few values were also supplied to the writer by Messrs. M.J. and R.P. Viljoen (viz. AA10, AA17, EE1, EE2, EE3, and EE5).

The granitic rocks analysed included Kaap Valley Granite, Nelspruit Granite (homogeneous as well as migmatitic and gneissic phases), M'pageni Granite, Salisbury Kop Granite, Consort Mine pegmatites, quartz and felspar porphyry bodies intrusive into the Jamestown Schist Belt, and several granitic pebbles from the Moodies basal conglomerate horizon (MdB). Sample localities are plotted in Figure 26, page 243. The K_2O and Na_2O values obtained for the various samples are listed in Table 22. The mean alkali values of six samples of Kaap Valley Granite [Table 22(a)] compare favourably with Nockold's (1954) average values of tonalites while the means of the various Nelspruit Granite phases compare well with average granodiorites and adamellites [Table 22(b)]. The quartz and felspar porphyry bodies are, however, more sodic than average tonalites [Table 22(c)], and the late intrusive granites, pegmatites, and micropegmatites, have broadly similar alkali values to the calc-alkali granites [Table 22 (d) and (e)].

The relationships of the various granites is, however, best explained in a standard alkali plot for the granitic rocks north of Barberton, illustrated in Figure 27, page 250. Harpum (1963) proposed the following K_2O/Na_2O ratios to act as petrographic divisions between the various granite rock-types :

tonalite to granodiorite	0.6
granodiorite to adamellite	1.0
adamellite to granite	1.5

The quartz and felspar porphyries concentrate in the high soda region of the diagram and are distinct from the cluster of values reflecting the Kaap Valley Granite diapiric pluton. One irregular value was, however, obtained for sample 94, which plots in the granodiorite field. This quartz and felspar porphyry may be related to a phase of the Nelspruit Granites or it may have been affected by some potash streaming from these rocks.

The Kaap Valley Granite is clearly a tonalitic granite while the various Nelspruit granite phases range in composition from granodiorite to adamellite. Sample W2 from the Kaap River section at Honeybird Siding demonstrates tonalitic affinities and may represent a remnant patch of Nelspruit Granite which avoided the potash soaking that these rocks apparently underwent at $\sim$ 3.00 m.y. ago. One of the pegmatite samples from the Consort Mine (OG108) falls on the tonalite-granodiorite boundary line while the other sample (OG107) falls in the granite category.

TABLE 22

DETERMINATION OF K_2O AND Na_2O VALUES OF GRANITIC ROCKS NORTH OF BARBERTON BY FLAME EMISSION

(a) Kaap Valley Granite

Sample Number	K_2O%	Na_2O%	K_2O/Na_2O
1	1.89	4.33	0.44
3	1.91	5.00	0.38
7	2.55	4.95	0.52
115a	1.19	5.25	0.23
CS1	1.07	4.71	0.23
KV1	1.16	5.44	0.21
Means	1.63	4.95	0.34
Average Tonalites	1.42	3.90	0.36

(b) Nelspruit Granite

Sample Number	K_2O%	Na_2O%	K_2O/Na_2O
2	4.23	4.34	0.97
K11a	3.48	4.35	0.79
K10	2.48	3.74	0.66
EE 1	3.87	4.60	0.84
EE 2	3.58	4.38	0.82
EE 3	2.77	5.14	0.54
EE 5	4.37	3.92	1.11
AA10	4.74	3.82	1.24
AA17	3.14	4.74	0.66
6	2.42	4.62	0.52
W2	0.81	4.50	0.18
T16A	4.17	3.10	1.35
T16C	3.94	4.08	0.97
N58	4.23	3.87	1.09
Means	3.45	4.23	0.84
Average Granodiorites	3.07	3.84	0.80
Average Adamellites	3.35	4.58	0.73

TABLE 22 (Continued)

(c) Quartz and Felspar Porphyries

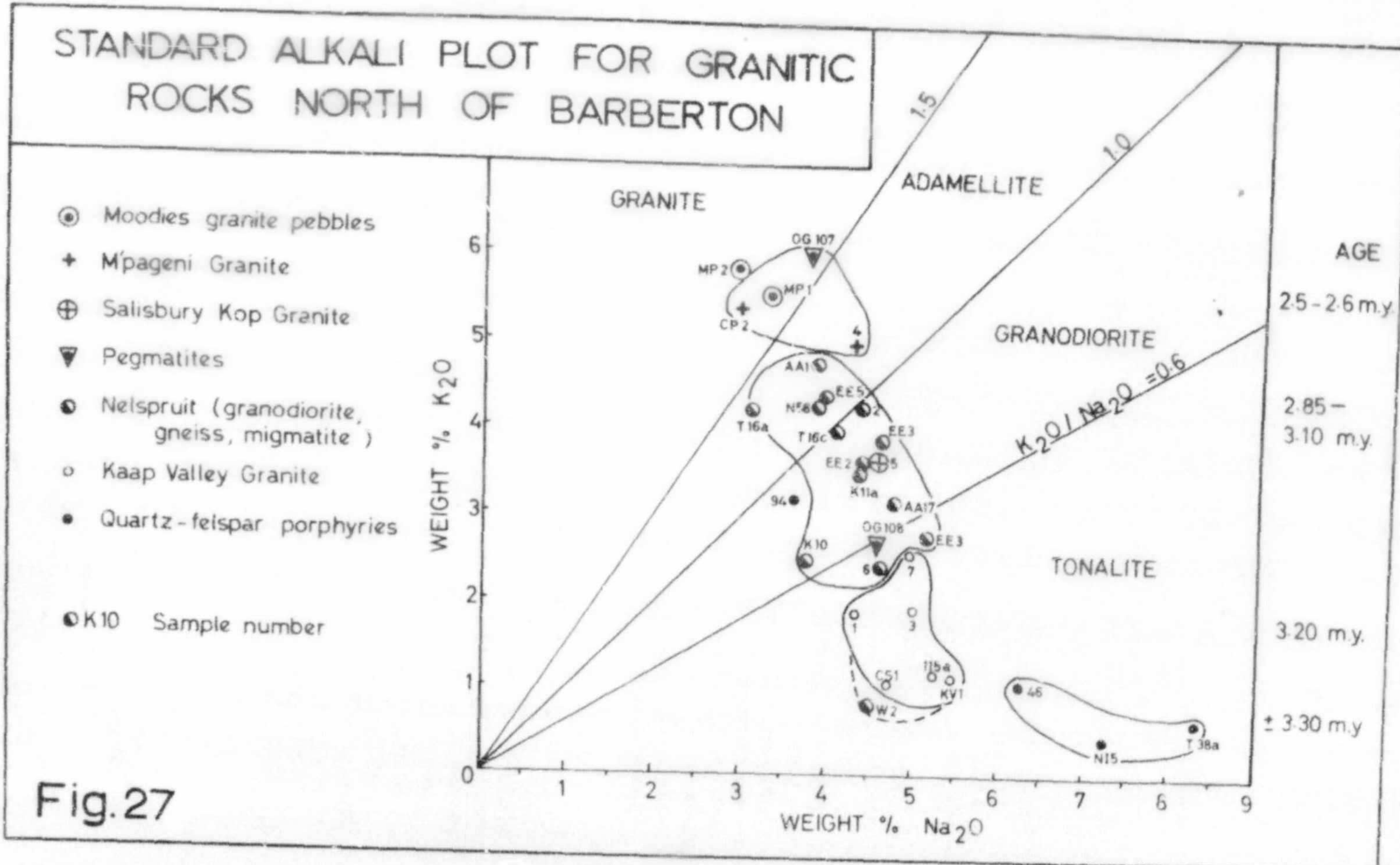
Sample Number	K_2O%	Na_2O%	K_2O/Na_2O
T38	0.66	8.31	0.08
94	3.18	3.60	0.88
N15	0.44	7.25	0.06
46	1.06	6.25	0.17
Means	1.34	6.35	0.30
Average Tonalites	1.42	3.90	0.36

(d) Late Intrusives (Pegmatites, M'pageni Granite, Salisbury Kop Granite)

OG107	5.98	3.75	1.59
OG108	2.68	4.55	0.60
4	4.99	4.27	1.17
CP2	5.38	2.93	1.84
5	3.63	4.53	0.80
Means	4.53	4.01	1.20
Average Calc-Alkali Granite	5.46	3.08	1.77

(e) Moodies Granite Pebbles (Micropegmatites)

MP1	5.50	3.29	1.67
MP2	5.81	2.92	1.99
MP3	7.72	0.18	42.89
Means	6.34	2.13	
Average Calc-Alkali Granite	5.46	3.08	



STANDARD ALKALI PLOT FOR GRANITIC ROCKS NORTH OF BARBERTON

Fig.27

The M'pageni granite, clusters in the adamellite-granite range as do the micropegmatitic granite pebbles from the Moodies conglomerates. The Salisbury Kop Granite, however, plots in the granodiorite field. For the method to be of real value it is necessary to have a number of alkali determinations carried out on the same granite-type. In this way sampling errors and normal chemical variations are overcome and an average value may reflect more accurately the true nature of the granites.

Also in Figure 27, page 250 the approximate ages of the various granites has been included to demonstrate the relationship of time to the potash-soda content of the rocks in a particular province. There is a clear, almost linear, increase of the K_2O/Na_2O ratio as the rocks get younger. One anomaly occurs, however, with the micropegmatitic conglomerate pebbles. These, according to the scheme outlined above, should theoretically have been very rich in soda. Instead, the reverse is true. The fact that the rocks are micropegmatites does, however, indicate that they are late-phase granitic rocks - an arrangement they may well have had in a possibly earlier granite cycle? If they were late-phase granitic rocks they would, most probably, have been responsible for the development of relatively elevated terrain, so typical of younger granites and pegmatites. Consequently these areas would be the first to erode, and, as is the case in the Barberton area, their presence may have been entirely obliterated. The abundance of oligoclase-albite, microcline, quartz, and perthite in the Moodies sediments adds support to this contention.

(b) The Rock Series of the Barberton Mountain Land

Mention has been made in the text, that the Barberton Mountain Land constitutes a calc-alkaline series or suite of rocks. Igneous rocks have for a long time been divided into two great groups, the rock suites of orogenic and non-orogenic areas being strongly contrasted in their chemical and mineralogical characters. The two groups of rock suites were initially referred to as the Atlantic (alkalic) province or the Pacific (calcic) province. The geographical connotation is now becoming obsolete and refinement has delimited a four-fold subdivision to take into account transitional rock suites (Barth, 1962A). Peacock (1931) proposed a scheme that goes beyond a fourfold division, however, and permits a quantitative determination to be made of the degree of alkalinity of the assemblages.

In order to ascertain precisely to what rock series the Barberton Mountain Land belongs, the writer made use of all the available chemical analyses of rocks in the area. These range from ultramafic to granitic rock-types and have been included in various tables throughout this text. A variation diagram was constructed wherein the Niggli values fm, c, al, and alk, are plotted against si, and mg is plotted against k (see Figure 28A, page 253). For comparison variation diagrams after Niggli (in : Cadisch, 1953) are included in the same figure. Figure 28B, represents a calcic province with rock assemblages ranging from peridotite to aplitic granite, while Figure 28C represents an alkalic plot. It can readily be seen that the Barberton rock suite is very similar to the calcic variation diagram. The "isofalie" or isofalic point, determined by dropping a perpendicular to the si axis from the point of intersection of the fm and al lines, gives a value of si = 214 i.e. within the calcic range of 170-220 given by Cadisch (1953).

In order to obtain some idea of the degree of alkalinity of the Barberton rock suites a refined variation diagram was constructed using the alkali-lime index proposal of Peacock (1931). This diagram, Figure 28D, is a plot of the alkalis (Na_2O + K_2O) against SiO_2, and CaO against SiO_2. The value of the abscissa of the point of intersection, expressed in terms of percentage SiO_2, is the alkali-lime index. The lines shown in the diagram were fitted by the method of least squares and the alkali-lime index was found to be 65, indicating that the Barberton rocks, from the chemistry available to the writer, are strongly calcic.

H. GENERAL DISCUSSION

The granitic rocks which surround, and often intrude, the Barberton Mountain Land are clearly responsible for the deformation and metamorphism. In some places the granites have almost entirely obliterated the supracrustal rocks so that only metamorphosed vestiges remain in the form of narrow, arcuate, schist belts or xenoliths.

The origin of the vast granitic assemblages, not only in the Barberton area, but in all the ancient shield areas of the world, has been the cause of much speculation and discussion, primarily because the recognition of the basement on which the early Precambrian greenstone belts were deposited is of major significance in regard to the development of the ancient crust. Although the granitic assemblages of the shields is probably of a secondary origin, having been derived from the mantle and from reworked primitive crust there are indications, however, suggesting that some early granitic crustal material did exist prior to the development of the typical greenstone belts.

VARIATION AND ALKALI-LIME INDEX DIAGRAMS FOR ROCK SUITES OF THE BARBERTON MOUNTAIN LAND

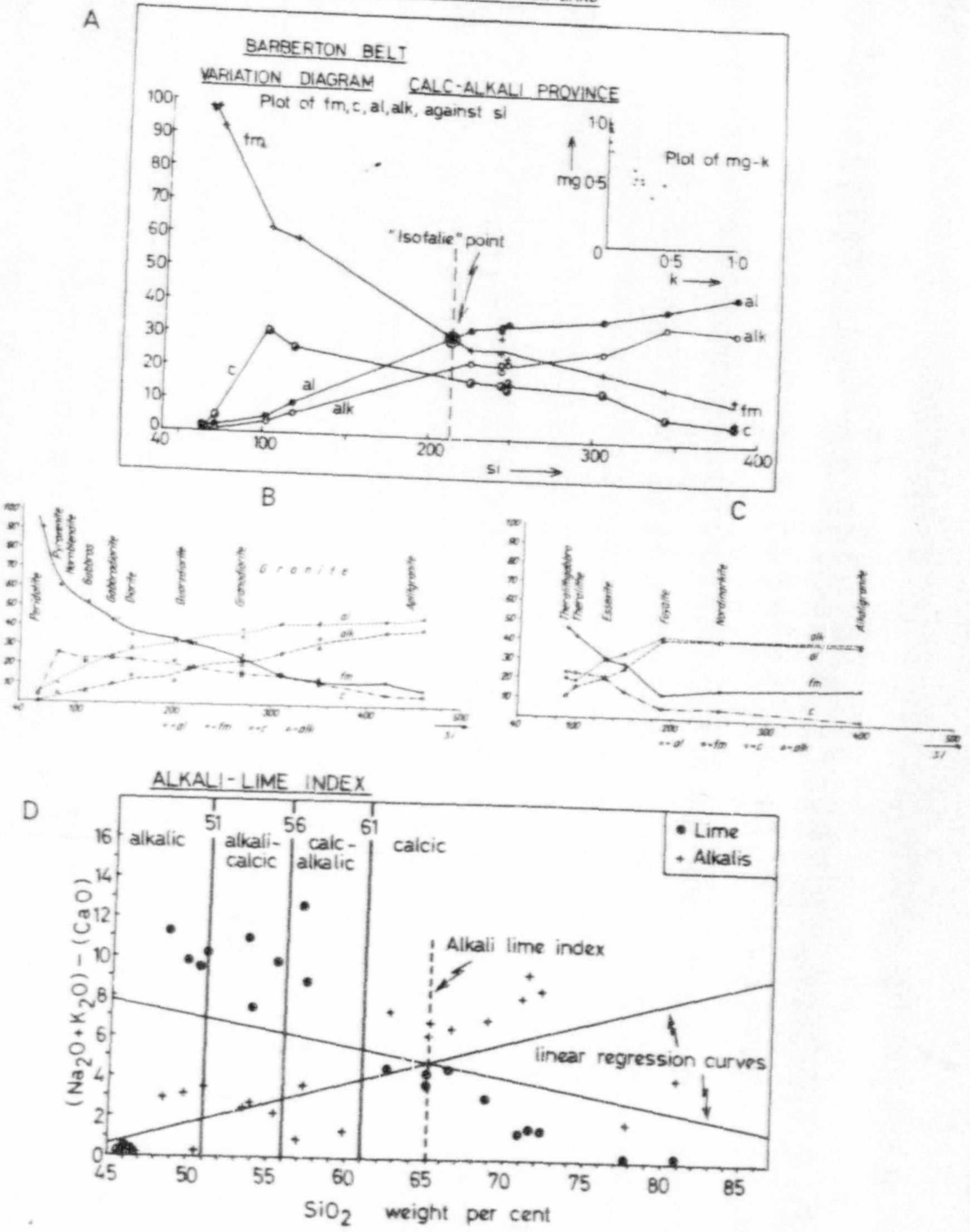


FIGURE 28: A. Variation diagram constructed from analytical values of ultramafic, mafic and salic rocks from the northwest flank of the Barberton Mountain Land. Calcic (B) and Alkalic (C) variation diagrams for comparison (after Niggli, in Cadisch 1953). D. Refined variation diagram indicating the degree of alkalinity of the Barberton rock suites.

In the Barberton Mountain Land the possibility does exist that parts of the migmatite terrain, like that of the Nelspruit gneisses and migmatites, might represent altered and granitized vestiges of an early crust. Since, however, no sedimentary or unconformable contact between the lowermost members of the Onverwacht Group and the underlying rocks can be identified anywhere in the area, it has not been possible to affirm this view. Indirect methods have had to be employed to establish the presence, or otherwise, of a primitive granitic crust. This has been done mainly by examining the sediments of both the Fig Tree and Moodies assemblages. Of interest is the high percentage of minerals such as quartz, potash felspar, plagioclase, zircon, and apatite found in these rocks. Roering (1967) reported an average value of 2.5 volume per cent (the highest value recorded being 5.3 volume per cent) of potash felspar in Fig Tree greywackes. The Moodies sedimentary succession provides more definite evidence of having been derived from granitic rocks. As mentioned earlier, pebbles of granite and quartz porphyry occur in the basal conglomerate and many of the quartzites are felspathic, containing microcline, perthite, and oligoclase-albite. Highly deformed dykes occur in the granite terrain surrounding the Barberton belt. These dykes are often folded, the axial planar structure of the migmatites being identical to the axial plane of the dykes. This fact led Roering (1967) to suggest that the dykes had been involved in the palingenesis of the surrounding migmatite and gneissic material. The inference to be gained from the involvement of the early dykes in the migmatite-gneiss palingenesis is evidence in support of this terrain being representative of an ancient, pre-Swaziland Sequence basement (Roering, 1967; Anhaeusser et al, 1967).

Certain features of greenstone belts suggest that they originally developed on a relatively thin crust. These have been outlined by Anhaeusser et al, (1968) and include such features as the telescoped nature of the metamorphic aureoles at the contacts with the younger granites, and the bimodal nature of the mineral facies (Engel, 1966). The absence of a blueschist facies of metamorphism also favours a thin early crust and a steep thermal gradient in early Precambrian times. Another line of evidence stems from the chemistry of the metabasalts which are generally low-potassium tholeiites, with compositions approximating closely those of oceanic tholeiites. The primitive, uncontaminated, nature of these metabasalts is possibly to be ascribed to their having passed through a relatively thin sialic and/or basaltic crust in very early Precambrian times (Engel et al, 1965).

Just how the vast "sea" of granite, that everywhere surrounds the greenstone belts, was able to develop is not fully understood. It has been suggested by Roering (1967) that granitic material was added to the crust in very early Precambrian times directly from a differentiative process in the upper mantle. This process of anorogenic granite addition may have ceased to operate in younger geologic times, or if it was in operation, it is suggested that the result was a sialic underplating of the continents with no visible surface manifestations.

Although little detailed information regarding the granitic rocks of the shield areas exists three main categories appear to be present (Anhaeusser et al, 1968). A complex array of migmatites and banded gneisses, together with more homogeneous granitic phases, constitute some of the oldest granitic rocks. A second distinctive type of granite forms circular or elliptical diapiric bodies. Thirdly a series of potash-rich, coarse-grained often porphyritic granites intrude and interrupt all earlier-formed trends and structures.

Parts of the Nelspruit migmatite-gneiss terrain are probably representative of the first category even although age determination studies indicate a uniform age of $\sim$ 3.00 b.y. Strong indications of widespread mobilization and potash metasomatism are present throughout this area and may reflect a "swamping" of the earlier formed material by an event through which geochronological studies have not been able to penetrate. There is a tendency, in the area north of the Consort Mine-Louw's Creek contact (see Figure 3, page 51), for the Nelspruit Granite terrain to act as a diapiric body, for it embays into the northwest flank of the Mountain Land. Numerous hornblende amphibolite xenoliths occur in the granite terrain west of Kaapmuiden and extend towards the Consort Mine area. These remnants resemble typical Onverwacht metabasalts and it is suggested that they may once have formed a part of the more extensive development of the Swaziland Sequence in the area. Migmatites, also found in this area, may represent the granitized products of the Onverwacht Group metavolcanics, as was suggested by the Geological Survey (Visser, compiler, 1956). If this is the case, the Nelspruit terrain as developed between Kaapmuiden, Louw's Creek, and the Consort Mine, may represent an embryonic diapiric body - one in which complete homogenization has been retarded, or prevented, by the potash streaming event mentioned previously. On this hypothesis, the Kaap Valley Granite represents an advanced stage in the development of a diapiric body and one in which stoping and assimilation of surrounding rocks has been allowed to develop to completion. It is possible that a body like the Kaap Valley Granite may have initially been strongly gneissic or even migmatitic. Continuing the process, the granite may gradually have homogenized leaving only relict "schlieren" and xenoliths to testify to its incorporation of surrounding rocks.

The circular or elliptical diapiric plutons, of which the Kaap Valley Granite is a classic example, are widely developed in the early Precambrian terrains where they are intimately associated with the greenstone belts, being mainly responsible for their deformation. They generally occur around the outer margins of the belts and it would appear that they probably originated as a response to gravitational adjustments following the downsagging of the greenstone belt depositories. The diapiric bodies are characterized by a low potash : soda ratio , and poorly developed associated pegmatite phases. This type of granite is usually responsible for the formation of the arcuate schist belt remnants, or tongues, which form such a striking feature of the schist areas - the so-called "early Precambrian greenstone-granite pattern" of Anhaeusser et al, (1968). These bodies, which vary tremendously in size, are responsible for the deformation in their immediate environment, and structures produced by them are frequently superimposed on to some earlier trend. The diapiric granites have clearly incorporated material from the greenstone belts, either as xenoliths or as diffuse, assimilated "schlieren", and probably formed by the slow upwelling and forceful emplacement of discrete granitic masses.

The Kaap Valley Granite, like most other diapiric bodies in the Barberton area and elsewhere, is responsible for the thermal, as well as the dynamic, metamorphism of the rocks into which it has intruded, and is also responsible for the formation of the distinctive arcuate Jamestown Schist Belt in the north, and the Nelshoogte Schist Belt in the south. Evidence of the dynamothermal metamorphism created by this granite is afforded by the nature of the foliations and lineations in the metabasalts which parallel those in the foliated margins of the granite . The foliation in the granites, it has been shown, is caused by the alignment of platy minerals, and is accentuated by aligned, metamorphosed mafic xenoliths. Towards the central part of the pluton the foliation becomes less pronounced, and may disappear altogether. This feature is also typical of the diapiric plutons in the Badplaas-Komati River Valley area (Viljoen and Viljoen, verbal communication, 1968). Although the diapiric Kaap Valley Granite is responsible for the thermal metamorphism of the rocks into which it intrudes, this metamorphism is of a low grade and only a narrow contact aureole is developed. This low-grade metamorphism is a feature characteristic of early Precambrian greenstone belts (Anhaeusser et al, 1968).

Finally, the remaining high-level, potash-rich, granite plutons are often circular, homogeneous, porphyritic, coarse-grained, non-foliated, late intrusive bodies. Unlike the granites described earlier, they characteristically cause abrupt truncation of earlier formed structures and trends and have generally caused very little metamorphic and structural changes in the rocks into which they intrude. Concentric faults and fractures may, however, surround these intrusives. Both the M'pageni and Salisbury Kop Granites belong to this category and are probably examples of the only true magmatic granites in the Barberton granite-greenstone terrain. These granites, with ages ranging between 2.5 and 2.8 b.y. were probably intruded into an already stable, relatively cool, cratonic environment (Anhaeusser et al, 1968).

Most of the main features pertaining to the various granites that have been described in the foregoing sections are summarized in a diagram appearing later in the text (see Figure 41, page 316).

* *

CHAPTER 7

STRUCTURE AND METAMORPHISM OF THE SWAZILAND SEQUENCE ON THE NORTHWEST FLANK OF THE BARBERTON MOUNTAIN LAND

A. INTRODUCTION

Since the study of Ramsay (1963A), in which he determined at least three deformations in the area north of Barberton, many other investigators have attempted to classify structural features found in their areas, into his structural framework. Anhaeusser (1964) and Viljoen (1964) found, for example, that they could add a fourth deformational event in the area between the Consort Mine and Louw's Creek, while van Vuuren (1964) was able to add a fifth, in the Ulundi Syncline area. Lastly, Roering (1965), in his attempt at synthesizing all the structural geological data available from the main gold producing area of the Mountain Land (i.e. the area north of Barberton), concluded that at least six phases of deformation had been active over the whole area.

The early ideas on structure were developed mainly in the area to the northeast and southwest of Barberton where intensive minor structural investigations were carried out in most cases. Not much was known at this stage, however, of the overall structure of the greenstone belt or of the granites that surround it. As more information was made available it became apparent that the role played by the granites, particularly the diapiric granites, had been considerable, and that they had been responsible for most of the superimposed structural features observed in the successions of the Barberton Mountain Land. It furthermore became evident, that it was unrealistic to correlate structures from widely separated areas of the greenstone belt unless it could be shown that they were developed by the same deforming stress.

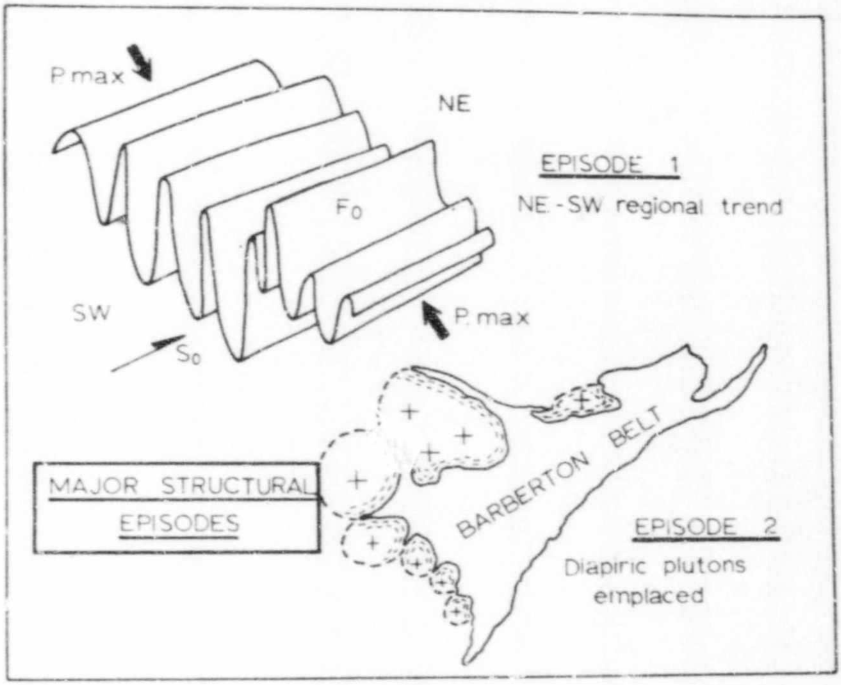
Thus far, throughout the previous sections of this thesis, the writer has purposely refrained from classifying various structures seen in the field, into separate phases of deformation. In this chapter it is intended to outline briefly the structural and associated metamorphic events that have affected the entire Barberton greenstone belt, and an attempt will also be made to illustrate, in more detail, the various phases of deformation that occurred on the northwest flank of the Mountain Land and to reconcile some of the metamorphic events with the structural events.

B. THE STRUCTURE OF THE BARBERTON MOUNTAIN LAND

Two major structural episodes are envisaged by the writer. The first, about which very little is known, caused the NE-SW regional fold trend of the Barberton belt and produced dynamothermal metamorphism of the greenschist facies. This first episode is illustrated diagrammatically in Figure 29A, page 259. The major regional trend was established at this stage by a deformation the writer will refer to as the F_0 deformation. This F_0 deformation may have created, locally, an S_0 planar fabric or schistosity, parallel to the regional trend. The fact that much of the central interior of the Barberton greenstone belt does not display any marked rock fabric suggests, however, that the S_0 event was not all-pervasive, or entirely penetrative, but was, most probably, restricted to the zones bordering the confining limits of the depository.

As mentioned previously the cause of the F_0 deformation is not known and can only be speculated over. Alpine-type tectonism or orogeny is not favoured as a model for the development of the deformations experienced by early Precambrian greenstone belts (Anhaeusser et al, 1968). The views expressed by these writers have been supported by Professor J. Sutton and Dr. J. Watson as well as by Professor H. Martin, (verbal communication, 1968), all of whom have recently visited the Barberton Mountain Land. The remarkable preservation of sedimentary and volcanic structures throughout the greenstone belt is strongly suggestive that the deformation experienced by the successions was of a relatively passive nature. For this reason it is suggested that the early tectonic history of the belt was controlled largely by gravity deformation. In this connection, the experimental work on gravity deformation by Bucher (1963), and Ramberg (1967), may hold several clues as to the development of the folds in the Barberton Mountain Land and, for that matter, in other greenstone belts. The preponderance of synclines and longitudinal strike faults that may, in fact, represent slides (for definition of a slide see Fleuty, 1964) is evidence to

A



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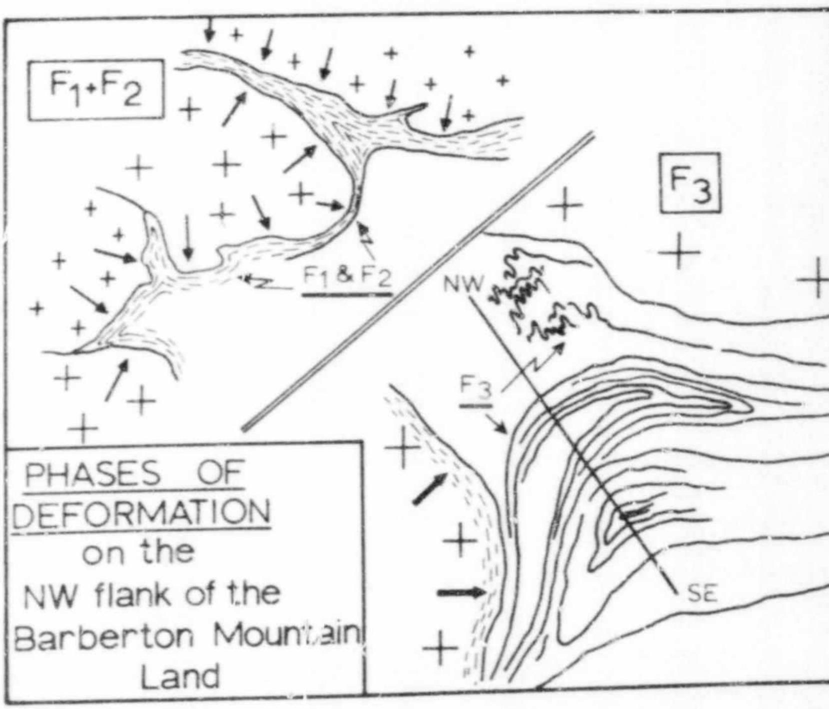


FIGURE 29: (A.) Diagram showing the main structural episodes that were responsible for the deformation of the Barberton greenstone belt.

(B.) Diagram indicating some of the phases of deformation north of Barberton that were produced by the emplacement of diapiric granite plutons.

support the gravity deformation hypothesis. No intense compression, other than that supplied by the confining margins of the depository, is envisaged for the primary episode of deformation.

The second major episode was initiated by the emplacement, into the Swaziland Sequence, of numerous, broadly synchronous, diapiric plutons, which resulted in the formation of narrow, tapering, arcuate schist belt remnants (see Figure 29A, page 259). The emplacement of these characteristically homogeneous granite plutons, the contact zones of which are invariably foliated, has been responsible for the disruption of the earlier trend and has produced localized regions of structural interference. The arcuate schist belt remnants sandwiched between granite plutons have been most severely affected but in places, depending on the size of the invading plutons, the structural affects may have been more far reaching. In the area to the north and north-east of Barberton, for example, at least four decipherable phases of deformation have been established. These phases do not, however, represent entirely separate and unrelated tectonic events but instead appear to be related to each other, forming part of a sequence, or progression of events, which can be considered for the most part, to belong to two, or possibly only one, major tectonic event.

C. PHASES OF DEFORMATION OF THE NORTHWEST FLANK OF THE BARBERTON MOUNTAIN LAND

In the area north of Barberton, and discussed in this thesis, the influence of the Kaap Valley Granite diapiric pluton has been particularly prominent and has resulted in much of the structural complexity displayed throughout the area. The influence of this granite has been so profound that the writer prefers to date all structures recorded in the area with respect to the emplacement of this pluton. Figure 29B, page 259 is a diagrammatic summary of the phases of deformation encountered in the area.

The schistosity wraps around the outline of the diapiric bodies and is parallel to the granite contacts. This deformation (F_1) has produced a schistosity that will be referred to as S_1. It can be seen that the F_1 deformation can produce structures aligned in any direction so that correlation of these cannot be made on orientation alone.

Superimposed on the F_1 and S_1 event there is invariably developed a stretch lineation produced mainly by the alignment of platy minerals, or micro-fold axes. This phase of deformation is designated

F_2 and the fabric produced by it is an S_2 fabric. In the area north of Barberton micro-structures associated with this event have already been illustrated (see Plate 13, page 183). These structures deform the earlier fabric but F_1 and F_2 phases of deformation are closely related, the one event following the other as the diapiric granite was emplaced. Although the F_0 event is believed to have been responsible for the initial folding of all the formations, it was probably the F_1 and F_2 events, however, that really began the intensification of the major as well as the minor fold deformations in the Jamestown Schist Belt as well as in other arcuate schist belts in the Barberton greenstone belt.

The third phase of deformation (F_3), seen by the writer as a progressive response to the earlier deformations, caused the arcuation of the Eureka and Ulundi Synclines on a large scale and was responsible, furthermore, for the NW-SE trending folds in the Consort Mine area and the isoclinal folds in the Jamestown Schist Belt. The folding also resulted in the production of an S_3 fabric which is essentially the superimposition of a further set of folds on to the earlier S_1 and S_2 surfaces. In some places in the Barberton Mountain Land this phase of deformation may never have eventuated despite the fact that diapiric invasion may have taken place nearby.

The third phase structures seen north of Barberton were produced as a result of a set of unusual circumstances, the most important of which were the type and competency of the rocks (Fig Tree and Moodies), the great number of regional longitudinal strike faults, the probable buttressing effect of the Nelspruit migmatite terrain to the north, and not the least important, the largest diapiric granite pluton (Kaap Valley Granite). It is envisaged that as the granite invaded, some detachment took place along the Barbrook and Saddleback Faults, with all the formations to the north suffering inflection as the deformation continued. This is a view also subscribed to by Roering (1965) and the disturbances created by the deformation may have been responsible for the transcurrent or wrench fault dislocations reported in the area by the writer (Anhaeusser, 1965).

A fourth phase of deformation is evidenced by the large number of late flat folds such as the accordion, crenulation, and conjugate folds discussed earlier, and shown in Plate 14, page 186 and 15, page 190. These late folds, which deform all earlier structures may represent the final tectonic pulse of the diapiric plutons or, as has been suggested earlier, they may be related to the late granites or to some reactivation along major fault zones in the area.

The cleavage deformation in the Eureka Syncline reported by Ramsay (1963A), and discussed previously, may have developed very early in the history of the area and may be regarded as a phase of deformation pre-F_1 in age (i.e. associated possibly with the F_0 tectonic events).

D. METAMORPHISM OF THE SWAZILAND SEQUENCE

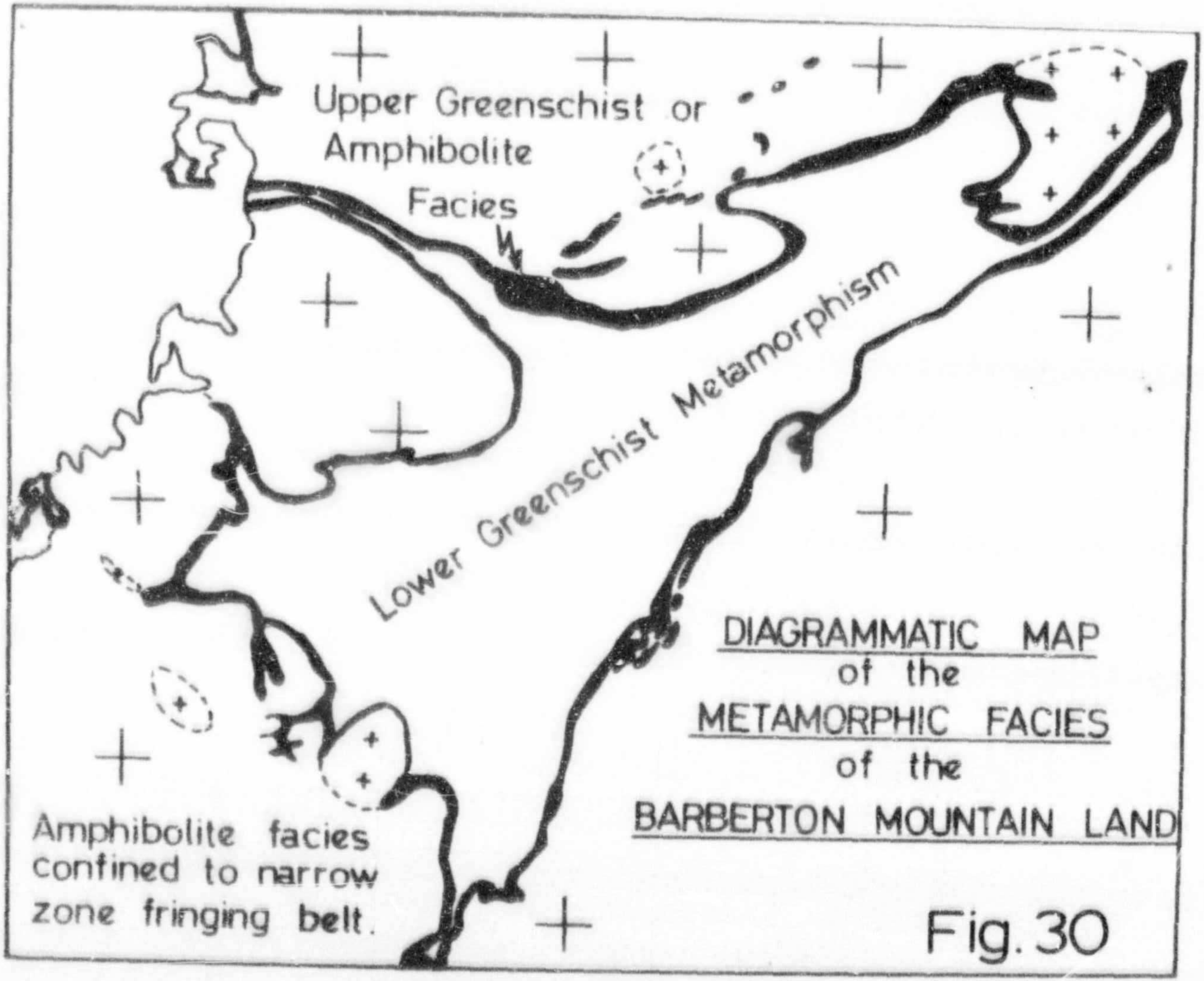
(a) Introduction

Low-grade greenschist facies metamorphism is typical of the major part of most greenstone belts throughout the world. There is usually an intimate relationship between metamorphism and deformation, and the sequence is generally comprised of two or more periods of mineral development and deformation, followed by widespread post-tectonic recrystallization and late stage retrogression in the waning phases of metamorphism.

The Barberton Mountain Land, being well-developed and well-exposed, affords a good opportunity for the study of metamorphism associated with an early Precambrian greenstone belt. Although the area has suffered a widespread low-grade metamorphic overprint, the original nature of the rocks can, in most cases, be ascertained, particularly in the interior regions of the belt and in the Komati River Valley.

A diagrammatic portrayal of the metamorphic facies present in the Barberton greenstone belt is shown in Figure 30, page 263. Fringing the granites, and shown as a narrow black rim, are the higher grade metamorphic rocks comprising assemblages that may be grouped in the upper greenschist facies, or the amphibolite facies, of regional metamorphism. Away from the margins of the belt the metamorphic grade drops off rapidly and in places, in the central regions, almost unmetamorphosed rock-types may be encountered. However, in most cases, the assemblages have suffered metamorphism and can generally be fitted into the lowest subfacies of the greenschist facies of regional metamorphism.

In Figure 31, page 264 the writer has attempted to summarize, in a series of tables, the primary lithological assemblages found in the Barberton Mountain Land and their presently observable metamorphosed derivatives. Anhaeusser et al, (1968) showed that the rocks in typical greenstone belts could be subdivided into an Ultramafic Group, a Greenstone Group and a Sedimentary Group. In the Barberton greenstone belt, rocks belonging to the first of these groups is listed in Figure 31A, while the assemblage typical of the Greenstone Group is shown in



DIAGRAMMATIC MAP
of the
METAMORPHIC FACIES
of the
BARBERTON MOUNTAIN LAND

Fig. 30

A

Ultramafic Group

Primary Lithological Types	Original Composition	Metamorphic Derivatives
GABBROS	plagioclase (labradorite) clinopyroxene (augite, diallage) olivine; some quartz at times (SiO_2 40 - 60%)	actinolite-tremolite hornblende, chlorite, albite, epidote, diopside talc-tremolite-actinolite
PYROXENITES	augite, diallage diopside, bronzite hornblende (SiO_2 40 - 55%)	talc-tremolite schists tremolite-chlorite schists tremolite-actinolite serpentinite
PERIDOTITES	biotite hornblende pyroxene (diallage, hypersthene) enstatite olivine (SiO_2 38 - 50%)	serpentinite (antigorite) talc-tremolite schists tremolite-chlorite schists talc-carbonate schists
DUNITES	olivine mainly some pyroxene (enstatite) chromite, magnetite (SiO_2 27 - 46%)	serpentinites (antigorite) talc-tremolite schists talc-carbonate-tremolite schists tremolite-chlorite-antigorite

B

Volcanic Rocks - Mafic - Intermediate - Siliceous

Primary Lithological Types	Original Composition	Metamorphic Derivatives
RHYOLITES	sanidine, oligoclase-andesine orthoclase quartz biotite, hornblende rarely (SiO_2 68 - 77%)	quartz, albite, sericite, muscovite chlorite, carbonates
DACITES	plagioclase (labradorite, in groundmass) pyroxene (diopsidic augite, hypersthene) hornblende biotite (SiO_2 58 - 61%)	chlorite, talc-chlorite schists sericite, clinozoisite, epidote actinolite, carbonates
ANDESITES	plagioclase (medium labradorite) clinopyroxene (diopside, augite) olivine in some (SiO_2 55 - 60%)	actinolite, hornblende schists chlorite-actinolite schists talc-chlorite-actinolite schists carbonates
THOLEIITIC BASALTS	clinopyroxene (pigeonite, diopside) plagioclase (labradorite) little or no olivine (SiO_2 + 50%)	actinolite schists hornblende schists chlorite, albite, quartz, epidote garnet, diopside, carbonates

C

Sedimentary and Pyroclastic Rocks

Primary Lithological Types	Original Composition	Metamorphic Derivatives
CHEMICAL PRECIPITATES banded ironstones cherts jaspilites	quartz, jasper, magnetite, hematite limonite goethite, carbonates (siderite, dolomite) quartz, chalcedony, carbonates, clays quartz, hematite	quartz recrystallized, grunerite, chlorite quartz recrystallized, sericite, chlorite quartz recrystallized, grunerite, chlorite
ARENACEOUS SEDIMENTS quartzites sandstones sub-greywackes conglomerates	quartz, felspar, accessory mafic material, quartz, felspar, clays quartz, felspar, clay, ferruginous material quartz, chlorite	quartz, chlorite, muscovite, sericite, (quartz recrystallized) quartz-chlorite phyllites quartz-chlorite-sericite phyllites chlorite, biotite, phyllites
ARGILLACEOUS SEDIMENTS shales greywackes fine grained quartzites	quartz, clay (kaolin, montmorillonite, limonite) quartz, chert, volcanic fragments, plagioclase quartz, felspar, accessory mafic material	biotite, chlorite, garnet, grunerite, cordierite, andalusite quartz-sericite-chlorite schists, phyllites quartz, sericite, chlorite, biotite fuchsite, muscovite, sillimanite
SILICEOUS, MAFIC, AND SALIC TUFFS, AGGLOMERATES, BRECCIAS, ASH BEDS, ALUMINOUS SEDIMENTARY AND VOLCANIC ROCKS	essentially intermediate to acid in composition quartz plagioclase (labradorite) hornblende, pyroxene cementing materials (carbonates, tridymite, zeolites)	quartz-sericite schists aluminous schists (pyrophyllite, andalusite, kyanite ?,sillimanite, chloritoid, staurolite) garnet, biotite, quartz-chlorite-sericite schists

FIGURE 31 : Tables indicating the probable original composition of various rock assemblages found in the Barberton Mountain Land and their presently observable metamorphosed derivatives.

Figure 31B. Rocks of the Sedimentary Group appear in Figure 31C. The columns depicting the original compositions are speculative as no unaltered rocks are to be found in the Barberton belt. The rock-types encountered in the area generally contain the mineral assemblages listed under the heading "Metamorphic Derivatives".

In the following sections it is intended, firstly, to discuss in more detail the metamorphism associated with the rocks in the area north of Barberton and, secondly, to indicate and illustrate the mineralogical evolution of the metamorphic assemblages along the northwest flank of the Mountain Land.

(b) Metamorphism Along the Northwest Flank of the Barberton Mountain Land

Although most of the early workers in the Barberton Mountain Land described the metamorphic minerals present in the area no attempt was made by them to subdivide the area into metamorphic zones according to the appearance of specific metamorphic index minerals. The first attempts at such subdivision were made by the writer (Anhaeusser, 1964), Viljoen (1964), and Anhaeusser and Viljoen (1965). These authors' subdivided the area into three facies of contact metamorphism. Progressively further away from the granite contact the successive facies recognized were listed as follows :

(i) a hornblende-hornfels facies

(ii) an albite-epidote-hornfels facies, and

(iii) a greenschist facies.

However, according to a recent definition given by Winkler (1967) "contact metamorphism is a static thermal metamorphism of local extent producing an aureole of metamorphic rocks around an intrusive body. Contact metamorphic rocks lack schistosity". Regional metamorphism or regional dynamothermal metamorphism, on the other hand, takes place with concomitant penetrative movement and regionally metamorphosed rocks show clearly the effect of directed pressure. A schistose structure is commonly developed, particularly in rocks with abundant platy or prismatic minerals. Regional metamorphism is also regarded by Winkler (1967), Ramberg (1958), Turner and Verhoogen (1960), and Turner (1948) as well as many others, as a process of metamorphism that takes place over vast areas, under the combined influence of raised temperature and variable pressure. The essential genetic difference of rocks produced by regional dynamothermal and by local contact metamorphism hinges, therefore, around the variation of pressure - the temperatures at which metamorphic reactions take place often being the same in both cases.

The rocks of the Barberton Mountain Land, and in particular those in the area north of Barberton, invariably have a schistose structure so that they cannot be regarded as contact metamorphic rocks sensu stricto. Most of the metamorphism is, however, localized around the margins of the belt in contact with the granites. If the rocks are classified as regionally metamorphosed assemblages, the restricted distribution of the metamorphism has also to be explained. It would appear that a combination of both contact and regional metamorphic effects are necessary to explain the phenomena observed. The granites, thus not only supplied a source of heat as they intruded but, in addition, they were responsible for some directed pressure. The unusual metamorphic relationships observed clearly centre around the distinctive style of emplacement of the diapiric granite plutons.

(c) Metamorphic Mineral Assemblages and Their Significance

The main mineral assemblages encountered in the area north of Barberton are generally as follows :

1. In metamorphosed ultramafic rocks:

   talc tremolite (antigorite-magnetite-carbonate)
   talc-chlorite-tremolite (magnetite-carbonate-quartz)
   talc-carbonate (magnesite, dolomite, calcite)
   antigorite (talc-tremolite-chlorite-magnetite)
   anthophyllite (or cummingtonite, or gedrite) -tremolite-antigorite

2. In metamorphosed mafic volcanics close to the granite contacts:

   hornblende-plagioclase (albite, oligoclase, andesine)
   hornblende-plagioclase (diopside-biotite-quartz)
   hornblende-quartz-almandine (plagioclase-epidote)
   actinolite hornblende-albite-quartz (epidote-almandine)

3. In metamorphosed mafic volcanic rocks away from the granite contacts:

   actinolite-tremolite-albite (almandine-quartz-epidote-diopside)
   tremolite-actinolite-epidote-albite (chlorite-quartz-carbonate)
   tremolite-actinolite-chlorite-talc (epidote-carbonate-quartz)

4. In metamorphosed gabbros and pyroxenites:

actinolite hornblende-diopside-sphene-quartz (diallage)
actinolite-tremolite-albite-quartz (epidote-chlorite-sphene)
actinolite-albite-epidote-sphene or leucoxene (talc-sericite)
anthophyllite-cummingtonite-albite-quartz

5. In metamorphosed siliceous schists close to the granite contacts:

sillimanite-muscovite-quartz (biotite-plagioclase)
sillimanite-muscovite-almandine-quartz (tourmaline-biotite)
staurolite-andalusite-quartz (muscovite-chloritoid)
andalusite-quartz-sericite (chloritoid-staurolite-silliminate-almandine)

6. In metamorphosed siliceous schists away from the contacts:

andalusite-quartz-muscovite (chloritoid-staurolite)
quartz-muscovite-fuchsite (chloritoid-andalusite-pyrophyllite)
quartz-sericite (fuchsite)

7. In metamorphosed pelitic rocks of the Fig Tree Group:

hornblende-actinolite-biotite-quartz (almandine-diopside)
grunerite, cummingtonite-actinolite-quartz (epidote-diopside)
actinolite-quartz-biotite (andalusite-almandine-cordierite)
quartz-epidote-biotite (plagioclase-chlorite)

In order to classify and group systematically the great variety of metamorphic rocks and metamorphic mineral assemblages Eskola (1915) established the concept of metamorphic facies. In general terms, the assemblages listed above fall either into the greenschist facies or into the amphibolite facies of regional metamorphism as defined by Turner and Verhoogen (1960), or more recently Winkler (1967).

With the progress being made in the study of metamorphism it has been revealed that regional metamorphisms of the world are much more diverse than were formerly supposed. The best known and most common type of regional metamorphism is the Barrovian-type, first described by Barrow (1893) in the Highlands of Scotland and which is often referred to as the "normal" regional metamorphism. However, the Barrovian-type regional metamorphism represented, ultimately, only a special type of regional metamorphism. It was Miyashiro (1961) who first pointed out that the range of temperature and pressure in a metamorphic terrain was usually too wide to be definitive of a single metamorphic facies and he therefore introduced the concept of metamorphic facies series. He indicated that "a metamorphic facies series can be represented by a curve or a group of curves in a temperature-pressure diagram". According to this view each facies series involves a definite regional distribution of temperature and pressure related to a geothermal gradient expressed in °C/km. Miyashiro (1961) recognized three standard types of metamorphic facies series which are briefly outlined below:

1. Kyanite-sillimanite type, characterized by the stability of kyanite in a lower grade and sillimanite in a higher grade. Andalusite and glaucophane are absent, almandine garnet occurs commonly in the middle and high grades; staurolite is common, while cordierite is absent. Type area in the Scottish Highlands.

2. Andalusite-sillimanite type, characterized by the stability of andalusite in a lower grade and sillimanite in a higher grade. Kyanite, staurolite and glaucophane, are absent. Type area in Abukuma Plateau, Japan.

3. Jadeite-glaucophane type, characterized by the stability of glaucophane and jadeite-quartz. Andalusite, sillimanite and cordierite are absent. Type area Kanto Mountains, Japan.

Miyashiro (1961) also pointed to the existence of many cases of regional metamorphism intermediate in character between the andalusite-sillimanite and kyanite-sillimanite type as well as between the kyanite-sillimanite type and the jadeite-glaucophane type. The first, he referred to as the low-pressure intermediate type and the second, the high-pressure intermediate type.

Winkler (1967) in his discussions on the petrogenesis of metamorphic rocks has largely adopted Miyashiro's facies series concept and has modified the earlier proposals only slightly. Hietanen (1967), on the other hand, has enlarged considerably on the initial classification and has proposed 9 facies series, each of which she states "seem to occur at different pressure levels and are distinguished by different series of mineral assemblages". A change in the mineralogy of chemically identical layers is regarded as being indicative of a change in temperature and/or in pressure and in chemical potential of the mobile components.

The applicability of the facies series concept of regional metamorphism to early Precambrian greenstone belts may not be entirely justifiable. In these belts a wide range of metamorphic rock-types and mineral assemblages are developed, not as the result of a single progressive metamorphic event, but by a series of separate events conditioned largely by the emplacement of discrete diapiric granite plutons. The structural and metamorphic features displayed in typical greenstone belts suggests to the writer that neither a uniform geothermal gradient, nor a uniform stress gradient were operative in these regions. In any one greenstone belt, for example, there may be a number of diapiric plutons intruded into the area, each of which may have behaved differently to the next. They may have intruded at different times and vary considerably in size. Some were emplaced passively, while others may have intruded more forcibly. The heat associated with the intrusions may also have been different in each case.

Thus, with all these possible combinations of events it is to be expected that a highly varied mineralogy might occur from place to place in any one greenstone belt. The degree of variation will also naturally be dependant, to a large extent, on the distribution of the particular rock-types. In one part of a greenstone belt, metamorphic mineral assemblages may be found that are indicative of very high pressures and temperatures, while in another part of the area the pressure may have been greatly reduced, but the temperature may have been sufficient to produce contact metamorphism. In general, most greenstone belts display an apparently similar mineralogy throughout, but it is with the index minerals that the differences become apparent.

In the Barberton Mountain Land the diagnostic minerals andalusite and sillimanite, at first suggest a facies series of the Abukuma-type of metamorphism. However, in places there are a number of key index minerals that do not fit into this facies series. Staurolite and chloritoid, for example, coexist with andalusite in the Jamestown Schist Belt and in the area north of Eureka Siding. Miyashiro (1961) has, however, indicated that this mineral association is not uncommon in many of the Precambrian metamorphic terrains in the Baltic and Canadian Shields, and he suggests that they belong to the low-pressure intermediate group. Referring to the PT diagram of Hietanen (1967) these mineral assemblages may be expected in the Buchan or Pyreneean-type facies series.

In the area north of Barberton there is a further complicating factor, viz. that of a superimposed contact metamorphic effect on the regionally metamorphosed rocks. This has been brought about by the intrusion of the high volatile phase of the Nelspruit Granite as well as by the numerous pegmatite bodies that intrude the area. Unlike the regional metamorphism, the contact metamorphic effects are extremely localized and result in the production of hornfelses. Contact metamorphic effects are best displayed in the pelitic sediments of the Fig Tree Group in the Consort Mine area where the invading pegmatite bodies reach their optimum development.

Not being able to establish precisely the facies series of metamorphism prevents an accurate subdivision of the metamorphic assemblages into various subfacies. As has been mentioned before, most of the rocks in the area fall into the greenschist facies with rocks of the amphibolite facies occurring only along the immediate contacts with the granites. Winkler (1967) has subdivided the greenschist facies of the "normal" or Barrovian-type facies series into 3 subfacies, viz.

Bl. 1 quartz-albite-muscovite-chlorite subfacies

Bl. 2 quartz-albite-epidote-biotite subfacies, and

Bl. 3 quartz-albite-epidote-almandine subfacies.

The transition to the almandine-amphibolite facies takes place at about 550°C and the appearance of staurolite, grossularite-andradite garnet, diopside, cummingtonite, anthophyllite, gedrite, as well as plagioclase containing at least 15 per cent An, is regarded as decisive for the identification of the facies.

The Abukuma-type has been subdivided into two subfacies, viz.

Al. 1 quartz-albite-muscovite-biotite-chlorite subfacies, and

Al. 2 quartz-andalusite-plagioclase-chlorite subfacies.

The transition from greenschist to amphibolite facies again takes place at approximately 550°C but at lower pressures than with the Barrovian-type. The first appearance of cordierite, staurolite, ortho-amphibole, diopside, and grossularite/andradite and the total disappearance of chlorite, marks the beginning of amphibolite facies. The reactions leading to the formation of staurolite, of the Mg/Fe amphiboles (anthophyllite, gedrite or cummingtonite) of diopside, grossularite/andradite and, under not too high a pressure, that of cordierite, mark simultaneously the lower limit of the almandine-amphibolite facies, the cordierite-amphibolite facies and the hornblende-hornfels facies (Winkler, 1967).

The chemical analyses listed in various parts of the text have been used to calculate the ACF and AFK ratios and are plotted in several diagrams in Figure 32, page 271. The chemical analyses had

ACF AND A'KF DIAGRAMS OF SOME METAMORPHOSED ROCKS FROM THE AREA NORTH OF BARBERTON

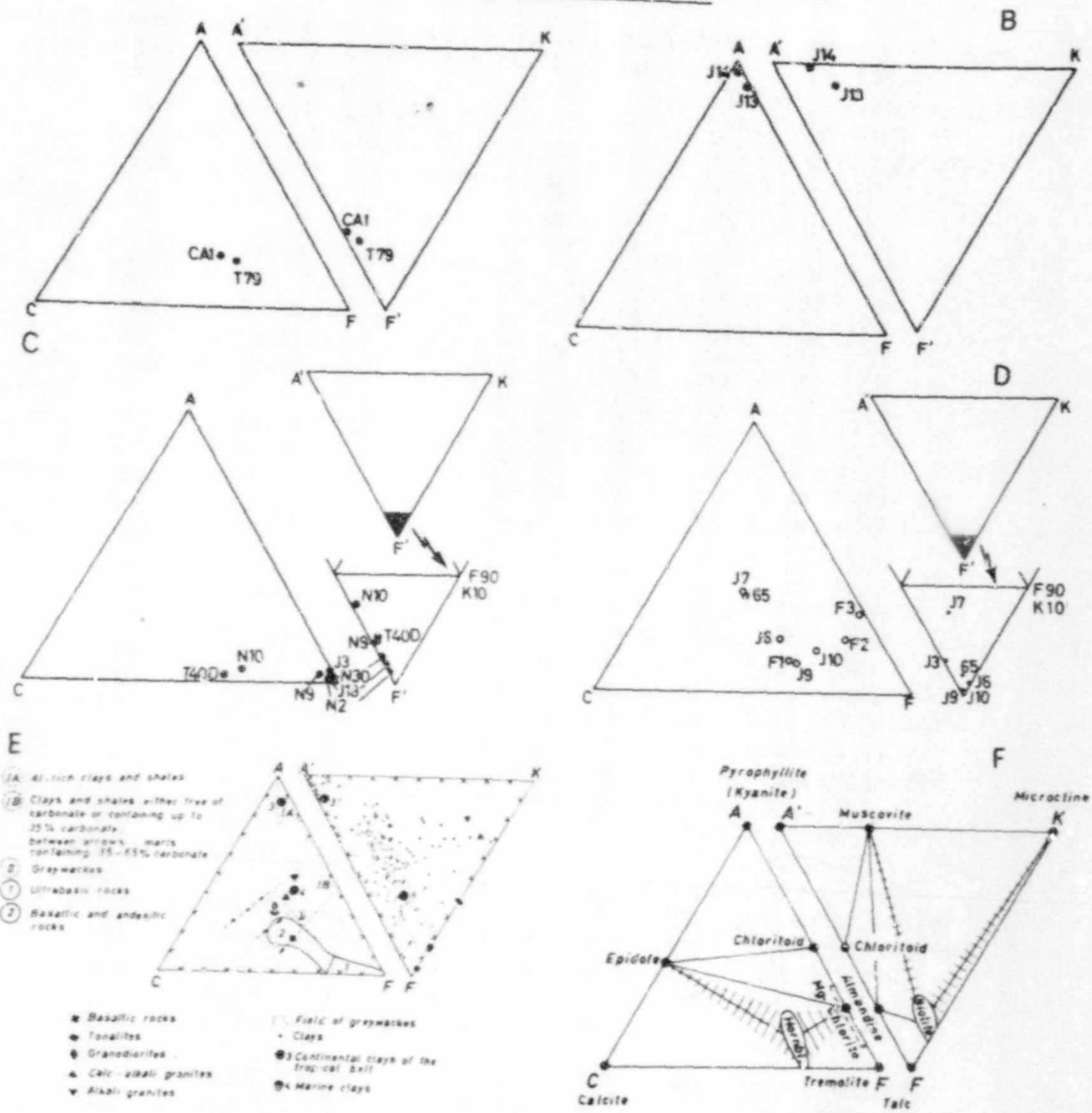


FIGURE 32:
A. Contact amphibole schists (upper greenschist or amphibolite facies).
B. Al-rich quartz-sericite schists (upper greenschist facies).
C. Ultramafic and mafic rocks, i.e. serpentinites, pyroxenite, meta-gabbro (greenschist facies).
D. Various low-grade basic schists (J Samples and 65) and Fig Tree shales and tuffaceous greywackes (F Samples). All greenschist facies.
E. The chemical composition of various magmatic and sedimentary rocks plotted on an ACF and A'FK diagram (Winkler, 1967).
F. ACF and A'KF diagram (after Winkler, 1967) of the quartz-albite-epidote-almandine subfacies of the greenschist facies, for general comparison with the Barberton rocks plotted in A, B, C and D above.

first, however, to be corrected for accessories and, in order to do this, their amount had to be determined by petrographical modal analyses. These modal analyses are also to be found in the various tables throughout the text. Two ACF and AFK diagrams after Winkler (1967) are included (Figure 32, E and F) for general comparison with the Barberton rocks which are plotted in the diagrams A, B, C, and D of the same figure.

The contact amphibolites listed in Table 2, page 63 are shown in the first diagram (A). They plot in the field of the basaltic rocks (cf., E) and both samples contain essentially hornblende, quartz, plagioclase, and epidote (cf., F). In most cases the plagioclase in the contact amphibolites is albite, thereby placing most of the contact amphibolites into the upper subfacies of the greenschist facies. In a few cases, however, andesine was recorded, allowing the rocks to be classified into the amphibolite facies. Sample CA1, from north of the Consort Mine, is of amphibolite facies grade while T79, from the Kaap Valley Granite contact in the Jamestown Schist Belt, belongs in the upper greenschist facies.

Siliceous schists, listed in Table 3, page 73 and found in the Jamestown Schist Belt, are plotted in Figure 32B. Both points fall in the field of Al-rich clays and shales (cf., E). Sample J14, in thin section, contains andalusite, chloritoid, sericite, and quartz, while J13 contains quartz, staurolite, and muscovite (sericite). The abundance of sericite in the rock is clearly brought out in the A'FK diagram (cf., F). The siliceous schists were also plotted on an AFM diagram wherein the relationships of minerals not capable of representation in either the ACF or A'FK diagram can be shown. These minerals include, for example, chlorite, chloritoid, pyrophyllite, the Al_2SiO_5 polymorphs, staurolite, cordierite, almandine garnet, and biotite, in addition to quartz, and muscovite, which are practically always present in the rocks particularly well-suited to representation in these diagrams. Samples J13 and J14 are plotted in Figure 33B, page 273, and can be compared with an AFM diagram after (Winkler, 1967), corresponding to the upper greenschist facies.

The various rocks present in the differentiated ultramafic bodies in the Jamestown Schist Belt are plotted on ACF and A'FK diagrams in Figure 32C, page 271. The serpentinized ultramafic rocks plot in a narrow field in the F corner of the diagram, corresponding to Winkler's (1967) ultrabasic field (cf., E). Samples N10 and T40D, being meta-gabbro and pyroxenite respectively, do not fall in either the basaltic or ultrabasic fields depicted, yet they occur very close to them.

AFM DIAGRAM

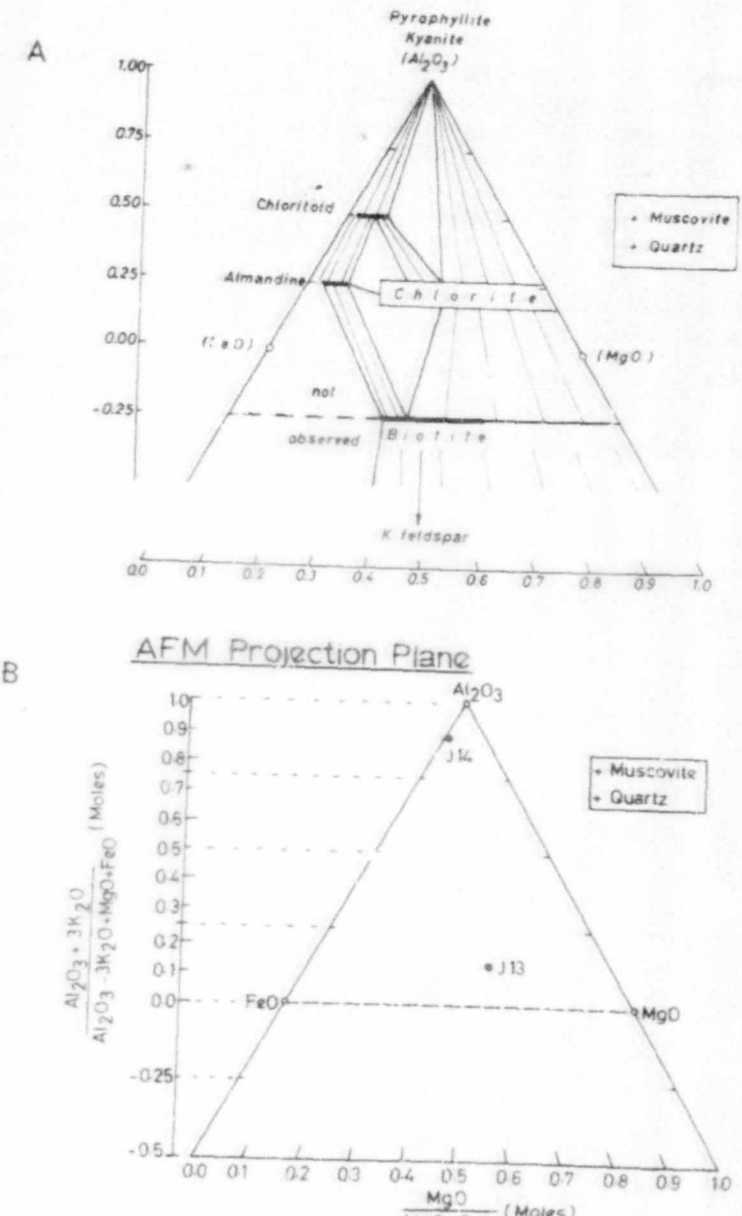


FIGURE 33: A. AFM diagram of the quartz-albite-epidote-almandine subfacies (Winkler, 1967). This corresponds to the albite-epidote-amphibolite facies of Turner (1948) - i.e. upper greenschist facies.

B. AFM diagram showing a plot of two alumina-rich quartz-sericite schists from the Jamestown Schist Belt. In thin section, Sample J14 contains quartz, andalusite, chloritoid and sericite, and Sample J13 contains mainly quartz and sericite with some andalusite. The assemblage thus falls into the upper part of the greenschist facies.

In Figure 32D, the writer has plotted various low-grade mafic schists from the area between Caledonian Siding and Louw's Creek, as well as Fig Tree shales and tuffaceous greywackes. The chemical analyses used for these plots are listed below in Table 23. The Fig Tree analyses used, were obtained from a publication of the Geological Survey (Visser, compiler, 1956) and a description of the samples and their localities are as follows, viz.

Sample F1, a black shale, occurring with the greywacke between the Zwartkoppie and Ulundi Bar in the Ulundi Syncline.

Sample F2, a medium-grained greywacke below the Ulundi Bar in the Ulundi Syncline, and

Sample F3, a so-called Fig Tree 'lava' (tuffaceous greywacke) from Sheba Siding.

TABLE 23

CHEMICAL ANALYSES : MAFIC AND ULTRAMAFIC SCHISTS FROM THE AREA BETWEEN CALEDONIAN SIDING AND LOUW'S CREEK

	J6	J7	J9	J10	65
SiO_2	56.28	49.64	55.11	48.36	54.11
Al_2O_3	8.38	12.63	4.25	3.75	14.42
Fe_2O_3	10.77	16.92	8.14	13.97	10.34
FeO	-	-	-	-	-
MgO	9.47	5.63	16.51	19.26	5.73
CaO	8.64	9.77	12.28	9.11	9.64
Na_2O	3.30	2.69	0.90	0.16	1.93
K_2O	0.29	0.37	0.02	0.03	0.14
H_2O+	1.00	1.06	1.41	3.55	2.42
H_2O-	0.23	0.08	0.14	0.58	0.07
CO_2	0.11	0.15	0.11	0.03	0.53
TiO_2	0.73	1.32	0.39	0.54	0.82
P_2O_5	0.07	0.15	0.06	0.04	0.12
MnO	0.15	0.19	0.15	0.19	0.15
NiO	0.04	0.06	0.05	0.18	0.11
Total	99.46	100.85	99.52	99.75	100.53

Description and localities of samples listed in Table 23 :

J 6. tremolite-actinolite schist from the farm Crystal Stream 323 JU, south of Honeybird Siding.

J 7. contact amphibolite from the Kaap River near Honeybird Siding.

J 9. tremolite-actinolite schist from the farm Annex Riverbank 279 JU south of Honeybird Siding.

J10. talc schist from the farm Crystal Stream 323 JU south of Honeybird Siding.

65. tremolite-actinolite schist from the farm Bramber 313 JU north of Caledonian Siding.

All analyses listed are the average of 3 comparative X-ray fluorescence and chemical analytical results. Analysts, National Institute for Metallurgy, and Corner House Laboratories, Johannesburg.

The variable spread of the J samples in Figure 32D is a reflection of the changes in the mineralogy of the rocks. Most samples contain either tremolite, actinolite or chlorite together with albite. The variations in the mineralogy include the presence of epidote, hornblende or actinolitic hornblende, talc, carbonate, almandine garnet, and quartz, as well as accessory minerals sphene, leucoxene, magnetite, and ilmenite. Most of the samples fall in the intermediate subfacies of the greenschist facies while sample J7 is in the upper greenschist facies. The Fig Tree samples plot approximately in the field of shales and greywackes (cf., Figure 32E) and, although no details of the mineralogy of these particular samples are available, the shales and greywackes of the Fig Tree Group in the Ulundi Syncline generally contain an abundance of chlorite and biotite, together with a wide range of minerals containing MgO, FeO, and MnO that help to position the rocks more towards the F corner of the ACF diagram.

The pressure/temperature conditions that prevailed during the development of the metamorphic mineral assemblages north of Barberton were very variable and no precise figures can be suggested. Winkler (1967), from his experimental work concluded that the greenschist facies must have commenced only at about 400°C and it must have encompassed the whole range up to about 550°C before giving way to the amphibolite facies. A maximum of about 650°C may have been obtained in places close to, or in contact with, the granites. It is estimated that the pressures involved in the metamorphism of the Barberton area may have ranged from just over 2,000 to about 4,500 bars water pressure.

E. MINERALOGICAL EVOLUTION OF THE METAMORPHIC ASSEMBLAGES NORTH OF BARBERTON

(a) Introduction

In an earlier section it was shown that four phases of deformation resulted from the emplacement of the Kaap Valley Granite diapiric pluton. The metamorphism produced by the granites caused reorientation of the foliation of the schists (S_0) produced by the F_0 deformation. Several periods of mineral development and deformation as well as post-tectonic recrystallization have also been observed in the area. Superimposed on the regional metamorphic events, particularly in the Consort Mine-Joe's Luck area, is a contact metamorphic aureole. The petrological variations that can be traced across this aureole reflect a progressively diminishing thermal gradient away from the Nelspruit Granite contact.

(b) Metamorphic Phases North of Barberton

Many attempts at relating metamorphic fabrics to structures have been made, particularly in the Dalradian rocks in the Central Highlands of Scotland (Rast, 1963; Johnson, 1963; Sturt and Harris, 1961), the Caledonides of northwest Scotland (Ramsay, 1963B), and in the Hercynian belt of the Central Pyrenees (Zwart, 1960; 1963).

The metamorphic rocks in the area along the northwest flank of the Barberton Mountain Land, like the areas mentioned above, also display a complicated history and it is possible to trace, in thin sections, the mineral evolution and phases of recrystallization which have taken place in the area. Most of the rocks display evidence of more than one generation of mineral development and movement but it i the Al-rich siliceous schists which show best the large number of different relations between porphyroblasts and the surrounding schist matrix. It was found that the most useful minerals to establish the different relations were the phyllosilicates (chlorite, muscovite/ sericite, biotite), the Al_2SiO_5 polymorphs (pyrophyllite, andalusite, sillimanite), the amphiboles (hornblende, actinolite, grunerite), and garnet, staurolite, and chloritoid. In most cases the crystalline components of the rocks were found to be clear and free from inclusions but in places internal schistosity, and the development of poecilob1asts, particularly of quartz, facilitated the elucudation of the metamorphic history step by step.

(i) Fl Metamorphic Event

The Fl phase of deformation was responsible for the creation of the strong mineral alignment that gave rise to the development of the schistosity (S1). In some places this deformation may also have caused the realignment of any earlier schistosity (S_0) that may have developed as a result of the production of the regional NE-SW trend by the F_0 deformation.

The S1 fabric or schistosity is illustrated in Plate 20, page 278. The strong alignment of the platy mineral muscovite, is evident in the first photomicrograph (A) of a quartz-sericite or muscovite schist from the Theespruit Formation in the Jamestown Schist Belt. Andalusite and quartz (B) and andalusite, staurolite, sericite, and quartz (D) are further examples from siliceous schist horizons, the former occurring in the Jamestown Schist Belt near the Nelspruit Granite contact and the latter occurring north of Eureka Siding. In photomicrograph D, the porphyroblasts are only just beginning to form recognizable crystal outlines, the development of which was arrested at an early stage. The early S1 fabric is not restricted to the siliceous schist horizons but is manifest in all the rock-types throughout the area. In photomicrograph C, for example, hornblende and quartz provide a strongly aligned schist matrix in which is developed an early garnet porphyroblast with its long axis parallel to the schistosity.

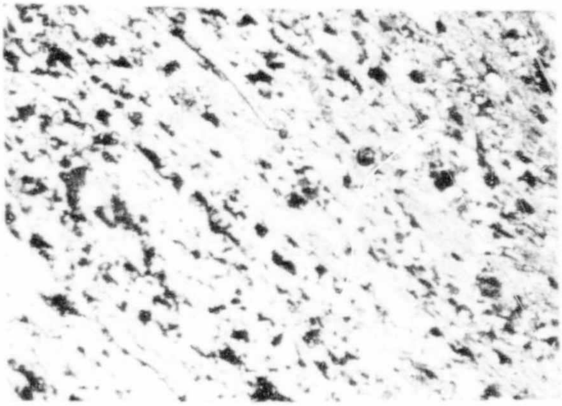
In the granites adjacent to the supracrustal rocks there is generally a pronounced foliation parallel to the granite contacts and the constituent minerals are aligned parallel to those in the neighbouring schists. The foliation, as seen in outcrops, and in thin sections, has already been discussed and illustrated in an earlier chapter (see Plate 17B, page 218 and Plate 19C, page 233).

(ii) F2 Metamorphic Event

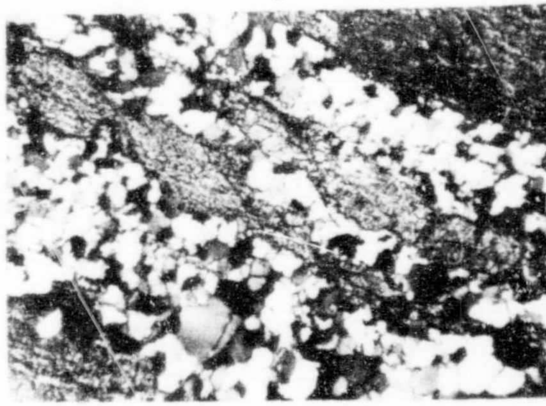
The early planar or linear S1 fabrics, produced as a result of the diapiric granite invasion, underwent further modifications as the progressive deformations continued in the area. The development of lineations, seen on a macroscale (Plate 13, page 183), resulted not only from mineral alignment or stretching but from folding on a minor scale. The micro-folding generally bent the earlier schistosity in a manner similar to that illustrated by the crenulated biotite and quartz fabric in Plate 21B, page 280 and the buckled muscovite and quartz fabric in Plate 23A, page 283.

PLATE 20

A



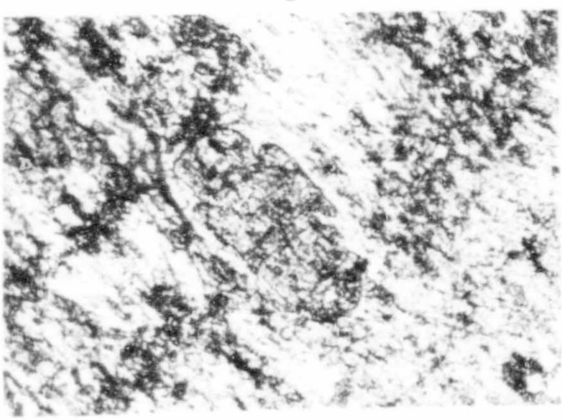
B



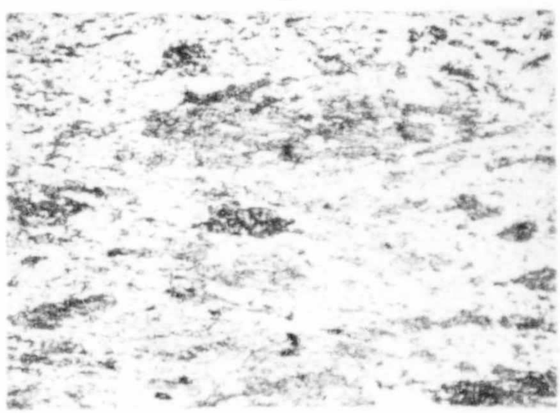
A. Photomicrograph (crossed nicols X75) of strongly aligned muscovite laths in a quartz-mica schist of the Onverwacht Group. This fabric, or schistosity, parallels the contact of the invading diapiric plutons.

B. Photomicrograph (crossed nicols X60) of an alumina-rich siliceous schist near the Nelspruit granite contact on the farm Riverside 245JU. There is a strong alignment of andalusite (dark bands) and microcrystalline quartz (Onverwacht Group).

C



D



[illegible] (uncrossed nicols X75) of an amphibole-garnet schist from Onverwacht meta-[illegible] near Honeybird Siding. The garnet formed at the same time as the hornblende schist [illegible] in the plane of the schistosity.

[illegible] (uncrossed nicols X75) of porphyroblastic development of andalusite (grey) [illegible] dark minerals, centre, and upper left) in an Al-rich quartz-sericite schist [illegible] Onverwacht Group, north of Eureka Siding. Note the alignment of the porphyroblasts

Porphyroblast development continued from the F1 metamorphic phase into this second, or F2, phase and the progressive deformations, responsible for the generation of the lineations mentioned above, also caused boudinaged porphyroblasts to form. In Plate 21C, page 280 a boudinaged andalusite porphyroblast displays retrogressive pyrophyllite, with crystals aligned at right angles to the central zone of tension. The Al-rich siliceous schist horizon in the Jamestown Schist Belt, from which the sample was collected, displays a lineation produced as a result of the boudinaged micro-structures developed in the rocks.

The growth of porphyroblasts was a further cause for the disruption of the initial fabric. For example, in Plate 24D, page 285 a garnet porphyroblast has pushed aside the early schistosity and quartz pressure shadows are developed in the zones of tension. Porphyroblasts formed early in the metamorphic history almost invariably show evidence of rotation brought about by the successive structural events.

(iii) F3 Metamorphic Event

Continued deformation in the area north of Barberton resulted in the production of a strong NW-SE fold trend. In thin sections the micro-structures can be correlated with the macro-structures. The micaceous minerals in the schist bands are folded and often develop a strain slip cleavage. Some recrystallization, particularly of quartz, took place.

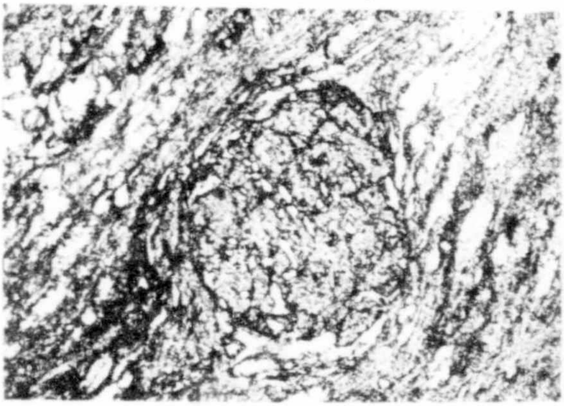
In Plate 22, page 282 photomicrographs showing some textures associated with the F3 deformational event are illustrated. Near the granite contact, north of the Consort Mine, sillimanite (A), and biotite (B) have been folded and some recrystallization of muscovite, biotite, and quartz has taken place. Further away from the contact the original S1 fabric of a quartz-chlorite schist has been strongly folded (C). Also in the Consort Mine area porphyroblasts developed by earlier metamorphic events have undergone rotation. In Plate 21B, page 280 an andalusite porphyroblast containing S-trails of a crenulated biotite-quartz-magnetite assemblage, has itself been rotated by the deformation. Quartz pressure shadows occur in the zones of tension on either side of the crystal, whose long dimension now lies almost at right angles to the crenulated S2 schistosity. Garnets have also undergone rotation during this, as well as subsequent, deformational events.

(iv) F4 Metamorphic Event

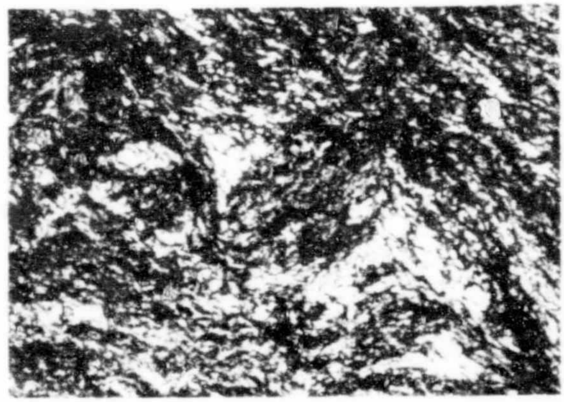
The late-phase deformation, responsible for the development of flat folds and conjugate folds, also produced micro-folds and also

PLATE 21

A



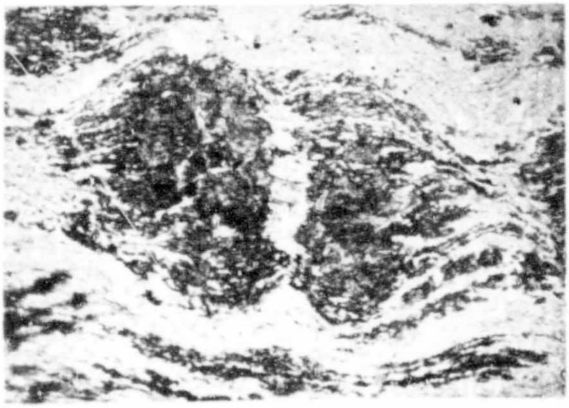
B



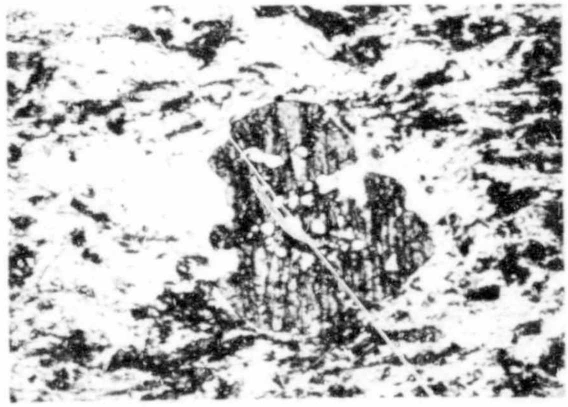
A. Photomicrograph (uncrossed nicols X75) showing poeciloblastic development of quartz in an almandine garnet porphyroblast. The quartz inclusions are aligned and were developed in the garnet during its early growth in the (S1) phase of crystallization. The garnet has suffered rotation during later phases of deformation.

B. Photomicrograph (uncrossed nicols X75) showing an andalusite porphyroblast containing S-trails of the matrix material of biotite, magnetite and quartz. The strings of inclusions are relict structures inherited from a folded fabric that existed prior to the growth of the porphyroblast.

C



D



C. Photomicrograph (uncrossed nicols X75) showing a boudinaged andalusite porphyroblast developed during the F2 phase of deformation. The slightly buckled S1 fabric (now S2) can be seen on either side of the porphyroblast. Pyrophyllite is developed in the centre of the andalusite porphyroblast, in the zone of tension.

D. Photomicrograph (uncrossed nicols X75) showing poeciloblastic quartz in a garnet porphyroblast. The garnet appears to have developed post-tectonically in a quartz-sillimanite-biotite schist, the fabric of which has been buckled (S2).

caused the development of a strain slip cleavage in some cases. Structures associated with this event have been shown in Plate 14, page 186 and occur in practically all rock-types in the area north of Barberton.

In Plate 22D, page 282 a photomicrograph of a late-phase kink-band fold, in quartz-sericite schist, is illustrated. The F4 deformation was responsible for the rotation of earlier produced porphyroblasts such as the one displayed in Plate 21A, page 280. Poeciloblastic inclusions of quartz were developed in the garnet parallel to the matrix schistosity. Subsequent rotation of the garnet resulted in the quartz inclusions being arranged almost at right angles to the S1 schistosity.

(v) Post-Tectonic Mineral Development

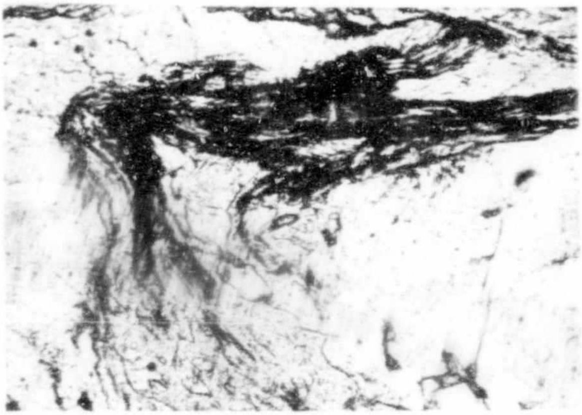
Post-tectonic crystallization of minerals took place either as a result of energy retained in the system following the late phase of deformation, or as a result of superimposed contact metamorphic effects. In thin sections the post-tectonic minerals are clearly evident as they are invariably randomly orientated and overprinted on all the earlier fabrics.

In Plate 23, page 283, some examples of post-tectonic mineral development are shown. In the first photomicrograph (A), a large muscovite crystal is superimposed on the F2 schistosity, while in (B) radiating blades and clusters of chloritoid are overprinted on a buckled original schistosity. In the third photomicrograph (C), grunerite crystals in metamorphosed Fig Tree shale are randomly orientated and superimposed over an earlier S1 fabric of amphibole and quartz. Garnet porphyroblasts may also develop as post-tectonic minerals. Plate 21D, page 280 shows a poeciloblastic almandine garnet porphyroblast, that may have developed as a late mineral in a quartz-sillimanite-biotite matrix. It is not always easy to decide precisely when the garnets formed as they have polyphase recrystallization tendencies. In the example just illustrated, viz. (D) the garnet does not appear to have undergone rotation and the matrix is not greatly disturbed, suggesting that the mineral may have formed post-tectonically.

The garnets shown in Plate 23D, page 283 are clearly developed as a result of contact metamorphism. The euhedral porphyroblasts are developed in a Fig Tree hornfels near a pegmatite body in the Consort Mine area. The matrix of actinolite and quartz has no schistosity and inclusions of amphibole occur in the garnets. Other minerals such as andalusite, cordierite, amphibole, diopside, biotite, and epidote were also formed in the various sedimentary assemblages between the Consort

PLATE 22

A

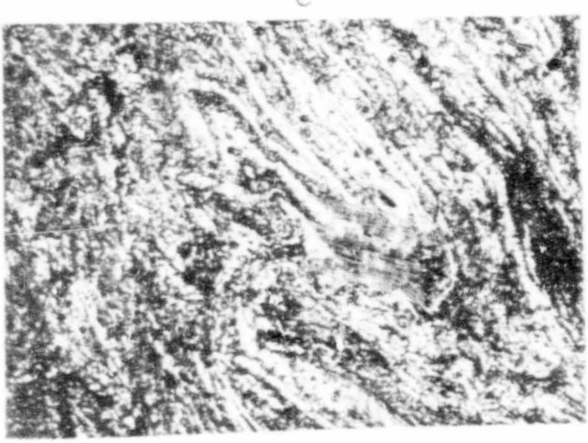


B

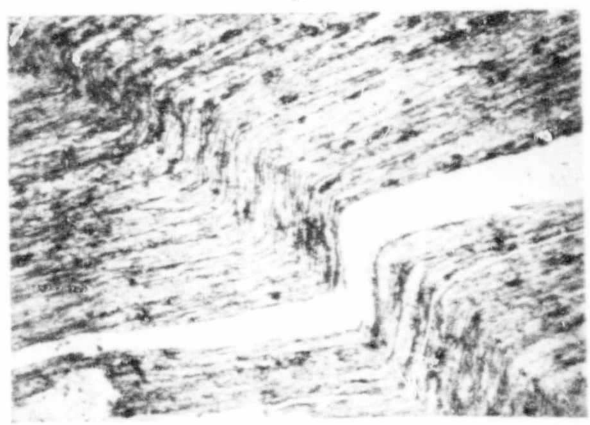
A. Photomicrograph (uncrossed nicols X75) showing matted sillimanite folded by the F3 phase of deformation. Biotite, muscovite and quartz occur with the sillimanite. Locality north of Consort Gold Mine.

B. Photomicrograph (uncrossed nicols X75) showing biotite blades and laths folded by the F3 phase of deformation. Quartz and muscovite occur with the biotite. Locality north of Consort Gold Mine.

C



D



C. Photomicrograph (uncrossed nicols X75) showing quartz and chlorite strongly contorted and folded by the F3 phase of deformation. The original S1 fabric can still be seen. Locality northwest of the Consort Gold Mine.

D. Photomicrograph (uncrossed nicols X75) showing typical late phase (F4) kink-band folding in brittle quartz-sericite schists of the Onverwacht Group. Locality - Lily Syncline north of the Eureka Syncline.