The Geology and Stratigraphic Evolution of the North-Central Part of the Early Archean Barberton Greenstone Belt, South Africa.

Louise Dorothy Hose

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The geology and stratigraphic evolution of the north-central part of the early Archean Barberton greenstone belt, South Africa

Hose, Louise Dorothy, Ph.D.
The Louisiana State University and Agricultural and Mechanical Col., 1990
THE GEOLOGY AND STRATIGRAPHIC EVOLUTION
OF THE NORTH-CENTRAL PART OF THE
EARLY ARCHEAN BARBERTON GREENSTONE BELT,
SOUTH AFRICA

A Dissertation

submitted to the Graduate Faculty of the
Louisiana State University and
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requirements for the degree of
Doctor of Philosophy

in

The Department of Geology and Geophysics

by
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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title page</td>
<td>i</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>ii</td>
</tr>
<tr>
<td>Table of contents</td>
<td>iii</td>
</tr>
<tr>
<td>List of tables</td>
<td>vi</td>
</tr>
<tr>
<td>List of figures</td>
<td>vii</td>
</tr>
<tr>
<td>List of plates</td>
<td>xii</td>
</tr>
<tr>
<td>Abstract</td>
<td>xiii</td>
</tr>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Introduction</td>
<td>2</td>
</tr>
<tr>
<td>References</td>
<td>6</td>
</tr>
<tr>
<td>Chapter 1: The stratigraphy and structure of a part of the north-central Barberton greenstone belt, South Africa</td>
<td>8</td>
</tr>
<tr>
<td>Abstract</td>
<td>9</td>
</tr>
<tr>
<td>Introduction</td>
<td>11</td>
</tr>
<tr>
<td>Geologic setting</td>
<td>12</td>
</tr>
<tr>
<td>Metamorphism, silicification, and carbonation</td>
<td>21</td>
</tr>
<tr>
<td>Stratigraphy</td>
<td>23</td>
</tr>
<tr>
<td>Structure</td>
<td>51</td>
</tr>
<tr>
<td>Summary</td>
<td>84</td>
</tr>
<tr>
<td>References</td>
<td>87</td>
</tr>
</tbody>
</table>

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Chapter 2: Petrography and petrology of the Moodies Group in the north-central part of the, Barberton greenstone belt, South Africa: Stratigraphic record of an Early Archean foreland region

Abstract
Introduction
Regional geology
Stratigraphy of the Moodies Group
Sandstone petrography
Pebble compositions
Shale geochemistry
Discussion
Conclusions
References

Chapter 3: Early Archean paleogeographic setting of the north-central Barberton greenstone belt, South Africa

Introduction
Paleogeographic model of the study area
Conclusions
References

Appendix 1 - Stratigraphic sections

a. Powerline Road Syncline
b. Saddleback Syncline Composite - Svengali Section 240

c. Saddleback Syncline West 270

d. Saddleback Syncline East 294

e. Saddleback Syncline - Lomati Water Tunnel 305

f. Moodies Hills - Princeton Tunnel of the Agnes Gold Mine 308

g. Moodies Hills - 22nd Level Adit of the Agnes Gold Mine 332

h. Moodies Hills - Devil's Staircase 335

Appendix 2 - Petrographic point count data 356

a. South of the Inyoka Fault 357

b. Saddleback Syncline 364

c. Moodies Hills 371

Appendix 3 - Elaboration of point count procedures 378

Vita 381

Approval Sheets 383
LIST OF TABLES

Chapter 1: The stratigraphy and structure of a part of the north-central Barberton greenstone belt, South Africa

1. A summary of the structural elements 52

Chapter 2: Petrography and petrology of the Moodies Group in the north-central part of the, Barberton greenstone belt, South Africa: Stratigraphic record of an Early Archean foreland region

1. Chemical analyses of Moodies greenstones. 136
LIST OF FIGURES

Introduction

1. Generalized geology map of the Barberton greenstone belt. 4

Chapter 1: The stratigraphy and structure of a part of the north-central Barberton greenstone belt, South Africa

1. Generalized stratigraphic column of the Swaziland Supergroup. 13

2. Map showing the major faults and tectonic blocks. 15

3. Map of melange within a part of the Inyoka Block. 17

4. Photo of scaly serpentinite along Ameide Fault. 29

5. Photomicrograph of ultramafic rock with slaty cleavage from the Pioneer Intrusive Complex. 32

6. Generalized stratigraphic column of the southern facies of the Schoongezicht Formation. 40

7. Photomicrograph of a Schoongezicht sandstone. 42

8. Embayed quartz grain within a Schoongezicht igneous rock. 43

9. Photomicrograph of a quartz-bearing diabase. 50

10. Equal area stereonet projections of the limbs and fold axes of two F1 synclines. 56
11. Equal area stereonet projections of the limbs and fold axes of three F₃ synclines.

12. Anticlinal fold along the Ameide Fault that may represent a D₁ structure.

13. Schematic diagrams showing alternative relationships of the Haki, Saddleback, and Auber Villier Faults.

14. Equal area stereonet projections of poles of foliation (S₃).

15. Equal area stereonet of the poles of foliation.

16. Photograph of stretched chert clasts in the Moodies Hills.

17. Residual gravity anomaly profile and generalized geologic cross-section.

18. Schematic cartoon showing the effects of the rise of the Kaap Valley Pluton during D₄ stage.


20. Map and equal area stereonet projection of the F₅ Shebang anticlinal-synclinal pair.

21. Detailed geologic map of a part of the Moodies Hills.

22. Map of the southeastern part of the study area.
Chapter 2: Petrography and petrology of the Moodies Group in the north-central part of the Barberton greenstone belt, South Africa:

Stratigraphic record of an Early Archean foreland region

1. Generalized stratigraphic column - Swaziland Supergroup. 105
2. Generalized geology map of the Barberton greenstone belt. 107
3. Map showing major blocks of the Moodies Group. 108
4. Mud cracks in the upper Clutha Formation. 112
5. Photograph of the Saddleback Syncline. 115
6. Photomicrograph showing carbonate replacement of primary grains. 119
7. Generalized stratigraphic sections of the Moodies Groups. 123
8. Proposed supplementary type section for the Clutha and Joe's Luck Formations. 129
9. Photomicrograph of a sandstone from the Schoongezicht Formation. 142
10. Quartz (Q)-Feldspar (F)-Lithic (L) ternary plot of detrital framework grains and petrographic classification. 144
11. Plot showing the volume percentage of monocrystalline quartz in the lower Clutha Formation and upper Schoongezicht Formations. 145
12. Granophyre clast in a Clutha A conglomerate. 146
13. Photograph of clast in a Clutha A conglomerate. 146
14. Chert clast displaying spinifex texture. 147
15. Carbonaceous chert clast in a Clutha A conglomerate. 148
16. Unaltered, tartan-twinned feldspar in a Clutha A sandstone. 149
17. Unaltered, untwinned feldspar in a Clutha A sandstone. 149
18. Feldspar crystal that has been severely corroded 150
19. Photomicrograph of a Clutha A sandstone. 153
20. Microlite clasts in a Clutha A conglomerate. 153
21. Photomicrograph of a Clutha A conglomerate. 154
22. Tightly packed quartz grains in a Joe's Luck sandstone. 157
23. Clasts in a Joe's Luck sandstone. 159
24. Photograph of a carbonaceous chert clast. 161
25. Photograph of Clutha A slab from Moodies Hills. 164
26. Na₂O-K₂O-CaO ternary plot of granitoid and metamorphite pebbles in the Moodies Groups and its equivalents. 167
   a. South side of the Powerline Syncline. 171
   b. Saddleback Syncline. 172
c. Moodies Hills. 173
Chapter 3: Early Archean paleogeographic setting of the north-central Barberton greenstone belt, South Africa

1. Schematic diagram showing the study area during the deposition of the Schoongezicht Formation.
2. Schematic diagram showing the study area during the deposition of the Moodies Group as described in Model 1.
3. Schematic diagram showing the study area during the deposition of the Moodies Group as described in Model 2.
4. Schematic diagram showing the study area during the deposition of the Moodies Group as described in Model 3.
5. Schematic diagram showing the study area following the deposition of the Moodies Group.
LIST OF PLATES

I. Geologic map of the north-central Barberton greenstone belt, eastern Transvaal, South Africa

II. Structural geologic map of the north-central Barberton greenstone belt, eastern Transvaal, South Africa
ABSTRACT

The north-central part of the 3.5 to 3.2 Ga Barberton greenstone belt, southwest of the town of Barberton, contains both the northern and southern facies of the Swaziland Supergroup including, from base to top, the Onverwacht, Fig Tree, and Moodies Groups. The facies are divided by the Inyoka Fault, a major thrust fault that was reactivated by dextral shearing. The two facies of Fig Tree and Moodies strata appear to be laterally gradational.

The Moodies Group, a 2800+ m sequence of predominantly lithic arenite, sublitharenite, and arkosic arenite was studied in four large, structurally isolated blocks in the north-central part of greenstone belt: the Moodies Hills, Saddleback Syncline, Maid of the Mist Mountain Syncline, and Powerline Road Syncline. The northern facies was derived from two provenances: the underlying greenstone and a granitic/metamorphic terrane. The crystalline terrane may have been a part of the Ancient Gneiss Complex. South of the Inyoka Fault, strata are solely composed of material eroded from the greenstone belt. The upper part of the Moodies Group was probably derived from reworked, cannabalized, older Moodies strata. Petrographic and stratigraphic evidence suggests that the Moodies Group was deposited in a
foreland basin formed by thrust faulting and uplift of the greenstone belt in the southeast. The depositional basin deepened to the north.

Multiple stages of large-scale lateral tectonics affected the Barberton greenstone belt. Thrust faulting and nappe forming throughout the belt ($D_1$ and $2$) accompanied deposition of the Fig Tree Group. Further thrust faulting and folding ($D_3$) following deposition of the Moodies. After emplacement of the Kaap Valley pluton ($D_4$), the area was further disrupted by predominantly dextral folds and faults ($D_5$). The final stage of structural development resulted in approximately north-south striking, vertically dipping faults ($D_6$).
INTRODUCTION
INTRODUCTION

Models and understanding of the development of the earliest crust primarily depend on the information obtained from the Earth's oldest preserved rocks. The Early Archean greenstone belts provide the greatest wealth of such information and it seems clear that a detailed understanding of the evolution of Early Archean greenstone belts will be a major step forward in our knowledge of the early evolution of the cratons. None of the Archean greenstone terranes, however, has been studied in comparable detail to most Phanerozoic orogenic belts. Even detailed maps of these terranes are rare. More detailed mapping and study of the Archean greenstone belts are required to resolve major issues concerning their history.

The approximately 3.5 to 3.2 Ga-old Barberton greenstone belt has served informally as the type example of an Archean greenstone belt (Anhaeusser, 1971, 1973; Anhaeusser et al., 1969; Condie, 1976; Coward, 1976). It is one of the best preserved, low-grade, early Archean greenstone belts in the world and has the added attributes of generally good to excellent exposures, moderate to good accessibility, and high vertical relief. Despite its importance and relatively amenable environment, published information on the Barberton greenstone belt is relatively sparse. Most detailed studies within the belt have been both geographically and subjectively restricted to areas of economic importance.
The Barberton belt straddles the South Africa-Swaziland border near the eastern edge of the Kaapvaal Craton (Fig. 1). It is made up of volcanic and sedimentary rocks of the Swaziland Supergroup. The basal unit is an eight to ten kilometers thick, predominantly mafic and ultramafic volcanic sequence, the Onverwacht Group. It is overlain by up to six km of volcanioclastic and orogenic sedimentary rocks of the Fig Tree and Moodies Groups (Anhaeusser, 1973; Lowe and Byerly, in review). Metamorphic grade is low, generally lower greenschist facies, except adjacent to intrusive bodies. Distinctive facies changes in the Onverwacht and Fig Tree Groups across the Inyoka Fault have been reported previously (Heinrich, 1969, 1980; Lowe and Byerly, in review). Approximately east-northeast-trending faults and folds juxtapose and repeat the strata.

Previous controversies regarding stratigraphic relationships in the Barberton greenstone belt have emphasized the importance of detailed mapping and the importance of resolving the stratigraphic and structural evolution of the belt (Lowe et al., 1985; de Wit and Ashwal, 1986; Lowe and Byerly, in review). This paper describes the geology of a 65 square km area along the north-central margin of the Barberton greenstone belt. The work was part of a continuing systematic study of the Barberton belt by Drs. D. R. Lowe and G. R. Byerly and their students since 1980.
Figure 1. Generalized geology map of the Barberton greenstone belt with the study area outlined and a location map insert.
The present study focuses on rocks of the Moodies Group, uppermost unit of the Swaziland Supergroup. Detailed mapping and structural studies serve as a basis for outlining the late structural evolution of the north-central part of the belt. The results of this study are presented in Chapter 1. In Chapter 2, stratigraphic and modal analysis of Moodies sandstones are used to develop a model for the provenance of the Moodies sediments. The combined implications of the structural, stratigraphic, and petrologic data for the late tectonic evolution of this part of the Barberton greenstone belt are presented in Chapter 3.
REFERENCES


CHAPTER 1

THE STRATIGRAPHY AND STRUCTURE
OF A PART OF THE
NORTH-CENTRAL BARBERTON GREENSTONE BELT,
SOUTH AFRICA
ABSTRACT

The north-central part of the 3.5 to 3.2 Ga-old Barberton greenstone belt contains both the northern and southern facies of the Swaziland Supergroup. The facies are divided by the Inyoka Fault, a thrust fault later reactivated by dextral shearing. Fig Tree strata show two principal facies that differ in both petrology and sedimentation. The facies boundary is roughly coincident with the Inyoka Fault. However, turbiditic sequences within the Fig Tree, formerly reported to be unique to the northern facies, are also exposed immediately south of the Inyoka Fault. The two facies of Fig Tree strata appear to be laterally gradational and probably do not represent two discrete depositional basins as has been previously proposed (Heinrich and Reimer, 1977). The Clutha Formation, the lowest unit of the Moodies Group, was also deposited in a single basin but uplift south of the Inyoka Fault resulted in either non-deposition or removal through erosion of the overlying Joe's Luck and Baviaanskop Formations. North-directed, post-depositional thrust faulting along the Inyoka Fault juxtaposed the southern and northern facies of the Moodies Group.

Multiple stages of large-scale lateral tectonics affected the Barberton greenstone belt. Thrust faulting and nappe forming throughout the belt (D₁ and 2) accompanied deposition of the Fig Tree Group. The study area experienced further thrust faulting and folding (D₃) following deposition of
the Moodies. After the relative uplift of the Kaap Valley pluton (D₄), the area was further disrupted by predominantly dextral folds and faults (D₅).

The final stage of structural development resulted in approximately north-south striking, vertically dipping faults (D₆). Many of these faults were sites of Late Archean to Early Proterozoic diabase intrusions.
INTRODUCTION

The northern and southern facies of all three units of the Swaziland Supergroup, the Onverwacht, Fig Tree, and Moodies Groups, are exposed in the north-central part of the Barberton greenstone belt. The area is divided by the Inyoka Fault, a major shear zone that separates the southern and northern facies (Heinrich, 1969; 1980; Hose, this volume, chap. 3; Lowe and Byerly, in review). Thus, the study area provides an excellent opportunity to compare the stratigraphy of the southern and northern facies and to examine the nature of the change across the fault.

The region is also one of the most structurally complex parts of the greenstone belt. Previous workers interpreted local faults and associated structures as the result of diapiric emplacement of the Kaap Valley Pluton into the overlying greenstone belt (Viljoen and Viljoen, 1969b; Anhaeusser, 1976; Fripp et al., 1980; Robb et al., 1986), thrusting directed towards the north (Fripp et al., 1980; Jackson et al., 1987), thrust directed towards the south (Daneel, 1986), and dextral shearing (Hose and Lowe, 1987). Six stages of deformation prior to the intrusion of Late Archean or Early Proterozoic diabase dikes have been identified by this study.
GEOLOGIC SETTING

The Barberton greenstone belt is a complexly deformed Early Archean orogen containing the Swaziland Supergroup, a sequence of predominantly volcanic and volcaniclastic, biogenic, and chemical sedimentary rocks of the Onverwacht and Fig Tree Groups (Viljoen and Viljoen, 1969b; Lowe and Byerly, in review) and lithic, quartzose, and arkosic sandstone, conglomerate, and siltstone of the Moodies Group (Hose, this volume) (Fig. 1). The greenstone belt, covering about 3000 square km in eastern South Africa and western Swaziland, is surrounded by penecontemporaneous to slightly younger plutonic rocks.

The granitoid rocks have been divided into three magmatic cycles (Anhaeusser and Robb, 1981). The first cycle plutonic rocks provide crystallization dates that are contemporaneous to the ages of the Swaziland Supergroup. The second and third cycles post-dated the deposition of the greenstone sequence. Emplacement of many of these granitic bodies, either as magmatic intrusions or as a remobilized solids (diapirs) was syntectonic and often responsible for the deformation of the greenstone belt (Visser, 1956; Ramsay, 1963; Anhaeusser and Robb, 1980; Jackson et al., 1987).

Onverwacht rocks, the oldest unit, line the greenstone belt along almost all sides and have prompted hypotheses that the Barberton greenstone belt is a synclinorium (Anhaeusser et al., 1969; Viljoen and Viljoen, 1969b;
Figure 1. Generalized stratigraphic column of the Swaziland Supergroup.

Onverwacht and Fig Tree stratigraphy is based on Lowe and Byerly (in review). Moodies Group stratigraphy is based on Hose (this volume).
Glikson, 1976), an interpretation that is not supported by this study.

Nine major, approximately east-west-trending faults cut all units of the Swaziland Supergroup and divide the study area into distinctive blocks (Fig. 2). The tectonic blocks are internally folded and faulted. Blocks comprising the Moodies Group are typically folded into large, isoclinal synclines with steeply dipping limbs and axial planes. Blocks in the study area that are made up predominantly of the Onverwacht and Fig Tree Groups are prevasively sheared and tightly folded, locally forming melanges.

Blocks south of the Inyoka Fault include the Powerline Road Syncline and Maid of the Mist Mountain Syncline, which are doubly plunging, open synclines. Both comprise coarse sandstone and conglomerate of the lower Moodies Group. The Schultzenhorst Block, situated west of the Powerline Road Syncline, is composed predominantly of dacitic volcaniclastic and intrusive rocks of the upper Fig Tree Group (Schoongezicht Formation). Isolated tectonic fragments of chrome-mica-rich chert, black chert, ferruginous chert, and komatiite displaying spinifex texture are scattered throughout the block. Heavy forestation development has resulted in poor exposures and prevents a clear understanding of the shearing and folding that has affected the Schultzenhorst Block.
Figure 2. Map showing the major tectonic blocks southwest of Barberton.
The Inyoka Block extends from the western boundary of the study area to the southeastern corner along the north sides of the Schultzenhorst Block and the Powerline Road and Maid of the Mist Mountain Synclines and along the south side of the Inyoka Fault. The Inyoka Block can be roughly divided into three sub-terranes (Fig. 3). The northwestern part of the block is composed predominantly of clastic rocks of the lower Fig Tree Group. This sub-terrane is pervasively folded but less sheared than the area to the south and southeast, although isolated fragments of black chert, chrome-mica-rich chert, and ferruginous chert crop out within the southern and eastern part of the sub-terrane. The central and southwestern part of the Inyoka Block is a melange with a matrix of pervasively sheared, talcose ultramafic volcanic rocks and fine-grained clastic rocks. Isolated fragments within the matrix include black chert, chrome-mica-rich chert, ferruginous chert, and quartz-rich sandstone. The eastern part of the Inyoka Block is a melange that has been extensively altered by metasomatism. Severe alteration has obscured the parentage of many of the rocks in the area. Two synclines of Moodies clastic and interbedded mafic volcanic strata as well as fragments of black chert and quartz-rich sandstone crop out within the eastern sub-terrane.

North of the Inyoka Fault, the Saddleback Syncline Block, in the east-central part of the study area, is bound on the south by the Inyoka Fault and on the north by the Saddleback Fault. The two faults merge into a single
Figure 3. Map of the melange within a part of the Inyoka Block. "B" represents fault traces, "F" designates fold axial plane traces, and the subscript numbers correspond to associated deformation event. See the text for further explanation.
shear zone in the western part of the study area. The Saddleback Fault has removed the northern limb of the Saddleback Syncline within the study area, leaving only the steeply dipping, north-younging southern limb. The Saddleback Syncline within the study area includes the upper approximately 20 meters of the Fig Tree Group and a more than 2800 m thick section of the Moodies Group.

The Haki Block extends east-northeast across the entire study area bounded by the Saddleback Fault to the south and the Haki Fault to the north. It is a pervasively sheared area in which rocks of the Onverwacht and Fig Tree Groups are thrown into tight to isoclinal folds. The terrane is predominantly fine-grained, ferruginous claylastic rocks of the lower Fig Tree Group but it also includes a large fragment of strongly foliated, pervasively sheared quartz-rich Moodies sandstone and isolated fragments of ferruginous chert.

The Zumpy Block also crosses the study area, bordered by the Haki Fault on the south and the Ameide Fault on the north. The eastern two-thirds of the block is composed of an extensively sheared and folded scaly serpentinite. Small, isolated fragments of black chert and ferruginous chert are enclosed within the serpentinite. The western part of the block is a steeply plunging, west-younging, isoclinal syncline comprised of talcose rocks of the Onverwacht Group and the lower strata of the Fig Tree Group.
The Brighton Kop Block is a terrane of extensively folded and faulted talcose and silicified ultramafic rocks and black chert of the Onverwacht Group and ferruginous sandstone, siltstone, and chert of the lower Fig Tree Group. The block is bound by the Ameide Fault on the south and another major fault along its eastern and northern side.

The Moodies Hills Block, north of the Ameide Fault and the Brighton Kop Block, is entirely composed of the Moodies Group and, possibly, rocks from the upper few meters of the upper Fig Tree Group. Nearly all of the strata are north-younging and steeply dipping. Minor shearing and folding have affected the sequence. The northern side of the block is bound by the Moodies Fault.

Extending across the entire north side of the study area, north of the Moodies Fault, is the Oorschot-Weltevreden Belt. Except for isolated fragments of lower Fig Tree ferruginous chert and sandstone and Onverwacht chromemica-rich chert along the Moodies Fault, the Oorschot-Weltevreden Belt within the study area is entirely composed of mafic and ultramafic volcanic and intrusive rocks of the Onverwacht Group.

The northernmost block in the study area is comprised of the tonolitic body called the Kaap Valley Pluton. The contact between the pluton and the Oorschot-Weltevreden Belt is sheared and provides no evidence of contact metamorphism.
North-south-trending, steeply dipping faults cross-cut all rock types, blocks, and the major faults in the study area. Undeformed, Late Archean to Early Proterozoic diabase dikes were emplaced in many of these younger faults. These faults and accompanying intrusions represent the youngest structures and rocks preserved in the greenstone belt.
METAMORPHISM, SILICIFICATION, AND CARBONATION

Extensive, low-grade alteration has affected rocks throughout the Barberton greenstone belt. Greenschist facies metamorphism, silicification, and carbonation are widespread and have affected nearly all lithologies. Contact metamorphism, locally developed along the margin of the belt (Viljoen and Viljoen, 1969a), does not occur in the study area.

Greenschist facies alteration is represented by abundant chlorite and sericite with minor epidote in the volcanic, volcanioclastic, and arkosic rocks. Quartz in the Moodies exhibits post-depositional strain and grain contacts are sutured in some tightly packed samples (Hose, this volume). Although all strata are altered to greenschist facies, lithologic names in this paper are given according to original composition and rock type, as can best be determined.

Widespread mobilization and deposition of silica accompanied by removal of some primary minerals has affected most of the Barberton belt. Cherts throughout the Onverwacht and lower Fig Tree Groups have been interpreted to represent a wide range of volcanioclastic and sedimentary rock types including volcanic rocks and volcanioclastic strata (Lowe and Byerly, 1986; Duchac, 1986; Duchac and Hanor, 1987), silicified evaporites (Fisher and Lowe, 1985; Worrell and Lowe, in review), carbonate layers, and sand- and silt-sized terrigenous sediments (Lowe and Byerly, in review). Silicification
in these strata occurred before significant tectonic deformation (Lowe and Byerly, 1986; Duchac and Hanor, 1987). The Moodies Group contains lensoidal beds of jasper in the Moodies Hills and elsewhere along the belt's northern margin (Anhauesser, 1973; Eriksson, 1978). Planar zones of nearly pure, interlocking, coarse-grained quartz along fractures has locally replaced Moodies clastic rocks in the Moodies Hills and Powerline Road Syncline and ultramafic rocks in the Oorschot-Weltevreden Belt.

Local units of Onverwacht and Moodies rocks with abundant dolomite and minor calcite, ankerite, and siderite were described by early workers (Hall, 1918; Visser, 1956; Anhaeusser, 1976) as primary carbonates. However, the carbonates are concentrated along major faults near mineralized zones (Cooke, 1965; Anhaeusser, 1976; Pearton, 1984). Within the study area, they are interpreted as products of secondary alteration. Carbonation occurred throughout the area but most affected the lower part of the Moodies Group in the Moodies Hills and extrusive volcanic rocks of the Onverwacht Group in the Oorschot-Weltevreden Block. Moodies sandstone collected in the Moodies Hills had carbonate contents of less than 5% outside of the mineralized areas and 50 to 90% with distinctive replacement textures in the Agnes Gold Mine (Hose, this volume, chap. 3). Wuth (1980) cites evidence of replacement of ultramafic rocks by carbonate north of the Moodies Fault and attributes it to an epigenetic/hydrothermal origin.
STRATIGRAPHY

Stratigraphy of the Barberton greenstone Belt has been studied in detail in selected and widespread areas (Reimer, 1967; Anhaeusser, 1969, 1973, 1975, 1976; Viljoen and Viljoen, 1969a, b; Condie, Macke, and Reimer, 1970; Eriksson, 1977; 1978; Lamb and Paris, 1988) but stratigraphic relationships between blocks are poorly understood. A scarcity of distinctive marker beds and poorly understood, complicated structural relationships inhibit correlations between tectonic blocks. Studies of the stratigraphy of portions of the study area have been made by Cooke (1965), Heinrich (1980), and Wuth (1980) but there has been no previous comprehensive investigation of this region.

The greenstone belt is comprised of the Swaziland Supergroup. This sequence includes the Onverwacht Group, a unit of predominantly ultramafic and mafic volcanic rocks about 10 km thick, overlain by 400 to 1200 m of predominantly volcaniclastic rocks of the Fig Tree Group (Lowe and Byerly, in review) and up to 2800 m of quartz-rich sandstones and conglomerates of the Moodies Group. Northern and southern facies, divided by the Inyoka Fault, have been identified in each Group (Heinrich, 1969, 1980; Reimer, 1975; SACS, 1980; Hose, this volume; Lowe and Byerly, in review). The study area contains the Inyoka Fault and portions of the northern and southern facies of all three Groups. Stratigraphic nomenclature used in this report for the
Onverwacht and Fig Tree Groups is based on Lowe and Byerly (in review).

Stratigraphic divisions for the Moodies Group follow the criteria suggested by Hose (this volume).

Onverwacht Group

The Onverwacht Group, oldest unit of the Swaziland Supergroup, consists predominantly of ultramafic, mafic, and some dacitic volcanic rocks, thin chert layers, and layered ultramafic intrusions. The igneous rocks in the study area are generally altered by serpentinization and pervasively sheared. A strong competence contrast between the ductile, serpentinized volcanic strata and the brittle cherts combined with severe deformation to produce Onverwacht terranes comprising foliated, talcose matrices with disarticulated chert fragments, particularly along major faults.

Distinctly different facies of the Onverwacht Group to the south and north of the Inyoka Fault have been reported by Lowe and Byerly (in review). They describe Onverwacht rocks in the central part of the belt, south of the fault, as a cyclic sequence of basaltic and serpentinized peridotitic komatiites and cherts, which are assigned to a new unit, the Mendon Formation. The northern facies is a thick succession of altered peridotitic and basaltic komatiitic lavas, basalts, layered ultramafic intrusions, and thin cherts. They hypothesize that the northern facies is younger than
the bulk of the southern facies and assigned it to a new unit of the Onverwacht Group, the Weltevreden Formation.

**Mendon Formation**

Outcrops of the uppermost 100 to 200 m of the Mendon Formation are concentrated in the core of anticlines and along fault planes in the Inyoka Block. Fragments are also scattered along minor faults within the Schultzenhorst Block. The rocks are predominantly serpentinized peridotitic komatiite. Weathered outcrops of the komatiite are typically pinkish brown with a rough "elephant-skin" texture. Fresh surfaces are dark green with prominent pyroxene needles. Talcose rocks are heavily weathered, appear chalky white to pale green with dark green marble-like streaks, contain pervasive penetrative cleavage, and feel very slippery. Spinifex textures are locally preserved in both fresh and altered rocks.

At the top of the volcanic sequence is a poorly to moderately preserved, laterally discontinuous basalt up to about 10 m thick. It is exposed at three places within the Inyoka Block (one site north of the Powerline Road Syncline and two sites in the central part of the block) and is adjacent to gray laminated, chrome-mica-rich, and/or banded cherts in each location.

The volcanic sequence is commonly overlain by an approximately 5 to 10 m thick layer of green, chrome-mica-rich chert with locally preserved
spinifex textures, interpreted elsewhere in the greenstone belt as silicified komatiites (Lowe and Byerly, 1986; Duchac and Hanor, 1987). Silicification occurred before significant tectonism. The silicified ultramafic zone is locally absent between the apparent top of the volcanic sequence and the base of the overlying cherts but it may have been removed by shearing. Conversely, disarticulated fragments of chrome-mica-rich chert are isolated within matrices of Fig Tree and Mendon rocks within the Inyoka and Schultzenhorst Blocks (Fig. 3; Plate I). They are interpreted as following the trend of minor faults.

Silicified ultramafic rocks are capped by chert, marking the top of the Onverwacht Group. The cherts change gradationally along strike and include gray laminated chert, ferruginous bedded chert, massive black chert, and black and white banded chert. It is uncertain whether the broken exposures of volcanic rock, silicified ultramafic rock, and chert sequences represent a single volcanic-sedimentary cycle repeated through faulting and tight folding or possibly multiple cycles.

Wellevreden Formation

The oldest rocks north of the Inyoka Fault are a thick sequence of serpentinized komatiitic and basaltic lavas, altered peridotitic layered intrusive rocks, and thin units of tuffaceous sediments and black cherts.
included in the Onverwacht Group (Viljoen and Viljoen, 1969a; Anhaeusser et al., 1981). Lowe and Byerly (in review) place these rocks in the Weltevreden Formation, a new formation within the Onverwacht Group and argue that the unit is probably younger than most of the Onverwacht Group south of the Inyoka Fault. The most detailed study of this unit was made by Wuth (1980) but was restricted to exposures north of the Moodies Fault.

**Volcanic sequence**

The predominant lithologies of the Weltevreden Formation are altered peridotitic and basaltic komatiites with lesser tholeiitic basalt and tuffaceous rocks (Wuth, 1980). Pervasive shearing, folding, and metasomatic alteration resulted in talc-carbonate, chlorite, and chlorite-amphibole schists, a nearly pure carbonate unit (Wuth, 1980), and scaly serpentine.

Between the Inyoka and Moodies Faults, the Weltevreden volcanic rocks crop out along the Saddleback, Haki, and Ameide Faults, in the core of an anticline in the Brighton Kop Block, and between the Brighton Kop and Moodies Hills Blocks (Fig. 2; Plate I). The rocks are severely altered and sheared, and their original textures have not been preserved. Volcanic outcrops along the Saddleback, Haki, and Ameide Faults, and in the Brighton Kop Block are heavily weathered, white to pale green, earthy talcose rocks, locally containing dark green marble-like streaks. A gray talc-carbonate
rock crops out along the central portion of the Saddleback Fault. Both rock types have pervasive penetrative cleavage and feels very slippery. A pervasively foliated and folded zone of serpentinites that can be disaggregated into polished chips, a fabric called "scaly serpentinite" by Cowan (1985), crops out along the Ameide Fault in the eastern three-fourths of the study area (Fig. 4).

Green, silicified rock cut by interwoven silica veinlets and, locally, a chrome-mica-rich chert with remnant spinifex texture separates the talcose rocks from a gray laminated chert in the core of an anticline in the Brighton Kop Block. The zone is conformable with the bedding in the gray laminated chert (Plate II), which is interpreted to overlie the volcanic sequence. The silicified rocks resemble the altered komatiites in the Mendon Formation to the south and are interpreted to have formed in a similar manner, although Lowe and Byerly (in review) suggest that the northern zones were altered in deeper water conditions. Three isolated slivers of silicified ultramafic rocks, including chrome-mica-rich chert, are prominent along the Saddleback Fault in the western half of the study area. One fragment in the Haki Block and several in the Brighton Kop Block are within matrices of fine-grained Fig Tree clastic rocks (Plate I). A larger zone of talcose and silicified komatiites crops out along the fault between the northwestern part of the Brighton Kop Block and the Moodies Hills.
North of the Moodies Fault, the Weltevreden Formation consists predominantly of dark green, altered peridotitic and basaltic komatiite with lesser quantities of tholeiitic basalt (Wuth, 1980). The ultramafic strata are serpentinized but locally display primary spinifex textures formed by both pyroxene needles and olivine blades. The tholeiitic basalts commonly show pillows and varioles. Some of the rocks in the Oorschot-Weltevreden Belt have been extensively replaced by secondary carbonate, mainly dolomite and ankerite. The carbonate bodies have a sugary texture and weather to an orangish-brown.

Figure 4. Photo of scaly serpentine along Ameide Fault. Note the small, hand sledge hammer in the lower left quadrant of the photograph.
**Cherts**

A zone, five to 20 m thick, of gray laminated, black and white banded, and massive black chert separates the silicified ultramafic rocks and chrom-mica-rich chert of the Weltevreden Formation from the lowest strata of the Fig Tree Group in the southern part of the Brighton Kop Block. All other exposures of Weltevreden chert in the study area occur as isolated, two to 20 m thick, disarticulated fragments with discordant dips that are encompassed by altered ultramafic rocks or fine-grained, clastic rocks. These tectonic slivers occur along the Saddleback, Ameide, and Moodies Faults, between the Brighton Kop and Moodies Hills Blocks, and within the Brighton Kop Block and Oorschot-Weltevreden Belt.

**Pioneer Intrusive Complex**

A layered ultramafic intrusion, the Pioneer Intrusive Complex, is interstratified with komatiitic volcanic units in the Weltevreden Formation north of the Moodies Fault. The intrusion is composed of incomplete cycles, from base to top, of serpentinized dunite, harzburgite/peridotite, orthopyroxenite, websterite, and norite/gabbro with rodingite dikes (Wuth, 1980; Anhaeusser, 1985). The serpentinized dunite and harzburgite/peridotite units form ridges parallel to the base of the Moodies Hills.
Extensive folding and faulting (Wuth, 1980) in the Pioneer Intrusive Complex resulted in steeply dipping layers. Severe flattening and shearing locally developed mafic and ultramafic schists, including conformable layers of a distinctive fine-grained rock composed of fibrous and platy crystals of talc, fibro-laminas of antigorite and chrysotile, chlorite, tremolite, and, locally, carbonate and magnetite (Fig. 5) (Wuth, 1980; Anhaeusser, 1985). These rocks, which are dark blue and resemble slate, have been described in several ultramafic intrusive complexes in the Barberton greenstone belt (Visser, 1956; Anhaeusser, 1969a; Wuth, 1980).

Fig Tree Group

The Fig Tree Group is an approximately 500 to 1500 m thick sequence of volcaniclastic and terrigenous shale, siltstone, sandstone, conglomerate, chert, and dacitic pyroclastic, intrusive, and extrusive rocks (Fig. 1). The sequence conformably overlies the Onverwacht Group but an unconformity separates the lower, predominantly ferruginous volcaniclastic and terrigenous sediments from the higher, dacitic sequence (Lowe and Byerly, in review).

Southern and northern facies, separated by the Inyoka Fault (Fig. 1), have been recognized in the Fig Tree Group (Heinrich, 1969; 1980; Heinrich and Reimer, 1977; SACS, 1980). The southern facies represents deposition in a
Figure 5. Photomicrograph of ultramafic rock with slaty cleavage from the Pioneer Intrusive Complex. Cross-nicols. Sample - LH 472.

predominantly proximal to locally distal environments (Lowe and Nocita, in review). The northern deposits are deep-water facies (Lowe and Byerly, in review). Heinrich and Reimer (1977) proposed that the facies were deposited in two discrete basins. The southern facies has also been interpreted as older than the northern facies rocks (Nocita, 1986; Eriksson et al., 1988) but a recently discovered spherule bed immediately above the black chert at the top of the northern facies Mendon Formation matches a spherule deposit at the base of the Fig Tree Group in the southern greenstone belt (Lowe and Byerly, in review). These layers are interpreted as products of a meteorite collision
and, therefore, provide a regional isochron at the base of the Fig Tree sequence (Lowe et al., 1989a).

The lower ferruginous strata make up the Mapepe Formation south of the Inyoka Fault and the Sheba and overlying Belvue Road Formations north of the fault. Only the younger, dacitic Schoongezicht Formation is recognizable in both areas (Reimer, 1967; Lowe and Byerly, in review).

**Mapepe Formation**

The Mapepe Formation consists of ferruginous sandstone and banded chert, silicified quartz-phyric ash, shale, siltstone, and, locally, lenticular chert-clast granule, pebble, and cobble conglomerate. The unit is reported to be between 200 to 700 m thick (Nocita, 1989; Lowe and Byerly, in review), although the top of the Mapepe Formation has never been identified. Within the study area, Mapepe strata are only exposed in the Inyoka Block, where lateral discontinuity and extensive structural disruption prevent an accurate estimate of thickness.

The lower contact between the black and banded chert of the upper Mendon Formation of the Onverwacht Group and the lower part of the Mapepe Formation is exposed at several locations in the Inyoka Block. It is conformable and transitional. The lowest part of the Mapepe Formation includes thin beds of fine-grained, ferruginous volcaniclastic and
terrigenous sandstone, siltstone, and shale. Silicification was most extensive near the lower contact; silicified rocks gradually diminish upsection. Conformable beds of gray to black chert, probably representing silicified clastic sediments, and jasper beds are common within 20 m of the lower contact. Two barite layers (Heinrich and Reimer, 1977), a chert-clast breccia (Lowe and Nocita, in review), and spherule beds (Lowe and Byerly, 1986; Lowe et al., 1989a) reported in the lower strata of the Mapepe Formation to the south have not been identified in the central part of the belt.

The Mapepe Formation includes a high percentage of partially to completely silicified tuffaceous sediments, up to 70% in some sections. Beds are typically one to three centimeters thick and reddish brown. Fresh exposures are pale gray, very fine-grained rocks. Lowe and Nocita (in review) report deposits of massive to well-layered air fall ash up to 200 m thick, current-worked cross-laminated, cross-stratified, and flat-laminated ash, and graded units with coarse terrigenous chert-sandstone bases and fine-grained ashy tops south of the study area.

The section coarsens upward and includes local, lenticular outcrops of immature sandstone and chert-clast granule, pebble, and cobble conglomerate. The Mapepe sandstone and conglomerate are composed predominantly of chert and chert-mica micromosaics that represent altered lithic fragments (Nocita, 1989). South of the study area, the Mapepe is
reported to be quartz-poor with a maximum of 20% quartz in the sandstone and conglomerate matrices (Lowe and Byerly, in review). Thick, terrigenous turbiditic sequences are absent. No clasts identifiable as exotic to the greenstone belt, such as plutonic rocks, quartzite, or detrital microcline grains, have been reported. Two channel deposits, each 3 to 5 m thick, containing quartz-bearing, chert pebble and cobble conglomerate crop out within fine-grained, quartz-poor, ferruginous sandstone in the east-central part of the Inyoka Block.

Larger exposures of conglomerate surrounded by Fig Tree ferruginous sediments are in the northwest part of the Inyoka Block. Some of these exposures have been previously identified as part of the younger Moodies Group (Visser, 1955; Anhauser et al., 1981). The conglomerates are laterally discontinuous lenses of massive, pebble and cobble conglomerates up to 15 m thick within well-bedded, laminated to medium thick beds of ferruginous sandstone with minor shale. Conglomerate clasts are predominantly black and black and white banded chert. The matrix contains about 2 - 10% quartz. The sandstone layers display graded beds, cross-beds, and planar beds that resemble turbiditic sequences. They contain up to 30% quartz. The rock is medium to dark gray in fresh exposures but weathers to a reddish brown. Folding in the study area makes a-thickness estimate uncertain but the
sandstone and conglomerate unit appears to be at least several hundred meters thick.

The depositional setting of the Mapepe Formation has been described based on sedimentological evidence as a quiet, deep-water, foredeep basin in front of a northward-directed fold and thrust belt (Jackson et al., 1987; Nocita, 1989; Lowe and Nocita, in review).

Sheba Formation

The Sheba Formation, the lowest division of the northern facies of the Fig Tree Group, crops out in the Haki, Zumpy, and Brighton Blocks and along the western part of the Moodies Fault. Lowe and Byerly (in review) have divided the approximately 500 m thick sequence into three subdivisions including, from bottom to top, banded ferruginous chert, very fine-grained, black, carbonaceous shale or claystone, and thick-bedded to massive, dark gray, fine- to coarse-grained immature turbiditic sandstone.

Immediately overlying the gray laminated and black chert at the top of the Weltevreden Formation is an approximately five to ten meters thick banded zone of slightly to moderately silicified ferruginous sediments that weather to reddish brown and thin beds of white chert. The only exposure of the Weltevredon-Sheba contact in the study area is in an anticlinal-synclinal fold pair at Brighton Kop. The banded chert zone thickens in the core of the
syncline but is missing from most of the north limb of the anticline (Plate I). Isolated, tectonic slivers of banded chert crop out along the Saddleback, Ameide, and Moodies Faults. The lowest subdivision of the Sheba Formation is interpreted by Lowe and Byerly (in review) as silicified sideritic oozes that contained fine volcanic ash, clay, and organic matter.

The cherty basal units grade upward into a 35 to 50 m thick, black, carbonaceous shale that weathers to reddish brown. It is exposed in the Haki, Zumpy, and Brighton Kop Blocks and in fragments along the Ameide, and Moodies Faults. Two laterally continuous, gray laminated and banded ferruginous chert layers within the lower part of the shale are exposed in the Zumpy Block and as isolated tectonic fragments in the Haki, Zumpy, and Brighton Kop Blocks (Plate I).

The upper part of the Sheba Formation is composed of thick-bedded to massive, fine- to coarse-grained immature turbiditic sandstone containing less than 20% quartz. Lowe and Byerly (in review) report that the sandstone is at least 500 m thick. Heavily weathered outcrops of Sheba sandstone are in the Haki and Brighton Kop Blocks and in a fragment along the Ameide Fault.

**Belvue Road Formation**

The middle unit of the northern Fig Tree Group, the Belvue Road Formation, is a deeply weathered, pale gray, brown, or pinkish shale and
fine-grained sandstone and siltstone with interbedded fine- to coarse-grained immature turbiditic sandstone (Reimer, 1967; Condie, Macke, and Reimer, 1970; Lowe and Byerly, in review). Fine-grained, ferruginous sediments in the Haki and Brighton Kop Blocks may represent the Belvue Road Formation in the study area but structural disruption and a lack of marker beds to distinguish it from rocks in the lower Sheba Formation preclude positive identification.

*Schoongezicht Formation*

The Schoongezicht Formation, recognizable both north and south of the Inyoka Fault, is the youngest unit of the Fig Tree Group. The sequence is made up of epiclastic sandstone, conglomerate, shale, and plagioclase-rich dacitic intrusions that typically weather to a light gray or light pinkish gray. Massive igneous breccias that crop out to the west (Byerly, in review) do not extend into the study area.

Clasts in the Schoongezicht Formation are subrounded to well rounded and derived from a predominantly dacitic terrane with minor contributions of black and chrome-mica-bearing chert pebbles from the Onverwacht. The clastic rocks were probably a part of an epiclastic debris apron surrounding a dacitic intrusive and volcanic terrane (Byerly, in review).
The southern facies of the Schoongezicht Formation covers a large area in the Schultzenhorst Block and also crops out in the Inyoka Block. Structural complexity, poor exposures primarily due to recent forestation development, and an absence of marker beds precludes the accurate construction of a stratigraphic column or thickness measurements within the study area but a generalized column, based on exposures on the south side of the Powerline Road Syncline, is shown in Figure 6. The lowest part of the sequence is an approximately 260 m thick, fining upward section of predominantly dacite-clast conglomerate and poorly sorted, coarse sandstone. The middle section, approximately 180 m thick, comprises interbedded dacitic lavas and coarse- to medium-grained, volcaniclastic sandstone. The upper 70 m of the Schoongezicht Formation includes predominantly medium-grained sandstone and siltstone.

The northern facies of the Schoongezicht Formation is composed of interbedded plagioclase-rich, fine- to coarse-grained turbiditic sandstone, conglomerate, and dark gray shale (Condie, Macke, and Reimer, 1970; Lowe and Byerly, in review). Within the study area, an approximately 20 m thick section of the northern facies, exposed along the south side of the Saddleback Syncline (Hose, this volume, Appendix 1b), consists of medium- to coarse-grained lithic arenite and dacite-clast conglomerate.

Primary mineralogies of the Schoongezicht rocks have been
GENERALIZED STRATIGRAPHIC COLUMN FOR THE SOUTHERN FACIES OF THE SCHOONGEZICHT FORMATION

Coarse- to very coarse-grained sandstone and cobble &-pebble conglomerate with predominantly chert and lesser dacitic clasts.

Well-bedded fine- and medium-grained sandstone and siltstone with moderate hematite.

Coarse-grained, dacitic, volcaniclastic sandstone with rounded to sub-rounded clasts.

Dacitic lava altered to fine-grained, chert-sericite aggregates.

Conglomerates and sandstones & with rounded to sub-rounded dacitic clasts containing volcanic quartz.

Poorly sorted, fine- to very fine-grained sandstone.

Predominantly felsic volcanic clasts conglomerate with fine-grained chert & mica matrix Minor chert clasts.

Purplish conglomerate with felsic volcanic clasts.

Ferruginous siltstone with less than 10% quartz.

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Figure 6. Generalized stratigraphic column of the southern facies of the Schoongezicht Formation.

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extensively altered to fine-grained chert-sericite mosaics and lesser amounts of calcite and chlorite. Plagioclase grains have been severely altered to fine-grained sericite (Fig. 7). The sandstones contain minor pure chert, carbonaceous chert, and chrome-mica-rich chert. Quartz grains are unstrained and commonly display embayments and beta-quartz outlines (Fig. 8). Tartan twinned feldspar and coarse quartz aggregates are present only near the upper contact with the Moodies Group. Detrital quartz content in the Schoongezicht Formation gradually increases upsection from 0 to 10%.

Moodies Group

The Moodies Group, the uppermost unit of the Swaziland Supergroup, is a 2800+ m sequence of quartzose, arkosic, and lithic sandstone, chert- and lithic-clast conglomerate, and siltstone with minor amounts of trachytic basalt, jasper, and shale. The quartz-rich strata markedly contrast with the underlying, predominantly volcanic and quartz-poor volcanioclastic, biogenic, and chemical sedimentary rocks of the Onverwacht and Fig Tree Groups (Viljoen and Viljoen, 1969b; Lowe and Byerly, in review). The Moodies is also less structurally disrupted than the older strata.

The Moodies Group is divided, from bottom to top, into the Clutha, Joe's Luck, and Baviaanskop Formations north of the Inyoka Fault (Anhaeusser, 1969a; 1976; Hose, this volume). South of the Inyoka Fault, only the lower part
Figure 7. Photomicrograph of a fine-grained chert-sericite mosaic in a Schoongezicht igneous rock. Plagioclase phenocrysts have been extensively altered to fine-grained aggregates of sericite. Cross-nicols. Sample - LH 160.

of the Clutha Formation crops out. The contact between the Schoongezicht and Clutha Formations is transitional on the south sides of the Powerline Road and Saddleback Synclines. A depositional or erosional contact at the top of the Moodies Group has never been reported.

The Moodies is exposed in four major tectonic blocks within the study area: the Powerline Road and the Maid of the Mist Mountain Synclines south of the Inyoka Fault and the Saddleback Syncline and Moodies Hills Block north
Figure 8. Embayed quartz grain within fine-grained, chert-sericite matrix in a Schoongezicht sandstone. Cross-nicols. Sample LH 536.

of the fault. Smaller blocks crop out within the structurally disrupted Inyoka Block south of the Saddleback Syncline. Undifferentiated, isolated tectonic slivers of Moodies sandstone are also exposed near the Saddleback Fault. The largest is a block of quartz-rich Moodies sandstone with black shale clasts and strong, pervasive cleavage along the Saddleback Fault in the eastern part of the Haki Block (Plate I).

**Clutha Formation**

The Clutha Formation has been split into five subdivision based on work in the Eureka Syncline. They are, from base to top, basal conglomerate,
calcareous quartzite, felspathic quartzite, shale, and jaspilite iron formation (Anhaeusser, 1976). The basal conglomerate contains pebbles and cobbles of black, gray, white, banded, and jasperoid chert, quartz and feldspar porphyries, quartzites, granite, granophyre, shale, graywacke, volcanic rocks and coarse-grained clasts that are predominantly quartz with lesser feldspar that interpreted by previous workers as metamorphites (Anhaeusser, 1969; 1976; Gay, 1969; Reimer et al., 1985; Daneel, 1986). The lowest subdivision also includes impure quartzite, calcareous and felspathic quartzites, arkoses, subarkoses, and subgraywackes (Anhaeusser, 1976).

The calcareous quartzite subdivision in the Eureka Syncline type area includes cross-bedded and graded-bedded calcareous sandstone, local zones of conglomerate, and narrow bands of impure dolomite or marble. Magnesium and calcium carbonate are abundant (Anhaeusser, 1976). The carbonate content markedly increases along shear zones or fault traces (Cooke, 1965; Anhaeusser, 1976; Pearton, 1984) but several early workers identified these layers as primary carbonates (Visser, 1956; Anhaeusser, 1976). Recent studies have interpreted the carbonate content in the north-central part of the belt as secondary mineralization (Daneel, 1986; Hose, this volume, Chapter 2; Lowe and Byerly, in review).

A thick sequence of arkose, subarkose, massive quartz arenite, and minor shale overlies the calcareous zone in the Eureka Syncline.
Immediately upsection is a unit of thin bedded, reddish brown shale. Reimer (1967) reported a lava bed within the shale zone in the Stolzburg Syncline that has not been recognized elsewhere. A well-developed banded magnetic shale and jasper zone caps the Clutha Formation (Anhaeusser, 1976).

The Clutha Formation in the study area is a fining upward sequence divisible into two sub-units (Hose, this volume, chap. 3). The lower, "A" division is exposed in the Moodies Hills, within the Inyoka Block, and in the Saddleback, Maid of the Mist Mountain, and Powerline Road Synclines. The higher, "B" division crops out in the Moodies Hills and Saddleback Syncline. Sharp petrographic and topographic changes mark the contact between the A and B sub-units of the Clutha Formation in the Saddleback Syncline. The Clutha A division forms the prominent, well-exposed Shokhohlwa ridge. The B division is poorly exposed and forms the Lomati River valley.

In the Saddleback Syncline, a complete section of the Clutha A division consists of 1138 m of laminated fine- to coarse-grained sandstone, trough and planar cross-bedded sandstone, and massive bedded sandstone, and open- and closed-matrix pebble and cobble conglomerate. Lithic clasts in both the conglomerate and sandstone beds are predominantly black, green, white, gray, and banded chert, with lesser amounts of jasper, felsic volcanic and volcaniclastic, mafic and ultramafic volcanic, banded iron formation, vein quartz, quartzite, granophyre, granitic, siltstone, and shale. Sandstone in the
lower approximately two-thirds of the division is predominantly lithic arenite and sublitharenite. A laterally discontinuous, up to ten meters thick zone of banded magnetic shale and jasper, is present only in the western part of the Moodies Hills. The upper 300 m of the A division, above the jasper zone in the Moodies Hills, is predominantly a subarkose.

The upper, B division of the Clutha Formation is a 790 m thick sequence of poorly cemented, severely weathered arkosic arenite and lithic arkose in the Saddleback Syncline and a sequence of fine-grained sandstone, siltstone, and shale that are locally carbonate-rich (>50%) in the Moodies Hills. Five zones of jasper interbedded with siltstone and sandstone are exposed in the central part of the Moodies Hills Block. Each zone is five to 45 m thick. The top of the highest jasper layer is 250 m below the upper contact of the Clutha Formation. In the eastern portion of the Moodies Hills Block, jasper is limited to a two meters thick zone. Jasper is absent in the Saddleback Syncline (Hose, this volume).

Joe's Luck Formation

Joe's Luck Formation was described by Anhaeusser (1976) as a fining upward sequence of conglomerate, quartz arenite, subgraywacke, and shale. He also reported a basaltic lava and a zone of ferruginous and magnetic shales.
with banded magnetic jasper in the middle of the formation. Jackson et al. (1987) have suggested that this sequence coarsens upward.

In the study area, the Joe's Luck Formation is composed of very fine- to very coarse-grained sandstone, siltstone, pebble and cobble conglomerate. It is 725 m thick in the Saddleback Syncline and 517 m to 575 m thick in the Moodies Hills. The basal unit is an approximately 100 m thick, planar bedded, medium- to coarse-grained quartz arenite with lenses of chert pebble conglomerate.

A quartz-chlorite-sericite greenstone, identified as an amygdaloidal, trachytic basalt, conformably overlies the quartz arenite. It is approximately 22 m thick in the Saddleback Syncline and zero to eight meters thick in the Moodies Hills (Hose, this volume). Amygdaloidal basalt is also exposed in two tectonic fragments within the eastern part of the Inyoka Block. Jasper beds immediately below and above the basalt in the Moodies Hills are absent in the Saddleback Syncline and Inyoka Block.

The upper two-thirds of the Joe's Luck Formation in the study area is a coarsening upward sequence of very fine-grained to very coarse-grained quartz arenite and sublitharenite (Hose, this volume). The sequence is capped by a massive chert pebble and cobble conglomerate that is 5 m thick in the Moodies Hills and about 200 m thick in the Saddleback Syncline. Throughout
the formation, grain sizes are consistently finer in the Moodies Hills than in equivalent layers in the Saddleback Syncline.

**Baviaanskop Formation**

Anhaeusser (1976) describes the Baviaanskop Formation in the Eureka Syncline type area as a fining upward sequence of quartz arenite, which is locally developed as a conglomerate, overlain by subgraywacke, sandstone, and shale. The top of the Baviaanskop Formation is locally capped by a pale, buff-colored arkose with pebbles of white chert and red jasper, the Bickenhall Member.

The Baviaanskop Formation is exposed in the Moodies Hills and in the Saddleback Syncline. It is composed of thin to medium bedded, siltstone and very fine-grained sublitharenite. The conglomerate assigned to the top of the coarsening upward Joe's Luck Formation is probably equivalent to the quartz arenite and conglomerate that was placed by Anhaeusser (1976) at the bottom of the Baviaanskop Formation. The contact between the top of the conglomerate and the base of the finer grained Baviaanskop is sharp. One bedded jasper-bearing layer, less than one meter thick, is about 90 m above the top of the conglomerate in the eastern part of the Moodies Hills. The Bickenhall Member is absent and the top of the Baviaanskop Formation is sheared.
Diabase Intrusions

Undeformed diabase intrusions extend across the study area and cross-cut all other rock types and generations of structures (Plate I). Visser (1956) and Viljoen and Viljoen (1969a) recognized that this set of dikes is nonconformably covered to the northwest by the Proterozoic (Cahen et al., 1984) Transvaal System. Most of the dikes intruded along faults and joints that strike approximately 30° west of north.

A quartz-bearing diabase, locally displaying graphic texture (Fig. 9), crops out along the north side of the Maid of the Mist Mountain Syncline at the southeastern end of the study area. This intrusion cross-cuts Moodies sandstones and appears to have been associated with severe metasomatic alteration of the adjacent terrane. Rocks in the valley between the Maid of the Mist Mountain Syncline and the Inyoka Fault and in pods within the Maid of the Mist Mountain Syncline have been severely altered by hydrothermal metasomatism that widely disguised their original parentages (Fig. 3; Plate I). The outcrops are composed of severely weathered, iron- and chlorite-rich, dark green and orangish-brown, earthy material with local fragments of identifiable Moodies and Fig Tree rocks.
Figure 9. Quartz-bearing diabase displaying a micrographic texture was collected along the north side of the Maid of the Mist Mountain Syncline.

Cross-nicols. Sample - LH 703.
STRUCTURE

Introduction

The northern margin of the Barberton greenstone belt, lying immediately adjacent to the Kaap Valley Pluton, consists of tightly folded rocks of the Swaziland Supergroup that are cut by numerous large and small faults. Previous workers have variously interpreted these structures as the result of diapiric emplacement of the Kaap Valley Pluton into the overlying greenstone belt (Viljoen and Viljoen, 1969b; Anhaeusser, 1976; Fripp et al., 1980; Robb et al., 1986), regional north-directed thrusting (Fripp et al., 1980; Jackson et al., 1987), south-directed thrusting (Daneel, 1986), and dextral shearing (Hose and Lowe, 1987).

In the present study, six phases of deformation, $D_1$ to $D_6$, are recognized that predate intrusion of Late Archean or Early Proterozoic diabase dikes (Table 1). The earliest deformation, $D_1$, is represented by faults and folds affecting Onverwacht and lower Fig Tree strata. A second period of deformation during Fig Tree time, $D_2$, also formed folds. Large, steeply dipping, approximately east-west striking thrust faults and associated folds and cleavage formed following deposition of the Moodies Group, $D_3$. A strong cleavage in the Moodies strata in the northern blocks and approximately east-west-striking normal faults in the northern part of the study area represent episode $D_4$. Dextral shearing and folding characterized $D_5$. Steeply dipping,
**STRUCTURAL DEVELOPMENT OF A PART OF THE NORTH-CENTRAL BARBERTON GREENSTONE BELT**

<table>
<thead>
<tr>
<th>PERIOD OF DEFORMATION</th>
<th>FOLDS</th>
<th>FAULTS</th>
<th>FOLIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-lower Fig Tree/pre-Moodies</td>
<td>$F_1$ - Tight to isoclinal, steep plunging folds with e-w trending axial planes.</td>
<td>$B_1$ - Faults cutting Onverwacht and Fig Tree strata.</td>
<td></td>
</tr>
<tr>
<td>$D_1$</td>
<td>$F_2$ - Tight folds plunging less than $10^\circ$. Approximately e-w striking axial planes.</td>
<td>$B_3$ - Large, n-e to w-northwest - e-southeast trending thrust faults.</td>
<td>$S_3$ - Pervasive cleavage in serpentinite along some faults. Scaly serpentinite. Associated cleavage in all rocks.</td>
</tr>
<tr>
<td>$D_2$</td>
<td>$F_3$ - Tight folds with axial planes that strike east-eastwest - west-southwest to east - west. First of the post-Moodies deformations.</td>
<td>$B_4$ - Arc-shaped fault separating Kaap Vaal Pluton from greenstone rocks.</td>
<td>$S_4$ - Cleavage and foliation developed in rocks along the northern part of the greenstone belt.</td>
</tr>
<tr>
<td>Post-Moodies</td>
<td>$F_4$ - Conjugate &amp; crenulation folds with sub-horizontal axes.</td>
<td>$B_5$ - Dextral faults. Shears are sub-parallel to nearly vertically dipping bedding.</td>
<td></td>
</tr>
<tr>
<td>$D_3$</td>
<td>$F_5$ - Predominantly dextral rotation folds.</td>
<td>$B_6$ - North-south striking, vertically dipping faults.</td>
<td></td>
</tr>
<tr>
<td>$D_4$</td>
<td></td>
<td></td>
<td>Table 1.</td>
</tr>
<tr>
<td>$D_5$</td>
<td></td>
<td></td>
<td></td>
</tr>
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</table>
minor, north-south-trending vertical faults formed during the last stage of deformation, \( D_6 \).

Previous studies

The only published detailed structural studies of the Barberton greenstone belt have reported polyphase deformation to the northeast of the town of Barberton (Ramsay, 1963; Anhaeusser, 1969b; 1972; 1976; Gay, 1969) and in the southern part of the belt (Lamb, 1984).

Two early episodes of folding associated with subhorizontal thrusting affected lower Fig Tree and older greenstone rocks in the central part of the belt according to Lowe et al. (1985). Their \( F_1 \) fold axes are steeply plunging, generally \( >50^\circ \). \( F_2 \) fold axes plunge \( <10^\circ \) to the east or northeast. They suggested that nappe-forming and thrusting accompanied Schoongezicht volcanism and intrusion.

Ramsay (1963) recognized three periods of deformation that followed the deposition of the Moodies Group in the northeastern part of the greenstone belt. Large (wave lengths greater than 1 km) folds with steeply inclined, northeast-southwest striking axial planes formed during the first period. The second deformation superimposed widespread slaty cleavage and schistosity across the older folds. Conjugate shear-folds formed during the
final period, which may have been contemporaneous with the bending of the axial planes of the Eureka and Ulundi Synclines northeast of the study area.

Anhaeusser (1976), also describing the belt to the northeast of this study, modified Ramsay's sequence by identifying four periods of post-Moodies deformation. In his model, diapiric emplacement of the Kaap Valley pluton accompanied and caused the fabric-forming, second episode and the arcuation of the Eureka Syncline, the third event. During the fourth period, a regional vertical primary compressive stress, which he attributed to the emplacement of younger granite plutons, formed conjugate and crenulation folds.

Lamb (1984) documented four phases of deformation in the southern part of the belt. The first was a period of regional stratigraphic inversion and nappe tectonics similar to the D_1 Fig Tree tectonics reported to the north. The second period involved high level synsedimentary folding and thrust faulting of alluvial deposits that are probably correlatable with the lower Moodies or upper Fig Tree strata. The third and fourth stages folded all greenstone strata and the earlier structures.
Pre-Moodies Deformation

$D_1$

Lowe et al. (1985) have described two generations of tight to isoclinal, folds within the Onverwacht and Fig Tree strata. F$_1$ folds are steeply plunging folds with axial planes that strike approximately east-west. Onverwacht and lower Fig Tree strata in the Inyoka (Fig. 3), Haki, Zumpy, Brighton Kop, and Oorschot-Weltevreden Blocks (Plate II) show this type of folding, which is absent in the Schoongezicht and Moodies strata. Fold amplitudes appear to be greater than 500 m.

Examples F$_1$ folds include the Brighton Kop syncline and folds in the central part of the Inyoka Block (Fig. 3). The Brighton Kop syncline plunges 79° S81°W and one in the central Inyoka Block plunges at approximately 80° S80°W, both trends based on extrapolation from limb intersections (Fig. 10). Neither the plunge of the fold axis nor the strikes and dips of the limbs of the syncline in the Zumpy Block could not be directly measured but the axial trace trends approximately N75°E and an electro-magnetic survey traversing across the eastern end of the syncline suggests that the axis plunges at greater than 30° (E. H. Stettler, written communication, 1987).

Lowe et al. (1985) documented east-directed thrust faults that predate deposition of the Schoongezicht Formation. Pre-Schoongezicht or pre-
Moodies faults may occur in the study area but have been obscured by later deformation events.

Figure 10. Equal area stereonet projections of the limbs and fold axes of two $F_1$ synclines. a.) Brighton Kop Syncline (see Figure 13 for a map of the syncline); b.) Syncline within the central part of the Inyoka Block.

$D_2$

Tight folds with sub-horizontal, approximately east-northeast-trending axial planes are common in the Mapepe conglomerate and sandstone strata.
immediately south of the Inyoka Fault and in several masses of black chert within the central Inyoka Block (Fig. 3; Plate II). The axial planes of these folds have been later refolded but direct measurement of the axes across canyons and over hills shows them to plunge at $<15^\circ$ to the east. Amplitudes of F$_2$ folds are typically 5 to 20 m.

F$_1$ and F$_2$ folds in the present area are compatible with the two periods of late Fig Tree age folding recognized by DeWit (1982) and Lowe et al. (1985), although evidence constraining the relative timing of the D$_1$ and D$_2$ was not found. The Moodies Group lacks the tight folding and shearing that characterize the Onverwacht and lower Fig Tree strata, and D$_1$ and D$_2$ structures do not extend across post-Moodies faults. No D$_1$ or D$_2$ structures were recognized within Schoongezicht rocks, but generally poor exposures due to weathering and forestation and the lack of distinctive marker layers may make them difficult to recognize.

Post-Moodies Deformation

Although stratigraphic changes suggest that the Moodies Group was deposited in a foreland basin in front of a northward or northwestward moving thrust belt (Jackson et al. 1987; Hose, this volume, Chapter 2), there is no evidence in the study area of deformation during deposition of the Moodies Group. Thrust faulting and folding contemporaneous with the deposition of
sandstones and conglomerates that are probably equivalent to the Moodies Group have been documented by Lamb (1984) in the southern part of the greenstone belt.

\[ D_3 \]

The oldest folds affecting Moodies strata are large, tight synclines with axial planes that typically strike east-northeast to east-southeast. Although no entire, first-order synclinal-anticlinal pair is preserved, the amplitudes and wavelengths of these F3 folds must be on the order of one kilometer or more. The axial planes of F3 synclines were bent during later deformational events. The Powerline Road Syncline, the southernmost F3, is a structural basin with an axis that plunge 18° S85°E at the west end (Fig. 11a) and 32° N83°W at the east end (Fig. 11b). Shears parallel and subparallel to bedding in the southwest, west, and northwest sides (Plate II) probably resulted from flexural slip during folding of the syncline.

Two other F3 structures, also south of the Inyoka Fault, are the doubly plunging Maid of the Mist Mountain Syncline, which plunges 53° S55°E in the northwest end to 6° S38°E in the west-central part (Fig. 11c-e) and a smaller, problematic unnamed syncline that deforms Moodies strata within the eastern part of the Inyoka Block. The unnamed syncline has been refolded and has an axis that plunges 63° S33°E (Fig. 11f; Plate II). Sedimentary structures in
Figure 11. Equal area stereonet projections of the limbs and fold axes of three $F_3$ synclines. a.) West end of the Powerline Road Syncline; b.) East end of the Powerline Road Syncline; c.) Northwest end of the Maid of the Mist Mountain Syncline; d.) Central part of the Maid of the Mist Mountain Syncline within the study area; e.) Southeast part of the Maid of the Mist Mountain Syncline within the study area; f.) An unnamed syncline within the eastern part of the Inyoka Block.
the Moodies show the south limb of the fold to be north-younging. Therefore, the structure is a syncline. Clearly the result of post-Moodies deformation, the form of the fold closely resembles $F_3$ structures. Rotation of the fold axis past vertical and towards the south probably resulted from later, dextral rotation.

The Saddleback Syncline is also a $F_3$ fold. The axial plane and northern limb have been removed within the study area by shearing along the Saddleback Fault but are preserved to the east where the axis plunges to the west and southwest (Visser, 1956). The north-younging block of Moodies strata in the Moodies Hills may be the southern limb of another syncline, possibly the western extension of the $F_3$-Eureka Syncline, but no axis or northern limb has been preserved within the study area.

$F_3$ anticlines in the Moodies Group have been removed by erosion of the higher levels of this fold belt. $F_3$ folding must have also affected the older greenstone rocks. The tightly folded, approximately east-west trending Fig Tree and Onverwacht terranes, including the Inyoka, Haki, Zumpy, and Brighton Kop Blocks, probably represent the tightly compressed, lower level cores of the $F_3$ anticlines.

Shearing along major steeply dipping faults ($B_3$) has juxtaposed the three greenstone groups. Fault traces generally trend east-northeast, sub-parallel to the regional strike of the beds and the $F_3$ axial planes (Visser, 1955;
Anhaeusser et al. 1981) (Fig. 2). Despite large apparent offsets, no allochthonous material has been reported. All \( B_3 \) structures in the study area are associated with tectonic melanges, defined by Cowan (1985) as fragments enveloped by a finer grained matrix (Plate II). Although not indicative of a specific setting, Phanerozoic melanges are broadly related to convergent boundaries along major strike-slip or reverse-slip faults (van de Fliert et al., 1980; Cowan, 1985). The matrices of the melanges are commonly serpentinite that locally disaggregates into lenticular polished chips, a fabric called "scaly serpentinite" (Cowan, 1985). Scaly serpentinite is an extremely mobile material that probably forms by cataclastic flow (Cowan, 1985; Saleeby, 1984).

The southern margin of the Moodies Hills and Brighton Kop Blocks is a major \( D_3 \) shear zone here named the Ameide Fault. Although this fault has been called the Sheba Fault by Daneel (1986), Tomkinson et al. (1988), and in mining company reports, there is no compelling evidence to suggest that it is a continuation of the Sheba Fault in the Sheba Hills. The Ameide Fault zone varies from approximately 20 to 250 m wide and is marked by serpentinite containing lenticular blocks of black chert and silicified lower Fig Tree strata. The fault in the eastern two-thirds of the area is a band of scaly serpentinite (Fig. 4).

To the west, the Ameide Fault extends just south of Brighton Kop and separates the Zumpy and Brighton Kop Blocks. A zone of talcose serpentinite
about 100 to 250 m wide characterizes this part of the fault. The talcose serpentinite extends into the core of the D₁ anticline at Brighton Kop (Fig. 12), suggesting that the Ameide Fault maybe a reactivation of an earlier B₁ structure. The Ameide Fault is vertical near the surface.

Figure 12. Anticlinal-synclinal fold pair along the Ameide Fault that may represent D₁ structures. Thus, the Ameide Fault may be a D₁ structure that was reactivated during the D₃ stage.

The southwestern boundary of the Moodies Hills Block separates lower Clutha conglomerate and sandstone from lower Fig Tree and Onverwacht rocks. A black, fine-grained siliceous rock that crops out along the contact between the Onverwacht and Moodies strata near the northwestern corner of
the Brighton Kop Block displays microboudons and "necking" structures and has been interpreted as a silicified mylonite (Daneel, 1987). Other fragments of black and banded chert with their longest dimensions parallel to the contact are exposed along the boundary adjacent to both the Fig Tree ferruginous sandstone and Onverwacht silicified ultramafic terranes (Plate I). This contact is interpreted as another D3 fault, although compelling evidence of shearing is lacking along most of the boundary between the Sheba sandstone in the Brighton Kop Block and the lower Clutha sandstone and conglomerate in the Moodies Hills Block.

The Haki Fault extends between the Zumpy and Haki Blocks and is delineated a zone 30 to 200 m wide of talcose serpentinite with ferruginous clastic rocks on each side. The fault is interpreted as a B3 structure based on its merger with the Ameide Fault about one kilometer east of the Princeton Mine (Fig. 2; Plate II).

The Saddleback Fault, another apparent B3 structure, forms the north side of the Saddleback Syncline and continues west through the Princeton Mine area, where drill cores show that the fault is vertical to a depth of at least 350 m. Tectonic inclusions of Moodies sandstone and banded and chrome-mica-rich chert are scattered within a sheared, fine-grained Fig Tree matrix along the north side of this fault. The largest fragment is a strongly foliated (S3) block of Moodies sandstone with flattened shale clasts in the
southeast portion of the Haki Block (Fig. 2; Plate II). A thin (<40 m wide), sheared, serpentinized and silicified ultramafic zone defines the Saddleback Fault in the western half of the area.

The Inyoka Fault is a broad zone of shearing ranging from about 50 to 450 m wide. The fault approximately marks the boundary between southern and northern facies in the Onverwacht (Lowe and Byerly, in review), Fig Tree (Heinrich and Reimer, 1977; SACS, 1980), and Moodies (Hose, this volume) Groups, emphasizing the structure's significance. Heinrich and Reimer (1977) proposed that shearing along the Inyoka Fault eliminated a submarine ridge that separated distinctive, but not necessarily distant, southern and northern Fig Tree facies. Upper Mapepe strata in the western half of the study area immediately south of the Inyoka Fault resemble the turbiditic sequences of the northern facies Sheba Formation. This observation suggests that transitional Fig Tree facies were juxtaposed by later lateral tectonics, rather than deposited in two discrete basins. The placement of older rocks on the south side against younger rocks along the north side further suggests that the fault was north-directed. Hose (this volume) argues that nearly identical Moodies clastic components on both sides of the fault also suggest a single basin during Moodies deposition.

The Schultzenhorst Fault, another probable B3 structure, separates Onverwacht serpentinite in the Inyoka Block from Schoongezicht rocks in
the Schultzenhorst Block (Fig. 2). Fragments of black chert and chrome-mica-rich chert crop out within the serpentinite along the trace of the fault. An outcrop of chrome-mica-rich chert is adjacent to the fault on the southern side. The fault is nearly vertical and the trace trends east-northeast. Near the Powerline Road Syncline, it bends sharply to the south-southeast; a trend abruptly terminated by the northwest side of the syncline.

The $D_3$ faults have juxtaposed strata, resulting in the elimination of over a kilometer of stratigraphic section along the Inyoka and Ameide Faults. The faults strike sub-parallel to the bedding in the southern limbs of associated synclines ($F_3$). The folds have sub-horizontal to moderately steep, west-plunging fold axes and verge to the north to north-northwest. The northern limbs of the associated folds have been truncated, suggesting the age of shearing generally youngs to the north. The Saddleback Fault completely truncates the Saddleback Syncline and eliminates the Inyoka Fault trace, probably representing a slightly younger age for the northern fault.

Based on this evidence, the nature of thrust terrains to migrate towards the foreland, and consistent with interpretations by Lamb (1984) of post-Moodies faults in the southern part of the greenstone belt, these faults are interpreted as north- or northwest-directed thrust faults.

Several large faults that appear to have been formed during the same stage of tectonism as the Inyoka and Ameide Faults do not meet the criteria of
north-directed thrust faults. The Schultzenhorst, Saddleback, and Haki Faults divide younger rocks to the south and older rocks to the north, contrary to the characteristics of north-directed thrust faults. If they are $D_3$ stage structures, they must represent back-thrust faults splaying off of the Inyoka and Ameide Faults. Alternatively, they may represent a unrelated, later generation of shearing (Fig. 13). A single, approximately north-south-trending fault that truncates pre-Moodies ($F_2$) structures (Fig. 3) probably represents a $D_3$ stage tear fault.

Planar fabrics within the study area include foliation, schistosity, and cleavage defined by alignment of talc, serpentine, micas, or flattened clasts. The oldest planar fabric that is preserved and recognized, $S_3$, is a pervasive cleavage in Onverwacht serpentinite and fine-grained Fig Tree rocks. $S_3$ fabric is found along the major $D_3$ faults. Foliation within the Haki and Zumpy Blocks clusters around N76°E 68°S (Fig. 14). The fabric within the northern half of the Inyoka Block is much more scattered, probably resulting from the later dextral rotation. Scaly serpentinite along the eastern two-thirds of the Ameide Fault displays a pronounced $S_3$ cleavage that is so severely contorted that measurements were not attempted (Fig. 4). A talc-carbonate schist also exhibits a strong, planar $S_3$ cleavage trending approximately N80°E 77°S along the Saddleback Fault about one-and-a-half kilometers east of the Princeton
Mine. As this fabric is most prominent within and along the major D₃ shear zones, it probably resulted from the folding and shearing associated with D₃ prior to emplacement of the Kaap Valley pluton.

a. Moodies, Haki, and Saddleback Faults are shown as backthrust faults.

b. Moodies, Haki, and Saddleback Faults are shown as normal faults.

Figure 13. Schematic diagram showing alternative relationships of the Haki, Saddleback, and Auber Villier Faults during D4. Further north-south compression following the emplacement of the Kaap Valley Pluton has resulted in the present-day tighter folds and steeper dipping limbs. See figure 12 for explanation of symbols.

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Figure 14. Equal area stereonet projections of poles of foliation ($S_3$) in: a.) Haki Block; b.) Zumpy Block; c.) Inyoka Block.

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Bedding, fold axial planes, and fault surfaces are steeply dipping to overturned throughout most of the greenstone belt (Plate II). These structures were probably rotated to nearly vertical during this period of tight folding and deformation.

$D_4$

A south-dipping (deBeer et al., 1988) normal fault ($B_4$) separates the greenstone belt from the uplifted Kaap Valley Pluton to the north. The sharp contact lacks a chill boundary. Plutonic rocks at the contact are severely weathered, coarse-grained tonalite representing slow cooling of the parent magma at a moderately deep level. Slivers of the granitic rock, extending for over 100 m into the ultramafic body, are also coarse-grained. Ultramafic rocks adjacent to the pluton provide no evidence of contact metamorphism.

There are no conclusive data on the age of shearing along this fault. Barton et al. (1983) reported a Rb-Sr isochron age for the pluton of 3.48 - 3.49 Ga. A common Pb age of about 3.2 Ga was provided for the tonalite by Robb et al. (1986) who hypothesized that the later date represents a time of isotopic resetting as a result of vertical rise and that the older, Rb-Sr date was the age of magmatic crystallization. Tegtmeyer and Kroner (1986) proposed a similar age (3.23 - 3.25 Ga) for the rising of the Kaap Valley pluton based on U-Pb isotopes in zircons and sphene. However, recent high-precision Pb-Pb zircon
dating of dacites indicate that the Schoongezicht Formation is as young as 3.225 Ga (Kroner et al., 1989). If correct, this date requires that D₃ through D₆ occurred after 3.225 Ga ago.

Folds with sub-horizontal axes and amplitudes of less than one meter are common in the Moodies sandstones and siltstones in the Moodies Hills but are absent in the Moodies strata to the south. These structures are similar to conjugate and crenulation folds in the Eureka Syncline described by Anhaeusser (1976), who suggested that they may have been second-order structures developed during the emplacement of the granitic plutons (D₄). Ramsay (1963) suggested that this style of folding developed synchronously with the deformation of the F₃ Eureka Syncline fold axes, an event (D₅?) that followed the uplift of the plutons. Absence of the small amplitude folds with sub-horizontal axis in the Saddleback Syncline and terranes to the south of the Inyoka Fault, a distribution that is characteristic of D₄ structures, support the suggestion that this style of folding was associated with the emplacement of the Kaap Valley Pluton.

The event that resulted in the faulted uplift of the Kaap Valley Pluton is identified as D₄ based on a planar fabric, S₄, that becomes stronger with proximity to the pluton. The strong cleavage, which is parallel and sub-parallel to the adjacent boundary of the Kaap Valley Pluton, is pervasive in the Oorschot-Weltevreden Belt (Fig. 15a). Clasts in the northern Moodies Hills
are flattened along the same plane (Fig. 15b). Flattening is particularly pronounced in the pebbles and cobbles in the conglomerate at the top of the

Figure 15. Equal area stereonet of the poles of foliation in: a.) Oorschot-Weltevreden Block, north of the Moodies Fault; b.) northern Moodies Hills; c.) Saddleback Fault Zone.
Joe's Luck Formation (Fig. 16). The planar fabric's strike and dip is sub-parallel to bedding providing evidence that the strata had been rotated to nearly vertical prior to the D₄ event.

Figure 16. Photograph of stretched chert clasts in the Moodies Hills.

The two generations of planar fabric in the study area, S₃ and S₄, display similar orientations (Fig. 14 and 15). They are distinguished by their differing penchant. The S₃ fabric is associated with D₃ shear zones and is not displayed within the major blocks of the Moodies sandstones and conglomerates. The S₄ fabric is prominently displayed within the sandstone and conglomerate outcrops in the northern part of the Moodies Hills and it becomes more strongly developed with proximity to the Kaap Valley Pluton.
Anhaeusser (1974) also recognized two planar fabric stages. The first was described as a slaty cleavage that developed during the earliest, post-Moodies folding event (D$_3$ in this study). The second was characterized by pebble flattening adjacent to the granite contacts in the western and northern limbs of the Eureka Syncline. Ramsay (1963) only identified one planar fabric producing stage in the northeastern part of the greenstone belt. He reported that the slaty cleavage and clast lineations cross-cut bedding and the fold axis in the Eureka Syncline (F$_3$), suggesting that it is a "superimposed structure" that developed after all major folds, including the Eureka and Ulundi Synclines. Both workers recognized that the planar fabric adjacent to and within the granitic bodies are parallel to the faulted contacts between the plutons and the greenstone belt and that they changes as the trend of the fault changes. The extension of parallel foliation and cleavage from the greenstone belt into the adjacent pluton shows that the fabric formed during or after the emplacement of the pluton, the second period of post-Moodies deformation (D$_4$).

The Moodies Fault (Fig. 2) is also interpreted as a D$_4$ structure. The fault separates the Onverwacht intrusive and extrusive rocks in the Oorschot-Weltevreden Belt to the north from the younger, clastic rocks in the Moodies Hills to the south. Resistivity and gravity data indicate that the Moodies fault dips at approximately 80° to the south (Fig. 17) (de Beer et al., 1988; E. H.
Stettler, 1987, personal communication). The Moodies Fault is a narrow, less than 30 m wide zone in the eastern and central part of the study area. Fragments of lower Fig Tree and upper Onverwacht cherts with exposed dimensions of less than 100 m crop out along the fault. The fault bifurcates to the west. The southern branch, the Morgan Fault, continues to the west (Wuth, 1980) as an approximately 50 m wide zone of sheared ultramafic rocks that separates a north-younging sliver of Sheba ferruginous banded chert.

Figure 17. Residual anomaly profile assuming mean regional density (2,670 kg/m³) and generalized geologic cross-section for a traverse that includes the study area (after de Beer et al., 1988). 1 g. u. = 0.1 mgal.
and clastic rocks from the north-younging Moodies strata in the Moodies Hills. The Moodies Fault continues along the northern boundary of the Fig Tree rocks, separating them from the Weltevreden outcrops (Plate II).

Rocks adjacent to the Moodies Fault throughout the study area are extensively sheared. Linear trails of chert inclusions, slickensides, and bands of ultramafic rocks with prominent slaty cleavage (Fig. 5) within the Oorschot-Weltevreden Belt are sub-parallel to the Moodies Fault as well as the faulted contact with the Kaap Valley Pluton.

The Moodies Fault is a normal fault. Its southerly dip precludes an interpretation of the structure as a D₃ backthrust fault. It is interpreted by this study as the result of a block of Weltevreden rocks, the Oorschot-Weltevreden Belt, being dragged up by the rising Kaap Valley Pluton. This shearing resulted in the uplift and later erosion of the north limb and hinge surface of a syncline, leaving part of the southern, north-younging limb to form the Moodies Hills on the hanging wall side (Fig. 18).

$D_5$

Flexural folds throughout the Moodies Hills represent clockwise rotation within the block. The folds, F₅, are almost entirely z-shaped and the fold axes plunges cluster around 43° S66°E (Fig. 19 and 20a). The Shebang fold, the largest of the z-shaped folds, has axes that plunge 36°N87°E (Fig. 20b).
Figure 18. Schematic diagrams showing the effects of the rise of the Kaap Valley Pluton during D₄ stage. a.) Proposed cross-section of the northern part of the study area at the end of D₃; b. Proposed cross-section of the northern part of the area at the end of D₄. See figure 12 for explanation of symbols.

Foliation planes of flattened Moodies clasts in the limbs of the Shebang fold have also been rotated and plots of their poles define fold axes that plunge about 70° S87°E (Fig. 20c). Flattened clasts in the study area are unique to the
Moodies Hills and were previously interpreted by this study as S₄. The dextral rotation event, D₅, clearly post-dates a foliation-forming event in the Moodies Hills, probably D₄.

![Stereogram of fold axes in the Moodies Hills](image)

Figure 19. Stereogram of fold axes in the Moodies Hills. Great circle defines the plane N42°E 45°SE.

The dextral rotation event also followed the major synclinal folding stage (D₃). The axial trace of the doubly plunging Powerline Road Syncline changes from 18° S85°E at its west end to 32° N83°W at the east end (Fig. 11a). The axial trace of the Maid of the Mist Mountain Syncline within the study...

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Figure 20. a.) Map showing the change in orientation of the bedding and foliation along the limbs of the Shebang fold limbs. See figure 12 for explanation of symbols; b.) Equal area stereonet projection of the limbs and fold axes of the $F_5$ Shebang anticlinal-synclinal pair in the Moodies Hills; c.) Equal area stereonet projection of the orientation of flattened clasts in the $F_5$ Shebang fold.
area varies from 61° S62°W at its northwest end to 6° S52°E to the southeast (Fig 10b). Folding of the synclinal axes of these two F3 structures probably also occurred during D5.

Although largely ignored in the literature of the last twenty years, early workers recognized a major dextral shearing event, D5, along the Sheba, Saddleback, and two other faults east and northeast of Barberton (Boardman, 1950; Visser, 1956; Roering, 1965). They described these structures as thrust faults, B3, that were reactivated as wrench faults, B5, following the development of slaty cleavage and the flattening of clasts, S4. Anhaeusser (1965) identified fractures, drag folds, cymoid loops or curves, and brecciated zones associated with dextral wrench faults east of Barberton as the most important controls of mineralization.

Dextral shearing sub-parallel to bedding across the north-central and northeastern Moodies Hills resulted in a maximum stratigraphic separation of about 700 m. The steeply dipping faults (B5) and strata in plan view resemble the cross-section of a thrust fault terrane (Fig. 21) (Hose and Lowe, 1987). Flexural-slip folds within the Moodies Hills block are almost entirely z-shaped reflecting a clockwise rotation that accompanied primarily dextral shearing and suggesting a plane of movement of N42°E 45°SE (Fig. 19). Foliation of clasts in the Moodies Hills have also undergone rotation across the mid-block faults. South of the dextral shear zone, foliation of pebbles and grains has
Figure 21. Detailed geologic map of a part of the Moodies Hills. B₃ are thrust faults formed during the third period of deformation (D₃). B₄ are normal faults formed during the uplift of the Kaap Valley Pluton. B₅ are dextral faults formed during the fifth stage of deformation. B₆ are north-south-striking, vertically dipping faults formed during the last period of deformation.
been rotated where the strata have folded clockwise (Fig. 20). Foliation data north of the fault are less scattered, due to the absence of large folds, and average about N80°E 45°S (Fig. 15a and 15b). Thus, the dextral shearing event, like the dextral folding stage, was probably younger than the foliation-forming event.

The dextral shearing event affected the central and southern parts of the study area as well. Blocks of Moodies sandstone and conglomerate adjacent to the north side of the Inyoka Fault have a dextral separation relative to the main block of the Saddleback Syncline, evidence of reactivation along the fault during D₅ (Fig. 22; Plate II). The axis of the Maid of the Mist Mountain Syncline also has a dextral separation of about 70 m along a west-northwest trending shear. The complexly folded and sheared rocks in the Inyoka Block in between Inyoka Fault and the Maid of the Mist Mountain Syncline were undoubtably greatly affected by the D₅ event.

\[ D₆ \]

North-northwest striking faults, B₆, displace all other structures, including the Moodies, Ameide, Saddleback, and Inyoka Faults and the dextral faults within the Moodies Hills (Fig. 20; Plate II). They appear to be nearly vertical dip-slip faults and are most common in the northern part of the belt.
Many of the B₆ structures are intruded by the youngest rocks in the Barberton area, the pre-Transvaal age (>2.3 Ga) diabase dikes (Plate I).

Figure 22. Map of the southeastern part of the study area emphasizing dextral faults (B₅) and folds (F₅).

Deep Structure

De Beer et al. (1988) identified a strong gravity positive throughout the Barberton greenstone belt and interpreted it to represent a thick layer of ultramafic material under the entire belt. Their DC resistivity and gravity study also suggests that the greenstone sequence is only four to eight
kilometers deep, approximately three to ten kilometers less than the
stratigraphic thickness of the Swaziland Supergroup, and is underlain by
rocks with densities similar to the surrounding granite and gneiss terranes.
Major faults are therefore probably rooted in the Onverwacht Group. Fripp et
al. (1980) suggested that the base of the Barberton greenstone belt is a major,
low-angle, south dipping sole thrust fault. The existence of a sub-horizontal
sole thrust at depth is likely but its presence at the base or within the
Onverwacht Group is unproven.
SUMMARY

The north-central Barberton greenstone belt southwest of the town of Barberton is crossed by the Inyoka Fault, a major boundary that separates northern and southern facies of the Onverwacht, Fig Tree, and Moodies Groups. Within the study area, both facies of all three lithostratigraphic units are exposed. No significant differences are displayed by the pervasively serpentinized and disarticulated upper Onverwacht outcrops north and south of the Inyoka Fault. However, the better preserved rocks of the Oorschot-Weltevreden Belt include the Pioneer Intrusive Complex and lack silicified shallow water sediments, thereby differing from the southern facies Onverwacht rocks in the central part of the belt. The lower Fig Tree strata display only subtle difference across the Inyoka Fault. The upper beds of the southern facies Mapepe Formation, previously described as non-turbiditic, quartz-poor sandstone and conglomerate, include turbiditic sequences with up to 30% quartz in the study area. These beds resemble the turbidites of the northern facies Sheba Formation. The northern facies of the younger Schoongezicht Formation has a limited exposure in the area but it displays petrologic and primary structural features similar to the southern facies. The two facies of Fig Tree strata appear to be laterally gradational and do not represent two discrete depositional basins. The Clutha Formation was also deposited in a single basin but uplift in the south resulted in either non-
deposition or removal through erosion of the Joe's Luck and Baviaanskop Formations south of the Inyoka Fault. Large-scale, north-directed, thrust faulting along the Inyoka Fault juxtaposed the southern and northern facies.

Multiple stages of large-scale lateral tectonics have played a central role in the development of the Barberton greenstone belt. Thrust faulting ($B_1$) and nappe forming ($F_1$ and $2$) occurred in the southern, central, and northern part of the belt during deposition of the Fig Tree Group. Moodies age thrust faulting and accompanying uplift appears to have interrupted deposition south of the Inyoka Fault, providing reworked sediments to a foreland basin to the north. Later thrust faulting ($B_3$), development of cleavage near faults ($S_3$), and folding ($F_3$), probably resulting from a northward migration of the earlier southern thrust belt, affected the Moodies and other greenstone rocks in the study area. Following uplift of the Kaap Valley pluton ($B_4$), minor folding ($F_4$) and the development of associated cleavage ($S_4$), the study area was further disrupted by predominantly dextral faults ($B_5$) and folds ($F_5$), some reactivating $B_3$ structures. The final deformation stage ($D_6$) is represented by steeply dipping, approximately north-south-trending dip-slip faults ($B_6$).

Contrary to classic models, the Barberton greenstone belt is not simply a large synclinorium. The tightly folded, south-younging Oorschot-Weltevreden Belt has been emplaced by faulting. The block is not the base of
a south-facing limb and the Onverwacht rocks north of the Moodies Fault have been interpreted as younger than the Onverwacht strata in the central part of the belt (Lowe and Byerly, in review). There is no evidence of overall younging to the south across the area nor within any of the blocks. Strata in the Inyoka Block, Saddleback Syncline, Brighton Kop Block, and Moodies Hills young to the north. The repetition of strata in this part of the greenstone belt is the result of large-scale, lateral faulting and is not due to systematic folding associated with a belt-wide synclinorium.
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CHAPTER 2

PETROGRAPHY AND PETROLOGY OF THE MOODIES GROUP IN THE NORTH-CENTRAL PART OF THE BARBERTON GREENSTONE BELT, SOUTH AFRICA: STRATIGRAPHIC RECORD OF AN EARLY ARCHEAN FORELAND REGION
ABSTRACT

The 3.2 to 3.1 Ga-old Moodies Group is the youngest unit of the Swaziland Supergroup in the Barberton greenstone belt, South Africa. The 2800+ m sequence of predominantly lithic arenite, sublitharenite, and arkosic arenite is divided, from base to top, into the Clutha, Joe's Luck, and Bavianskop Formations. It overlies volcanic and volcaniclastic rocks of the Fig Tree Group and, locally, the Onverwacht Group. The top of the Moodies is not exposed.

The petrology and stratigraphy of the Moodies Group was studied in four large, structurally isolated blocks in the north-central part of greenstone belt: the Moodies Hills, Saddleback Syncline, Maid of the Mist Mountain Syncline, and Powerline Road Syncline. The sublitharenite, lithic arenite, arkosic arenite, and subarkose of the Clutha Formation north of the Inyoka Fault were derived from two provenances: the underlying greenstone strata and a felsic crystalline terrane. The crystalline terrane may have been a part of the Ancient Gneiss Complex. Strata south of the Inyoka Fault are solely composed of material eroded from the greenstone belt. The quartz arenite, sublitharenite, and subarkose of the Joe's Luck and Bavianskop Formations were probably derived from reworked, cannabalized, older Moodies strata. Stratigraphic units equivalent to the Joe's Luck and Bavianskop Formations are absent south of the Inyoka Fault.

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The Moodies Group was deposited in a foreland basin formed by thrust faulting and uplift of the greenstone belt in the south or southeast. The depositional basin deepened to the north and distinctive northern and southern facies terrains are divided by the Inyoka Fault. It is proposed that a plutonic/felsic crystalline terrane provided detritus to the part of the basin comprising the northern facies but was isolated from the present southern blocks. The northern and southern blocks were juxtaposed during thrust faulting and later dextral shearing.
INTRODUCTION

The approximately 3.2 to 3.1 Ga-old Moodies Group is the uppermost unit of the Swaziland Supergroup in the Barberton greenstone belt of South Africa (Fig. 1). It consists of 2800+ m of quartzose, arkosic, and lithic sandstone, siltstone, and chert- and lithic-clast conglomerate with minor amounts of amygdaloidal basalt, jasper, and shale. The quartz-rich strata contrast markedly with underlying, predominantly volcanic and quartz-poor volcaniclastic, biogenic, and chemical sedimentary rocks of the Onverwacht and Fig Tree Groups (Viljoen and Viljoen, 1969; Lowe and Byerly, in review).

The depositional setting of the quartz-rich Moodies Group remains controversial. Early workers considered it a molasse assemblage deposited in a geosyncline (Anhaeusser, 1964; Viljoen, 1964). This idea was later abandoned in favor of ensialic sag models in which the Moodies sediments were derived from surrounding highlands uplifted by diapiric plutons around the greenstone belt (Anhaeusser et al., 1969; Anhaeusser, 1973) or from the walls of an intra-cratonic rift (Hunter, 1974). Later, Eriksson (1980) argued that the Fig Tree and Moodies Groups represent a passive-margin sequence deposited along an Atlantic-type continental margin. Recent discoveries of syndepositional folds and thrust faults in the Onverwacht (de Wit et al., 1983) and Fig Tree Groups (Lowe et al., 1985) in the central part of the greenstone belt and upper Swaziland Supergroup strata to the south (Lamb, 1984) have
Figure 1. Generalized stratigraphic column of the Swaziland Supergroup.

Onverwacht and Fig Tree Groups stratigraphy is based on Lowe and Byerly (in review).
prompted a reassessment of the depositional setting of the Moodies Group. Jackson et al. (1987) combined stratigraphic evidence from the Fig Tree and Moodies Groups and structural data from both the Barberton greenstone belt and the Ancient Gneiss Complex (AGC) to infer that Moodies deposition accompanied progressive uplift and unroofing of the older parts of the Swaziland Supergroup and the AGC to the south. They argued for a foredeep setting during deposition of both the Fig Tree and Moodies Groups.

The Moodies Group was studied in the north-central part of the Barberton greenstone belt, southwest of the town of Barberton (Fig. 2). Moodies strata occur in four large, structurally isolated blocks that are bounded on the north and south sides by major faults: the Moodies Hills, Saddleback Syncline, Maid of the Mist Mountain Syncline, and Powerline Road Syncline (Fig. 3). This paper provides detailed petrologic and stratigraphic data from these blocks that support a model of deposition along the foreland side of a thin-skinned fold-thrust belt.
Figure 2. Generalized geology map of the Barberton greenstone belt with the study area outlined and a location map insert.
Figure 3. Map showing the major faults and tectonic blocks southwest of Barberton.
INTRODUCTION

The Barberton greenstone belt is a sequence of slightly metamorphosed and extensively metasomatized volcanic and sedimentary rocks located near the eastern margin of the Early Archean Kaapvaal Craton (Fig. 2). The strata are complexly folded and faulted. The slightly older AGC has been thrust against the southeastern boundary of the greenstone belt (Jackson, 1984). The AGC and the greenstone belt are completely surrounded by contemporaneous and younger, Archean age granitoid plutons.

ANCIENT GNEISS COMPLEX

The Ancient Gneiss Complex, exposed to the southeast of the Barberton greenstone belt in Swaziland, is composed of metavolcanic and metasedimentary rocks, metadiorite dikes, meta-anorthosite, tonalitic gneiss, quartzite, quartzofeldspathic gneiss, taconite, amphibolite, micaceous cordierite gneiss, and siliceous diopside-bearing gneiss and granulite (Hunter, 1973). Modal analyses by Hunter (1973) showed quartz to be ubiquitous (≤37.5%) in the AGC. Plagioclase, predominantly oligoclase (~An_{20-30}), and potassium feldspar, including microcline, perthite, and myrmekite, occur in most samples. Biotite and hornblende are common constituents. Accessory minerals include cummingtonite, garnet, diopside, cordierite,
epidote, magnetite, sphene, zircon, sillimanite, tourmaline, apatite, hypersthene, and grunerite (Hunter, 1974).

Compston and Kroner (1988) reported a \( 3.644 \pm 0.004 \) Ga date for a tonalitic gneiss remnant within the Ancient Gneiss Complex. Determined by U-Pb ion microprobe techniques, this date is the oldest age reported for the AGC and was proposed as the time of precipitation from the original magma. Therefore, the AGC is the oldest known regional lithologic unit. Structures within the AGC have been interpreted as recording progressive northwest-verging overthrust movement that began about 3.4 Ga ago (Jackson, 1984). Jackson et al. (1987) suggested that uplift may have caused an unroofing of the metamorphites and provided detritus to the Moodies Group in the Barberton greenstone belt basin.

BARBERTON GREENSTONE BELT

Stratigraphy of the Swaziland Supergroup

The 3.5 to 3.4 Ga old Onverwacht Group is the oldest unit of the Swaziland Supergroup (Lopez-Martinez et al., 1984; Brevart et al., 1986) but is younger than much of the AGC (Compston and Kroner, 1988). The Onverwacht was divided into six formations by Viljoen and Viljoen (1969). Lowe and Byerly (in review) have recognized distinctive northern and southern facies. They describe the southern facies as an 8 to 10 km thick sequence of
komatiite, basalt, and dacite with thin, chert layers. The northern facies is also composed of komatiite, basalt, and chert as well as layered ultramafic intrusive complexes.

Overlying the Onverwacht Group is the Fig Tree Group, the middle unit of the Swaziland Supergroup, which has also been divided into distinctive northern and southern facies (Heinrich and Reimer, 1977). The lower section of the northern facies is approximately 1500 to 1800 m of turbiditic shale, siltstone, and sandstone overlain by black and white chert layers (van Eeden, 1941; Lowe and Byerly, in review). The upper section of the northern facies, the Schoongezicht Formation, is approximately 200 to 450 m of turbiditic, plagioclase-rich sandstone and mudstone (Lowe and Byerly, in review). The lower section of the southern facies is described by Lowe and Byerly (in review) as 200 to 700 m of terrigenous shale, chert-grit sandstone, and chert-clast conglomerate interstratified with thick units of fine-grained dacitic pyroclastic and volcaniclastic sediments and minor amounts of chert, jasper, and barite. It is overlain by the 200 to 500 m thick southern Schoongezicht Formation comprising dacitic intrusive, extrusive, and volcaniclastic rocks.

The youngest unit of the Swaziland Supergroup is the Moodies Group including, from base to top, the Clutha, Joe's Luck, and Bavianskop Formations. These rocks are remarkably well-preserved despite their antiquity. Primary features such as embayments in quartz grains, euhedral
beta quartz crystals, cross-beds, dewatering structures, and mud cracks are commonly displayed (Fig. 4).

Figure 4. Mud cracks in the upper Clutha Formation in the Saddleback Syncline.

Structure

Moodies strata are more coherent than the adjacent, severely deformed, and older units of the Swaziland Supergroup, the Fig Tree and Onverwacht Groups. The north-central part of the greenstone belt has experienced four
periods of deformation following deposition of the Moodies Group (Hose, this volume, chap. 2). The earliest post-depositional episode resulted in large-scale, north-verging thrust faults and folds nappes. Only the steeply dipping limbs and synclinal troughs of these high-level folds have been preserved within the Moodies strata. The next stage of deformation caused south-dipping, normal faults and approximately east-west striking foliation along and near the northern boundary of this part of the greenstone belt. The later periods of deformation resulted in dextral shearing and transpressive folding followed by north-northwest striking, high-angle faulting.

The approximately east-west striking Inyoka Fault (Fig. 3) is a major north-verging thrust fault (Hose, this volume, chap. 2) that divides the southern and northern facies of the Onverwacht (Lowe and Byerly, in review) and Fig Tree (Heinrich and Reimer, 1977) Groups. It also separates distinctive facies within the Moodies Group.

The blocks of Moodies rocks that are south of the Inyoka Fault, the Powerline Road and Maid of the Mist Mountain Synclines, are structural basins (Fig. 3; Plate II). The Powerline Road Syncline is a 810 m thick sequence of coarse- and very coarse-grained Moodies sandstone and conglomerate that includes the lower contact with the Schoongezicht Formation on the south side of the syncline. The contact appears to have been removed by faulting on the north side. The Maid of the Mist Mountain
Syncline contains about 500 m of coarse- and very coarse-grained Moodies sandstone but encompassing faults have removed the massive basal conglomerate layers that abound in the Powerline Road Syncline. Unlike most of the study area, both blocks have strata with moderate to shallow dips.

North of the Inyoka Fault, the Saddleback Syncline is composed of a 2800 m thick section of north-younging Moodies rocks. The north limb of the syncline has been removed from the study area by shearing along the Saddleback Fault (Fig. 3). Strata are vertical to overturned and have only minor amounts of internal shearing and folding (Fig. 4). The northernmost, major block of Moodies rocks is the Moodies Hills, which comprises an approximately 2700 m section of the Moodies Group. Beds are nearly vertical to overturned and almost uniformly young to the north.

**Alteration**

Rocks throughout the Barberton greenstone belt have been altered to lower greenschist facies (Viljoen and Viljoen, 1969). The Moodies Group is less pervasively altered than the older rocks, in part due to its relative youthfulness and, possibly, due to shallower burial. Carbonation and silicification have also extensively altered the sequence. Again, the Moodies Group is less affected, possibly due to the discontinuation of the volcanism associated with the earlier Onverwacht and Fig Tree Groups. Four periods of
post-depositional deformation have resulted in cataclastic alteration and a prominent microscopic and megascopic flattening of grains, particularly along the northern margin (Hose, this volume, chap. 2).

Figure 5. Photograph of the Saddleback Syncline looking northwest from the Svengali area.

Silicification has widely affected rocks of the Swaziland Supergroup. Chert layers in the Onverwacht and Fig Tree Groups represent silicified evaporites (Fisher and Lowe, 1985; Worrell and Lowe, in review), carbonates, sand- and silt-sized terrigenous sediments (Lowe and Byerly, in review), volcanic rocks, and volcaniclastic strata (Lowe and Byerly, 1984; Duchac, 1986; Duchac and Hanor, 1987). Silicification of many komatiitic volcanic rocks in the Onverwacht Group occurred before significant tectonic deformation (Lowe and Byerly, 1984; Duchac and Hanor, 1987). Clasts of jasper, silicified
volcanic rocks, and black, white, and banded chert that were derived from the
Onverwacht and lower Fig Tree Groups occur within the basal conglomerate
of the Moodies Group and demonstrate that silicification of these rocks
occurred prior to deposition of the Moodies strata. The Moodies Group is little
affected by silicification. A checkerboard pattern within the Powerline Road
Syncline is displayed by nearly pure, coarse-grained megaquartz sandstones
that appear to have been hydrothermally altered. Similar rocks crop out
along shear zones in the Moodies Hills.

Fine-grained sericite aggregates, often associated with
microcrystalline quartz (GMC), are common alteration products within the
Moodies Group. These aggregates are particularly common in the lower parts
of the Clutha A and are interpreted as lithic volcanic fragments based on the
presence of embayed and euhedral bipyramidal quartz microphenocrysts,
remnant microlitic textures, and ghost outlines of glass shards in some grains.
Fine-grained aggregates of nearly pure sericite (>90% sericite) compose up to
16% of Moodies sandstone strata south of the Inyoka Fault and up to 10% north
of the fault. Throughout the Moodies Group, many identifiable feldspar
grains, mostly plagioclase, contain patches of fine-grained sericite.
Aggregations of sericite that are lath-shaped are interpreted as feldspar
grains that have been diagenetically altered. Because of the fragility of the
nearly pure sericite aggregates, some and perhaps all of the sericitization probably occurred after deposition.

All plagioclase with symmetric extinction were optically identified on a flat microscopic stage as An0-10. Although the albite composition of the plagioclase is consistent with the sodium-rich Early Archean tonalite and trondhjemite, plutonic and gneissic complexes surrounding the greenstone belt, including the AGC, and the sodium-rich volcanic rocks lower in the greenstone sequence, the apparent absence of oligoclase suggests that calcium-bearing plagioclase grains were removed or altered. Albite is the stable plagioclase in greenschist facies rocks. The ubiquitous development of albite in lieu of other plagioclase also may be the result of secondary albitization of primary feldspar resulting from metasomatism or burial diagenesis (Milliken et al., 1981; Boles, 1982). Walker (1984) suggests that sodium is derived from the alteration of sodium-bearing plagioclase to sodium-free clay and is transported by connate or marine pore water. Thus, diagenetic alteration of potassium feldspar and plagioclase is greater in alluvial facies than marine facies as early cementation of marine facies preserve original composition. It is doubtful that calcium-bearing plagioclase would have survived burial, diagenesis, and regional metamorphism.
Secondary carbonation is locally so severe that altered units within the Onverwacht Group (Visser, 1956) and Clutha Formation (Anhaeusser, 1976) have been interpreted as primary carbonates. In the carbonate-rich units in the study area, however, the carbonate can be identified as a diagenetic product by a lack of the strain that is present in associated detrital grains, corrosion embayments of carbonate into detrital grains, and, along the northern boundary of the greenstone belt, the development of masses of coarse mosaic spar that cross lithologic boundaries (Fig. 6). Pods of nearly pure, coarse mosaic carbonate spar are contained within sandstones in the Moodies Hills, particularly in the B division of the Clutha Formation, and in volcanic rocks of the Onverwacht Group north of the Moodies Fault. The preferential distribution of carbonate within radically different lithologic sequences in adjacent but independent tectonic blocks probably represents a mobilization and/or infusion of carbonate after the development of the Moodies Fault and after the introduction of any strain fabric. The proximity of carbonated areas to present and past gold mines is also noteworthy. At the Devil’s Staircase in the eastern portion of the Moodies Hills, a non-mineralized area, samples from the Clutha B contained less than 5% carbonate. Clutha B samples from the Princeton Mine Tunnel, approximately 3.2 km to the west and near a mineralized zone, contained 50 to 90% carbonate. The pods of
nearly pure carbonate rocks within the Onverwacht Group are also within mineralized areas.

Figure 6. High relief carbonate has replaced parts of primary quartz and feldspar grains. Sample - LH 825; Princeton Tunnel in the Moodies Hills; ppl.

The original source of the carbonate is unknown. All carbonate-rich samples studied lacked any primary carbonate textures or other indications of the presence of early, depositional carbonate. The areal association of
carbonate bodies with epigenetic mineralization suggests a source external to the greenstone belt.

Post-depositional strain in the study area has resulted in a prominent flattening of clasts and pressure solution along grain contacts within the Moodies sandstones and conglomerates (Hose and Lowe, 1987; Hose, this volume, chap. 2). Anhaeusser (1976) calculated a 61% thinning of the Moodies Group in the Eureka Syncline due to this strain. Flattening is most severe along the northern boundary of the greenstone belt and is not apparent in the Saddleback Syncline or to the south (Hose, this volume, chap. 2). Nearly all quartz grains in the Moodies Group exhibit undulatory extinction and some grain contacts are sutured in tightly packed samples.

GRANITOIDS

Archean granitoids of the Kaap Vaal craton have been divided into three magmatic cycles based on age and geochemical composition (Anhaeusser and Robb, 1981; Meyer et al., 1986). Only the first cycle, which commenced about 3.5 Ga ago, is older than the Moodies Group. These plutons are biotite trondhjemite and hornblende tonalite, with some occurrences of complex gneiss and migmatite, that contain quartz and plagioclase (albite-oligoclase) in approximately equal amounts, 10 to 15% biotite, and minor
microcline and chlorite, and accessory amounts of sphene and apatite (Robb and Anhaeusser, 1983; Meyer et al., 1986).
STRATIGRAPHY OF THE MOODIES GROUP

NOMENCLATURE

Anhaeusser (1969; 1976) divided the Moodies Group in the Eureka Syncline into three formations. From base to top, these are the Clutha, Joe's Luck, and Baviaanskop Formations. Each formation was further divided into from two to five informal subdivisions (Fig. 7). This nomenclature has been accepted by the South African Code of Stratigraphic Terminology and Nomenclature (SACS, 1980). Anhaeusser (1976) interpreted each formation as a sharp-based, fining upward unit having conformable contacts with overlying and underlying Moodies subdivisions. The Clutha Formation in the Eureka Syncline consists of interlayered conglomerate, impure quartzite, calcareous and feldspathic quartzite, and subgraywacke. It conformably overlies a series of very coarse-grained sandstone, shale, banded chert, iron formation, and pyroclastic rocks of the Schoongezicht Formation of the Fig Tree Group. The middle sequence, the Joe's Luck Formation, has a basal quartzite and conglomerate covered by an amygduoidal basalt and jasperoid layer and topped by shale. The base of the Baviaanskop is described as a basal quartzite and conglomerate overlain by shale. In the core of the Eureka Syncline, a thin layer of conglomerate and coarse sandstone, the Bickenhall Member, overlies the uppermost Baviaanskop shale with a sharp contact.
**Figure 7.** Generalized stratigraphic sections of the Moodies Group comparing nomenclature and units of Anhaeusser (1976) for the Eureka Syncline, this study based on the Moodies Hills and Saddleback Syncline, and Eriksson's (1980) sedimentological models based on the Eureka and Saddleback Syncline.
Anhaeusser interpreted this unit as the remnant of a fourth fining upward cycle.

Eriksson (1977; 1978) divided the Moodies Group in the Eureka, Stolzburg, and Saddleback Synclines into five informal units, MD1 through MD5, distinguished by sedimentological evidence of changing depositional environments (Fig. 7). MD1 correlates with the base of the Clutha Formation and is a fining upward sequence of conglomerate, impure sandstone, and siltstone. Up to five fining upward cycles of quartzose sandstone (90 to 95% quartz), siltstone, shale and jasper compose MD2, which is absent in the Saddleback Syncline. MD3 comprises shale, siltstone, and sandstone capped by a layer of orthoquartzitic (>95% quartz) sandstone. An amygdaloidal "lava" defines the base of a coarsening upward MD4 sequence of shale, iron formation, conglomerate, and impure sandstone. The impure sandstone, siltstone, and shale of MD5 were only identified in the Eureka Syncline.

Lamb and Paris (1988) divided the post-Onverwacht portion of the Swaziland Supergroup in the southern part of the greenstone belt into two informal units, the Diepgezet and Malolotsha Groups. The lower part of the Diepgezet Group is composed of iron-rich chert, shale, siltstone, and tuff conformably overlying the Onverwacht Group. The upper strata are arenites and conglomerates that are characterized by predominance of sand-sized chert over monocrystalline quartz. The Diepgezet Group appears
approximately equivalent to the Fig Tree Group (Lamb and Paris, 1988; Lowe and Byerly, in review). The Malolotsha Group comprises quartz-rich conglomerate, sandstone, siltstone, and shale and appears to resemble the Clutha Formation, particularly south of the Inyoka Fault. Lamb and Paris (1988) describe the contact between the upper conglomerate of the Diepgezet and lower conglomerate of the Malolotsha as varying from transitional and apparently conformable to an erosional surface with an angular discordance of up to 90°.

This study uses the nomenclature of Anhaeusser (1976) for the formation-level subdivisions of the Moodies Group. Systematic lithologic differences in the lower and upper Clutha Formation are recognized and informally designated the A and B divisions, respectively. The amygdaloidal basalt that was previously included in the Joe's Luck Formation (Visser et al., 1956; Anhaeusser, 1976) is shown to transgress lithostratigraphic boundaries and is within the Clutha Formation south of the Inyoka Fault, establishing the time transgressive character of the Clutha-Joe's Luck boundary. Deposition of the Clutha Formation continued later in the south.

The contact between the underlying Schoongezicht Formation and the Clutha Formation appears transitional and conformable on the south side of the Saddleback Syncline. In the Powerline Road Syncline, Schoongezicht strata have a slight angular truncation at the contact with the Moodies and it
is unclear whether the discordance is depositional or the result of shearing sub-parallel to bedding. The base of the Moodies Group has been reported elsewhere to unconformably overlie Fig Tree sedimentary and Onverwacht volcanic rocks (Visser et al., 1956; Eriksson, 1979). The top of the Baviaanskop is reported to be a sheared contact or an erosional surface everywhere.

AGE CONSTRAINTS

Felsic crystalline clasts from the basal conglomerate of the Moodies Group yielded crystallization ages between 3.47 Ga and 3.3 Ga using U-Pb zircon systematics (Tegtmeyer and Kroner, 1986). The Salisbury Kop pluton in the northern part of the belt reportedly intrudes the Moodies Group and has been dated by U-Pb and Pb-Pb methods using zircon and apatite (Oosthuyzen and Burger, 1973). Cahen et al. (1984) noted the considerable scatter of the Salisbury Kop data about the chord (mean square of weighted deviates - MSWD=5.7) and adopted the least discordant \( \frac{207}{206} \text{Pb} \) apatite age of 3.195±0.30 Ga as the best minimum age of the Moodies Group.

High precision Pb-Pb zircon dates from the Schoongezicht Formation were recently reported to mainly fall between 3.225 and 3.259 Ga (Kroner et al, 1989). These data indicate that the overlying Moodies Group is younger than 3.225 Ga consistent with the inferred age of the intrusive Salisbury Kop Pluton.
REGIONAL FACIES

The Inyoka Fault strikes roughly east-west across the study area and has been proposed as a boundary between markedly different facies in the Fig Tree (Heinrich and Reimer, 1977) and Onverwacht (Lowe and Byerly, in review) Groups. The southern facies of the Onverwacht Group is a sequence of komatiite, basalt, and dacite containing lesser quantities of largely silicified sedimentary layers. The northern Onverwacht rocks are composed of altered peridotite and basaltic komatiite, layered ultramafic intrusions, and thin chert. The two facies of the Fig Tree Group are compositionally similar but the southern strata were deposited in predominantly shallow, proximal to locally distal environments (Lowe and Nocita, in review) while the northern rocks are deep-water facies (Lowe and Byerly, in review).

The Inyoka Fault also appears to separate contrasting facies in the Moodies Groups. Eriksson (1978), Lamb (1984), and Lamb and Paris (1988) have previously reported that strata in the middle and southern parts of the greenstone belt, probably correlative with Moodies rocks in the north, were deposited in alluvial to possibly marginal marine settings, environments similar to the Clutha Formation. The results of the present study also indicate that the Moodies strata south of the fault are much coarser grained, richer in chert clasts, and more depleted in feldspar than the northern facies. In northern sections, Moodies rocks include thick marginal marine and shelf
facies (Eriksson, 1978; 1979). Granitoid clasts are common constituents of northern facies conglomerates but are rare and distinctively different in the south.

SVENGALI SECTION - A SUPPLEMENTAL TYPE SECTION FOR THE CLUTHA AND JOE'S LUCK FORMATIONS

The type area for the Moodies Group is located in a heavily mineralized and deformed part of the Eureka Syncline. A stratigraphic section measured through the west end of the Saddleback Syncline near the Skokhohlwa trigonometrical beacon (Plate I) is less affected by alteration, particularly carbonation, and appears to contain the entire Clutha and Joe's Luck Formations without repetition or loss of strata (Appendix 1b). It is proposed as a supplementary type section, the Svengali Section, for the Clutha and Joe's Luck Formations (Fig. 8). The name is taken from an Anglo-American Prospecting Service mining prospect in the Clutha Formation approximately one kilometer west-southwest of the Skokhohlwa trigonometrical beacon.

GENERAL LITHOLOGY

Clutha Formation

The Clutha Formation is divided into two lithostratigraphic divisions, A (lower) and B (upper). The A division is a sequence of pebble and cobble
Figure 8. Proposed supplementary type section for the Clutha and Joe's Luck Formations from the Saddleback Syncline. Location of the section shown on Plate I.
conglomerate and lithic- and quartz-rich sandstone that marks a transition between the volcanic and volcaniclastic Schoongezicht Formation and the reworked, quartz- and chert-rich clastic rocks that form most of the Moodies Group. The B division is composed mainly of arkosic arenite and subarkose with jasper bands in the northernmost blocks (Moodies Hills and Eureka Syncline). It is poorly cemented, resulting in rapid erosion and development of strike valleys. Overall, the Clutha fines upward in the Eureka Syncline (Visser et al., 1956; Anhaeusser, 1976), Moodies Hills, and Saddleback Syncline.

In the Svengali Section, the Clutha A consists of 1138 m of creamy white to medium gray, laminated fine- to coarse-grained sandstone, trough and planar cross-bedded sandstone, massive bedded sandstone, and open- and closed-matrix pebble and cobble conglomerate (Fig. 8). The unit fines to the north. Conglomerate strata are most abundant in the Powerline Road Syncline. The lower beds of the Clutha A are medium- to coarse-grained lithic arenite and conglomerate. They are composed of up to 95% fine-grained, homogeneous chert-sericite mosaics that are the products of altered dacitic, volcaniclastic sediments. Because of the transitional nature of the contact between the Schoongezicht and Clutha Formations, the contact has been arbitrarily placed at the bottom of the lowest chert-clast conglomerate. Pebbles and cobbles are well-rounded, predominantly black chert and black and white banded chert derived from the Onverwacht Group. The basal
conglomerate contains up to 50% felsic volcanic or volcaniclastic clasts
derived from the underlying Schoongezicht Formation. In addition, Clutha A
conglomerates contain clasts of chrome-mica-rich green chert derived from
the Onverwacht Group and ferruginous bedded chert and jasper from the
lower Fig Tree Group. In the Moodies Hills, the lowest beds of the A division
are missing and the contact between the A and B divisions has been
obliterated by post-depositional alteration, primarily carbonation.

The Clutha A is rich in preserved primary depositional structures. In
the Powerline Road Syncline and Saddleback Syncline, planar and trough
cross-beds, some over a meter high, are abundant. Mud cracks in both of
these blocks represent intermittent subaerial exposure of the sediments (Fig.
5). Fluid escape structures in several beds in the upper half of the Saddleback
Syncline that are not accompanied by any convoluted beds suggest rapid
deposition on a shallow slope. Anhaeusser (1976) identified the entire
Moodies Group as a fluvio-deltaic deposit. In a more detailed study of the
Moodies Group, Eriksson (1978) concluded that deposition of this lowest part
was dominated by braided fluvial processes in a basin deepening towards the
northern blocks. The A division of the Clutha Formation is generally
resistant to erosion and well-exposed in prominent ridges (Plate 1).

The B division of the Clutha Formation in the Saddleback Syncline is a
790 m thick sequence of yellowish white to pale gray, medium- to very coarse-
grained arkosic arenite and subarkose. The lower half of the unit contains minor amounts of thin bedded, chert pebble conglomerate (Fig. 8). Minor quantities of chert pebbles occur in the sandstone throughout the Clutha B. Most outcrops display trough and planar cross-beds representing predominantly eastward flow although some exposures contain bimodal cross-beds. Inspection of a tunnel traversing the upper 500 m of the Clutha B in the Lomati River Valley, about five kilometers northeast of the Shokholmwa trigonometrical beacon, revealed that the rocks, although friable and essentially uncemented, consist entirely of medium- to coarse-grained subarkose and sublitharenite (Appendix 1e).

In the Moodies Hills, the arkosic arenite and subarkose of the Clutha B consists of fine-grained sandstone and siltstone with minor, shale partings. The unit is approximately 1200 m thick and locally carbonate-rich (>50%). Cross-beds are sparse in this block where laminated beds separated by jasper beds or less than two centimeter thick shale partings are common. Eriksson (1978) described this part of the Moodies Group as the product of a braided alluvial environment in the Saddleback Syncline and as tidal-flat, back barrier and deltaic sites in blocks to the north.
Joe's Luck Formation

The Joe's Luck Formation is composed of very fine- to very coarse-grained quartz arenite, sublitharenite, and subarkose, siltstone, pebble and cobble conglomerate, and jasper beds. The sequence is 725 m thick in the Saddleback Syncline and 517 to 575 m in the Moodies Hills. The boundary between the Clutha and Joe's Luck Formations is placed at the base of a resistant quartz arenite that overlies the easily erodible arkosic arenite and subarkose sequence at the top of the Clutha B. Although Anhaeusser (1976) describes the Joe's Luck as a fining upward sequence, the Svengali Section clearly shows a coarsening upward trend with pebbles more abundant towards the top of the unit (Fig. 8 and Appendix B). In the Moodies Hills, the Joe's Luck appears to coarsen upward but the grain sizes are consistently finer than in Saddleback Syncline. A prominent conglomerate composed of well-rounded pebbles and cobbles of black and white chert was taken as the base of the overlying Baviaanskop Formation by Anhaeussers (1976). However, the conglomerate is here interpreted as capping a coarsening upward trend within the Joe's Luck Formation. The upper boundary to the Joe's Luck is placed at the abrupt change from conglomerate to fine-grained sandstone, siltstone, and shale of the overlying Baviaanskop Formation (Fig. 8).
Beds in the Joe's Luck Formation are predominantly planar with some planar and trough cross-beds in the lower part of the unit. Channel structures formed in the upper, coarser layers in the Saddleback Syncline. Eriksson (1979) describes the depositional environment as a shelf consisting of a barrier beach (Saddleback Syncline) and an estuary-delta (northern blocks).

A quartz-chlorite-sericite-bearing greenstone with domains of quartz that are ≤1 cm in diameter, identified as an amygdaloidal basalt, overlies the basal quartz arenite of the Joe's Luck Formation (Fig. 8 and Appendix B). Some samples display a trachytic texture in thin sections. Two separate but sequential basalt flows are distinguishable by variations in vesicular size and abundance in the Saddleback Syncline and the Moodies Hills. These basalts are the only isochronous layers and regional marker beds in the Moodies Group. The basalt thins to the north and the volcanic center was probably to the south or southeast. It is less than 8 m thick to locally missing in the Moodies Hills but at least 22 m thick in the western part of the Saddleback Syncline. Lamb (1984) and Lamb and Paris (1988) described a quartz-chlorite-sericite-plagioclase volcanic layer with possible silicified or carbonated vesicles overlying quartz arenite in the southern part of the greenstone belt. The layer is up to 100 m thick. Similar amygdaloidal volcanic rocks are also interbedded with coarse-grained sandstone and conglomerate of the Moodies
Group in a structurally isolated block between Maid of the Mist Mountain and Saddleback Synclines (Plate II), where several meters of chert cobble conglomerate appear to separate two basalt flows, and on the Farm Baviaanskloof approximately 11 kilometers south of the study area (Lowe and Byerly, in review).

Whole rock chemical compositions of the amygdaloidal greenstones within the Moodies Group compare favorably and probably represent a single, short-lived volcanic episode (Table 1). Bulk compositions suggest that these rocks were tholeiitic basalts. Compared with Phanerozoic volcanic rocks, zirconium is moderate, niobium is low, and titanium is intermediate, which are typical signatures of tholeiitic basalts. Like most Archean volcanic rocks, chromium and nickel contents are high, particularly in the Swaziland rocks. Silica, magnesium, iron, and aluminum percentages are consistent with tholeiitic basalts. Calcium, sodium, and potassium contents vary greatly, representing significant differences from typical tholeiites. Mobilization during diagenesis, however, has resulted in localized enrichment and depletion of calcium, sodium, and potassium throughout the greenstone belt.

The basalt flows appear to have been restricted to the basin and were not present in the orogenic belt. No increase in lithic material or fine-grained sericite and chlorite matrix is displayed in the overlying clastic beds.
### Chemical Analyses of Moodies Amygdaloidal Greenstones, Barberton Greenstone Belt, South Africa

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**TOTAL** 90.487 92.158 99.98 99.08 98.98

| LOI     | 11.62 | 8.72  | 3.56 | N.A.  | N.A.  |

270 - From Lamb (1984a). Collected in the southern part of the greenstone belt in Swaziland.

Table 1. Chemical analyses of amygdaloidal quartz-chlorite-sericite-bearing greenstones based on XRF data from Anhaeusser (1974), Lamb (1984a), and this study.
This observation is compatible with a tholeiitic basalt erupted in a backarc that is being filled by a prograding deposit.

**Baviaanskop Formation**

The Baviaanskop Formation in the study area is composed predominantly of thin to medium bedded, very fine-grained sublitharenite, siltstone, and minor shale. Anhaeusser (1974) reported abundant shale in the Eureka Syncline. The Baviaanskop is a heavily weathered, uniform, red, laminated siltstone in the Saddleback Syncline. Rocks in the Moodies Hills vary from shale to coarse-grained sandstone and include one thin jasper bed. They are thin-bedded to laminated with trough cross-beds in a few layers. The contact between the conglomerate of the Joe's Luck Formation and finer grained clastic rocks of the Baviaanskop Formation in both blocks is sharp but conformable. The top of the unit is marked by a fault contact in the Moodies Hills and the Saddleback Syncline, where the measured thicknesses of the Baviaanskop are 561 m and 135 m respectively.

Eriksson (1979) concluded that the Baviaanskop Formation was a deltaic deposit. Anhaeusser (1974) defined this sequence (along with the underlying conglomerate) as fining-upward. Jackson et al. (1987) described it as coarsening upward. A clear fining- or coarsening-upward trend was not recognized by this study.
SANDSTONE PETROGRAPHY

The modal composition of terrigenous Phanerozoic sandstones has been shown to be a useful tool for inferring the tectonic setting of depositional basins and provenances (Dickinson, 1970; Dickinson and Suczek, 1979; Dickson et al., 1983). The approach has been extended to Proterozoic and Archean metasedimentary sequences (Condie and Martell, 1983; Jackson et al., 1987; DiMarco and Lowe, 1989).

PROCEDURES

Detailed stratigraphic sections were measured and sandstone samples were collected on the south side of the Powerline Road Syncline, in the western portion of the Saddleback Syncline, and along the Devil’s Staircase and in the Princeton Mine in the Moodies Hills (Plate I). Sandstone samples were also collected at approximately 100 m intervals in the Lomati Tunnel, which is 5 kilometers northeast of the Shokhohlwa Trigonometrical Beacon in the Saddleback Syncline, and in the 22nd Level Adit, a tunnel that crosses strike approximately midway between the Princeton Tunnel and the Devil’s Staircase (Moodies Hills) (Plate I). One sample from the Maid of the Mist Mountain Syncline and three from the surface southwest of the Princeton Tunnel (Moodies Hills) were also collected. A total of 126 thin sections were examined from this collection (Appendix 2).
Eighty-two samples of Moodies sandstone were point counted using the procedures outlined by Dickinson (1970) and Dickinson and Suczek (1979). Thirty-three samples were from the Clutha A, 17 from the Clutha B, 22 from the Joe's Luck, and 10 from the Baviaanskop Formations. Most were medium-grained sandstone, but the mean grain size of individual samples ranged from 0.18-0.78 mm. Three hundred framework grains were counted in each sample. A complete tabulation of the results and site locations are given in Appendix 2. The remaining 44 samples were deemed inappropriate for this technique because either mean grain size was less than 0.18 mm or diagenetic alteration obscured the original composition. Secondary carbonate was the primary culprit replacing original grains. Only samples with less than 9% carbonate by volume were counted.

The basic categories of framework grains were those defined by Dickinson and Suczek (1979) (Appendix 3). Monocrystalline grains, coarse polycrystalline grains, and coarser identifiable grains within aphanitic rock fragments were counted as single grains according to the composition of the grain under the cross-hair. Chert and fine-grained polycrystalline quartz grains were included with the category of polycrystalline quartz (Qp), a component of quartz (Q) and of total lithic contents (Lt). Counts were tabulated on a grid of 34 different grain types vs. a single grain column plus nine rock types. Points of cement, matrix, secondary carbonate, and holes
were tabulated separately from framework grains. The sandstone classification system and nomenclature of Dott (1964) are used throughout this study.

Special attention was given to any potential feldspar grain. The calcium- and potassium-specific stains used on some thin sections in this study were not absorbed by some of the sodium-rich plagioclase, which were distinguished by albite twinning. In addition, some stained feldspars displayed no twinning. These findings necessitated careful examination of all potential feldspar grains, even in stained thin sections, for twinning, relief greater than quartz, cleavage, undulatory extinction, interference figures, and alteration.

Aphanitic lithic grains were common in most of the sandstones. Many samples included a complete spectrum of grain types from pure chert through fine-grained mica and chert aggregates to fine-grained mica aggregates. Grains with >90% GMC (chert) were counted as Qp; grains with <90% GMC were included in L. Fine-grained mica and chert aggregates (10 to 90% GMC) to fine-grained mica aggregates (>90% mica) are the predominant component of the upper Schoongezicht and lower Clutha Formations in the Powerline Road Syncline and Saddleback Syncline. Embayed and euhedral bipyramidal quartz microphenocrysts, remnant microlitic textures, and ghost outlines of glass shards in some aggregates in both the Moodies and the upper
Schoongezicht/lower Clutha A sandstones suggests derivation from Schoongezicht volcaniclastic rocks.

The petrography of the chert (>90% GMC) clasts consistently match known black, white, carbonaceous, and chrome-mica cherts from the Onverwacht Group and bedded ferruginous cherts and jasper from the Fig Tree Group. Some of these cherts are probably silicified tuff and other volcanic rocks (Duchac and Hanor, 1987; Lowe, in review) and therefore are properly counted as lithic volcanic grains. Other greenstone belts cherts, however, are of a sedimentary origin (Fisher and Lowe, 1985; Walsh, 1989; Lowe, in review) and properly counted as lithic sedimentary grains. Distinction of these different types of chert is generally impossible in the Moodies sandstones.

Eleven samples from the upper Schoongezicht Formation (10 from Powerline Road Syncline and one from Saddleback Syncline) and 13 matrix-rich basal Clutha A samples (nine from Powerline Road Syncline and four from Saddleback Syncline) were also examined. Identifiable framework grains constitute less than 38% of all samples and were limited to quartz, chert, and minor amount of plagioclase in the Schoongezicht sandstones. Lath-shaped sericite aggregates, some with remnant albite twinning, were interpreted as altered feldspars. The bulk of the rocks consist of a fine, homogeneous quartz-sericite mosaic representing altered vitric debris and
lithic grains (Fig. 9). Only 300 points were counted in these samples to determine monocry stalline quartz abundances. Tabulations from these counts are also included in Appendix 2.

Figure 9. Clasts in the Schoonegezicht and Moodies sandstones include a variety of fine-grained chert (>90% GMC), chert-sericite (10 to 90% GMC), and sericite aggregates (>90% sericite). The clast in the upper left corner is nearly pure chert. The clast in the lower right corner is nearly pure sericite. The clasts in the upper right corner and the matrix is composed of both chert and sericite. Sample - LH 531; South side of the Powerline Road Syncline; cross-nicols.
Counts and size measurements of 296 identifiable pebbles in the conglomerate capping the Joe's Luck Formation in the western part of the Saddleback Syncline and 81 pebbles in the Clutha A basal conglomerate in the south-central part of the Moodies Hills were made and the findings have been combined with previous reports on the conglomerates by Daneel (1986), Reimer et al. (1985), and Gay (1969).

GRAIN COMPOSITION AND MODAL RESULTS

*Clutha Formation - A division*

The A division of the Clutha Formation is predominantly sublitharenite with lesser amounts of lithic arenite, quartz arenite, and subarkose. Quartz (Q) comprises 27 to 95%, averaging 72%, of the framework grains (Fig. 10a). Monocrystalline quartz content (Qm), which averages 55%, increases upsection from 3 to 89% (Fig. 11). Monocrystalline quartz occurs as individual grains and within lithic fragments, including granophyre clasts (Fig. 12) and clear aggregates of quartz and feldspar. The clear aggregates are composed of fine to coarse grains of predominantly quartz with lesser amounts of potassium feldspar and plagioclase (Fig. 13). Many of the clear aggregates are exclusively coarse-grained quartz and most are predominantly quartz, suggesting a high-grade, metasedimentary parentage. However, no
Figure 10. Quartz (Q)-Feldspar (F)-Lithic (L) ternary plot of detrital framework grains and petrographic classification according to Dott (1964). a. A division of the Clutha Formation. b. B division of the Clutha Formation. c. Joe's Luck Formation. d. Baviaanskop Formation.
Figure 11. The plot shows the volume percentage of monocrystalline quartz in the total sample versus distance from the Schoongezicht and Clutha Formations contact. (Data from the Powerline Road and Saddleback Synclines.)

distinctive high-grade metamorphic mineralogy was noted and, therefore, the clasts may have been derived from a quartz-bearing plutonic terrane from which quartz-rich derivatives were selectively preserved. Nearly all quartz grains in the sandstones display evidence of strain including pervasive undulatory extinction and, less abundant, sutured contacts between
Figure 12. Granophyre clast in a Clutha A conglomerate. Sample - LH 814; Princeton Tunnel in the Moodies Hills; cross-nicols.

Figure 13. Clast in a Clutha A conglomerate with quartz (left) and plagioclase (right). Carbonate has replaced part of both grains. Sample - LH 817; Princeton Tunnel in the Moodies Hills; cross-nicols.
domains and deformation lamellae. Pre-depositional and post-depositional quartz overgrowths are common. Embayments and distinctive beta-quartz shapes are also preserved. Polycrystalline quartz, including GMC with a variety of domain sizes, chert displaying spinifex texture (Fig. 14), iron-rich chert, carbonaceous chert (Fig. 15), stretched chert, and recrystallized chert is ubiquitous in the Clutha A in all three blocks.

Figure 14. Chert clast displaying spinifex texture. Sample - LH 725; Powerline Road Syncline; ppl.
Feldspar (F) constitutes 1 to 35%, averaging 13%, of samples in the Saddleback Syncline and the Moodies Hills, but is always less than 2% in the Powerline Road Syncline. Plagioclase grains are not preserved in the lower 750 m of the Powerline Road Syncline or in the Clutha A division of the Saddleback Syncline but may be represented by heavily sericitized grains that constitute up to four percent of the framework grains in these blocks. Plagioclase makes up to four percent of the Clutha A sandstones in the Moodies Hills. Preserved plagioclase throughout the Moodies Group of the study area is unzoned.

Figure 15. Carbonaceous chert clast in a Clutha A conglomerate. Note the molding of the clast to surrounding grains. Sample - LH 814; Princeton Tunnel in the Moodies Hills; ppl.

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Figure 16. Unaltered microcline feldspar in a Clutha A sandstone. Sample LH 817; Princeton Tunnel in the Moodies Hills; cross-nicols.

Figure 17. Unaltered, untwinned feldspar in a Clutha A sandstone. Sample LH 736; Saddleback Syncline; cross-nicols.
Potassium feldspar is missing in the Powerline Road Syncline but tartan twinned (Fig. 16), untwinned (Fig. 17), and perthitic feldspars are common in the Saddleback Syncline and Moodies Hills. Microcline grains are generally well-preserved but the perthitic grains have been extensively replaced by fine-grained sericite or display corrosion holes. Staining revealed untwinned potassium feldspars. These grains were distinguished in unstained sections from quartz by their cleavage and by differences in relief and alteration. Most of the untwinned feldspars appeared cloudy due to alteration to sericite or had corrosion holes within them (Fig. 18). Distinct differences in the severity of alteration and types of twinning, often in the

Figure 18. Feldspar crystal that has been severely corroded is in the lower left corner. Dark areas within the grain are holes. The black clast in the upper right corner is a carbonaceous chert. The matrix is fine-grained chert-sericite mosaic. Sample - LH 736; Saddleback Syncline; cross-nicols.
same thin section, suggest that the potassium feldspars were derived from at least two different sources.

Like most Archean sandstones (Taylor and McLennan, 1985), plagioclase-to-total feldspar (P/F) ratios in the Clutha Formation, and all of the Moodies Group, are very low. A partial explanation of the low ratio despite the surrounding Na-rich tonalite and trondhjemite batholiths, the underlying, plagioclase-rich Schoongezicht strata, and, possibly, the Na-rich AGC may be that potassium-bearing minerals alter much more slowly than plagioclase in plant-free environments (Basu, 1981; Maynard et al., 1982). The three highest P/F ratios of the 33 Clutha A samples point counted were 0.22 to 0.50. The others clustered below 0.19 (Appendix 2).

The Moodies Group has a poor diversity of mineral components. In addition to quartz and feldspar, trace amounts of muscovite, biotite, epidote, zircon, apatite, rutile, tourmaline, hematite, pyrite, and other opaques were the only individual detrital mineral grains observed.

Lithic content (L), excluding polycrystalline quartz, is 0 to 72%, averaging 18%. Total lithic grains (Lt) composition, including chert and fine-grained polycrystalline quartz (Qp + L), averages 32% but composes up to 85% of the framework grains in the Powerline Road Syncline, 64% in the Saddleback Syncline, and 20% in the Moodies Hills.
Fine-grained sericite and quartz mosaic clasts and matrices compose up to 97% of samples from the lower part of the Clutha A. The clasts range from nearly pure, chert with minor sericite to pure fine-grained sericite aggregates (Fig. 9). Many of the aggregates are iron-rich. They resemble the immediately underlying Schoongezicht dacitic volcanic and volcaniclastic rocks.

Lithic clasts of feldspar intergrowths, chlorite aggregates (Fig. 19), microlites (Fig. 20), and other mafic and ultramafic rock fragments probably represent volcanic or volcaniclastic rocks derived from the underlying greenstone sequence. Clasts of mafic and ultramafic volcanic rocks, common near the base of the Clutha A in the Saddleback Syncline and Moodies Hills, are absent in the lowest 300 m of the Powerline Road Syncline. Granophyre clasts (Fig. 12) and a rare, possibly phonolite clast that was only observed in one sample do not resemble any known rocks from the greenstone belt or Ancient Gneiss Complex. Clasts of siltstone, sandstone, and shale, interpreted as derivatives of underlying greenstone strata, are a minor but widely distributed component throughout the Moodies Group (Fig. 21).

Matrix in the Clutha A is composed predominantly of fine-grained sericite and sericite and chert mosaic. The rocks have been subjected to deformation of sericite and chert aggregates, sericite aggregates, and detrital muscovite grains. Distinguishing lithic grains from matrix is difficult as the
Figure 19. Photomicrograph of a Clutha A sandstone. Note the tight packing of quartz grains and the dark, central clast composed of an aggregate of fine-grained chlorite. Sample - LH 720; Powerline Road Syncline; ppl.

Figure 20. Microlite clast in a Clutha A conglomerate. Sample - LH 836; Moodies Hills; cross-nicols.
matrix appears to have been formed by these crushed rock fragments. Hematite and chlorite cements fill pore spaces within the Clutha A in the Powerline Road Syncline and Saddleback Syncline.

Figure 21. Photomicrograph of a Clutha A conglomerate. Most of the photograph is a single clast of quartz and chert-sericite-bearing sandstone. A grain of chert-sericite aggregate is in the lower left corner. A microlite grain is in the upper right. Sample - LH 742; Saddleback Syncline; cross-nicols.

**Clutha Formation - B division**

The B division of the Clutha Formation is predominantly arkosic arenite and subarkose (Fig. 10b). Quartz (Q) ranges from 51 to 81%, averaging 64%. Monocrystalline quartz (Qm) content averages 55%, fluctuating between 38% and 68%, and does not vary systematically with stratigraphic position. As in
the A division of the Clutha, monocristalline quartz occurs in the B division as individual grains and in fine- to coarse-grained aggregates with lesser amounts of potassium feldspar and minor biotite, in myrmekite grains, and in granophyre clasts. Quartz grains show pervasive undulatory extinction. Quartz overgrowths, embayments, and distinctive beta-quartz shapes are common. Polycrystalline quartz includes a variety GMC, chert displaying spinifex texture, jasper, carbonaceous chert, stretched chert, and recrystallized chert. The fine-grained chert has been preferentially replaced by carbonate in some samples.

The Clutha B is distinguished from the A division by an increase in feldspar content. Samples contain 11 to 42%, averaging 24%. Feldspars are predominantly tartan-twinned microcline, perthite, and untwinned potassium feldspar. The perthitic and untwinned grains have typically been severely altered to sericite or corroded. Some of the potassium feldspar grains have overgrowths. Samples from the Moodies Hills contain up to 5% plagioclase. Powerline Road Syncline and Saddleback Syncline samples have less than 1% plagioclase. The highest P/F in the Clutha B was 0.38. All other samples were less than 0.19. The less abundant plagioclase grains are relatively unaltered.

The variety of mineral components in the Clutha B sandstones is virtually identical to the A division. In addition to quartz and feldspar,
framework mineral grains include trace quantities of muscovite, biotite, epidote, ankerite, hematite, pyrite, and other opaques. Carbonate replacement of a variety of grains including fine-grained chert, quartz, potassium feldspar, and plagioclase, is particularly evident in this unit.

Lithic (L) composition averages 12% and ranges from 3 to 21%. Total lithic (Lt) composition ranges from 12 to 26% and averages 21%. Sericite, sericite and chert, and chert aggregates, similar to clasts in the Clutha A, are the most abundant lithic fragments. Other lithic fragments in the B division include granophyre, microlitic volcanic rock fragments, chlorite aggregates, fine- to coarse-grained aggregates of quartz and lesser amounts of potassium feldspar, aggregates of intergrown quartz and feldspar, hematite aggregates, iron-rich sericite and chert aggregates, iron-rich siltstone and sandstone, and myrmekite.

As in the A division, the matrix of the Clutha B is predominantly fine-grained sericite and chert with lesser amounts of chlorite probably derived from the underlying dacitic volcanic and volcaniclastic Schoongezicht Formation. Hematite cement fills corrosion holes and other pore spaces.

Joe's Luck Formation

The Joe's Luck Formation is mostly quartz arenite with lesser amounts of sublitharenite in the Saddleback Syncline, and subarkose in the Moodies.
Hills (Fig. 10c). This unit, the most quartz-rich division of the Moodies Group, has a quartz content of 69 to 99%, averaging 90%, and a monocrystalline quartz (Qm) composition of 24 to 90%, averaging 73%. The greater abundance of quartz in the Joe's Luck Formation has concentrated greater strain in these grains resulting in increased undulation, sutured contacts between domains, and recrystallization of some quartz. Many of the quartz grains also display overgrowths (Fig. 22).

![Photomicrograph](image)

Figure 22. Photomicrograph showing tightly packed quartz grains in a cross-bedded Joe's Luck sandstone. Some carbonate cement and replacement is displayed by the high relief patches. Sample - LH 798; Saddleback Syncline; cross-licols.
Quartz grains in the B division of the Clutha Formation include monocrystalline grains, quartz with embayments contained within a sericite and chert matrix, and grains contained in clasts of vein quartz, granophyres and other granitoids, and fine- to coarse-grained aggregates of quartz with lesser amounts of potassium feldspar and plagioclase. Monocrystalline grains include tourmaline, rutile, apatite, and zircon. The polycrystalline quartz grains include pure chert with a variety of size domains, carbonaceous chert, and recrystallized chert.

Framework mineral composition in the Joe's Luck Formation is similar to the underlying Clutha Formation but is distinguished by a scarcity of feldspars. Feldspars comprise 0 to 24% of the Joe's Luck sandstones, averaging 5%, and include fresh-looking microcline and plagioclase grains and heavily sericiticized untwinned potassium feldspar, perthite, and plagioclase. The average P/F is less than 0.1. Other framework grains include trace quantities of muscovite, biotite, hematite, pyrite, and other opaques.

Lithic clasts (L) content ranges from 1 to 69%, averages 6%, and includes a variety of fine-grained, chert and sericite aggregates, feldspar and quartz intergrowths, feldspar intergrowths, microlites, granophyres, chlorite aggregates, and iron-rich siltstone (Fig. 23). The total lithic (Lt) content is 5 to 69%, averaging 23%.
The most abundant matrix is composed of sericite and/or chert with some fine grains of hematite and chlorite. It appears to represent crushed lithic grains. Cements, including carbonate, hematite, and phyllosilicates, fill the pore spaces.

Figure 23. Clasts in a Joe's Luck sandstone. Mottled grain in the upper, central part of the photo is composed of intergrowths of feldspar. Grain in the lower left is an aggregate of sericite and chert. Fine-grained, pure chert composes the grain in the lower, central area. Most of the remaining grains are quartz. Sample - LH 825; Princeton Tunnel in the Moodies Hills; cross-nicols.
**Baviaanskop Formation**

The Baviaanskop Formation is a sublitharenite with higher lithic and lower monocrystalline quartz contents than the Joe's Luck Formation (Fig. 10d). Samples contain 68 to 89% quartz, averaging 81%. Monocrystalline quartz (Qm) composition, which averages 57%, ranges from 31 to 67%. Quartz includes individual grains, domains within granitoids, granophyres, and fine- to coarse-grained aggregates of quartz and potassium feldspar, and embayed grains within fine-grained, pure chert. Polycrystalline quartz includes GMC in a variety of size domains, jasper, carbonaceous chert, recrystallized chert, and stretched chert.

Feldspar content in the Baviaanskop ranges from 0 to 19%, averaging 8%, and includes heavily sericitized perthite and untwinned potassium feldspar, lesser amounts of fresh-appearing tartan-twinned microcline, and plagioclase. Potassium feldspars in the Saddleback Syncline display corrosion holes similar to those described in the Clutha B. The maximum P/F is 0.26 with most samples having much lower ratios.

Framework minerals in the Baviaanskop Formation are less varied than in the underlying Clutha and Joe's Luck Formations. Quartz, feldspar, and trace amounts of muscovite, pyrite, and chlorite were the only framework minerals noted in the 10 samples that were point counted.
The Baviaanskop sandstones contained 6 to 17% lithic (L) grains, averaging 11%, and 25 to 59% total lithic clasts (Lt), averaging 35%. Lithic clasts included fine-grained sericite and/or GMC aggregates, iron-rich sericite and chert aggregates, sericitized feldspar and quartz intergrowths, plagioclase intergrowths, microlites, and carbonaceous chert with silicified, euhedral crystals that were probably primary evaporites (Fig. 24).

Figure 24. Carbonaceous chert clast displaying silicified, euhedral crystals that resemble possible carbonate or evaporite crystals. Sample - LH 822; Princeton Tunnel in the Moodies Hills; ppl.

The matrix of the Baviaanskop sandstone is predominantly sericite with GMC. Hematite, silica, and carbonate cements fill pore spaces.
HEAVY MINERALS

Heavy minerals typically made up less than one percent of the points counted. Opaques, predominantly hematite and pyrite, made up to three percent in two samples. Zircon, tourmaline, and rutile grains were always less than 0.5% of any sample examined in this sections but were widely present. Trace amounts of detrital epidote in the Clutha Formation and apatite in the Clutha and Joe's Luck Formations were the only other heavy minerals observed. Undoubtedly, a larger variety and a higher percentage of heavy minerals in the source areas was removed by the extensive weathering during transport through eolian, alluvial, and beach environments.
PEBBLE AND COBBLE COMPOSITIONS

A frequency count of 81 identifiable pebbles and cobbles from the Clutha Formation in the Moodies Hills southwest of the Woodbine Shaft included 68% black or white chert, 11% intermediate volcanic rocks, 7% red and white banded chert, jasper, and banded iron formation, 7% vein quartz or quartzite, and 6% clastic sedimentary rocks. Daneel (1986) counted a total of 460 pebbles in the Clutha A from three locations in the Moodies Hills and reported 60% chert, 6% ultramafic rocks, 12% jasper and banded iron formation, 9% quartzite, 9% clastic sedimentary rocks, and 2% granitoid clasts.

At Ezzy's Pass on the north limb of the Eureka Syncline, Reimer et al. (1985) reported 85% chert, 8% sandstone and volcanic rocks, 5% granite, and 2% vein quartz in the basal conglomerate. Most Clutha A lithic clast composition in the Saddleback Syncline is consistent with material available from the underlying Swaziland Supergroup and consist of green, black, white, gray, and banded chert, felsic volcanic and volcaniclastic, mafic and ultramafic volcanic, banded iron formation, and minor siltstone and shale clasts. Granophyre and granitoid rock fragments are present in trace quantities.

The abundance of lithic fragments of granitic, granophyric, and coarse-grained aggregates of quartz with lesser amounts of potassium feldspar in the Clutha A division is locally and regionally variable. Reimer et
al. (1985) report a 5% abundance of granitoids and clasts they interpreted as metamorphites at Ezzy's Pass but Reimer (1967) found only 0.5% in the pebble-bearing sandstone of the lower part of the Moodies Group in the Stolzburg Syncline. In the Moodies Hills, these clasts constitute from 1 to 7% of the conglomeratic portions of the Clutha A (Fig. 25). In the Svengali Section (Saddleback Syncline) to the south, however, felsic crystalline clasts are less than 1% of the volume. Bell (1967) reported 2% granite pebbles on the south limb of the Saddleback Syncline east of this study area.

Figure 25. Photograph of Clutha A slab from the Moodies Hills. "A" marks granophyre clasts. "B" identifies felsic volcanic clasts. "C" marks chert clasts.

At Ezzy's Pass, Krupicka (1975) found granitic pebbles in the basal conglomerate of the Clutha Formation to be granodiorite and granite. In the
same area, Reimer et al. (1985) reported clasts of quartz-rich granitoid, alkali-feldspar granite, and normal granite compositions. Their investigation of the geochemistry of these granitic clasts found high K$_2$O, Sr, K$_2$O/Na$_2$O, and K/Rb compared to most granites of similar modal composition. They reported a small light rare earth element enrichment, large negative Eu-anomalies, and a slight depletion and fractionation of heavy rare earth elements. They concluded that the clasts were not derived from presently exposed rocks and suggested that the source plutons originated through partial melting of the AGC or cooling of a plagioclase-depleted magma at a depth of <7 km in a thick sialic crust. Pebbles from the same location and study with micaceous (sericite) and quartzofeldspathic bands that resemble some volcanic rocks within the Onverwacht Group were identified by Reimer et al. (1985, Fig. 4c) as metamorphites. They had higher Fe$_2$O$_3$, TiO$_2$, and Cr and a greater LREE enrichment than the granitic clasts. They also had large negative Eu-anomalies. Their precursors were described as felsic volcanic rocks.

No granitoid pebbles or clasts were observed south of the Inyoka Fault during this study. In the southern portion of the belt, Lamb (1984a), Visser (1956), and Gay (1969) reported minor quantities of granitoid and granophyre clasts but Paris (1984) found none. Whole rock XRF analysis of two granitoid clasts from the Swaziland side of the greenstone belt (Lamb, 1984) provide a distinctly different composition from similar analysis provided by Reimer et
al. (1985) for granitoid pebbles in the Eureka Syncline on the north side of the greenstone belt. In addition to differences in proportions and quantities of sodium, potassium, and calcium (Fig. 26), Lamb's samples were higher than any of Reimer's in iron, magnesium, and cobalt, and much lower in barium.

A frequency count of 296 pebbles and cobbles was made at four sites at the top of the Joe's Luck Formation near the Svengali Section in the Saddleback Syncline. The conglomerate has 82% black and/or white chert, 5% ferruginous bedded chert, 1% jasper, 7% quartz-rich lithic clasts that appear to be quartzite, 3% vein quartz, and only one granitic clast. No volcanic fragments were noted but trace amounts of chrome-mica-bearing green chert from the Onverwacht Group are present lower in the Joe's Luck Formation.
Figure 26. Na$_2$O-K$_2$O-CaO ternary plot of granitoid and "metamorphite" pebbles in the Moodies Groups and its equivalents and of components of the Ancient Gneiss Complex.

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SHALE GEOCHEMISTRY

Geochemical investigations by McLennan et al. (1983) of five shales from the Moodies Hills conclude that the Moodies was derived from a mix of mafic volcanic, tonalite-trondhjemite, and felsic volcanic sources. They found very high chrome and nickel and high iron and magnesium contents, although the Moodies was lower in nickel, iron, and magnesium than older Fig Tree shales. They argued that the high nickel and chrome contents are evidence against an island arc origin and probably were derived from the ultramafic and mafic material of the older Onverwacht Group and enriched by secondary processes. K$_2$O/Na$_2$O in the Moodies shales is approximately 2-3, light rare earth elements were enriched in all samples, and there is an apparent slight negative Eu anomaly that probably resulted from a granitic provenance. La/Th is high and thorium and uranium contents and Th/U are low.
DISCUSSION

PROVENANCE

Moodies sandstones and conglomerates throughout the study area display clear evidence of substantial derivation from the older greenstone strata, the Fig Tree and Onverwacht Groups to the south. Mafic and ultramafic volcanic fragments, chrome-mica-bearing chert, and black and white chert clasts derived from the Onverwacht and lowest Fig Tree Groups are throughout all sections. Fine-grained sediments and chert, commonly ferruginous, are consistent with detritus available from the Fig Tree Group.

A second source terrane provided fine- to coarse-grained crystalline rock fragments that are quartz-rich with lesser amounts of microcline and plagioclase, granophyre, granitoid, and rare phonolite clasts to the northern blocks. Quartz-rich, coarsely crystalline rock fragments in the Moodies Group have been interpreted by previous workers as derivatives of a high-grade, metamorphic quartzite (Anhaeusser, 1976; Reimer et al., 1985). This study, however, did not observe any clear metamorphites. Although the source clearly included quartz-rich rocks and microcline-bearing plutonic units, there is no definite evidence that high-grade metamorphic rocks were present. It is also uncertain whether the parent crystalline rocks were associated with the Ancient Gneiss Complex, the plutons surrounding the
greenstone belt, or plutons associated with the older, felsic igneous rocks within the greenstone belt.

Volcanic and felsic crystalline fragments, lithic clasts of fine-grained chert-mica aggregates, banded iron formation, feldspar, and fine-grained lithic material are all less abundant upsection in the Saddleback Syncline and Moodies Hills. The cleaner, quartzose Joe's Luck and Baviaanskop Formations were probably derived by cannabalizing older Moodies strata to the south and enriched in quartz by high-energy alluvial and marginal marine conditions.

Southern and northern facies

The framework components of the Moodies sandstones are remarkably consistent although relative abundances vary (Fig. 27a, b, c). Systematic changes in grain composition are more evident laterally between blocks than stratigraphically within blocks. Distinct facies changes across the Inyoka Fault have been previously documented in the Onverwacht (Lowe and Byerly, in review) and Fig Tree Groups (Heinrich and Reimer, 1977; Lowe and Byerly, in review). The Moodies has more subtle changes. From north to south, fine-to coarse-grained quartz and quartz-feldspar aggregates, monocrystalline quartz, total quartz, alkali feldspar, and identifiable felsic and intermediate plutonic clasts decrease but mafic volcanic and fine-grained chert-mica and chert aggregates, interpreted as remnants of the underlying greenstone belt.
Figure 27a. Generalized stratigraphic columns showing %Qm, %F, mean grain size of samples point counted, and occurrence of key minerals and rock types in Moodies sandstones. South side of the Powerline Syncline.
Figure 27b. Generalized stratigraphic columns showing %Qm, %F, mean grain size of samples point counted, and occurrence of key minerals and rock types in Moodies sandstones. Saddleback Syncline.
Figure 27c. Generalized stratigraphic columns showing %Qm, %F, mean grain size of samples point counted, and occurrence of key minerals and rock types in Moodies sandstones. Moodies Hills.
in increase.

South of the Inyoka Fault, granitoid clasts are rare and those described in Swaziland are apparently chemically distinguishable (Fig. 26). Granophyre clasts, common in the northern blocks of Moodies, have not been observed in the south. No granitoid, granophyre, or potassium feldspar clasts were observed in the Powerline Road Syncline. The abundance of total lithic fragments is higher and grain sizes are coarser than in equivalent units to the north. Strata presently south of the Inyoka Fault received most or all of their detritus from the greenstone belt to the south or southeast.

North of the fault, in the Saddleback Syncline, microcline, perthite, and trace amounts of graphic and granitic clasts reflect a combined provenance of the greenstone belt and a relatively distal felsic crystalline area. In the Moodies Hills, despite sedimentological evidence that rocks are of a more distal facies than to the south (Eriksson, 1978; 1979), the graphic, granitic, and coarse-grained felsic crystalline clasts are larger and more abundant than in the Saddleback Syncline. The Moodies Hills was more proximal to a plutonic/felsic crystalline source.

The Moodies was probably deposited in a single basin. Types of constituents in the sandstones of all three blocks are nearly identical both vertically and laterally, with the exception of the missing felsic crystalline components in the Powerline Road Syncline. The amygdaloidal basalt unit in
the Moodies Group progressively thins to the north and is interpreted as the product of a short-lived volcanic event during the time of late Clutha deposition south of the fault and early Joe's Luck deposition north of the fault. The thinning basalt flows covered all but localized areas in the northern part of the greenstone belt.

The northern blocks were more distal from the southern provenance and sediments were deposited in deeper water than the southern facies. But, the northern blocks were also west of their present location relative to the Powerline Road Syncline. Several workers have documented east-west to northeast-southwest trending, post-Moodies dextral shears in the northern part of the greenstone belt (Boardman, 1950; Visser, 1956; Roering, 1965; Anhaeusser, 1965; Hose and Lowe, 1987; Hose, this volume, chap. 2). Therefore, the more abundant felsic crystalline clasts in the northern blocks may have been derived from the southwest. Portions of a crystalline terrane may have been exposed earlier and more extensively to the south of the basin. Alternatively, the felsic crystalline component may have been derived from the northeast or northwest, but this concept is hard to defend in light of presently known sedimentological data.
Comparison with Phanerozoic sandstones

Ternary plots that place chert and fine-grained polycrystalline quartz grains (Qp) as part of the lithic components (Lt) and limit quartz to monocrystalline crystals (Qm) are more appropriate than standard Q-F-L diagrams for comparing the Moodies with Phanerozoic provenance data. Distinction between altered sedimentary and volcanic lithic grains in the Moodies was commonly impossible. Comparisons of Qm-F-Lt plots eliminate errors introduced by misidentified sedimentary chert fragments and silicified volcanic lithic clasts.

Following the parameters defined by Dickinson and Suczek (1979) and refined by Dickinson et al. (1983) (Fig. 28), most samples in this study resemble Phanerozoic sandstones derived from recycled orogens and, to a lesser extent, dissected arcs (Fig. 29). Recycled orogens are sites where stratified rocks are deformed, uplifted, and eroded including subduction zones, suture belts, and foreland fold and thrust belts (Dickinson and Suczek, 1979). The potential provenance settings provide oceanic and continental material to the adjacent basins that reflect ultimate derivation from cratonic, arkosic, and volcanioclastic sources (Dickinson, 1985).

Phanerozoic foreland fold and thrust belts are typified by sedimentary and metasedimentary strata that are continental derivatives deposited on a shelf. Although volcanioclastic detritus is not abundant in most foreland
basins, arc-derived material has been recognized as an important component in the evolution of some Phanerozoic backarc foreland deposits where the basin was close to the arc and it received drainage from the eruptive center (McBride et al., 1975; Misko and Hendry, 1979).

*Clutha Formation - A division*

The transition from Schoongezicht volcaniclastic sandstone and conglomerate to Clutha A lithic arenite, sublitharenite, and subarkose marked the end of widespread volcanism and deep-sea conditions in the region. The
Figure 29. Ternary plot of detrital framework grains compositions. a. A
division of the Clutha Formation. b. B division of the Clutha Formation. c. B
division of the Clutha Formation in which matrix volume is calculated as a part
of Lt. d. Joe's Luck Formation. e. Baviaanskop Formations.

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with minor components of green, red, black, and white chert derived from older Fig Tree and Onverwacht rocks. The Onverwacht Group is unconformably overlain by Moodies strata in parts of the southern greenstone belt and apparently provided a source of detritus during deposition of the lower beds of the Clutha Formation.

The lithic-rich compositions of the Clutha A division, particularly in the Powerline Road Syncline, are similar to Phanerozoic sedimentary rocks derived from recycled orogens of lithic and quartzose composition (Fig. 29a). Recycled orogens are described by Dickinson et al. (1983) as terranes with sedimentary strata and subordinate amounts of volcanic rocks, partially metamorphosed, and raised by orogenic uplift of fold belts and thrust sheets.

Although the lowest strata of the Clutha A are almost completely derived from the arc-related, volcanic and volcanioclastic Schoongezicht Formation, they plot along the Qm-Lt legs of the triangular diagram and not within the arc-derived fields (Fig. 29a). These rocks were probably deposited in a basin close to the arc. Breakdown of the Schoongezicht-derived material resulted in the abundant chert-sericite matrix, framework grains of plagioclase, and minor quartz. The plagioclase grains have almost entirely changed to sericite matrix with minor discrete sericite aggregates. If the plagioclase phenocrysts had survived as discrete feldspar grains, the Clutha A
sandstones probably would have plotted within the undissected and transitional arc fields.

The progressive increase in monocrystalline quartz throughout the upper Schoongezicht and the Clutha A sandstones (Fig. 11) may reflect four causes. First, erosion of the Schoongezicht strata exposed turbiditic quartz-bearing sandstones and conglomerates in the Mapepe and Sheba Formations causing a reworking of the sediments and enrichment of quartz. Some quartz-bearing, immature sandstone clasts that resemble material from the upper Mapepe Formation occurred in the basal conglomerate in the Moodies Hills (Fig. 21). Remnants of syntaxial quartz overgrowths also demonstrate that the provenance included at least some lithified, clastic rocks.

A second cause of the increase in monocrystalline quartz may have been uplift in the south causing earlier deposited Moodies strata to be cannibalized, reworked, and enriched in quartz. Lamb (1984b) has documented syndepositional folding and faulting in units equivalent to the upper Fig Tree and lower Moodies Groups in the southern part of the belt and attributes this deformation to a period when thrust sheets were transported for at least 10 km towards the northwest. Thus, uplift and deformation of the greenstone belt was occurring in the south or southeast during deposition of the Moodies Group.
The potential third source of the increasing proportion of monocrystalline quartz may have been a quartz-rich crystalline terrane exposed by uplift and erosion. Jackson (1984) reported that the AGC to the south of the greenstone belt experienced progressive northwest-verging uplift, folding, and shearing beginning around 3.4 Ga old, preceeding deposition of the Moodies Group. This complex may have provided some of the detritus, although distinctive components of the AGC, such as diopside-bearing gneiss, amphibolite, anorthosite, and garnet grains, were not preserved in the Moodies sandstones and conglomerates in this study. Alternatively, felsic plutons related to the greenstone belt may have provided some of the detritus. Erosion of the Schoongezicht volcanic rocks may have also exposed associated, deeper seated felsic plutons that had fed the earlier Schoongezicht lava flows.

The change from a fluvio-deltaic and deep-water environment during Fig Tree time to a braided alluvial environment during deposition of the Clutha Formation (Eriksson, 1980) may have been a fourth factor contributing to enrichment of quartz. Studies of modern sands derived directly from igneous or metamorphic provenances have shown that prolonged exposure to intense chemical weathering while stored on alluvial plains and gentle, subaerial slopes in tropical environments can enrich quartz content from ~30% in the source area to greater than 95% at the depositional basin (Suttner
et al., 1981; Basu, 1985; Johnsson et al., 1988). Although plants were not available to assist chemical weathering in the Archean, alteration and corrosion of minerals by the Archean atmosphere and hydrosphere during extended residence on alluvial plains prior to lithification may have greatly enriched the quartz content of the Moodies sandstones.

Plagioclase grains are not preserved in the lower 800 m of the Powerline Road Syncline or in the lower Clutha Formation of the Saddleback Syncline but relatively fresh-appearing plagioclase is a ubiquitous minor component throughout the Moodies Hills and in the upper Clutha, Joe's Luck, and Baviaanskop Formations of the Saddleback Syncline. Heavily sericitized plagioclase grains are more abundant to the south although they often occur in the same thin section with unaltered plagioclase. The distinct difference in severity of alteration suggests that the two types of feldspars were derived from different sources. The sericitized grains probably came from the older greenstone strata. The close correlation in abundance and occurrence of fresh appearing plagioclase with coarse crystalline clasts, some also containing fresh-appearing plagioclase (Fig. 13), probably represents a common high-grade metamorphic or plutonic source terrane.

Mafic and ultramafic volcanic fragments, chrome-mica-bearing chert, black and white pure chert, carbonaceous chert, and recrystallized cherts clasts in the A division of the Clutha Formation were derived from the
Onverwacht. Fine-grained lithic material, ferruginous chert, banded iron formation fragments, fine-grained chert-mica mosaics, and some monocristalline quartz, pure chert, and sericitized plagioclase were probably derived from the Fig Tree Group.

The fine- to coarse-grained, quartz-rich crystalline rock fragments, microcline, perthite, myrmekite, stretched quartz, biotite, muscovite, epidote, zircon, apatite, and some of the monocristalline quartz, volcanic, and plagioclase grains in the Clutha A strata of the Saddleback Syncline and Moodies Hills were probably derived from either a moderately deep-seated plutons associated with the greenstone belt or the AGC. Hornblende, polycristalline lithic fragments, and accessory minerals common in the AGC may have been selectively removed by eolian processes, which intensely affected pre-Silurian sands because of the lack of land plants (Sloss, 1988), during long residence time in alluvial environments and by high energy alluvial and marginal marine settings (Eriksson, 1978). These environmental conditions would have enhanced quartz and other hardy minerals while decomposing the more unstable grains, medium- and coarse-grained polycristalline lithic fragments, and other less resistant clasts. Lack of early cementation in the alluvial deposits of the Moodies may have also allowed extensive diagenetic alteration of unstable grains. Graphic texture and coarse-grained granitic clasts, whose occurrences closely corresponded with
the presence of other, quartz-rich crystalline material, probably represent intrusive bodies that were removed by erosion and are no longer exposed.

Krupicka (1975) has proposed two sources for these plutons. They may have been emplaced due to partial melting of portions of the AGC or derived from a plagioclase-depleted magma.

**Clutha Formation - B division**

The B division of the Clutha Formation, with greater concentrations of alkali feldspar, plots in a variety of fields (Fig. 29b). Some samples, mostly in the Moodies Hills, match sandstones derived from transitional continental, quartzose recycled, and mixed crust where erosion has cut deep (Dickinson et al., 1983). However, matrix contents of these rocks range from 16-26% and is higher than the other units. It is predominantly fine-grained sericite and chert, a similar composition to many of the lithic fragments in the Moodies Group. Therefore, the matrix probably resulted from a breakdown of unstable lithic grains. A plot of the Clutha B showing all matrix points tabulated as Lt lies primarily within the mixed field but there is some overlap into the dissected arc and quartzose recycled fields (Fig. 29c).

The increase in feldspar content, primarily alkali feldspars, in the B division of the Clutha Formation probably resulted from increased exposure of the felsic crystalline terrane. The southern facies, exposed in the Powerline
Road and Maid of the Mist Mountain Synclines, did not receive detritus from the crystalline terrane. Thus, deposition of the A division of the Clutha Formation, derived solely from the underlying greenstone strata, continued in the region now south of the Inyoka Fault while in the northern blocks, which received detritus from both the greenstone belt and the felsic crystalline terrane, the Clutha B division accumulated.

Joe's Luck Formation

The Joe's Luck sandstones and conglomerates, deposited only in the blocks now north of the Inyoka Fault, are composed of the same types of minerals and rock fragments as the underlying Clutha Formation. Like the northern facies of the Clutha Formation, the clasts represent a mixed provenance of the older greenstone strata and a crystalline terrane. The Qm-F-Lt ratios plot within the quartzose recycled field (Fig. 29d). The increase in monocrystalline quartz and chert and the decrease in feldspar and other less stable grains probably resulted, in part, from the high energy of its barrier beach and fluvial depositional environment (Eriksson, 1979). Abrasion of the sediments along the shoreline would enhance the quartz content. The Joe's Luck may also have cannibalized Clutha sandstone and conglomerates, resulting in quartz-enriched strata.
Baviaanskop Formation

The Baviaanskop Formation plotted in the quartzose and transitional recycled fields (Fig. 29e). Like the underlying Joe’s Luck, it also represents a mixed provenance and was probably derived from uplifted and predominantly sedimentary rocks, probably older Moodies. Fine-grained sercite and/or GMC aggregates, feldspar and quartz intergrowths, plagioclase intergrowths, microlites, jasper, carbonaceous chert, recrystallized chert, and some of the quartz and plagioclase grains were derived from the older greenstone strata. Alkali feldspar, stretched quartz, muscovite, and part of the quartz and plagioclase grains probably came from the crystalline terrane.

TECTONIC SETTING

The tectonic settings classified as recycled orogens by Dickinson et al. (1983) include the subduction complexes of arcs, uplifted suture belts of collision orogens, and thin-skinned foreland fold-thrust belts along the continental sides of arc or collision orogens. Subduction complexes are deposited in a deep marine environment and exhibit penecontemporaneous deformation. The Moodies sandstones and conglomerates accumulated in marginal marine and alluvial environments. The overall, fining upward Moodies Group does not resemble deposits adjacent to an uplifted suture belt.
Basins adjacent to collision orogens are raised with time and their deposits typically reflect shallowing conditions and coarsen upward.

The A division of the Clutha Formation is composed predominantly of detritus that was probably eroded from older strata of the greenstone belt uplifted by an active thin-skinned foreland fold-thrust belt to the south or southeast of the study area. Uplift, and the downwarping of a companion basin to the north may have resulted from north-verging thrust faults or may have initially been the product of compressional flexure. The alkali feldspar-rich samples from the Saddleback Syncline and Moodies Hills (Fig. 29a) reflect input from a felsic crystalline terrane, most likely uplifted by thrust faulting southwest of the study area. The crystalline material may, however, represent a separate, distal orogen along the northwest or northeast side of the study area.

Deposition of the finer grained, more feldspathic B division of the Clutha Formation may have been contemporaneous with northwest-verging thrusts in the south. Load resulting from thrusting on an elastic lithosphere will rapidly deepened a foreland basin and initially cause finer grain sediments to be deposited (Burbank et al., 1988). Immediately adjacent to the thrust front, however, coarse sediments will continue to be deposited. Thus, the areas presently south of the Inyoka Fault continued to receive coarse-
grained sand, pebbles, and cobbles while the deepened north received finer grained sediments.

The Joe's Luck Formation is lensoidal, coarsens upward, and appears to have prograded basinward (northwestward). This is the response predicted by Flemings and Jordan (1987) for a foreland basin when crustal thickening (thrusting) stops. Deposition of the Joe's Luck may mark a period when thrusting stopped to the southeast. A brief period of volcanism produced the amygdaloidal basalt near the base of the Joe's Luck Formation in the northern facies and near the top of the Moodies strata in the southern facies. There is no evidence of erosion prior to the deposition of the overlying beds and no clasts of the basalt are recognized in the overlying strata. The lava flows must have been blanketed with sediments immediately after their emplacement, protecting them from erosion, as would be expected in a prograding deposit.

Renewed foreland (northwestward) migration of the thrust belt ultimately raised previously deposited Moodies strata, exposing them to erosion and stopping deposition in the southern blocks. These cannibalized sediments were reworked by high-energy environments of transportation and deposition, resulting in the quartzose composition of the Joe's Luck sandstones.

Clasts from the crystalline provenance are finer grained and less abundant components of the Joe's Luck strata than in the Clutha Formation.
At that time, the plutonic-high grade terrane was either removed as a source area by erosion, the transportation path between it and the basin had been blocked by intervening uplift, or its contributions were overwhelmed by the abundance of greenstone, including older Moodies, detritus.

The dramatic decrease in grain size at the base of the Baviaanskop Formation suggests a rapidly deepened basin, possibly as an elastic response to renewed thrusting and loading in the south. The quartz-rich sediments continued to be derived from cannibalized Moodies strata, uplifted Fig Tree and Onwerwacht Groups, and portions of the plutonic/metamorphic terrane.
CONCLUSIONS

The Early Archean Moodies Group in the north-central part of the Barberton greenstone belt was derived from two provenances. The majority of the sediments came from an orogen that lifted up the older greenstone strata. The orogen was most likely a thin-skinned foreland fold-thrust belt south of the study area. A granitic/high-grade metamorphic(?) terrane provided sediments to a portion of the basin. Although some of the crystalline fragments resemble rocks of the Ancient Gneiss Complex south of the greenstone belt, other potential components from that high-grade terrane were missing in the sandstones and conglomerates investigated in this study. No definitive metamorphites were identified. Granophyre and granitoid clast that do not resemble presently exposed rocks may have been associated with the Ancient Gneiss Complex or felsic plutons surrounding or within the greenstone belt. The felsic crystalline provenance may have been uplifted by the same thrust belt to the southwest of the study area or may have been part of a separate, distal orogen to the north.

The Clutha Formation in the study area was deposited on the foreland side of the fold and thrust belt. North of the Inyoka Fault, the unit is composed of detritus from both provenances. South of the fault, sediments came from older greenstone strata, solely. As the thrust belt migrated towards the foreland (northwest), sediments from earlier deposited Moodies strata
were uplifted, eroded, reworked, and deposited in the younger Moodies deposits to the north resulting in the more mature Joe's Luck and Baviaanskop Formations in the northern blocks. The uplift resulted in the discontinuation of deposition in the southern part of the greenstone belt. Thus, the Joe's Luck and Baviaanskop Formations are absent south of the present Inyoka Fault.

The Inyoka Fault divides distinctive northern and southern facies of the Moodies Group. North of the fault, potassium feldspar, granophyre, and coarse-grained, felsic crystalline rock fragments are common within the Moodies Group, all of which are absent within the study area south of the fault. Granitic pebbles described by others in the southern part of the belt contain a distinctively different composition. The Baviaanskop, Joe's Luck, and upper Clutha Formations are absent south of the fault.

Amygdaloidal basalt in the Moodies and equivalent rocks throughout the greenstone belt is interpreted as the result of one volcanic episode and may provide a regional isochron within both the southern and northern facies of the Moodies. The basalt layer is within lithic-rich, coarse-grained sandstone and conglomerate, similar to the lower Clutha Formation, in blocks south of the Inyoka Fault but crops out within the lower part of the Joe's Luck Formation to the north of the Inyoka Fault.
This study has also shown that detrital framework modes can be a useful tool for determining the provenance of sandstones as old as Early Archean. Interpretations based on detrital modes were consistent with other stratigraphic data and field observations. Special note should be made, however, that debris derived from a felsic volcanic arc and deposited in the foreland basin plotted within the field of a recycled orogen. Where alteration is minimal, detrital framework modes have the potential of resolving many questions about the sedimentary environments of Precambrian greenstone belts throughout the world.
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CHAPTER 3

EARLY ARCHEAN PALEOGEOGRAPHIC SETTING OF THE
NORTH-CENTRAL BARBERTON GREENSTONE BELT,
SOUTH AFRICA
INTRODUCTION

The north-central part of the Early Archean Barberton greenstone belt was adjacent to a convergent boundary following deposition of the Onverwacht Group. Recent papers have suggested that the lower Fig Tree strata were deposited in a foredeep setting bounded by a fold and thrust belt to the southeast (Jackson et al., 1987; Nocita, 1989). East-verging thrust faults cutting the lower Fig Tree rocks but not the younger Schoongezicht Formation (Dokka and Lowe, 1984; Lowe et al., 1985) suggest that a convergent boundary was west of the study area following deposition of the lower Fig Tree strata. The Schoongezicht Formation at the top of the Fig Tree Group and the entire overlying Moodies Group provide evidence of deposition on the upper plate of a convergent boundary (Byerly et al., 1989; Byerly, in review; Hose, this volume, Chap. 3). That boundary appears to have been south or southeast of the study area during Moodies deposition.

Four periods of deformation following deposition of the Moodies Group clastic rocks have been documented in the northern part of the greenstone belt (Anhaeusser, 1976; Hose, this volume, Chap. 2). Preserved structures recording each of these events are compatible with Phanerozoic models of a terrane on the foreland side of an upper plate along an evolving convergent boundary.
The following discussion focusses on the nature of the evolving convergent boundary and its influence on the development of the north-central part of the Barberton greenstone belt during and following deposition of the Moodies Group. Except where noted, the model developed depends on the data reviewed in the preceding two chapters.
PALEOGEOGRAPHIC MODEL OF THE STUDY AREA

Pre-Moodies (Schoongezicht Formation) Time

The Schoongezicht Formation in the north-central part of the Barberton greenstone belt is divided into a northern and southern facies. The southern facies is composed predominantly of dacite-clast sandstone and conglomerate with interbedded dacite. The northern facies is reported to include turbiditic sandstone, conglomerate, and shale (Condie, Macke, and Reimer, 1970; Lowe and Byerly, in review), representing a basin deepening to the south. Based on the distribution of the extrusive igneous rocks, massive volcanic breccias, and epiclastic conglomerates and sandstones, the volcanic center appears to have been west or southwest of the study area. Byerly et al. (1989) reports that the geochemical affinities of the volcanic rocks are suggestive of an island arc origin.

The upper part of the Schoongezicht Formation displays an increase in monocry stalline and polycrystalline (chert) quartz abundance and is transitional with the overlying, quartz-rich Moodies Group. The shift from the volcaniclastic dominated basin during Schoongezicht time to the accumulation of the predominantly orogenic-derived Moodies Group probably represents the uplift of the source area to the south and the discontinuous of volcanism.
Although there is little published information about the sedimentology of the Schoongezicht Formation, including paleocurrent directions, evidence of a basin deepening northward or northwestward away from an island arc suggests that the region was on the upper plate of a convergent boundary with a subduction zone to the south (Fig. 1).

![Figure 1. Schematic diagram showing the study area during the deposition of the Schoongezicht Formation.](image-url)
Moodies Group Time Through $D_3$

Deposition of the Moodies Group coincided with uplift and erosion of the greenstone belt to the south or southeast and the exposure of a coarse-grained, crystalline terrane. The greenstone belt provided detritus to the entire basin. Only the northern part of the study area, north of the Inyoka Fault, however, clearly received material from the crystalline terrane. It is also noteworthy that crystalline particles in the Saddleback Syncline are limited to sand size grains whereas pebbles and cobbles of granitoid rocks occur in the Moodies Hills.

The source of the crystalline terrane remains a mystery. Contrary to previous interpretations (Jackson et al., 1987), detailed petrographic and lithologic observations during this study failed to identify any conclusive, high-grade metamorphic rock fragments or minerals in the Moodies sandstones or conglomerates. However, granitic rock fragments were clearly identified.

This study did recognize clasts that were previously described as metamorphic material (Reimer et al., 1985). Coarse-grained, crystalline lithic clasts made up of predominantly quartz with lesser feldspar failed to provide compelling evidence of a high-grade metamorphic parentage, although such an origin is not precluded. These clasts may instead represent vein deposits within the greenstone belt or selectively preserved, quartz-rich parts of the
granitic provenance. Fine-grained clasts with "micaceous and quartzofeldspathic bands", similar to "metamorphite" clasts described by Reimer et al. (1985, Fig. 4c) are common in the Moodies Group but resemble volcanic rocks in the Onverwacht Group and are interpreted as derivatives of the greenstone belt by this study.

Reimer et al. (1987) found that the REE distribution pattern of the granitic pebbles in the Moodies Group were not compatible with presently exposed portions of the Ancient Gneiss Complex. They suggested that the granite were derived from plagioclase-depleted, residual magmas and crystallized at depths of less than seven kilometers, or they resulted from a partial melt of a part of the Ancient Gneiss Complex.

Any model of the tectonic setting of the basin during deposition of the Moodies Group must account for the following observations:

1. The basin deepened and the Moodies generally fines to the north.
2. Within the study area, granitoid rock clasts occur in the Moodies Hills and Saddleback Syncline but not in Moodies outcrops south of the Inyoka Fault.
3. Crystalline material is more abundant and coarser in the Moodies Hills than in the Saddleback Syncline.

Three models are proposed that meet these limitations. The first model places the crystalline terrane to the southwest of the present study area and
rely on large-scale, post-depositional, dextral shearing to juxtapose the rocks north and south of the Inyoka Fault. The second model places the crystalline terrane to the north of most of the study area. The third model positions the crystalline rocks to the south of the study area but requires that most of the Moodies rocks within the study area and south of the Inyoka Fault are younger than the base of the Moodies Group north of the fault.

Model 1

The transition from the Shoongezicht Formation to the Clutha Formation marked a change from island arc volcanism to a fold and thrust belt in the southern part of the greenstone belt. The underlying Fig Tree and Onverwacht Groups were uplifted, eroded, and their detritus were carried in the foreland basin to the north (Fig. 2a). A granitic pluton and associated rocks were lifted up and exposed to the southeast of the basin. The northern facies of the Moodies Group was deposited to the north of the crystalline terrane, in the northwest part of the basin. The southern facies was deposited in the southeastern part of the basin and did not receive crystalline detritus.

The sediments were deposited in braided fluvial environments (Erikkson, 1979). The larger size and somewhat greater abundance of the crystalline clasts in Moodies Hills compared to the Saddleback Syncline was probably the result of lateral facies changes. Although the entire Moodies
Figure 2. Schematic diagram showing the study area during the deposition of the Moodies Group as described in Model 1. a.) Clutha Formation; b.) Joe's Luck Formation; c.) Bavianskop Formation. See figure 1 for explanation of symbols.
Group generally fines to the north, the Clutha Formation in the Saddleback Syncline within the study area lacks the massive, pebble and cobble conglomerates found in the Moodies Hills. Crystalline clasts are the richest in these deposits.

Continued north-verging thrust faulting deepened the basin and further exposed the plutonic body. These changes resulted in the finer grained, arkosic B division of the Moodies Group in the northern facies. The southern facies, deposited along the edge of the orogen, continued to receive coarse, lithic-rich material during later Clutha time.

Consistent with the nature of most Phanerozoic thrust belts, the front edge of this thrust belt migrated northward causing the uplift and cannibalism of earlier Moodies strata along the southern edge of the basin (Fig. 2b). Second- and third-generation sediments formed the quartz-enriched Joe's Luck Formation. The migration and uplift of the region north of the crystalline terrane probably separated the basin from the pluton. Although feldspar and crystalline clasts occur throughout the entire northern facies Moodies Group, granitic detritus in the Joe's Luck and younger strata are less abundant and probably recycled from older Moodies rocks.

Uplift would have stopped deposition along the southern edge of the basin. However, the amygdaloidal basalt within Moodies Group-equivalents in
Swaziland suggest that this area was south of the present boundaries of the greenstone belt.

Thrusting temporarily stopped approximately at the beginning of deposition of the Joe's Luck Formation, although plate convergence and subduction probably continued south of the region. The coarsening upward, prograding Joe's Luck sandstones and ultimately conglomerates filled the depressed foreland basin. The amygdaoidal basalt with tholeiitic affinities within the lower part of the Joe's Luck resembles eruptive material in Phanerozoic backarcs and suggest that the basin was temporarily an extensional environment.

Reinstatement of north-verging thrust faulting south of the basin caused the study area to rapidly deepen. The much finer grained Baviaanskop Formation was deposited at that time (Fig. 2c). Northward migration of the thrust belt continued, progressively lifting up the basin from south to north and ultimately stopping deposition. These north-verging thrust faults and associated back thrust and folds comprise the prominent D₃ structures.

**Model 2**

Tectonic evolution of the basin in Model 2 is the same as in Model 1 (Fig. 3). The only difference is the placement of the crystalline terrane adjacent to the northern part of the basin. Its exact location is unclear. The presence of
Figure 3. Schematic diagram showing the study area during the deposition of
the Moodies Group as described in Model 2. a.) Clutha Formation; b.) Joe's Luck
Formation. See figure 1 for explanation of symbols.

crystalline material, including some coarse grains, in the sub-aerial deposits
of the Saddleback Syncline requires that the granitic source was along the
northwest or northeast edge of the basin since material this size would not
move upslope under these conditions. As in Model 1, the larger size and
greater abundance of granitic material in the Moodies Hills are the result of
lateral facies changes.
The origin and method of emplacement of the crystalline terrane adjacent to the northern part of the basin is problematic. The lack of earlier evidence of an evolving, unroofing crystalline terrane to the north suggests that a previously uplifted and exposed pluton was emplaced against the greenstone belt basin by shearing that was more or less concurrent with the uplift of the greenstone belt to the south. Although the details of this model are unclear, it is an attractive explanation for the distribution of the crystalline material.

Model 3

The third model proposes that deposition of the Moodies Group started earlier in the southern part of the basin than in the northern part of the basin. The sediments represented in the Powerline Road and Maid of the Mist Mountain Synclines were laid down prior to uplift and exposure of the crystalline terrane to the south (Fig. 4). Northward migration of the thrust belt depressed the basin further to the north, resulting in the initiation of deposition of the northern basin after the pluton was exposed. Crystalline material may have accumulated in the southern part of the basin during the latter phases of deposition but those strata are not preserved in the Powerline Road and Maid of the Mist Mountain Synclines.
Figure 4. Schematic diagram showing the study area during the deposition of the Moodies Group as described in Model 3. a.) Early Clutha Formation (southern facies only); b.) Later Clutha Formation (southern and northern facies). See figure 1 for explanation of symbols.

Although not as appealing as Models 1 and 2, Model 3 can not be eliminated without further detailed petrographic study of the southern facies of the Moodies Group, particularly the strata adjacent to the amygdaloidal basalt. The transitional contact between the Schoongezicht and Clutha Formations both north and south of the Inyoka Fault seems to argue against
this model, however. Modifications or rejection of Model 3 should be possibly with further study of the southern facies of the Moodies Group.

**D₄-D₆**

The emplacement of the Kaap Valley Pluton has been generally regarded as the result of diapiric instability and uplift (Anhaeusser, 1964; 1973; Viljoen, 1964; Roering, 1967; Robb and Anhaeusser, 1983; Robb et al., 1986; Tegtmeyer and Kroner, 1986). Jackson et al. (1987) suggested that the thrust sheets acted as a thermal blanket, trapping heat in the buried tonalitic pluton. Unable to release its heat, the pluton remobilized as a hot but solid mass, piercing the overlying layers. The rising pluton dragged up lower strata (Oorschot-Weltevreden Belt) along the north side of the greenstone belt (Fig. 5a and b). However the Kaap Valley Pluton was emplaced, northward-directed, approximately horizontal compression of the greenstone belt continued during, or at least soon after, the pluton rose leading to tightened folds, sub-vertical strata, vertical faults, and pebble flattening.

During D₅, lateral tectonics continued in the study area but changed in style. Dextral shearing replaced north-directed, thrust faulting (Fig. 5c). The Inyoka Fault and probably other D₃ thrust faults were reactivated as D₅ wrench faults. Associated z-folds formed in the Moodies Hills and Inyoka Block. The synclinal axial planes of the Powerline Road and Maid of the Mist
Figure 5. Schematic diagram showing the study area following the deposition of the Moodies Group. a.) End of D₃; b.) End of D₄; c.) End of D₅.
Mountain Synclines were folded. This event, along with D3, undoubtedly contributed to the melange character of the Inyoka Block and other predominantly Onverwacht and Fig Tree terranes adjacent to the major faults.

Many questions remain unanswered about the origin and importance of the D5 events. The strike-slip faults and transpressive folds may be products of escape tectonics that resulted from continued north-south compression due to convergence south of the study area. Alternatively, the convergent boundary to the south may have evolved into a transform boundary between D4 and D5, analogous to the west coast of North America during the early Tertiary (Atwater, 1970).

Shearing along these faults was sub-parallel to the regional strike of bedding and the scale of displacement is presently uncertain. Model 1 requires at least 30 kilometers of relative right-lateral offset along the Inyoka Fault to explain the crystalline clasts in the Moodies Group within the Eureka and Saddleback Synclines and the Moodies Hills and the absence of any granitic material in the Powerline Road and Maid of the Mist Synclines. Models 2 and 3 are consistent with our present understanding of D5 but the magnitude of this event is irrelevant to these scenarios.

The final tectonic event, D6, included the formation of steeply dipping, typically north-northwest-striking, dip-slip faults commonly intruded by diabase dikes. They probably represent the roots to continental flood basalts.
that have been stripped away from the region by erosion. Continental basalts
and their feeder dikes are typically associated with back-arc settings and
suggest that the area was on an upper plate adjacent to a subduction zone.
Whether the $D_6$ tectonism and magma generation was a continuation of the
convergent-style tectonism of earlier $D_3$ or not is unclear. Alternatively, $D_6$
faulting and dike emplacement may have been in a tear-apart basin adjacent
to a transform boundary. Some workers have suggested that continental
basalts in the Basin and Range of the western United States are associated with
the transform boundary along the west coast of North America. The absolute
timing of this last tectonic event is poorly constrained and may also represent
an entirely separate tectonic setting than the previous stages.
CONCLUSIONS

The Barberton greenstone belt was adjacent to an evolving convergent boundary during most of its post-Onverwacht history until cratonization. The study area was on the northeastern, and possibly northern, flanks of an island arc during deposition of the upper Fig Tree Group's Schoongezicht Formation. The transition from Schoongezicht strata to the Moodies Group marks the discontinuation of volcanism and the initiation of north-verging fold and thrust orogenesis to the south or southeast of the study area. Older greenstone material was lifted up and eroded. The reworked sediments compose the quartz-enriched Clutha Formation.

In the part of the basin that is now north of the Inyoka Fault, the base of the Clutha Formation also marks the exposure of a felsic terrane that provided granitic and other coarsely crystalline detritus to the Moodies Hills and Saddleback Syncline. Three models were proposed to explain the lack of crystalline clasts south of the Inyoka Fault. The first model placed the crystalline terrane to the southwest of the study area. Northward transport deposited granitic sediments in the basin but the sediments did not reach the southeastern part of the basin. Later dextral shearing sub-parallel to the former orogenic belt juxtaposed the northern facies of the Moodies Group, which was deposited in the northwestern part of the basin, and the southern facies, which was deposited in the southeastern part of the basin. The second
scenario shows the granitic terrane along the northwestern or northeastern border of the basin, separated from the fold and thrust belt. The third model places the crystalline source area within the southern orogenic belt but requires that deposition of most of the southern facies took place prior to uplift and exposure of the granitic body.

Except for a brief hiatus during Joe's Luck time, north-verging thrust faulting continued throughout deposition of the Moodies Group, eventually lifting up the basin and stopping deposition in the study area. Following thrust faulting in the study area, the Kaap Valley Pluton rose, piercing the overlying greenstone belt. Northward-directed compression following this event.

The tectonic style of the study area changed to strike-slip faulting possibly representing escape tectonics caused by prolonged north-south compression or reflecting a change in the adjacent plate boundary from convergent to transform. The magnitude of displacement associated with this event is presently undetermined.

North-south-striking, steeply dipping, dip-slip faults and dike emplacement represented the final stage of tectonism in the study area. An extensional environment may have resulted in the upper plate of an evolving convergent boundary or the region may have been torn apart by an adjacent transform boundary. The absolute timing of this last tectonic event is poorly
constrained and may represent an entirely separate tectonic setting than the previous stage.
REFERENCES


Byerly, G. R., in review, Petrology and geochemistry of dacites in the Schoongezicht Formation, Fig Tree Group, in Lowe, D. R., and Byerly, G. R., eds., Geologic evolution of the Barberton greenstone belt, South Africa: Geological Society of America Memoir.


APPENDIX 1

STRATIGRAPHIC SECTIONS
EXPLANATION

- CONGLOMERATE
- SANDSTONE
- SILTSTONE
- SHALE
- Amygdaloidal Lava
- Banded Iron Formation
- Diabase
- Covered
- Chert; Jasper
APPENDIX 1a
SECTION LH XV - POWERLINE ROAD SYNCLINE

TOP LOCATION: LAT. 25°53'00"  LONG. 31°00'55"

BOTTOM LOCATION: LAT. 25°53'21"  LONG. 31°00'09"

Stratigraphic Thickness: 810 m

Scale: 1 cm = 5 m

This section was measured through the upper part of the south side of the Powerline Road Syncline on the Schultzenhorst Farm. It includes 155 m of Schoongezicht Formation and 655 m of the lower Clutha A Formation.
Coarse to very coarse grained ss. Lissgang rings wrap around a 70° corner near top - obviously not a mud pool.

LH 547 - Very coarse grained ss.; 10% 5-10 mm clasts; max. clasts size - 1 cm; ~30% quartz
Bs. with ~15% pebbles of plag. porphyry ss., fuchsitic chert & black chert.

Very coarse grained ss.; ~25% 5-10mm clasts of predominantly plag. porphyry.

LH 546 - Medium grained ss.; ~40% quartz; beta-quartz; possible tuff.

LH 545 - Pebble eg.; max. clasts size - 8 cm; ~60% quartz in matrix. Some fuchsitic chert clasts.

Medium grained ss. with ~20% pebbles
Medium grained ss. with ~15% quartz in matrix

LH 544 - Medium grained ss.; ~15% quartz in matrix

Very coarse grained ss.; ~15% quartz in matrix

Bs. with minor amt. of chart clasts; very sheared and foliated

LH 543 - Bs. within a eg.; quartz in the matrix

Cobble and pebble eg.; clasts are predominantly plag. porphyry; quartz in matrix; no fuchsitic chert clasts noted.

LH 542 - Cobble eg.; max. clasts size - 12 cm; ~20% quartz in matrix

Very coarse grained ss.; ~15% quartz in matrix

Cobble & pebble eg.; max. clasts size - 9 cm; clasts are ~50% plag. porphyry, 30% black chert, 10% bedded chert, 5% jasper, 2% bedded Fe formation; probably close matrix; foliation N83E 90.

MOODIES GROUP

SCHOONGEZICHT FORMATION

LH 541 - Bs.; ~15% quartz

Section: Powerline Road Suncline
Interval: 0 m to 95 m
Page number 1 of 9 pages.
Sandstone; plagioclase-rich with 40% quartz

Coarse to very coarse sandstone; plagioclase-rich and ~5% quartz; massive.

LH316 - Medium grained sandstone; ~30% quartz
LH549 - Sandstone

LH720 - Medium grained sandstone; ~80% quartz; well-sorted and well-rounded.

Sandstone; limonite-rich; crudey

Medium to coarse grained sandstone; very heterogeneous and includes 10% clasts; max. clasts size 8 cm; ~5% quartz and also includes chert, jasper, plagioclase-rich sandstone.

Medium to very coarse grained sandstone; some pebbles; plagioclase-rich, 30% quartz.

LH548 - Siltstone; 5% quartz (luffaceous?)
Medium grained sandstone; 10% quartz

Conglomerate; max. clasts size ~10 cm; clasts of banded chert, black chert, and plagioclase-rich sandstone; matrix ~5% quartz.

Section: XV - Powerline Road Syncline
Interval: 95 m to 195 m

Page number 2 of 9 pages.
Section: XV  - Powerline Road Syncline  
Interval: 195 m to 295 m  
Page number 3 of 9 pages.

LH 722 (nearby) - Medium to fine grained sandstone; 20% quartz.

Very coarse grained sandstone

Fine to coarse grained sandstone; ~50% quartz; sheared

LH 552 - Pebble and cobble conglomerate; max. clasts 14 cm and average clasts size 1 cm; 70% black chert, 20% banded chert, 3% plagioclase-rich clasts, 1% vein quartz, <1% fuchsitic chert.

LH 721 - Coarse sandstone; 60% quartz; "mud" cracks - infilling of coarser sand in medium to fine grained sandstone

Fine grained sandstone; 30% quartz

Medium to fine grained sandstone; 40% quartz

Very sheared, cleaved, appears like mylonite.

LH 551 - Sandstone with 60% quartz; in a sheared zone

Very coarse grained sandstone with quartz and plagioclase

LH 550 - Medium to very coarse sandstone with >50% quartz.

Sandstone; plagioclase-rich with 5-10% quartz
Conglomerate; average clasts ~4 cm; predominantly black chert with some fuchsite; clast-supported.
Fine grained sandstone; crudey

LH 723 - Sandstone; 80% quartz

Section: XV - Powerline Road Syncline  Interval: 295 m to 395 m
Page number 4 of 9 pages.
LH 726 - Medium grained sandstone

Massive

Fine to medium grained sandstone; ~20% quartz.

LH 725 - Massive sandstone with 5% clasts; matrix has ~20 quartz; clasts are 80% black chert, 2% fuchsitic chert, 2% plagioclase-rich clasts, 5% Fe pod clasts, 5% banded chert.

LH 724 - Conglomerate with coarse to very coarse grained sandstone lenses; matrix is 80% quartz; massive.

Sandstone; 70% quartz, ~20% limonitic clasts (1-3 mm).

Section: XV - Powerline Road Syncline  
Interval: 395 m to 495 m  
Page number 5 of 9 pages.
- 20% jasper in a 70 cm area; max. clast ~13 cm
- Some clast-supported; some matrix-supported.

- 20% clasts

- Very coarse grained sandstone
  - Conglomerate; ~45% banded chert, 35% black chert, 10% limonite, 3% fuchsitic chert, and 5% plagioclase-rich clasts.

- Massive
- 3-6 cm beds; ~40% quartz

- Massive
  - LH 727 - Conglomerate; max. clast ~5 cm; bottom scoured
  - Massive
  - 10 cm beds

- Fine to medium grained sandstone; ~70% quartz, 20% black chert, 5% limonite; massive.

- Fine to very coarse grained sandstone

- Faint, thin bedding
Giant cross-beds!
Beds 4-80 cm.
Some giant cross-beds.

75% fine grained quartz but not well-cemented; a covered area.
Generally massive to medium beds.

Very crudey and only found in the road. Otherwise it is covered.

Massive

Very coarse grained sandstone; ~30% quartz, 15% limonite clasts (~1 cm).

LH 728 - Conglomerate; max. clast ~15 cm.

Section: XV - Powerline Road Syncline
Interval: 595m to 695m
Page number 7 of 9 pages.
LH 730 - Fine to medium grained sandstone; 80% quartz.

Thicker beds - 4-20 cm.

Fine grained sandstone; 85% quartz, 5% black chert, 2% limonite, <1% plagioclase-rich clasts, 7% unknown.

Planar beds 2-8 cm

LH 729 - Medium-grained sandstone; 90% quartz

Beds 2-10 cm

Beds 2-8 cm.
LH 731 - Conglomerate; fine to medium grained matrix; 70% quartz

Section: XV - Powerline Road Syncline  Interval: 795m to 810m
Page number 9 of 9 pages.
APPENDIX 1b
SADDLEBACK SYNCLINE COMPOSITE
(SVENGALI SECTION)

Stratigraphic Thickness: 2811 m
Scale: 1 cm = 5 m

This section is a composite base on the Saddleback Syncline West and Saddleback Syncline East measured sections. The portion including the Clutha and Joe's Luck Formations is proposed as a supplemental type section for these units which have previously been described only by type areas.
Siltstone; 15% limonite, 5% quartz; crudey.
Large hematite cubes in an isolated spot - ≤7 m
Beds 3-50 cm.

Fine to coarse grained sandstone; 30% quartz.

Fine to coarse grained sandstone; 30% quartz, 5% Fe pod;
beds 3-10 cm.

Sandstone; ~25% quartz, an arkose; planar beds ~1 cm.

LH 734a - Conglomerate; aver. elasts size ~2 cm, max.
~10 cm; 70% black chert, 5% banded chert, 20% plag.
porphyry, 1% fuchsitic chert, some pyrite; massive.

CLUTHA FORMATION A

SCHOONGEZICHT FORMATION

LH 734b - Sandstone; 20% plagioclase, 5% quartz;
~1 cm beds

LH 734a - Conglomerate; plagioclase porphyry-rich.

INYOKA FAULT

Section: SADDLEBACK COMPOSITE
Interval: -15 m to 80 m
Page number 1 of 29 pages.
Laminated; occasional single black or fuchsitic chert pebbles.

**LH 737** - Medium grained sandstone; ~50% quartz.

**LH 736** - Fine to medium grained sandstone; ~30% quartz; beds 2-8 cm.

**LH 735** - Medium to coarse grained sandstone; ~20% quartz; some lensing.
Same; appears to have \( \approx 10\% \) quartz.

Predominantly fine grained sandstone; \( \approx 60\% \) quartz.

Fine grained sandstone with 2 mm thick lenses of coarse grained sandstone.

\textit{LH 738} - Medium grained sandstone; \( \approx 60\% \) quartz; laminated.

Section: SADDLEBACK COMPOSITE  
Interval: 180 m to 280 m  
Page number 3 of 29 pages.
Some laminated.

LH 740 - Predominantly fine grained sandstone; 60% quartz; beds 3-10 cm; no more Svengali-like partings.

Same

LH 739 - Fine to coarse grained sandstone; ~50% quartz, 10% chert; laminated beds as at Svengali.
Predominantly medium to coarse grained sandstone, some very coarse grained sandstone; max. size 17 cm; predominantly black chert with some fuchsitic chert floating in matrix; laminations. Beds 5-20 cm thick.

LH 741 - Fine grained sandstone; laminated. Very coarse grained sandstone layers. Minor planar cross-bedding; definitely up to north. Isolated chert pebble. Grit and predominantly coarse grained sandstone; some laminations (Svengali) and fine sandstone.

DOG LEG IN THE MEASURED SECTION

Svengali-like laminations

Fine to coarse grained sandstone; 60% quartz, 10% black chert, 30% unidentified; predominantly laminated to 10 cm. Some laminated.
Section: SADDLEBACK COMPOSITE  
Interval: 480 m to 580 m

Page number 6 of 29 pages.
Up to north.

Generally thin or cross-bedded.

Same

Beds are laminated to 30 cm.

LH 744 - Fine to medium grained sandstone; 80% quartz.

Bedding is 2-10 cm.

Massive; only ~2% black chert but the largest is 20 cm.

Massive here.

Section: SADDLEBACK COMPOSITE

Interval: 580m to 680m

Page number 7 of 29 pages.
Section: SADDLEBACK COMPOSITE
Interval: 680m to 780m
Page number 8 of 29 pages.
Section: SADDLEBACK COMPOSITE  
Interval: 780m to 880m  
Page number 9 of 29 pages.
Medium grained sandstone; laminated.

Medium grained sandstone; possibly laminated.

Medium to coarse grained sandstone; beds ~1-10 cm thick, some possibly laminated.

Medium to coarse grained sandstone; massive.

Beds ~10-100 cm.
This area has honeycomb weathering.

Predominantly medium grained sandstone; laminated.

Predominantly medium grained sandstone; laminated.

Start of 1st Svengali drillhole; drilled north (LH 611)

Dog leg in measured section

Section: SADDLEBACK COMPOSITE  
Interval: 980 m to 1080 m
Page number 11 of 29 pages.
LH.617 - Medium to coarse sandstone; no pebbles or very coarse sand; 90% quartz; beds 10-80 cm; some cross-beds.

Laminated section; no cross-beds; probably like LH.611.
Section: SADDLEBACK COMPOSITE
Interval: 1280 m to 1380 m
Page number 14 of 29 pages.
Medium to very coarse grained sandstone with layers of very coarse grains and dispersed chert pebbles; a few thin (<3 cm) layers of chert pebble conglomerate; heavily cross-bedded - all nw-se except 2 thin lenses.

Abundant evidence of up to north.
Section: SADDLEBACK COMPOSITE  
Interval: 1480 m to 1580 m

Page number 16 of 29 pages.

Predominantly coarse grained sandstone.  
Very weathered (all that remains is quartz).

Very weathered
LH 614 - Predominantly medium to coarse grained sandstone  
with some layers of very coarse sandstone; ~80% quartz;  
~2% chert pebbles clasts.

LH 615 - Medium to coarse sandstone; 90% quartz;  
herringbone cross-beds.

Mud cracks
Beds ~2-10 cm.  
No pebbles present.

Medium to very coarse sandstone.  
Massive beds ~80 cm to 1.4 m.  
Beds 2-10 cm.

LH 616 - Medium to very coarse grained sandstone with  
some very coarse grained layers; very coarse grained  
black chert layers; cross-bedded.
Medium and coarse grained sandstone; beds ~10-25 cm and cross-bedded; highly weathered.
Medium to very coarse grained sandstone; ~80% quartz; heavily cross-bedded; up to north.

All cross-sets trend ne-sw.

Sandstone; massive.

Section: SADDLEBACK COMPOSITE Interval: 1680 m to 1780 m

Page number 18 of 29 pages.
Coarse sandstone; beds ~1-7 cm; maybe in a shear zone.

Top to north.

LH 369 - Sandstone with some matrix-supported chert pebbles; cross-bedded.

Channel with trough cross-bedding.
1980

LH 367 - Medium to coarse grained sandstone; bedded 1-10 cm.
No cross-bedding in this section.

1975

1970

1965

Predominantly coarse grained sandstone.

1960

1955

JOE'S LUCK FORMATION

CLUTHA FORMATION B

1950

1945

1940

1935

1930

1925

LH 368 - Medium grained sandstone; dirty with abundant quartz.

1920

1915

1910

1905

1900

1895

1890

1885

1880

Section: SADDLEBACK COMPOSITE
Interval: 1880 m to 1980 m
Page number 20 of 29 pages.
Conglomerate with clasts ≤ 11 cm.

Coarse sandstone with 0.5 mm to 1 mm black chert clasts; beds ~1-10 cm, major partings 5-30 cm; rounded to sub-rounded clasts.

Very coarse sand.

LH 366 — Medium to coarse grained sandstone; quartz-rich, no fuchsitic chert clasts.

Monotonous section

Section: SADDLEBACK COMPOSITE  Interval: 1980 m to 2080 m
Page number 21 of 29 pages.
Coarse to very coarse grained sandstone with some 1-2 cm pebbles.

Less clast abundance; definitely matrix-supported.

Very coarse grained sand matrix.

Probably matrix-supported. Pebble conglomerate; 1-2 cm clasts; predominantly black and white chert with some fuchsitic chert; matrix-supported.

Cherty layer - looks like replacement of sediments.

Matrix is coarse to very coarse sand; matrix-supported; clasts are ≤ 2 cm.

Surface appearance like LH 354. Fresh pieces different.

More limonitic and more vuggy.

LH 199 - Amygdaloidal flow rock.

Same as LH 199.
Section: SADDLEBACK COMPOSITE   Interval: 2180 m to 2280 m
Page number 23 of 29 pages.

Conglomerate; clast-supported.

LH 354 - Siltstone; tuffaceous (?); red and green - similar to Fig Tree Fe-rich sedimentary rocks; conchoidal fracture. Bed thickness averages ~3-7 mm.

Coarse to very coarse sandstone. Massive beds.
No clasts are seen.
Coarse to very coarse grained sandstone; poorly sorted.
1 cm in diameter chert clast.
Coarse to very coarse grained sandstone.

LH 355 - Siltstone (tuffaceous?); similar to LH 354; buff color with tints of red and green.
Coarse to very coarse grained sandstone.
Massive beds.
Coarse to very coarse grained sandstone; 1-2 cm clasts; probably matrix-supported.

Very coarse grained sandstone

Coarse to very coarse grained sandstone; 1 clasts (~5 cm) of black chert seen in outcrop.

Sandstone; quartz-rich; massive; weathered surface has honeycombed texture.

Fuchsitic chert clast
6 cm x 3 cm x 1 cm piece of bedded chert. Otherwise, few clasts and clasts are smaller.

Coarse to very coarse grained sandstone; aver. clast size ~1 cm, max. ~3 cm; clasts are well-rounded; more clasts than higher in section but matrix-supported. Bedded.
Coarse grained sandstone; max. clasts size ~ 5 cm; bedded.

1H 353 - Sandstone; matrix-supported; massive.

Very coarse grained sandstone matrix.

Very coarse grained sandstone with some pebble clasts.

Sandstone with a few 1–2 cm pebbles; cross-bedded.

All debris is matrix-supported conglomerate with coarse to very coarse sand matrix.

Planar cross-beds always dip se-nw.

Very coarse grained sandstone.

No clasts seen in this part of the section.

Clasts are rare.

Coarse to very coarse grained sandstone; medium beds to massive.
Sandstone; quartz-rich.

Very coarse grained sandstone; quartz-rich. Average >1 cm. Predominantly small clasts with occasional 1-1.5 cm clasts; aver. ~5 mm.

Medium to coarse grained sandstone; quartz-rich.

Very coarse grained sandstone with 1 cm clasts.

Very coarse grained sandstone; massive.

Very coarse grained sandstone with small (2 mm) granules. A planar contact

Conglomerate with large clasts (max. 15 cm); massive.

Conglomerate with small pebbles; similar to LH 352.

Conglomerate similar to LH 350.

Coarse sandstone with some small (<2 cm) pebbles.

Coarse sandstone; bedded (1-7 cm thick). Some small clasts (<1 cm) pebbles.

Very coarse sandstone.

Coarse sandstone with <1 cm pebble clasts.

Coarse sandstone with occasional 2 cm clasts of chert; matrix-supported. A laver ~25 cm thick with mostly pebbles. aver.~1-2 cm. Like LH 351

Conglomerate like LH 351; youngest rock has tiny bits of fuchsite chert in the clasts. Slight deformation of bedded chert clasts

Section: SADDLEBACK COMPOSITE
Interval: 2480 m to 2580 m
Page number 26 of 29 pages.
**Section: SADDLEBACK COMPOSITE**

**Interval:** 2580 m to 2680 m

Page number 27 of 29 pages.
Monotonous!

More massive, 2-10 cm beds; no obvious laminations.

Beds ~1-3 cm with laminations.

1 cm thick quartz vein.

"Location of LH 349. Taken from outcrop just up hill.
Thicker beds aver. ~10 cm but still with laminations.
Siltstone and shale; beds aver. ~1 cm; red.
One bed (~3 mm) of chert.
Monotonous

Siltstone; tuffaceous appearing with quartz; very similar to LH 349 but with visible quartz.

Siltstone; tuffaceous.

Section: SADDLEBACK COMPOSITE        Interval: 2680 m to 2780 m
Page number 28 of 29 pages.
Thin beds ~1 cm and laminated.

Slightly more yellowish for ~70 cm.

Laminated to massive.

Same stuff as below.
APPENDIX 1c
SECTION LH XII - SADDLEBACK SYNCLINE WEST

TOP LOCATION: LAT. 25°51'15" LONG. 31°00'47"

BOTTOM LOCATION: LAT. 25°52'19" LONG. 31°01'56"

Stratigraphic Thickness: 2270 m

Scale: 1 cm = 5 m

This section was measured through the western end of the Saddleback Syncline west of the Skokohla Trigonometric beacon, on the Schultzenhorst and Ameide Farms. The lower 300 m has been affected by faulting.
Predominant coarse with some medium grained sandstone; 90+95 quartz; laminated beds ±1 cm.

Pebble conglomerate; predominantly chert clasts

Abundant chert pebbles (~30%)

LH 620 - Medium to coarse grained sandstone; 90+95 quartz

Very coarse grained sandstone with chert pebbles

~15% fuchsitic chert, ~85% chert.

Pebble conglomerate with some pebbles; predom. chert
Coarse and medium grained sandstone
Cobble and pebble conglomerate

Cobble and pebble conglomerate; predominantly chert; matrix 170+95 quartz.

Medium to coarse grained sandstone; ~90% quartz
Pebble conglomerate; average clasts size ~1 cm, max. clasts size ~3 cm; predominantly chert with ~10% fuchsitic chert.

Pebble conglomerate with <1% cobbles; predominantly chert clasts.
Coarse to very coarse grained sandstone; a few chert pebbles.

LH 619 - Medium to coarse grained sandstone; 40% quartz.

Bed average ~10 cm, may be laminated.

Medium to coarse grained sandstone; 90% quartz; beds average ~10 cm
Laminated
Coarse and very coarse sandstone

*1H.618* - Predominantly coarse sandstone, some pebbles; black, white, and fuchsitic chert sand and pebbles; large fuchsitic chert cobbles.

Coarse to very coarse sandstone; some open matrix chert pebble sandstone; massive.
Medium grained sandstone; possibly laminated.

Medium to coarse grained sandstone; beds ~1-10 cm thick, some possibly laminated.

Medium to coarse grained sandstone; massive.
Beds ~10-100 cm.

Highest chert pebble conglomerate; some fuchsitic chert; open matrix; appears to be a very small (~3 m wide) channel.
Predominantly medium grained sandstone; laminated.

Start of 1st Svengali drillhole; drilled north (LH 611)

Dog leg in measured section

Medium grained sandstone; laminated.

Section: SADDLEBACK SYNCLINE I
Interval: 395m to 495m
Page number 5 of 23 pages.
Laminated section; no cross-beds; probably like LH 611.

This area has honeycomb weathering.

Predominantly medium grained sandstone; laminated.
CLUTHA FORMATION-DIVISION B

CLUTHA FORMATION-DIVISION A

LH 617 - Medium to coarse sandstone; no pebbles or very coarse sand; 90% quartz; beds 10-80 cm; some cross-beds.

Section: SADDLEBACK SYNCLINE

Interval: 595 m to 695 m

Page number 7 of 23 pages.
Medium to very coarse grained sandstone with layers of very coarse grains and dispersed chert pebbles; a few thin (<3 cm) layers of chert pebble conglomerate; heavily cross-bedded - all nw-se except 2 thin lenses.

Abundant evidence of up to north.
**Section: SADDLEBACK SYNCLINE I**

**Interval: 895 m to 995 m**

Page number 10 of 23 pages.
Medium and coarse grained sandstone; beds ~10-25 cm and cross-bedded; highly weathered.

Predominantly coarse grained sandstone.
Very weathered (all that remains is quartz).

Very weathered

LH 614 - Predominantly medium to coarse grained sandstone with some layers of very coarse sandstone; ~80% quartz; ~2% chert pebbles clasts.
All cross-sets trend ne-sw.

Sandstone; massive.

Section: SADDLEBACK SYNCLINE 1
Interval: 1095 m to 1195 m
Page number 12 of 23 pages.
Top to north.

**LH 369** - Sandstone with some matrix-supported chert pebbles; cross-bedded.

Channel with trough cross-bedding.

Medium to very coarse grained sandstone; ~80% quartz; heavily cross-bedded; up to north.

**Section:** SADDLEBACK SYNCLINE I  
**Interval:** 1195 m to 1295 m  
Page number 13 of 23 pages.
LH 368 - Medium grained sandstone; dirty with abundant quartz.

Coarse sandstone; beds ~1-7 cm; maybe in a shear zone.

Section: SADDLEBACK SYNCLINE I
Interval: 1295 m to 1395 m
Page number 14 of 23 pages.
Monotonous section

1495 - LH 367 - Medium to coarse grained sandstone; bedded 1-10 cm.

No cross-bedding in this section.

Predominantly coarse grained sandstone.

Section: SADDLE BACK SYNCLINE 1  
Interval: 1395 m to 1495 m

Page number 15 of 23 pages.
Cherty layer - looks like replacement of sediments.

Matrix is coarse to very coarse sand; matrix-supported; clasts are ≤ 2 cm.

Surface appearance like LH 354. Fresh pieces different.
More limonitic and more vuggy.

LH 199 - Amygdaloidal flow rock.

Same as LH 199.

Conglomerate with clasts ≤ 1 cm.

Coarse sandstone with .5 mm to 1 mm black chert clasts; beds ~1-10 cm, major partings 5-30 cm; rounded to sub-rounded clasts.
Very coarse sand.

LH 366 - Medium to coarse grained sandstone; quartz-rich, no fuchsitic chert clasts.
Section: SADDLEBACK SYNCLINE I

Interval: 1595 m to 1695 m

Page number 17 of 23 pages.
Coarse to very coarse grained sandstone; aver. clast size ~1 cm, max. ~3 cm; clasts are well-rounded; more clasts than higher in section but matrix-supported. Bedded.

Conglomerate; clast-supported.

LH 354 - Siltstone; tuffaceous (?); red and green - similar to Fig Tree Fe-rich sedimentary rocks; conchoidal fracture. Bed thickness averages ~3–7 mm.
All debris is matrix-supported conglomerate with coarse to very coarse sand matrix.

Planar cross-beds always dip se-nw.
Very coarse grained sandstone.
No clasts seen in this part of the section.

Clasts are rare.

Coarse to very coarse grained sandstone; medium beds to massive.

Coarse to very coarse grained sandstone; 1-2 cm clasts; probably matrix-supported.

Very coarse grained sandstone

Coarse to very coarse grained sandstone; 1 clasts (~5 cm) of black chert seen in outcrop.

Sandstone; quartz-rich; massive; weathered surface has honeycombed texture.

Fuchsitic chert clast
6 cm x 3 cm x 1 cm piece of bedded chert. Otherwise, few clasts and clasts are smaller.

Section: SADDLEBACK SYNCLINE 1
Interval: 1795 m to 1895 m
Page number 19 of 23 pages.
Conglomerate with large clasts (max. 15 cm); massive.

Conglomerate with small pebbles; similar to LH 352.

Conglomerate similar to LH 350.

Coarse sandstone with some small (<2 cm) pebbles.

Coarse sandstone; bedded (1-7 cm thick).
Some small clasts (<1 cm) pebbles.

Very coarse sandstone.

Coarse sandstone with <1 cm pebble clasts.
Coarse sandstone with occasional 2 cm clasts of chert; matrix-supported.
A layer ~25 cm thick with mostly pebbles, aver.~1-2 cm.

Like LH 351
Conglomerate like LH 351; youngest rock has tiny bits of fuchsitic chert in the clasts. Slight deformation of bedded chert clasts
Coarse grained sandstone; max. clasts size ~5 cm; bedded.

LH 353 - Sandstone; matrix-supported; massive.

Very coarse grained sandstone matrix.

Very coarse grained sandstone with some pebble clasts.

Sandstone with a few 1-2 cm pebbles; cross-bedded.
Sandstone; high quartz content; scoured lower surface.

**LH 351** - Sandstone; massive; both surfaces are irregular.

Like LH 350.

Conglomerate; max. clasts size ~1.5 cm, aver. ~5 mm.

Planar contact.

Scoured contact.

**LH 352** - Conglomerate; smaller pebble clasts than above and below; massive.

Sandstone; quartz-rich.

Sandstone; quartz-rich.

Very coarse grained sandstone; quartz-rich.

Average >1 cm.

Predominantly small clasts with occasional 1-1.5 cm clasts; aver. ~5 mm.

Medium to coarse grained sandstone; quartz-rich.

Very coarse grained sandstone.

Very coarse grained sandstone with ~1 cm clasts.

Very coarse grained sandstone; massive.

Very coarse grained sandstone with small (2 mm) granules.

A planar contact

Section: SADDLEBACK SYNCLINE I

Interval: 1995 m to 2095 m

Page number 21 of 23 pages.
Siltstone; tuffaceous appearing with quartz; very similar to LH 349 but with visible quartz.

Siltstone; tuffaceous.

BAVIAANSKOP FORMATION

JOE'S LUCK FORMATION

LH 350 - Conglomerate; aver. diameter of clasts ~1 cm, max. diameter ~18 cm; predominantly black and white chert, some red chert and quartz; well-rounded clasts; planar foliation of clasts - ellipticity aver. 2:1, max. ~5:1; no fuchsitic chert.

Conglomerate; aver. clasts size ~4 mm.

Sandstone; 80% quartz.

Conglomerate like LH 350.
Thin beds ~1 cm and laminated.
Slightly more yellowish for ~70 cm.
Laminated to massive.
Same stuff as below.

Monotonous!

More massive, 2-10 cm beds; no obvious laminations.

Beds ~1-3 cm with laminations.

1 cm thick quartz vein.

"Location of LH 342. Taken from outcrop just up hill. Thicker beds aver. ~10 cm but still with laminations.
Siltstone and shale; beds aver. ~1 cm; red.
One bed (~3 mm) of chert.
Monotonous

Section: SADDLEBACK SYNCLINE 1
Interval: 2195 m to 2270 m
Page number 23 of 23 pages.
APPENDIX 1d
SECTION LH XIV - SADDLEBACK SYNCLINE EAST

TOP LOCATION: LAT. 25°51'48"  LONG. 31°02'03"
BOTTOM LOCATION: LAT. 25°52'15"  LONG. 31°02'34"

Stratigraphic Thickness: 968 m
Scale: 1 cm = 5 m

This section was measured through the western end of the Syncline at the Skokohla Trigonometric beacon, on the Heemstede, Mendon, Schultzenhorst and Ameide Farms. The lower 216 m is through the Schoongezicht Formation. The upper 752 m is in the Clutha A.
Siltstone; 15% limonite, 5% quartz; crudey.

Large hematite cubes in an isolated spot - ≤7 mm.

Beds 3-50 cm.

Fine to coarse grained sandstone; 30% quartz.

Fine to coarse grained sandstone; 30% quartz, 5% Fe pod; beds 3-10 cm.

Sandstone; ~25% quartz, an arkose; planar beds ~1 cm.

LH 734c - Conglomerate; aver. clasts size ~2 cm, max. ~10 cm; 70% black chert, 5% banded chert, 20% plag. porphyry, 1% fuchsitic chert, some pyrite; massive.

Clutha Formation - Division A

Schoongezicht Formation

LH 734b - Sandstone; 20% plagioclase, ~5% quartz; ~1 cm beds
LH 734a - Conglomerate; plagioclase porphyry-rich.
Laminated; occasional single black or fuchsitic chert pebbles.

**LH 737** - Medium grained sandstone; ~50% quartz.

**LH 736** - Fine to medium grained sandstone; 30% quartz; beds 2-8 cm.

**LH 735** - Medium to coarse grained sandstone; 20% quartz; some lensing. Beds are generally massive.

Section: SADDLEBACK SYNCLINE II  
Interval: 95 m to 195 m  
Page number 2 of 10 pages.
Same; appears to have ~10% quartz.

Predominantly fine grained sandstone; ~60% quartz.

Fine grained sandstone with 2 mm thick lenses of coarse grained sandstone.

LH 73B - Medium grained sandstone; ~60% quartz; laminated.
Some laminated.

LH 740 - Predominantly fine grained sandstone; 40% quartz; beds 3-10 cm; no more Svengali-like partings.

LH 739 - Fine to coarse grained sandstone; ~50% quartz, 10% chert; laminated beds as at Svengali.

Section: SADDLEBACK SYNCLINE II  
Interval: 295 m to 395 m
Page number 4 of 10 pages.
Large clasts ~ 3 cm; predominantly chert.

Predominantly medium to coarse grained sandstone, some very coarse grained sandstone; max. size 17 cm; predominantly black chert with some fuchsitic chert floating in matrix; laminations.

Beds ~5-20 cm thick.

LH 741 - Fine grained sandstone; laminated. Very coarse grained sandstone layers

Minor planar cross-bedding; definitely up to north. Isolated chert pebble. Grit and predominantly coarse grained sandstone; some laminations (Svengali) and fine sandstone.

DOG LEG IN THE MEASURED SECTION

Svengali-like laminations

Fine to coarse grained sandstone; 60% quartz, 10% black chert, 30% unidentified; predominantly laminated to 10 cm.

Section: SADDLEBACK SYNCLINE II
Interval: 395m to 495m
Page number 5 of 10 pages.
Massive here.

Fine to medium grained sandstone; 70% quartz.
Rare fuchsitic chert; more black chert.

Generally thin; some cross-bedded.

Beds are laminated to 15 cm; rare black chert ~2 cm pebbles.

LH 743 - Fine to medium grained sandstone; 60% quartz; laminated but not Svengali-type.

Fine to medium grained sandstone; ~40% quartz.

Beds 2-10 cm.

LH 742 - Conglomerate; includes plagioclase porphyry-rich and minor fuchsitic chert clasts; <70 cm thick beds.

Section: SADDLEBACK SYNCLINE II  
Interval: 495m to 595m 
Page number 6 of 10 pages.
All cross-beds dip to west.

Fine to medium grained sandstone; ~70% quartz; beds ~3-20 cm thick.

Up to north.

Generally thin or cross-bedded.

Beds are laminated to 30 cm.

LH 744 - Fine to medium grained sandstone; 60% quartz.
Bedding is 2-10 cm.
Massive; only ~2% black chert but the largest is 20 cm.

Section: SADDLEBACK SYNCLINE II
Interval: 595 m to 695 m
Page number 7 of 10 pages.
Fine to medium grained sandstone; 90% quartz. Beds are medium thick to massive.

**LH 795** - Medium grained sandstone (arkose); ~50% quartz, 2% chert pebbles and cobbles, lots of Kspar, 2% fuchsite chert. Beds 4-70 cm.

5% jasper and black chert cobbles. Conglomerate; predominantly black chert pebbles with ~5% fuchsite and 1% jasper pebbles.

Conglomerate; black, white, and fuchsite pebbles.

Medium grained sandstone; 60% quartz; beds 5-20 cm. Many thin (~10 cm) layers of cl similar to LH 794; occas. chert cobbles. This area has repeated seq. of ~15 cm sandstone, 4 cm cl.

Medium to coarse grained sandstone; 80% quartz, 1% fuchsite chert.

Medium to very coarse grained sandstone with ~2% chert pebbles and cobbles. Conglomerate like LH 794; 0-2 cm thick. Very coarse grained sandstone.

Medium grained sandstone with rare black chert pebbles and cobbles: max. size 12 cm; 70% quartz; beds ~10 cm to massive. Same type of conglomerate.

**LH 794** - Conglomerate; pebble size clasts of black, white, and fuchsite chert; ~25 cm thick, thinning to 15 cm approx 10 m to the east; difficult to follow laterally; MARKER BED.

**Section:** SADDLEBACK SYNCLINE II  
**Interval:** 695m to 795m  
**Page number:** 8 of 10 pages.
Conglomerate; pebbles of black, white, & fuchsite chert pebbles; clasts 2-12 cm.

LH 795 - Medium to very coarse grained sandstone; 70% quartz; clasts generally sub-angular. Predominantly chert granules. Minor Syengali-like partings.

Conglomerate with chert pebbles. Pebble conglomerate; max. clast size 11 cm, pred. pebble size; 50% black chert, 15% fuchsite chert, 15% sandstone; 2% jasper, 18% unidentifiable; 2-25 cm thick.

Medium grained sandstone; 80% quartz. Includes fuchsite and black chert pebbles.

20 cm black chert cobble.

Conglomerate; pebbles of black, white, & fuchsite chert; bed 0-10 cm thick. Very fine grained sandstone parting.
Massive; weathers to appear laminated.

Cross-beds commonly 1 m high.

Beautiful cross-beds. Up is clearly to the north.

**LH 798** - Fine to medium grained sandstone; 80% quartz; beds ~2-10 cm.

**LH 797** - Medium grained sandstone; ~2-3 m thick beds with giant cross-sets.

Fine grained sandstone; 80% quartz; beds 5-20 cm.
APPENDIX 1e
LOMATI WATER TUNNEL
SADDLEBACK SYNCLINE

TOP LOCATION: LAT. 25°48'01" LONG. 31°04'22"

BOTTOM LOCATION: LAT. 25°48'38" LONG. 31°06'03"

Stratigraphic Thickness: ~2900 m

Scale: 1 cm = 50 m

This column shows the approximately sample locations from the Lomati Water Tunnel being built by the town of Barberton. Samples were taken from cores and from tunnels leading from the East and West Portals on 6 January 1987. Tunnel locations are based on paced distances from surveyed points in the tunnel. Core samples are projected based on a geologic longitudinal section of the tunnel by T. N. Pearton and J. Keenan and provided by the town of Barberton.
Section: BARBERTON WATER TUNNEL
Interval: 2000 m to 2950 m
Page number 2 of 2 pages.
APPENDIX 1f
PRINCETON TUNNEL OF THE AGNES GOLD MINE
MOODIES HILLS

TOP LOCATION: LAT. 25°50'00" LONG. 30°58'57"

BOTTOM LOCATION: LAT. 25°50'48" LONG. 30°58'43"

Tunnel Distance: 2269 m

Scale: 1 cm = 5 m

This section was measured through the Princeton Tunnel of the Agnes Gold Mine within the Oorschot and Ameide Farms. Thicknesses are not corrected to stratigraphic thickness. The base of the section is 2269 m from the Ben Lomond entrance.
LH 814 - Cobble conglomerate; predominantly chert clasts; ~50 cm wide band within sandstone.

LH 815 - Medium grained sandstone; quartz-bearing. Predominantly sandstone; max. clast 10 cm; no jasper.

Some jasper clasts; max clasts ~11 cm.

LH 816 - Cobble conglomerate; chert and granitic cobbles.

LH 827 - Cobble conglomerate; chert and granitic clasts; open matrix.

CLUTHA FORMATION - DIVISION A
Diabase; "Alpine Dike"

LH 913 - Pebble conglomerate; predominantly chert and jasper.

Conglomerate; cobble and pebble clasts.

Sandstone; abundant quartz, rare chert pebbles; minor pyrite.
Sandstone

Shale; ~40 cm thick.

LH 812 - Sandstone with rare pebble clasts.
Some cross-beds with up to the north.
Some laminated beds.

Siltstone

Diabase; "Alpine Dike"
LH 817 - Sandstone; cross-bedded.

Fine grained sandstone; cross-bedded.

Section: PRINCETON TUNNEL
Interval: 300 m to 400 m
Page number 4 of 23 pages.
Fine grained sandstone and siltstone.

LH 818 - Fine grained sandstone

Siltstone to fine grained sandstone

Siltstone to fine grained sandstone

Section: PRINCETON TUNNEL  
Interval: 400 m to 500 m  
Page number 5 of 23 pages.
Interbedded siltstone and sandstone.

Siltstone; rippled.

LH 812 - Fine grained sandstone

Diabase
Interbedded sandstone and siltstone.

LH 820 - Interbedded fine grained sandstone and siltstone.

Alpine Mine connection

Interbedded sandstone and siltstone.

Section: PRINCETON TUNNEL  Interval: 600 m to 700 m
Page number 7 of 23 pages.
Shale to fine grained sandstone; laminated.

**LH 850** - Siltstone and jasper; carbonated and maroon.

**LH 846** - Very fine grained sandstone and siltstone; laminated.

Predominantly very fine grained sandstone; laminated; minor shale partings on top of ripples.
Section: PRINCETON TUNNEL  
Interval: 800m to 900m
Page number 9 of 23 pages.
Siltstone; laminated, undulating; abundant shale partings.

**LH 848** - Fine grained sandstone.

Siltstone; laminated.

Diabase

Fine grained sandstone and siltstone; laminated.

Siltstone with shale partings; thinly bedded to laminated.

Diabase

Siltstone with shale partings; thinly bedded to laminated.

Ripples; undulating bedding; some thin quartz (<5 mm) quartz veins

Section: PRINCETON TUNNEL  
Interval: 900 m to 1000 m

Page number 10 of 23 pages.
Fine grained sandstone and siltstone with no jasper; laminated.

Fine grained sandstone with jasper; laminated.

Siltstone with shale partings; laminated.

LH B49 - Fine grained sandstone and siltstone; laminated.

Siltstone; laminated.

Diabase

Siltstone and very fine grained sandstone with shale partings; laminated.

Very fine grained sandstone and siltstone; laminated.

Siltstone; laminated, undulating.
Very fine grained sandstone and siltstone with jasper; some contortion of the beds.

Predominantly siltstone and very fine grained sandstone; some carbonated beds; no jasper.

LH 835 - Medium grained sandstone, siltstone, and jasper.

Magnetic jasper
Siltstone; lots of quartz veins, pyrites.

Diabase

Siltstone and fine grained sandstone with no jasper.

Fine grained sandstone with jasper; laminated.
Siltstone and fine grained sandstone; laminated; no jasper

Fine grained sandstone and siltstone with jasper; laminated; more contorted than layers below; less jasper.

Equivalent to the AMEIDE JASPER zone.

Very fine to fine grained sandstone; abundant jasper (<.2 cm thick beds); laminated; abundant quartz veins.

Fractured and quartz veins.

LH 834 - Very fine grained sandstone

Very fine grained sandstone and siltstone with jasper bands; laminated; minor contortion; some carbonated zones.

Section: PRINCETON TUNNEL

Interval: 1200 m to 1300 m

Page number 13 of 23 pages.
Siltstone with thin jasper beds (1 mm); carbonated.

Siltstone with minor, thin jasper beds (1 mm); carbonated.

Fine grained sandstone and siltstone.

Some minor contortion of laminations.

**LH 633** - Very fine to fine grained sandstone; laminated.

Very fine grained sandstone and siltstone; laminated; some contortion; abundant pyrite.
Fine grained sandstone and siltstone; laminated; some shale partings.

LH 832 - Very fine to medium grained sandstone

Fine grained sandstone to siltstone; laminated; no jasper.

Fault

Siltstone with thin jasper beds (1 mm); carbonated.

Section: PRINCETON TUNNEL  Interval: 1400 m to 1500 m
Page number 15 of 23 pages.
Fine grained sandstone to siltstone with shale partings; ~60% quartz.

Siltstone and fine grained sandstone with some shale partings (1 mm); laminated to 2 cm.

LH 831 - Fine grained sandstone; laminated to 2 cm beds.

Fine grained sandstone with shale partings; laminated.
JOE'S LUCK FORMATION

CLUTHA FORMATION - DIVISION B

LH 830 - Fine to medium grained sandstone; "gray wacke"; beds 0.5 - 4 cm thick.

Fine to medium grained sandstone; predominantly 60% - 90%.
Siltstone to fine grained sandstone with shale partings.

Fine to medium grained sandstone; predominantly 60% - 90%.

Fine grained sandstone with abundant shale partings; ~60% quartz.
Amygdaloidal lava.
Very fine grained sandstone and siltstone.
Quartz veins.

Medium to coarse grained sandstone; 90+% quartz; some layers have ~2% black chert granules; beds ~3-15 cm.; some silt interbeds.

Medium to coarse grained sandstone; 90+% quartz; beds ~3-15 cm.

LH 829 - Medium grained sandstone; 90+% sandstone; looks baked.

Fine to medium grained sandstone; predominantly 60% - 90%.

Very fine to medium grained sandstone; much quartz veining.
Diabase

Very fine grained sandstone.

Siltstone with some pyrite.

Some jasper beds.

LH 827 - Siltstone.

Very fine to medium grained sandstone

Siltstone; carbonated.

Siltstone to very fine sandstone; laminated.

Jasper beds; non-magnetic.

LH 828 - Amygdaloidal lava

Section: PRINCETON TUNNEL
Interval: 1800 m to 1900 m
Page number 19 of 23 pages.
Section: PRINCETON TUNNEL  Interval: 1900 m to 2000 m
Page number 20 of 23 pages.
Coarse grained sandstone; abundant quartz; abundant quartz veining.

**BAVIAANSKOP FORMATION**

**JOE'S LUCK FORMATION**

Pebble conglomerate; aver. clast ø1 cm; predominantly chert; strongly foliated.

**LH 824** - Coarse to granule sandstone; some pebbles; ~70% quartz, 15% jasper, 10% chert.

Coarse grained sandstone; 70% - 90% quartz, 1% jasper, iron rich.

Conglomerate; predominantly chert pebbles; strongly foliated parallel to bedding.

**LH 823** - Coarse to granule sandstone; abundant quartz, ~2% jasper; minor pebbles (chert).

Conglomerate; abundant chert pebbles, minor fuchsitic chert clasts; ~90% quartz; foliated.

Medium to coarse grained sandstone; 90+% quartz.

Conglomerate; abundant chert pebbles.

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**Section: PRINCETON TUNNEL**

**Interval:** 2000 m to 2100 m

Page number 21 of 23 pages.
Section: PRINCETON TUNNEL
Interval: 2100m to 2200m
Page number 22 of 23 pages.
Predominantly very fine grained sandstone; some siltstone; minor pyrite; laminated.

LH 821 - Medium grained sandstone to siltstone.

Predominantly very fine grained sandstone
APPENDIX 1g
22nd LEVEL ADIT OF THE
AGNES GOLD MINE
MOODIES HILLS

TOP LOCATION: LAT. 25°49'27"  LONG. 31°01'17"

BOTTOM LOCATION: LAT. 25°50'17"  LONG. 31°00'11"

Tunnel Distance: 1717 m

Scale: 1 cm = 50 m

This section shows the location of samples from the 22nd Level Adit of the
Agnes Gold Mine within the Oorschot and Ameide Farms. Thicknesses are not
corrected to stratigraphic thickness. Samples were taken at 100 m intervals.

The base of the section starts at the Woodbine Reef at the Woodbine Shaft.
Section: 22ND LEVEL ADIT Interval: 1000 m to 1800 m
Page number 2 of 2 pages. UNADJUSTED FOR STRIKE AND DIP
APPENDIX 1h
SECTION XIII - DEVIL'S STAIRCASE
MOODIES HILLS

TOP LOCATION: LAT. 25°49'13" LONG. 31°01'09"

BOTTOM LOCATION: LAT. 25°50'48" LONG. 31°00'37"

Stratigraphic Distance: 1926 m

Scale: 1 cm = 5 m

This section was measured along the east side of the Devil's Staircase Road on
the Brommers, Oorschot and Ameide Farms. The base of the section is at the
Ameide Fault and the top is at the Moodies Fault.
Beds ~2-10 cm thick.

Some shale partings ~2 cm thick; brownish.

Medium grained sandstone; poorly cemented.

Bedding ~2-10 cm.

Average bed thickness ~1 mm to 4 cm.

Interbedded sandstone and gray shale (possibly tuff); like LH 480; shale partings usually 1-4 mm thick; thickest sandstone lenses 4 cm; no scouring noted but some pinch and swell of beds; still looks smeared.

Fine to medium grained sandstone.

Fine to medium grained sandstone; ~60% quartz; still looks smeared.

LH 480 - Medium grained sandstone interbedded with shale; ~60% quartz; some Fe-rich beds.

Shale-size, smeared grains; looks similar to LH 461.

Clutha Formation - Division A

Onverwacht Formation

LH 257

Section: XIII - Devil's Staircase

Interval: 0 m to 95 m

Page number 1 of 20 pages.
Ripples; some beds look like oscillation ripples.
Wavy laminations

Ripples - Up to north.
Large cross-sets (~60 cm amplitude).
Medium grained sandstone; laminated.

2-10 cm thick beds.

LH 492 - Medium to coarse grained sandstone; ~50% quartz;
prominent outcrops.
~4-10 cm thick beds of sandstone.

Medium grained sandstone; laminated; very grungy with
quartz vein riddling.

~2-10 cm thick beds; very grungy sand beds.

Beds ~1-3 cm.

CLUTHA FORMATION - DIVISION B
CLUTHA FORMATION - DIVISION A

Beds are 2-15 cm.

LH 491 - Medium grained sandstone with pebbles and cobbles;
largest clast ~5 cm (jasper); clasts are jasper and black
and fuchsitic chert; up is to north both by cross-beds and
impression on lower beds by clasts at base of bed. No scour.

Conglomerate; max. clast size ~9 cm; matrix - medium to
course grained; clasts are predominantly black and white
chert with minor fuchsitic chert, clasts are elongated;
bed is ~15 cm wide; rocks look very leached.
Predominantly medium grained sandstone; poorly cemented.
70% quartz content.

Low quartz content.

~70% quartz.

Light colored but only ~5% visible quartz.

Laminated sand.

LH 495 - Medium grained sandstone; ~30% quartz.

LH 494 - Medium grained sandstone; <10% quartz; quite weathered.

Beds ~1-3 cm.

Fine grained sandstone; 10% quartz, smeared-looking.

Medium grained sandstone; ~5% visible quartz.

Medium beds.

1-2 cm thick beds.

Very grungy.

LH 493 - Medium grained sandstone; ~40% quartz.

Quartz vein.

Medium grained sandstone; beds ~4-8 cm thick; red.

Fine and very fine grained sandstone.
Siltstone and fine grained sandstone; beds 1-25 cm thick.

Fine grained sandstone; ~30% quartz.

Medium grained sandstone; 60% quartz.

Fine to medium grained sandstone; ~50% visible quartz.

Low quartz.

Fine to medium grained sandstone; ~80% quartz.

Fine grained sandstone; low quartz.

70% quartz

~60% quartz

Quartz veins

Grungy, low quartz.

LH 496 - Medium grained sandstone; ~70% quartz.

Medium grained sandstone; 70% quartz; 1-5 cm beds.

Medium grained sandstone; ~40% quartz; weathered.

Fine to medium grained sandstone; low quartz; beds 1-4 cm.

Siltstone; beds 1-5 cm.

Siltstone and shale; rare quartz (~2%); one grain looked like beta-quartz.

Low quartz.

Very coarse grained sandstone; ~5% visible quartz, ~7% specks of green - chlorite or fuchsitic chert; ~20 cm wide.

Medium grained sandstone; low quartz content.

70% quartz content
Section: XIII - DEVIL'S STAIRCASE

Interval: 395 m to 495 m

Page number 5 of 20 pages.
Fine grained sandstone; ~50% quartz.

Fine grained sandstone; ~40% quartz; 1-4 cm thick beds.

Diabase

Fine grained sandstone; beds ~2-3 cm.

Laminated to 2 cm.

Same as LH 501.

Fine to medium grained sandstone; 60% quartz.
Medium grained sandstone; <10% quartz, Fe-rich; grungy.
Cross-beds are again up to the north; quartz veins are subhorizontal.
Quartz veins

LH 501 - Fine to medium grained sandstone; ~30% quartz;
Cross-beds seem to indicate up to south (only place seen).
Shale; laminated.

Siltstone; laminated.

Very fine grained sandstone; Fe-rich but not jasper; thin 1-2 cm wide beds of chert. Jasper layers.

Siltstone and sandstone, interbedded; laminated.

Very fine to fine grained sandstone.

Section: XIII - DEVIL'S STAIRCASE  Interval: 595m to 695m
Page number 7 of 20 pages.
Predominantly fine grained sandstone with some very fine grained sandstone.

Silt size grains may be result of weathering; fine grain & low quartz.

Siltstone and medium grained sandstone.

Siltstone; laminated.

Quartz veins

Fine grained sandstone.
Up to the north. Most foresets are northeast-southwest. A few are reverse.

**LH 604** — Medium to coarse grained sandstone.

- Fine grained sandstone; laminated.
- Very fine to fine grained sandstone; ≤1% black chert pebbles; laminated.
- Predominantly fine grained sandstone; 90+% quartz.

**JOE’S LUCK FORMATION**

- Medium grained sandstone; beds 1-15 cm.

**CLUTHA B FORMATION**

- Siltstone and fine grained sandstone.
- Medium grained sandstone; ~80% quartz; aver. bed thickness ~1 cm.
- Siltstone and fine grained sandstone; laminations (?); weathered.
- Fine grained sandstone.
- Medium grained sandstone.
- Siltstone and fine to medium grained sandstone.

**LH 621** — Medium grained sandstone; 80% quartz, <1% black chert pebbles.

- Predominantly fine grained sandstone; laminated.

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Section: XIII - DEVIL’S STAIRCASE Interval: 795m to 810m

Page number 9 of 20 pages.
Jasper bed.

Medium grained sandstone; bedding 0.5 cm to ~13 cm thick.

LH 60% - Remanent of rocks that are extremely weathered and fine grained (no grains visible). Full of odd-shaped, elongate holes. Presumed to be the amygdaloidal basalt.

Layers of jasper

Medium grained sandstone; ~90% quartz; beds ~6-15 cm thick; rippled.

Massive quartz

Medium to coarse grained sandstone; ~90% quartz.
Medium grained sandstone; "1% black chert granules.

Medium grained sandstone; quartz-rich.

Medium grained sandstone; argillaceous.

Fine to medium grained sandstone; predominantly laminated.

Siltstone; quartz-bearing.

Siltstone and fine grained sandstone; ferruginous and quartz-rich.

Siltstone to very fine sandstone with interbedded jasper beds; "1-2 cm thick beds.

Section: XIII - DEVIL'S STAIRCASE
Interval: 995m to 1095 m
Page number 11 of 20 pages.
Cross beds up to north; herringbone.
Medium to coarse grained sandstone.

Medium to coarse grained sandstone; abundant quartz, 5% black chert granules and pebbles.

Medium grained sandstone.

LH 602 - Medium grained sandstone with 1% black chert pebbles and granules; abundant quartz.

Section: XIII - DEVIL'S STAIRCASE  Interval: 1095 m to 1195 m
Page number 12 of 20 pages.
Very fine to fine grained sandstone.

Coarse grained sandstone; ~90% quartz.

LH 601 - Medium to coarse grained sandstone; 85% quartz.

Predominantly medium grained with some coarse grained sandstone; 90+% quartz.
Section: XIII - DEVIL'S STAIRCASE
Interval: 1295 m to 1395 m
Page number 14 of 20 pages.
LH 598 - Predominantly fine grained sandstone; abundant quartz but predomin. greywacke; partings aver. 1-2 cm. Cross-beds definitely up to the north.

Siltstone and shale

Very fine grained sandstone
One, thin jasper band.

Siltstone and shale.

LH 599 - Siltstone and shale; ~5% quartz, ferruginous.

Shale and siltstone

Section: XIII - DEVIL'S STAIRCASE
Interval: 1395 m to 1495 m
Page number 15 of 20 pages.
1595
1590—
1585—
1580—
1575—
1570—
1565—
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1550—
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1540—
1535—
1530—
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1520—
1515—
1510—
1505—
1500—
1495—

Fine and medium grained sandstone.

Siltstone and very fine grained sandstone; 5% quartz.
Sandstone; cross-beds

Fine grained sandstone.

Very fine to fine grained sandstone.

Section: XIII - DEVIL'S STAIRCASE  Interval: 1495 m to 1595 m
Page number 16 of 20 pages.
Section: XIII - DEVIL'S STAIRCASE

Interval: 1595 m to 1695 m

Page number 17 of 20 pages.
Fine to medium grained sandstone; probably still laminated.

Fine grained sandstone; laminated.
Dog leg in measured section

Fine to medium grained sandstone; laminated.

Laminated sandstone.

Fine grained sandstone; quartz present; laminated.

Very fine grained sandstone; laminated.
Siltstone; "1% quartz, carbonate-rich, chloritic-looking; smeared-looking.

LH 595 - Siltstone

Siltstone; "10% visible quartz; less chloritic-looking, less carbonate-looking but still carbonated.
Very fine grained sandstone.

Predominantly fine grained sandstone; "50% quartz.

LH 596 - Medium grained sandstone; thickest beds "10 cm (rare), partings aver."1-2 cm, probably laminated in fresh section; very carbonated, abundant quartz veining.
Sheared appearing throughout the section; chloritic-looking here.
Black chert (Onverwacht Group)  

BAVIAANSKOP FORMATION  

MOODIES FAULT 

LH594 - Probably a tectonite; foliated, sheared; carbonate-rich; shot through with quartz.

Section: XIII - DEVIL'S STAIRCASE  
Interval: 1895 m to 1926 m  
Page number 20 of 20 pages.
APPENDIX 2
PETROGRAPHIC POINT COUNT DATA
APPENDIX 2a
POINT COUNT DATA
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APPENDIX 3
ELABORATION OF POINT COUNT PROCEDURES
DEFINITION OF FRAMEWORK GRAINS

Qm = monocrystalline quartz grains

Qp = polycrystalline quartzose lithic fragments (varieties of chert and fine-grained aggregates of chert-sericite that comprise >90% chert by volume)

Q = Qm + Qp

F = monocrystalline feldspar grains (plagioclase + potassium feldspar)

L = unstable polycrystalline lithic fragments of volcanic, metavolcanic, sedimentary, and metasedimentary types. L is limited to microcrystalline aphanitic materials containing no crystals larger than the matrix limit (0.0625 mm). Single crystals larger than this size are counted as mineral grains (see below).

Lt = L + Qp

TREATMENT OF ROCK FRAGMENTS DURING POINT COUNTING

Point counting procedures restricted lithic fragments to microcrystalline aphanitic materials containing no crystals larger than 0.0625 mm. Larger single crystals were counted as mineral grains. The original tally sheet distinguished separate clastic particles and large crystals within the various types of rock fragments but they are combined within this work. Aphanitic volcanic rock fragments were counted as lithic fragments when the microscope crosshair centered above part of the groundmass of a volcanic rock fragment or a microphenocryst <0.0625 mm. Larger phenocrysts were counted as mineral grains. Constituent crystals within coarser grained rock
fragments (granitic or quartzite) were commonly large enough to tally as individual mineral grains.

This treatment of rock fragments reduces the effect of grain size on sandstone compositions. Counting all polycrystalline particles as lithic fragments will result in a disproportionate count of lithic fragments in coarse-grained sandstones than in fine-grained sandstone, in which rock fragments have generally disintegrated into individual mineral grains.

FINE-GRAINED CHERT, CHERT-SERICITE, AND SERICITE AGGREGATES

Many of the Schoongezicht and Moodies sandstone samples included a complete spectrum of grain types from pure chert through fine-grained mica and chert aggregates to fine-grained mica aggregates. During the point counting procedures, grains with >90% GMC were considered chert and counted as Qp; grains with 10 to 90% mica were counted as mica and chert aggregates and included in L; grains with <10% GMC and ≥90% mica were classified as sericite aggregates and counted separately but also included with L in this report.
VITA
VITA

A native of southern California, Louise D. Hose received a B. A. degree in education from Arizona State University in 1974. After teaching junior high school in Tucson, Arizona, she returned to her education and complete an M. Sc. degree in geology from California State University, Los Angeles. Work in the petroleum industry in Denver, Colorado filled about three years until she entered the doctoral program at Louisiana State University. She has been a full time instructor at the Geology Department of the University of Colorado at Colorado Springs since August 1988.
DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Louise D. Rose

Major Field: Geology

Title of Dissertation: The Geology and Stratigraphic Evolution of the North-Central Part of the Early Archean Barberton Greenstone Belt, South Africa

Approved:

[Signatures]

Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

[Signatures]

Date of Examination:

February 15, 1990
PLEASE NOTE:

Oversize maps and charts are filmed in sections in the following manner:

LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

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GEOLOGIC MAP
OF A PART OF THE
IN GREENSTONE BELT, EASTERN
Plate 1

Kaen Valley Pluton

Dorschot

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AFRICA

EXPLANATION

Middle to Late Archean
c. 3.5–3.3Ga

Tantalite

Swaziland Supergroup
Altered rocks of uncertain parentage

Moodies Group

Baviaanskop Formation
Sandstone and siltstone

Joe's Luck Formation
Conglomerate
Amygdoloidal basalts
Predominantly sandstone
Jasper

Clutha Formation—B division
Sandstone and minor siltstone

Clutha Formation—A division

* Polka dot sandstone marker bed

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Fig Tree Group
Schoongezicht Formation
Pinolite-rich conglomerate, sandstone, volcaniclastic rocks, and minor intrusive rocks
Undifferentiated
Ferruginous sandstone, siltstone, and chert with minor shale and conglomerate

Onverwacht Group
Black chert and gray laminated chert
Classified ultramafic rocks and chrome-mica bearing cherts
Ultramafic-mafic igneous rocks
Talcose schist
Scaly paragonite schist
PLEASE NOTE:

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UMI
STRUCTURAL GEOLOGIC MAP OF A PART OF THE BERTON GREENSTONE BELT, EAST
AFRICA

EXPLANATION

Middle to Late Archean
c. 3.5–3.3 Ga

Tonalite

Swaziland Supergroup
Altered rocks of uncertain parentage

Moodies Group
Baviaanskop Formation
Sandstone and siltstone

Joe's Luck Formation
Conglomerate

Amphidolitoidal breccia
Part of the Clutha A south of the Baviaanskop Fault
Predominantly sandstone

Clutha Formation—B division
Sandstone and minor siltstone
Polka dol sandstone marker bed

Clutha Formation—A division
Conglomerate & sandstone with minor siltstone & shale

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Clutha Formation—A division
Conglomerate & sandstone with minor limestone & shale.

Fig Tree Group
Schoongezicht Formation
Plagioclase-rich conglomerate, sandstone, volcaniclastic rocks, and minor intrusive rocks.
Undifferentiated
Ferruginous sandstone, siltstone, and chert with minor shale and conglomerate.

Onverwacht Group
Black chert and gray laminated chert
Clastic ultramafic rocks and chrome-mica bearing chert
Ultramafic maﬁc igneous rocks
Telgenkloof Sandstone

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CONTOUR INTERVAL 200 FEET

Geology and drafting by Louise D. Haza

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