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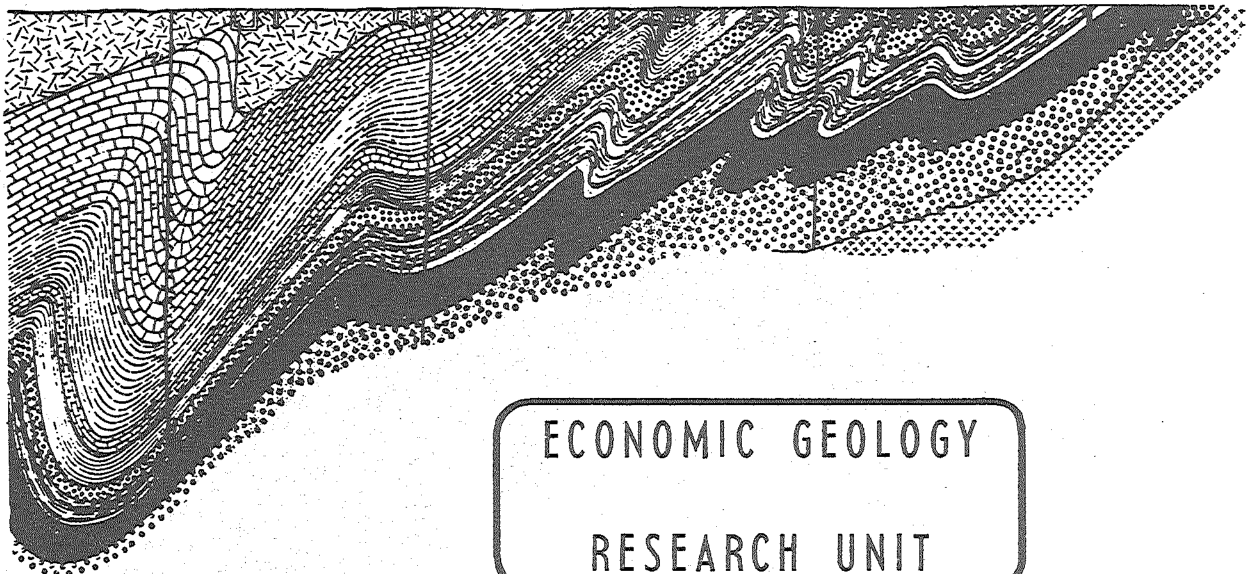

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# WRENCH FAULTING AND ITS RELATIONSHIP TO GOLD MINERALIZATION IN THE BARBERTON MOUNTAIN LAND

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by

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## ABSTRACT

A generalized geological background and a brief summary of existing and new ideas on the structure of the Barberton Mountain Land are presented as a foundation upon which the importance of faulting related to mineralization is discussed. The paper deals essentially with wrench faulting and the second-order phenomena associated with horizontal or sub-horizontal strike-slip movement. The more important characteristics of wrench fault tectonics are briefly reviewed. Previous findings with respect to faulting in the Barberton area are dealt with. The relationship of the recently formulated structural phases of deformation in the Barberton Mountain Land to the localization of the gold mineralization is included to indicate the intimate nature of the relationship.

Wrench faults, it is suggested, were formed mainly by reactivation of pre-existing longitudinal thrust fault planes by the third period of deformation (F3) that was responsible for the arcuate folding of the Eureka and Ulundi Synclines. The possible stress fields responsible for the formation of the 3rd phase folds and the wrench faults are reviewed. The importance of regenerative stresses in the form of second-order phenomena associated with wrench fault tectonics is emphasized, using several examples from various mines in the region. The Lily Mine is considered in detail, and a structure termed a cymoid loop, or curve, is analysed, using principles of wrench fault mechanics. This type of structure is considered to be of considerable importance as a locus of rich payshoots in gold reefs. The Sheba and French Bob's mines, among others, are also discussed to show that either direct or indirect effects of wrench faulting are responsible for producing structures suitable for ore deposition.

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WRENCH FAULTING AND ITS RELATIONSHIP TO GOLD MINERALIZATION IN THE BARBERTON MOUNTAIN LAND

## CONTENTS



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# WRENCH FAULTING AND ITS RELATIONSHIP TO GOLD MINERALIZATION IN THE BARBERTON MOUNTAIN LAND

## INTRODUCTION

The importance of faults in the development and distribution of gold mineralization in the Barberton Mountain Land has long been recognized. The most conspicuous of these are the extensive, longitudinal strike faults - such as the Lily, Sheba, Barbrook, Moodies, and Saddleback faults - which divide the Archean fold belt into a series of long, narrow blocks trending east-northeastwards, parallel to the regional grain of the Mountain Land. It has been contended by most previous investigators that these strike faults were originally thrusts, and that they acted as the main channelways for the gold-bearing hydrothermal solutions emanating from depth. Conceding that these deductions might well be right, two phenomena indicate that the story might be more complicated : (1) there is abundant evidence that horizontal movements have taken place on the fault planes, and (2) the most important deposits of gold are, for the most part, not in the strike faults themselves. From the first it is clear that wrench movements have been operative along the longitudinal faults, irrespective of whether they were thrusts at any stage or not, and from the second it would appear that the features responsible for the localisation of the gold deposits lie adjacent to, and not in, the regional dislocations, and that they might therefore be associated second-order fractures, and not the first-order strike faults themselves. The aim of this paper is to show that the second-order features are related to the horizontal movements, and that the gold mineralization is, therefore, intimately related, in many instances, to the effects of wrench faulting.

## A. GENERALIZED STRATIGRAPHY

The Barberton Mountain Land comprises part of an ancient fold belt of volcanics and sediments belonging to early Precambrian formations of Southern Africa, and having an age in excess of 3000 million years. These rocks are surrounded by a mass of granites, gneisses, and migmatites of varying compositions and tectonic levels. The ancient layered rocks have been subjected to several periods of igneous intrusion and deformation, resulting in a complex history of events.

The most comprehensive account of the general geology of the area has been prepared by the South African Geological Survey (Visser et al, 1956). Several controversial points still exist concerning the actual succession. For the purposes of this paper, the Swaziland System has been taken as comprising four sub-divisions : Onverwacht Series at the base, Fig Tree Series, Moodies Series, and Jamestown Series, the youngest group. The Onverwacht Series consists of acid and basic volcanics with intercalated clastic and non-clastic sediments. The Fig Tree Series is characterized by fine- and coarse-grained graywackes, shales, banded ironstones, massive and banded cherts, and schistose talc and carbonate rocks. It is taken to represent a flysch facies of a typical geosynclinal sequence. The arenaceous and rudaceous rocks of the Moodies Series overlie the Fig Tree assemblage with a pronounced angular unconformity in places. A basal conglomerate, containing many pebbles derived from Fig Tree rocks, is followed by an extensive development of quartzite, with subordinate jasper, shale, and lava horizons. The Jamestown Series is represented essentially by a suite of intrusive basic and ultrabasic rocks. Included in this group are various basic schists, serpentinites, amphibolites, and diabases. Hypabyssal rocks, in the form of dykes and sills, are abundant throughout the area, and make up a systematically orientated pattern conforming, for the most part, with the structural controls responsible for the overall deformation of the Mountain Land.

A striking feature of all these rocks is the apparent absence, or low grade, of metamorphism, despite the fact that they are surrounded by intrusive granites.

## B. OUTLINE OF STRUCTURE

### (a) Phases of Deformation

Hall (1918) recognized the complexity of the Barberton Mountain Land, but did not attempt a structural analysis of the area. He ascribed the complex structure to "granite intrusion", i.e. to the intrusion of the Nelspruit Granite and the Kaap Valley Granite. Van Eeden (1941), from a more detailed study of the Sheba Hills area, concluded that :

(i) the forces responsible for the deformation of the Mountain Land acted at right angles to the major linear trend of the area, i.e. from a direction of $150^{\circ}$;

(ii) the general strike of the axial planar traces of the main folds is roughly N.$60^{\circ}$E. which conforms to the strike of the Mountain Land, in general, and of the prominent longitudinal faults;

(iii) the major force from the south-southeast resulted in overfolding to the north-northwest;

(iv) the deformation of the rocks and the intrusion, or formation, of the Nelspruit Granite took place at the same time, but the granite was not fully consolidated after folding ceased;

(v) the Kaap Valley Granite was already a solid mass at the time of deformation, and caused marked changes in the strike of the bedding and the fold axes in adjacent rocks;

(vi) horizontal elongation in the Nelspruit Granite, parallel to the length of the Mountain Land, took place while the stratified rocks were elongated close to the vertical as a result of the folding;

(vii) only one major period of deformation affected the Barberton Mountain Land.

Hearn (1943) considered the Kaap Valley Granite to be the younger of the granites. Folding and metamorphism were due to the intrusion of the Nelspruit Granite. Later the Kaap Valley Granite intruded, and was responsible for the complex structural conditions in the Consort Mine area.

More recently, Ramsay (1963) revealed the presence, in the northwestern part of the Mountain Land, of at least three successive periods of deformation :

(i) The original geosyncline comprising the rocks of the Barberton Mountain Land underwent folding which led to the development of a series of major and minor folds (F1), the traces of which probably trended northeast or north-northeast. This period of deformation corresponds to the one, and only, period of deformation described by Van Eeden (1941). The great strike faults that parallel the major formations developed in the overturned limbs of first-fold anticlines. They were probably initiated during the first period of deformation, although most appear to have been reactivated during the later periods of folding. Late movements on the Sheba Fault, for example, have brecciated the cleaved slates of the Fig Tree Series.

(ii) The second deformation followed a regional compressive strain oriented north-northwes This led to the development of widespread slaty cleavage and schistosity which was superimposed across the F1 folds. Only locally were new folds (F2) developed. The Nelspruit Granite intruded at this time, thermally metamorphosing the adjacent strata, as well as introducing, probably later during this deformation, the main period of gold mineralization.

(iii) The final phase of deformation led to the folding of the slaty cleavage and schistosity by large- and small-scale folds (F3) in the north of the region. The development of the great arcuate structure of the Eureka Syncline and of the slaty cleavage was possibly contemporaneous with this folding. Conjugate folds and faults may have formed synchronously with the arcuate structure.

Recent work undertaken by the Economic Geology Research Unit has modified Ramsay's (1963) observations regarding three phases of deformation. From work carried out in the area around the Consort Mine (Viljoen, 1964), between Sheba Siding and Louw's Creek (Anhaeusser, 1964), in the Ulundi Syncline (van Vuuren, 1964), around the Agnes Mine (Poole, 1964), in the Moodies Hills (Cooke, 1965), and around the Montrose Mine (Herget, 1963), the following summary of the tectonic history of the main gold-producing area of the Mountain Land has been compiled by Roering (1965) :

| 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<br>minor folds<br>mineral orientation in contact metamorphic rocks | F.1 and F.2 | emplacement and intrusion of G.4 Granite and Nelspruit Granite (homogenized phase)<br>regional strike faulting<br>first phase of gold mineralization? |
| Montrose Trend | N. - S. to NNW. | minor folds and weak cleavage<br>conjugate folds and faults | believed to be part of F.3 | emplacement and intrusion of granites of Badplaats area |
| Consort Trend | NW. | minor folds<br>planar fabric in incom-petent rocks | F.3 | emplacement and intrusion of Kaap Valley Granite<br>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<br>accordion folds<br>conjugate folds | believed to be part of F.3 | rising up of Nelspruit Granite<br>reactivation of strike faults?<br>intrusion of younger granites (Mpageni, G.5)? |

(b) The Major Faults

The Geological Survey (Visser et al, 1956) recognized that many of the major faults were initiated concurrently with the folding deformations that affected the area. An extremely complex fault and fracture pattern is superimposed on an equally complex fold pattern. At present very little is known about the fault tectonics, or how intimately they are related to the fold deformations. No systematic study of fault trends has yet been attempted, despite the fact that practically all the gold mineralization is directly connected to fault and fracture disturbances. Apart from the individual mines where the structure and fault patterns are known to be directly responsible for the localization of the mineralization, no detailed studies have been affected with regard to the dating of the various movements, the correlation of particular fault or fracture styles, or the fault geometry as related to folds or first-order regional faults.

Regionally, large faults which are orientated parallel or sub-parallel to the general strike of the Mountain Land, have been referred to as longitudinal, or strike,faults (Visser et al, 1956). The major faults previously recognized included the Sheba, Barbrook, Saddleback, Inyoka, Kamhlabane, and Scotsman Faults. Recent work has added the Main Southern Fault and the Lily Fault to the list (Viljoen, 1964; Anhaeusser, 1964). Practically all these faults are essentially high-angled thrust faults that dip steeply to the southeast and strike roughly in a northeasterly direction. The main over-thrust stress has been from the southeast in most instances.

The Sheba Fault is essentially a thrust plane along which argillaceous Fig Tree rocks have been pushed over arenaceous Moodies rocks to the northwest. West of Fig Tree Creek, and especially in the Sheba group of mines, where the fault strikes east-west the Geological Survey (Visser et al, 1956) found that right-lateral wrench movement had occurred along the fault zone.

To the south of the Sheba Fault another major break, the Barbrook Fault, also behaves essentially as a steeply inclined thrust fault, especially in the west. To the east its nature is not certain, but the Geological Survey (Visser et al, 1956) believed that movement along the fault plane was largely horizontal, and that, as in the case of the Sheba Fault, right-lateral wrench displacement had taken place. There was no indication as to whether it was thought the thrust faults gave way to wrench faults synchronously in one plane, or that the phenomenon resulted from local changes of strike, or that the thrust-wrench relationships along the Barbrook Fault resulted from a superimposition, at some later stage,of a horizontal movement.

According to the Geological Survey (Visser et al, 1956), the Saddleback Fault, south of the Barbrook Fault, behaves similarly to the other faults in the Mountain Land. The central section of the fault zone has Onverwacht rocks to the north of the fault, and Fig Tree and Moodies rocks to the south. The fault plane was reported to dip steeply to the southeast, with a down-throw to the northwest. It is difficult, however, to reconcile the above fault movements with the outcrop map. Horst movements seem to explain the relationship more clearly. It was stated that, southwest of the Barberton-Havelock road, the fault becom in effect, a wrench fault, although it was pointed out that extensive upthrusting must also have taken place.

The Inyoka and Kamhlabane Faults occur well into the centre of the Mountain Land, and are bot high-angled thrust faults dipping steeply to the southeast. The Main Southern Fault and the Lily Fault occur close to the northern rim of the Mountain Land, and both appear to be thrust faults. The Lily Fault shows evidence of some later movement and displacement, indicating that the north side of the fault moved to the east relative to the south side which moved west. Not much is known about the Sctosman Fault west of Louw's Creek, but its similarity to other longitudinal strike faults in the area seems to favour its also being a high-angled thrust fault. A further regional fault, the Moodies Fault, has recently been added to the geological map of the area southwest of Barberton by Cooke (1965).

It is noteworthy that the strike faults invariably occupy positions between major synclines throughout the entire Mountain Land. The Lily and Main Southern Faults are located between the Lily and Eureka Synclines. The Sheba Fault occurs between the Eureka and Ulundi Synclines, while the Barbrook and Saddleback Faults occupy positions between the Ulundi and Saddleback Synclines.

Ramsay (1963) believed that the major faults in the Mountain Land probably developed at the same time as the major folding, and that they both represented his F1 structures. They were thus formed early in the tectonic history of the area. Subsequent deformations either rejuvenated or reactivated the movements along, or adjacent to, the fault planes. Boardman (1950) was the first to report on the wide-spread occurrence of horizontal or sub-horizontal movement of bedding and fracture planes in various mines throughout the Barberton District. The movement directions observed appeared to indicate a constant regional southwesterly wrenching, or shearing, motion which caused the strata on the south side of a faulted zone to move westwards relative to the rocks on the north side. The sub-horizontal shearing recorded by striae, slickensides, drag folding, and puckering alongside shear and fracture planes was found to occur over a widespread area of the Barberton Mountain Land.

## C. THE NATURE OF THE GRANITES

Hall (1918) was the first to describe the two varieties of granite to the north of Barberton. He considered that both the Nelspruit and Kaap Valley granites were of the same age, but that they represented different conditions of consolidation. Both granites were found to be intrusive into the basic, as well as the sedimentary, rocks of the Mountain Land. The main granitic body was visualized as having "split off on three sides" to consolidate after having assimilated the surrounding basic rocks of the Jamestown Series. Hearn (1943) considered the Kaap Valley Granite to be younger than the Nelspruit Granite. He wrote : "the rocks around the New Consort Mine have thus been first intruded, folded and altered by the Nelspruit Granite. Later came the intrusion of the De Kaap Valley boss, the effects of which were superimposed upon those of the Nelspruit Granite. It is largely this latter intrusion which has given rise to the complex structural conditions observed in the workings of the New Consort Gold Mine. It is also this latter intrusion which has been responsible, for the most part, for the mineralization of the district". The Geological Survey (Visser et al, 1956) regarded the Kaap Valley Granite as being the acid phase of a differentiated plutonic complex of rocks - the Jamestown Igneous Complex. It was shown that the hornblende granite is everywhere surrounded by basic rocks - the contact between the two always being sharp. Van Eeden (1941) concluded that the Kaap Valley Granite was already a solid mass at the time of major folding of the sedimentary rocks to the south. The Nelspruit Granite was considered by the Geological Survey (Visser et al, 1956) to have been emplaced at a later stage, and was deemed mainly responsible for the metamorphism and structural disturbances in the area.

Read (1951) interpreted the Nelspruit Granites as being products of the migmatization of semi-pelitic and more siliceous rocks. He considered the Kaap Valley Granite as representing a high-level pluton. Ramsay (1963) was of the opinion that the Nelspruit Granites represented the original basement on which the Swaziland System were later deposited. He considered the whole to have been deformed and intruded by later granites. Basing his opinion on structural features, he also concluded that the Kaap Valley Granite is representative of a high-level pluton. Viljoen (1964) considered that the main mass of Nelspruit gneisses and migmatites was approximately of the same age as the gneisses and migmatites of Swaziland, and that both represented, for the most part, intensely granitized sediments of a pre-Swaziland suite of rocks. These gneisses, he contended, formed the basement on which, at a much later date, the Swaziland System was deposited. The Kaap Valley boss was thought to be a granite dome which rose and was emplaced during the third phase of deformation (F3).

Recently, the writer has noted that the Kaap Valley Granite in the Caledonian Siding locality is strongly foliated along the immediate contact with the basic schists. In addition to the foliation, there exists a marked lineation of mineral constituents in the granite. This lineation was found to be identical in attitude to a similar lineation in the pre-Fig Tree basic schists along the granite contact, and also to be parallel to the flattening and long axis orientation of pebbles in the Moodies basal conglomerate of the Eureka Syncline. It would thus appear that the structures in all three adjacent rock-types were possibly produced by the same stress phenomenon. It might also imply that the Kaap Valley Granite had already been emplaced prior to this deformation. It was previously believed (Visser et al, 1956) that the Kaap Valley Granite contact with adjacent rocks was everywhere a sharp one. This is not the case near Caledonian Siding where a gradational contact exists, with the granite apparently intrusive into the strongly cleaved basic rocks. The intrusive relationships in this area are not of the cross-cutting type, but instead the granite has apparently stoped its way up along the cleavage planes in the schists. If this cleavage is the same as Ramsay's (1963) F2 slaty cleavage, it would mean that the Kaap Valley Granite was introduced later than the second deformation, and probably played a major role in the subsequent third deformation phase. Ramsay (1963) mentioned "that if the granite was at some stage in the structural history a resistant, competent mass, then this state must have been reached after the development of the slaty cleavage". A difficulty unfolds, however, from the observations in the Caledonian Siding area. Here the granite appears to have intruded into the cleavage planes of the schists, yet there are lineations also coincident with the same cleavage. The writer has found that, elsewhere in the Barberton Valley, the Kaap Valley Granite possesses a marked foliation that everywhere appears to parallel the contact with the Swaziland System, and it may merely be fortuitous that the cleavage, foliation, and lineations in the Caledonian Siding area coincide.

## D. GOLD MINERALIZATION

### (a) Distribution of Mineralization

The more important gold mines occur in the northern portion of the Barberton area, in the zones immediately adjacent to the Kaap Valley Granite. This close association of the granite with many of the mines that have collectively yielded over 95 percent (Pretorius, 1965) of the total gold recovered from the area, has led many investigators to believe that the mineralization was introduced by this granite intrusion.

The main faults in the Mountain Land have for a long time been held partially, or wholly, responsible for the introduction of gold and sulphide mineralization into the various host-rocks of the Swaziland System. Several of the largest mines in the district occur in close proximity to the major faults, undoubtedly indicating a major link between the two. The most important of these faults, from the mining point of view, are the Sheba and Barbrook lines of disturbance. Two of the most important mines in the district - the Fairview and Sheba gold mines - occur in the vicinity of the Sheba Fault. Gribnitz et al (1961) considered that the primary avenues for the hydrothermal solutions introduced into the area were undoubtedly the regional strike faults. These faults, he believed, extended further than shown by the Geological Survey (Visser et al, 1956).

However, in only a few instances have the major fault planes themselves provided economically recoverable gold. Generally, the payable ore has been found in the smaller associated fractures that diverge from the main faults or fractures. Boardman (1950) reported that many such minor fractures which branch off from the parent fractures at angles of between $30^{\circ}$ and $45^{\circ}$ have proved to be the most important economic ore horizons.

The factors determining the position of the usually narrow and well-defined ore-shoots within the reefs are not fully understood. Gribnitz et al (1961) stated that variations in the physical properties of the ruptured strata, bifurcations of faults and fractures, and changes of dip and strike must all be interrelated. Boardman (1950) suggested that the shape, elongation, and plunge of many of the ore-shoots are related to the puckering and folding associated with shearing fractures. Mining has apparently shown that the mineralizing solutions preferentially settled in the most shattered and disturbed zones in the rock-mass. Strong fractures are often found that have been bypassed for nearby weakly developed fractures or strongly brecciated and sheared zones.

### (b) Periods of Mineralization

Ramsay (1963) was of the opinion that the main period of gold mineralization was broadly synchronous with a late-stage development in the second phase of regional deformation. In the Consort Mine the mineralization pre-dates the development of slightly sheared granite pegmatites which were deformed during the second regional deformation. The ore-shoots are linear, and are thought to coincide in attitude with minor structures believed to be parallel to the axes of second folds (F2). These ore-shoots are deformed by F3 structures. Viljoen (1964) expressed the opinion that the localization of the Consort mineralization was due, partly, to the fact that the contact between competent Fig Tree and Moodies rocks and incompetent basic pre-Fig Tree schists proved to be a zone of extensive differential movement. It was thought probable that the embryonic F3 folds started developing late in the second period of deformation, and played a part in the localization of ore deposits. The whole mineralized contact was then strongly deformed by the F3 folds.

Ramsay (1963) and the Geological Survey (Visser et al, 1956) both suggested that the ore-fluids responsible for the introduction of the gold might have been related in time and space to the intrusion of the Nelspruit Granite.

Recently, during the course of mapping the Eureka Syncline, the writer came to the conclusion that much of the gold mineralization was introduced either during or after the third phase of deformation. Radiating roughly perpendicular to the Sheba Fault in the inner arc (southern limb) of the folded syncline are numerous tension fractures. These fractures are essentially filled with gold-quartz veins, and are comparatively free of sulphide mineralization. It is believed that the F3 folding of the arenaceous Moodies rocks resulted in numerous tension gashes forming in the hard competent quartzite horizons. The majority of the fractures are vertical or steeply dipping, and lie at right angles to the bedding planes. A few fractures, however, cut obliquely across the strata, and may owe their orientation to shears related to the conjugate folding of the third structures described by Ramsay (1963). The subsequent invasion of the fractures by hydrothermal gold-quartz veins would tend to suggest that the mineralization was not confined solely to the second period of deformation, as suggested earlier by Ramsay (1963), but that it continued to be precipitated in favourable traps produced in structures formed by the third period of deformation. Examples of these fractures, either mined out or presently being mined, are the Joe's Luck and Thomas fractures, the series of fractures belonging to the Victory Hill workings, and the numerous fractures mined in and around the Fairview Mine. Of the last-mentioned group, the Kimberley-Sheba, Strydom, Blue Rock, Kidson, and Little Kent, to name but a few, all occur in the hard massive Moodies quartzite horizons.

Also associated with the third period of folding in the Eureka Syncline are numerous fractures that roughly parallel the Sheba Fault. These occur mainly in the localities immediately flanking the F3 fold axis, and in the core of the arcuate structure between Fairview Mine and the Sheba group of mines. The origin of these fractures may well be explained by concentric shearing as a result of strike-slip movement between the folded bedding units. The concentric shear surfaces, coupled with overthrust movements, produced suitable structures subsequently invaded by hydrothermal mineralizing solutions containing essentially free gold and vein-quartz, with lesser amounts of sulphide material.

Thus it can be seen that, as far as is known at present, the mineralization was introduced over a wide range of time, beginning, as Ramsay (1963) has intimated, during the second phase of deformation, and continuing through into the third phase. From this it would appear that the third phase of deformation that affected the Mountain Land was probably very significant from the point of view of providing numerous suitable structural traps for the mineralizing solutions. The mineralization was possibly of two different types, with the earlier gold intimately associated with sulphides, and the later gold virtually devoid of sulphides.

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## WRENCH FAULTING IN THE MOUNTAIN LAND

### A. CHARACTERISTICS OF WRENCH FAULTS

Wrench faults are also known as strike-slip faults, tear faults, and transcurrent faults. Moody and Hill (1956) adopted the term "wrench fault" from Kennedy (1946) and Anderson (1951) to describe ruptures in the earth's crust in which the dominant relative motion of one block to the other is horizontal, and the fault plane is essentially vertical. Reference to the apparent relative direction of movement of the two blocks, viewed in plan, is right-lateral and left-lateral, as described by Hill (1947). Right-lateral and left-lateral terminology is synonomous with the dextral and sinistral usage of de Sitter (1956). The former implies clockwise and the latter counter-clockwise separation of the blocks. By adding the term "wrench", Moody and Hill (1956) extended the use of right- and left-lateral so that actual horizontal slips were implied.

Briefly, wrench faults are generated by compressive stresses. The fault plane is invariably vertical or sub-vertical. The greatest, as well as the smallest, stress lies in the horizontal plane. The median stress is vertical. The faults generally belong to a late phase of a folding process, and have variable characteristics. Very often wrench faults revert to, or merge into, thrust faults, since both types are produced by lateral compression. Length may vary from very small faults, a few centimetres in size, to faults many hundreds of miles long. Evidence for wrench faulting is most frequently seen in slickensides, fault-breccias, mylonites, or ultra-mylonites along the fault line, in stream off-sets, in off-sets in structures and outcrop patterns, and in drag folding. Studies of thicknesses, lithofacies, biofacies, and depositional fabrics can also yield evidence of strike-slip movement.

Moody and Hill (1956) have indicated, in a synthesis of wrench fault mechanics, based on earlier work by Anderson (1951), Hubbert (1951), and Billings (1954), that there is a system to the manner in which wrench faults behave tectonically. They showed that, if a material acted elastically rather than plastically, and was stressed beyond its strength, it would rupture. Planes of maximum shearing stress were found theoretically to parallel the intermediate stress axis, and to lie at angles of $45^{\circ}$ on either side of the maximum compressive stress. The planes of actual shear, they found, did not coincide with the planes of maximum shearing stress, but made an angle $\beta$ (the angle of shear, having an average value of $30^{\circ}$) between the maximum compressive stress and the actual shear plane itself. The maximum compressive stress for both thrust and wrench faults is orientated in the horizontal plane. The compressional stresses can be relieved along either the wrench or the thrust fault surfaces, depending on the orientation of the minimum stress. If the minimum stress is vertical, thrust faults developed; if it is horizontal, wrench faulting results.

McKinstry (1953) showed that second-order effects invariably result from movement in a "master shear". The result of the second-order effects is to cause failure on a new pair of mutually complementary planes, one of which makes an acute angle with the master shear. A reorientation of stresses inevitably results from inertial and frictional forces involved during any movement along a shear surface. McKinstry considered that the forces involved decrease rapidly, and are not regenerative. Anderson (1951) explained a mechanism which is regenerative. He indicated that body forces developed by movement along a fault can also yield local stress reorientation which may result in second-order features. Moody and Hill (1956) added that, if continued compression is applied on fault blocks, a continuous change of shape of the blocks themselves will result in an ensuing stress reorientation.

One, or a combination, of the mechanisms mentioned above must result in locally reorientated compressional forces that eventually generate new strain directions called second-order shears. The process is believed to continue beyond this point. Thus, from a single primary stress orientation there can arise two first-order shear directions, four second-order shear directions, eight third-order shear directions, and sixteen fourth-order shear directions. The later shear directions cannot, however, be continuous across the primary faults. An infinity of shear directions does not arise, and the system can be resolved into eight major wrench directions. The ideal system is seldom attained, however, as a great many variables are involved, ranging from the type and direction of stresses to the variability of rock-types and rock mechanics. Beyond a certain stage the geometry of the fracture orientations is repeated, and the younger directions approach very close to the older surfaces of dislocation.

## B. FORMATION OF WRENCH FAULTS IN THE MOUNTAIN LAND

Any definitive explanation as to the cause of the wrench faulting in the Barberton Mountain Land would require a considerably greater knowledge of the area and of the surrounding granites than exists at present.

Boardman (1950) speculated that the shear fractures exhibiting constant regional similarities might have resulted from some drifting movement in the earth's crust, and that the massive granite bodies on the Swaziland side of the Mountain Land drifted in a southwesterly direction relative to the granite massifs to the north. He postulated that the Swaziland System geosyncline constituted a weak zone in the earth's crust, and that the shearing and torsional movements were mainly taken up by the relatively weak and yielding sedimentary formations. The Kaap Valley Granite was regarded as a resisting buffer, forcing the formation of an abnormal number of shear planes in the adjoining weak sedimentary rocks. Certain horizons, it was pointed out, were more prone than others to taking up shearing movements. Good examples of weak and unresisting strata that absorbed bedding plane slip or shear are the argillaceous members of the Fig Tree Series, together with the intercalated banded ironstone horizons. Many zones in this series contain an abundance of carbonaceous shales. It was noted that in many instances the carbonaceous or graphitic material had acted as an excellent lubricant, facilitating greatly the shearing movements along bedding planes in the shales.

From recent detailed research that has enabled a sequence of structural events in the Barberton Mountain Land to be recognized, a mechanism resulting in the production of wrench faults can be derived from one or other of the stress fields that were responsible for folding the geosynclinal successions. As has been shown earlier, at least five periods of deformation can be recognized that are post-Moodies in age. Each successive period is portrayed by a different style of deformation. The Main Phase of disturbance was responsible for the large regional folds and faults, and the subsequent superimposition of minor structures in addition to cleavage and schistosity. The longitudinal strike faults that formed behaved essentially as high-angled thrust faults. A strong force acted from the southeast, and produced overfolding of the successions to the northwest. The thrust faults appear to have developed in the over-turned limbs of the anticlines, now all eroded away.

The third period of post-Moodies folding (F3), that resulted in the arcuate bending of the Eureka Syncline and the production of minor folds, is also believed to have had other far-reaching effects on the formations in the area. Generally, folds and structures formed at this time were most strongly developed in the northern portions of the Mountain Land. Immediately north of the Eureka Syncline, in the Consort Mine area, the Consort folds are developed, and the locality is one of the most structurally complex zones in the entire region. To the southwest and east of the Eureka Syncline the formations are much less undisturbed, and Anhaeusser (1964) and Poole (1964) have shown that evidence of the third deformation becomes progressively weaker away from the locus of maximum bending of the present arcuate forms.

The great arcuate bending resulted in a general shortening of the formations. Considerable drag and shearing associated with this folding took place. There is much evidence for the effects produced by the deformation, in the form of bedding-plane slip and shear, wrench fault or strike-slip movements, concentric shear surfaces, minor drag folding and puckering, slickenside surfaces, and drag on and along fractures and dykes. In some instances the displacement was only of the order of inches, but, where the major regional strike faults were reactivated as wrench faults in a new stress field of different orientation, movement was considerable, thereby enabling second-order phenomena to develop. These second-order features consist essentially of faults and fractures that branch or splay from the primary shear surfaces.

Roering (1965) has concluded that the forces responsible for the F3 deformation were oriented SW-NE, and originated from the intrusion and emplacement of the Kaap Valley Granite pluton. This was a unique event in the tectonic history of the area, and was not related to, or dependant on, the Swaziland Granites from which, he believed, were derived the northwest-acting forces responsible for the Main Phase (F1 and F2) of the deformation of the Mountain Land.

The writer favours a different theory for the generation of the forces which produced the F3 structures and the associated reactivation of the original thrusts as wrench faults. The essential features of this alternative explanation are presented in Figure 1, where the assumption has been made that the Kaap Valley and Nelspruit Granites had both been emplaced, and had both consolidated before arcuation of the Eureka and Ulundi Synclines during the F3 phase.

It is agreed by all investigators that a stress from the southeast overfolded the major first folds (F1) to the north, and caused regional thrust faults with planes dipping steeply to the southeast. Hills (1963, quoting Aubert, 1949) showed that there are instances where folding is produced by an over-riding movement originating as a result of the push of up-thrust faults in the basement. It is suggested that, in the Barberton Mountain Land, the same stress field which produced the NE-SW trending folds (F1) also produced the F3 arcuation, as the process of folding and overthrusting progressed. The buttresses of the two granites in the northern region of the geosyncline acted as pivots between which the folding occurred. The Eureka Syncline, a steeply dipping structure, possibly forced its way in between the two granites. Movement to the northwest was presumably aided by the occurrence of incompetent basic talcose and schistose rocks underlying the formations to the north. If the F3 folding was actually produced by some direction of stress other than that from the southeast, then it must have been affected at a later date by a force again acting from the southeast which caused considerable overthrusting to the northwest. Van Vuuren (1964) indicated a late phase of folding with a northeast-southwest trend (Late Ulundi Trend) the Fig Tree succession of the Ulundi Syncline, which could only have been produced by southeast-northwest compression.

It can be seen from Figure 1 that, where the southeast stress acted at right angles to the Sheba Fault and the sedimentary formations west of the Sheba Mine, the compression was greatest, and concentric shear surfaces formed, in preference to tension fractures. These shears developed into a series of over-riding thrusts. Where the southeast stress and the formations along the Sheba Fault intersect, the angles of incidence decrease with increasing distance from the axial plane of the F3 folds. Thus, the Sheba Fault appears to change from a thrust in the core of the structure, through an oblique-slip type of movement, to a type of wrench displacement. The fact that the Fairview Mine and the Sheba group of mines both occur in the region where the possible transition from thrust to wrench takes place on either side of the F3 axial plane seems to be possibly more than fortuitous. The second-order effects of such a stress combination would, no doubt, be considerable, as well as complex. The complexity would be aggravated by the alternation of competent and incompetent units of the formations, such as are present in the Fig Tree Series.

Extending the wrench effects away from the influence of the Eureka and Ulundi folds, it can be seen that a somewhat similar relationship exists along the Barbrook Fault. As mentioned earlier, the Geological Survey (Visser et al, 1956) maintained that this fault behaves as a high-angled, thrust fault in the west, but that to the east some wrench movement has taken place. Many mines are concentrated along the Barbrook Fault Zone, especially in the area near the headwaters of Louw's Creek. It is suggested that here, again, the stress field emmanated from the granites in Swaziland, and acted in a northwesterly, or even west-northwesterly direction, to produce the maximum compressive force that resulted in shearing along the Barbrook line. Although the angle between the fault plane (shear surface) and the SE. or ESE. stress (maximum compressive stress) is considerably greater than the average value of 30$^{o}$ suggested by Moody and Hill (1956), it is believed that the difference can be accounted for by the anisotropy of the rocks. Donath (1963) states that "layering, cleavage, schistosity, and other foliation constitute types of planar anisotropy that can alter appreciably the geometric relations between structure and stress distribution". Experiments led him to the conclusion that the angle of faulting can vary considerably in anisotropic rocks, and is dependent on the inclination of the anisotropy with respect to the principle stress directions. Faults were found to develop parallel to the cleavage for inclinations up to 45$^{o}$. In addition, the angle of faulting was strongly affected in the 60$^{o}$ and 75$^{o}$ orientations.

There are certain aspects that are difficult to explain, if it is assumed that the major stress acted from the southeast. The Consort folds, for example, are orientated with their axial planes trending northwestwards (similar to the F3 Eureka fold). The attitude of these tight isoclinal folds suggests that the maximum compressive stress responsible for their formation came from the southwest or northeast. If the Eureka Syncline moved northwestwards, the compression involved would result in folds with the axial planes trending at right angles to the compressive stress, i.e. northeast-trending folds. Folding of this nature does appear to have occurred in the basic rocks west of the South Kaap River (see Figure 1). The Consort folds might be explained if it is assumed that the Kaap Valley Granite intruded prior to the F3 folding of the Eureka Syncline. The granite intrusion might have provided the necessary stress from the southwest. The effect of the Kaap Valley Granite emplacement might also have been responsible for the initiation of the bending of the Eureka Syncline, which arcuation became more intensified as the stress from the southeast increased.

Roering (1965) considered that the wrench movements might also have been caused by the emplacement of the Kaap Valley Granite during which was formed a huge disharmonic fold comprising the arcuate Eureka and Ulundi Synclines, with a detachment plane on the Barbrook-Saddleback Faults. An alternative explanation proposed by Roering (1965) was that an east-west pressure forced the already consolidated Kaap Valley Granite pluton eastwards to form the arcuate folds, also by means of disharmonic folding. He recognized that a north-northwest force never ceased to act, and that continued compression is evident in the Ulundi Syncline where van Vuuren (1964) described late northeast-trending folds.

A further idea, based more on a regional approach, has been suggested by D. A. Pretorius (personal communication). He is of the opinion that two dominant regional fold trends have generally been active throughout the geological history of Southern Africa. The first is a northeast fold trend and the second a northwest fold trend. The Barberton Mountain Land regionally conforms to the northeast fold pattern, and was presumably caused by a northwest compression. Superimposed on this initially deformed geosynclinal cell was a second, and later, fold system with the maximum compression operating approximately in a northeast or east-northeast direction. It is suggested that a differential stress field was applied from an active granite source, probably in the area southwest of the Mountain Land, namely in the Badplaas-Lochiel area (see Figure 2). The resulting compression began to produce regional movements of the wrench fault type along the major fault zones. The dominant movement generated by the stresses appears to have been essentially right-lateral displacement along the fault traces. As the stress continued, the resistance increased, and resulted in the formation of a massive disharmonic fold. The regional faults, and especially the Barbrook Fault, probably acted as detachment surfaces, enabling the formation of disharmonic folds in the north. The area northeast of the Mountain Land might conceivably have been a static resistance in the form of a more elevated land mass in the area now occupied by the Mocambique Plain. Thus, with the active stress field being derived from the area southwest of Barberton the compression of the already folded synclines (F1 and F2 folds of the Eureka and Ulundi Synclines) increased, causing a buckling of the formations. The resulting structure produced is considered to be a type of reverse fold with the nose of the fold being forced in a northwesterly direction. The final shape of the arcuate structures was largely controlled by the buttressing effects of adjacent formations, such as the Nelspruit Granite, and the reactivation of the southeast stress field that was probably generated by movement of the Swaziland Granites.

Although several theories exist as to the possible mechanism of formation of the great arcuate structures, there seems little doubt that the F3 folds produced considerable disturbances along the northern fringe of the Mountain Land. One of the most important effects was the reactivation of the strike faults as wrench faults. Some remobilization of the granites along the contact zones probably also took place. The reactivated granites were partly responsible for local structural variations, as well as for contact metamorphism, and for the mobilization of mineralized solutions.

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## GOLD MINERALIZATION AND WRENCH MOVEMENTS

The main areas of gold mineralization occur in the northern and northwestern portions of the Barberton Mountain Land. The localization of the mineralization is considered to be due to two intimately related factors - the Kaap Valley and Nelspruit Granites, and the structures correlated with the third phase of deformation. Several mines are discussed below to illustrate the relationship between the localization of certain ore-bodies and the horizontal movement of the strata which took place in the third phase. In addition to these, many other examples can be mentioned that appear to have been affected by similar horizontal wrench displacements. These include the Alpine, Barbrook, Bonny Dundee, Clifford Scott Section of French Bob's, Mount Morgan, Montrose, Maid of the Mountain, Princeton, and Rosetta Mines, to name but a few. In all these, deformation in the form of wrench movements and bedding plane shears have been responsible for the generation of second-order structures such as faults, fractures, shears, drag folds, cymoid loops or curves, and brecciated zones that provided traps for ore deposition.

## A. THE LILY GOLD MINE

The Lily Gold Mine was, until the end of 1962, one of the few remaining small-scale gold mines still in operation in the Barberton District. It occurs approximately three miles south of Louw's Creek Station, and is situated in thinly-bedded shales, graywackes, and banded ironstones of the lower part of the Fig Tree Series. This succession abuts against talcose rocks to the north, that are probably part of the underlying group of Onverwacht rocks. Along the contact the Fig Tree rocks form a zone of sheared, silicified, and brecciated rocks known as the Main Reef Zone. The Lily Fault (Anhaeusser, 1964) is a longitudinal strike fault that is coincident with the Main Reef Zone in the mine. It is thought to be related to the large regional strike faults such as the Barbrook Fault. Essentially, the Lily Fault acted as a high-angled thrust, and was probably initiated during the F1 deformation, together with all the other major faults that were thought by Ramsay (1963) to have formed at this time. In addition to the Main Reef Zone, which proved to be the most consistent lode in the mine, several other reefs, often containing free gold, were worked.

The central portion of the mine, therefore, contained numerous vertical, or near-vertical, east-west-trending quartz-filled fractures, some of which were well mineralized. The fractures, parallel to the strike of the formations, are considered to have been formed by strike-slip movements along the bedding planes. The steeply dipping formations in the mine are strongly deformed, and are folded into tight isoclinal structures that plunge to the east at between $50^{O}$ and $75^{O}$. The axial planes of these isoclinal folds provided the weak planes along which most of the fractures developed. This vertical fracture system is cross-cut by a later flat fracture system that dips at shallow angles to the southeast. The vertical fracture system is the most strongly developed, and the bulk of the mineralization is related to it. In the central portion of the mine four separate reefs were mined. These reefs gradually merged with depth.

Characteristic of certain of the vein fractures was a shape that may be described as a cymoid loop or curve. McKinstry (Figure 36, 1955) stated that "a cymoid loop is a reverse curve in which a line or fracture swerves from its course and then swings back again resuming a direction parallel to its former course, but not in line with it. The two branches enclose a lens of wall-rock shaped like a cam - a cymoid lens". The structure described is complex, and involves the splitting up of veins into several smaller veins which may either continue along the same general course, or may curve abruptly away from it, forming a "horse-tailing" structure. The fracture pattern in the mine (Figure 3a) behaved similarly to the description given above, and formed, in the third dimension, a pipe-like ore-shoot. This shoot was found to have an average plunge of $50^{O}$ to the east.

The formation of this cymoid loop might well have been related to features associated with strike-slip, or wrench fault, tectonics. McKinstry (1953) showed how movement of a main fault or "master shear" could cause stresses to develop in adjoining rocks, which ultimately resulted in the formation of second-order shears. Theoretical considerations, based on work done on wrench faulting by Moody and Hill (1956), may be used to explain the formation of the cymoid structure in the Lily Mine.

Ideally, as stated earlier, the planes of actual shear in a system are not coincident with the planes of maximum shearing stress (usually $45^{O}$ either side of the maximum compressive stress), but lie closer to the axis of maximum compression, and form an acute angle $\beta$ (the angle of shear with an average value of 30°). In Figure 3(c), based on Moody and Hill (1956), AB represents the fault plane, and XY the maximum stress, equal to the compressive force. CD is a vector of the second-order, with CE and CF both second-order wrenches. CG is a second-order anticline, or thrust fault, at right angles to CD. CG forms an angle with the parent shear (AB), which has an average value of 15°. It can be calculated that the angles BCF and ACE equal 45° and 75° respectively. Figure 3(d) shows how the structure in the mine can be related to the above theory. FG represents the vertical shear plane corresponding to the average strike of the vertical fracture system (bearing 85°), and E and E' the poles to this plane. BC represents the plane of the cymoid loop (bearing 120°) that lies at approximately 30° to the vertical shear plane. The dip of the cymoid fracture is to the northeast at an average value of 75°. A is the pole to the plane of the cymoid loop. The two planes FG and BC intersect at H, a point that coincides with the plunge of the isoclinal folds in the mine. The dip of the cymoid plane, represented by BKC, is roughly the same as the plunges of the fold S. The intermediate, or 'b', tectonic axis of folding lies in the same plane as that contained by the bedding and master shear. H is also represented as the P intermediate stress. The poles A of the cymoid structure and E and E' of the vertical shear lie on a great circle or 'ac' plane. The point I, or maximum compressive force, is located on this plane, making an angle of 30° to the shear plane FG. The minimum stress J lies 90° away from P maximum, also on the 'ac' plane. The pole to the cymoid loop (point A) and E', the pole to the master shear plane (FG), make an angle with one another of 38°. This is 7° less than the theoretical value of 45°, as calculated for the angle (BCF), between the second-order shear and the main fault in Figure 2(c).

The cymoid loop can, therefore, be satisfactorily accounted for as a second-order structure which resulted from reorientated stresses adjacent to the main east-west strike-slip shear. Further lateral movement along the shear plane in the mine, subsequent to the formation of the second-order fractures, could explain the flattening out of the structure into a cymoid loop, with an angle to the master shear of less than the 45°. The attitude of the cymoid structure indicated that the rocks had been affected by right-lateral wrench movements related to movements along the Lily Fault. Indications of horizontal movement having taken place are everywhere evident in the mine in the form of slickenside surfaces of bedding plane shears. There are, in addition, many other directions of movement displayed by slickensides, that may be indicative of superimposed deformations.

The Lily Fault, or Main Reef Zone, in the Lily Mine contained abundant sulphide mineralization, replacing the brecciated rock adjacent to the fault plane, whereas the mineralization in the vertical fracture system consisted of abundant quartz and free gold. Two separate phases of mineralization might be present, as at the Fairview Mine. However, the reefs mined were almost always in oxidized zones, and the true character of the lodes could not be fully assessed.

## B. THE SHEBA GOLD MINE

The Sheba Mine occurs northeast of Barberton, in Fig Tree rocks of the Ulundi Syncline. The mine is situated adjacent to the Sheba Fault that separates the arcuate Eureka Syncline from the Ulundi Syncline. The group of workings also incorporate lodes that occur in the Moodies formations to the north, among which is the famous Golden Quarry deposit. The economic gold mineralization in the Sheba Hills area has generally been ascribed to hydrothermal solutions introduced into the area along the Sheba Fault which, in the neighbourhood of the mine, dips approximately 55° to the south. The Fault is generally believed to be a high-angled thrust fault, but Gribnitz et al (1961) thought that horizontal movements predominated, with the hanging-wall moving to the west, or southwest, thereby indicating right-lateral wrench displacement. Movement along the regional fault was believed to have been repeated by sympathetic movements, on a smaller scale, along some of the bedding planes in the adjacent Fig Tree shales. This resulted in a characteristic fracture pattern that proved to be of economic importance in the Sheba Mine. Several fracture types exist in the Sheba Mine. Fractures which strike northwest and dip southwest, and have a right-lateral movement along the fracture plane (van Vuuren, 1964), occur mainly in the north limb of the Zwartkoppie Anticline. Fractures along the south limb of the anticline strike northeast and dip southeast, and have a left-lateral component of displacement.

Ramsay (1963) concluded that the structures at the Sheba Mine behave as a conjugate set of fractures. He deduced that they were formed by the same maximum stress deformation (F2) that led to the formation of the cleavage. He also noted that some wrench faults north of Sheba displace the mineralized fractures. It was thought that, because these faults lie parallel to the axial planes of the conjugate shear folds, they were possibly related to a deformation post-dating the slaty cleavage, and were, perhaps, formed synchronously with the third deformation arcuate structure. It was also suggested that the faults might have developed at a later stage in the structural history. Van Vuuren (1964) considered that the conjugate folds described by Ramsay (1963) would be difficult to distinguish from second-order features caused by fault movements of the wrench type.

The pattern of faulting in the Sheba Mine can be satisfactorily related to a horizontal or sub-horizontal wrench displacement of the Sheba Fault. Using the relationships of wrench fault tectonics described by Moody and Hill (1956), the fracture pattern can be resolved into a set of second-order phenomena directly coupled to the effects of the major wrench to the north. If the folds in the Zwartkoppie Horizon in the Sheba Mine area are regarded as having been formed during the first period of deformation, the fractures which post-date the folds might conceivably have been generated by wrench movements coincident with the third period of deformation that caused the inflection of the Eureka Syncline. Figure 4(c) shows the main fractures in the mine and their relative movement directions. Inset into the figure is a diagram after Moody and Hill (1956, Figure 4a) that shows the relationships of the second-order wrench faults to a first-order right-lateral wrench. It can be seen that there is a definite correspondence between the Sheba fracture movements and the theoretical movement directions. The Sheba Fault, it was shown earlier, behaves as a right-lateral wrench fault. Van Vuuren (1964) found that along the part of the Sheba Fault that strikes east-southeast, movement reverted to an oblique direction between a right-lateral horizontal wrench and a vertical thrust, with the fault becoming strongly transgressive on to the Moodies rocks. The wavy outline of the Sheba Fault on the plan is mainly due to topographic expression, although van Vuuren (1964) thought that the fault trace had been folded to a certain extent.

Several interesting features concerning the type and style of fracturing in the Sheba Mine were noted by Winter (1964). Many fractures change their strike due to deflections on the bedding planes, especially where the fractures intersect beds of different competency, e.g. on chert-shale, chert-graywacke, or green-schist-graywacke contacts. Frequently, fractures split in the vicinity of chert bars, changing their strike and dip, and the splits diverge and rejoin to form a type of cymoid loop structure. An example of this feature can be seen along the Insimbi Fracture which behaves as a right-lateral wrench fault. In many instances structures formed by horizontal shear movements along the fracture planes have created favourable depositories for hydrothermal gold mineralization and quartz filling, as is the case with the northwest-trending Mac's Fault (Winter, 1964 - Figure 4b). Precisely similar relationships hold with northeast-striking fractures, except that, in their case, the reverse movement has taken place to provide openings favoured by the hydrothermal solutions.

## C. GOLD MINES ALONG THE BARBROOK LINE

### (a) French Bob's Mine

This mine is located immediately north of the Barbrook Fault, near the headwaters of Louw's Creek. It is situated in graywackes, shales, banded ironstones, cherts, and crushed and cherty shale horizons of the Fig Tree Series. Recent investigation of the area by Rand Mines Limited has led Macaulay (1964a) to believe that the French Bob shale horizon is an anticlinal structure allied to the Zwartkoppie Zone of the Daylight Mine. Shears in the mine are generally found close to shale - graywacke contacts, and are often parallel to primary chert bars. The shear zones are shale breccias invaded and replaced by several generations of silica and carbonate material. Graphitic shales, common in the mine, apparently assisted shear movements.

Longitudinal shears strike east-west, parallel to the formations, and dip at steep angles to the south. Horizontal striations invariably indicate east-west movement directions. Numerous small-scale drag folds in the mine are believed to have been produced by the wrench, or longitudinal, shear deformation. The folds indicate movement to the west on the south side. Macaulay (1964a) has observed that these drag folds pass gradually into shears. The rock on either side of a well-developed shear surface is relatively undisturbed and normally bedded. Mining has proved that, where strong longitudinal shears progressively get weaker and the side rocks progressively more contorted, the shears die out completely.

It has been proved that small transverse or wrench faults have had an important local effect on gold distribution throughout the mine. Macaulay (1964a) has been able to relate the structures to a series of cymoid loops similar to the one postulated for the Lily Mine. The cymoid structures in French Bob's Mine are modified in places by small faults. The shears branching off from the main shear plane are not cross-fractures, but diverging longitudinal shears that have encouraging gold values associated with intensely silicified zones (see Figure 5). There is much branching off and rejoining of subordinate fractures, but the whole structural system tends to remain an entity. The intensity of the shears invariably determines the sulphide and gold content. Where two main shears join, or diverge, there is a considerable increase in the degree of silicification involved. The silicified zone consists of brecciated country rock with replacement quartz or cherty material. Adjoining graywackes are also frequently affected by the replacement silica. Often chert bars are shattered, and the breccia silicified with quartz. The silicified areas contain approximately two-thirds dark gray quartz and one-third iron-rich calcite. The silicified zones carry good values, in most instances, while veins of white buck quartz are barren. It would appear that there are several generations of gold, sulphide, and quartz in the mine. Gold is associated with small amounts of quartz and carbonate within the sheared graphitic shales, and with quartz, carbonate, and galena in areas where the original shale has been completely replaced. Much of the sulphide mineralization consists of pyrite and pyrrhotite with subordinate arsenopyrite.

Structure and mineralization in French Bob's Mine, as usual, are intimately linked, with the Barbrook Fault having played a vital role in the localization of the mineralization. Initially a high-angled thrust, the fault was later reactivated in such a manner that it behaved as a wrench fault. The primary wrench was responsible for the secondary fractures, folds, and shears that developed, and were subsequently mineralized, in the adjacent Fig Tree strata.

(b) The Crown Mine

To the east of French Bob's workings the Crown Mine occurs in a stratigraphic and structural environment almost identical to that prevailing in many of the other mines located along the Barbrook Line. Again, the main controlling factor for the localization of mineralization is thought to be the Barbrook Fault, which is situated about 250 yards southeast of the actual mine. Movement along fractures in the mine is reported to be mainly horizontal, as can be seen in horizontal striations and west-southwesterly plunging drag folds. The direction of displacement is uncertain.

(c) The Daylight Mine

The Daylight Mine occurs to the north of French Bob's Mine in rocks regarded as belonging to the Zwartkoppie Zone of the Fig Tree Series. A closed anticline of shaly rocks is surrounded by graywackes, and the whole structure plunges to the east. Greenschist, and talcose and carbonate rocks occur in the core of the anticline. Secondary chert is sporadically developed along the schist-shale and graywacke-shale contacts. Mineralization occurs mainly along, or near, the schist-shale contacts where shearing has locally been intense. The shear zones are generally of the longitudinal type, and parallel the formations. Macaulay (1964b) has observed that numerous branch shears diverge from the main shear zones, and that some of the richest ore-bodies occur in these second-order structures. The ore-bodies plunge either sub-vertically, or at steep angles to the east. The shear zones are generally wider than in French Bob's Mine, but are otherwise similar. Everywhere they consist of a partial quartz-carbonate replacement and impregnation of the shattered carbonate schists.

In the numerous sections of the mine, mineralization is related to one or other of the following structures (Macaulay, 1964b) :- (i) a chert bar on contact; (ii) shearing along contact; (iii) drag folding; or (iv) shearing parallel to the plunge of drag folding. The structures indicate that the initial shearing was probably produced during the major folding of the Mountain Land (F1 period), when anticlinal folds and high-angled thrust faults resulted from strong compressional stresses. Subsequent east-west shearing, similar to that which affected the French Bob's area, produced cross-fractures and drag folds. The wrench movements, responsible for the majority of the mineralized shear zones, resulted in displacement to the west on the south side.

(d) The Vesuvius Mine

This mine occurs to the west of French Bob's and the Daylight mines, and is also close to the Barbrook Fault. A brief description of the mine is given by the Geological Survey (Groeneveld, 1964), from which its structure and mineralization seem to be similar in many respects to the other mines in the area. Mineralization is along a continuous shear zone striking along the whole length of the mine. The main shear dips steeply northwest, but is also vertical, or steeply dipping to the southeast. The shear strikes slightly oblique to the bedding strike, but along short sections lies parallel to the bedding. Branching from the main shear are numerous small fractures with mineralization extending short distances from the primary structure which is also well mineralized. This shear is seldom single, but usually consists of two or more parallel shears, or a plaited structure of numerous branching and joining shears forming a crush zone. It appears that the shears are localized in incompetent banded ironstones sandwiched between more massive cherts and sandstones. Again, there are indications in the mine that some horizontal movement has taken place, and striations are prominent. It is considered that the mineralization is connected with this disturbance.

D. THE CLUTHA MINE

The mine, occurring south of Noordkaap consists of four separate workings. The Geological Survey (Groeneveld, 1964) indicated that the main fractures in the Central Section are bedding plane shears in slaty quartzite. In addition, there are numerous oblique shear fractures that are well mineralized. These fractures generally make acute angles of $30^{\circ}$ - $45^{\circ}$ with the main bedding shears. The movement direction of the shears may have had a vertical component, but it is clear from drag and displacement of other fractures and dykes that horizontal movement was the most important. The shears are thus mainly wrench faults.

The most important structural feature in the Clutha Mine is a bedding plane shear running through all levels, and dipping steeply to the southeast, in conformity with the country rocks. It is locally referred to as the "Clay Seam". Oblique fractures diverging from this parent shear generally localized the gold at the intersection of the fractures. The intersections of the two planes create linear ore-shoots in which quartz, free gold, and arsenopyrite occur together. Away from the fracture intersections the mineralization rapidly dies out. The direction of wrench displacement along the "Clay Seam" is apparently right-lateral, but conflicting evidence is presented by a dyke that appears to have moved in the opposite sense. However, more than one movement may have taken place along the fracture zone.

E. THE FLORENCE AND DEVONIAN MINES

These mines occur in Fig Tree rocks of the Ulundi Syncline, northeast of Barberton. The area is isoclinally folded, with a regional formational strike trending approximately northeast, and dipping steeply to the southeast. The Geological Survey (Groeneveld, 1964) has reported the presence of sub-horizontal shear movements, and indications of shears associated with gradual upthrust movement. Fault plane striations plunge at shallow angles to the west ($5^{\circ}$ - $10^{\circ}$). Movement along the fractures is not clear, but it appears that, as elsewhere, the south side moved west relative to the northern side. The gold mineralization is reported to be directly coupled with the shearing movement.

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## SUMMARY AND CONCLUSIONS

There appears to be a definite relationship between gold mineralization and structure, with horizontal displacement frequently involved. The horizontal movements are believed to have been due to the reactivation of pre-existing regional thrust faults during one or other phase of deformation in the Mountain Land. The most effective deformation was probably the 3rd phase folding which produced the striking inflection of the Eureka Syncline. The reactivation produced wrench, or strike-slip, movements that, in turn, were responsible for the generation of second-order structures, including fractures that proved favourable for ore deposition. The mechanisms that caused the wrench movements and the apparently consistent regional right-lateral displacements cannot be defined precisely.

A few examples from mines in the district illustrate clearly the effects of horizontal displacement associated with major faults. The possibility exists that, by using geometrical relationships, an explanation of the fracture patterns encountered in mining can be more fully understood, and other mineralized fractures can possibly be predicted. This requires detailed studies of fault and fracture behaviour, as well as an understanding of their relationships to changes in rock-types, to the regional structure, and to mineralization. The cymoidal structure, with fractures splitting from and rejoining major, shears, may be more prevalent than is at present known. In areas where it can be established that horizontal wrench movements have taken place, fractures that splay off from major mineralized shears should be examined carefully, as many of them may be second-order structures, and may be well mineralized.

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## LIST OF FIGURES



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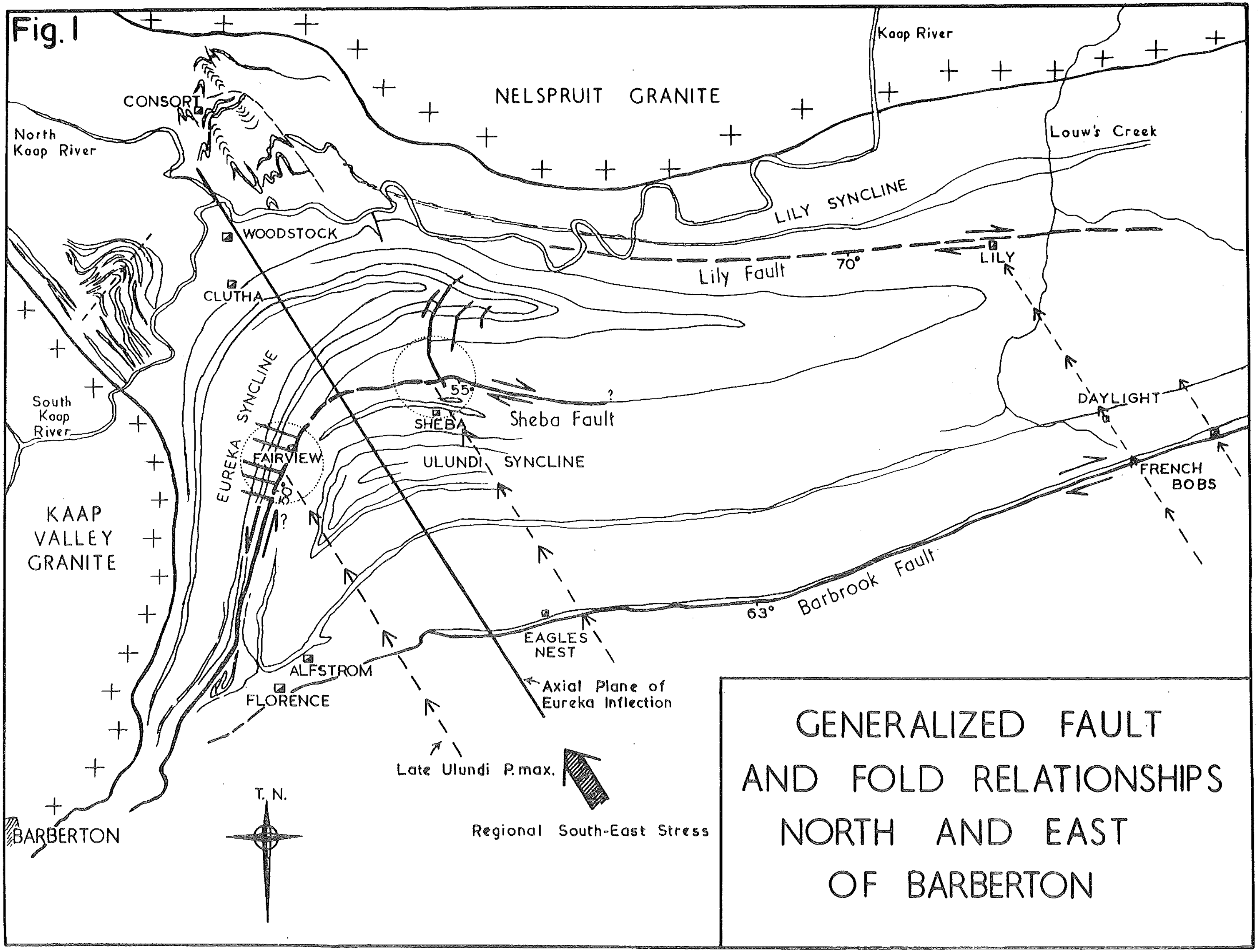
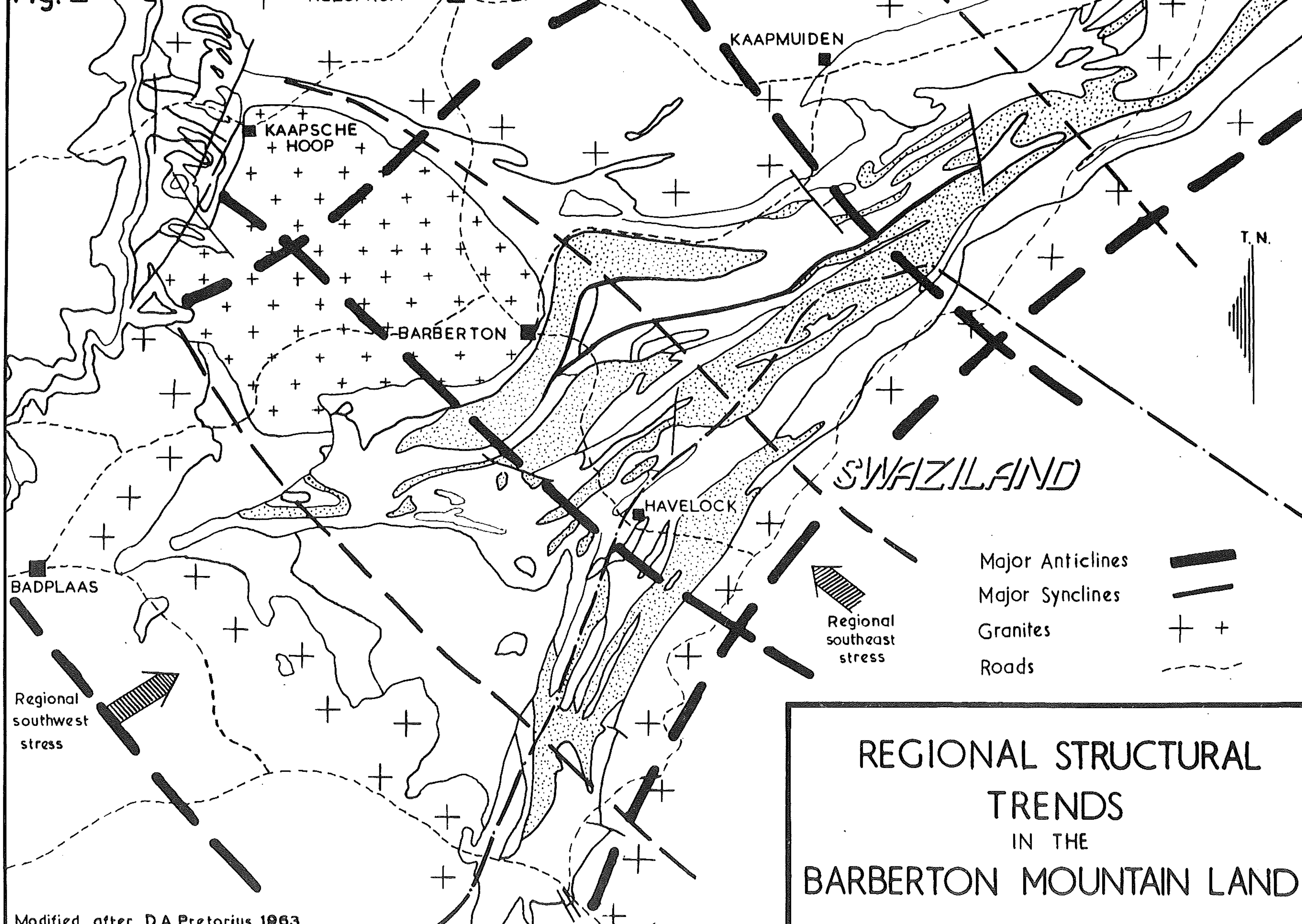


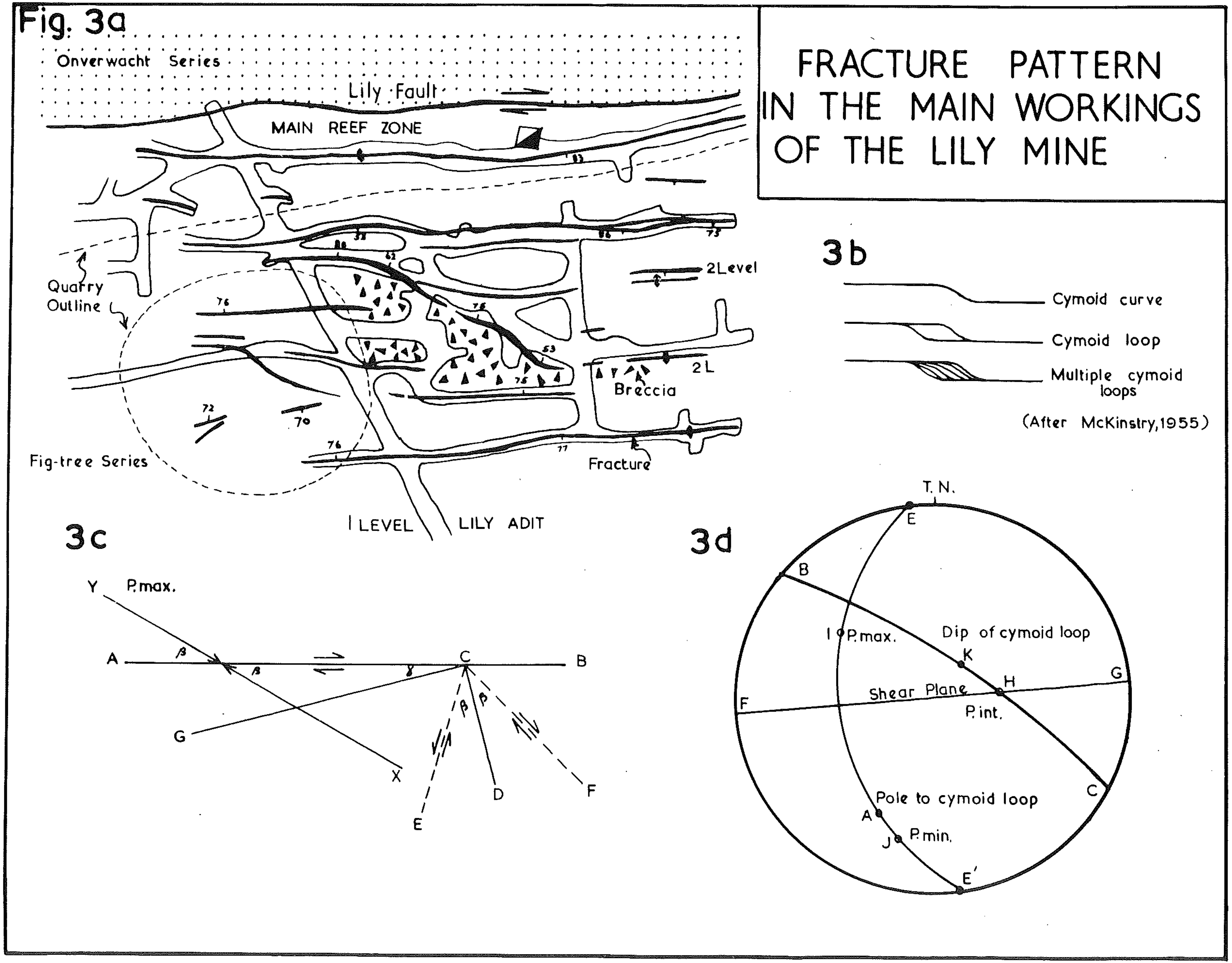

Fig. I

GENERALIZED FAULT AND FOLD RELATIONSHIPS NORTH AND EAST OF BARBERTON

Fig. 2


NELSPRUIT
KAAPMUIDEN
KAAPSCHE HOOP
BARBERTON
HAVELOCK
BADPLAAS
SWAZILAND
T.N.
Regional southwest stress
Regional southeast stress
Major Anticlines
Major Synclines
Granites
Roads
REGIONAL STRUCTURAL TRENDS IN THE BARBERTON MOUNTAIN LAND
Modified after D.A. Pretorius, 1963

# FRACTURE PATTERN IN THE MAIN WORKINGS OF THE LILY MINE



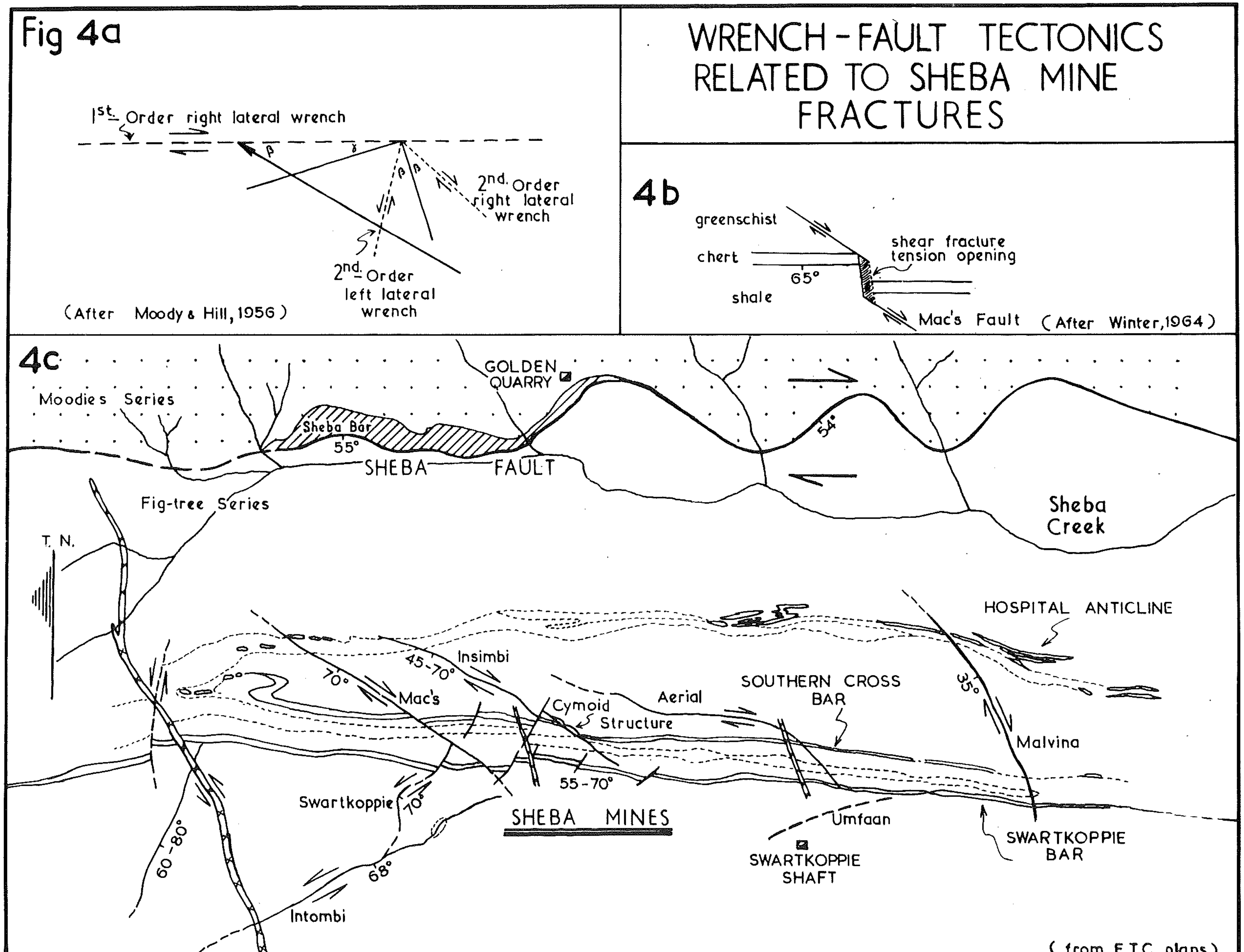
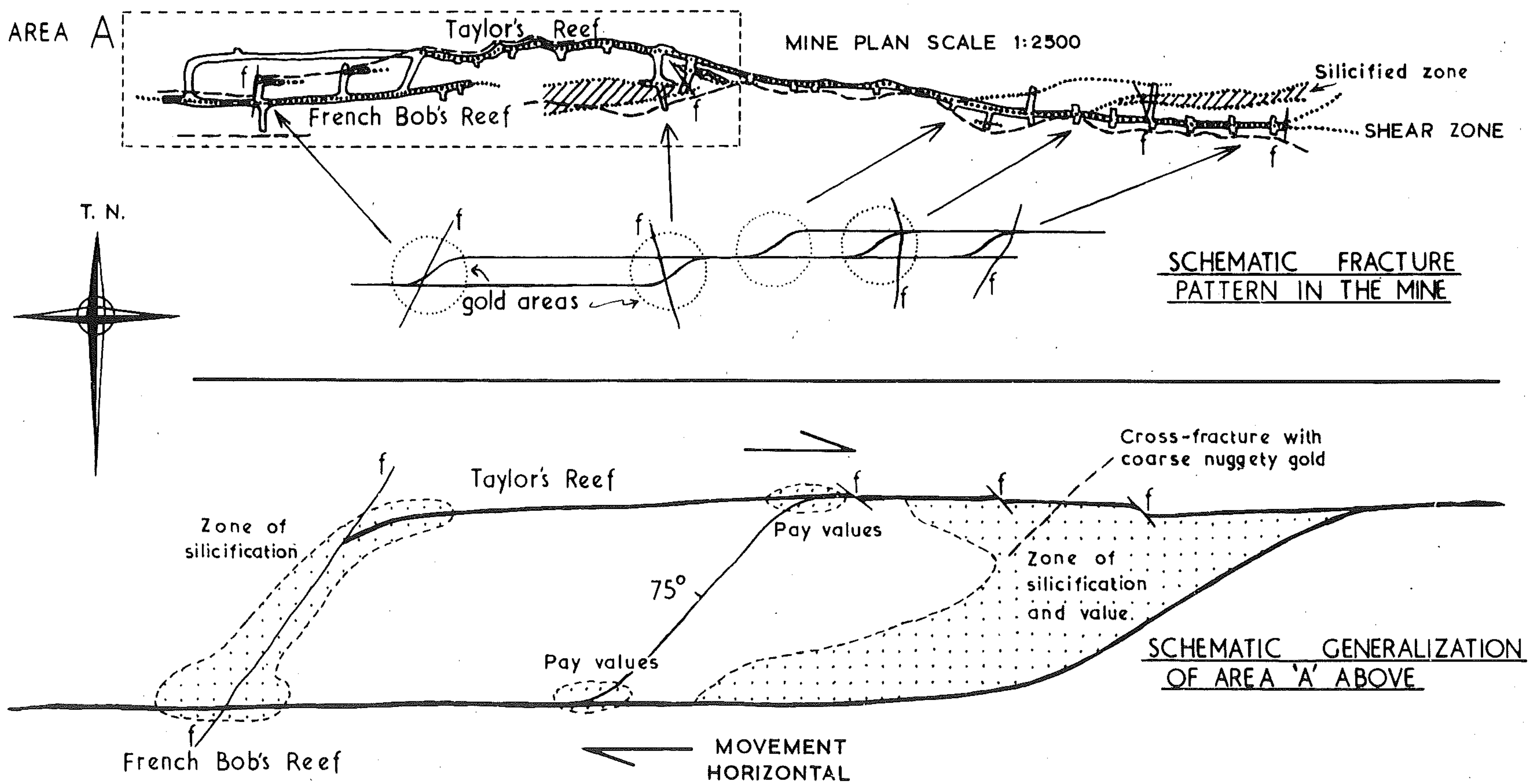


Fig 4a
WRENCH - FAULT TECTONICS RELATED TO SHEBA MINE FRACTURES
1st Order right lateral wrench
2nd Order right lateral wrench
2nd Order left lateral wrench
(After Moody & Hill, 1956)
4b
greenschist
chert
shale
65°
shear fracture
tension opening
Mac's Fault
(After Winter, 1964)
4c
Moodies Series
Fig-tree Series
GOLDEN QUARRY
Sheba Bar
55°
SHEBA FAULT
54°
Sheba Creek
T. N.
HOSPITAL ANTICLINE
Insimbi
45-70°
70°
Mac's
Cymoid Structure
Aerial
SOUTHERN CROSS BAR
35°
Malvina
55-70°
Swartkoppie
70°
SHEBA MINES
Umfaan
SWARTKOPPIE SHAFT
SWARTKOPPIE BAR
60-80°
68°
Intombi
(from E.T.C. plans)

Fig. 5

# CYMOID STRUCTURES IN THE FRENCH BOB'S GOLD MINE




Revised after D.S. Macaulay and H. P. Formanek