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1963
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THE GEOLOGY OF THE LILY SYNCLINE AND PORTION OF THE EUREKA SYNCLINE BETWEEN THE CONSORT MINE AND JOE'S LUCK SIDING, BARBERTON MOUNTAIN LAND

by

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Thesis submitted for the degree of Master of Science
in the Faculty of Science, University of the Witwatersrand,
Johannesburg.

1963.

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ABSTRACT

The following is an account of the stratigraphy, structure, metamorphism and mineralization in a complexly deformed area of the northwest part of the Barberton Mountain Land. It is situated at the eastern extremity of the Jamestown Hills and covers a region along the contact zone between the ancient layered rocks of the Archaean Complex and the Nelspruit Granite.

In the first section is given a fairly comprehensive account of previous work done in the Barberton region, especially as it applies to the area under discussion. This is followed by a consideration of the petrology and stratigraphy of the area and a description of the various structures encountered. A more detailed statistical treatment of the minor structures is also included and from these results an attempt is made to unravel the tectonic history of the area and to fit it into the regional structural pattern of the Mountain Land as a whole.

The area mapped consists of two basically identical successions separated by a major high angled thrust fault. The northern succession, which has been quite strongly thermally metamorphosed, represents the fairly steeply south dipping northern limb of the Lily Syncline. That to the south has suffered very little metamorphism and forms part of the northern limb of the Eureka Syncline.

A well developed and layered basic suite of rocks lying below the Fig-tree Series, and constituting the basal zone of the Lily Syncline, is classed in the Onverwacht Series. It lies in direct contact with the Nelspruit Granite and is considered to represent a metamorphosed succession of impure dolomites with arenaceous and minor shaly horizons, together probably with some basic and acid lavas. The Onverwacht rocks are overlain by metamorphosed Fig-tree shales and "lavas", and these in turn by metamorphosed conglomerates and quartzites of the Moodies System. At the base of the hornfelses lies the Consort "Contact" or Consort "Bar", a silicified, mineralized zone which is the main ore horizon of the Consort Mine. The hornfelses grade into rocks which have been termed "lavas", but which are thought to be more of the nature of crystalline tuffs.

The succession to the south of the Main Fault is on a broad scale identical to the one just described above, differing mainly in metamorphic state. Thus, whereas the Onverwacht rocks of the northern succession have been converted to hornblende and tremolite-actinolite schists, similar rocks to the south of the Main Fault have been changed to carbonate-bearing talc and chlorite phyllites.

The basic intrusive rocks of the Jamestown are considered to be of a much smaller distribution than was previously thought, and are represented mainly by the massive bodies of pure serpentinite. There is a possibility however, that certain of the purer talc-carbonate schists along the Kaap River, represent altered ultrabasic intrusives.

The Nelspruit gneiss and migmatite is considered to represent a completely granitized pre-Swaziland System sequence which at a much later date acted as the basement upon which the layered rocks of the Mountain Land were deposited. A re-mobilized border phase of this migmatite was largely responsible for the contact metamorphism around the edge of the Mountain Land and late hydrothermal solutions from this same intrusive granite resulted in the mineralization of the area. The isolated patches of black amphibolites situated well within the granite outcrop area, are considered to be isolated downfolded remnants of a once more extensive sheet of Onverwacht. Their high grade metamorphic state, as with the Onverwacht rocks along the immediate contact zone, is due to the effects of the intrusive granites plus the re-heated migmatite.

Three distinct facies of contact metamorphism (related to the Nelspruit Granite) are recognised in the area.

The area can be divided into three fairly distinct structural zones, each one characterized by the good development (as compared to the other zones) of one or more particular types or styles of deformation. Thus in the Consort Mine area (Zone I), a north-west-trending fold system is the strongest and most apparent structural feature. In the southern part of the area (Zone II), minor crenulation and conjugate folds are very well developed. In the rocks along the granite contact zone (Zone III), a metamorphic fabric and well developed lineations associated with strong shearing, are the most noteworthy structural features.

Special attention was devoted to the accurate observation and recording of minor structural features. As a result of this, 4 distinct phases of deformation, corresponding fairly closely to those described by Ramsay (1963), were recognised. The first resulted in strong folding about northeast-trending axes and caused the formation of the major synclines

(including the Eureka and Lily Synclines) and the major faults (including the Lily, Main Southern and Woodstock Faults). The first period was followed by the widespread development of cleavage, associated with which is the marked flattening and elongation of conglomerate pebbles, and development of various types of lineations including the alignment of metamorphic minerals along the immediate contact belt. Certain of the lineations appear to have formed mainly after crystallization of the granite, and are closely connected with the mechanical deformation (in the form of strong differential shearing) which affected the rocks along the contact. At a late stage during the 2nd period, hydrothermal solutions from the granites entered zones of strong shearing and structural disturbance which had started to develop in the layered rocks. The initial development of the 3rd fold structures (especially in the northwest part of the Mountain Land) is considered to have played an important part in the localization of these ore fluids.

Both the 1st and 2nd formed structures have been strongly deformed by a northwest-trending fold system. These 3rd phase folds reach their best development in the Consort Mine area where they constitute by far the strongest structural feature. This period of folding, which during the very early stages probably played a part in the localisation of the ore fluids, outlasted the mineralizing episode and in the Consort Mine area, strongly deformed the mineralized "Contact". The marked inflection in the northwest part of the Mountain Land, including the "bending" of the Eureka and Ulundi Synclines, occurred at this stage. Most of the major faults truncate the 3rd folds and are thought to have formed, or to have been rejuvenated, at a late stage during this period of deformation.

The 4th and final phase of deformation is represented by the fairly widespread development of minor crenulation and conjugate folds. Their development is largely controlled by the rock types and they only occur in lithologically favourable varieties. The maximum deforming stress which caused these folds must have been nearly vertical. These 4th structures are completely separate and unrelated to the main northwest-trending fold system (3rd structures) with which they were classed by Ramsay (1963).

From an economic point of view, three zones of potential mineralization, corresponding in all cases to zones of strong shearing and structural disturbance, occur in the area. The most important is the silicified and mineralized zone (within the northern limb of the Lily Syncline) between basic schists of the Onverwacht and the overlying Fig-tree hornfelses, known as the Consort "Contact" or Consort "Bar". Another potential zone of

mineralization is the westward extension of the so-called Lily Fault which occupies exactly the same stratigraphic position as the Consort "Contact", viz. between shales and basic rocks of the Fig-tree and Onverwacht Series respectively, but within the northern limb of the Eureka Syncline. Finally, certain shaly horizons within the "footwall" quartzitic layers of the Consort Mine area also show signs of weak mineralization.

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THE GEOLOGY OF THE LILY SYNCLINE AND PORTION OF THE EUREKA SYNCLINE BETWEEN THE CONSORT MINE AND JOE'S LUCK SIDING, BARBERTON MOUNTAIN LAND

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INTRODUCTION

A. GENERAL STATEMENT

The present work was done as part of an intensive geological investigation of the Barberton Mountain Land at present being undertaken by the Economic Geology Research Unit of the University of the Witwatersrand, in conjunction with other mining companies operating in the area.

The whole program was embarked upon with a view to gaining a much more intimate knowledge of the various factors controlling the gold mineralization of the area, especially the structural control, but including also a thorough consideration of stratigraphical, petrological and mineralogical controls.

With the above broad aims in mind, detailed work was begun in the Barberton area early in 1961, particular attention naturally being devoted to areas where mineralization was known to occur. Most of the work has consisted of detailed, systematic, structural and geological surface mapping, although on two mines very detailed minor structural work was done as well.

E. J. Poole started the work in the area with a detailed structural investigation of the Agnes Gold Mine and vicinity. During the latter part of 1961, J. Ramsay of the Imperial College, London, spent a number of weeks in the Barberton area working mainly in the northwest part of the Mountain Land and applying modern structural techniques that have been used on a very limited scale in South Africa before. This reconnaissance work was important in that it showed how these methods could be profitably used and applied in the Barberton area, in addition to which it indicated the most critical zones where further detailed investigations could be carried out.

Work was first concentrated in the area to the east and to the southwest of Barberton. A detailed structural analysis of the Saddleback Syncline just to the east of Barberton was done by C. Roering, and G. Herget investigated in detail the stratigraphic and structural problems in the Montrose area to the southwest of Barberton. R. Cooke, field geologist of Eastern Transvaal Consolidated Mines Ltd., mapped the whole mineralized belt stretching southwest from Barberton to Montrose and compiled a composite map incorporating the areas mapped by Herget, Poole and Roering.

During 1962, C. J. van Vuuren made a detailed structural study of the Ulundi Syncline north of Barberton. This included a reconnaissance investigation of the minor structures present in the Sheba and Fairview Mines. N. Gay, working on free gold samples collected from numerous mines in the area, made a trace and minor element study and a study of the gold to silver ratios with a view to finding some geochemical factor of possible significance in further prospecting.

Finally during 1962, C. Anhaeusser and the author were engaged in a detailed structural and petrological investigation of an area along the northern contact between the Archaean System and the Nelspruit Granite. C. Anhaeusser mapped the area between Louw's Creek Station and Joe's Luck Siding and undertook a thorough examination of the Lily Gold Mine. The author mapped the area between Joe's Luck Siding and the Consort Mine.

The above work completes the major first phase of the program in the Barberton area, and it is clear that a considerable amount of new and significant data, concerning especially the structure and stratigraphy of the Mountain Land, has come to light.

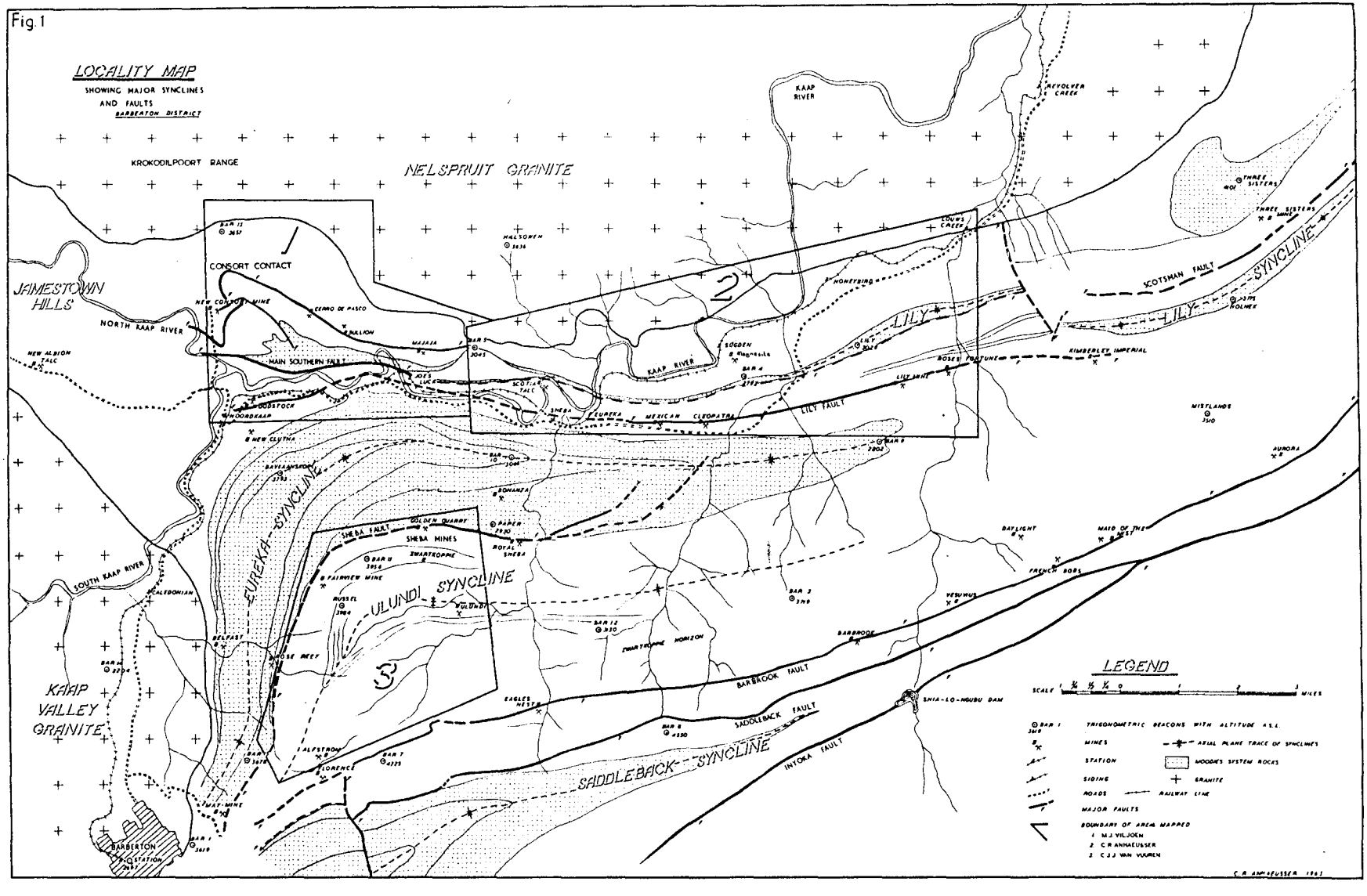
B. LOCALITY AND SIZE OF AREA (See Fig. 1)

The area chosen for the project is situated about 11 miles north of Barberton on the northern fringe of the Mountain Land. The country mapped lies between the New Consort Gold Mine and Joe's Luck Siding some 4 miles to the east, and covers an area of 14 square miles. Noordkaap is situated at the southwest corner and the southern boundary lies just south of the new road from Noordkaap to Kaapmuiden. The mapping was conveniently ended here as immediately to the south lies the Eureka Syncline forming a very compact and uniform separate structural entity. The granite hills to the north, which actually represent the southern foothills of the Krokodilpoort ranges, form the northern limit of the area. Bar 13 trigonometrical beacon (3,657 feet) is situated close to the granite contact due north of the Consort Mine and the beacon Bar 5 (3,045 feet), is situated at the extreme eastern part of the area in the vicinity of Joe's Luck.

The country mapped is rather rugged, mountainous and strongly dissected by small streams. The elevation varies from 4,150 feet (the highest granite hill in the northern part of the area) to 1,800 feet near Joe's Luck Siding. The elevation of the Consort Mine office is 2,200 feet.

The Kaap River, representing the only drainage channel from the Kaap Valley, flows in an easterly direction close to the southern boundary of the area, and the road and railway-line to Kaapmuiden follow this river valley eastwards. The only real tributary of the Kaap River in the area is Dicey's Creek

Fig. 1


LOCALITY MAP
SHOWING MAJOR SYNCLINES AND FAULTS
BARBERTON DISTRICT
KROKODILPOORT RANGE
NELSPRUIT GRANITE
JAMESTOWN HILLS
NORTH KAAP RIVER
CONSORT CONTACT
MAIN SOUTHERN FAULT
KAAP RIVER
LILY
LILY FAULT
SCOTSMAN FAULT
SYNCLINE
EUREKA SYNCLINE
SHEBA FAULT
SHEBA MINES
ULUNDI SYNCLINE
SOUTH KAAP RIVER
KAAP VALLEY GRANITE
BARBERTON
BARBROOK FAULT
SADDLEBACK FAULT
SADDLEBACK SYNCLINE
INYOKA FAULT
SHIA-LO-NGUBU DAM
LEGEND
SCALE
MILES
TRIGONOMETRIC BEACONS WITH ALTITUDE A.S.L.
MINES
AXIAL PLANE TRACE OF SYNCLINES
STATION
MOODIES SYSTEM ROCKS
SIDING
GRANITE
ROADS
RAILWAY LINE
MAJOR FAULTS
BOUNDARY OF AREAS MAPPED
1 M.J. VILJOEN
2 C.R. ANHAEUSSER
3 C.J.J. VAN VUUREN
C.R. ANHAEUSSER 1963

which trends southeast across the centre of the region and joins the river near Joe's Luck.

The precise locality is between 31°4'30" and 31°9'15" east and 25°37' and 25°40'30" south.

C. GEOLOGICAL FEATURES OF THE BARBERTON MOUNTAIN LAND - A SUMMARY OF PREVIOUS WORK

(a) Method of Treatment

This section deals with the previously accepted ideas on the geology and also with more recent developments. The most important contributions to the geology of the Mountain Land up to date, applying especially to the area under discussion, are reviewed.

(b) Classification of the Sedimentary and Volcanic Rocks

The primitive layered rocks that form the Barberton Mountain Land were first mapped by Hall (1918). He suggested a threefold subdivision, viz:

(i) a group of extrusive acid and basic rocks which he named the Onverwacht Series;

(ii) a group of sedimentary rocks comprising argillaceous and arenaceous types which he designated the Moodies Series; and

(iii) a group of basic and ultrabasic rocks, presumably intrusive, which he called the Jamestown Series.

The Nelspruit and Kaap Valley Granites were regarded as being intrusive into the above layered rocks.

Subsequent work by the Geological Survey (Visser et. al., 1956), showed that this subdivision was no longer tenable and they divided the rocks into two systems, viz:

(i) the Swaziland System and

(ii) the Moodies System.

The former and older of the two comprises a lower series known as the Onverwacht and an upper series known as the Fig-tree.

The Onverwacht rocks were long regarded as being the oldest in the area, but more recent work by Kuschke and Gribnitz et. al. (1961), and by Herget (1962), has cast doubt on this interpretation. Gribnitz suggests that another series lying below the Onverwacht should be established. To this series

he gives the name Oorschot from the farm where Kuschke first suggested the possibility that certain dolomitic rocks, previously mapped as belonging to the basic rocks of the Jamestown, might well represent the oldest known sediments of the Swaziland System.

Hall (1918) also encountered difficulty in interpreting the relationship between the Jamestown and "Moodies Series" (or what is now known as the Fig-tree Series) and states that "sometimes a narrow band of problematic carbonate rocks separates the granite from the Moodies Series" (Hall, 1918, p. 114). He also states that "in the Clutha area such dolomitic rocks lie sharply against shaly phases of the "Moodies Series" and the sequence appears conformable, but in many cases the contact is not exposed". (Hall, p. 114).

(i) The Oorschot Series

According to Gribnitz (1961), these rocks consist of partly arenaceous calcareous sediments intimately associated and interbedded with banded cherts and ironstones (itaberites). At least one case of an intraformational conglomerate in the form of rounded chert pebbles is mentioned, as well as subordinate beds of black carbonaceous shale. He contends that subsequent kinemetamorphic influences converted large portions of the carbonate-bearing rocks into talc carbonate and quartz sericite schists, various occurrences of which have previously been placed into the Onverwacht and/or Fig-tree Series, as well as into the Jamestown Complex.

(ii) The Onverwacht Series

According to the Geological Survey (Visser et. al., 1956), this series consists almost entirely of volcanic rocks and has been divided into a lower basic phase consisting of massive, fine-grained andesitic lava, and an upper acid phase consisting of quartz and felspar porphyries. Gribnitz (1961) however, feels that the Onverwacht consists mainly of basic rocks, generally intrusive into the Oorschot Series, but with extrusive varieties as well. On the Geological Survey map these are partly grouped as Onverwacht and partly as basic Jamestown rocks (Gribnitz, 1961).

According to van Eeden (1941), basic lavas are often represented by talc-carbonate schists, talcose schists, schists with long amphibole needles and even serpentine. It is pointed out that such rocks cannot be distinguished in many cases from similar rocks which were evidently formed from the alteration of basic intrusive rocks e.g. the Jamestown rocks. Thus, where such rocks occur in isolated patches without associated volcanic rocks, it is very difficult to classify them.

South of the Lily quartzite line in the northern part of the Mountain Land, van Eeden (1941) describes certain basic rocks consisting of serpentinite, talc carbonate schists, talc schists and amphibole

schists. They are associated with mica-quartz schists and from their field relationships he tentatively classifies them as altered basic and acid lavas of the Onverwacht. He considers the serpentinites as possibly representing original basic intrusives belonging to the Jamestown and suggests that the remainder may perhaps be altered sediments rather than altered lavas.

(iii) The Fig-tree Series

The overlying Fig-tree Series consists typically of a thick group of predominantly argillaceous rocks with a subordinate development near the top of the succession of what have been classed by van Eeden (1941), as lavas. The sequence is characterized by a great development of banded chert and banded ironstone together with laminated shales and graywackes. At the base of the Series, and mainly known from the Sheba Mine area, occurs the so-called "Zwartkoppie" zone consisting of chert bars and various varieties of schists.

Recent investigations by Ramsay (1963), cast some doubt on the classification of certain rocks near the top of the Fig-tree Series as lavas. He contends that the succession is essentially sedimentary and that the "lavas" of van Eeden are coarse felspathic graywackes.

Some difficulty also exists as regards the origin of the "Zwartkoppie" zone. As mentioned, it consists of chert bars underlain by "green schists" and the latter underlain by "grey schists". The grey schist consists mainly of talc and carbonate whereas the green schist, due to its strong chemical and mineralogical affinity to a graywacke (Koen - 1947), probably represents a mylonitized product of the latter. According to Gribnitz (1961), "there is abundant field evidence that the dolomites etc. of the Oorschot Series, represent the unmetamorphosed parent rock of these schists". Ramsay (1963) is of the opinion that the green schists represent deformed laminated cherts of secondary origin derived from the replacement of graywacke and possibly some calcareous sediments and talc-phyllites.

Urie (1959), working in the Bomvu Ridge area of Swaziland, came to the conclusion that much of what he terms the "basal zone" of the Fig-tree Series, was originally largely composed of argillaceous and carbonate-bearing formations together with narrow interbedded siliceous (banded chert) horizons. This basal zone which lies conformably below typical Fig-tree rocks, was later highly altered, the argillaceous material being assimilated by a process of "re-active solution" and converted into ultrabasic rocks. The basification was evidently due to the effects of the Jamestown Complex. The siliceous horizons were totally unaffected by this assimilation process which must have thus been highly selective. The latter occur today as siliceous bands within basic schists. As stated by Urie, very great difficulties attend this process of selective assimilation.

(iv) The Moodies System

This System, which according to the Geological Survey (Visser et. al., 1956), follows unconformably on the Swaziland System, consists mainly of arenaceous rocks with minor sandy shale horizons and a rather characteristic and persistent basal conglomerate. Hall (1918) originally considered the basal conglomerate of the Moodies to rest conformably on the Fig-tree sediments. As mentioned by the Geological Survey (Visser, et. al., 1956), it is extremely difficult to find an angular unconformity between the two as they have both been involved in tight folding. However, after detailed work in the Sheba Hills area, van Eeden (1941) concludes that an unconformity is definitely present. The Swaziland Geological Survey recognise the presence of an unconformity but still retain the term Moodies Series because they consider the whole Swaziland succession as having been laid down as a more or less continuous series in the same geosyncline (Hunter, 1961). du Toit (1954), and Gribnitz (1961), are inclined to the view that there is no justification to emphasise the disconformity below the Moodies sediments and to elevate the Moodies Series to a system for correlation purposes.

(c) Predominantly Intrusive Rocks

(i) The Jamestown Complex

The Geological Survey (Visser et. al., 1956) considers the next episode after the deposition of the Moodies System, to have been the intrusion of a suite of basic and ultrabasic rocks now represented by green and blue serpentinite, amphibolite, diabase and various basic schists. As pointed out previously, considerable uncertainty now exists as to the valadity of this interpretation. This episode of basic intrusion was followed by the intrusion of a granodiorite magma which broke through the basic rocks and at the same time invaded the adjacent, older sedimentary formations. This granodiorite is locally known as the Kaap Valley Granite, and together with the suite of older basic rocks constitutes what the Geological Survey (Visser et. al., 1956) have termed the Jamestown Igneous Complex.

1. Basic Rocks

Due to the abundance of basic inclusions in the Nelspruit gneiss north of the main contact, it was suggested by Hall (1918) that the whole area south of the Crocodile River Valley, from Kaapmuiden in the east to below the escarpment in the west, as well as part of the Kaap Valley down to Caledonia Siding, "were originally occupied by basic rocks of which the present Jamestown Series represents merely

the intensely metamorphosed schistose remnant".

Although a number of localities are mentioned by the Geological Survey where basic rocks intrude Fig-tree and Moodies sediments, it can be seen that this is not a large scale phenomena within the Mountain Land. In numerous cases it has been shown that a cross-cutting relationship is due to faulting. In the Montrose area, Herget (1962) showed that certain basic bodies formerly classed as Jamestown rocks, always underlie the Fig-tree Series, occupy cores of anticlines and can in fact be correlated with Onverwacht rocks.

Almost all previous workers have recognised original olivine and pyroxene crystals in serpentinite bodies at many places and this has been interpreted as being indicative of therehaving been true intrusive basic and ultrabasic bodies. As noted by Gribnitz (1961), these original bodies may be part of the Onverwacht Series which he regards as being largely intrusive into the Oorschot Series. According to him there is not a single proved case where basic in- or extrusive rocks have been transformed into talc-carbonate schists. He is convinced that the vast majority of the green and grey schists mapped largely as Jamestown, are altered products of dolomites, limestones, arenaceous limestone and cherts of his proposed Oorschot Series.

2. The Kaap Valley Granite

Hall (1918) was the first to describe the hornblende granite of the Kaap Valley and to distinguish it from the Nelspruit Granite. He regarded both granites as being of the same age, but manifestations of different conditions of consolidation, the Kaap Valley Granite attaining its more basic character due to assimilation of basic Jamestown rocks.

As noted by the Geological Survey (Visser, et. al., 1956), this hornblende-granite is everywhere surrounded by basic rocks and the contact between it and the latter is always a sharp one. The contact between the Kaap Valley and the Nelspruit Granite in the southwest is never exposed so that no field relationships have been determined. It is considered to be post Moodies and van Eeden (1941) concludes that it was already a solid mass at the time of major folding. The above age discrepancy precludes the possibility that the Kaap Valley Granite represents an endomorphically modified phase of the Nelspruit Granite as first suggested by Hall (1918).

Heam (1943) considers this granite to be considerably younger than the Nelspruit Granite and Ramsay (1963), basing his conclusions on structural evidence, is of the same opinion.

Fairly recently an age of 3,200 $\pm$ 150 m.y., was obtained for the Kaap Valley Granite (Nicolaysen - 1962).

One curious phenomenon of this granite is the remarkable absence of contact metamorphism when compared with the intrusive portions of what has been mapped as Nelspruit Granite. In composition it differs markedly from the latter granite and is generally rather poorly gneissic.

Read (1956) is of the opinion that it represents a high level pluton.

The gneissic G3 Granite of Swaziland which pre-dates the extensive G4 Granite of the territory, is shown by Hunter (1961) to be lithologically and chemically similar to the Kaap Valley Granite.

(ii) The Nelspruit Granite

All previous workers who have investigated the contact zone of this granite have noted the classic intrusive relationship between it and the Archaean System rocks.

The normal granite, excluding the contact belt, is described by Hall (1918) as being a "greyish-white, medium to coarse-grained, massive, biotite granite, free from directional properties and presenting general uniformity in appearance over considerable distances". According to him, as the contact with the Jamestown schist belt is approached, the gneissic habit increases markedly and within 100 or 200 yards of the contact it is very pronounced with planes of gneissosity sensibly parallel to the average strike of the schist belt.

According to van Eeden (1941), most of the granite of the Eastern Lowveld from the Barberton Mountain Land to the Murchison Range, is very similar in all respects. He describes it as being of medium to fine grain size, grey and biotite-bearing throughout. It is described as a "primary gneiss" comprising "flow bands" consisting of alternating layers with and without biotite, together with "flow lines" in the form of large basic inclusions which have the same strike as the "flow bands".

Chemical analyses of the Nelspruit Granite (Geological Survey - Visser et. al., 1956) show it to be grano-dioritic or quartz-dioritic.

As mentioned previously, Hall (1918) regards the granite as having migmatised a large mass of basic Jamestown rocks while van Eeden (1941) feels that large quantities of Swaziland, Moodies and Jamestown rocks must have been incorporated in the granite. According to him, flow structures and inclusions in the granite become much less frequent at depth so that the shallower portions are gneissic as a result of the incorporation of older rocks. The deeper portions are considered to have formed from an original magma. The intrusive stock-like body of light-red, coarse-grained intrusive granite known as the M'pageni Granite is free of directional properties and is thought to be a deep, nearly pure magma phase of the Nelspruit-type Granite.

The granite intrusion has caused strong thermal metamorphism of the rocks along the contact zone but the rocks within the Mountain Land are virtually unaffected. An anomalous situation exists in that a huge tract of essentially autochthonous granite lies in juxtaposition with a large remnant of completely unmetamorphosed layered rocks of the Mountain Land. In between the two there occurs a comparitively negligible strip of metamorphic rocks. Read (1957) has suggested that the belt of basic rocks which surrounds the Mountain Land has acted as a basic resister shielding the Swaziland and Moodies System rocks from granitization. He suggests that in general the Nelspruit gneiss has resulted from the migmatization of semipelitic and more siliceous rocks and that the large number of basic inclusions represent relics of basic resisters.

An age measurement done on coarse biotite from the Nelspruit gneiss yielded a figure of 2,570 ± 150 m.y. (Nicolaysen - 1962).

(d) Metamorphism

The Geological Survey (Visser et. al., 1956) recognises the effects of dynamic and thermal metamorphism but states that regional metamorphism is absent.

(i) Dynamic Metamorphism

According to the Geological Survey (Visser et. al., 1956), dynamic metamorphism on a large scale is absent, but along some major thrust faults the sediments have been crushed and mylonitized and in places also silicified so that the faults may be traced by means of the outcrops of secondary chert.

The green schist of the Zwartkoppie Zone in the Sheba area represents a mylonitized graywacke according to Koen (1947), and the greenschist-chert horizon near Noordkaap known as the "Woodstock Bar", is considered by van Eeden (1941) to be a mylonite marking the position of a fault.

(ii) Contact Metamorphism

Most writers have found very little, if any evidence, of metamorphism due to the intrusion of the basic rocks of the Jamestown. van Eeden (1941) is of the opinion that much of the silicification in the vicinity of the Kaap River (e.g. the Lily Line), should largely be ascribed to the effects of the Jamestown.

Metamorphism due to the Kaap Valley Granite has been noted by most writers to be inexplicably absent, and all are unanimously agreed that the intrusion of the Nelspruit Granite caused

by far the greatest amount, if not all the metamorphism in the area. The rocks mainly effected are basic varieties belonging to the Jamestown Series, but in places, especially in the Consort Mine area, metamorphosed shales, "lavas" and quartzites are well exposed.

van Eeden (1941) has mapped a large stretch of rocks along most of the northern contact as being of unknown origin. They consist mainly of basic schists and cherty rocks and in some instances it can be shown that they are derived from sediments whereas in other cases their origin is uncertain.

According to van Eeden (1941), the metamorphism took place during the folding of the rocks, but came to an end after the beds had already been sharply folded. Some of the minerals that formed underwent dynamic metamorphism after crystallization. For example, amphibole that formed early and far from the granite underwent more deformation than later minerals and minerals that formed at the contact. He concludes that this is a good indication that the amphibole did not originate as a result of the intrusion of the Jamestown rocks.

Amphibole is described by van Eeden (1941) as being the most important metamorphic mineral, whereas Hall (1918) does not consider it to be a metamorphic mineral but instead a primary mineral derived from basic intrusive and extrusive rocks.

Except in the case of quartz-rich sediments, amphibole is stated by van Eeden (1941) to occur in all the metamorphosed rocks. Shales, sandy shales and graywackes have been altered to amphibole-rich rocks in which biotite, garnet and tourmaline may also occur in abundance. Quartzitic rocks close to the contact have been recrystallised and the impurities changed to sericite, chrome-sericite (fuchsite) and felspar. Sillimanite, garnet and andalusite may also be present. In calcareous rocks which also contain magnesium, amphibole and diallage have developed, whereas the iron-rich sediments have been altered to grunerite-cummingtonite schists. The basic rocks are considered to have been metamorphosed to amphibole, talc and carbonate schists.

(iii) Grades of Metamorphism

No subdivisions into contact metamorphic zones have been made according to the appearance of specific metamorphic index minerals. It was noted, however, (van Eeden, 1941), that sillimanite and garnet are found only along, or very close to the Nelspruit Granite whereas tourmaline, biotite and amphibole are present over the entire width of the zone. The latter mineral however, is best developed close to the granite contact.

(e) A Brief Description of the Structure of the Barberton Mountain Land

(i) Hall's Observations

Hall (1918) ascribes the complex structure of the Mountain Land to "granite intrusion", i.e. Kaap Granite and Nelspruit Granite, which he considers to be of the same age. He states (p. 113), "It is clear that the intrusion of the large mass of granite must have been accompanied by great pressure, and the marked absence of cataclastic structures in the igneous formation is one argument in favour of the view that the complex tectonics of the Moodies Series do not belong to a period subsequent to that of the consolidation of the granite, but are directly due to the intrusion of the latter". Hall also states (p. 114) that his "Moodies Series" was succeeded towards the northwest by a great development of basic rocks "of which the present Jamestown Series represents only a fraction; and that subsequently, due to the intrusion of a large massive granite under conditions of great regional pressure, both groups were intensely altered, the more resistant sediments being affected mainly as regards structure - excepting along their granite contact - while the igneous phase acquired the habit of cyrstalline schists, though the occasional occurrence of minor residual areas of still massive rocks (e.g. serpentine) shows a variation in the intensity of structural change".

"For these reasons the two groups now form a more or less conformable sequence of which the schistose one would appear to have been originally intrusive into and thus younger than the Moodies Series".

(ii) van Eeden's Conclusions

1. General

A detailed structural investigation of the Sheba Hills area was carried out by van Eeden (1941) and he states that one of the major features of the structure of the Mountain Land is that the rocks have been folded along axes trending roughly east-northeast or west-southwest and have undergone shortening in a direction at right angles to this trend.

This main folding is ascribed to the intrusion of the Nelspruit Granite. No major folding is considered to have occurred before this, although pebbles of contorted banded chert have been found in the basal conglomerate of the Moodies System which possibly indicates that the rocks of the Swaziland System had been folded to some extent before the deposition of the Moodies System.

van Eeden found that the "flow banding" in the granite trends away from the contact at an angle of about 55 - 60°. This is about the same direction as the length of the Mountain Land. At the contact however, the "flow bands" swing to a position parallel to the contact. This phenomenon he ascribes to the Kaap Valley Granite (see later). According to him, structures in the Nelspruit Granite indicate that it has undergone an elongation in a direction parallel to the length of the Mountain Land (i.e. movement and extension of rock elements has been in a horizontal rather than in a vertical direction). On the other hand, as all the upthrusts in the Swaziland System are parallel to the fold axes, it is considered that these layered rocks were vertically elongated.

The elongation in the Nelspruit Granite, mentioned above, is more or less parallel to the length of the Mountain Land and it would be a peculiar coincidence if the granite was a much later intrusion which had nothing to do with the folding. It is thus concluded that the intrusion of the granite took place at the same time as the folding.

2. The Influence of the Kaap Valley Granite on the Deformation

van Eeden (1941) came to the conclusion that the Kaap Valley Granite is responsible for the marked change in strike of the various layered rocks which surround it. For additional evidence that it was indeed a solid body before the major folding, he cites the fact that a great number of dykes in the granite and surrounding rocks strike at right angles to the trend of the Mountain Land. He interprets these dykes as occupying tension joints which developed due to the elongation of the granite by the same forces which folded the older rocks (mentioned above).

Pressure was directed from the northwest and southeast and the solid mass of Kaap Granite which did not yield to deformation, acted as a resistant buttress against which the less competent and bedded rocks were compressed and deformed.

It is considered that the major deforming stress was from the southeast where a granite of Nelspruit age on the Swaziland side of the Mountain Land, intruded at the same time as the latter. This explains the strong overfolding of all the rocks to the northwest, and the major inflection in the Eureka Syncline which must have developed as the beds were dragged past the "nose" of the mass of Kaap Valley Granite and were pressed to the northwest.

According to van Eeden (1941) the neutral plane where pressure from the northwest and pressure from the southeast cancelled each other out, is located in the Kaap Valley. It is understandable that the greatest amount of bending took place closest to this plane and becomes less and less away from this area until it is completely absent i.e. the strike of the fold axes will then be parallel to the

regional strike of the Mountain Land. van Eeden notes that as a result of the influence of the Kaap Granite, folds developed whose axes are nearly parallel or sometimes even parallel to the forces operative on the Mountain Land, and it is thus obvious that the relationship between deformation and stress in the area is very involved and complex.

3. Indication of Elongation in the Stratified Rocks

van Eeden (1941) was the first to recognise an "a" elongation in these rocks. He noted that all the conglomerate pebbles that are not round, lie with their long axes parallel to the dip of the beds. It was found that the long axes seldom differed more than 10° from the direction of dip. The short axes were found to be at right angles to the bedding and the intermediate axes horizontal. This orientation was also found to hold roughly for the "autoliths" in the "lava" underlying the basal conglomerate.

It was concluded however that the pebbles underwent little deformation or flattening. This is based on the fact that elongated cherts are found together with almost perfectly rounded granite pebbles, a fact which he found difficult to reconcile with his assumption that granite was more susceptible to deformation and elongation than chert. The elongated cherts were, therefore, thought to be undeformed and deposited with their long axes all in one direction. van Eeden considers it to be a coincidence that all the pebbles should be lying in the "a" direction of the folds and the only other explanation is that the present orientation was derived due to differential movement between the beds during folding.

4. Summary

(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. 150°.

(ii) The major force was from the south-southeast and resulted in overfolding to the north-northwest.

(iii) The general strike of the axial planar traces of the main folds is roughly N 60° - 62° E, which also conforms to the strike of the Mountain Land in general and to the major faults.

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

(v) Horizontal elongation in the Nelspruit Granite, parallel to the length of the Mountain Land, took place while the stratified rocks were mainly elongated close to the vertical as a result of the folding.

(vi) 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 fold axes in adjacent rocks.

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

(iii) Hearn's Conclusions

As mentioned, Hearn (1943) considers the Kaap Valley Granite to be the youngest of the granites. The Nelspruit Granite intruded first and caused folding and metamorphism. After this, the Kaap Valley boss was intruded and caused the complex structural conditions in the Consort Mine area.

(iv) Ramsay's Work

Recent work by Ramsay (1963) in the northwest part of the Mountain Land has revealed the presence of at least three successive periods of deformation.

1. 1st Structures

His first period of deformation corresponds to what van Eeden (1941) regards as the one and only period of deformation. As noted by the latter author, this gave rise to many large folds whose axial planes were probably initially oriented in a northeast - southwest direction.

2. 2nd Structures

The second deformation resulted in the widespread development of slaty cleavage and schistosity which cuts obliquely across the first folds. The flattening and elongation of clastic particles in the Fig-tree Series and Moodies System, as first mentioned by van Eeden (1941), has been ascribed by Ramsay to this period of deformation. The particles are flattened in the plane of cleavage and their long axes are usually fairly steeply inclined within these cleavage planes.

Evidence of Superimposition of 2nd and 1st Structures

The cross-cutting relationship of cleavage across 1st structures is well revealed in the Clutha Mine area where, contrary to the normal geometrical relationship of cleavage to overturned bedding, the cleavage dips at shallower angles than the latter (Ramsay, 1963). Similar evidence was

obtained from the Sheba Mine area where the cleavage cross-cuts the axial plane and limbs of an earlier fold.

According to Ramsay (1963), "When two successive strains are superimposed in a plastic substance, the result of the combination of the two individual strain ellipsoids, is a third strain ellipsoid. There will only be one direction of total maximum compressive strain, and this appears to account for the presence of only one slaty cleavage in these rocks, even though the rocks have been deformed in two acts".

From the attitude of the slaty cleavage, Ramsay concludes that if the Kaap Valley Granite was a resistant, competent mass at some stage in the structural history, then it must have reached this state after the development of the slaty cleavage.

A notable feature of the second phase of deformation is that very few major folds are developed.

At some localities, the superimposition of second generation minor folds onto similar folds developed during the first period of deformation, has led to the development of a complex arrangement of interfering domes and basins.

2nd Structures along the Granite Contact Zone

Proceeding northwards from the Eureka Syncline, the metamorphic state increases rapidly as the granite margin is approached, and although difficult to trace, Ramsay maintains that in view of the structural conformity of the slaty cleavage in the northern part of the Eureka Syncline with the schistosity in the metamorphosed rocks, and even within the granite, there is a strong argument for relating the two in time.

Tectonically produced structures which developed while the rock was crystallising are interpreted as indicating that the granite emplacement and the second deformation were broadly synchronous. Strongly mylonitized rocks are found along the contact and Ramsay is of the opinion that these formed as the granite cooled, but are related to the same general period of deformation that caused the cleavage.

3. 3rd Structure

Ramsay"s final phase of deformation deforms the slaty cleavage and is best developed in the north-western part of the Mountain Land. A shear cleavage, coincident with the axial planes of

minute crenulation folds which give the rock a "crinkled appearance", is well-developed in the Noordkaap area. The attitude of the fold axes and axial planes is almost horizontal and the development of these structures is closely controlled by the lithology, being confined to slaty or phyllitic rocks.

These crenulation folds deform second fold lineations and Ramsay shows how the movement direction of the younger folds can be obtained from these deformed lineations.

The major northwest-trending folds of the Consort Mine area are related to this deformation and Ramsay states:- "These structures are correlated with the third folds because they fold the schistosity in the phyllites, they deform the second fold mineral orientation lineations and have a shear cleavage parallel to their axial planes. The orientation of the axial planes of these structures changes northwards from Noordkaap; they become steeper, pass through the vertical in parts of the Consort Mine, and dip south westwards in the Top Section synform". (Ramsay, 1963).

One of Ramsay's main problems is the explanation of the significance of the great arcuate structure seen in both the first folds and in the superimposed cleavage. The axial planar trace of the large inflection of the Eureka Syncline has the same general orientation as the third folds in the Consort area, but neither the dips of the axial planes nor the plunge of these folds coincide. They are classified together however because both structures deform the slaty cleavage and both have axial traces which trend north westwards along the length of the main Jamestown belt.

The development of conjugate folds in certain slate horizons in the Eureka Syncline may have been synchronous with the formation of the arcuate structure, but they are considered to possibly post-date it and to be related to a fourth period of deformation.

4. The Relationship of Faults to the above Periods of Deformation

Ramsay considers the main strike faults to have been initiated during the first period of deformation although most appear to have been reactivated during later periods of folding.

5. Relationship of the Mineralization to the Structures

In the Consort Mine, the mineralization predates the development of some slightly sheared granite pegmatites which were deformed during the second regional deformation.

The ore shoots are linear and are thought to run parallel to minor structures which are believed to be parallel to the axes of second folds. These ore shoots are deformed by the third fold structures.

From the above Ramsay suggests that the arrival of the ore fluids was broadly synchronous with the development of the second period of regional deformation, possibly at a fairly late stage in the movement and thus roughly synchronous with the intrusion of the Nelspruit Granite.

6. Conclusions

Ramsay concludes that:- "In view of the close orientations of the positions of the general maximum compressive strain axes of the first and second deformations, it seems likely that these movements may have been phases of a single orogeny. The general orientation of the maximum compressive strain of the third deformation is approximately at right angles to those of the earlier deformations. If this feature is not just the result of some abnormal local stress condition it suggests that some considerable interval of time may separate the second and third deformations".

(f) General Description of the Mineralization in the Barberton Area

(i) Distribution of Mineralization

Hall (1918) noted that in a large number of instances, on both sides of the Mountain Land, the gold mines of the Barberton District lie within the Jamestown or the outer margin of "Moodies Series", but nearly always close to the junction with the "granite". (i.e. Kaap Valley and Nelspruit Granites).

At the time of writing (1918) he states that over 80% of the mines occurred within the "mineralogical or tectonic aureole of the granite". He also noted that mines such as the Barbrook, French Bobs, etc., situated a long way from the granite junction, were never developed into really successful mines.

As noted by du Toit (1953) as well, "only a few mines are situated among the higher strata away from the contact zone of the granite", and in such cases they are commonly related to faulting and thrusting.

(ii) The Hydrothermal Mineralization

J. E. de Villiers (1957) has made a general study of the mineralogy of the gold ores of the Barberton area, but no really exhaustive work exists, although Hearn (1943), has made a detailed study of the mineralogy of the Consort and Sheba Mines. Other work is confined to reports of the Mining

Companies working in the area.

(iii) Structure of Ore Bodies

According to Gribnitz (1961), three types of ore bodies are known to occur.

(a) metasomatic replacement of the foot and hanging wall rocks of faults.

This consists mainly of sulphide mineralization with the actual fracture-filling consisting predominantly of non-metallic minerals such as quartz, felspar and calcite.

As examples of this type he cites the four major mines of the district i.e. Consort, Fairview, Sheba, Agnes and others.

(b) Gold/quartz veins

These contain very little sulphides, and the gold is finely distributed within the vein quartz and rarely enters the hanging or footwall of a vein. Examples are the Fortuna, Pioneer and others.

(c) Pipes

These are considered to have formed by mineral stoping. They are all confined to the Sheba Mine and include the famous Cathedral Shoot in the footwall of the Sheba Fault.

(iv) Mineral Assemblage

de Villiers (1957) recognises four main types of ore, viz:-

(a) ore containing arsenopyrite and pyrrhotite.

(b) pyritic ore.

(c) lead-bearing ore.

(d) antimonial ore.

To this Gribnitz (1961) adds a fifth type, viz. gold/quartz ore.

According to de Villiers, "the ore containing pyrrhotite and arsenopyrite of the New Consort and Lily Mines, formed at high temperature and at great depth".

The pyritic deposits, which constitute by far the largest proportion of the Barberton occurrences, are mineralogically uniform and simple and are characteristically hypothermal.

The lead-bearing ore from Rosetta Mine has a mineral assemblage characteristic of the mesothermal zone.

(v) The Relationship between various Rock-types, Faulting and Mineralization

According to Gribnitz (1961), it is a well established fact that at least all auriferous ore bodies of any significance are located on, or directly adjacent to planes or zones of movement.

He states that the primary avenues for the hydrothermal solutions and also frequently the place of deposition, are undoubtedly the regional strike faults which he regards as being much more numerous and extending further than shown on the Geological Survey map (Visser et. al., 1956). Secondary fault systems received their share of mineralization from the former primary system.

He mentions that it is generally unknown what determines the usually narrow and well defined position of ore shoot zones. One reason is undoubtedly the variation of the physical properties of the ruptured strata (relatively competent and incompetent rocks). Other factors are intersections, bifurcations of faults and fractures, and changes of strike and dip.

The chemical composition of the host rock also plays a part, the coarse-grained pyritic ores for example being almost exclusively found in banded cherts and banded ironstones.

From observations on various mines, Gribnitz (1961) concludes that:-

(a) the amount and grade of ore will, under a given set of conditions, improve or deteriorate in the same direction in which the relative movements become stronger (increasing displacement) or weaker (decreasing displacement).

(b) a fault or fracture will become poorly mineralized or barren before the actual fault plane disappears.

(vi) Regional Distribution of Ore Types

This is not very distinct but there could be a zonal arrangement of the auriferous ore in the Barberton District.

According to Gribnitz (1961), the arsenopyrite ores have their focal point at the New Consort Mine and decrease rapidly towards the south and southwest.

There then follows a zone of pyritic ores in which the pyrite crystals are very small. Finally there is a zone of coarse-grained pyritic ores.

Most of the gold/quartz veins are found close to the Kaap Valley Granite and do not seem to fit into the above picture.

Gay (1963) found that the fineness values of gold samples collected throughout the Barberton region, show a regular distribution with the highest values around the Consort and Agnes Mines.

(vii) Origin of the Mineralization

de Villiers (1957) feels that the Barberton gold deposits formed during a single metallogenic epoch and that they are genetically related to the Nelspruit Granite. van Eeden (1941) also ascribed the source of the hydrothermal solutions to the Nelspruit Granite and Hall (1918) felt that the mineralization was related to the "granites", (including the Kaap Valley and the Nelspruit Granites). Hearn (1943) suggested that it was the Kaap Valley Granite for the most part which was responsible for much of the mineralization in the district.

D. REASONS FOR, AND AIMS OF THE PRESENT INVESTIGATION

(a) Reasons for the Choice of Area

The area constitutes part of the northern extension of the Barberton Mountain Land where the so-called Archaean System rocks abut against the Nelspruit Granite. As a consequence of a number of factors mentioned below, it is considered to be one of the most interesting and probably also one of the most critical areas in the Mountain Land.

(i) The area is well mineralized; the Consort Mine is one of the largest in the district, and in terms of total tonnage of sulphide mineralization it is probably the richest. Other mines which are not working at the moment, include the Woodstock, Cerro de Pasco, Majaja and Bullion mines. The Clutha Mine is situated just out of the area to the southwest. The fact that a considerable amount of mineralization is known to occur in a relatively small area suggests that the major controlling factor or factors, whether being close proximity to the source of ore fluids, a particularly favourable structural environment, or any other such optimum condition, possibly existed at the time of the mineralizing episode.

(ii) As shown by Ramsay (1963), the area is structurally very complex and he found it difficult to explain the marked inflection of the Eureka Syncline which occurs immediately to the south of the area investigated. The east-southeast trending sequence of basic rocks forming the Jamestown Hills is terminated abruptly by the massive competent block of quartzites forming the Eureka Syncline and the situation of the Consort Mine at the junction of these two major structural trends is possibly of significance.

(iii) The fact that the Consort Mine is situated in close proximity to the Nelspruit Granite and is at the same time not too distant from the Kaap Valley Granite, may be of significance.

(iv) The area represents one of the few places along the whole contact of the Mountain Land where typical Fig-tree shales and graywackes and Moodies quartzites have been fairly extensively thermally metamorphosed and where these can be well studied.

(v) A regular succession of basic rocks with intercalated quartzitic horizons lying conformably below the Fig-tree shales has been mapped by the Geological Survey (Visser, et. al., 1956), as being of unknown origin. It was hoped that some clue might be obtained as to their place in the stratigraphic succession and to their origin.

(b) Aims of the Work

It was felt that a detailed petrological and structural investigation might help to ellucidate the following:-

(i) the various phases or periods of deformation which have affected the area, and possible also the whole Barberton Mountain Land.

(ii) the time of the mineralization in relation to the various periods of deformation.

(iii) the structural control of the mineralization.

(iv) the origin of the mineralization - whether genetically related to the Nelspruit Granite or to the Kaap Valley Granite or to some other granite.

(v) the time of intrusion of the Nelspruit Granite and its relationship to the deformation in the area; associated with the above is the allied problem of the age of the metamorphism and its relationship to the periods of deformation.

(vi) the eastward extent of the potentially economically important horizon known as the Consort "Contact".

(vii) the origin of the basic suite of rocks lying below the Fig-tree shales and graywackes.

(viii) the subdivision of the area into various facies of contact metamorphism.

E. WORK ACCOMPLISHED

With the above aims in mind, detailed geological and structural mapping was commenced early in February, 1962, and the field work completed in seven months. In addition to the usual type of detailed mapping of different rock units and the recording of strike and dip of bedding, particular attention was paid to the observation and recording of so-called "minor structural features" such as small folds, lineation etc., a fuller discussion of which appears on page 83.

Mapping was done directly onto enlarged aerial photographs (scale approximately 1 : 5,000). Subsequently the field data obtained were transferred on to a specially prepared base map, scale 1 : 10,000, and a detailed geological and structural map compiled. It was realised at an early stage that the recording of minor structural features would be valueless unless these could be accurately plotted on a base map of suitable scale. The only existing maps of the area were those confined to local mine properties and the 1 : 50,000 Geological Survey map of the whole Barberton District - both unsuitable for the kind of work envisaged. It was for this reason that the Economic Geology Research Unit, in conjunction with E.T.C. Mines Ltd., and Federale Mynbou Beperk, decided to have an accurate 1 : 10,000 base map of the more important mineralized portions of the Mountain Land constructed. This detailed, contoured base map proved of great value in the construction of the subsequent geological and structural maps.

Numerous diagrams were compiled from the recorded structural data. These are mainly stereographic plots of structural parameters, but include others such as plots of the ratios of deformed to undeformed conglomerate pebbles. In all, over 2,000 structural observations, including a measurement of all the parameters mentioned, (see page 83), were made. A detailed microscopic investigation was made of over 220 thin sections.

A structural interpretation of the Consort Mine was not attempted as very little underground work was done. However, from numerous field observations, a structural interpretation of the area as a whole was attempted, and while in no way claiming to give a complete structural picture of the area, it is hoped that the major structural patterns have been accounted for satisfactorily.

F. ACKNOWLEDGEMENTS

The author is indebted to Eastern Transvaal Consolidated Mines Limited, for a considerable amount of financial support and for supplying accommodation at the New Consort Gold Mine during the time spent in the field. Also to the Economic Geology Research Unit and the C. S. I. R. for financial

assistance granted for the undertaking of the project, the writer would like to express his appreciation.

Much useful assistance was afforded the writer by the geological staff of E. T. C. Mines Limited, and for valuable information, guidance and critiscism during the period spent in the Barberton area, the author is very grateful.

Finally, I would like to thank various members of the Economic Geology Research Unit, and in particular Mr. C. Roering, for valuable suggestions and critiscism on all aspects of the work.

- -

RESULTS OF THE PRESENT INVESTIGATION

A. GENERAL GEOLOGY OF THE CONSORT MINE - JOE'S LUCK AREA

(a) Classification and Distribution of Rock-Types (See Geological Map - Fig. 2).

Throughout the area mapped, there occurs a fairly distinctive and persistent stratigraphical succession which can be identified and traced the whole way from the Consort Mine to Joe's Luck Siding.

To the north, and forming part of the Krokodilpoort ranges, lies the main mass of the Nelspruit Granite displaying an intrusive relationship along its contact. It is followed to the south by a more or less east-west trending and southward dipping suite of basic rocks; mainly amphibolites and serpentinites, with intercalated quartzitic and minor shaly horizons.

The above-mentioned suite forms the so-called "footwall schists" of the Consort Mine area and has been classified by the Geological Survey (Visser et. al., 1956), as metamorphosed basic and acid rocks of unknown origin. The author is of the opinion that the majority of these basic rocks are of sedimentary origin, associated however with undoubted basic intrusives and probably also some acid and basic extrusives. As will be shown, the altered sediments could well have formed from "parent rocks" of a similar composition to Gribnitz's proposed Oorschot Series. It is considered unwarranted however, to group these original dolomitic rocks in a separate series, for the following reason. They lie close to the base of the Archaean System and invariably in close proximity to intrusive granites which have usually caused fairly strong thermal metamorphism along the immediate contact zone. The end products of fairly high grade metamorphism of a basic or ultrabasic intrusive, a basic lava, and an impure dolomitic rock, will be very similar, so that any definite distinction between these types in the field must of necessity be rather precarious. It is mainly for this reason that all the basic rocks in the area, barring most of the serpentinite bodies, are classed in the Onverwacht Series. The serpentinite bodies are invariably best developed in, and intimately associated with the basic rocks of the Onverwacht Series. However, they also intrude rocks of the Moodies System. They are classed in the Jamestown Series.

To the south, the stratified basic rock sequence discussed above, is immediately overlain by the so-called "Consort Contact" along which silicified, cherty rocks (the Consort "Bar"), and the gold mineralization in the area, are invariably developed.

The "Contact" is overlain by the "hanging-wall" rocks or "shales" of the Consort area. These comprise a succession of metamorphosed shaly sediments which grade upwards into rocks which have been regarded as lavas, but which, as will be shown later, are definitely unlike typical lavas.

All of these rocks belong to the Fig-tree Series.

The "lavas" are overlain (apparently conformably in this area) by a conglomerate zone which grades upwards into an impure type of quartzite. These arenaceous rocks, forming the western extremity of the "Lily quartzite line", belong to the Moodies System. They form the uppermost member of the succession and as with all the rocks in the area, have a regional east-west strike and southerly dip.

The thickness of the entire succession mentioned above, decreases from about 9,500 feet in the Consort Mine area to about 3,600 feet near Joe's Luck. . The succession east of here becomes a bit more complicated; the Onverwacht and Fig-tree Series diminish rapidly towards Bar 5 beacon, and the Lily quartzite line becomes complex in that it is split and intruded by numerous bodies of serpentinite, resulting in a very wide outcrop.

The "Lily" quartzites are truncated along the southern portion of the area (just north of the Kaap River) by a major reverse or high angled thrust fault (the Main Southern Fault). The latter has an upthrow to the south and has resulted in the exposure of "lavas", certain shaly and greenschist type of rocks, and impure quartzites with poorly developed conglomerates. The above belong to the Fig-tree Series and Moodies System. In addition, basic talc schists and serpentinites are exposed to the south of the fault.

In the Joe's Luck area, talc schists are brought into contact with the "Lily" quartzites. These are followed upwards in the sequence (i.e. going south), by shales, "lavas", conglomerates and quartzites, forming another regular succession and representing part of the northern limb of the Eureka Syncline.

Going west from Joe's Luck along the southern (upthrow) side of the major fault, are found "lavas", quartzites, and just east of No. 7 Shaft, a narrow zone of arenaceous graywackes and Zwartkopple-type greenschists. Immediately south of the greenschist zone is another exposure of Moodies quartzites and south of the latter, basic schists occur.

To the southwest of the area, in the vicinity of the Woodstock Mine, high angled thrust-faulting, possibly accompanied by basic intrusion, has resulted in the occurrence of a conglomerate and quartzite block of the Moodies System within basic talc schists and serpentinites. The silicified green-schist horizon known as the "Woodstock Bar" represents a major high-angled thrust fault which bounds the quartzite block to the south.

(b) Structure (See Structural Map - Fig. 3)

As can be seen from the map, the only large-scale structures that become apparent after detailed mapping are the major folds and faults in the Consort Mine area. As a result of the interpretation of the minor structural data however, it becomes evident that four distinct phases or acts of deformation have affected the area. Much of the work agrees with Ramsay"s (1963) findings, but as a result of a much longer and more detailed investigation of a small area, the author cannot agree with all of his interpretations.

The structural history of the Consort Mine - Joe's Luck area is thought to be briefly as follows:

(i) Strong folding about axes trending northeast - southwest. These folds were over-folded roughly to the northwest and their original presence is determined partly from the effects that this original folded surface had on younger folds which developed,and partly from evidence outside the area. The northern succession actually represents the northern limb of the Lily Syncline and the succession to the south of the Main Southern Fault, the northern limb of the Eureka Syncline. These folds belong to Ramsay's 1st period of folding.

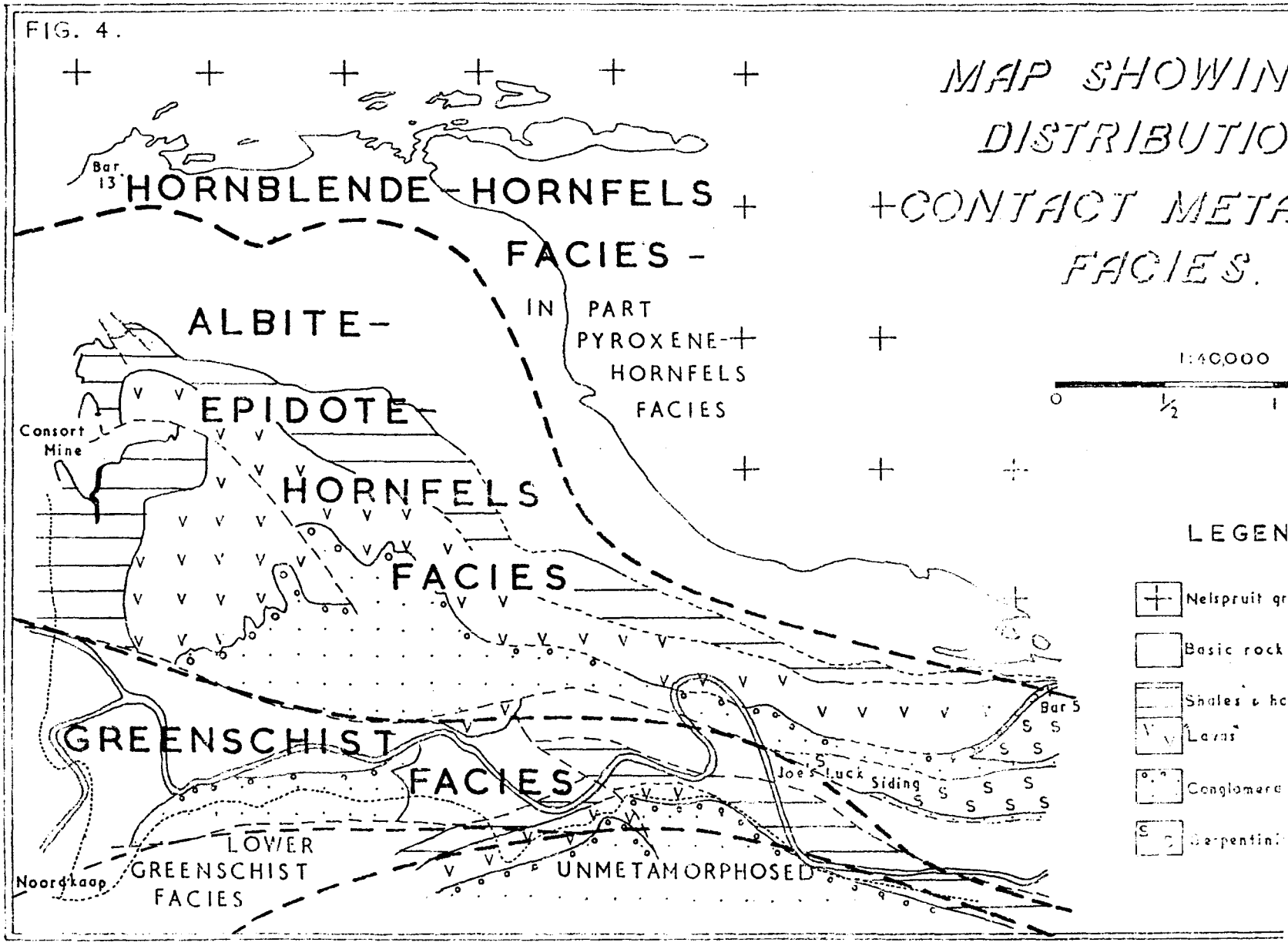
(ii) A strong development of cleavage associated with the intrusion of a mobilized border phase of the gneissic Nelspruit Granite (migmatites). The elongation of clastic particles and the parallel arrangement of prismatic minerals in the metamorphic aureole of the intrusive granite took place at this time. This agrees with Ramsay's findings.

Shortly after cooling there followed a period of cataclasis which was more or less confined to the intrusive granite contact and to the metamorphosed rocks, especially the quartzitic horizons. This mechanical deformation is thought to have been due to the updoming of the gneissic mass of Nelspruit Granite, an event which must have started at the time of intrusion of the granite and ended after it had cooled.

(iii) The final stages of updoming of the gneiss are considered to have caused the major northwest-trending folds in the Consort area, as well as the arcuate form of the Eureka and Ulundi Synclines. This folding represents the 3rd period of deformation.

(iv) Finally the widespread development of minor crenulation and conjugate folds, the latter indicating a vertical stress field, affected the whole area but is only developed in lithologically favourable horizons.

FIG. 4.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Joe's Luck Siding
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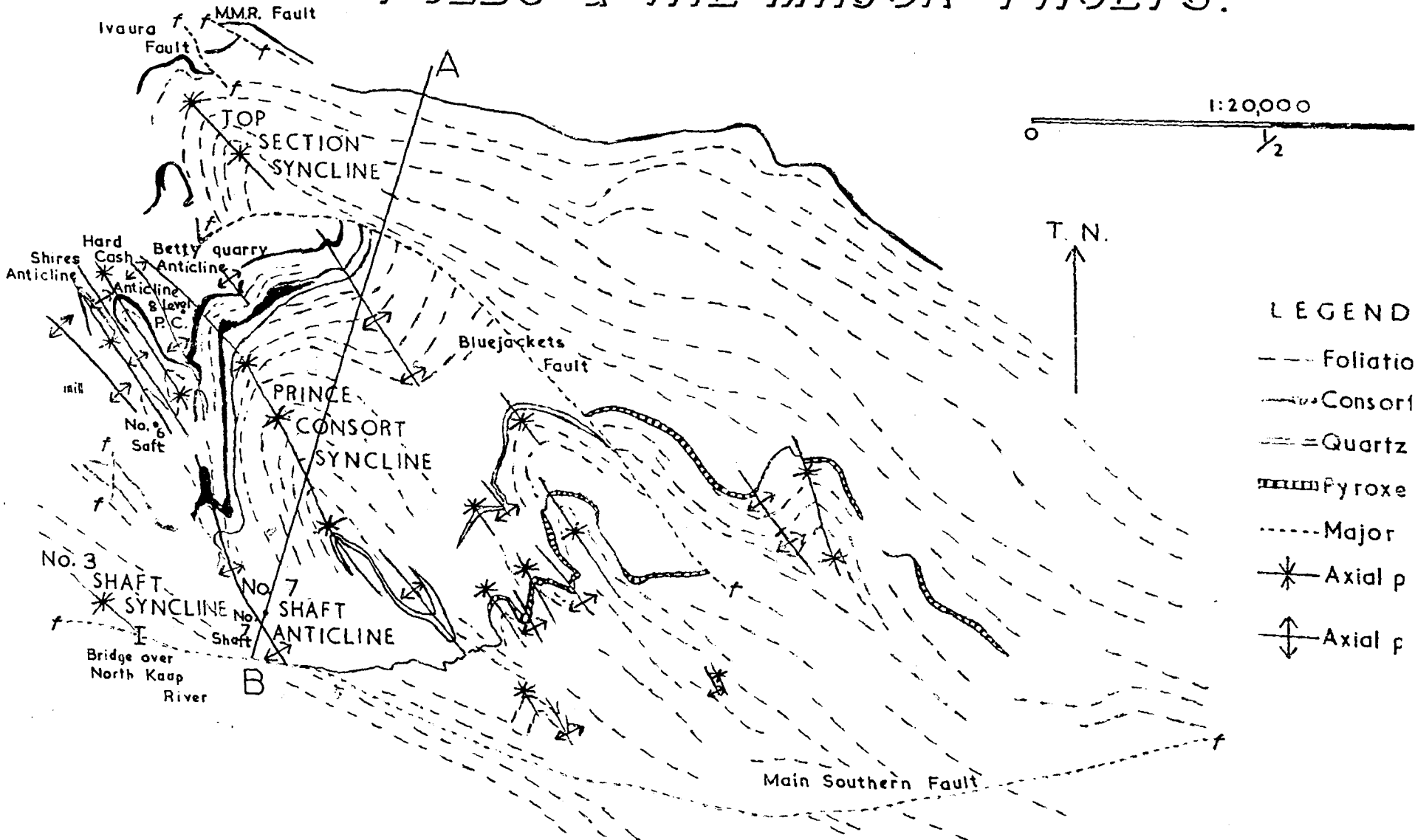
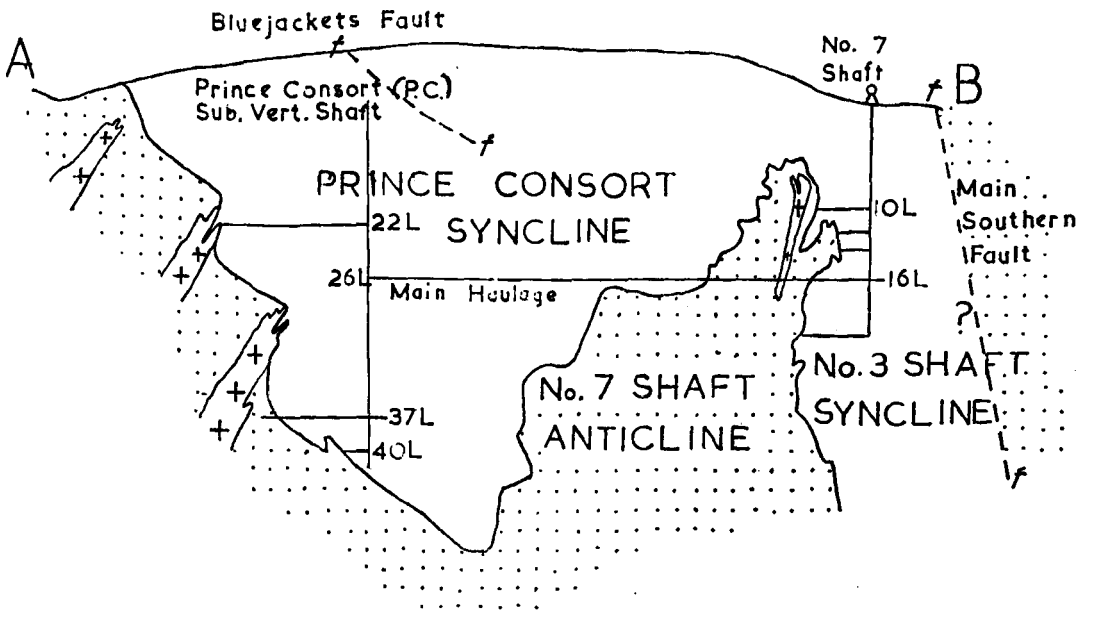
LEGEN
Nelspruit gr
Basic rock
Shales & ha
Lavas
Conglomera
Serpentini

DETAILED STRUCTURAL MAP OF THE CONSORT ARE
SHOWING THE MAIN FOLIATION TRENDS, MAJO
FOLDS & THE MAJOR FAULTS.



SECTION AB OF FIG. 5.



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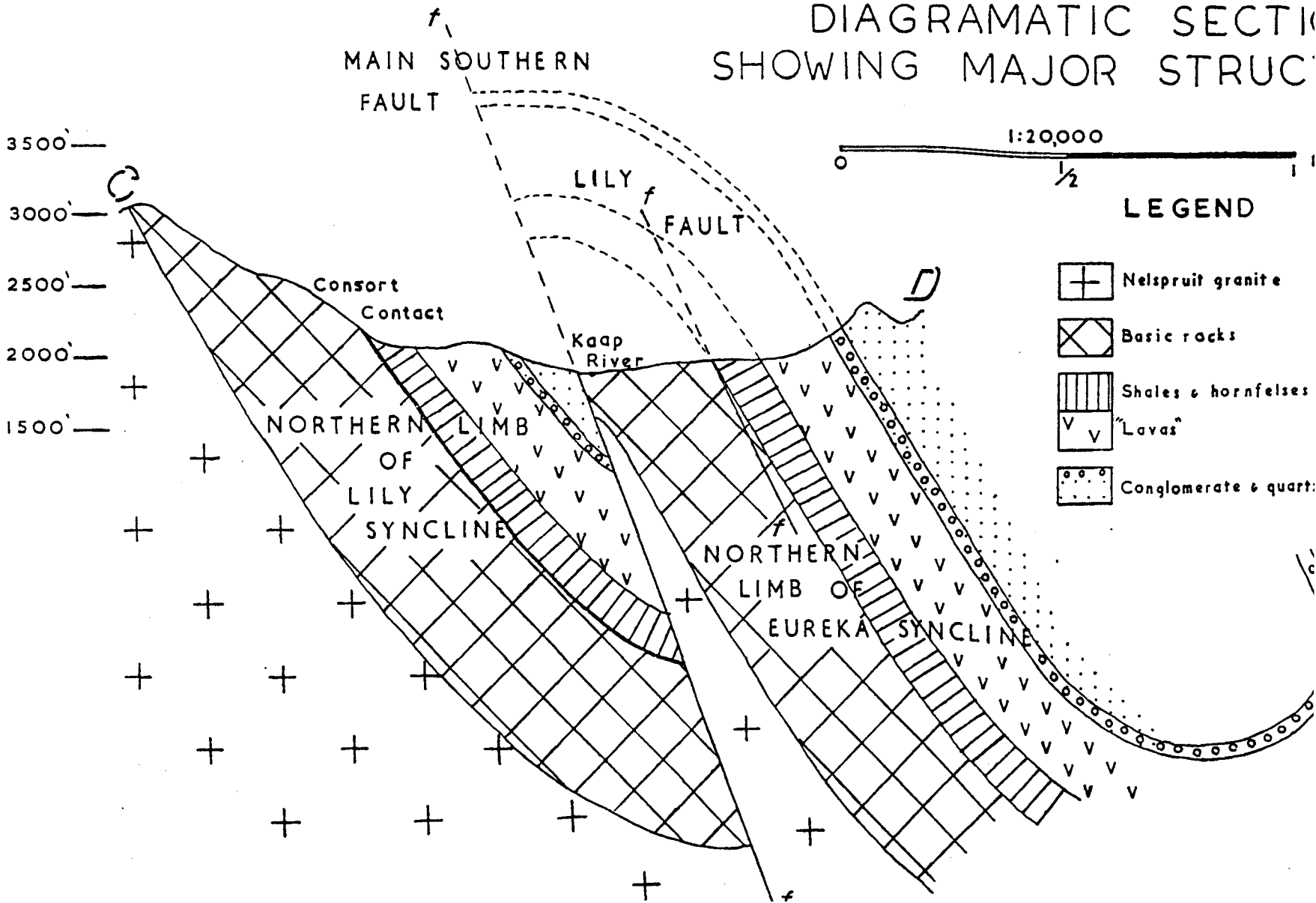
LEGEND

- Shale & "lava" — Fig tree Series
- Basic schists — Onverwacht Series
- Pegmatite bodies

N-S SECTION ALONG 7 SHAFT - P.C. SHAFT HAULAGE SHOWING COMPLEX NATURE OF MAJOR FOLDS. (E.T.C. Mines section).

FIG. 5a.

SECTION C-D OF FIG. 2.



The major high angled thrust faults along the Kaap River are thought to have developed very early in the tectonic history of the area, probably during the 1st phase of deformation. Most of the faults in the Consort Mine area are much younger than this and most likely developed during the 3rd period of deformation. There is strong evidence to suggest that some of the older faults were re-activated, possibly several times, during later periods.

(c) Metamorphism (See Map Showing Distribution of Metamorphic Facies - Fig. 4)

The area can be conveniently divided into three distinct facies of contact metamorphism related to the Nelspruit Granite, and more particularly the mobilized border phase of the latter. These are viz:-

(i) the hornblende-hornfels facies along the immediate contact zone.

(ii) the albite-epidote-hornfels facies covering most of the central part of the area, including the Consort Mine.

(iii) the greenschist facies along the Kaap River and extending as far south as the Woodstock Mine and Noordkaap.

In addition, quite severe dynamic metamorphism has occurred along the granite contact zone due to the possible updoming of the Nelspruit gneiss. Some of the major faults have resulted in a considerable amount of local dynamic metamorphism.

Although no conclusive evidence exists, there is a possibility that the widespread dynamic action along the contact zone may have led to a certain amount of retrograde metamorphism.

(d) Mineralization

Most of the mineralization in the area is confined to the so-called Consort "Contact" and is thought to be related to the mobilized portion of the Nelspruit gneiss. As suggested by Ramsay (1963), it was probably introduced at a late stage during the second period of deformation. The two subsequent periods of deformation, and more particularly the third one, resulted in strong folding of the mineralized zone and caused the complex structure of the Consort ore-bodies. The "Contact" was traced for a distance of 5 miles from the mine to just north of Bar 5 beacon and represents a very distinct zone of potential mineralization.

Another zone of possible mineralization occurs along the extension of the Lily Fault. This zone of chert bars runs roughly past Joe's Luck Siding, along the northern side of the Kaap River, and

appears to join up with the Woodstock Fault.

Lastly, certain shaly horizons within the quartzitic bands of the "footwall schists", often show signs of sulphide mineralization and have been trenched in numerous places.

B. DETAILED DESCRIPTION OF THE AREA

(a) Introduction - Method of Treatment

As mentioned previously, some uncertainty exists as to the origin of certain of the basic rocks in the area and it was therefore considered most suitable for purposes of description and understanding, to group them all together and describe them purely as a number of petrologically different varieties. At the end of each description, suggestions will be put forward as to their possible origin.

As most of the basic rocks with their associated quartzitic horizons, regarded by the author as belonging mainly to the Onverwacht Series, represent the oldest layered rocks in the area, a description of them will be given first. This will be followed by a description of the overlying Consort "Contact", the Fig-tree shales, and then the Fig-tree "lavas". The Moodies System rocks occurring in the area will be dealt with, and finally the Nelspruit Granite will be considered. A mention of dyke rocks, quartz veins and recent deposits will also be made.

More emphasis has been placed on the structures and fabrics of the rocks as seen in the field and as seen on a micro-scale, rather than on a very detailed petrological description. A description of the micro-structures and any fabrics observed will be given in this section, but a discussion of their significance will be reserved for a later section on structure.

(b) Stratigraphic Column (See Table 1)

Generally the succession north of the Main Southern Fault is a very regular and persistent one not made complicated due to faulting and folding except in the Consort Mine area. Here strong folding has resulted in the development of a much broader outcrop thickness of "lavas" and quartzites than is actually the true stratigraphic thickness of these units.

The succession east of Joe's Luck is not considered here as the whole Fig-tree Series thins rapidly in the area approaching Bar 5 beacon and disappears completely a bit further to the east thereof. The overlying Lily conglomerate and quartzite line however, extends for many miles to the east and is in places extensively intruded by ultrabasic bodies (now converted to serpentinites). This is the case in

the area just east of Joe's Luck where the true thickness of the quartzites is greatly exaggerated as a result thereof.

The succession along the Kaap River south of the Main Southern Fault is not considered as it is not known what exact effect the high angled thrust faults have had in this area.

The major succession between the Consort Mine and Joe's Luck Siding is a complete one although most units have been completely obliterated in one or more places due to extensive granite and pegmatite intrusion. This is especially true in the area approaching Joe's Luck.

The rapid "wedging-out" of the rock units towards the east is entirely due to a stratigraphic thinning. It is thought that in the immediate environs of the Consort Mine where all rock units are represented and exceptionally well developed, a fairly deep and well-formed basin of deposition existed. This shallowed gradually towards the east and accounts for the drastic "thinning" of the rock units in that direction.

The following Table gives the approximate maximum and minimum thickness of each unit and of the combined units as a whole.

TABLE I

STRATIGRAPHIC COLUMN OF THE CONSORT MINE - JOE'S LUCK AREA

Predominantly Sedimentary and Volcanic Rocks

Unit	Rock-Types	Thickness in Feet of Rock-Types and Units		Total Thickness
Moodies System	Quartzites	500 - 1,000	500 - 1,100	3,600 - 9,500
	Conglomerate zone	5 - 250		
Fig-tree Series	"Lavas"	500 - 1,600	1,400 - 3,000	
	Shales and graywackes - cherts	500 - 1,600		
Onverwacht Series	Consort "Contact"	0 - 80	1,400 - 6,200	
	Green tremolite schists	1,100 - 4,000		
	Intercalated quartzitic horizons	0 - 400		
	Dark contact - amphibolites	0 - 1,200		
Predominantly Intrusive Rocks				
Partly Basement ?	(Nelspruit granitic suite			
Jamestown ?	(Green and blue serpentinite bodies Dykes			

(c) Basic Rocks (Mainly Belonging to the Onverwacht Series)

The basic rocks in the area can fairly conveniently be divided into five main types, viz:-

(i) black to dark green hornblende-amphibolites.

(ii) green amphibole schists (tremolite-actinolite).

(iii) carbonate-bearing talc and chlorite schists.

(iv) green serpentinites.

(v) blue serpentinites.

Of these, the first three can be classed in the Onverwacht Series, whereas the massive serpentinites are generally considered to be intrusive and are classed in the Jamestown Series. The basic rocks can usually be ascribed to one of these five groups according to the predominant mineral or minerals, but it should be stressed here that this classification is not rigid and in many places there is a gradation between two or more of the above types.

In general there is a fairly regular distribution of these various rock-types with respect to the Nelspruit Granite. The dark-coloured hornblende amphibolites are confined to the immediate vicinity of the granite contact and almost all the xenoliths occurring in the granite are of this type. Moving away from the contact, rocks consisting mainly of tremolite-actinolite become the dominant types and they usually form the so-called "footwall" rocks of the Consort Mine area. These rocks frequently grade into nearly pure, green serpentinites. The carbonate-bearing chlorite and talc schists occur furthest away from the granite and are best developed along the Kaap River. Serpentinites, of which the green variety predominates, occur in a number of places throughout the area, but there is no apparent regular distribution of these bodies with respect to the granite contact.

The above spacial relationship of the various basic rocks to the granite, appears to be almost identical at a number of places right around the Mountain Land. Along the northern contact from the Consort Mine to Louw's Creek (a distance of 15 miles) this relationship has been found by C. Anhaeusser and the author, to hold. In the southeast part of the Mountain Land near Forbes Reef, Pretorius (1948) describes hornblende, tremolite and chlorite schists in the vicinity of the granite contact with talc groups becoming more and more dominant away from it.

Urie (1959), working in the Bomvu Ridge area of northwest Swaziland, also found a decided relationship between degree of alteration within basic rocks classed as Jamestown, and relative distance from the granite contact. The mineral assemblages from the granite contact to lower temperature areas are given by him as follows:-

(i) tremolite with cores of olivine - also chlorite.

(ii) tremolite and chlorite, with olivine cores altered to antigorite - talc begins to appear.

(iii) tremolite partially altered to talc.

(iv) talc and flakes of chlorite.

(v) finally talc carbonate schists.

Urie also mentions the occurrence of quartz-hornblende or biotite, or quartz-actinolite-zoisite assemblages, very near to the contact. Occasional anomalies are noted in the above general sequence but they are generally only of minor extent.

The mineral assemblages of Urie mentioned above indicate a lower temperature association closer to the granite contact than is the case in the Consort area. However, the assemblages occurring at progressively decreasing temperatures, bear a marked resemblance to those occurring in progressively lower temperature zones in the Consort area.

A characteristic feature of these basic schists is the presence of numerous fairly continuous and apparently intercalated quartzitic horizons, which will be discussed later. They are more or less confined to the tremolite schists and green serpentinites in the area north of the Consort Mine and were never observed in the talc-carbonate schists along the Kaap River.

The serpentinite bodies, although in most cases intimately associated with the basic suite lying below the Fig-tree Series, are also found as more or less conformably intrusive bodies within the Moodies System. They may either represent true, post-Moodies magmatic intrusions, or else tectonic intrusions which were "squeezed" into higher levels during deformation of the Mountain Land. In the latter case they would represent more or less "cold" intrusions derived possibly from the basic pre-Fig-tree suite.

(i) Black, Contact-type Amphibolites

1. Field Occurrence and Description

The Nelspruit Granite is intrusive along the contact into rocks that have a highly distinctive appearance almost right the way from the Consort Mine to Louw's Creek. They attain their best development north of the mine and in this area are often separated from the northernmost quartzite horizon by a green serpentinite layer. In about the centre of the area, a tongue of black amphibolite with hundreds of associated xenoliths, runs out into the granite. Other occurrences have been recorded (van Eeden - 1941) from deep within the granite. The greatest thickness of a belt consisting predominantly

of dark amphibolites is about 700 feet, but it is often much less. The maximum thickness of the whole belt of amphibolitic rocks, defined by the last located xenoliths in the granite to the north, is about 2,000 feet. In the field there is more or less a gradation from a zone consisting predominantly of amphibolite (with numerous intrusive pegmatitic, granitic, aplitic and quartz veins) to a zone close to the main granite mass consisting predominantly of granitic rocks with many amphibolite xenoliths. In almost all cases there is found to be a sharp contact between intrusive granite and black amphibolite (see Plates 1 and 28).

In appearance these rocks are very dark, and in many places they are black in colour. In other areas they have a mottled black appearance with numerous white flecks, or else the colour is dark green. They frequently show a mineralogical banding (see Plate 1) with bands of nearly pure amphibole and other bands with about half amphibole and half quartz and felspar.

Microscopically the rock is seen to consist predominantly of green pleochroic hornblende together with plagioclase, the latter being close in composition to andesine. In certain areas fair amounts of quartz may be present. Locally the rock is composed essentially of hornblende to the near exclusion of felsic constituents. Diopside, occurring quite abundantly in some areas close to the granite contact, was also noted, in addition to garnets in a few localised areas, and minor amounts of biotite.

2. Structure

The well developed banding or foliation invariably runs parallel to the granite contact and dips at intermediate to steep angles to the south. The orientation of the xenoliths is usually elongated parallel to the contact and the strike of foliation within the xenoliths is parallel to it. In numerous places, small-scale, strong isoclinal folding is developed with axes striking roughly east-west, i.e. parallel to the contact, and with axial planes generally coincident with the banding , i.e. dipping at intermediate to steep angles to the south. The plunge of the fold axes,although impossible to measure in most places, appears to be nearly horizontal. The folds are developed on a rather small scale and the amplitudes hardly ever exceed 9 inches.

Often there is a very distinct orientation of hornblende crystals with the long or c axes aligned parallel or sub-parallel to give a lineation which on close inspection is seen to be parallel or nearly parallel to the minor fold axes. This lineation is not always apparent in outcrop and is very difficult to measure, being on a micro rather than on a megascopic scale. Generally it appears to be nearly horizontal and to lie parallel to the contact.



PLATE 1 . Sharp contacts between intrusive granite and dark contact-type amphibolites. Note well developed banding in amphibolites. North of Consort Mine

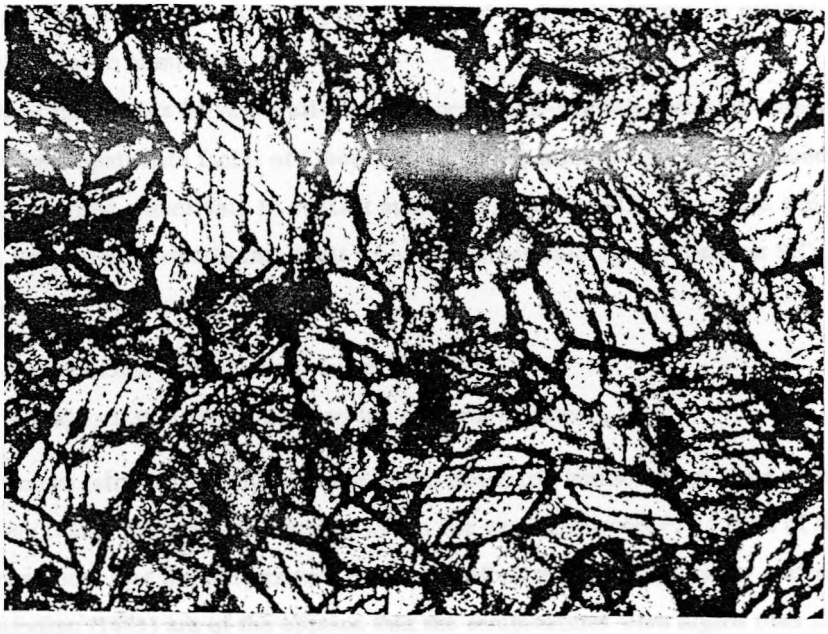


PLATE 2 : Basal sections of hornblende revealed in an "ac" section of a fold. Dark hornblende-rock from close to granite contact. North of Consort Mine. (Crossed nicols x 75).

Under the microscope it becomes clear that this mineral alignment is very nearly coincidental with the axes of the minor folds mentioned above. An "ac" section through a fold reveals almost exclusively basal sections of hornblende (see Plate 2), whereas "ab" and "bc" sections almost all reveal prismatic sections (see Plate 3). (The directions a b and c used here refer to fabric axes). From the foregoing considerations it is clear that the mineral elongation approximates more closely to a "b" rather than to an "a" lineation (b defining the fold axis).

In connection with this mineral orientation it is interesting that Mehliss (1961), describes a rude alignment of hornblende crystals in dark amphibolites close to the granite contact in the Hlatikulu - Mankaiana district of Swaziland. This is apparently of an identical nature to the alignment described above.

3. Grade of Metamorphism

These rocks have undergone metamorphism and correspond rather well to Harker's term amphibolite i.e. schistose hornblende-plagioclase rocks (Harker - 1956). According to the latter author, in the higher grades of metamorphism, hornblende may be replaced to a greater or lesser degree by diopside in bands which were presumably richer in lime. This appears to be the case in a number of places where a considerable amount of diopside, confined to definite layers, is present, together with layers much richer in hornblende.

The majority of these rocks fit very well into the hornblende-hornfels facies of Turner and Verhoogen (1960), or into the amphibolite facies of Eskola (1921). Such assemblages are described by Turner and Verhoogen as occurring extensively in contact aureoles and as xenoliths in granite and granodiorite. The mineral assemblage fits almost perfectly into their scheme of an assemblage with excess SiO_2 and of a basic nature. Such assemblages consist of:-

- plagioclase-hornblende (-quartz-biotite).
- plagioclase-hornblende-diopside (-quartz-biotite).

Sillimanite occurs fairly abundantly in some of the quartzitic horizons very close to the contact and according to Ramberg (1952), this mineral is stable within the very uppermost P.T. field of the amphibolite facies. He concludes that the temperature of the amphibolite facies only rarely exceeds 400 - 500°C. Turner and Verhoogen (1951) are of the opinion that the temperatures were higher than this and correlate the hornblende-hornfels facies with temperatures of about 550 - 700°C in the water vapour pressure range of 1,000 - 3,000 bars.

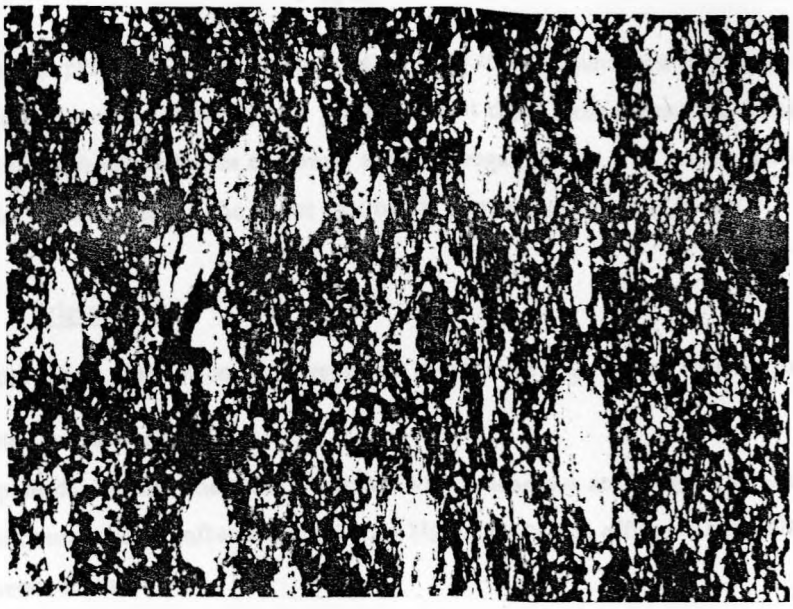


PLATE 3 : Prismatic sections of tremolite revealed in an "ab" section of a fold. Quartz-tremolite schist north of Consort Mine. (Crossed nicols x 75).



PLATE 4 : Radiating tremolite needles. Tremolite schist - Consort Mine. (Crossed nicols x 75).

Thus, although pyroxene and sillimanite occur, and in fair abundance in certain places, here is always a substantial amount of hornblende present so that these rocks cannot be classed in the higher temperature pyroxene-hornfels facies of Turner and Verhoogen (1961). As stated above, the mineral assemblage best classes them in the upper part of the hornblende-hornfels facies.

4. Origin

Rocks of the above description could represent products of high grade metamorphism of either:-

(i) basic igneous rocks.

(ii) impure dolomitic limestones, together with calcareous and magnesian shales.

(iii) sedimentary rocks influenced by FeO - MgO - CaO-rich effluents from ultrabasic igneous rocks.

It is the author's contention that they represent the metamorphic products of some type of impure dolomitic sediments. Firstly, the very marked mineralogical banding so often observed, is considered to be indicative of a sedimentary rather than an igneous origin. Secondly, the close association of these rocks with quartzitic horizons of undoubted sedimentary origin (see later) support this view.

The amphibolites however, are unlike any of the typically metamorphosed Fig-tree Series and Moodies System rocks which are well exposed in the Consort Mine area. The original composition of these sediments must, therefore, have been very different from the latter two groups. van Eeden (1941) suggests that they might represent altered Moodies shales, but as shown above, the basic nature of these rocks definitely precludes such a possibility. Furthermore, they occur at the base of a stratigraphic succession which lies conformably below Fig-tree shales and graywackes, so that from a structural point of view, the likelihood of these representing altered Moodies or Fig-tree shales is indeed very remote.

Dolomitic rocks of the type from which such amphibolites could easily have been derived, exist below the Fig-tree Series in many other parts of the Mountain Land. These have been classed by Gribnitz (1961), as belonging to a proposed Oorschot Series and it is suggested by the author that the amphibolites might well represent the strongly metamorphosed equivalents of such rocks. However, the establishment of a separate series is not deemed necessary and these rocks are regarded as representing part of a metamorphosed sedimentary suite within the Onverwacht Series.

(ii) Green, Tremolite-Actinolite Schists

1. Field Occurrence and Description

Most of the rocks lying between the dark, contact-type amphibolites and the Consort "Contact", can be classed in this group. They constitute the largest mass of basic rocks occurring in the area and vary in colour from light green to dark green, but never black as in the case of the contact amphibolites.

There is commonly a fairly extensive zone of serpentinite separating these schists from the contact amphibolites. The tremolite-actinolite schists themselves are very prone to alteration to antigorite and anywhere within this zone there might be local development of serpentinite bodies. It is in this zone that the majority of quartzitic horizons (to be discussed later) occur.

Underground work (Hearn, 1943), has shown that towards the "hanging wall" contact, thin shaly lenses of a few inches to a few feet in thickness become fairly numerous in the basic schists and in places make the contact a gradational one. Generally though, the "schist-shale" contact is a sharp one.

The dominant rock type consists almost entirely of a mass of greenish needles easily distinguishable in hand specimens. They usually occur in radiating groups forming a felted mass (see Plate 4), but occur sometimes orientated in all azimuths in parallel planes.

These needles consist mainly of slightly pleochroic tremolite or actinolite which commonly constitute the whole rock. Occasionally cummingtonite occurs but it is generally of rather limited distribution. As mentioned, these rocks frequently grade to serpentinites so that antigorite is a fairly dominant mineral in some specimens (see Plate 5). The development of these serpentinite bodies within the tremolite schist zone seems to be at random, although areas of almost pure serpentinite generally tend to occur as lensoid bodies parallel to the general schist foliation. It is impossible to say with certainty whether the tremolite is altering to antigorite or vice versa, but from a general consideration the author is inclined to the former view.

In the northern part of the Ivaura Section of the Mine and at some localities underground, occurs a peculiar banded rock consisting of bands of actinolite and bands of almost pure pyroxene with an altered, brownish, pleochroic mineral (probably biotite) associated with the former. Some zoisite and green chlorite is also present. The occurrence of much diopside in a restricted area close to silicified and mineralized zones of the "Contact" type, is thought possibly to be the result of the higher temperature associated with the mineralizing fluids acting on original lime-rich bands in the vicinity. However, it might also represent a new gangue mineral formed in the zone of wall rock alteration associated with the mineralization.

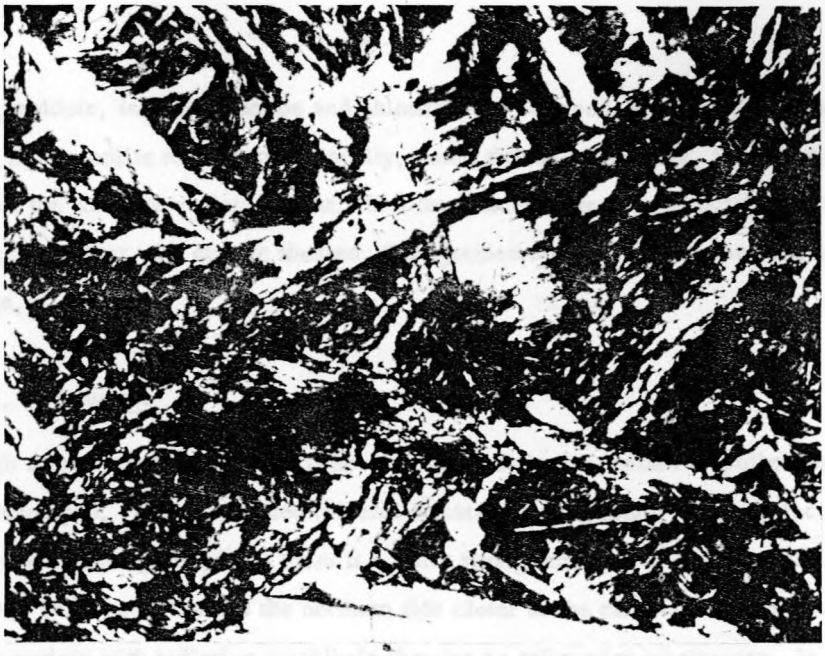


PLATE 5 : Rock composed of about equal amounts of tremolite (white) and antigorite (grey and black). Difficult to say whether antigorite is replacing tremolite or vice-versa. North of Consort Mine. (Crossed nicols x 75).

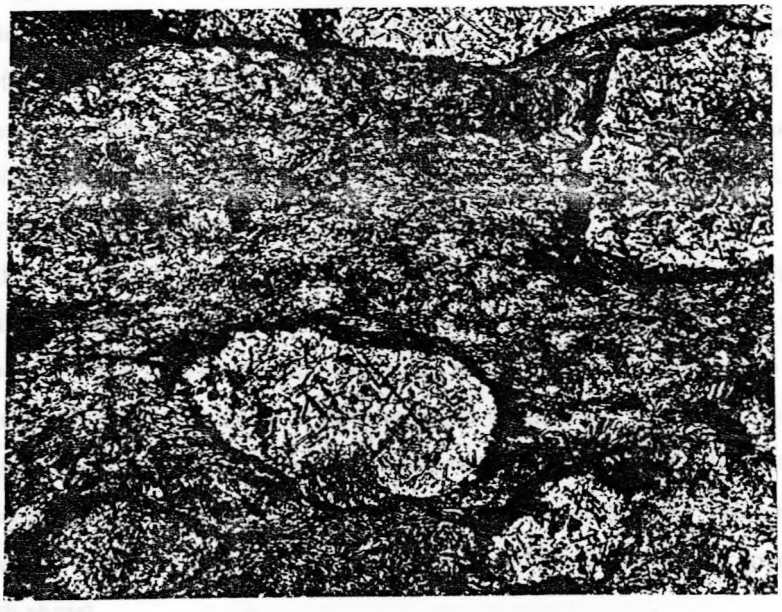


PLATE 6 : Large patches of calcite in a fine-grained matrix of small talc laths. Talc-carbonate schist exposed in railway cutting near Joe's Luck Siding. (Crossed nicols x 75).

Zoisite, epidote, soda-plagioclase and chlorite were observed, developed to a greater or lesser degree within the tremolite schist zone. Locally, zones rich in large, dark, idiomorphic tourmaline crystals of the schortite variety, occur. In a few places there is an association of tremolite and fine-grained talc, together with certain sheared, fine-grained zones of talc and sericite with minor amounts of tremolite.

2. Structure

Although a mineralogical banding is not as distinct as in the contact amphibolites, there is often a schistosity developed. The pronounced mineral orientation so common in the contact rocks is generally not as apparent although in places there is a fairly strong tendency towards parallelism of mineral constituents. This occurs towards the northern side closer to the contact. Mostly the rock is a massive, crystalline variety with radiating amphibole showing no orientation whatsoever. In a number of localities an arrangement of amphibole needles, and in places tourmaline crystals, at all azimuths in planes which define a very strong foliation, is very marked.

More often a fairly strong foliation can be observed which appears to be mainly due to the effects of a later cleavage and/or shearing (see later). Boudinage structures lying in the planes of foliation, were sometimes observed and these indicate a strong deformative stress. The development of sericite together with fine-grained talc in places, is interpreted as being partly the result of intense shearing of a felspar-bearing basic rock. Finally, in numerous localities, but not everywhere, tremo lite needles were seen to be folded and bent and definitely deformed. This indicates a post metamorphic deformation, probably related to the 3rd phase of deformation.

These rocks are noticably devoid of minor structures and it is only in a few small areas and in particularly favourable rocks, viz. fine-grained tremolite, talc and sericite schists, that minor folds are developed. These folds where best developed, occur as a set of small crenulations with fold axes generally striking about east-west and plunging at shallow angles to the west, and with almost horizontal axial planes. More often they are only developed on a micro-scale in which case only a set of very fine lineations, representing numerous minor fold axes, can be seen in hand specimens. These minor folds deform the earlier developed foliation planes and represent the manifestation of a later (younger) phase of deformation (the 4th phase).

3. Grade of Metamorphism

The mineral assemblage noted above, appears to be typical of the albite-epidote-hornfels facies of Turner and Verhoogen (1960), or the epidote-amphibolite facies of Ramberg (1952). The mineral assemblage in this facies, as noted by Turner and Verhoogen, has much in common with those of the greenschist facies so characteristic of low grade regional metamorphism. Ramberg (1952), points out that "many green schists themselves, do not belong to the green schist facies proper, in which they are too often placed; but such rocks may develop on apparent green schist mineral association because of their particular bulk chemical composition".

Precisely the above has happened in the case of the green actinolite-tremolite schists described in this section. Mineral assemblages are encountered which are identical to quite a number of typical true greenschist assemblages of low grade metamorphism as listed by Turner and Verhoogen (1960). The presence however, of abundant higher temperature grossular garnet and andalusite in the metamorphosed argillaceous Fig-tree sediments which overlie the tremolite-actinolite schists (and are even further away from the granite contact than the latter), indicate the proper place in the facies scheme of these "camouflaged" rocks.

There must have been a considerable amount of movement along the Consort "Contact", and although there are no direct indications of large scale displacement, the possibility cannot be ruled out that the metamorphic assemblage (higher than greenschist) of the Consort area, was moved into its present position by faulting. This would mean that the Fig-tree and Moodies rocks were brought from higher temperature zones lower down into juxtaposition with a lower grade greenschist assemblage to the north.

The author does not favour the latter idea, as there is no sign of large-scale displacement, and it is concluded that the green tremolite-actinolite schists belong mainly to the upper part of the albite-epidote-hornbels facies and perhaps in part to the higher grade hornfels facies. Due to the "camouflage" effect referred to above, it is impossible to be more specific about the classification.

The pressure-temperature conditions for this facies are shown to be approximately P H_2O = 1,000 bars and 400°C, although at temperatures as low as 200 - 250° tremolite can form (Bowen in Barth, 1952).

4. Origin

As will be mentioned later, remnants of fairly large olivine and pyroxene crystals have been found in serpentinite bodies within this green schist zone. This is interpreted as indicating the existence of at least some ultrabasic intrusive material, now represented by the more massive serpentinite occurrences. These are different from the zones and patches of partly serpentinized tremolite schists which are always

strongly foliated and often banded.

The majority of the green tremolite-actinolite schists are considered to represent the slightly less metamorphosed equivalent of the black contact - amphibolites, and in a number of places a gradation between these two is evident. The strong foliation, banding, and the close association of these basic schists with quartzitic horizons, which, as will be shown later, are fairly definitely of a sedimentary origin, seems to indicate that as with the contact amphibolites, these green schists are also mainly of sedimentary origin.

The possibility cannot be excluded however, that at least some of these rocks represent basic lavas and that some of the associated quartzitic horizons represent acid lavas. This seems to apply especially to certain of the less well banded and more massive basic schists and also to the sericite-rich quartzitic horizons. While conceeding that the above might be the case in certain instances, the author is more inclined to the view that, as with the contact amphibolites, these rocks are for the most part derived from original sedimentary rocks which must have been close in composition to siliceous magnesian limestones. They are classed in the Onverwacht Series.

(iii) Carbonate-bearing Talc and Chlorite Schists and Phyllites

1. Field Occurrence and Description

Although most of the green tremolite schists described above may be partly talcified, this is not very common in the area to the north of the mine. Talc-carbonate and some chlorite schists are classically developed south of the Lily quartzite line along the Kaap River.

The occurrence of these basic rocks, apparently lying above the Moodies quartzites and then again below the Fig-tree shales (which form part of the northern limb of the Eureka Syncline), is ascribed to faulting, possibly accompanied by the intrusion of basic or ultrabasic rocks.

On fresh outcrop the talc-carbonate schists have a distinctive greenish-grey colour, but where weathered may have a dirty pinkish brown colour. Locally, patches of very pure, light-green talc are found, and in some places secondary magnesite veins may be present.

A typical talc-carbonate schist consists of numerous amygdale-like patches varying in size from about 0.25 mm. to nearly 0.50 inch. These patches consist of either a pure white carbonate, probably calcite, or sometimes a pinkish to brownish carbonate which is possibly siderite. The groundmass consists predominantly of fine-grained talc laths, sometimes well orientated (see Plate 6). Varying amounts of fine-grained chlorite occur, together with quartz grains and a few grains of felspar. On weathering of the carbonate patches, the rock develops a very characteristic "pocked" surface consisting

of numerous hollows, either clean, or partially filled with a limonitic material. In addition to a small amount of talc and carbonate material, chlorite may also be present as a major constituent. In some areas the chlorite occurs as very long, individual crystals, arranged in a sub-parallel fashion and giving a marked lineation. East of Joe's Luck, bodies of tremolite-bearing schists appear close to, and partly within talc-carbonate schists. Euhedral pyrite crystals, usually partly altered to limonite, were also found in these talc schists and often have well developed pressure shadows of secondary quartz or calcite.

In the area immediately south of the Woodstock "Bar", occurs a zone of poorly exposed talcose and dolomitic rocks and in the underground workings of the Woodstock Mine, distinct varieties of dolomite with talcose rocks have been mapped (unpublished E.T.C. Mines report). In the Clutha Mine area to the south of this, and lying just out of the region mapped, dolomitic rocks were first noted by Hall (1918). Subsequent detailed mapping in this area by R. Cooke (unpublished map, E.T.C. Mines), showed the existence of quite an extensive zone consisting of different varieties of dolomitic rocks.

2. Structure

These schists or phyllites are usually very strongly sheared or cleaved and in the Noordkaap area are very strongly lineated. This lineation usually plunges to the north at very steep angles and in places can definitely be ascribed to a mineral elongation. For example, in chlorite schists near Noordkaap, a very marked sub-parallel arrangement of extremely elongate chlorite crystals gives a steeply plunging lineation (see Plate 7). In other localities this lineation occurs as faint markings of slightly different colour in fine-grained talc schists,and it is difficult to ascribe this feature to mineral elongation with certainty.

The lineations have been deformed in many places by a set of minute crenulation folds with near horizontal axial planes and fold axes, the latter striking generally east-west (see Plate 8). In many areas around Noordkaap the folds are extremely well developed and stand out as hundreds of small corrugations (see Plate 9). However, they are often only developed on a micro-scale and appear then in hand specimen as a series of minute "crinkles" or very narrow parallel lines that pervade the whole rock and which are scarcely perceptible to the naked eye (see Plate 7).

The above features, although occasionally discernable elsewhere in talc schists along the Kaap River, undoubtedly attain their best development in the Noordkaap area.

3. Grade of Metamorphism

The mineral assemblage described above,fits best into the greenschist facies first introduced by Eskola (1921), and characteristic of chlorite-rich green stones or green schists resulting from the lowest

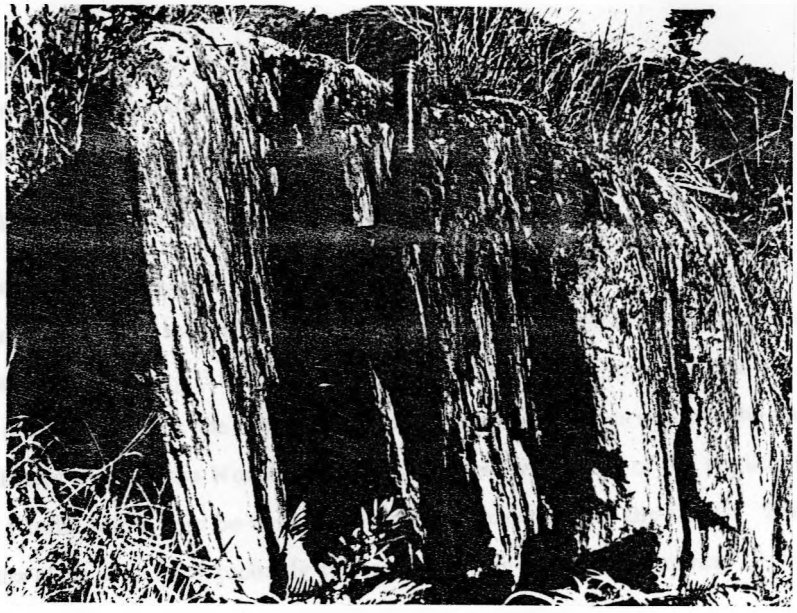


PLATE 7 : Steeply plunging mineral lineation together with a strong cleavage. Whole outcrop pervaded by a set of minute "crinckles" only discernable on close inspection. Talc-chlorite phyllites - Noordkaap.



PLATE 8 : Steeply plunging lineations deformed by extremely well developed crenulation folds with near horizontal fold axes and axial planes. Talc-chlorite phyllites in railway cutting northeast of Noordkaap.

grade of regional metamorphism.

The following reaction according to Ramberg (1952), is one of the critical ones as far as the establishment of the uppermost border of the greenschist facies goes:-

calcite + chlorite + silica ⇌ actinolite + epidote + water + carbon dioxide.

Turner and Verhoogen (1960) however, allow actinolite into the upper part of their greenschist facies and their definition covers a somewhat higher grade than that of Eskola's original greenschist facies and the greenschist facies of Ramberg (1952), (see above reaction). The tremolite-bearing rocks just east of Joe's Luck belong most probably to the upper part of the greenschist facies whereas the dolomitic and talcose rocks immediately south of the Woodstock Mine, together with some of the slightly talcose dolomitic rocks near Clutha Mine, can be classed in the very lowest part of the facies. The majority of the rocks in the Clutha Mine area have probably suffered none, or at the most, a very slight amount of thermal metamorphism.

4. Origin

Tilley (1948) has discussed the earlier stages in the metamorphism of siliceous dolomites and finds a definite sequence. This sequence, when compared to the actual sequence occurring in the area discussed above, is found to be almost identical.

He regards talc as being the first new-formed phase and he ascribes its formation to a reaction between dolomite and quartz. This first formed talc zone is divided into two sub-zones of which the association of talc with fine granular calcite is very similar to the main assemblage along the Kaap River (see Plate 6). His outer or lower grade zone consisting of subordinate talc associated with calcite and dolomite, is very similar to the mineral assemblage occurring immediately south of the Woodstock "Bar", and partly similar to the assemblage mapped in the Clutha Mine area. In the latter area, the main rock types are dolomitic with generally only a subordinate amount of talc, and are considered by the author to be rather similar to the parent rock from which many of the basic schists described previously, could well have been derived.

The occurrence of tremolite in certain areas just east of Joe's Luck is of interest. It probably represents a higher grade of metamorphism, but still within the greenschist facies. This tremolite is in immediate contact with well developed chert horizons of the Fig-tree Series, and might be of a similar nature to the tremolite development described by Tilley (1948). He found that at more advanced stages of metamorphism of siliceous dolomites, still within the greenschist facies however, and nearly always in close proximity to chert horizons, tremolite is invariably developed. This tremolite is fringed towards

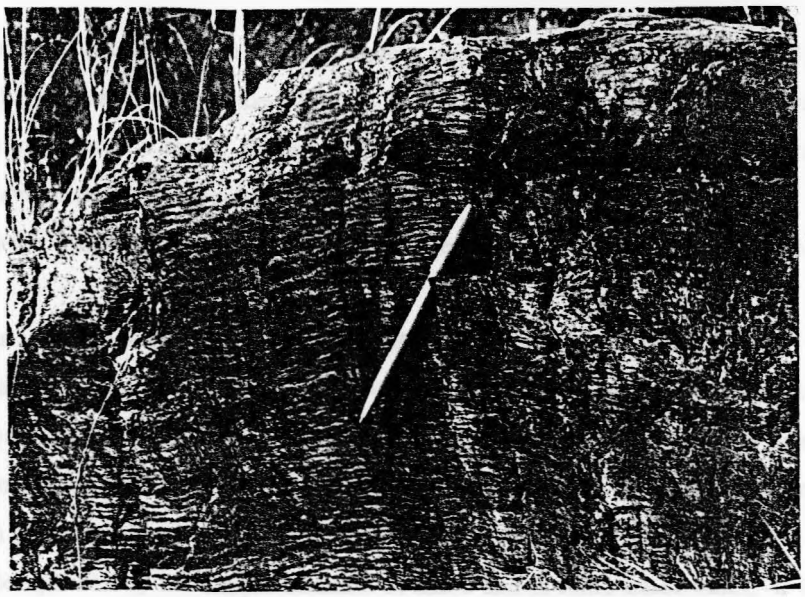


PLATE 9 : Very well developed crenulation folds with near horizontal fold axes and axial planes. Talc-chlorite phyllite - Noordkaap.

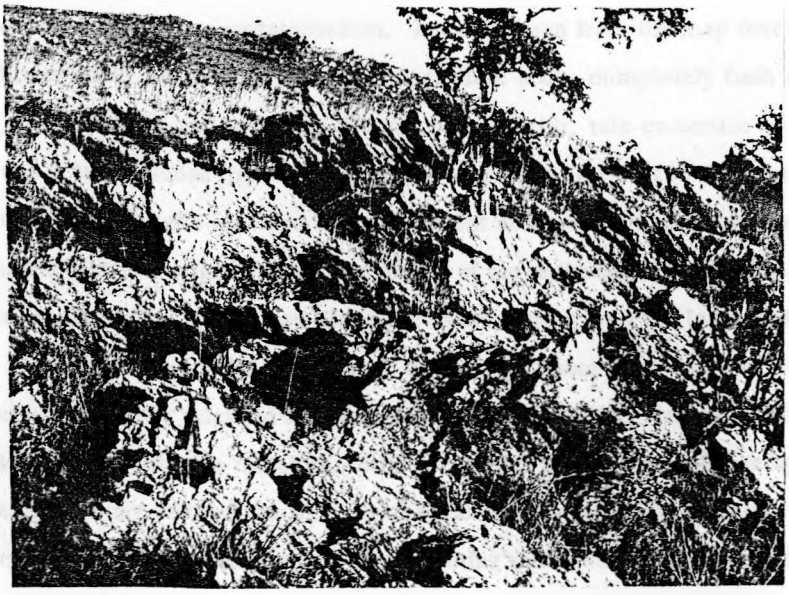


PLATE 10 : Rough outcrop of resistant, massive, green serpentinite. Near Bar 5 beacon - north of Consort Mine.

the dolomite "parent rock" by a talc zone in which incipient tremolite needles are to be found.

From the above considerations, the author is inclined to the view that these rocks originated from the metamorphism of dolomitic rocks, siliceous in part, and containing considerable amounts of impurities in places as evidenced by the occurrence of fairly well developed zones of chlorite. As shown by Tilley (1948), the latter mineral does not occur at any stage in the metamorphism of a pure siliceous dolomite.

These rocks are considered to constitute part of the Onverwacht Series.

It should be pointed out here that carbonate-bearing rocks of an identical composition to those described above,can also be derived from original ultrabasic bodies which have been submitted to carbon-dioxide metasomatism, (Turner and Verhoogen, 1960). According to them, steatization, or the hydrothermal alteration of an ultrabasic body leading to a talcose end product, (Hess in Turner and Verhoogen) may be accomplished by the simple addition of silica and in some cases water, to serpentinized peridotites. Further, if carbon dioxide metasomatism is involved (which is considered to be more commonly the case), then dolomite or magnesite may appear as constituent phases of the end product.

Steatization is considered to be a hydrothermal process connected with intrusion of granite magma and it could be argued that there was in the Nelspruit Granite, a ready source for such solutions. However,it would also be expected that such lime-bearing hydrothermal solutions should have affected all serpentinite bodies in the zone subjected to metasomatism. It can be seen from the map that in the area to the south of the Woodstock Mine, occurs a fairly large serpentinite body, completely fresh and with no signs of talcification, surrounded by,and evidently in sharp contact with, talc carbonate and dolomitic rocks. From this it is concluded that carbon-dioxide metasomatism played little part in the development of the carbonate rocks in the area and that the present abundance of carbonate material is for the large part inherited from the original dolomitic nature of the sediments. The serpentinite body referred to above is considered to represent an ultrabasic rock intrusive into the latter sediments. It should be mentioned, that in the area to the northwest of Noordkaap, there is an apparent gradation from a talc-carbonate schist to a partly talcified serpentinite, and the possibility cannot be ruled out that this represents a case of carbon-dioxide metasomatism. However, this is in a higher temperature zone than the fresh serpentinite body south of the Woodstock Mine and the carbonate material is thought to have been derived largely from the surrounding carbonate-bearing rocks rather than from a hydrothermal source.

(iv) Green Serpentinites

1. Field Occurrence and Description

The green variety is by far the most widespread type of serpentinite occurring in the area. In many cases as mentioned previously, serpentinite bodies grade into the well foliated tremolite schists. Although no proof exists, the author is inclined to the view that these serpentinites have formed in most cases from the partial or complete alteration of the tremolite schists. The much more massive bodies of pure antigorite are considered to represent altered ultrabasic intrusives.

The zones of alteration or serpentinization within the tremolite schists, occur generally as lensoid patches, apparently randomly distributed within the belt of schists and showing all gradations between areas of nearly pure amphibole and areas of antigorite (see Plate 5). Just to the north of the Consort Mine, nearly pure serpentinite bodies invariably stand out as more resistant masses within the schists.

The massive serpentinite bodies, in which asbestos veinlets are often noticeable, reach their optimum development in the northern part of the area in a strip, usually a few hundred yards in width, lying between the contact-type amphibolites and the tremolite-actinolite schists. Within talc schists near Noordkaap, occurs an apparently slightly talcified variety and just south of the Woodstock Mine is a large outcrop of fresh serpentinite which closely resembles those occurring near to the granite contact. In the area immediately south of Bar 5 beacon, extensive bodies of green serpentinite occur between bands and rafts of quartzite of the Lily Line. These bodies peter out towards the east as the quartzitic horizons coalesce to form the main Lily Ridge.

On slightly weathered surfaces the colour is brown, but fresh specimens range in colour from fairly dark-green to olive-green to a peculiar lemon-coloured variety with mica flakes in it. Microscopically the serpentinite as typically developed, consists of a fibrous mass of antigorite and serpentine, usually with a few irregular magnetite grains. Palimpsest olivine and pyroxene forms are sometimes seen, consisting of numerous moderately birefringent remnants all with identical optical orientation (if part of the same original crystal), and set in a groundmass of low birefringent antigorite. No completely fresh olivine or pyroxene was encountered. A fairly frequently noted mineral, occurring usually in areas of close proximity to pegmatite bodies, is muscovite, and sometimes fuchsite or chrome muscovite. It seems as though much of this mica may have been formed by a pneumatolytic process accompanying the intrusion of these bodies.

In numerous places close to the contact, veins of cross fibre chrysotile asbestos occur. A notable feature of these occurrences is that they always seem to be very close to, or right next to intruded pegmatite bodies. In one place the asbestos reaches exceptional quality with fibres over an inch in length and with a very high tensile strength. The asbestos however, occurs as a few very small,

impersistent, lenticular bodies. In other localities, asbestos veinlets varying from about 0.12 inch to a fraction of this in thickness, occur. The quality seems to be reasonably good and the percentage fibre in these bodies is fair, but they are generally of rather small dimensions.

2. Structure

The serpentinites are invariably the most massive rock-types present, although a rude foliation, coinciding with the attitude of the surrounding foliation, can generally be detected. This weak foliation is thought to be due to a cleavage development or to an indistinct type of shearing. The bodies are usually lensoid and elongated parallel to the general foliation around them. Plate 10 shows a rough patch of fairly resistant massive green serpentinite displaying only very slight indications of foliation, and in this respect being very different from the well foliated and banded rocks which surround it.

3. Origin

As mentioned, altered olivine and sometimes pyroxene crystals have been observed. The Geological Survey (Visser et. al., 1956), records unaltered olivine kernels in serpentinite from some localities and there is no doubt that many of these bodies have formed from original olivine and pyroxene-bearing rocks e.g. peridotites, pyroxenites etc. This is supported by the fact that many of them are fairly high in nickel content and often contain numerous magnetite grains. In the area just east of Bar 5 beacon, there has been trenching and drilling along a talcose zone within massive green serpentinites. As shown by Partridge (1943), this shear zone is fairly rich in the nickel minerals trevorite and nepouite.

The serpentinite bodies, together with many of the other basic rocks, have previously been regarded as belonging to the Jamestown Complex. However, as shown above, many of the basic rocks lying below the Fig-tree Series have probably, for the large part, been derived from dolomitic sediments and extrusive basic rocks, and are best classed in the Onverwacht Series. The true intrusive ultrabasics are considered to be of a much smaller extent than was formerly supposed.

An interesting feature is that the majority of basic rocks underlie the Fig-tree Series. However, serpentinite bodies are also found right at the top of the succession within Moodies quartzites. They always appear to lie conformably with the latter, and phenomena such as serpentinite dykes or embayments etc., cutting across the quartzite foliation, are never found. Furthermore, there are never any signs of contact metamorphic phenomena, and the author is of the opinion that these bodies may have been tectonically moved or "squeezed" (in a more or less "cold" state) from the basic, pre-Fig-tree complex, into higher rock strata, during deformation of the area.

The formation of serpentinite from ultrabasic rocks is a process which is not fully understood. It is a process unrelated to weathering and allied surface phenomena and is generally believed to have been accomplished by late-magmatic aqueous solutions acting on still heated rock (Turner and Verhoogen, 1960). According to the latter authors, serpentine can form at temperatures as high as 500°C by the action of water alone on olivine - enstatite mixtures, but above 500°C olivine cannot be converted to serpentine by any means. It is shown by them that serpentinization of peridotite by equal volume replacement demands great quantities of available water to facilitate the removal of large quantities of $MgO + SiO_2$ from the system. This would also mean noteworthy magnesia metasomatism of the adjoining rocks which according to them is seldom conspicuous. In the Consort area, few if any signs of magnesia metasomatism are evident.

A number of possibilities are discussed by Turner and Verhoogen and embodied in their conclusion of the problem as follows:-

"We are now able to accept as a satisfactory working hypothesis the dual concept of intrusion of peridotite magma in a largely crystalline condition, with simultaneous or subsequent serpentinization of its constituent minerals (olivine and enstatite) through the activity of aqueous solutions derived for the most parts from surrounding geosynclinal sediments or from intrusive bodies of granitic magma". In the area, both the geosynclinal sediments and the intrusive granite are available as possible sources for the aqueous solutions mentioned above and this hypothesis seems quite a feasible one.

(v) Blue Serpentinites

A few rather small bodies occur close to the granite contact in the area north of the Consort Mine. This rock is characterized by its dark blueish-green colour and its greater resistance to weathering as compared to the surrounding green variety.

The discussion of the green serpentinites applies equally well here. Although no original pyroxene or olivine crystals were encountered, microscopically this variety is almost identical to the majority of green serpentinites. According to the Geological Survey (Visser et. al., 1956), the blue serpentinites were originally probably closer to pyroxenites or olivine hypersthenites rather than peridotites.

(vi) Other Basic Rocks

In this group are classed certain basic rocks which can generally be accommodated in the above subdivision but which may not have the same origin as the surrounding rocks, or which have some peculiarity.

In the north, and lying within the zone of the contact-type amphibolites, there occurs a whole string of xenoliths which are totally different from the associated black hornblende amphibolites.

The rock is generally green to dark green in colour and varies from coarse textured to a very fine textured variety. Microscopically it consists mainly of antigorite which passes in places to an amphibole and phogophite-bearing variety. Well developed micro-folding is observed in places, and is of a very similar nature to the crenulation folds seen at Noordkaap. A string of these serpentinite xenoliths forms a nearly straight line parallel to the granite contact and to the foliation of the surrounding amphibolites. It is regarded as marking either the approximate position of a serpentinized ultrabasic sill, or a horizon of a much more basic nature intercalated in the surrounding contact-type amphibolites.

In a few areas to the north of the Consort Mine, but specially well developed in the immediate Mine area, occur irregular bodies and zones of talcose rocks. As shown by Hearn (1943), these bodies can usually be related to a zone of movement or faulting. The author is of the same opinion and found that almost all zones of talcose rocks north of the main Southern Fault, invariably occur in areas of strong structural disturbance.

(vii) Quartzitic Horizons Within the Basic Schists

1. Field Occurrence and Description

These horizons are generally confined to the zone of serpentinites and the green tremolite-actinolite schists in the area between the contact amphibolites and the Consort "Contact". However, in the area north of Joe's Luck, where only a very narrow layer of serpentinites is present, metamorphism has been more intense, and the more northerly quartzitic horizons (which have narrowed markedly here) are surrounded by black contact amphibolites.

The horizons obviously form a very integral part of the whole basic suite lying below the Fig-tree Series, and it is for this reason that they are discussed in the present section.

They occur as more or less intercalated bands in the schists and are conformable to the schist foliation. It appears as though about five dominant horizons are present, but they pinch and swell and disappear completely in certain places, and no single band of uniform thickness could be traced right across the area. In addition, certain bands seem to represent intensely silicified amphibolites and in places a gradation can be seen from an amphibole-bearing rock to a nearly pure quartzite. Only the bands which are nearly free of amphibole were mapped as separate quartzitic horizons, the partly silicified varieties being classed with the nearly pure amphibolites. They are best developed in the area north of the Consort Mine, and as with all the rock groups in the area, become much narrower in the Joe's Luck area.

In colour they are generally whitish to grey, but often have a greenish tinge due to the presence of fuchsite or chrome muscovite. They are commonly extremely fine-grained and resemble cherts. In places a very marked banding is present.

Two distinct types of allied quartzitic horizons can be distinguished, viz:-

1. a very pure variety consisting almost entirely of fine-grained quartz.
2. a sericite-bearing variety consisting of about equal amounts of quartz and sericite (or fine-grained muscovite), with occasional small grains of plagioclase.

The purer variety consists mainly of fine irregular quartz occurring as bands of coarse and finer textured material. Some very fine grains of sericite are invariably present as well, usually occurring in zones which are much richer in this mineral. In some specimens the rock is evenly fine-grained and sericite forms a very insignificant proportion as minute flakes, together with small magnetite grains. An occasional small crystal of plagioclase is sometimes observed.

In some of the northerly quartzitic horizons occur large subhedral garnets (composition probably almandine-spessartite), either forming a discontinuous trail along foliation planes, or sometimes as randomly occurring specks in the quartzite. These garnets are often up to about 0.33 inch in diameter and appear as rather friable reddish-brown patches in the white quartzite. They are generally much more prone to weathering than the quartzite and as a result of this selective weathering they are often completely removed and leave a "pocked" quartzite with fair sized hollows.

In certain areas, mainly along the northern contact of the most northerly band in the hills above the Consort Mine, occurs a poorly banded brown and white rock consisting of white quartz stringers and thin bands of brown tourmaline. The extreme whiteness of the quartz and the general proximity to the granite contact, lead to the conclusion that this rock is a quartz vein highly charged with tourmaline, rather than a recrystallized quartzite.

A number of quartzitic horizons, especially in the area approaching Joe's Luck, have a distinct greenish colour which at times becomes very pronounced and is reminiscent of the green colour of the Hospital Hill Quartzite of the Lower Witwatersrand System. The colour is imparted to the rock by green chrome-muscovite or fuchsite. In the area just north of Joe's Luck the mineral is often fairly coarse-grained and aggregates of pure green fuchsite are quite plentiful.

In a few horizons close to the contact, and better developed in the quartzitic rocks approaching Joe's Luck than in those to the north of Consort Mine, fine, fibrous needles of sillimanite are often encountered. Both Hall (1918) and van Eeden (1941), describe sillimanite from close to the contact zone and in addition, Hall mentions a sillimanite-corundum-tourmaline rock. This is indeed a remarkable rock,

occurring as an isolated small outcrop, some 550 feet west of the old coach road over Bullion Hill and about 300 feet from the main granite contact, close to an area of quite extensive granitic and pegmatite intrusion. The rock consists exclusively of large corundum crystals (up to about 3 cms. in diameter), together with a very dark coloured tourmaline, in a mass of long fibrous sillimanite needles, the latter often penetrating the former minerals. This outcrop could not be traced into any of the nearby quartzitic horizons and must be considered a separate lensoid body surrounded largely by serpentinite bodies. Plate 11 is a photomicrograph showing fibrous sillimanite penetrating a large corundum crystal.

Altered shaly horizons are often present within more or less pure quartzites. Numerous prospect trenches intersect these horizons and in places there are signs of sulphide mineralization, although due to surface oxidation it is seldom strikingly apparent. These horizons are probably much more persistent than would appear on first inspection, but due to their greater rate of decomposition and weathering as compared to the surrounding quartzites, it is only in certain favourable localities and where prospect trenches intersect them, that they are revealed. A thin section of a typical shale horizon taken from the hills about a mile and a half north of Consort Mine, reveals a light green amphibole as the dominant mineral, together with almost solid bands of garnets (probably almandine), invariably associated with much magnetite and sulphides.

The quartzites described above are generally the most resistant rocks in the area and where well developed, especially in the area north of Consort Mine, stand out as distinct ridges in the surrounding basic rocks. These purer quartzites constitute the dominantly occurring variety and are sometimes associated with less-resistant more felspathic-looking rocks. There is often quite a sharp contact between the two but they also seem to grade into each other at times.

This softer quartzitic rock is composed predominantly of sericite with quartz usually forming less than half of the rock. Darker bands are sometimes present, and then in addition to sericite and quartz, hornblende and clino-zoisite usually occur. In the hills north of Consort Mine a similar rock has almost a shaly appearance. It is very fine-grained and dark-grey in colour, and consists of very fine-grained sericite, quartz, and much magnetite, the latter occurring as numerous very small specks. In a few places garnets were observed in these sericite schists. Small crystals of plagioclase are invariably found as minor constituents of this type of quartzite.

2. Structure

All the above quartzitic rocks have undoubtedly been very strongly sheared at some stage. The purer varieties are often nearly chertified and in places they could almost be termed mylonites.

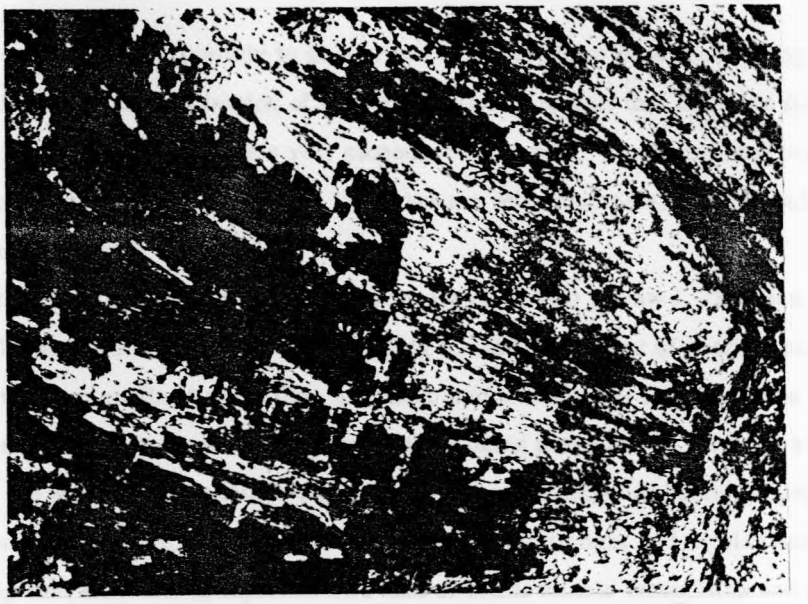


PLATE 11 : Corundum crystal (black) penetrated by needles of sillimanite (white). Bullion hill - north of old Bullion Mine. (Crossed nicols x 75).



PLATE 12 : Accordion folds developed in sericite schist. North of Consort Mine. (Crossed nicols x 75).

The formation of sericite is possibly to be ascribed to a breakdown of felspars during a period of strong shearing. A microscopical examination of the sericite variety reveals that the mica flakes are very well aligned in planes which give the rock a very pronounced foliation. Muscovite, not being a prismatic mineral, can never give a lineation so that the flakes are orientated parallel to the schistosity with their basal (001) sections normal thereto.

In addition to being strongly foliated, these rocks are often well lineated. Two sets of lineations are present. These include a steeply south-plunging set and another set of nearly horizontal lineations. The former type are confined to the pure quartzitic horizons whereas the latter type are very well developed in the sericite schist horizons although sometimes being developed in the purer varieties as well. The lineations are not evenly distributed throughout the area, locally not being developed at all. The horizontal lineations in the sericite schists appear as a series of very straight and regular lines which on a microscopic investigation are found to represent fold axes of rather minute crenulation and accordion type folds (see Plate 12). The well-aligned sericite and mica flakes have been bent, broken and folded and have definitely been subject to post-crystalline deformation (see Plate 13). The steeply plunging lineations are often seen to be parallel to fold axes of tight isoclinal folds in the quartzite, but in other places it is difficult to say whether they lie parallel to such fold axes or not.

Banding in these quartzitic rocks is often very tightly folded. This occurs especially in the vicinity of the granite contact, but due to the hard, compact nature of the quartzites, it is very difficult to measure the attitudes of these folds or to obtain a three dimensional view of them.

North of the Ivaura Section of the Mine, some extremely well developed conjugate folds were found in a finely laminated cherty rock. The largest one is about 2.50 feet in size (see Plate 14), and a plot of the stress field calculated from this fold indicates a nearly vertical maximum stress direction, probably related to the 4th phase of folding (see later).

3. Grade of Metamorphism

A fairly extensive development of sillimanite in quartzitic horizons close to the contact, in addition to garnet and corundum at one place, indicates a very high grade of metamorphism (probably the pyroxene-hornfels facies of Turner and Verhoogen, 1960). However, the abundance of the hydrous minerals, hornblende and muscovite (or sericite), in associated basic and quartzitic rocks respectively, which are characteristically absent from the pyroxene-hornfels facies, indicates that the bulk mineral assemblage cannot be higher than the hornblende-hornfels facies. The presence of sillimanite probably indicates a position for the quartzitic rocks close to the contact in the upper part of the latter facies.

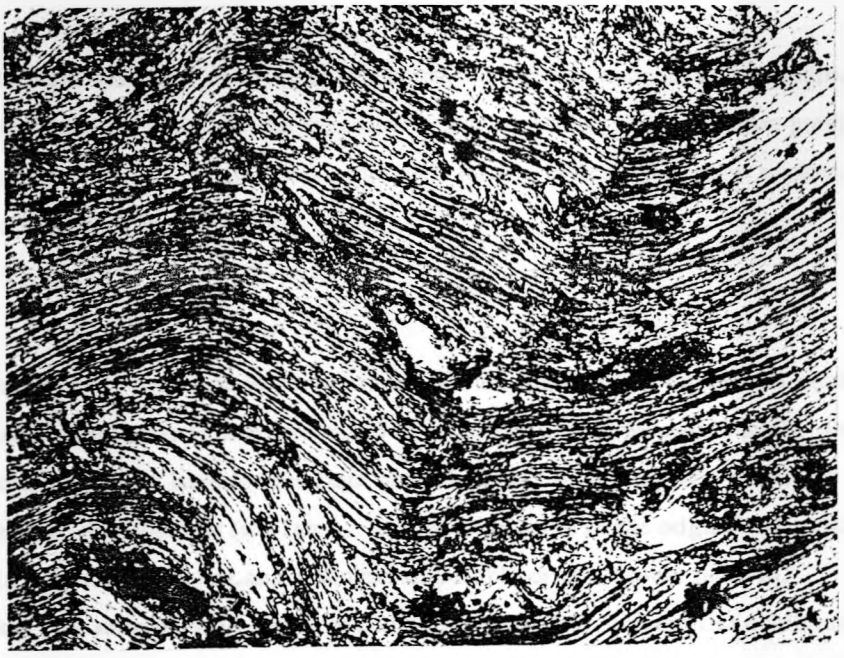


PLATE 13 : Folded, contoited and bent mica flakes. North of Consort Mine. (Crossed nicols x 75).



PLATE 14 : Well developed conjugate fold in finely laminated quartzitic horizon. Stress field calculated from this fold indicates a near vertical P. max. North of Consort Mine.

Sillimanite was never observed in the southern quartzitic horizons and in addition, the association of these siliceous horizons with tremolite-actinolite schists, which as shown previously belong probably to the upper part of the albite-epidote-hornfels facies, indicate that these southernmost quartzitic horizons can also be classed in this facies.

4. Origin

As mentioned, it is considered that much of the sericite might represent a mineral derived from the results of intense dynamic metamorphism of original siliceous felspathic rocks. On the other hand, some of the sericite could also have formed from normal contact metamorphism associated with granite intrusion and cleavage development (see later). In any event, some of the original quartzitic rocks must have been rich in felspathic material, and a number of possible origins appear possible.

Firstly, the suite of basic rocks containing the quartzitic horizons lies conformably below the Fig-tree Series and, as mentioned, might represent part of a highly altered succession of Onverwacht lavas. To the east of the area, van Eeden (1941), has suggested that a similar basic succession, containing a felspathic quartzitic rock, may represent highly altered basic and acid lavas of the Onverwacht Series. On the other hand they could also represent original quartzitic horizons within a predominantly sedimentary succession.

In the area mentioned by van Eeden, which lies well to the east of Joe's Luck, the siliceous rocks are always rich in sericite and occur as one or two broad horizons as compared to numerous fairly thin horizons in the Consort area. In addition, the quartzitic horizons in the Consort area are invariably more siliceous and usually resemble cherts, although, as mentioned, quartz-sericite schists do occur as well. In this connection it should be noted that the main southern quartzitic horizon reaches considerable dimensions in the area just west of the Bullion Mine, and is very rich in sericite. From the above considerations it seems feasible that this might have represented an original acid lava. However, certain factors are regarded as fairly strong evidence against the majority of the quartzitic horizons representing original acid lavas. These include:-

(i) the strong mineralogical banding seen in the closely associated contact-type amphibolites and the banding often observed in the quartzites, is considered to point to a sedimentary origin for both of these, rather than a volcanic one.

(ii) persistent, thin, quartzitic horizons are more easily visualized as original arenaceous beds in a sedimentary succession rather than numerous, thin, acid lava flows.

(iii) while it is agreed that the siliceous nature of many of the horizons could be due to secondary silicification, the author is of the opinion that the present condition is rather an expression of their original very siliceous nature.

(iv) in a number of the most northerly horizons, garnets are fairly abundantly encountered, often in distinct bands. This is taken as additional evidence for a sedimentary origin.

(v) possibly the main argument for a sedimentary origin is the presence in a number of these quartzites, of shaly horizons, consisting now of garnet-amphibole hornfelses often charged with magnetite.

Whereas some of the broader sericite schist horizons and associated more homogeneous tremolite schists may well represent altered acid and basic lavas respectively, the author is of the opinion that the majority of these rocks are sedimentary in origin. This applies particularly to the well layered and banded rocks towards the base of the succession along the granite contact.

All of these rocks are classed in the Onverwacht Series. In this area the latter series would thus constitute a suite of sedimentary rocks near the base, overlain by sediments and/or lavas.

(d) The Fig-tree Series and Moodies System

(i) The Consort "Contact" or Consort "Bar"

1. Field Occurrence and Description

Much detailed work has already been done on this important economic horizon, notably by M. G. Hearn (1943), so only a brief description will be given here and new findings added.

At the uppermost contact of the thick succession of basic schists described above, and underlying the Fig-tree shales, there is invariably a development of what is called the Consort "Bar". According to Hearn (1943), it is characteristically an exceedingly hard, almost chert-like, dark-brown rock, varying in thickness from 1 inch to 80 feet, but more usually from 2 to 6 feet thick. In the Consort area, irrespective of whether mineralization is present or not, this "Bar" is invariably developed. Its outcrop has been mapped in detail in the Consort area by Schoeman et. al. (1946), where it is found to be strongly folded on a large scale (see Geological Map, Fig. 2). From the most northerly or Ivaura Section of the mine, the "Contact" trends regularly eastwards, more or less following the northern side of Dicey's Creek. As can be seen, "Bar" development is very strong in the immediate mine area, whereas going eastwards it becomes more and more feeble until at the old Bullion Mine it is very poorly developed. In the latter area, and especially to the north of Joe's Luck, extensive granitic and pegmatitic bodies have completely obliterated the "Contact". However, its approximate position can usually be

judged from the position of the underlying tremolite schists and the overlying garnet-bearing hornfelses, the line between these two invariably representing its position. Where "Bar" development is very feeble or absent, the above criterion was used in locating the expected position of the "Contact". More recent work in the area between Joe's Luck and Sheba Siding has shown that, although extensively intruded and obliterated by granitic intrusion, isolated patches with fairly good "Bar" development occur. Just to the northwest of Bar 5 beacon, between Joe's Luck and Sheba Sidings, several feet of "Bar", extending for quite a few hundred yards, and extensively trenched, was found. Thus the "Contact" horizon, while not always being well developed or in many places completely destroyed by granite intrusions, could be traced the whole way from the Consort Mine to Bar 5 beacon, a total distance of about 5 miles.

Microscopically, the typical "Bar" according to Hearn (1943), consists mainly of quartz with a great number of minute, brown, pleochroic, biotite flakes arranged parallel to the banding. Other minerals mentioned include zoisite, muscovite and rutile, together with a little apatite, sericite and greenish-brown tourmaline. It is thought by the above writer that the minute flakes of biotite impart the characteristic brown colour to the "Bar".

Detailed mapping by Schoeman et. al (1946), has shown that there occurs in the hornfelses above the main "Contact - Bar", parallel to the latter, and on the average about 200 feet away from it, a zone of basic, mainly tremolite schists, of variable thickness but usually averaging about 50 feet. A prominent "Bar", very often better developed than that of the main "Consort - Bar", is almost invariably present on the lower contact of this "hanging wall" band. On the upper contact of the latter, bar development is of insignificant proportions and more often than not, completely absent (see Fig. 2).

The hanging wall band is well developed in the area south of the Bluejackets Fault and follows the main contact conformably. North of the Bluejackets Fault it is not very well formed and is in addition, very highly disturbed by intrusions of granite and pegmatite, and probably also by small-scale faulting. Along the northern contact in the vicinity of Dicey's Creek, no hanging wall band occurs.

2. Structure

As noted by Hearn (1943), there is a strong alignment of biotite flakes parallel to the banding in the "Bar". It is also evident that the "Bar" has been strongly folded both on a major and minor scale. This will be referred to later (page 86).

3. Origin of the "Bar"

The most widely held view on the origin of the "Bar" (Hearn, 1943 : Schoeman et. al. 1946, etc.) is that it resulted from the silicification of an intensely sheared zone occurring between a competent rock (hanging wall hornfelses) and an incompetent rock (footwall schists). This sheared contact horizon afforded an easy passage for ascending hydrothermal solutions which are thought to have originated from the Nelspruit Granite. According to Hearn (1943), the siliceous solutions were apparently post-pegmatite but mainly pre-mineralization. It is thought that strong silicification occurred first, followed later by mineralizing fluids, both being derivatives of the same hydrothermal source.

The silicification and chert-like nature of the "Bar" is in many respects similar to the intense silicification of most of the major faults in the Mountain Land. The Consort "Bar" represents a zone of intense shearing and therefore of much movement, and the author is of the opinion that it may well mark the position of a fault. However, there is little evidence of lateral displacement, extensive overthrusting, or truncation of bedding, and the actual amount of displacement could not have been very great.

(ii) Fig-tree Shales and Graywackes and Associated Chert Horizons

1. Field Occurrence and Description

These occur in two main areas and in a third smaller area.

(a) Typical banded shales and graywackes together with associated chert horizons, occur just south of the Kaap River in the eastern part of the area where they dip to the south and constitute part of the northern limb of the Eureka Syncline.

(b) Metamorphosed shales and graywackes and associated chert horizons occur in the immediate vicinity of the Consort Mine and in a narrow strip along the north side of Dicey's Creek. They overlie the Consort "Contact" and extend eastwards as far as Bar 5 beacon (see Fig. 2). They have been strongly thermally metamorphosed in this area and are more correctly termed hornfelses.

(c) To the east-southeast of Number 7 Shaft, a narrow strip of arenaceous graywackes and shales, probably belonging to the Fig-tree Series, together with an associated strip of greenschist, the latter considered as being part of the Zwartkoppie zone of the latter series, has been upthrown by the major high angled thrust fault referred to before, and occurs immediately to the south thereof.

Unmetamorphosed Shales and Graywackes

The typical unmetamorphosed shale is usually a well-banded, fine-grained, dark rock, consisting of quartz and some plagioclase with chlorite and much carbonate in places. Where there has been local shearing, sericite is fairly plentiful.

The unmetamorphosed graywackes are dark-grey to black in colour, but weather to a reddish-brown colour. They consist mainly of angular sericitized felspar fragments with fragments of chert and quartz, all of varying size. The finer matrix material consists mainly of quartz with a bit of carbonate, together with chlorite and clay minerals.

Description of the Consort Mine "Hanging Wall Shales" or Hornfelses

Much attention has been paid to these rocks, representing as they do some of the few examples in the whole Barberton area of typically metamorphosed shaly rocks of the Fig-tree Series. Hearn (1943), made a detailed study of these rocks on the Consort Mine, and van Eeden (1941), in his description of the Sheba Hills region, also describes them in a fair amount of detail. The optical properties of most of the metamorphic minerals have been determined by the above two authors so that they will not be mentioned in detail in this description.

When partly weathered, the hornfelses have a distinct shaly appearance and if large porphyroblasts are not immediately apparent, the fresh rock may also resemble an undecomposed type of graywacke. Towards the bottom of the succession, outcrops often show a peculiar weathering effect in that more resistant bands stand out in relief and very often resistant porphyroblasts give the rock a peculiar "knotted" or "warty" surface.

In hand specimen, long slender amphibole needles, usually about 0.50 cm. in length and randomly orientated, are apparent. In numerous sections studied, certain minerals are found to occur time after time. In certain other areas additional typically metamorphic minerals occur, but they are not nearly as widespread. A typical hornfels is usually quartz-rich and almost all sections examined reveal tremolite and/or actinolite together with biotite. The above minerals occur very abundantly in all the hornfelses. Other minerals, generally occurring in lesser amounts, include plagioclase, more rarely chlorite and sericite, and a greenish pleochroic amphibole which is probably a variety of hornblende. In certain bands, euhedral garnets (composition almandine-spessartite - Hearn, 1943), occur abundantly, and locally they may comprise the major mineral constituents (Plate 15). Other bands contain numerous, large, bladed and irregular, randomly orientated andalusite crystals, displaying

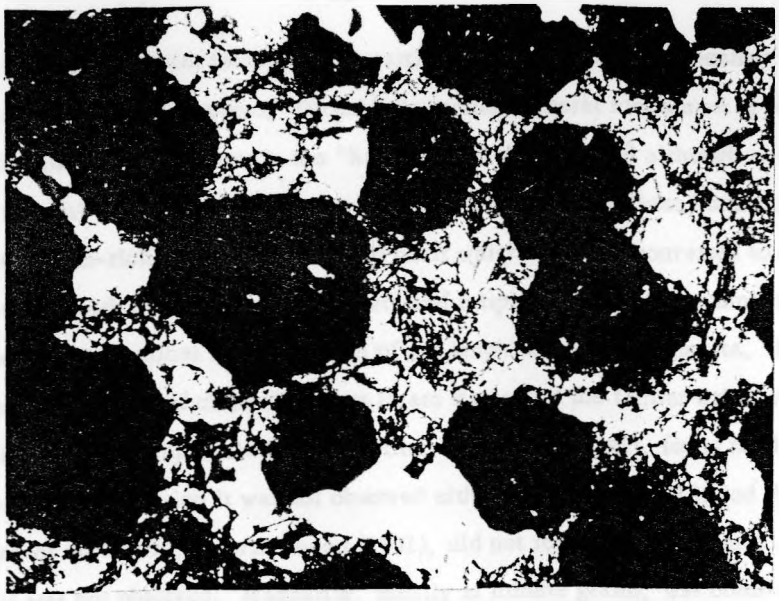


PLATE 15 : Euhedral garnets (almandine-spessartite) in hornfels. Vicinity of the old Bullion Mine. (Crossed nicols x 75).

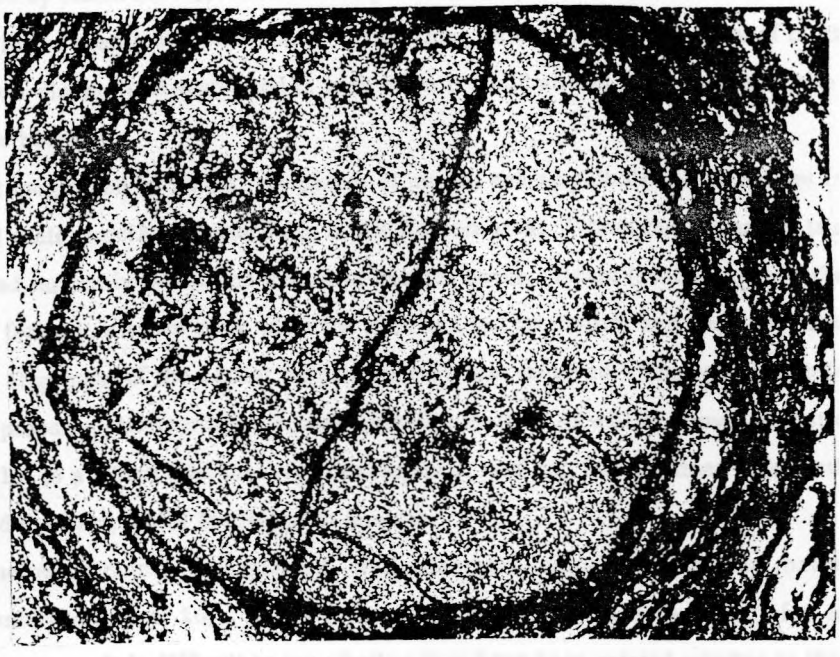


PLATE 16 : Amphibole and chloritic material "wrapping" around garnet crystal. Consort Mine (x 100).

extreme sieve texture and crowded with inclusions of quartz and biotite. Zoisite, together with olive-green epidote and chloritoid, were also noted. Diopside is another mineral mentioned by Hearn (1943), as occurring locally in considerable amounts in the "hanging wall shales", and although a few narrow bands containing this mineral were observed, it is by no means widespread in these hornfelses. van Eeden (1941), describes an iron-rich layer from a banded chert which has been converted to a grunerite-cummingtonite-garnet rock with minor amounts of quartz and felspar. The author examined a similar rock and found it to be nearly identical but with much of the amphibole cummingtonite. Hall (1918), mentions an extensive development of chiastolite, but Hearn states that the former writer probably mistook the abundantly occurring amphibole for chiastolite. van Eeden (1941), found no sign of this mineral and in the present investigation it was not observed either. Both Hall (1918) and Hearn (1943), mention the occurrence of cordierite, but van Eeden (1941), did not recognise this mineral and in the present investigation it was not observed. Magnetite, usually as minute grains, was observed in most sections examined and small crystals of zircon are invariably present as well.

2. Structure

As noted by Hearn (1943), there is a very marked alignment of biotite flakes as well as amphibole needles in the metamorphosed shales. This strong arrangement, especially of biotite flakes, often gives the rock a distinct schistosity and in such cases it could almost be termed a biotite amphibole schist, rather than a hornfels.

As first mentioned by Hearn, the planes of biotite and amphibole alignment are folded by the major folds and their associated minor folds in the Consort area. Where the alignment is not so strong, larger, radiating and randomly orientated tremolite needles occur. Hearn (1943), suggests that such amphibole crystals formed at a late stage when the rock had lost its fissility and when the stress that caused the marked alignment of the earlier formed minerals was removed. The randomly orientated andalusite crystals probably also represents a later formed mineral. As will be shown, this strong mineral orientation is parallel to a widespread cleavage development resulting from a strong deformative stress which accompanied the intrusion of the Nelspruit Granite.

In numerous instances, fine-grained, well orientated, chloritic groundmass material "wraps" around euhedral garnets (see Plate 16). As the garnets are invariably well formed, with few inclusions and no helicitic structures, it is difficult to say whether they have been rotated relative to the enveloping material, although from the attitude of the latter at times, it seems very likely that at least some rotation after crystallization has occurred. In other places there is no bending of minerals around garnet

porphyroblasts (e.g. Plate 15), and in such rocks there is generally a very weak mineral alignment.

In numerous cases it is evident that amphibole crystals have been bent, broken and folded and this also indicates a post metamorphic deformation. In the unmetamorphosed argillaceous rocks no mineral alignment is apparent, but often a fairly strong cleavage is observed with planes of cleavage generally very close to the bedding foliation.

3. Grade of Metamorphism

It is obvious that the grade of metamorphism of the Fig-tree Series in the Consort Mine area is not very great. The extreme sieve texture of the andalusite and some of the biotite, together with the presence of minerals such as zoisite, epidote, biotite and even chlorite, indicates a relatively low temperature. Almandine-spessartite garnet, together with actinolitic amphibole and diopside, and possibly some hornblende, are perhaps indicative of a slightly higher temperature than the previously mentioned minerals. However the vast majority of the above-mentioned minerals fit comfortably into the albite-epidote-hornfels facies of Turner and Verhoogen (1960), or the epidote-amphibolite facies of Ramberg (1952).

4. Origin

From their stratigraphic position and their composition, there is no doubt that these rocks represent metamorphosed graywackes, shales and associated minor chert horizons of the Fig-tree Series. The metamorphic mineral assemblage indicates an original rock similar to a sandy shale or graywacke with occasional very minor carbonate-bearing horizons.

(iii) Fig-tree "Lavas"

1. Field Occurrence and Description

The Fig-tree shales and graywackes in both the Consort Mine area and in the area south of the Kaap River, pass gradationally upwards into rocks that have been regarded as lavas - (van Eeden, 1941). As will be shown from the present investigation, these can no longer be regarded as true lavas.

The "lavas" south of the Kaap River can be regarded as more or less typical of the unmetamorphosed variety, whereas those in the Consort Mine area, although retaining the same general appearance, have been reconstituted due to metamorphism. A third occurrence of partly metamorphosed "lavas" is found immediately south of the Main Southern Fault in about the centre of the area.

Unmetamorphosed "Lavas"

In hand specimen, these rocks when well developed, are distinctive. They are dark-green in colour and are characterised by numerous white felspar crystals usually about 1 mm., but often as much as a few mms., in size. These give the rock a distinct porphyritic appearance and led to van Eeden (1941) suggesting the very suitable field name of "felspar porphyry", for the typical "lava".

Towards the top of the succession, and immediately underlying the basal conglomerate of the Moodies System, the rock has a marked nodular structure with slightly lighter coloured nodular masses giving very much the appearance of pebbles in a conglomerate. Chert and jasper pebbles are occasionally found in this zone. van Eeden (1941) termed these nodular masses "autoliths".

A typical "lava" consists mainly of fairly large, often partly sericitized soda-plagioclase and microcline crystals in a finer-grained groundmass. These felspars are often zoned with respect to the crystal boundaries. Although the vast majority of the felspar crystals are sub-hedral to euhedral, there also occur very angular and ragged, almost shattered grains of felspar. The groundmass consists of finer-grained quartz, a greenish amphibole (probably actinolite - which is often partly or wholly changed to chlorite), together with some biotite and sericite. Epidote, apatite and specks of magnetite, together with some secondary calcite may also be present.

It is difficult to see a microscopic difference between the nodular masses and the groundmass in which they occur, but the percentage of ferromagnesian contact of the latter is usually higher.

Metamorphosed "Lavas"

The best development of these "lavas" anywhere in the Mountain Land, occurs in the area immediately to the east of the Consort Mine (see Fig. 2). They have been metamorphosed in this area and the change from altered shale to altered "lava" is usually so subtle and imperceptible in the field, that in many cases the mapped contact represent roughly the centre of zone which might be of the order of 300 feet or more in outcrop width.

The same nodular conglomeratic mass occurring near the top of the "lava" succession mentioned previously, is very well developed in the area east of the Consort Mine, and in addition, two very distinct "marker horizons" occur within the "lavas" here.

These "lavas" are invariably rich in small laths of green actinolitic hornblende. In the transition stage from hornfels to "lava", the rock is often very finely banded and consists of much fine-grained quartz and smaller amounts of plagioclase, microcline, epidote and biotite. Larger laths of green actinolitic hornblende are also present.

In the vicinity of the hydro-electric plant near Joe's Luck, occurs a metamorphosed variety consisting predominantly of quartz, acid plagioclase and biotite, with smaller amounts of actinolite. The greater abundance of quartz in the "lava" rocks close to intrusive granite bodies in the Joe's Luck area is probably partly due to secondary silicification.

Plate 17 shows typical deformed autoliths from the metamorphosed variety north of Joe's Luck.

Marker Horizons Within the "Lavas"

Occurring towards the top of the succession, and only present in the sequence east of the Consort Mine, occur two very distinctive and persistent marker horizons which have not previously been mentioned.

They proved of great value in indicating the exact position in the stratigraphical succession in the area north of Joe's Luck where the whole sequence has thinned drastically. They also proved of use in giving an idea as to the structure in certain areas, especially in the complex region just east of the Consort Mine.

The "Lower Quartz-Bleb Marker" Horizon

Towards the top of the succession and within the "autolith" zone, occurs a rather persistent, peculiar, laminated horizon, containing abundant highly sheared and flattened quartz lenses or "blebs".

The maximum width of this horizon is about 80 feet, but it is generally about 25 - 30 feet wide and may sometimes even be absent. It is generally situated about 700 - 900 feet below the "lava" - conglomerate contact, but this distance may be considerably less and in the Joe's Luck area it is about 250 feet.

The lower contact is generally very sharp, but passing upwards the quartz "blebs" become fewer and the contact is rather gradational. In hand specimen the rock is unmistakable and consists of hundreds of elongated quartz slivers, which are actually more plate-like than lensoid, set in a sheared, greenish matrix (see Plate 18).

Microscopically the rock consists mainly of an intergrown mass of fine-grained quartz with larger soda-plagioclase and microcline crystals. The ferro-magnesians consist dominantly of a light-green tremolite, often associated with, and partly changed to chlorite, together with some green hornblende and an abundance of small granular grains of zoisite and lesser amounts of epidote. At fairly

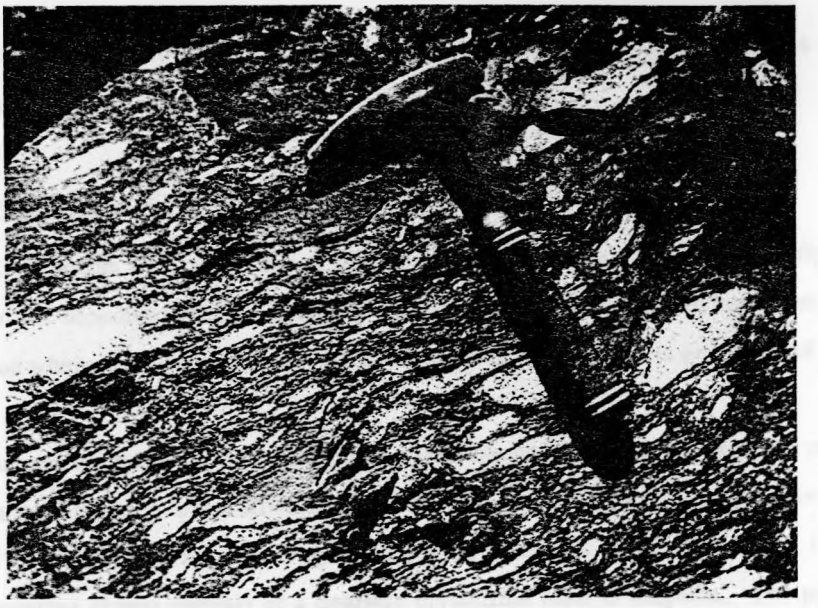


PLATE 17 : Typical "nodules" or "autoliths" in metamorphosed "lava". North of Joe's Luck Siding.

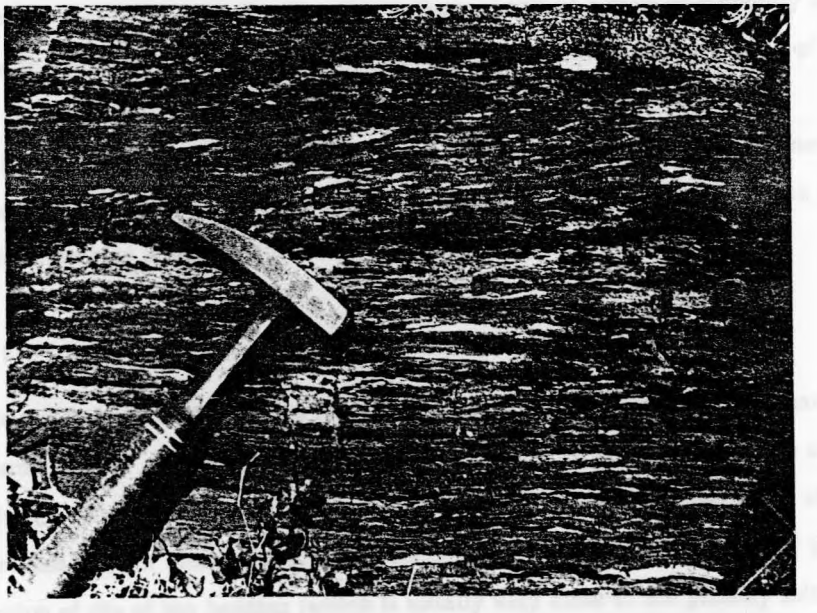


PLATE 18 : "Quartz bleb" marker horizon. Note hundreds of small, white quartz fragments, flattened and elongated in plane of cleavage. North of Joe's Luck Siding.

close intervals, occur large bands of an almost pure intergrown quartz mosaic representing the quartz "blebs" as seen in hand specimen.

The "Upper Pyroxene Marker" Horizon

This horizon occurs right at the top of the "lava" succession, immediately underlying the basal conglomerate of the Moodies System. It is very persistent and is found occupying the same stratigraphical position wherever outcrops occur. The thickness of this horizon is generally of the order of 35 feet.

In appearance the rock can be described as a well banded, greenish, crystalline rock. The composition varies quite markedly, but it always retains its well banded appearance. In places, especially in the Joe's Luck area, it becomes very silicified. Just east of the Consort Mine, it is light green in colour and consists almost entirely of a coarsely crystalline mass of diopside. The pyroxene crystals are very large in size and show a very coarse type of sieve texture with numerous small plagioclase and microcline crystals and a few quartz inclusions. Nearby there occur, in addition to bands of diopside, narrow zones consisting mainly of tremolite with zoisite and some plagioclase. The above minerals may also all occur as more or less isolated individuals within and adjacent to large diopside crystals.

Not very far from the above locality, the marker consists of a mass of randomly orientated actinolite needles with some zoisite, all in a finer-grained groundmass consisting mainly of quartz with smaller amounts of plagioclase.

In the Joe's Luck area the horizon has suffered intense shearing and certain zones consist of such intensely mylonitized material that it is completely unidentifiable. In the latter area it consists mainly of actinolite crystals in a fine-grained matrix of quartz and felspars.

2. Structure

The "autoliths" or nodular masses in the upper part of the "lava" succession have invariably been strongly deformed and in all cases have suffered the same type of deformation as the overlying conglomerate pebbles. They are flattened in the planes of cleavage and their long axes, although difficult to measure due to their blending with the groundmass material, plunge generally at fairly steep angles in the direction of dip of the bedding (which is usually very close to the primary foliation in these rocks). Plate 19, when compared to Plate 17, gives some idea of the type of intense deformation which these rocks must have suffered locally.



PLATE 19 : Intensely elongated, flattened and "stretched" nodules or autoliths. Metamorphosed "lavas" near Joe's Luck Siding.

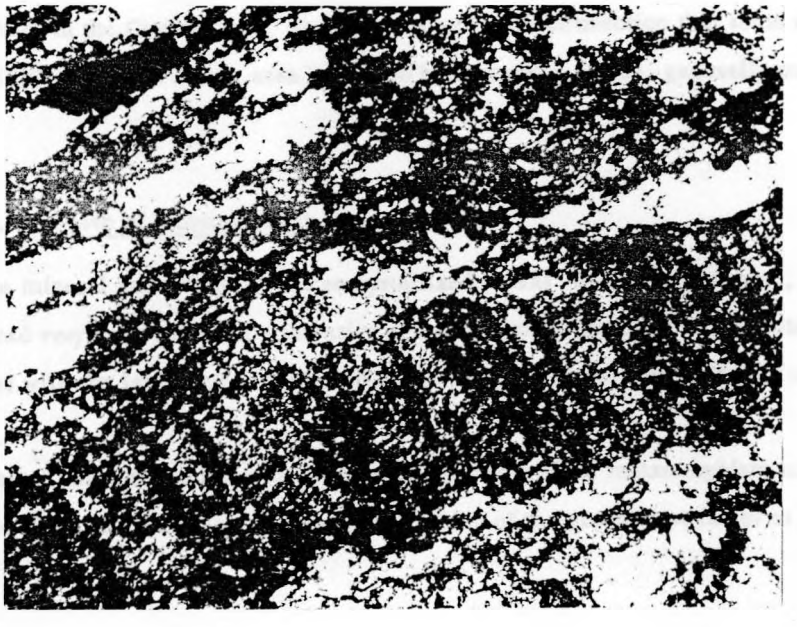


PLATE 20 : Crenulation folds developed in fine-grained partly sheared "lava". Southeast of Consort Mine. (Crossed nicols x 75).

As with all the rocks in the Joe's Luck area, the "lavas" here are also very strongly lineated. This lineation is best seen in the biotite-type lava in which there is a very pronounced orientation of biotite flakes together with minute amphibole needles, plunging at shallow to intermediate angles in a southeasterly direction.

The typical felspar porphyry "lavas", which are best developed in a strip underlying the northern limb of the Eureka Syncline, are generally more massive although a general foliation conformable to the bedding in the surrounding sediments, is often observed. Elongated elements in the groundmass of this type of "lava" invariably "wrap" around the large felspar crystals and there are often indications of intense shearing, especially in a narrow zone immediately underlying the basal conglomerate of the overlying Moodies System. A definite micro-folding is sometimes present in the groundmass, but this is not usually observed in hand specimen (see Plate 20).

The "quartz bleb" marker horizon has suffered intense deformation and wherever outcrops occur, the horizon is seen to consist of intensely sheared, drawn-out and flattened quartz fragments together with a very strong alignment of amphibole needles parallel to the same plane of flattening (see Plate 18).

As can be seen from the map, the very strong mineral alignment foliation has been folded by the main system of folds in the Consort area. It is interesting in this connection that some of the elongated and flattened "autoliths" in the Joe's Luck area have also been strongly folded, generally on a small scale however.

3. Grade of Metamorphism

From the mineral assemblage of the recrystallized "lavas" in the Consort area, it is obvious that they have suffered very nearly the same intensity of thermal metamorphism as the underlying hornfelses. Together with the latter they are classed in the albite-epidote-hornfels facies of Turner and Verhoogen (1960).

The "lavas" south of the Kaap River have suffered very little metamorphism and at the highest they could possibly be classed in the lowermost division of the greenschist facies as defined by Ramberg (1952).

4. Origin

Ramsay (1963) has recently questioned the terminology of "lava" for these rocks and he feels that the term felspathic graywacke would be more correct.

As a result of the present investigation it becomes obvious that these rocks have certain features which suggest that they were originally of an extrusive igneous origin and others which suggest that they may have been essentially of a sedimentary origin.

In the field, no flow structures or other typical "lava" structures are observed, although the presence of many white patches of felspar which strongly resemble phenocrysts, seems to point to an extrusive igneous origin.

The nodular masses towards the top of the succession are difficult to interpret. van Eeden (1941) suggested that they may represent autoliths, formed slightly earlier by congealing when the partly crystallised lava was still in a fluid state. In support of this he cites the occurrence of structures (which he interprets as "pillows") that contain similar nodular masses occurring in such a fashion as to suggest that they formed together with the "pillows" when the lavas were still plastic. Another possible solution cited by van Eeden is that the nodular masses formed as a result of flowage during folding. A supporting fact, as mentioned above, is that the lengths of the nodules always lie in the direction of dip of the beds, i.e. at right angles to the stress direction, and due to this, he concludes that they formed most probably as a result of flowage in the solid rocks during folding. The author is of the opinion that the nodular masses are an integral part and primary features of the original rock and that subsequently, due to strong deformation, they were flattened and elongated to give the marked orientation observed today.

Under the microscope the problem of the origin of these "lavas" does still not resolve itself very easily. In favour of an igneous origin is the fact that there is very little, if any quartz as compared to a graywacke, and the large felspar crystals are invariably euhedral and are not infrequently zoned. In support of a sedimentary origin is the angular nature of a fair number of the smaller felspar fragments.

According to Shand's classification - (van Eeden, 1941), these "lavas" are soda-trachytes. A comparison of the "lava" analysis with the analysis of a typical graywacke from the Fig-tree Series, shows clearly that the latter is much richer in silica and there is quite a substantial discrepancy in the other elements as well. Thus, from a chemical compositional point of view, these rocks cannot be classed as typical graywackes of the Fig-tree Series. Ramsay (1963) suggested the name felspathic graywacke, but a graywacke consisting entirely of felspar grains, usually in the form of well formed crystals and generally not as angular fragments, is difficult to visualize.

It is suggested that for the most part, these rocks represent crystalline tuffs (as defined by Pettijohn - 1957). The latter author describes pyroclastic deposits formed by volcanic eruption as being porphyritic in part. He mentions the close microscopic similarity between these rocks and graywackes. Zoning in the crystals may be ascribed to formation in the partially solidified mass prior to explosive

extrusion. The absence of glass fragments, shards and spicules, as well as the fact that no welded tuffs are found, seems to indicate that the volcanic mass, prior to expulsion, was fairly cool and partially crystalline. The angular fragments are interpreted as having formed due to a breaking up during explosion.

The nodular occurrences or "autoliths" would represent explosive bomb-like concentrations of congealed magma. Later deformation flattened these masses and caused the elongation.

The presence of chert and jasper inclusions is more difficult to explain. It is thought that they represent clastic fragments which were transported into the environment of waning volcanic activity which preceded the deposition of extensive conglomerate formations (essentially of chert and jasper) which constitute the base of the immediately overlying Moodies System.

Origin of the Marker Horizons

It is possible that the quartz "bleb" marker represents an original amygdaloidal lava flow, which, together with all the other rocks was intensely sheared. It is suggested that the elongated and flattened quartz "blebs" might represent original amygdales. However, these rocks are very siliceous and they may represent some kind of altered intraformational sediment.

The upper marker must have been calcic to yield a pure diopside rock in places. It is suggested that it is essentially a sedimentary layer formed at the end of the period of volcanic activity and representing some type of re-worked "lava" material lying immediately below the basal conglomerate of the Moodies.

(iv) The Moodies System

1. Field Occurrence and Description

Moodies rocks are well developed in the area and occur in four separate localities:-

(i) the best development of these arenaceous rocks is represented by the western extremity of the so-called "Lily Line" which can be traced as a very well developed and resistant quartzitic horizon or horizons for about 15 miles to the east of the Consort Mine.

Between the Consort Mine and Joe's Luck, these arenaceous rocks attain their maximum development in a broad, strongly folded synclinorium which is underlain by "lavas" and which terminates about a mile to the east of the mine.

Formerly it was considered by the Geological Survey (Visser - 1956) that the "Lily Line" extended more or less due east of Joe's Luck Siding along the northern side of the Kaap River. As a result

of detailed mapping however, it soon became apparent that the conglomerate zone in the area east of Joe's Luck, swings sharply to the northeast, narrows considerably, and eventually disappears in the area just north of Bar 5 beacon. Well developed conglomerate is again encountered some way to the east, immediately northwest of Scotia Talc Mine, and from here eastwards this quartzite and conglomerate zone stands out very clearly as the high,resistant "Lily" quartzite ridge. In the area immediately south of Bar 5 beacon the quartzites appear to have been extensively intruded by basic rocks so that numerous separate quartzitic horizons and "rafts" appear today within serpentinite bodies. The thickness of the succession is greatly increased due to this intrusion but thins rapidly eastwards as the individual bands coalesce to form the main Lily Line.

The rocks in this succession have been thermally metamorphosed.

(ii) part of the conglomerate and quartzite mass forming the northern limb of the Eureka Syncline was mapped along the southeastern part of the area.

(iii) a strongly dynamically metamorphosed block of Moodies sediments surrounded by basic rocks occurs near Noordkaap.

(iv) a few smallish patches of Moodies quartzites occur on the upthrow side of the Main Southern Fault (see Fig. 2).

The Moodies System rocks are all characterized by the presence of a conglomerate zone near the base. This zone, which is locally absent, can be as much as 250 feet thick. It is not simply a single conglomerate layer but a zone of numerous conglomeratic bands separated by quartzite horizons. Going upwards in the succession the concentration of pebbles becomes less and less, but even a few hundred yards or more above the last well developed conglomerate band, the odd pebble is still found. Due to this close association of conglomerate and quartzite, the two are treated together in this discussion.

As mentioned, the Lily Line quartzites have been thermally metamorphosed, whereas the quartzite mass near Noordkaap has been strongly dynamically metamorphosed. For this reason the conglomerate - quartzite zone of the Eureka Syncline will be treated first as it has suffered little if any metamorphism and is more or less typical of the lowermost part of the Moodies System in the area.

Unmetamorphosed Arenaceous Rocks

The quartzites forming the Eureka Syncline can be regarded as representing typical Moodies System rocks.

The majority of pebbles occurring in the basal conglomerate consist of various types of banded cherts and black cherts. Granite and quartzitic pebbles, together with quartz porphyry and some felspathic grits, were also noted. The latter types invariably stand out clearly as well rounded and nearly spherical particles as compared to the rounded but well flattened and elongated chert pebbles.

A typical quartzite from the Lower Moodies consists of numerous angular grains of quartz, fresh felspar (mainly microcline) and a fair amount of plagioclase in places as well. These larger fragments are all set in a finer matrix consisting predominantly of quartz grains. Sericite, biotite, carbonates and some chlorite, are commonly occurring associated minerals.

Certain impure shaly horizons occur higher up in the succession but these were not mapped during the present investigation.

In this area, the conglomerates appear to rest completely conformably on the underlying "lavas".

The Metamorphosed "Lily" Quartzites

These rocks are basically identical to those described above, with a well developed basal conglomerate etc., but due to metamorphism they have been largely recrystallized and new minerals have formed. Generally the quartzites are fairly pure and as noted by van Eeden (1941), they have probably been subjected to a certain amount of secondary silicification, especially in the area from Joe's Luck eastwards.

The typical metamorphosed quartzite consists of a fine-grained intergrown quartz mosaic with quite a substantial amount of plagioclase of albite composition, together with some muscovite and a few specks of biotite. Locally, and especially in the Joe's Luck area, rather impure quartzites occur and in places they could almost be termed arenaceous hornfelses. There is then often quite a good development of amphibole, usually of the tremolite-actinolite variety, together with some biotite. In about the middle of the main quartzite mass in the centre of the area, an impure quartzitic rock was found to consist of an interlocking quartz mosaic with some plagioclase and an abundance of diopsidic-pyroxene; zoisite was also noted. From the above it is concluded that this particular zone must have been fairly rich in carbonate.

The Quartzite Block near Noordkaap

Immediately south of the Kaap River in the western part of the area, occurs a patch of more or less normal Lower Moodies quartzites with poorly developed conglomeratic patches. These quartzites

are typical of the unmetamorphosed Moodies quartzites in the area and consist of fairly large angular quartz grains together with a few plagioclase grains in a fine-grained, partly sheared, quartz matrix with some sericite (see Plate 21). Going south from the river, sericite becomes more and more plentiful until in the vicinity of the main road, the rock is unrecognisable as a quartzite. It has been so intensely sheared that it now consists almost entirely of very fine-grained sericite, the minute flakes having a very strong alignment. Minor amounts of fine-grained quartz are also present. A few zones were found which consist of altered plagioclase grains together with quartz grains in a fine-grained matrix, the latter containing substantial amounts of sericite.

The "Woodstock Bar", forming the southern boundary of this quartzite block, together with a very similar "green bar" exposed along the main road to the northeast of Noordkaap, represent silicified fuchsite schists. In some parts these "greenschist" rocks are very silica-rich, consisting almost exclusively of fine-grained quartz with subordinate amounts of sericite and fuchsite. In other zones however, they consist dominantly of sericite and are best described as finely-laminated sericite schists. Some fuchsite and a few narrow partings of fine-grained quartz are generally present in the latter schists.

2. Structure

Along the northern side of the Eureka Syncline there is a very strong cleavage development, not generally observable in the quartzites, except microscopically when a partly sheared type of matrix indicates a secondary foliation. It is best observed in the conglomerate horizons where, as mentioned, the chert pebbles have been strongly flattened in planes which define a marked foliation. There are good exposures of highly deformed conglomerate pebbles in a road cutting southwest of Joe's Luck and it is seen that the long axes of the pebbles plunge at intermediate angles to the northwest and are flattened in the plane of the bedding which dips steeply to the north. As mentioned, quartzitic, granitic and rhyolitic pebbles have hardly been affected at all by this deformation.

An identical type of flattened pebble is found in the Lily quartzite line. The flattened and elongated pebbles are well exposed just north of Joe's Luck and they are found to plunge at shallow angles to the east-southeast, the plane of flattening cutting the bedding foliation at a small angle and dipping fairly steeply to the south. The strong lineation which pervades all the rocks in the Joe's Luck area, mentioned previously, is parallel to the elongation direction of these deformed pebbles. In the same area, a few small folds were noted which have an identical lineation also parallel to their fold axes. This will be referred to later under structural geology. A later section is also devoted to consideration of the deformed conglomerate pebbles in the area.



PLATE 21 : Impure, partly sheared quartzite. Large grains mainly quartz with some felspar. Matrix mainly fine-grained quartz, sericite and plagioclase. Northeast of Noordkaap. (Crossed nicols x 75).

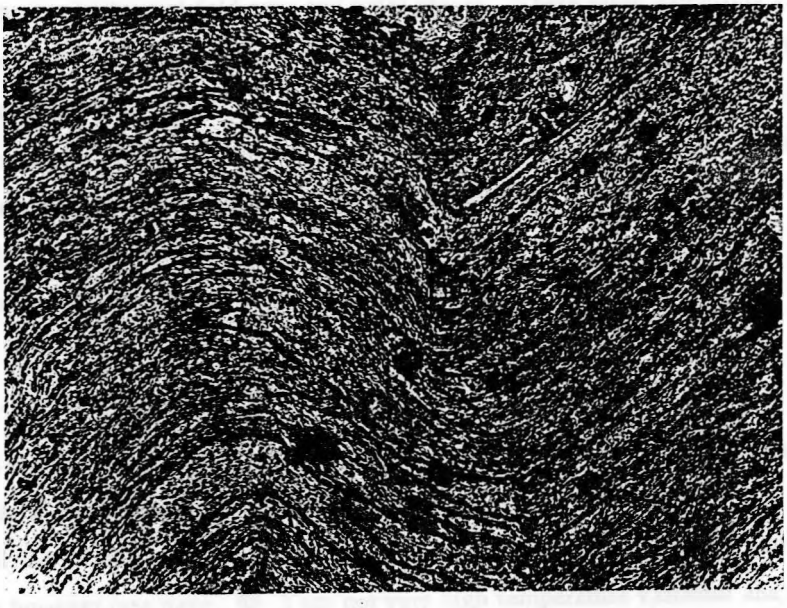


PLATE 22 : Strongly sheared and folded sericite-quartz schist. Northeast of Noordkaap. (Crossed nicols x 75).

The broad block of quartzites forming the extreme western limit of the Lily Line, attains its great outcrop thickness just east of Consort Mine due to strong folding, both on a major and a minor scale. These folds deform the elongated and flattened elements of the Lily Line.

The quartzitic block near Noordkaap represents a highly sheared patch of impure Moodies rocks. The intensity of the shearing increases towards the south so that right next to the Kaap River the rock has suffered very little or no dynamic metamorphism (see Plate 21). In the latter area the quartzite is poorly conglomeratic and the pebbles that were observed are strongly flattened in planes of cleavage which cut obliquely across the bedding plane foliation. As noted by Ramsay (1963), the direction of elongation is at steep angles to the west-northwest. From between the river and the main road, sericite starts to appear and in the road - cutting the rock is nearly a pure sericite-quartz schist. The chertified greenschist type of rocks forming the "Woodstock Bar" in the extreme south of this block, and an allied "Bar" which cuts the road northeast of Noordkaap, probably represent zones of maximum shearing and probably also fault zones. van Eeden (1941) regards the "Woodstock Bar" as a mylonitized fault zone and the author agrees with this interpretation. The strong silicification can probably be ascribed to a process of secondary silicification of a mylonitized fault zone.

A striking feature of this sericitized quartzite block is the development of abundant, minute, crenulation folds with near horizontal fold axes and axial planes. These folds, occurring generally as hundreds of small, well developed crenulations in the purer sericite schists, but often simply as finer lineations in the more quartz-rich schists, pervade most of these rocks and can be detected in many places. Plate 22 is a thin section cut through a crenulated sericite schist from this area. The unmetamorphosed massive quartzites near the river have not picked these small folds up, although a series of fine lineations are well developed in some of the more pelitic pebbles close to the river.

The above structures will be discussed more fully, later.

3. Grade of Metamorphism

As with the shales and "lavas" lying south of the Kaap River, the quartzites have suffered extremely low grade, if any thermal metamorphism.

The "Lily Line" quartzites on the other hand have been recrystallized and new minerals have formed. The latter however (see page 63) are not very high temperature varieties and the mineral assemblage fits quite well into the albite-epidote-hornfels facies of Turner and Verhoogen (1960).

The quartzite block near Noordkaap is regarded as having suffered intense dynamic metamorphism but comparitively little thermal metamorphism.

4. Origin

The origin of the arenaceous Moodies rocks has been discussed at length by van Eeden (1941) so that it will not be considered here.

(e) The Nelspruit Granite

(i) Introduction

The main mass of the Nelspruit Granite lies about 1.50 miles to the north of the Consort Mine and forms the highest ridge behind the latter. Going eastwards however, the layered sequence thins rapidly and the contact swings abruptly to the south so that near Joe's Luck, it lies 4 miles almost due east of the mine.

The granite is by no means homogeneous in character, and although a detailed study was not made, two distinct types, with minor variations, became apparent at once. These are:-

1. a migmatitic variety - the dominant type.
2. a homogeneous intrusive variety along the immediate contact.

(ii) The Migmatitic Granite

The Nelspruit Granite-migmatite constitutes the dominant variety occurring in most of the area from the Consort Mine to Nelspruit, and occupies the whole tract of Lowveld country up to the Murchison Range (van Eeden - 1941).

It is predominantly a gneissic, light-grey, biotite-granite or migmatite with the gneissic banding invariably highly contorted and folded in a very confused manner (see Plates 23 and 24). van Eeden (1941) notes the occurrence of numerous bodies of dark hornblende amphibolites well within the granite outcrop area, but no such bodies were encountered in the contorted gneiss of the Consort area.

The typical gneiss consists of alternating bands of darker and lighter material, usually about a few inches wide. These, as mentioned previously, have been intensely folded and contorted in a very irregular manner and represent flowage folds (see Plates 23 and 24). Microscopically the rock consists dominantly of soda-plagioclase, microcline, quartz and biotite, the darker bands being exceptionally rich in the latter mineral. Very little hornblende is present. At no place was a sharp contact seen between gneissic granite and black contact-type amphibolites, although "ghost-like" relics consisting of rather diffuse, darker-coloured zones, and also irregular patches of nearly pure femic minerals (mainly biotite



PLATE 23 : Tight flowage folding in gneissic granite or migmatite. North of Consort Mine.

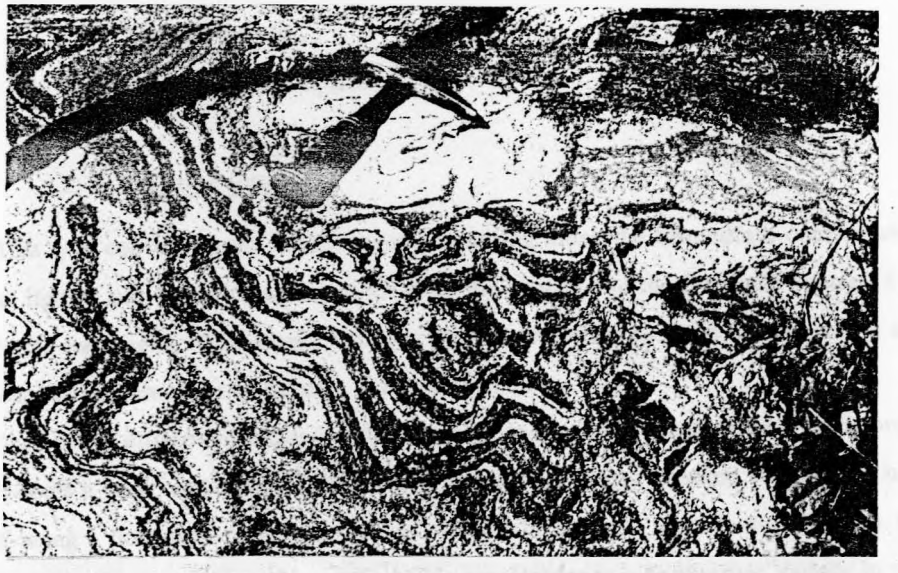


PLATE 24 : Flowage folding in well banded gneiss. North of Consort Mine.

with some hornblende), are fairly plentiful in the folded gneiss (see Plate 25).

Norm calculations (Geological Survey - Visser et. al., 1956), show the granite to be mainly quartz-dioritic and in part granodioritic.

Definite intrusive granite veins, pegmatites etc., cut the gneiss in many areas; these will be referred to in the following section.

(iii) Intrusive Granite

Along the immediate contact zone is a relatively narrow belt of more homogeneous but often intensely sheared intrusive granite and associated pegmatites. The average width of this zone appears to be about 1,200 feet, but this evidently varies quite considerably. It is difficult in many cases to demarcate the contact between intrusive and gneissic granite and there is often a zone consisting largely of gneissic granite but containing many embayments, veins etc., of intrusive granite.

The phenomena seen along the contact can only be interpreted as representing an intrusive relationship between granite and the amphibolites lying to the south thereof. This same intrusion is thought for the large part, to have caused the strong thermal metamorphism described previously.

For purposes of description, the intrusive material is divided into:-

1. foliated granite.
2. pegmatites and aplites.

1. Foliated Granite

This type constitutes the major variety occuring along the immediate contact zone. No broad bands of lighter and darker material occur as in the gneiss, and the intensely contorted flowage folds of the latter are absent. The strong foliation planes are always parallel to the contact and invariably parallel to xenoliths which occur frequently within this granite.

Two fairly distinct varieties, which often grade into each other, appear to be present. Firstly there occurs a grey, extremely well foliated and often strongly lineated variety which gives the impression of being a fine-grained type of gneiss. The main minerals include quartz, soda plagioclase, biotite, some orthoclase and microcline. The latter type grades to a porphyritic variety in which large felspar phenocrysts have often been rounded due to intense shearing, and the crystalline groundmass surrounding them has been thoroughly ground up (see Plates 26 and 27). In some places and especially noticeable in the area north of Joe's Luck rail bridge, there is a confinement of aligned biotite flakes to

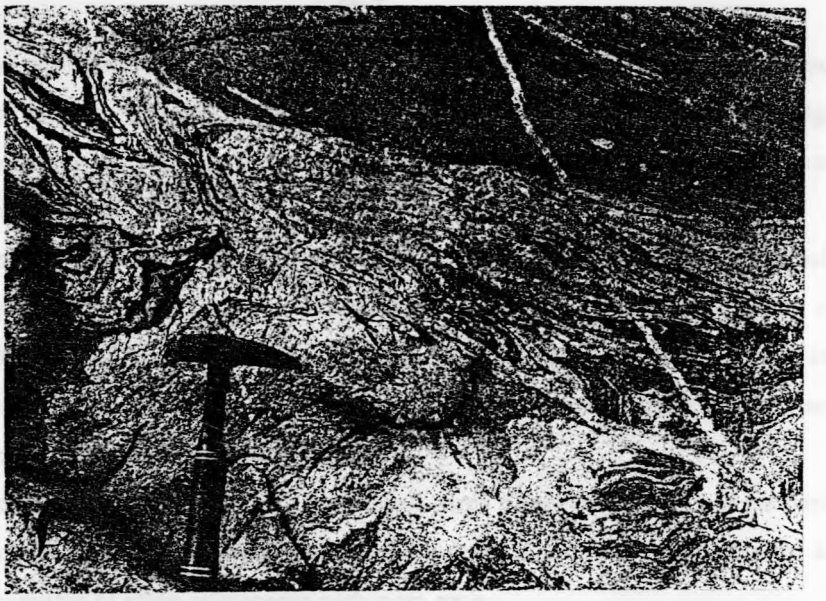


PLATE 25 : "Ghost relics" and fragments of material rich in femic minerals, mainly biotite. Nelspruit migmatite - north of Consort Mine.



PLATE 26 : Typical well foliated intrusive porphyritic granite. North of Consort Mine.

thin bands which gives the intrusive material a distinct gneissic appearance. The felspar phenocrysts, consisting normally of oligoclase, orthoclase, or microcline, are generally elongated and aligned parallel to the foliation. The latter, strongest in the immediate vicinity of the contact, tends to become weaker as the migmatite is approached.

Where intrusive masses of granite cut the sediments, they are often coarse-grained and pegmatitic in character. The main minerals occurring in the latter are orthoclase, quartz, microcline, muscovite and some plagioclase. Biotite and other ferromagnesian minerals generally occur very sparingly and these rocks are potash and soda-rich. There is always a very sharp boundary between intrusive granitic and pegmatitic sheets and the contact amphibolites (see Plates 1 and 28).

In one locality within the intrusive granites, a large olive-green body was encountered. It consists exclusively of epidote and quartz and can thus be termed an epidosite. It is thought to represent the metamorphosed remnant of some arenaceous carbonate rock.

In a few places, garnets and magnetite crystals were noted.

2. Pegmatites and Aplites

Pegmatites

The coarse-grained granites frequently grade into bodies which are definitely pegmatitic in character. In addition to the above, individual and often very coarse-grained irregular pegmatite bodies of varying size, occur in many localities throughout the area. There is an abundance of intrusive coarse-grained granitic and pegmatitic material in the Joe's Luck area and in the valley of Dicey's Creek. In the latter area, the intruded sheets have been guided to a large extent by the bedding surfaces of the metamorphosed shales and graywackes of the Fig-tree Series, so that they form a series of regular sheets and veins which seldom transgress the bedding. In a number of places these sheets have been drawn out into boudins (see Plate 29).

Pegmatites are younger than all the granitic rocks mentioned above, and are often found cutting the gneissic granite and the well foliated intrusive granite. Very coarsely crystalline pegmatites not infrequently transgress earlier formed and more finely grained pegmatite bodies. The majority of the pegmatites in the area generally consist of the following mineral combinations:-

1. quartz-albite-microcline-orthoclase.
2. quartz-albite-muscovite-microcline-orthoclase.

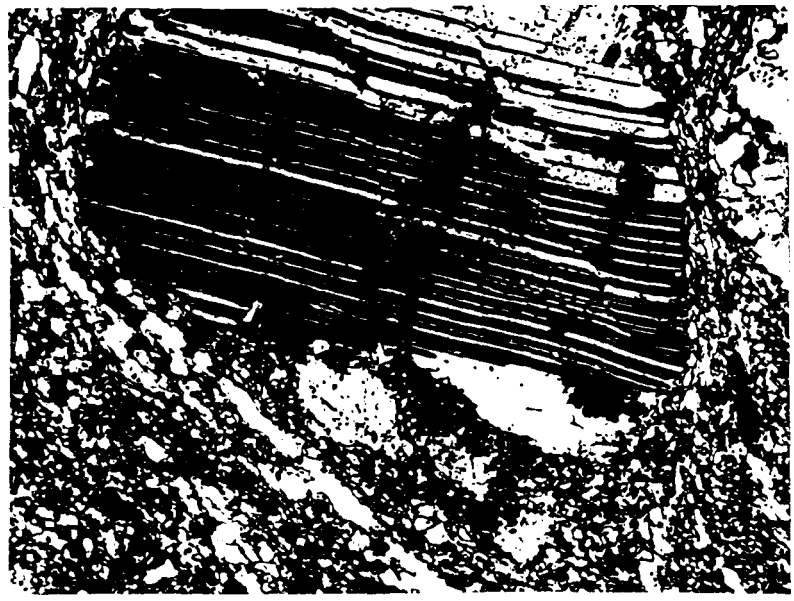


PLATE 27 : Strongly sheared quartz and felspar groundmass "wrapping" around large plagioclase crystal. Sheared, porphyritic intrusive granite. North of Joe's Luck Siding. (Crossed nicols x 75).



PLATE 28 : Well foliated intrusive granite in sharp contact with hornblende amphibolites. North of Consort Mine.

The latter are invariably the most coarsely-grained and generally occur as isolated, irregular, non-foliated masses of greatly varying size within the layered sequence. They seldom, if ever, occur as sheets and veins, the latter type of body invariably being composed mainly of quartz and felspar. The muscovite is often rather coarse-grained with individual large crystals frequently well over an inch across. Zoning is generally absent but a few of the larger bodies have well developed milky-white to slightly translucent quartz cores. Occasionally magnetite crystals were encountered, but no economic minerals such as the cassiterite, euxinite, monazite etc., of the mineralized pegmatites of Swaziland, were noted.

Aplites

Aplites are much rarer than pegmatites and only occur as narrow veins and dykelets. They are confined to the immediate contact zone and were never noted from deep within the layered sequence. The largest aplite dyke observed was not more than 18 inches wide. They are generally fine- to medium-grained and usually have a light-grey to yellowish-white colour. The rock consists mainly of quartz and oligoclase with small biotite shreds, but no hornblende. In addition, apatite and zircon were noted. There are signs of strong shearing and mylonitization.

(iv) Structure of the Granite

The typical, banded, biotite gneiss, is invariably intensely contorted and folded in a most irregular fashion. Measurements of the axial planar trace direction of these flowage folds, even over a small area, vary greatly (see Plates 23 and 24). The plunges of such folds were generally impossible to obtain. Few signs of cataclastic structures such as strained quartz grains were observed in the migmatite itself, but a few very pronounced shear zones occupied by quartz veins, lying parallel to the contact, and probably related to the updoming of the migmatite, occur (see later - page 81).

The most striking feature occurring in all the intrusive granites is the very strong foliation, always parallel to the metamorphosed layered sequence to the south (see Plate 26). This appears to be partly due to the strong alignment of its mineral components under high pressure during cooling of the granite, coupled with a later, very intense dynamical shearing. The latter led to a mechanical grinding up of the granitic material and must have occurred mainly after crystallization. The parallel orientation of both these planar features has had the effect of greatly intensifying the overall foliation. Naturally, it also makes the distinction between these two types in the field very difficult.

The strong preferred orientation of minerals (mainly mica and amphibole) in the metamorphosed sediments, has already been discussed. The granites themselves show an identical type of preferred

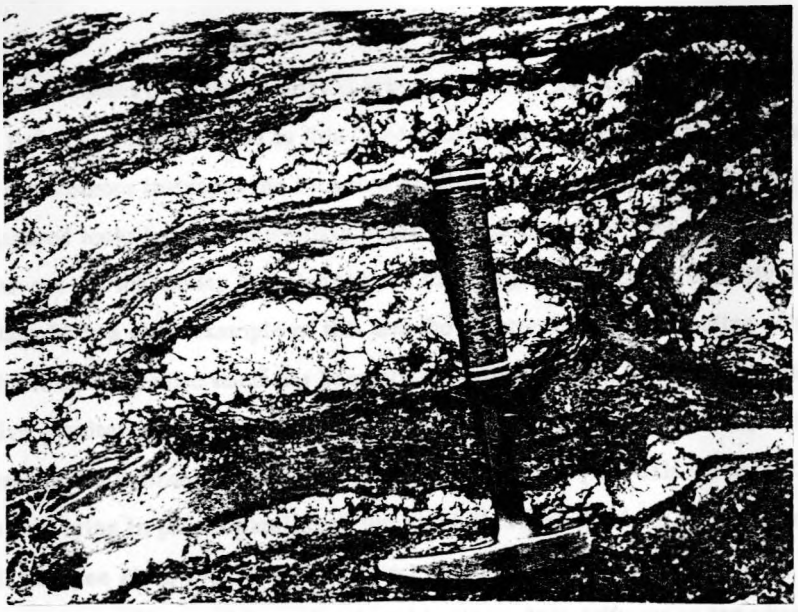


PLATE 29 : Intrusive pegmatite sheets drawn out into boudins. Hornfels in vicinity of old Cerro de Pasco Mine.



PLATE 30 : Parasitic-type folding and boudinage revealed in pegamtite vein intrusive into hornfelses. North of Joe's Luck Siding.

orientation of constituent elements (mainly micas) all lying parallel to the strong foliation of the granites. Frequently these mica flakes are concentrated in thin bands which invariably gives the granite a distinct gneissic appearance. In numerous instances the intrusive granitic and pegmatitic sheets lying parallel to the schistosity of the layered rocks have been strongly deformed and drawn out into boudins (see Plate 29). Those veins which cross-cut the schistosity and cleavage at high angles have been radically shortened, mainly by folding. Plate 30 is a good example of this and shows intense parasitic folding of a pegmatite vein. Furthermore, the foliated granite itself has been strongly folded and it is clear that the strong lineation in the intrusive granites (referred to below) is parallel to these minor fold axes. An "ac" (kinematic) section through the intensely folded core of one of these folds, reveals a very strong alignment of rock particles, all lying in planes parallel to the axial planes of the folds and representing a strong axial plane foliation (see Plate 31). From the latter photo-micrograph it is clear that the granitic material has been strongly sheared, shredded, and reduced in size. It is difficult to say whether this shearing phenomenon is intimately connected with the initial development of the fold or whether it represents a strong dynamically produced fabric imprinted on an already existing, tight, "similar"-type of fold. The author is inclined to the latter view.

The intrusive granite is often seen to be very strongly lineated as well. Lineations are excellently developed and well exposed in the bed of the Kaap River just to the north of Joe's Luck rail bridge. In the latter area, a set of fairly shallow-plunging lineations pervade granite bodies together with impure meta-sediments and lavas. They plunge to the east-southeast at about 30° and are developed in the tongues of intrusive porphyritic granite (see Plates 32 and 33). In a nearby conglomerate, the "a" direction of deformed and elongated pebbles parallels this lineation and indicates that it has resulted essentially from an elongation of elements within the rock.

In other parts of the area a similar type of lineation is developed in well-foliated, non-porphyritic gneissic-type of intrusive granite. These lineations plunge at moderate to steep angles to the south.

For the production of lineations of the kind depicted in Plates 32 and 33, a primary foliation must have existed in the granite. This primary foliation is probably to be found in the aligned mica flakes, concentrated in thin bands within the intrusive granites, as mentioned previously. As shown before, these lineations are intimately connected with some of the folds which might be of a cataclastic type. If this is the case, then the lineations would also have formed during the period of cataclasis (see below).

The dynamic process of mechanical deformation, which must have taken the form of intense shearing, was apparently superimposed on the already existing schistosity and cleavage. It is very marked in the granites, and in most places the whole intruded mass is evenly sheared. Often though, the intensity



PLATE 31 : Well developed axial plane foliation in folded intrusive granite. North of Joe's Luck rail bridge.

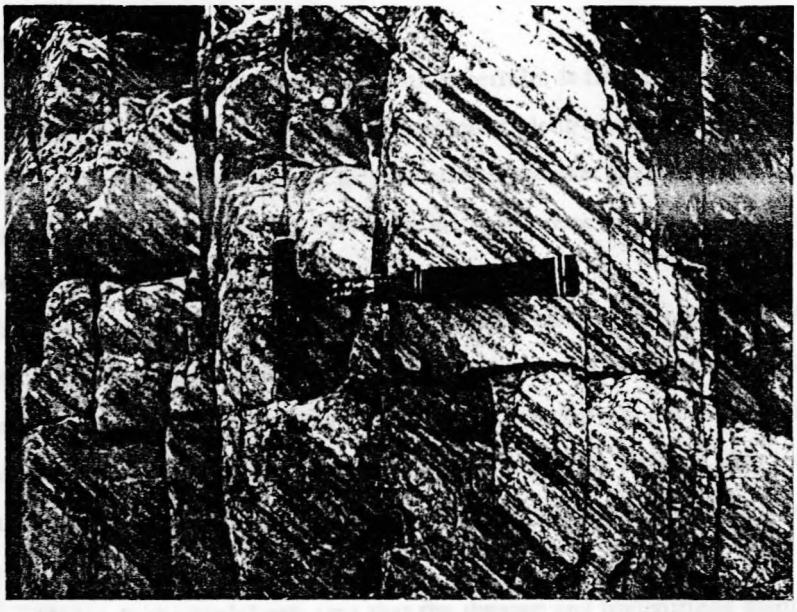


PLATE 32 : Intensely lineated intrusive granite. Handle of hammer indicates strike of foliation. North of Joe's Luck Siding.

of the movement varies, and in such cases, severe shearing is confined to fairly distinct bands or zones. Invariably it has been strong enough to have completely obliterated the earlier schistosity and cleavage.

These granites are good examples of originally fairly coarsely crystalline rocks, that as a result of shearing, involving an intimate breaking-down of the solid rock with internal slipping, have been converted into what may almost be termed mylonites in places. The typical sheared granite consists of relatively large and more or less lenticular relics of plagioclase crystals all with one general orientation (see Fig. 8 and Plate 26). These lenticular remnants which are invariably plagioclase, but may also occasionally be quartz crystals, vary in size from about nearly an inch down to microscopic dimensions where fragmentation has been more intense. The uncrushed lenticular crystal masses give the rock a characteristic "augen" or "eyed" structure, the lenticular shape being the most suitable for resisting further crushing under the particular type of strain.

Under the microscope the process of grain reduction is very evident and frequently large felspar crystals occur in an extremely fine-grained matrix of completely broken-up rock fragments which invariably "wrap" around the large lensoid "augen" felspars (see Plates 27 and 34). When the "augen" themselves are ground down and disappear so that the rock consists exclusively of very fine fragments, it could easily be termed a mylonite. This occurs rarely in the area, but often the groundmass if so fine that in hand specimen it resembles a chert.

A substantial amount of fine-grained muscovite or sericite is frequently present and is aligned parallel to the planes of shearing. Some of this mica is developed along surfaces of slipping and very strong shearing and it seems probable that much of this material represents the product of intense dynamic metamorphism of original felspar. This also appears to be the case where sericite flakes "wrap" around large, rolled felspar crystals (see Plate 27).

The whole process is considered to be a purely dynamic one which took place under "cold" conditions. Although the newly intruded granitic material must have still been under a fairly high temperature when the dynamic metamorphism was initiated, it was definitely not in a plastic state. Although a certain amount of recrystallization must have taken place, this was on a very localised scale and probably confined to the micas. From the above it seems very likely that a certain amount of local retrograde metamorphism must have taken place.

There is evidence in the Joe's Luck area that the sheared and mylonitized granites themselves, have been strongly folded.

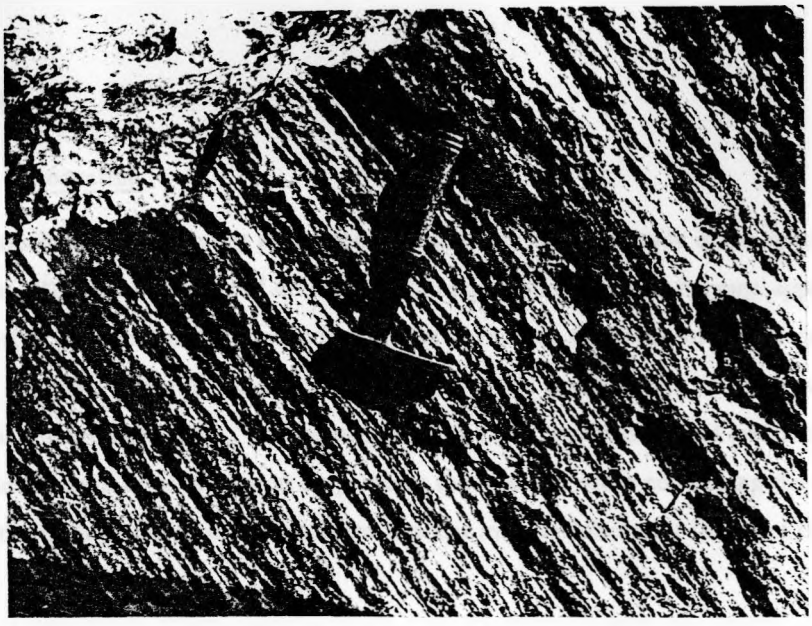


PLATE 33 : Intensely lineated intrusive granite. North of Joe's Luck Siding.



PLATE 34 : Fine-grained, sheared quartz and felspar groundmass "wrapping" around large, rounded, lensoid felspar crystal. Sheared granite north of Consort Mine. (Crossed nicols x 75).

(v) Origin

1. Introduction

It must be stressed from the outset that a specific and very detailed study of the granitic suite in the area was not made. During the course of detailed field mapping however, it became apparent that a number of very distinctive yet peculiar features exist. These have been described in the foregoing sections, and in any theory which attempts to cast some light on the origin of the granite, they must be satisfactorily accounted for. The most important features, representing mainly field observations and relationships, are given below and are followed by a brief discussion on previous theories and ideas concerning the origin of the granites. Finally a theory is proposed which seems to account most satisfactorily for all of these observed facts.

2. Features Considered Important in any Theory Concerning the Origin of the Granite Suite

(i) Most of the granite is best described as a biotite gneiss or migmatite. It is a typical deep-seated migmatite, well banded, and intensely folded, the latter being of a flowage type.

(ii) Numerous basic hornblende-amphibolite bodies occur within the granite. They are well banded and foliated and small folds are often developed, but the intense flowage folding of the gneiss is never apparent.

(iii) The gneissic granite seldom seems to be in direct contact with these amphibolite bodies and the latter are certainly never intimately associated with, and folded together with the migmatites.

(iv) Classic intrusive relationships occur all the way along the contact, but the intruding material is much more homogeneous in composition and very different from the contorted migmatites.

(v) There is always a sharp contact between intrusive granite and the intruded rocks. All the black amphibolite xenoliths occur in the zone of intrusive granite and there is very little sign of contamination of either.

(vi) The rocks along the contact have been strongly thermally metamorphosed and this metamorphism appears for the most part to be related to the intrusive granites rather than to the contorted gneiss.

(vii) A strong foliation, due mainly to an alignment of crystalline components, is present in the intrusive granite right the way along the contact and this parallels the latter.

(viii) There is abundant evidence of a very strong mechanical deformation or shearing in most places along the immediate contact zone.

(ix) The layered rocks of the Mountain Land show no signs of regional metamorphism; they represent high level sediments which could never in their history have been covered by a very thick layer of superincumbent rock.

3. Previous Theories and Ideas Concerning the Origin of the Nelspruit and Swaziland Granites

Hardly any detailed work has been done on the Nelspruit Granite, but on the Swaziland side of the Mountain Land, the last few years have seen a very extensive examination of the complex granitic suite in that territory, (Hunter, 1961).

A number of writers have expressed the view that the bulk of the Nelspruit gneiss represents the granitized equivalent of the Swaziland and Moodies Systems. van Eeden (1941) suggests that large quantities of Archaean System rocks, including also Jamestown rocks, must have completely disappeared into the gneiss as a result of granitization. He considers the homogeneous stock-like mass of M'pageni Granite to be a younger intrusion representing possibly a deep phase of the Nelspruit Granite. He concludes that distinctly different phases of the Nelspruit Granite exist and that the shallower portions are gneissic as a result of incorporation of older rocks whereas the deeper portions are more homogeneous and closer to true magmas.

Read (1956) is also of the opinion that much of the Nelspruit gneiss represents granitized Archaean System rocks and suggests that the abrupt passage from the regionally metamorphosed gneiss to the unaltered layered rocks, might be due to resisters in the form of basic rocks which set up barriers against the metasomatizing agents. He mentions the possibility that basic bodies lying deep within the granites might also represent basic resisters.

Hunter (1961) has shown that granitization of Swaziland System sediments has definitely occurred and is responsible for many of the gneisses in Swaziland. In almost all cases described by Hunter, the gneisses are very regular, dip conformably with, and grade into the less intensely metamorphosed Swaziland System sediments which overlie them. At least three different ages of intrusive granites, derived essentially from the older gneissic granites, are known in Swaziland.

Ramsay (1963) expressed the view that much of the Nelspruit gneiss and the gneisses of Swaziland formed a fundamental basement complex on which the layered Archaean System rocks were deposited. The contact phenomena and the local metamorphism around the edge of the Mountain Land are considered to be due to another younger intrusive granite.

4. Theory of Origin of the Nelspruit Granite Suite

The author is of the opinion that the typical Nelspruit migmatite represents for the most part, the "basement" upon which all the layered rocks of the Mountain Land were deposited. The intensely folded and strongly banded gneisses are considered to represent the granitized remnants of some pre-Swaziland formation, now completely granitized.

In the cases of granitization of Swaziland System rocks cited by Hunter (1961), the gneisses are always described as being very regular, dipping conformably with, and grading into less intensely metamorphosed sediments. No such phenomena were encountered by the author on the northern side of the Mountain Land. Hunter apparently makes no mention of a gradation from an intensely contorted gneiss of the kind shown in Plates 23 and 24 to definite Swaziland System sediments, and it is suggested by the author that none exists and that the contorted gneisses represent much older rocks, in fact the original basement.

It is extremely difficult to visualize how the great pressures which must have been operative to produce a contorted gneiss or migmatite of the type depicted in Plates 23 and 24, and which must have converted vast quantities of sediments into gneisses, could have left others only a mile or so from the contact, completely unaltered. Read (1956) has suggested the basic resister idea as an explanation. However, the author finds this difficult to visualize. In the first place the change from an intense plastic type of flowage folding to a regular layer sequence where cleavage is developed, within as little as a half a mile in many cases, is considered to preclude this. In addition, where the basic rocks are poorly developed, the increase in extent of the metamorphic aureole within the other rocks is barely noticeable. It is also inconceivable how the typically high temperatures and pressures associated with the huge wave of intense regional metamorphism and granitization, could be so abruptly halted by a meagre layer of basic rocks which in places does not even exceed 0.50 of a mile. In true granitization areas, the passage from a gneiss to a relatively unaltered sediment usually occurs over many miles and all rocks in any way connected with the granitization process, show signs of high grade regional metamorphism.

The comparitively small metamorphic aureole is considered to have been caused essentially by heat effects of the intrusion of a relatively small strip of mobilized granite (coupled with the effects of a partially remobilized basement migmatite) than by a tremendous wave of granitization.

The possibility has been suggested by Read (1956), that the large amphibolite bodies lying deep within the granites, might also represent basic resisters. If these were true basic resisters within a layered suite of rocks, one would have expected to find that these bodies had been intensely folded and contorted together with the presumably more shaly and sandy layers, now represented by the strongly folded

gneiss. More basic patches do indeed occur in the migmatite, but these are more in the nature of contorted "ghost" relics, representing rather diffuse patches rich in femic minerals (usually biotite), and considered to be more-basic phases in the granitized pre-Swaziland System suite (see Plate 25). On the other hand, the large "rafts" of well banded and uncontorted black amphibolites, which in the Consort area show very little sign of contamination or alteration and are always in sharp contact with the intrusive granites, are very different from the rather small, diffuse patches of biotite within the migmatite.

These amphibolitic "rafts" are identical in all respects to the black contact amphibolites occurring at the base of the Onverwacht Series and described previously. It is tentatively suggested that they represent "outliers" or "islands" of the lower-most succession of the Onverwacht Series rocks which were deposited on, and originally extended over much larger tracts of the gneissic basement in a number of areas. It is thought that these bodies, which trend parallel to the length of the fold belt, might represent downfolded synclinal remnants of the original more extensive sheet which were folded with the other layered rocks of the central part of the Mountain Land about northeast - southwest trending axes. It also seems probable that the folding may have been accentuated due to down-sagging of the amphibolites into the re-heated and semi-plastic migmatite, coupled with differential updoming of the latter in places. This updoming and intrusion or emplacement of migmatite and mobilized migmatite, appears to have played quite a substantial role in isolating these amphibolite "rafts", and divorcing them completely from the edge of the compact layered sequence of the Mountain Land proper. The early stages of this process are possibly to be witnessed in the area north of Joe's Luck, where extensive intrusion of granite and pegmatite has definitely had the effect of "forcing apart" and isolating some fairly large patches of Swaziland System rocks (see Fig. 2). Naturally the structure of these outlying amphibolitic bodies and their exact relationship to the migmatite will have to be carefully investigated to establish the validity of the above suggestions. The present high grade metamorphic state of these basic rocks, as with the contact-type amphibolites which they closely resemble, is ascribed to the effects of the younger granites (which in many cases intrude these rocks) together with the heat that must have been liberated from the partially mobilized basement migmatite.

Evidence that the migmatites were in a plastic state is afforded by the fact that the "flow bands" in the close vicinity of the contact (van Eeden, 1941), extend parallel to the length of the Mountain Land. This parallelism, not very marked away from the contact, becomes more pronounced as the latter is approached, and reaches its optimum development in the strongly foliated intrusive granites along the immediate contact zone. This feature is ascribed to a "moulding" effect that the strong deforming pressures had on the semi-plastic migmatite, together with strong differential movement parallel to, and more or less confined to the intrusive granite along the immediate contact zone as the migmatite moved up. (See later).

The question now remains as to the origin of the intrusive granite. It is the author's contention that this material represents the most mobilized part of the re-heated and plasticized Nelspruit basement migmatite, and that the presence of this strip of granite along the immediate contact zone, as well as the fabrics developed in it, are all features related to the updoming of the main body of migmatite.

Under certain conditions of very high pressure, mobilization of the migmatite occurred at depth. In the first instance, a migration of volatile material to the cooler margins of the reheated migmatite, i.e. towards the Archaean System sediments, occurred. This phenomenon has been discussed by Kennedy (in Poldevaart, 1955), and shown to hold for many magma chambers. The outward migration and concentration of volatiles facilitated the greater mobility of the granitic material in this border zone, which as a result became completely eruptive.

At about this time, and probably synchronous with the mobilization, updoming of the main body of the migmatite occurred. This resulted in a strong differential shear movement, invariably along the border zone of migmatite and layered rocks, and it was into this zone that the palingenetically eruptive material, already concentrated along the border area, as shown above, found an easy avenue of movement and access to lower temperature and pressure areas higher up.

The above does not mean that the intrusive material is solely restricted to the border zone and it seems very likely that detailed mapping of the Nelspruit granitic suite, will reveal many more comparible intrusive granite bodies.

There still remains the explanation of the very marked foliation in the intruded granitic material. It is best explained by regarding the updoming of the migmatite mass as a continuous process which in the initial stages, as pointed out above, created zones of differential shear close to the contact along which intruding material moved. The strong "guiding" effect that these planes of differential movement must have had on this material, is thought to have been largely responsible for the planar alignment of the minerals (especially the micas), as the granite cooled.

After crystallization of the intruded material, the updoming process continued and strong shearing along zones of differential movement caused the grinding and near mylonitization in places, which is such a marked feature of these granites. At an even later stage, the culmination of the updoming caused strong folding of the already strongly sheared rocks, and is thought to have caused the major 3rd age folds so well developed in the Consort area, and correlated with the major inflection of the Eureka and Ulundi Synclines. It is the author's opinion that the emplacement or updoming of the Kaap Valley Granite occurred at this stage as well.

The Nelspruit granitic suite bears a marked similarity to Read's Granite Series (1956). The majority of the folded and contorted gneisses and migmatites appear to be identical to his autochthonous

granites. However, considering the fact that these migmatites have been mobilized to a certain degree and have probably moved up a certain amount, they may be closer to his parautochthonous granites. The mobilized granitic material might well represent the first stages of development of the high level intrusive granite plutons which represent the final stage of the series. According to Read (1956) early members of the series tend to be deep-seated and granodioritic in composition, whereas late members tend to invade the upper levels and have a more potassic composition. Norm calculations done on two samples of gneiss (Geological Survey, Visser et. al., 1956), show it to be quartz-dioritic and granodioritic. Although no analyses of the intrusive granite along the contact exist, a microscopic examination shows them to be comparitively richer in potash and soda.

(f) Metamorphism produced by the Granite

It is the author's opinion that much of the thermal metamorphism in the area has been caused by the intrusion of a mobilized border phase of the Nelspruit migmatite. At the time of this mobilization, the whole basement must have been reheated and plasticized to a certain extent and undoubtedly played some part in the metamorphism as well, but what exact effect this "background" heat had, is not known. For some inexplicable reason, very little if any thermal metamorphism can be ascribed to the emplacement of the Kaap Valley Granite.

By examining the mineral assemblages in successive stages away from the granite, it was possible to subdivide the area into three distinct facies of contact metamorphism (see Fig. 4). Starting at the granite contact and moving progressively away from it, these facies are:-

1. the hornblende-hornfels facies.
2. the albite-epidote-hornfels facies.
3. the greenschist facies.

Each of the above has been treated more fully earlier in the report. Suffice it here to mention the overall distribution of the facies and the most important metamorphic minerals in each.

1. Along the immediate contact zone is a mineral assemblage characteristic of the hornblende-hornfels facies as defined by Turner and Verhoogen (1960). The characteristic minerals are dark hornblende and plagioclase of intermediate composition, together with garnet, diopsidic pyroxene and sillimanite. At one locality within the high temperature aureole is a rock containing a substantial amount of corundum together with sillimanite and tourmaline.

The presence of sillimanite in some of the quartzitic horizons close to the granite contact, together with bands of diopsidic pyroxene within the hornblende amphibolites in the same area, probably indicate that, where the composition of the original rocks was suitable, temperatures were locally high enough to have formed minerals characteristic of the higher grade pyroxene-hornfels facies of Turner and Verhoogen (1960).

2. To the south of this, including the Consort Mine area, and bounded roughly by the Main Southern Fault on the north side of the Kaap River, is an assemblage of lower temperature minerals, including tremolite-actinolite, biotite, diopside, garnet and andalusite, which is typical of the albite-epidote-hornfels facies of Turner and Verhoogen (1960).

3. Finally, along the Kaap River, and extending to just south of the Woodstock Mine and Noordkaap, is an assemblage consisting dominantly of carbonate-bearing talc and chlorite schists with minor occurrences of tremolite, all characteristic of the greenschist facies as defined by Ramberg (1952).

South of this in the "lavas", shales and quartzites of the Eureka Syncline, and in dolomitic or slightly talcified dolomitic rocks around Clutha Mine, the effects of contact metamorphism are invariably absent or at the most, very slight.

It appears very likely that the strong mechanical deformation of the crystallized granite and of some of the metasediments to the south thereof, has caused a certain amount of retrograde metamorphism. This is well revealed in zones of intense shearing where it is clear that much of the original felspar has been broken down to sericite. In general however, this retrograde process appears to be more or less confined to local zones of intense shearing, and it is not considered to be a very widespread phenomenon in the area.

The marked absence of regional metamorphic effects within the Mountain Land, suggests that the Barberton rocks, as old as they may be, were never buried beneath a great stratigraphic cover in the past.

(g) Dykes

(i) Introduction

Various different and distinct varieties of hypabyssal rocks in the form of dykes, occur in the area. Where they cut the granite, the dykes invariably stand out very clearly, often as a low ridge of black boulders in strong contrast to the light-coloured granite. Some varieties weather to a slight depression in the granite, but in all cases they are marked by a narrow line of bushes.

In other rock-types occurring in the area, and especially in lower lying and flatter ground,

the dykes are not apparent and are generally only known from road and rail cuttings, and from where the Kaap River and tributary streams and gullies have cut and exposed them.

The dykes generally conform in strike to definite directions and the majority in the area strike about north-northeast to northeast, controlled by a fairly pronounced direction of jointing in the granite. A few strike roughly north-south and others occur as structureless circular to ovoid bodies with no extension in any particular direction.

Four main varieties occur in the area, viz:-

dolerite dykes
gabbroic dykes
diabase dykes
amphibolite dykes.

(ii) Detailed Descriptions of the Dykes

1. Dolerite Dykes

Only a few such dykes were encountered in the area. Close to the old road over Bullion Hill, a thin ridge of black boulders marks the position of a fairly persistent dyke. Close by occurs another, and exposed in the Kaap River to the west of Joe's Luck Siding is a small outcrop of dolerite.

The dolerite is characterized by its remarkable freshness. It consists typically of felspar and pyroxene, the former being the most abundant. The plagioclase, occurring as elongated crystals, is labradorite and the pyroxene is of a composition close to pigeonite. Small grains of magnetite and a few ragged chlorite cyrstals are usually observed. A typical ophitic texture is invariably developed. These dykes follow the north-northeast - northeast direction and are regarded as being of Karroo age.

2. Gabbro Dykes

A very coarse-grained dyke, resembling more a plutonic than a hypabyssal rock, runs in an east-northeast direction a few hundred yards west of the hydro station at Joe's Luck. The dyke is about 40 feet wide where it cuts the granite, and forms a marked, bush-lined depression in the latter. Southwest of this it is only sporadically exposed where it has been uncovered by streams, gullies and the Kaap River. van Eeden (1941) describes the same dyke as running from the Sheba Mine area right up to the M'pageni beacon, well to the north of the area.

It is composed of fairly fresh, coarse-grained plagioclase of labradorite composition, together with a fairly coarse-grained monoclinic pyroxene which in places is altered to actinolite. Biotite flakes, often partly altered to chlorite, as well as some quartz and accessory apatite and magnetite, are also present. This dyke is probably also of Karroo age.

3. Diabase Dykes

Most of the other dykes in the area are of a diabasic composition. On freshly exposed surfaces they can usually be distinguished by the prevalent shades of green. The variation between different types is sometimes considerable, but they all contain minerals that are extensively altered.

Most contain ortho and clino-pyroxene, often partly or completely altered to pleochroic green actinolite. Plagioclase of about andesine composition is present, invariably showing extreme alteration to sericite. Associated alteration products usually include epidote, pleochroic chlorite, magnetite and in a number of cases, talc and carbonate.

Exposures are generally poor, but the dykes occurring in the southern part of the area trend roughly north-south. In a dyke exposed in a road cutting just east of Noordkaap, minor crenulation folds were observed. These dykes are apparently not deformed by the 1st three major periods of deformation, but the presence of crenulation folds in them, suggests that they might be pre-4th or final phase of deformation.

4. Amphibolite Dykes

Immediately south of the Joe's Luck rail bridge, and also in the area to the east of number 7 Shaft of the Consort Mine, occur two peculiar round to ovoid patches of a greenish, massive dyke-rock. From their shape and field distribution they do not resemble dykes. However, under the microscope, they contain distinct traces of ophitic texture. One is composed almost entirely of a green pleochroic amphibole which is probably actinolite, and the other consists of actinolite in addition to some extensively sericitized plagioclase.

These highly altered dykes are regarded as being pre-metamorphism in age.

(h) Quartz Veins

Two very long and extremely well developed quartz veins and numerous smaller ones, occur in the area.

Cutting right across the southern part of the region just north of the Kaap River, is a very well developed vein occupying the position of a high angled thrust fault, (the Main Southern Fault), which might be a bifurcation of the Lily Fault (see later). The vein cannot be traced continuously right across the area, but for the most part it forms a resistant bush covered ridge of milky white quartz. It is exceptionally well developed in the area to the east of number 7 Shaft and again further to the east towards the Joe's Luck hydro plant where it forms a fairly prominent feature cutting across flat and low lying lands. In between these two main areas, minor occurrences of the same vein - quartz occur at intervals. Where well developed, the vein averages about 10 - 25 feet wide and is often in the form of a sheeted vein with abundant quartz veinlets and stringers in the rock adjacent to a pure quartz core. These stringers diminish fairly rapidly however, as one proceeds from the central part of the vein. The whole sheeted mass dips steeply to the south.

Within the migmatite to the north of the area, a very well developed white quartz vein, extending right across the area from east to west, is found. It reaches dimensions of over 10 feet in width and runs parallel to the contact. It occupies the centre of a zone of intense shearing which is probably related to the updoming of the migmatite (see previously).

Within the contact amphibolite zone, white quartz veins are exceptionally abundant. They are never of large dimensions and occur typically as rather thin bodies parallel to, or cutting across the foliation. At odd localities throughout the area, quartz veins of no special note are also present.

Found in many quartz veins and especially abundant in a thick sheeted vein on the north side of the most northerly quartzite horizon, and in close proximity to the granite, is a dark-brown tourmaline, invariably of the schorlite variety. The large tourmaline-bearing mass is in the form of a sheeted vein with stringers of milky white quartz, vitreous quartz and brown tourmaline. These white veins are barren of mineralization.

Associated with the Consort "Contact", and occurring at times in shaly horizons, are small stringers and veinlets of vitreous, transparent to transluscent quartz, often with a blackish or blueish hue. Mineralization often seems to be associated with this type of quartz.

(i) Recent Deposits

(i) River Terraces

Three fairly distinct but relatively low lying terraces, all associated with the Kaap River, appear to be present. These are, viz:-

a low, very recent, unconsolidated boulder and sand terrace.

a higher ouklip and calcrete terrace.

an older and still higher, large, soil covered terrace.

The most recent terrace, invariably well developed on the concave side of large bends in the Kaap River, consists of large rounded boulders of all types, together with unconsolidated pebbles and sand. It is generally about 5 feet high and in most places forms part of the present flood channel of the river.

This terrace passes gradationally or sometimes fairly abruptly upwards to a higher terrace, generally in the form of very well developed ouklip bands exposed at various points along the river. They consist typically of a rather coarse, impure lateritic type of groundmass with rock inclusions of all types, shapes and sizes.

Lying slightly above the former in the close environs of the river, are large tracts of fertile alluvium which are suitable for agricultural purposes. These flat, low-lying areas are thought for the most part, to represent a higher, much older, soil covered alluvial terrace.

(ii) Scree and Soil

Fairly thick accumulations of partly soil-covered scree slopes are found on most of the steep hillsides. Many large angular blocks of tallus characterise the slopes adjacent to the more resistant quartzitic horizons. The soil over most of the area, developed mainly on basic rocks, shales and "lavas", is very fertile, but steep slopes usually preclude cultivation. In the flatter areas approaching the Kaap River, fertile soil-covered slopes occur and in the immediate vicinity of the river as mentioned, flat, fertile alluvial and soil covered terraces are invariably found.

C. GENERAL STRUCTURAL CONSIDERATION OF THE AREA

(a) Introduction

Most of the structural features encountered have already been described or mentioned in the first section under the description of rock-types. What follows is a more detailed and methodical statistical treatment of the minor structures observed. From these results an attempt is made to unravel the tectonic history of the area and to fit it into the regional structural pattern of the Mountain Land as a whole.

The structural terminology used in the report is that defined by de Sitter (1956), Weiss (1958) and Ramsay (1962, 1963). The significance of small-scale linear and planar structural features, especially as they apply to the Barberton area, have been discussed by Ramsay (1963), so that only a brief mention of structural parameters encountered in the area is given below.

(b) Structural Parameters Observed and Measured

Besides the systematic measurement of strike and dip of bedding, the following structural parameters were observed and measured:-

(i) Minor, small-scale, crenulation folds with amplitudes varying from a fraction of a mm. up to about 2 cms. in size. Where the folds are larger, the attitudes of fold axes as well as axial planes were measured. Where they are developed on a very small or micro-scale, the fold axes appear as a set of fine parallel lines, and in such cases, the latter were simply measured as lineations.

(ii) Intermediate size folds with amplitudes generally of the order of a few inches to several feet. In such cases the attitudes of fold axes and axial planes were measured.

(iii) Conjugate folds varying in size from a few cms. to over a foot. The fold axes and the axial planes (representing the two conjugate shear surfaces) were measured.

(iv) The following types of lineations:-

1. microfold axes.
2. elongated rock particles; e.g. deformed conglomerate pebbles.
3. mineral orientation.

(v) The following types of foliation or planar rock fabric:-

1. planes of shearing.
2. cleavage, corresponding to planes of flattened rock particles.
3. schistosity.
4. shear cleavage corresponding to axial planes of minor crenulation folds.

(c) The Main Structural Features of the Area

Before entering into a more specific and detailed account of the smaller scale structural features in the area, it is important at this stage to consider the major overall structural entities. These, due to their very large scale, do not become obvious in a small area where it is impossible to obtain a

synoptic view, and their precise form and nature is thus deduced mainly from evidence in adjoining areas.

The Consort area is conveniently divided into two main structural units separated by a major high angled thrust fault, the Main Southern Fault. To the north of this fault occurs a complete and conformable, steeply south-dipping and fairly strongly thermally metamorphosed succession of Swaziland and Moodies System rocks. South of the Fault is found an identical southward dipping succession, the only main difference being that these rocks have suffered very little thermal metamorphism.

The southern succession forms part of the northern limb of the Eureka Syncline whereas the succession north of the fault forms the northern limb of the Lily Syncline (see Fig. 2a). The latter is best known from the area near Louw's Creek, but from here westwards towards the Consort Mine (see Fig. 1) a major fault (which is thought to be an extension of the Main Southern Fault) truncates this Syncline, probably just to the south of its steeply south-dipping axial plane. This has resulted in the exposure of basic rocks of the Onverwacht Series to the immediate south. As can be seen from Fig. 2a, the anticlinal area between the two major synclines has been largely erradicated due to this fault.

Thus, although no direct evidence exists in the area, it is clear from the above that the steeply dipping strata represent the limbs of large synclines. These folds made by far the strongest imprint and all other phases of deformation are invariably on a much more insignificant scale.

D. DETAILED STRUCTURAL DESCRIPTION OF THE AREA

(a) Method of Treatment

It was found convenient for purposes of description and understanding, to divide the area into three fairly distinct structural zones, viz:-

(i) the Consort Mine area, bounded in the north by Dicey's Creek and in the south by the major east-west trending Main Southern Fault mentioned previously. The area extends for about two miles east of the mine.

(ii) the southern part of the area, south of the Main Southern Fault.

(iii) the so-called "footwall" rocks of the Consort Mine and the whole granite contact zone.

Each of the above zones is characterized by the very good development of one or more styles or types of deformation. This does not imply that if a certain style of deformation attains its optimum development in one particular zone, it is absent from the others. On the contrary, all four phases and styles of deformation can generally be recognised in all three zones. However, as stressed above, one or

two of these styles are exceptionally well developed in each zone.

A summary of Ramsay's (1963) findings, as well as a general summary of the author's findings, has been given earlier. Slight differences in interpretation however, exist between the two. To help clarify the following sections therefore, a brief comparitive summary of Ramsay's findings and the conclusions of the author, will be given first.

In the more detailed account of the three main zones which follows, the major structural features in each zone (where developed) are described first, followed by the deductions made from these. The minor and micro structures are dealt with in a similar way, and in the light of all the above, conclusions are drawn as to the number of phases of deformation present in a particular zone. These are all correlated and compared in more detail with Ramsay's findings. Finally, the structures observed or deduced from all three zones are correlated, and the overall structural history of the area given.

(b) A Brief Comparitive Summary of the Findings of Ramsay (1963) and the Author

Ramsay recognised 3 main phases of deformation in the Mountain Land, with a possibility of a 4th one. The author is of the opinion that 4 distinct phases of deformation are present. The first two agree with the two first deformations of Ramsay, but evidence of two additional phases, representing subdivisions of Ramsay's 3rd and final phase of deformation, exists.

A tabulated summary of the phases of deformation recognised by Ramsay, and those recognised by the author in the Consort area, is given below.

Phase	J. G. Ramsay	Consort Area
1	Major folding about northeast - southwest	Major northeast - southwest folding. Formation of Lily and Eureka Synclines. Deduced mainly from evidence outside the area.
2	Intrusion of granite and metamorphism. Development of cleavage, lineations etc., shearing.	Intrusion of granite and metamorphism. Development of cleavage, lineations etc., shearing.
3	Consort folds, refolding of main synclines, crenulation and conjugate folds.	Main Consort folds, refolding of main synclines.
4	?	Crenulation and conjugate folds.

All future reference to periods of deformation, unless otherwise stated, will be to the 4 main phases recognised in the Consort area.

(c) Zone I - The Consort Mine Area (See Fig. 5)

This is by far the most complex zone. Due to poor exposures in the rather critical immediate mine area however, interpretation is made difficult.

(i) The Major Structures

1. Major Folds

The Main Consort Folds

Previous work (Hearn, 1943; v. d. Berg et. al., 1946) has shown that the area is complexly folded. Numerous large folds occur with axial planar traces striking roughly south-southeast and with axes plunging at variable angles in the same direction. These folds and their associated smaller folds, form by far the strongest structural feature of Zone I. The folds from north to south are:- (Fig. 5)

The Top Section Syncline
The Prince Consort Syncline
The No. 7 Shaft Anticline
The No. 3 Shaft Syncline.

The Top Section Syncline

The Consort "Contact", trending east-west and exposed along the northern side of Dicey's Creek, together with the hanging wall hornfelses, swing south in the northern part or Ivaura Section of the mine, to form the Top Section Syncline. This is a rather tight fold, apparently overfolded to the northeast and truncated at an oblique angle in the southern part by the major Bluejackets Fault.

The Prince Consort Syncline

South of the Bluejackets Fault occurs the largest and best exposed of the major folds, viz:- the Prince Consort Syncline. Due to good exposures and the apparently regular nature of this structure, a detailed and systematic measurement of the dip and strike of the folded bedding at 90 different points around the syncline were made. The poles to these bedding planes were plotted on an equal area net to give the contoured pye diagram depicted in Fig. 6. As can be seen, a very irregular pattern emerges, the significance of which will be discussed later.

As seen from the outcrop pattern and as indicated by strike changes of bedding in the field, a few smaller folds are associated with the main syncline, e.g. Betty Quarry Anticline.

No. 7 Shaft Anticline

In the southern part of the area occurs the main No. 7 Shaft Anticline. It is complicated in the area between the mill and the main mine entry point (viz: 8 Level Prince Consort (P.C.) adit) by a series of fairly large synclines and anticlines e.g. the Hard Cash Anticline and Shires Anticline. These folds occupy a position at the crest of the main No. 7 Shaft Anticline, and as with all the main folds, plunge to the southeast. On surface these folds are very poorly exposed, covered for the large part, by scree, and they are thus mainly known from underground workings.

No. 3 Shaft Syncline

The No. 3 Shaft Syncline is apparently a very broad, open syncline which occurs for the most part to the southwest, and out of the limits of the area mapped. Part of its northern, south-dipping limb, is represented by a series of southward dipping graywackes exposed in the area from just south of No. 6 Shaft to the North Kaap River. From evidence obtained outside the area mapped, and from the occurrence of a small patch of "lavas" on the immediate north bank of the river, it seems likely that the synclinal axial trace strikes about northwest and passes roughly under the bridge over the North Kaap River. Furthermore, the occurrence of basic rocks immediately south of the river seems to indicate that a large fault, which could possibly represent the western extension of the Major Southern Fault, occupies a position close to the axial plane of this syncline (see later).

In general, the axial planes of the above folds appear to be nearly vertical, or slightly southwest dipping. The fold axes have a variable plunge to the south-southeast. Fig. 5a represents section AB of Fig. 5 and shows the irregular nature of three of the above major folds as revealed by underground workings of the Consort Mine.

Other Large Folds

It is difficult to trace these major folds eastwards, but about 0.50 of a mile east of the mine, a number of fairly large anticlines and synclines become apparent after mapping of the lava-conglomerate contact (see Fig. 5). The two marker horizons in the "lava", mentioned previously, were of great value in giving an indication of the folded nature of this poorly exposed contact zone.

The largest syncline, occurring to the north, is truncated along its axial plane by a major fault which is an extension of the Bluejackets Fault of the mine area (see later). Three fairly large anticlines and three quite large synclines (amplitudes averaging about 400 feet) occur south of this. Their axial planes have a consistent south-southeast strike and are near vertical or dip steeply to the southwest i.e. the folds are possibly slightly overfolded to the northeast.

In other places where bedding is well exposed, sharp changes in strike indicate the presence of fairly large folds. All such folds invariably have identical orientations to the main ones described above (see Fig. 5).

All of the above-mentioned folds, including the main Consort folds, deform a very strong rock fabric in the form of flattened and elongated rock particles and well aligned metamorphic minerals (see later).

2. Major Faults

The Bluejackets Fault

The so-called Bluejackets Fault is the main fault present in the mine area, and as mentioned, cuts obliquely across the south side of the Top Section Syncline. It has a horizontal displacement of about 2,400 feet and according to Hearn (1943), a reverse vertical displacement of an unknown amount. One of the most striking features is the curved fault trace which in the central part of the area strikes east-west, thereby truncating the folds as shown in Fig. 5. In this area planes of shearing along the fault zone are evident and the fault plane is intruded by pegmatites in a number of places. At about the point where it truncates the Consort "Contact", the fault trace, only indicated in this area by a truncation of the "lava" foliation, changes strike and trends parallel to the axial planar trend of the major folds, i.e. south-southeast. At its eastern extremity as mentioned previously, the fault dislocates one of the northern synclines situated at the western end of the quartzitic Lily Line. It occupies a position coinciding with the axial plane of this syncline and consequently leaves only the northern limb of the latter.

Hearn (1943) notes that the Bluejackets Fault is post mineralization in age. From Fig. 5, it is clear that it must post-date the major northwest fold trend in the area as well. The approximate length of the fault trace is 9,000 feet.

The Ivaura and Main Reef (M.M.R.) Faults

In the far northern or Ivaura Section of the mine, two major faults, the Ivaura and Main Reef (M.M.R.) Faults, are described by Hearn (1943). They are shown by him to dip steeply to the south and to have reverse throws. As can be seen from Fig. 5, they cause a pronounced displacement of the Consort "Contact" horizon.

The Main Southern Fault

The Main Southern Fault is a very large reverse or high angled thrust fault with an upthrow to the south, exposing rocks that are characteristic of the lower part of the stratigraphical succession in the area. It truncates the fold trends of the strongly folded quartzite block which lies to the north, and can be clearly traced from Joe's Luck Siding to a point just east of No. 7 Shaft.

The fault plane, dipping at intermediate to steep angles to the south, is quartz filled for much of its length and the precise position of the fault trace is often marked by a resistant, bush-covered ridge of milky-white quartz. The various rock types which are upthrown on the south side of the fault, have been discussed previously.

Although there is quite a substantial amount of scree cover in the area to the south of No. 7 Shaft, and notwithstanding the fact that no vein quartz was encountered, the author is of the opinion that the fault continues in a westerly direction and causes the marked truncation of the very resistant greenschist and quartzite ridge just southeast of No. 7 Shaft. Going still further west from here, the fault continues and truncates the No. 7 Shaft Anticline at an oblique angle just south of No. 7 Shaft. It then cuts obliquely across the axis of the No. 3 Shaft Syncline in the vicinity of the bridge over the North Kaap River, and exposes basic schists and serpentinites to the south thereof. From here it follows approximately the course of the North Kaap River and appears to be continuous with the large fault described by Voges (unpublished report E.T.C. Mines Limited), situated about half a mile to the west, and separating a block of Moodies quartzites from basic schists to the south thereof.

East of Joe's Luck, exposures are very poor and the succession becomes complicated due to the presence of large bodies of serpentinite within the quartzitic "Lily Line". No sign of a fault could be found in this area, but it is interesting to note that a well developed, nearly chertified quartz horizon occurs a few hundred yards east of Joe's Luck Siding, and this might well represent an extension of the Main Fault. This resistant chert band trends southeast and possibly merges with the main Lily Fault Zone. From a structural point of view on the other hand, it seems very likely that the fault continues

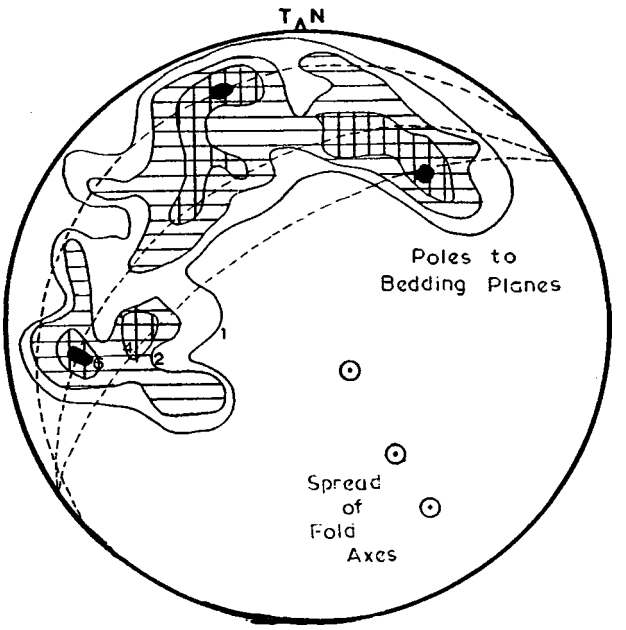


FIG. 6 : Pye diagram of the Prince Consort Syncline showing very irregular spread which is interpreted as indicating an original deformed surface. Contours join areas of equal data density and do not represent percentage contours. Plot of 90 points, maxima represent 6 points and over

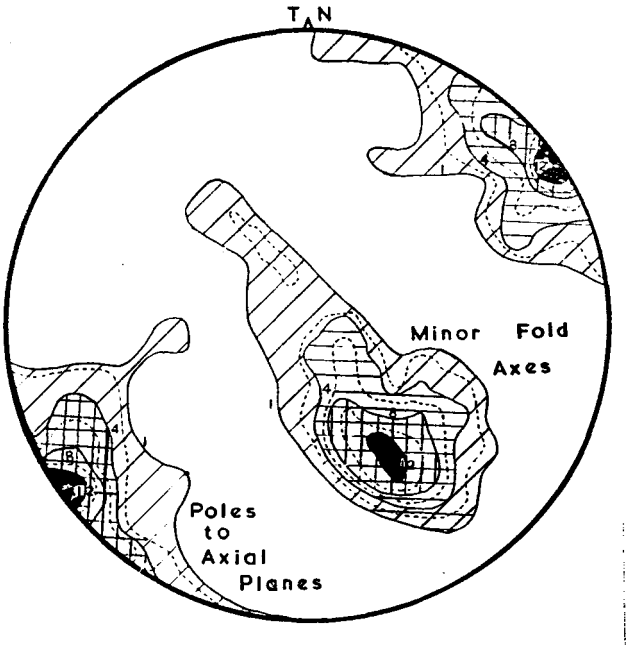


FIG. 7 : Plot of the minor folds associated with the major system of folds in the Consort area. Note marked spread in plunge of minor fold axes. This is due to the existence of an earlier folded terrain consisting of fairly tight folds overfolded in a general northwest direction. Plot of 60 folds. Maxima represent 12 points and over.

along the south side of the Lily quartzite line. In the Joe's Luck area where the fault is definitely known to occur, basic Onverwacht rocks are brought into direct contact with the quartzitic Lily Line. Exactly the same relationship holds in the area to the east of Joe's Luck Siding, and it seems reasonable to assume therefore, that the fault continues into this area. Although no vein quartz comparable to that occupying the plane of the fault in the Consort area was encountered, the quartzites to the east of Joe's Luck Siding, are intensely sheared and mylonitized and there are strong indications that much movement has occurred along this zone (see Figs. 1 and 2a).

3. Deductions from the Main Structures

The most striking feature of all the major folds is the very regular orientation of their axial planar traces which have an average bearing of 145°. The vast majority of the folds plunge at various angles to the south-southeast and the attitude of their axial planes is often nearly vertical or steeply southwest dipping, indicating slight overfolding to the northeast.

Fig. 6 is a pye diagram of the Prince Consort Syncline, the largest of the major folds, the best exposed, and apparently the most regular. If this particular fold, and all the associated major folds mentioned above, had affected or deformed normal flat-lying or uniformly orientated strata, the poles to the bedding planes would have formed a regular great circle, the pole to this representing the fold axis. As can be seen (Fig. 6), this is not the case and there is a large spread of the poles so that a series of great circles with variable dips and having more or less the same strike, can be constructed from the pye diagram. The poles to the numerous possible great circles all lie roughly in one plane but have variable plunges to the south-southeast.

From the above evidence it can be concluded that some type of irregular and deformed surface must have existed in the Consort area prior to this folding.

All of the major folds deform a very strong fabric foliation which contains well aligned metamorphic minerals and flattened rock particles (see later).

All the faults in the area truncate the major Consort folds and the last movement on these must have been post folding. The possibility has been suggested that the Main Southern Fault represents bifurcation of the Lily Fault. The latter, according to C.R. Anhaeusser (verbal communication) is a chertified, mineralized zone, occupying roughly the anticlinal position between two major synclines (the Eureka and Lily Synclines) and in this respect is identical to the other major faults of the Mountain Land. However, the great amount of white quartz occupying the fault plane of the Main Southern Fault in the Consort area, is not developed along the Lily Fault in the area to the east of Joe's Luck and this

casts some doubt on the fault representing a branch of the latter.

On the other hand, it has been pointed out previously that there is fairly strong evidence to suggest that the Main Southern Fault continues eastwards along the south side of the Lily quartzite line. This would explain the juxtaposition of basic Onverwacht rocks with the Lily quartzites, a fact otherwise very difficult to satisfactorily account for. The fault is thought to occupy the anticlinal position between the Eureka and Lily Synclines (see Fig. 1a). This will be referred to later.

(ii) Minor and Micro Structures

1. Small Folds Associated with the Major Consort Folds

The best developed and most wide-spread of all the minor structures, which are developed in all the rock-types throughout the Consort area, are small-scale folds. The attitude of these is very similar to the major folds described above, and they are obviously related to the same period of deformation as the latter.

They vary in size from about 1 cm. to several feet in amplitude, and in the quartzites especially, appear to be mainly of a concentric or sometimes a flattened concentric type e.g. Plate 35. Slaty cleavage or axial plane foliation is not a conspicuous feature of these folds.

In some places, especially in the more incompetent rock-types such as the "lavas", small parasitic folds occur in the centres of some of the larger folds (see Plate 36). This variety of folding is essentially of the "similar" type. In other places, certain competent bands are concentrically folded with an inner slightly less competent core of intensely folded material (see Plate 37). The latter represent parasitic folds and are also of the "similar" type.

Concentric folds of this type are often seen to deform rocks that have previously been intruded by granitic sheets. Plate 38 shows a hornfels near the Consort Mine, intruded by granitic sheets, and both rock-types folded together in a concentric manner. This indicates that these folds are post intrusive granite in age.

Fig. 7 is a plot of the attitudes of 60 of these minor folds. As can be seen, the axial planes are fairly constant, dipping either vertically or steeply to the northeast or southwest. The fold axes, although all having a fairly constant direction of plunge averaging about 145°, show a very marked variation in angle of plunge from about 20 to 80°, with a few plunging nearly vertically and some plunging steeply to the northwest. The maximum concentration of axes plunge at about 50° to the south-southeast.



PLATE 35 : Smaller-scale concentric fold associated with the major north-west-trending fold system in the Consort area. Fold axes plunging 52° to the southeast and axial plane nearly vertical. East of Consort Mine.

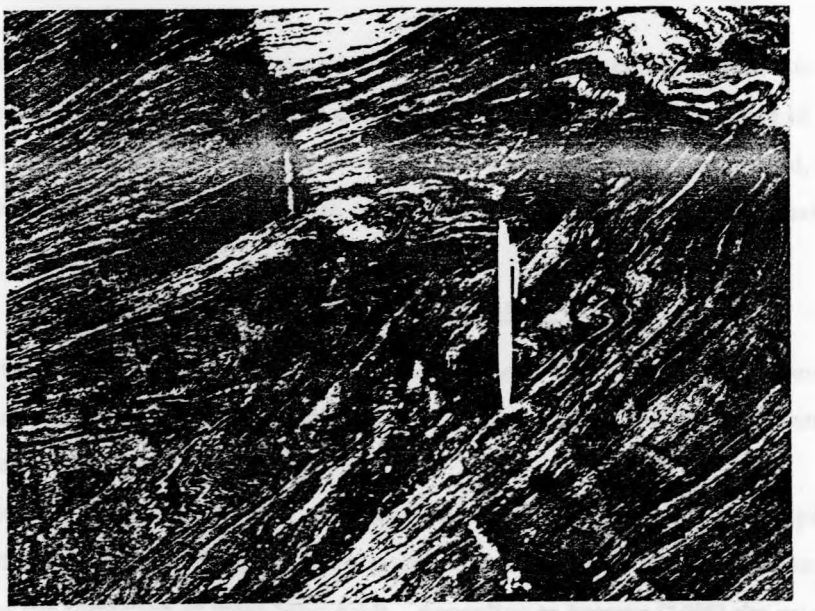


PLATE 36 : Well developed parasitic folds in the centre of a larger fold. These folds are of a "similar" type. "Lavas" east of Consort Mine.

2. Foliation

Very often the major folds and their associated minor folds mentioned above, are seen to deform a strong foliation. The latter, which corresponds to a strong cleavage, often almost identical in attitude to the original bedding, is best developed in the more incompetent rock-types and is seldom observed in the arenaceous rocks. It is strikingly apparent in the "quartz-bleb" marker horizon within the "lavas" (mentioned previously) in that hundreds of small quartz fragments have been intensely sheared and flattened in the plane of cleavage (see Plate 18).

Associated with this foliation, a sub-parallel arrangement of metamorphic amphibole and biotite crystals (where developed) is usually observed on a microscopic scale. These minerals are often seen to be bent, folded, or broken, invariably by the main northwest trending fold system in the area.

3. Other Small Folds

In some of the Ivaura Section quarries a number of intermediate sized folds (amplitudes 1 - 4 feet), with axes plunging at shallow angles to the west, and with near horizontal axial planes, were encountered. They fold the metamorphosed shales as well as a pronounced foliation in certain pegmatitic granites.

The area to the north and west of the main Prince Consort adit becomes complicated as a result of strong faulting and folding and is made difficult to investigate due to the abundance of soil and scree cover. From time to time, well developed folds with various attitudes were encountered, but it was generally found very difficult to relate these with certainty to any known period of deformation.

4. Deductions from the Minor and Micro-Structures

The most striking feature of the minor folds associated with the main northwest-trending Consort folds, is the very regular orientation of their fold axes, coupled with a marked variation in the angle of plunge of these (see Fig. 7).

If these folds had deformed uniformly orientated surfaces, then one would have expected a single maximum of fold axes. It must, therefore, be concluded that some type of folded surface was originally present before the formation of these later folds. According to Ramsay (1958), the orientation of axes of folds is directly related to the inclination of the surfaces before the development of these folds. Thus, for example, where first fold limbs are isoclinal or fairly steeply overturned, the plunge of any fold axes which are superimposed on them, will also be fairly steep. The dominant plunge of the minor



PLATE 37 : Concentrically folded band with inner core of parasitic folds, the latter representing "similar" folds. Fold axis plunging 78° to the S.S.E. - axial plane nearly vertical. Quartzites east of Consort Mine.



PLATE 38 : Intrusive granite sheets concentrically folded and also faulted together with the hornfelses into which they intrude. This indicates a post-granite deformation. Consort Mine area.

folds to the south-southeast can only be explained by assuming original tight, almost isoclinal folds, overfolded probably in a general northwest direction. Nothing can really be said of the original axial planar trends of these earlier folds, as the intensity of the later deformation has destroyed almost all signs of them.

The strong cleavage foliation and associated mineral orientation has been folded by the main Consort folds, and is thus a manifestation of an older period of deformation. The bending, folding and deformation of amphibole and biotite crystals by these folds, indicates that they are post-metamorphism in age.

The folds with near horizontal axial planes deform the strong foliation. Their attitudes are different to the major northwest trending Consort folds and they possibly represent a different phase of deformation.

(iii) Summary and Conclusions for Zone I

From a general consideration of all scales of structures in Zone I, the following appears to be the sequence of events.

1. The development of strong, almost isoclinal folds, probably overfolded to the northwest, but nothing really known about their original orientation. In the field these early folds have been entirely obliterated due to the development of the younger northwest trending folds so that their original presence is deduced from the effects they have had on these younger folds.

The strong northwest-trending folds also deform a rock fabric in the form of cleavage associated with flattened rock elements and aligned metamorphic minerals.

The above earlier features might well be linked with periods 1 and 2 of Ramsay, but it is impossible to differentiate between the two because of the strong superimposed northwest fold trend.

2. The major northwest folding tends to obliterate most earlier formed structures and represents by far the strongest deformation in the area. It deforms all the above-mentioned earlier structures and was classed by Ramsay as his 3rd and final phase of deformation.

3. Finally, some intermediate sized folds with almost horizontal axial planes might compare with the horizontal folds grouped as part of Ramsay's 3rd period of deformation. It is not clear what their ages are with respect to the northwest fold trend.

4. The main faults of the area are considered to have formed at a late stage during the development of the northwest fold trend. The Main Southern Fault was probably initiated at a very early stage in the structural history, but rejuvenated at a later date as it now also truncates the northwest-trending folds.

(d) Zone II - South of the Main Southern Fault

(i) Major Structures

1. Major Fault.

As shown previously, the Woodstock "Bar" and associated greenschist "bars" represent the silicified fault planes of high angled thrusts. It is difficult to trace the Woodstock "Bar" eastwards, but it is possible that the chertified and greenschist-type "bars" close to the contact of talc schists and shales in the area close to the Kaap River, might indicate the position of a faulted zone extending eastwards from the Woodstock Fault. This zone passes immediately south of Joe's Luck Siding and a bit further to the east thereof, appears to merge with the main Lily Fault Zone mapped by Anhaeusser (verbal communication).

About three quarters of a mile west of Joe's Luck Siding, the basal zone of the Eureka Syncline, including the basal conglomerate and the underlying Fig-tree "lavas", has been duplicated due to faulting. The fault trace strikes approximately northwest and probably continues across the Kaap River to displace the chert horizons mentioned above. The broad alluvial terrace on the north side of the Kaap River however, makes detailed mapping of the fault trace impossible.

2. Deductions from the Major Structures

It seems very probable that the Woodstock Fault represents an extension of the Lily Fault. The latter, as shown by Anhaeusser (verbal communication), is mineralized and is identical in nature to the other major faults of the Mountain Land, i.e. high angled thrusts occupying the anticlinal position between adjacent synclines.

The fault displacing the lower members of the Moodies System and underlying Fig-tree Series in the northern part of the Eureka Syncline, is identical in character to the Bluejackets Fault of the Consort Mine area (described previously). The fault trace has the same strike, the relative movements are the same, and both faults are considered to be of the same age.

(ii) Minor and Micro Structures

1. Shear Cleavage, Crenulation and Conjugate Folds

Widespread over the whole of this area, but best developed in various schistose rocks near Noordkaap, is a very well developed shear cleavage as described by Ramsay (1963). It constitutes the best developed and most marked structural feature in Zone II.

Pervading many of the basic talc and chlorite schists and phyllites in the area to the immediate north and west of Noordkaap, are a set of minute crenulation folds. These invariably have shallow plunging fold axes with nearly horizontal axial planes, the latter defining the very pronounced shear or crenulation cleavage. In places, where well developed, the amplitudes of these folds may be about 1 cm. (see Plates 8 and 9), but often they are only visible on a microscopic scale. The fold axes in such cases appear in the field as a set of extremely fine lineations which are barely visible to the naked eye. In some cases the folds do not give a symetrically crenulated or corrugated surface, but occur rather as a set of accordion-type folds with long straight limbs as shown in Plate 39, but still with an identical attitude to the crenulation-type folds.

The massive quartzites along the Kaap River to the northeast of Noordkaap, are completely devoid of small folds. In certain fine-grained pelitic pebbles towards the base of the quartzite succession as noted by Ramsay (1963), minute horizontal "crinkles" of an identical type to the crenulation folds mentioned above, are developed. It is obvious that the development of these structures is strongly controlled by the lithology, so that as seen above, they will only develop in certain very favourable rocks and even then may be on such a minute scale that they appear to the naked eye simply as a set of very fine lineations.

Most of the impure quartzitic block lying north of the Woodstock Mine has been intensely sheared and is now dominantly a sericite schist. Where secondary silicification of more intensely sheared, faulted and mylonitized zones has taken place, it can be called a quartz-sericite schist, e.g. the Woodstock "Bar". The extreme northern part of this block has not been sheared and is a massive quartzite with no apparent structures developed in it. In the sheared part however (from about the main road southwards) hundreds of small crenulation folds with an identical orientation to the "crinkles" in the pelitic pebbles (mentioned above), are very well developed (see Plate 40). In the Woodstock and associated greenschist "bars", one of which is exposed on the main road north of the Woodstock Mine, these minor folds attain probably their best development anywhere in the area. Extremely well developed accordion folds with amplitudes well over 1 cm., are typical (see Fig. 9). Their axes, which are invariably knife-sharp,



PLATE 39 : Accordion-type folds with long straight fold limbs. These folds have an identical orientation to nearby crenulation folds which have near horizontal fold axes and axial planes. Talc-chlorite phyllites exposed in rail cutting northeast of Noordkaap.



PLATE 40 : Crenulation folds developed in sericite schists. Road cutting northeast of Noordkaap. (Crossed nicols x 45).

stand out very clearly as a set of east-west striking lineations plunging at very low angles to the east, and their axial planes approach horizontal although there may be a considerable north or south dip (see Fig. 10).

In the finely laminated quartz-sericite varieties, conjugate folds (see Fig. 11) are very well developed, and are clearly very intimately associated with the accordion folds. As shown by Ramsay (1962), the stress field that caused the formation of a conjugate fold can be calculated directly from a plot of its two conjugate shear surfaces. This was done in the case of 10 conjugate folds and a very consistent plot was obtained (see Fig. 12).

This type of crenulation folding is generally not developed or poorly developed in most of the other rock-types in the area. However, in a rail cutting southwest of Joe's Luck, fairly well developed crenulation folds of a rather similar type to those mentioned above, occur in fine-grained Fig tree shales. In the same area, a set of larger folds with amplitudes up to about 6 inches, have a very similar orientation to the crenulation folds. Fig. 13 is a composite plot of both types of folds and shows the dominant plunge of fold axes at shallow angles to the northeast. The poles to the axial planes, although approaching a vertical position, are offset to the southeast by about 25 degrees.

Crenulation folds were also noted in a diabase dyke to the northeast of the Woodstock Mine, and in partly sheared "lavas", minute crenulation folds are sometimes apparent (see Plate 20).

2. Lineations in Basic Schists and Phyllites

In the Noordkaap area, there occurs a set of very steeply plunging lineations (see Plate 7). They are developed in talc and chlorite phyllites and plunge either vertically or else very steeply to the north or northwest (see Fig. 14). As shown by Ramsay (1963) these are deformed by the crenulation folds described above (see Plate 8) and were formed at the time of strong cleavage development in the area (see later).

Using the method described by Ramsay (1963), the "a" or movement direction of the younger crenulation folds can be obtained from the lineations which they deform. This was done in the Noordkaap area. As might be expected, the movement direction is found to be almost horizontal or to plunge at a very shallow angle to the south-southeast in a direction of about 165 degrees (see Fig. 14).

3. Cleavage Development

A very strong foliation is present in many of the basic schists and represents a strong cleavage development. It is closely connected with the mineral lineation mentioned above.

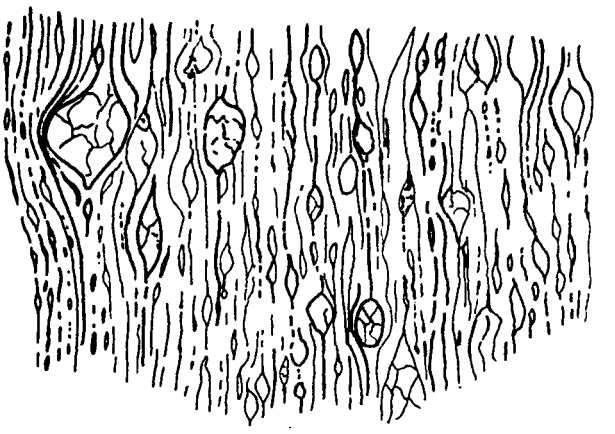


FIG. 8 : "Augen structure" developed in a porphyritic intrusive granite as a result of severe dynamic metamorphism and near mylonitization. Natural size tracing from polished surface of sheared and lineated granite. North of Joe's Luck Siding.

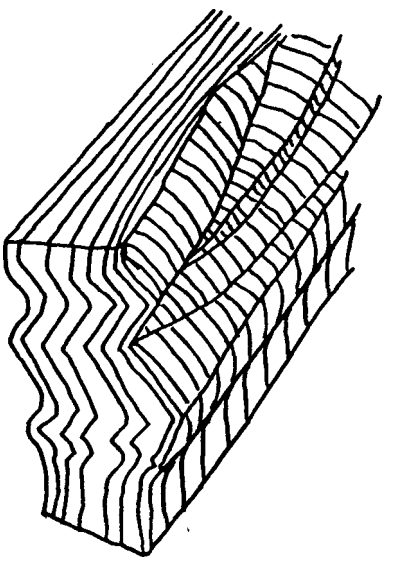


FIG. 9 : Well developed accordion-type folds in "greenschist bar". Very sharp, near horizontal fold axes trending east-west. Axial planes almost horizontal. Natural size. Exposed on main road northeast of Noordkaap.

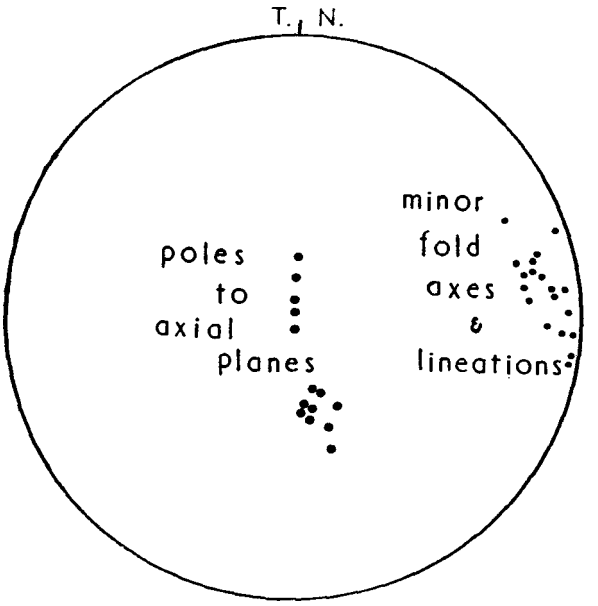


FIG. 10 : Plot of accordion folds developed in "greenschist" horizon northeast of Noordkaap. The fold axes plunge at shallow angles to the east and the poles to axial planes, although showing a marked north-south spread, approach vertical. Plot of 19 folds.

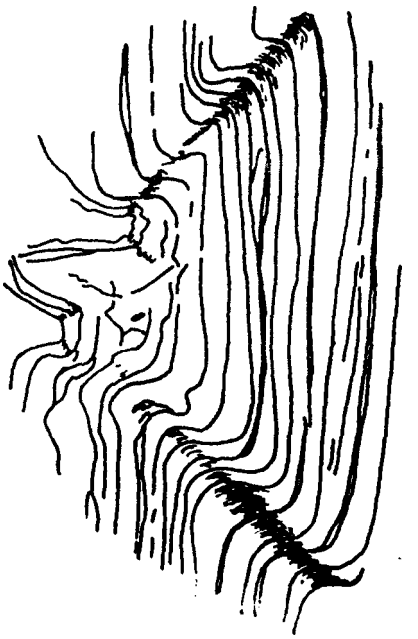


FIG. 11 : Well developed conjugate fold in partly silicified and finely laminated "greenschist bar", closely associated with accordion and crenulation folds. Natural size tracing of polished section. Exposed on main road northeast of Noordkaap.

This same cleavage is undoubtedly present in most of the rocks in the area, but it is only recognised in certain favourable types. It is sometimes evident in the shaly horizons, but it was found very difficult to measure in many instances due to its development almost parallel to the primary bedding foliation.

In the basal conglomerate of the Moodies System however, this same cleavage is well revealed as a result of the marked flattening and elongation of constituent pebbles that it has caused. The planes of flattening or cleavage are veritably coincident to the primary bedding plane foliation, and this holds for most of the basal conglomerate forming part of the northern limb of the Eureka Syncline as exposed in the area. The "inclusions" in the zone of "nodular lava" underlying the basal conglomerate also show a marked flattening and elongation. The long axes of all the above flattened particles as noted by van Eeden (1941), are generally fairly steeply plunging.

To the southwest of Joe's Luck, part of the lower zone of the Eureka Syncline has been faulted and this has resulted in a sliver of basal conglomerate cutting obliquely across the main road. Flattened and elongated pebbles are beautifully exposed at this locality. The planes of bedding and cleavage dip steeply to the northeast and the direction of pebble elongation, giving a marked lineation, is about 115 degrees plunging at intermediate angles to the northwest (see Fig. 15). Deformed and elongated pebbles were also found in the northern part of the conglomerate block lying to the north of the Woodstock Mine. As noted by Ramsay (1963) the planes of flattening or cleavage cross-cut the bedding in this area.

The significance of the deformed and elongated pebbles and how they can be used to obtain some idea as to the amount of deformation that the area has suffered, will be discussed later.

4. Other Folds

In a quartzitic block exposed by the Kaap River in roughly the centre of the area, are some well developed folds which appear to be mainly of a flattened concentric type. They are very similar in character to the northwest trending folds encountered in the Lily quartzite mass to the north (see Zone I), plunge at shallow angles to the southeast, and have nearly vertical axial planes (see Fig. 17).

In shales and basic schists to the west of Joe's Luck, minor folds, plunging generally at shallow angles to the west-northwest, are exposed in a rail cutting. As can be seen from Fig. 16, there is a large spread in the attitudes of the axial planes, the poles to the latter being deformed systematically on a great circle.

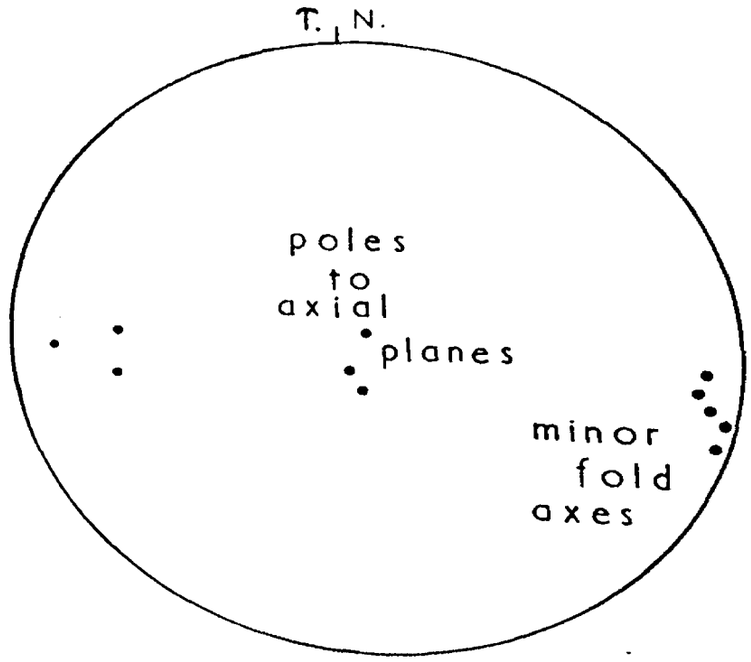


FIG. 12 : The stress field calculated from 10 conjugate folds developed in the Woodstock and associated "greenschist bars". Northeast of Noordkaap.

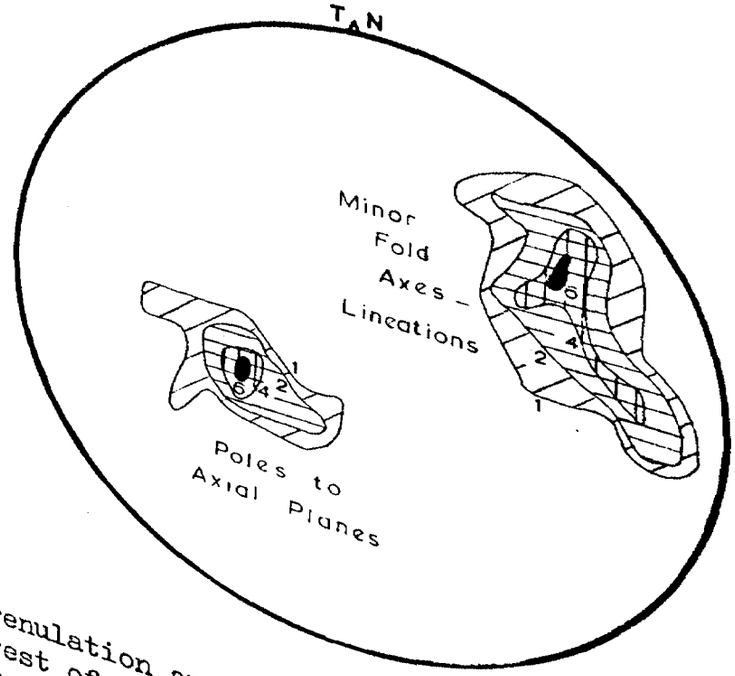


FIG. 13 : Plot of crenulation and larger folds developed in shaly rocks to the southwest of Joe's Luck Siding. General plunge of fold axes at shallow angles to the northeast and poles to axial planes approaching vertical. Plot of 20 folds. Maxima represent points and over.

5. Deductions from the Minor and Micro Structures

Crenulation and Conjugate Folds

It is seen from the calculation of the stress field from conjugate folds, that a nearly vertical maximum stress direction (P.max) is obtained (see Fig. 12). As shown, these conjugate folds are closely associated with the minor crenulation and accordion folds and must have developed at the same time, under the same stress conditions. A comparison of Figs. 10 and 12 shows the marked coincidence between poles to axial planes of accordion folds, and the P. max. direction obtained from conjugate folds. The minor fold axes and the P. min. direction are also very close.

The folds are essentially of a brittle type and it is thought that they formed under fairly high pressure but low temperature conditions. They deform the strongly developed cleavage foliation.

Cleavage

A fairly strong, steeply dipping cleavage is present over the whole area, but is usually very difficult to detect in the competent and more massive rock types. In addition, it often parallels the bedding and this also makes it more difficult to recognise. Flattened pebbles, elongated in the planes of cleavage and generally fairly steeply plunging, together with a strong alignment of chlorite crystals in some of the basic schists, are typical of this phase of deformation.

The crenulation and conjugate folds mentioned above deform this foliation.

Other Folds

The strongly developed folds in a quartzite block next to the Kaap River, are very similar in most respects to the main northwest-trending folds in the Consort area. The angle of plunge of the fold axes is fairly shallow (about 15 degrees) to the southeast, and their direction of strike, although very close, is not quite the same as the strike of those in the Consort area. Their axial planes are nearly vertical (c.f. Figs. 7 and 17). The discrepancy in direction and angle of plunge between these folds and the northwest trending Consort folds, is ascribed to the effects of the Main Southern Fault.

The folds developed in shales and schists to the southwest of Joe's Luck, plunge at gentle angles to the northwest, and judging by the spread of the poles to their axial planes, have been folded about similarly trending axes (see Fig. 16). They probably represent co-axial folds, folded a second time by the northwest fold trend of the Consort area.

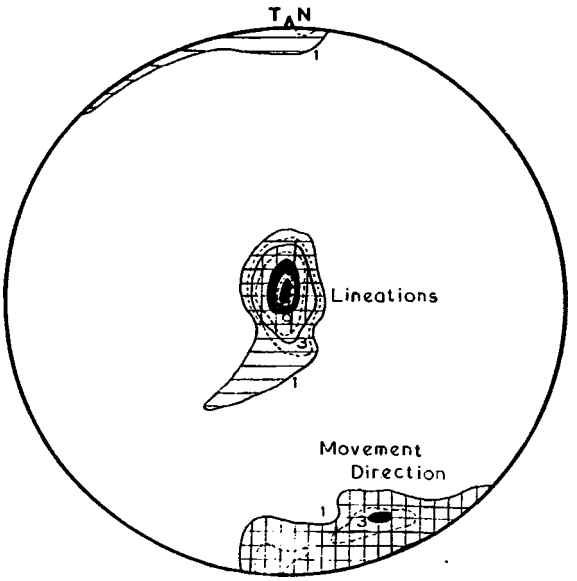


FIG. 14 : Plot of 21 steeply plunging lineations and the "a" or movement direction of minor crenulation folds calculated from them. Noordkaap area.

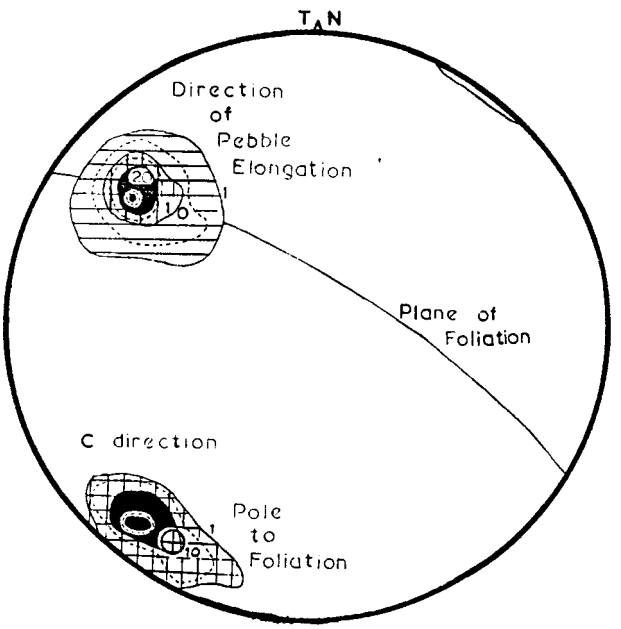


FIG. 15 : Direction of elongation ("a") of conglomerate pebbles. Also direction of shortest pebble axis ("c"). Plane of cleavage is coincident with the bedding plane so that flattened pebbles lie in this plane and the pole thereto corresponds to the "c" direction. Southwest of Joe's Luck. 35 readings, maxima represent 20 points and over.

(iii) Summary and Conclusions for Zone II

The following is the recognisable sequence of events that occurred in this area.

1. The development of a strong cleavage foliation trending generally east-west and steeply dipping; flattening and elongation of pebbles and the development of a metamorphic fabric, the latter best observed in chlorite phyllites near Noordkaap. This foliation is classed in Ramsay"s 2nd period of deformation and is strongly deformed by minor crenulation and conjugate folds.

Certain folds with deformed axial planes probably also formed about this time, and have been folded by the northwest-trending Consort folds.

2. The main northwest-trending Consort folds are also developed in this area. They probably fold the earlier cleavage foliation. As mentioned above, similar northwest-trending folds deform the axial planes of earlier folds.

3. All structures appear to be deformed by the minor crenulation and conjugate folds. Their exact relationship to the northwest folds is, however, not clear.

4. The Woodstock Fault, like the other major faults of the Mountain Land, probably formed at an early stage in the structural history of the area.

The northwest-trending fault is difficult to date, but because of its close similarity to the Bluejackets Fault which truncates the northwest fold structures, it is considered to be of the same age and, therefore, post northwest folding as well.

(e) Zone III - "Footwall" Rocks and Granite Contact Belt

(i) Minor and Micro-Structures

1. Introduction

No major structures are present in this area, and the "footwall" rocks form a very regular and relatively uninterrupted succession (actually part of the northern, southward dipping limb of the Lily Syncline) stretching right across the region from east to west. Within this zone the grade of thermal metamorphism is very much higher than that seen in Zone II south of the Main Southern Fault (see previously). However, certain minor structures with identical characteristics to the structures found in the zones discussed above, can be identified in the contact zone and can easily be correlated with these.

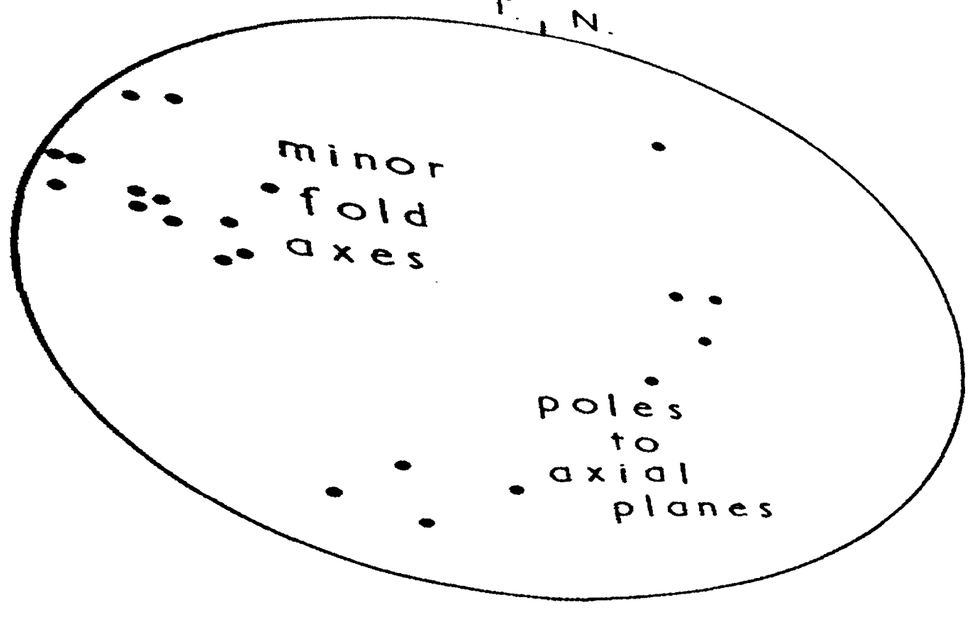
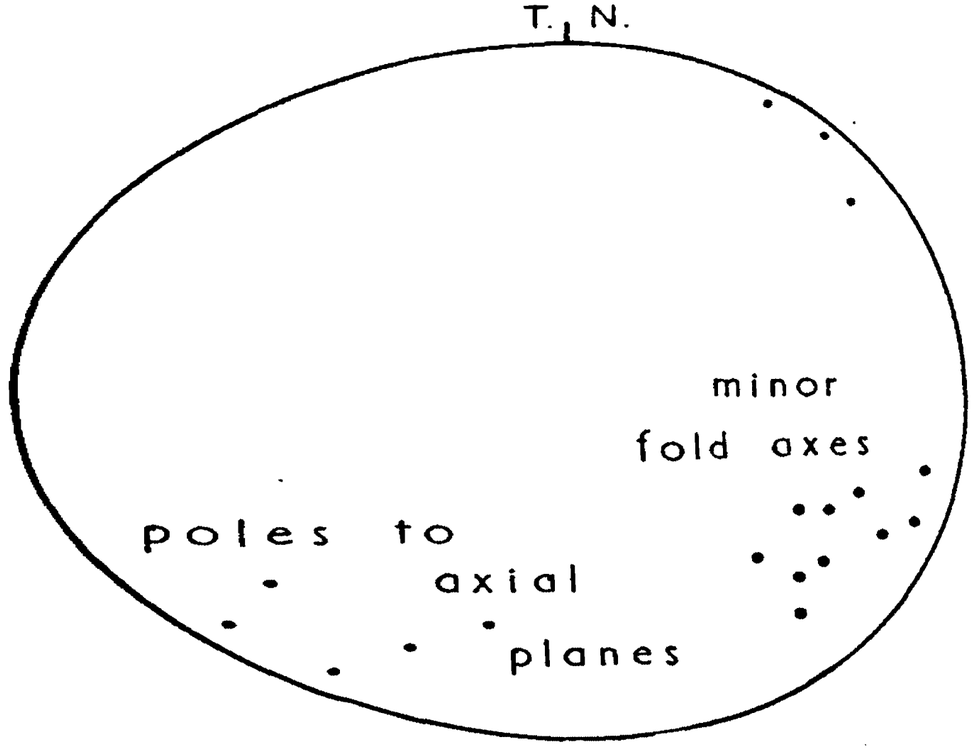


FIG. 16 : Plot of 13 minor folds developed in shales and schists near Joe's Luck Siding. Fold axes have a consistent shallow plunge to the northwest, but there is quite a considerable spread of axial planes, the poles thereto falling on a great circle.



Plot of the attitude of 10 flattened concentric folds developed tightly folded quartzite block immediately south of the Kaap

2. Cleavages, Lineations and Associated Folds

A very strong foliation is present along the whole contact zone.

Chert pebbles in the basal conglomerate of the "Lily Line" are well exposed north of Joe's Luck and are seen to be strongly flattened and elongated in planes which undoubtedly define a very strong cleavage. The style of deformation is identical to that found in the basal conglomerate of the northern limb of the Eureka Syncline (see above) and the planes of cleavage in both areas have roughly the same strike. The direction of elongation of the pebbles in the northern area, however, is at shallow to moderate angles to the northeast (Fig. 18) i.e. roughly at 115° from the direction of elongation of pebbles in the Eureka Syncline (see Fig. 15).

Intrusive granite sheets and adjacent meta-sediments exposed in the large bend in the Kaap River immediately northwest of Joe's Luck Siding, are intensely lineated (see Plates 32 and 33) and also strongly folded in places; the folds often have a very pronounced axial plane foliation as was noted by Ramsay (1963) - (see Plate 31). The strong lineations are invariably parallel to these minor fold axes and plunge at shallow to moderate angles to the southeast (see Fig. 18).

Similar lineations are sometimes well developed in the quartzitic horizons and are quite frequently encountered in the granite at various places along the contact zone. However, they attain their best development in the vicinity of a large stock of intrusive, porphyritic granite north of Joe's Luck Siding. An interesting feature concerning the strong lineations north of Joe's Luck, is that in addition to being parallel to minor fold axes, they are also coincident with a strong lineation caused by elongation of chert pebbles in the Lily Line north of Joe's Luck (see Fig. 18). This indicates an elongation parallel to the fold axes (b) of minor folds, and these lineations thus represent "b" lineations (b fabric axis).

Amphibolites along the contact zone are often strongly folded on a small scale and there is a very pronounced "b" lineation associated with these. It is caused by the near horizontal orientation of hornblende crystals parallel to these fold axes (see Plates 2 and 3).

Where pegmatite sheets intruded along planes parallel to the foliation, as is often the case, they have been stretched out and flattened and often drawn out into boudins (see Plate 29). Where such veins cross-cut the foliation, they have been shortened and folded, often by an intense type of parasitic folding as shown in Plate 30.

3. Evidence of Dynamic Metamorphism

As shown previously, the narrow zone of intrusive granite right the way along the contact, has been subjected to particularly intense dynamic metamorphism as a result of strong shearing. Plate 26

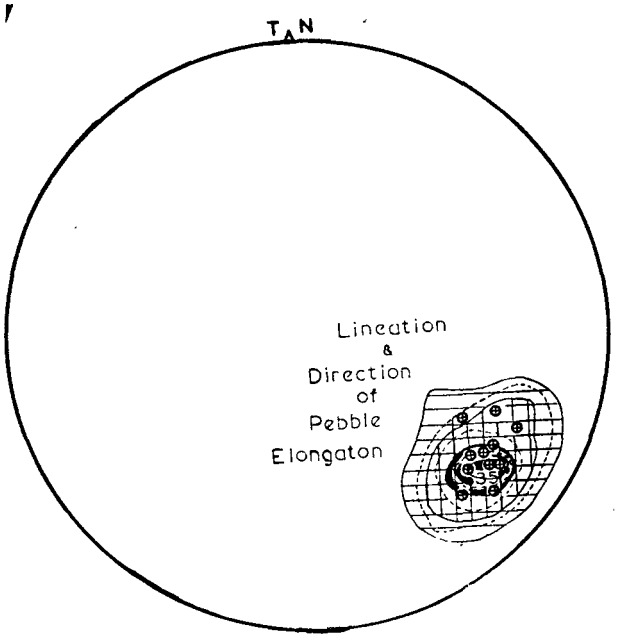


FIG. 18 : Plot of 54 lineations occurring in granitic, quartzitic and "lava"-type rocks in the Joe's Luck area. Circled crosses are plots of the elongation direction of 12 deformed pebbles in the "Lily Line" conglomerate occurring in the same area. Maximum concentration represents 35 points and over.

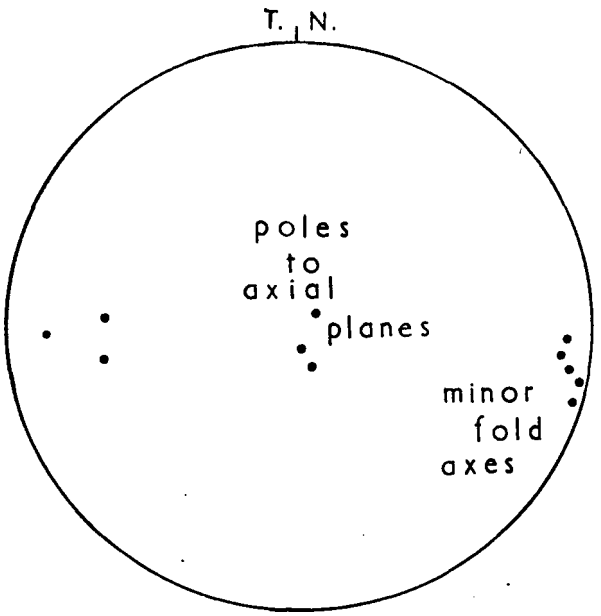


FIG. 19 : Attitudes of 8 minor crenulation folds developed in quartzitic and sheared talcose rocks north of the Consort Mine. (c.f. similar folds near Noordkaap - Fig. 10).

shows the very pronounced and regular planes of shearing and Fig. 8 shows a fairly advanced stage of mechanical breakdown with the typical "augen" structures that invariably develop.

South of the intrusive granite, evidence of shearing in the basic rocks is not always marked, but the intercalated quartzitic horizons are usually strongly sheared and often almost chertified with the development of much sericite in places.

This dynamic metamorphism is considered to post-date the thermal metamorphism and cleavage development in the area. In the field however, it is invariably very difficult to distinguish between the cleavage foliation and the foliation produced by mechanical grinding and reduction of grain size. This is due to the fact that both these planar surfaces are very similarly orientated.

4. Other Folds

In a few places, and especially in the Joe's Luck area, flattened and elongated "lava" nodules were found which have clearly been strongly folded after elongation. Sheets of well foliated intrusive granite are commonly folded with the rocks into which they are intrusive, but a number of these folds are not of an intense "similar" type associated with cleavage development (as shown in Plate 30), but are rather of a much less severe concentric type of folding (see Plate 38). As noted by Ramsay (1963) mylonitized or severely "crushed" granites are themselves strongly folded in places.

5. Crenulation and Conjugate Folds

At scattered intervals throughout the area, minor crenulation folds and lineations of an identical nature to those described previously in Zone II, were encountered. Their development is largely confined to the quartz-sericite schist horizons and some sheared talcose horizons, and are thus strongly controlled by the lithology. To the north of the Consort Mine, and occurring in a restricted zone about half a mile north of the Ivaura Section of the mine, are found well developed crenulation folds and fine lineations. The fold axes and the lineations are all nearly horizontal and strike nearly east-west. The crenulation folds, well developed in sheared talcose schists, have almost horizontal axial planes and are identical to those found in the vicinity of Noordkaap (see Fig. 19). The lineations are found in a nearby magnetite-bearing quartz-sericite schist and are seen on a microscopic scale to represent the axes of minute crenulation folds which deform the mica flakes in a series of "crinkles".

Next to the above crenulation folds, and developed in a sheared and finely laminated quartzite horizon, are found two perfectly developed conjugate folds (see Plate 14). The stress field calculated from these folds is as shown in Fig. 20 and as can be seen, gives a near vertical P. max.

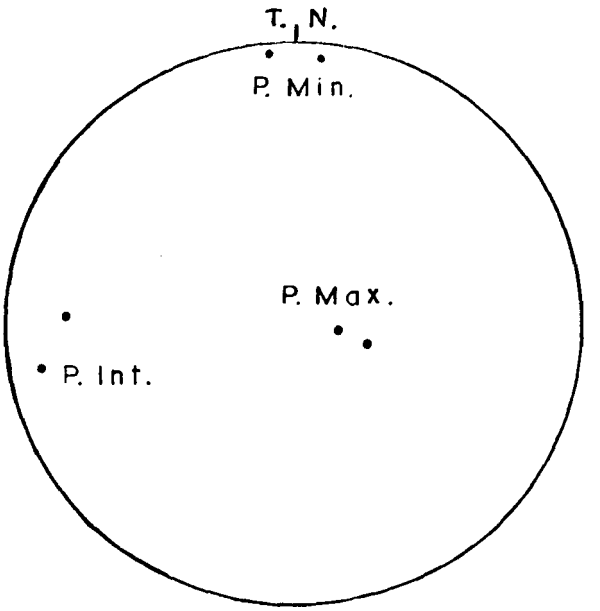


FIG. 20 : Plot of stress field calculated from two conjugate folds occurring north of the Consort Mine. One of these folds is shown in Plate 14. (c.f. this diagram with the stress field calculated from conjugate folds near Noordkaap - Fig. 12).

At a number of other places, identical types of crenulation folds were encountered, all with a very similar attitude to those described above. Plate 41 is a photo-micrograph of a crenulation fold occurring in a magnetite-bearing sericite schist to the north of the Bullion Mine. The strike of the crenulation fold axes in this area is roughly east-west and the axial planes are fairly flat-lying.

6. Deductions from the Minor and Micro-Structures

Cleavage and Lineations

A strong cleavage is undoubtedly present, but due to its similar orientation to a later shearing deformation, it is often difficult to distinguish between the two in the field. The cleavage development is intimately connected with the intrusion of the granite, the metamorphism, and possibly with the development of a strong lineation.

In the Joe's Luck area it has been shown that the lineation is parallel to minor fold axes as well as to elongated conglomerate pebbles. In other areas closer to the contact, there is a marked elongation of hornblende crystals parallel to minor fold axes and from the above two facts, it is concluded that a strong "b" lineation developed along the contact zone at this time.

The lineations so well developed in the intrusive granite bodies north of Joe's Luck Siding, are intimately associated with folds which are probably partly of a cataclastic type (see Plate 31). With the latter folds, the formation of these lineations is, thus, probably in part related to this slightly later period of superimposed dynamic metamorphism.

Dynamic Metamorphism

At a stage shortly after the crystallization of the granites, strong shearing, best developed in the intrusive granite and in quartzitic horizons, occurred, and resulted in a strong mechanical breakdown of these rocks. As pointed out above, it is often difficult to distinguish between the effects of this shearing and those of the strong cleavage.

The formation of certain of the cataclastic-type folds (see Plate 31) as well as the lineations in the granite, probably occurred at this time.

Other Folds

It is clear that some of the elongated and flattened rock particles in the area north of Joe's Luck Siding, as well as the sheared and mylonitized granites, have been quite strongly folded. Thus,

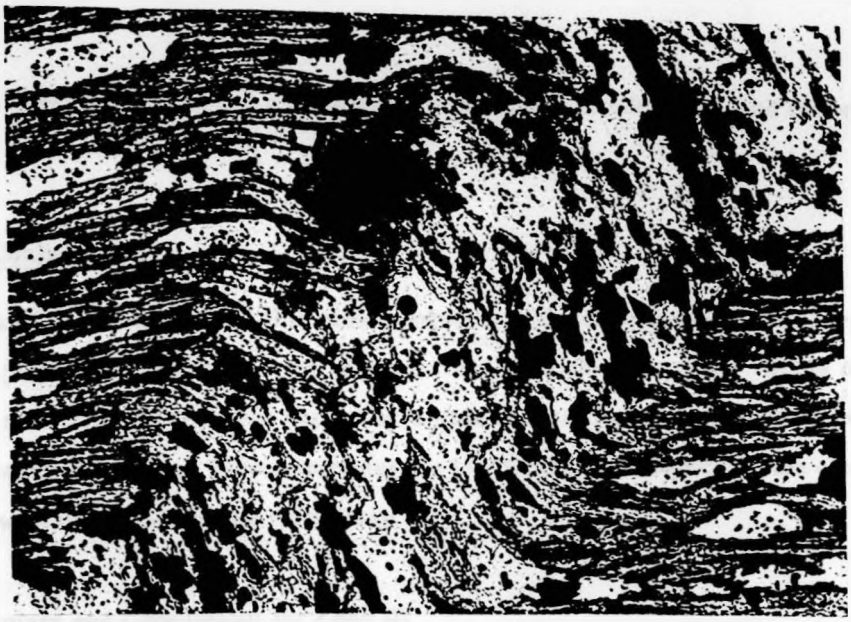


PLATE 41 : Folded magnetite-bearing sericite schist. North of old Bullion Mine. (Crossed nicols x 45).

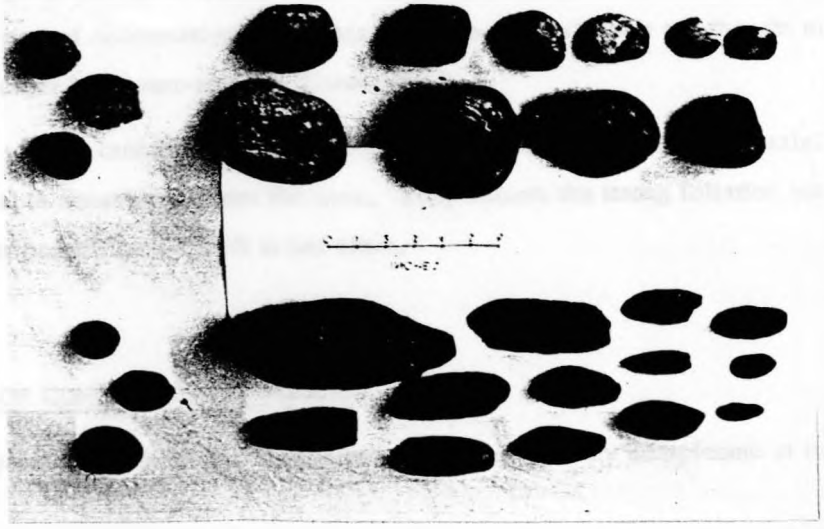


PLATE 42 : Deformed and undeformed chert and banded-chert pebbles. On left hand side, deformed and undeformed granitic pebbles showing sensibly no difference in size. Deformed pebbles from just south-west of Joe's Luck Siding and undeformed pebbles from locality 10 miles due south of Joe's Luck on the Shia Lo Ngubu - Havelock road.

a period of deformation later than that which caused the marked metamorphic fabric and the strong shearing, is present.

Crenulation and Conjugate Folds

Crenulation folds and associated lineations, together with conjugate folds, are very well developed in numerous places throughout the area where favourable rock-types exist. Where developed, they deform all earlier structures. They were caused by a near vertical stress field which must have been operative over a fairly extensive area. These structures are identical in all respects to the crenulation and conjugate folds so well developed in the Noordkaap area.

(ii) Summary and Conclusions for Zone III

1. The first recognisable event that was strongly imprinted on all the rocks along the contact zone, was the development of a very marked foliation in the form of cleavage and a metamorphic fabric, followed by powerful superimposed shearing. These events, broadly synchronous with the intrusion of the granite, are classed in Ramsay's 2nd phase of deformation.

2. In a number of places the strong foliation referred to above has been folded and it is clear that a period of deformation post-dates this. These small folds are thought to represent the equivalents of the major northwest-trending Consort folds.

3. Minor crenulation and conjugate folds, the former having flat axial planes, occur in certain favourable zones throughout the area. They deform the strong foliation but their relationship to the other post-foliation folds is not clear.

E. DEFORMATION OF CONGLOMERATE PEBBLES

As noted previously, deformed conglomerate pebbles are very conspicuous at two localities in the area, viz:-

(i) at the base of the Lily quartzite line just to the north of Joe's Luck, and

(ii) in the area southwest of Joe's Luck, exposed along the Noordkaap-Kaapmuiden road.

The pebbles in both localities occur as flattened and elongated ellipsoids in planes of cleavage that, as shown by Ramsay (1963), were superimposed upon the first folded structures of the Mountain Land. It was possible in these two places to extract the deformed pebbles from their partly decomposed and weathered matrix and measure them. The amount of deformation in both areas was found to be identical. In the area north of Joe's Luck however, the cleavage planes cut the bedding foliation at a slight angle, whereas in the road cutting, cleavage and bedding planes are coincident. It was for this reason that this latter locality was studied.

Fig. 15 is a plot of 35 elongated pebbles from the road cutting southwest of Joe's Luck and shows the very marked concentration of long axes. The latter plunge at shallow to moderate angles to the northwest and are flattened in planes of bedding which are coincident with the cleavage, (see Fig. 15).

Various types of chert pebbles are by far the most abundant in the Moodies conglomerate, and the dimensions (A, B and C) of over 30 of these deformed types, varying in size from an inch to about 10 inches in length, were measured. Quartzitic and granitic pebbles are found much less frequently, but where they do occur, they are considerably less deformed than the chert pebbles. The dimensions of five such pebbles from the same locality were also measured. The results obtained from all the pebbles measured were plotted (see Fig. 21).

About 10 miles to the south-southeast of the above locality in the heart of the Mountain Land, and exposed on the Shia Lo Ngubu - Barberton road, occur basal Moodies conglomerates identical in character to those in the Joe's Luck area, but which have suffered no deformation or at the most, very little. The pebbles are mainly banded chert types with some granitic, rhyolitic, graywacke and gritty varieties, set in an impure quartz matrix. These pebbles were easily freed from the decomposed matrix, and size measurements of over thirty chert and five granitic or quartzitic pebbles, were made. In a similar way to the deformed pebbles, the ratios of A : B and A : C for the undeformed pebbles were also plotted (see Fig. 22). The tabulated data of the A : B : C ratios for both the deformed and undeformed types, is given below (Table II).

Plates 42 and 43 show the marked difference between deformed and undeformed pebbles and give a visual idea as to the amount of deformation that these pebbles have suffered in the Joe's Luck area. On the left hand side of Plate 42, granitic pebbles from the deformed area are compared with those from the undeformed area and as can be seen, there is visually very little difference between the two.

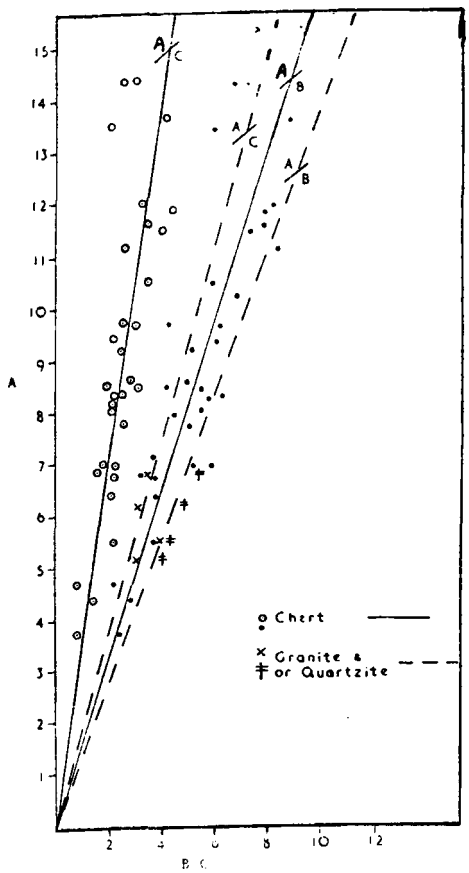


FIG. 21 : $^{A}/_{B}$ and $^{A}/_{C}$ ratios for deformed chert and granite pebbles obtained from southwest of Joe's Luck Siding. Measurement of 30 chert pebbles and 5 granitic or quartzitic types.

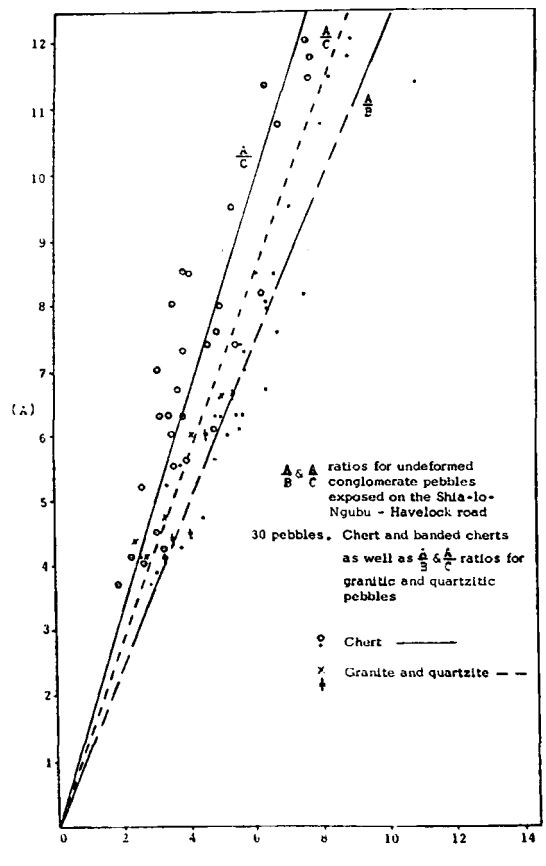


FIG. 22 : $^{A}/_{B}$ and $^{A}/_{C}$ ratios for undeformed chert and granite pebbles obtained from 10 miles south of Joe's Luck on the Shia-Lo-Ngubu - Barberton road. Measurement of 30 chert pebbles and 5 granitic or quartzitic types.

TABLE II

Ratios of Deformed and Undeformed Chert and Granitic or Quartzitic Pebbles

Pebble Type	State of Pebble	A	B	C
chert	undeformed	5	4	3
chert	deformed	5	3	1.25
granitic and quartzitic	undeformed	5	4	3.50
granitic and quartziti(	deformed	7.75	5.25	4

If the assumption is made that the original pebbles were spherical, or, if not spherical then randomly orientated triaxial ellipsoids, the following formula for a unit sphere will hold:-

$$d = \sqrt[3]{a.b.c.}$$

where a, b and c represent the dimensions of a sphere or an ellipsoid and d represents the mean dimension of a, b and c.

N.B. In the above formula the half axes of the sphere (a, b and c) are used. As ratios are involved, the use of the full axial lengths A, B and C does not affect the final result.

The value D was calculated, and after substituting the values of A, B and C in the formula $A = \frac{A - D}{D} \times 100$ for A, etc., the following results were obtained:-

(a) for chert pebbles.

1. A percentage elongation in A of 87.6%
2. A percentage elongation in B of 12.46%
3. A percentage decrease in C of 53.20%

(b) for granitic and quartzitic pebbles

1. A percentage elongation in A of 41%
2. A percentage decrease in B of 3.7%
3. A percentage decrease in C of 27%

As seen from the ratios obtained from undeformed pebbles however (see Table II) it is clear that they are not spherical but invariably ellipsoidal. Furthermore, as shown by Ramsay (1963), their

orientations are not completely random, but lie with their long axes arranged at all azimuths in a plane which defines the bedding.

Taking into account the above considerations, another set of values for the percentage deformation in A, B and C, were calculated using the formula for a unit ellipsoid, viz:-

$$\text{vol. of ellipsoid} = 4\frac{\Pi\ abc}{3}$$

The ratios of the undeformed and then the deformed pebbles were substituted in the above formula. From this the percentage deformation in A, B and C directions was calculated using the relationship:-

$$\frac{A_1 - A}{A} \times 100 = \text{percentage deformation in A, where}$$

A = value for undeformed pebbles and

A_1 = value for deformed pebbles.

Similar calculations were made for the percentage deformation in B and C, and the following results obtained:-

(a) for chert pebbles

1. A percentage elongation in A of 47.4%
2. A percentage elongation in B of 10.55%
3. A percentage decrease in C of 38.6%

(b) for granitic and quartzitic pebbles

1. A percentage elongation in A of 16.9%
2. A percentage decrease in B of 2.87%
3. A percentage decrease in C of 14.00%

From the above it is clear that the percentage deformations in A and C directions is very much greater for chert pebbles than it is for granitic and quartzitic types. It can also be seen that there is never a large deformation in B. This is in accord with the results obtained by Cloos (1947) who found that there was no significant deformation in the B direction of deformed oolites.

As mentioned before, Ramsay (1963) showed that the long axes of undeformed conglomerate pebbles in the centre of the Mountain Land are orientated in all directions within a plane that defines the bedding. The same conditions can reasonably have been expected to hold for the Moodies conglomerate in the Joe's Luck area. It has previously been shown that in this area, the pebbles are now flattened in the

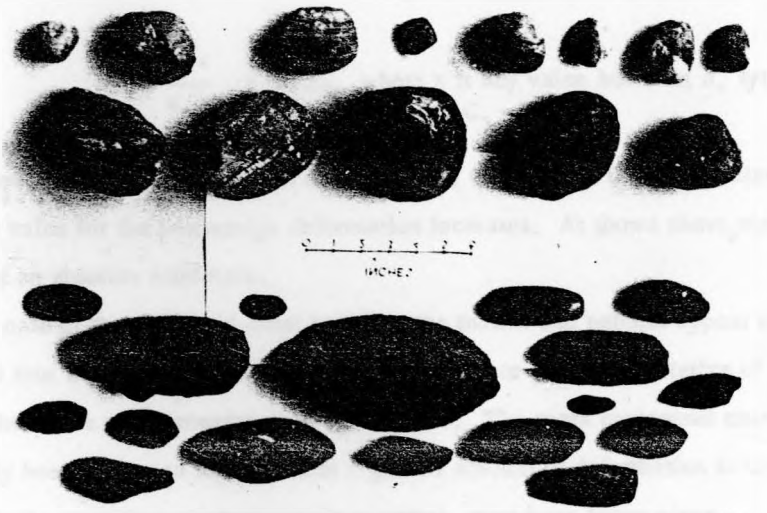


PLATE 43 : Deformed and undeformed chert and banded chert pebbles.
Same localities as for Plate 42.

plane of bedding which thus also coincides with the plane of cleavage (see Fig. 15). It can be concluded from the above that the values obtained for A (for the chert pebbles) represent an absolute minimum amount of deformation that must have affected the area. In the relationship:-

$$\frac{A_1 - A}{A} \times 100\% = \text{percentage deformation in A,}$$

the assumption is made that the original long dimension (A) of the undeformed peb ble, parallels the deformed long dimension A_1. Naturally this will only rarely be the case so that normally the relationship will be:-

$$\frac{A_1 - x}{x} \times 100\%, \quad \text{where x is any value less than A, lying between A and C.}$$

As x becomes smaller, i.e. as it approaches C, the ratio of the above relationship becomes larger and thus the value for the percentage deformation increases. As shown above, the value for A must thus. also represent an absolute minimum.

In the case of the deformed chert pebbles, the matrix and pebbles appear to have reacted almost as one, and thus the values obtained are probably more or less representative of the amount of deformation that the whole conglomerate zone has suffered. The more competent quartzitic and granitic pebbles have hardly been deformed at all so that a greater amount of deformation in the immediately surrounding, relatively more incompetent matrix material, must have taken place.

The exact mode of deformation is unknown, but there are indications that a certain amount of rotation or rolling may have taken place. In many of the deformed pebbles and especially well seen in the area north of Joe's Luck, there is very often a slight "warping" or "twisting" of the flattened "ab" plane of the pebble. This is invariably accompanied by fractures cutting at right angles to the length of the pebble, which often result in its breaking up into a number of segments. These features are undoubtedly related to the deformation of the pebbles and the "twisted" appearance of many of them, appears either to have been caused by a certain amount of rotation during deformation, or else by the "moulding" effect imprinted by adjacent pebbles onto each other during flattening. In the latter case these features would then represent interference phenomena.

The part played by shearing in the deformation of pebbles has not been considered in this discussion as it is almost impossible to distinguish its affects from those of pure flattening (Ramsay, 1963).

F. STRUCTURAL SYNTHESIS AND HISTORY OF THE CONSORT AREA AS DEDUCED FROM STRUCTURES OBSERVED IN ALL THREE ZONES

(a) Introduction

In the subdivision of the area into phases of deformation, the author has followed the scheme used by Ramsay (1963). The subdivision is basically identical, differing only in that Ramsay's 3rd and final phase has been divided into two, giving a total of 4 distinct periods of deformation in the account which follows.

It must be stressed from the outset that the phases or periods of deformation recognised and described above in the various zones, do not represent entirely separate and unrelated tectonic events. However, in that a very marked time relationship exists between the various structures observed, they can conveniently be classed into distinct phases of deformation. As pointed out above, most of these phases appear to be related to each other and simply form part of a sequence of events which are considered for the most part to belong to two or possibly even only one major tectonic episode. In the opinion of the author these are closely related to, and were probably caused by, updoming of the gneissic Nelspruit basement.

The structural history of the area, divided into four phases of deformation, appears to have been as follows:-

(b) 1st Structures

The Eureka Syncline (part of the northern limb of which occurs in the area) has been shown by Ramsay (1963), to represent a first formed structure. The Lily Syncline is a comparable structure and as shown previously, its northern limb constitutes most of the strongly metamorphosed sequence to the north of the Main Southern Fault. The Lily, Eureka and all of the other main 1st folds in the Barberton area, have been shown by van Eeden (1941) to be slightly overfolded to the northwest. In this connection it is interesting that in Zone I, the northwest-trending Consort folds are very irregular in plunge (see Figs. 6 and 7), and it was concluded that some original folded surface, probably in the form of fairly tight folds overfolded in a general northwest direction, must have existed. From the above consideration it might almost be concluded that this first folding was responsible for the irregular plunge of the northwest-trending folds. It must be borne in mind however, that the strong foliation and cleavage development also pre-dates the northwest fold trend, and although as shown by Ramsay (1963), this foliation is very similarly orientated, it truncates the first fold trend and thus, represents a distinctly younger phase of

deformation. Although its effects were probably very small, as few if any major structures developed at this time (Ramsay, 1963), it must undoubtedly have played some part in the deformation of the folded surface which existed before the development of the northwest trending folds. Due to the intensity of the latter deformation however, it is impossible to distinguish between the effects of these two earlier deformations.

From Fig. 2a it appears very likely that the Main Southern Fault, occupying the anticlinal position between the Eureka and Lily Synclines, is intimately connected with these earlier synclinal structures and undoubtedly formed at roughly the same time. It therefore represents a 1st structure. In the Consort area this fault truncates the much younger Consort folds and it must have been rejuvenated at a later stage.

There is very strong evidence for regarding the so-called "Lily Line" as a major fault (i.e. the mineralized, chertified and partly brecciated zone lying to the south of the resistant Lily quartzite ridge - Anhaeusser - verbal communication). It seems likely that this fault continues into the area along the Kaap River and eventually joins up with the well developed Woodstock Fault near Noordkaap. Like the Sheba Fault that occupies a position between the Eureka and Ulundi Synclines, and the Barbrook and Saddleback faults that occupy positions between the Ulundi and Saddleback Synclines, so the proposed Lily Fault together with the Main Southern Fault referred to above, occupy positions between the Eureka and Lily Synclines (see Figs. 1 and 2a). As shown by Ramsay (1963) the major faults in the Mountain Land e.g. Sheba, Barbrook etc., probably developed at the same time as the major folding, i.e. during the 1st period of deformation. From the above it is concluded that the Lily and Main Southern faults are of the same age as the other major faults of the Mountain Land, and thus also represent 1st deformation structures.

(c) 2nd Structures

The second formed structures, shown by Ramsay (1963) to be superimposed on the first ones, are represented in the Consort area by very strong cleavage development. Associated with this is the pronounced mineral lineation so well represented by the aligned hornblende crystals in the meta-sediments along the immediate contact zone. This lineation is also evident in the talc and chlorite phyllites in the vicinity of Noordkaap. The flattening and elongation of pebbles, "lava" nodules, quartz fragments and probably also the development of strong lineations in the intrusive granite bodies, also occurred at this time. These features are all related to the intrusion of a mobilized border phase of the Nelspruit migmatite and their formation is broadly synchronous with the metamorphism of the area.

It is suggested that the updoming of the gneiss, an event which probably started during the 1st major phase of deformation, was intensified during the second phase. Much differential movement or shearing occurred along the contact zone between basement and overlying sediments, and it was into this area that the palingenetically eruptive portions of the basement gneiss found easy avenues of access to the lower pressure regions. The homogenized granite intruded into the border zone and crystallized under the strong "guiding" control of the planes of differential movement. This resulted in the marked alignment of prismatic minerals and the strong foliation within the intruded material.

The updoming of the gneiss continued and was still taking place after crystallization of the granite. This led to the widespread shearing and mechanical grinding down of the latter which is so marked along the contact zone. This process, involving a severe reduction in grain size, was not confined to the intrusive granites and many of the rocks of the metamorphosed suite, especially the quartzitic horizons, show signs of intense dynamic metamorphism. As the process was more or less a continuous one, the earlier formed planes of mineral orientation and cleavage, became planes of intense shearing along which a mechanical grinding down of rock particles occurred. This parallel superimposition resulted in the extremely strong development of the foliation planes, a feature which characterises the intrusive granites.

The main mineralizing episode is considered to have occurred shortly after the granite crystallization, at about the same time as the intense shearing and mechanical breakdown of the rocks began.

(d) 3rd Structures

These are by far the best developed of all the structures in the Consort area. All of the major folds of the immediate mine area (having a very regular axial planar trend of 145°) together with most of the main faults, are of this age.

They fold 2nd structures including the near mylonitized granites, and appear to be mainly of a concentric or flattened concentric type, although the folded cores of less competent rock types are sometimes of a "similar" variety. No axial plane foliation is generally apparent. Both major and minor folds plunge in a very irregular fashion to the south-southeast. This feature, as shown previously, is due to the original irregular terrain caused probably by first period folds (see Figs. 6 and 7).

The great number of these folds in the shales, "lavas" and quartzites of the immediate mine area is noteworthy, and is thought to be largely a reflection of the relatively well layered and more competent nature of these rocks as compared to the surrounding basic schists. This outlying patch of layered

rocks at the western end of the Lily Line, ends abruptly in the immediate Consort Mine area and it is significant that the major third age folds, so well developed in these rocks, die out rapidly in this area as well. Further to the west, only basic schists occur, the strike of the schist foliation being parallel to the Jamestown Hills and very nearly parallel to the axial traces of the 3rd folds. If folds are developed in these incompetent basic rocks, they must be very tight and are by no means apparent, so that all that is generally observed is a strong schistose foliation. In an easterly direction the layered rocks do not end abruptly against basic rocks as in the Consort area, but wedge out gradually so that conditions were not suitable for the large folds of the Consort type to develop. Third age folds do occur in this eastern part, but they are on a small scale and of rather restricted distribution.

From the above it is concluded that while the large patch of layered and competent rocks of the immediate Consort Mine area was strongly folded, the incompetent basic rocks surrounding these, and occurring immediately to the west thereof, were for the most part intensely compressed and converted into schists; the effects of the major folds only being transferred for a short way into them.

As the trend of the axial trace of the folded Eureka and Ulundi Synclines is identical to the trend of the major 3rd folds in the Consort area and as it also deforms a superimposed cleavage, the author is of the opinion that this major inflection in the northwest part of the Mountain Land also developed during the 3rd period of deformation.

Most of the faults in the area truncate 3rd age folds. This is very well shown by the Bluejackets Fault in the northern part of the mine area. The writer considers that the majority of these faults developed late at a stage during the 3rd phase of deformation and were probably in part synchronous with the formation of the main folds. The Main Southern Fault, which as shown above, formed during the 1st phase of deformation, must have been rejuvenated at a late stage during the 3rd deformation as it now truncates the major 3rd folds.

As with the previous deformations it is thought that the updoming of the basement Nelspruit migmatite played an important role in the formation of the 3rd structures.

(e) 4th Structures

Finally, the widespread development of minor crenulation and conjugate folds, the latter indicating a near vertical stress field, affected the whole area. These folds are only observed in lithologically favourable horizons. They are exceedingly well developed in talc, chlorite and sericite schists in the Noordkaap area, and to the north of the Consort Mine. In a number of other scattered localities, folds of an identical nature and orientation also occur. Fig. 23 is a composite plot of all

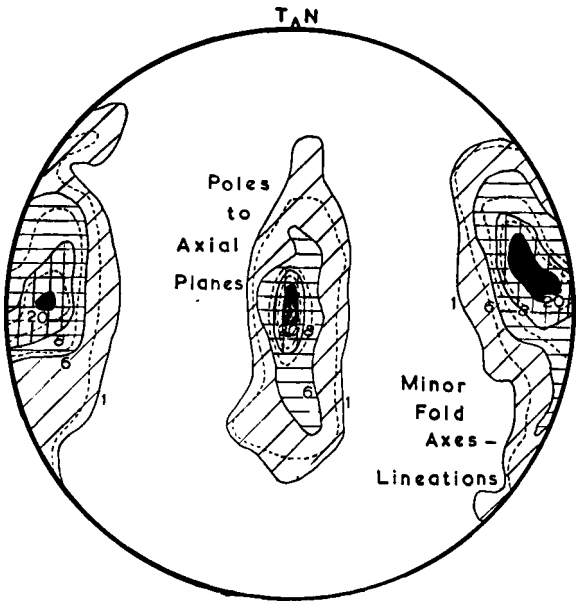


FIG. 23 : Composite plot of minor crenulation folds and associated lineations occurring throughout the area. Total of 162 minor folds and lineations. Maxima represent 20 points and over.

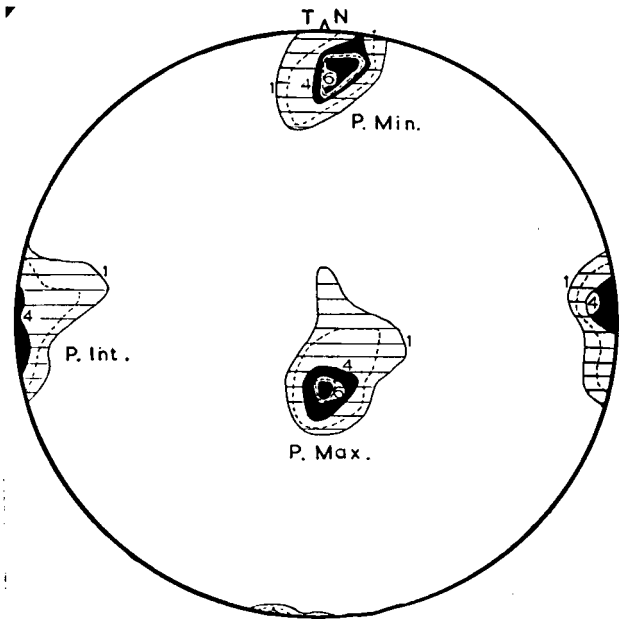


FIG. 24 : Plot of the stress field calculated from all of the conjugate folds in the area i.e. from the Noordkaap area and from north of Consort Mine. Stress field from 12 folds. Maxima represent 6 points. c.f. Fig. 23.

the minor crenulation folds in the area, while Fig. 24 is a plot of stress directions obtained from all the conjugate folds. As can be seen, a near vertical stress field is indicated, the vertical P. max. corresponding favourably with the poles to axial planes of minor crenulation folds.

Where developed, these folds deform all earlier structures. What effects this last period of folding has had on the Consort area is difficult to say, but certain larger folds with near horizontal axial planes might be of this age.

The formation of these late, rather "brittle" folds, was possibly due to the upward movement of late, intrusive granite plutons such as the M'pageni mass, and the G 5 plutons of Swaziland. Similar bodies can reasonably be expected to exist in places under the extensive pile of layered rocks forming the Mountain Land. On the other hand, their formation may be due in part to the overall updoming of the whole basement gneiss.

G. MINERALIZATION IN THE AREA - RELATIONSHIP TO STRUCTURE AND ECONOMIC CONSIDERATIONS

(a) Introduction

A specific and detailed investigation of the actual mineralization as seen on the Consort Mine or elsewhere in the area, was not attempted. The following is more a generalized consideration of the distribution, origin and structural control of the mineralized or potentially mineralized zones.

From an economic point of view, three main zones of potential mineralization, corresponding in all cases to zones of strong shearing, appear to be present. These are viz:- the Consort "Contact", the westward extension of the Lily Fault and certain of the quartzitic horizons within the "footwall" rocks.

(b) The Consort "Contact"

This is the most important of the mineralized zones and occurs between the basic "footwall" schists and the "hanging wall" hornfelses. It can be traced intermittently for a distance of 5 miles to the east of the Consort Mine. In addition to the Consort Mine, the old Cerro de Pasco, Bullion and part of the old Majaja mines, occur along the "Contact".

So-called "bar" development or silicification along this "Contact" often gives an indication as to the amount of shearing that has occurred, together with the amount of gold and sulphide mineralization that is present. Thus, in the Consort Mine area, "bar" development is very pronounced

and it is here too that the strongest mineralization is found. Going eastwards down Dicey's Creek, the "bar" becomes more feeble and in places it appears to be absent. Nevertheless, the presence of the old mines mentioned above, is an indication that a certain amount of mineralization is undoubtedly present along this zone. Even at the extreme eastern limit of the "Contact", in the vicinity of Bar 5 beacon, extensive trenching along a poorly developed "bar", indicates that there must have been fairly promising signs of mineralization.

This "bar" and associated mineralization is strongly folded in the Consort area by the main 3rd age folds and must therefore, be mainly pre-3rd period of deformation. From the following account, it is shown that the mineralization was probably introduced during a fairly late stage of the 2nd phase of deformation.

During the 2nd period of deformation when the intruded granites had almost completely crystallized, mineralized hydrothermal solutions, representing late derivatives of this same granite, made their way into zones of strong differential shearing and dislocation which had already started to develop in the suite of rocks around the Consort Mine area. Naturally the strong silicification and associated mineralization occurred in zones where movement started first and where this was the strongest. The latter was the case along the schist-shale contact along Dicey's Creek and westwards to Bar 5 beacon, where the juxtaposition of competent and incompetent rock-types led to strong differential movement and shearing.

The extensive "bar" development of the Consort Mine, with which is associated some of the best developed and richest gold mineralization in the Mountain Land, was probably due to certain rather unique and specialized conditions. As pointed out, the Lily Line quartzites with associated "lavas" and shales, ends abruptly in the mine area and is followed immediately to the west by basic schists. This fact is regarded as being of the utmost importance and in the writer's opinion, was the main factor responsible for the localisation of the strong Consort mineralization. This was partly due to the fact that the contact between the competent, layered, Fig-tree Series and Moodies System rocks, and the incompetent, basic Onverwacht schists immediately to the west thereof, as with the contact along Dicey's Creek, proved a zone of extensive differential movement; but probably more so because of the fact that this contact trends roughly north-south and was thus broadly parallel to the main deforming stress during the initiation of the 3rd period of deformation. During the initial stages of development of the 3rd folds (probably late during the 2nd phase of deformation), these two rock types reacted in a completely different manner and in addition to the strong differential movement mentioned above, this contact zone must have been under extreme tension. This occurred as the competent layered rocks became folded,

whereas incompetent basic rocks right next to them, did not fold but suffered rather intense compression and developed into schists. It was naturally in this zone therefore, that the strongest silicification and mineralization took place. It seems very probable that the embryonic 3rd folds which as shown above, probably started developing late in the 2nd period of deformation, played a part in the localization of ore deposition. The whole mineralized contact was then strongly folded as the major 3rd folds reached their full development in the Consort area. The effects of the 4th period of deformation on the immediate mine area are not known, but it is thought that they are possibly more widespread and better developed than might be expected.

From the above considerations, it would appear as though the present structural complexity of the "Contact" and of the Consort ore bodies and payshoots, was probably controlled to a greater or lesser degree by all the phases of deformation.

(c) The Westward Extension of the Lily Fault

The possibility has been suggested that certain of the chert "bars" in the Joe's Luck area might represent an extension of the Lily Fault zone. This zone of cherts is generally poorly exposed in the area but can be traced along the north side of the Kaap River where it crosses the latter in the centre of the area, and in all probability joins up with the Woodstock Fault.

Like the other major faults in the Mountain Land, the Lily Fault is mineralized and has at least 5 old mines situated along it. It thus represents a potentially economic horizon although due to poor exposure over most of its length it is not a striking feature and has not received much attention.

In the area southeast of Joe's Luck, there has been extensive trenching along this line. Much further to the west is situated the Woodstock Mine which was still operating up till a few years ago. The latter is situated immediately south of the Woodstock Fault.

It is interesting that the Lily Fault for much of its length, occupies a position on, or very close, to the contact between basic rocks of the Onverwacht (and Jamestown) and the overlying Fig-tree shales. In this respect it is identical to the Consort "Contact" which occupies the same stratigraphic position, but within the metamorphosed northern limb of the Lily Syncline. As was shown to be the case for the development and localization of the Consort "Contact" and associated mineralization, differential shearing and movement along the shale - schist contact (Lily Fault) within the northern limb of the Eureka Syncline, has also caused a certain amount of silicification and mineralization along this zone. It is of interest that the Clutha Mine is situated on, or very close, to this same horizon, and it seems possible that this mineralization may thus also occur on an extension of the Lily Fault zone.

The Main Southern Fault running along the north side of the Kaap River, is occupied by a sheeted vein of milky-white quartz and there appears to be no trace of mineralization.

A chertified greenschist "bar" occurring to the southeast of No. 7 Shaft, has been trenched in a number of places, but very little sign of mineralization was noted.

(d) Sheared Quartzitic Horizons in the "Footwall" Rocks

As mentioned, the ascending hydrothermal solutions took advantage of zones of strong structural disturbance and weakness. The intense shearing and disturbance along the Consort "Contact" created the most favourable avenue for these solutions, but a substantial amount of shearing also took place along the footwall quartzitic horizons. The major movement occurred along the shaly horizons within these quartzites and it is commonly in such zones that there is some sign of mineralization. Along the whole northern part of the area, intercalated shaly horizons have been trenched at various intervals and it appears as though a substantial part of the workings of the old Majaja Mine north of Joe's Luck are situated in some of these footwall horizons.

H. GENERAL IDEAS ON THE EVOLUTION OF THE BARBERTON MOUNTAIN LAND, INCLUDING A CONSIDERATION OF STRATIGRAPHY, STRUCTURE AND MINERALIZATION

The following is a very brief and generalized account of the evolution of the Mountain Land. It is based mainly on conclusions arrived at in the Consort area, but includes also a number of ideas and suggestions which are by no means proven, and which at the moment represent mainly speculation.

The main mass of the Nelspruit gneiss and migmatite, together possibly with the older, contorted gneisses and migmatites of Swaziland, are considered to be roughly of the same age. They represent for the most part, intensely granitized sediments of a pre-Swaziland suite of rocks. These gneisses formed the basement on which, at a much later date, were deposited the Swaziland and Moodies Systems.

In a slowly sagging northeast - southwest geosynclinal depression was deposited on the Onverwacht Series of rocks. These appear to have been mainly impure magnesian limestones with arenaceous and minor shaly horizons, together with large quantities of basic (and probably partly ultrabasic) and acid lavas. The distribution of these rocks was much more extensive than is apparent

today, and it is thought that the numerous basic rafts within the granite area, identical to the strongly metamorphosed Onverwacht rocks occurring around the edge of the Mountain Land, and extending in some cases for many miles into the granite, represent isolated, downfolded remnants of this once much more extensive and probably continuous sheet of Onverwacht rock.

The Fig-tree and Moodies rocks were deposited in succession on top of the Onverwacht Series and are generally confined to the central part of the region. Whether these argillaceous and arenaceous rocks extended further afield than the present outer rim of Onverwacht, and have subsequently been removed by erosion, is difficult to say.

Soon after deposition of the above successions, the major first period of folding, which was probably initiated during the down-sagging and deposition of the geosynclinal sediments, reached its maximum force. This resulted in the development of the major first fold structures (including the Lily Syncline) as well as the major faults (including the Lily and Main Southern Faults) and caused the very pronounced northeast - southwest trend of the Mountain Land.

It was probably during this first period of folding that the serpentinite bodies, representing either true late intrusives, or bodies tectonically "squeezed" into higher zones from the predominantly basic and ultrabasic pre-Fig-tree rocks, were emplaced into higher levels e.g. into the Lily quartzite line near Joe's Luck Siding.

The first period was followed by the widespread development of cleavage, associated with which is the marked flattening of conglomerate pebbles and alignment of metamorphic minerals along the immediate contact belt. The above features are related to the intrusion of a mobilized border phase of the Nelspruit migmatite which, together with the re-heated migmatite, caused the marked metamorphism around the edge of the Mountain Land and also resulted in the high grade metamorphism of the isolated patches of Onverwacht lying on the migmatite a long distance from the contact. The concentration of the mobilized granite around the marginal areas of the Mountain Land is largely due to the fact that this intrusive material found easy avenues of access in the zones of differential shear which developed along the border zone as a result of the updoming of the gneissic basement. The updoming, which continued after crystallization of the granite, also caused the mechanical grinding down of the intruded material and was largely responsible for the marked foliation within these granites.

Flattened pebbles and orientated amphiboles have been described from the Swaziland side of the Mountain Land and these features are apparently identical to those encountered along the northern contact. They definitely seem to be better developed in the marginal areas, and towards the centre of the Mountain Land, especially in the more competent rock-types, 2nd structures appear to be completely

absent. This cleavage developed shortly after the first folds when the operative stress field had not changed very much, so that the planes of cleavage are very nearly parallel to the axial planes of the 1st folds, but as shown by Ramsay (1963) definitely cross-cut them.

The extent of the migmatite on the Nelspruit side of the Mountain Land is unknown, but it seems as though it is far in excess of the mobilized portions. The mobilized material is considered to be identical in origin and character to the widespread G4 granite of Swaziland which also shows intrusive relationships along the contact with the Mountain Land. The extensive development of the G4 granites in Swaziland, leads to the conclusion that the level of this type of granite in the territory is much higher than that of the Nelspruit Granite. This also explains the greater abundance of pegmatites and of economic pegmatites in Swaziland as compared to the Nelspruit side.

The major discrepancy between the two is in age, the G4 from four scattered localities giving an age of 3070 ± 150 m.y. (Allsop et. al., 1962) and the Nelspruit migmatite, 2570 ± 150 m.y. (Nicolaysen - 1962). This might be explained by the fact that the ages for the G4 were obtained from "total" rock samples whereas the age for the Nelspruit migmatite was obtained from coarse biotite. The latter age may thus represent the age of a younger period of metamorphism superimposed onto the migmatites by intrusion of one or other of the younger granites.

At a late stage during the 2nd deformation, probably shortly after the crystallization of the granites and at a stage when strong mechanical deformation in the form of intense shearing had started to develop, hydrothermal solutions, representing late derivatives of the intrusive granites, entered the numerous disturbed zones, especially in the area fairly close to the contact, and resulted in the main mineralizing episode. In the northwest part of the Mountain Land, the embryonic 3rd folds (by far the best developed in this area) had started to form, and together with the reactivated major faults and other localized zones of strong shearing, proved important, especially in the Consort area, in localising the mineralizing fluids. This period of folding well outlasted the mineralizing episode and in the Consort area, these 3rd folds strongly deform the mineralized "Contact". In the latter area they have steeply dipping axial planes and the movement direction was roughly vertical. However, the huge competent masses of the Eureka and Ulundi Synclines, instead of moving vertically during this period of folding, apparently moved horizontally towards the northwest to create the marked inflection in this part of the Mountain Land. Folds with identical orientations to these 3rd folds have been recorded from a number of places at localities over a wide area, including the Bomvu Ridge area of northwest Swaziland (Urie, 1959), and the Montrose area south of Barberton (Herget, 1962). It is of significance that the major inflections tend to occur in areas between large granite domes such as the Kaap Valley boss and it is the writer's contention that the rising of granite domes played an important part in this period of folding.

This would imply that the Kaap Valley Granite was either emplaced, or domed up in some way during the 3rd phase of deformation.

The trend of the 3rd structures (about 145°) is roughly at right angles to the major, earlier formed trend. The 3rd structures deform all earlier formed structural phenomena.

The final phase of deformation is represented by the fairly widespread development of minor crenulation and conjugate folds. They attain probably their best development in the Noordkaap area, but are also known from numerous other localities in the northwestern part of the Mountain Land. Their development is largely controlled by the rock-types, and about 95% of the crenulation folds occur in talc, chlorite and sericite schists, and all the conjugate folds occur in finely laminated quartz-sericite schists. The major deforming stress which caused the formation of these folds must have been nearly vertical. This could either have been due to a final overall updoming of the whole basement gneiss, or to the upward movement of late granite plutons, some of which could reasonably be expected to occur below the Mountain Land.

From the almost complete absence of regional metamorphism, it is clear that the layered rocks of the Mountain Land could never have been covered by a very great thickness of superimcumbent strata, although it seems very likely that they must have been covered by Transvaal System sediments at some stage in the not too distant past.

I. SUMMARY AND CONCLUSIONS

In broad terms,the area mapped consist of two almost identical successions separated by a major fault, the Main Southern Fault. Both these successions, comprising Onverwacht, Fig-tree and Moodies rocks, strike roughly east-west and dip generally at fairly steep angles to the south. The northernmost succession lies in direct contact with the Nelspruit Granite and has suffered fairly strong thermal metamorphism whereas the southern succession has only been slightly thermally metamorphosed. As shown in Fig. 2a, the sequence lying to the north forms the northern limb of the Lily Syncline, the latter truncated roughly along its axial plane by the Main Southern Fault. This major high angle thrust fault has eliminated the southern limb of the Lily Syncline as well as the anticlinal divide between the latter and the Eureka Syncline to the south. This has resulted in the northern limb of the Eureka Syncline (forming the succession to the south) being brought into direct contact with the northern limb of the Lily Syncline.

At the base of the northern succession, lying between the Nelspruit Granite and the overlying Fig-tree sequence, occurs a layered suite of predominantly basic rocks which is classed in the Onverwacht Series. It probably represents a fairly strongly metamorphosed sequence of impure dolomites with arenaceous and minor shaly horizons, together possibly with some basic and acid lavas. The typical metamorphic mineral in the immediate granite contact zone is dark-green to black hornblende with actinolite-tremolite occurring further away. The Onverwacht rocks are overlain by the normal Fig-tree succession and this in turn is overlain by the Moodies System rocks. At the base of the Fig-tree hornfelses lies the Consort "Contact" or Consort "Bar", a silicified mineralized zone which is the main ore horizon of the Consort Mine. The hornfelses, containing garnet, andalusite, biotite and amphibole, grade upwards into rocks which have been termed "lavas" but which are thought to be more of the nature of crystalline tuffs. Two very distinctive marker horizons, the so-called "quartz-bleb marker" and the "pyroxene marker", occur within these "lavas". The main metamorphic mineral is amphibole while diopside is developed in certain calcium-rich bands. The "lavas" are overlain by conglomerates and quartzites of the so-called "LilyLine". The whole succession reaches its best development in the Consort Mine area. Going east from here all the rock units thin rapidly and in the vicinity of Bar 5 beacon (between Joe's Luck and Sheba Sidings) the Fig-tree Series disappears completely. From this point eastwards only the basic rocks of the Onverwacht and the main "Lily Line" quartzites persist.

The weakly metamorphosed succession to the south of the Main Southern Fault is on a broad scale identical to the one just described above. It is very regular in the Joe's Luck area, but going west from here the basal zone becomes somewhat more complicated. The basic rocks of the Onverwacht and Jamestown (generally occurring immediately to the south of the fault) reach considerable dimensions in the Noordkaap area where they merge with the eastern extremity of the basic Jamestown Hills. Complex faulting, mainly in the form of high angled thrusts, coupled possibly with strong folding, has resulted in the occurrence of blocks and slivers of Moodies and Fig-tree rocks within these basic schists. The main rock-types are carbonate-bearing talc and chlorite schists and phyllites and it is clear that the state of metamorphism is very much lower than for the strip of Onverwacht rocks along the immediate granite contact. The shales, "lavas", conglomerates and quartzites overlying these basic rocks, form a very regular and undisturbed sequence constituting the northern limb of the Eureka Syncline. These rocks have suffered little if any thermal metamorphism.

The basic intrusive rocks of the Jamestown are considered to be of a much smaller distribution than was previously thought and are represented mainly by the massive bodies of pure serpentinite. The

possibility cannot be ruled out however, that certain of the talc-carbonate schists along the Kaap River represent altered ultrabasic intrusives. It is considered however, that the majority of such rock-types as well as most of the other basic schists in the area (excluding the massive serpentinite bodies) represent metamorphosed impure dolomitic rocks, together probably with some basic lavas of the Onverwacht Series.

The main mass of the Nelspruit gneiss and migmatite is considered for the most part to represent the granitized product of some pre-Swaziland System succession. At a much later date it acted as the basement upon which were deposited the layered geosynclinal rocks of the Swaziland and Moodies Systems.

Soon after deposition of the above successions, the major first period of folding, which was probably initiated during the down-sagging and deposition of the geosynclinal sediments, reached its maximum force. This resulted in the development of the major first fold structures including the Lily and Eureka Synclines, as well as the major faults, including the Main Southern Fault, and also caused the very pronounced northeast trend of the Mountain Land.

It was probably at this time, as suggested by Ramsay (1963), that the serpentinite bodies, representing either true late intrusives, or bodies tectonically "squeezed" into higher zones from the predominantly basic and ultrabasic pre-Fig-tree assemblage, were emplaced into higher levels, e.g. into the "Lily Line" quartzites near Joe's Luck Siding.

The first period was followed by the widespread development of cleavage, associated with which is the marked flattening and elongation of conglomerate pebbles, development of lineations and alignment of metamorphic minerals along the immediate contact belt. The above features are related to the intrusion of a mobilized border phase of the Nelspruit migmatite which, together with the re-heated migmatite, caused the marked metamorphism around the Mountain Land and also resulted in the high grade metamorphism of isolated patches of basic rock lying on the migmatite a long distance from the contact. It is thought that these isolated patches or "rafts" of basic material within the granite area, identical to the strongly metamorphosed Onverwacht rocks occurring along the immediate granite contact zone, and extending in some cases for many miles into the granite, represent isolated, down-folded remnants of a once much more extensive and probably continuous sheet of Onverwacht.

The concentration of the mobilized granite along the northern margin of the Mountain Land is largely due to the fact that this intrusive material found easy avenues of access in the zones of differential shear which developed along the border zone as a result of the updoming of the gneissic basement. The intrusive material was guided by the planes of differential shearing and this played

a part in the alignment of micas within the granite. The updoming continued after the crystallization of the granite, and continued shearing led to a strong mechanical grinding down of the intruded material. This process, superimposed onto the probable earlier foliation (caused by the preferred orientation of minerals during crystallization) was largely responsible for the very marked overall foliation (parallel to the contact) which is such a marked feature of the intrusive granites.

The area can be divided into three fairly distinct facies of contact metamorphism related to the Nelspruit Granite. The dark hornblende assemblage along the immediate contact zone is classed in the hornblende-hornfels facies. To the south of this, including the Consort Mine area and extending as far south as the Main Southern Fault, is a lower temperature assemblage which can conveniently be classed in the albite-epidote-hornfels facies. The carbonate-bearing talc and chlorite assemblage along the Kaap River fits into the lowest temperature greenschist facies. The essentially dolomitic rocks occurring to the south of the Woodstock Mine and also near the Clutha Mine, have suffered little if any metamorphism.

At a late stage during the 2nd deformation, probably shortly after the crystallization of the granites and at a stage when strong mechanical deformation in the form of intense shearing had started to develop, hydrothermal solutions, representing late derivatives of the intrusive granites, entered the numerous disturbed zones, especially in the area fairly close to the contact, and resulted in the main mineralizing episode. In the northwest part of the Mountain Land, the embryonic northwest-trending 3rd folds (by far the best developed in this area) had started to form and together with the reactivated major faults and other localized zones of strong shearing, proved important, especially in the Consort area, in localising the mineralizing fluids.

The strong foliation described above, developed shortly after the formation of the first folds when the operative stress field had not changed very much so that the planes of cleavage are very nearly parallel to the axial planes of the 1st folds, but as shown by Ramsay (1963) definitely cross-cut them. Both these earlier phases of deformation have been strongly deformed by a northwest-trending fold system. These 3rd phase folds (both on a large and a small scale) reach their best development in the Consort Mine area where they constitute by far the strongest structural feature. They have steeply dipping axial planes and plunge at greatly varying angles to the south-southeast, a feature related to the earlier deformed surface on to which they were superimposed. This period of folding, which during the very early stages probably played a part in the localisation of the ore fluids, outlasted the mineralizing episode and in the Consort Mine area, strongly deformed the mineralized "Contact". The marked inflection in the northwest part of the Mountain Land, including the "bending" of the Eureka and Ulundi Synclines, occurred at this stage. It is thought that rising of granite domes played an important part in this period of folding and it is the writer's contention that the Kaap Valley Granite was either emplaced or domed up in some

way during the 3rd phase of deformation.

Most of the major faults, including the Main Southern Fault, truncate the 3rd folds and are thought to have formed at a late stage during this phase of deformation. The main Southern Fault which formed during the 1st period of deformation, was rejuvenated at a late stage during the 3rd deformation.

The final phase of deformation is represented by the fairly widespread development of minor crenulation and conjugate folds. They attain probably their best development in the Noordkaap area but also occur in favourable rock-types to the north of the Consort Mine and in numerous other localities. Their development is largely controlled by the rock-types and about 95% of the crenulation folds occur in talc, chlorite and sericite schists, and all the conjugate folds occur in finely laminated quartz-sericite schists. The major deforming stress which caused the formation of these folds must have been nearly vertical. This could either have been due to a final overall updoming of the whole basement gneiss, or to the upward movement of late granite plutons, some of which could reasonably be expected to occur below the Mountain Land.

From an economic point of view, three zones of potential mineralization, corresponding in all cases to zones of strong shearing and structural disturbance, occur in the area. The most important is the silicified and mineralized contact zone (within the northern limb of the Lily Syncline) between basic schists of the Onverwacht and the overlying Fig-tree hornfelses, known as the Consort "Bar" or Consort "Contact". It reaches by far the best development in the immediate Consort Mine area, but was traced intermittently to near Bar 5 beacon, a distance of 5 miles to the east. Three old mines occur on or very close to this horizon. The exceptionally well developed "Bar" and mineralization in the Consort Mine area is ascribed to the rather abrupt termination of the Fig-tree and Moodies rocks in this region. During the initial development of the 3rd folds, the relatively more competent shales and quartzites were strongly folded and in this respect reacted completely differently to the basic Onverwacht rocks which did not fold but were rather compressed and eventually converted into schists. The contact zone between these major rock units proved to be the strongest area of shearing and disturbance and was thus the most strongly silicified and mineralized.

Another potential zone of mineralization is the westward extension of the so-called "Lily" Fault, along which in the area to the east, are situated at least 5 old mines (Anhaeusser - verbal communication). This fault occupies exactly the same stratigraphic position as the Consort "Contact", viz. between shales and basic rocks of the Fig-tree and Onverwacht Series respectively, but within the northern limb of the Eureka Syncline. This fault zone, fairly extensively trenched in the area just to the southeast of Joe's Luck Siding, and consisting of various chert horizons together with silicified greenschist-

e rocks, extends along the area close to the Kaap River and possibly merges with the Woodstock Fault. nediately to the south of the latter in the Noordkaap area, is situated the old Woodstock Mine. It is gested that the mineralization of the Clutha Mine, situated close to the contact between dolomitic rocks he Onverwacht and over-lying Fig-tree shales, might also have been derived from, and localised by, the e of strong movement and shearing which developed between these two rock-types. If this is the case, then eems quite possible that the Clutha Mine may also be situated on an extension of the Lily Fault zone. From above it is clear that the various Onverwacht-Fig-tree contact horizons in the northwest part of the untain Land, represent in all cases, zones of potential mineralization. It is considered significant that this lso the area where the 3rd folds attain their best development.

Finally, certain of the quartzitic horizons within the predominantly basic Onverwacht suite ming the so-called "footwall" rocks of the Consort Mine area have been extensively trenched. Fairly ng shearing and a certain amount of mineralization appears to have taken place along minor shaly izons within these quartzites and they also represent potential zones of mineralization.

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