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GEOLOGY AND GOLD MINERALIZATION

OF THE

HHOHHO AREA, NORTHWESTERN SWAZILAND

BY

D. H. JONES B.Sc (HONS)

GEOLOGY AND GOLD MINERALIZATION

OF THE

MHLOHHO AREA, NORTH-WESTERN SWAZILAND

BY

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Submitted for the degree of M.Sc.

at the

University of the Witwatersrand

Johannesburg.

March, 1969.

This is to certify that the thesis presented for the Degree of Master of Science at the University of the Witwatersrand, is my own work and has not been presented at any other University.

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THE GEOLOGY AND GOLD MINERALIZATION OF THE HHOHHO AREA NORTHWESTERN SWAZILAND

A B S T R A C T

This dissertation deals with the geology of a portion of the Archean fold belt of northwestern Swaziland in the vicinity of the Hhohho area. Layered Archean rocks, constituting the Swaziland System, have been complexly folded and faulted by at least three phases of deformation and lie immediately adjacent to intrusive granites. Consequently, these Archean rocks have been subjected to both dynamic and thermal metamorphism. Gold mineralization occurs in the metamorphosed rocks lying within the aureole of the granites, the localization of which has been influenced by lithological and structural controls.

A detailed description is given of the lithological characteristics of the wide variety of rocks occurring in the area with the aim of determining their likely origin and, in the case of the layered Archean rocks, their stratigraphical position in the Swaziland System. A reassessment of the stratigraphical column in the Hhohho area appears necessary and rocks previously regarded as members of the Jamestown Complex and Figtree Series are now assigned to the Onverwacht Series. Thus, the Swaziland System in this area is considered to consist only of members of the Moodies Series and an underlying Onverwacht Series and no formations are present which can unequivocally be included in the Figtree Series.

At least three phases of deformation of post-Moodies Series age can be recognized in the area, but any evidence of a pre-Moodies deformation has been obliterated and is now only expressed by the unconformable relationship between the Moodies Series and the underlying Onverwacht Series The earliest of the post-Moodies phases of deformation, the so-called Main Phase, was responsible for the folding of the Swaziland System formations into a number of near isoclinal, northeast aligned folds The second phase of deformation imposed east-northeast striking cleavage

on the earlier structures whereas the so-called Later Phases of deformation resulted in cross-folding along northwest and north-south aligned axes.

The relationship between the layered Archean rocks and the intrusive granites is also described so as to establish their age and time of intrusion. The granites are considered to be of a late-orogenic type having been emplaced when the stresses of the Main Phase of deformation were waning. These granites were emplaced in a number of heaves and two ages of granite can be recognized in the Mhohho area. The earlier is the more extensive in distribution and grades imperceptibly into a foliated granite towards its margins. The later granite is coarse-grained and homogeneous occurring as small bosses and tongues within the main mass of granite and also in the adjacent Swaziland System rocks.

The emplacement of the granites imposed metamorphism on the Swaziland System rocks lying in their aureole and three distinct facies of contact metamorphism can be defined. The effects of polymetamorphism and metasomatism are also apparent.

An account is given of the gold mineralization to establish the time of formation relative to the phases of deformation and the intrusion of the granites. The formation of gold is thought to be closely associated with the intrusion of the granites but it is debatable whether the auriferous solutions emanated from the granites themselves or whether the gold was originally present in trace amounts in basic lavas of the Onverwacht Series and was mobilized when these rocks were subjected to contact metamorphism. The gold occurs mainly with quartz in the ore-bodies but there is also an intimate association with pyrite and pyrrhotite. Both lithological and structural controls have influenced the localization of gold. The principal deposits occur at or adjacent to the contacts between relatively competent and incompetent rocks especially where open shear or fault planes, sympathetic with structures of the Main and Second Phases of deformation and re-activated by the stresses of the Later Phases of deformation, are present.

The Hhohho area is considered to constitute an intrinsic part of the Barberton Mountain Land and consequently a comprehensive account is given of previous work both in Swaziland and the Mountain Land especially where applicable to the area investigated in this thesis.

GEOLOGY AND GOLD MINERALIZATION OF THE HHOHHC AREA, NORTHWESTERN SWAZILAND

C O N T E N T S

P A R T 1

INTRODUCTION

PAGE

GENERAL STATEMENT 1

LOCALITY AND SIZE OF THE AREA 3

GEOLOGICAL FEATURES OF SWAZILAND AND THE BARBERTON MOUNTAIN LAND - A SUMMARY OF PREVIOUS WORK 4

INTRODUCTION 4

CLASSIFICATION OF THE LAYERED ARCHEAN ROCKS 4

THE OOBSCHOT SERIES 5

THE ONVERWACHT SERIES 5

THE FIGTREE SERIES 9

THE MOODIES SERIES 11

THE JAMESTOWN COMPLEX 12

THE NELSPRUIT AND SWAZILAND GRANITES AND GNEISSES 16

INTRODUCTION 16

THE NELSPRUIT GRANITE AND GNEISSES 16

THE SWAZILAND GRANITES AND GNEISSES 17

PART 1 (CONTINUED)

	PAGE
METAMORPHISM	18
REGIONAL METAMORPHISM	18
DYNAMIC METAMORPHISM	19
CONTACT METAMORPHISM	20
STRUCTURAL GEOLOGY	21
GOLD MINERALIZATION	24
THE LOCALIZATION OF GOLD	24
THE MINERALOGY OF THE GOLD DEPOSITS	27
THE ORIGIN OF THE GOLD	31
REASONS AND PURPOSE OF THE PRESENT INVESTIGATION	32
WORK ACCOMPLISHED	33
ACKNOWLEDGEMENTS	34

PART II

RESULTS OF THE PRESENT INVESTIGATION

GEOLOGICAL SETTING	35
STRATIGRAPHY	37
INTRODUCTION	37
THE SWAZILAND SYSTEM	38
THE ONVERWACHT SERIES	39

PART II (CONTINUED)

PAGE

THE LOWER STAGE OF THE ONVERWACHT SERIES 39

Basic Rocks and Talcose Schists Lying Within the Metamorphic Aureole of the Granites..... 40

1) The dark-green hornblende amphibolites 40

Distribution:- 40
Petrology:- 40
Structural Features:- 41
Grade of Metamorphism:- 41
Origin:- 42

2) The pale-green unfoliated amphibolites 43

Distribution:- 43
Petrology:- 44
Structural Features:- 44
Grade of Metamorphism:- 44
Origin:- 45

3) The foliated green-grey amphibolites 45

Distribution:- 45
Petrology:- 47
Structural Features:- 48
Grade of Metamorphism:- 48
Origin:- 49

4) & 5) The talc-amphibole schists, talc-chlorite-carbonate talc-carbonate and talc-chlorite schists 49

Distribution:- 49
Petrology:- 50
Structural Features:- 51
Grade of Metamorphism:- 52
Origin:- 52

Siliceous Horizons Lying Within the Metamorphic Aureole of the Granites 54

1) The quartz-biotite schists 54

PAGE

Distribution:- 54
Petrology:- 54
Structural Features:- 58
Grade of Metamorphism:- 55
Origin:- 53

3) The quartz-chlorite schists 56

Distribution:- 56
Petrology:- 56
Structural Features:- 57
Grade of Metamorphism:- 58
Origin:- 58

3) The quartz-sericite schists 58

Distribution:- 58
Petrology:- 58
Structural features:- 59
Grade of Metamorphism:- 59
Origin:- 60

4) The quartzitic and chert horizons 61

Distribution:- 61
Petrology:- 61
Structural Features:- 62
Grade of Metamorphism:- 63
Origin:- 64

Basic Rocks Occurring in the vicinity of Bearded Man Peak ... 64

The basic rocks 64

Distribution:- 64
Petrology:- 65
Structural Features:- 65
Grade of Metamorphism:- 66
Origin:- 66

Siliceous and Argillaceous Horizons Occurring in the Vicinity of Bearded Man Peak 66

PART II (CONTINUED)

PAGE

The greywackes, shales and mudstones 65

Distribution:- 65
Petrology:- 67
Structural Features:- 67
Grade of Metamorphism:- 68
Origin:- 68

THE UPPER STAGE OF THE AMEWACHT SERIES 69

1) The shales 70

Distribution:- 70
Petrology:- 70
Structural Features:- 71
Grade of Metamorphism:- 71
Origin:- 72

2) The greywackes, quartzites, grits and conglomerates 73

Distribution:- 73
Petrology:- 74
Structural Features:- 75
Grades of Metamorphism:- 76
Origins: 76

3) The quartz-pebble series 77

Distribution: 77
Petrology:- 77
Structural Features:- 78
Grade of Metamorphism:- 78
Origin:- 78

4) The cherts 79

Distribution:- 79
Petrology:- 80
Structural Features:- 80
Grade of Metamorphism:- 80
Origin:- 81

SUMMARY AND CONCLUSIONS 81

	PAGE
THE MOODIES SERIES	85
INTRODUCTION	85
THE LITHOLOGICAL ZONES	86
1) The Basal Conglomerate	86
Distribution:-	86
Petrology:-	87
2) The $M.S.^1$ Zone	87
Distribution:-	87
Petrology:-	88
3) The $M.S.^2$ Zone	88
Distribution:-	88
Petrology:-	89
4) The $M.S.^3$ Zone	89
Distribution:-	89
Petrology:-	89
5) The $M.S.^4$ Zone	90
Distribution:-	90
Petrology:-	90
6) The $M.S.^5$ Zone	90
Distribution:-	90
Petrology:-	91
STRUCTURAL FEATURES OF THE MOODIES SERIES	91
METAMORPHISM OF THE MOODIES SERIES	93
ORIGIN OF THE MOODIES SERIES	93
SUMMARY AND CONCLUSIONS RELATING TO THE SWAZILAND SYSTEM IN THE MOOHHC AREA	93

PART II (CONTINUED)

PAGE

THE INTRUSIVE ROCKS 97

THE GRANITES 97

INTRODUCTION 97

THE LATE-OROGENIC GRANITE 98

Distribution:- 98
Petrology:- 98
Structural Features:- 100

THE LATER-PHASE OF THE LATE-OROGENIC GRANITE 100

Distribution:- 100
Petrology:- 101
Structural Features:- 101

THE EPIDOTE, QUARTZ AND PEGMATITE VEINS 102

THE EPIDOTE VEINS 102

Distribution:- 102
Petrology:- 102
Structural Features:- 102

THE QUARTZ VEINS 103

Distribution:- 103
Petrology:- 103
Structural Features:- 103

THE PEGMATITE VEINS 104

Distribution:- 104
Petrology:- 104
Structural Features:- 104

THE PETROGENESIS OF THE GRANITES AND ASSOCIATED ACID ROCKS 104

THE DYKES 110

PART II (CONTINUED)

PAGE

INTRODUCTION 110

THE DIABASE DYKES 110

Distribution:- 110

Petrology:- 110

Structural Features:- 111

THE DOLERITE DYKES 111

Distribution:- 111

Petrology:- 111

Structural Features:- 111

METAMORPHISM 112

INTRODUCTION 112

TYPES OF METAMORPHISM 112

DYNAMIC METAMORPHISM 112

CONTACT METAMORPHISM 113

THE METAMORPHIC FACIES 113

The hornblende hornfels facies:- 114

The albite-epidote hornfels facies:- 114

The greenschist facies:- 115

POLYMETAMORPHISM 116

METASOMATISM 117

STRUCTURAL GEOLOGY 122

INTRODUCTION 122

THE PHASES OF DEFORMATION 122

THE MAIN PHASE OF DEFORMATION 122

THE SECOND PHASE OF DEFORMATION 124

THE LATER PHASES OF DEFORMATION 126

PART II (CONTINUED)

PAGE

FAULTING 128

SUMMARY AND SYNTHESIS OF THE TECTONIC HISTORY OF THE HHOHHO AREA 129

GOLD MINERALIZATION 133

INTRODUCTION 133

GEOLOGY OF THE GOLD MINES 134

STRATIGRAPHY 134

1) The Daisy Mine 134
2) The Gordon Mine 137
3) The Jackal Prospect 139

STRUCTURAL GEOLOGY 139

1) The Daisy Mine 140
2) The Gordon Mine 143
3) The Jackal Prospect 143

THE LOCALIZATION OF GOLD 144

1) The Daisy Mine 144
2) The Gordon Mine 147

THE MINERALOGY AND PARAGENESIS OF THE ORE BODIES 148

PYRITE 148
PYRRHOTITE 149
CHALCOPYRITE 149
GOLD 150

SUMMARY AND CONCLUSIONS OF THE GOLD MINERALIZATION 150

PART III

SUMMARY AND CONCLUSIONS OF THE PRESENT INVESTIGATION 153

LIST OF REFERENCES 160

GEOLOGY AND GOLD MINERALIZATION OF THE HHOHHO AREA, NORTHWESTERN SWAZILAND

PART I

INTRODUCTION

GENERAL STATEMENT

The present work was undertaken as part of an intensive geological investigation of the Archean fold belt of Swaziland commenced in 1961 by the Geological Survey of that Territory. The aim of the investigation has been to obtain more pertinent information regarding the distribution of economic deposits of gold, iron and asbestos and to determine what structural and/or lithological controls are responsible for their localization. In conjunction with this aim, thorough consideration has been given to the petrology of the rocks occurring in the fold belt particularly with regard to the suite of basic and ultrabasic rocks associated with the layered succession of the Swaziland System. Furthermore, the styles of various granites constituting the southeastern boundary of the fold belt and their metamorphic effects upon adjacent layered rocks were studied. D.N. Davies, the former Director of the Geological Survey, studied the mineral deposits, particularly tin, as well as describing some of the basic and ultrabasic rocks which he attributes to the Jamestown Complex. D.R. Hunter has contributed a great deal of information regarding the Swaziland granites and has also examined gold mineralization in the Wyldsdale and Havelock area. Another member of the Survey, J.G. Urie, has investigated the ferruginous horizons of the Figtree Series, especially in the Bomvu Ridge area near the southwestern extremity of the fold belt. In addition,

he has mapped in detail the Swaziland System rocks in the Forbes Reef area with particular attention to structural geology and the metamorphosing influences of the adjacent granites. More recently, D.R. Hunter and the author have examined gold occurrences in the Hhohho Valley and J.G. Uri[illegible] and the author have described metamorphic zoning in the Swaziland System rocks along the granite contact throughout the fold belt in Swaziland. Besides mapping in detail the Hhohho area, the geology of which will be described in this present work, the author has surveyed in equal detail an area of some 276 square miles extending from Forbes Reef in the southwest to the Hhohho area in the northeast of the fold belt.

In the country constituting the Barberton Mountain Land, to which northwestern Swaziland must be considered an intrinsic part, members of the Economic Geology Research Unit of the University of the Witwatersrand, in conjunction with mining companies operating in the area, have undertaken a similar programme. [illegible].J. Poole started the work with a detailed structural account of the Agnes Gold Mine and vicinity and the relationship between gold distribution and geological structures. During the latter part of 1961, J. Ramsay of Imperial College, London, spent some weeks in the Barberton Mountain Land applying modern techniques to elucidate many structural problems. C. Roering carried on and undertook a detailed structural analysis of the Saddleback Syncline just east of Barberton and F. Herget investigated in detail the stratigraphical and structural problems of the Montrose area to the southwest of Barberton. The mineralized belt stretching south-westwards from Barberton to Montrose, has been mapped by R. Cook of Eastern Transvaal Consolidated Mines Ltd thereby compiling a composite map incorporating the areas investigated by Herget, Poole and Roering. During 1962 C.J. van Vuuren made a detailed structural study of the Ulundi Syncline north of Barberton which included a reconaissance investigation of minor structures present in the Sheba and Fairview Mines. N. Gay

has studied the trace and minor elements constituents and gold to silver ratios of free gold samples collected from numerous gold mines in the Mountain Land with a view to finding some geochemical factor of possible value in future prospecting. Detailed investigations have been made by C. Anhaeusser and M.J. Viljoen of structural, stratigraphical and gold mineralization problems in the vicinity of the Lily and Eureka Synclines along the northern contact between the Archean rocks and the Nelspruit Granite. More recently M.J. Viljoen and R.P. Viljoen have re-assessed and classified the Onverwacht Series in the Komati River Valley.

LOCALITY AND SIZE OF THE MHOHO AREA

The area selected for this thesis lies in the northwestern extremity of Swaziland adjacent to the Transvaal Province of the Republic of South Africa (Fig 1). It comprises a tract of country covering some 30 square miles in the vicinity of Mhohho, 17 miles northeast of Pigg's Peak village. The Swaziland-Transvaal border constitutes the area's northern and northeasternmost boundaries. The southeastern margin roughly follows the banks of the Lomati River and the South-western boundary is defined by an imaginery line from Bearded Man Peak to the confluence of the Mgubudhla and Lomati Rivers.

The tract of country thus demarcated lies on slopes and foothills of the escarpment formed by the Makonjwa Range. The precipitous slopes of the range, rising to an elevation of 3,900 feet, dominate the scenery. They overlook a gently undulating plain, at an elevation of 1,200 feet above sea-level, through which the Lomati River flows north-eastwards into the Transvaal. The tributaries of the Lomati, such as the Mgubudhla, Ndulitshe, Mhlotshana, Mbongosi and Ngugwane Rivers, flow generally southeastwards cascading down the escarpment and cutting deep gorges and sheltered kloofs in the foothills of the Makonjwa Range.

As they approach their respective confluences with the Lomati River they become gently flowing and meander over flat terrain. The tributaries are set in a dendritic pattern cutting across the area's structural grain though in their upper reaches there is a tendency to follow lines of structural weakness.

GEOLOGICAL FEATURES OF SWAZILAND AND THE BARBERTON MOUNTAIN LAND - A SUMMARY OF PREVIOUS WORK

INTRODUCTION

It is proposed to review previously accepted ideas and also more recent contributions on the geology of Swaziland and the Barbertor Mountain Land in as far as they apply to the area under discussion

CLASSIFICATION OF THE LAYERED ARCHEAN ROCKS

The layered rocks of Swaziland and the Mountain Land were first mapped by Hall (1918). He advocated a three-fold division as follows:-

i. The Onverwacht Series comprised of extrusive basic and acid rocks

ii. The Moodies Series consisting of sedimentary rocks of both arenaceous and argillaceous type.

iii. The Jamestown Series made up of a suite of basic and ultrabasic rocks presumably of intrusive origin.

Subsequent work by the Geological Survey of South Africa, (Visser et al., 1956) proved this sub-division to be inapplicable and they divided the layered rocks into an upper Moodies System overlying the Swaziland System consisting of a lower Onverwacht Series and an upper Figtree Series.

More recently Gribnitz et al., (1961) and Herget (1962) have

disputed that the Onverwacht rocks are the oldest in the succession and m intain that certain dolomitic rocks, previously regarded as basic rocks of the Jamestown, be included in another series which they named the Doornhoek.

THE DOORNHOEK SERIES

According to Gribnitz (1961) the series comprises partly arenaceous calcareous sedimentary rocks with interc lated bands of ch rt and ironstones, as named itacorites. His opinion is that many of the carbonate rocks were converted by subsequent kinematic influences into talc-carbonate and quartz-sericite schists which had previously been place into the Onverwacht and/or Fig tree Series as well as into the Jamestown Complex.

THE ONVERWACHT SERIES

The Geological Survey of South Africa (Visser et al., 1956) describes the series as consisting essentially of volcanic rocks. The lower phase is basic comprising fine-grained andesitic lavas, whereas the upper phase is acid being made up of quartz and feldspar porphyries. Gribnitz (1961) maintains the Onverwacht Series to be basic in character, generally intrusive into his Doornhoek Series, but also including extrusive rocks

After carrying out detailed investigations in the Barberton-Noordkaap-Louw's Creek area, M.J. Viljoen (1964) and C. Anhaeusser (1964) came to the conclusion that the succession of predominantly schistose basic rocks, occurring along the contact of the Nelspruit Granite and the Fig tree Series and should be regarded as members of the O . Series. The succession is described as consisting of alternating ..olites and acid schist horizons together with interc lations of shaly material. The basic assemblage consists of dark, contact amphibolites (hornblende schists), green amphibolites (tremolite-actinolite) and a variety of talc-chlorite and talc-carbonate schists. Intercalated

conformable zones of quartz ...
equivalents of more acid material. The assemblages, in the mass, are thought to represent a fairly strongly metamorphosed sequence of dolomites with calcareous, arenaceous and shaly horizons together with intercalations with calcareous, arenaceous and shaly horizons together with intercalations of basic and acid extrusive rocks. Both Anhaeusser and Viljoen recognized three distinct facies of contact metamorphism within the aureole of the intrusive phase of the Nelspruit Granite. Along the immediate contact the dark hornblende amphibolites are placed in the hornblende-hornfels facies of Turner and Verhoogen (1960). The lower temperature assemblage of tremolite-actinolite schists occurring further away from the granite contact are included in the albite-epidote-hornfels facies. At increasing distances from the granite, the carbonate-bearing talc and chlorite schists fall into the lowest temperature of the greenschist facies. The talc, chlorite and phyllitic assemblages grade into unmetamorphosed dolomitic, argillaceous and arenaceous rocks of the Swaziland System . Basic intrusive rocks attributable to the Jamestown Complex are considered to be smaller in extent than was previously supposed and are mainly represented by massive bodies of serpentinite. Anhaeusser and Viljoen express the view that some of the purer talc-carbonate schists along the Kaap River were derived from Jamestown Complex, ultrabasic intrusive rocks but that the bulk of such rocks as well as other basic schists, represent metamorphosed impure dolomitic rocks and basic lavas of the Onverwacht Series.

Cook (1965) working on the Onverwacht Series in the Moodies Hills area, came to similar conclusions to those of Viljoen and Anhaeusser summarized above. He describes the Onverwacht Series as consisting of a metamorphosed succession of impure dolomites with arenaceous and minor shaly horizons together with likely basic and acid lavas.

Studying the basal rocks of the Swaziland System in the Fairview area and Steynsdorp Valley, Steyn (1965) advocates the partial revision of the accepted stratigraphical sub-division of the Swaziland System and Jamestown formations. He recognizes deformation of the Onverwacht

Series prior to the deposition of the Figtree succession and considers it to "constitute a diastrophic event of considerable magnitude which must have extended over a lengthy period of time during the Archaeozoic Era". Steyn, therefore, assigns the Onverwacht and Figtree rocks to the taxonomic rank of System together with the Moodies System to form a Swaziland Complex. The Onverwacht System comprises predominantly basic rocks with intimately associated siliceous units. Chlorite-hornblende-epidote schists and epidiorites (greenstones) are considered to be the metamorphic derivatives of basic lavas. In the Steynsdorp Valley, the basic lavas are most commonly represented either by dense, dark-green microcrystalline rocks or by fine-grained rocks varying in colour from light green to olive-green. Amygdaloidal types are only sporadic in distribution. In the Fairview area, the lavas are represented by an olive-green coloured fine-grained rock or a dark-green aphanitic rock and types resembling both andesitic lavas and epidiorites are to be found. The main sedimentary horizons encountered in the basic assemblage are carbonate-rich beds and highly siliceous banded rocks such as cherts. Steyn is of the opinion that the carbonate-rich beds are converted by metamorphism to talc-carbonate schists which constitute "well-defined lithostratigraphic units within the Onverwacht Series."

Recently, W.J. Viljoen and R.P. Viljoen (1967) have re-assessed and correlated the Onverwacht Series in the Komati River Valley. They sub-divide the series into three distinct lithological units. The Lower Onverwacht or Theespruit Stage is characterized by metamorphosed basaltic rocks in which pillow structures are present together with interlayered siliceous sediments and a few narrow cherts. Serpentized ultrabasic zones in the form of lenses and bands are typical. This succession was previously regarded as part of the Jamestown Complex by the Geological Survey of South Africa (Visser et al, 1956). The Middle Onverwacht or Komati River Stage comprises a substantial sequence of alternating pillow basalts and ultrabasic horizons. Unlike the Upper or Lower Onverwacht, the stage is "characterized by a complete absence of interlayered

siliceous or acidic material." The Upper Onverwacht or Hoogenoeg Stage is sub-divided into a lower and upper part. The lower consists essentially of a sequence of basic to intermediate lavas with well-developed pillow structures. Interlayered with these lavas, are a number of relatively narrow horizons of intermediate-acid lavas, the latter associated with banded cherts and carbonate bearing sediments. The upper part comprises mainly massive acidic material in a large rather irregular zone. Viljoen and Viljoen maintain that the quartz-sericite sediments or cherts in the Onverwacht succession are almost totally devoid of ferruginous or clay material. They state that "they probably represent accumulations of volcanic emmanations and contain very little transported sedimentary material derived from erosion of surrounding land areas". They include the possibility, however, that shaly and ferruginous sediments may be associated with lavas in other parts of the Mountain Land.

The Geological Survey of Swaziland have, until quite recently, been hesitant to correlate any of the gneissic and hornfelsic rocks or the amphibolitic, chloritic, talcose and carbonate-bearing schists occurring within the metamorphic aureole of the granite as Onverwacht Series. Pretorius (1947) sub-divided the schists in the vicinity of the granite contact into a number of classes and noted a broad metamorphic zoning of such rocks. Amphibolitic and chloritic schists were observed near the granite contact whereas the preponderance of talcose and carbonate bearing schists occur at increasing distances away from it. Pretorius (1947) considered all the schists to be of igneous origin and classified them as belonging to the Jamestown Complex. Later, Hunter (1950) and Urie (1957) re-mapped parts of the southwestern extremity of the Archean fold belt in Swaziland and divided the schists of the peripheral metamorphic zone into metasedimentary and meta-igneous varieties. The former were included in the Figtree Series and the latter as members of the Jamestown Complex. In the northeastern part of the fold belt and in the Mkhondo area itself, Lenz (1955) was unable to distinguish altered ultrabasic rocks attributed to the Jamestown Complex and micaceous schists

and phyllites of the Figtree Series from Onverwacht lavas reported by the Geological Survey of South Africa (van Eeden et al., 1956) as passing into Swaziland. Amygdaloidal basic lavas were recognised at the foot of Bearded Man Peak, however, and were correlated as belonging to the Onverwacht Series.

More recently, Urie and Jones (1965) studied the metamorphic zoning of rocks along the granite contact. A distinction was drawn between rocks regarded as being originally derived from sedimentary rocks and those originating from ultrabasic igneous rocks. The former were placed into the Figtree, whereas the latter, termed magnesia-rich schists, were considered to be metamorphosed ultrabasic rocks of the Jamestown Complex. The presence of any lavas in the succession was not unequivocally established and it was felt, at that time, that there was insufficient evidence to warrant any further subdivision. Urie and Jones did, however, appreciate that the schists might differ considerably in age and mode of emplacement and need not necessarily all be derived from ultrabasic rocks.

The Onverwacht-Jamestown Complex problem in Swaziland is of considerable interest and will be discussed more pertinently in a later section dealing with the Jamestown Complex.

THE FIGTREE SERIES

The overlying Figtree Series is essentially argillaceous in character with well-developed cherts, meta-quartzites and banded ironstones. Included in the succession are greywackes, grits and narrow conglomerate bands.

Van Eeden (1941) was of the opinion that subordinate lavas were developed at the top of the succession. Ramsay (1963) has, however, disputed that the rocks so classified by van Eeden are in fact lavas and suggests that they are coarse, feldspathic greywackes.

At the base of the series in the Mountain Land occurs a succession of chert bars underlain by green schists which in turn overlie "grey schists".

This succession constitutes the so-called Zwartkoppie Zone. The first mentioned schists consist of talc and carbonate and the latter, according to Koen (1947), have a mineralogical resemblance to greywackes and probably represent a mylonitized product of such a rock. Gribnitz (1961) is of the opinion that many of the schists are the metamorphic derivatives of dolomitic rocks. According to Ramsay (1963) the parent rocks of the greenschists were deformed, laminated secondary cherts formed from greywackes and possibly some calcareous sediments and talc phyllites.

Steyn (1965) in his suggested "Swaziland Complex", divides his Figtree System into a lower Zwartkoppie Series and an upper Sheba Series. The former consists predominantly of calcareous rocks and the latter is of a ferruginous character.

Working in the vicinity of Bomvu Ridge in Swaziland, Urie (1957) recognized a basal zone of the Figtree Series which consisted originally of argillaceous and carbonate bearing rocks with interbedded chert horizons. Lying conformably below typical Figtree Series formations, this basal zone became altered due to assimilation by solutions of the Jamestown Complex. Such process of assimilation was highly selective and ultrabasic rocks only formed in horizons originally occupied by argillaceous formations. The more siliceous cherts were immune and so remain as rafts within an ultrabasic assemblage now represented by various talcose schists. Urie was, however, conscious of the great difficulties attending such a process. He suggested the Figtree sequence to be as follows:-

4. Siliceous and ferruginous shales and interbedded cherts with subordinate horizons of ironstones.

3. Grits and minor conglomeratic grits.

2. Siliceous and ferruginous shales, interbedded cherts and banded ironstones with subordinate argillaceous and sericitic sandstones.

1. Basal zone composed entirely of metamorphic rock types: predominantly re-crystallized cherts, quartz-

chlorite-feldspar-carbonate schists and amphibole-bearing gneisses and granulites.

Further north, in the vicinity of the Havelock mine, Mehliss (1946) found great difficulty in elucidating the stratigraphic succession. The following rock types were found to be present:-

5. Extrusive feldspar porphry.
4. Banded ironstones.
3. Siliceous facies.
2. Argillaceous facies.
1. Staurolite schists.

The above list is not arranged according to a stratigraphical succession. Recent work by the author in the same area (1966, 1967,) has revealed that many of Mehliss's siliceous zones are either mylonites or acid lava flows. Also that the extrusive feldspar porphyries are extensive in distribution and are, in fact, acid or acid-intermediate lavas in which pillow structures are well-preserved. Argillaceous rocks, such as shales and phyllites, do occur in the succession, but in many cases the so-called "argillaceous facies" contain numerous and extensive lava flows ranging in composition from intermediate to basic. It is the author's opinion that the bulk of the rocks occurring in the Havelock area should be placed in the upper part of the Onverwacht Series, though the banded ironstones and accompanying ferruginous shales are retained in the Figtree succession. The Figtree Series in the northwestern part of Swaziland is, therefore, much less extensive than was originally supposed and consists primarily of shales, cherts, banded ironstones, grits, quartzites and greywackes.

THE MOODIES SERIES

Most workers in the Barberton Mountain Land recognize an unconformable relationship between the argillaceous Figtree formations and

the overlying arenaceous rocks of the Moodies and so place the Moodies on the taxonomic rank of a system. The author, however, like other members of the Geological Survey of Swaziland, whilst recognizing this unconformable relationship favours the retention of the term Moodies Series for reasons to be stated later.

THE JAMESTOWN COMPLEX

As previously stated, the Swaziland Geological Survey have, in the past, attributed the bulk of the basic and talcose schists occurring along the granite contact of the Archean fold belt to the Jamestown Complex. The Jamestown-Onverwacht controversy in Swaziland is of interest and it is proposed to briefly summarize the topic.

Pretorius (1948), mapping the country lying between the Komati and Ushushwana Rivers, observed that talc-carbonate schists occurred intercalated with shale and chert horizons of the Figtree Series. The preponderance of hornblende, tremolite, chlorite, quartz, magnetite, talc and biotite and the absence of cordierite, sillimanite, andalusite, staurolite and kyanite were thought to be indicative of an original igneous group of rocks representing the Jamestown Complex. The limited shale and quartzitic bands associated with the schists were regarded as being of minor importance. Patches of conglomerate occurring in the schist assemblage were thought to represent xenoliths of Moodies rocks brought up in the intrusion of basic rocks of the Jamestown Complex. The possibility that some of the talcose schists were originally calcareous sedimentary rocks was not considered.

Way (1952) divided the Figtree Series into an upper and a lower group. The former consists of argillaceous phyllites with associated chert bands. The lower group comprises metamorphosed "originally sedimentary rocks" represented by meta-quartzites, cherts, amphibole schists and gneisses, granulites and serpentines. An assemblage of talc, carbonate and chlorite schists together with amphibole gneisses and schists were placed in the Jamestown Series as defined by Hall (1918).

Such rocks were, in Way's opinion, originally of volcanic origin.

Later, Davies (1956) maintained that the assemblage including amphibolites and talcose schists represented ultrabasic rocks of the Jamestown Complex which were intruded into flat-lying formations. He considered that portions of the Figtree Series were absorbed and partially or wholly assimilated by ultrabasic solutions. Peculiar mixed rocks resulted such as talc-chlorite, psammitic and amphibole schists together with talcose rocks and many others. Certain zones, he reported, were extremely pelitic indicating possibly an impure mixture of ultrabasic and argillaceous rocks. The ultrabasic intrusions were visualized to be sill-like being always concordant with the country, sedimentary rocks. Siliceous bands (cherts) in the succession almost completely resisted assimilation. Where unaltered ferruginous or sandy shales occurred it was thought that continuous chert and banded ironstone horizons behaved as protective barriers to the assimilating intrusions. The Moodies Series suffered almost no assimilation because of the absorbing effects of the resistant, underlying series.

Working in the Bomvu Ridge area of Swaziland, Urie (1957) expressed the opinion that the "basal zone" of the Figtree Series was originally comprised of argillaceous and carbonate-bearing formations with narrow interbedded chert horizons. The "basal zone" was assimilated by a process of "re-active solutions" and converted largely into ultrabasic rocks This basification was thought to be due to the effects of the intrusive Jamestown Complex. The process of assimilation was highly selective and occurred only in argillaceous formations. Siliceous horizons (cherts) were unaffected and remained as "arms" or "disconnected rafts" with little or no disarrangement of their relative positions to the country rocks. It was visualized, therefore, that very little thrusting aside accompanied the intrusions.

Hunter (1961) used Way's (1952) sub-division of the Figtree Series and recognized an upper argillaceous group of rocks overlying a

meta-sedimentary assemblage. This lower assemblage was intruded and metamorphosed by the Jamestown Complex. He reported, however, that the Jamestown Complex had been intruded into both the Figtree and Moodies Series. Its petrology was variegated and complex for the following reasons:-

i. The influences of metamorphism;

ii. Probable differentiation occurring within the magma itself.

iii. The effects of having assimilated pre-existing sedimentary rocks.

iv. Metamorphosing influences of the younger granite intrusions.

Metamorphism was held to include both serpentinization and steatization. The meta-sedimentary rocks are now represented by quartz-mica gneisses with garnets, quartz-amphibole gneisses (viz: actinolite-epidote and hornblende gneiss) and calc-silicate grading into hornblende gneisses. Colour banding in the gneisses was though to reflect compositional differences in the original sedimentary rocks. Structural evidence, states Hunter (1961), indicates these rocks to be highly metamorphosed and metasomatized equivalents of a supra-structural Figtree Series of the Swaziland System.

In 1963 the author described rocks, regarded then as Jamestown Complex, in the Malolotsha valley area in Swaziland. Such rocks occur in three distinct forms. The first occur in association with Figtree Series rocks in the cores of folds. The second intruded into the Moodies Series as narrow, intercalated lenses especially around the noses of folds. The third form are confined to major fracture and fault zones in the area. Three alternative interpretations were offered at that time:-

i. The intrusives pre-dated the Moodies Series.

ii. A pre-existing ultrabasic magma became remobilised

as a result of tectonism.

iii. The intrusions occurred in a number of pulsations spanning from pre-Figtree to post-Moodies in time.

In a study of metamorphic zoning in the Archean fold-belt of Swaziland, Urie and Jones (1965) classified the various schists present. Along the peripheral zone, adjacent to a late-orogenic granite, occur serpentinites, gneisses and hornfelsic rocks together with amphibolitic, chloritic, talcose and carbonate-bearing schists. On a mineralogical basis and with regard for nickel and chrome contents the rocks were divided into meta-sedimentary and magnesia-rich groups. The former included derivates of carbonate-bearing shales and possibly some volcanic material. The presence of lavas in the succession was not, however, unequivocally established. Evidence to substantiate a definite correlation was lacking and such rocks were regarded as metamorphic derivatives of the Figtree Series. The magnesia-rich rocks in all their variations, invariably containing a low but remarkably constant nickel and chrome content, were thought to be derived largely from ultramafites which had suffered retrogressive metamorphism. They were regarded as Jamestown Complex though it was "appreciated that they may differ in age and mode of emplacement and, indeed, all may not be derived from ultramafic rocks". In contrast, M.J. Viljoen (1964) and C. Anhaeusser (1964), working in the vicinity of the Lily and Eureka synclines in the Barberton Mountain Land, were both of the opinion that the bulk of the basic assemblage represents metamorphosed calcareous sedimentary rocks. Occurring within the assemblage are possible basic and acid lavas.

Finally, D.R. Hunter and the author (1966) in an explanation to accompany Geological Survey of Swaziland, Sheet 2531CD covering the northwestern part of the fold belt of the territory state as follows. "Some doubt now exists as to existence of the Jamestown Complex in this area. It is possible that some of the rocks placed in the Jamestown Complex should be regarded as belonging to the Onverwacht Series, possibly

representing basic lava flows."

THE NELSPRUIT AND SWAZILAND GRANITES

INTRODUCTION

It is proposed first to review work carried out on the Nelspruit Granite and Gneisses in the Barberton Mountain Land. This will be followed by a summary of the views by members of the Geological Survey of Swaziland on the various granites and gneisses occurring in that territory.

THE NELSPRUIT GRANITES AND GNEISSES

Hall (1918) noted a classic intrusive relationship between the Nelspruit Granite and layered Archean System rocks. He regarded the granite as having migmatised a large mass of basic Jamestown rocks along its immediate contact.

Van Eeden (1941) suggested that extensive portions of the Archean System were convertac into gneiss as a result of granitization. He concluded that different phases of Nelspruit Granite exist, the shallowest being gneissic as a result of incorporating older rocks, whereas the deepest portions are more homogenous and closer to a true magma.

Read (1957) was also of the opinion that the Nelspruit Granite represented granitized Archean rocks. The abrupt contact existing between granitized rocks and unaltered layered formations was attributed to "resisters" in the form of basic rocks which behaved as barriers against the metasomatizing agents.

The conclusions of Ramsay (1963) were that much of the Nelspruit and Swaziland Gneisses formed a pre-Archean fundamental complex. Contact metamorphism in the Mountain Land was thought to be the result of the intrusion of a younger granite.

Viljoen (1964) and Anhaeusser (1964) are of the opinion that

Nelspruit migmatities represent for the most part the basement upon which were deposited the rocks of the Mountain Land. The strongly banded and intensely folded gneisses are considered to represent the granitized remnants of some pre-Swaziland System formations. The intrusive granite represents a mobilized part of the re-heated and plasticized Nelspruit basement migmatite and was responsible for inflicting contact metamorphism on adjacent Archean rocks.

THE SWAZILAND GRANITES AND GNEISSES

Extensive work has been done on the Swaziland granites and gneisses by Hunter (1950, 1956, 1957, 1961 and 1965). His classification of the Swaziland granites in 1957 was based on their structural, macroscropic, microscopic and petrochemical differences. Five types were recognized. The oldest, termed G1, was sub-divided into a coarse-grained, dark-coloured and crudely foliated migmatic granite and a coarse, porphyritic, pale-coloured homogenous granite. The form of the migmatitic type was not recognized, but the homogeneous granite was seen to be occurring in small plutons with sharply-defined margins. The succeeding granite, namely G3, is a dark, greenish-black coloured, foliated granite with feldspar porphyroblasts. The form of this granite phase was not established. The G4 granite is normally a coarse-grained, grey granite which may be locally porphyritic or foliated and contains numerous pegmatites. The granite was described as occurring possibly in a sheet-like form with sharp contacts on the upper surface of the sheets. The lower contacts were described as being gradational. The following G4/5 granite was described as being very coarsely porphyritic grading to coarse-grained. Pegmatites are absent in the coarser portions. The attitude of this granite was not established. The youngest of the Swaziland granites, termed G5 is coarse-grained and porphyritic without any pegmatites and occurs as clearly-defined plutons. In the above classification by Hunter, the G4 granite is broadly synonymous with the Nelspruit Granite.

In 1965, Hunter re-classified the Swaziland granites according to their position in an orogenic cycle. At least two major cycles are recognized. The earliest is only fragmentary and involves biotite and biotite-hornblende gneisses in which rare relics of meta-sedimentary rocks are found. Such gneisses are named the Ancient Gneiss Complex which is considered to have undergone deformation and synorogenic granitization. The second cycle involves the deposition of the Swaziland System upon these ancient gneisses in geosynclinal conditions and subsequent deformation. During deformation a differentiated magmatic suite ranging from quartz-diorite to leuco-granodiorite was emplaced. Later, the Swaziland System and pre-existing rocks were intruded by a late-orogenic granite (viz. G4) which Hunter considers as a mobile magma "whatever the ultimate origin of the magma was". Finally post-orogenic granites were intruded into the Archean layered rocks and existing granite masses as well defined plutons.

METAMORPHISM

REGIONAL METAMORPHISM

In the Barberton Mountain Land the Geological Survey of South Africa (Visser et al., 1956) recognized the effects of dynamic and thermal metamorphism but stated that regional metamorphism is absent. Viljoen (1964) was also of the opinion that there are no regional influences present in the vicinity of the Lily and Eureka Synclines. He concludes that 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 superincumbent strata, although it seems likely that they must have been covered by the Transvaal System sediments at some stage in the not too distant past".

In Swaziland, Hunter (1961) states that the "great period of orogony which followed the termination of geosynclinal conditions in Swaziland resulted in many changes in the rocks involved in the folding. In the

early stages of the orogeny the rocks were depressed and thereby suffered regional metamorphism".

Urie and Jones (1965) remark, however, that the sedimentary rocks of the Archean fold belt are remarkably little altered and that "metamorohism seldom rises higher than the phyllite grade". Fringing the fold belt adjacent to the granite contact higher grades of contact metamorphism are encountered whereas at increasing distances from the granite the main effects are the results of dynamic metamorphism.

DYNAMIC METAMORPHISM

Dynamic metamorphism, according to the South African Geological Survey (Visser et al., 1956), is not apparent on a large scale except along major thrust faults. Under such circumstances the rocks have been crushed, mylonitized and also silicified so that faults may be traced by means of outcrops of secondary chert.

Both Viljoen (1964) and Anhaeusser (1964) have described in detail cleavage development, foliations, lineations and deformation of clastic particles imposed upon the Archean rocks as a result of tectonic stress. Also, Anhaeusser and Viljoen (1965) state that severe dynamic metamorphism occurs along the Nelspruit Granite contact zone due to the updoming of the Nelspruit Gneiss. They conclude that, despite conclusive evidence, there is a possibility that widespread dynamic action along the contact zone might have led to a certain amount of retrograde metamorphism.

Hunter (1961) observes that varying degrees of mylonitization and silicification of Swaziland System and Jamestown Complex rocks are expressions of dynamic metamorphism as a result of intense folding. Major faults are frequently marked by hard"bars" of secondary chert and mylonite which are usually aligned in a northeasterly direction. These bars may bifurcate and coalesce to enclose large lenses of less disturbed strata up to a mile or more in length. The re-orientation of clastic particles parallel to the regional cleavage pattern and the imposition of a regional

schistosity on Jamestown Complex rocks are further expressions of dynamic metamorphism. Hunter also maintains that an important effect of faulting on more massive serpentinites is a secondary and intense serpentinization with which may be associated deposits of chrysotile asbestos.

CONTACT METAMORPHISM

Most writers in considering the Barberton Mountain Land attribute contact metamorphism to the intrusion of the Nelspruit Granite. Few workers have been able to establish any evidence of metamorphism resulting from Jamestown Complex intrusions, though van Eeden (1941) was of the opinion that silicification in the vicinity of the Kaap River could be attributed to this source.

In the Barberton district both Anhaeusser (1964) and M.J.Viljoen (1964 have described the effects of the intrusive phase of the Nelspruit Granite on the rocks of the Swaziland System. They established three facies of contact metamorphism as follows:-

i) a hornblende-hornfels facies along the immediate contact zone,

ii) an albite-epidote-hornfels facies at an increasing distance from the contact,

iii) a greenschist facies as an expression of contact metamorphism furthest away from the granite margin.

In Swaziland, Urie and Jones (1965) have given an account of the influences of the late-orogenic granite on immediately adjacent layered Archean rocks. They describe the mineralogical variations in both meta-sedimentary and magnesia-rich schists, the latter being considered derivatives of ultramafites, in a higher temperature zone along the granite contact and at a lower temperature increasing distances away from it. In the higher temperature zone amphiboles, albeit of differing composition, characterize both the meta-sedimentary and magnesia-rich rocks. In the

lower grades of metamorphism chlorites and carbonates are common to both.

STRUCTURAL GEOLOGY

Hall (1918), in his comprehensive survey of the Mountain Land, ascribed its structure to the intrusion of various granites. To quote: "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 formations (granites) is an 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."

Van Eeden (1941), from a structural investigation of the Sheba Hills area, deduced that the forces responsible for the formation of folds in the Mountain Land originated from the south-southeast. These forces caused overfolding to the north-northwest so that the folds were orientated at right-angles to the major stress. Thus, the trace direction of the axial planes is roughly west-northeast. The deformation of the supra-crustal rocks and the intrusion or formation of the Nelspruite Granite were synchronous events. Only one period of deformation was thought to have occurred.

Hearn (1943) considered the folding to have been caused by the compression of the Archean rocks between the Nelspruit Granite and the Swaziland granites. After the consolidation of these granites further tectonism occurred as a result of the emplacement of the Kaap Valley Granite resulting in the bending of the strata in the Sheba Hills area.

More recently Ramsay (1963) undertook an investigation of the structural geology in the northwestern part of the Mountain Land. He established at least three successive periods of deformation as follows:

1) The first period, corresponding to the only tectonism of van Eeden (1941), gave rise to large folds whose axial planes were orientated in a

northeast-southwest direction.

ii) A second period of deformation resulting in extensive development of slaty cleavage and schistosity oblique to the axes of the first folds. Ramsay also attributes the flattening and elongation of clastic particles in the sedimentary rocks of the Swaziland System, as first mentioned by van Eeden (1941), to this period.

iii) The third period of deformation resulted in northwest trending folds which are particularly well-expressed in the northwestern part of the Mountain Land. He classifies together the arcuation of the Eureka Syncline and the Consort area folds since the axial planar trace of the former corresponds with the general orientation of the latter. The development of conjugate folds in some [illegible] horizons is considered by Ramsay to be synchronous with the arcuation of the Eureka Syncline but the possibility that they post-dated it is considered.

In 1964 M.J. Viljoen, working in the Lily and Eureka Syncline area, recognises the first and second periods of deformation established by Ramsay (1963) but divides the third phase into two parts. The third phase was responsible for the main folds in the Consort area and a fourth phase resulted in the formation of crenulation and conjugate folds.

Recent work by Roering (1965) considers six successive periods of deformation to have been active in the Barberton Mountain Land. He summarizes the deformational events as shown in Table 1.

Roering deduces that the force which produced the main deformation acted from the south-southeast, the emplacement of the late- orogenic granite in Swaziland being responsible. Later fold phases started to act whilst the Main Phase stress was still active. Post-Main Phase deformation was caused by a stress operating almost parallel to the regional strike of the bedding giving rise to the Montrose Fold Trend. The Consort Trend deformation may have been brought about either by the intrusion of the Kaap Valley Granite or the eastward movement of an already consolidated Kaap Valley pluton on to the Nelspruit Granite. The north-northwest acting forces are thought to have been always active resulting in continuous compression and to be expressed by complex faulting in the northwest of the Eureka Syncline, disharmonic folding near the Clutha mine and by folds of the Late Ulundi Trend. The vertical stress, causing flat folds which represent the final imprint of deformation, may have been instigated either by the rising up of the Nelspruit Granite or by the emplacement of an unexposed pluton of younger Mpageni Granite or the post-orogenic granite (viz G5) of Swaziland.

In Swaziland Hunter (1961) has suggested the following sequence of events in the history of the Precambrian:-

i) A geosynclinal phase during which the rocks of the Swaziland System were deposited.

ii) A phase of initial magmatic activity represented by the Jamestown Complex.

iii) Imposition of regional metamorphism.

iv) A main orogenic pulsation: migmatization and granitization.

v) Inter-tectonic sedimentation and volcanism: Inzusi and Mozaan Series.

vi) A second orogenic phase and widespread intrusion of G4 (late-orogenic) granite.

vii) A post-orogenic phase expressed by the incrusion

of granite plutons (G5).

A reconnaissance structural survey has recently been undertaken by Urie (1965) in the Forbes Reef area situated near the southwestern extremity of the Archean fold belt in Swaziland. This survey reveals that sedimentary rocks of the Swaziland System and magnesia-rich rocks attributed to the Jamestown Complex have been subjected to at least two periods of folding. The earliest and strongest phase was about northerly to northeasterly trending axes whereas a later and less intense phase occurred along axes trending in a northwestern direction. Urie suggests from available evidence that the "granite which surrounds the fold belt was emplaced in the waning phases of the early period of deformation, but that its complete consolidation only followed the later phase of folding".

GOLD MINERALIZATION

THE LOCALIZATION OF GOLD

Hall (1918) observed that on both sides of the Mountain Land gold mines lie either within his Jamestown Series or along the outer margins of the Moodies Series close to the junction of the "granite" (i.e. Kaap Valley and Nelspruit Granites). Du Toit (1954) also noted that very few instances of gold mineralization occur in the "higher strata" away from the contact zone of the "granite" and in such instances they are usually related to faulting and thrusting.

Main fault zones have been considered wholly or partially responsible for the introduction of gold and sulphide mineralization into the host rocks of the Swaziland System by many previous investigators. Gribnitz (1961) is of the opinion that faults are the primary avenues for passage of hydrothermal solutions.

Poole (1964) has studied the gold mineralization in the Agnes Mine in the Barberton Mountain Land and found a very close connection between second phase structures, as defined by Ramsay (1963), and gold mineralization

particularly in the location and pitch of pre-shoots. Mineralization in the Agnes Mine has been localized in a shaly horizon which has been subjected to intense deformation especially where axial plane cleavage and lineations are best developed. People also noted that individual pre-bodies appear to be localized at the contacts between rock types of different competencies. A further control appears to be minor variations in the strike and/or dip of the sedimentary host rocks. The relationship between the pitch of the pre-shoo and lineations related to the second phase of deformation is also apparent since they both plunge to the east in the plane of foliation at angles varying fro 45 degrees to 60 degrees.

W.J. Viljoen (1964) expressed the opinion that the localization of the Consort Mine mineralization was due partly to the fact that the contact between competent Figtree and Moodies rocks and incompetent pre-Figtree schists was a zone of extensive differential movement. Mineralization tends to be concentrated when a strongly developed siliceous "bar" is present. The "bar" is strongly affected by third phase folds which play an important role in the localization of gold. Viljoen concludes that during the second phase of deformation, when the intrusive Nelspruit Granite has almost completely crystallized, mineralized hydrothermal solutions, representing late derivations of the granite, made their way into zones of strong differential shearing and dislocation. Silification and associated mineralization concentrated where movement was strongest. It was important that this contact should have been broadly parallel with the main deforming stress during the initiation of the third phase folds. Thus, in the initial development of third phase folds, which probably started developing late in the second period of deformation, the contact zone came under extreme tension. This tension occurred as the competent rocks became folded whereas the incompetent basic rocks did not fold but suffered intense compression and developed into schists.

Anhaeusser (1964), during the course of mapping the Eureka Syncline, came to the conclusion that much of the gold mineralization was introduced either during or after the third phase of deformation. In the inner arc (southern limb) of the folded syncline numerouse tension fractures

radiate roughly perpendicular to the Sheba Fault. These fractures are filled by gold bearing quartz veins which are comparatively free of sulphide mineralization. Anhaeusser believes that folding of the arenaceous Moodies rocks resulted in numerous tension gashes forming in the hard competent quartzite horizons. Generally vertical or steeply dipping the majority of the fractures lie at right angles to the bedding planes. A few fractures, however, cut obliquely across the strata and may owe their orientation to shears related to the conjugate folding of the third structures described by Ramsay (1963). Subsequent invasion of the fractures by hydrothermal gold-quartz veins are concluded to suggest that the mineralization was not confined solely to the second period of deformation, a possibility put forward by Ramsay (1963), but that gold continued to be precipitated together with quartz in favourable traps produced in structures formed by the third period of deformation. Also associated with the third period of folding are numerous fractures roughly parallel to the Sheba Fault. These occur mainly at localities immediately flanking the third phase fold axis and in the case of arcuate structure between the Fairview Mine and Sheba group of mines. Anhaeusser explains the origin of these fractures by concentric shearing as a result of strike-slip movement between the folded bedding units. The concentric shear surfaces, coupled with overthrust movements, produced suitable structures which were subsequently invaded by hydrothermal mineralizing solutions containing essentially free gold and vein quartz with lesser amounts of sulphide material. Anhaeusser (1965) has also described wrench faulting in the Barberton Mountain land and its relationship to gold mineralization. He maintains that there is a definite association between structures, with horizontal displacement frequently involved, and the localization of gold. Wrench faults are suggested as having been formed by the re-activation of pre-existing longitudinal thrust fault planes by the third period of deformation which was responsible for the arcuate folding of the Eureka and Ulundi Synclines. Anhaeusser emphasises the importance of regenerative stresses in the form of second-order phenomena. The Lily Mine was

considered in detail and a structure termed a cymoid loop or curve was analysed using the principle of wrench fault mechanics. This type of structure is maintained to be of considerable importance as a locus of rich payshoots in gold reefs. The Sheba, French Bob's and other mines were also discussed to show that either direct or indirect effects of wrench faulting are responsible for producing structures suitable for ore deposition.

Members of the Geological Survey of Swaziland have also recognized a relationship between geological structures and mineralization. Hunter (1960) describing the Emlembe Mine noted that gold mineralization is situated in sheared basic schists of the Jamestown Complex adjacent to an east-northeast striking mylonite zone. The basic schists are invaded by a stockwork of quartz veins striking north-northeast, southeast and south-southeast. Again Hunter (1959) relates the gold mineralization in the Wyldsdale Mine to shear zones striking slightly north of east in a granodiorite boss. In the adjacent Lomati Mine the localization of gold appears to be associated with a mylonite zone striking northeastwards.

The author (1962 [a]) attributes the concentration of gold in the Kobolondo and Black Diamond Creek Mines to silicified shears which strike northeastwards in sympathy with the regional structural grain. Also the gold mineralization in the Devil's Reef Mine is considered by the author (1962 [b]) to have been localized in a ferruginous wad breccia adjacent to a northeast trending strike fault. In the Havelock-Piggs Peak area the author (1965) has concluded that deposits of gold, iron, asbestos and cinnabar are concentrated where cross-folding (F^3 phase of Ramsay 1963) or arcuation of pre-existing main phase structures (F^1 of Ramsay 1963) has occurred.

THE MINERALOGY OF THE GOLD DEPOSITS

A general study of the mineralogy of gold ores of the Barberton Mountain Land was made in 1957 by de Villiers. He recognizes four main

types of ore:

i) ore containing arsenopyrite

ii) pyritic ore

iii) lead-bearing ore

iv) antimonial ore

According to de Villiers the ore from the New Consort and Lily Mines, which contains pyrrhotite and arsenopyrite, was "formed at high temperature and at great depth." The pyritic ores, which are representative of the bulk of the Mountain Land gold deposits, are mineralogically simple and are characteristically hydrothermal (mesothermal). The lead-bearing ore, as from Rosetta Mine, is mineralogically typical of the mesothermal zone.

Gay (1963) undertook spectroscopic and other analyses of native gold from the Barberton area. From the examination of 62 specimens it was found that the composition of gold to be relatively simple. Silver, copper, iron and silicon are present in all the specimens; magnesium in 58 of them; aluminium in 53; nickel in 27; lead in 23; antimony in 12; tin in 11; bismuth in 10; cobalt in 7; mercury and calcium, manganese, palladium and vadadium in one. Of these trace elements it is believed that beryllium, bismuth, cobalt, manganese, mercury, molybdenum, palladium, silver, tin and vanadium occur as alloy constituents in solid solution with the gold. Antimony, copper, iron, lead, nickel, titanium and zinc are also thought to be present in the gold lattice, but the possibility that they represent mineral inclusions in the gold cannot be disregarded. Aluminium, calcium, magnesium and silicon are probably present as mineral inclusions.

Gay (1963) concluded from the composition and geochemical associations of native gold that it is very widely but sparsely distributed. The gold tends to be associated with definite minerals especially pyrite, galena, arsenopyrite, chalcopyrite, pyrrhotite, sphalerite, carbonates and quartz. Individual deposits may be characterized by the same elements. Furthermore,

trace elements in the associated individual minerals, especially pyrite, are characteristic for any deposit and may indicate the type of deposit. It was also considered that the associated minerals, trace elements and elements in individual minerals are all effected by the conditions of formation. Thus, they may indicate the type of mineralization and though there is a qualitative similarity for all three in ore deposits, there are, nevertheless, marked variations quantitatively. It was found too that sub-microscopic gold is generally confined to definite minerals. The gold may be widely dispersed in the sulphide minerals whereas in the native state it occurs in solid solution with the sulphides or else as minute flakes or inclusions.

Gribnitz (1961) adds a fifth type of ore to those recognized by de Villiers (1957), namely a gold/quartz ore.

Poole (1964) has made a detailed study of the Agnes Mine ore-body and comes to the conclusion that the ore is typically hydrothermal in nature. Mineralogically it consists of pyrite with minor amounts of sphalerite, chalcopyrite and gold occurring in a gangue composed of quartz and lesser amounts of ankerite. In view of the mineral assemblage and probable temperature (350°Centrigrade plus) Poole considers the deposit to belong to the mesothermal class of hydrothermal deposits.

A detailed description of the mineralogy of the Lily and Rose Fortune Mines has been given by Anhaeusser (1964). The ore deposit in the first mentioned mine contains pyrrhotite and arsenopyrite with subordinate amounts of chalcopyrite and melnikovite-pyrite. The paragenetical sequence of mineralization was found to be arsenopyrite followed by pyrite, pyrrhotite, chalcopyrite and melnikovite-pyrite. Two ages of gold deposition are considered to have occurred. The first is thought to have been introduced contemporaneously with some of the arsenopyrite since it is found in intimate association with this mineral.

The second age of gold was precipated prior to and together with secondary quartz in veins and breccia cavities. Although no gold is seen in association with pyrrhotite it nevertheless occurs with that mineral as

is indicated by assay sampling. The gold deposited in hypogene form, together with such minerals as arsenopyrite and pyrite, was probably liberated in the altered and oxidized zones. The gold taken into solution was re-precipitated as supergene gold. Other supergene minerals produced by chemical weathering include a goethite-limonite association. These minerals were formed over a considerable range of time right up to the present and were probably derived from the alteration of iron minerals in banded ironstones as well as from some of the pyrrhotite. The only non-metallic mineral associated with the ore is quartz. This mineral has a complex history being introduced at an early stage and again with the supergene minerals.

The mineralogy and chemical behaviour of some refractory gold ores from the Barberton Mountain Land has been described by Schweigart and Liebenburg (1965). They observed that a large percentage of the gold, such as that from the New Consort Mine, occurs "free" as small individual grains associated with gangue minerals of which quartz and sericite predominate. In addition to the free gold much of the gold is associated with a large number of minerals of which pyrite and, to a certain extent arsenopyrite, are the most important gold carriers. In addition to these sulphides, Schweigart and Liebenburg observed twenty-three minerals acting either as hosts or found in association with gold as follows:- native antimony, native bismuth, chalcocite, chalcopyrite, chloanthite-skutterudite (types 2 and 3), native copper, covellite, enargite, famatinite, galena, goethite, jamesonite, leucoxene, loellingite, magnetite, neodigenite, pyrrhotite, native silver, sphalerite, tetrahedrite and ullmannite. The particles of gold found in the ores vary from over 5 millimetres across to particles less than 0.5μ and sub-microscopic particles of gold were also suspected to be present. The gold particles, especially those in association with sulphide minerals were found to be small being in the order of 10 μ in diameter. Frequent localization of gold along cracks through older minerals "that apparently represent first-generation pyrite, arsenopyrite and pyrrhotite" is thought to indicate that the gold

mineralization is fairly young in age.

THE ORIGIN OF THE GOLD

According to Hall (1918) the likely source of the gold-bearing hydrothermal solutions was related to the "granites", by which he meant both the Kaap Valley and Nelspruit Granites.

Hearn (1945) suggested that for the most part the Kaap Valley Granite was responsible for the mineralization.

De Villiers (1967) regarded the gold deposits, however, as being formed during a single metallogenic epoch and as being genetically related to the Nelspruit Granite.

Most workers in recent years including Visser et. al. (1956), Ramsay (1963) and Viljoen (1964) have suggested that the fluids responsible for the introduction of gold were related to the intrusion of the Nelspruit Granite.

The Economic Geology Research Unit, Pretorius (1966), expresses the opinion that gold may well have been present in trace amounts in, and have been derived from ,the huge pile of basic lavas of the Lower and Middle Onverwacht Stages. On metamorphism of these lavas, the gold might have been mobilised and could have migrated upwards to be emplaced in suitable open fractures higher up. The intermediate lavas at the base of the Upper Onverwacht Stage and the porphyry bodies within the Middle Onverwacht sequence are the first competent rocks to be encountered higher in the succession and it is in the open fractures in these that the gold-bearing quartz veins were emplaced. It is concluded that the greater concentration of exploitable gold in the northern part of the Mountain Land is probably a function of the higher degree of thermal and dynamic metamorphism which the Onverwacht Series has suffered.

In Swaziland, members of the Geological Survey, Jones (1963) and Hunter (1965) express the opinion that gold mineralization is associated with the intrusion of the late-orogenic granites and is localized by

structural and lithological controls.

REASONS FOR AND PURPOSE OF THE PRESENT INVESTIGATION

The Hhohho area was selected for this present investigation since geologically it is intrinsically connected with the rest of the Barberton Mountain Land. A number of interesting features are present:-

i) Layered rocks of the Swaziland System come into immediate contact with intrusive granites.

ii) The Swaziland System rocks adjacent to these granites have been subjected to contact metamorphism.

iii) Gold mineralization is localized close to the granite contact at the Daisy and Gordon Mines and this feature may be of significance.

iv) Structurally the area is complex for not only have the Swaziland System rocks been tightly folded along northeast trending axes but warping and cross-folding along north-south and northwesterly directions has also occurred.

In the Barberton Mountain Land many workers have contributed valuable information, as summarized above, to the structural, stratigraphical and mineralization problems connected with the Archean rocks. It is the author's intention to describe and attempt to elucidate the following features in northwestern Swaziland where no detailed work has previously been undertaken:-

a) To describe the lithological characteristics of a wide variety of rocks occuring in the area.

b) To determine the probable origins of basic and talcose rocks lying in the immediate vicinity of the intrusive granites.

c) To establish the stratigraphical position of such basic and talcose rocks together with the sedimentary rocks

which are intercalated with them.

d) To sub-divide the area into various facies of contact metamorphism.

e) To determine the relationship of the intrusive granites with the layered Archean rocks and their age and time of intrusion.

f) To describe the various periods of deformation which have affected the area and their relationship to those stresses known to have occurred in parts of the Mountain Land.

g) To determine the relationship between such periods of deformation and the intrusion of the granites.

h) To establish the relationship between the intrusion of the granites and the metamorphism suffered by adjacent country rocks.

i) To describe the gold mineralization occurring in the Rhohho area and the reasons for its localization.

j) To establish the time of mineralization in relation to the phases of deformation and the possible origin of the gold bearing solutions.

k) To describe the mineralogy of the ore-body and its likely paragenesis.

WORK ACCOMPLISHED

With the aims described above in mind, detailed geological mapping was undertaken in the Rhohho area. Mapping was done directly on to aerial photographs enlarged to a scale of 1:10,000, the data derived then being re-plotted on 1:25000 scale topographical maps. The latter were prepared by the British Overseas Geological Survey from an aerial survey carried out in 1961. In the environs of the Daisy, Dawson and Jackal Mines a plane-table survey was prepared on a scale of 1:1000 since

nc accurate plans of the mined areas were in existence. The data derived from this survey was later reduced to a scale of 1:2000 for reasons of practicability.

Underground wokrings were also surveyed and examined and the geological information obtained was projected to surface to supplement outcrop mapping.

In 1962 and 1963 eighteen boreholes were sunk in the vicinity of the mines by the Geological Survey of Swaziland as part of a programme to determine the economic potentials of the mines. A total of 8710 feet of core from these boreholes was examined to determine the lithological character of both the ore-body and the host rocks. In addition borehole information was used to elucidate geological structures in the mines.

Furthermore, 121 thin sections were examined to determine the mineral constituents of the various rock types occurring in the area and polished sections of the ore-body were examined for information regarding its mineralogy and paragenesis.

ACKNOWLEDGEMENTS

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PART II

RESULTS OF THE PRESENT INVESTIGATION

GEOLOGICAL SETTING

The Mhohho area is underlain predominantly with rocks of the Swaziland System into which have been emplaced intrusive granites. The rocks of the Swaziland System can be sub-divided on a lithological basis into three distinct units. (Fig. 2 and Table 2)

Along the northern extremity of the area the heights of the Makonjwa Range are built by essentially arenaceous and rudaceous rocks typical of the uppermost member of the Swaziland System, namely, the Moodies Series. In accordance with opinions of members of the Geological Survey of Swaziland such as Orie (1956) and Hunter (1961) together with workers in the Barberton Mountain Land such as du Toit (1954) and Gribnitz (1961), the author, for reasons to be stated later, feels there is no justification to elevate the Moodies to the rank of a system.

Underlying the Moodies Series and confined to the foothills of the Makonjwa Range is a succession consisting primarily of shales and greywackes with intercalations of quartzites, conglomerates and secondary cherts. This succession was previously regarded as representing the Figtree Series in northwestern Swaziland, Lenz (1954-1955), Hunter (1961) Jones (1963). It is the author's contention, however, that, for reasons to be given later, these rocks should be more appropriately placed in the Onverwacht Series.

The low-lying ground intervening between the foothills of the Makonjwa Range and the contact of the intrusive granites to the southeast, is occupied by rocks which have been considerably altered due to the effects of contact metamorphism. The origin of these rocks, now represented by

a suite of basic rocks and talcose schists, is a debatable topic. Previous workers, such as Lenz (1954-1955) Hunter (1961) and Jones (1963b) regarded this assemblage of rocks to represent metamorphosed representatives of the Jamestown Complex. For reasons also to be stated later, the author maintains that these rocks should also be regarded as belonging to the Onverwacht Series.

The granites occurring along the southwestern margin of the area under discussion form the low-lying ground along the banks of the Lomati Valley. Both foliated and unfoliated varieties are present and an explanation for this variation will be put forward later. Only the margins of the granites were examined in this investigation.

Transecting both the rocks of the Swaziland System and the granites are dykes of basic composition following either an east-northeasterly direction or trending west of north. The significance of these directions will also be discussed.

Structurally it will be seen (Fig. 2) that the layered Archean rocks have been folded into a series of compact, large-scale folds along axes trending northeast-southwest. Such folds are preserved intact in the arenaceous and rudaceous rocks of the Moodies Series. In the less competent Onverwacht formations at the foothills of the Makonjwa Range the folds are frequently dislocated by extensive strike faulting. (Figures 2 and 3). The Onverwacht Series rocks lying within the metamorphic aureole of the granites have also been subjected to the same stresses but the outlines of the folds are not so apparent. This is attributable to the fact that the soft, incompetent character of the essentially basic assemblage did not lend itself readily to folding. Strike faulting also occurs in these metamorphosed rocks, but such faults are not readily located in the generally schistose basic and talcose rocks.

Three distinct facies of contact metamorphism related to the intrusion of the granites can be recognized (Fig. 4) :-

i) a hornblende-hornfels facies along the immediate contact.

ii) an albite-epidote-hornfels facies covering the central strip of the area.

iii) a greenschist facies varying in degree of intensity over the remainder of the area.

The effects of dynamic metamorphism are also apparent especially in the Onverwacht and Moodies Series rocks occupying the foothills of the Makonjwa Range. At this locality the formations have been subjected to intensive faulting and folding.

Gold mineralization is confined to the Gordon and Daisy Mines situated in the west-northwestern extremity of the area. Northeast of the Daisy Mine further underground workings known as the Jackal Mine represent an unsuccessful attempt to establish an extension of the Daisy ore-body. The gold mineralization in both the Daisy and Gordon Mines is confined to the same stratigraphical horizon in folded rocks of the Onverwacht Series at no great distance from the granites.

STRATIGRAPHY

INTRODUCTION

It is proposed to describe the rocks occurring in the area, not only petrologically, but also to give an account of their structural characteristics, degrees of metamorphism and possible origins. As previously mentioned, the Swaziland System in Mbohho contains three distinct lithological units, the uppermost of which has been placed in the Moodies Series and the two underlying units in the Onverwacht Series. Reasons for including the last-mentioned in the Onverwacht will be given after a detailed description of the various rocks in each unit has been given. Viljoen and Viljoen (1967) have sub-divided the Onverwacht Series in the Komati

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River area into upper, middle and lower stages. Similarly, the author proposes a sub-division of the Onverwacht Series at Mhohho into two parts or stages and will attempt to correlate them with the stratigraphical sequence established by Viljoen and Viljoen. As will be shown, the suite of basic rocks occurring adjacent to the granites are regarded by the author as being the oldest rocks in the Mhohho succession and a description of them will be given. This will be followed by an account of the uppermost part or stage of the Onverwacht Series, and then the rocks of the Moodies Series will be described.

Finally, the granites will be considered and mention made of the dyke intrusions, quartz veins, epidote veins and pegmatite veins.

THE SWAZILAND SYSTEM

As will be seen from Figure 2, by far the greater part of the area is underlain by rocks of the Swaziland System, but even so, the System is not fully represented due to a number of factors.

The full succession of the basic rocks and talcose schists constituting the lower part of the Onverwacht Series cannot be accounted for. Firstly, to the southeast, granites are intruded in a gently transgressive manner across this succession. Secondly, its relationship with the upper part of the Onverwacht Series is very largely a faulted one except immediately northeast and southwest of the middle reaches of the area where, for a distance of 7400 feet, it is overlain conformably by the upper part of the succession. Thirdly, the relationship of the Moodies Series with the Onverwacht Series is unconformable. In the southwestern portion of the area, the basal beds of the Moodies rest upon the upper part of the Onverwacht whereas near the northeastern margin, they rest upon basic rocks and schists of the lower part.

Similarly, the upper part of the Onverwacht cannot be accounted for fully. Intense folding and strike faulting makes it impossible to determine a definite stratigraphical succession. Its relationship with the underlying part of the series is very largely obscured by faulting except in

the southwestern part of the area as previously mentioned. The unconformable relationship of the overlying Malolotja Series also prevents the full succession from being exposed. The combined effects of this unconformity and the strike faulting is that the upper part of the Onverwacht Series occurs in a wedge that has its base in the southwest and its apex at the foot of Komhlabeni Peak on the northwestern boundary of the area.

The basic lavas occurring at the foot of Bearded Man Peak are also overlain unconformably by the Malolotja Series and their exact position in the Onverwacht succession cannot be ascertained, but for reasons to be stated, most likely belong to the lower stage.

The uppermost member of the Swaziland System, namely the Malolotja Series, is also not fully exposed in the present area due to the effects of erosion. A stratigraphical succession has been determined in the series and it is apparent that a number of intraformation unconformities occur. Table 2 summarizes the essential rock types characterizing the Swaziland System occurring in the area under investigation.

THE ONVERWACHT SERIES

It is proposed to describe the Onverwacht Series in two divisions, namely a lower stage and an upper stage. Each rock type of the stages will be described with regard to its distribution in the area, its petrological characteristics, structural features, grade of metamorphism and possible origin. When all the rock types have been thus described, a summary will be made and reasons given for including the succession in the Onverwacht Series.

THE LOWER STAGE OF THE ONVERWACHT SERIES

The distribution of rocks included in the lower stage is twofold. Firstly, a succession of essentially basic rocks and talcose schists with narrow intercalations which, lying adjacent to the granites, are thought to be the result

of thermal metamorphism. Secondly, a succession of comparatively unmetamorphosed basic lavas with interlayered sedimentary bands occurring within the core of an anticlinal arch at the foot of Bearded Man Peak. The succession comprising the so-called lower stage lying adjacent to the granites will be described first.

Basic Rocks and Talcose Schists Lying Within the Metamorphic Aureole of the Granites

The basic rocks and talcose schists lying adjacent to the granite may be conveniently divided into the following types:-

1) Dark-green hornblende amphibolites
2) Pale-green unfoliated amphibolites
3) Greenish-grey foliated amphibolites
4) Talc-amphibole schists
5) Talc-chlorite, talc-chlorite carbonate and talc- carbonate schists

1) The dark-green hornblende amphibolites.

Distribution: These hornblende bearing rocks are confined to the south-western extremity of the area (Fig. 2). Near that boundary they form a roughly wedge-shaped mass tapering to the northeast. At the base of this wedge, over a distance of some 1200 feet, the dark-green hornblende amphibolites are bounded by the main mass of the granites to the southeast and by a tongue of granite to the northwest. Followed northeastwards, however, pale-green unfoliated amphibolites intervene between the dark-green amphibolites and the granites.

Petrology: In appearance the hornblende amphibolites are dark-green to almost black in colour and somewhat granular and coarse-grained in texture. Being comparatively harder than other basic rocks of the Onverwacht Series in this locality, they are responsible for building a prominent hill in the

otherwise low-lying ground of the southwestern portion of the area. Thin sections of the dark-green amphibolites show their mineralogy to be simple, consisting almost entirely of amphibole and minor quantities of quartz (Plate 1). The amphibole, identifiable as hornblende, is moderately birefringent, pleochroic, with a colour range from pale green to dark green and with maximum extinction angles ($\gamma \wedge c$) varying between 15 degrees and 28 degrees. The quartz forms the matrix of the rock and occurs as a granular mosaic. Minor quantities of diopside may be present in amphibolites lying very close to the granite contact. Small quantities of plagioclase feldspar and epidote are also encountered, the former sometimes identifiable as andesine. Accessories include sphene, iron ores and zircon. The last-mentioned mineral is in the form of rounded grains and appears to be of detrital origin.

Structural Features: The main structural feature in the dark-green hornblende amphibolites is illustrated by the behaviour of the intercalated narrow siliceous horizons which appear to be banded meta-quartzite. They will be fully described in the section dealing with siliceous rocks of the lower stage of the Onverwacht Series. The meta-quartzite horizons seldom exceed five feet in thickness and may be traced for several hundreds of feet along strike. Their relationship to one another is remarkably regular and concordant. Also their contacts with the under and overlying amphibolites is sharp and appears to be a bedding contact. No structural features are apparent in the dark-green amphibolites themselves. The hornblende is haphazardly orientated but there is a tendency for the crystals to concentrate in irregular bands and clusters.

Grade of metamorphism: The amphibolites described above compare favourably with the definition given for amphibolites by Winkler (1965). He defines an amphibolite as a rock "consisting predominantly of hornblende and plagioclase which is produced by metamorphism of basaltic magmatic rocks, tuffs or marls". The mineral assemblage of the dark-green hornblende amphibolites together with their proximity to the contacts of intrusive granites leaves

little doubt that they represent a product of contact metamorphism. They can be conveniently placed in the hornblende-hornfels facies of Turner and Verhoogen (1960) or the amphibolite facies of Eskola (in Barth, Correns and Eskola, 1939), and Winkler (1965). Such assemblages are usually extensively developed, in contact aureoles and as xenoliths in granite or granodiorite. In the higher grades of metamorphism hornblende may be partly replaced by diopside as is the case with the dark-green amphibolites lying in close proximity to the contact. Ramberg (1952) maintains that the temperatures of the amphibolite facies rarely exceeds 400° - 500° Centigrade. Turner and Verhoogen (1960) are of the opinion that temperatures were higher than this and suggest that the hornblende-hornfels facies should be correlated with temperatures of 550° - 700° Centigrade in the water-pressure range of 1000 to 3000 bars. Winkler (1965) considers that the facies begins at 530° ($\pm$ 15°) Centigrade at 1000 bars or at 540° ($\pm$ 20°) Centigrade at 2000 bars.

Origin: Four alternative suggestions can be presented for the origin of the dark-green hornblende amphibolites, namely that they are metamorphic derivatives of: -

i) ultrabasic igneous rocks

ii) basic igneous rocks

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

iv) carbonate-bearing sedimentary rocks

The author is of the opinion that the dark-green hornblende amphibolites are derived from carbonate-bearing sediments for a number of reasons. The manner in which these amphibolites occur interbedded with quartzitic horizons would suggest a sedimentary origin. Furthermore, the quartzitic horizons themselves are distinctly banded consisting of alternating layers of siliceous and amphibolitic rock up to 0.5 inches thick. The amphibolitic layers are indistinguishable in character and mineralogy from the bulk of the dark-

green hornblende amphibolites and are considered, therefore, to be of the same origin. Also, as previously mentioned, hornblende tend to concentrate in clusters and irregular bands and there are roughly concordant with the quartzitic horizons and would support the contention that these amphibolites are of sedimentary rather than igneous origin. That the rocks are derived from carbonate bearing sediments is also supported by the mineral assemblage of a siliceous carbonate rock subjected to contact metamorphism and described by Winkler (1965) as follows:-

An-rich plagioclase + hornblende + diopside or anthoohyllite ± biotite ± muscovite

Such an assemblage compares favourable with that shown by the dark-green hornblende amphibolites of the Mohho area. Finally, the composition of such a rock is shown in rock type No. 1, Table 3, and it is noteworthy that the ratio CaO to MgO approximates that of dolomite. The presence of 10.97 per cent alumina, however, suggests, that the siliceous carbonate rock was somewhat argillaceous in character.

2) The pale-green unfoliated amphibolites

Distribution: (Fig 2) The pale-green unfoliated amphibolites lie along the contact of the granites from the Mgubudhla River in the southwest to the northeastern boundary of the area forming an aureole some 2,500 feet wide. They also occur as a tongue in talcose schists which extends northeastwards from the Mgubudhla River to the Mhlotshana River. Southwest of the Mgubudhla, the pale-green unfoliated amphibolites wrap around the wedge of dark-green hornblende amphibolites and intervene for short distances between these rocks and the tongue of granite to the northwest and the main mass of granites to the southeast. Only a sliver of the unfoliated amphibolites occurs along the northwesternmost contact of the granite gongue, the significance of which will be dealt with later. A number of small lens-shaped bodies of these amphibolites also occur scattered within

masses of talcose schists throughout the area.

Petrology: The pale-green unfoliated amphibolites occur as "blocky" outcrops which weather to a dull khaki colour. Petrologically, they consist of amphibole altered extensively to chlorite and minor quantities of fine-grained talc chlorite. The amphibole (tremolite or actinolite), occurs in a felted mass of ragged flakes and needles (Plate II). Orientation of crystals is haphazard, although very occasionally a crudely parallel alignment of the amphibole, may occur. The talc occasionally may be seen in association with tremolite.

Structural Features:- The pale-green unfoliated amphibolites are devoid of any structural features other than the occasional crude alignment of the amphibole crystals. Such alignment corresponds approximately with the principle cleavage direction of the area (viz N68^{o}E).

Grade of Metamorphism: The mineral assemblage described above has, as noted by Turner and Verhoogen (1960), much in common with that occurring in the greenschist facies of low grade metamorphism. The author, however, favours placing this assemblage in the albite-epidote-hornfels facies of Turner and Verhoogen (1960) or the epidote-amphibolite facies of Ramberg. (1952). A number of reasons can be given to support this contention. Reference to the distribution of the pale-green unfoliated amphibolites (Fig 2) will show that southwest of the Mgubudhla River they lie in contact with hornblende amphibolites. The latter have been regarded as belonging to the hornblende-hornfels facies for reasons previously stated. For the last-mentioned facies to have been brought into contact with the lower grade greenschist facies in this area could only have been effected by considerable faulting. There is, however, no field evidence of any faulting in the area in question. A more reasonable explanation is afforded by a description of greenschists by Ramberg (1952) who states: "Many talc rocks and soapstones, as well as even greenstones or 'greenschists' themselves, do not belong to the greenschist facies proper, in which they are too often placed,

but such rocks may develop an apparent greenschist mineral association because of their particular bulk chemical composition. The content of tremolite, anthophyllite (perhaps even pyroxene), and/or garnet with but small amounts of MnO may show the proper place in the facies scheme of such 'camouflaged' rocks."

The author believes that such a "camouflaging" can be applied to the unfoliated pale-green amphibolites of the Mhohho area and that they can rightfully be placed in the albite-epidote-hornfels facies. The fact that the amphibolites lie adjacent to the contact of the granite may either indicate that the "camouflaging" effect has been very marked or that retrogressive metamorphism has influenced these rocks. The last-mentioned possibility will be discussed more fully in the section dealing with metamorphism, but in either case it appears reasonable to include the assemblages described in the higher grade hornfels facies. Pressure - temperate conditions for the albite-epidote-hornfels facies begin, according to Winkler (1965) at slightly below 400°Centigrade at 2000 bars.

Origin: The origin of the pale-green unfoliated amphibolites is difficult to determine. Anhaeusser and Viljoen (1965) maintain that similar amphibolites in the Barberton-Noordkaap-Louw's Creek area of the Mountain Land represent less metamorphosed equivalents of dark hornblende-bearing contact amphibolites. They conclude that such rocks are of sedimentary origin being derived from formations close in composition to siliceous magnesian limestones. Anhaeusser and Viljoen do not exclude the possibility, however, that the tremolite-actinolite rocks could represent altered basic lavas.

In the Mhohho area, a number of features occur that suggest the pale-green unfoliated amphibolites are of entirely different composition to the hornblende amphibolites. In their investigation of metamorphic rocks in the Archean fold belt of Swaziland, Urie and the author (1963) show the chemical compositions of various rock types (Table 3).

It will be noted that the magnesia content in these amphibolites is

nigh and Urie and Jones (1965) have concluded that such rocks were derived from ultramafites. The absence of any structural features such as pronounc foliation or possible bedding would suggest that these rocks are not of sedimentary origin. The manner in which the unfoliated amphibolites are conformably aligned with chert and quartzitic bands would, however, indicate that they are interlayered members of the succession rather than intrusive bodies. Two possibilities can be put forward as to their origin:-

i) that they are layers of ultrabasic rocks

ii) that they represent lava flows of a basaltic or very basic nature.

No definite conclusion as to the origin of the unfoliated amphibolites can be made from field evidence alone since outcrops are scanty and badly weathered. It is possible that if more analyses were undertaken subtle variations of composition from very basic to ultrabasic would be revealed. It is suggested that the amphibolites being discussed were derived very largely from lavas of a very basic nature containing numerous layeres of ultra-basic composition. No evidence can, however, be produced to substantiate this contention.

3) The foliated green-grey amphibolites

Distribution: (Fig 2). The greenish-grey coloured amphibolites are particularly evident in the vicinity of the Daisy and Gordon Mines where they constitute the host rock to the gold mineralization. They occupy the core of a tight anticlinal fold with a northwesterly trending axis, which structure will be more fully described in a later section dealing with the localization of gold in the Hhohho area. The foliated amphibolites also occur extensively along the lower foothills of the Makonjwa Range from the easternmost tributary of the Ngubudhla River to the Transvaal border in the southeast. They occupy a strip with an average width of 2400 feet though it is likely that duplication has occurred as a result of strike faulting.

Between the easternmost tributary of the Mgubudhla River and the Mhlotshana the amphibolites under discussion are faulted against quartzites of the Moodies Series. From the Mhlotshana River to the Transvaal border they are directly overlain by the basal conglomerate of the Moodies Series and an unconformable relationship is apparent. The overall strike of the amphibolites is N73^{o}E whereas that of the Moodies Series is N82^{o}E.

Petrology: The foliated green-grey amphibolites are medium-grained and occur as subdued outcrops which when weathered, have a brownish-green colour. Fresh exposures and specimens from borehole cores show the rock to have a speckled appearance due to the presence of elongate felsic blebs. The characteristic amphibole belongs to the actinolite-tremolite group and occurs in both fibrous and elongate laths(Plate III).-The amphibole may be orientated either parallel to the cleavage in the rock or the orientation may be completely haphazard. In the latter case it would appear to be a later generation of amphibole profusely penetrating aligned minerals and cleavages planes. Weakly pleochroic hornblende is sometimes present as anhedral plates enclosed by the haphazardly orientated actinolite-tremolite. This relationship would seem to indicate that the alteration of hornblende to tremolite occurred either during contact metamorphism or when the subsequent amphibolitization took place. The latter process will be discussed later when dealing with the metamorphic influences of the intruded granites upon these rocks Quartz is present in a fine mosaic either as elongate blebs or in bands arranged conformably with the grain of the rock. The proportion of quartz may range from minor quantities to as much as 50 per cent. White-grey and blue quartz stringers are also present following the schistosity of the rocks but showing no evidence of deformation. There can be little doubt, therefore, that such vein quartz was introduced subsequent to the imposition of foliation. Minor quantities of plagioclase feldspar either anhedrally or sub-euhedrally developed have frequently been observed in thin sections of the foliated amphibolites. The plagioclase is seldom clear and invariably shows sericitization. Potassic

feldspar, normally clear anhedral microcline, is also present in small quantities. The possibility that feldspathization has occurred as a result of the intrusion of the granites will be discussed in a later section dealing with metamorphism. Carbonate is common and appears to replace the amphibole, the latter remaining as ragged cores in anhedral plates of the former. This phenomena is, again, to be considered in the section describing the metamorphic effects of the intrusive granites. Accessory minerals are sphene and tourmaline the former occurring as isolated individual euhedral crystals and the latter either as stubby crystals or as individual grains in impersistent veinlets. The pleochroism of the tourmaline ranges either from fawn to dark-brown or from pale blue to deep-blue.

Structural Features: The most pronounced structural feature of the amphibolites under discussion is their foliation which results in a banded appearance. Such banding is very largely emphasised by alternating layers of amphibolitic rock and felsic material, up to 0.25 inches in thickness. Schistosity parallel to the cleavage developed in the rock is apparent though it is frequently masked by a later generation of amphibole developing across it. Associated with the foliated amphibolites are numerous narrow bands of quartz-biotite, quartz-chlorite and quartz-sericite schists varying in thickness from a few inches up to eight feet. These bands lie parallel with the foliations in the amphibolites and their contacts with that rock are invariably clean and sharp. The various schists will be described fully in the section dealing with the more siliceous members of the lower stage of the Onverwacht Series in the area.

Grade of Metamorphism: The foliated amphibolites, like the dark-green amphibolites previously described, are characterized by the presence of hornblende. When compared with the dark-green amphibolites, however, it is apparent that the quantity of hornblende is reduced whereas the tremolite-actinolite content is correspondingly increased. The mineral assemblage of the foliated greenish-grey amphibolites qualifies it for inclusion in the albite-epidote hornfels facies of Turner and Verhoogen (1960) or the epidote-

amphibolite facies of Ramberg (1952). Referring to Winkler (1965), however, the assemblage could not be included in his albite-epidote-hornfels facies since the reaction

chlorite + tremolite + epidote + quartz $\rightleftharpoons$ hornblende

characterizes the beginning of the hornblende hornfels-facies. It is the author's contention, therefore, that the foliated amphibolites lie transitionally between the albite-epidote-hornfels facies and the hornblende-hornfels facies of Turner and Verhoogen (1960). The pressure-temperature conditions would therefore range between 1000 bars at 400° Centigrade and 1000 - 3000 bars at 550-700° Centigrade.

Origin: The green-grey foliated amphibolites display foliation and banding concordant with associated quartzitic, chert and siliceous schist horizons. Such banding suggests a bedding feature and would, therefore, seemingly indicate a sedimentary origin. Their mineral assemblage is what could be expected if siliceous limestones were subjected to contact metamorphism and it is the author's conclusion that they do, in fact, represent the less metamorphosed equivalents of the dark-green hornblende amphibolites previously described. (p 40).

There is a possibility that the amphibolites being discussed are metamorphic derivatives of basic lavas and that some of the siliceous bands, particularly those with abundant sericite, represent acid lavas. The bulk of the siliceous horizons, however, are quartzitic in character consisting of angular grains of clastic quartz and with pronounced banding. There can be little doubt that they are of sedimentary origin and their close relationship with the amphibolites would appear to be indicative of the fact that the latter are also sedimentary.

4 and 5) The talc-amphibole, talc-chlorite, talc-chlorite-carbonate and talc-carbonate schists

Distribution: The talcose schists form the outer rim of the metamorphic

aureole of the granites, though between the Mgubudhla and Mhlotshana River the schists form a northeast aligned tongue in pale-green unfoliated amphibolites. In the vicinity of the Daisy and Gordon mines talcose schists occupy the flanks of the Daisy anticline (Fig. 2 and 3) and sweep around the nose of the fold to occupy most of the area drained by the middle reaches of the Mgubudhla River. Between the last mentioned river and its easternmost tributary, the talcose schists are faulted against Woodies Series quartzites to the northwest, though followed southwestwards they lie conformably below rocks regarded as the upper stage of the Onverwacht Series. In this area too, the talcose schists are in direct contact with the granites and this relationship will be discussed when dealing with the metamorphic effects of these granites. It will be noted (Fig 2) that a number of lens-shaped bodies of talcose schists occur within the upper stage of the Onverwacht Series. The largest of these lenses, occurring along the foothills of the Makonjwa Range on the western flank of the Mhlotshana River, measures 1400 feet on its long axis and 460 feet at its widest point. The possible origin of schists forming these lenses will be discussed in the appropriate forecoming section.

Petrology: The talc-amphibole, talc-chlorite, talc-chlorite carbonate and talc-carbonate schists seldom give rise to topographical features because of their inherent softness. Being chemically resistent to weathering, however, they yield meagre soil and are suprisingly well exposed. Outcrops are characterized by a dirty-cream colour and a marked schistose appearance.

The essential constituents of the talc-amphibole schists are talc and tremolite-actinolite. The foremost mentioned mineral develops as a confused aggregate frequently consuming and ultimately pseudomorphosely replacing the amphibole. The amphibole, tremolite-actinolite, occurs in slender laths some of which are crudely aligned and other completely haphazard in their orientation. Carbonate may be present in fair abundance and is sometimes seen embaying and enclosing the amphibole laths indicati-

that it is the youngest mineral of the assemblage.

The division between the talc-chlorite, talc-chlorite-carbonate and the talc-carbonate schists is arbitary depending upon the abundance or absence of the respective mineral constituents. In the talc-chlorite schists there is no amphibole present, in contrast to the talc-amphibole schists previously described, and there is no evidence of it having been present even in the form of pseudomorphs. Talc is again present in confused frond-like aggregates and chlorite occurs in wispy ribbons and flakes or in the form of knots and patches parallel to the cleavage in the rock.

In the talc-chlorite-carbonate schists talc is the preponderant mineral occurring in a mesh of minute shreds. Orientation of the shreds is rare despite the schistose and cleaved nature of these rocks. Parallelism, when present, is generally a feature inherited from the chlorite arranged either as slender wisps or flakes or in clusters and irregular sub-parallel ribbons. Carbonate, in both the talc-chlorite-carbonate and talc-carbonate schists occurs both interstitially to the talc and as large anhedral crystals. Compared to the talc-chlorite-carbonate schists, the chlorite content of the talc-carbonate schists is reduced whereas the carbonate is more abundant. In the latter schists weathering out of this carbonate imparts a pock-marked appearance to surface out-crops. Iron ore is a common accessory which is sometimes disseminated within the carbonate.

Structural Features: The talcose schists have schistosity and cleavage imposed upon them, the latter frequently transecting or obliterating the schistosity, and are mildly lineated. This lineation, which dips generally in an east-southeasterly direction, is emphasised to a certain extent by mineral elongation. The cleavage generally conforms to the regional pattern direction of N68^{o}E though instances have been noted where locally developed cleavage parallel to minor faults occurs and which is oblique to the regional cleavage. No minor folds have been observed in the talcose schists but it has been noted that in areas where major folding has

occurred the schistosity frequently conforms with the bedding of the folded strata especially at the nose of the fold. It is considered possible that the schistosity in such instances is the result of concentric shearing related to the early stages of the formation of the fold. Cleavage, parallel to the axial plane of the fold, transects and even obliterates the earlier schistosity.

As was previously mentioned, talcose schists also occur in lens-shaped bodies near major faults. Since their long axes are invariably parallel with the strike of such faults it is considered that they are intrusive in character as a result of re-mobilization of pre-existing magma due to tectonic influences. The emplacement of these intrusions is remarkably selective being generally confined to argillaceous horizons. Their contacts with the argillaceous rocks is normally sharp and with a marked absence of high temperature minerals. Cleavage is developed conforming with the direction and dip of the fault planes.

Grade of Metamorphism: The mineral assemblages of the rocks described can be placed in the greenschist facies as described by Turner and Verhoogen (1960). The facies is characterized by an abundance of low temperature hydrous minerals such as micas and chlorites and by the absence of garnets (except spessartite), pyroxenes and aluminous amphiboles. The amphibolites of the albite-epidote amphibolite facies merge into the greenschists of the greenschists facies as aluminous hornblende gives way to actinolitic amphibole and as chlorite becomes increasingly abundant. Within the greenschist facies itself there is a tendency for actinolitic schists to pass over into chloritic schists with the amphibole diminishing. It will be noted that Turner and Verhoogen (1960) allow actinolite in the upper part of their greenschist facies so that their definition is of a somewhat higher grade of metamorphism than either Eskola's (in Barth, Correns and Eskola 1939), or Ramberg's (1952) concepts.

Origin: The talcose schists could have been derived from three possible origins as a result of low grade metamorphism:

i) That they were derived from dolomitic rocks;

ii) That their origin was from ultrabasic intrusive rocks;

iii) That they were derived as a result of the alteration of basic lavas.

Tilley (1948) has discussed the earlier stages in the metamorphism of siliceous dolomites and submitted a definite sequence. The production of talc and tremolite in the outer aureole is ascribed to a series of reactions involving increased de-carbonation. Talc is considered to be the first new formed phase and its formation results from the reaction between dolomite and quartz. Viljoen and Annhaeusser (1965) contend that the carbonate-bearing talc and chlorite-bearing schists occurring in the Barberton-Noordkaap-Louw's Creek area were formed under the conditions described by Tilley and that such schists stemmed from siliceous dolomites. The possibility is not excluded, however, that some of the purer talc-carbonate schists were derived from either "basic igneous bodies" or from "original serpentized ultrabasic rocks".

According to Turner and Verhoogen (1960) it is possible for talcose schists to be formed from ultrabasic rocks if they have been submitted to carbon-dioxide metasomatism. Hess (in Turner and Verhoogen 1960) maintains that steatization or the hydrothermal alteration of an ultrabasic rock may lead to a talcose end-product. This may be accomplished by the simple addition of silica and, in some cases, water to serpentized peridotites. Furthermore, if carbon-dioxide metasomatism is also involved dolomite or magnesite might occur as constituent phases of the end-product. Steatization is considered to be a hydrothermal process connected with the intrusion of a granite magma and it is possible, as will be discussed later, that such a process could have occurred in the Mhohho area as a result of the intrusion of the granites. Certainly, the compositions of many talcose schists approximates those of ultrabasic rocks. Urie and Jones (1965) have shown that the compositions of some of the schists of the Archean fold belt of northwestern Swaziland approximate those of ultramafit

as shown in Table 4.

A partial analysis of two talc-carbonate schists is also given in Table 5 and their chemical affinity to the ultramafic group of rocks is obvious. The talcose schists in the Mhohho area, however, tend to be concordant with the siliceous horizons (cherts) and with the exception of the lens-shaped bodies along fault planes, there is no evidence to suggest that the schists represent steatized intrusive ultrabasic rocks.

The third possibility exists that the talcose schists are the metamorphic derivatives of basic lavas. The author contends that the bulk of the talcose schists are the equivalents of the pale-green unfoliated amphibolites (previously described) at a lower grade of metamorphism. The contacts between the last-mentioned amphibolites and the talcose schists are gradational which would lend support to this conclusion. Elsewhere in northwestern Swaziland, the author has observed talcose rocks which pass along strike into pale-green amphibolites which in turn grade, in undisturbed areas, to basic lavas with prominent pillow structures. The possibility however, that some of the purer carbonate-bearing talcose schists are derived from ultrabasic rocks cannot be overlooked as shown in Table 5. The absence of amphiboles in the talc-chlorite schists even as pseudomorphs may well indicate inherent differences of composition and it is credible that ultrabasic bands could have been present in the main mass of basic lavas prior to metamorphism.

Siliceous Horizons Lying within the Metamorphic Aureole of the Granites

Intercalated within the suite of basic rocks and talcose schists previously described are more siliceous and comparatively narrow horizons. Typical of these siliceous rocks are quartz-biotite schists, quartz-chlorite schists, quartz-sericite schists, quartzitic rocks and cherts.

i) The quartz-biotite schists

Distribution: The quartz-biotite schists are not extensive in distribution and are confined to the Daisy and Gordon mines where they have been

observed in underground workings and borehole cores. These schists occur as narrow bands within the foliated greenish-grey amphibolites which have been previously described. It is likely that quartz-biotite schists occur elsewhere in the Mhohho area in association with other occurrences of foliated amphibolites. Both these rock types weather readily, however, and are not easily distinguishable in the field.

Petrology: The quartz-biotite schists are medium-grained, brown in colour and with a well foliated appearance. In thin sections they are seen to consist of a granular mosaic of quartz and ragged flakes of biotite, the latter being strongly pleochroic ranging from pale-brown to reddish-brown (Plate IV). Carbonate, as ill-formed crystals with polysynthetic twinning, occurs literally throughout. Accessory minerals include grains of sphene, clinozoite and tourmaline. Veins of blue coloured quartz and carbonate frequently impregnate cleavage planes and emphasise the schistosity of the rock.

Structural features: The quartz-biotite schists occur as well-defined bands, ranging in thickness from a few inches up to eight feet, in the foliated greenish-grey amphibolites. Such bands have a conformable relationship with each other, neither diverging or coalescing. The biotite flakes in the schists show a marked inclination to be orientated within the planes of the foliation thereby emphasising the fabric of the rock.

Grade of Metamorphism: Since the quartz-biotite schists are intimately associated with foliated amphibolites, then like those last mentioned rocks they too are placed within the albite-epidote-hornfels facies of Turner and Verhoogen (1960) and Winkler (1965). Reasons for placing the amphibolites in this facies have already been given (p. 48).

Origin: The manner in which the schists under discussion are intercalated with foliated greenish-grey amphibolites and their very sharp contacts with the last mentioned rocks would suggest that they are of sedimentary origin. As previously stated, it is the author's opinion that the foliated greenish-

grey amphibolites represent metamorphosed carbonate rocks possibly resembling siliceous dolomites. It seems a reasonable assumption that the quartz-biotite schists are the metamorphic derivatives of impure arenaceous bands intercalated with such rocks. As Harker (1960) shows quartz grains in an impure grit subjected to thermal metamorphism are re-crystallized to form a mosaic, whilst the sericite, chlorite and limonite present may give rise to biotite. The mineral assemblage of the quartz-biotite schists under discussion complies with that described by Harker and could be considered as support of their suggested origin.

2) The quartz-chlorite schists

Distribution: The quartz-chlorite schists occur as distinct bands intervening in the greenish-grey foliated amphibolites. The most prominent quartz-chlorite schist occurs in the Daisy Mine where it forms the footwall of the ore zone (Figs 2 and 3), as will be shown when dealing with the geological features of that mine.

Petrology: The quartz-chlorite schists are fine-grained, light-green in colour and occur as hard, slabby outcrops. They comprise essentially of quartz and chlorite with varying quantities of mica and carbonate. Examination under the microscope reveals that the bulk of the quartz is present as clastic grains though coarse crystalline quartz in lenses, bands or veinlets may also be encountered. The last-mentioned quartz may either follow cleavage planes within the quartz-chlorite schists or cut across them and is obviously of a later generation than the clastic quartz. Pale-green to green chlorite occurs either in small irregular laths or elongate wisps. Occasionally chlorite flakes cluster in lenticular masses so that the schists take on a flecked appearance. The micas include sericite, biotite and muscovite, the last two mentioned in minor quantities only. The biotite occurs as ragged flakes forming the outer rim of the chlorite crystals. Flamberg (1952) points out that chlorite is often altered into biotite as a result of even low degrees of metamorphism.

Since chlorite does not contain the potassium necessary to transform it into biotite, biotitization of chlorite is only possible by the reaction with some potash-bearing minerals like muscovite or potash feldspar. Rambery considers a possible reaction between muscovite and chlorite as follows:-

$$2KAl_3Si_3O_{10}(OH)_2 + 3/3\,(Mg,Fe)_6Si_4O_{10}(OH)_8 \rightleftharpoons$$

muscovite chlorite(a)

$$2K(Mg,Fe)_3AlSi_3O_{10}(OH)_2 + (Mg,Fe)_4Al_4Si_2O_{10}(OH)_8 + \frac{14}{3}SiO_2 + \frac{8}{3}H_2O$$

biotite chlorite(b)

In the above reaction the right hand side, with biotite and the alumina rich chlorite, is the stable assemblage at high temperatures. Muscovite occurs as large flakes usually in association with the more crystalline quartz. Regular crystals of carbonate, represented by calcite, dolomite and ferrous carbonate, may locally constitute up to 30 per cent of the rock and in such circumstances they can justifiably be regarded as a quartz-chlorite-carbonate schist.

Structural Features:- The quartz-chlorite schists, which may occur in bands up to 20 feet thick, are associated with the foliated greenish-grey amphibolites. Their contacts with the latter rocks are invariably sharp and well-defined and the bands themselves are concordant with the chert and other siliceous horizons in the succession. The mineral constituents of the schists are commonly orientated parallel to the planes of the principal cleavage of the area (viz, N.8°E). Minor folds are sometimes preserved and folds of both similar habit with northeast trending axes and modified concentric folding around north-south and northwest striking axes have been observed. The axial planes of the similar habit folds are transected by the east-northeast striking cleavage, whereas the cleavage is buckled and bent by the north-south and northwest trending folds. The significance of these relationships will be discussed more fully in the

section dealing with the structural geology of the Hhohho area.

Grade of Metamorphism: The quartz-chlorite schists occur as intercalations within the greenish-grey foliated amphibolites which, for reasons previously stated, are included in the albite-epidote-hornfels facies of Turner and Verhoogen (1960) or the epidote-amphibole facies of Ramberg(1952). Due to their close association with such amphibolites the quartz-chlorite schist are considered as belonging to the same facies.

Origin: The schists being described show a sharp relationship with the foliated amphibolites and are concordant with chert bands and other siliceous horizons in the succession. It is concluded that the quartz-chlorite schists are probably of sedimentary origin being derived from impure arenaceous rocks as envisaged by Harker (1960) and therefore, have similarities to the quartz-biotite schists previously described.

3) The quartz-sericite schists

Distribution: The distribution of quartz-sericite schists in the Lower Stage of the Onverwacht Series is not extensive. They are mainly confined to the area lying between the easternmost tributary of the Mbongosi River and the Transvaal border (Fig.2). In this area the schists overlie the so-called Onisy Bar, (to be defined and described later) and attain an average thickness of some 25 feet, though they show a tendency to become gradually thinner traced southwestwards so that they are absent in the vicinity of the Onisy Line. Narrow bands of quartz-sericite schists are also associated with greywackes and quartzitic bands in the vicinity of the Nsulitshe River but since they seldom exceed 6 feet in thickness, it has not been possible to show them in the accompanying geological map of the Hhohho area. (Fig. 2)

Petrology: The quartz-sericite schists occur in off-white to pale-fawn coloured outcrops with marked schistosity. Mineralogically they consist

of a finely granular quartz matrix and prolific quantities of interstitial sericite. The latter mineral occurs in minute needles orientated parallel to and emphasising the schistosity of the rock. Not infrequently some of the quartz-sericite schists take on a fawn colour and are characterized by a knotted appearance. The "knots" are formed by anhedral crystals of andalusite up to 0.25 inches in diameter, which are commonly replaced by quartz. Small needles of rutile have been observed in association with the quartz. When andalusite and/or quartz "knots" are present, the sericite in the ground-mass tends to follow the outlines of the knots in a wavy fashion. It appears that the "knots" controlled the orientation of needle growth and were, therefore, earlier than the sericite in age.

Structural Features: The contacts between the quartz-sericite schists with the underlying Daisy Bar and the overlying foliated amphibolites northeast of the Mbongosi River is sharp and clean. In the Nsulitshe area the quartz-sericite schists interculated with greywackes and quartzitic bands are also defined with sharp contact conformable to those last mentioned rocks. Crenulate folding has been observed in the quartz-sericite schists in the Nsulitshe area. The axial planes of the folds are aligned at 013°E, dipping at 77 degrees to the east, whilst the plunge of the folds is southwards at 43 degrees.

Grade of Metamorphism: The quartz-sericite schists in the Mbongosi River area are immediately overlain by greenish-grey foliated amphibolites which have been considered by the author (p4) to belong to the albite-epidote-amphibole facies of Turner and Verhoogen (1960) or the epidote-amphibole facies of Ramberg (1952). The quartz-sericite schists described above are thus included in the same facies. The presence of andalusite in some of these schists, however, adds complications. Turner and Verhoogen (1951) regard andalusite as a characteristic mineral of the higher grade pyroxene-hornfels facies and Ramberg (1952) maintains the mineral to be stable at high temperature and low pressure. Winkler (1965) however, allows andalusite in the highest temperature part of his albite-epidote hornfels facies

In view of Winkler's conclusion and the association of the quartz-sericite schists with foliated amphibolites, they too are considered by the author to belong to the albite-epidote-hornfels facies.

In the Usuli/Shebe River area, the quartz-sericite schists occurring intercalated with greywackes and quartzitic rocks are flanked by foliated amphibolites and are, in consequence, again placed in the same facies.

The effects of dynamic metamorphism cannot be overlooked and it is possible that the sericite in some of the quartz-sericite schists was derived from the breakdown of feldspar during strong shearing.

Origin: It is a possibility that the schists containing primarily quartz and sericite could represent lavas of acid composition. The author has observed many quartz-sericite horizons in other parts of the Archean fold belt of Swaziland which grade laterally into lava flows with well-developed pillow structures. Conversely, other quartz-sericite schist horizons contain rounded pebbles of quartzitic rock or angular chips of quartz and undoubtedly represent the metamorphic derivatives of what were originally feldspathic sediments or greywackes. The quartz-sericite schists observed in the Lower Stage of the Onverwacht Series display no definite structural features such as pillows or clastic grains by which a definite diagnosis of their origin can be made. Their close association with the foliated greenish-grey amphibolites and quartzitic and chert horizons could well be indicative of a sedimentary origin. It is suggested that the quartz-sericite schists represent metamorphosed feldspathic shales or fine-grained greywackes intercalated in a succession composed preponderantly of siliceous limestones. The presence of andalusite in association with quartz and sericite in the schists presents an assemblage bearing a close resemblance to the mineral assemblage described by Winkler (1965) for metamorphosed shales poor in potash but rich in alumina. Such metamorphosed shales contain andalusite and muscovite with or without cordierite and plagioclase and are included by Winkler in the hornblende-hornfels facies or the upper part of the albite-epidote hornfels facies.

4) The Quartzitic and Chert Horizons

Distribution: Intercalated within the succession of the Lower Stage of the Onverwacht Series so far described are a number of narrow bands of quartzitic rocks and primary and secondary cherts. Such essentially siliceous rocks are associated with the dark-green hornblende amphibolites and greenish-grey foliated amphibolites though they may also, as in the vicinity of the Ngubudhla River, occur with talcose schists. Although the cherts and quartzites are relatively minor members of the succession they are, nevertheless, prominent since they are harder than the main mass of the succession and are responsible for the whale-back shaped ridges which are a feature of the area's topography. The quartzitic and chert bands constitute useful marker horizons for elucidating fault and fold structures in the Lower Stage of the Onverwacht Series.

Petrology: In colour the quartzitic bands are generally grey or greyish-brown but frequently a greenish tinge may be imparted due to the presence of chrome muscovite. The quartzites generally consist of irregular quartz grains occurring as bands of coarse and fine textured material. Sericite is invariably present in minor quantities, though zones may occur which are richer in this mineral. Mica sometimes occurs as large flakes in felted clusters of the sericite. Some quartzite horizons are characterized by a well defined banding due to alternating layers of quartzite and re-crystallized shaly material up to 0.25 inches thick.

The cherts, varying in thickness from a few inches to tens of feet, range in colour from pale grey to almost black. Both massive and banded types are common, the latter due to alternating layers of white-grey and black chert up to three inches thick. This banding may either be remarkably consistent over hundreds of feet or rapidly anastomosing over a few yards Microscopically the cherts are seen to consist almost entirely of quartz in a fine interlocking mosaic though minor quantities of sericite may be present interstitially. Some of the pale-coloured cherts, if containing chrome muscovite, may take on a pale-green tinge.

Observations in the field reveal that many cherts pass laterally into quartzites, grits or, less frequently, siliceous slates and shales. A distinction is drawn on the accompanying geological map (Fig. 2), therefore, between primary cherts and those of secondary origin. A banded quartzite with paper thin shaly partings was studied along its strike to the point where it resembles a chert. It was seen in thin sections that in the initial stage shearing had occurred in the quartzite along the shaly partings with the the development of sericite parallel to the shear direction (Plate V). Coinciding with this shearing the clastic quartz grains in the quartzitic layers show a tendency to be re-orientated and elongated so that their long axes lie parallel to the shear direction. In the next stage (PlateVI) re-crystallization of the clastic grains was noted so that they become an interlocking mosaic frequently displaying strain extinction. The granular texture of the quartzite is, however, still faintly evident. The sericite content is reduced though slender needles orientated parallel to the shear direction are still apparent. Surface outcrops of the rock at this stage bear a superficial resemblance to chert except that the rock is comparatively brittle and fractures into slaty slivers when broken. Finally, complete re-silicification has occurred and the rock resembles a chert proper (Plate VII) consisting of a microcrystalline mosaic of quartz with occasional needles of sericite present on and aligned parallel to the shear planes. The rock is now hard and fractures conchoidally.

Instances are known where renewed and more intense shearing upon both primary and secondary cherts results in brecciation. A pseudo-conglomerate is produced in which ellipsoidal shaped chert fragments are set in a re-crystallized siliceous matrix. The sub-rounded form of the fragments is attributable to "rolling" as a result of intense shearing. As might be expected the process for forming the secondary cherts and pseudo-conglomerates is frequently accompanied by acute mylonitization.

Structural Features: As shown, the rocks described have suffered intense shearing which is emphasised by the orientation of the sericite and the

re-orientation of clastic grains and eventual re-crystallization. In the case of many of the siliceous rocks the formation of sericite could well be due to the breakdown of any original feldspar constituent during the period of shearing. The quartzitic and cherty rocks are often intensely folded, the contortions being emphasised by banding in the rock. Due to their hard and compact nature, however, it is difficult to measure the attitudes of these folds as it is rarely that a three-dimensional view can be obtained The well-aligned sericite flakes in many such folded rocks are bent and broken suggesting they have been subjected to post-crystalline deformation.

Grades of Metamorphism: Banded quartzites occur in association with dark-green hornblende amphibolites near the granite contact at the southwestern extremity of the area. They are made up of alternating layers of pure quartzite and amphibolite up to 0.25 inches thick. The siliceous layers consist entirely of quartz grains and interstitial sericite and this rock has a sugary texture due to the effects of re-crystallization. The amphibolitic layers are similar in composition to the bulk of the adjacent amphibolites with hornblende constituting the main amphibole. These features together with their close association with the amphibolites warrants their inclusion into the hornblende-hornfels facies of Turner and Verhoogen (1960) or Winkler (1965).

The cherts and quartzites occurring with greenish-gray foliated amphibolites are, like those amphibolites, included in the albite-epidote-hornfels facies. Similarly the less frequent quartzitic and chert bands found within the unfoliated pale-green amphibolites or the talcose schists are regarded as belonging to the albite-epidote-hornfels facies or greenschist facies respectively.

The metamorphic grade of many of the quartzitic and chert horizons, especially secondary cherts, is obscured since mechanical processes have contributed to their creation. Consequently, the effects of dynamic metamorphism are more pronounced than those of contact metamorphism resulting from the emplacement of the granites.

Origin: As previously mentioned the sericite present in the quartzitic rocks and some of the cherts is thought to have formed due to the breakdown of feldspar as a result of dynamic metamorphism. The possibility exists, however, that some of the sericite may also have been formed from normal contact metamorphism. In either case the rocks could have contained feldspathic material and two possible origins can be considered. The unbanded quartzitic and chert horizons associated with the unfoliated amphibolites and some of the talcose schists could represent acid lava flows that have undergone re-crystallization and even re-silification in some cases. The origin of the quartzites with banding developed does, however, seem more positive since such banding is more likely to be a sedimentary feature. Similarly, it is the author's opinion that many of the banded cherts occurring through the Mahho area were, in fact, originally banded quartzites which have suffered re-crystallization by the processes of dynamic metamorphism previously described for the formation of secondary cherts.

In the case of the primary cherts it is envisaged that they were formed under quieter periods in the depository when chemical precipitation was possible. It is not unlikely that the depository flow was enriched by silica as a result of the extrusion of lava flows enabling such precipitation to take place in the form of chert layers.

Basic Rocks Lying in the Bearded Man Peak Area

The Basic Rocks

The basic rocks to be described are [illegible] the core of the Mooiplaas Anticline (Fig. 2 [illegible] 3) and are direct[illegible]lain by arenaceous rocks of the Moodies Series. Metamorphism of these basic rocks is less severe than that imposed upon the Onverwacht assemblage lying within the contact aureole of the granites.

Distribution: The basic rocks occupy the softly undulating valley, named Mooiplaas Valley, at the foot of Bearded Man Peak. On the eastern flank of

the peak they sweep northeastwards to cross over the border into the Transvaal. Traced east-northeast from the Mgubudhla River the basic rocks form a narrow tongue occupying the core of an anticlinal fold the limbs of which are constituted by arenaceous rocks of the Moodies Series. West-southwest of the Mgubudhla River they wrap themselves around the arenaceous and rudaceous rocks of the Moodies Series which lie in the core of the Mooiplaas Syncline (Figs 2 & 3). The contact to the northwest with the Moodies rocks, which build Bearded Man Peak, is a faulted one, the basic rocks of the Onverwacht Series being brought directly against Moodies quartzites by the action of the Bearded Man Fault. (Figs 2 & 3).

Petrology: The basic rocks in the Bearded Man Peak area are greenish-grey in colour and occur in sharp, serrated, "shark's tooth" type outcrops. Microscopic examination shows them to consist of a microcrystalline plexus of plagioclase feldspar and pale-green amphibole (possibly actinolite) extensively altered to chlorite. The plagioclase laths are usually turbid and sericitized but may be occasionally identified as andesine. The groundmass is made up of sodic feldspar and yellow-coloured palagonite. Accessory minerals include magnetite, allanite, epidote and occasionally carbonate. The greater proportion of the basic rocks is amygdaloidal, the amygdales being made up of quartz, zeolites, epidote and carbonate. Much of the last mentioned mineral is ferrous. Where weathering has removed the amygdales surface outcrops have a distinctive pock-marked appearance.

Structural Features: The basic rocks, as previously mentioned, occur in the core of an anticlinal arch formed by the effects of later phases of deformation (see later). The primary structure is the Mooiplaas Anticline (Fig 3) with accompanying satellite folds (e.g. the Mooiplaas Syncline and Barnside Antincline) the axial traces of which strike northeastwards. Cleavage is developed along a east-northeasterly direction and it has been noted that amygdales in the rocks may be elongated within the planes of this cleavage.

Grade of Metamorphism: The basic rocks described above occur nearly two miles from the nearest known occurrence of granite. The degree of metamorphism they have suffered is considerably less than that suffered by the basic assemblage near the granites' contact. The alteration of actinolitic amphibole to chlorite is typical even in the lowest limit of the greenschist facies and in consequence it is in this facies that these rocks are placed. The presence of epidote and zeolites in the amygdales is considered to be the latest product of crystallization in the magma as will be shown later.

Origin: The basic rocks described contain two intercalated, narrow horizons consisting of greywackes, shales and mudstones (Fig.2). These horizons will be described in a later section. The contact of the basic rocks described with these horizons is sharp and characterized by an increasing fineness of grain and a relative increase in the incidence of amygdales. Furthermore, the contacts of the basic rocks consistently follows the folded disposition of the sedimentary horizons. It is concluded, therefore, that the basic rocks in the Bearded Man Peak area are layered basic lava flows; a conclusion substantiated by their mineral assemblage and amygdaloid character. Harker (1950) maintains that the minerals of epidote, chlorites, chalcedony and zeolites are typical occurrences within the steam vesicles of amygdaloidal basalt and represent the latest products of mineralization from the magma rather than being of secondary origin.

Siliceous and Argillaceous Horizons occurring in the Vicinity of Bearded Man Peak

The Greywackes, Shales and Mudstones

Distribution: Associated with the basic rocks described above are narrow horizons of greywacke, shales and mudstones forming two distinct horizons (Fig 2). Occurring in the Mooiplaas Valley these horizons strike in a sinuous manner due to the arching of the Mooiplaas Anticline by later phases of folding (see later).

Petrology: The individual bands of greywacke, shale and mudstone seldom attain any great thickness and at maximum are about 8 feet thick. The relationship between the various rock types is gradational, but in turn their contact with the basic rocks is clean cut.

The greywackes are fairly coarse-grained and with a dark-grey colour. They are made up of angular fragments of chert, quartz and sericitized feldspar set in a matrix of quartz, chlorite and clay minerals. Due to the degree of sericitization it has not been possible to determine the composition of the feldspar. When the incidence of chlorite fragments is high, the greywackes take on a dull, greenish-grey colour.

The shales are not prominently exposed due to their inherent softness. They are well laminated and brown to greenish-grey in colour. Examination of thin sections shows the shales to consist of quartz and sericite together with chlorite and clay minerals.

The mudstones outcrop in the form of slabs or pavestones with a sombre greenish-grey colour. Narrow gritty bands frequently give these rocks a somewhat streaky appearance, though compared with the shales there is no pronounced lamination. Thin sections show that the mudstones consist of a fine-grained siliceous matrix with chlorite grains and a high percentage of unidentifiable clay minerals.

Structural Features: The greywackes, shales and mudstone emphasise the folded disposition of the otherwise homogenous basic assemblage of the Lower Stage of the Onverwacht Series in the Mooiplaas Valley. The individual bands are remarkably conformable with one another though one horizon of mudstone pinches out on the northwestern flank of the Barnside Anticline (Fig 2 and 3). Immediately at the foot of Bearded Man Peak, the bands of greywacke, shale and mudstone lie against quartzites of the Moodies Series due to the action of the Bearded Man Fault and in this vicinity cleavage parallel to the fault direction is occasionally developed. In the Mooiplaas Anticline the sedimentary horizons under discussion are absent on the immediate banks of the Mgubudhla River since they are overlain unconformably

by the basal conglomerate of the Moodies Series. Along the north-north-western flank of the Kooiplaas Anticline the unconformable relationship of the overlying Moodies Series is also apparent. Greywacke lies in direct contact with the Moodies quartzites at this locality whereas on the south-southeastern flank of the same fold, the sedimentary horizons are absent. Where cleavage following an east-northeast direction has been imposed on the greywackes it is noticeable that the feldspar grains become sericitized until shredded clusters of sericite are found aligned parallel to the cleavage planes. Also clastic grains of quartz are re-orientated and elongated so that they are contained in the planes of cleavage. On the eastern side of the Mgubudhla River the stresses which gave rise to the Mgubudhla Anticline, which is aligned in a northwesterly direction (Fig 2 & 3), have domed pre-existing structures. (see later) Minor folds corresponding to the northwesterly trace of the main fold fold the earlier cleavage so that the sericite contained in the last mentioned cleavage is frequently bent and fractured.

The effects of tectonic stress on the shales and mudstones is not easily assessed. With cleavage development they become extremely friable and susceptible to weathering so that they decompose rapidly.

Grade of Metamorphism: The greywackes, shales and mudstones occur in association with basic rocks which, for reasons already stated, have been included in the lowest part of the greenschist facies of metamorphism. Consequently, the associated intercalations are included in the same facies.

Origins: The manner in which the intercalations described above are disposed in layers conformably with one another together with their sharp contacts with the basic rocks would seem to indicate bedding features. It is considered that sedimentary rocks were laid down during periods of quiesence between outpourings of basic lava. The mineral content of the sedimentary intercalations (e.g. chlorite, feldspar and quartz) could have been derived, in part, from erosion of already existing basic lavas.

THE UPPER STAGE OF THE ONVERWACHT SERIES

Succeeding the assemblage of essentially basic rocks constituting the so-called Lower Stage of the Onverwacht Series occurs a succession consisting of shales, quartz-sericite schists, greywackes, quartzites, narrow conglomerate bands and primary and secondary cherts. This assemblage of rock occurs in a comparatively rhythmically banded fashion with a complete absence of basic rocks. Previous workers in the area such as Z (1954 - 1955) Hunter (1959, 1961) and Jones (1963) regarded the succession as representing the Fig Tree Series. The author, however, is of the opinion that this succession should be included in the Onverwacht Series and reasons will be given for this opinion after the various lithological units have been fully described.

The Upper Stage of the Onverwacht forms an elongated wedge-shaped strip which is close to a mile wide in the south-western extremity of the Mhohho area but tapering to a mere 700 feet at the northeastern boundary (Fig. 2). It forms, therefore, the main part of the lower foothills of the Makonjwa Range. The wedge-like distribution of this stage of the Onverwacht Series is due to faulting and the unconformable relationship of the overlying Moodies Series. Thus, the Kamhlabane, Mhlotshana and Mashobeni Faults (Figs 2 & 3) have considerable structural effects and very largely obscure the relationship between the Upper and Lower Stages of the Onverwacht. The southeastern limit of the wedge is defined by the Mhlotshana Fault which has the effect of throwing the Upper Stage formations against those of the Moodies Series on its southeastern side. Only in the vicinity of the Ngubudhla River is the relationship undisturbed and in this locality a 6 feet thick, almost black-coloured, impure fine-grained quartzite overlies talcose schists of the Lower Stage of the Onverwacht Series. This quartzite is regarded as defining the base of the Upper Stage for above it there is a complete absence in the succession of either talcose schists or basic rocks.

The distribution of the Upper Onverwacht Stage is also affected by the unconformable nature of the overlying Moodies Series thereby delimiting the

northwestern side of the wedge. From the southwestern boundary of the Hhohho area to Mhlotshana River the Moodies Series is in direct contact with shales and greywackes of the Onverwacht. The unconformable relationship is apparent not only from variations in strike between the formations of each series but also in differences in dip. Thus, where the easternmost tributary Mgubudhla River intersects the Moodies/Onverwacht contact, the former strikes at N72° and the latter at N58°. The dips are 60 degrees and 75 degrees respectively to the south-southeast and south. Followed northeastwards from the Mhlotshana River to the Transvaal border the relationship between the two series is again obscured by the action of the Kamhlabane Fault (Figs 2 & 3).

As in the case of the Lower Stage of the Onverwacht Series, no definite stratigraphical sequence could be established for the formations of the Upper Stage. It is proposed, therefore, to describe the various rock types forming the stage with reference to their distribution, structural features, grades of metamorphism and origins.

1) The shales

Distribution: The shales of the Upper Stage are exposed on the flanks of the Mgubudhla River where they are folded, together with greywackes, in the core of the Kamhlabane Anticline (Figs 2 & 3). Due to the action of the Kamhlabane Fault they are repeated and so occur again between the Mgubudhla River and its easternmost tributary. Shales also lie between the Mhlotshana River and the northeastern boundary of the Hhohho area forming a narrow tapering wedge between the Kamhlabane and Mhlotshana Faults (Figs 2 and 3).

Petrology: The shales weather readily and in consequence are not prominently exposed. Outcrops are generally subdued and well cleaved showing considerable ranges in colour varying from yellow and pale-green to pink, red and black.

The yellow, pale-green and pink shales consist essentially of fine-grained quartz with varying proportions of interstitial chloritic matter

and clay minerals. When sericite is abundant the rocks take on a silky lustre on fresh surfaces. The abundance of sericite increases where the shales are heavily cleaved, as when they are adjacent to zones of faulting so that they may grade into phyllites. Shales containing quantities of chlorite take on a greenish tinge the intensity of which varies with the amount of that mineral contained. When minor amounts of finely divided iron-oxides are present, the shales become pink to red in colour. Black shales are sporadically intercalated with the micaceous varieties described above but seldom more than a few inches thick. They are soft and friable and possibly carbonaceous in composition.

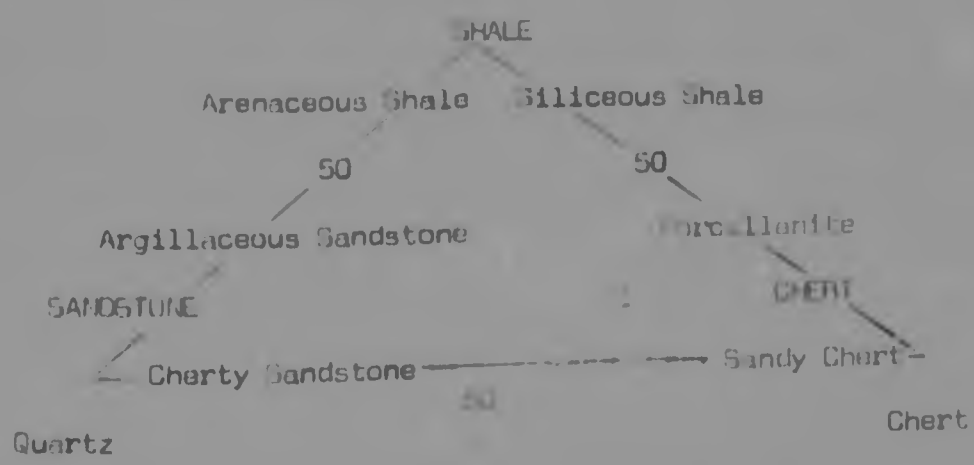
Individual shale horizons when traced along their strike frequently become more arenaceous in character, less micaceous, and have a greenish tinge. Microscopic examination of such sandy shales shows them to comprise of variable sized grains of quartz, crudely aligned elongate clusters or irregular ribbons of chlorite and shreds of sericite.

Structural Features: The development of cleavage along a direction of N68^{o}E is well displayed in the shales, rendering them soft and brittle. Minor folds are sometimes preserved and may correspond with either the northeast trending phase of folding or with a north-south or northwesterly direction. Such folds will be described more fully in a later section dealing with the structural geology of the Mhohho area. Sericite and chlorite present in shales affected by the main cleavage pattern (i.e. northeast) shows a tendency to be orientated sympathetic with that cleavage. In localities where such cleavage has been also effected by the north-south and northwest aligned folds, the grains of sericite and chlorite may be buckled, bent and fractured.

Grades of Metamorphism: The shales described have suffered comparatively little in the way of thermal metamorphism. The presence of chlorite and sericite may qualify their inclusion in the greenschist facies, but even then only at its lowest part. It seems more probable that the very fine interstitial chlorite is a primary constituent rather than a product

of thermal metamorphism. It will be remembered from the petrological description of the shales given above that sericite increases in abundance in the vicinity of faults and shears so that they more accurately described as phyllites. Such a phenomenon is obviously an expression of dynamic metamorphism and in consequence it would appear that the shales of the Upper Stage of the Onverwacht Series are influenced more by dynamic rather than thermal metamorphism. It is possible that the sericite in many shales results from the breakdown of feldspar fragments due to shearing and that their characteristic fineness of grain is inherited from the parent rock rather than indicating advancing metamorphism. Individual shale horizons with quartz in excess of sericite frequently show re-crystallization of their clastic grain when subjected to dynamic metamorphism and a hard siliceous slate or even a secondary chert may result.

Origin: The shales described above are associated with a succession of greywackes, cherts, quartzites and minor conglomerate bands which constitute the Upper Stage of the Onverwacht Series. There can be little doubt that they represent the accumulation of the finest products of rock erosion. The tendency of individual shale horizons in the Mohho area to grade along their strike into sandy shales or for more siliceous shales to pass into siliceous slates or even secondary cherts illustrates the intimate relationship between these various formations. Krumbein and Gloss (1951) relate the shales into a common sedimentary family as follows:-



The same authors suggest the following conditions of origin for various

shales which could apply to those occurring in the Mhohho area:-

i) Chloritic shales, according to Krumbein and Sloss (1951) are normally associated with greywackes and represent relatively finer detritus under conditions of rapid deposition. Silt and clay were derived from rapidly eroded orogenic areas and, like the corresponding sandstone, chloritic shales literally "poured" into a rapidly subsiding depositional area. It is interesting to note here that Roering (1965) considers the Figtree greywackes of the Barberton Mountain Land to have been deposited by turbidity currents in deep water.

ii) Micaceous shales are maintained by Krumbein and Sloss (1951), to be commonly associated with sub-greywackes and, like their corresponding sandstone, were deposited under moderately unstable conditions in the sedimentary basin.

iii) Feldspathic shales have not been observed in the Mhohho area. As previously mentioned, however, there is a likli-hood that some of the sericite in the shales may have been derived from the mechanical breakdown of feldspar frag-ments. According to Krumbein and Sloss (1951) felds-pathic shales, characterized by a feldspar content of over 10 per cent, are commonly associated with arkose rocks. The shales represent a winnowing out of finer material from coarser arkose debris and were deposited under quieter phases of the same general conditions which produced the arkose deposits.

2) The greywackes, quartzites, grits and conglomerates

Distribution: The arenaceous members of the Upper Stage of the

Onverwacht Series are represented by greywackes, quartzites, grits and conglomerates. Such rocks occur most prominently in the west-northwestern part of the Mhohho area and, being more resistant than the shales, are responsible for building most of the foothills of the Makonjwa Range in the vicinity. A prominent ridge is formed where such rocks occur as a wedge between the Mhlotshana and Kamhlabane North Faults (Figs 2 and 3). To the northwest of the last mentioned fault greywackes, quartzites, grits and conglomerates occupy the core of the Kamhlabane Anticline. A prominent conglomerate band lies on the southeastern limb of the anticline but it is not exposed on the opposing limb being transgressed by the Moodies Series.

Petrology: The greywackes are medium grained and characterized by a dark greenish-grey colour which weathers to a dull brown. Thin sections show that they consist of chert and quartz fragments together with angular grains of sericitized feldspar of varying sizes. The fine-grained matrix is made up of quartz with subordinate amounts of chlorite and clay minerals.

The grits occur as narrow and impersistent intercalations within the the greywackes and, in association with the shales already described. They are medium to coarse-grained and contain small, sub-angular pebbles of chert and quartzite. The relatively finer-grained matrix is made up predominantly of an interlocking mosaic of clastic quartz with minor quantities of interstitial sericite. The grits may frequently grade locally into greywacke or arkose. The last mentioned rock contains prolific quantities of unidentifiable feldspar together with quartz fragments set in a matrix consisting of chlorite, carbonate and possibly carbonaceous matter. Mica and sericite occur interstitially but only in minor quantities.

The quartzites occur interlayered with chert bands and also as narrow intercalations within the shaly horizons and greywackes. They are generally fine to medium-grained and vary in colour from buff to orange or dark-grey to almost black. The buff to orange coloured quartzites are massively bedded and under the microscope are seen to consist of sub-angular clastic quartz grains and sporadic fragments of feldspar set in a siliceous matrix

containing minor quantities of muscovite, biotite and accessory iron oxides. The last mentioned minerals are, in the main, responsible for the orange tinge imparted to the quartzites. The dark-grey to almost black coloured quartzites are less gritty than those previously described and rather impure. They are well bedded and are made up of small sub-angular chips of chert and quartz set in a microcrystalline matrix of blue-grey coloured quartz and moderate amounts of clay material. A quartzite of this type is regarded as constituting the lowest unit of the Upper Stage of the Onverwacht Series (see later), in the westernmost part of the Mhohho area in the vicinity of the middle reaches of the Mgubudhla River. It has a closely laminated appearance due to partings of dark 'shaly' material approximately 0.15 inches thick. Where these partings are somewhat ferruginous the quartzite may locally be regarded as a poorly developed banded ironstone. The quartzite frequently contains finely disseminated sulphides, principally pyrite and to a lesser extent chalcopyrite.

The conglomerates occur as narrow bands in association with the quartzites and greywackes described above. They are compact and ill-sorted consisting of pebbles of chert, quartz and quartzite varying from pea-size to two inches in diameter. Such pebbles are set in a matrix composed of sericite, chlorite fragments and grains of clastic quartz

Structural Features: Minor folds are seldom well preserved in the quartzite grits, greywackes and conglomerates due largely to their massively bedded nature. The most prominent structural feature is the re-orientation of clastic particles so that they are contained within the planes of the regional cleavage. In the case of the conglomerates re-orientation of pebble constituents is particularly apparent. Pebbles of hard rock, such as chert, tend to be ellipsoidal in shape whereas the softer quartzitic components are extremely flattened. Such re-orientation is normally in the direction of the regional cleavage (viz. N68^{o}E) but instances are known where re-folding has occurred along a north-south or northwesterly direction.

Grades of Metamorphism: The essentially arenaceous rocks described above are associated with shales and phyllites and like those argillaceous formations have possibly been subjected to low grade thermal metamorphism. Such metamorphism is, however, very largely obscured by the effects of dynamic metamorphism. The alteration of feldspar to sericite in many of the greywackes and quartzites is prominent especially where such rocks have been subjected to shearing. The resultant mesh of sericite in such cases is orientated in sympathy with shearing or cleavage plane directions as are also the clastic particles. It seems reasonable to assume that sericitization and reorientation of clastic particles was synchronous process evolving from dynamic stress.

Origins: The greywackes described above conform in definition to such rock described by Krumbein and Sloss (1951) as poorly sorted sandstones or greywackes with more than 20 per cent matrix. Particles include angular fragments of quartz and detrital chert with more than 10 per cent of feldspar. The matrix of such sandstones or greywackes is composed mainly of clay minerals, chlorite and sericite. According to Fischer (in Krumbein and Sloss 1951), greywackes are "poured in" sediments derived from the rapid erosion of tectonic source areas. The high content of matrix implies lack of sorting or winnowing action. Keunen and Migliorini (in Krumbein and Sloss 1951) suggest that density currents may form greywackes with graded bedding.

The grits, as previously mentioned, frequently grade along their strike into greywacke or arkose. It is considered, therefore, that their conditions of deposition were very similar to those appertaining to the greywackes.

The quartzites of the Upper Stage of the Onverwacht Series in the Mhohho area resemble in some cases rocks defined as sub-greywackes by Krumbein and Sloss (1951). According to these authors, a sub-greywacke is a sandstone resembling a true greywacke except that it contains less than 10 per cent of feldspar and chlorite may be less prominent. Sub-greywackes are considered to represent "washed" greywackes with some winnowing action

which occurred during transportation to produce a cleaner type of sand. They were deposited in sedimentary basins where the rate of burial was rapid enough to prevent thorough winnowing action by transportational agents.

It will be observed that the depositional conditions under which the arenaceous rocks so far described, as well as the shales, were laid down were unstable. Thus, the narrow conglomerate bands occurring in the succession are considered to emphasise such unstability and it is possible that, in some cases, they represent minor intraformational unconformities.

3) The quartz-sericite schists

Distribution: Quartz-sericite schists occur as five separate horizons in the area lying along the foothills of the Makonjwa Range between the middle reaches of the Ngubudhla and Msulithe Rivers (Fig. 2). The northernmost of these horizons is overlain by the conglomerate band which forms part of the southeastern limb of the Kamhlabane Anticline. It is not exposed on the opposing limb of the anticline, for, as previously mentioned, that limb is absent due to the transgressive and unconformable nature of the overlying Moodies Series (Fig 2 and 3). Traced along their strike, the length of all the quartz-sericite schist horizons is limited due to the effects of the Kamhlabane and Mhlotshana Faults and the greatest strike length over which they may be observed is just over 3 miles.

Petrology: The quartz-sericite schists range in colour from very pale-pink to almost white in colour. They are soft and weather readily to form soft, powdery rounded outcrops. The schists are frequently characterized by a finely gritty texture due to the presence of small angular "chips" of quartz which are studded indiscriminately throughout the rock. Unlike the quartz-sericite schists occurring in the Lower Stage of the Onverwacht Series, the schists of the Upper Stage are devoid of andalusite. Examination under the microscope shows the schists to consist of a fine grained matrix of quartz and sericite in which are set angular "chips" or "grains" of quartz. These "chips" or "grains" may either be sharply defined or, more frequently

have "furry" margins with the matrix. In a few extreme cases it is found that the original boundaries of the "grains" are defined only by optically continuous "ghosts" lying within the matrix. The significance of this feature will be more pertinently discussed when dealing with the likely origin of the quartz-sericite schists. One specimen examined contains an angular fragment made up of haphazardly orientated laths of chlorite and unidentifiable feldspar. The textural character of this fragment would suggest that it is a clastic grain of basic lava.

Structural Features: The quartz-sericite schists are relatively soft and susceptible to weathering so that preservation of minor structural features is limited. The most prominent feature within the schists is the orientation of the sericite occurring in the matrix to give a marked foliation. The relationship of the quartz-sericite schists with the underlying and overlying shales, quartzites, greywackes or conglomerates appears to be conformable. One horizon, however, in the vicinity of the middle reaches of the easternmost tributary of the Ngubudhla River, "pinches out" when traced northeastwards. The behaviour of the other quartz-sericite schist horizons along strike is unknown since they are truncated by the major strike faults occurring along the foothills of the Inkonjwa Range. (Fig. 2)

Grade of Metamorphism: The quartz-sericite schists are associated with shales, quartzites, greywackes and conglomerates the metamorphism of which do not rise above the phyllite grade. The effects of thermal metamorphism would seem to be quite low and the whole assemblage could only be included in the lower part of the greenschist facies. The area in which these rocks occur has, however, been heavily sheared due to major strike faulting and the parallel orientation of sericite in the matrix of the quartz-sericite schists would suggest that this mineral reflects the influence of dynamic metamorphism to a large extent.

Origin: Field observation indicates that the quartz-sericite schists are interlayered with arenaceous and argillaceous rocks and two possible

conclusions can be made regarding their likely origin. Firstly, that the schists were derived from a siliceous sedimentary rock with abundant feldspar and containing fragments of clastic quartz. Such a rock subjected to thermal and dynamic metamorphism could be readily converted to a quartz-sericite schist, the sericite being derived from the original feldspar content. The fragment of possible lava observed in one thin section (see p. 78) would support the conclusion of a sedimentary origin for the quartz-sericite schists.

A second possibility exists that the quartz-sericite schists are the metamorphic derivatives of inter-layered lavas of acid composition. It will be recalled from the petrological description of these schists that the so-called "grains" of quartz commonly present a "furry" margin to the fine-grained matrix and in extreme cases are defined by optically continuous "ghosts" in such a matrix. These relationships would suggest that the quartz "grains" are in actuality phenocrysts in a magma and that they have been partially resorbed during cooling. The angular fragment containing chlorite and feldspar laths previously mentioned has relatively sharp margins with the matrix and might well represent a detrital grain of a more basic lava which was caught up during the extrusion of acid material.

There is no conclusive evidence to enable a definite decision to be made regarding the two likely origins of the quartz-sericite schists. The author has, however, mapped in detail the Eyldsdale and Kobolondo areas lying immediately southwest of the area now under discussion. In those areas formations, which can be correlated on the same stratigraphic level as the Upper Stage of the Onverwacht Series now being described, are characterized by a preponderance of inter-layered acid lava flows. These acid lavas frequently contain pillow structures in undisturbed areas, but where intense cleavage development has occurred, they are converted to quartz-sericite schists similar in many respects to those just discussed.

4) The cherts

Distribution: Chert horizons are prominent members of the Upper Stage

of the Onverwacht Series in the Mhonho area especially between the middle reaches of the Mguburhla and Mhlotshana Rivers. They are responsible for building the impressive ridge between the Kamhlabane North and Mhlotshana Faults (Fig. 2) where they occur inter-banded with shales, slates, grits quartzites and greywackes of the Upper Stage.

Petrology: The cherts are similar to those occurring in the Lower Stage of the Onverwacht Series though may be considerably thicker being measurable in some cases in hundreds of feet. Massive and banded varieties are typical, the latter consisting of alternating layers of white, grey or black chert up to three or four inches thick. Remarkable consistency is attained by the banding over distances up to half a mile though occasionally minor bifurcation may occur. Both primary and secondary cherts are present, the latter frequently passing gradually into grits and quartzites and, less frequently, slates and shales. Microscopically the cherts are seen to comprise of a quartz mosaic with minor quantities of interstitial sericite, particularly in the secondary chert bands. Chrome-muscovite or fuchsite has been observed in some of the cherts but, unlike those of the Lower Stage never in sufficient quantity to impart a green tinge to the rock.

Structural Features: The attitude of the primary cherts is normally conformable and sharp. The development of secondary cherts is largely a reflection of dynamic metamorphism and they are, consequently, less clearly defined. Minor folds are preserved in some of the cherts, though generally their hard, compact nature is not conducive to three dimensional views of the folds being developed and only rarely can the fold attitudes be measured. One pattern of folds occurs around northeast aligned axes whereas cross-folds are along either northwesterly or in an north-south direction. A more detailed description of these folds will be given when describing the structural geology of the Mhohho area in a later section.

Grade of Metamorphism: Due to their highly siliceous nature, the cherts do not reflect, to any marked extent, the effects of thermal metamorphism.

Occasional instances of re-crystallization have been observed in which case a finely granular, "sugary" texture may result. The effects of dynamic metamorphism are far more apparent particularly in the secondary cherts. The process whereby grits, quartzites and sometimes shales are converted to chert has been previously described (p [illegible]) and will not be repeated here, but clearly the process is mainly mechanical and attributable to dynamic metamorphism.

Origin: The intimate and conformable relationship of the primary cherts with shales, greywackes, quartzites, grits and conglomerates together with their frequently banded appearance would indicate their origin to be sedimentary. It has been previously mentioned that the arenaceous and argillaceous rocks occurring in the Upper Stage of the Onverwacht Series were deposited under unstable conditions. Consequently, it is envisaged that the primary cherts were formed under quieter periods in the depository when chemical precipitation was possible. The origin of secondary cherts has been described earlier and will not be repeated.

SUMMARY AND CONCLUSIONS

The descriptions given of the various rock types constituting the Onverwacht Series in the Mhohho area clearly indicate that a distinction can be drawn between the assemblage forming the lower division of the series, namely the Lower Stage, and that occurring at the top or so-called Upper Stage.

The Lower Stage is characteristically of a basic nature being represented by amphibolitic rocks and talcose schists. For reasons previously given, it is considered that the Lower Stage was comprised originally of basic lavas, probably of basaltic composition, together with carbonate-bearing sediments, impure grits and aluminous shales, primary cherts and possibly some ultrabasic rocks. A possibility exists that some of the siliceous

units in the succession, such as the quartz-sericite schist, could have originally been lavas of acid composition. Contact metamorphism induced by the emplacement of granites has converted this succession to its present state. In the Mooiplaas Valley area, are exposed amygdaloidal basic lavas with narrow sedimentary intercalations. This assemblage too is included in the Lower Stage of the Onverwacht Series as it cannot successfully be correlated with the succession constituting the Upper Stage. The Lower Stage is not fully exposed due to the intrusion of granites along the southeastern margin of the Hhuhho area, but approximately 2,000 feet can be accounted for.

The so-called Upper Stage of the Onverwacht Series is made up of shales, greywackes, grits, quartzites, cherts, narrow conglomerates and quartz-sericite schists. The origin of the last-mentioned schists is debatable and they could have either been derived from feldspathic sediments or from acid lavas. The Upper Stage succession has not been markedly affected by contact metamorphism since they lie some 1½ miles from the granites' contact to the southeast. Dynamic metamorphism is more pronounced, however, and is reflected by orientation of clastic grains and the parallelism achieved by the mica constituents of some of the rocks. The relationship between the Upper and Lower Stages is generally obscured by faulting except in the vicinity of the Ngubudnla River. In this vicinity a conformable relationship can be observed over a strike length of just under 1½ miles. The contact is defined by a 50 feet thick impure quartzite horizon since above it the succession is devoid of any basic rocks comparable to, even at a lower grade of metamorphism, any occurring in the Lower Stage. Furthermore, the only rocks occurring in the Upper Stage which might conceivably be regarded as extrusive are, as previously mentioned, some of the quartz-sericite schists. The Upper Stage is not fully exposed in the Hhuhho area due to unconformable relationship of the overlying Moodies Series. Previous workers in northwestern Swaziland have regarded the rocks now placed in the Upper Stage of the Onverwacht Series as members of the Figtree Series. Such a correlation is regarded by the author, however, as unsatisfactory for the following reasons:-

i) Elsewhere in the Archean fold-belt of Swaziland formations which can be unequivocally regarded as Figtree Series are characterized by ferruginous shales and banded ironstones as well as shales, greywackes and cherts. No ferruginous formations are present in the Upper Stage of the Onverwacht Series in the Mhohho area.

ii) Traced southwestwards to the Wyldsdale-Kobolondo areas (Fig. 1 ;) Upper Stage formations which may be correlated with those of the Mhohho area display an increased incidence of extrusive rocks. Acid lavas with amygdales and pillow structures occur inter-layered with shales, quartzites, greywackes, cherts and minor conglomerate bands. As previously mentioned, the Upper Stage is not fully exposed in the Mhohho area. In the Wyldsdale-Kobolondo areas and again further southwestward to the Havelock area (Fig. 1) the Upper Stage is, however, fully developed. The author has mapped these areas in great detail and it has been observed that as the succession is traced upwards lavas occur more frequently ranging in composition from acid to basic. As the lavas become preponderant in the succession so the sedimentary horizons become less significant. In view of the essentially extrusive character of the Upper Stage it is considered unrealistic to include it in the Figtree Series.

iii) In the area lying between Havelock and the Komati River (Fig. ; 5) the Upper Stage is overlain by a succession of cherts, banded ironstones, ferruginous shales and greywackes. No flows are present in this latter succession and there can be little doubt that it represents the Figtree Series in northwestern Swaziland.

Viljoen and Viljoen (1967) have determined a type section for the Onverwacht Series in the Komati River Valley area of the Barberton Mountain Land as shown in Table 6. A correlation can be made with the Onverwacht Series occurring in the Mhohho area, but it must be borne in mind that the two areas are over thirty miles apart and that such correlation is purely tentative. Viljoen and Viljoen have divided the Onverwacht Series into

a Lower Onverwacht or Theespruit Stage, a Middle Onverwacht or Komati River Stage and an Upper Onverwacht or Hooggenoeg Stage. The first mentioned comprises a sequence of meta-basalts with numerous narrow interlayered siliceous, sedimentary horizons and several interlayered ultrabasic bands. The Middle Onverwacht or Komati River Stage is characterized by alternating pillow basalts and ultrabasic bands. The Upper Onverwacht or Hooggenoeg Stage consists essentially of basalts and andesites together with narrow, interlayered horizons of more acid lavas as well as chert bands. It is considered that the Upper Stage of the Mhohho area could be included in the Upper Onverwacht or Hooggenoeg Stage of Viljoen and Viljoen (1967). Both stages are characterized by lavas of basic intermediate and acid composition and both underlie the Figtree Series, though the latter does not apply in the Mhohho area itself, this relationship only being observed between Havelock and the Komati River. (Fig. 1). Reference to Table 6 will show that the lowest sub-stage of the Upper Onverwacht or Hooggenoeg Stage is characterized at its base by a zone approximately 200 feet thick of carbonate-bearing sediments, slaty sediments and cherts. In the Mhohho area the Upper Stage of the Onverwacht Series is represented by a succession of shales, grits, conglomerates, quartzites, greywackes and cherts with narrow zones of quartz-sericite schists. Neither the precise thickness of this succession nor its exact sequence can be ascertained due to the complexity of the geological structures in the area. Even so, taking into account crustal shortening as a result of tight folding and faulting, the succession must be at least 1200 feet thick. It is possible that the so-called Upper Stage in the Mhohho area could be correlated with the sedimentary zone at the base of the Hooggenoeg Stage but showing variations not only in thickness but also in character.

The Lower Stage of the Onverwacht Series in the Mhohho area is thought, for reasons previously given, to be made up of basic lavas, carbonate-bearing sediments, impure arenaceous bands, aluminous shales, cherts, ultrabasic layers and possibly some acid lavas. Except in the Mooiplaas Valley area the succession has been subjected to contact metamorphism and only the

metamorphic equivalents of those listed rocks remain. Reference to Table 6 shows that Viljoen and Viljoen (1967) divide their Middle Onverwacht or Komati River Stage into two sub-stages. The lower sub-stage is made up essentially of ultrabasic rocks whereas the upper sub-stage is composed predominantly of amphibolitized basic lava. Both stages are characterized by an absence of any sedimentary formations. The uppermost sub-stages of the Lower Onverwacht or Theespruit Stage are made up of basic lavas with minor chert and quartz-sericite horizons together with possible acid lava in sub-stage 6. Ultrabasic rocks are notably absent in the two uppermost sub-stages of the Lower Onverwacht.

It is difficult to correlate the succession constituting the Lower Stage in the Mhohho area with either the Middle Onverwacht or upper part of the Lower Onverwacht as defined by Viljoen and Viljoen (1967) since it contains both sedimentary and likely ultrabasic rocks. The hornblende amphibolites are, for reasons already given, regarded as the metamorphic derivatives of carbonate-bearing sediments. Consequently they could be included in the sedimentary zone typifying the base of the Hooggenoeg Stage and in this case the remaining basic rocks and talcose schists in the Mhohho area could be included in the upper sub-stage of the Middle Onverwacht or Koma[illegible]er Stage. The presence of siliceous, quartzitic and chert intercale[illegible]s does, however, discredit such a correlation. Nevertheless, it is the [illegible]e opinion that because of the conformable relationship between the [illegible] and Lower Stages in the Mhohho Valley, the last mentioned should be regarded as the equivalent of the Middle Onverwacht.

THE MOODIES SERIES

INTRODUCTION

Overlying the Onverwacht Series is a succession of essentially arenaceous and rudaceous rocks which constitutes the Moodies Series. Being of a hard and siliceous nature the succession is comparatively resistant to

weathering and so is responsible for building the escarpment face, crest and mountain peaks of the Makonjwa Range in the Hhohho area. Unlike the Onverwacht Series it has been possible to determine a stratigraphical succession in the Moodies Series (Table 2). It is proposed, therefore, to describe the distribution and petrological characteristics of each stratigraphical horizon or zone. This will be followed by an account of the structural features, grade of metamorphism and conditions of deposition relating to the Moodies Series. Finally, a summary and discussion of the Swaziland System as a whole will be presented together with the reasons for regarding the Moodies succession as a series rather than in the taxonomic rank of a system.

THE LITHOLOGICAL ZONES

1) The Basal Conglomerate

Distribution: The basal conglomerate of the Moodies Series is consistently present along the foot of the Makonjwa Range escarpment its absence at any particular locality being attributable to the effects of faulting. Thus, between the southwestern boundary of the area under discussion and the westernmost tributary of the Mhlotshana River it prominently demarcates the base of the Moodies Series attaining a maximum thickness of 80 feet on the southwesternmost limb of the Kamhlabane Anticline (Figs 2 and 3). From the Mhlotshana River to the northeastern boundary the basal conglomerate is absent, being cut off by the Kamhlabane Fault. It re-appears again in the terrain lying between the Mhlotshana and Ngugwane Rivers on the southeastern side of the Mhlotshana Fault where it lies in direct contact with foliated amphibolites of the Onverwacht Series. In the vicinity of the Mgubudhla River the basal conglomerate forms part of the southeastern limb of the Kamhlabane Anticline for about three-quarters of a mile before being faulted out. It is present again, however, between the Mhlotshana and Mashobeni Faults where it forms part of the nose of the Mashobeni Syncline (Figs 2 and 3).

On the crest of the Makonjwa Range in the Mooiplaas Valley area, the basal conglomerate occurs only intermittently at the base of the Moodies Series where it forms in part the limbs of the Mooiplaas Syncline. Along the foot of Bearded Man Peak the conglomerate is absent due to the effect of the Bearded Man Fault.(Figs 2 and 3). It occurs again, however, on the southeastern limb of the Mooiplaas Anticline at the southwestern boundary of the Mhohho area. Traced northeastwards over a distance of just under two miles, it gradually narrows and is eventually absent in the easternmost limits of the Mooiplaas Valley. Since there is no evidence of faulting, it must be assumed that the basal conglomerate was not deposited in this particular vicinity.

Petrology: The basal conglomerate is normally compact and ill-sorted, containing rounded pebbles of pale and dark-grey chert, shale, banded iron-stone, grit, greywacke and quartzite. Most pebbles are two to three inches in diameter but sub-angular buck-shot sized pebbles of chert, quartzite and, less frequently, shale,also occur. The matrix is a heterogeneous mixture of sand, silt and clay. Quartz, feldspar, chlorite and sericite are prominent and the cementing material is made up of secondary silica.

2) The M.S.[1] Zone

Distribution: The M.S.[1] Zone constitutes the lowermost quartzite horizon of the Moodies Series in the Mhohho area with a thickness varying between 400 and 600 feet. In the area lying between the southwestern boundary and the Mhlotshana River it forms the precipitous escarpment face of the Makonjwa Range. At the extreme northwestern corner the M.S.[1] Zone forms the steep slopes of Bearded Man Peak and lies in direct contact with the Onverwacht Series due to the effect of the Bearded Man Fault (Figs 2 and 3). The zone also occurs in a narrow wedge forming a prominent ridge in the foot-hills of the Makonjwa Range between the Mgubudhla and Mhlotshana Rivers. In this wedge, the M.S.[1] Zone occupies the core of the Mashobeni Syncline though the limbs of the fold are faulted out by the Mashobeni and Mhlotshana

Faults (Figs 2 and 3). Traced northeastwards into the area lying between the boundary of the Hhohho area, the wedge widens out and the M.S.[1] Zone is exposed on the southeastern limb of the fold to form the escarpment face of t the Makonjwa Range at this locality.

Petrology: The M.S.[1] Zone is made up of a medium-grained, poorly-bedded quartzite with a sombre grey colour. Under the microscope it is seen to consist of angular and sub-angular quartz grains set in a siliceous matrix containing interstitial sericite, shreds and anhedral plates of chlorite and isolated fragments of feldspar. Rounded and sub-angular quartzite and chert pebbles up to 1.75 inches in diameter are scattered indiscriminately throughout the quartzite. Numerous narrow and loosely packed conglomerates occur intermittently throughout the zone but only the major bands are shown on the accompanying geological map (Fig. 2). These conglomerates tend to pinch and swell rapidly along their strike. Numerous grit bands, essentially feldspathic or calcareous in character, are also prevalent particularly in the vicinity of the Mooiplaas.

3) The M.S.[2] Zone

Distribution: The M.S.[2] Zone of the Moodies Series is confined to the northernmost part of the Hhohho area where it occurs on the crest of the Makonjwa Range.

Between the southwestern boundary of the area and the easternmost tributary of the Mgubudhla River the zone occurs at three localities. At Bearded Man Peak it occupies the uppermost slopes of this peak. It occurs again on the Transvaal/Swaziland border where it is preserved on the limbs of the Mooiplaas Syncline (Figs 2 and 3). At this particular locality the zone attains its maximum thickness of 370 feet. The M.S.[2] Zone also forms the narrow core of the Makonjwa Syncline which closes when traced northeastwards from the southwestern boundary of the area.

In the northeastern sector of the area in the vicinity of Kamhlabane Peak, the M.S.[2] Zone again occurs in the Makonjwa Syncline underlying the

M.S.^{1} Zone. On the northwestern limb of the syncline the M.S.^{3} Zone thins out before reaching the Transvaal border so that the M.S.^{2} Zone comes into contact with the M.S.^{4} Zone, a feature that will be discussed later. Traced along the southwestern limb of the fold, the zone is cut off by the Kamhlabane Fault in the vicinity of the Mhlotshana River (Fig. 2) and is thereafter absent in the northeastern sector of the Mhohho area.

Petrology: The M.S.^{1} Zone is comprised of a fine to medium-grained quartzite with a somewhat sugary texture. Grains of clastic quartz are set in a matrix made up of feldspar fragments and shredded laths of mica and chlorite set in a cement of secondary silica. The quartzite is frequently characterized by festoon type cross-bedding.

4) The M.S.^{2} Zone

Distribution: The M.S.^{2} Zone occurs in three localities. In the extreme northwestern corner of the area it builds the crest of Bearded Man Peak (Fig. 2). In the centre of the northern border the zone occupies the core of the Mooiplaas Syncline forming a prominent but un-named peak. In both the above mentioned localities the zone is not fully developed being partially eroded away. In the northeastern corner of the area the M.S.^{3} Zone occurs on the limbs of the Makonjwa Syncline (Figs 2 and 3), where it attains a thickness of between 400 and 620 feet. On the northwestern limb the zone eventually swings northeastwards out over the Transvaal border. The zone on the opposing limb of the syncline forms the steep slopes of Kamhlabane Peak but is only partially exposed due to the effects of the Kamhlabane Fault.

Petrology: The M.S.^{2} Zone is made up of a hard, fine-grained quartzite consisting of clastic quartz grains set in a matrix of quartz and minor quantities of shredded sericite laths interstitial to the quartz. The quartzite tends to become somewhat micaceous in places with an increase in the content of sericite and also containing shredded plates of muscovite.

Scattered rounded pebbles of grit and quartzite up to 0.5 inches in diameter occur scattered indiscriminately throughout the quartzite. The removal by weathering of softer pebbles of quartzite or grit results in outcrops frequently having a "honeycomb" appearance. A loosely packed, ill-sorted conglomerate containing rounded and sub-angular pebbles of quartzite and chert up to 5 inches in diameter is sporadically developed at the base of the zone and it is exposed in the core of Mooiplaas Syncline three-quarters of a mile due east of Bearded Man Peak (Fig. 2).

5) The $M.S.^{4}$ Zone

Distribution: The $M.S.^{4}$ Zone is confined to the extreme northeastern corner of the Hhohho area. It occurs in the core of the Makonjwa Syncline (Figs 2 and 3) where it is overlain by the $M.S.^{5}$ Zone. The zone is best developed on the northwesternmost limb of the syncline where it attains a maximum thickness of 200 feet. On the southeastern limb the zone is less well developed and only a thickness of 80 feet can be observed.

Petrology: The $M.S.^{4}$ Zone comprises a compact, ill-sorted conglomerate with pebbles of grit, and black chert, banded ironstone, shale, ferruginous shale, grit, greywacke and quartzite. Such pebbles average three inches in diameter and vary from well-rounded to sub-angular. The matrix of the conglomerate is medium to coarse-grained, quartzitic and containing abundant small angular chips of chert. At Kamhlabane Peak the conglomerate contains abundant jasper pebbles. Three-quarters of a mile southwest of the peak, it is made up almost entirely of chert boulders. The boulders, up to six inches in diameter, are tightly packed so that outcrops have a distinctive "cobblestone" appearance.

6) The $M.S.^{5}$ Zone

Distribution: The uppermost beds of the Moodies Series, or the so-termed $M.S.^{5}$ Zone, occur only in the vicinity of Kamhlabane Peak where they occupy

the core of the Makonjwa Syncline (Figs 2 and 3). Due to erosion it is only possible to account for some 350 feet of the zone.

Petrology: The zone consists of a coarse-grained sombre grey coloured quartzite. Grains of clastic quartz and less frequently "chips" of chert are set in a matrix made up of a mixture of sand, silt and clay and in which occur feldspar, chlorite and sericite fragments. The cementing material is secondary silica. Well-rounded chert and quartzite pebbles up to 0.5 inches in diameter are scattered throughout the quartzite.

STRUCTURAL FEATURES OF THE MOODIES SERIES

The most important structural feature displayed by the Moodies Series is its unconformable relationship with the oldest members of the Swaziland System. Thus, the basal beds of the Moodies Series rest upon the Upper Stage of the Onverwacht Series along the foot of the Makonjwa Range escarpment from the southwestern extremity of the area to the Mhlotshana River. In the Wooiplaas Valley and from the Mhlotshana River to the northeastern boundary, however, the base of the Moodies Series rests on formations of the Lower Stage of the Onverwacht Series. At actual contacts differences of strike directions up to 20 degrees have been observed together with changes of dip. With regard to the latter, the beds of both the Moodies and Onverwacht Series generally dip southeastwards with the Onverwacht being inclined 15 - 20 degrees steeper than the Moodies. Occasionally, however, as may be observed at the Moodies/Onverwacht contact between the easternmost tributary of the Mqubudhla River and the Mhlotshana River, the unconformable relationship is clearly indicated by dip directions. At one locality the Onverwacht Series on the limb of the Kamhlabane Anticline (Figs 2 and 3) dips north-northwestwards at 74 degrees whereas the Moodies Series dips southeastwards at 85 degrees.

Intraformational unconformities occur within the Moodies Series succession, the most prominent of which can be observed two miles west of Kamhlabane Peak. At this locality, the M.S.$_3$ Zone is overlapped by the

succeeding $M.S.^2$ Zone so that the former, when traced northeastwards, peters out completely near the Transvaal border.

It is possible that many of the narrow conglomerate bands which are scattered throughout the succession, particularly in the $M.S.^2$ Zone as rapidly pinching and swelling lenses, signify minor intraformational unconformities.

Due to the generally massive bedded character of the Moodies Series formations, minor folds are rare and seldom well preserved. Large scale folds are apparent, however, when detailed mapping of the individual zones is undertaken. Reference to the geological map of the area (Fig. 2) will show that such folds, with the exception of the Mgubudhla Anticline, are aligned northeastwards. The folds are generally of an "open" character except for the Makonjwa Syncline (Figs 2 and 3). In the last-mentioned axial plane cleavage is particularly well developed in the $M.S.^2$ Zone, quartzites occupying the narrow core of the fold. As a result of this cleavage the quartzite weathers in slab-shaped outcrops resembling tombstones (Plate VII.) In some outcrops the cleavage planes are warped and bent by later stresses; a phenomenon to be more fully discussed when dealing with the structural geology of the Mhohho area. The development of a fourth striking phase of cleavage which transects the axial plane cleavage, is frequently accompanied by the flattening and re-alignment of clastic particles so that their long axes lie within the planes of the cleavage. The fabric produced is particularly noticeable in conglomerate bands which have been subjected to excessive tectonic stress. The re-orientated pebbles plunge at moderate angles to the east-southeast and dip steeply to the southeast. In extreme cases many conglomerates thus effected take on an almost banded appearance due to strongly aligned tabular fragments as little as 0.25 inches thick but as much as 4 inches long. Urie (1957) maintains that the tabular fragments are caused by longitudinal fracturing along the lamination planes of pebbles which are rotated into alignment and subsequently sheared along natural lines of weakness.

METAMORPHISM OF THE MOODIES SERIES

The essentially psephitic and psammitic sedimentary rocks of the Moodies Series have, as one would expect, suffered little, if at all, from the effects of thermal metamorphism since they lie over 1½ miles from the granites' contact. In the area investigated no new minerals attributable to such metamorphism have been found. The most prominent effects are those produced by dynamic metamorphism and reflected by re-crystallization of quartz and by the re-aligment of clastic particles as already described previously.

ORIGIN OF THE MOODIES SERIES

The generally coarse-grained nature of the Moodies Series rocks together with such features as cross-bedding and the frequent development of conglomerates would indicate that deposition occurred in shallow water conditions. Some 2,000 feet of the series are represented in the Hhohho area and this thickness of purely arenaceous rocks could be attained if isostatic re-adjustments occurred during deposition. The presence of intraformational unconformities in the Moodies Succession possibly verify that such re-adjustments occurred.

SUMMARY AND CONCLUSIONS RELATING TO THE SWAZILAND SYSTEM IN THE HHOHHO AREA

A full understanding of the relationships of the various lithological units comprising the Swaziland System cannot be gleaned from so small an area as that under discussion no matter how detailed the study. It is necessary, therefore, to relate the Swaziland System succession at Hhohho to the findings and views of other investigators in Swaziland and the Barberton Mountain Land.

Many workers, such as Orie (1957), Viljoen (1964) and Roering (1966) are in favour of fitting the entire Swaziland System pile into a typical

geosynclinal sequence. Urie (1967) believes that "sediments and major intrusions are part and parcel of a single tectonic cycle which involved a geosynclinal phase accompanied by orogenic phases of at least two pulsations and various magmatic phases". The geosyncline is considered by Urie to be of eugeosynclinal type, namely an actively subsiding linear trough with associated volcanics. The sedimentary formations in this ancient geological entity suffered intense deformation and the present Mountain Land is presumably merely the root of a more extensive chain reduced by prolonged erosion. Such features are concluded by Urie to be "striking evidence in favour of a geosynclinal origin, for it is generally accepted that intensely folded mountain systems arise from the reaching up of pre-existing geosynclinal sediments. In fact, a geosynclinal trough is invariably the forerunner of fold mountains".

Other investigators, including Boering (1965) also favour fitting the Swaziland System assemblage into a typical geosynclinal sequence. The Onverwacht Series could well represent an early magmatic phase in a geosyncline. In the Hhohho area, Wildsdale, Kobolondo and Havelock area of Swaziland as well as in the Barberton Mountain Land, the series has been observed to consist primarily of a variety of lava flows with intercalated cherts and sedimentary horizons. The author has already commented that the conditions of deposition for the Onverwacht Series sediments probably were unstable and in deep water. Although no pillow structures have been observed in the basic rocks of the Hhohho area, they have been observed elsewhere in north-western Swaziland by the author (1967), and in the Mountain Land by Viljoen and Viljoen (1967). Such pillow structures serve to substantiate the deep water conditions of deposition. The association of primary cherts with lavas can be taken as further evidence for many authors, including Ramberg (1952) believe that submarine volcanic action may enrich the ocean with silica which precipitates in the form of chert layers.

The succeeding Figtree Series is not present in the Hhohho area, a significant feature to be discussed later, but elsewhere in the Archean fold belt of Swaziland and in the Mountain Land it is characterized by rhythmic

banding and regular lamination. Urie (1957) is of the opinion that the series represents the deposition of pre-orogenic sediments under relatively quiet conditions during the initial subsidence of the geosynclinal trough. It is envisaged that towards the end of this initial phase, the rate of subsidence in portions of the depositional basin was accelerated and the greywackes and coarser clastic rocks found towards the upper portion of the Figtree Series "poured into the deepening trough". Hoering (1965) suggests that the Figtree succession represents a flysch deposition in the fore-deep of the geosyncline and that the greywackes were deposited in deep water by turbidity currents. The Figtree Series does not occur in the Hhohho area and whether or not it was deposited there is a debatable topic. As has been shown, the Upper Stage of the Onverwacht Series at Hhohho is characterized by a predominance of shales with accompanying greywackes and arenaceous rocks similar in many respects to those observed in the Figtree Series in other parts of the Archaean fold belt. Unlike the Figtree Series, however, there is a complete absence of ferruginous shales and banded ironstones, and furthermore, it is known from working in adjacent areas that the sedimentary formations of the Upper Stage are followed by a great thickness of volcanics with minor sedimentary intercalations. Between Havelock and the Komati River (Fig. 1) these volcanic rocks are superceded by a succession consisting predominantly of ferruginous shales and banded ironstones of the Figtree Series. Although no accurate assessment has yet been made of the thickness of the Figtree Series, it is apparent that the succession is poorly developed and does not exceed a thickness of 2,000 feet. The fact that the basal conglomerate of the overlying Moodies Series in the Hhohho area contains fragments, pebbles and boulders of ferruginous shale and banded ironstone so typical of the Figtree Series would seemingly suggest that a thin sliver of Figtree Series once overlay the Onverwacht Series but was eroded prior to the deposition of the Moodies Series. It can be argued that the well rounded character of the pebbles in the Moodies conglomerates would indicate that the material was derived from a source some distance away. Pettijohn (1957), however, maintains "that roundness of cobbles,

however, does not necessarily signify long transportation for it has been shown that rounding of coarse debris is rather easily accomplished even by short transportation."

The fact that the Moodies Series could well have derived some of its material from the Figtree Series and is known to lie unconformably on the lower members of the Swaziland System would imply a pre-Moodies orogenic pulsation to have occurred. In this case there is much to favour the suggestion by Roering (1965) that the Moodies Series represents the "shedding of erosion products of the deformed belt into a post-orogenic molasse basin". As Roering points out, however, no conclusive evidence has so far been obtained as to whether the Onverwacht, Figtree and Moodies Series represent respectively the initial magmatic phase, flysch and molasse deposits in geosynclinal condition. The problem hinges upon the origin of the Moodies Series. Both the Moodies Series and the lowest members of the Swaziland System have been affected by a number of post-Moodies orogenic pulsations (see later), the most intense of which threw the Swaziland System formation into major isodinal folds aligned generally northeastwards. It is impossible to identify the different degrees of folding between the oldest members of the Swaziland System and the Moodies Series other than that the former exhibit numerous additional plications. Such plications still follow the trend of the major folds and could merely imply slumping in the depository itself rather than a pre-Moodies orogeny. In the Mhohho area, however, it has been shown that the Figtree Series is absent and that the Moodies Series rests upon the Onverwacht Series in an unconformable manner transgressing from Upper Stage to Lower Stage formations. Such a relationship would seemingly indicate that even if no major pre-Moodies orogeny occurred, then certainly there was tilting of the Figtree and Onverwacht Series prior to the deposition of Moodies sediments. In such a case the Figtree Series may be regarded as a normal pre-orogenic phase and the Moodies Series as a synorogenic phase of deposition..

In view of relationship between the Onverwacht and Figtree Series and the Moodies formation is seems realistic to regard the Moodies as a series

rather than elevate it to the taxonomic rank of a system. Not only is the Moodies derived in part from the Figtree Series, but they are both products of the evolution of a tectonic cycle. It would seem, therefore, that they were all formed in the same depositional basin and the lithological differences and unconformity existing between them are largely, if not solely, the result of tectonic disturbances within the basin.

THE INTRUSIVE ROCKS

The Hhohho area has been subjected to igneous activity varying widely in both composition and age. The intrusion of granites constitutes the major phase of such activity but these in turn were later injected by basic intrusions in the form of dykes.

THE GRANITES

INTRODUCTION

The granites form the southeastern boundary of the area under discussion and consequently only their margins have been investigated. Two types may be recognized. Firstly, a medium-grained, grey-coloured biotite granite which frequently displays foliation. This granite was originally classified as G4 by Hunter (1967) but has subsequently been re-named as late-orogenic granite by the same author (1968). The second variety of granite is porphyritic in texture, paler-grey in colour and with a complete absence of foliation. For reasons to be stated later the writer regards it as a later phase of the late-orogenic granite.

It is proposed to first describe the distribution, petrology and structural features of the foliated granite and then to deal with the unfoliated granite in a similar manner. This will be followed by an account of the aplite, epidote, quartz and pegmatite veins associated with the granites. Finally, the petrogenesis of the granites and associated acid rocks will be considered together with conclusions regarding the relationships

of the two varieties of granite to one another and also the relationship between the granites and the layered Archean rocks with regard to age and time of intrusion.

THE LATE-OROGENIC GRANITE

Distribution: The late-orogenic granite forms the southeastern margin of the area from just south of the confluence of the Mgubudhla and Lomati Rivers to the Transvaal/Swaziland border to the northeast (Fig. 2). Outcrops are rare being confined to isolated tors and exposures along the banks and in the bed of the Lomati River.

Petrology: The petrology of the foliated late-orogenic granite has been fully described by Hunter in various publications (1955, 1957 and 1965). Its petrological characteristics in the Mnohho area, however, will be briefly summarized here.

The foliated granite is typically a medium-grained biotite granite consisting of an inequigranular mosaic of quartz, microcline, plagioclase and biotite. Quartz, occurring in interlocking grains, constitutes about 25 per cent of the rock. Feldspar accounts for between 60 per cent and 70 per cent by volume with potassic feldspar exceeding plagioclase by approximately two-thirds. Biotite is the main mafic mineral contributing about 5 per cent by volume of the rock.

Microcline, the principal potassic feldspar, occurs as irregularly shaped grains the size of which may vary with the texture of the rock. It is of the type characterized by indefinite cross-hatching or streaky undulatory twinning. Consistently fresh and without trace of alteration, the microcline frequently replaces and embays earlier formed plagioclase. Consequently, relicts of plagioclase in large grains of microcline are common. In some thin sections large areas of microcline are composed of a number of individuals with plagioclase relics occurring not only within them but also irregularly along the contacts between such individuals.

Orthoclase is generally subordinate to microcline. It occurs in

irregularly shaped plates which, like microcline, embay and replace plagioclase. It has been observed in a few isolated cases that the orthoclase plates have microcline cross-hatching beginning indefinitely on the margin.

Perthitic textures are common in most grains of microcline and orthoclase-perthite and myrmekite frequently occurs wherever microcline and perthite replace plagioclase. The myrmekite may occur either as protuberances to plagioclase embayed by microcline or perthite, as marginal zones between plagioclase and potassic feldspar, or as isolated blobs in plates of potassic feldspar.

Plagioclase is the more subordinate of the feldspars. Identifiable as oligoclase it is normally quite fresh with secondary alteration occurring only if the potassic feldspars have begun their corrosion. Under such circumstances the plagioclase tends to become turbid and with indefinite zoning so that the altered cores may be surrounded by a clear rim. Hunter (1965) states that the indefinite zoning occurs with a progressive increase of the albite content towards the margin of the rim. The plagioclase feldspar shows complex multiple twinning with combinations of Carlsbad and albite type being most prominent. Pericline twinning tends to be more restricted in development.

Biotite occurs as ragged flakes which tend to be orientated in a subparallel manner when the granite is foliated. Frequently it displays pleochroic haloes surrounding grains of zircon and, more rarely allanite. The biotite normally gives pleochroic colours of deep-yellow and olive-green or brown except when it is wholly or partially altered to chlorite. In such cases it takes on the pleochroism of the chlorites.

Hornblende is sometimes present in the granite as a result of contamination with or assimilation of country rocks but is not otherwise an essential constituent. It occurs as irregular grains with marked pleochroism.

Pin-head sized garnets occur throughout the granite They are pale in colour and are surrounded by rims of quartz and feldspar. As a rule they show little alteration.

Accessory minerals include sphene, apatite, zircon, allanite, epidote

and magnetite. The sphene occurs as either subhedral or euhedral grains whereas the apatite is present as stubby columnar grains or hexagonal prisms. The zircon is found either as rounded individuals in the mica or as euhedral grains in the groundmass. Allanite is usually associated with epidote in euhedral crystals which are honey-brown in colour and often zoned or twinned.

Structural Features: The most prominent structural feature of the late-orogenic granite in the Mhohho area is the development of foliation. Such development is confined to a zone approximately one mile wide along the granite contact. The foliation, emphasised by the sub-parallel orientation of biotite crystals, dips generally at moderate angles towards the contact. Its strike approximates that of the principal cleavage, ($N68^{o}E$), developed in the adjacent layered rocks of the Swaziland System. Traced from the marginal zone of the granite, the foliation fades rapidly and imperceptibly to non-foliated late-orogenic granite. The possible reasons for the development of foliation near the granite contact will be given in a later section when the petrogenesis is discussed and conclusions concerning the granites are made.

The contact between the granite and the amphibolitic rocks of the Onverwacht Series is nowhere exposed in the Mhohho area. It will be necessary, therefore, to describe the relationship as known in other parts of the Archean fold belt in northwestern Swaziland. This subject will also be discussed with the petrogenesis of the granites.

THE LATER-PHASE OF THE LATE-OROGENIC GRANITE

Distribution: The so-called later-phase of the late-orogenic granite is confined to the southwestern corner of the area under discussion (Fig. 2). Between the confluence of the Mgubudhla and Lomati Rivers and the southwestern limit of the area it forms a boss which is bounded on its northwestern side by hornblende amphibolite and pale-green unfoliated amphibolite

of the Onverwacht Series. The northeastern nose of the boss and part of its southeastern margin is in contact with the last mentioned variety of amphibolite whereas the remainder and the southwestern nose is in contact with foliated late-orogenic granite. Numerous smaller bosses occur within the hornblende amphibolite along the banks of the lowest tributary of the Mgubudhla River. In addition, two tongue-shaped bodies extend from the southwestern limit of the area. The first occurs on the banks of the Lomati River whereas the second, and larger, extends to the Mgubudhla River near the foothills of the Makonjwa Range. The former is intruded into hornblende amphibolite whereas the latter's southwestern contact is also with the same amphibolite but its northwestern, northeastern and southeastern contacts are mainly with talcose schists. The significance of the contact between granite and talcose schists will be discussed later. Outcrops of the granite are scarce and generally poor except in river beds.

Petrology: The later-phase granite is pale-grey in colour and with a porphyritic texture. Quartz constitutes about 25 per cent of the rock and feldspar accounts for between 60 per cent and 70 per cent. Plagioclase is the subordinate feldspar accounting for about one third of the feldspar content. Examination of thin sections reveals that orthoclase occurs in equal quantity with the microcline. It occurs not only in the groundmass as laths equal in size to those of microcline, but also as ragged-edged phenocrysts enclosing biotite and quartz. The orthoclase is somewhat sericitized whereas the microcline is comparatively fresh. There is a tendency for microcline in the groundmass to develop myrmekitic heads. Biotite is the principal mafic mineral and accessory minerals include sphene, zircon, epidote, apatite and iron ores.

Structural Features: Compared with the late-orogenic granite, the later-phase variety is devoid of any foliation whatsoever. Its relationship with the main mass of the late-orogenic granite in the Hhohho area is obscure since at no point is its actual contact exposed. The orientation of the small bosses and tongues of the later-phase granite is broadly northeastwards

so that they are oblique not only to the contact of the main granite mass but also to the foliation occurring within it. No enclaves have been observed but as previously mentioned exposures of the granites are rare and even then so badly weathered that such phenomena could easily be overlooked. In other areas of northwestern Swaziland, however, the author has observed porphyritic granite, similar in composition to that occurring at Mhohho, occurring as distinct bosses and also extending as tongues from the main mass of grey granite. Such tongues insinuate themselves along cleavage planes of the country rocks and where they join the main body of granite a cross-cutting relationship frequently develops. The significance of such relationships between the two varieties of granite will be discussed in a later section.

THE EPIDOTE, QUARTZ AND PEGMATITE VEINS

THE EPIDOTE VEINS

Distribution: The epidote veins are only known in the foliated portion of the late-orogenic granite. They are confined solely to the vicinity of the Lomati Bridge (Fig. 2).

Petrology: The veins are made up almost entirely of an interlocking mosaic of anhedral epidote grains. No quartz was observed associated with the epidote in any of the veins.

Structural Features: The epidote veins are only inches thick and persist in length for a maximum of fifteen feet. They occupy steeply dipping joints which have undergone slight shearing. The average strike direction of the veins is N63^{o}W but some veins, especially east of the Lomati Bridge have a direction ranging between N58^{o}E and N72^{o}E. These directions approximate the principal cleavage direction of N68^{o}E which is developed in the rocks of the Swaziland System. Comment will be made in a later section on the significance of the strike direction attained by the epidote veins.

THE QUARTZ VEINS

Distribution: Prominent quartz veins occur most commonly in the rocks of the Swaziland System but numerous veins too small to be shown in the accompanying geological map (Fig. 2) also occur in the foliated portions of the late-orogenic granites. The most prominent veins in the Swaziland System rocks occur in the area lying on the foothills of the Makonjwa Range between the Mgubudhla River and its easternmost tributary. A quartz vein with a strike length of 1100 feet and an average width of three feet is present three-quarters of a mile northwest of the Gordon Mine. Only minor quartz veins were observed in the later-phase of the late-orogenic granite.

Petrology: In colour the quartz veins vary from milky-white to dark smokey-grey. The former are very finely crystalline whereas the latter tend to be of a coarser texture. The grey quartz veins frequently contain sporadic sulphide mineralization, principally pyrite though chalcopyrite and, less often, pyrrhotite has also been observed. Quartz veins near the contacts of the granites are commonly associated with black schorl tourmaline.

Structural Features: The majority of the quartz veins are seldom more than a few inches thick and measurable in tens of feet along their length. The most common strike direction of the quartz veins is N60E degrees, corresponding with the principal cleavage direction of the area. Thus, in the area lying between the middle reaches of the Mgubudhla and Mhlotshana Rivers quartz veins are frequent in cleaved shales and greywackes of the Onverwacht Series occupying the core of the Kamhlabane Anticline (Fig. 2 and 3). As previously mentioned quartz veins emphasise the foliation in the late-orogenic granite but may also occupy vertically inclined joint planes striking at either N60°W or at N10°W. As in the case of the epidote veins the various directions followed by the quartz veins will be commented on in a later section.

THE PEGMATITE VEINS

Distribution: Pegmatite veins occur in the late-orogenic granite but are generally too small in dimension to be shown on the geological map of the area (Fig. 2). Only one pegmatite vein is known in the later phase granite and it is situated on the western flank of the Mgubudhla River.

Petrology: Two varieties of pegmatite have been recognized in the area. Firstly, pegmatite containing quartz and feldspar and a second type containing quartz, feldspar and mica. Microcline-perthite is the feldspar common to both and the mica in the last mentioned type of pegmatite is invariably muscovite. The quartz occurs as cores in addition to its presence with the feldspar.

Structural Features: The pegmatite veins are steeply inclined and seldom exceed a width of two feet. The veins have clean contacts and do not extend for any great distance along strike, the maximum measured length being eighty feet. In the foliated parts of the late-orogenic granite they may either be aligned parallel with the foliation or seal joints striking at N10°W. In the later-phase granite the pegmatite veins occur along joints striking between N40°W and N10°W. Comments will be made later on the significance of the directions stated above and also upon the paragenesis of these rocks.

THE PETROGENESIS OF THE GRANITES AND ASSOCIATED ACID ROCKS

In the Barberton-Noordkaap-Louw's Creek area of the Barberton Mountain Land, Anhaeusser and Viljoen (1966) have recognized that the Nelspruit Granite is not homogeneous in character and that two distinct types with variations and gradations are present. There is a migmatic type, which is more common, and an intrusive variety along the contact with the layered formations of the Swaziland System. Anhaeusser and Viljoen are of the opinion that the typical Nelspruit migmatite represents, for the most

part, the basement upon which all 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. They contend that the intrusive granite represents the mobilized part of the re-heated and plasticized Nelspruit basement migmatite. The presence of this strip of granite along the contact zone is thought to be related to the updoming of the main body of migmatite.

In Swaziland the character of the so-called late-orogenic granite is entirely different. The main body of granite is a homogeneous, medium-grained biotite type with foliation developed only along its immediate contact zone. Hunter (1955) is of the opinion that the late-orogenic granite was emplaced as a mobile magma "whatever the ultimate origin of the magma was." Hunter maintains the CIPW norms for the late-orogenic granites (see Table 2) is chemical evidence favouring a magmatic origin. The normative albite, orthoclase and quartz was plotted and compared with the experimentally placed positions of the isobaric ternary minims in the system $NaAlSi_3O_8$ - $KAlSi_3O_8$ - SiO_2 - H_2O at various water vapour pressures and the "ternary" eutectic at 4000 kg/cm^2. It was observed that the plots lie, with exception of the pegmatite, in the central area and close to the locus of the isobaric ternary minims as determined by Tuttle and Bowen (1958). To quote those authors, the "... concentration of analyses near the centre of the diagram is readily explained if a magmatic history is involved in the origin of most granites. On the other hand, no method of arriving at such a composition by solid diffusion or hydrothermal metasomatism has been discovered."

In the area covered by this thesis, there are no outcrops to show the contact relationship between the late-orogenic granites and the ancient gneisses. Elsewhere in the Archean fold-belt of northwestern Swaziland, however, there is sufficient evidence to favour that the late-orogenic granites were emplaced as a magma. Immediately south of Pigg's Peak the author has observed tongues of biotite granite intruding gneisses of the Ancient Gneiss Complex and in the same area xenoliths of gneiss in the granites are not uncommon. North of Piggs Peak the intrusive nature of the

granites is again apparent, tongues of grey, medium-grained granite cutting granodioritic gneisses. To the southeast of the Hhohho area xencliths of ancient gneiss are caught up in the main mass of the late-orogenic granite. The distribution of the granites in relation to the ancient gneisses and Swaziland System rocks is shown in Figure 5.

The contact relationship between the granites and the layered rocks of the Swaziland System is nowhere exposed in the Hhohho area. To comment, therefore, on this relationship, reference must again be made to observations made in adjacent areas. Immediately south of Pigg's Peak wedges of typical late-orogenic granite have been driven between the intensely folded layered formations of the Swaziland System. Also xenoliths of talcose rocks occur within the granites. Furthermore, stocks of granite are to be found within the highly folded formations of the Swaziland System. In the Hhohho area itself boreholes drilled by the Swaziland Geological Survey during a prospecting programme intersected bands of grey foliated granite up to 20 feet thick at depths between 129 and 249 feet below surface at the Gordon Mine. The bands of granite are arranged parallel to the foliation of greenish-grey amphibolites of the Onverwacht Series. The presence of these bands is undetectable on surface. According to Hunter (verbal communication) the granite is typically of late-orogenic type.

From its relationships between the granites with the ancient gneisses as well as with the layered formations of the Swaziland System there can be little reasonable doubt that the granites were emplaced as a mobile magma. The development of foliation along the contact of the granites does, however, need some explanation. Working in the Barberton-Noordkaap-Louw's Creek area of the Barberton Mountain Land, Anhaeusser and Viljoen (1965) observed that a striking feature in the intrusive Nelspruit Granite is the very strong foliation developed along the contact zone parallel to the metamorphosed rocks of the layered sequence of the Swaziland System. They concluded that such foliation appears to be due partly to the strong alignment of mineral components under high pressure during crystallization and partly to a later, intensive, dynamic shearing. The latter led to a mechanical grinding of the

granitic material occurring mainly after crystallization. The parallel orientation of both these fabrics has had the effect of intensifying the overall foliation making the distinction between these two types difficult in the field. Anhaeusser and Viljoen contend that the fabrics are both related to the updoming of the main body of the Nelspruit migmatite. The intrusive material is visualized as being guided by planes of differential movement and shearing and this played a part in the alignment of the micas within the granite.

In Swaziland, however, it has already been shown that the granites were emplaced as a mobile magma. Reference has been made also to the fact that the granites are intruded in places (e.g. south of Pigg's Peak) along foliation planes of folded Swaziland System formations. The foliation developed along the contact zone of the granites corresponds in direction to those seen in the Swaziland System. The overall direction of the foliation is east-northeastwards which, as will be shown later, was induced by one of the main phases of deformation affecting the Archean fold belt of northwestern Swaziland. Hunter (1965) has suggested that because of the extensive distribution of the granites, it is reasonable to suppose their emplacement occurred in several heaves. The manner in which the granites are foliated along their contacts whereas the main mass is homogeneous and devoid of foliation tends to support such a contention. It seems reasonable to conclude that the foliated granite represents an earlier intrusion during the time that the stress field of the main orogeny was still mildly operative. Hunter (1965) maintains that the foliation in the granite "resulted from the presence of the partially crystallized magma against the country rocks with a resulting parallel arrangement of the early formed crystals. As the effect of the stress field waned the remaining mass of the granite was intruded, insinuating itself along the plane of weakness in the country rock." Under such a concept the so-called later-phase granite observed in the Hhohho could represent one of the final "heaves" of emplacement and in this respect its relationship with the main mass of the late-orogenic granite will now be discussed.

It will be recalled that the so-called late-phase of the late-orogenic granite is confined to the extreme southwestern corner of the Hhohho area where it occurs as tongues and lenses not only in the rocks of the Swaziland System but also in the late-orogenic granite itself. The orientation of the tongues and small bosses is broadly northeastwards so that they are oblique not only to the contact of the main granite mass but also to the foliation occurring within it. The fact that porphyritic granites similar in composition to the later-phase granite of the Hhohho area are definitely intrusive into the bulk of the late-orogenic granite elsewhere in the Archean fold-belt seems indicative that a similar relationship exists at Hhohho. Further substantiation is afforded by the relationship of the later-phase granite to the metamorphic facies developed within the aureole of the granites. Reference to Figure 4 will show that the tongue of later-phase granite extending from the southwestern boundary of the area to the confluence of the Ngubuohla and Lomati Rivers transects both the hornblende-hornfels and the albite-epidote facies whereas along its northern margin the metamorphic grade does not rise above the greenschist facies limit. It appears, therefore, that the tongue of later-phase granite was intruded into the various metamorphic facies resulting from the emplacement of the late-orogenic granite. The metamorphic effects of the later-phase granite itself are not apparent and the inference must be, therefore, that the later-phase granite represents a high level intrusion of a semi-crystalline "mush" in which the dissipation of heat was rapid.

The pegmatite, quartz and epidote veins represent the final phase of igneous activity associated with the granites. The quartz veins occurring within the layered succession of the Swaziland System and the foliated portions of the late-orogenic granite are generally aligned in sympathy with the principal cleavage direction and foliation respectively, (viz: N68°E). No evidence of cataclastic structures, such as strain quartz, have been observed and there can be little doubt that their intrusion post-dated the stress field responsible for the imposition of such cleavage and foliation. Less frequently, quartz veins seal north-northwesterly aligned joints which

most certainly post-date the main stress field since they transect both foli[illegible]nd cleavage. Whether or not the quartz veins following the diff[illegible]nt directions quoted above are of a different generation cannot be ascertained.

The epidote veins too occur in veins following two directions, namely northwestwards and east-northeast. Such veins occupy steeply dipping sheared joints and whereas the east-northeasterly trending variety correspond broadly with the principal cleavage developed in the area the northwesterly aligned sheared joints cannot be successfully related to the various stress f[illegible]lds responsible for the ultimate structure of the Hhohho area.

Like the quartz veins the pegmatites are devoid of any cataclastic structures and no strain quartz or orientation of micas is apparent. It is concluded, therefore, that they post-date the main stress field even though they are frequently orientated in an east-northeasterly direction. The pegmatite veins striking northwestwards are of coarser texture than the variety just discussed, though mineralogically they are similar. Elsewhere in the Archean fold belt of northwestern Swaziland the coarser-grained pegmatites striking northwestwards transect the finer-grained, east-northeasterly trending variety and are, therefore, of younger generation. Although no such relationship has been observed in the area under discussion, it is though reasonable to assume that the coarse and fine-grained pegmatite veins are similarly of different generations.

To summarize, therefore, it is vizualized t[illegible]t the late-orogenic granite was emplaced in several heaves. The main mass was intruded as the stress fields responsible for the northeast aligned folding and the imposition of the east-northeasterly cleavage and foliation in the Swaziland System was waning with the result that only limited portions of the crystallizing magma were foliated in response to th[illegible]s stresses.

The emplacement of the main mass of the late-orogenic granite resulted in contact metamorphism of the rocks of the Swaziland System. One of the later "heaves" of the granite intrusion is represented in the Hhohho area

by the so-called later-phase granite which was emplaced as a high level intrusion. Finally, quartz, epidote and pegmatite veins express the final phases of igneous activity associated with the granites

THE DYKES

INTRODUCTION

Intruded into all the rock types so far described are a number of basic intrusions in the form of dykes. Two varieties are known: firstly, diabase dykes which are thought to be pre-Karroo System in age, and secondly, dolerite dykes which post-date the Karroo System

THE DIABASE DYKES

Distribution: The main concentration of diabase dykes is along the flanks of the Mgubudhla River where they are impartially distributed in both the granites and the rocks constituting the Lower Stage of the Onverwacht Series (Fig. 2). A similar dyke is intruded into Moodies Series quartzites just over two miles east of Bearded Man Peak. In the vicinity of the Jackal Prospect a prominent diabase dyke transects amphibolites and talcose schists of the Lower Stage of the Onverwacht Series.

Petrology: The diabase dykes are fine-grained with a dark-green colour when freshly exposed. Weathering, however, results in outcrops having a rusty-brown coloured skin. Thin sections show they consist of plagioclase, normally andesine or labradorite, augite and varying quantities of diallage. The augite is commonly altered to green hornblende. Plagioclase and pyroxene are frequently set in a sub-ophitic relationship, though exceptional cases have porphyritic texture. Minor quantities of quartz may be present. Accessory minerals include sericite, chlorite, epidote, and dustings of magnetite. Deuteric alteration has been observed in some dykes resulting in myrmekitic or granophyric texture, the latter being discernable with the

naked eye. The feldspar, occurring as phenocrysts, is recognizable as andesine when not heavily sericitized. The principal mafic mineral is again augite altering to green hornblende. Leucoxene, chlorite and magnetite constitute the main accessory minerals.

Structural Features: The diabase dykes are orientated along either a direction west of north or strike northeastwards. As will be shown in the section dealing with the structural geology these directions correspond with the tension joints developed in the area.

THE DOLERITE DYKES

Distribution: The only prominent dolerite dykes occur in the area in the vicinity of the Daisy Mine (Fig. 2). They are intruded into amphibolites and talcose schists of the Lower Stage of the Onverwacht Series.

Petrology: The dolerite dykes, also dark-green in colour, are comparatively fresher in appearance than those described above. Their texture is granular idomorphic to almost gabbroidal. Two varieties of dolerite can be distinguished as follows:-

a) An olivine dolerite consisting of andesine-labradorite feldspar, augite and olivine. The last-mentioned mineral is well represented by partly rounded and fractured grains.

b) An enstatite dolerite containing andesine-labradorite feldspar, enstatite and augite. Olivine may be present in subordinate quantities or entirely absent.

Secondary minerals common to both varieties are quartz and chlorite with iron ores as the main accessories.

Structural Features: The dolerite dykes described above are represented on surface by piles of spheroidal boulders striking northeastwards. This direction corresponds with one of the tension joint directions developed in the area, a feature which will be discussed when dealing with structural geology.

METAMORPHISM

INTRODUCTION

It will be apparent from the petrological descriptions given of the rocks constituting the layered succession of the Swaziland System that they have, nearly without exception, been affected by varying degrees and types of metamorphism. Within the aureole of the intrusive granites the influence of thermal metamorphism and metasomatism are in evidence whereas at increasing distances from the granites, dynamic metamorphism, in the classical sense of the term, was operative in the Hhohho area.

TYPES OF METAMORPHISM

DYNAMIC METAMORPHISM

The effects of dynamic metamorphism are particularly apparent along the foothills of the Makonjwa Range where rocks of the Upper Stage of the Onverwacht Series have been subjected to severe shearing and folding. The most prominent expression is the re-crystallization and mylonitization of rocks subjected to such conditions. The process whereby secondary cherts are formed by mechanical means and accompanying re-crystallization has already been described and will not be dealt with again here. Mylonitization is generally the result of excessive shearing and along shear planes the mylonites frequently bifurcate and coalesce to enclose lenses of less disturbed strata.

Sericitization is a further expression of this type of metamorphism. Thus, the conversion of feldspar bearing rocks, such as acid lavas and

greywackes, to quartz-sericite schists commonly occurs and as such the metamorphism must be regarded as retrogressive in effect.

The development of cleavage, the parallel alignment of mineral constituents and the re-orientation of clastic particles are structural features imposed upon many rocks as a result of dynamic metamorphism.

CONTACT METAMORPHISM

The emplacement of the intrusive granites into the rocks of the Swaziland System has been responsible for the major metamorphic effects in the Hhohho area. Within the metamorphic rocks lying in juxtaposition to the granites three distinct metamorphic facies can be recognized.

THE METAMORPHIC FACIES

The concept of metamorphic facies was established by Eskola and in 1939 he stated: "A certain metamorphic facies comprises all rocks exhibiting a unique and characteristic correlation between chemical and mineralogical composition, in such a way that the rocks of a given chemical composition have always the same mineralogical composition, and differences in chemical composition from rock to rock are reflected in systematic differences of their mineralogical composition." The same author goes on to add: "The significance of this principle is based on the observation that the mineral parageneses of metamorphic rocks in many cases conform to the laws of chemical equilibrium...". Thus, as Winkler (1965) points out, a facies comprises a large number of rocks and, therefore, a group of mineralogical parageneses. The different parageneses are derived from rocks of very different chemical composition but are formed during metamorphism within the same range of conditions typical of this facies. Furthermore, the mineralogical composition of any rock belonging to a specific facies is strictly determined by the chemical composition of the rock; all rocks of the same chemical composition have the same mineralogical composition if they belong in the same facies.

The three metamorphic facies recognized in the Mhohho area, moving progressively away from the granites, are as follows:

i) a hornblende-hornfels facies,

ii) an albite-epidote-hornfels facies,

iii) a greenschist facies

The inclusion of the so-called greenschist with facies typical of contact metamorphism will be explained later.

The Hornblende-Hornfels Facies

The hornblende-hornfels facies, as defined by Turner and Verhoogen (1960), occurs along the immediate contact of the granites. Characteristic minerals of the facies are dark hornblende and plagioclase of intermediate composition. Close to the granites' contact, diopsidic pyroxene frequently makes an appearance. Sillimanite and garnet have not been observed in the Mhohho area. The dark-green hornblende amphibolite, previously described (p-3) is a typical rock type occurring in this facies.

ii) The Albite-Epidote-Hornfels Facies

The albite-epidote-hornfels facies includes lower temperature minerals such as tremolite-actinolite, biotite, chlorite and andalusite. The quartz-biotite, quartz-chlorite and quartz-sericite schists are rock types of the Mhohho area which are included in this facies. The pale-green unfoliated amphibolites (see p4), are also included despite a mineral assemblage appropriate to the greenschist facies since they are compared to the "camouflaged" rocks described by Hamberg (1952). For reasons previously stated, (p), the greenish-grey foliated amphibolites, containing some hornblende together with tremolite-actinolite, are considered as members of the albite-epidote-hornfels facies or even transitional between such facies and the higher grade hornblende-hornfels facies.

iii) The Greenschist Facies

The greenschist facies is made up predominantly of carbonate-bearing talc and chlorite schists containing some tremolite. Thus, the talc-amphibole, talc-chlorite, talc-chlorite-carbonate and talc-carbonate schists occurring in the Mhohho area typify the rocks of this facies.

THE DISTRIBUTION OF THE METAMORPHIC FACIES

In Figure 4 the distribution of the three metamorphic facies is shown in relation to the granites. It will be seen that the hornblende-hornfels facies is confined to the extreme southwestern corner of the area where both the late-orogenic and the later-phase granite have been emplaced. Along the contact of the main mass of the late-orogenic granite along, the metamorphic grade is no higher than the albite-epidote-hornfels facies. The last mentioned facies runs roughly parallel with the granite contact extending away from it for an average width of some 3500 feet. It seems, therefore, that the highest grade of metamorphism, (viz: the hornblende-hornfels facies), is only attained when both phases of granite were emplaced and embayed the rocks of the Swaziland System.

In the area extending from the middle reaches of the eastern-most tributary of the Ngubudhla River to the northeastern boundary of the area, the metamorphic grade is of the uppermost part of the albite-epidote-hornfels facies or even transitional between it and the hornblende-hornfels facies. The presence of such a metamorphic grade at an average distance of over 6000 feet from the granite contact may seem unrealistic. It will be remembered, however, from the discussion on the granites that bands of biotite granite have been observed at depths between 129 feet and 249 feet in the boreholes drilled at the Gordon Mine. It seem reasonable to conclude that the granites lie at no great depth, possibly in the form of a concealed cupola, so that a local zone of higher metamorphic grade than would be expected is formed away from the known granites' contact.

A further feature which requires comment is the manner in which tongues

of rocks, with mineral assemblages appropriate to the greenschist facies, intervene in facies of higher metamorphic grade. In this respect some conclusion must be made as to the likely conditions which prevailed to form the greenschist facies. It seems reasonable to assume that low grade metamorphism heralded the actual intrusion of the granites and at a time when the stress field responsible for the main phase of folding (see later) was still active. A greenschist facies thus formed under both thermal and dynamic metamorphism cannot be regarded as regional metamorphism in the classical sense of the term as is borne out by the fact that the grade of metamorphism in the facies itself deteriorates at increasing distances from the granites. When the granites were finally intruded, higher grade contact metamorphism was imposed on Swaziland System rocks already metamorphosed to greenschist facies grade, not only along the contacts of the granites but also in isolated zones where the granites were not far below the surface. With such a process of metamorphism it is possible to explain the somewhat irregular distribution of the greenschist facies in the Hhohho area.

POLYMETAMORPHISM

The emplacement of the granites in a number of "heaves" has induced polymetamorphic features in some of the Swaziland System rocks lying within the metamorphic aureole of the granites. Thus, in the foliated greenish-grey amphibolites and many of the talc-amphibole schists, two distinct ages of amphibole have been observed. The earliest of these is orientated parallel with the foliation or cleavage of the rock in question and must have been formed under conditions of contact metamorphism when the principle stress field (see later) was still operative. The haphazardly orientated amphibole, however, growing in a stellate fashion across both foliation and cleavage, was obviously formed later. There are no apparent petrological differences between the two ages of amphibole and it is assumed, therefore, that although they are of different generation

they are genetically related. The younger amphibole probably represents re-crystallization of the older as a result of thermal metamorphism after the stress field had become inactive.

There is evidence too that some retrogressive metamorphism has occurred within the metamorphic aureole of the granites. In the greenish-grey foliated amphibolites, which have been placed by the author as either in the albite-epidote-hornfels facies or transitionally between such facies and the higher temperature hornblende-hornfels facies, hornblende is enclosed by actinolite. As Turner and Verhoogen (1960) point out "... retrogressive metamorphism can only be diagnosed with certainty where metastable or partially destroyed relicts of the higher-temperature assemblages persist in an association of low-temperature minerals."

METASOMATISM

Turner and Verhoogen (1960) maintain that with the intrusion of magma the introduction of elements such as boron, fluorine and chlorine is almost universal. The gaseous transfer of such material from a crystalline granite pluton into adjacent rocks may well lead to metasomatic reactions and to the formation of minerals requiring introduced constituents.

In the Mhohho area it has been observed in some of the quartz-chlorite schists that besides the quartz and chlorite constituents, biotite, muscovite and sericite also occur. Such a mineral association together with observations that some chlorite flakes have an outer fringe of biotite would suggest that biotitization has taken place. As previously mentioned (p.56), the potassium necessary to transform chlorite to biotite may have been possible by reaction with some potash mineral such as muscovite or potash feldspar. The quartz-chlorite schists are, however, intimately interlayered with greenish-grey foliated amphibolites. In these last mentioned rocks plagioclase feldspar is invariably sericitized whereas the potash feldspar is remarkably clear. It would seem from the observations in both the above mentioned rock types that the potassium was introduced and it is

concluded that alkali metasomatism has occurred.

As the outer aureole of contact metamorphism in the Mhohho area is approached so the essentially basic rocks of the Lower Stage of the Onverwacht Series become increasingly steatized. It will be remembered from the description given of the talc-amphibole schists that the talc occurs as a confused aggregate frequently consuming and sometimes pseudomorphosely replacing both the orientated and the haphazard amphibole. Also in the talc-chlorite, talc-chlorite-carbonate and talc-carbonate schists, the talc shows no apparent sympathetic orientation with the schistosity of these rocks but occurs in frond-like aggregates. It is concluded, therefore, that talc was formed late in the paragenesis of these rocks the chemical analyses of which (see Table 3) indicates they are the metamorphic derivatives of either ultramafites or lavas of very basic composition. Hess (1933) defines the steatization of ultrabasic rocks as "... that process of hydrothermal alteration of an ultrabasic which in its final stages results in the formation of talcose rock." Turner and Verhoogen (1960) maintain that steatization may be accomplished by the addition of silica, and in some cases water, to serpentinized peridotites. The same authors conclude that more commonly " ... carbon dioxide metasomatism is involved, and dolomite or magnesite then appear as constituent phases of the end product." It will be noted in the Mhohho area that in the rocks which have undergone steatization, carbonate becomes a major mineral constituent. The carbonate occurs both interstitially to the talc and as large anhedral crystals enclosing talc and amphibole. In the latter condition there can be little doubt that the carbonate is the youngest mineral in the assemblage and it is reasonable to assume that carbonitization as a result of carbon dioxide metasomatism has taken place. Turner and Verhoogen (1960) state a number of possible reactions leading to the development of talc-carbonate schists as follows:

i) By the simple addition of CO_2, serpentine may be converted to a talc-magnesia rock without any appreciable change of volume.

$$2H_4Mg_3Si_2O_9 + 3CO_2 \rightarrow H_2Mg_3Si_4O_{12} + 3MgCO_3 + 3H_2O$$

Serpentine (220cc) — Talc (140cc) — Magnesite (84cc)

In the presence of lime bearing solutions dolomite may form instead of magnesite by a reaction involving the exchange of CaO by MgO a possible reaction being as follows:-

$$2H_4Mg_3Si_2O_9 + 1.23CaO + 2.46CO_2 \longrightarrow$$

Serpentine

(552gm.; 220cc) (68gm.) (108 gm.)

$$H_2Mg_3Si_4O_{12} + 1.23CaMg(CO_3)_2 + 1.77MgO + 3H_2O$$

Talc — Dolomite — (71gm) — (54 gm)

(378gm.; 140cc) (220gm.; 80cc)

ii) At higher temperatures ultrabasic rocks originally containing CaO, or exposed to lime-bearing solutions, tend to give an actinolite rock or, (if Al_2O_3 is present), actinolite-chlorite as a product of hydrothermal metamorphism. In the lower temperature of the greenschist facies, partial substitution of CO_2 for SiO_2 gives the assemblage talc-dolomite in place of actinolite. Likewise, talc may replace chlorite provided Al_2O_3 and some MgO can be removed in solution from the assemblage. Turner and Verhoogen (1960) suggest the following equations for reaction without change of volume:-

(1)

$$Ca_2Mg_5Si_8O_{22}(OH)_2 + 4CO_2 \longrightarrow 2CaMg(CO_3)_2 + H_2Mg_3Si_4O_{12} + 4SiO_2$$

Tremolite — Dolomite — Talc — (Removed in solution)

(810gm.; 270cc) (368gm.; 130cc) (378gm.; 140cc)

(2)

$$4H_4Mg_2Al_2Si_2O_9 + 6H_4Mg_3Si_2O_9 + 13.2SiO_2 \longrightarrow$$

Pennine

(2,768gm.; 1.025cc)

$$7.3H_2Mg_3Si_4O_{12} + 4.1MgO + 4Al_2O_3 + 12.7H_2O$$

Talc (Removed in solution)

(2,759gm.; 1.022cc)

iii) Alternatively, dolomite may be formed by the direct replacement of serpentine without the intervening appearance of talc. The composition of the active solutions, especially with regard to the concentration of lime and carbon dioxide, is likely to be the factor determining whether talc and dolomite or dolomite alone are ultimate products of metasomatism.

iv) At sufficiently high pressures of CO_2 under conditions allowing the removal of silica from the system, talc may be converted to a magnesite-quartz rock at the lowest temperatures of hydrothermal metamorphism. Turner and Verhoogen (1960) suggest the following equation of reaction without change of volume:-

$$H_2Mg_3Si_4O_{12} + 3CO_2 \longrightarrow 3MgCO_3 + 2.5SiO_2 + H_2O + 1.49SiO_2$$

Talc Magnesite Quartz Silica removed in solution

(378gm.; 140cc) (252gm.; 84cc.) (151gm.; 56cc) (89gm)

The same authors maintain that direct replacement of serpentine by an equal volume of magnesite and quartz under similar conditions could be expressed thus:- (see overleaf)

$$H_4Mg_3Si_2O_9 + 3CO_2 \longrightarrow 3MgCO_3 + 1.17SiO_2 + 2H_2O + 0.83SiO_2$$

Serpentine	Magnesite	Quartz	Silica removed in solution
(276gm.; 110cc)	(252gm.; 84cc)	(70gm.;26cc)	(50gm.)

Both equations given above are based on the assumption that the material removed in solution is silica.

Mention has already been made of the presence of tourmaline in the metamorphic rocks lying adjacent to the granites. Tourmaline is frequently associated with quartz veins transecting foliation and cleavage development and it can be reasonably assumed that the tourmaline represents the effects of boron metasomatism.

STRUCTURAL GEOLOGY

INTRODUCTION

Reference to the geological map of the Hhohho area (Fig.2) will show that essentially the layered formations of the Swaziland System have been piled into a series of northeast trending folds. There is evidence, however, that subsequent stresses have also been active and although less intense have, nevertheless, left their imprint on the ultimate structural pattern of the area. It is proposed to describe the various phases of deformation which have occurred and to relate them, whenever possible, to the observations made by other investigators in Swaziland and the Barberton Mountain Land. This will be followed by a summary and synthesis of the structural history of the area.

THE PHASES OF DEFORMATION

At least three phases of deformation, post-dating the Moodies Series in age, are known to have occurred. It is possible that these deformations have been superimposed upon the structures of an earlier orogeny which preceeded the deposition of the Moodies Series. Little is known of this earlier orogeny, however, as any evidence of it has been obliterated and, in consequence, only the post-Moodies deformations can be described in any detail.

THE MAIN PHASE OF DEFORMATION

The so-called Main Phase was by far the most intense of the folding phases operative in the area, compressing the rocks of the Swaziland System into near isoclinal folds with a general northeast trend. The Mooiplaas, Kamhlabane and Daisy Anticlines and the Mooiplaas, Makonjwa and Mashobeni Synclines (see Figs. 2 and 3) typify the folds of this phase of deformation. Any structural analysis of any of these large scale folds has been prohibited by the general paucity of small scale folds and planar

structures related to any one individual major fold. Consequently, the author has been compelled to make observations of small scale structures from the area as a whole.

Observations in the field confirm the intensity of the stresses responsible for the structures of this phase of deformation for the majority of the small scale folds are so acutely appressed as to be almost isoclinal. In Fig. 6[a] a stereogram plot of small scale folds related to the Main Phase of deformation is shown. The method adopted is similar to that used by Ramsay (1963) in the Barberton area, the data being plotted on an equal area, lower hemisphere stereogram. It should be noted here that all directions given in the following text refer to true north. From Figure 6[a] it can be seen that the fold axes plunge steeply at angles varying between 50 and 80 degrees either to southeast or in a direction east of north. Such severity of plunge is difficult to explain unless it is inferred that this phase of folding was imposed on beds which were no longer horizontal. Ramsay (1958) maintains that the orientation of axes folds is directly related to the inclination of the surface before the development of these folds. Thus, where first fold limbs are isoclinal or fairly steeply inclined, the plunge of any fold axes superimposed on them will be fairly steep. In the Rhohho area, as previously mentioned, there is no evidence existing of pre-Main Phase folding. There is, however, substantiation that tilting of the pre-Moodies surface took place for the rocks of the Moodies Series lie unconformably on the Onverwacht Series and formations that can be correlated with the Figtree Series are completely absent (pp.39,70,91).

Axial plane cleavage is pronounced particularly in argillaceous beds or near the hinges of folds. Such cleavage is particularly well developed too in the core of the Makonjwa Syncline so that Moodies Series quartzites weather into slab shaped outcrops resembling tombstones (see Plate VIII). More commonly, however, cleavage development is less apparent in siliceous rocks and where they have suffered extreme appression adjustment is afforded by minor fractures and thrusts, buckling and occasional brecciation and

recrystallization on the intrados of the fold. In beds of differing competencies, diffraction of the cleavages may be frequently observed. Generally however, axial plane cleavages are concordant with the axial planes of the folds and both are steeply inclined either to the northwest or to the southeast, though as is shown in Figure 6, the mean average dip is at 86 degrees to the southeast. The average strike of the axial planes and axial plane cleavages is in the direction N 4° East. The "fanning" achieved by these structures is a further indication of the intensity of the compressive forces responsible for the Main Phase folding. According to Hills (1963):

"Regional variations in the dip of cleavage so as to form a 'fan' as seen in cross-section has been described in several regions. With local exceptions due to inhomogeneities and to the special features of individual folds. cleavage fans are related to the tectonic setting of a folded belt". It seems likely in the Rhohho area that the essential structure is part of an synclinorium formed as a result of continuous and intensive stresses acting in a southeast - northwest direction. Such an interpretation is substantiated by geological maps of the Geological Survey of South Africa, (1956).

The spread of the axial plane and axial cleavage plane poles on a great circle, as can be seen in Figure 6, requires some comment. Two alternatives are possible; either it resulted from the imposition of the planar fabric on a previously folded surface or buckling has taken place caused by later phases of deformation. Since there is no evidence of pre-Main Phase folding but only of tilting and because, as will be shown later, the cleavage of the Second Phase show a similar "spread", it is concluded that the second alternative is more likely.

The orientation of the folds of the Main Phase in the Rhohho corresponds with that of the F.1 Phase as described by Ramsay (1963) and the Main Phase of deformation accounted for by Roering (1966).

THE SECOND PHASE OF DEFORMATION

It has been frequently mentioned in the text so far that a prominent structural feature in the area is the development of cleavage along

a direction of N68°East . The parallel alignment of metamorphic minerals in many schists and the flattening and re-orientation of clastic particles in arenaceous rocks of the Swaziland System is almost invariably sympathetic with the direction of this cleavage. Reference to Figure 6b shows that the average dip of the cleavage is at 81° degrees to the south-southeast but, as in the case of the axial planes and axial plane cleavages of the Main Phase, there is a marked tendency for "fanning" to occur. Thus, individual cleavage planes may either be inclined to the north-northwest or to the south-southeast. There can be little doubt that this cleavage post-dates the folding of the Main Phase for the following reasons:-

i) The Second phase cleavage has been observed in the field to be oblique to the axial planes and axial plane cleavages associated with Main Phase folds as is shown in Figure 6c.

ii) It has also been seen that the Second Phase cleavage not only transects the axial plane cleavage but also the bedding of strata forming the limbs of Main Phase folds. Figure 6d is a diagrammatic sketch of a small scale fold associated with the Makonjwa Syncline and illustrates the relationship.

The "fanning" effect achieved by the cleavage in the Mhohho area and the manner in which it is spread slightly along a great circle (Fig. 6b & 6c) is very similar to that displayed by axial planes and cleavages of the Main Phase. The author has concluded, therefore, that like the Main Phase structures, the cleavage of the Second Phase has also been buckled and bent by stresses of a subsequent phase or phases of deformation.

Both Ramsay (1963) and Boering (1965) working in the Barberton Mountain Land recognized similar imposition of cleavage on earlier structures. The former author classifies the cleavage as the F2 phase and the latter as part of his Main Phase of deformation.

THE LATER PHASES OF DEFORMATION

Throughout the Hhohho area there is evidence that later and less intense phases of deformation have been superimposed on all the structures so far described.

The only large scale manifestation of the Later Phases is in the "arching" of the northeast aligned Mooiplaas Anticline at the foot of Bearded Man Peak. This arching is about a northwest trend and constitutes the so-called Mgubudhla Anticline (see Figures 2 and 3). No statistical analysis of the Mgubudhla Anticline is possible as there is insufficient data available. This is due to the fact that the massively bedded nature of the Moodies quartzites and homogeneous character of the underlying basic lavas of the Onverwacht Series inhibits the preservation of minor folds. Furthermore, the contact between the quartzites and lavas is seldom well exposed. Consequently, as was the case with the folding of the Main Phase, it has been necessary to collect data of the Later Phases of deformation from the area as a whole.

The folds of the Later Phases of deformation are generally of concentric or modified concentric type, as illustrated in Plate IX and are best developed in narrow beds of banded chert or quartzite. The folded units maintain almost constant thickness and folds change shape and die out both upwards and downwards. In less competent argillaceous beds folds of accordion type and occasionally of similar type may be developed. The accordion folds are characterized by nearly straight limbs and sharply curved crests and troughs and the form of the folds continues unaltered for quite appreciable distances. Thickening of the beds in the apical positions is only slight and the presence of slickensliding indicates that bedding slip has occurred. In the case of folds of similar habit thickening of the beds near the fold hinges and their attenuation on the limbs is obvious though not excessively developed. Axial plane cleavage is seldom well developed and is the exception rather than the rule.

The folds of the Later Phases of deformation are aligned in two distinct

directions; one set striking almost north-south and the other in a north-westerly direction as is shown in Figures 6^e and 6^f. The axial planes of the north-south aligned folds dip on average at 71 degrees to the east. Fold plunges are steep [illegible] generally about 70 degrees in a southeasterly direction (Fig. 6[illegible]). The axial planes of the northwest aligned folds dip to the northeast at between 45 and 75 degrees to the east-northeast or southeast.

It has not been possible to determine the relative ages of the two differently orientated folds described above which constitute the so-called Later Phases of deformation. Working in the Barberton Mountain Land, Ramsay (1963) recognized a third period of deformation (F3) the folds of which trend northwestwards whilst Urie (1965) carrying out a reconnaissance structural investigation in the Forbes Reef area of Swaziland maintains that cross-folding along northwest axes has been imposed on the main structural pattern of that area. Roering (1965), however, divides the F3 Phase of Ramsay into a Barberton Trend and a Consort Trend. The former embraces folding about north-south aligned axes and the latter folding along north-west striking axes. The style and directions of the folds of these trends corresponds closely with alignment of the Later Phases of folding in the Mhohho area and the author correlates them accordingly.

Although no conclusion can be made as to the relative ages of the two differently aligned folds of the Later Phases to each other, there is sufficient evidence to conclude that they were superimposed on the structures of both the Main and Second Phases of deformation.

i) Minor folds around either north-south or north-west aligned axes have been in the field to buckle and fold axial plane cleavages developed in folds of the Main Phase of deformation.

ii) Slaty cleavage of the Second Phase of deformation is frequently seen to be buckled and folded about either north-south or northwest aligned axes. Thus, in the Mgubudhla Anticline sericite contained within such cleavage has been seen to be bent and broken in a direction corresponding with the

axial trend of the anticline. Further evidence occurs in the Makonjwa Syncline where slaty cleavage of the Second Phase is deformed and gently folded about both north-south and northwest trending axes.

iii) Reference to Figures 6^e and 6^f will show that the plunges of Later Phase folds are steep and that a slight spread occurs of minor fold axes on the axial plane. Such phenomena indicates that the folds have been superimposed on a previously deformed surface.

It is noteworthy here that the general alignment of the basic dykes in the area is either east-northeast or slightly west of north. Similarly, the quartz, epidote and pegmatite veins strike east-northeast, northwest or in a north-south direction. Such directions correspond with those of the various phases of deformation described above and there can be little doubt that these intrusions follow lines of structural weakness induced by such deformations.

FAULTING

Regional strike faulting is prominent in the structural pattern of the Mhohho area as can be seen from Figures 2 and 3. In most cases the faults are poorly exposed and little information can be obtained of such structural phenomena as slickenslides, tension cracks, shear planes, lineations or folds adjacent to such faults. In the field the strike faults are usually indicated by zones of extensive mylonitization which effectively obliterate such structural phenomena. Consequently, any analysis of the faulting must be very largely speculative.

The majority of the faults appear to be high angle thrusts inclined to the southeast and down throwing to the northwest as typified by the Bearded Man, Kamhlabane and Mashobeni Faults (Figs 2 and 3). The dips of the faults correspond broadly with the axial planes of the major northeast

aligned folds and their strike is roughly coincident with the trend of such folds. It would seem, therefore, that the development of Main Phase folds and the strike faulting is related. Ramsay (1963) is of the opinion that the major strike faults in the Barberton Mountain Land were developed as thrusts on the overturned limbs of early anticlines and this is very largely substantiated in the Mhohho area (Fig.3). Due to the complex structural history of the area it is very probable that more than one movement direction has occurred on the fault planes. It is reasonable to conclude that the faults have been repeatedly reactivated in different stress fields and as a result become thrust-wrench faults with an essentially dextral movement, as is particularly noticeable in the case of the Kamhlabane, Mhlotshana and Mashobeni Faults (Figs 2 and 3). A number of faults corresponding with the maximum shear direction associated with the major strike faults occur throughout the area, the Nothma and Ufafa Faults being typical examples.

SUMMARY AND SYNTHESIS OF THE TECTONIC HISTORY OF THE MHOHHO AREA

It has been shown that the layered rocks of the Swaziland System have been subjected to at least three phases of deformation which postdate the Moodies Series in age. Little is known of any earlier orogeny other than that tilting occurred prior to the deposition of the Moodies rocks with the result that they lie unconformably upon formations correlated as part of the Onverwacht Series and that no Figtree Series is known in the area. The tilting is reflected by the steepness of the plunges attained by the folds of the so-called Main Phase of deformation.

The stresses of the Main Phase must have operated in a northwesterly or southeasterly direction so that the layered rocks constituting the Swaziland System were piled into a series of near isoclinal folds with a northeast to southwest trend. The axial planes and axial plane cleavages of these folds are on average steeply inclined to the southeast but a "fanning" effect is apparent due to some of the planes dipping to the northwest. It seems likely, therefore, that the essential structure of the Mhohho area is that

of part of a northeast aligned synclinorium.

Subsequent to the folding about northeast-southwest aligned axes a marked regional cleavage was imposed by the stresses of the so-called Second Phase of deformation. Such stresses, presumably operating along a south-southeast to north-northwesterly direction, resulted in cleavage development on a strike of N60°E. This cleavage, in which parallelism of amphiboles and micas and the re-orientation of clastic particles is frequently contained transects the limbs, axial planes and axial plane cleavages of the northeast aligned folds and so there can be little doubt that its development post-dates the Main Phase of deformation. A stereogram plot of the cleavage planes shows that they are inclined either to the north-northwest or to the south-southeast so that a "fanning" effect results. Such "fanning" of regional cleavage is a common feature in fold belts and it seems likely, therefore, that although the development of the east-northeast striking slaty cleavage post-dated the northeast aligned folds of the Main Phase, the stresses responsible for the two phases are "genetically" related. It is visualized by the author that the stress which imposed the slaty cleavage was a later pulsation of the Main Phase operating in a slightly different direction.

Further complexities of structure are afforded by cross-folding on the structures so far discussed by the stresses of what are termed as the Later Phases of deformation. The folds of these later phases are essentially of concentric or modified concentric type though in some more argillaceous formations, especially in the core of minor folds, folds of accordion type may develop. The Later Phases folds occur either along northwest to southeast or north to south trending axes which correspond respectively to the Consort and Montrose folding trends recognized by Roering (1965) in the Barberton Mountain Land. There is insufficient information in the Mhohho area to determine the relative ages of the differently trending folds but there can be little doubt that they have been superimposed upon the structures of the Main and Second Phases of deformation. This is substantiated not only by the steepness of their plunges, indicating that the folds occurred

on an already deformed surface, but also by evidence in the field of axial plane cleavages of the Main Phase and slaty cleavage of the Second Phase being buckled by folds with either northwest or north-south trending axes.

Strike faults play an important role in the structural pattern of the area under discussion and the manner in which their dips and strikes correspond with the axial planes of Main Phase folds suggest that they are closely associated with the development of such folds. The faults are mainly wrench-thrust faults with dextral movement, which in some isolated cases is confirmed by slickensliding, and it would seem that reactivation by more than one stress force has occurred along them.

In an area as small as the one used for the topic of this thesis it is difficult to determine the origins of the various stress fields which have contributed to its structural history. The possibility that the rocks of the Swaziland System were laid down in geosynclinal conditions has been expressed by such workers as Urie (1957), Hunter (1961), Viljoen (1964) and Roering (1965). The author visuallizes that the sedimentary rocks and lavas of the Onverwacht Series were deposited in a sagging northeast aligned geosynclinal depression. Early crustal disturbances preceeded the deposition of the Moodies Series in the Rhohho area as is indicated by the unconformable relationship existing between the Onverwacht and Moodies formations and the absence of any formations which can be correlated with the Figtree Series. Soon after the deposition of the Moodies Series the first period of folding, probably initiated during the down-sagging and deposition of the geosynclinal sediments, reached its maximum force resulting in the development of major, northeast trending golds of the Main Phase.

The folding of the Main Phase was followed by the widespread development of cleavage with an east-northeasterly strike with which is associated the flattening and re-orientation of clastic particles and the parallel alignment of metamorphic minerals. The last-mentioned minerals, mainly micas and amphiboles, occur within the contact zone of the granites and indicate that thermal metamorphism was active when the stress fields were still operative. The inference must be, therefore, that the emplacement of the

granites was either broadly synchronous with the Second Phase of deformation or it occurred when its operative stresses were waning. The latter is more likely to apply since the bulk of the granites is unfoliated except for a comparatively narrow zone along the contact.

The origin of the stresses responsible for the Later Phases of deformation cannot be ascertained in the Hhohho area. Roering (1966) suggests that the cause of the cross-folding in the Barberton Mountain Land was due either to the emplacement of the Kaap Valley Granite or the northeast movement of an already consolidated Kaap Valley Granite pluton towards the Nelspruit Granite. The same stresses could also have been responsible for the right-lateral wrench fault component observed on many of the regional strike faults. The age relationship between the granites and the Later Phases of deformation cannot be determined in the Hhohho area. Urie (1965), however, has measured the strike and dip of marginal foliation in the granite to the south of the Motjaan Valley in the Forbes Reef area of Swaziland and has observed that these are gently arcuate about a northwest trending fold axis. Furthermore, Hunter (1965) has noted in the Motjaan Valley that granite dykes intrude along the median planes of northwest trending fold axes. It is concluded, therefore, that the Later Phases of deformation took place after the emplacement of the late-orogenic granites but prior to its complete consolidation.

GOLD MINERALIZATION

INTRODUCTION

Three derelict gold workings, namely the Gordon and Daisy Mines and the Jackal Prospect, are located in the Mhohho area. They lie at the foot of the Makonjwa Range on the flanks of the Mhlotshana River. The history of the mines dates back to 1886 when the mineral rights were granted to McLachlan and Scott. Later in the same year the concession was transferred to the Horo Concession Exploration Company subsequently re-named the New Horo Concession Company. Between the years 1886 and 1890 this company mined gold from what is now known as No.1 Quarry of the Daisy Mine (Fig. 7). In 1903 the concession was tributed to the Swaziland Corporation Limited who conducted operations until 1914 when mining ceased. In 1910 the Gordon Mine was opened but closed again in the following year.

In 1913 the concession was numbered No. 32A and in 1926 was ceded to the Swaziland Corporation (1934) Limited. Finally it passed into the hands of New Consolidated Goldfields who in 1961 surrendered the concession to the Crown. The concession is now vested in the Swazi Nation in terms of a ruling by the Secretary of State for Commonwealth Affairs.

Production figures for the Daisy and Gordon Mines are shown in Table 8 and refer only to the years from 1907 onwards. There are no records whatsoever relating to the Jackal Prospect which was only discovered by the author in 1967.

Available old records state that in the years 1908 to 1913 about 60,000 tons of ore were milled and treated in a 20-stamp mill at the Daisy Mine which indicates that the average grade over this period was just over 2 dwts./ton.

Except for a brief description by Hall (1916) in his survey of the Barberton Mountain Land gold belt no previous publications are known relating to the gold occurrences in the Mhohho area. In 1961 the author undertook an investigation of the gold mineralization on behalf of the Geological Survey

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Department of Swaziland. The department subsequently undertook a drilling programme at the Daisy and Gordon Mines the results of which were published by Hunter and Jones (1962).

GEOLOGY OF THE GOLD OCCURRENCES

It will be shown that the localization of gold mineralization in the Mhohho area can be attributed to both lithological and structural controls. It is proposed, therefore, to describe the stratigraphical succession in each occurrence as well as the structural geology. This will be followed by a discussion on the localization of the gold, a description of the mineralogy of the ore bodies and finally an account of their paragenesis.

STRATIGRAPHY

The stratigraphical succession of the rocks occurring in the Daisy mine will be described first to be followed by similar accounts of the Gordon Mine and Jackal Prospect. The gold deposits all occur within rocks correlated as the Lower Stage of the Onverwacht Series.

1) The Daisy Mine

The gold mineralization of the Daisy Mine occurs on the north-western or "footwall" side of a hard siliceous zone henceforth referred to as the Daisy Bar (Figs 8 and 9).

Overlying this 'bar" is a succession consisting primarily of amphibolites in which occur narrow zones of quartz-biotite and quartz-sericite schists, meta-quartzites and cherts. The amphibolites are of the foliated, greenish-grey coloured variety which have been previously described (see pp. 46 - 48) To summarize briefly, they are medium-grained with a speckled appearance due to the presence of elongate felsic blebs. The characteristic amphibole belongs to the actinolite-tremolite group which occurs either in fibrous form or as elongate laths. The amphibole is usually orientated parallel to the foliation though a later generation of actinolite-tremolite occurs in

haphazard fashion across the foliation. Weakly pleochroic hornblende is sometimes present as anhedral plates enclosed by the haphazardly orientated actinolite-tremolite. Quartz, ranging from minor quantities to as much as 50 per cent, occurs in a fine mosaic either as elongate blebs or in bands conformable with the grain of the rock. Stringers of blue and white-grey coloured quartz frequently emphasise the foliation of the rock but show no evidence of deformation so it can be concluded that they post-date the foliation. Minor quantities of sericitized plagioclase feldspar and clear microcline are present as anhedral or sub-anhedraly developed plates. Carbonate is common and appears partly to replace the amphibole, the latter remaining as ragged cores in the former. Accessory minerals are sphene and tourmaline.

The narrow zones of quartz-biotite schist have sharp contacts with the amphibolites described above and vary in thickness from a few inches up to eight feet. They consist essentially of a granular mosaic of quartz and flakes of strongly pleochroic biotite. Carbonate occurs liberally throughout as ill-formed crystals with polysynthetic twinning.

Approximately sixty feet above the Daisy Bar ribs of chert and meta-quartzite appear in the succession. The cherts, which seldom exceed three feet in thickness, are grey-coloured cryptocrystalline in texture and devoid of any banding. The meta-quartzites have an average thickness of five feet. They have a laminated appearance due to alternating layers of shaly material and bands consisting of clastic quartz and minor quantities of ragged muscovite. Small amounts of reddish-brown biotite are also present.

The Daisy Bar itself varies in thickness from a minimum of 30 feet to a maximum of 100 feet. It is debatable as to whether this variation is due to original conditions of sedimentation or to duplication resulting from shearing though, as will be shown later, the latter case is considered more likely to apply. The upper portion of the "bar" consists of a coarse-grained, granular grey quartz schist which attains a maximum thickness of 25 feet. Underlying this schist is a brown-coloured cryptocrystalline chert varying from 5 feet to 30 feet in thickness. The chert is often strongly fractured

the fractures being filled by quartz veinlets. Below the chert is a distinctly foliated, green-coloured quartz-sericite schist varying in thickness from 25 feet to 60 feet. Bands of pyrite up to two inches wide lie conformably with the foliation giving the rock a distinctive appearance. No gold is associated with this schist.

Underlying the Daisy Bar, for a maximum of 175 feet, is a succession of amphibolites and quartz-biotite schists similar to those described occurring above the Daisy Bar. In general, however, the quartz-biotite schist are more abundant over the bottom thirty feet. The schists tend to be more siliceous in composition than their equivalents lying above the Daisy Bar. Also the succession is invaded by a complex network of quartz and carbonate veins and contains an appreciable quantity of sulphides. Tourmaline is commonly associated with the veinlets of carbonate and quartz.

A distinctive green-coloured schist underlies the amphibolites and quartz-biotite schist previously mentioned. This schist consists of a fine-grained aggregate of quartz and chlorite together with some sericite. In thickness it varies from 5 feet to 20 feet and, as in the case of the Daisy Bar, it is considered that the variations are the result of strike faulting rather than conditions of deposition.

An unknown thickness of talc-amphibole schists occur beneath the quartz-chlorite-sericite schist. Not infrequently a narrow zone of quartz-biotite schist intervenes between it and the talcose schists though the quartz-biotite schist seldom exceeds fifteen feet in thickness. The talc-amphibole schists are soft, pale to dark-green in colour and often intensely contorted. The characteristic amphibole is tremolite which is crudely aligned to give the schists a foliated appearance. Narrow zones of slightly darker greenish-grey coloured rocks containing actinolite occur within the bulk of the tremolite bearing schists. These zones are devoid of any well-defined foliation and their contacts are usually sharp and abrupt. Examination under the microscope shows that they consist of laths of pale-green coloured actinolite and minor quantities of wispy biotite. The actinolite shows no preferred orientation and tends to develop in a stellate fashion.

Carbonate is common and may occur in quantities only slightly subordinate to that of the amphibole and may be frequently seen replacing laths of actinolite. Tourmaline is the most prominent accessory mineral.

Numerous narrow zones consisting of amphibolite, quartz-biotite and quartz-chlorite schists and chert occur sporadically within the talc-amphibole schists. The most prominent are as follows:

i) In the vicinity of No.1 Quarry of the Daisy Mine a zone consisting of quartz-biotite and quartz-chlorite schists occurs some twenty to thirty feet below the uppermost contact of the talc-amphibole schists (Fig. 7 and 8). The zone, which is approximately forty feet thick, is richly impregnated with sulphides of which pyrite is the most prominent.

ii) Some 600 feet east-northeast of No.1 Quarry, known as the Daisy Mine Eastern Extension (See Fig. 8), foliated greenish-gray amphibolites, granular quartz schists and chert occur 120 feet below the top contact of the talc-amphibole schists. The quartz schists immediately overlie and underlie the chert, those above being approximately ten feet thick whereas the thickness of those below is unknown.

One borehole, namely No. 177, situated at the south-southwestern corner of the mine intersected narrow bands of granite just over three feet thick at depths of 70 feet and 324 feet below the base of the Daisy Bar in the talcose schists.

2) The Gordon Mine

The Gordon Mine is situated 2,700 feet southwest of the Daisy Mine and along the same strike (Fig. 7). As in the case of the Daisy Mine the gold mineralization is localized on the northwestern or "footwall" side of the Daisy Bar. The stratigraphical succession too is similar but with variations in the thicknesses of the individual lithological units. (Fig. 8).

Above the Daisy Bar occur an unknown thickness of foliated greenish-grey amphibolites with narrow zones of quartz-biotite schists which become increasingly well developed as the uppermost contact of the Daisy Bar is approached. Some 22 feet above the Daisy Bar a three feet thick chert band is present in the succession..

The Daisy Bar itself is reduced to a maximum thickness of 25 feet at the Gordon Mine. Granular quartz schist constitutes the upper part of the "bar" but seldom exceeds 15 feet in thickness. It differs from the equivalent schist in the Daisy Mine in as far as it contains narrow zones enriched with amphibole and biotite. Immediately below the quartz schist occurs a dense cryptocrystalline chert with a greyish-brown colour and which seldom exceeds a thickness of five feet.

The succession underlying the Daisy Bar is made up of foliated greenish grey amphibolites and quartz-biotite schists but in contrast to the Daisy Mine it is reduced in thickness from 175 feet to a mere 25 feet. It is not known whether this variation is due to original conditions of deposition or to the effects of strike faulting. Since, however, considerable strike faulting occurs in the Daisy Mine it is assumed that similar conditions apply in the Gordon Mine (see later). The distinctive green-coloured quartz-chlorite-sericite schists which mark the base of the amphibolite succession in the Daisy Mine is completely absent in the Gordon Mine, possibly due also to the result of faulting.

Below the rocks described in the preceeding paragraph is a succession of talc-amphibole schists the thickness of which is unknown. The characteristic amphibole in these schists is tremolite. Narrow bands of actinolite bearing rock and thin zones of quartz-biotite schist occur in the succession the most prominent of these being a three feet wide zone some fifty feet below the top contact of the talc-amphibole schists.

Bands of granite up to twenty feet thick occurring both above and below the Daisy Bar were intersected by the boreholes sunk at the Gordon Mine. (Fig. 10)

3) The Jackal Prospect

The Jackal Prospect is situated 1,400 feet northeast of the Daisy Mine on the banks of the westernmost tributary of the Mbongosi River (Fig.7) The working consists of two levels both of which are developed on the north-western or "footwall" side of the Daisy Bar. The uppermost level consists of a cross-cut driven for 115 feet in a northwesterly direction through a succession of foliated amphibolites, quartz-chlorite-sericite schist and chert. It is considered that this succession corresponds to that occurring 175 feet below the Daisy Bar in the Daisy Mine.

The lower level follows a northeast striking lenticular shaped body of foliated greenish-grey amphibolite enclosed by talc-amphibole schist. The amphibolite body probably represents an isolated zone similar to those described in the Daisy Mine.

In the Jackal Mine area the Daisy Bar is overlain by a quartz-sericite schist zone which attains a maximum thickness of 25 feet (Fig. 2). It consists of a finely granular quartz matrix and prolific quantities of interstitial sericite. Quite commonly the schists have a "knotted" appearance due to the presence of anhedral crystals of andalusite. The zone thins out when traced southwestwards so that it is entirely absent in the vicinity of the Daisy Mine. Overlying the quartz-sericite schist are foliated pale greenish-grey amphibolites similar to those occurring in the Daisy and Gordon Lines.

STRUCTURAL GEOLOGY

The general inaccessibility of the underground workings and the paucity of surface outcrops makes an elucidation of the structural geology difficult. Furthermore, the rocks have been subjected to the effects of both thermal and dynamic metamorphism so that original lithological features have been very largely destroyed. Information derived from boreholes drilled in the vicinity of the mines, however, enable an interpretation of the geological structures to be made.

1) The Daisy Mine

Geological mapping of the Mhohho area has shown that the rocks of the Swaziland System have been piled into a series of near isoclinal folds with a northeasterly trend. It is considered that the gold workings are situated on the limbs of such a fold. Thus, in the vicinity of No. 1 Quarry of the Daisy Mine, small scale 'S' type folds with northeast trending axes can be observed in the Daisy Bar. Boreholes sunk in the vicinity of the quarry (Figs 7 and 9) confirm the development of such 'S' folds on a larger scale below the level of the quarry floor. No structural analysis of these folds has been possible since they are almost invariably developed in hard siliceous rocks and insufficient three dimensional measurements can be obtained. Some folds, however, are seen to plunge at 45 degrees to the east and have quite well developed axial plane cleavage. The cleavage is generally inclined at 80 degrees to the southeast whereas the average bedding dip is at 67 degrees in a similar direction indicating that the major fold in the environ of the mines is anticlinal. The development of 'S' folds in the Daisy Mine area further suggests that the axis of this fold (viz: the Daisy Mine) lies somewhere to the southeast.

As has been observed throughout the Mhohho area a subsequent cleavage, the result of the second Phase of deformation, is apparent especially in the amphibolites and siliceous schists so that the bulk of the amphibole and micas in these rocks is aligned parallel with the cleavage. Such cleavage is slightly oblique to the axial plane cleavage and also transects the limbs of the northeast aligned folds. No folds which can be related to the Later Phases of deformation have been observed in the Daisy Mine.

Strike faults play an important role in the geological structure of the mine the most prominent of which is the so-called Daisy Fault (Figs 7 and 9). The strike of the faults is generally northeastwards and, although slightly oblique to the axes of the northeast aligned folds, it seems reasonable to suppose that their development was closely associated with the folding (see p 129). As is common throughout the Mhohho area the faults are steeply inclined thrust-wrench faults with a dextral movement. The

Daisy Fault itself, however, is exceptional being a sinistral fault with a normal downthrowing movement on its southeastern side. It has considerable effect upon the behaviour of the quartz-chlorite-sericite schist zone lying at the base of the foliated greenish-grey amphibolites. Thus, in boreholes No. 162 and No. 173 the succession of amphibolites with quartz-biotite schists below the Daisy Bar are duplicated by this fault and the borehole positions of the quartz-chlorite-sericite schist zone cannot be correlated with its surface outcrops (Fig. 11).

The thrust-wrunch character of the majority of the strike faults can be attributed to two reasons:-

i) The vertical or thrusting movement represents a means of relief from acute compression induced by the Main Phase stress field which operated in a northwest-southeast direction. The lateral component could be the result of re-activation along the fault planes due to the stresses of the Later Phases of deformation operating in a northeasterly direction.

ii) The nett movement responsible for the development of the thrust-wrench faults was upwards at approximately 45 degrees resulting in the two apparent components in a vertical and lateral or horizontal sense. The fact that the fold axes in the Daisy Mine plunge at 45 degrees in an easterly direction could be regarded as substantiation in this respect. Any movement along the fault planes would be at right angles to the fold axes or, in other words at 45 degrees upwards. The nett movement, thus, could be resolved into two components (i.e. vertical and lateral or horizontal) giving both reverse and wrench movement components to the faults. The sinistral movement of the Daisy Mine can be explained in a like manner though it is very probable that it is, in fact, part of a fault zone which overall has a thrust-wrench component of movement and only the relative movement of the individual "blocks" makes is appear a left-lateral

or sinistral fault with a normal downthrow.

There is insufficient data available in the mine workings to enable a structural analysis of the faults and so any discussion of the origin of the stresses responsible for their mechanism must be very largely speculative. In an area, such as that being discussed, it seems reasonable to assume that the complex history of folding resulted in more than one direction of movement along the fault planes and that they have been repeatedly re-activated in different stress fields. Thus, although two reasons can be proposed for the thrust-wrench movement of the strike faults, it is probable that their movement resulted from a combination of both.

Some comment must be made of the so-called Quarry Fault which occurs in the vicinity of No. 1 Quarry (Figs. 7 and 8). The pattern of underground development in the Daisy Mine (Fig. 1.) would suggest that this northwest striking fault displaces the ore-body. The fault dips to the north at approximately 50 degrees and has a downthrow of about twenty feet in the same direction though its main component of movement is laterally in a sinistral sense. It is interesting to note that both the Daisy and Quarry Faults have left-lateral wrench component of movement and in relation to one another the former may be regarded as a first order left-lateral wrench whereas the latter is consistent with a second order left-lateral wrench fault. The primary stress field would, therefore, have been operative in a northwesterly direction according to Hills (1963). Such a direction in the Mhohho area corresponds with one of the stress fields of the Later Phases of deformation as already discussed in the section dealing with the structural geology. For reasons stated above it is thought that the Daisy Fault was formed firstly as part of a thrust zone in close association with the northeast aligned folding of the Main Phase of deformation and possibly that its lateral or horizontal movement resulted from re-activation by this later stress field along the fault plane. The left-lateral wrench component of movement of both the Daisy and Quarry Faults would thus be regarded as substantiation that such re-activation has occurred. With lateral or

horizontal movement taking place along the Daisy Fault the sympathetic development of a second order left-lateral wrench, namely the Quarry Fault, seems feasible. Since the Quarry Fault apparently displaces the ore-body in the Daisy Mine, the inference must be that the localization of the gold took place at an early stage of the Later Phases of deformation (see later). As previously mentioned, however, the faults are poorly exposed and no concrete evidence can be produced to substantiate the above conclusions.

2) The Gordon Mine

Other than the variations in the thicknesses of the various lithological units compared with those in the Daisy Mine, there are no important structural effects apparent in the Gordon Mine. It has been previously mentioned how the Daisy Bar is reduced to a maximum thickness of 25 feet and that the underlying succession of foliated greenish-grey amphibolites does not exceed 75 feet (i.e. a total decrease in the succession of 225 feet). Furthermore, the quartz-chlorite-sericite schist at the base of the amphibolites in the Daisy Mine is completely absent in the Gordon Mine. As such variations in the succession occur over a strike length of only 2,700 feet it seems likely that they are the result of strike faulting rather than original conditions of deposition.

3) The Jackal Prospect

Little is known of the structural geology of the Jackal Prospect since its surface area is covered by dense bush and the underground workings are limited in extent. The only structural features are confined to the Daisy Bar in which two sets of cleavage and some small scale folds can be observed. One set of cleavage strikes northeastwards at N54°E and the other at N68°E the latter transecting the former. The northeast striking cleavage corresponds with the general direction of axial plane cleavage developed in folds attributable to the Main Phase of deformation (Fig. 6^B), and the east-northeast cleavage with the cleavage of the Second

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Phase of deformation (Fig. 6^b).

The small scale folds are of modified concentric type, the axes of which trend north-south and since the folds buckle and bend the two sets of cleavage mentioned above, there can be little doubt that they are related to the so-called Later Phases of deformation.

THE LOCALIZATION OF GOLD

The gold mineralization in the Daisy and Gordon Mines is associated with impregnations of quartz and sulphides below the Daisy Bar. The auriferous zones occur at or adjacent to the contacts of rocks of differing competencies and particularly where such rocks have been effected by folding and strike faulting. It is proposed to describe the localization of gold in each of the two mines in turn but no comment will be made of the Jackal Prospect as sampling of its underground workings proved negative with regard to gold values.

1) The Daisy Mine

Reference to Figures 8 and 9 will show that the gold mineralization in the Daisy Mine occurs mainly in the foliated, green-grey amphibolites and associated quartz-biotite schists lying below the Daisy Bar and above the quartz-chlorite-sericite schist horizon. The main concentration lies in the vicinity of No. 1 Quarry though no surface outcrops now exist due to the fact that mining operations have excavated the ore-body to the plane of the Quarry Fault. Boreholes sunk to intersect the ore-body beneath the fault plane found auriferous zones occurring where 'S' folds and northeast aligned strike faults are extensively developed. Thus, boreholes No. 255 and No. 155 intersected a number of parallel aligned auriferous zones mainly occupying fault planes sympathetically aligned with the Daisy Fault (Fig. 13). In the former mentioned borehole three zones occur, one immediately below the bottom contact of the Daisy Bar and the other two at distances of78 feet and 100 feet lower, carrying values of 58.68 inch/dwts, 13.00 inch/dwts and

93.00 inch/dwts respectively. In the latter mentioned borehole the auriferous zones, carrying 132.75 inch/dwts, 122.40 inch/dwts and 627.30 inch/dwts, occur respectively at 105 feet, 140 feet and 175 feet below the bottom contact of the Daisy Bar. The lowermost and richest zone in this borehole is almost in immediate contact with the distinctive green-coloured quartz-chlorite-sericite schist. Boreholes No. 250 and No. 178 also intersected gold values and in both cases the gold mineralization is localized above the quartz-chlorite-sericite schist zone. (Figs 14 and 15). The highest values were intersected in borehole No. 152, namely 1063.04 inch/dwts, 132.84 inch/dwts and 171.72 inch/dwts, in three zones lying between eighteen and six feet above the quartz-chlorite-sericite schist (Fig. 16).

Except for the gold mineralization concentrated on the bottom contact of the Daisy Bar in borehole No. 256, the auriferous zones described above can be correlated with strike faults. Reference to Figure 9 will show that these faults, when traced southwestwards, truncate the limbs of the 'S' folds intersected in borehole No. 171 though they tend to be barren with regard to gold mineralization at this locality. No auriferous zones were found in the talc-amphibole schists lying below the quartz-chlorite-sericite schist in the vicinity of No. 1 Quarry.

In the surface cutting linking No. 1 and No. 2 Quarries gold occurs in a zone varying in thickness from 31 inches to 77 inches along the upper contact of the quartz-chlorite-sericite schist. The values in this zone range from 1.50 dwts/ton to 7.50 dwts/ton.

Boreholes No. 183 and No. 170, which were drilled to intersect the auriferous zones below No. 2 Quarry also intersected gold values. The former found a zone carrying 57.00 inch/dwts lying approximately seven feet below the plane of the Daisy Fault and five feet above the quartz-chlorite-sericite schist (Fig. 9). The latter borehole intersected two zones, the uppermost occurring six feet above the quartz-chlorite-sericite schist and along the plane of the Daisy Fault and lowermost zone a quartz impregnated shear 60 feet deeper in the talc-amphibole schists. The two zones in this borehole have values of 294.10 inch/dwts and 88.80 inch/dwts respectively.

No gold mineralization is apparent in the vicinity of No. 3 Quarry both surface sampling and borehole No. 168 being completely barren.

The gold mineralization in No. 4 Quarry is exceptional in as far as it occurs below the quartz-chlorite-sericite schist zone (Fig. 9). In the quarry itself mining has been carried out in foliated greenish-grey amphibolites intervening between the bottom contact of the last mentioned zone and the underlying talc-amphibole schists. The exact localization of the gold mineralization cannot be ascertained due to the thoroughness of quarrying operations and the fact that underground workings are no longer accessible. Boreholes No. 162 and 173 which were drilled to intersect the ore-body beneath the quarry floor did not locate gold in the foliated amphibolites (Fig. 11). Gold was located, however, by both boreholes in quartz-filled shears in talc-amphibole schist below the quartz-chlorite-sericite zone. In borehole No. 173 gold mineralization with a value of 115.20 inch/dwts occurs between the quartz-chlorite-sericite schist zone and a possible fault and further gold with a value of 56.10 inch/dwts some 44 feet deeper. In borehole No. 162, gold mineralization with a value of 98.60 inch/dwts occurs 48 feet below the quartz-chlorite-sericite schist and is possibly a continuation of the deeper auriferous zone described in borehole No. 173.

Although gold bearing zones were found in talc-amphibole schists by boreholes No. 170, 162 and 173, these rocks are generally barren. It is concluded that the incompetent nature of the schists inhibited the development of open fault or shear planes which would have been congenial to the emplacement of gold.

From the distribution of gold mineralization in the Daisy Mine, it can been seen that the highest values occur where structural phenomena, such as 'S' folds and strike faults are most intensely developed. With the exception of the No. 4 Quarry area the auriferous zones occur mainly along the planes of the various strike faults thereby confirming the opinions of Anhaeusser (1965) that there is association between structures with a horizontal displacement and the localization of gold. It is apparent in the

Daisy Mine, however, that the varying degrees of competency between rocks of differing compositions have also influenced such localization. Thus, it is noteworthy that the auriferous zones occur mainly below the Daisy Bar and above the quartz-chlorite-sericite schist horizon. It would seem, therefore, that these competent siliceous rocks acted as effective barriers to the auriferous solutions restricting their emplacement to suitable channels in the less competent amphibolitic rocks. Such a conclusion is substantiated by the presence of gold immediately below the Daisy Bar in borehole No. 155 and of gold mineralization along the uppermost contact of the quartz-chlorite-sericite schist in the surface cutting between No. 1 and No. 2 Quarry.

2) The Gordon Mine

In the underground workings of the Gordon Mine, consisting of two adits 35 feet vertically apart driven northeastwards, gold mineralization lies adjacent to the bottom contact of the Daisy Bar. Gold is confined to a zone, which on average is four feet wide, consisting of many narrow quartz veinlets impregnating foliated greenish-grey amphibolite and quartz-biotite schist. These blue-grey coloured veinlets often coalesce to form a single vein which strikes northeastwards and dips at 75 degrees to the southeast. The highest value obtained from systematic sampling of the zone only realized 1.60 dwts/ton over an average width of 31 inches.

Two boreholes were drilled at the Gordon Mine to determine whether the auriferous zone persisted at depth. Borehole No. 185 intersected a value of 4.60 dwts/ton over a true width of 15 inches in the immediate footwall of the Daisy Bar at a depth of 219 feet down dip from the surface (Fig. 10). In borehole No. 180 core was lost at the base of the Daisy Bar but fragments of quartz vein were recovered which when crushed revealed the presence of gold. In the same borehole a 36 inches wide quartz impregnated zone was intersected in talc-amphibole schists 52 feet below the bottom contact of the Daisy Bar. The gold value in this zone was low, however, only realizing 1.20 dwts/ton (Fig. 10).

It would seem that the gold mineralization in the Gordon Mine was localized by the presence of the Daisy Bar rather than by structural controls. The hard, competent character of the "bar" probably presented an effective barrier to the auriferous solutions resulting in the concentration of gold along its hanging contact. It is possible that the zone of gold mineralization intersected by borehole no. 100 in talc-amphibole schists occupies a shear zone or fault plane but such a statement cannot be substantiated.

THE MINERALOGY AND PARAGENESIS OF THE ORE BODIES

The mineralogy, the relationships between minerals and the paragenetic sequence of ore deposition were studied by means of polished sections under an ore microscope.

It was seen that the ores from the Daisy and Gordon Mines are identical consisting mainly of pyrite with lesser amounts of chalcopyrite and pyrrhotite set in a fine-grained gangue composed of quartz, carbonate, amphibole, biotite and other micaceous silicates. Small crystals of rutile and chromite are scattered sparingly throughout the gangue constituents. The ores are, therefore, consistent with the pyritic group of ores according to the classification of de Villiers (1937).

PYRITE

Pyrite is the most common sulphide in the ore and is readily detected in hand specimens. It is scattered indiscriminately throughout the quartz veins as well as in the immediately adjacent wall-rock of the ore-bodies. Individual grains generally have euhedral or sub-euhedral form and seldom exceed 0.2 mm in diameter measured in polished sections. The pyrite is frequently surrounded or partly surrounded by other sulphides as is shown in Plate X. This feature, together with the normal paragenetic sequence of mineral deposition suggested by Lindgren (1937), would indicate that it was deposited prior to the introduction of the other ore minerals.

The absence of any pressure shadows in the pyrite would indicate that the pyrite mineralization occurred either after the Later Phases of deformati or at least at a time when the stress fields of these phases were waning.

PYRRHOTITE

Practically all the ore examined contains pyrrhotite. The miner lacks external crystal form and occurs either moulded within its surroundings or as discreet anhedral particles. The particles measure up to 0.2 mm in diameter and occasionally it occurs as pseudomorphs after pyrite or the gangu minerals. Chalcopyrite is commonly associated with the pyrrhotite as an irregular intergrowth and in a few cases "flames" of pentlandite up to 0.0 mm in length can be seen in the pyrrhotite. Examination of some polished sections, however, indicate that the chalcopyrite is slightly younger than the pyrrhotite since it imposes itself between grains of the last-mentioned mineral and with different orientations along the grain boundaries (Plate X). In one polished section, namely specimen No. DM1A, a vein of chalcopyrite was observed transecting a grain of pyrrhotite (Plate XII). The manner in which pyrrhotite moulds itself around the margins of euhedral grains of pyrite indicates that it is younger than the latter mineral, but in turn is older than the chalcopyrite as mentioned above.

CHALCOPYRITE

Chalcopyrite is nearly always associated with pyrrhotite though is not present in such abundant quantity. It may occur either moulded around pyrite crystals or as small individual grains. The latter are highly irregular in shape and vary in size from 0.001 mm to 0.20 mm. The relationship between chalcopyrite and pyrrhotite has already been described and will not be repeated again here, but there can be little doubt that chalcopyrite represents the youngest of the sulphide minerals.

GOLD

Unlike pyrite, pyrrhotite and chalcopyrite which were readily detected in every polished section examined, gold was found to occur in only a few specimens. Even so the gold is not visible to the naked eye and its presence was only confirmed by means of an ore microscope. It occurs as irregular shaped particles varying in size from 1 micron to 25 microns in the quartz (Plate XIII), but may also be found in the approximate vicinity of the sulphide minerals. In the latter case the gold commonly occupies interstitial positions between the grains of the sulphide minerals [redacted] or, as in other cases, a more intimate relationship can be observed. Thus, in the polished section of specimen No. DM13 a bleb of gold occurs in a euhedral crystal of pyrite [Plate XIV] and the No.DM14 vein gold is closely related with pyrrhotite (Plate XV). It can be seen, therefore, that although gold occurs primarily in the quartz it cannot be completely divorced from the sulphide mineralization. Furthermore, its association with pyrite and pyrrhotite, as described above, indicates that it was emplaced late in the paragenetical history of the ore-bodies.

SUMMARY AND CONCLUSIONS OF THE GOLD MINERALIZATION

The bulk of the gold mineralization in the Mhokho area is confined to the Daisy Mine and, to a lesser extent, the Gordon Mine. In both instances the localization of the gold has been influenced by both lithological and structural controls. Thus, the so-called Daisy Bar, a hard competent siliceous horizon, is considered to have formed an impervious barrier to the auriferous solutions resulting in the concentration of gold in the comparatively softer and incompetent amphibolites with associated quartz-biotite schists lying below the bar. At the base of the amphibolites occurs another competent horizon in the form of a narrow quartz-chlorite-sericite schist and it is immediately above this horizon that the richer ore deposits lie.

Structurally, it is thought that the Daisy and Gordon Mines are situated on the limb of a northeast aligned anticlinal fold developed as a result

of the stresses of the so-called Main Phase of deformation. Evidence of such folding is afforded by the curvilinear margins of the Mhohho iron and by the presence of symmetrical 'S' folds especially in the vicinity of the [illegible] of the re essentially thrust-wrenches with a pronounced dextral component of move- [illegible] associated with the folds is a number of strike faults which are essentially thrust-wrenches with a pronounced dextral component of move- ment. The strike of these faults is only slightly oblique to the axial planes of the 'S' folds and it would seem that they were initially thrust faults the development of which was intimately associated with the folding of the Main Phase of Deformation. Their lateral movement was probably induced by the stresses of subsequent deformations especially that operating in a northeasterly direction. In the Daisy Mine the gold mineralization is localized where such faulting has occurred in the amphibolitic rocks and quartz-mixtite schist underlying the Daisy Bar. At the Cordon Mine the effects of structural controls are less obvious and the gold mineralization is confined mainly along the hanging contact of the Daisy Bar. It would seem, therefore, that the gold mineralization in the Mhohho area has been localized near or at the contacts of rocks of differing competencies and particularly where the incompetent rock have been subjected to strike faulting these strike faults offering suitable channels for the auriferous solutions.

The mineralogy of the ore-bodies is comparatively simple consisting of pyrite, pyrrhotite and chalcopyrite set in a gangue consisting primarily of quartz and lesser quantities of carbonate and micaceous silicates. Gold itself occurs mainly as irregularly shaped isolated particles in the quartz. Its association, in some cases, with pyrite and pyrrhotite, however, suggests that its deposition was closely related with the sulphide mineralization and late in the paragenetical history of the ore-bodies. The ores appear to be typically hydrothermal and, considering their mineral assemblage, in the mesothermal class of ore deposits.

The fact that no pressure shadows were observed in the pyrite would signify that the sulphide and gold mineralization took place late in the structural history of the Mhohho area. Since it is considered that the lateral component of movement of the strike faults was probably induced by the stresses

of the later phases of deformation, it is inferred that the gold mineralization occurred either after such stresses had ceased or when they were diminishing. The so-called Quarry Fault, which is consistent with a second order left-lateral wrench fault, appears to be barren of gold mineralization and also to displace the auriferous zones in the Daisy Mine. As this fault was probably developed as a result of the stresses of the later phases of deformation it must be concluded that the deposition of gold occurred during the dying stages of that particular deformation.

Any comments on the origin of the gold is speculative as no substantiative evidence can be put forward. In the present area, however, it is obvious that gold mineralization is confined to essentially basic rocks which have been metamorphosed by the intruding granites. Two possibilities arise, therefore, either that the gold and its associated quartz gangue originated from the granites or that the gold was present in trace amounts in the basic lavas of the Lower Stage of the Onverwacht Series. In the former case the quartz and associated gold would represent the final phase of igneous activity associated with the intrusion of the granites. In the latter case the gold inherently present in the basic lavas was mobilized when they were metamorphosed by the intrusive granites and migrated to be emplaced in congenial zones such as adjacent to the contacts of competent and incompetent rocks or in open fault or shear planes. A geochemical survey, undertaken in the area by the United Nations Development Project (Mineral Surveys) on behalf of the Geological Survey of Swaziland, shows that the arsenic and antimony decrease towards the granites but are more prominent in the basic rocks of the Onverwacht Series and as such could be regarded as a possible substantiation of the above theory. It cannot be overlooked, however, that the distribution of antimony and arsenic could also indicate that the sulphide and gold bearing solutions were expelled completely from the granites and migrated considerable distances away into suitable zones in the adjacent country rocks.

PART III

SUMMARY AND CONCLUSIONS OF THE PRESENT INVESTIGATION

Along the northwestern border of Swaziland, layered Archean rocks occur in a narrow fold belt extending from Ubhoh at its southwestern extremity to Hhohho at its northeastern extremity. The present work gives an account of the geology over a tract of country covering some 30 square miles in the Hhohho area. The area was selected since it is an intrinsic part of the Barberton Mountain Land and contains a number of interesting features. Thus, the layered Archean rocks constituting the Swaziland System have been complexly folded and faulted by at least three phases of deformation and lie immediately adjacent to intrusive granites. In consequence these rocks have been subjected to both dynamic and thermal metamorphism. Gold mineralization occurs in the metamorphosed rocks lying within the aureole of the granites, the localization of which has been influenced by lithological and structural controls.

The lowest member of the Swaziland System is represented by rocks correlated as belonging to the Onverwacht Series. The series can be conveniently divided into two parts, namely a Lower Stage and an Upper Stage.

The Lower Stage of the Onverwacht Series consists essentially of an assemblage of basic rocks in which siliceous zones occur as narrow intercalations. The full thickness of the assemblage cannot be ascertained as it is intruded by granites along the southeastern margin of the Hhohho area. As a result of contact metamorphism it is now represented by amphibolitic rocks and talcose schists with narrow zones of quartz-biotite schist, quartz-sericite schist meta-quartzite and primary and secondary chert .

The amphibolitic rocks are thought to be derived in some cases from sedimentary origins and in others from interlayered lavas of basic to ultrabasic composition. Thus, the dark-green hornblende amphibolites and the foliated green-grey amphibolites display marked banding which is concordant with associated quartzitic rocks, cherts and siliceous horizons suggesting

bedding features. Chemical analyses show that the ratio CaO to MgO approximates that of dolomite and it is concluded that these amphibolites were derived from carbonate-bearing sedimentary rocks resembling siliceous limestones. Other amphibolites, such as the unfoliated pale-green variety, consist primarily of tremolite-actinolite which occurs in a felted mass of flakes and needles without any marked mineral alignment. The chemical compositions of such amphibolites is consistent with rocks of basic or ultrabasic composition since they contain a relatively high magnesia content. The manner in which these amphibolites comply with siliceous horizons, meta-quartzites and chert bands indicates they are interlayered in the succession. It is concluded, therefore, that they represent lava flows although no substantiating evidence such as amygdales or pillow structures have been observed. At an increased distance from the contact of the granites, the basic and ultrabasic rocks are represented by calcose schists. In this manner it is considered that the talc-amphibole schists are the equivalent of the pale-green unfoliated amphibolites at a lower grade of metamorphism. In the talc-chlorite, talc-chlorite-carbonate and talc-carbonate schists, however, no amphibole is apparent, not even in the form of pseudomorphs after that mineral, and so it is assumed that it was never present as a constituent in these rocks. Their chemical analyses, high magnesia content and the presence of a low but consistent quantity of nickel and chrome would indicate that such schists were derived from ultramafites.

Many of the siliceous rocks occurring in the metamorphosed Lower Dore succession can be regarded as having been derived from sedimentary origins. Thus the majority of the quartzitic horizons have distinct bedding characteristics and contain grains of clastic quartz. Also the primary and secondary cherts are also of sedimentary origin, the former as a chemical precipitate and the latter as a result of recrystallization induced by dynamic metamorphism. The origin of the quartz-biotite and quartz-chlorite schists, however, is debatable and it is suggested that they are both derived from impure grits. The quartz-sericite schists may represent the metamorphic derivatives of either sedimentary or extrusive rocks. Thus,

those schists containing quartz, sericite and andalusite are thought to be derived from alumina-rich shales whereas those containing only quartz and sericite may have originated from feldspathic sediments, tuffs or acid lava flows.

At the foot of Bearded Man Peak in the core of the Mooiplaas Anticline occur amygdaloidal and non-amygdaloidal lavas which have suffered little from the effects of thermal metamorphism. The lavas, which are essentially of basic composition, contain narrow intercalations of greywacke, shale and mudstone. The succession is regarded as belonging to the Onverwacht Series, though whether in the Upper or Lower Stage cannot be determined, and is directly overlain by the basal beds of the Moodies Series.

The Upper Stage of the Onverwacht Series is distributed mainly along the foothills of the Makonjwa Range and consists of shales, greywackes, quartzites, narrow conglomerate bands, primary and secondary cherts and quartz-sericite schists. With the exception of the last mentioned schists, many of which may have been derived from acid lavas, the sedimentary rocks dominate the succession. The rocks of the Upper Stage were in the past regarded as belonging to the Figtree Series. Detailed mapping undertaken by the author to the southwest of the Mhohho area, however, shows that this so-called Upper Stage of the Onverwacht Series in the Mhohho area is overlain by at least 2000 feet of acid and basic lavas, tuffs with only minor intercalations of sedimentary rocks. Such a succession can only be realistically included in the Onverwacht and not in the Figtree Series.

The relationship between the Upper and Lower Stages of the Onverwacht Series in the Mhohho area is usually obscured by faulting except near the westernmost margin where a conformable contact can be observed. The Upper Stage is not fully developed, however, since it is overlain unconformably by the Moodies Series and in consequence any formations which could be correlated with the Figtree Series are absent.

The overlying Moodies Series is made up of over 3,000 feet of quartzite and conglomerates. At the base of the series occurs a well-developed, compact, ill-sorted pebble conglomerate frequently containing pebbles of ferruginous

banded cherts and limestone typical of the Figtree Series and they were in all probability derived from such a source. It is debatable as to whether the Figtree Series was ever deposited in the Mhohho area, but in view of the presence of the pebbles mentioned above it seems reasonable to assume that the series was eroded away prior to the deposition of the Moodies rocks.

Above the basal conglomerate the Moodies Series consists of quartzites of both micaceous and felspathic type which contain scattered pebbles of quartzite and chert together with numerous ill-sorted conglomerate horizons.

It is visualized that the rocks of the Lower Stage of the Onverwacht Series were deposited in unstable, deep water conditions. The conditions for the deposition of the succeeding Upper Stage were also unstable though the depository must have been comparatively shallower. Such conditions must have been surely true for, as previously mentioned, the Upper Stage in Mhohho is overlain by a considerable thickness of lavas further to the southwest and there can be little doubt that these last-mentioned rocks were deposited in comparatively deep water conditions. The complete absence of formations which can be correlated with the Figtree Series would indicate that a pre-Moodies Series orogeny occurred, as is substantiated by the unconformable relationship between the Moodies and the Onverwacht Series. The generally coarse-grained nature of the Moodies Series rocks together with such features as cross-bedding and the frequent development of conglomerates would suggest that they were laid down in shallow water conditions. As some 2,000 feet of essentially arenaceous rocks are present, it is thought that isostatic re-adjustments occurred to enable such a thickness to be deposited as is indicated by the intraformational unconformities in the succession.

Subsequent to the deposition of the Moodies Series the rocks of the Swaziland System were complexly folded and faulted by a number of deformational phases. The first and most severe phase, the so-called Main Phase of deformation, piled the layered Archean rocks into a number of near isoclinal folds along northeast aligned axes. Strike faults developed in close association with the folding on the overturned limbs of early anticlines. Continuous compression seemingly produced thrust slices which moved upwards to different

levels over successive blocks to the northwest. The Second Phase of deformation resulted in the imposition of cleavage with an east-northeasterly strike. This phase, which transects the axial plane cleavages and the limbs of the Main Phase folds, was responsible for the re-orientation of clastic particles in arenaceous rocks and the parallel alignment of metamorphic minerals in the schists and amphibolites lying in the aureole of the granites. The stresses of the so-called Later Phase of deformation resulted in cross-folding and the buckling of pre-existing structures around either north-south or northwest aligned axes and also re-activated the thrust strike faults so that their component of movement is now consistent with thrust-wrench faults.

As the stresses of the Main Phase of deformation were waning, intrusive granites were emplaced into the folded rocks of the Swaziland System along the southeastern margin of the Archhaean. Two types of granite can be recognized. The main mass of granite, which is classified as late-orogenic type, is typically a medium-grained biotite granite which is frequently foliated along its margins. The second granite is coarser-grained with a porphyritic texture and devoid of any foliation. This last mentioned granite is regarded as a later phase of the late-orogenic granite since it transects the contact and marginal foliation of the earlier granite as well as invading its metamorphic facies of contact metamorphism. The final phases of the acid intrusions is expressed by the numerous quartz, pegmatite and epidote veins which seal foliation and joint planes in the granites. Quartz veins are also frequently found emphasising foliation and cleavage planes as well as shears and other lines of structural weakness in the rocks of the Swaziland System. Igneous activity in the Archhaean concluded with the intrusion of basic rocks in the form of dykes into the rocks of the Swaziland System and the granites. Both diabase and dolerite dykes are represented, the former being regarded as pre-Karroo System in age and the latter as post-Karroo System in age.

All the rocks in the area have been affected by metamorphism in varying degrees. The most intensive metamorphism occurs within the aureole of the granites whereas at increasing distances from it the effects of dynamic metamorphism become more pronounced. In the vicinity of the granites where contact

metamorphism is apparent, three distinct metamorphic facies can be recognized. A hornblende-hornfels-facies occurs along the immediate contact followed by an albite-epidote-hornfels facies and a greenschist facies, the latter being farthest away. The inclusion of a greenschist facies in the facies of contact metamorphism is proposed on the basis that low grade metamorphism heralded the actual intrusion of the granites and at a time when the stress field of the main phase of deformation was still active. A greenschist facies thus formed cannot be regarded as an expression of regional metamorphism in the classical sense of the term as is borne out by the parallel alignment of metamorphic minerals in the facies and the fact that its grade depreciates at increasing distances from the contact of the granites. It is concluded that the higher grades of metamorphism, such as the hornblende-hornfels-facies and the albite-epidote-hornfels facies, were subsequently imposed when the granites were actually emplaced.

It is visualized that the emplacement of the granites occurred in a number of 'pulses' resulting in polymetamorphism being inflicted on the rock of the Basement Complex lying within the margin of the granites. Evidence of such a process is afforded by the two generations of amphibole occurring in some of the amphibolitic rocks and also by the retrogressive metamorphism which takes place in the foliated grey-grey amphibolites. In the latter rocks, hornblende is partly replaced by actinolite and this association of relicts of a higher temperature mineral with a lower temperature mineral is regarded as diagnostic of retrogressive metamorphism.

As is almost universal with the intrusion of a magma, the gaseous transfer of elements into the country rocks to cause metasomatic reactions is thought to have also occurred in the Nhohho area. Thus, the biotitization occurring in some quartz-chlorite schists is attributed to the introduction of potassium rather than a reaction between chlorite and some potash mineral such as muscovite or potash feldspar. Furthermore, the quartz-chlorite schists are frequently associated with amphibolites in which the plagioclase feldspar is invariably sericitized whereas the potash feldspar is remarkably clear. It would seem, therefore, that in both cases the potassium was

introduced and that alkali metasomatism has taken place. In the amphibole, chlorite and carbonate bearing schists too, which occur in the greenschist facies, stratigraphy has taken place which is attributed to metasomatic processes. In the talc-amphibole schists, the talc consumes and sometimes pseudomorphously replaces the two generations of amphibole, whereas in the talc-chlorite-carbonate and talc-carbonate schists, the talc occurs as haphazard fresh-like aggregates without any preferred orientation. It is concluded, therefore, that talc was formed very late in the paragenetical history of these schists by metasomatism. A further expression of metasomatism is the presence of tourmaline in the metamorphic rocks lying adjacent to the granites. It is frequently associated with quartz veins which transect foliation and cleavage planes and it is assumed that the tourmaline was deposited as a result of boron metasomatism.

The deposition of gold in the present area is thought to be closely associated with the emplacement of the granites. It is debatable, however, as to whether the auriferous solutions emanated from the granites themselves or if the gold was originally present in trace amounts in the basic lavas of the Onverwacht series. In the latter case, the gold may well have been mobilized when the lavas were subjected to contact metamorphism and the gold migrated to be emplaced in congenial zones. Both lithological and structural controls have played a role in the localization of gold and the main deposits occur at or adjacent to the contacts between relatively competent and incompetent rocks or in open shear or fault planes.

Although the gold occurs mainly with quartz in the ore bodies, it cannot be entirely divorced from the sulphide mineralization for in some polished sections vein gold is seen in association with pyrite and pyrrhotite. The mineralogy of the ores is simple, consisting of pyrite, pyrrhotite and chalcopyrite, the first mentioned mineral being the oldest and the last mentioned the youngest in the paragenetic sequence, set in a fine-grained gangue of quartz, carbonate and minor quantities of micaceous silicates. The association between gold and pyrrhotite mentioned above suggests that the gold was deposited late in the history of the ore bodies.

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TABLE I

CHARACTERISTICS OF THE SIX DEFORMATIONAL PHASES RESPONSIBLE FOR THE STRUCTURAL DEVELOPMENT OF THE MAIN GOLD PRODUCING AREA OF THE BARBERTON MOUNTAIN LAND

Deformational Phase	Trend	Minor Structures Associated with Folding	Equivalent Phases of Ramsay 1963	Associated Regional Geological Events
Early Trend	?	?	Not recognized	Possible pre-Moodies orogeny
Mc. 1 Phase Deformation	E N E	Schistosity, cleavage, minor folds, mineral orientation in contact metamorphic rocks	F1 and F2	Emplacement of G4 Swaziland Granite (i.e late orogenic granite of Hunter 1965) and Nelspruit Granite (homogenized phase) Regional strike faulting First phase gold mineralization
Montrose Trend	N S to N N W	Minor folds and weak cleavage, conjugate folds and faulting	Believed to be part of F3	Emplacement and intrusion of granites in Badplaats area
Consort Trend	N W	Minor folds Planar fabric in incompetent rocks	F3	Emplacement and intrusion of Koap Valley Granite Second phase of gold mineralization
Late Ulundi Trend	E N E	Minor folds	Not recognized	Continued N N W stress derived from G4 Granite (i.e late orogenic in Swaziland
Flat Folds	Horizontal axial planes	Crenulation cleavage, accordion folds, conjugate folds	Believed to be part of F3	Rising up of Nelspruit Granite Re-activation of strike faults Intrusion of younger Granites (eg Mpageni, G5 of Swaziland.

After Roering (1965)

TABLE 2

STRATIGRAPHICAL SUCCESSION OF THE SWAZILAND SYSTEM IN THE HHOHHO AREA.

Unit	Rock Types	Thickness in feet
Moodies Series	Coarse grained quartzite with scattered pebbles	350+
	Compact pebble and boulder conglomerate	80-200
	Fine grained sometimes micaceous quartzite with scattered pebbles	400-620
	Fine to medium grained micaceous and feldspathic quartzite	0-370
	Medium grained quartzite with feldspathic grits, scattered pebbles and intermittent conglomerate bands	400-600
	Compact pebble and boulder conglomerate (Basal Conglomerate)	0-80
Onverwacht Series Upper stage	Greywackes, shales, phyllites, quartz-sericite schists, greenschists, grits, quartzites, secondary and primary cherts	?
Onverwacht Series Lower stage	Basic lavas, amphibolitic rocks, talcose schists, quartzites, phyllites, secondary and primary cherts	?

Explanation of Rock Type Numbers shown in Table 3:

1) Amphibole gneiss (Forbes Reef) of same type as dark hornblende amphibolite described in the Hhohho area

2) Biotite gneiss (Hhohho area) to be described later with regard to Hhohho area

3) Siliceous gneiss (Oshoek area) consisting of granular mosaic of quartz, partially sericitized sodic feldspar, interstitial grains of microcline and disorientated or rudely aligned ragged flakes of biotite Not recognized in the Hhohho area.

4) Olivine bearing amphibolite (Forbes Reef area) not present in the Hhohho area

5) Antigorite - amphibole schist (Forbes Reef area) not present in the Hhohho area

6) Amphibole - chlorite - talc schist (Forbes Reef area) similar to the pale-green amphibolites under discussion from Hhohho area.

7) Talc - chlorite schist (Forbes Reef area) to be discussed later with regard to Hhohho area

TABLE 3

TABLE 3. CHEMICAL ANALYSES OF METAMORPHIC ROCKS LYING WITHIN THE AUREOLE OF THE GRANITES IN THE ARCHEAN FOLD BELT OF SWAZILAND

Constituent	Rock Type Number						
	1	2	3	4	5	6	7.
SiO_2	50 74	51 74	72 40	43 60	42 10	49 80	50 60
Al_2O_3	10 97	17 04	11 90	4 60	5 06	4 89	5 26
Fe_2O_3	1 55	1 60	0 72	1 53	2 71	1 61	2·51
FeO	9 65	8 74	2 20	4 14	3 95	6 54	3 14
MgO	9 34	5 62	3 25	31 68	32 63	27 24	28 51
CaO	11 07	7 86	4 08	4 82	2 32	2 50	1 72
Na_2O	2 66	0 61	0 43	0 10	0 06	0 05	0 06
K_2O	0 34	2 68	1 16	0 11	0 07	0 04	0 07
H_2O+	1 45	1 48	1 90	7 19	10 25	6 42	6 80
H_2O-	0 05	0 07	0 06	0 18	0 48	0 21	0 45
CO_2	0 92	0 80		1 72	0 02	n.d	0 03
TiO_2	0 70	1 12	0 94	0 08	0 07	0 20	0 08
P_2O_5	0 05	0 05	0 07	0 03	0 02	0 05	0 04
S	0 55	0 49	0 40	0 06	n d	n d	n.d.
Cr_2O_3				0 37	0 37	0 37	0 36
MnO	0 22	0 13	0 23	0 10	0 11	0 17	0 05
NiO				0 1+	0 2+	0 2+	0 2+
BaO			0 42	n d+	0 01	0 01+	0 1+
SrO				n d+	n d.	n d	n.d.
F		0 03					
less (O = F) (O = S)	0 21*	0 01 0 18*	0 15*	0 03			
Total	100 05	99 93	100 01	100 38	100 43	100 30	99 89

After Urie and Jones (1965)

n d — not detected

\+ — determined spectographically

* correction based on assumption that all sulphur content present as pyrite

TABLE 4 A PARTIAL ANALYSIS OF TALCOSE SCHISTS.

Constituents	Specimen A	Specimen B
	Talc amphibole – chlorite schist	Talc – chlorite schist
SiO_2	49 8	50 6
Al_2O_3	4 89	5 26
Fe_2O_3	1 61	2 51
FeO	6 54	3 14
MgO	27 24	28 51
CaO	2 50	1 72
Na_2O	0 05	0 06
K_2O	0 04	0 07
H_2O+	6 42	6 80
H_2O-	0 21	0 45
CO_2	n d	0 0[illegible]
TiO_2	0 20	0 03
P_2O_5	0 05	0 04
S	n d	n d
Cr_2O_3	0 37	0 37
MnO	0 17	0 05
NiO	0 2+	0 2+
BaO	0 01+	0 01+
SrO	n d	n d
F	—	—
Total	100 30	99 89

After Urie B Jones (1965)

n d — not detected

\+ — determined spectographically

Analysts Overseas Geological Surveys (Mineral Resources Division) London

Specimens A and B were collected from the Forbes Reef Area

TABLE 5. PARTIAL ANALYSIS OF TALC-CARBONATE SCHISTS

Constituents	Specimen C	Specimen D
	1%	2%
Acid insolubles	60 24	61 32
CaO	0 32	1 27
MgO	35 11	35 52
Fe_2O_3	5 43	5 43
Al_2O_3	3 93	3 04
Cr_2O_3	Present	Present
CO_2	16 64	17 00
As	0 03	0 03
S	0 05	0 04
P	0 04	0 05
Cl	n d	n d

n d — not detected

After Urie & Jones (1965)

Analysts – Barclays Bank, Johannesburg

Specimens C and D were collected from the Forbes Reef Area

TABLE 7

CIPW NORMATIVE VALUES OF THE LATE-OROGENIC GRANITE

	SPECIMEN NUMBER									
	H1272	H516A	H85?	Pegma-tite	H 334	H892	H540	H506	H1174	Grout
Quartz	27 8	24 7	27 8	41 4	29 3	30 9	35 5	29 8	41 4	43 4
Orthoclase	17 8	22 8	35 0	1 7	27 2	38 4	28 9	28 4	18 4	25 6
Albite	39 8	36 2	21 5	42 4	34 1	23·1	26 7	34·1	31 4	21 0
Anorthite	6 1	8 3	7 2	3 6	5 0	2 5	–	5 6	4 7	3 1
Corundum	–	0 2	0 4	2 1	0 8	1 3	3 1	–	1 4	0 8
Diopside	2 9	–	–	–	–	–	–	–	–	–
Hypersthene	1 7	4 1	4 6	1 7	2 5	1 4	2 3	1 3	0 7	2 6
Magnetite	3 0	1 4	1 6	5 8	0 7	1 6	0 9	0 7	0 9	1 6
Ilmenite	0 8	0 8	0 8	–	0 2	0 6	0 3	0 2	–	0 6
Apatite	0 3	1 0	0 3	–	–	0 3	2 4	–	0 3	0 7
TOTALS	100 2	99 5	99 2	98 7	99 8	100 1	100 1	100 1	99 2	99 4

After D R Hunter 1965

TABLE 8.

PRODUCTION FIGURES FOR THE DAISY AND GORDON MINES, HHOHHO AREA

	Daisy Mine		Gordon Mine	
YEAR	OUNCES	VALUE R	OUNCES	VALUE R
1907	2,125 65	16,603 +	—	—
1908	2,406 00	18,767 +	—	—
1909	1,081 83	8,767	41 73	354
1910	1,259 90	10,703		
1911	1,141 10	9,692	—	—
1912	714 80	6,075	—	—
1913	99 90	848	—	—
1932	7 90	46	—	—
Totals	8,837 08	71,278	41 73	354

+ Estimated Value

(after Hunter and Jones 1963)

PLATE I

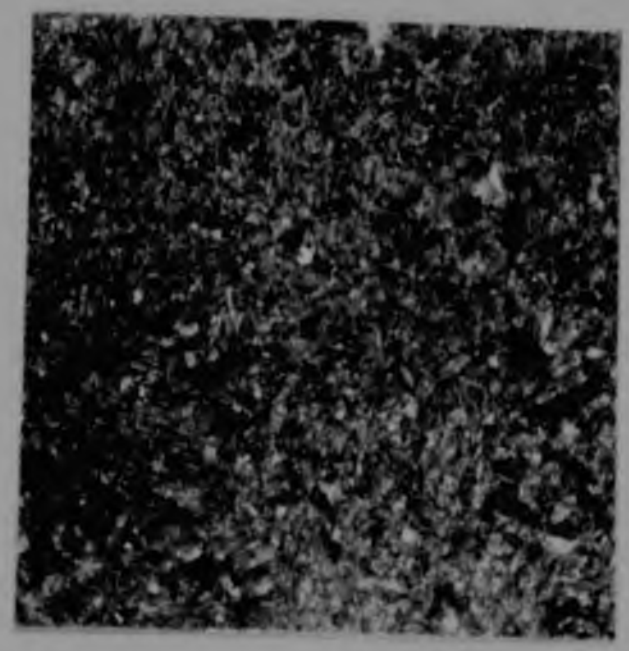
Hornblende amphibolite
Spec. No J416 x 25 (ord. light)
from 2¾ miles southwest of Hhohho
Police Post.

PLATE II

Pale-green unfoliated amphibolite
Spec. No J90 x 25 (X-nicols)
from ¼ mile west of Hhohho Police Post

PLATE III

Foliated green-grey amphibolite
Spec. No J97 x 25 (ord. light)
from vicinity of No.1 Quarry, Daisy
Mine



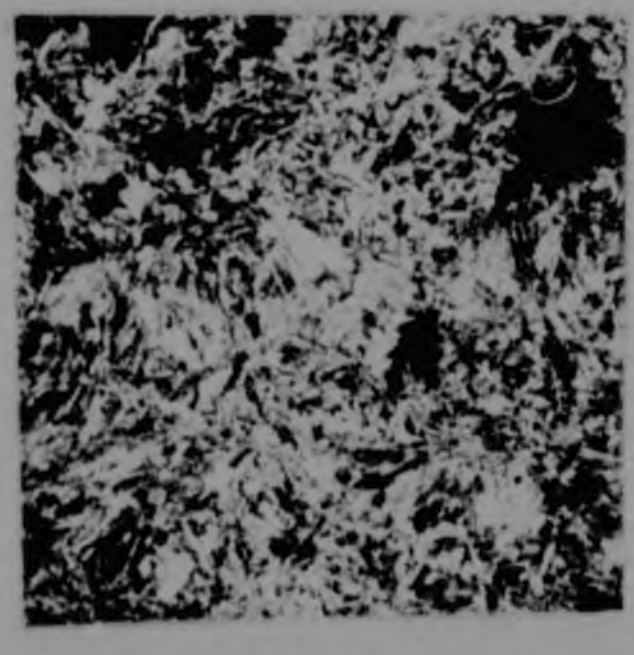




PLATE IV

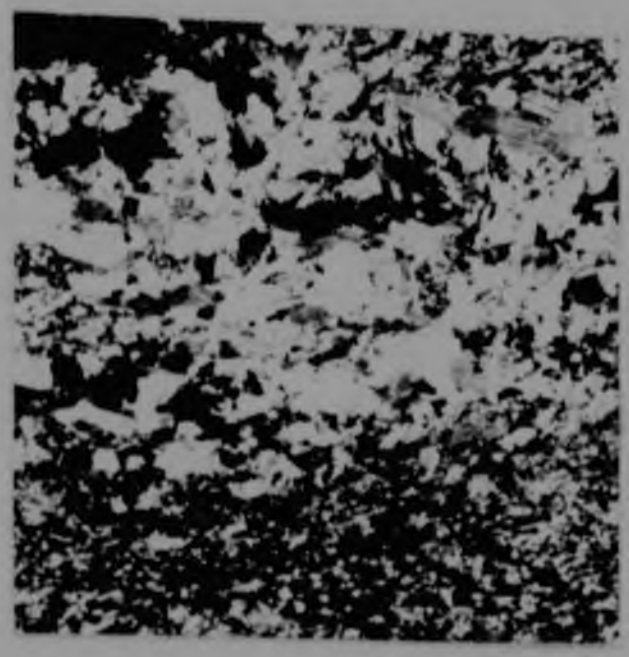
Quartz-biotite schist.
Spec. No J96 x 25 (x-nicols) from
No.1 level adit, Daisy Mine

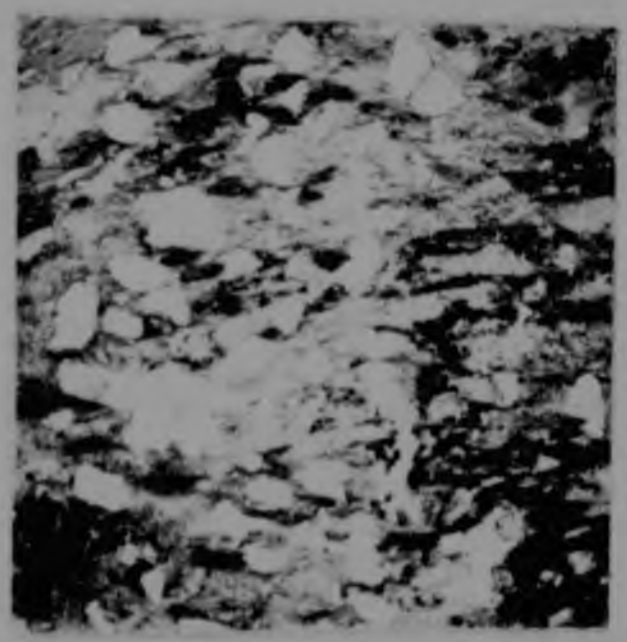
PLATE V

Sheared quartzite showing development
of sericite along sheared shaly partings.
Spec. No J83 x 25 (ord. light) from
½ mile west of Gordon Mine

PLATE VI

Sheared quartzite showing re-crystallization
of clastic quartz grains.
Spec. No J577 x 25 (ord. light) from
½ mile west of Gordon Mine





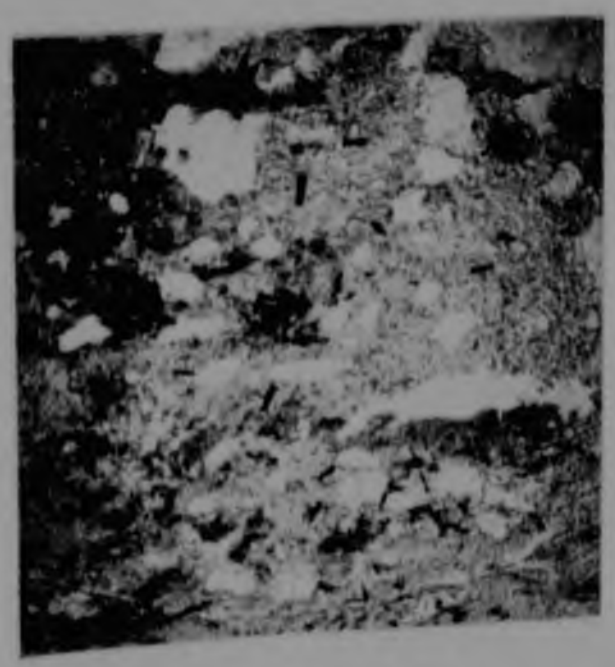


PLATE VII

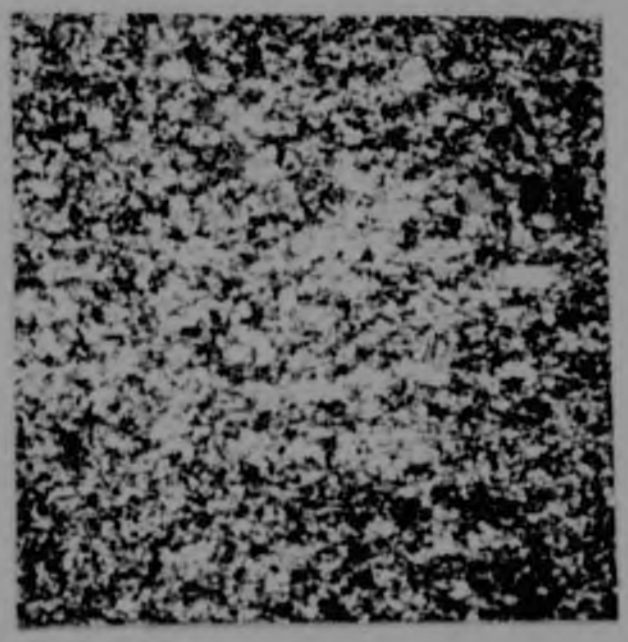
Sheared quartzite completely re-crystallized to resemble chert. Spec. No J494 x 25 (x-nicols) from ½ mile west of Gordon Mine

PLATE VIII

Cleaved quartzite of the M.S.[illegible] Zone of the Woodies Series in the core of the Makonjwa Syncline ¾ miles southeast of Mooiplaas Valley

PLATE IX

Modified concentric fold formed, as a result of the Later Phases of deformation, in the Daisy Bar 1½ miles northeast of the Daisy Mine.







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PLATE X

Polished section showing the relationship between pyrite, chalcopyrite and pyrrhotite. The pyrite (white) is surrounded by chalcopyrite (slightly darker and with lower relief) and pyrrhotite (slightly darker than chalcopyrite).
Spec. No D.M.1 x 100 from Daisy Mine

PLATE XI

Polished section showing pyrrhotite/chalcopyrite relationship on boundary of pyrite crystal. Pyrrhotite occurs on the northwest edge of the pyrite and chalcopyrite on the southwest edge. On the westernmost corner of the pyrite crystal chalcopyrite imposes itself between grains of pyrrhotite.
Spec. No D.M.1 x 100 from Daisy Mine.

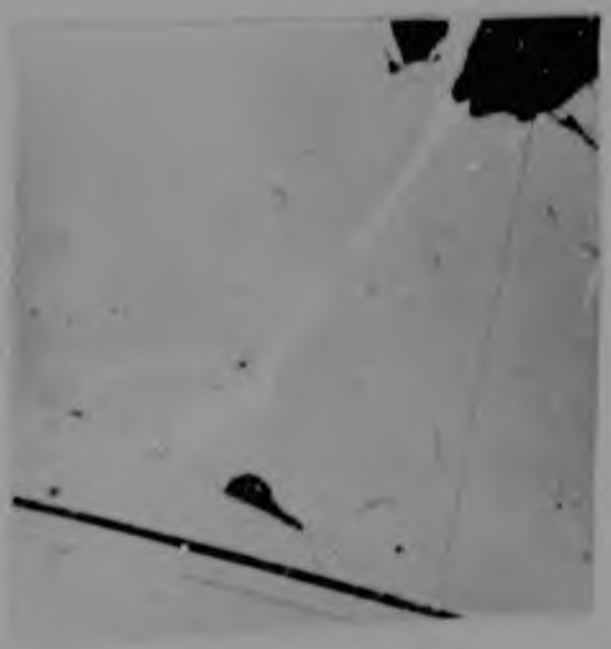
PLATE XII

Polished section showing vein of chalcopyrite in a grain of pyrrhotite.
Spec. No D.M. 14 x 800 from Daisy Mine.

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PLATE XIII

Polished section showing gold grain in quartz gangue near to pyrrhotite.
Spec. No. D.M. 14 x 400 from Daisy Mine.

PLATE XIV

Polished section showing bleb of gold in a euhedral crystal of pyrite, (the latter surrounded by pyrrhotite and chalcopyrite).
Spec. No D.M.19 x 200 from Daisy Mine.

PLATE XV

Polished section showing intimate relationship between gold and pyrrhotite vein.
Spec. No D.M.14 x 400 from Daisy Mine.



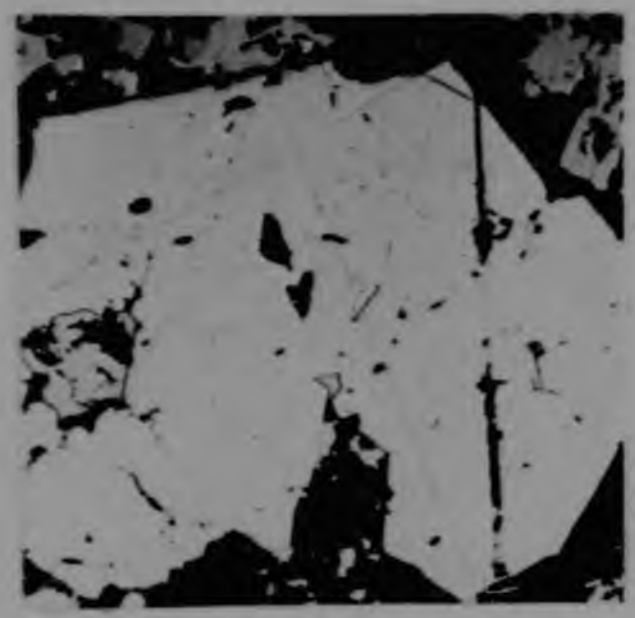




PLATE XVI

Polished section showing relationship of gold to sulphides. The gold occurs predominantly in the quartz gangue but can also be seen replacing pyrrhotite. Spec. No D.M.19 x 400 from Daisy Mine.

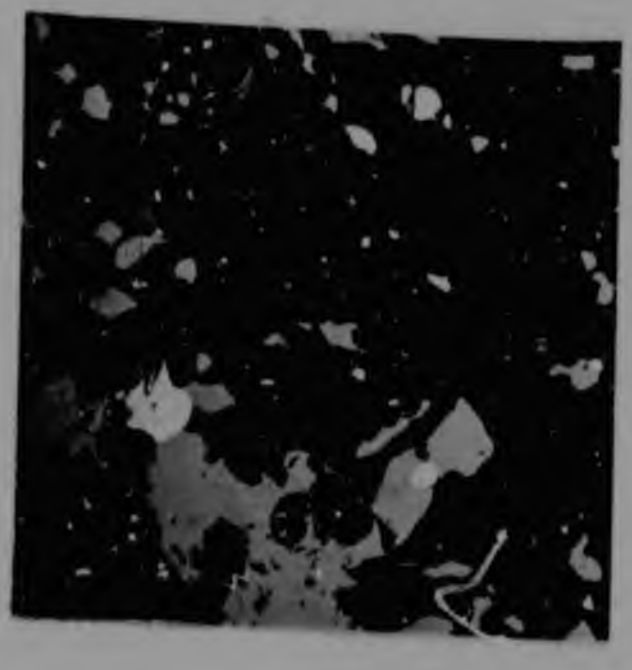
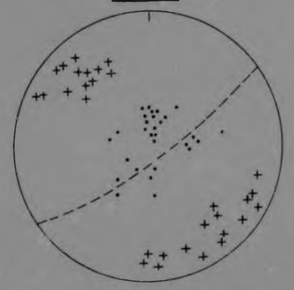


FIG. 6

STRUCTURAL ANALYSIS OF THE PHASES OF DEFORMATION IN THE HHOHHO AREA

FIG. 6a



MAIN PHASE OF DEFORMATION

· = Plot of minor folds

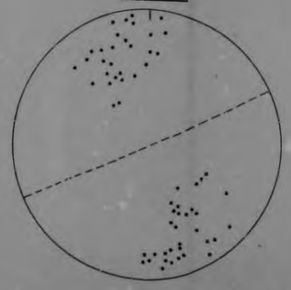
+ = Poles to axial plane cleavages

---- Average strike of axial plane cleavages = N54°E

Average dip of axial plane cleavages = 86° to S.E.

Spread of axial plane cleavages on a great circle indicates bending of Main Phase folds

FIG. 6b



SECOND PHASE OF DEFORMATION

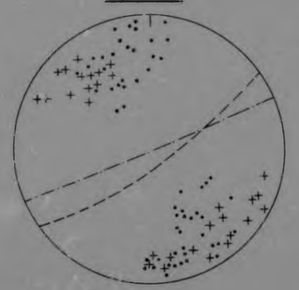
· = Poles to cleavage

--- Average strike of cleavage = N68°E

Average dip of cleavage = 89° to S.SE

Spread and "fanning" of Second Phase cleavage indicates subsequent bending

FIG. 6c



MAIN PHASE AND SECOND PHASE CLEAVAGES

Poles to cleavages

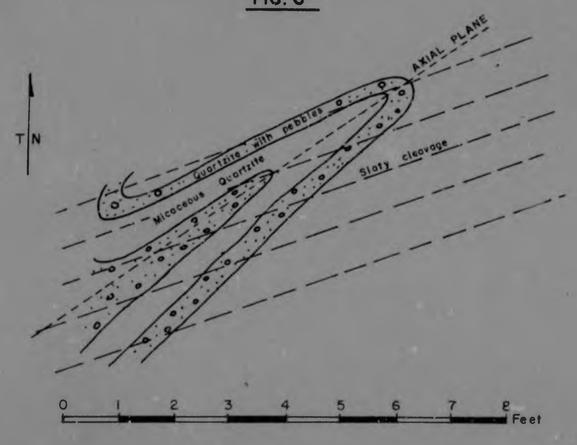
+ = Poles to axial plane cleavages of Main Phase of Deformation

· = Poles to cleavages of Second Phase of Deformation

---- = Average of Main Phase cleavages

—·— = Average of Second Phase cleavages

FIG. 6d



Showing relationship of slaty cleavage to Main Phase Fold.

FIG. 6e



LATER PHASES OF DEFORMATION

(Montrose Trend)

· = Plot of minor folds

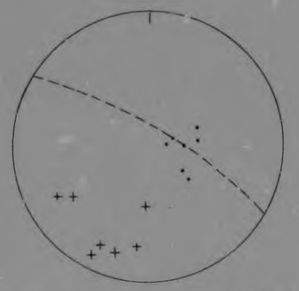
+ = Poles to axial planes of folds

---- Average strike of axial planes = N5°E

Average dip of axial planes = 71° to E

Steepness of plunge of minor folds indicates folding superimposed or deformed surface.

FIG. 6f



LATER PHASES OF DEFORMATION

(Consort Trend)

· = Plot of minor folds

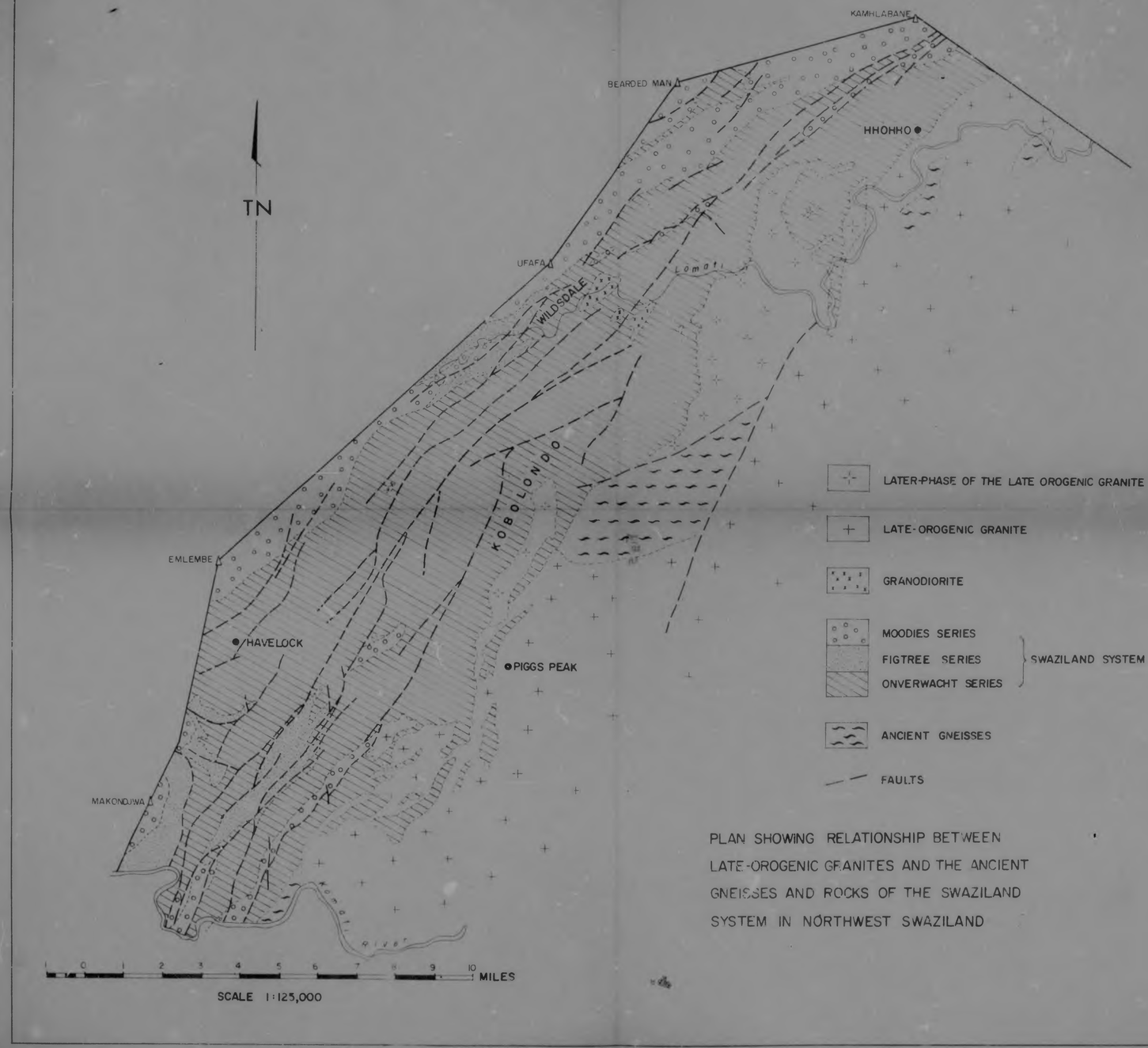
+ = Poles to axial planes of folds

---- Average strike of axial planes = N12°E

Average dip of axial planes = 71° to N.E.

Steepness of plunge of minor folds indicates folding superimposed on deformed surface.

FIG.5



PLAN SHOWING RELATIONSHIP BETWEEN LATE-OROGENIC GRANITES AND THE ANCIENT GNEISSES AND ROCKS OF THE SWAZILAND SYSTEM IN NORTHWEST SWAZILAND

FIG. 4.

THE METAMORPHIC FACIES OF THE HHOHHO AREA

Scale 1:25,000



D N Jones . 1968

FIG. 3

TRANSVAAL

BEARDED MAN.

KAMHLABANE.

TRUE NORTH

TRANSVAAL

RIVER

LOMATI

STRUCTURAL GEOLOGY OF THE HHOHHO AREA NORTHWEST SWAZILAND.

SCALE IN ENGLISH FEET

LEGEND

Fold traces of the Main Phase of Deformation

Fold traces of the Later Phase of Deformation

Major Strike Faults

Secondary Faults

Cleavage and foliation (Vertical)

Joints (Inclined)

Intrusive contacts

Dykes

FIG. 2.



GEOLOGY OF THE HHOHHO AREA NORTHWEST SWAZILAND

Scale in ENGLISH FEET

	Alluvium.	RECENT
	Dolerite. (Post-Karroo System).	INTRUSIVE ROCKS
	Diabase. (Pre-Karroo System).	
+ +	Coarse-grained porphyritic granite. (Later phase).	
	Medium-grained biotite granite. (Late-orogenic).	
	Coarse-grained gritty quartzite with scattered pebbles. (MS^5 Zone)	SWAZILAND SYSTEM
	Compact pebble and boulder conglomerate. (MS^4 Zone)	MOODIES SERIES
	Fine-grained sometimes micaceous quartzite with scattered pebbles. (MS^3 Zone)	
	Fine-medium grained micaceous and feldspathic quartzites. (MS^2 Zone)	
	Medium-grained quartzite with scattered pebbles and narrow conglomerates. (MS^1 Zone)	
	Compact pebble and boulder conglomerate (Basal conglomerate)	
	UNCONFORMITY	
	Shales, slates and phillites with bands of primary and secondary chert, quartzite and conglomerate.	Upper Stage of the ONVERWACHT SERIES
	Greywackes with bands of primary and secondary chert, quartzite and conglomerate.	
	Quartz-sericite schists with bands of chert.	
	Basic lava with intercalations of shale, mudstone, and greywacke.	Lower Stage of the ONVERWACHT SERIES
	Talc-amphibole, talc-chlorite, talc-chlorite-carbonate and talc-carbonate schists with bands of primary and secondary chert.	
Qs	Pale-green unfoliated tremolite-actinolite amphibolite with bands of primary and secondary chert, quartzite and and quartz-sericite schist (Qs).	
Qs Qc	Green-grey foliated amphibolite with bands of primary and secondary chert, quartz-sericite schist (Qs) and quartz-chlorite schist (Qc).	
	Dark-green hornblende amphibolite with quartzite bands.	

e	Epidote veins.	81	Dip and strike of joints.
q	Quartz veins.	+	Vertical joint.
p	Pegmatite veins.	——	Faults known.
72	Dip and strike of bedding.	– – –	Faults assumed.
78	Dip and strike of foliation and cleavage.	——	International boundary.
	Deformed cleavage.	KAMHLABANE PEAK 3954'	Trigonometrical beacon.

Geology by D.H.JONES 1968

LOCALITY MAP

FIG.I

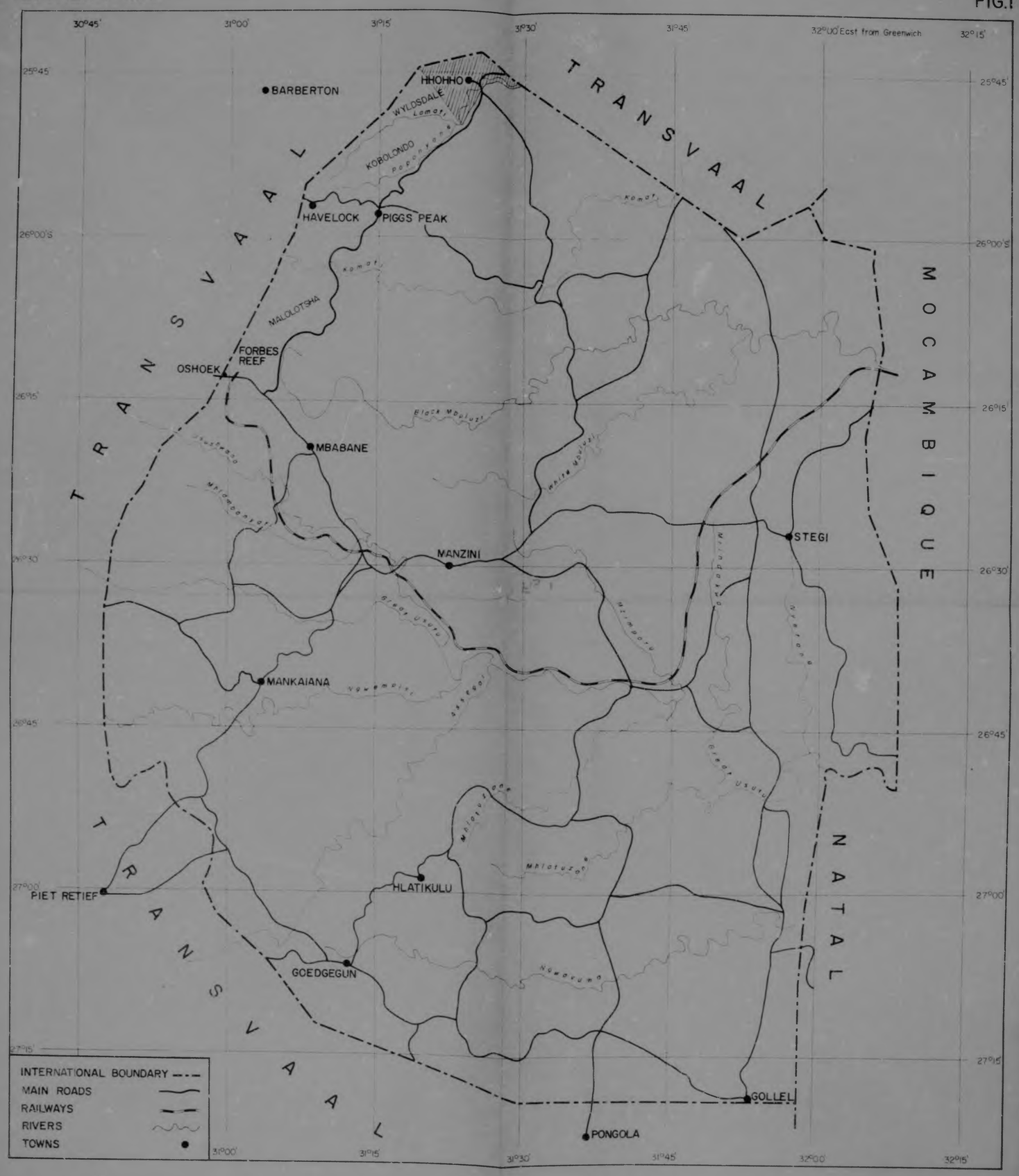


FIG. 8 12



Broken lines on plan indicate surface workings
Dotted areas on plan indicate distribution of "reef"
1 level shown in red
1A level shown in blue
2 level shown in black
3A level shown in green
3 level shown in violet
4 level shown in yellow
4A level shown in orange
Broken lines in section indicates "off reef" development

PLAN AND SECTION OF THE DAISY GOLD MINE

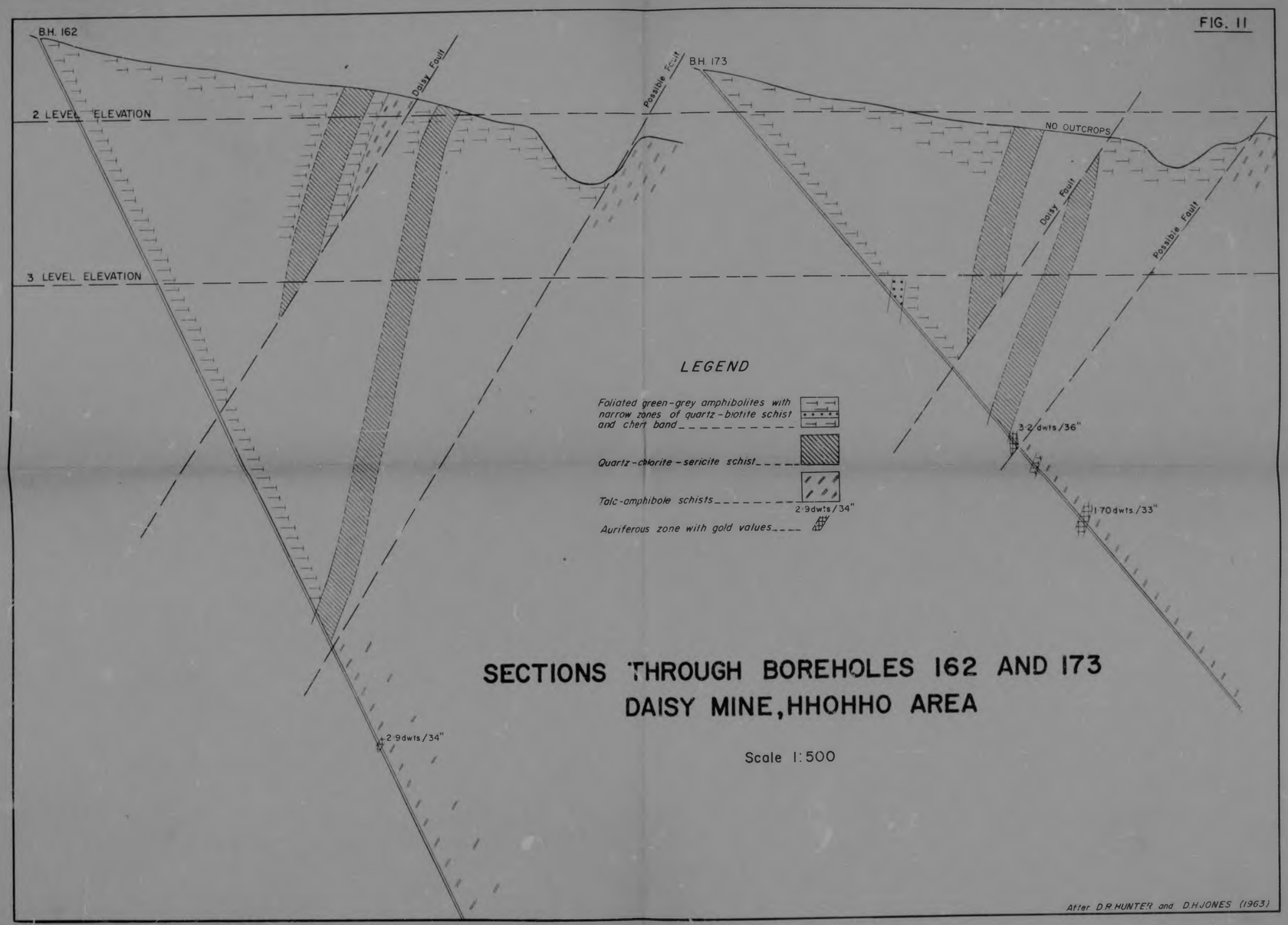
LAPSED MINERAL CONCESSION No. 33 PORTION "A"

PIGGS PEAK DISTRICT

SCALE 1:1,000

Compiled from old Swaziland Corporation Plans and from survey by D.H. Jones 1962)

FIG. 11

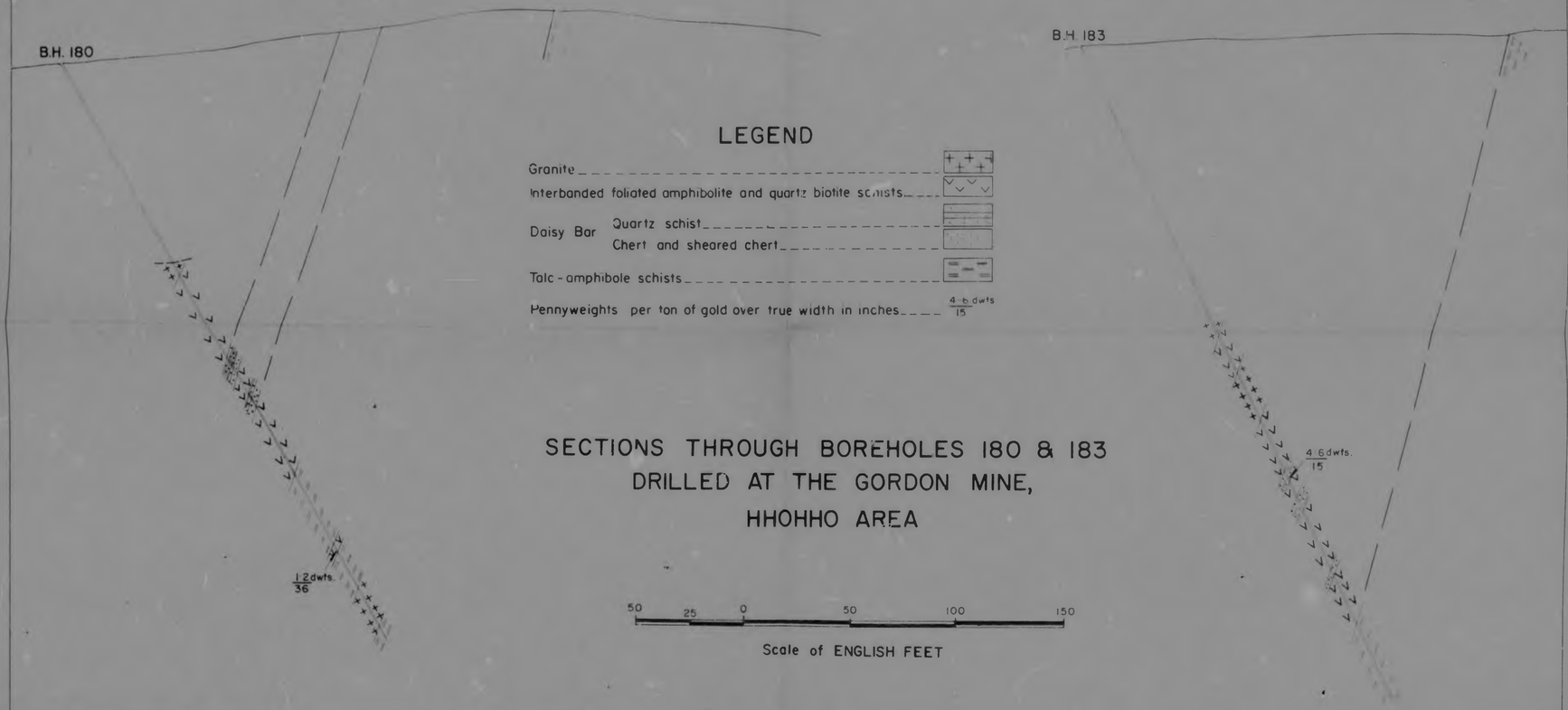


SECTIONS THROUGH BOREHOLES 162 AND 173 DAISY MINE, HHOHHO AREA

Scale 1:500

After D.R.HUNTER and D.H.JONES (1963)

FIG. 10



SECTIONS THROUGH BOREHOLES 180 & 183
DRILLED AT THE GORDON MINE,
HHOHHO AREA

After D.R.Hunter and D.H.Jones (1963)

FIG 9

ISOMETRIC PROJECTION OF THE DAISY GOLD MINE.

SCALE 1:1000

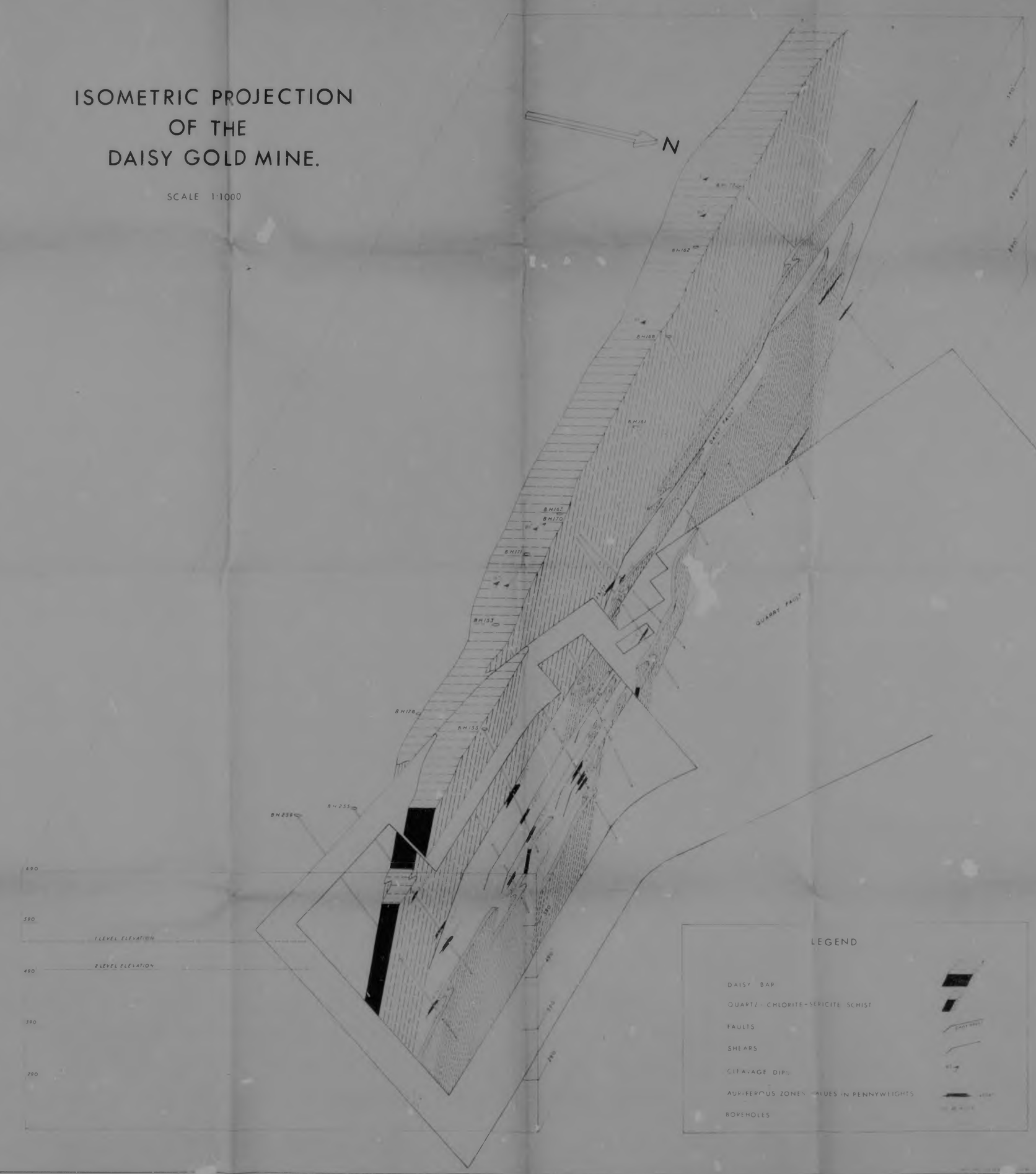
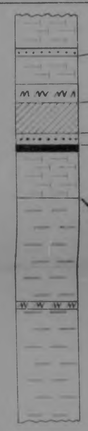


FIG. 8

STRATIGRAPHIC COLUMNS OF THE DAISY AND GORDON MINES

GORDON MINE



Foliated green-grey amphibolite with narrow zones of quartz-biotite schist, occasional garnets present

Chert band ± 3'

Foliated green-grey amphibolite with ±14' narrow zones of quartz-biotite schist

Quartz-biotite schist with rare garnets ± 8'

Grey granular quartz schist with zones rich in amphibole and biotite ± 15'

Grey-brown cryptocrystalline chert ±5'

Auriferous zone

Foliated green-grey amphibolite with narrow zones of quartz-biotite schist ±2'

Talc-amphibole schists with zones of actinolite bearing rock

Quartz biotite schist ±3'

Talc-amphibole schists with zones of actinolite bearing rock

DAISY MINE No.4 Quarry Area



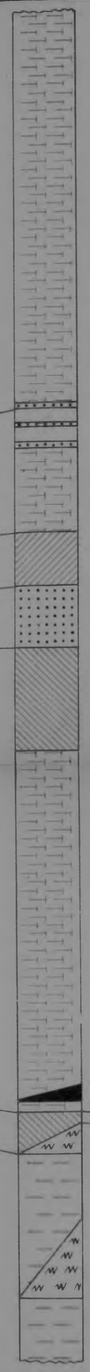
Foliated greenish grey amphibolite and zones of quartz-biotite schist

Quartz-chlorite-sericite schist 5'-20'

Quartz-biotite schist 6'-10'

Talc-amphibole schist with narrow zones of quartz-biotite schist and actinolite bearing rock

DAISY MINE No.1 Quarry Area



Foliated green-grey amphibolite with narrow zones of quartz-biotite schist

Narrow chert and meta-quartzite bands

Foliated green-grey amphibolite with narrow zones of quartz-biotite schist Moderate abundancy of pink garnets occur near bottom contact

Grey, granular quartz schist ± 25'

Dense, cryptocrystalline, brown coloured chert ± 25'

Foliated, green quartz-sericite schist 25'-60'

Foliated green-grey amphibolite with numerous narrow zones of quartz-biotite schist Succession invaded by quc and carbonate veins and containing sulphide mineralization ±175'

Main concentration of auriferous zones

Quartz-chlorite-sericite schist 5'-20'

Quartz-biotite schist 0-15'

Talc-amphibole schists with narrow zones of actinolitic rock 30'

Quartz-biotite and quartz-chlorite schist with abundant sulphide mineralization 0-40'

Talc-amphibole schists with narrow zones of actinolitic rock

DAISY MINE EASTERN EXTENSION



Foliated green-grey amphibolite with zones of quartz-biotite schist

Quartz-chlorite-sericite schist 10'-20'

Talc-amphibole schist with narrow zones of actinolite bearing rock ± 120'

Granular quartz schist 10'

Banded chert 30'

Granular quartz schist

Drawn by D.H.JONES 1968

FIG. 7

GEOLOGY OF THE DAISY AND GORDON MINES

SCALE 1:2000





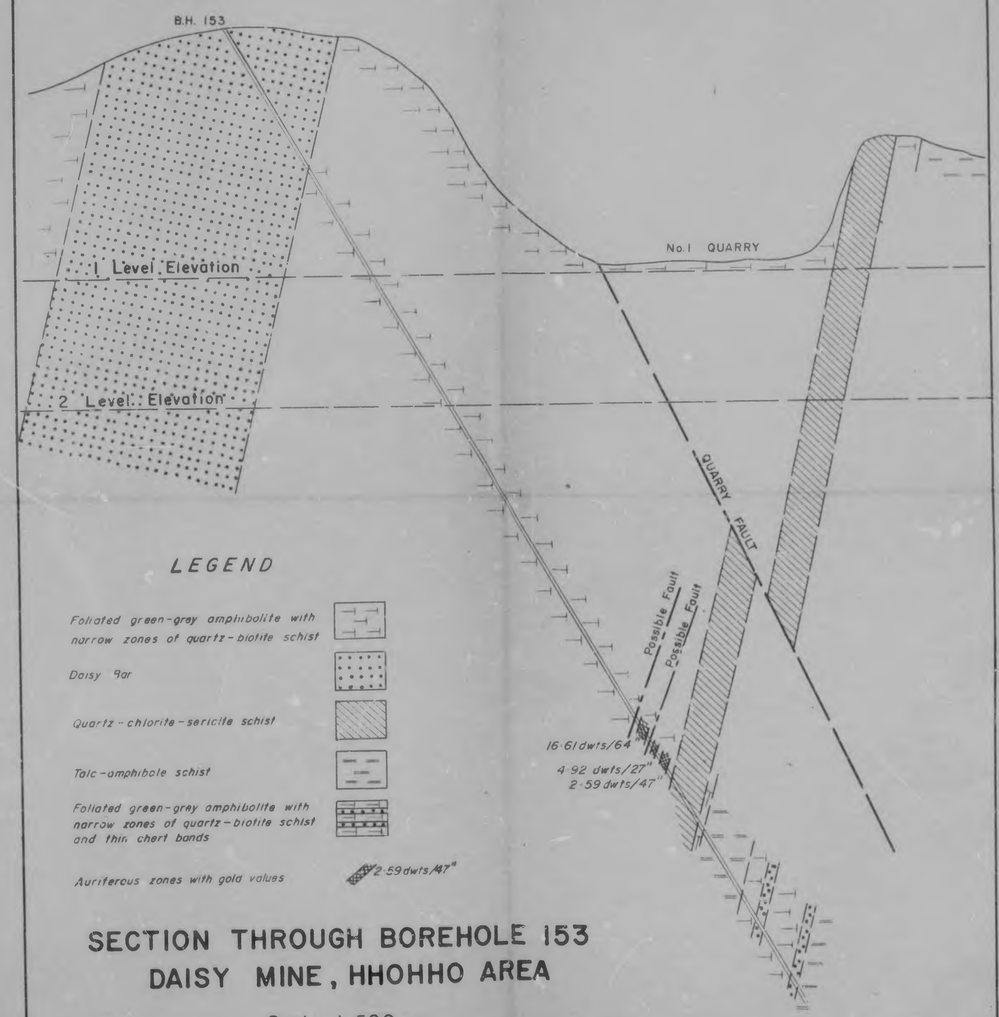
LEGEND

POST-SWAZILAND SYSTEM

SWAZILAND SYSTEM
Onverwacht Series only

TRUE NORTH

FIG. 16



SECTION THROUGH BOREHOLE 153
DAISY MINE, HHOHHO AREA

Scale 1:500

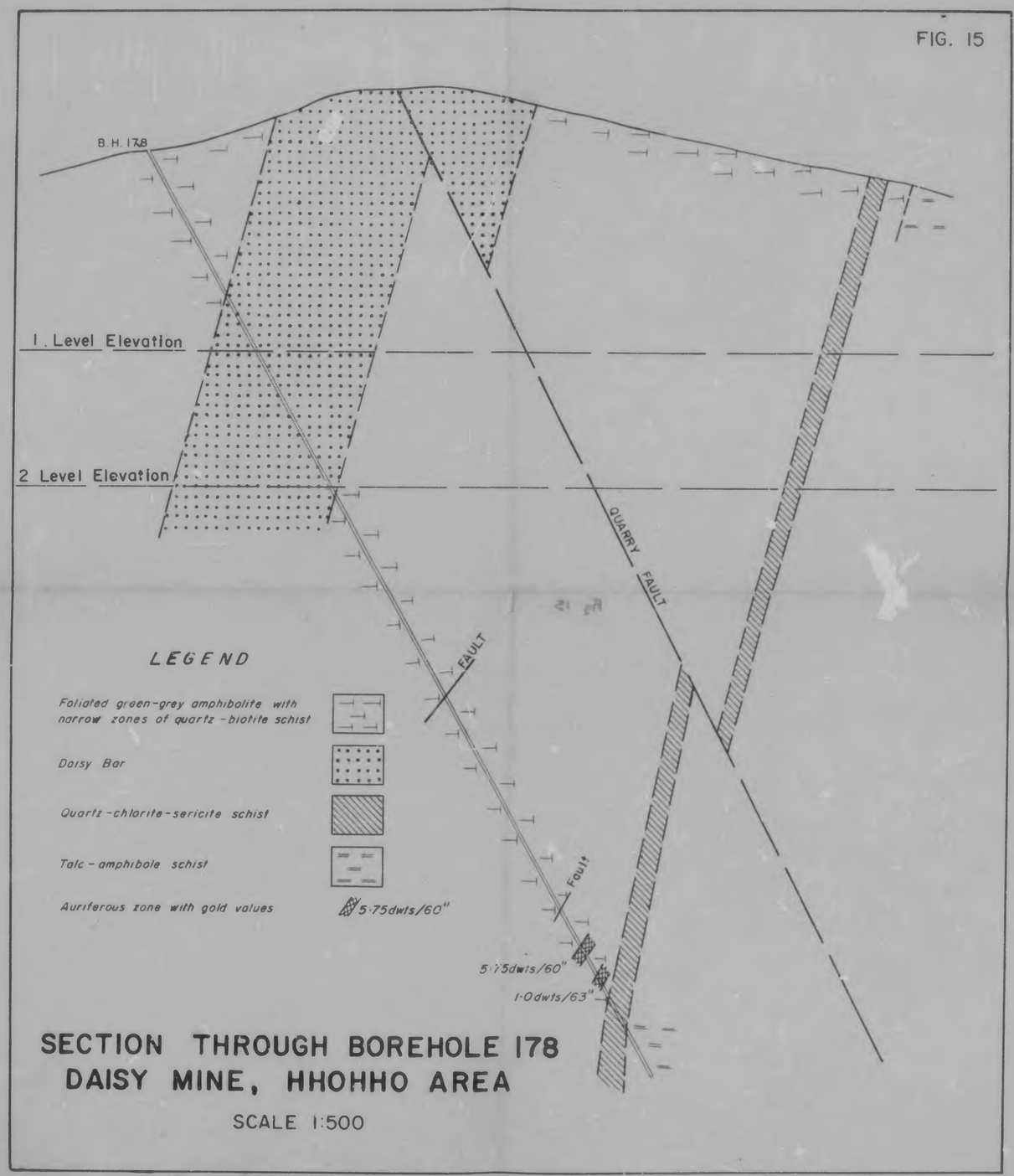
TABLE 6

TYPE SECTION OF THE STRATIGRAPHIC COLUMN OF THE ONVERWACHT SERIES IN THE KOMATI RIVER VALLEY AREA OF THE BARBERTON MOUNTAIN LAND

STAGE	Sub-Stage No.	DESCRIPTION	Thickness
UPPER ONVERWACHT or HOOGGENOEG STAGE — UPPER DIVISION	1.	Acid lavas with minor variations and containing acid pyroclasts, tuffs and chert bands. Banded black and white chert occurs at base.	2800 – 4000
UPPER ONVERWACHT or HOOGGENOEG STAGE — LOWER DIVISION	5.	Acid lavas with cherty green schist and substantial banded chert locally developed. Underlain by basic to intermediate lava with pillow structures and amygdales. Discontinuous ultrabasic bands occur.	200 – 600
	4.	Sporadically developed black chert marks top of sub-stage below which occurs acid lavas with amygdales and pillow structures. Underlain by basic-intermediate lava with pillow structures.	±1100
	3.	Acid lava underlain by basic lava. Former overlain by narrow chert.	±1000
	2.	Acid lava sometimes overlain by corbonaceous chert. Below acid lava occurs lava of basic to intermediate composition.	±1800
	1.	iii) Acid lavas with pillow structures. ii) Basic to intermediate lava with pillow structures and some narrow ultabasic bands. i) Lower sedimentary horizon consisting of carbonate-bearing sediments, banded cherts and slaty sediments.	±1500
UPPER ONVERWACHT or KOMATI RIVER STAGE	2.	Predominantly amphibolitized basic lava with amygdales and pillow structures. A few isolated bands and lenses of interlayered ultrabasic rocks present.	3450 – 6660
	1.	Mainly ultrabasics with interlayered amphibolitized lavas containing pillow structures.	2700 – 5150
LOWER ONVERWACHT or THEESPRUIT STAGE	7.	Dominantly basic lavas containing isolated minor chert and quartz-sericite bands.	750 – 1740
	6.	Mainly basic lavas with interlayered quartz-sericite schists. Banded chert and possibly acid lava occur in the upper horizon.	340 – 950
	5.	Dark green basic lavas with amygdales and pillow structures.	±1400
	4.	Carbonated basic lavas with interlayed quartz-sericite horizons containing narrow black chert bands and lenses. Serpentized ultrabasic zone also present.	1140 – 2900
	3.	Mainly amphibolitized basic lava.	±500
	2.	Amphibolitized basic lava with interlayered siliceous sediments. Two interlayered serpentinized ultrabasic bands.	±430
		Amphibolitized basaltic lavas with sheared pillow structures. Two interlayered serpentized ultrabasic bands occur.	1900(Maximum)

After VILJOEN & VILJOEN (1969)

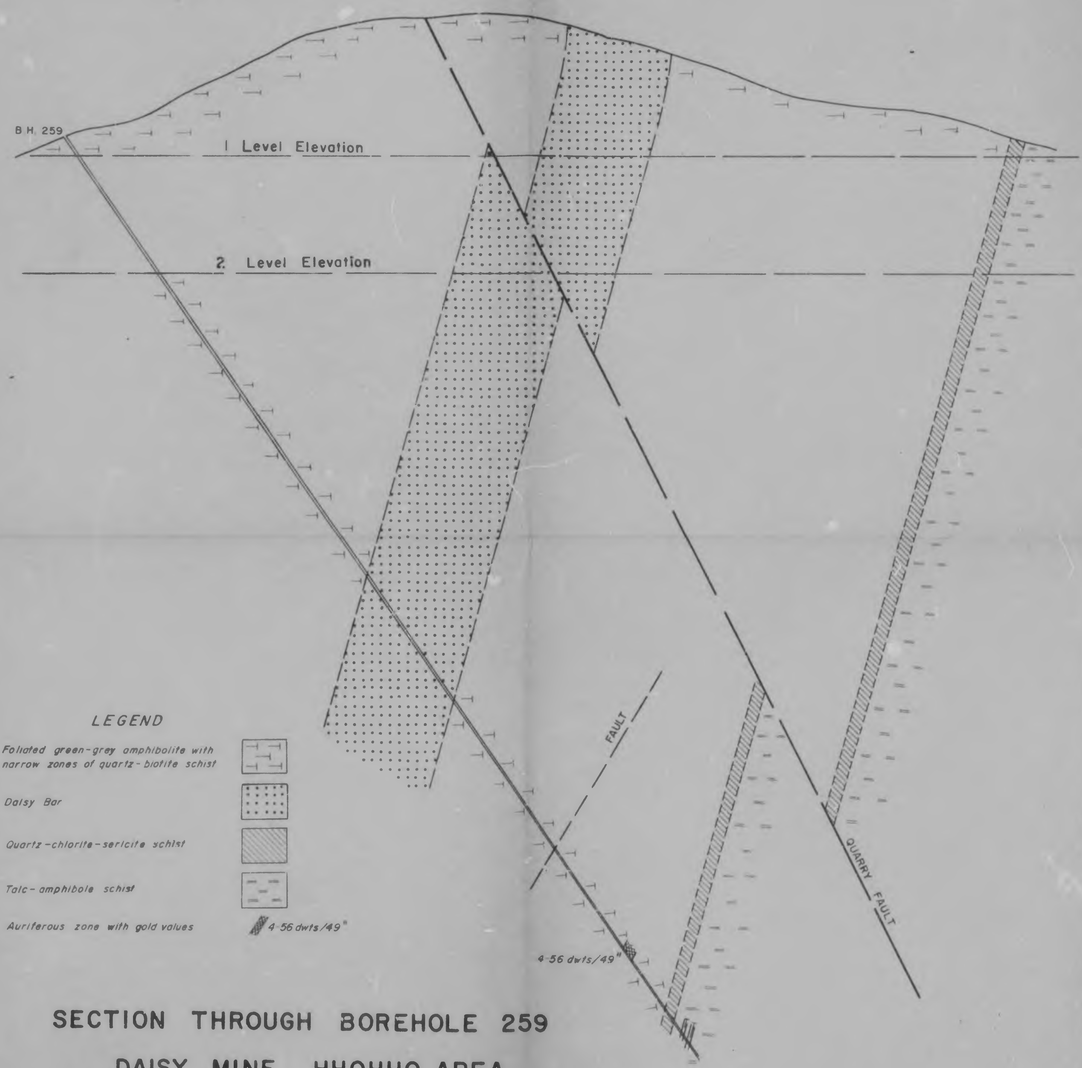
FIG. 15



SECTION THROUGH BOREHOLE 178
DAISY MINE, HHOHHO AREA

SCALE 1:500

FIG . 14



LEGEND

- Foliated green-grey amphibolite with narrow zones of quartz-biotite schist
- Daisy Bar
- Quartz-chlorite-sericite schist
- Talc-amphibole schist
- Auriferous zone with gold values — 4·56 dwts/49"

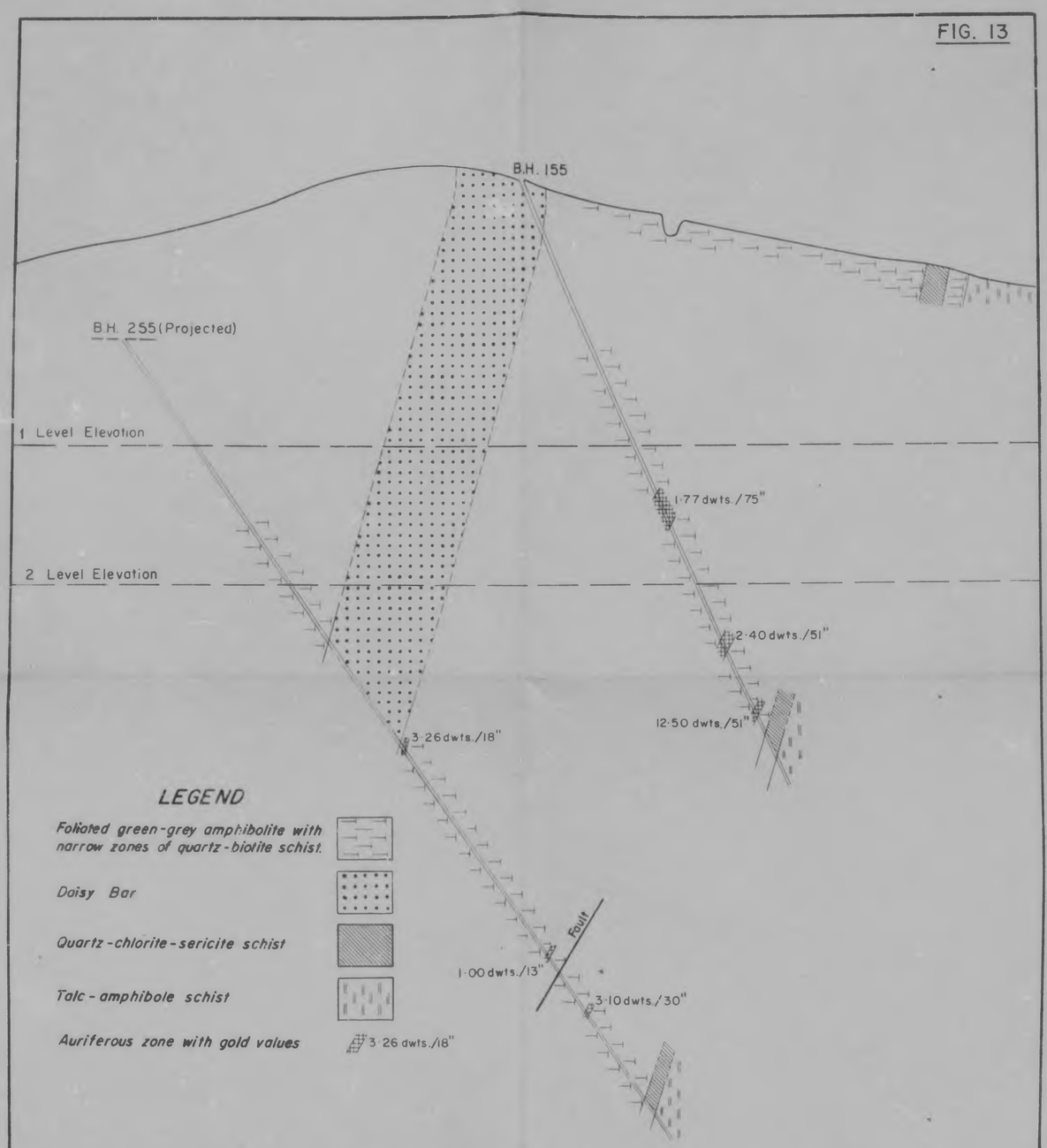
SECTION THROUGH BOREHOLE 259

DAISY MINE, HHOHHO AREA.

SCALE 1:500

Fig 14

FIG. 13



SECTIONS THROUGH BOREHOLES 155 AND 225

DAISY MINE, HHOHHO AREA

Scale 1:500

Geology by D.H.JONES 1968

Author Jones D H
Name of thesis Geology and Gold Mineralization of the HHOHHO Area, North Western Swaziland 1969

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