathic sandstones, siltstones, and shales, with local developments of banded ironstones. Conglomerate pebbles are made up of black chert, banded ironstone, red banded jasper, greywacke, grit, quartz porphyry, and granite. Many of the pebbles are identical with rocks found in the Fig Tree Series. Visser et al (1956) reported the presence of contorted banded chert pebbles, and suggested that the Fig Tree succession had been subjected to folding prior to the deposition of the Moodies Series. The quartzites show abundant cross-bedding and ripple-marking. Mud-cracks have also been reported (Visser et al, 1956; Ramsay, 1963).

The latter sedimentary features plus the development of conglomerates (which locally show very poor sorting) indicate deposition in shallow water, contrasting sharply with the deep-water environment of the Fig Tree greywackes.

In support of Visser et al's (1956) conclusion concerning a period of pre-Moodies folding, Urie (1961), from investigations in Swaziland, stated that there was evidence to indicate an initial, and weaker, orogeny which elevated the Fig Tree sediments before the Moodies Series was formed.

(e) Intrusive Jamestown and Granitic Rocks

Among the intrusive rocks, the granites are the most important. The Nelspruit Granite is clearly intrusive into all the members of the Swaziland System, while the Kaap Valley Granite definitely intrudes basic schists of the Onverwacht Series. The latter might also be intrusive into Moodies sediments, as shown by a xenolith of deformed conglomerate and quartzite occurring in granite on Moodies Estates (R. Cooke, personal communication). On the south side of the Mountain Land, the Swaziland rocks have been intruded by the G.4 Granite. The eastern and western extremities of the area also reveal intrusive granite relationships.

Serpentinites are known to occur along many of the major longitudinal faults in juxtaposition with Moodies rocks. Other serpentinites occur as conformable bodies in pre-Fig Tree rocks, and a third variety is represented by a large mass which has squeezed its way into the Moodies sediments of the Lily Syncline east of Joe's Luck Siding (Anhaeusser, 1964; Viljoen, 1964). Anhaeusser (personal communication) has observed peridotit intrusive into Moodies sediments of the Eureka Syncline.

A very pronounced dyke trend (west-northwest) indicates another stage of magmatic invasion (post-granite). The dykes are oriented at right angles to the regional trend of the fold belt, occupying regional zones of tension.

B. THE POSSIBLE ORIGIN OF THE SWAZILAND SYSTEM

There is much in favour of fitting the entire sedimentary and igneous pile of the Swaziland System into the typical geosynclinal sequence consisting of an initial phase of magmatism, deposition of flysch in a foredeep of the geosyncline, a major orogenic period, and, finally, shedding of erosion products of the deformed belt into a post-orogenic molasse basin. However, no conclusive evidence of these relationships has so far been gathered in the Mountain Land.

The main problem hinges on the origin of the Moodies sediments. Do they represent erosion products resulting from a major orogenic pulse within a geosyncline in which the Fig Tree assemblage was deposited as a flysch facies? Deformed Fig Tree banded chert, occurring as pebbles in Moodies conglomerates, has been used to suggest that the Fig Tree sediments were subjected to folding prior to the deposition of the Moodie Series, but the deformation of these banded cherts could equally well have been formed by slumping in the depository itself. The fact that many of the conglomerate pebbles were derived from the Fig Tree Series does not necessarily imply previous orogeny, but might point merely to erosion of uplifted Fig Tree rocks. Is there a difference in the degree of deformation of the Fig Tree and Moodies rocks which might be used as an indication of a pre-Moodies orogeny? The deformational phases described in this paper are all post-Moodies in age, but are certainly superimposed on earlier structures about which very little is known. It has been impossible to identify different degrees of folding in the Fig Tree and Moodies Series in the area covered by this synthesis. However, there need be no conspicuous differences in fold styles between the molasse and the lower members of a geosyncline, since the former is deposited on the margin of the orogenic belt where the older rocks need not have suffered severe deformation.

If it were possible to identify the whole orogenic belt with its axial, internal, external, and marginal zones, more could be said about the origin of the Moodies sediments. However, at present, it appears that only a small segment of a possibly very much larger orogenic belt is exposed, since the Mountain Land itself does not contain all the typical structural members of a geosyncline. Until more data are obtained, sedimentological criteria cannot be used to define a possible earlier orogeny. Only the finding of characteristic sediments in a typical space-time model of a geosyncline would permit such deductions to be made.

If the Fig Tree Series does, in fact, represent a flysch facies, and the Moodies a molasse deposit, then the following conclusions have to be drawn :

(i) the Barberton Mountain Land represents only a portion of a larger geosyncline, and is only a marginal remnant;

(ii) the deformation observed in the Mountain Land is younger than, and superimposed on, the main orogeny of the larger geosyncline.

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DESCRIPTIVE STRUCTURAL GEOLOGY

A. MAJOR STRUCTURES

(a) Eureka Syncline

The most striking structure on the geological map of the Barberton Mountain Land (Visser et al, 1956) is the arcuate Eureka Syncline composed of Moodies rocks (see Plate 1). From a closure on the western part of the farm Lilydale, this refolded syncline continues in a westerly direction for approximately 8 miles to a point south of the Woodstock Mine where it changes trend to a southerly direction. It attains a maximum outcrop width of $2\frac{1}{4}$ miles south of the Woodstock Mine where the pronounced change of strike of the axial plane trace takes place. Within the area where the syncline shows this marked inflexion, the plunge is everywhere to the west, southwest, or south, often at high angles.

Westwards and then southwards from the old Royal Sheba Mine the southern limit of the syncline is the Sheba Fault. The northern contacts appear to be normal. In the 7-mile stretch where the syncline has a north-south trend, it narrows considerably, particularly just east of Barberton town where it is approximately $\frac{1}{2}$ mile wide. This narrowing is a result of tectonic thinning caused by faulting and flattening (Anhaeusser, personal communication), and of sedimentary facies changes which are clearly indicated on the Geological Survey map (Visser, 1956). The southern portion of the structure is overturned to the north and northwest.

South and southwest of Barberton the same structure can be followed. Immediately south of the town itself it is very complex because of faulting and folding, but becomes simpler again in, and west of, the Fortuna locality. The structure swings from a north-south to a southwest trend south of Barberton. It maintains this direction for two miles to a position south of the Great Scott Mine where it assumes a west-southwest trend, and steadily widens over a distance of 5 miles to just north of the Princeton Mine where an outcrop width of $1\frac{1}{2}$ miles is attained. To the northwest of the Princeton Mine the Moodies basal conglomerate rests unconformably on older rocks, the general strike of the unconformity being north to northwest. Only a portion of the syncline is exposed between the unconformity in the west and Barberton in the east. The overturned sequence of Moodies rocks is bounded on the north by the Moodies Fault, and on the south by the continuation of the Sheba Fault. The Moodies Fault is thought to die out to the north of Barberton. The axial plane trace of the syncline is probably very close to the Moodies Fault, as Cooke (1965) has found beds which are the right way up in the locality where the Agnes Road crosses the fault.

The most westerly extension of this structure is fault-bounded, and forms a narrow sliver of sediments extending from south of the Mount Morgan Mine to just north of the Estada Mine.

(b) Lily Syncline

Occurring between the Nelspruit Granite and the Lily Fault and at a distance of $\frac{1}{2}$ - 1 mile north of the Eureka Syncline is the narrow (generally less than $\frac{1}{2}$ mile in outcrop width), so-called Lily Line which is, in fact, an overturned, isoclinally folded syncline of Moodies rocks. In the area under consideration it can be followed westwards from a point approximately 2 miles south of Louw's Creek Station to just north of Eureka Siding, passing immediately north of the Scotia Talc Mine into the larger mass of Moodies rocks occurring $1\frac{1}{2}$ miles southwest of the Consort Mine. In the Consort area, only the northern limb of the Lily Syncline is developed, and this has been refolded by younger, northwest-trending folds which are abruptly terminated in the south by the Main Southern Fault. An extension of this fault may form the southern boundary of the Lily Line east of Joe's Luck Siding. The precise westwards continuation of the Lily Fault is not known, but it might be contained within the numerous faults present in the Woodstock-Clutha locality.

(c) Saddleback Syncline

This structure, made up of Moodies rocks, occurs on the farms Wonder Scheur 362 JU, Dycedale 368 JU, De Bilt 372 JU, and Oosterbeek 371 JU. In the east and south the Moodies sediments overlieFig Tree rocks. The structure is overturned to the north-northwest, and has an axial planar trace which strikes east-northeast. On the northern side the syncline is transgressed by the Saddleback Fault which cuts its way in from outside the fold on Wonder Scheur, through the lower members of the Moodies Series, into the axial plane approximately 1 mile north of the Lomati River on the farm Oosterbeek. This fault is essentially parallel to the regional strike faults of the Mountain Land. The western limit of the structure is fault-controlled. A narrow sliver of Moodies rocks extends westwards from the main structure towards the Princeton Mine for approximately two miles. Beyond the Princeton Mine the fault-bounded strip forms an arc passing $\frac{1}{2}$ mile south of Maid of the Mountain Mine, and ending approximately 1 mile south of the Montrose Mine. The northern limit of this sliver is the Saddleback Fault, while the southern is another strike fault.

(d) Ulundi Syncline

Lying between the Sheba, Barbrook, and Saddleback Faults, is an upthrown block made up essentially of the Fig Tree Series, though pre-Fig Tree rocks also occur. The block resembles a horst of Fig Tree and Onverwacht rocks bounded on the north and south by Moodies strata. Immediately south and east of the arcuate portion of the Eureka Syncline is the nearly isoclinal Ulundi Syncline which abuts against the Sheba Fault in the north and the Barbrook Fault in the south. This structure is overturned to the north and the west, and constitutes a refolded syncline with dimensions comparable to the Eureka structure. South and east of the Sheba Fault, from the old Royal Sheba Mine to a point near Hislop's Creek, several isoclinal anticlines are formed near the outer limit of the syncline. These very tight anticlines have cores of talc-carbonate phyllite surrounded by green schist and chert, as can be well seen around Sheba Mine. Similar structures form the Zwartkopje Horizon on the southern side of the Ulundi Syncline. These anticlinal structures intersect in the very complex area around Hislop's Creek.

Between the Barbrook and Saddleback Faults there occurs a zone made up of serpentine and chert. Eastwards,Fig Tree and Moodies rocks occur in this fault block.

Following the Sheba and Saddleback Faults southwestwards it can be seen that the structural 'horst' persists as far as a point south of the Agnes Mine. Within this area several larger folds can be recognized, their axial plane traces being parallel to the major strike faults. No extension of the Sheba Fault has been found west of the Princeton Mine area. In the Fig Tree rocks around Montrose, Estada, Maid of the Mountain, and Brighton Kop several anticlines expose pre-Fig Tree rocks in their cores. These anticlines define two prominent trends - east-northeast, and approximately north-south.

(e) Granite Contact Zone

Flanking the Kaap Valley Granite are basic schists with intercalated serpentinites, gabbros, and limestones belonging to the Onverwacht Series. South and west of Barberton these are faulted against Moodies rocks by the Moodies Fault. This relationship does not persist as clearly, if at all, to the north of Barberton. The Kaap Valley Granite definitely intrudes the schists, as is clearly revealed on the lower part of the Agnes road, in the Queens River exposures, and at the Barberton prison where numerous modified xenoliths are known.

Occurring on the northwestern side of the Eureka Syncline is the pronounced northwest-trending Jamestown schist belt which separates the Kaap Valley and Nelspruit Granites. Within this belt on the farms Handsup 305 JU and Dixie 311 JU is a pronounced fold of serpentinites and talc schists 2 miles west of the Clutha Mine. This structure appears to be disharmonious, being terminated on the southwest by northwest-trending strata.

The main mass of the Nelspruit Granite is essentially migmatitic, and is mantled by a zone of homogenized granite several thousand feet in width which is clearly intrusive into all rocks of the Swaziland System, including the Moodies Series.

B. MINOR STRUCTURES

Minor structures are generally present throughout the area, but they become less pronounced from the Saddleback Syncline further southeastwards. Their most spectacular development is close to the Nelspruit Granite contact. It must be appreciated that, in many cases, minor structures can serve to date only the younger deformations, since, in the process of formation of the later structures, older features can be completely obliterated. However, these younger structures, when definitely superimposed, can give certain information about the older structures. The discussion that follows starts with a unified period of deformation which developed over the whole area, and which was superimposed on pre-existing structures, possibly belonging to an earlier orogeny. This later, extensive deformation is referred to as the Main Phase of deformation, but it should be borne in mind that other, older phases might have been of equal, or greater, importance.

(a) Main Phase of Deformation

(i) Distribution

The effects of this deformation can be recognized throughout the area as minor structures, in the form of planar and linear fabrics. The most important are the planar structures, since all linear fabrics lie within synchronously developed axial planes or axial plane cleavages. The distribution of planar fabrics associated with this phase of folding is shown in Plate 1.

In the complex Eureka and Ulundi Synclines the generalized trend of the slaty cleavage is shown in relationship to the axial plane trace of the folds. The cleavage clearly has a different orientation to this trace, and therefore is not synchronous with the folding (Ramsay, 1963).

Observations by R. Cooke (personal communication) in Fig Tree sediments on the western side of the Havelock Road, immediately north of the Saddleback Fault, reveal a tight fold which plunges to the south-southwest at an angle of 54° (Plate 1, Figures 1 and 2). The average orientation of the axial plane is : strike 048°, dip 75° SE. The orientation of the cleavage developed in Moodies rocks adjacent to the Havelock Road between the Sheba and Moodies Faults is very similar to that described above - strike 053°, dip 68° SE. (Plate 1, Figure 3). It seems reasonable to relate these trends to those found immediately to the north in the Eureka and Ulundi Synclines - cleavage : strike 035°, dip 69° SE. (Ramsay, 1963). Figures 2 and 3 show that the poles to the axial planes and cleavages are spread on a great circle, pointing to the fact that even well southwest of the main arcuation, these minor structures have been slightly bent.

Proceeding westwards towards the Fortuna Mine, Cooke (personal communication) has found that the Moodies strata define folds which plunge to the southwest at 60° (Figure 4). Figure 5 reveals that the orientation of the cleavage associated with this folding has an east-northeast strike, and dips steeply towards the south. Similar cleavage and axial planar data have been found in the Agnes-Shebang area in which the Moodies strata are bent into a fold which plunges to the east at an angle of 40° (Plate 1, Figure 6). The orientation of the cleavage associated with this fold is : strike 084°, dip vertical (Figure 7).

Figure 8 shows the planar fabric data and associated fold axes in the Fig Tree Series north, north-east, and northwest of the Princeton Mine. The average orientation of the axial plane is : strike east-west, dip vertical. The systematic spread of the fold axes within the axial plane indicates that this folding must have been superimposed on already deformed strata. Figures 9 and 10 show an almost identical picture for the Moodies rocks south of the Princeton Mine. The general spread of the fold axes on the axial plane great circle provides further evidence of superimposition of these structures.

Further westwards, in the Estada, Maid of the Mountain, and Montrose localities, the same structures can be identified (Herget, 1963). A shale horizon, occurring in the westernmost faulted sliver of the continuation of the Saddleback Syncline, is intensely deformed, and minor folds abound. The orientation of the axial planes and fold axes of these minor folds (Figures 11, 12, 13,and 14) indicate that they were superimposed on some pre-existing structure. A distinct change in the plunge of the minor fold axes can be seen between Figure 12, where they are flat, and Figure 13, where they are steeper. The axial planar orientation of each diagram is different, due to folding of the axial planes about a vertical axis by the younger Montrose Fold Trend. This latter folding could not have given rise to the change in plunge of the fold axes observed in Figures 12 and 13, and the plunge difference is, therefore, believed to be a primary feature due to superimposition of the fold axes on a deformed surface. It can also be seen that the axial planes are systematically rotated from a point south of the Maid of the Mountain Mine to a point due east of the Montrose Mine. Proceeding further southwest to where the Moodies rocks end, the axial planes of the minor folds become strongly rotated by the younger north-northwest to north-south Montrose Fold Trend (Plate 1).

Round the closure of the Saddleback Syncline, near the Havelock Road, a similar type of symmetry to the other structures described from south of Barberton is revealed. Although cleavage and minor folds are not abundantly developed, a cleavage which dips steeply to south-southeast and strikes 065^{o} is genetically related to the folds of the area (Figure 15 a and b).

The planar fabric related to the Main Phase folds can be recognized to the north and east of the Eureka Syncline. In this area Anhaeusser (1964) has shown that the axial plane cleavage, schistosity, and bedding in the Moodies rocks have the same orientation, proving that the folding must be isoclinal. All measured lineations lie in this plane (Figure 16). As the Lily Line approaches the Joe's Luck locality, and particularly round the Consort Mine, this planar fabric becomes rotated by later movements (Figure 17). The same relationship applies to minor structures in the Fig Tree and pre-Fig Tree rocks.

(ii) Evidence of Superimposition

Ramsay (1963) was the first to observe that the Main Phase of deformation is superimposed on older structures. He found that :

1. the cleavage traces and the axial plane traces of the Eureka and Ulundi Synclines are not coincident;
2. at the Clutha Mine the bedding dips steeper than the cleavage; if the latter were related to the major folds (Eureka Syncline), this relationship would indicate that succession (from oldest to youngest beds) is Moodies -, Fig Tree - and Onverwacht Series; there is no doubt that the reverse order is the correct sequence; therefore the cleavage must be superimposed; furthermore, graded-bedding also shows that the succession "gets younger" towards the southeast, and not towards the northwest, as the cleavage-bedding relationships would seem to indicate (Figure 18);
3. minor structures in the Ulundi Syncline also suggest that the cleavage is superimposed on older folds, since it makes a distinct angle with the axial plane of the fold (Figure 19).

Within the Eureka and Ulundi Synclines no new folds were developed synchronously with the cleavage, except,possibly, for some occurring on the southern side of the latter structure.

The Lily structure provides no evidence of earlier fold trends, as the cleavage and axial planar trace are parallel (Figure 16).

South of Barberton and west of the Havelock Road, the axes of the major folds show distinct variations. (Figures 1, 4, 6, 10,and 15a). This could mean that post-Main Phase folding deformed the Main Phase structures, or that the Main Phase folds were superimposed on pre-existing structures. Since there is very little evidence of strong cross-folding of a younger age between Barberton and the Maid of the Mountain Mine, superimposition of the Main Phase folds appears more likely. Further arguments in favour of superimposition include the folding of an earlier planar tectonic fabric by the Shebang Fold (Poole, 1964), and the suggestion of superimposition of younger folds in the Moodies rocks south of the Princeton Mine where two definite maxima of minor fold axes lie in the uniformly oriented axial plane of the Main Phase folding (Figures 9 and 10). The plunge of the Saddleback Syncline of 40° to the southwest points to the fold having been superimposed on a surface which had a dip of at least 40°, probably brought about by folding (Figure 15).

Three distinct styles of deformation occur which are related to the Main Phase - (1) cleavage is superimposed on the Eureka and Ulundi Synclines; (2) the Shebang Fold is superimposed on the westward extension of the larger Eureka Syncline; and (3) major folds related to the Main Phase are the Saddleback and Lily Synclines. Styles (1) and (2) are essentially the same, differing only in the fact that the Shebang Fold was formed synchronously with the cleavage. In both cases the angle that the new axial planar structures made with the axial planar traces of the larger folds was small. In the Eureka Syncline the new structures intersect the older ones in a clockwise sense, while the Shebang Fold behaves in an anti-clockwise sense (Plate 1 and Figure 27).

Superimposition is thought to have been associated with an unique situation which existed north of the Saddleback and Barbrook Faults, where regional east-northeast folds were bent, as clearly indicated by the Sheba Hills. It is assumed that inflection started while the stresses associated with the Main Phase were still active. The original Main Phase Eureka and Ulundi Folds were formed; were then slightly bent by trends which became stronger at a later date (Consort Trend), were subjected to the superimposition of the Main Phase cleavage, and were then again subjected to a more intense deformation by the younger (Consort) trends. Overlap of the various phases of deformation is thus clearly indicated.

South of the Saddleback and Barbrook Faults the situation was different. The Main Phase deformation gave rise to the major Saddleback Syncline which was not subjected to arcuation, as were the Eureka and Ulundi Synclines. Thus, the cleavage and the fold are synchronous in time, and are geometrically compatible.

The Lily Syncline was probably in a more plastic state, to account for the folding and the cleavage also being compatible. This syncline occurs adjacent to the Nelspruit Granite, and, because the Main Phase deformation and the intrusion of the Nelspruit Granite are believed to be synchronous, it is thought that its location in space favoured its higher degree of plasticity, or lower viscosity.

It must be borne in mind that steep plunges are found in all the major synclinal structures, indicating that, in spite of the complexities described above, the Main Phase of deformation was superimposed on pre-existing structures about which very little is known.

(iii) Nature of Associated Fabrics

The nature of the cleavage varies over the whole area. In general, it is a true slaty cleavage, though closer to the Nelspruit Granite a schistosity is developed in the contact metamorphic rocks. Within this contact zone the individual pebbles of the Moodies conglomerates have been intensely flattened in the plane of the cleavage. Various estimates as to the amount of flattening that the pebbles have undergone give values of the order of 40 percent (Ramsay, 1963; Anhaeusser, 1964; Viljoen, 1964).

The axial planar fabric is closely associated with the metamorphism of the rocks adjacent to the contact with the Nelspruit Granite, e.g. amphibolites often have the amphiboles oriented with their long axes in the fabric plane, and talc and chlorite are oriented parallel to the schistosities, as are the micas in the case of the slaty cleavage. Thus, from the highest metamorphic grade to the lowest, the metamorphic minerals grew under stress conditions which were produced by the Main Phase deformation. The emplacement of the Nelspruit Granite must have been associated with this event, in order to have provided the necessary heat-energy gradient for the observed contact metamorphic effects (Anhaeusser and Viljoen, 1965).

(iv) Essential Features of the Main Phase

The Main Phase of deformation was responsible for the dominant east-northeast fold trend in the Mountain Land. It produced the strong cleavage which was superimposed on the Eureka and Ulundi Syclines, as well as the superimposed Shebang Fold. These effects were restricted to the area north of the Saddleback and Barbrook Faults. They were produced by a continuation of the Main Phase stress that initially gave rise to the Eureka and Ulundi Synclines, which structures also started responding to younger phases of folding (the Consort Trend) before the superimposition of the cleavage.

South of the Saddleback Fault, the Saddleback Syncline contains cleavages and fold shapes which are geometrically compatible. Within this area the effects of the younger cross-folds were not strong enough to make any visible imprint.

The Lily Syncline is also compatible with the Main Phase cleavage, and no direct superimposition has been observed. This is probably due to the proximity of the fold to the Nelspruit Granite which was intruded during the Main Phase deformation.

(b) Subsequent Deformation of Main Phase

If Plate 1 is examined, and the undulatory distribution of the Main Phase cleavage and associated axial planes is considered, it is reasonable to assume that this cleavage initially had a uniform orientation which was subsequently deformed. However, the possibility also exists that the cleavage formed at right angles to a stress which itself had a different orientation from one locality to the next. A solution has been obtained by an analysis of minor structures. Such a study has shown that deformation subsequent to the Main Phase took place, and that the old cleavage surfaces were rotated into new folds in a systematic manner.

(i) The Consort Trend

The above situation occurs in the Consort Mine area where Viljoen (1964) observed that a Main Phase planar fabric is systematically rotated by younger folds which trend northwestwards. The "Quartz Bleb Marker" which contains numerous quartz fragments flattened in the Main Phase cleavage plane shows this later deformation particularly well. Thin-sections show that biotite and amphibole, which are in subparallel arrangement in the cleavage plane, are bent, broken, or folded by the northwest fold system.

On a larger scale, these northwest folds form a striking pattern, giving rise to numerous synclines and anticlines (Figure 20). An equal-area plot of the axial planes and fold axes in the area (Figure 17) reveals a uniformly oriented axial plane striking at 145°, and dipping almost vertically. The fold axes are spread in this axial plane, indicating superimposition of the northwest fold trends on an irregular surface. Since there is a concentration of fold axes at about 50° SE., it appears that the majority of the surfaces had a similar orientation. This agrees with what would be expected, since the structure represents a refolded limb of the Lily Syncline, which towards the east, is an isoclinal syncline overturned to the north.

As the Main Phase folds are refolded about new folds trending northwestwards, a major stress at right angles to this trend is indicated. Such a stress could well have been responsible for the refolding of the Eureka and Ulundi Synclines, since these structures are also bent about northwest-trending axial planes.

Extending northwestwards from the Consort area is the Jamestown schist belt which is seen to envelop the Kaap Valley pluton up to the point where it disappears beneath the escarpment of post-Swaziland rocks. The Geological Survey map (Visser et al, 1956) reveals that the major linear trends of this basic schist belt vary from northwest in the south to east-west in the north. In fact, the fold trends are all controlled by the shape of the Kaap Valley pluton, being aligned parallel to its outline. Thus, the regional fabric of the Jamestown belt was formed either by the emplacement of the Kaap Valley Granite, which stoped its way in and shouldered away the rocks on its margin, or by the movement of an already crystallized pluton towards the Nelspruit Granite. Anhaeusser (personal communication) observed that the Kaap Valley Granite has intruded its way along the Main Phase cleavage planes in the locality west of the Eureka Syncline.

It is not unreasonable to conclude that the emplacement of the Kaap Valley Granite and the formation of the northwest (Consort) fold trends were intimately associated.

(ii) The Montrose Trend

The Montrose locality also reveals evidence of a post-Main Phase deformation (Herget, 1963). West of the Princeton Mine, the orientation of the Main Phase planar fabric follows its normal trend up to a point south of Maid of the Mountain Mine. South of the Montrose Mine the planar fabric becomes strongly rotated (Figures 11, 12, 13, and 14). Figure 13 is a plot of the locality where the rotation of the planar features begins, the poles to the axial planes of the minor folds spreading out from the maximum on to a great circle. In Figure 14 the poles to the axial planes are spread about the periphery of the diagram, indicating that they have been folded about a vertical axis.

Within this locality a series of younger folds with a consistent axial planar orientation of north-northwest has been observed. The Fig Tree sediments provide evidence of two major intersecting anticlinal trends - one east-northeast, and the other north-south to north-northwest. The latter trend is the same as that revealed by the minor structural data. Further evidence of the northerly fold trend has been obtained from minor structures in the syncline extending northwards from the Montrose Mine. Figures 21 and 22 show the orientation of the axial planes of the folds associated with the major trend.

The Montrose folds post-date the Main Phase deformation, and have a trend varying between north-south and north-northwest. It is not known if this period of folding is synchronous with the northwest fold trend of the Consort locality.

In the area to the east of that described above, Poole (1964) and Cooke (personal communication) have found folds which might be related to those described by Herget (1963). The Agnes-Fortuna locality was subjected to an east-west stress in post-Main Phase times, which resulted in the formation of numerous conjugate folds and faults disturbing the Main Phase cleavage and lineations. From the conjugate fold geometry in this westerly extension of the Eureka Syncline, Poole (1964) deduced a maximum stress which operated horizontally and in an east-west direction. The minimum stress direction was essentially horizontal and oriented north-south (Figure 23). Herget (1963) was unable to determine the orientation of the kinematic axes for the Montrose locality, and a direct comparison of the later folds in this locality and in the Agnes-Fortuna locality is thus not possible. However, it would appear that the maximum stresses operated in essentially the same direction, and the Montrose folds and the conjugate structures have been tentatively correlated.

Ramsay (1963) found conjugate folds in the Eureka Syncline, which he related to the period of arcuation of the syncline, i.e. to the northwest fold trend of Viljoen (1964) (Figure 24). However, these structures are very similar to those present in the Agnes-Fortuna locality, and it is possible that they might have been produced by an east-west stress (or a stress parallel to the strike of the bedding), which operated prior to the arcuation of the Eureka Syncline. The Montrose Trend would then pre-date the Consort Trend.

(iii) Essential Features of the Consort and Montrose Trends

Although more data are required to accurately date and correlate the post-Main Phase deformations, it would appear that two different stress fields operated subsequent to the Main Phase. South of Barberton east-west stresses appear to have acted, while, to the north, southwest-northeast stresses were operative. It seems unlikely that the two trends were caused by the same stress field. The Consort folds in the Jamestown belt are believed to be related to movement of the Kaap Valley Granite on to the Nelspruit Granite. In the northern extremity of the belt, the east-west strike must have been formed by a north-south stress at the same time as the Consort folds. It would seem as if the Jamestown schist belt was deformed by a radial stress acting outwards from the Kaap Valley Granite. Thus, where the beds have an east-west strike on the southern side of the pluton it is difficult to conceive of a totally different set of conditions having existed. A north-south stress would also have prevailed in the Agnes-Fortuna locality, not an east-west stress, as deduced from field observations.

It is thought that the Montrose folds, the conjugate folds of the Agnes-Fortuna locality, and the conjugate folds of the Eureka Syncline are related to a single stress which operated in an east-west direction subsequent to the Main Phase, and prior to the intrusion of the Kaap Valley pluton. The Consort folds were then developed, as well as the structures of the Jamestown schist belt, both being the result of the emplacement of the pluton.

(iv) The Late Ulundi Trend

Younger movements appear to have been responsible for the deformation of the northwest-trending folds in the Consort-Noordkaap area. The pronounced fold on the farms Handsup 305 JU and Dixie 311 JU, 2 miles west of the Clutha Mine is an important indicator of this deformation (Plate 1). This structure, as pointed out previously, is distinctly disharmonic, with a detachment plane parallel to the northwest fold trend on the western side of the fold. On aerial photographs it can be seen that the actual detachment plane is low-lying with respect to the relief, and controls the local drainage. Ramsay (1963) classified this structure as an early fold trend pre-dating the Main Phase of deformation. It seems, however, that, if the northwest folding was intense enough to produce the conspicuous fold pattern of the Consort locality, where Moodies as well as Fig Tree sediments were involved, then the more incompetent basic schists would have suffered even stronger deformation. The fact that the disharmonic fold is still prominent is more convincingly attributed to its having been superimposed on the Jamestown fabric, and not to its representing an undisturbed remnant of a pre-Main Phase structure. Immediately to the east of this fold it can be seen that the northwest linear Consort trend was forced outwards by the development of the fold, changing strike to an east-southeast, and ultimately, to an almost east-west trend (Plate 1). The stress responsible for the disharmonic fold must have acted in a southeast-northwest direction.

Several faults occur in the Consort-Noordkaap locality which post-date the northwest fold trend (Plate 1). The Bluejacket Fault is an example, and, where this fault is parallel to the axial plane trace of the Consort folds, it shows a dominant wrench component. According to Viljoen (1964), this fault plane is occupied by pegmatitic material. Granite activity of an unknown age thus post-dates the formation of the fault. The Main Southern Fault is another post-Consort trend fault (Plate 1). Viljoen (1964) concluded that it is a reactivated strike fault, possibly originally developed during the very earliest phases of deformation. However, if this were so, then it would have been deformed by the northwest fold trend. It must, therefore, be concluded that this fault is also post-Consort trend in age. Numerous other younger faults occur just north of the Eureka Syncline.

It appears, therefore, that within the triangular area between the Nelspruit Granites, the Kaap Valley Granites, and the Eureka Syncline considerable structural complexity exists. The northwest fold trend is affected by a later stress which apparently acted from the south-southeast, forcing the Eureka Syncline northwards between the two granite masses which were already in their present position. Strong evidence for such a stress can be seen in the Ulundi Syncline where van Vuuren (1964) found that, after the arcuation of the Eureka Syncline, east-northeast-trending folds were formed (Plate 1). This indicates that, subsequent to the intrusion of the Kaap Valley pluton with its attendant radial stress field, the south-southeast stress responsible for the Main Phase of deformation became active once more to produce the Late Ulundi Trend.

(v) The Youngest Flat Folds

In the Consort-Noordkaap locality, particularly in some of the more foliated and lineated basic schists occurring north of the Eureka Syncline, numerous minor structures are developed which are related to an almost vertical stress. These folds are best developed in talc, chlorite, and sericite schists, and are of several types. In some chloritic schists crenulation cleavage gives rise to parallel linear traces where the axial planes of the folds intersect the rock surface. Other localities show a striking development of accordion folds, the wavelength of the individual folds being of the order of 1 - 2 inches. These accordion folds are generally found in sericite-quartz schists, and conjugate folds are also present in places. More massive rock-types, such as cherts and quartzites, tend to deform somewhat differently, with conjugate folds being produced. These structures are all related, and were formed from a vertical stress, the orientation of which can be accurately determined from conjugate folds and from the poles to crenulation cleavages (Figures 25 and 26).

To the east of this area, as far as Louw's Creek, Anhaeusser (1964) found similar, but less abundant, folds. The conjugate folds near the Bonanza Mine belong to this group and are not the same as those described by Ramsay (1963) as being related to the bending of the Eureka Syncline about the northwest-trending folds.

Cooke (personal communication) found evidence of a vertical stress in the area south and west of Barberton, which appears to be directly related to the major longitudinal faults. Flat folds occur only close to the faults, and might represent a type of second-order stress developed adjacent to the faults.

For the area between Barberton and Louw's Creek, Anhaeusser and Viljoen (1965) suggested that the vertical stress might have been caused by the intrusion at depth of younger granites related to the Mpageni Granite or the G. 5 Granite of Swaziland. It is also possible that the flat folds might represent second-order phenomena related to the rising up of the Nelspruit Granite late in the tectonic history of the area.

C. REGIONAL STRIKE FAULTS

In most cases the extensive strike faults are not sufficiently well exposed to the extent that structural phenomena can be observed within them (slickensides), or adjacent to them (tension cracks, shear planes, folds, and lineations). The complex history of folding outlined above has produced more than one movement direction on the fault planes, and they have been repeatedly reactivated in different stress fields. Consequently, any analysis of faulting at this stage must be considered as largely speculative.

The most striking feature of the faults of the Mountain Land is the fact that they are responsible for placing syncline next to syncline (Plate 1). From this, previous investigators have concluded that faulting took place in the anticlines through some type of thrust mechanism.

The Sheba Fault was folded together with the Eureka and Ulundi Synclines. Movements on the fault brecciated cleaved slates of the Fig Tree Series (Ramsay, 1963). The Barbrook Fault was probably folded by the Main Phase deformation at the time of formation of the cleavage (Ramsay, 1963). The generally parallel orientation of the fold trends and the longitudinal faults suggests a close relationship between folding and faulting, and Ramsay (1963) concluded that the faults were developed as thrusts on the overturned limbs of early anticlines. Continuous compression from the south-southeast produced extensive thrust slices which moved upwards to different levels over successive blocks to the north.

Anhaeusser (1965) observed that these faults were subsequently reactivated as right-lateral wrench faults which produced second-order structures that acted as favourable loci for gold mineralization. Such movements must have been brought about by a force acting essentially in an east-west direction. A stress of identical orientation has been deduced as having produced the Montrose north-south fold trend and the associated conjugate folds in the Agnes-Fortuna locality and in the Eureka Syncline. However, the possibility cannot be entirely dismissed that the wrench movements might have been caused by the emplacement of the Kaap Valley Granite and the consequent formation of a large disharmonic fold, comprising the arcuate Eureka and Ulundi Synclines, with a detachment plane on the Barbrook and Saddleback Faults.

A fault of major importance is situated along the contact of the supra-crustal rocks and the Nelspruit Granite. Within the contact locality numerous shear zones are characterized by mylonites and blasto-mylonites. Anhaeusser (1964) showed that the fabric developed in the contact zone is unrelated to the other fold fabrics and post-dates the intrusion of the homogenized phase of the Nelspruit Granite. It is also later than the Main Phase deformation. Anhaeusser (1964) and Viljoen (1964) both favour the idea that this localized fabric resulted from the rising up of the Nelspruit Granite at some time after its emplacement. Around Joe's Luck Siding and northwestwards towards the Consort locality this fault fabric follows the Main Phase foliation and cannot be geometrically separated. However, in several other localities strong local folding in the contact zone can be seen to deform the Main Phase foliation.

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TECTONICS OF THE AREA

A. SUMMARY OF STRUCTURAL DEFORMATIONS

Work since the classic remapping of the Barberton Mountain Land (Visser et al, 1956) has revealed that the main gold-producing area has a complex tectonic history comprising several phases of deformation. Forces acting from the south-southeast in a north-northwesterly direction produced the regional fold trend (east-northeast), the parallelism of the regional thrust faults and the fold trend, and the overturning of the folds to the north. This Main Phase folding was superimposed on earlier folds about which very little is known. Later fold phases started to act while the Main Phase stress was still active. Incipient arcuation of the supra-crustal rocks north of the Saddleback and Barbrook Faults caused a slight deformation of the Main Phase Eureka and Ulundi Synclines, and the superimposition of Main Phase cleavages on the distorted larger folds. The Shebang Fold was superimposed at the same time on the westward extension of the Eureka Syncline. The angular difference between the original fold orientation and the superimposed cleavages (or folds) is slight, thus indicating only a small amount of rotation prior to the superimposed effects. South of the Barbrook and Saddleback Faults no evidence of superimposition has been found, and the cleavage and fold shapes are geometrically compatible. The Lily Fold is also geometrically compatible, but this is probably due to a lower degree of viscosity of the rocks undergoing deformation as a result of the intrusion and associated metamorphism of the Nelspruit Granite. Instead of a superimposed cleavage, as in the Eureka Syncline to the south, new folds were formed.

Post-Main Phase deformation was probably first caused by a stress acting almost parallel to the regional strike of the bedding, resulting in the north-northwest to north-south Montrose Fold Trend and conjugate folds in the Agnes-Fortuna and Eureka Syncline areas. After this, another major period of deformation was responsible for the northwest Consort Fold Trend and arcuation of the Eureka and Ulundi Synclines. This deformation might have been brought about by either the intrusion of the Kaap Valley Granite, which post-dates the Main Phase cleavage, or the eastwards movement of an already consolidated Kaap Valley pluton on to the Nelspruit Granite. Either event could have produced a large disharmonic fold (Eureka and Ulundi Synclines) on a detachment plane represented by the Barbrook and Saddleback Faults. Either this period of deformation or the preceeding phase which gave rise to the Montrose Trend could have been responsible for the regional right-lateral wrench fault component observed on the regional strike faults.

The north-northwest-acting forces were always active. Continuous compression is revealed by the complex faulting in the locality northwest of the Eureka Syncline, by the disharmonic fold 2 miles west of the Clutha Mine, and by a late-phase east-northeast fold trend which is superimposed on the rotated Main Phase cleavage in the Ulundi Syncline. This folding was superimposed on, and occurred after, the northwest folding. The Eureka Syncline, possibly being more competent, was forced up on to the area of basic schists lying between the Nelspruit and Kaap Valley Granites to give rise to the complexities mentioned above.

The final imprint of deformation is represented by the flat folds. South and west of Barberton these fabrics are intimately related to faulting. In the Consort locality they appear to be developed on a more regional scale. The vertical stress necessary for their development might have been produced by the rising up of the Nelspruit Granite, or by the emplacement of an unexposed pluton of younger Mpageni or G. 5 Granite.

The post-Main Phase mylonitic zone along the contact zone with the Nelspruit Granite might represent a major thrust plane along which the supra-crustal rocks moved up on to the granite. It might be related in time to the Main Southern Fault south of the Consort Mine. Alternatively, the mylonitic zone might have originated at more-or-less the same time as the flat folds consequent upon the rising up of the Nelspruit migmatites relative to the fold belt.

A regional dyke pattern in the north-northwest major stress direction was developed late in the tectonic cycle, as the dykes are essentially unaffected by the inflection of the folds in the Sheba Hills locality. The pattern is superimposed on all earlier inhomogeneities. Large tension joints developed in the Swaziland rocks after the latter had accommodated themselves by folding and faulting, and dyke material entered and filled the tension cracks.

Table 1 has been constructed to summarize the important deformational events in the area under review.

Deformational Phase	Trend	Minor Structures Associated with Folding	Equivalent Phases of Ramsay (1963)	Associated Regional Geological Events
Early Trend	?	?	not recognized	possibly a pre-Moodies orogeny?
Main Phase Deformation	ENE.	schistosity-cleavage minor folds mineral orientation in contact metamorphic rocks	F.1 and F.2	emplacement and intrusion of G.4 Granite and Nelspruit Granite (homogenized phase) regional strike faulting first phase of gold mineralization?
Montrose Trend	N.-S. to NNW.	minor folds and weak cleavage conjugate folds and faults	believed to be part of F.3	emplacement and intrusion of granites of Badplaats area
Consort Trend	NW.	minor folds planar fabric in in-competent rocks	F.3	emplacement and intrusion of Kaap Valley Granite second phase of gold mineralization
Late Ulundi Trend	ENE.	minor folds	not recognized	continued NNW. stress derived from G.4 Granite in Swaziland
Flat Folds	horiz. ax. planes	crenulation cleavage accordion folds conjugate folds	believed to be part of F.3	rising up of Nelspruit Granite reactivation of strike faults? intrusion of younger granites (Mpageni, G.5)?

Table 1 : Characteristics of Six Deformational Phases Responsible for the Structural Development of the Main Gold-Producing Area of the Barberton Mountain Land

B. THE ORIGIN OF THE DEFORMING STRESSES

Deformation of the Swaziland System, as determined from minor structural analysis, is post-Moodies in age. If the Moodies Series represents a true post-tectonic molasse deposit, then the original geosyncline must have been subjected to earlier orogeny. The effects of such an orogeny cannot be deciphered under the imprint of the post-Moodies deformation. Therefore, any structural analysis can refer only to the second of at least two periods of folding and faulting. It is consequently not possible to present the complete tectonic story.

It has been deduced that the force which produced the main deformation presently observable acted from the south-southeast. It can be seen that a large mass of G.4 Granite, including smaller granite bosses of different type, occurs on the south side of the Mountain Land (Hunter, 1961). The emplacement of this 3,070 million year-old G.4 Granite is thought to have been responsible for the deformation. Hunter (1961) observed that the G.4 Granite has a steeper foliation in northern Swaziland than in the south of the territory, and concluded that "it appears to have a much greater affinity to the folding which affected the Swaziland System". Urie and Jones (1965) indicate that the Swaziland System and Jamestown Complex have been complexly folded, or invaded, by the late-orogenic G.4 Granite.

The development of granite is generally related to folding and metamorphism in the axial zone of an orogen. At depth, the granite is syn- and late-tectonic in age; at higher levels, it is generally late- or post-tectonic. However, irrespective of their level, large granite plutons are invariably found in a eugeosynclinal environment, and very rarely encroach on the miogeosynclinal environment (Eardley, 1962; Knopf, 1960).

The question arises as to whether or not the G.4 Granite can be compared with granites of orogenic belts. If this granite were related to such a belt, then the eugeosyncline would have covered most of Swaziland. A further problem is raised by the fact that the G.4 Granite emplacement was also responsible for the deformation and metamorphism of the Pongola System in the southern part of Swaziland. This presents certain problems, viz: are the Pongola and Swaziland Systems then of the same age? If so, the former must represent some type of basin deposit, being made up of lavas and well-sorted shallow water sediments, and the Swaziland System must represent a deep eugeosynclinal deposit. Alternatively, are the two systems of different ages? If so, and if the depositional cycles ended with the emplacement of granite, then, to which system is the granite related? If the G.4 Granite is associated with the Pongola System, then the latter must be younger than the Swaziland System - in accordance with present concepts of South African stratigraphy. If the G.4 Granite belongs to the deformation of the Swaziland System, then the Pongola rocks must have deposited before those of the Swaziland System - which necessitates a considerable change in accepted correlations. A third possibility is that the granite may be related to neither depositional cycle, but might be associated with some independent, fundamental process in the mantle.

The 3,000 million year epoch might thus have been characterized by granite invasion of the crust, granites appearing as rounded diapiric masses deforming supra-crustal rocks into synclinal structures surrounding granite domes. A comparison can be made with the 'gregarious batholiths', of Southern Rhodesia, draped by synclinal schist belts (Macgregor, 1951). If the granites originated in this manner, then the sediments and basement of the Pongola and Swaziland Systems must be very old. These problems emphasize the need for more age determinations of the relatively fresh sediments in the two systems, and of their basements, where these can be found.

The other granites surrounding the Barberton Mountain Land must also be considered. The Nelspruit Granite is considered to intrude the Swaziland System, but only a narrow mobilized zone adjacent to the contact is injective. Migmatites and gneisses are prominent rock-types throughout the main mass of the 'granite'. Whether this 'granite' represents the basement of the Swaziland System or the deeper roots of another huge granite mass of G.4 age, which has moved upwards to a higher crustal level, cannot be said from present data. The Kaap Valley Granite also appears to be an intrusive diapiric dome. The biotite of the granite gives an age around 3,000 million years (Nicolaysen, personal communication). Too much granite seems to have developed at that time, which is not clearly related to an orogenic belt. There is an anomalous juxtaposition of vast amounts of granite with high level sediments which have been folded, and which are rimmed by narrow zones of contact metamorphism.

If the highly granitic terrain contained high-grade metamorphics, and thus represented a deeper level of an orogen, then the tectonic pattern of the Barberton Mountain Land would present a straight-forward conventional story. However, there is an abundance of magmatic "high-level" granite (G.4 and Kaap Valley) in contact with relatively unmetamorphosed sediments. If the other granites of the belt (Nelspruit granites and migmatites; granites of the Badplaats area) are of a similar age, then the anomalous geological situation of a small remnant of essentially unmetamorphosed sediments completely surrounded by vast areas of mobile granitic material must be accepted as hard fact. That the structural events appear to have followed one another closely in time, and that the cross-fold trends were all completed before the dying-out of the north-northwest stresses must be taken to indicate that the observed tectonism was completed entirely within the period of cooling and emplacement of the G.4 Granite in Swaziland. It is quite possible, therefore, that most of the granitic material belongs to the 3,000 million year epoch.

This granitic material is not obviously related to a linear orogenic belt, as is the case in younger geological terrains. The only parallel known to the author is Southern Rhodesia with its "gregarious batholiths" and interspersed schist belts. Younger orogenic belts do, in some cases, contain large amounts of granitic material in contact with relatively unmetamorphosed sediments, as is the case with the West Coast batholiths of North America. However, even in such instances, the granites are generally confined to the eugeosyncline and encroach on the miogeosyncline only in very exceptional circumstances (Eardley, 1962). They can still be clearly related to the original geosyncline, which is certainly not the case with granites of the Barberton Mountain Land.

It is concluded that a fundamental difference exists between the very ancient fold belts and the younger linear fold belts, and that a uniformitarian approach must be used with great caution, when studying the Precambrian fold belts of Southern Africa.

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KEY TO FIGURES

Figure 1 : Poles to bedding planes. Fig Tree sediments in the Ulundi Syncline, southeast of Barberton, on the Havelock Road. 38 observations. Contoured at 0-3, 7, 10, 16, and 23%. Fold axis plunges at 45^{o} in the direction 194^{o}. (from Cooke, personal communication).

Figure 2 : Poles to axial planes and cleavages. Same locality as Figure 1. 50 observations. Contoured at 0-2, 4, 10, 14, and 18%. Average orientation of axial plane is : strike 048^{o}, dip 75^{o} southeast. Orientations of 7 minor fold axes are shown in relation to the axial planar great circle (from Cooke, personal communication).

Figure 3 : Poles to cleavage planes. Moodies sediments in the Eureka Syncline along the Havelock Road. 45 observations. Contoured at 0-2, 4, 6, 12, and 22%. Average orientation of axial plane is : strike 053^{o}, dip 68^{o} southeast (from Cooke, personal communication).

Figure 4 : Poles to bedding planes. Moodies sediments in the Fortuna locality. 191 observations. Contoured at 0-1, 2, 3, 4, 5, and 11%. Fold axis plunges at 60^{o} in the direction 212^{o}. (from Cooke, personal communication).

Figure 5 : Poles to cleavage planes. Moodies sediments in the Fortuna locality. 20 observations. Contoured at 0-5, 10, 15, 30, and 35%. Average orientation of axial plane is : strike 080^{o}, dip 68^{o} southeast (from Cooke, personal communication).

Figure 6 : Poles to bedding planes. Moodies sediments in vicinity of the Shebang Fold. 104 observations. Contoured at 0-1, 3, 5, 10, 20, and 30%. Fold axis plunges at 40^{o} in the direction 094^{o} (from Cooke, personal communication).

Figure 7 : Poles to cleavage planes. Moodies sediments in the Shebang locality. 25 observations. Contoured at 0-4, 8, 12, and 24%. Average orientation of cleavage is : strike 084^{o}, dip vertical (from Cooke, personal communication).

Figure 8 : Poles to cleavages and axial planes (open circles), and orientation of minor folds (filled circles). Fig Tree sediments north, northeast, and northwest of Princeton Mine. Lineations tend to lie in axial plane of folds (from Cooke, personal communication).

Figure 9 : Poles to axial planes of minor folds. Moodies sediments south of Princeton Mine. 45 observations. Contoured at 0-2, 4, 8, 15, 25, and 30%. Average orientation of axial plane is : strike 075^{o}, dip 80^{o} south (from Cooke, personal communication).

Figure 10 : Orientation of minor fold axes. Moodies sediments south of Princeton Mine. 45 observations. Contoured at 0-2, 4, 8, 12, and 14%. Fold axes lie in the axial plane direction determined in Figure 9 (from Cooke, personal communication).

Figure 11 : Orientation of poles to axial planes (periphery of the diagram), and minor fold axes (lying on great circle trace of average orientation of axial plane). Moodies sediments east of Maid of the Mountain Mine. Poles to the axial plane : 63 observations. Contoured at 1, 4, 10, and 20%. Fold axes : 26 observations. Contoured at 4, 8, 16, and 28%. Average orientation of the axial plane is : strike 057^{o}, dip 76^{o} southeast (from Herget, 1963).

Figure 12 : Orientation of poles to axial planes and minor fold axes. Moodies sediments southwest of Maid of the Mountain Mine. Poles to the axial planes (data occurring in north and south of diagram) : 54 observations. Contoured at 2, 4, 10, and 20%. Fold axes (lying on great circle trace of average orientation of axial plane) : 43 observations. Contoured at 2, 4, 10, and 20%. Average orientation of axial plane is : strike 082^{o}, dip 76^{o} south (from Herget, 1963).

Figure 13 : Orientation of poles to axial planes and minor fold axes. Moodies sediments southeast of Montrose Mine. Poles to the axial planes (northwest and southeast part of diagram) : 75 observations. Contoured at 1, 4, 10, and 10%. Fold axes (lying on great circle trace of average orientation of axial plane) : 53 observations. Contoured at 2, 4, and 10%. Poles to axial planes show spread on periphery of diagram, indicating rotation of these surfaces about vertical fold axis. Average orientation of each axial plane is : strike 050^{o}, dip 82^{o} southeast (from Herget, 1963).

Figure 14 : Poles to axial plane of minor folds. Moodies sediments south of Montrose Mine. 62 observations. Contoured at 1, 4, and 9%. Complete spread of poles about periphery of diagram indicates intense folding of surfaces about vertical fold axis. Orientation of plane representing average orientation of younger set of axial planes (north-northwest strike, vertical dip) shown as dotted line in diagram (from Herget, 1963).

Figure 15a : Orientation of poles to bedding planes. Moodies sediments in Saddleback Syncline. 225 observations. Wulfe plot. Fold axis plunges at 40^{o} in a direction 215^{o}.

Figure 15b : Orientation of poles to cleavages. Moodies sediments in Saddleback Syncline. 31 observations. Wulfe net. Cleavages belong to π-girdle defined in Figure 15a, and are thus synchronous with fold formation. Average orientation of axial plane (represented by cluster of poles) is : strike 075^{o}, dip 60^{o} south-southeast.

Figure 16 : Orientation of structural data north of Eureka Syncline between Sheba Siding and Louw's Creek. Small dots at north and south of diagram are poles to cleavage, schistosity, and bedding. East-west line shows average orientation of these surfaces. Oriented within this plane are lineations in quartz-sericite schists northeast of Eureka (open circles), plunges of isoclinal folds (filled circles), and pebble elongations (small dots) (from Anhaeusser, 1964).

Figure 17 : Minor folds associated with major system of folds in Consort locality. 60 folds. Axial plane poles on periphery of diagram. Orientation of minor fold axes in centre and southeastern part of diagram. Contours at 1, 4, 8, and 12 points per unit area. Orientation of axial plane is : strike 145^{o}, dip vertical (from Viljoen, 1964).

Figure 18 : Cleavage-bedding relationships at the Clutha Mine office. Since bedding is steeper than cleavage, it could be suggested that beds are overturned. Graded bedding indicates that beds, in fact, young towards southeast. Indicates cleavage superimposed on structure, and not synchronous with formation of major folds (from Ramsay, 1963).

Figure 19 : Relationship of cleavage to folds. One mile west-northwest of Sheba Mine. Dotted : greywacke. Dashed : fine-grained cleaved greywacke. Dashing shows orientation of cleavage to fold. Cleavage makes an angle with line joining hinges of fold, i.e. cleavage makes an angle with axial plane (from Ramsay, 1963).

Figure 20 : Structural map of Consort locality, showing main foliation trends, major folds, and major faults. For orientation of map compare with Plate 1 (from Viljoen, 1964).

Figure 21 : Orientation of poles to axial planes (periphery of diagram) and fold axes (centre of diagram). Fig Tree sediments in north-trending syncline north of Montrose Mine. Axial planes : 48 observations. Contoured at 4 and 6%. Fold axes : 35 observations. Contoured at 6 and 10%. Data defines a north-south-trending and vertically-dipping axial plane (from Herget, 1963).

Figure 22 : Orientation of poles to axial planes (periphery of diagram) and fold axes (on great circle defining average orientation of axial planes). Fig Tree sediments in north-trending syncline north of Montrose Mine. Figures 21 and 22 taken from the same locality, and represent data from south and north respectively. Axial planes : 55 observations. Contoured at 4 and 6%. Fold axes : 55 observations. Contoured at 4 and 6%. Data defines an axial plane striking 160^{o}, and dipping 65^{o} west-southwest (from Herget, 1963).

Figure 23 : Poles to axial planes of conjugate folds. Moodies sediments in Agnes Mine locality. 21 observations. Constructed kinematic axes reveal that main compressive stress was almost horizontal and essentially parallel to bedding (from Poole, 1964).

Figure 24 : Orientation and amount of plunge of kinematic axes associated with conjugate folds. Eureka Syncline. Arrow pointing towards junction is main compressive axis. Arrow pointing away from the junction represents minimum strain axis. Principal stress lies parallel to bedding, and is essentially flat. A notable exception, due possibly to later deformation, occurs in the southwest (from Ramsay, 1963).

Figure 25 : Orientation of kinematic axes associated with conjugate folds. Woodstock and associated "greenschist bars". Northeast of Noordkaap. 10 folds observed. Vertical principal stress indicated (from Viljoen, 1964).

Figure 26 : Crenulation and larger folds developed in shaly rocks. Southwest of Joe's Luck Siding. 20 folds observed. Contoured at 1, 2, 4, and 6 parts per unit area. Vertical stress indicated (from Viljoen, 1964).

Figure 27 : Sketch showing relationship of Main Phase folds to Main Phase cleavage at time of formation of latter. Slight arcuation probably due to effects of younger fold trends which started to act during, and together with, Main Phase. Northeastern part of diagram represents Eureka Syncline. Southwestern part represents Shebang locality (from Poole, 1964).

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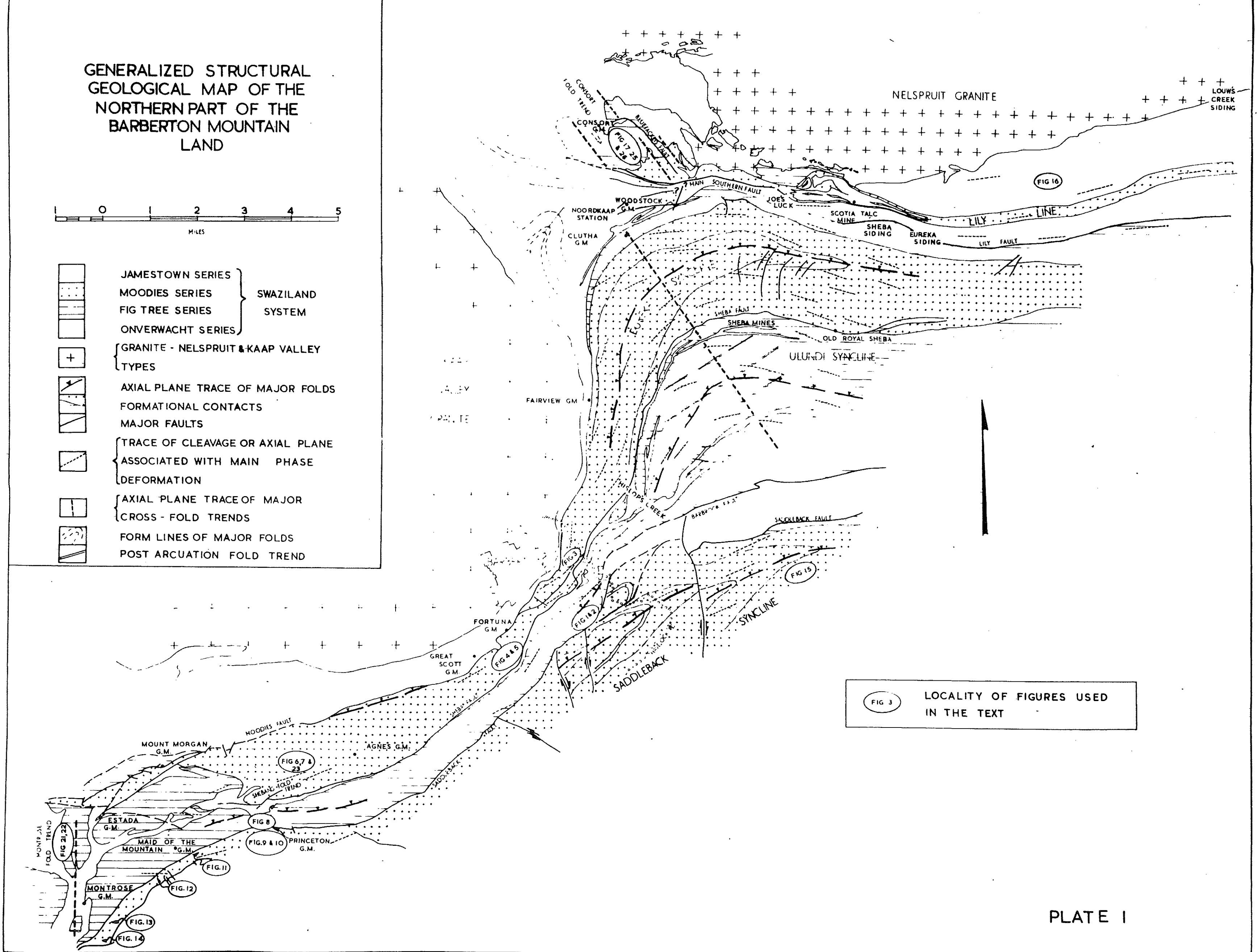

GENERALIZED STRUCTURAL GEOLOGICAL MAP OF THE NORTHERN PART OF THE BARBERTON MOUNTAIN LAND
0 1 2 3 4 5
MILES
JAMESTOWN SERIES
MOODIES SERIES
FIG TREE SERIES
ONVERWACHT SERIES
SWAZILAND SYSTEM
GRANITE - NELSPRUIT & KAAP VALLEY TYPES
AXIAL PLANE TRACE OF MAJOR FOLDS
FORMATIONAL CONTACTS
MAJOR FAULTS
TRACE OF CLEAVAGE OR AXIAL PLANE ASSOCIATED WITH MAIN PHASE DEFORMATION
AXIAL PLANE TRACE OF MAJOR CROSS - FOLD TRENDS
FORM LINES OF MAJOR FOLDS
POST ARCUATION FOLD TREND
NELSPRUIT GRANITE
LOUWS CREEK SIDING
CONSORT FOLD TREND
CONSORT G.M.
FIG 17 25 & 26
FIG 16
MAIN SOUTHERN FAULT
WOODSTOCK G.M.
NOORDKAAP STATION
CLUTHA G M
JOES LUCK
SCOTIA TALC MINE
SHEBA SIDING
EUREKA SIDING
LILY LINE
LILY FAULT
SHEBA FAULT
SHEBA MINES
OLD ROYAL SHEBA
ULUNDI SYNCLINE
FAIRVIEW GM
HISLOPS CREEK
SADDLEBACK FAULT
FIG 3
FIG 15
SYNCLINE
SADDLEBACK
FIG 1 & 2
FORTUNA G M
GREAT SCOTT G.M.
FIG 4 & 5
MOODIES FAULT
MOUNT MORGAN G.M.
AGNES G.M.
FIG 6,7 & 23
SHEBA FOLD TREND
ESTADA G.M.
FIG 8
FIG 21,22
FOLD TREND
MAID OF THE MOUNTAIN G.M.
FIG.9 & 10
PRINCETON G.M.
FIG.11
FIG.12
MONTROSE G.M.
FIG.13
FIG.14
FIG 3
LOCALITY OF FIGURES USED IN THE TEXT

PLATE I

FIG 1

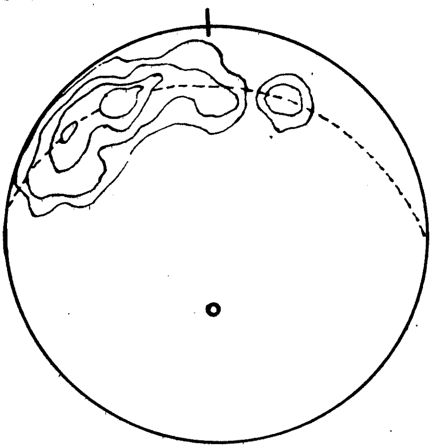


FIG 2

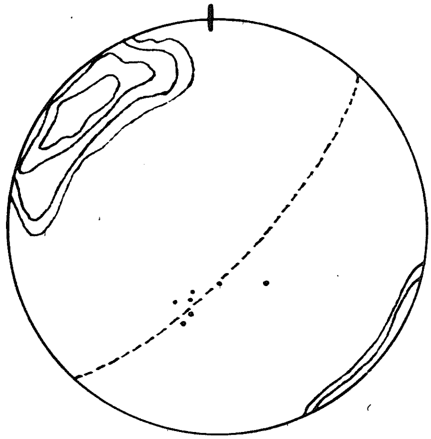


FIG 3

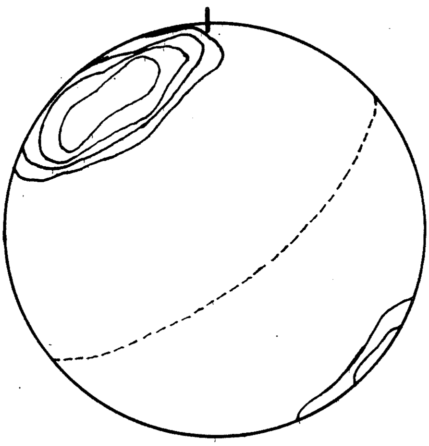


FIG 4

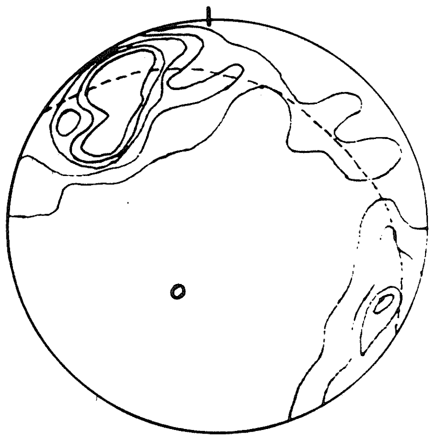


FIG 5

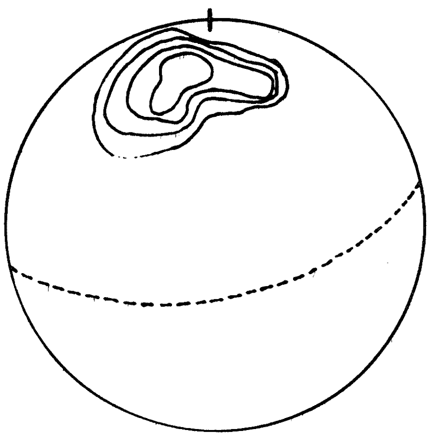


FIG 6

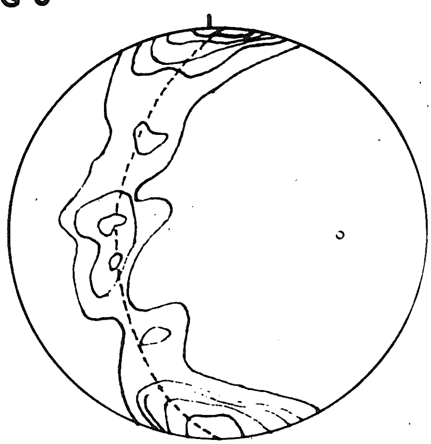


FIG 7

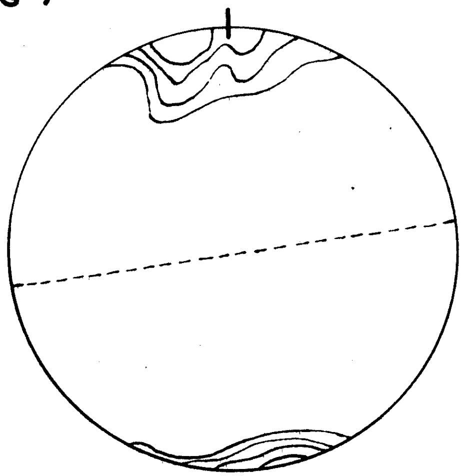


FIG 8

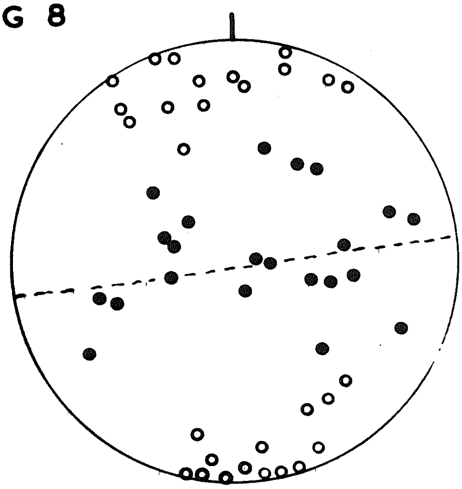


FIG 9

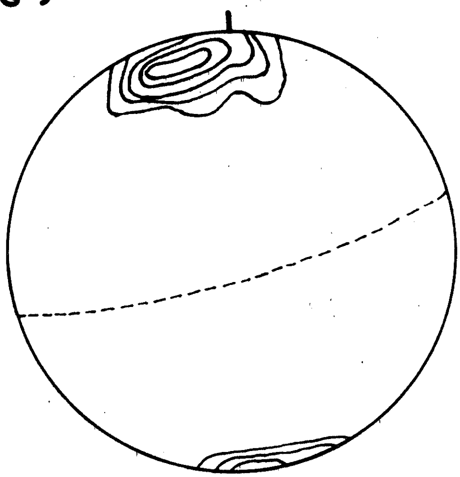


FIG 10

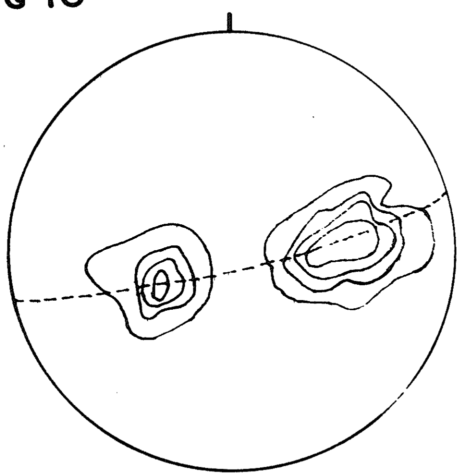


FIG 11

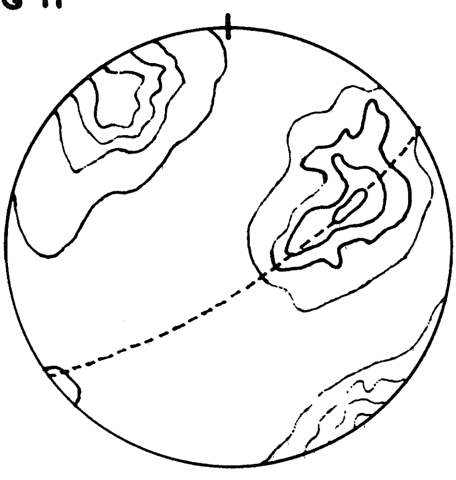


FIG 12

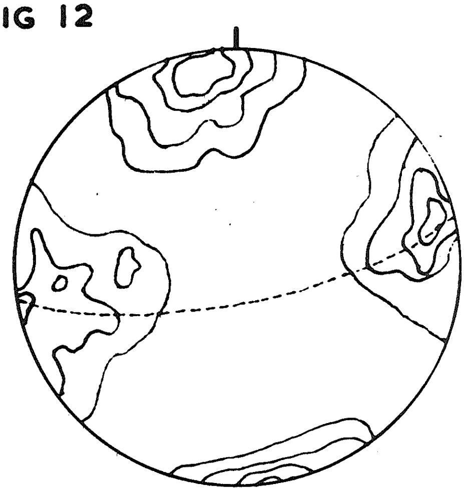


FIG 13

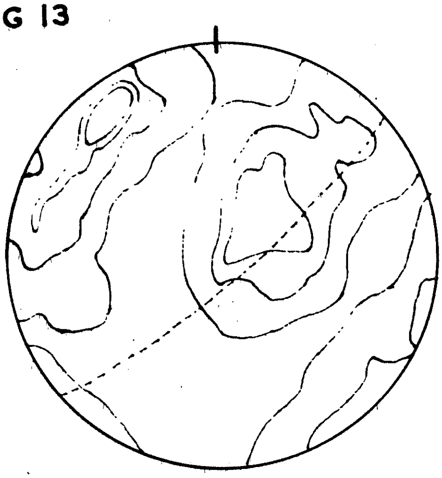
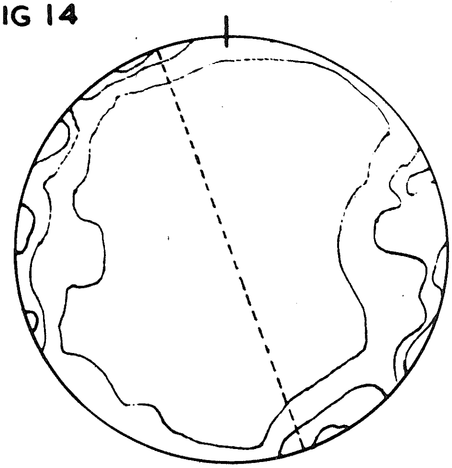


FIG 14



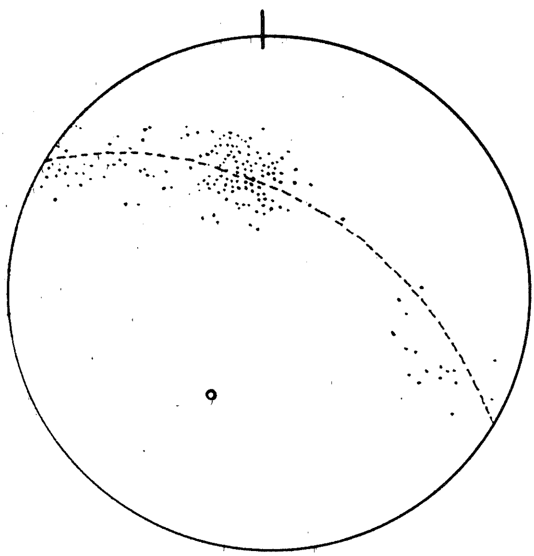


FIG 15a

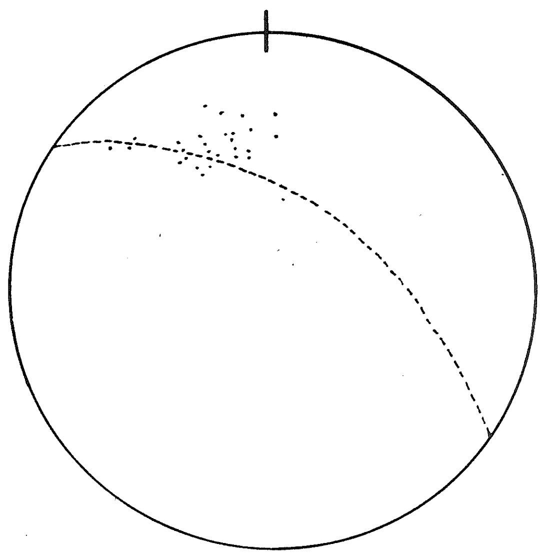


FIG 15b

FIG 16

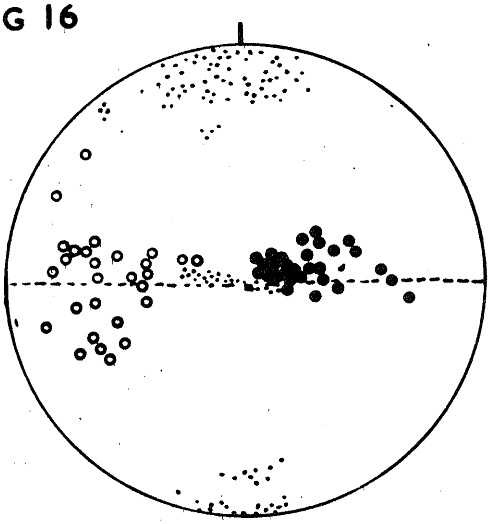
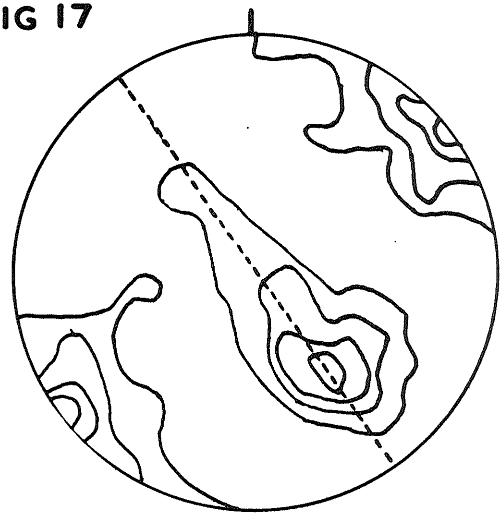


FIG 17



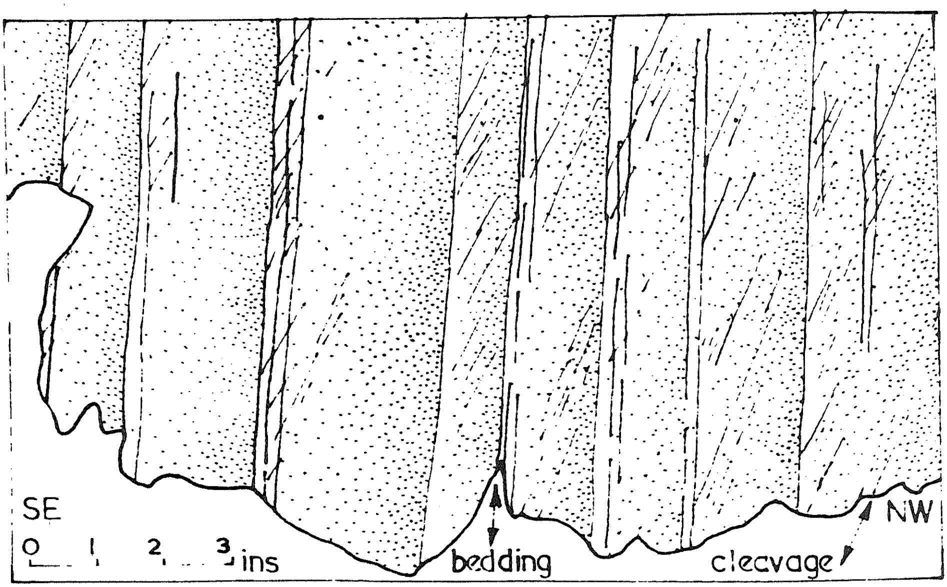


FIG 18

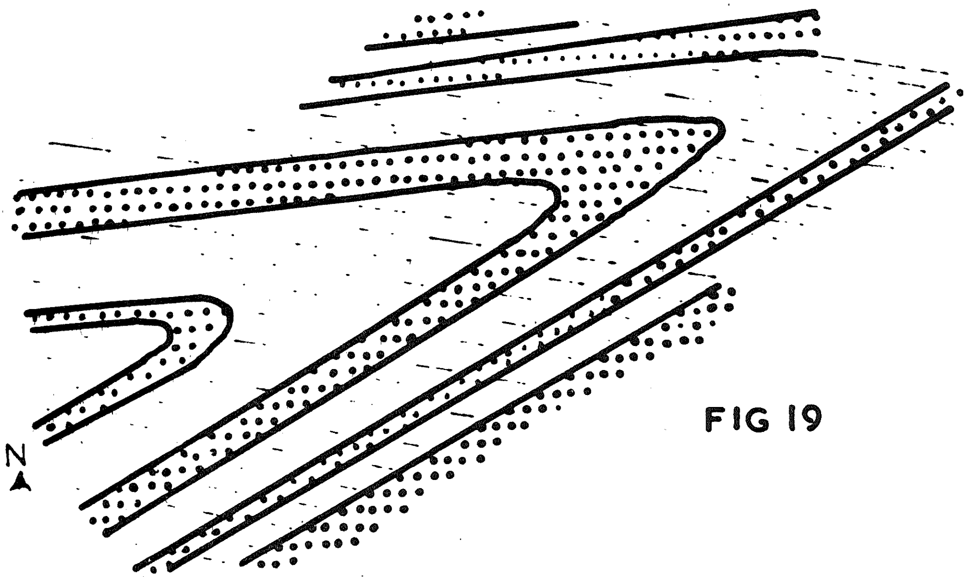
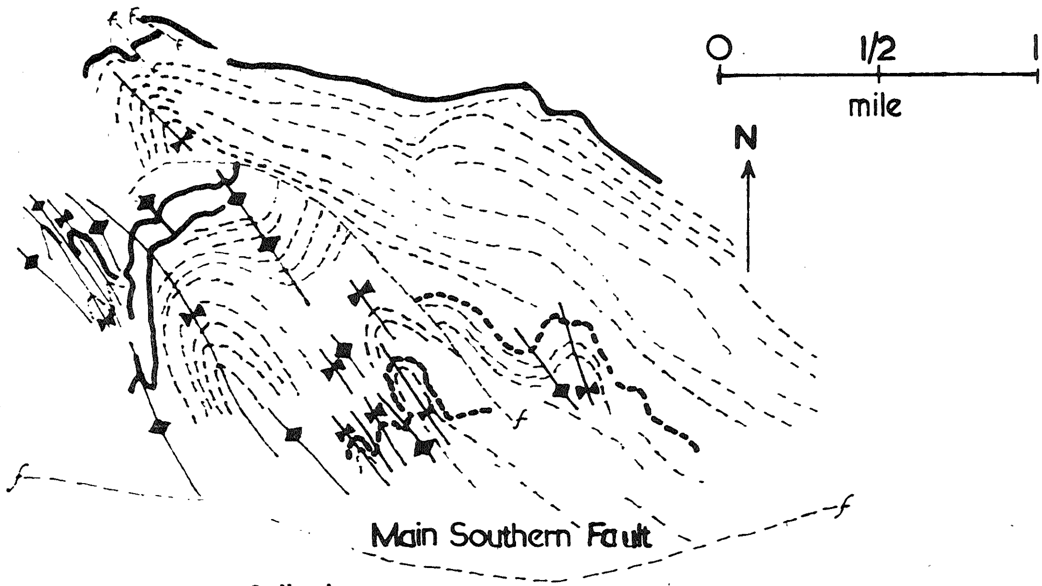


FIG 19



- - - foliation
Consort contact
- - - - pyroxene marker
f - - - f faults
synclinal axial plane trace
anticlinal " " " .

FIG 20

FIG 21

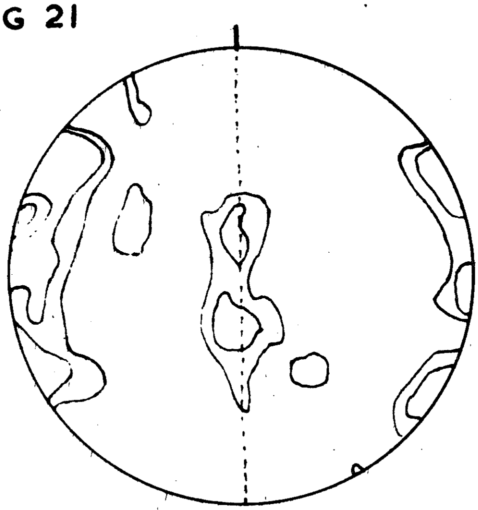
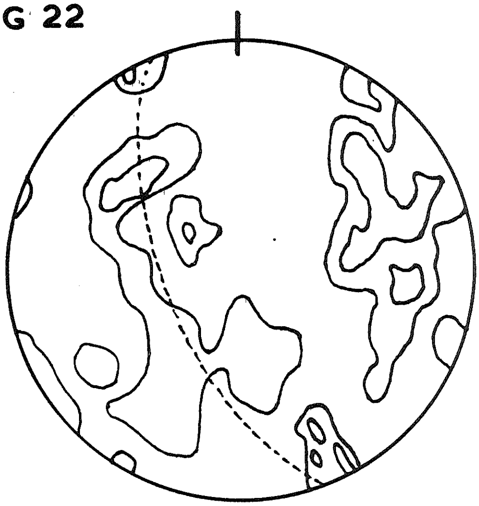


FIG 22



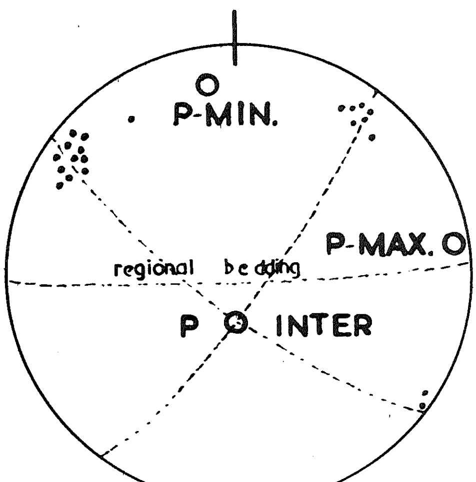


FIG 23

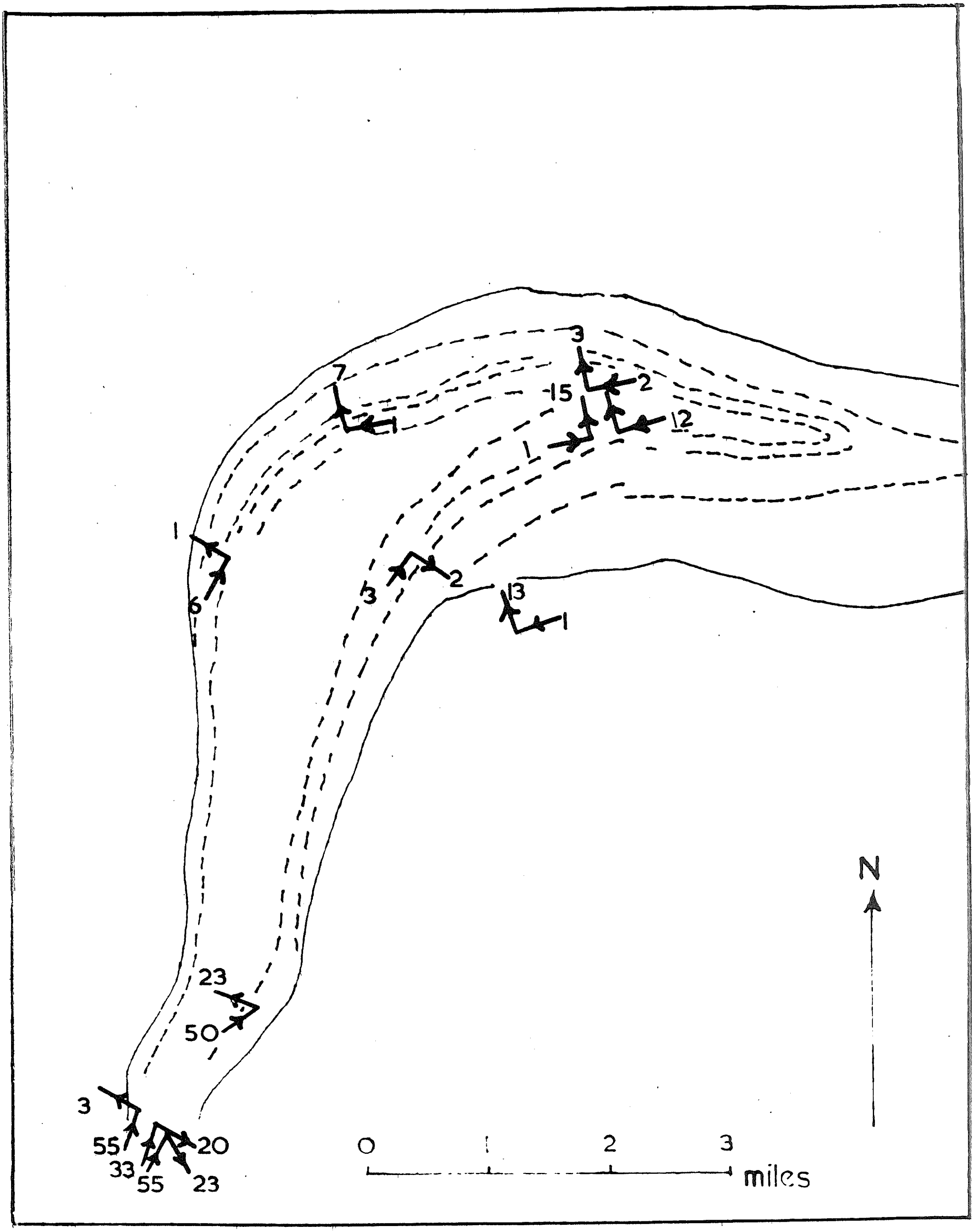


FIG 24

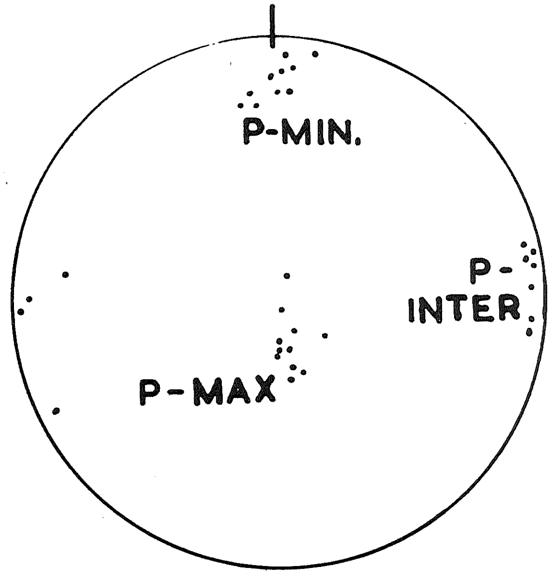


FIG 25

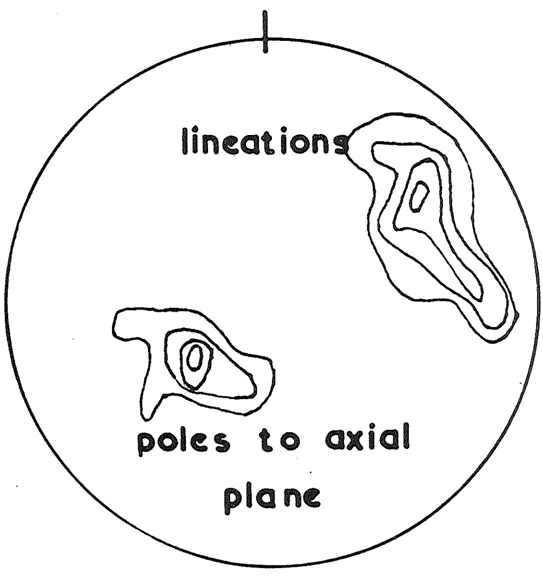


FIG 26

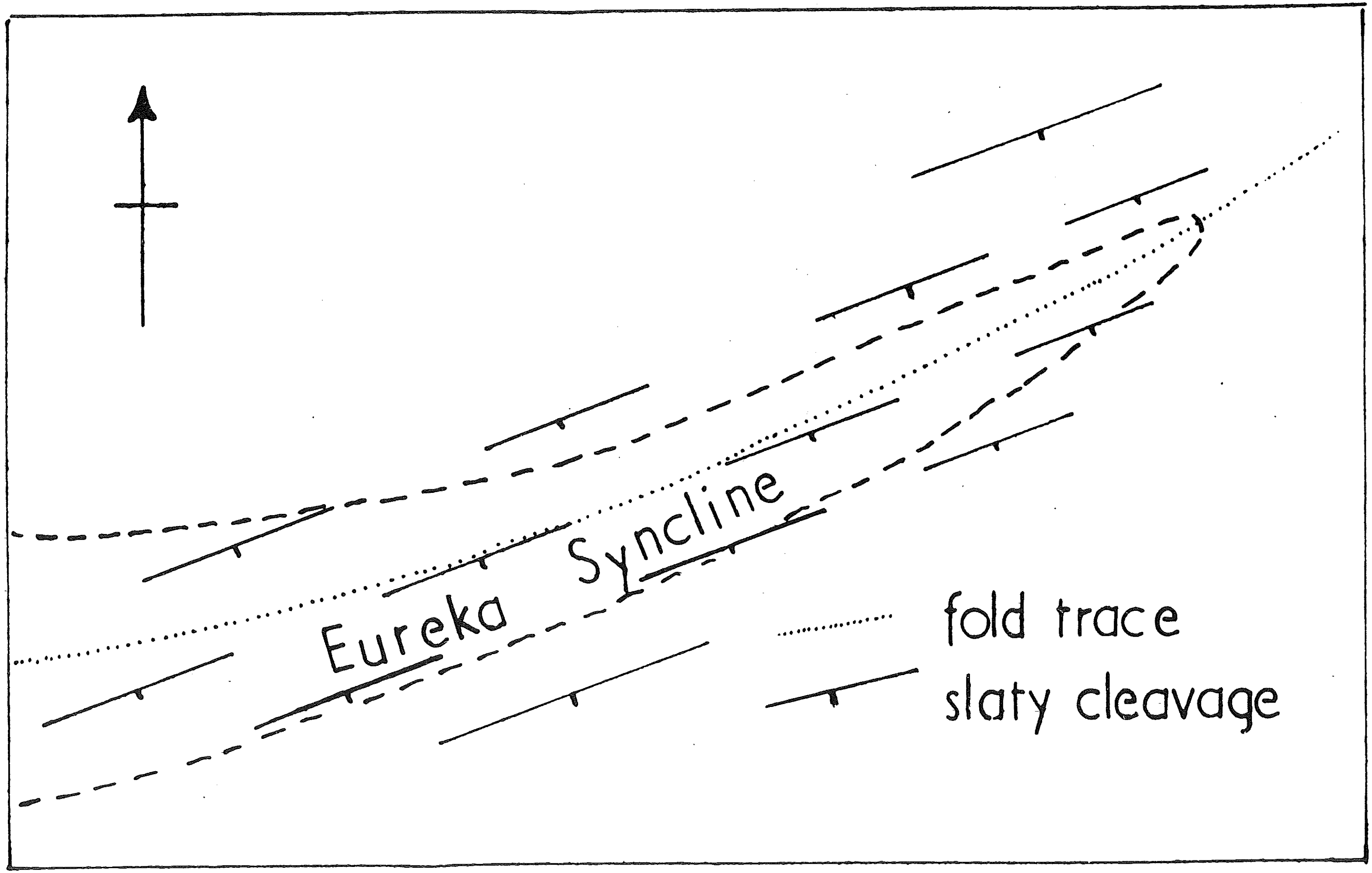


FIG. 27