RHODES UNIVERSITY
DEPARTMENT OF GEOLOGY

THE PRECAMBRIAN METALLOGENY OF KWAZULU-NATAL

BY

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ABSTRACT

The Precambrian rocks of KwaZulu-Natal comprise the Archaean granite-greenstone remnants of the Kaapvaal craton and Late Archaean volcanics and sediments of the supracratonic Pongola Supergroup. These Archaean rocks have been intruded by numerous mafic/ultramafic complexes and voluminous granitoid intrusives of various ages. To the south, the basement rocks are represented by the Mid- to Late-Proterozoic Natal Metamorphic Province (NMP). The NMP comprises three discontinuity-bound tectonostratigraphic terranes. These are, from north to south, the Tugela, Mzumbe and Margate Terranes. The Tugela Terrane has been interpreted as an ophiolite suite that was thrust northwards onto the stable Archaean craton as four nappe structures. Continued thrusting resulted in the two southern terranes being thrust northwards over each other, resulting in numerous sinistral transcurrent shear zones and mylonite belts. The greenschist facies Tugela terrane has been intruded by mafic-ultramafic complexes, alpine serpentinites, plagiogranites and a number of alkaline to peralkaline granitoids. The Mzumbe and Margate Terranes comprise arc-related, felsic to mafic supracrustal gneisses and metasediments that were intruded by syn-, late- and post-tectonic granitoids.

Mineralisation in the granite-greenstones consists of structurally-hosted lode-gold deposits. These deposits have many characteristics in common with lode-gold deposits found in other granite-greenstone terranes throughout the world. The Nondweni greenstones also contain volcanogenic-related massive sulphide deposits. The Pongola Supergroup is host to lode-gold mineralisation and placer gold mineralisation. These placer deposits have been correlated with deposits found in the similarly-aged Witwatersrand Basin in an adjacent part of the craton.

The metallogeny of the NMP can be described in relation to the various stages in the tectonic evolution of the belt. The initial, rifting and extension-related stage was characterised by arc-related magmatism and volcanic arc activity. Alkali basalt magmatism due to hot-spot activity in the oceanic basin in which the Tugela Terrane initially accumulated, produced magmatic segregation deposits, while volcanic-arc activity is responsible for the submarine-exhalative massive sulphide mineralisation.

All the mineralisation within the NMP is structurally-related. These thrusts and shear zones were developed during obduction and thrusting during the NMP event, and created the paths necessary for the migration of mineralising fluids. Alpine-type ophiolite deposits were also emplaced along these zones. Epigenetic, shear zone-hosted gold mineralisation occurs in the Tugela and Mzumbe Terranes. Mineralisation occurs within quartz veins and is also disseminated within the sheared host-rocks. The Mzumbe Terrane also contains small showings of massive sulphide deposits that were related to volcanogenic exhalative processes during the formation of this terrane. Potential for finding further mineralisation of this type appears to be good. The massive sulphide deposits formed early in the evolution of the belt, and were deformed and metamorphosed during the later accretionary processes. The southernmost Margate Terrane is characterised by a lack of metalliferous mineralisation, but hosts the extensive, and economically important, limestone deposits of the Marble Delta. The recently discovered spodumene-rich pegmatite deposits of this terrane may also be considered for exploitation. Post-collisional magmatism and metamorphism resulted in extensive rapakivi-type granite/charnockite plutons.

TABLE OF CONTENTS

PAGE

CHAPTER ONE

1.Introduction

CHAPTER TWO

CHAPTER THREE

3. Metallogenic Framework: The Archaean

CHAPTER FOUR

CHAPTER FIVE

5. Metallogeny of the Precambrian deposits

CHAPTER SIX

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

1.INTRODUCTION

1.1. Definition

Metallogeny has been defined by Guild (1972) as: "The study of the genesis of ore deposits in their total geologic environment. Metal in this sense derives from a Greek word meaning mine; thus metallogeny treats of both metallic and nonmetallic minerals. The fossil fuels are commonly excluded."

Metallogenic studies are considered most important for exploration as even though genetic interpretations may prove incorrect, documentation of the field characteristics from known mineral deposits can provide the first step in the exploration for new deposits where analogous situations exist.

1.2 General

The area studied (Fig. 1.1) is bound by latitudes 27°20′S, 31°30′S and longitudes 30°30′E, 30°32′ E, which is included in part of the following 1:250 000 map sheets: 2730 (Vryheid), 2830 (Dundee and Richards Bay), 2930 (Durban) and 3030 (Port Shepstone).

Due to the contrasting underlying lithologies there is great variation in the topography of the study area from west to east. The plateau in the east is covered by rolling hills and grassland which is underlain by sandstone and shale of the Karoo Supergroup. Extensive intrusions of Karoo dolerite generally alter the relief of the area in the form of more resistant sills and dykes. Fault-bounded rocks of the Karoo Supergroup also outcrop before the narrow coastal strip in the east. This area is intensively cultivated.

In the central part of the area more resistant quartz-arenites of the Natal Group have been extensively block-faulted to produce horst and graben structures. This lithology generally forms elevated cliffs adjacent to the Karoo rocks and the variably resistant rocks of the Natal Metamorphic Province (NMP).

The basement rocks of the NMP crop out in the form of inliers which trend subparallel to the coastline and displays a rugged topography that is deeply dissected. The steep, deeply eroded valleys are sparsely inhabited and cloaked in dense thornbush, which makes access difficult. Only subsistence farming is practised here by the local inhabitants.

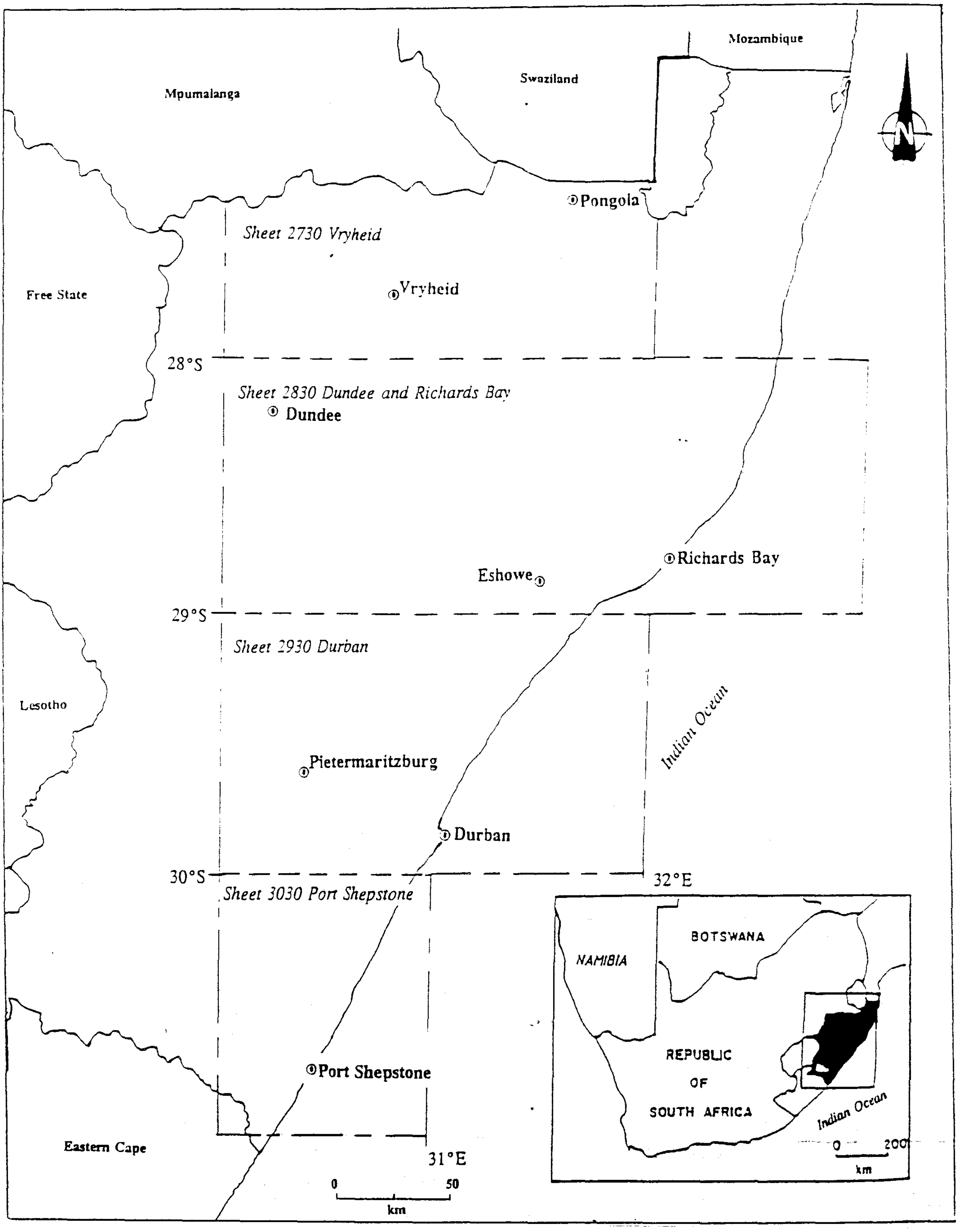


Fig.1.1: Outline of the KwaZulu-Natal province showing the extent covered by the various 1:250 000 geological maps under investigation.

The coastal strip is easily accessible and large parts of this belt, on hills as well as the flat plains, are covered by extensive sugar cane plantations.

The climate is subtropical in the coastal areas with hot, humid summers and moderate, dry winters, which has enhanced the tourism potential of these areas. However, because of the increased altitudes of the inland areas, frost is common in winter. This has led to extreme chemical weathering, especially of basement rocks, restricting outcrops to the actively eroding stream and river beds.

The drainage in KwaZulu-Natal is well developed, with several river systems in the north, central and southern areas which run southeast from the highlands to the ocean, deeply dissecting the rugged topography and forming deeply incised valleys.

1.3 **Previous Investigations**

Much geological work has been carried out in the KwaZulu-Natal province since the early 1900's. Many workers have concentrated on the Archaean rocks in the north and the Proterozoic basement rocks of the NMP, which are the most interesting from a metallogenic point of view. Studies describing the entire Namaqua-Natal Mobile belt have been put into context with evolution of the southern part of Africa as a whole.

Until recently, there was a general lack of geological interest in this region as no significant deposits of metalliferous mineralization existed, in contrast to the western Namaqua sector of the belt, from which numerous mineral deposits are exploited. Apart from the successfully exploited heavy mineral sands deposits in the vicinity of Richards Bay and the Klipwal gold mine near Pongola, there are a few other small gold mines and prospects that have been worked in the past and produced a small quantity of gold. Other deposits that may have exploitation potential include chrome, vanadium and numerous industrial mineral deposits. Many obstacles have hindered exploration projects in the Province, particularly the inaccessible mountainous terrain, dense natural vegetation cover and poor outcrop. However with modern advances in exploration techniques, new potential may be realised.

A list of some of the more important contributors involved in describing the mineralisation within the Province and also a short description of their work is given below.

Hatch (1910) was the first to give detailed assessments of the most important mineral resources in the entire province known at the time. A brief description of the geology as well as chemical assays were also undertaken. Many later studies were based on these initial investigations. Later, Du Toit (1920, 1931, 1946) compiled various geological maps and explanation sheets throughout the then Colony of Natal. Lithological and mineralisation descriptions were markedly accurate and still used as a basis for compiling maps.

Matthews (1959,1972,1981a) was instrumental in documenting the geology of the northern margin of the Natal Metamorphic Province and suggested the ophiolite theory for this area. Together, Matthews and Charlesworth (1981) produced a map of the northern margin for the National Geodynamics Project. Matthews (1990) also proposed a plate-tectonic model for the Pongola Supergroup in northern KwaZulu-Natal. Thomas (1989a) and Thomas et al. (1990a; 1994b) researched many papers on the Natal Metamorphic Province concentrating on mineral deposits in the area and their genesis. Thomas (1988b) also compiled the 1:250 000 Port Shepstone and Durban sheets and was instrumental in revising the subdivisions of the NMP into the three distinct tectonostratigraphic terranes now recognised. With various co-workers, he analyzed and unravelled much of the tectonic evolution and lithological details in the KwaZulu-Natal province.

Wuth & Archer (1986) suggested that the Sithilo ore body in the Tugela Terrane, which was mined on a limited scale in the early 50's for high grade chrome concentrates, was the Precambrian equivalent of an alpine-type ophiolitic chromite deposit. Reynolds (1986) studied the titaniferous ores of the Mambula layered mafic complex and suggested that it formed by the fractional crystallization of a mafic magma. Scogings (e.g. 1985, 1986, 1989a) researched various aspects of the peralkaline intrusives in the northern part of the Natal Metamorphic Province.

Beukes and Cairncross (1991) provided detailed correlations between the Mozaan Group in northern KwaZulu-Natal and Witwatersrand Supergroup lithologies of the Gauteng and

Mpumalanga Provinces.

Numerous contributions to the geology of the Archaean rocks were made by Armstrong et al. (1982, 1986), Wilson and Carlson (1989) and Watchorn (1980a,b).
Also relevant to this study are various papers on the evolution of the Namaqua-Natal Mobile Belt and the special issue of the South African Journal of Geology (Vol.92(4), 1989) which concentrated on problematic areas of the Proterozoic rocks in the Province (Fig.1.2).

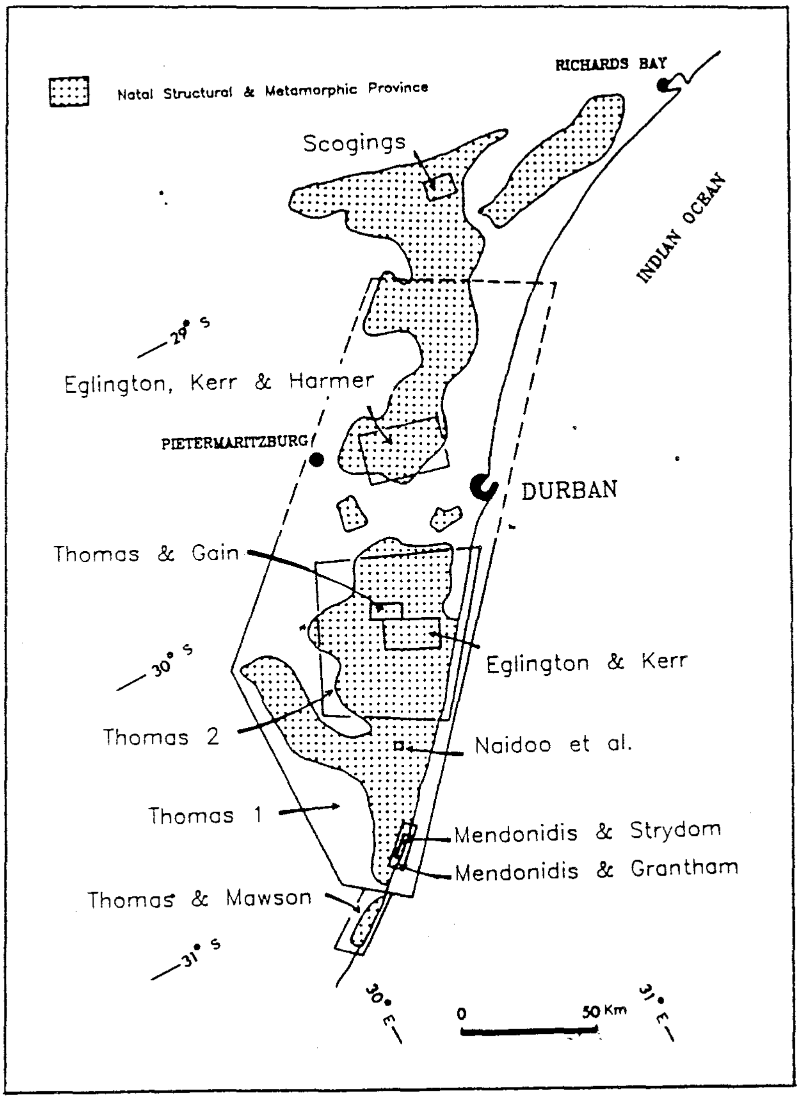


Fig.1.2: Areas covered in the Special Issue of the S.A. Journal of Geology on Proterozoic rocks of the NMP.

The South African Development Trust Corporation (STK) were also active in exploration for new deposits in many of the undeveloped parts of the province and many of their reports are available at the Geological Survey of South Africa in Pretoria. Various mining companies known to currently have exploration programmes in the Province, however no details have yet been released.

Important contributions to the geology and mineralisation within the study area were obtained from various M.Sc and Ph.D theses, e.g. Otto (1977), Charlesworth (1981), Evans (1984), Versfeld (1988), Bullen (1990), Gold (1993), etc.

The Geological Survey of South Africa has produced four 1:250 000 geological map sheets and explanation booklets in the late 1980's covering the area and the stratigraphic nomenclature used in the text is largely based on these maps and the explanation booklets by Linström (1987a,b,c) and Thomas (1988b).

1.4 **Aims of Present Study**

This study was initiated by the Economic Geology Division of the Geological Survey of South Africa who are currently involved in the production of 1:250 000 scale metallogenic maps covering various parts of South Africa. All information derived from research, including field investigations is captured on SAMINDABA (South African Mineral Deposits Data Base) using the Oracle computer programme. Information may then be called up to produce maps showing the exact location of mineral occurrences, size of deposits, associated mineralisation, host lithologies, orientation of ore-bodies, depositional environments etc. Metallogenic maps of sheets 2830 (Dundee and Richards Bay), 2930 (Durban) and 3030 (Port Shepstone) Sheets are in advanced stages of compilation and data is in the process of being captured. These sheets will also be digitised and will show the simplified geology and depositional environments of the host lithologies.

A brief description of the Precambrian lithologies and related intrusives in chapter two provides a geological overview to the rocks hosting the mineral occurrences. The object of this investigation is to document the mineral occurrences (chapters three and four) and classify the important metalliferous occurrences according to ore deposit models. This classification will then be used to assess the depositional environments, tectonic settings and other relevant characteristics of deposits within the study area. These characteristics will then be compared to those of similar deposits that have been analysed in published literature (chapter five) to provide a better understanding the metallogeny of the study area and aid in the exploration for other deposits in similar geological settings.

The contents of this thesis will form part of the explanation booklets to accompany the metallogenic maps mentioned above. These explanation booklets will also include descriptions of all the known Post-Proterozoic mineral deposits that occur in KwaZulu-Natal.

CHAPTER TWO

2. Geological Overview

Introduction

The oldest rocks recognised in the study area belong to two major tectonic provinces, the Archaean Kaapvaal Craton and the Mid- to Late-Proterozoic Natal Metamorphic Province (NMP). The southeastern portion of the Kaapvaal Craton is exposed in the northern parts of KwaZulu-Natal to as far south as the Natal Thrust Front as various inliers and constitutes a typical granite-greenstone terrane with ages of up to 3.64 Ga (Compston and Kröner, 1988). Each of these remnants is lithologically distinct and comprise volcanic rocks (ranging in composition from komatiites to basalts) and clastic and chemical sediments (Hunter and Wilson, 1988).

Unconformably overlying the granite-greenstones of the southeastern Kaapvaal Craton, are the volcanics and metasediments of the Pongola Supergroup, which is exposed in northern KwaZulu-Natal, Mpumalanga Province and southern Swaziland. This Late-Archaean (± 2.94 Ga, Hegner et al., 1984) supracrustal sequence is one of the oldest to have developed on a craton, and thus serves to confirm the early stabilisation of the Kaapvaal Craton. The Pongola Supergroup comprises volcanics of the Nsuze Group and overlying arenites, argillites and iron-formations of the Mozaan Group. Studies by Matthews (1990) revealed that the Nsuze Group was deposited in response to rifting within an epicratonic basin, while the Mozaan Group developed in a post-rift, subsidence basin.

Precambrian rocks to the south of the craton belong to the NMP, which has been dated at between ± 1 250 and ± 950 Ma (Eglington et al., 1989; Thomas and Eglington, 1990) and forms part of the Namaqua tectonic event *sensu stricto* (Gibson et al., 1996) although it was previously included as the late part of the Kibaran *sensu lato* (Thomas et al., 1994b). The boundary between the two tectonic provinces in KwaZulu-Natal is a zone of imbrication known as the Natal Thrust Front, where the northern margin of the NMP has been interpreted as an ophiolite complex that was obducted onto the southern margin of the Kaapvaal Craton as four major flat-lying thrust nappes (Matthews, 1972).

The NMP forms the eastern sector of the Namaqua-Natal Metamorphic Province which is a 200 - 400 km-wide, easterly to east-southeasterly-trending belt of complexly deformed and metamorphosed rocks adjacent to the southern and southwestern margin of the Kaapvaal Craton (Fig. 2.1). The outcrops in Namaqualand are separated from those in KwaZulu-Natal by a thick cover of Phanerozoic Karoo sediments. Similar isotopic ages and structural histories however, indicate that a continuous belt exists (e.g. Nicolaysen and Burger, 1965; Jacobs et al., 1993).

Furthermore, a variety of geophysical methods have been used to precisely map the position of the belt under cover and its relationship to the Kaapvaal Craton and the Kheis Province in Namaqualand (e.g. De Beer and Meyer, 1984; Corner et al., 1990; Barkhuizen and Matthews, 1990; Thomas et al., 1992c). Within a Gondwana context, apart from the westward continuation of the NMP into Namaqualand, the rocks have also been equated to the east with those of similar geological characteristics in the Falkland Plateau (Adie, 1952; Rex and Tanner, 1982; Martin and Hartnady, 1986; Mitchell et al., 1986); the Western Drönning Maudland in Antarctica (Grantham et al., 1988), and also northwards into the N-S-trending Mozambique Belt (Thomas et al., 1994b) (Fig. 2.1).

Central and southern KwaZulu-Natal are characterised by outcrops of the NMP, which has been subdivided by Thomas (1989a) into three discontinuity-bounded tectonostratigraphic terranes. These are the Tugela Terrane in the north, and the central and southern Mzumbe and Margate Terranes. Metamorphic grades increase from greenschist facies in the north to granulite facies in the south. The southern margin of the NMP is not exposed. The pretectonic Sikombe Granite recognized south of the Margate Terrane in the Eastern Cape however, is thought to represent the exposed fragment of a fourth tectonic domain (Thomas and Mawson, 1989). The Mzumbe and Margate Terranes are intruded by distinctive pre- and syntectonic plutonic suites. Late-tectonic granitoids however, crop out throughout the two southern terranes. Intrusives identified in the Tugela Terrane supracrustal rocks include plagiogranites, mafic-ultramafic complexes and serpentinites (Matthews, 1972) and a number of alkaline to peralkaline granitoids (Scogings, 1989a).

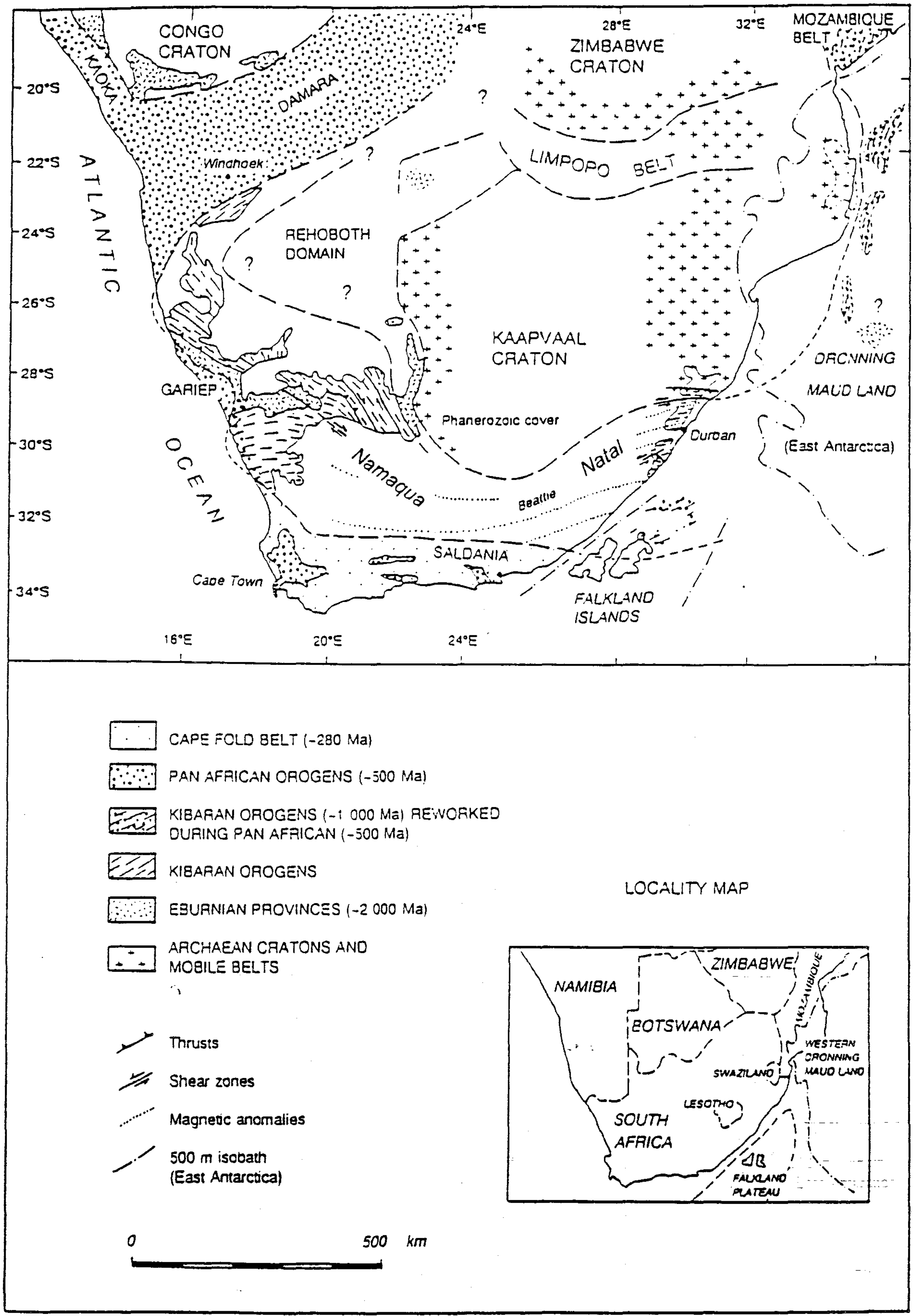


Fig.2.1: Regional tectonic setting of the Namaqua-Natal Province and the position of the Natal Metamorphic Province in a Gondwana Context (after Thomas et al., 1992a).

The NMP is unconformably overlain by Lower Ordovician red-bed Natal Group sandstones in the north and pale grey, fossiliferous, marine Devonian quartz arenites of the Msikaba Formation south of 30°30'S (Thomas et al., 1992e). The change in lithology was found to occur abruptly on either side of the Dweshula Basement High (Thomas et al., 1990c), which is an area of non-deposition of the sandstone lithologies in southern KwaZulu-Natal (Fig. 2.2).

The Msikaba sandstones were deduced to have been deposited in a near-shore shallow marine environment, with the sediments having a provenance area in the northeast (Visser, 1974; Hobday and Mathew, 1974; Kingsley, 1975). Thomas et al. (1992e) concluded that: "the rocks of the Natal Group represent a continental, post-orogenic mollase deposit, derived from the rapid erosion of a rising Pan-African mountain chain situated to the east of present day Natal, and laid down by fluvial systems in an adjacent fault-bounded trough."

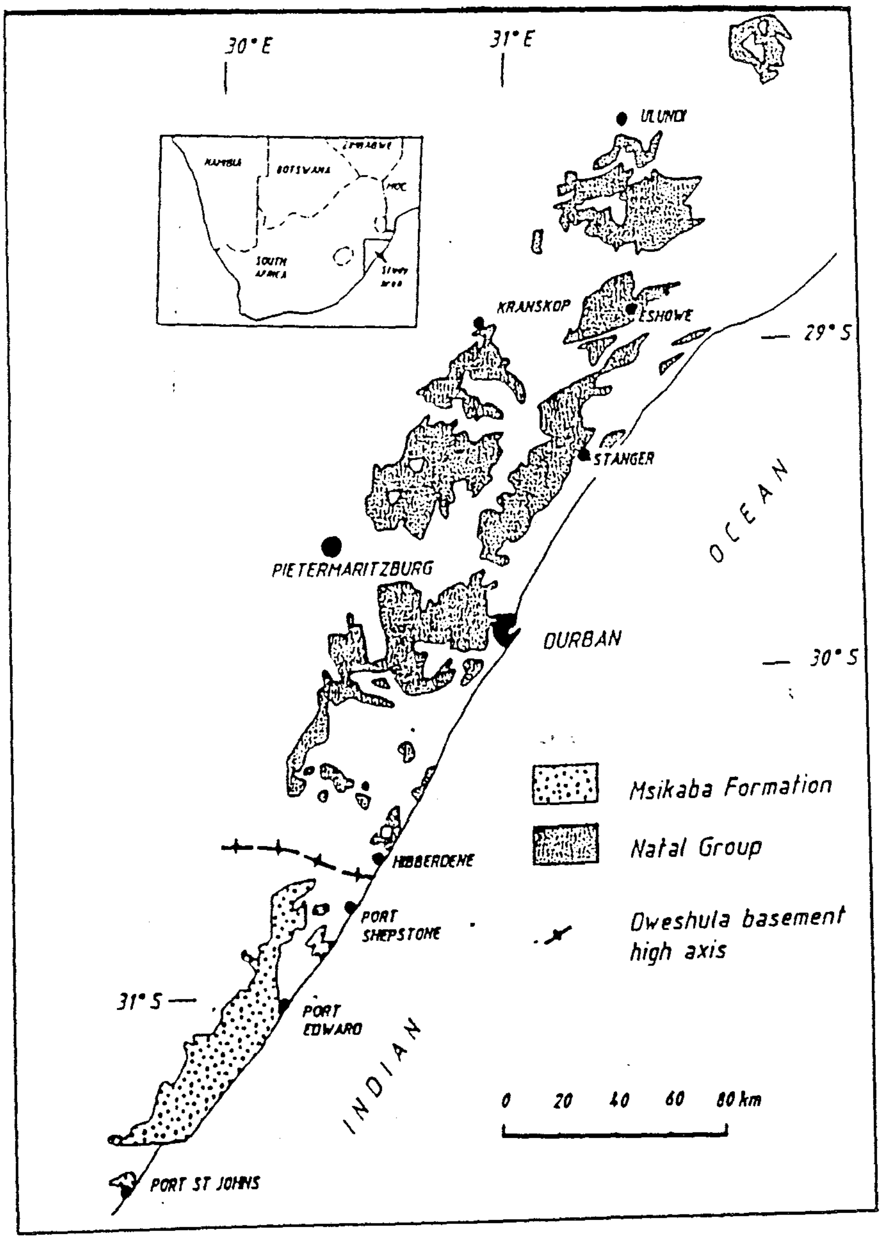
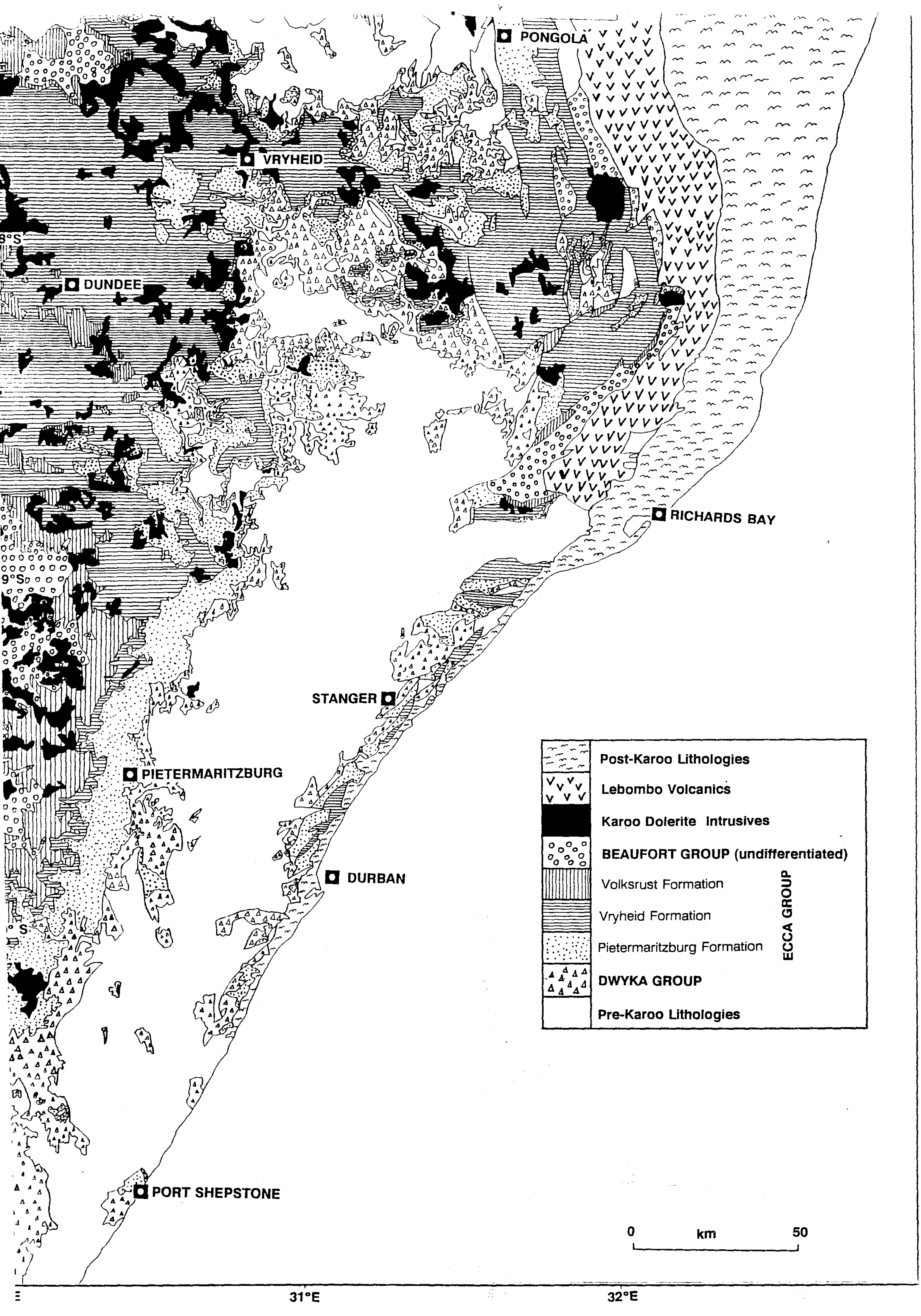


Fig.2.2:Distribution of the Natal Group and Msikaba Formation in KwaZulu-Natal (after Thomas et al., 1992e).

The older sandstones are overlain by Carboniferous to Jurassic sediments and volcanics of the Karoo Supergroup (Fig. 2.3). The eastern boundary of the Kaapvaal Craton comprise the Lebombo monocline of Jurassic volcanics associated with the break-up of Gondwana (De Wit et al., 1992). The Permo-Carboniferous Dwyka Group at the base of the Karoo sometimes oversteps the older sandstones to lie directly on the basement rocks. The Karoo Supergroup is most extensively developed in the western and northern parts of the Province, with a thin strip also developed adjacent to the coast in the central and southern areas. Quaternary sands interspersed with Cretaceous sediments occupy the coastal belt along the eastern seaboard.

(overleaf)**Fig. 2.3:**Distribution of the Karoo Supergroup in KwaZulu-Natal (after the 1:1 000 000 Geological Map of Southern Africa published by the Geological Survey of South Africa (1984).


PONGOLA
VRYHEID
DUNDEE
8°S
9°S
S
RICHARDS BAY
STANGER
PIETERMARITZBURG
DURBAN
PORT SHEPSTONE
Post-Karoo Lithologies
Lebombo Volcanics
Karoo Dolerite Intrusives
BEAUFORT GROUP (undifferentiated)
Volksrust Formation
Vryheid Formation
Pietermaritzburg Formation
ECCA GROUP
DWYKA GROUP
Pre-Karoo Lithologies
0
km
50
31°E
32°E

2.1. The Archaean

The Archaean crust of southern Africa comprises the granite-greenstone terranes of the Kaapvaal and Zimbabwe cratons (Fig. 2.1). The oldest rocks in KwaZulu-Natal belong to the Archaean Kaapvaal Craton and are exposed as a number of inliers of variable size (Fig.2.4). Five geographically and lithologically distinct Archaean greenstone sequences that occur south of the Barberton greenstone belt to the Natal Thrust Front have been recognised by Hunter and Wilson (1988). These are, from north to south, the Dwalile, Assegai, de Kraalen, Commondale and Nondweni suites.

According to Hunter (1991) volcanism and sedimentation in the Nondweni, Commondale and Assegai remnants occurred in shallow water environments overlying sialic crust and this is probably the reason for the differences in lithological associations when compared to the Barberton sequence, which developed in a predominantly marine environment.

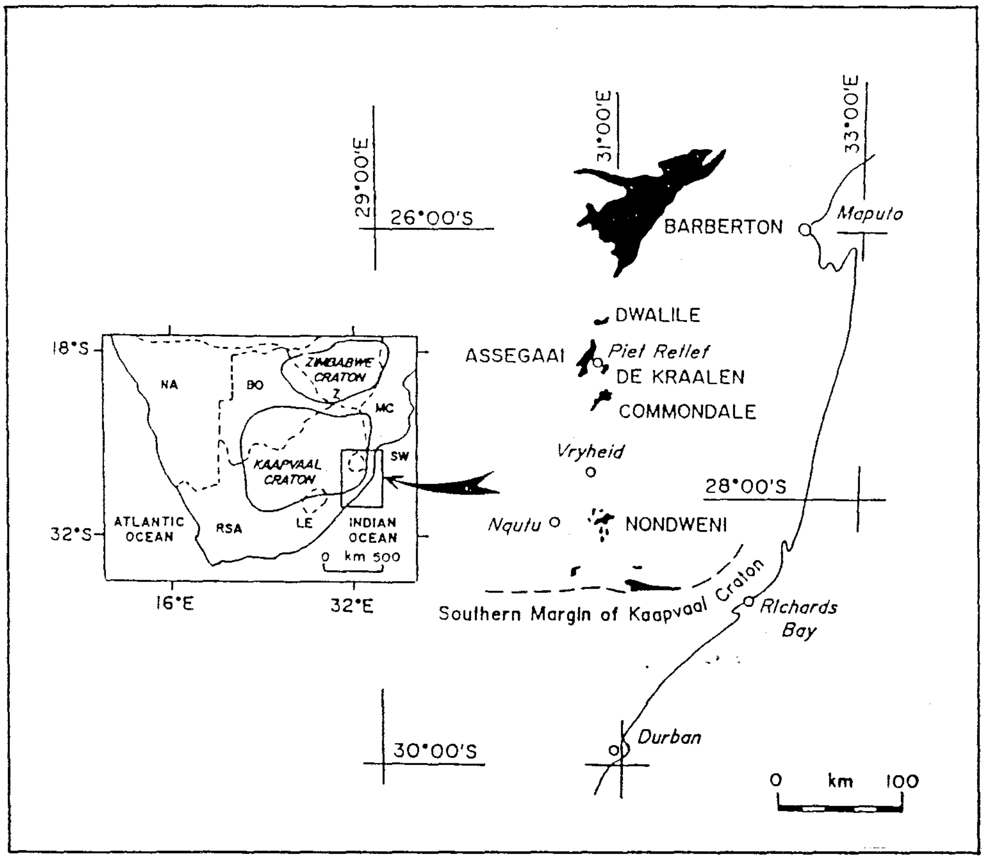


Fig.2.4: Map showing the outcrop of the Barberton greenstone belt and smaller greenstone fragments to the south (after Wilson and Versfeld, 1994a).

The Commondale and Nondweni remnants occur in the area under investigation, along with the previously undifferentiated "Melmoth Granite-Greenstone Relic" described by Bullen (1991). A detailed account of the Nondweni greenstones was given by Versfeld (1988) and Wilson and Versfeld (1994a,b). The granulites of the Empangeni Group were described by Charlesworth (1981). In addition, Thomas et al. (1995a, 1997) recently described the geology of the Archaean Nzimane Inlier in the Hlabisa area in northeastern KwaZulu-Natal.

According to Thomas et al. (1993a), the Dominion, Witwatersrand, Pongola and Ventersdorp basins are believed to have developed during extension in the central and southern parts of the Kaapvaal Craton, which occurred at the same time as accretion of Late Archaean granite-greenstone terranes in the western and northern parts. The Pongola Supergroup occurs in two connected but contrasting structural domains in the southeastern region of the Kaapvaal Craton (Matthews, 1990) and is exposed in northern KwaZulu-Natal as various inliers from the northern border with Swaziland up to the Natal Thrust Front (Fig. 2.5). A brief description of these Archaean rocks, related intrusives and stratigraphic relationships follows.

2.1.1. **Granite-Greenstone Basement**

2.1.1.1. **Commondale Formation**

This greenstone remnant is predominantly made up of a pile of mafic and serpentinized ultramafic metavolcanic rocks (amphibolite, tremolite-actinolite schist, talc-magnesite schist, serpentinite) with minor metapelites, banded iron-formation, quartzite and calc-silicate interlayers (Hunter, 1990a). The rocks are preserved in two synformal keels which are separated by a major NNE-trending shear zone. In areas of high strain the ultramafic rocks have retrogressed to talc-chlorite schists, whereas a rhythmically alternating sequence of spinifex-textured and cumulate layers is preserved in an area of low strain in the core of the southern synform (Hunter and Wilson, 1988). The fold closure at the eastern end is defined by a steeply northward dipping layered sequence of thinly bedded, ferruginous quartzites, talc schists and amphibolites.

Wilson and Carlson (1989) found the development of the rhythmic layering to be unique as there was no indication that this succession formed as lava flows. They also reported that the spinifex-textured layers were unusual because of the presence of primary orthopyroxene.

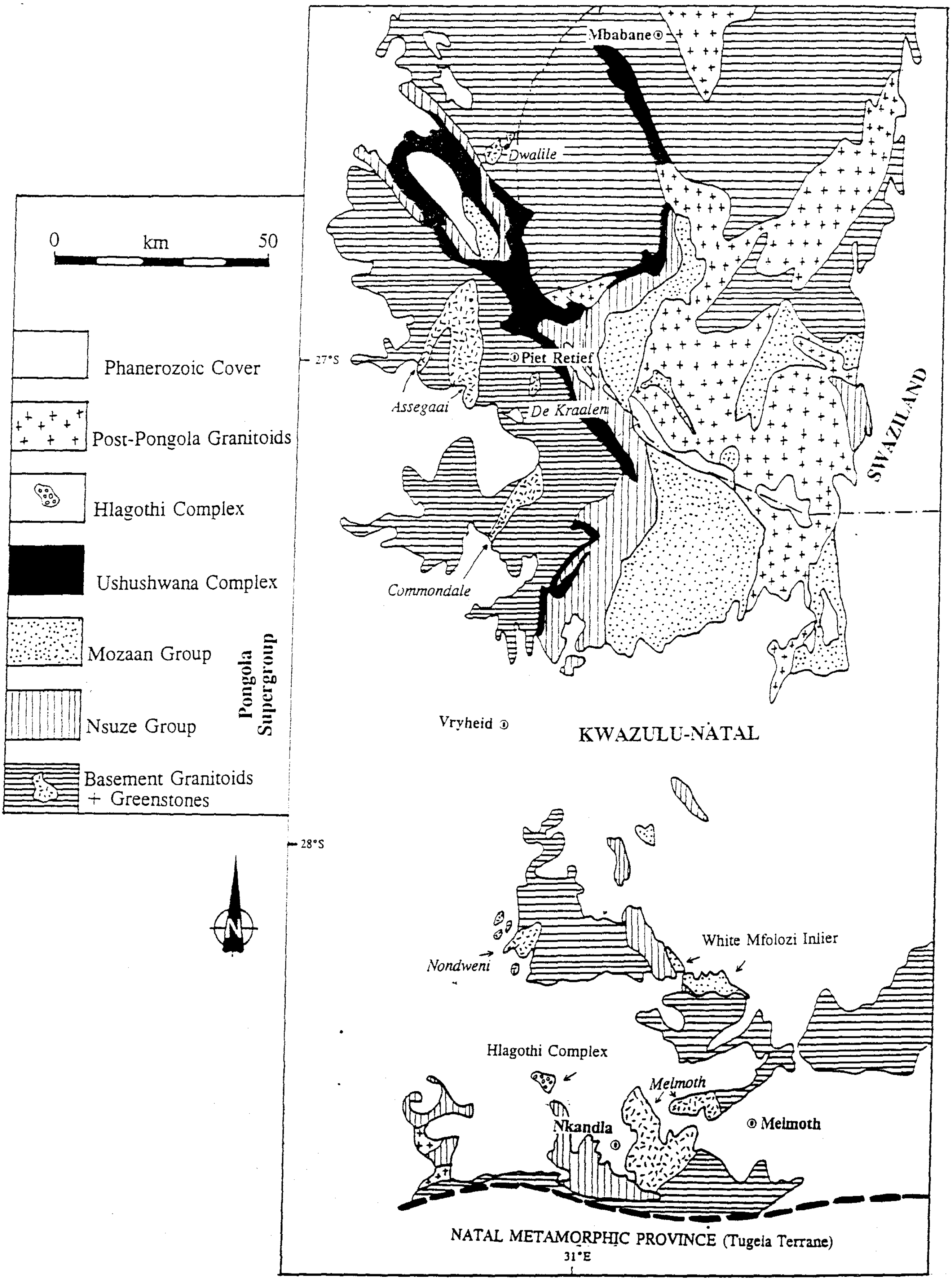


Fig.2.5: Simplified geological map showing distribution of the Archaean rocks in northern KwaZulu-Natal (after Tankard et al., 1982; Hunter and Wilson, 1988; Bullen, 1990)

2.1.1.1.1. **Commondale Formation Intrusives**

Medium- to coarse grained tabular bodies of leucotonalites and trondhjemites of the Anhalt Granitoid Suite (Hunter, 1990b) intrude the Commondale supracrustals (Hunter et al., 1992; Hunter and Wilson, 1988). These bodies are characterised by mylonitic foliation at or near to the contact with the supracrustal rocks.

The Matshempondo Peridotite, preserved within the northern flank of the Commondale synform occupies an area of about 10 km^2 and is up to 640 m thick (Hunter and Smith, 1990). The intrusion comprises 18 units 9-63 m thick, each consisting of an upper olivine spinifex zone and a lower cumulate zone. The cumulate rocks make up 90% of the volume of the peridotite. According to Hunter and Wilson (1988), gneissic leucotonalites containing poorly exposed xenoliths, possibly of the Commondale remnant, crops out east and northeast of the Commondale exposures. Foliated hornblende granodiorite that intrudes the northeastern part of the Commondale remnant are also reported.

2.1.1.2. **Nondweni Group**

The Nondweni Group greenstones form a series of inliers near the village of Nondweni in northern KwaZulu-Natal (Figs.2.5 and 2.6), about 50 km to the south of Vryheid. These rocks are broadly similar to, and of approximately the same age as, the Barberton Greenstone Belt which outcrops some 300 km to the north (Wilson and Versfeld, 1994a).

The stratigraphic succession of the Nondweni Group comprises mafic and ultramafic volcanic rocks with minor intercalations of acid lavas, pyroclastics and sedimentary rocks, with pillowed basalts interlayered with komatiitic basalts forming the most predominant lithologies. Wilson and Versfeld (1994a) recognised the following five classes of mafic/ultramafic volcanic rocks within the Nondweni Group. These are komatiites, komatiitic basalt, komatiitic andesite, basalt and basaltic andesite. Hunter and Wilson (1988) report well-developed spinifex-textured units within both the komatiitic basalts and komatiitic ultramafic rocks, but an entire absence of olivine spinifex. Metamorphism of the Nondweni greenstones is predominantly of greenschist grade, except where affected by intrusives, as contact metamorphism increases grades to amphibolite facies (Matthews et al., 1989).

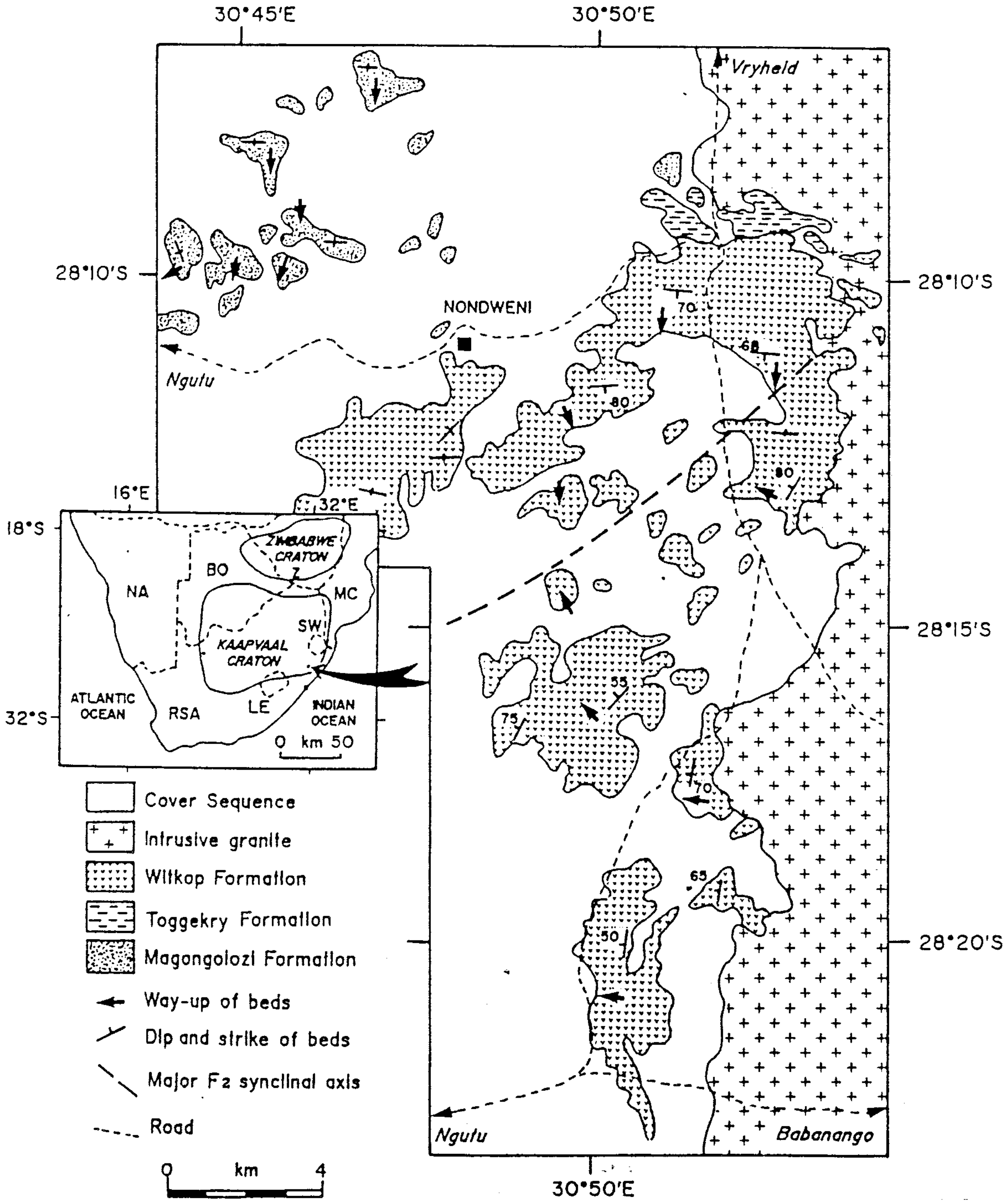


Fig. 2.6: Exposures of the Nondweni Group and its constituent Formations (after Wilson and Versfeld, 1994a).

The Nondweni Group has been subdivided by Versfeld (1988), on the basis of field relationships and lithology, into three formations (Table 2.1).

Table 2.1: Subdivisions of the Nondweni Group.

Formation	Lithology	Thickness*
Witkop (Wilson and Versfeld, 1992b)	Dominantly spinifex-textured komatiites, komatiitic basalts, pillowed basalt, and minor diorite, chert, felsic tuff, rhyolite, quartzite and calc-silicate rocks.	7 500 m
Toggekry (Versfeld and Wilson, 1992b)	Massive and foliated felsic (quartz-feldspar-sericite) schists containing small Cu-Zn massive sulphide bodies, and rhyolite with minor mafic schists, serpentinite, metaquartzite and graphitic schist and feldspar porphyry.	2 000 m
Magongolozi (Wilson and Versfeld, 1992a)	Dominantly consists of pillowed lavas of intermediate composition (komatiitic andesites and basaltic andesites), spinifex-textured layered (pyroxene) mafic rocks, diorite and pyroxenite layers, fine-grained massive volcanic rocks and minor chert bands.	7 000 m

* : Thickness of individual formations from Wilson and Versfeld (1994a).

Investigations by Matthews et al. (1989) revealed that the greenstones are intruded by a large granitoid body dated at approximately 3.29 Ga. According to Wilson and Versfeld (1994a), the best available age was obtained from an ion microprobe analysis of zircons from a rhyolite flow in the Witkop Formation, which gave an age of 3406 ± 3 Ma.

In the model proposed by Versfeld (1988) to explain the formation of the Nondweni greenstone succession, the basal Magongolozi Formation was interpreted to have been deposited in shallow water and subaerial environments. The unaltered lavas of the formation were deposited subaerially or emplaced as high level sills, while the highly altered pillowed outcrops indicate emplacement in shallow, water-filled basins. Deposition of the overlying Toggekry Formation, which consists of reworked felsic tuffs, rhyolites and massive sulphide deposits, may be related to local development of a major felsic eruptive centre, with reworking and deposition of tuffaceous material in flanking basins. The uppermost Witkop Formation indicates a return to mafic and ultramafic volcanism extruded in a dominantly subaqueous environment, with thin lava flows suggesting movement in less restricted basins. Cherts are common here, with many being the product of felsic tuffaceous volcanism. The uppermost exposures of the Witkop Formation consist of a succession of reworked felsic tuffs, with evaporites at the top indicating a shallow water, possibly playa lake or breached crater environment.

Versfeld (1988) postulated that the greenstone belt developed in an island arc environment close to the margin of the developing Kaapvaal Craton. The absence of sialic sedimentation further suggested deposition in a marginal interarc basin, which was surrounded by emergent volcanic arcs that are believed to have prevented input of continental sediment on both continental and oceanic sides.

2.1.1.2.1. **Nondweni Group Intrusives**

Four suites of widely varying ages are known to intrude the Nondweni greenstones. Versfeld (1988) correlates one set of these with the Karoo-aged dolerite dykes and sills, and another set of probably Mid-Proterozoic aged NE-SW trending metadolerite bodies.

The older intrusives have been documented in Matthews et al. (1989), who recognised two main granitoid lithologies in the area. These are the homogeneous fine- to medium-grained Mvunyana granodiorite and an undifferentiated heterogeneous grey or migmatitic gneiss. The felsic part of the migmatitic gneisses is a fine- to medium-grained granitoid, while the darker components vary from fine- to medium-grained amphibolitic gneisses. The gneisses are exposed in a river bed and are characterised by steep (about 80°) N-dipping foliations and possibly contain at least three generations of granitic sheets and pegmatite veins.

The Mvunyana granitoids are fine- to medium-grained and occur in batholithic proportions. The contact in the northeastern area with the intensely folded formations of the Nondweni group is highly irregular. Along these contacts the greenstones contain a host of granite and aplite-pegmatite dykes and sheets up to 2 m in width. In addition, the granodiorite has a number of enclaves containing lithologies that have been equated with those of the Nondweni Group.

In the Golden Valley Inlier, a northern extension of the Nondweni Greenstones, several highly altered intrusions have been identified by Mckenzie (1992). Detailed geochemical and petrological criteria were used to classify the intrusions, which include tonalite, quartz-feldspar porphyry, dolerite, gabbro, high-Mg dykes, diabase dykes and Karoo dolerite.

2.1.1.3. **Melmoth Granite-Greenstone Relic**

This previously undifferentiated poorly exposed greenstone sequence, named by Bullen (1990), outcrops over some 360 km^2 to the west of Melmoth (Fig. 2.5) in northern KwaZulu-Natal. These rocks were subject to a detailed study by Bullen (1991), mainly for their economic significance as host to gold mineralisation, and because they could provide essential information with regards to exploration for gold in similar host rocks in the study area.

The Melmoth greenstones consist mainly of mafic (tholeiitic and komatiitic) metalavas (± 70%) with lesser serpentinite, talc schist, dacitic tuff, quartz-muscovite schist, quartzites and calc-silicate rocks. Mineralogical studies indicate that the metalavas have undergone greenschist facies metamorphism. Four phases of deformation with associated metamorphism are recognised. The second phase of this deformation, which is associated with granodiorite intrusions, north-south compression, folding about east-west trending axes and major brittle-ductile shearing, is most important as it is also associated with the gold deposits in these greenstones. The auriferous reefs are located in the west trending, 40-150 m wide Koningsberg shear zone.

2.1.1.3.1. **Melmoth Granite-Greenstone Remnant Intrusives**

This greenstone sequence has been intruded by syntectonic trondhjemitic gneisses, late-tectonic granodioritic gneisses and post-tectonic granite dykes (Bullen, 1991). These leucocratic, K-rich granite dykes intrude the granodioritic gneisses which crop out to the south of the greenstone sequence. Other intrusives comprise a probably Late-Archaean, sill-like metagabbro (Hlagothi Complex) as well as a number of Karoo-aged dolerite sills and dykes. The emplacement of the late-tectonic granodiorites was thought to be responsible for the generation of the shear zones that host the mineralisation (Bullen, 1991).

2.1.1.4. **Empangeni Group**

These predominantly granulite-grade supracrustal cratonic rocks comprise two formations (Table 2.2) and outcrop in the vicinity of Empangeni in northeastern KwaZulu-Natal. They are of similar age to the Nondweni Group but are lithologically and metamorphically distinct (Charlesworth, 1981). The amphibolite grade Ngweni Formation is thought to represent retrograde equivalents of the Lubana Formation (Charlesworth, 1981).

Table 2.2 : Subdivisions of the Empangeni Group (after Linström, 1987a)

Formation	Predominant Lithology
Ngweni	Generally foliated amphibolites consisting mainly of hornblende, hypersthene and diopside with very minor plagioclase and opaque minerals.
Lubana	Mainly melanocratic pyroxene-garnet-magnetite-quartzite granoblastites with interbanded gneisses. These lithologies have undergone granulite grade regional metamorphism.

2.1.1.4.1. Intrusives

The Nseleni Granitoid Gneiss is correlated with gneisses intruding the Nondweni Group (Linström, 1987a).

2.1.1.5. Nzimane Inlier

The Nzimane Inlier is exposed as several scattered fault-bounded outcrops of Archaean basement in the Hlabisa area in northeastern KwaZulu-Natal (Thomas et al., 1995a, Fig. 2.7). The Wela Formation consists of a ~500 m-thick greenstone succession of quartzites, Fe-rich and aluminous schists and banded iron-formation. As the Wela Formation was deformed and metamorphosed under amphibolite facies conditions, it is thought to provide a link between the greenschist facies greenstone assemblages in northwest KwaZulu-Natal and the Archaean granulites of the Empangeni Group that occur further to the south (Thomas et al., 1997).

This inlier is also believed to comprise the most easterly outcrops of the Mozaan Group yet discovered, thus extending the known limits of the Pongola Basin (Thomas et al., 1997). The Ntombe Formation of the Mozaan Group exposed here consists of ferruginous mudstones, fine-grained sandstones, rhythmites and iron formations. These Mozaan Group sediments were intruded by the Nzimane Granite which consist of a coarse-grained diorite-tonalite and porphyritic granite and medium- to fine-grained leucocratic granite (Thomas et al., 1995a).

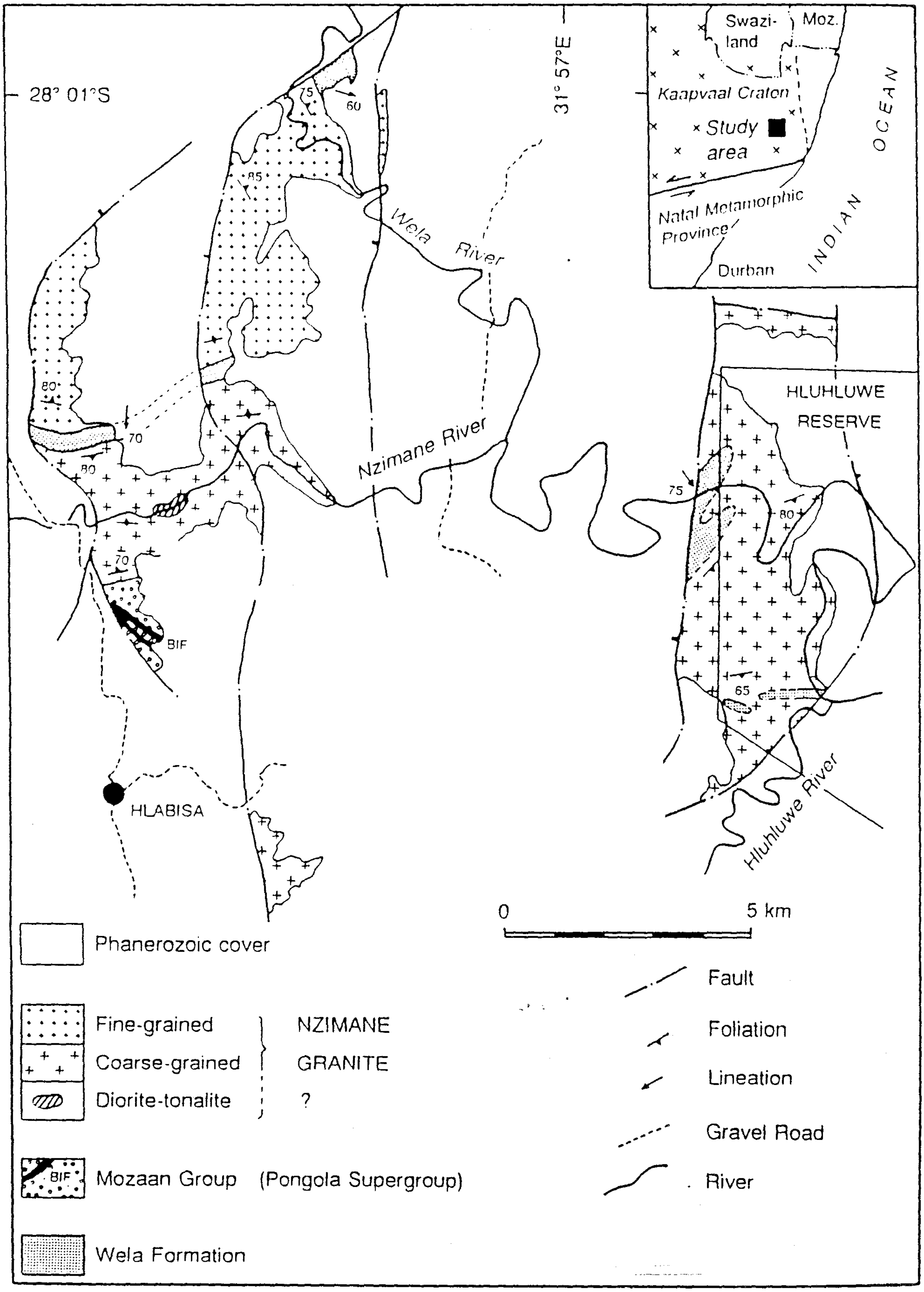


Fig. 2.7: Geology of the Nzimane Inlier, northeastern KwaZulu-Natal (after Thomas et al., 1995a).

2.1.2. THE PONGOLA SUPERGROUP

The Pongola Supergroup (Fig. 2.5), which unconformably overlies the granite-greenstone basement of the Kaapvaal Craton (SACS, 1980; Button, 1981) is one of the earliest known supracrustal sedimentary successions to have developed on a stabilised craton, and shows many features which suggest deposition in a continental rift environment (Burke et al., 1985).

Matthews (1990) concluded that deposition of the Pongola Supergroup occurred in two connected but contrasting structural domains. The N-S trending northern structural domain evolved as a half-graben, syndepositional rift-basin or aulacogen, while the E-W trending southern structural domain evolved originally as part of an epicratonic basin which probably opened southward onto a continental margin. Rifting in the northern domain was accompanied by extensive volcanism, resulting in the extrusion of most of the Nsuze Group volcanics. This was followed by thermal subsidence where predominantly shallow water sediments of the Mozaan Group were deposited. Late- to post-Pongola tectonothermal events followed, which were firstly, upper Mozaan volcanism, followed by extensive normal faulting and lastly widespread intrusives (Ushushwana Complex and granitoid plutons) which caused accommodation folding. The predominantly sedimentary southern domain with minor volcanic formations was thought to be deposited within a slowly subsiding epicratonic basin. Initial sedimentation (up to 5 km thick) was followed by up to 5 periods of deformation. Deformation included an episode of extensional tectonics that produced extensive N-dipping half-graben structures which contained up to 5 km of Nsuze Group lithologies. Regional uplift and erosion followed, after which regional subsidence and renewed sedimentation occurred as the post-rift thermal-subsidence basin of the Pongola aulacogen expanded southward to coalesce with the epicratonic basin.

The Pongola Supergroup has been subdivided into a lower volcano-sedimentary Nsuze Group and an upper sedimentary Mozaan Group which has been correlated with the Witwatersrand Supergroup (see Beukes and Cairncross, 1991). The lithologies outcrop as various inliers in northern KwaZulu-Natal, Mpumalanga and Swaziland (Fig.2.5). Each inlier is characterised by localised stratigraphic variances (Fig 2.8). A generalised stratigraphy for the entire Pongola Supergroup however, will be presented.

2.1.2.1. **Nsuze Group**

The Nsuze Group comprises an almost 8 km-thick succession of sediments, basaltic to andesitic lavas, and dacitic to rhyolitic lavas. The sediments at the base of the Nsuze Group rest on a palaeosaprolite up to 8 m thick, which indicates prior subaerial exposure of the underlying granitoid basement (Matthews and Scharrer, 1968; Watchorn and Armstrong, 1980). Subaerial weathering of the granitoids was accompanied by the development of braided stream systems, which deposited immature clastic sediments represented by the quartzites at the base of the Nsuze Group in certain areas (Armstrong et al., 1986). Complex interdigitation of mafic, intermediate and acidic lava flows are the result of lavas of variable composition being extruded simultaneously (Armstrong et al., 1982).

According to Hunter and Wilson (1988), the presence of pyroclastics and vesicular lava flows indicate that the last phases of Nsuze volcanism were fairly explosive. The final stages of Nsuze Group deposition are characterised by decreased volcanism and an increase in sedimentary rocks. Essentially the Nsuze Group is made up of four formations (Table 2.3), and these are characteristically developed in the different type areas. Table 2.3 is derived from descriptions given by Armstrong et al. (1982), while Table 2.4 briefly describes the Nsuze Group in the Nkandla area.

In the White Mfolozi inlier, SE of Vryheid, the Nsuze Group attains a maximum thickness of 2 000 m and is subdivided into six formations (SACS, 1980), composed mainly of quartzitic sandstones, shales and lavas.

Until recently, no attempt had been made to establish regional correlations of the different Nsuze Group units throughout the various outcrop areas. Detailed lithostratigraphic studies of the entire outcrop area of Nsuze strata by Cole and Beukes (1995) have solved this shortcoming and presented a generalised stratigraphy of the entire depository of the Nsuze Group (Table 2.5).

Table 2.3 : Predominant Nsuze Group Lithologies (after Armstrong et al., 1982).

Formation	Thickness	Predominant Lithologies
Roodewal	5 - 600 m	Predominantly consists of pyroclastic and volcanogenic sediments (fine-grained rocks composed mainly of sedimentary and pyroclastic debris). This formation is transitional with the overlying Mozaan Group. Argillites and air-fall tuffs with arenaceous and volcanic lenses are developed here. Intercalated with the volcanogenic sediments are lenses of epiclastic volcanic breccias, accretionary lapilli tuffs, arenaceous sediments and minor lava flows. Highly vesicular dacitic to rhyolitic lava flows (< 5 m thick) are sporadically developed.
Bivane	± 7500 m	A volcanic unit with minor intercalated volcaniclastic and sedimentary rocks. The lavas comprise basalts, basaltic andesites, andesites, dacites and rhyolites, with flows of different compositions complexly interfingered. Pyroclastics consist of ash-flow tuffs, pumice fragments, tuff agglomerates, and well-stratified air-fall tuffs. Hyaloclastites (unstratified breccia made up of angular, dacitic fragments set in an arenaceous matrix) are also reported. Immature arenaceous rocks (quartz wackes) make up most of the sediments.
Mantonga	± 800 m	Intercalated sandstones, lavas and volcaniclastic rocks resting on a granite palaeosaprolite. Conglomeratic lenses (up to 50 cm thick) are best developed in the lower 100 m. The lava flows are 2 to 30 m thick and range in composition from basaltic andesite through andesite and dacite to rhyolite. The pyroclastics are mainly air-fall tuffs with minor agglomeratic phases and a welded ash-flow unit (± 10 m thick).
Wagendrift		Only developed in certain areas. Basaltic lavas with locally developed sandstone lenses. Formation is generally poorly exposed. The lavas chemically and petrologically resemble those of the Bivane Formation.

The exposures near Nkandla are the southernmost outcrops of the Nsuze Group, where it is subdivided into five formations, three of which were recently revised (Table 2.4).

Table 2.4: The Nsuze Group in the Nkandla Area

Formation	Description
Msukane (SACS, 1980)	Phyllites with intercalated sheared amygdaloidal lavas.
Dlabe (SACS, 1980)	Quartzites with amygdaloidal basalt near the top.
Mome (Linström and Matthews, 1990a)	Predominantly pure quartzites capped by a subordinate phyllite unit. Minor amygdaloidal metalavas (basaltic to andesitic) and BIF occur locally near the top of the formation.
Mabaleni (Linström and Matthews, 1990b)	Predominantly pure quartzites with an overlying phyllite unit containing minor interbedded BIF.
Hlathini (Linström and Matthews, 1990c)	Alternating fine-grained quartzite and laminated to thin-bedded phyllite. Unconformably overlies the uppermost formations of the Nondweni Group.

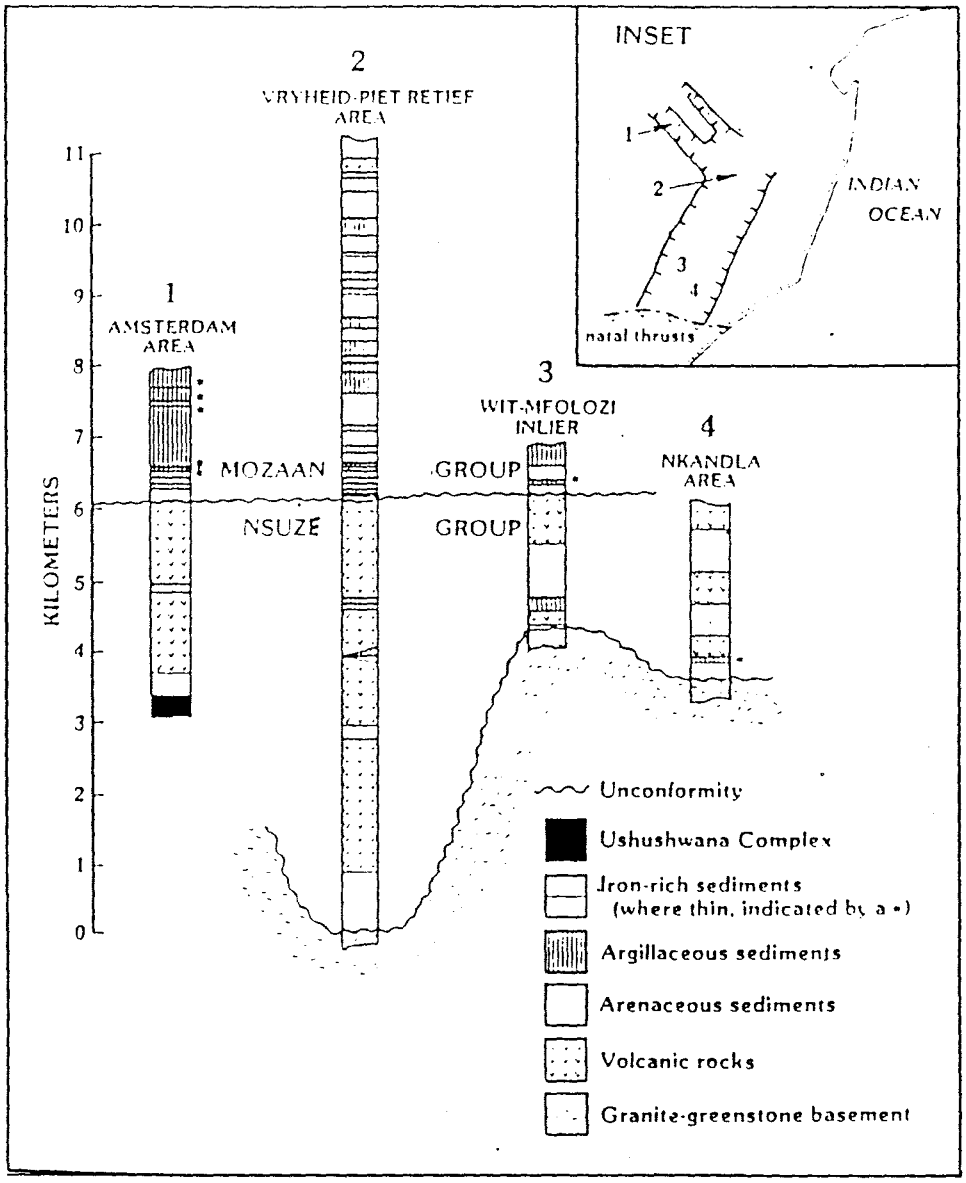


Fig. 2.8: Simplified stratigraphic columns of some inliers of the Pongola Supergroup (after Burke et al, 1985).

Table 2.5: Regional Stratigraphy of the Nsuze Group (after Cole and Beukes, 1995)

Formation	Description
Nzimini *	Highly deformed diamictite unit that is only preserved in the southernmost outcrops in the vicinity of Nqutu.
Ekombe	An upper lava unit that is only preserved in the Nkandla area.
Mkuzane	A largely argillaceous unit that is best preserved in the northeastern outcrop areas.
Vutshini/Langfontein	A predominantly arenaceous unit that is in some places characterised by a basal sedimentary/volcaniclastic unit termed the Roodewal Member. The Vutshini Formation outcrops in the Nkandla area and is a southern correlate of the Langfontein Formation.
Agatha	A middle lava unit within which a shale-rich subunit (Ntambo Member) is developed in the northern outcrop area. To the south, the shale unit becomes quartzitic.
White Mfolozi	A middle sedimentary unit predominantly composed of quartzite and shale with subordinate siltstone, diamictite and a characteristic stromatolitic carbonate marker bed (the Chobeni Member).
Pypklipberg	A dominantly mafic, amygdaloidal lava unit.
Mantonga	A basal sedimentary unit composed primarily of quartzite, with subordinate shale, diamictite and conglomerate.

* : The Nzimini Formation has limited outcrop and structural complexities which precludes the establishment of an exact stratigraphic position.

2.1.2.2. **Mozaan Group**

The Mozaan Group rests with a broadly gradational contact (Watchorn, 1980a) over the Nsuze Group and comprises mainly arenaceous and argillaceous sedimentary rocks. However, in the White Mfolozi inlier, the Nsuze-Mozaan contact forms a marked unconformity, as a progressive overstep has removed approximately 1 200 m of Nsuze Group stratigraphy (Gold, 1993). The lithologies are mainly mudstone, siltstone and sandstone, interlayered with conglomerate, banded iron-formation (BIF) and recently-recognised Archaean diamictite (von Brunn and Gold, 1993; Gold, 1993).

Two depositional environments for the Mozaan sediments are proposed (Beukes and Cairncross, 1991). The first is a mainly current-, wave- or storm-dominated marine shelf environment which formed shale-siltstone/quartzite successions, iron formation and magnetic mudstone, which are interbedded with marine shelf environment laminated sediments. The former depositional environment is interbedded with a fluvial braidplain environment that is typified by very coarse-grained to pebbly sandstones and a virtual absence of mudstone. Metamorphism is generally of lower greenschist facies except where the lithologies were affected by effects of contact metamorphism due to granite and mafic-ultramafic intrusives (Linström, 1987b).

A composite reference stratigraphic profile for the Mozaan Group from type areas in the Bivane and Mozaan River gorges is detailed by Beukes and Cairncross (1991). The nine subdivisions recognised are briefly described in Table 2.6. This profile is important in that it shows many similarities with the Witwatersrand Supergroup (see chapter six). Stratigraphic profiles of specific areas have been detailed by SACS (1980), Gold (1993) and Gold and Von Veh (1995).

Table 2.6: Subdivisions of the Mozaan Group (After Beukes and Cairncross, 1991).

Formation	Thickness	Lithological Description
Ntanyana	± 150 m	Finely-laminated shale at the base overlain by ferruginous, immature quartzites and siltstones.
Gabela	± 150 m	Coarse-grained and agglomeratic at the base with green, massive, quartz-bearing volcaniclastic greywacke towards the top.
Bongaspoort	± 250 m	Coarse-grained, slightly argillaceous, khaki-coloured quartzite, siltstone and shale. Has sharp contact with the overlying Gabela Formation.
Khiphunyawa	± 510 m	Mainly laminated ferruginous shales and magnetic mudstones. The 40 - 50 m thick Tobolsk mafic lava member occurs here and is highly amygdaloidal, with thin tuffaceous beds at the top and bottom. The lavas are overlain by shales, siltstones and quartzites.
Delfkom	± 1 000 m	Consists predominantly of coarse-grained quartzites with interbedded shales and magnetic mudstones. Thin, lenticular chert-clast lag conglomerates also occur. Numerous mafic sills intrude the succession.
Hlashana	± 125 m	Consists mainly of medium- to coarse-grained quartzites with well-developed sedimentary structures. Angular chert pebble lags are present at the base of some units.
Thalu	± 720 m	Basal ± 40 m thick quartzite overlain by a prominent 10 m-thick BIF (Scots Hill member). This is overlain by five units of shale-interlaminated shale/siltstone facies successions. The uppermost part of this formation is obscured by a 360 m thick mafic sill which is in direct contact with the quartzite if the Hlashane Formation.
Ntombe	± 1 300 m	Comprises successions (up to 200 m thick) of carbonaceous shale and interlaminated shale/siltstone, with some successions capped by quartzites. Iron-formation present in the upper part has irregular chert-mesobanding.
Sinqeni	± 580 m	Consists of two major quartzite units (Dipka and Kwaaiman members) separated by an 80 m thick Ijzermijn shale member containing a distinct 5 m thick bed of jasper-banded iron-formation. The basal Dipka quartzite member (± 330 m thick) rests with a sharp contact on underlying Nsuze Group lithologies.

2.1.2.3. **Pongola Supergroup Intrusives**

Pongola Supergroup volcanism and sedimentation was followed by the emplacement of mafic and ultramafic intrusions mainly into the stratigraphically lowest formations of the Nsuze Group (Hunter and Wilson, 1988). This was followed by renewed granitoid magmatism between 2.7 and 2.5 Ga (Tankard et al., 1982). The youngest intrusives are represented by Karoo-aged dolerite dykes and sills.

The Ushushwana Intrusive Suite (Fig.2.5) predominantly comprises quartz gabbro, diorite and granophyre (Hunter and Wilson, 1988) and outcrops in three different areas. The Suite has been dated, using Sm-Nd/whole rock isochron, at 2 876 ± 30 Ma (Hegner et al., 1984). In

KwaZulu-Natal it occurs as a sill like body at the base of the Nsuze Group.

The Hlagothi Complex (Fig. 2.5), recognised in the southern inliers in the lowermost formations of the Nsuze Group, was found to have many similarities with Archaean basaltic komatiites (Groenewald, 1984). In several sills, the upper lithologies contain skeletal pyroxene blades in a fine-grained groundmass that resemble the spinifex texture in extrusive komatiitic basalts (Groenewald, 1984) which are found in the Barberton greenstones, and in the underlying Nondweni remnant (Hunter and Wilson, 1988). The intrusion comprises several differentiated sills, each consisting of successive layers of peridotite, pyroxenite, olivine gabbronorite and gabbro (Hunter and Wilson, 1988). Marked variations in average compositions of the various units were noted with the layering resulting from the successive fractionation of olivine, clinopyroxene and orthopyroxene. From age determinations and field relations Groenewald (1988) speculated that the intrusion occurred during the deposition of the Pongola Supergroup, which would have several implications on the age suggested for the complete stabilisation of the southeastern part of the craton. Other locally transgressive ultramafic bodies also occur e.g. the Brandlaagte intrusive suite, which has been tentatively correlated with the Hlagothi Complex and the Ushushwana Complex (Versfeld, 1988).

A suite of post-Pongola granitoids were intruded mainly along the eastern and southern margins of the Pongola Supergroup depositional basin. Matthews (1985) delineated three distinctive granites along the eastern margin. In KwaZulu-Natal the extensive coarse-grained Spekboom Granite and finer-grained Godlwayo granite were identified, each with a narrow (± 1 km) contact aureole. The granites have similar mineral assemblages, composed essentially of quartz, K-feldspar and plagioclase with minor biotite and accessory sphene, apatite, zircon and iron ore.

Due to locally developed accommodation structures (such as superimposed fold patterns) in the adjacent Mozaan Group sediments, Matthews (1985) considered these plutons as anorogenic intrusions and concluded from structural and stratigraphic evidence that these granite plutons were emplaced at depths of approximately 6 to 7 km.

2.2. THE PROTEROZOIC: Natal Metamorphic Province

Thomas (1989a) recognised three discontinuity bounded tectonostratigraphic domains in the Natal Metamorphic Province (Fig 2.9). These are (from north to south) the Tugela, Mzumbe and Margate Terranes. These terranes were intruded by magmatic rocks of various ages. The southern, western and eastern limits of the belt are concealed beneath younger cover rocks. The Tugela Terrane boundary with the Archaean Kaapvaal Craton is known as the Natal Thrust Front which has been previously described in this chapter, where the Tugela Terrane nappes have been obducted onto the southeastern margin of the craton (Matthews, 1972).

The amphibolite- to greenschist-grade Tugela Terrane is separated from the upper amphibolite-grade Mzumbe Terrane by the Lilani-Matigulu Shear Zone (Jacobs et al., 1993; Thomas et al., 1994b) while in the south, the Melville Thrust (Thomas, 1989a) separates the granulite-grade Margate Terrane from the Mzumbe Terrane. The Lilani-Matigulu shear zone also represents the geophysical southern margin of the Kaapvaal Craton (Thomas et al., 1994b), which further validates the obduction theory. The southern margin of the Margate terrane is not exposed. Thomas and Mawson (1989) however, reported a return to amphibolite facies and a unique pretectonic Sikombe Granite in the Eastern Cape Province, which may represent the remnants of another tectonic domain lying to the south of the Margate Terrane. The Sikombe Granite may be related to the Margate Granite Suite (Thomas, 1990d).

The rocks of the Tugela Terrane have been interpreted by Matthews (1972) as being an ophiolite assemblage that was deposited in an oceanic basin to the south of the Kaapvaal Craton. This terrane was then intruded by mafic-ultramafic complexes, alpine serpentinites, plagiogranites and a number of alkaline to peralkaline granitoids (e.g. Scogings, 1989a). The oldest rocks recognised in the Mzumbe and Margate Terranes comprise arc-related, felsic to mafic metavolcanic supracrustal gneisses with subordinate metasediments (Thomas et al., 1992d). According to Thomas and Eglington (1990), volcanic arcs associated with the subduction of the Tugela Ocean were responsible for the development of the two southern terranes. The NMP has been regarded as a juvenile orogen, since no trace of older basement or floor upon which the rocks may have been deposited is recognised (Thomas and Eglington, 1990).

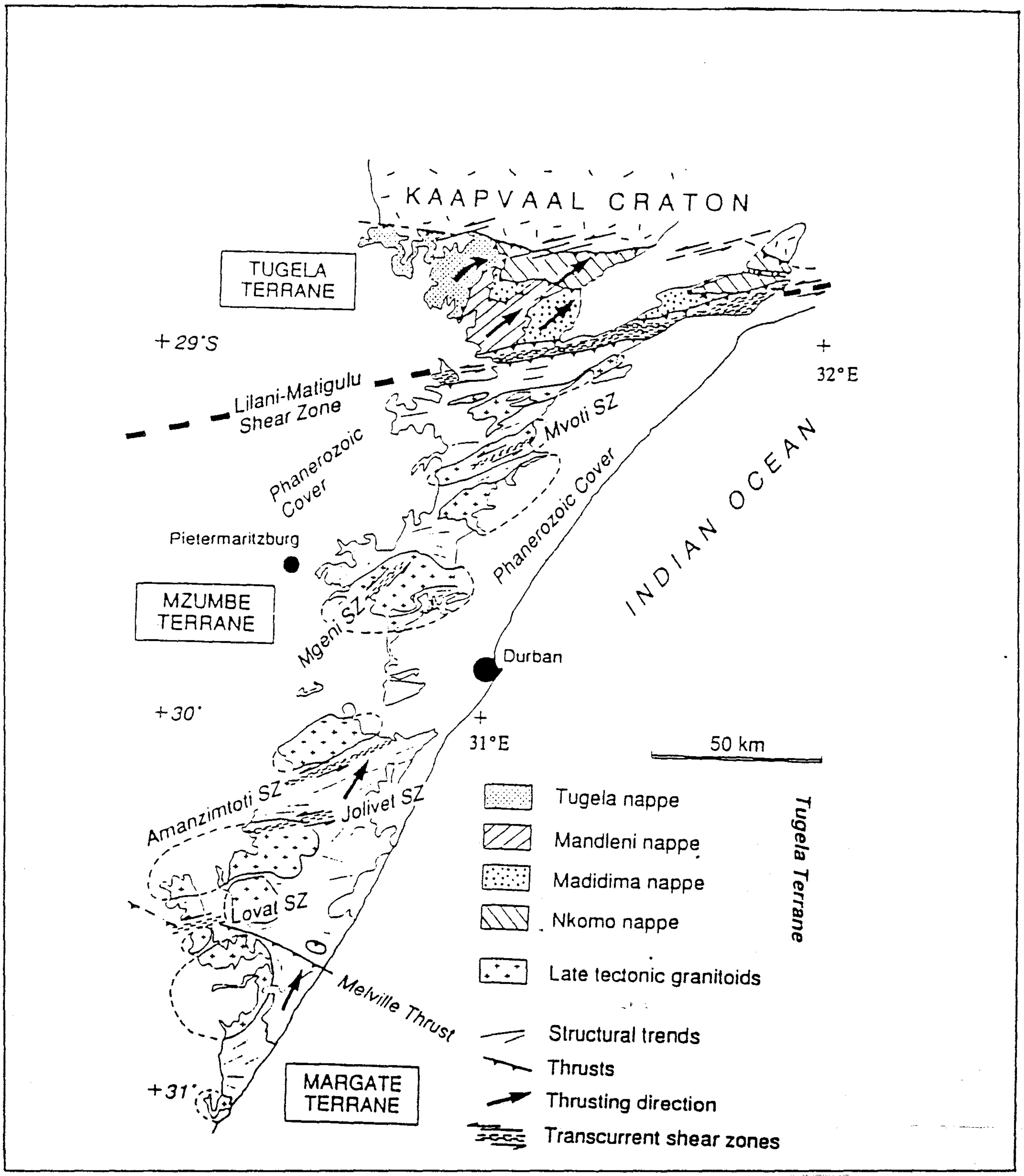


Fig. 2.9: Major tectonostratigraphic subdivisions, thrust directions and transcurrent shear zones of the NMP (after Matthews and Charlesworth, 1981; Thomas, 1989a, Jacobs et al., 1993).

The following account, from Thomas et al. (1994b, 1995b), briefly describes the sequence of events that occurred in the NMP. During an early phase of NE-directed thrusting and nappe emplacement, which resulted from oblique arc-continent collision associated with the closure of the Tugela Ocean, the three NMP Terranes were accreted onto the SE margin of the Kaapvaal Craton. This led to an inverse metamorphic stacking across the belt, such that the southern granulite Margate Terrane was thrust over the upper amphibolite Mzumbe Terrane (Fig.2.10). The Mzumbe Terrane was thrust over the amphibolite/greenschist facies Tugela Terrane, which was in turn thrust onto the craton to the north (Thomas et al., 1994b).

From thermobarometric studies in southern KwaZulu-Natal, it has been noted in Thomas et al. (1992a), that while the peak metamorphic temperatures of the two southern terranes are different (Margate Terrane >800°C and Mzumbe Terrane <750°), pressures were generally similar throughout at between 5-8 kb. This led Thomas et al. (1992g) to suggest that the southern granulite terrane does not represent a deeper portion of the crust than the northern amphibolite terrane and the higher temperatures were probably attained due to more extensive magmatic underplating.

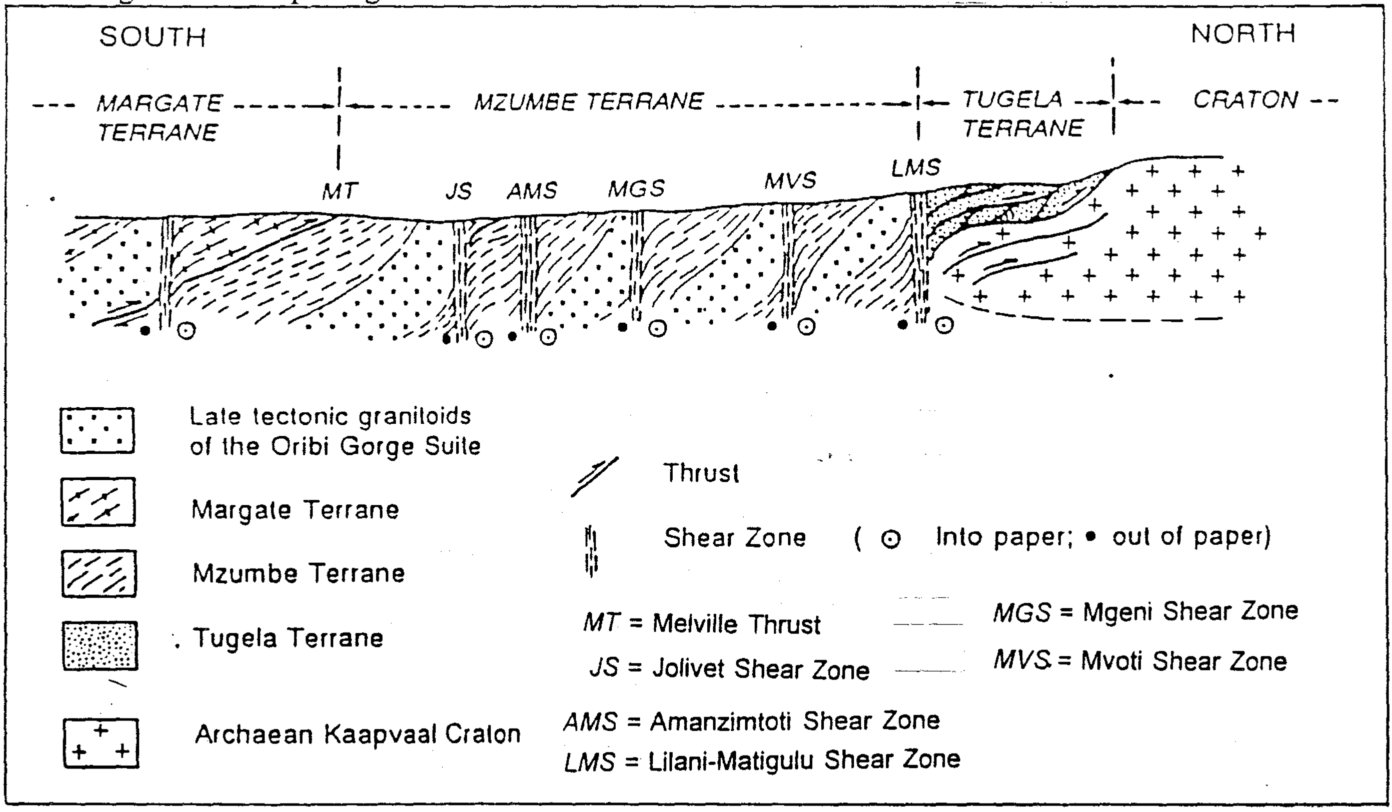


Fig.2.10: Schematic cross-section of the Natal Metamorphic Province (after Thomas et al., 1994b).

The initial phase of NE-directed thrusting led to crustal thickening, which progressed to ductile transcurrent shearing with continued thrusting. This collision-induced crustal thickening caused intense deformation, while high-grade metamorphism led to widespread melting and the generation of vast granitoid magmas that intruded the southern terranes (Figs. 2.11A,B,C).

These early (~ 1.3 Ga) gneisses were intruded at ~ 1.2 Ga by calc-alkaline, I-type granitoid orthogneisses, probably in a mature volcanic-arc setting (Thomas and Eglington, 1990) and by syn-, late- and post-tectonic granitoids between ~ 1.1 and 1.0 Ga (Eglington et al., 1989; Thomas et al., 1990b, 1992d,e). The syn-tectonic magmatic events produced intrusions of sheet-like granitic gneisses, of which many are peraluminous, S-type granites derived from partial melting of the supracrustal sequences (Thomas et al., 1994b). Late-tectonic magmatism was ascribed by Thomas (1988a) to be represented by voluminous rapakivi-textured granitoid/charnockite plutons of the Oribi Gorge Suite. Post-tectonic magmatic activity is considered to be represented by a small swarm of microgranite dykes in the Margate area (Thomas et al., 1990b).

Continued NE-directed thrusting onto the Kaapvaal Craton (which can be regarded as a SW-directed indentor) resulted in pervasive left-lateral transcurrent shearing in Natal (Fig.2.9). As a result, the Mzumbe and Margate Terranes are extensively deformed by numerous SE- to SSE-trending sinistral transcurrent shear zones and mylonite belts (Figs. 2.9 and 2.11C). As noted earlier, the Lilani-Matigulu Shear Zone coincides with the geophysically-determined southern margin of the Kaapvaal Craton. This oblique wrench structure is thought to represent a reactivation of a major long-lived transform margin (Matthews, 1990) which initially separated the Kaapvaal Craton from the Tugela Ocean. The Tugela-Terrane thrust nappes overlie the rigid cratonic crust and were not affected by later shearing. It is likely that large amounts of this strain were accommodated along the old transform margin, resulting in the formation of the Lilani-Matigulu Shear Zone (Thomas et al., 1995b).

The tectonic evolution and mineralisation in the Natal Metamorphic Province will be discussed in detail in Chapter Six.

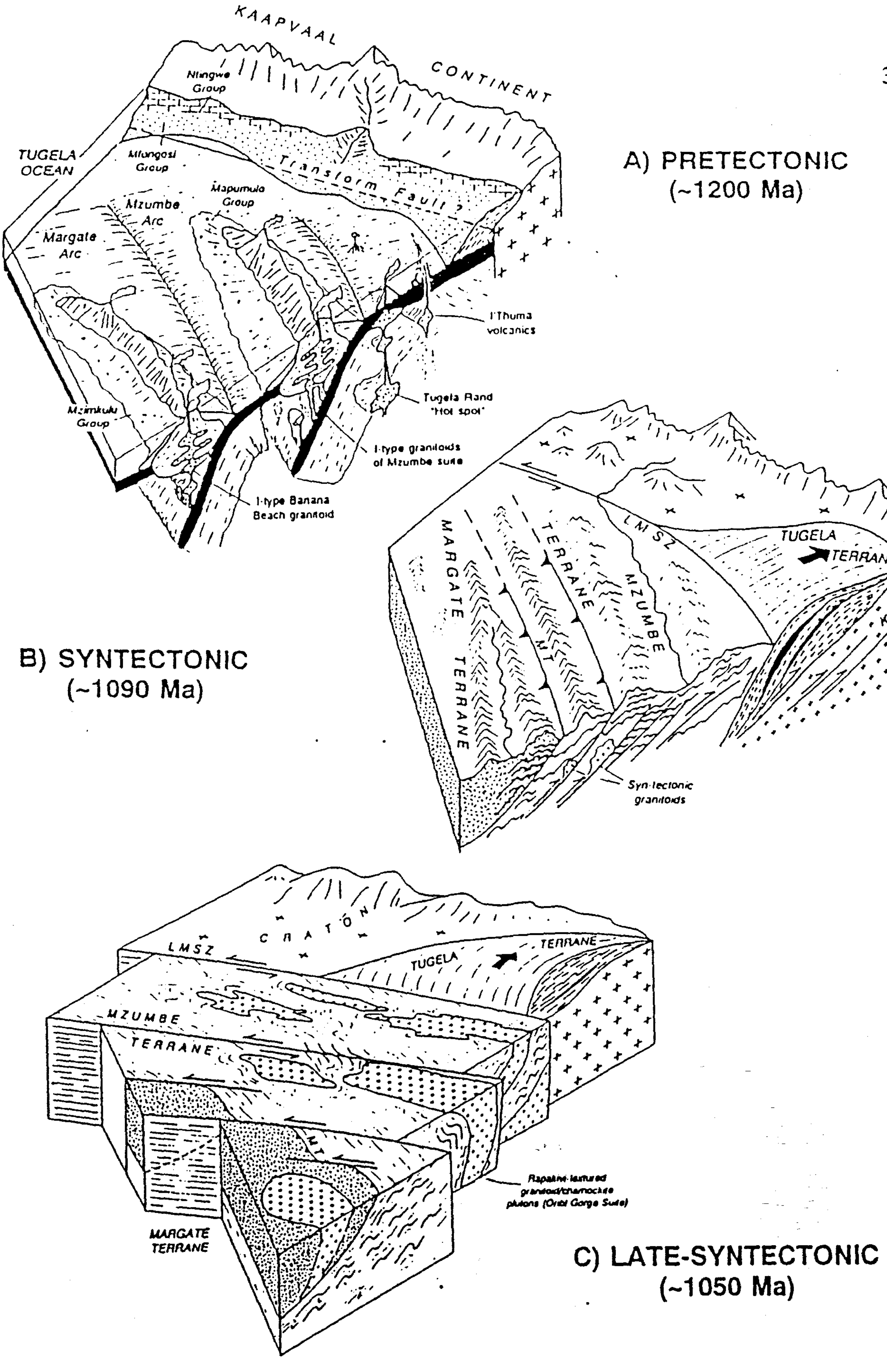


Fig.2.11: Block diagrams illustrating the possible tectonic evolution of the NMP terranes (after Jacobs and Thomas, 1994).

2.2.1. **The Tugela Terrane**

This northern terrane comprises the intensely folded and imbricate Natal Thrust Front (maximum 12 km wide) and a nappe zone (Fig.2.12). The northernmost part of the terrane is in tectonic contact with rocks of the Kaapvaal Craton. Matthews (1972) suggested that the thrust front represents a deformed and metamorphosed Proterozoic obduction zone, consisting of mafic/ultramafic oceanic crust overlain by pelagic metasediments and metalavas which were interpreted as the middle and upper parts of an ophiolite complex. These rocks were transported northwards in a series of thrust nappes onto the SE margin of the Kaapvaal Craton along a sole décollement known as the Mfongosi Thrust (Matthews and Charlesworth, 1981). The southern extremity of the Tugela Terrane is represented by the Matigulu Steep Belt.

The Tugela Terrane has been subdivided by Linström (1987a) into four groups, based on data derived from Matthews (1959, 1981a), Matthews and Charlesworth (1981) and (SACS, 1980). The Ntingwe and Mfongosi Groups have been recognised in the thrust front. To the south, the four thrust nappes have been collectively placed into the Tugela Group, while the Matigulu Group represents the steep belt. The various formations that make up these groups in the different areas are summarised in the tables below. All lithologies are in descending order. For outcrops of the individual formations, the reader is referred to the 1:250 000 scale Geological Survey Map of Dundee.

2.2.1.1. **Natal Thrust Front: Ntingwe Group and Mfongosi Group**

According to Matthews (1959) and Cain (1975), the Ntingwe Group lithologies represent stable shallow water shelf sediments, while the Mfongosi Group comprises a "mixed volcanic-tuffaceous-flyschoid-argillite sequence". The Ntingwe Group unconformably overlies the older granites and supracrustal sequences of the Kaapvaal Craton. It is overlain by the Mfongosi Group which had been thrust onto it.

The Mfongosi Group occurs in two sectors along the frontal part of the thrust belt, with four formations delineated in each of the eastern and western sectors (Fig.2.12). Predominant lithologies are greenschist facies chlorite-rich metalavas (with pervasive carbonate alteration) and phyllitic/schistose meta-pelites, with locally developed, thin, laterally persistent graphitic schist horizons (Thomas et al., 1990a).

Table 2.7 : Ntingwe Group Lithologies

Formation	Thickness	Lithology
Makasana	± 90 m	White limestone with a few thin argillite beds and a sandy, ferruginous dolomitic limestone with a number of thin interbedded mudstones.
Manzawayo	± 170 m	Alternating beds of blue mudstone and grit overlain by massive to coarsely bedded mudstone and shale with impressions of carbonaceous material. Minor intercalated red and white limestones also present.
Dlolwana	± 100 m	Coarse clastics ranging from arkosic grit to conglomerate and breccia containing fragments of foreland lithologies up to 30 cm in diameter.

Data from Matthews (1959), SACS (1980) and Linström (1987a).

Table 2.8a : Mfongosi Group - Western Sector (after Linström, 1987a)

Formation	Predominant Lithology
Matigwe Schist	Phyllitic schist and contorted quartz-muscovite (chlorite) schists containing abundant quartz segregation veins.
Ngubevu Schist	Metamorphosed amygdales and deformed pillow lavas. Chlorite-epidote schist with some talc, carbonate and albite, and fine-grained amphibolite. A ± 6 m thick BIF occurs interbedded within the schist and amphibolite.
Dinuntuli Schist	Laminated quartz-chlorite-sericite schist with intercalations of quartz-carbonate-chlorite schists (which are often altered to calc-silicates). Thin units of fine-grained quartzite (pebbly in places) are locally developed.
Samangu Schist	Foliated and massive amphibolite with relict amygdaloidal and deformed pillow structures. Undifferentiated, banded pyroxene- or biotite-bearing hornblende gneiss.

Table 2.8b : Mfongosi Group - Eastern Sector (after Linström, 1987a)

Formation	Predominant Lithology
Sibudeni Schist	Quartz-chlorite-sericite schist with subordinate sandy phyllite, quartzite and BIF. Also present are chlorite-amphibole schist, siliceous chlorite mylonite and garnet-chlorite-quartz schist.
Bope Schist	Fine- to medium-grained, crenulated quartz-sericite schist which is chlorite rich in places.
Nkunzana Schist	Well-foliated, quartz-chlorite phyllitic schist with minor biotite and sericite. Siliceous mylonite also occurs.
Mazula Schist	Succession of fine-grained biotite-muscovite-quartz schist with porphyroblasts of red garnet and brown staurolite. Discontinuous granular quartz lenses and veins concordant with the schistosity also noted.

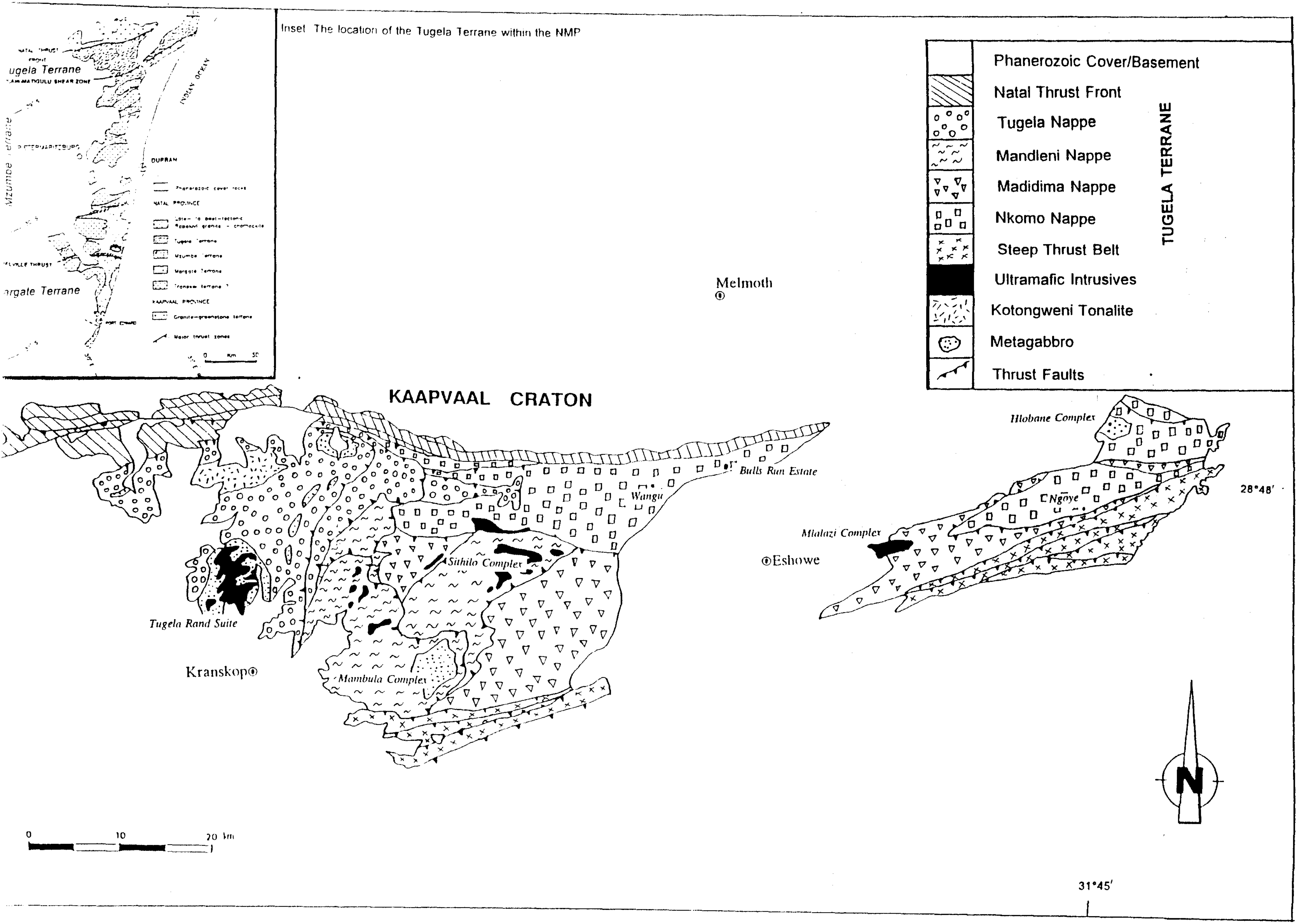


Fig 2.12: Simplified tectonic map showing subdivisions of the Tugela Terrane (after Matthews and Charlesworth, 1981).

Nappe Zone: Tugela Group

The Tugela Group is present in the four sub-horizontal thrust sheets which comprise the Nkomo, Madidima, Mandleni and Tugela Nappes (Linström, 1987a) , with each nappe or thrust sheet divided into a number of formations in either the eastern or western sector of the Tugela Terrane (Fig.2.12). These are tabulated below, from the lowest thrust sheet upward with brief descriptions of each formation from SACS (1980) and Linström (1987a). The intrusives in each nappe will also be described.

2.2.1.2.1. Nkomo Nappe

This lowermost thrust sheet, which occurs in both the eastern and western sectors of the Tugela Terrane, was mapped in detail by Charlesworth (1981, cited in Linström, 1987a) and consists mainly of amphibolite and granitoid gneiss.

Table 2.9: Nkomo Nappe: Formations and Lithologies (after Linström, 1987a)

Western Sector	
Khomo Formation Woshane Formation	Foliated, fine- to medium-grained, melanocratic amphibolite with dominant hornblende and plagioclase. Subordinate biotite and chlorite also present.
Eastern Sector	
Mtengu Formation	Similar to the Khomo and Woshane Formations above

2.2.1.2.1.1. Nkomo Nappe Intrusives

Hlobane Complex

The Hlobane Complex, in the eastern sector, consists of weakly foliated to massive, medium- to coarse-grained meta-igneous rocks. According to Linström (1987a), the rocks grade in composition from olivine norite through troctolite gabbro to normal gabbro. Thin anorthosite and serpentinite bands also occur.

Bulls Run Complex (BRC)

This Complex (Fig. 2.13) forms a prominent easterly trending ridge, some 15 km long and up to 1,5 km wide, above the north bank of the Mhlatuze River. The BRC is lithologically complex and comprises a variety of geochemically related undersaturated to saturated alkaline/peralkaline syenitic gneisses and minor dyke- or sheet-like intrusive phases of peralkaline microsyenite dykes, alkaline mafic gneiss and carbonate gneisses (Scogings, 1989b, 1991a). The carbonate gneisses were interpreted as metamorphosed carbonatites by Scogings and Forster, (1989).

Three syenite gneisses have been recognised here, namely nepheline syenite, albite syenite and muscovite syenite. The nepheline and albite syenites form the elongate central core of the complex. The nepheline syenites in the eastern part of the complex are pyroxene-bearing mafic varieties while in the central and western parts, the syenites are biotite-rich and are leucocratic. The albite syenites are leucocratic and relatively siliceous. The muscovite syenites form an envelope around the nepheline and albite syenites and are characterised by high muscovite contents. Several small plug-like occurrences of nepheline syenite gneiss also occur towards the eastern end of the complex. Detailed mineralogical and geochemical analyses on this Complex were carried out by Scogings (1989b) and Scogings and Forster (1989).

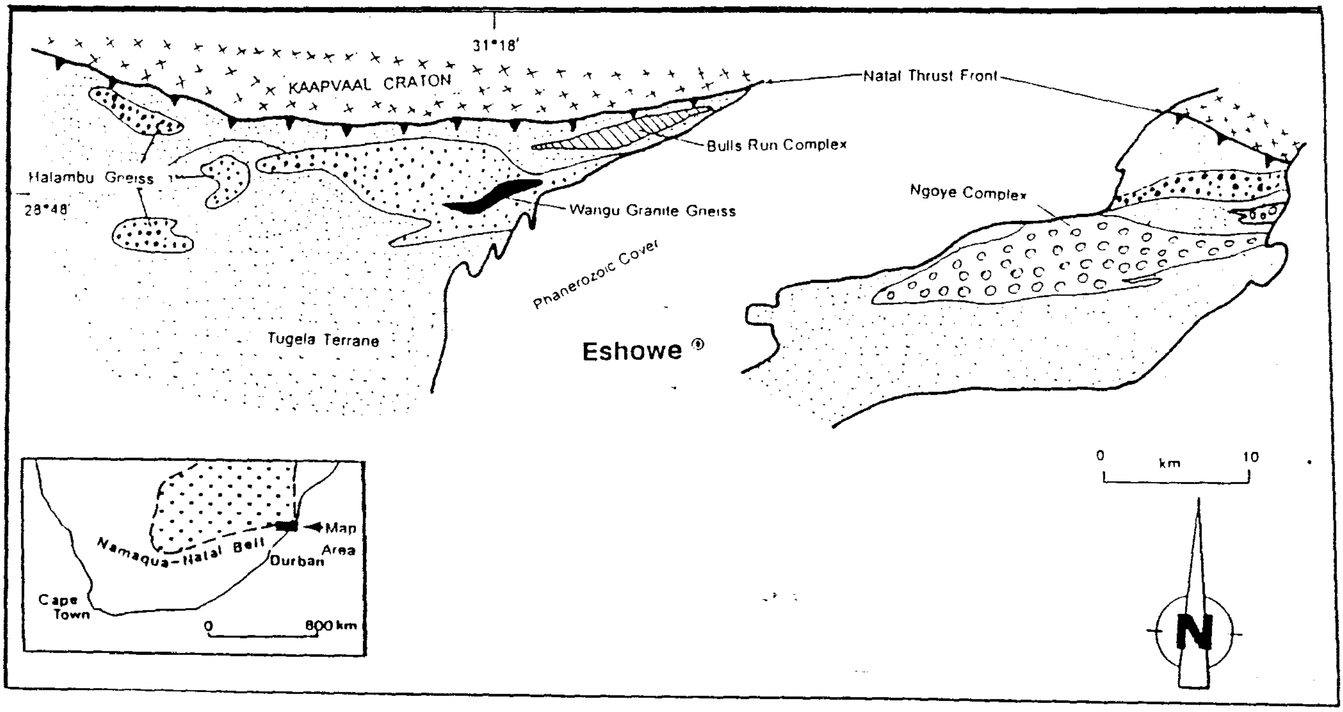


Fig 2.13: Distribution of the Bulls Run Complex, Wangu Gneisses, Ngoye Complex and Halambu Formation gneisses within the Tugela Terrane (from Scogings, 1989a; 1991b).

Ngoye Complex

The Ngoye Hills SW of Empangeni (Fig.2.13), in the eastern sector of the Tugela terrane, consists mainly of rocks of the Ngoye Complex (Scogings, 1990). The intrusion forms a prominent easterly-trending whaleback massif about 30 km long and up to 4 km wide, with a height of 300 m above the country rocks. A smaller satellite body, about 3 km long occurs NE of the main intrusion.

The Complex essentially consists of geochemically related alkaline to peralkaline A-type granitoid gneisses and minor monzodioritic and syenitic gneiss phases (Scogings, 1985; 1986; 1990). The lithologies have been subdivided according to geochemistry and mineralogy into three broad varieties of granite gneisses, namely peraluminous, peralkaline and metaluminous types. The peraluminous granites are muscovite- and garnet-bearing while the metaluminous varieties contain pale-green biotite and hornblende. The peralkaline variety consists of riebeckite granite gneiss and magnetite microgranite gneiss, with fluorite and zircon as common accessory phases.

Halambu Granitoid Gneiss

These deformed intrusive gneisses of calc-alkaline, granodioritic affinity outcrop in both the eastern and western sectors of the Nkomo Nappe. The rocks show a strong pervasive east-west foliation and were metamorphosed to upper amphibolite grades. Charlesworth (1981) was first to give a detailed description of these intrusive rocks, which were further differentiated by Scogings (1989a).

Wangu Granite Gneiss

These alkaline/peralkaline granitoid gneisses with minor alkaline mafic intrusive phases have recently been differentiated within the granodioritic gneisses of the Halambu Formation in the western sector of the NMP (Scogings, 1989a; 1991b). The intrusion is an elongate easterly-trending body some 6 km long and up to 1 km wide (Fig. 2.13). Two granitic gneisses and one mafic gneiss have been recognised on the basis of modal mineralogy (Scogings, 1991b). Leucocratic magnetite granite gneiss predominates, with biotite and fluorite as accessory phases, while aegerine granite gneiss forms the other granitic phase. The mafic gneiss occurs as sheets up to 30 m long and 1 m thick, and contains xenoliths of peralkaline granitoid gneiss

(Scogings, 1991b).

2.2.1.2.2. **Madidima Nappe**

This nappe occurs in the eastern and western sectors and comprises six formations as shown in Table 2.10.

Table 2.10 : Madidima Nappe Formations and Lithologies (after Linström, 1987a).

Western Sector	
Silambo Formation Zwaneni Formation	Banded and homogeneous amphibolite formations which comprise a variety of mineral assemblages but with dominant hornblende and plagioclase and local concentrations of garnet or epidote. Dolomite, quartzite and magnetite quartzite are associated with the homogeneous amphibolite in places.
Zidoni Formation	Streaky and banded amphibolitic gneiss containing plagioclase, hornblende and biotite.
Gazeni Formation	Well-foliated micaceous schist and gneiss containing biotite, muscovite, quartz, plagioclase, garnet and staurolite.
Thawini Formation	Light-grey, well-foliated gneiss made up of plagioclase, quartz and biotite, ± hornblende, with minor epidote, garnet, magnetite, sillimanite, staurolite and cordierite.
Eastern Sector	
Endlovini Formation	Essentially similar lithologies to the Silambo and Zwaneni Formations above.

2.2.1.2.2.1. **Madidima Nappe Intrusives**

The Zwaneni and Silambo Formations are intruded by small bodies of serpentinite.

Mlalazi Complex

This Complex, confined to the eastern sector (Fig. 2.12), comprises a thrust-bound serpentinite body, an ultramafic schist unit, and a metagabbro (Linström, 1987a). The serpentinite body is well-foliated and contains minor amounts of metapyroxenite, with thin layers of talc schist along some of the thrust boundaries. The fine- to medium-grained ultramafic schist contains variable amounts of talc, amphibole and chlorite, while the leucocratic to melanocratic gabbro (also fine- to medium-grained) contains numerous amphibolite inclusions.

2.2.1.2.3. **Mandleni Nappe**

The Mandleni Nappe, confined to the western sector, consists of four formations (Table. 2.11) and two intrusive mafic and ultramafic bodies.

Table 2.11: Mandleni Nappe Formations and Lithologies (after Linström, 1987a).

Formation	**Predominant Lithologies**
Wosi	Well foliated, dark grey to greenish black amphibolite with > 50% hornblende and white feldspar specks which form streaked-out lenses parallel to the foliation. Fine- to medium-grained quartzite and magnetite-bearing quartzite occur as narrow bands or lenses.
Tondweni	Dark-coloured hornblende-plagioclase gneiss (with or without diopside and quartz) characterised by prominent folded migmatitic banding.
Dulumbe	Primarily a metapelite, comprising quartz-biotite gneiss and quartz-sillimanite-garnet-biotite gneiss. Porphyroblastic garnet, concentrated in bands and lenses is very common.
Dondwana	Intense folding and prominent migmatitic banding characterise these grey biotite-feldspar gneiss and hornblende-biotite gneiss. Main minerals are quartz, plagioclase and biotite with subordinate hornblende. Locally developed small lenses of garnetiferous gneiss also occur.

2.2.1.2.3.1. **Mandleni Nappe Intrusives**

Sithilo Complex

The Sithilo Complex is one of a number of east-west trending ultramafic bodies that occur in the area (Fig.2.12). It is approximately 3 km long and varies in width from 0.5 to 1 km. The bulk of the Sithilo body is composed of serpentinised dunite and olivine peridotite in which primary cumulate textures are locally developed. Harzburgite and pyroxenite are usually developed around the outer rim of the body. Dunite is host to the economically exploited chromite mineralisation at Sithilo. The Sithilo Complex is intruded by several late-stage aplite dykes, along whose sheared contacts are developed cross-fibre chrysotile asbestos. According to Wuth and Archer (1986), the lithology, structure and tectonic setting of the body indicate that the Sithilo Complex is a Precambrian equivalent of younger, alpine-type ophiolitic chromite deposits found in other parts of the world.

Mambula Complex

The Mambula layered mafic complex outcrops over an area of 25 km^2 about 20 km east of Kranskop, near the confluence of the Tugela and Mambula Rivers (Fig.2.12). The Complex, which intrudes the Dondwana, Tondweni and Wosi Formations (Linström, 1987a), consists largely of medium-grained gabbro with subordinate norite, websterite, and vanadium-bearing titaniferous magnetite layers, and is intruded by coarse-grained to pegmatitic diallagite and anorthosite dykes and sills (Schulze-Hulbe, 1979). A broad saucer or funnel-like shape is envisaged for the body due to the radially dipping contacts of the layering.

Reynolds (1986) concluded that the Mambula Complex formed by the fractional crystallisation of a mafic magma, with the ores forming during the later stages of the crystallisation sequence. He also states that the more felsic and Fe-rich nature of the Complex suggests that it represents the higher part of a layered complex than the nearby Tugela Rand Layered Suite (TRLS). Like the TRLS, the Mambula Complex was also affected by deformation and metamorphism during the development of the NMP, where it was subject to amphibolite facies metamorphism (which modified the texture of the Fe-Ti oxide ores) and northward directed thrusting.

2.2.1.2.4. Tugela Nappe

This tectonic unit is made up of two formations (Table.2.12) and a number of intrusive bodies such as an ultramafic complex, tonalites, sheets of metagabbro, diorite and granite.

Table 2.12: Tugela Nappe Formations and Lithologies (after Linström, 1987a).

Formation	Predominant Lithologies
Manyane	Interfolded medium-grained, streaky, veined or massive amphibolite. Predominant minerals are hornblende (50%), plagioclase and quartz.
Tuma	Interlayered sequence of metapelitic schist and gneiss, metapsammitic schist and gneiss and metavolcanic schist and gneiss, with rare graphitic schists also occurring. The metavolcanic unit consists of amphibolite and chlorite-actinolite schist. The amphibolite often displays deformed pillow structures composed of a fine-grained aggregate of epidote, hornblende and actinolite with subordinate chlorite. In zones of intense shearing the amphibolite has been altered to chlorite-actinolite schist due to retrograde metamorphism.

2.2.1.2.4.1. Tugela Nappe Intrusives

Tugela Rand Layered Suite (TRLS)

The TRLS (Wilson, 1990) is located 10 km north of Kranskop (Figs. 2.12 and 2.14) and consists of a well-layered association of mafic and ultramafic rocks which crop out over some 64 km^2. Predominant rock-types include wehrlite, gabbronorite, clinopyroxenite, bronzitite, lherzolite and serpentinite, with minor troctolite, websterite, harzburgite and chromitite (Wilson, 1990). According to Wilson, the TRLS formed as a result of repeated, and sometimes continuous, emplacement of magma into a chamber which at the same time was undergoing crystallisation, while subsequent deformation altered the original sheet-like form of the intrusion. Many primary magmatic structures such as fine-scale layering, erosion and truncation of layers, slumping and modally graded layers are preserved.

The Suite is intrusive into the Manyane Formation and Mkondene Diorite Gneiss and is intruded by the Dimane granite.

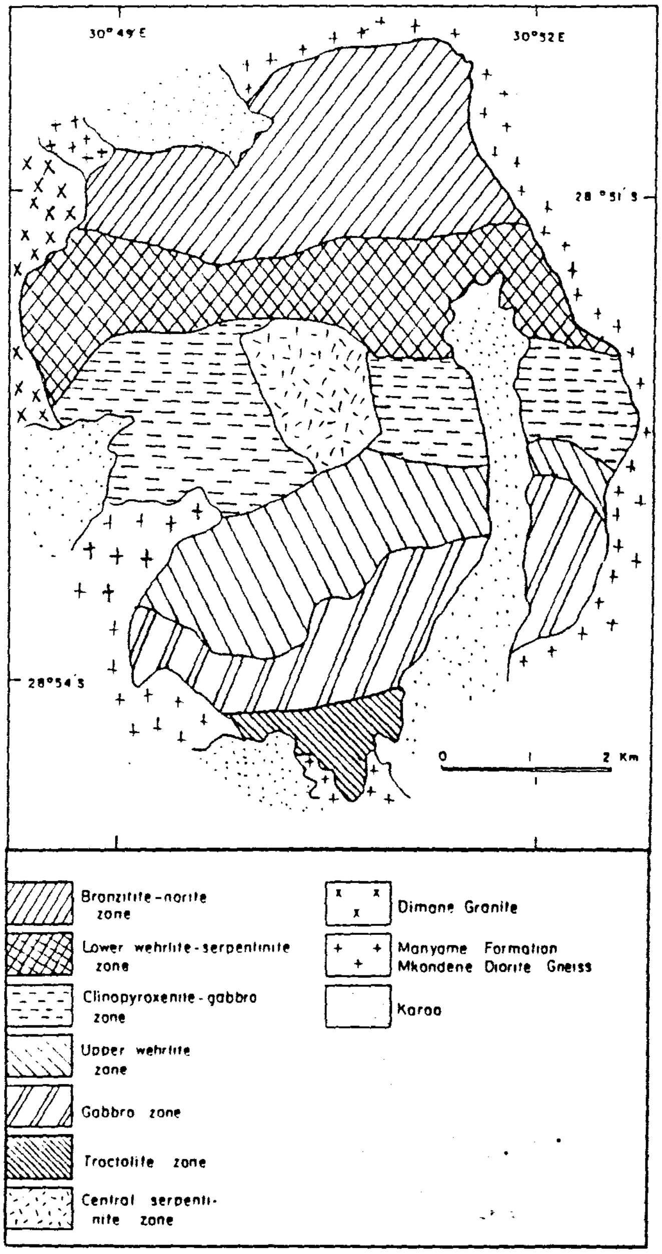


Fig. 2.14: Lithologic subdivisions of the Tugela Rand Layered Suite (after Wilson, 1990).

Mkondeni Diorite Gneiss

This unit consists of numerous medium-grained mesocratic, biotite-bearing dioritic rocks with minor hypersthene which locally grades into a medium-grained biotite-hornblende gneiss. Injection migmatite with flow folds is common, and usually developed along the Manyane Formation - diorite contact.

Kotongweni Tonalite

This coarse-grained tonalite body (in the western sector) (Fig. 2.12) contains up to 30% hornblende, with minor amounts of red-brown garnet. Narrow sheets and irregular lenses of pegmatite occur within the tonalite, which also contains rafts (10 to 50 cm in length) of amphibolite.

Dimane Granite

These medium- to coarse-grained, pink to orangish granites with minor biotite intrude the Mkondeni Diorite and the TRLS. Increasing biotite contents accentuate the westerly dipping foliation. Fine-grained, leucocratic, aplitic sheets, possibly related to this granite, are intrusive into Manyane Formation amphibolites and other Tugela Nappe intrusives.

Sheets of Metagabbro

These coarse-grained, unfoliated hornblendites which grade into plagioclase amphibolite are intrusive into the Manyane Formation. Relict pyroxene and igneous textures were observed in thin section (Linström, 1987a) and the rocks can be termed metapyroxenite, metagabbro or anorthositic metagabbro.

Macala Complex

This meta-igneous complex is also intrusive into the Manyane Formation. It comprises mainly gabbroic rocks with minor serpentinite and thin bands of titaniferous magnetite.

2.2.1.3. Matigulu Group

The Matigulu Group represents the steep thrust belt which marks the southern limit of the Tugela Terrane (Fig. 2.12). This Group comprises four formations (Table 2.13) and is intruded by the Buhleni Granitoid-Gneiss.

Table 2.13 : Matigulu Group Formations and lithologies (after Linström, 1987a).

Formation	**Predominant Lithologies**
Mpisi	Occurs in the western part of the steep belt and consists of biotite-feldspar gneiss with minor hornblende. The rocks are strongly foliated with intense folding.
Sequembi	Also in the western part of the steep belt. Consists predominantly of well foliated, dark-green to black amphibolite with hornblende predominant and minor diopside and/or epidote. Thin bands and lenses of magnetite quartzite and dolomitic limestone occur at various levels throughout the formation. Agmatite (made up of banded and streaky amphibolite breccia and rafts) are common within the amphibolites.
Intuzi	Occurs in the eastern regions. Fine-grained, grey, highly deformed, finely banded and streaky biotite-rich gneiss with a number of infolded, thin, impersistent quartz-feldspar veins and sheets.
Thondo	Occurs in the SE part of the thrust belt. Composed of banded biotite-bearing amphibolitic gneiss. Locally grades into the Intuzi gneisses.

2.2.1.3.1. **Matigulu Group Intrusives**

The Buhleni Granitoid-Gneiss intrudes the Thondo and Intuze Formations in the central and eastern parts of the steep belt. The intrusion is made up of banded quartz-feldspar gneiss, biotite-granite gneiss, flaser gneiss and mylonite. Bands and lenses of amphibolite also occur, along with bands of pegmatite.

2.2.2. <u>The Southern Terranes</u>

Previous literature (Thomas, 1988b; SACS, 1980) collectively placed the rocks of the NMP south of the Tugela Terrane into the Mapumulo Group. However, subsequent detailed investigations by Thomas (1989a) revealed several distinctions in the southern part of the NMP. It was found that certain formations of the supracrustal gneisses all previously included in the Mapumulo Group are confined to either the northern or southern parts of the Province. The gneisses to the north and south of Melville could not be correlated. Also, Thomas (1988c) noted that the northern terrane was of amphibolite grade compared to a granulite-grade terrane further south.

Other factors noted were the distinctive character of the pre- and syntectonic plutonic rocks within these regions to the north and south of the Melville Shear, a major structural discontinuity that was found to separate the two regions. However, the late-tectonic granitoids, such as the Oribi Gorge Suite, are found to outcrop throughout (Thomas, 1988a). Thomas (1989a) thus suggested that these northern and southern parts represent exposed fragments of two distinct tectonostratigraphic terranes and the earlier nomenclature was revised. It was then proposed in Thomas (1989a) that these two tectonic blocks be referred to as the Mzumbe Terrane (in the north) and the Margate Terrane (in the south), separated by the Melville Shear Zone (Figs. 2.9 and 2.10). Furthermore, the older gneisses in the two terranes recognised above are lithologically distinct, and are placed within the Mapumulo Group in the Mzumbe Terrane, and those within the Margate Terrane are placed within the Mzimkulu Group.

2.2.2.1. **The Mzumbe Terrane: Mapumulo Group**

Two formations (the Quha and Mpambanyoni Formations) of banded paragneisses and migmatites, and a fine-grained, leucocratic pink acid gneiss sequence were initially recognised within the Mapumulo Group by Thomas (1989a). However, subsequent work by Thomas et al.(1991e) found that the original subdivision was not justified, and the Quha Formation now includes the Mpambanyoni Formation.

The pink gneisses are typical of the Mzumbe Terrane but have not been given formation status yet as they are thought to be representative of diverse protoliths (Thomas, 1989a). However Thomas et al., (1991d) differentiated some of the pink gneisses of the Mapumulo Group in the southern part of the Mzumbe Terrane into the Ndonyane Formation on the basis of field evidence (Fig. 2.15). Similar lithologies to the Quha and Ndonyane Formations have been reported from undifferentiated rocks of the Mapumulo Group in the northern part of the Mzumbe Terrane in the Lilani Area, though no formal correlation has been made (Thomas, 1992a).

Much evidence regarding the origin of these rock types is lacking, as primary textures have largely been destroyed by polyphase deformation, metamorphism and migmatization. Thomas (1989a) regarded some of the highly siliceous rocks (up to 80% quartz + accessory magnetite) to represent metamorphosed quartzitic sediments, while less siliceous gneisses with flattened mafic inclusions were considered to be deformed granites. Fine-grained sillimanite and tourmaline-bearing pink gneisses were thought to have originated from volcanic/volcaniclastic rocks. The predominant lithologies are outlined in Table 2.14 and detailed petrographic descriptions and localities are given in Thomas (1988b).

Table 2.14 : Mapumulo Group Formations and Lithologies

Formation	**Predominant Lithologies**
Pink Acid Gneiss (Thomas, 1989a)	Varies from quartz-feldspar gneiss and migmatite to very fine-grained pink, streaky gneiss and saccharoidal quartzitic gneiss. Also contains rare mafic pods and white quartzites.
Ndonyane (Thomas et al., 1991d)	Pink and/or grey, fine- to medium-grained, heterogeneous leucogneisses/migmatites. Restricted to southern part of the Mzumbe Terrane and may be correlated with the pink gneisses above.
Quha (Thomas et al., 1991e; 1992d)	Grey biotite quartz-feldspar gneiss; layered pelitic and semi-pelitic paragneisses, migmatites, schists and psammitic gneisses; amphibolites, hornblende gneisses and cummingtonite amphibolites; and minor quartzites, calc-silicates and marbles.

Interpretations of protoliths of the individual rock units in the Quha Formation are detailed in Thomas et al., (1992d). It was found that the gneisses represent a supracrustal package, derived from rocks of volcanic/volcaniclastic origin ranging from intermediate (andesitic) to mafic (basaltic) composition. Bands of thinly layered pyrite-garnet (Mn-rich)-quartz rocks are also present, which are thought to have formed in a hydrothermal, subaqueous volcanogenic environment (Thomas et al., 1992d).

2.2.2.1.1. Mzumbe Terrane Pre- and Syntectonic Intrusives

Extensive outcrops, over 500 km^2, of the major pretectonic Mzumbe and Mkomazi Suites occur in the Mzumbe Terrane. The Mzumbe Granitoid Suite (Thomas, 1990b) are the oldest intrusives in the Mzumbe Terrane (with a U-Pb isochron date of 1 207 ± 10 Ma; Thomas and Eglington, 1990) and have a distinct calc-alkaline, volcanic-arc chemical signature (Eglington, 1987; Thomas, 1989c). A mafic dyke swarm probably related to the Equeefa Metabasite Suite post-dated the emplacement of the Mzumbe Gneiss Suite. Three younger, syntectonic plutonic intrusives of essentially similar granitic compositions are represented in the Mzumbe Terrane by the Mzimlilo and Mahlongwa Suites and the Humberdale.Granite. Descriptions of these

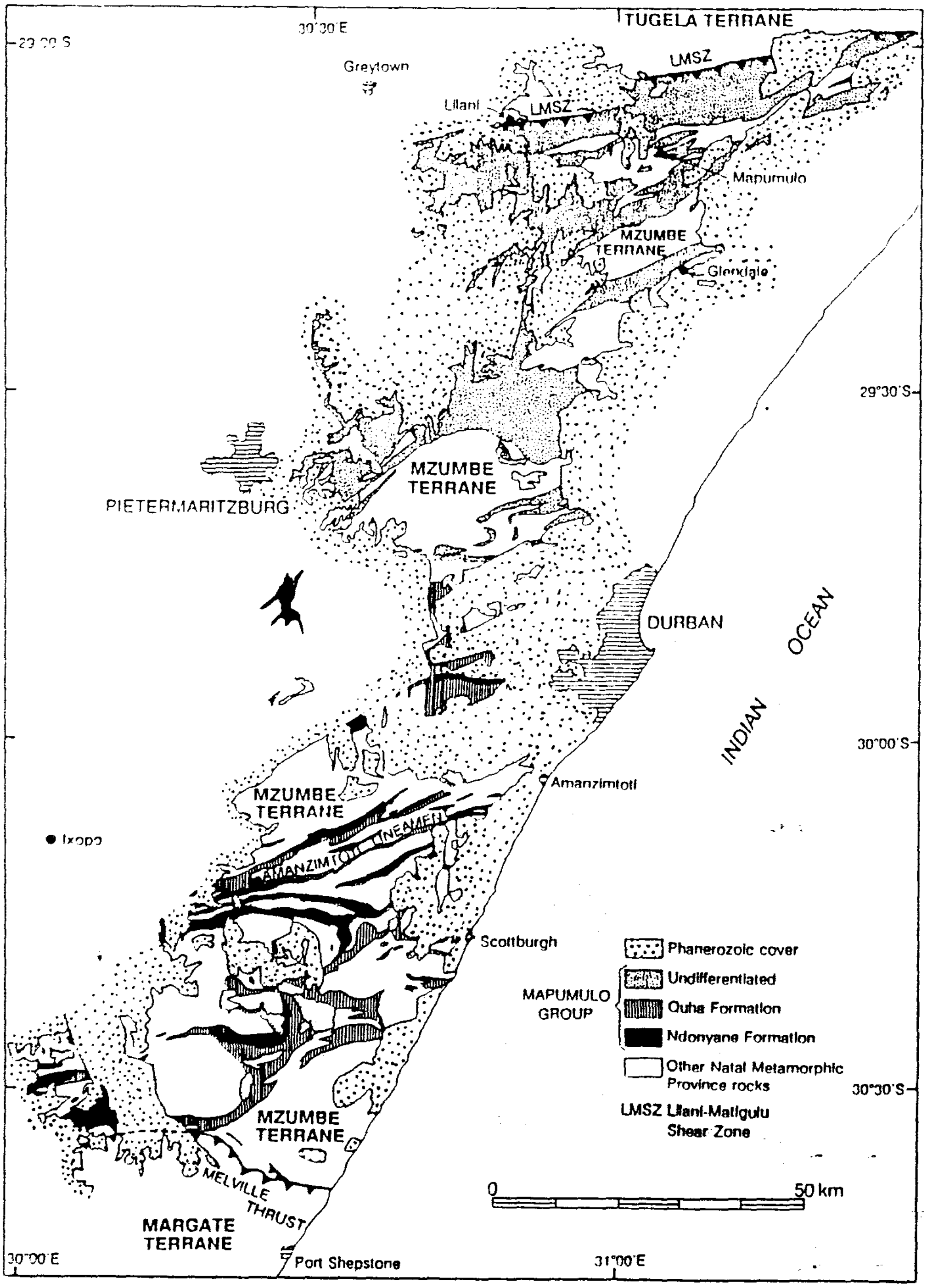


Fig. 2.15: Distribution of the Mapumulo Group with the constituent formations only shown from south of Durban (after Thomas 1992a).

Table 2.15: Pre- and Syntectonic Intrusives of the Mzumbe Terrane

Timing	Intrusive Suite/Pluton	Description
Syntectonic granites	Mahlongwa Granite (Thomas et al, 1991b)	A number of deformed sheets and plutons of strongly foliated, pink, megacrystic, K-feldspar-porphyritic biotite granite and quartz-syenite. Intrudes Mapumulo Group gneisses and the Mzumbe Suite.
	Humberdale Granite (Eglington et al., 1991)	Medium- to coarse grained, pink-weathering, porphyritic, foliated biotite-hornblende granite with finer-grained granite and aplitic phases. Rb-Sr whole-rock age of 981 ± 35 Ma (Evans et al., 1987). Intrudes gneisses of the Mapumulo Group and metabasites of the Equeefa Suite.
	Mzimlilo Granite (Thomas, 1991d)	A number of sheet-like bodies (1-2 km thick) of pink-weathering, grey, medium- to coarse-grained, leucocratic, mildly porphyritic, K-feldspar-rich, biotite hornblende ± garnet granite gneiss. Grain size variations, biotite-rich paragneissic xenoliths and schlieren form a crude banding. Granites show S-type affinities (Thomas and Gain, 1989). Rb-Sr whole-rock age: 1089 ± 14 Ma (Evans et al., 1987). Intrudes Mapumulo Group gneisses and the Mkomazi Gneiss, and occurs as xenoliths in the Humberdale Granite.
Pretectonic intrusive gneisses	Mkomazi Gneiss (Thomas, 1991c)	Layered, biotite-garnet (± sillimanite and cordierite) granitic augen gneiss. Typically coarse-grained with large K-feldspar megacrysts. Forms irregular sheet-like bodies and a tabular batholith. Contains layers and elongate xenoliths of Mpambanyoni Gneisses and/or the pink gneisses. Thus they show characteristics of being crustal, S-type, peraluminous granites. Intrudes the Quha and Ndonyane Formations and is intruded by the Mzimlilo Granite and garnet leucogranite veins and sheets.
	Equeefa Suite (Thomas et al., 1991c)	A metamorphosed suite of mafic and minor ultramafic intrusive rocks (harzburgite, olivine orthopyroxenite and orthopyroxenite) which consist of a large mafic/ultramafic intrusion, an extensive amphibolite dyke swarm and minor podiform noritoids. These are deformed by, and terminate against, the Melville Shear. Dated at 1024 ± 32 Ma (Evans et al., 1987). Intrudes the Mapumulo Group gneisses and the Mzumbe Suite.
	Mzumbe Granitoid Suite (Thomas, 1990b)	Highly distinctive, quartz diorite-tonalite-trondhjemite-granodiorite grey gneiss suite with high-Al_2O_3, low-K, calc-alkaline, I/M-type granitoid affinities (Thomas, 1989c). Occur as extensive, flat tabular bodies which have undergone intense polyphase deformation, amphibolite-facies metamorphism and migmatisation.

Descriptions mainly from Thomas (1989a), unless otherwise referenced.

2.2.2.2. The Margate Terrane: Mzimkulu Group

The older supracrustal rocks in the Margate Terrane are designated the Mzimkulu Group (Thomas, 1992b) and are estimated to make up less than 10% of the exposed basement outcrops in this southernmost Terrane (Fig. 2.16), with voluminous pre-, syn- and late-tectonic intrusives making up the balance.

This terrane differs from the Mzumbe Terrane in many respects. Migmatites and pelitic gneisses are rare, with only the Leisure Bay Gneiss Formation containing metapelites. Three formations have been recognised within the supracrustal gneisses (Thomas, 1989a) shown in Table 2.16 below. The northernmost outcrops of the Mucklebraes Formation lie within a thrusted klippen structure in the Mzumbe Terrane (Thomas, 1992b). These granulite facies rocks lie with tectonic contact above the sheared Mzumbe Terrane Granitoids (Fig.2.12).

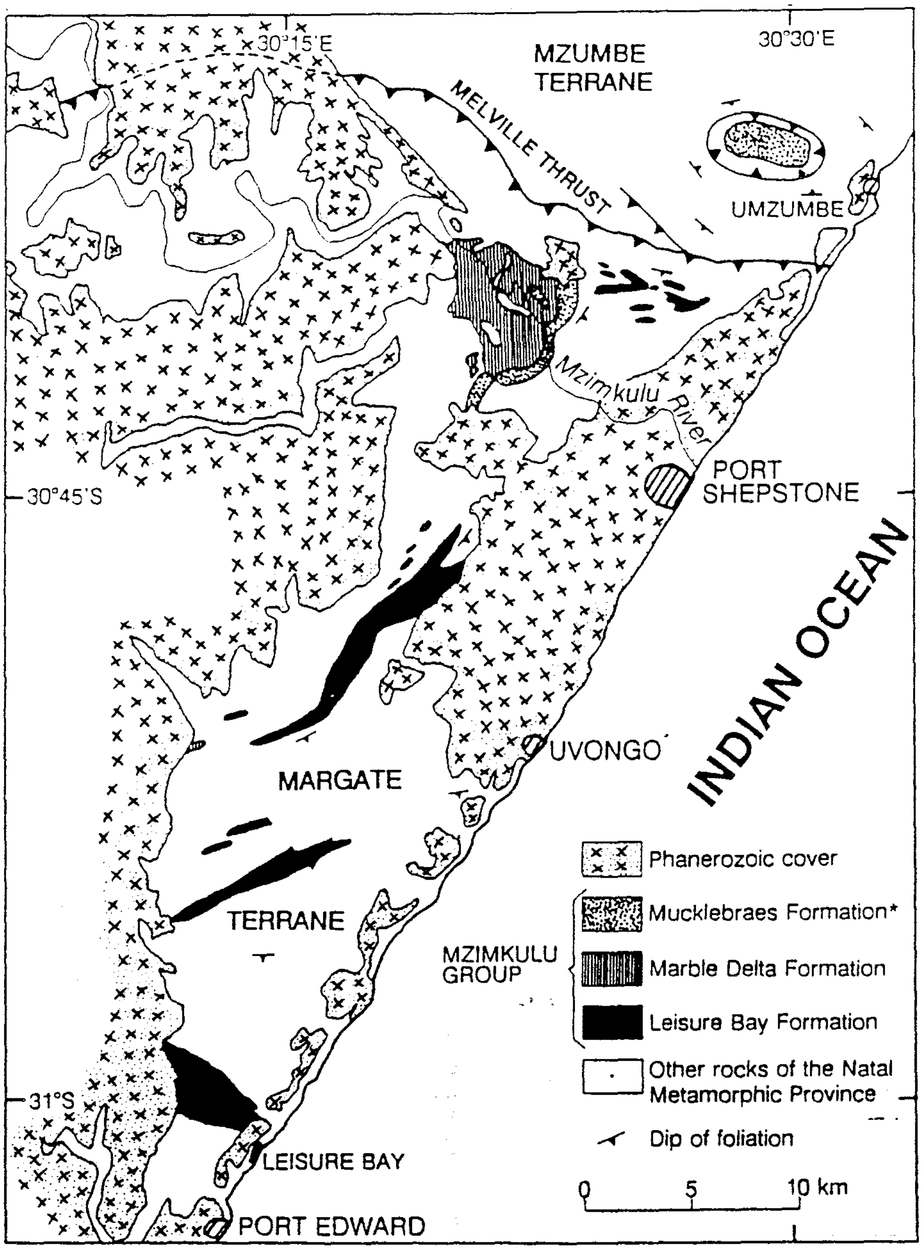


Fig. 2.16: Distribution of the Mzimkulu Group and its constituent formations (after Thomas 1992b).

Table 2.16: Mzimkulu Group Formations and Lithologies

Formation	Description
Mucklebraes (Thomas, 1988b)	Orthopyroxene-bearing mafic gneisses with layered augite amphibolites, two-pyroxene granulites and calc-silicate gneiss.
Marble Delta (Thomas and Otto, 1991)	Unique metacarbonate sequence comprising coarse-grained, high-grade dolomitic marbles overlain by calcitic marbles. Quartzite units are intercalated with the dolomite marbles and amphibolite layers and boudins are intercalated with the calcite marbles.
Leisure Bay (Grantham et al., 1991)	Layered, coarse-grained metapelitic gneisses which contain thin boudinaged and folded layers of calc-silicates, kinzigite rafts and rare metabasic gneisses. The kinzigites are medium-grained migmatitic rocks with conspicuous porphyroblasts of pink garnet in hand specimen (Thomas, 1988b).

2.2.2.2.1. Margate Terrane Pre- and Syntectonic Intrusives

These Margate Terrane intrusives are described in Table 2.17, with outcrops shown in Fig. 2.17. The Turtle Bay Suite (Thomas, 1988b, 1989a, 1991b), originally included in the Mapumulo Group as the felsic-dominated Turtle Bay Formation and mafic-dominated Mhlwazini Formations, was later found to represent fragments of a dismembered, layered intrusive body. The Turtle Bay Suite occurs as tectonic slivers along the Melville Thrust in the northern margin of the Margate Terrane. According to Thomas et al. (1992a), the mafic and felsic components have a close spatial association but were not co-magmatic and crystallisation from two discrete, enriched liquids was suggested. They also proposed that the noritic and monzonoritic components were the result of melting of a mantle source which fractionated prior to emplacement. Further studies were recommended by Thomas et al. (1992a) with regards to the timing of emplacement of this suite.

The pretectonic intrusives in the Margate Terrane are similar to those in the Mzumbe Terrane as they also comprise foliated, tonalitic, I-type granitoids and peraluminous, possibly S-type, granite gneisses. However, they are genetically unrelated as evidenced by differences in petrography and geochemistry (Thomas, 1989c). The pretectonic intrusives were post-dated by a suite of granulite facies mafic rocks of the Munster Metabasite Suite. The syntectonic granitoids in the southern terrane are represented by the Margate Suite. The origin of the various charnockite rock-types in the Munster, Oribi Gorge and Margate Suites is analyzed in Thomas et al. (1992g).

The Munster and Oribi Gorge Suites were concluded to be primary charnockites which crystallised from high temperature magmas at high pressure, while those from the Margate Suite are thought to be replacement charnockites generated by the breakdown of garnet and/or biotite to hypersthene.

Table 2.17 : Margate Terrane Pre- and Syntectonic Intrusives

Timing	**Intrusive Suite/Pluton**	**Description**
Syntectonic granites	Highbury Pegmatite (Thomas et al., 1994c)	Thin veinlets to large sill-like bodies (boudinaged) of white pegmatite and aplite, which are characteristically garnetiferous and locally spodumene-bearing. Part of the Margate Granite Suite and confined to the Mucklebraes klippe, where it intrudes the mafic gneisses.
	Margate Granite Suite (Thomas et al., 1991a)	Intrusions range in size from cm-scale boudinaged veins to large sheet-like bodies several hundreds of metres thick. Comprise mainly garnetiferous gneissose leucogranites and leucocharnockites. Xenoliths include paragneisses, kinzigites and calc-silicate rocks and range from cm size inclusions to elongated rafts. Intrudes the Leisure Bay and Marble Delta Formations and the Munster and Mzumbe Suites and is intruded by the Oribi Gorge Suite.
Pretectonic intrusive gneisses	Glenmore Granite (Mendonidis et al., 1991)	Coarse-grained, yellow-weathering, grey, foliated, biotite-garnet granite gneiss with K-feldspar megacrysts. Contains paragneissic xenoliths of the Leisure Bay Formation. Intrudes the Leisure Bay Formation and is intruded by, and occurs as enclaves within, the Margate Granite Suite.
	Munster Suite Mendonidis and Grantham, 1990)	Numerous sheet-like intrusions of foliated, equigranular to blastoporphyritic, mafic two-pyroxene granulites. Intrudes the Leisure Bay Formation and Glenmore Granite.
	Banana Beach Gneiss (Thomas, 1991a)	Possible sheet-like intrusion of coarse-grained, dark grey tonalitic gneiss. Contains finer-grained, flattened mafic dioritic xenoliths that may represent restites. Intruded by acid sheets that may be related to the Margate Granite Suite.
Uncertain	Turtle Bay Suite (Thomas, 1991b; Thomas et al., 1992a)	Bimodal, mafic two-pyroxene granulites with felsic enderbite and charnockite + rare noritic and monzonoritic rocks. Intruded by the Oribi Gorge Suite.

2.2.2.3. Late- to Post-Tectonic Intrusives

These granitoid intrusions (Table 2.18) are common to both the southern terranes and comprise a varied assemblage of weakly- to unfoliated granitoids (Ingwe Granodiorite, Belmont Suite and Sezela Suite) and a major suite of batholiths and plutons (Oribi Gorge Suite). The Belmont and Oribi Gorge Suites are most extensive and occur throughout the two terranes. The late-

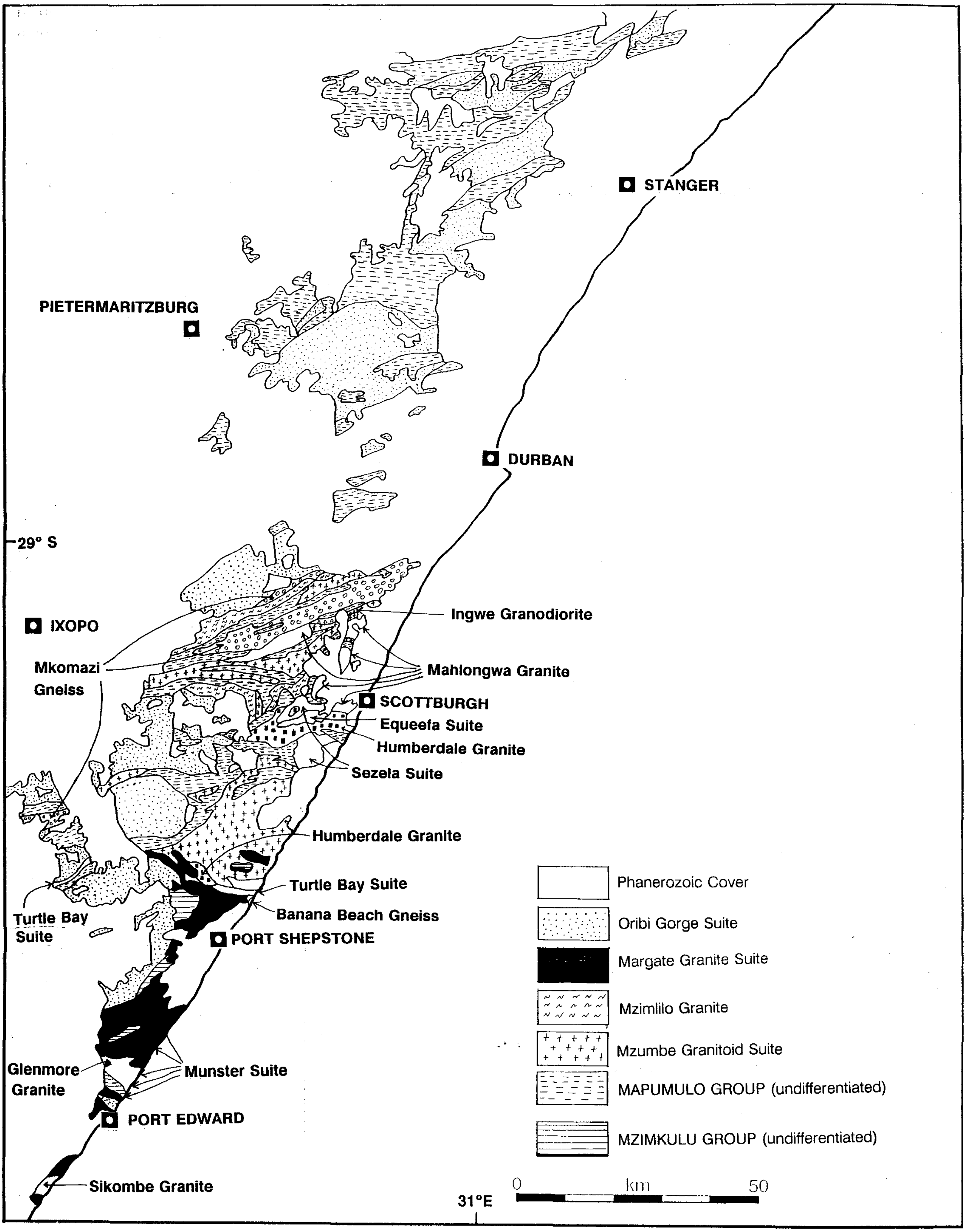


Fig. 2.17: Mzumbe and Margate Terrane Intrusives (after Thomas, 1990b,c,d; 1991a,b,c,d; 1992a,b,c).

syntectonic Oribi Gorge Suite (Figs. 2.17 and 2.18) was emplaced at between 1030 to 1070 Ma (Thomas et al., 1992g) and includes the megacrystic granitoids and charnockites of the Valley of a Thousand Hills and those in the Stanger-Mapumulo area. Major bodies have been recognised from southern KwaZulu-Natal (Port Edward pluton) to the Lovu River in the north (KwaLembe pluton).

The Mbizana Microgranite (Thomas, 1992c) was previously included in the Belmont Suite. Geochemical and isotopic studies on the microgranites however, revealed that they were of different age and mineralogical/geochemical character (Thomas et al., 1990b). The Mbizana Microgranites represent the youngest intrusive unit in the southern part of the NMP and are related to the cessation of magmatism in the NMP (Thomas, 1992c), dated at 1026 ± 3 Ma using U-Pb zircon data (Thomas et al., 1993b). According to Thomas et al. (1994b), the younger Rb-Sr whole-rock and mineral ages of ~ 950 Ma (Eglington et al., 1986; Thomas et al., 1993c) previously obtained are a sign of the prolonged, near-isobaric cooling of the entire complex (e.g. Grantham et al., 1993).

Table 2.18: Late- to Post-tectonic Intrusives of the Mzumbe and Margate Terranes

Intrusive Body	Description
Aplite alaskite, pegmatite	Sheets and dykes of various ages.
Mbizana Microgranite (Thomas, 1992c)	Fine- to medium-grained, subvertical to vertical, grey microgranite dykes with no tectonic foliation. Intrude and contain xenoliths of the Margate Granite and cross-cut the local regional metamorphic fabrics.
Belmont Suite (Thomas et al., 1990b)	Poorly foliated to unfoliated, medium-grained, equigranular, leucocratic biotite granites. Intrudes gneisses of the Mapumulo Group.
Oribi Gorge Granitoid Suite (Thomas, 1991e)	Consists of a number of extensive plutons (Fig.2.14) of coarse-grained, porphyritic, (pink or grey) rapakivi granite and dark green charnockite. Some intrusions are completely granitic, while others are exclusively charnockitic, though granite and charnockite are present in most bodies. Intrusive into gneisses of the Mapumulo and Mzimkulu Groups and plutonic rocks of the Margate and Turtle Bay Suites, Mkomazi Gneiss and the Mzimlilo Granite. Xenoliths of country rocks are concentrated in zones at margins of the intrusions.
Sezela Suite (Evans et al., 1991)	Consists of a number of sheet-like intrusions and two larger, pluton-like bodies. Comprises mainly medium- to coarse-grained pink syenitoids (syenite, quartz syenite, quartz monzonite, granite) and grey syenitoids (monzonite, quartz monzonite, granite). Rb-Sr whole-rock isochron age of 951 ± 16 Ma (Eglington and Kerr, 1989). Intrudes Mapumulo Group gneisses, Humberdale Granite and Equeefa Suite. Xenoliths of country rocks common at intrusive margins.
Ingwe Granodiorite (Thomas, 1990c)	Single, lens-shaped body up to 1 km thick consisting of medium- to coarse-grained, unfoliated to weakly layered, quartzose leucogranodiorite. Intrudes gneisses of the Mapumulo Group and tonalitic gneisses of the Mzumbe Granitoid Suite.

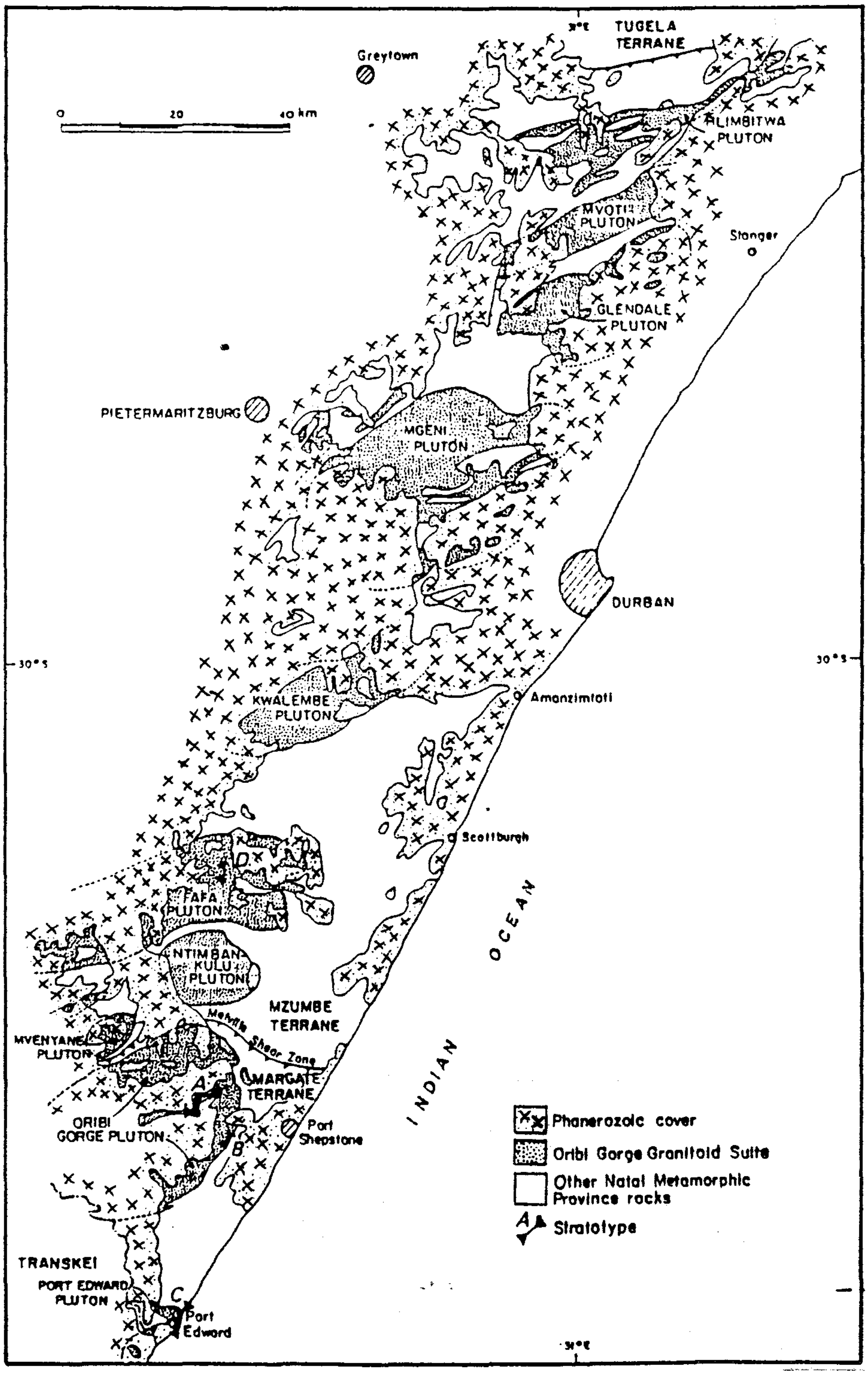


Figure 2.18: Distribution of the Oribi Gorge Suite, with informal pluton names (after Thomas, 1991e).

CHAPTER THREE

3. Metallogenic Framework: The Archaean Rocks of KwaZulu-Natal

Introduction

Mineralised Archaean rocks in KwaZulu-Natal are represented by the Nondweni and Melmoth granite-greenstone remnants and Late-Archaean Pongola Supergroup volcanics and sediments. In this chapter all the important metalliferous mineral deposits of KwaZulu-Natal in rocks of Archaean age are documented. Important industrial mineral deposits are also mentioned. Gold mineralisation is discussed in detail, using data from authors who have worked in the area. Placer gold deposits are especially significant in light of the recent correlation of the Mozaan Group with Witwatersrand stratigraphy (Beukes and Cairncross, 1991). The deposits are grouped according to mineralization styles, where applicable. Minor occurrences are tabulated. Production statistics from some of the workings are also included.

Archaean Lode Gold Deposits

Archaean lode gold deposits in the Province are hosted in both the older granite-greenstone remnants and in the Late-Archaean Pongola Supergroup (see section 3.3). The various lode gold deposits of the Province are documented along with descriptions of the individual deposits. Aspects of the genesis and general characteristics of lode gold deposits follow in chapter five, to provide a better understanding of the processes involved in the formation of such deposits.

3.1. The Granite-Greenstone Terrane

Characteristics of the most important lode gold deposits hosted in the granite-greenstone terrane of KwaZulu-Natal are summarised in Table 3.1. Detailed descriptions of individual deposits follow.

Table 3.1: Characteristics of some Archaean Greenstone Belt Gold Deposits of KwaZulu-Natal

Mine/Prospect Name	**Host Rocks**	**Deposit Type**	**Ore Mineralogy**	**Alteration**
Golden Valley [1]	Nondweni Greenstones (volcanics)	Steep NE-dipping, oblique-slip shear zone with superimposed N-dipping, brittle-ductile shear zones which host the auriferous quartz reefs. Mineralising fluids rich in K_2O, SiO_2, S and CO_2.	Au + quartz with minor Py, Cpy, Bn, Aspy. Aurostibite, electrum and silver present as discrete phases.	Late pervasive carbonate alteration.
Sisters [1][2]	Occurs within a carbonatised and silicified calc-silicate unit (mainly altered komatiite or komatiitic basalt) enclosed by talc schists	Three generations of quartz veins and quartz filled en echelon tension gashes in highly fractured host rocks. Host rock is highly competent, in contrast to the surrounding talc schist. CO_2 and H_2O rich alkaline fluids. Could extend for some distance downplunge.	Ankeritic dolomite, fuchsite, quartz, arsenic, native Au, pyrite, Aspy, goethite.	Carbonate alteration silicification and fuchsitization.
Enterprise [1]	Pillowed komatiitic basalt	Steeply dipping quartz vein	Au + quartz, Py, Po and Cpy.	No alteration envelope is present
Goodrickes Workings [3]	Mafic schist xenolith in Nondweni Greenstones	Cupriferous quartz veins show highest gold values. Four anomalous sulphide-bearing zones with generally low gold values but elevated base metal concentrations.	Au + quartz, Cpy	Talcification
Harewood [4]	Highly altered trondhemitic gneisses, quartz-sericite schists	Second generation quartz reefs in a steep, S-dipping brittle-ductile shear zone which is related to a larger shear zone. Mineralising fluids were not CO_2-bearing.	Tourmaline (schorl), specularite, native Au + quartz, Po, sphalerite	Carbonatisation is **absent.** Argillic, sericitic and chloritic alteration well developed.
Vira [4]	Metalavas altered to a chlorite-quartz assemblage.	Second generation ferruginous quartz veinlets and quartz infilled extension fractures in the central (clay-rich) part of the major shear zone.	Goethite from the weathering of Fe sulphides.	Argillic, sericitic and chloritic.

Py = pyrite, Cpy = chalcopyrite, Bn = bornite, Aspy = arsenopyrite, Po = pyrrhotite
[1] - Bullen et al, (1994); [2] - Versfeld (1988) [3] Brown, (1988b) [4] Bullen (1990, 1991)

3.1.1. Nondweni Group

3.1.1.1. Golden Valley Mine

This mine occurs some 15 km south-east of Vryheid (Fig. 3.1) on the farm Golden Valley 13508 HT, in rocks which have been correlated with the Nondweni Group (McKenzie, 1992).

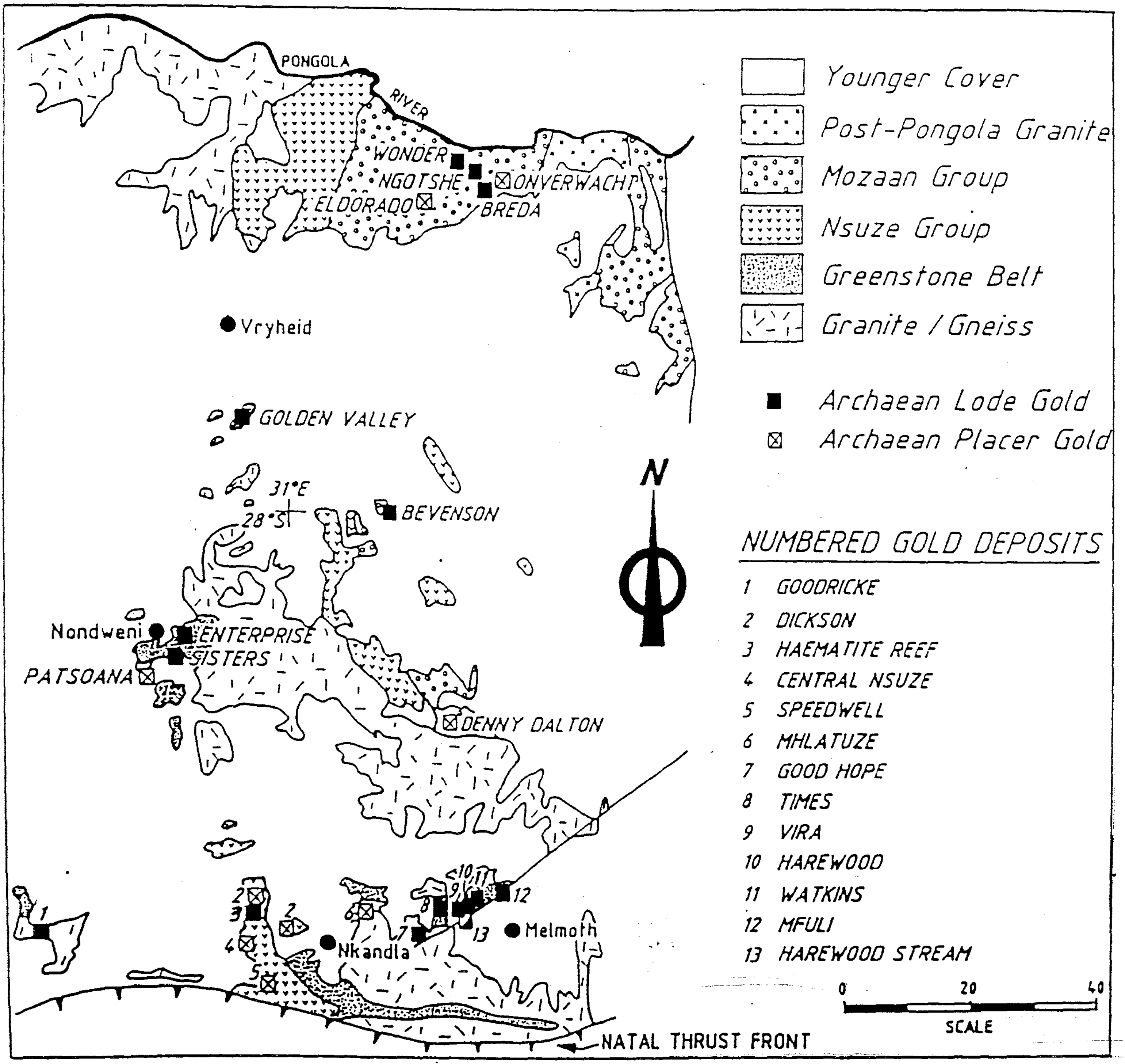


Fig. 3.1: Gold occurrences in the Archaean of Northern KwaZulu-Natal, south of the Pongola River (after Bullen et al., 1994).

The gold is hosted in approximately 1 m wide auriferous quartz reefs within steeply north-dipping, brittle-ductile shear zones that were superimposed on the steep northeast-dipping oblique-slip Golden Valley Shear Zone, as a result of progressive deformation.

Detailed geological studies by McKenzie (1992) and Bullen et al. (1994), have revealed that evolving hydrothermal fluids rich in K_2O, SiO_2, S and CO_2 , appear to have exploited structural discontinuities in the sheared greenstones, depositing silica and gold in the E-W trending shear zones, accompanied by extensive carbonate alteration. Mineralisation occurs mainly as free gold, though minor amounts are associated with pyrite, chalcopyrite, bornite and arsenopyrite. Portions of the reef which are rich in native gold also contain aurostibite, electrum and silver as discrete phases.

This deposit was first worked in 1884 and production took place intermittently until 1959. Small-scale production resumed in 1980, initially with the reprocessing of the old slimes dams, then in the underground workings. According to Bullen et al. (1994), this mine contains many potentially exploitable reefs and viable small-scale production should be sustainable once systematic and detailed prospecting of the structurally lower, quartz lodes has been undertaken. Refer to Table 3.3 for production statistics.

3.1.1.2. **Nondweni Goldfield**

At the turn of the century, gold was produced on a small scale from two mines, the Enterprise and Sisters Mines (Table 3.3), and various small prospects within the Nondweni Greenstone belt (Fig. 3.2). In this goldfield, the mineralisation is hosted by mafic to ultramafic rocks of the Witkop Formation. Gold bearing quartz veins occur mainly within pillowed and komatiitic basalts and carbonated komatiites (Versfeld, 1988). Numerous small prospects occur, predominantly in the northern limb of the greenstone belt on outcrops of Witkop Formation meta-basalt. These workings targeted the steeply dipping quartz veins in the pillowed and komatiitic basalts. The locations of these small workings, which were given names by the early prospectors, are shown in Fig. 3.2. Based on the size of excavations and dumps, very little production is assumed to have occurred from these prospects.

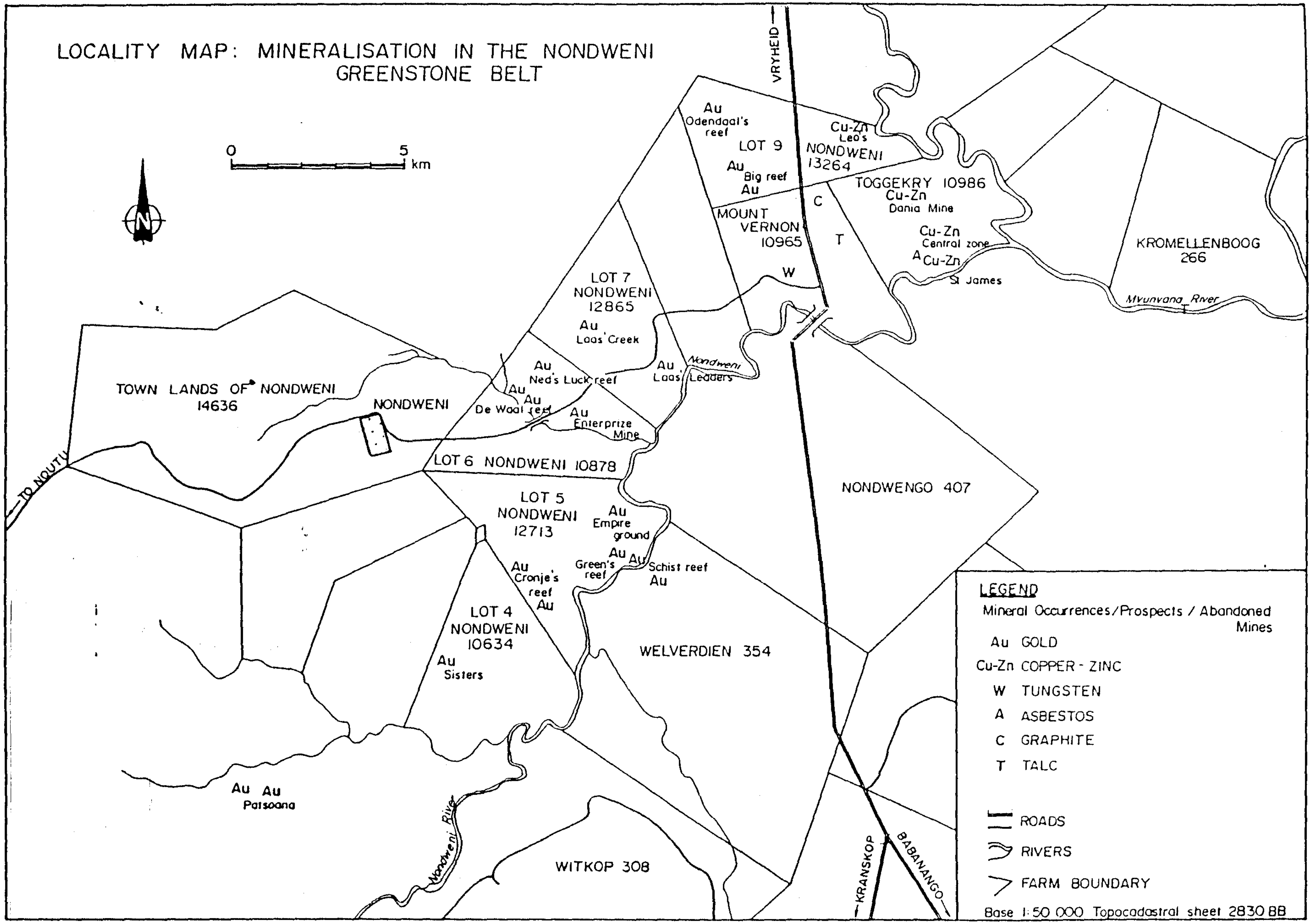


Fig.3.2: Mineral occurrences in the vicinity of Nondweni, northern KwaZulu-Natal (after Versfeld, 1988).

3.1.1.2.1. Sisters Mine

The mine is situated some 6 km southeast of Nondweni on the farm Lot 4 Nondweni 10634 (Fig. 3.2). The mineralisation is hosted in a 50 m thick calc-silicate unit enclosed by talc schists. The calc-silicates display remnant spinifex textures implying that this unit represents highly altered spinifex textured komatiite or komatiitic basalt. In addition, these calc-silicates are intensely carbonatised and silicified and were exploited in zones comprised entirely of ankeritic dolomite, fuchsite and quartz. Mineralisation is concentrated in quartz veins and stringers which are situated below a 2 m thick, north-dipping chert unit. Some of the old workings also exploited quartz-filled *en echelon* tension gash fractures (Versfeld, 1988). The quartz veins comprise an early generation of narrow stringers and veins which has been cross-cut by a second generation of coarser-grained veinlets. The last generation cross-cut the earlier sets of quartz veins.

There are no accurate records of past production. Channel sampling across the old excavations by Versfeld (1988) returned a maximum value of 1.3 g/t Au over 1 m, while sampling of diamond drill core gave a maximum value of 0.19 g/t Au. At the Sisters Mine, Versfeld (1988) proposed that gold was leached from an earlier, relatively gold-enriched, carbonatised alteration envelope by CO_2 and H_2O-rich alkaline fluids, and concentrated in residual silica-rich fluids. These latter fluids precipitated within fractures in the carbonate rocks. Hydrothermal fluid/wall rock reactions are also thought to have influenced the selection of favourable sites for gold deposition, as no significant gold mineralisation was found in the relatively non-reactive overlying chert units, which may also have acted as an impervious barrier to the mineralising fluids.

Investigations by the South African Development Trust Corporation (STK) (De Klerk, 1987), also revealed that the best gold grades were situated in the highly fractured and altered carbonate rocks. However, De Klerk states that the mineralisation in this unit was probably the result of the intense fracturing, which was used by the mineralising fluids as conduits en-route to the final site of Au deposition located stratigraphically higher in the volcanic pile, and which has subsequently been removed by erosion.

3.1.1.2.2. **Enterprise Mine**

These workings, just north of the Sisters Mine on the farm Lot 6 Nondweni 10878 (Fig. 3.2), are found in a steeply dipping quartz vein up to 1 m thick which is hosted in east-west striking, sub-vertical, pillowed komatiitic basalt. No characteristic alteration envelope has been recognised in the host rocks over the 600 m strike length of this vein. Pyrite, pyrrhotite and minor chalcopyrite is present in vein quartz found in the old dumps. Versfeld (1988) proposed that the Enterprise and other minor Au vein deposits in the area were formed by hydrothermal fluids leaching gold from lower levels in the greenstone succession and then precipitating it in dilational structures at higher levels in the more competent lithologies (Versfeld, 1988). No recent prospecting has been done in this area, which is densely populated.

3.1.1.3. **Goodrickes Workings**

These old workings occur some 45 km west of Nkandla (Fig 3.1) within the Sifula inlier of the Nondweni Group. Cupriferous quartz veins, hosted in a mafic schist xenolith, were exploited at the turn of the century (Bullen et al., 1994). Brown (1988b) identified four anomalous sulphide-bearing zones (Table 3.2), each of which contained trace amounts of gold, along with elevated base metal (Cu, Zn, Co) and Ba concentrations.

Table 3.2: Characteristics of the Sulphide-bearing zones at Goodrickes Workings (after Brown, 1988b).

Zone	Description	Highest Element Concentrations
A	Meta-argillaceous horizon with disseminated sulphides at base which are underlain by layered, highly altered felsic volcanics.	Cu: 75 ppm; Co: 400 ppm, Zn: 547 ppm.
B	Banded iron formation containing disseminated sulphides which overlie an ultramafic unit which has been subsequently altered to talc.	Cu: 351 ppm Zn: 1 183 ppm Co: 441 ppm
C	Intensely folded and altered felsic tuffs and meta-argillites containing a thin mineralised horizon with elevated Au values.	Au: 300 ppb.
D	Highly sheared ultramafics (with locally developed chrysotile) and meta-argillites which are enriched in sulphides along the shears.	Cu: 1 246 ppm. Low Au concentrations.

The highest gold value reported was 4.9 ppm in a quartz reef of limited strike length (40 m). The limited size of the deposit coupled with its relative inaccessibility militate against its being viable at present. Further prospecting is, however, recommended.

3.1.2. **Melmoth Granite-Greenstone Remnant**

Six quartz vein-hosted gold deposits have previously been worked in this remnant. For production and grades, the reader is referred to Table 3.3. Bullen (1990, 1991) completed a detailed study on the mineralised part of the greenstone succession (see section 2.1.1.3). Four phases of deformation and metamorphism were recognised in the greenstones, which comprise mainly mafic metalavas with minor serpentinite, talc schist, dacitic tuff, quartz-muscovite schist, quartzite and calc-silicate rocks. Syn-tectonic trondhjemitic gneisses, late-tectonic granodioritic gneisses and post-tectonic granite dykes, form the main intrusive phases. The inaccessible Times, Watkins, Mfuli and Good Hope deposits have not been explored in detail, however Bullen's (1990) study covered the Harewood and Vira workings in detail.

The Harewood workings occur in highly altered trondhjemite (now quartz-sericite schists), while at the Vira deposit, the workings are located in metalavas, just below the contact of the Natal Group sandstones. Mineralisation at both localities is confined to shear zone-hosted, second-generation quartz veins, which cross-cut earlier barren, and texturally different quartz veins. The mineralised veins are composed of medium-grained, equigranular quartz, with minor tourmaline, specularite and sericite. Pyrrhotite, sphalerite and native gold occur in trace amounts. These quartz veins are confined to the centre of a major east-west-trending, brittle-ductile, steep, southerly dipping shear zone. This shear zone was generated during the emplacement of a late-tectonic granodioritic pluton. Gold was concentrated in economic quantities (up to 5.6 ppm) in dilational sites which formed due to refraction of the shear zone as it crossed the different lithologies. The mineralised veins are arranged *en echelon* as they were deposited parallel to "P" shears, thus forming oblique shear veins. Quartz-infilled extension gashes also contain trace amounts of gold. The central part of the shear zone has the most intense shearing and may have been highly permeable, allowing the ingress of large volumes of hydrothermal fluids necessary for the formation of the gold deposits.

The Harewood and Vira deposits exhibit similar wall-rock alteration features (e.g. sercitization, chloritization) despite the fact that they are hosted in different rocks. This suggests that both deposits formed under similar conditions and that the mineralising fluids were of a uniform composition. From mineralogical studies, these fluids were considered to be of both magmatic and metamorphic origin. Magmatic fluids, believed to have been generated by the intruding granodiorite pluton during pressure release and magma crystallisation, were oxidising in nature and deposited the silicate and oxide phases. The contact metamorphic effect of the pluton on the adjacent greenstones resulted in later, chemically reduced metamorphic fluids which deposited the sulphide phases and Au.

Deposition of the gold was principally in response to fluid/wall rock interaction. Though similar wall rock alteration is present at both deposits, sericitization dominates at Harewood (because of the original granitic host rocks), whereas chloritization is more prevalent at Vira because of the mafic nature of the original lavas. Argillic alteration is pronounced immediately adjacent to the orebodies, and this is surrounded by a wider halo of chloritic alteration.

Table 3.3: Summary of available production statistics for greenstone-hosted lode-gold deposits in KwaZulu-Natal.

Mine/Working Name	Production Period	Production	Average grade
Golden Valley	1884 - 1887 1890 - 1910 1910 - 1932 1932 1953 - 1959 1980 - 1992	---- ---- 10 kg 1.6 kg from 329 t ---- ± 40 kg from 8 700t	To date, ± 54 kg Au produced at an average grade of 5.46 g/t. Grades highly variable, with up to 25 g/t in places. Some exposed quartz reefs give values of 40 - 60 g/t (Bullen et al., 1994).
Enterprise Mine Sisters Mine	1887 - 1899	90 kg	± 7 g/t (Hammerbeck, 1976)
Harewood	± 1894 - 1909	13 kg from 709t	18.24 g/t
Vira	as above	9.31 kg from 1222t	7.63 g/t
Times	as above	0.93 kg from 926t	1.01 g/t
Watkins		3.79 kg	3.70 g/t

[Data from Bullen et al. 1994, Bullen, 1990.(obtained from Commissioner of mines reports and Du Toit, 1931).]

3.2. **Pongola Supergroup: Placer Gold Deposits**

Archaean placer gold deposits are restricted to the northern parts of the Province and occur in the sedimentary lithologies of the Nsuze and Mozaan Groups of the Pongola Supergroup (Fig. 3.1). These deposits attracted attention mainly because of stratigraphic and other geological similarities with the richly mineralised Witwatersrand conglomerates. This correlation was confirmed by Beukes and Cairncross (1991) (see chapter 5). However, the complex fluviatile systems that re-concentrated the mineralisation in the Witwatersrand Basin appear to have been absent in this area (Dix, 1984), and extensive, high-grade gold deposits have not yet been located. Mineralisation was impersistent and all the old workings have been abandoned.

3.2.1. **Nsuze Auriferous Conglomerates**

These conglomerates, which were worked in the early 1900's, are exposed in the Nsuze River gorge, some 12 km west of Nkandla. According to Bullen et al. (1994), three large synclines host the mineralised conglomerates, quartzites and phyllites of the Nsuze Group. The South and Central Nsuze synclines plunge to the west at 30 to 40° and the North Nsuze syncline plunges to the east at 20°. The synclines are separated by thrust faults so direct lateral correlation between the three synclines is impossible. Gold occurrences have been documented in each of the three synclines.

3.2.1.1. **North Syncline: Dickson Mine**

This mine is located on the farm Qudeni 34 and the old workings consisted of adits and trenches in two zones of steeply north-dipping, pyritic conglomerate. The reefs, up to 35 cm thick, can be traced for 6 km along strike. Total production recorded from this early venture was about 760 g Au at an average grade of 10 g/t (Hatch, 1910). Drilling carried out during the last exploration attempt in the area indicated that gold grades decreased with depth, from 9 g/t at surface to 1 g/t below the water table, which is suggestive of supergene enrichment (Bullen et al., 1994). The drilling also showed that the mineralised shoots had a limited lateral extent and the gold was very erratically distributed within them, which suggests that they would be sub-economic.

3.2.1.2. **Central Syncline: Central Nsuze Reef**

These workings were mined unsuccessfully during 1903-1904 and consisted of 5 inclined shafts and 14 small adits (Weilers, 1990). The reef can be traced for 1 km along strike and contains a well-developed ore-shoot grading at 6.93 g/t Au over 87 cm (Winfield, 1982). This compares with assays by Hatch (1910) who reported a highest concentration of 6.2 g/t. However, gold distribution here is sporadic and projected reserves are sub-economic.

3.2.1.3. **South Syncline: Speedwell Mine**

These workings occur near the village of Ntingwe on the farm Qudeni 25. Mining was carried out intermittently until the 1940's, and numerous adits and shafts are still visible over a width of 80 m. The reefs are steeply dipping and can only be traced for 600 m along strike, terminating against faults in the east and disappearing beneath younger cover rocks in the west (Bullen et al., 1994). There are no production records from the old ventures, however Hatch (1910) analyzed 10 conglomerate samples from this mine, which yielded an average of 3.1 g/t Au over a sampling width of 45 cm.

3.2.1.4. **Cooper's Store/Randalhurst Gold Occurrence**

This 1 to 4 m thick auriferous Nsuze Group conglomerate layer crops out in the Mhlatuze River valley, south of the Nkandla-Melmoth road, some 10 km northeast of Nkandla. According to Saager et al. (1986), the mineralised conglomerates are clast-supported, with elongated pebbles and are very well mineralised in parts. Also recognised in these layers are detrital pyrite, pseudomorphic haematite and Fe-hydroxides. Up to 1910, 105 tons of ore were mined from several shafts and adits on the mineralised conglomerate zone, yielding ± 288 g of gold at an average grade of some 2.7 g/t (Hatch, 1910). As the general tenor of the reef was low, the workings were abandoned.

3.2.1.5. **Patsoana Prospect**

This prospect is situated some 10 km south of Nondweni on Bantu Reserve No.18 7638. The 2.5 m thick conglomerate unit prospected here occurs near the base of the Nsuze Group and is overlain by cross-bedded quartzites and grits (Versfeld, 1988). The adits, pits and trenches here were abandoned prior to 1900 as the workings were not profitable. Channel sampling by Versfeld (1988) indicated a peak assay value of 0.55 g/t in this matrix supported conglomerate, and the clasts, mainly chert, quartzite and vein quartz, are considered to have been derived from the Nondweni Group. The low concentration of gold in the Nsuze Group in this vicinity was attributed by Versfeld (1988) to the immaturity and polymict, matrix-supported nature of the conglomerates.

3.2.2. **Mozaan Auriferous Conglomerates**

3.2.2.1. **Denny Dalton Mine**

The Denny Dalton mine, which operated intermittently between 1894 and 1930, is situated 38 km northwest of Melmoth on the farm Tusschenby 411. A total of about 14 kg of gold was produced from this mine. According to Saager et al. (1986), a basal conglomerate layer, which overlies a 30 m thick quartzitic sandstone unit at the base of the Mozaan Group at Denny Dalton, constituted the prime target for mining as it closely resembled the Witwatersrand ores, in both mineralogy and texture. Dix (1984) noted some fluvial reworking of the conglomerates at Denny Dalton, which he believed, had been responsible for the upgrading of the heavy mineral content. However, this process did not seem as effective or long lasting here as it must have been in the Witwatersrand deposits.

The auriferous horizon, known as the Mozaan Contact Reef (MCR) is up to 7 m thick and contains large (up to 1 cm), rounded, compact pyrite grains, arsenopyrite and minor brannerite (Saager et al., 1986). This is followed by an upper layer where small pyrite grains occur, disseminated in the conglomerate matrix, or concentrated in foresets of cross-bedding. The clasts consist mainly of vein quartz and chert. Economically exploitable mineralization was only found in the lowermost 0.5 to 1.0 metre of this reef, which dips at between 5 and 10° east-northeast and crops out intermittently over a strike length of 10 km (Bullen et al., 1994). The old mine workings, which consist of open pits and adits, are situated in a stream bed which has exposed the reef. The highest grades (around 20 g/t) were reported from near-surface ore, which suggests supergene enrichment (Bullen et al., 1994). Recent exploratory drilling revealed a maximum down-dip extent of the MCR to be less than 600 m from the surface, which would not make this a viable mining venture.

3.2.2.2. **Gunsteling**

On the farm Gunsteling 21 on the north bank of the Pongola River, a few layers of sulphide minerals occurring in a 7 m-wide conglomerate zone in quartzites of the Mozaan Group, were investigated by Saager et al. (1986). In addition, relatively high U and Th contents were found in the phyllites underlying the conglomerate zone. At the base of the Mozaan Group is an alternating sequence of clast- and matrix-supported conglomerates. The auriferous conglomerate layers were found to occur in the clast-supported, upper part of the zone, which also contains limonite pseudomorphs after sulphide minerals. No production has been recorded from this occurrence, however 3 m deep trenches indicate that some gold prospecting has been attempted in the past.

3.2.2.3. **Eldorado and Onverwacht**

Two gold-bearing Mozaan Group conglomerates were discovered on the farms Eldorado 13 and Onverwacht 395, at the turn of the century (Humphrey and Krige, 1932). In 1915, about 5 kg of gold was mined from 624 tons at Onverwacht, the workings having since been abandoned. Gold grades on these farms vary between 0.8 and 3.1 g/t at surface and have generally been considered uneconomic because of the limited extent of the ore horizon.

3.3. Pongola Supergroup:Lode Gold

The quartz lode gold deposits in the supracrustal Pongola Supergroup show many similarities to the lode gold deposits found in the underlying granite-greenstone terrane. These epigenetic deposits are also structurally related and the mineralisation was precipitated from deeply-sourced hydrothermal fluids. Characteristics of some of these deposits are summarised in Table 3.4.

Table 3.4: Characteristics of some Archaean Lode Gold Deposits in the Pongola Supergroup

Mine/Prospect Name	**Host Rocks**	**Deposit Type**	**Ore Mineralogy**	**Alteration**
Klipwal Mine (Gold, 1993)	Shales, quartzites and diabase sills (Mozaan Group)	Gold in syntectonic quartz and carbonate veins within the Klipwal shear zone and disseminations within the host rocks and in fault gouge	Arsenopyrite, Pyrite, Pyrhottite, chalcopyrite, native Au	Phyllic, chloritic, carbonaceous
Wonder Mine (Bullen et al., 1994)	Shales of Mozaan Group	Shear zone-hosted, steep NE-dipping quartz reefs related to the major strike-slip Bumbeni Shear. Supergene enrichment at surface	Pyrite, native Au	Ferric
Ngotshe Mine (Bullen et al., 1994)	Quartzites and ferruginous shales of Mozaan Group	Saddle-Reef type where mineralised quartz veins occur in the core of a steeply NE-plunging anticline, the western limb of which was displaced by the Klipwal Shear.	Pyrite, native Au	N/A
Kortnek Prospect (Weilers, 1990)	Quartzite and shale (Mozaan Group)	Located on or near an E-W zone of thrusting. Sub-horizontal mineralised shale beds and multiple auriferous quartz veins located on the axis of an open anticline.	Quartz, pyrite, chalcopyrite, native Au.	N/A
Bongaspoort Prospect (Brown, 1989)	Ferruginous shales (Mozaan Group)	Subparallel, auriferous quartz reefs which cross-cut the host lithologies. Related to a brittle-ductile shear zone and hydrothermal fluids. Three mineralised zones comprising: 1] A Main Quartz Vein with subsidiary veinlets; 2] Fe-rich shale horizon; 3] A lower quartz vein	Native Au, Pyrite, chalcopyrite. Enriched in base metals (Cu, Zn, Pb) and arsenic.	Argillic, ferric and silicic
Altona (Weilers, 1990)	Shales of Mozaan Group	Disseminated sulphides (Py and Cpy) in BIF and shales. Associated with NW-trending shear or wrench faults. Mineralisation not continuous at depth.	Pyrite, Chalcopyrite.	N/A

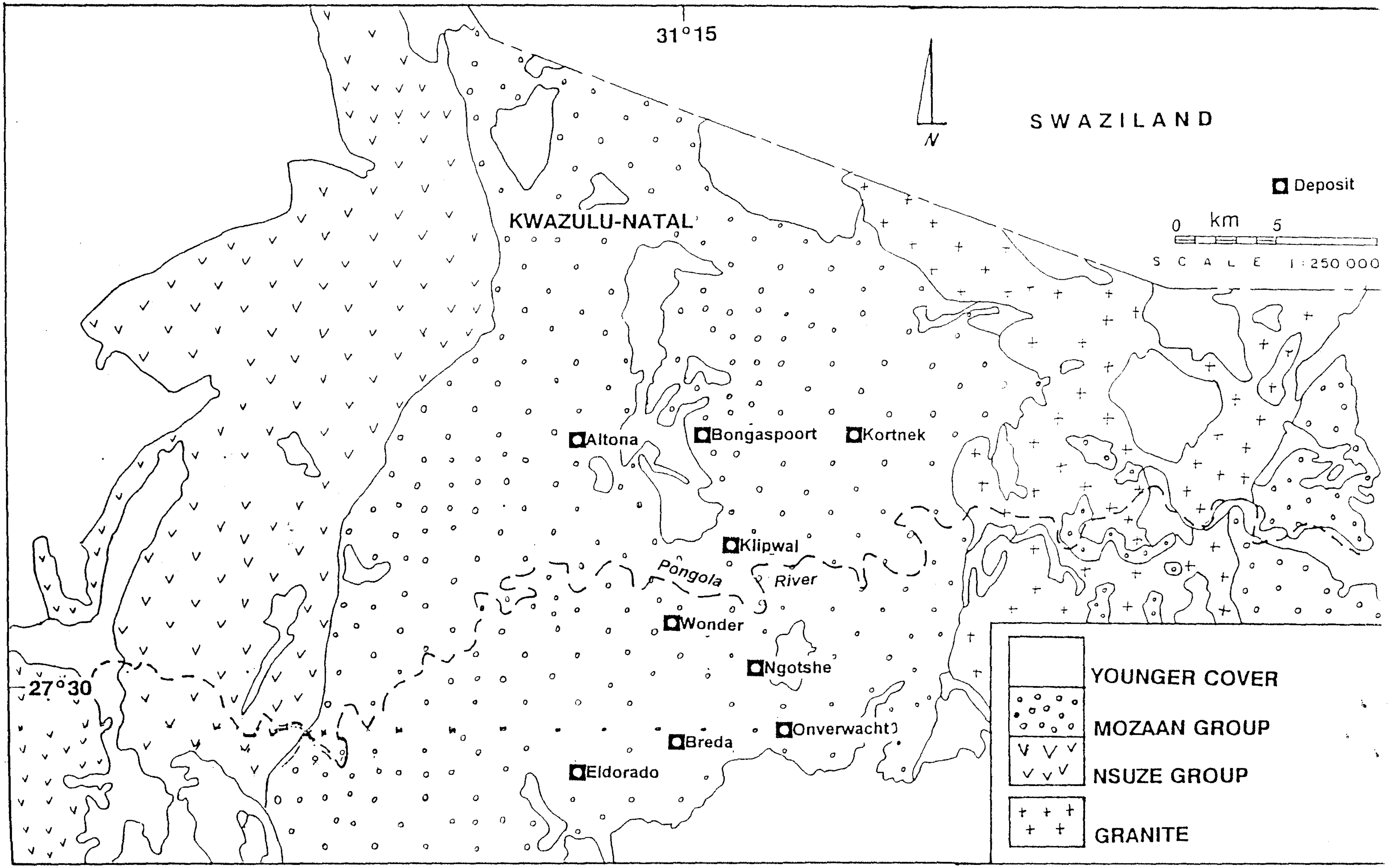


Fig 3.3: Gold occurrences hosted in the Mozaan Group in northeastern KwaZulu-Natal (after Brown, 1989).

3.3.1. **Klipwal Gold Mine**

The Klipwal Mine (Figs. 3.3 and 3.4) is currently the only producing gold mine in the Province. The mine is situated some 35 km southwest of Pongola in northern KwaZulu-Natal, on the farm Klipwal 49 HU. The gold mineralisation is hosted in the shales and quartzites of the Mozaan Group as well as in intrusive dolerites. The mine is located within the Klipwal Shear Zone (Fig.3.3), a north-trending, east-dipping structure that is identified from north of the Pongola River southwards (Bullen et al., 1994).

The largest concentration of gold is found within the main shear zone, where it is associated with syntectonic quartz and carbonate veins (Gold, 1993). Gold and sulphide mineralisation is also found disseminated within the silicified and sericitized hanging wall quartzites and footwall shales, as well as in deformed intrusive dolerite dykes. Minor ore bodies occur in variably orientated secondary fractures and faults in the hanging wall. Gold is also present in fault gouge, which has abundant quartz veining, and has developed between the quartzites and shales. Normal faults at this locality are known to displace strata from a minimum of 800 m up to 3.5 km. The complex pattern of veining developed here was attributed to the sequential development and distortion of the veins during progressive deformation (Gold, 1993).

The structural deformation and gold mineralisation at Klipwal was attributed to the intrusion of the Spekboom granite by Weilers (1990). Matthews (1990) also attributed some of the tectonic stresses in the Pongola-Mozaan basin to the intrusion of granitoid plutons. However, detailed structural analyses by Gold (1993) and Gold and Von Veh (1995) revealed that the effects of the intrusions are very localised, whereas deformation in the Pongola-Mozaan basin is regionally persistent. They ascribe deformation in the basin to an early north-northwest-verging thrusting event associated with north-directed thrusting described from many other parts of the Kaapvaal Craton (reviewed in De Wit et al., 1992, cited in Gold and Von Veh, 1995).

From detailed mineralogical studies at Klipwal by Russell (1985; cited in Gold, 1993) it was concluded that the ore was deposited from hydrothermal solutions introduced into the shear zones from the following evidence:

(i) an association with quartz veining
(ii) wall-rock alteration
(iii) decrease in the ore grade away from the shear zone (indicating high permeability in the centre of the shear zone).

Also noted from the association of arsenopyrite-pyrite-pyrrhotite was that the temperature of formation of the gold mineralisation was in the order of 350 to 400° C (i.e. mesothermal). According to Gold (1993), broad, generally barren pyrite veins cross-cut the shear fabric of the host rock whereas narrower auriferous veins of pyrite are concordant with it. Contemporaneous deposition of gold with sulphides is confirmed by their intimate textural relationship. Detailed mineralogical studies by Russell (1985) showed that 52 vol% of the gold is associated with pyrite, 22 vol% is associated with arsenopyrite, and 7 vol% is associated with fractures in pyrite or arsenopyrite grains.

The deposition of mineralisation here is typical of hydrothermal deposits, and was precipitated in response to fluid/wall rock interaction. Abundant carbonate and phyllic alteration, typified by the assemblage quartz-sericite-pyrite, was recognised at Klipwal. These types of hydrothermal alteration are common in gold quartz lodes (Pirajno, 1992). Hydrothermal fluids exploited the deep seated faults and ductile shear zones, which enabled the circulation of large volumes of fluid. Most of the economic gold mineralisation is found in or near the centres of the shear zones, where permeability is thought to be highest. It was also noted that only the east-dipping shears (~ 50°), contained gold, whereas the near-vertical shears are almost always barren (pers. Comm. D. Gold, 1995).

Mining at Klipwal has been continuous since 1974 when the property was acquired by Lonrho South Africa Ltd. Production since 1980 is about 3.5 tons Au, and current production runs at approximately 500 kg per annum (pers. comm. R. Hobbs, 1996).

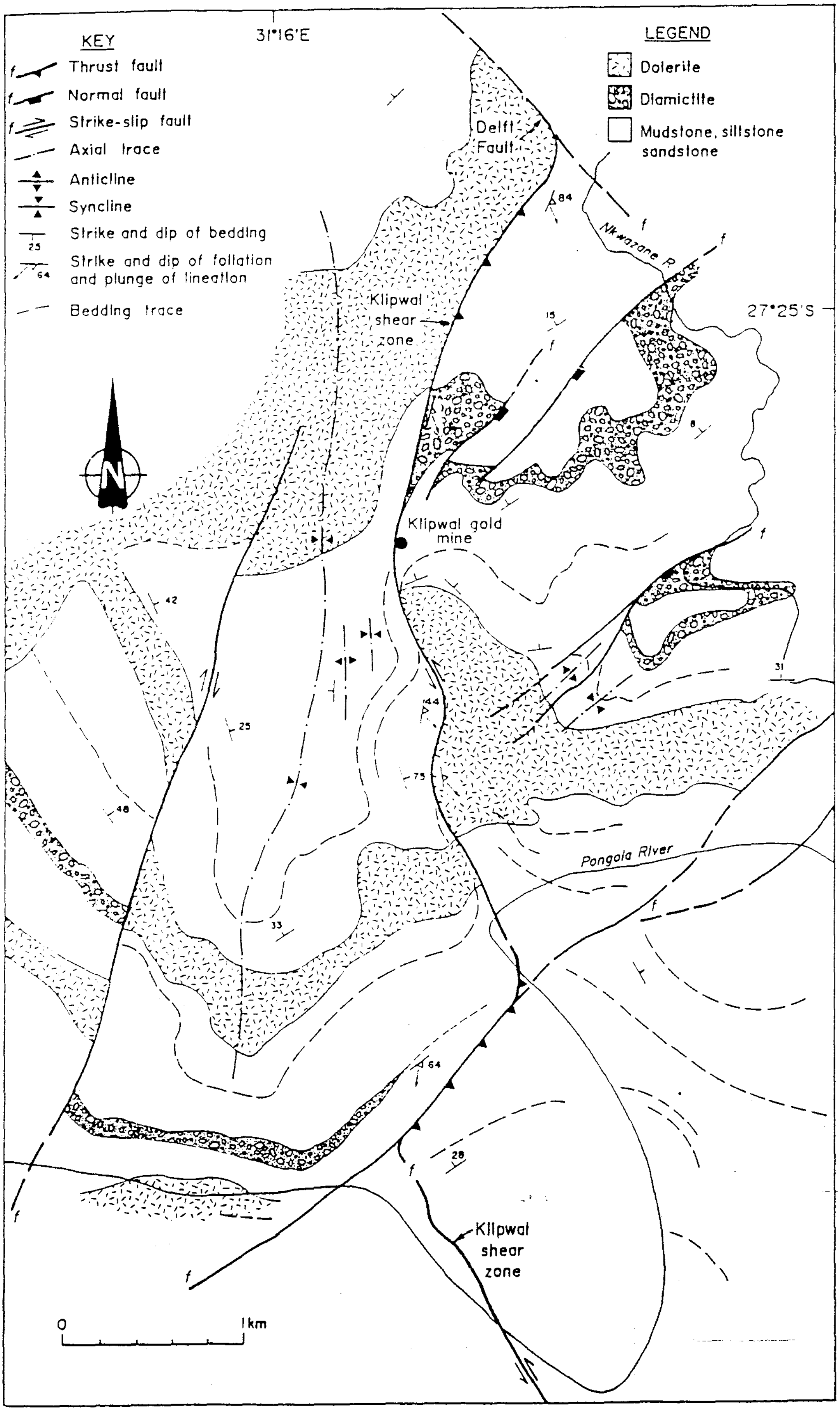


Fig.3.4: Location of the Klipwal Mine and Geology of the Klipwal shear zone (from Gold and Von Veh, 1995).

3.3.2. **Wonder Mine and Ross Reef**

The Wonder Mine is situated some 5 km southwest of the Klipwal Mine in an area which is now the Itala Nature Reserve and on which prospecting is not permitted. The mine was intermittently worked between 1905 and 1933 (Table 3.5). Up to 1913, near-surface mining was undertaken on the weathered, oxidised portions of the reef where supergene-enriched free-milling gold was exploited (Bullen et al., 1994). The tailings, which contained refractory gold in pyrite, were later treated using cyanidation.

Numerous quartz reefs are hosted in Mozaan Group shales and crop out in the steep-sided Pongola River valley. According to Bullen et al. (1994), the northwest-trending, steep (~ 70°) northeast-dipping reefs, lie subparallel to the s-fabric of a north-south trending, strike-slip shear zone and thus form oblique shear veins. They relate this structure to the Bumbeni shear, which crops out to the north of the Pongola River. The reefs are situated about 20 m apart and are between 0.10 and 1.22 m thick. However they are of limited strike extent. Some 2 km south of the Wonder Mine, and along strike from it, the Ross Reef and Wonder extension reefs are reported to occur (Weilers, 1990).

3.3.3. **Ngotshe Mine**

This mine is located 3 km southeast of Wonder Mine, also within the boundaries of the Itala Nature Reserve (Figs. 3.1 and 3.3). According to Bullen et al. (1994), the mineralisation occurs in three subparallel quartz veins lying 40 to 60 m apart, between hanging-wall quartzites and ferruginous footwall shales of the Mozaan Group. The reefs are up to 40 cm thick and dip to the northeast at ~ 40°. In contrast to the reefs at Wonder Mine, the reefs here are either bedding-parallel or cross-cut the bedding at a shallow angle. Weilers (1990) reported that, in places, the wall rocks are also gold-bearing.

This mine lies a few hundred metres to the east of the Klipwal shear, which probably acted as the principal conduit for the mineralising fluids. Mineralisation is located within the core of a steeply northeast-plunging anticline, the western limb of which was displaced by the shear. The fluids were moved along the shear and deposited the gold and silica in adjacent areas of low strain. Mineralisation here, although related to a shear zone, is thus of a saddle reef type, in contrast to Wonder Mine, which is shear zone-hosted.

Table 3.5: Production statistics from the Wonder and Ngotshe Mines (after Bullen et al., 1994)

Mine Name	Production period	Production	Grade
Wonder Mine	1905 - 1913 1919 - 1933	126.5 kg 20.7 kg	Up to 35 g/t recorded, with average of 10 g/t
Ngotshe Mine	1911 - 1915 1943 - 1967	129 kg 8.3 kg	Average grade: 26 g/t : 1.8 g/t

3.3.4. Other Lode Gold Prospects in the Pongola Supergroup

These occurrences, outlined below have previously been investigated, but were found to be of no economic significance at the time. Where available, results and conclusions regarding the potential of the deposit obtained from various exploration projects will be given.

3.3.4.1 Gold mineralisation on the Farm Kortnek

According to Weilers (1990), five mineralised localities are known to occur on the farm Kortnek 50 HU, which lies northeast of the Klipwal Mine (Fig 3.3). Four of these, together known as the Gorge Reefs, were investigated in 1945, and comprise subhorizontal mineralised shale beds with associated quartz. The fifth prospect, referred to as the Mammoth Reef consists of a northwest-dipping quartz, chlorite, sulphide body, with a quartzite footwall.

Investigations by Anglo American Corporation in the 1980's, using adits and trenches, concluded that only two of the prospects had potential. Sampling on the first prospect indicated an average grade of 13.8 g/t Au over a width of 58 cm, but this was of very limited extent. At the other prospect, which comprises multiple quartz veins located on the axis of an open anticline, trench sampling provided values ranging from 17 g/t Au over 60 cm, to 116 g/t Au over 462 cm. The potential strike length was reported to be of the order of 300 m. Lonrho's investigations comprised seven shallow diamond drill holes. Five of these returned values ranging from 1.4 g/t Au over 158 cm to 96.0 g/t Au over 175 cm. This indicated a relatively high grade ore shoot over a strike extent of 90 m (Weilers, 1990).

3.3.4.2. Gold Mineralisation on the Farm Bongaspoort

This farm (Bongaspoort 48 HU) also occurs in the Klipwal area north of the Pongola River, some 40 km west of Pongola (Fig 3.3). Brown (1989) conducted a detailed investigation on this farm for the South African Development Trust Corporation (STK). The mineralisation style here was found to have many similarities with the other quartz vein deposits in the Mozaan sediments in that it is related to shear zones. The ferruginous, sulphide-rich wall rocks also show signs of mineralisation. Mineralising fluids exploited the semi-ductile shear zones, depositing gold and silica, with the ferruginous shales providing an ideal chemical environment for the precipitation of gold.

Based on geological mapping, geochemical and mineralogical studies, Brown (1989) concluded that an epithermal or hydrothermal system was active along the shear zone that cross-cuts the farm. This resulted in extensive leaching, associated with argillic, ferric and siliceous alteration of the country rock. This alteration pattern is characteristic of hydrothermal mineralisation normally related to gold mineralisation. Mapping and sampling of the old workings revealed a series of subparallel quartz veins with an east-west strike that obliquely cross-cut the host lithologies and three mineralised zones as follows:

(i) A Main Quartz Vein: 1-3 m thick, with subsidiary veinlets. Samples from the offshoot veinlets revealed Au values of 3.5 and 9.2 ppm. The main Quartz Vein sample which included shale xenoliths contained 9.1 ppm Au. The gold is associated with enhanced base metals (260-630 ppm Cu; 70-240 ppm Zn; 20-700 ppm Pb) and As concentrations of between 260-3400 ppm.

(ii) An Fe-rich Shale Zone: Below (i), this zone contains a network of quartz stringers and disseminated sulphides. Channel sampling revealed gold contents from 0.55 ppm to 6.90 ppm, with an average grade of 2.75 ppm Au over 0.5 m. Associated with the gold are high concentrations of copper (260-630 ppm Cu); lead (20-700 ppm Pb); zinc (70-240 ppm Zn) and arsenic (260-3400 ppm As).

(iii) A Lower Quartz Vein: A 0.2 - 0.5 m thick sulphide-bearing quartz vein which outcrops north of the old workings. Six grab samples revealed gold concentrations of 4.4 to 41.9 ppm Au. Associated with the Au are copper (700-5100 ppm Cu); lead (200-3800 ppm Pb); zinc (40-500 ppm) and arsenic (75-340 ppm As).

Pyrite and chalcopyrite were the most common sulphides associated with the Au mineralisation. Brown (1989) suggested that, as gold mineralisation had been established here, this prospect would be an excellent target area in the exploration for structurally controlled, epithermal gold mineralisation.

Tennick (1990) reported a possible resource at Bongaspoort of 13 400 t at an average grade of 2.8 g/t over a strike length of 60 m, an average width of 4.0 m and an assumed downdip extension of 20 m. A "Mixed Zone" was identified as containing the highest grades. This zone comprises a fractured, ferruginous shale horizon containing numerous cross-cutting quartz veins and stringers. Lower grades were reported from adjacent massive quartz veins and the shale/greywacke country rocks. A drilling programme was outlined by Tennick to test the depth extent of the mineralisation and the strike extension of the "Mixed Zone". The possibility of finding other such "Mixed Zones" at depth was not discounted. No further work has been reported since.

3.3.4.3. **The Altona Prospect**

A prospecting adit, soil sampling and trenching within banded iron and shales of the lower Mozaan Group on the farm Altona 47 HU (Fig 3.3), revealed disseminated sulphide mineralisation. Investigations by Lonrho (Weilers, 1990) showed low-grade gold mineralisation to a depth of 30 m associated with pyrite and chalcopyrite. Mineralisation over a 32 m strike length in structurally disturbed ground yielded average gold grades of 2.06 g/t sampled over a width of 167 cms. The Altona prospect is apparently associated with northwesterly trending shear or wrench faults (Weilers, 1990).

3.3.4.4. **Haematite Reef**

This occurrence (reported by Bullen et al., 1994) was discovered in 1893 and is situated 12 km northeast of Nkandla (Fig. 3.1) on Reserve No.19 7638. The orebody is hosted in quartzite and phyllite of the Nsuze Group and mineralisation occurs in a 1 m thick, bedding-parallel quartz reef which contains cubic pseudomorphs of haematite after pyrite, with the haematite giving way to pyrite at depth. Some exceptionally rich pockets of ore with grades of up to 204 g/t gold were located. However, mineralization was sporadic and apparently refractory at depth, which may cause beneficiation problems. These factors have rendered the reef uneconomic and no detailed prospecting has been reported since.

3.3.4.5. **Bevenson**

Old workings on the farm Bevenson 483, some 40 km southeast of Vryheid (Fig. 3.1), were first reported by Humphrey and Krige (1932). Mineralisation occurs in auriferous quartz stringers which are locally developed in a diabase sheet intrusive into the metasediments of the Mozaan Group. No recent investigations have been carried out.

3.3.4.6. **Breda**

Humphrey and Krige (1932) reported the discovery of gold in quartz veins within the Mozaan Group on the farm Breda 261, in 1909. Several other occurrences were discovered in the same area during 1914, but the general tenor of the ore was poor and the workings were subsequently abandoned.

3.4. **Other Metalliferous Deposits in the Greenstones**

Few important mineral occurrences exist within the greenstones. The more important of these are described below. The location of these and other minor occurrences in the Nondweni area (Versfeld, 1988) are shown in Figure 3.2. Distribution of the Toggekry Formation and location of the Dania and St.James workings are shown in Figure 3.5.

3.4.1. **Copper - Zinc Deposits**

Three base metal sulphide occurrences are recorded from the Toggekry Formation of the Nondweni Group. Detailed descriptions of these deposits and analyses of samples taken from them were undertaken by Versfeld (1988). The Toggekry Formation consists predominantly of quartz-feldspar-sericite schists which are interpreted as reworked felsic tuffs, and also contains significant felsic volcanics, minor tuff beds and possible rhyolite flows (Versfeld, 1988). Versfeld (1988) concluded that these massive Cu-Zn sulphide bodies within the Nondweni Group originated as syngenetic, chemically precipitated ores, that were deposited together with immature fine-grained sediments which represent reworked felsic tuffs. The metals and sulphur are thought to have been convectively leached from the underlying volcanic pile of the Magongolozi Formation by circulating seawater. Thereafter, the hydrothermal fluids are believed to have been discharged along active fault lines and deposited in a trough with accumulating felsic tuffaceous sediments. Episodic mineralising events resulted in the deposition of sulphide ore at different stratigraphic levels. The sulphides were subsequently remobilised and concentrated in fold hinges, resulting in small, lensoid, folded ore shoots which rarely exceed 4 m in width.

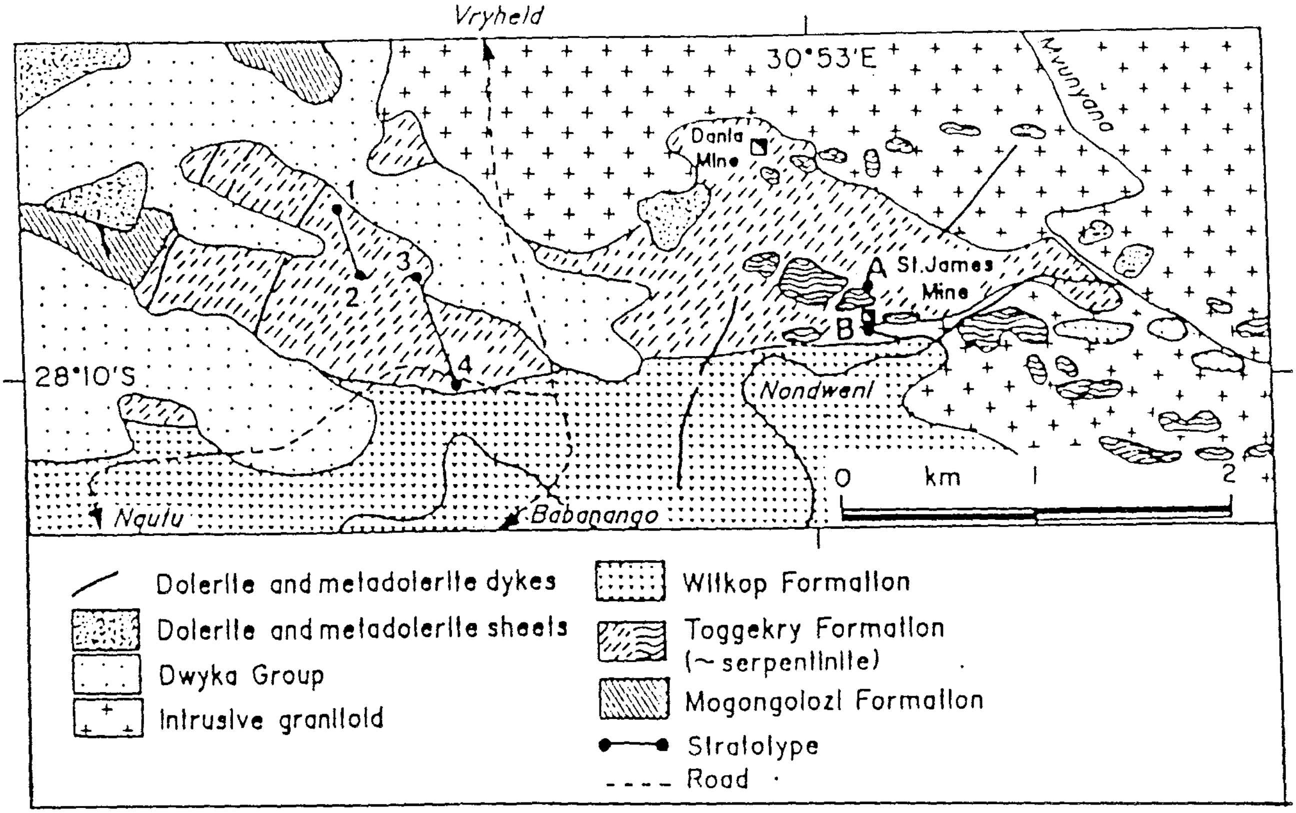


Fig.3.5: Geology and distribution of the Toggekry Formation (Nondweni Group) and Locations of the Dania Mine and St.James Mine (after Wilson and Versfeld, 1994a).

3.4.1.1. **Dania Mine**

Limited copper was produced at the turn of the century using an experimental production plant at the Dania Mine (Hatch, 1910). The deposit, whose underground workings have since collapsed, is located on the farm Toggekry 10986, some 20 km northeast of Nondweni. Remnant gossan is observed at surface. According to Versfeld (1988), the sulphide orebody has a pinch and swell structure and is hosted in quartz-sericite schists of the Toggekry Formation. The schist is intruded by granite which cross-cuts the foliation of the schists and also intrudes the sulphide bodies. Minor shearing was noted at the granite-schist contact. The granite/schist/orebody relationship can be seen in the cross-section by Hatch (1910, Fig.3.6) which was drawn from the underground workings. Mineralisation is concentrated in fold closures which are tight and isoclinal in nature. Sulphide minerals identified in hand specimen by Versfeld (1988) include sphalerite, chalcopyrite and pyrrhotite, while ore in the dumps is stained by malachite, with rarer chrysocolla and azurite.

Recent diamond drilling (Versfeld, 1988), indicated low grades and narrow intersection widths (generally less than 1 m), with a lack of continuity of the mineralisation between boreholes. The best values were obtained at depths of 30 to 50 m, e.g. 15% Zn, 0.16% Cu over 5 m intersected width, and 0.9% Zn, 1.42% Cu, 6 g/t Ag over 11 m intersected width. Extensive drilling by major mining companies did not reveal significant ore reserves at depths of more than 100 m.

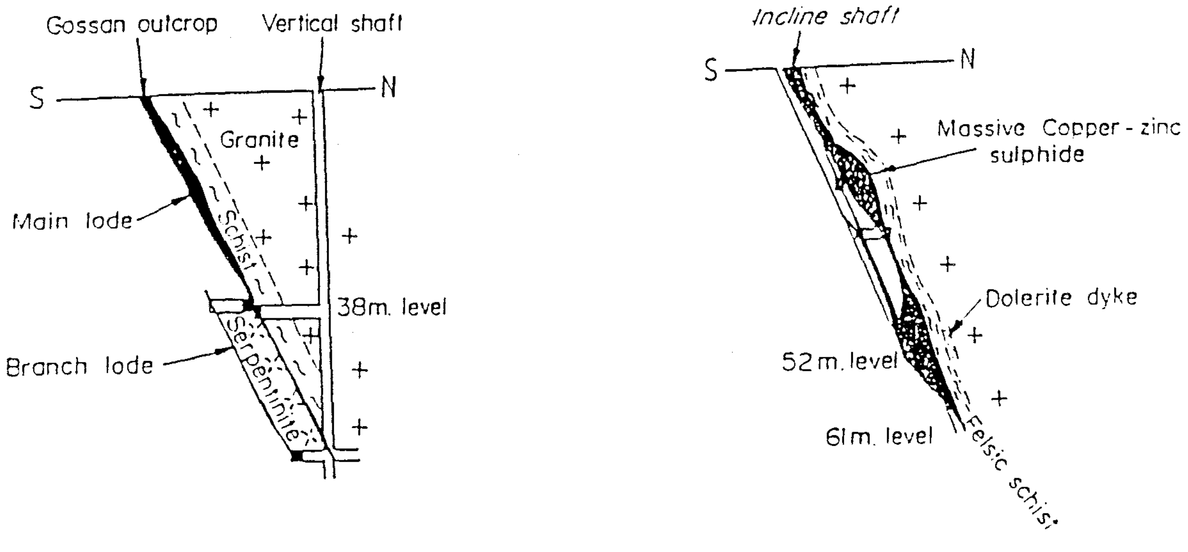


Fig.3.6:Sections through the Dania Mine Workings (after Hatch, 1910)

3.4.1.2. **Central Zone Prospect**

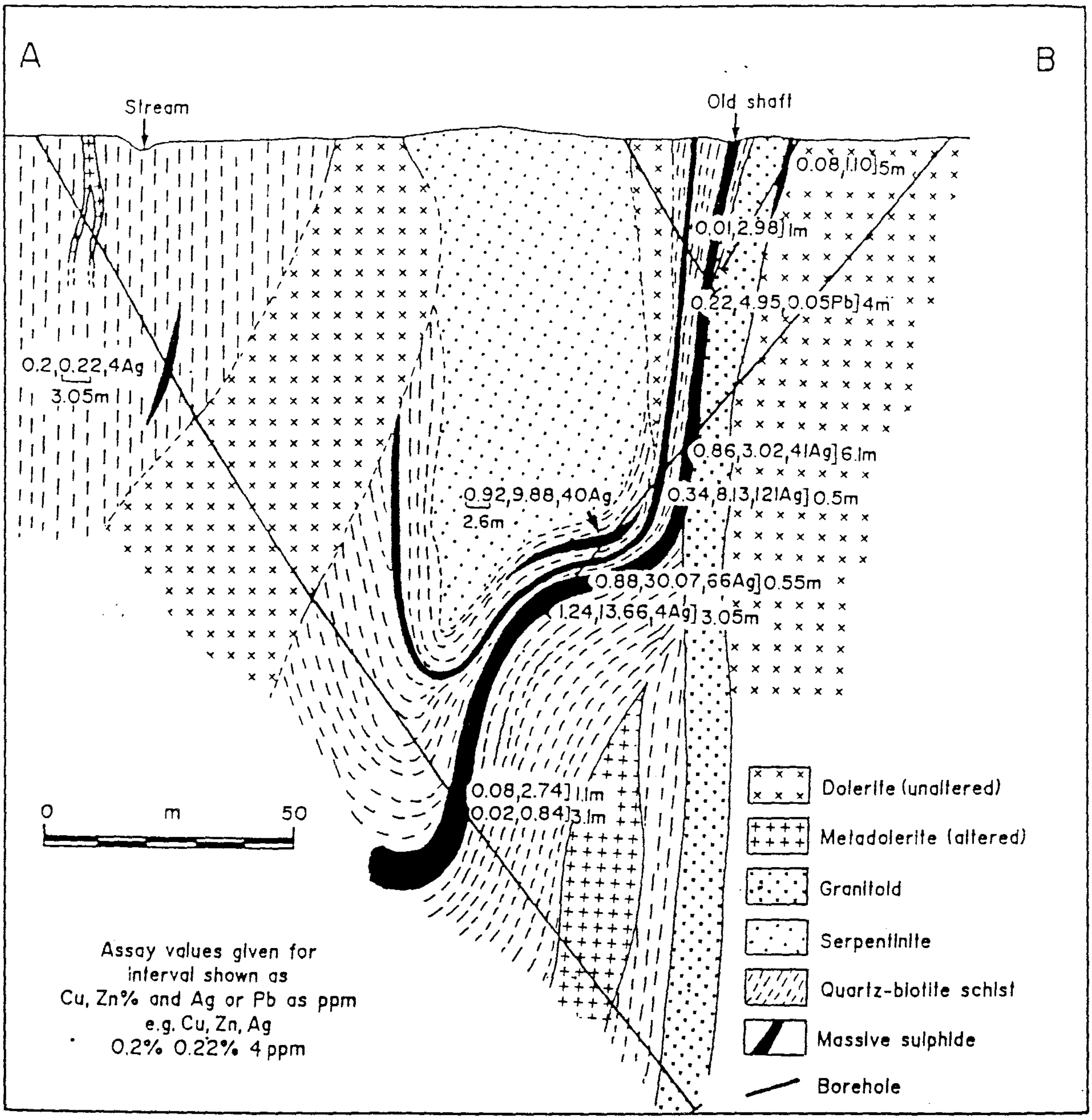
No production was ever recorded from this prospect, on the farm Toggekry 10986 (Fig. 3.2). However, evidence of earlier workings in the form of pits and trenches was noted. The most recent prospecting included diamond drilling by Iscor in the early 1970's. Studies by Versfeld (1988) revealed that the sulphides are hosted in a recrystallised quartzite or chert member, between 2 and 20 m in thickness, which crops out over a strike length of 1.5 km. This member is isoclinally folded about an east-west striking axial plane and is hosted in schists of the Toggekry Formation. The schists adjacent to the quartzite member are reported to exhibit weak sulphide mineralisation in places. The Central Zone is intruded by granitoids as well as Karoo dolerites.

Gossanous material is exposed in the surface outcrops of the quartzites and is best developed in the hinge zones of folds (Versfeld, 1988). The highest values obtained from the sampling of diamond drill cores were 4.57% Zn and 0.26% Cu over 1.32 m and 16.4% Zn over 1.06 m. However, the mineralised zones lack continuity along strike, indicating low tonnage potential. In addition, Ag values were insignificant and there is no associated gold mineralisation (Versfeld, 1988).

3.4.1.3. **St. James Mine**

The old workings here comprise filled-in shaft and a collapsed decline, along with an adjacent small dump, on the farm Toggekry 10986. Samples from the dump consist of high grade secondary zinc mineralisation and boulders of massive sulphide containing pyrrhotite, sphalerite and chalcopyrite.

According to Versfeld (1988), the ore occurs as stringers and pods of massive sulphide, hosted in schists of the Toggekry Formation (Fig.3.5). The mineralisation appears to be concentrated in the fold closures of minor folds which occur on the limb of a large-scale fold which wraps around a serpentinite body. Diamond drilling also indicated massive sulphide ore in contact with granite that intrudes the serpentinite body. Core from the Toggekry Formation revealed that zones of ore grade mineralisation are bedded, and lie conformably within foliation planes of the quartz-sericite schist host rock. However, no significant tonnage of ore was proven despite a number of high grade intersections with mineralised zones (Fig. 3.7).



Assay values given for
interval shown as
Cu, Zn% and Ag or Pb as ppm
e.g. Cu, Zn, Ag
0.2% 0.22% 4 ppm

Fig.3.7: Section through the St. James Mine Interpreted from surface exposure and diamond drilling (from Wilson and Versfeld, 1994a).

3.4.2. **Tungsten**

An occurrence of scheelite mineralisation was located on the farm Mount Vernon 10965 (Fig. 3.2) in the Toggekry Formation. Blebs of scheelite up to 4 mm in diameter are disseminated in a complex succession of silicified felsic tuffaceous sediments which are interlayered with highly silicified and deformed pillow basalts (Versfeld, 1988). Drilling in 1982 indicated significant tungsten mineralisation associated with minor quartz veins in a strongly mylonitised zone. Several quartz vein samples from the core revealed anomalous tungsten values ranging from 100 ppm to 0.30%, however indicated reserves were found to be low as the ore-bearing zones show little continuity. Further investigations by STK (Schutte, 1984), which included diamond drilling, concluded that the scheelite was very erratically distributed, as promising earlier results from prospecting by Anglo American could not be repeated. Ore reserves were calculated at 68 000 t with an average grade of 0.3% WO_3, which was considered uneconomic. A hydrothermal origin was suggested for this mineralisation.

3.4.3. **Tin**

Cassiterite-bearing pegmatite veins exposed in river beds are reported to have been mined in the early part of the century from two prospects, some 12 km east of Melmoth in northern KwaZulu-Natal (Hatch, 1910). The pegmatites are intrusive into gneisses of the Nondweni Group. The first prospect, Hazelhurst's Claims, assayed a maximum of 0.32% Sn, but the pegmatite body was too small to be of economic significance. The Premier prospect assayed a maximum value of 0.24% Sn, and was also considered uneconomic, even though the pegmatite body was of substantial dimensions. No recent prospecting has been recorded.

3.5. **Industrial Mineral Deposits : Granite-Greenstone Terrane**

3.5.1. **Talc**

Abandoned talc workings have been reported by Versfeld (1988) on the eastern part of the farms Mount Vernon 10965 and Kromellenboog 266 (Fig 3.2). The talc formed by alteration of serpentinite near the contact with intrusive granites. A large body of talc is also developed in the alteration zone around the Sisters gold prospect and its formation is ascribed to the hydrothermal alteration of komatiitic volcanic rocks. The talc was found to be highly impure due to the presence of carbonate minerals, iron oxides and amphiboles (Versfeld, 1988). The deposit was never exploited.

3.5.2. **Graphite**

Uneconomic concentrations of graphite occur in schists exposed in old prospecting pits on the farm Mount Vernon 10965 (Fig.3.2)(Versfeld, 1988). Additional graphitic units at depth were detected using horizontal loop electromagnetic techniques and percussion drilling. These 1 to 5 m thick bodies were found to occur as conformable units within felsic tuffaceous sediments of the Toggekry Formation. Microscopic examinations revealed very finely divided flakes of graphite and these bodies were considered to be of no economic significance (Versfeld, 1988).

3.6. **Industrial Mineral Deposits: Pongola Supergroup**

3.6.1. **Kyanite**

Kyanite occurrences were investigated some 10 - 15 km south of Nkandla in the late 1970's (Meinster, 1978), hosted in argillaceous sediments of the Nsuze Group on Reserve No.19 7638. Regional metamorphism (Meinster, 1978) and granite intrusives resulted in contact metamorphism of the alumina-rich sediments to the quartz-mica-kyanite schists of interest (Blain et al., 1976). However, accessory minerals such as ilmenite and secondary goethite could have a detrimental effect on the quality of the kyanite. Meinster's (1978) investigations in the area revealed two potentially mineable ore bodies with reserves estimated at 15 Mt of ore grading at an average of 40% kyanite. Tests conducted on material from these sites proved that kyanite could be successfully extracted and a small-scale open-cast working to exploit the ore was recommended. One such deposit is known to have been worked. However the workings in the area are currently abandoned.

3.6.2. **Andalusite**

Large crystals of andalusite in schists of the Mozaan Group have been documented in the northeastern part of KwaZulu-Natal (Linström, 1987a). These andalusite porphyroblasts are thought to be the result of the contact metamorphic effects due to the intrusion of the Spekboom granite (Weilers, 1990).

3.6.3. **Corundum**

Corundum-aplite is found in irregular pegmatite veins which are intrusive into serpentinite within the Mozaan Group in northeastern KwaZulu-Natal (Linström, 1987a), and small-scale exploitation of these was thought to be viable (Du Toit, 1931).

CHAPTER FOUR

4. Metallogenic Framework: The Proterozoic Rocks of KwaZulu-Natal

Introduction

A detailed account of the known mineral occurrences in the Mid- to Late-Proterozoic host rocks and their approximate location in KwaZulu-Natal is presented. Some deposits, where literature is available, are analyzed in more detail than others. This chapter is thus a synthesis of data from various authors who have worked on mineral deposits in the Province. Where available, details of their interpretation of the genesis and mineralisation style is provided. Occurrences are subdivided according to the age of the lithologies in which they are present and grouped according to mineralization styles, where applicable. Minor occurrences are tabulated.

No significantly large mineral deposit has yet been discovered in the Natal Metamorphic Province. This may be because of the relatively inaccessible terrain, deep weathering and dense vegetation in this sub-tropical area. Mineralisation may also lie undiscovered beneath the thick younger cover rocks of the Karoo Supergroup.

The three distinct tectonostratigraphic terranes that make up the NMP (see Chapter 2) are characterised by distinct styles of mineralisation in each of the terranes (Thomas et al., 1990a). The low-grade metamorphosed Tugela Terrane is host to many of this mineralisation (Fig. 4.1), with the number of occurrences decreasing in the higher grade terranes in the south. Each terrane will be discussed separately. There have recently been several papers on mineralisation within the Province, e.g. Thomas 1990a; Thomas and Bullen, 1992; Thomas et al., 1990a, 1994b; Bullen et al., 1994, which provided much of the data required for this synthesis.

A discussion of the overall genesis of the important metalliferous mineral deposit types is presented in Chapter five.

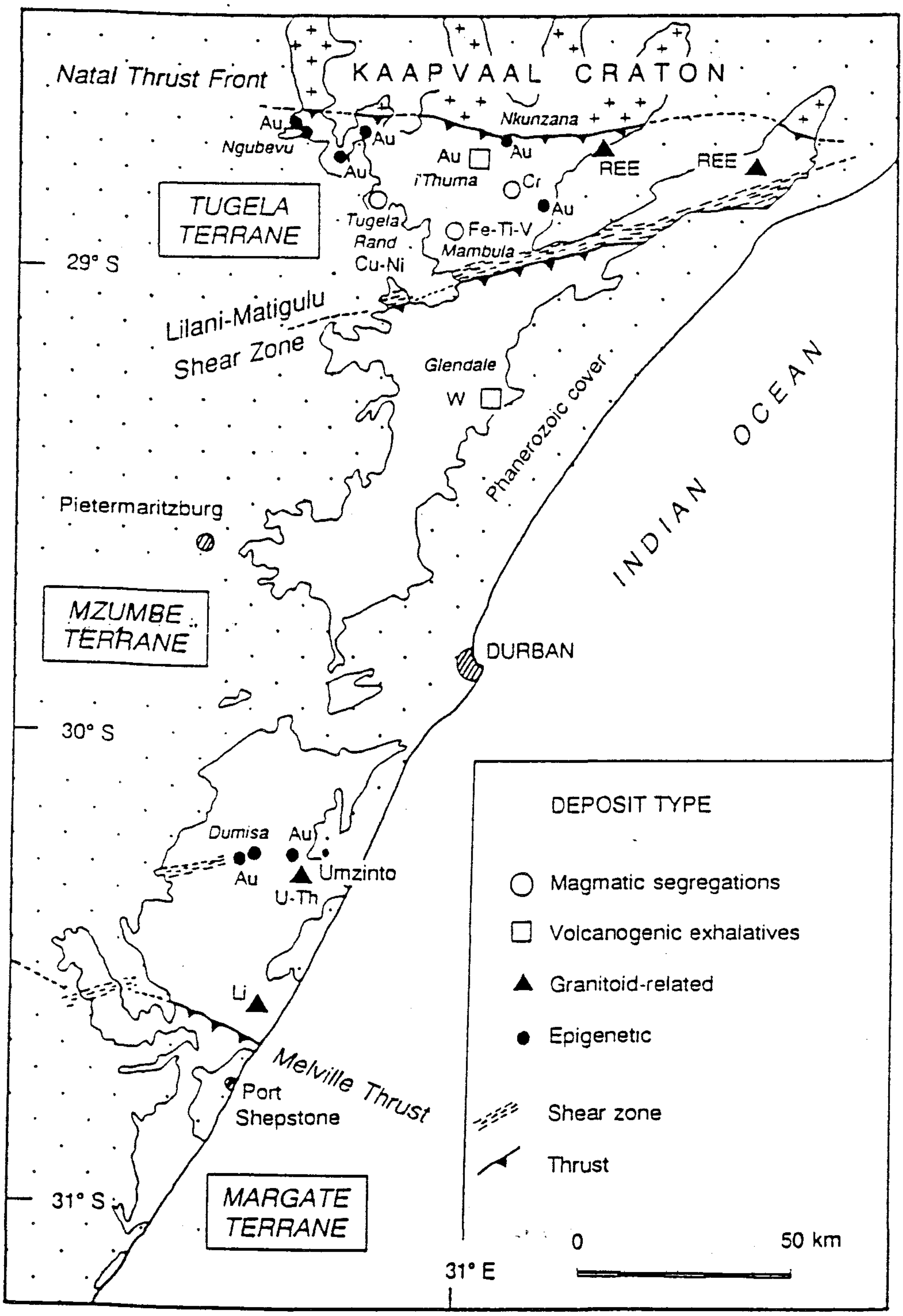


Fig.4.1: Location of the important known metalliferous mineral occurrences in the NMP (after Thomas et al., 1994b).

4.1. The Tugela Terrane

This terrane occupies the area from the thrust front to the Lilani-Matigulu Shear Zone (Fig 2.5 and 2.7). Much exploration work has been centred on this terrane, and all documented work will be described below. The metallic mineral occurrences within this terrane are outlined in Fig. 4.2.

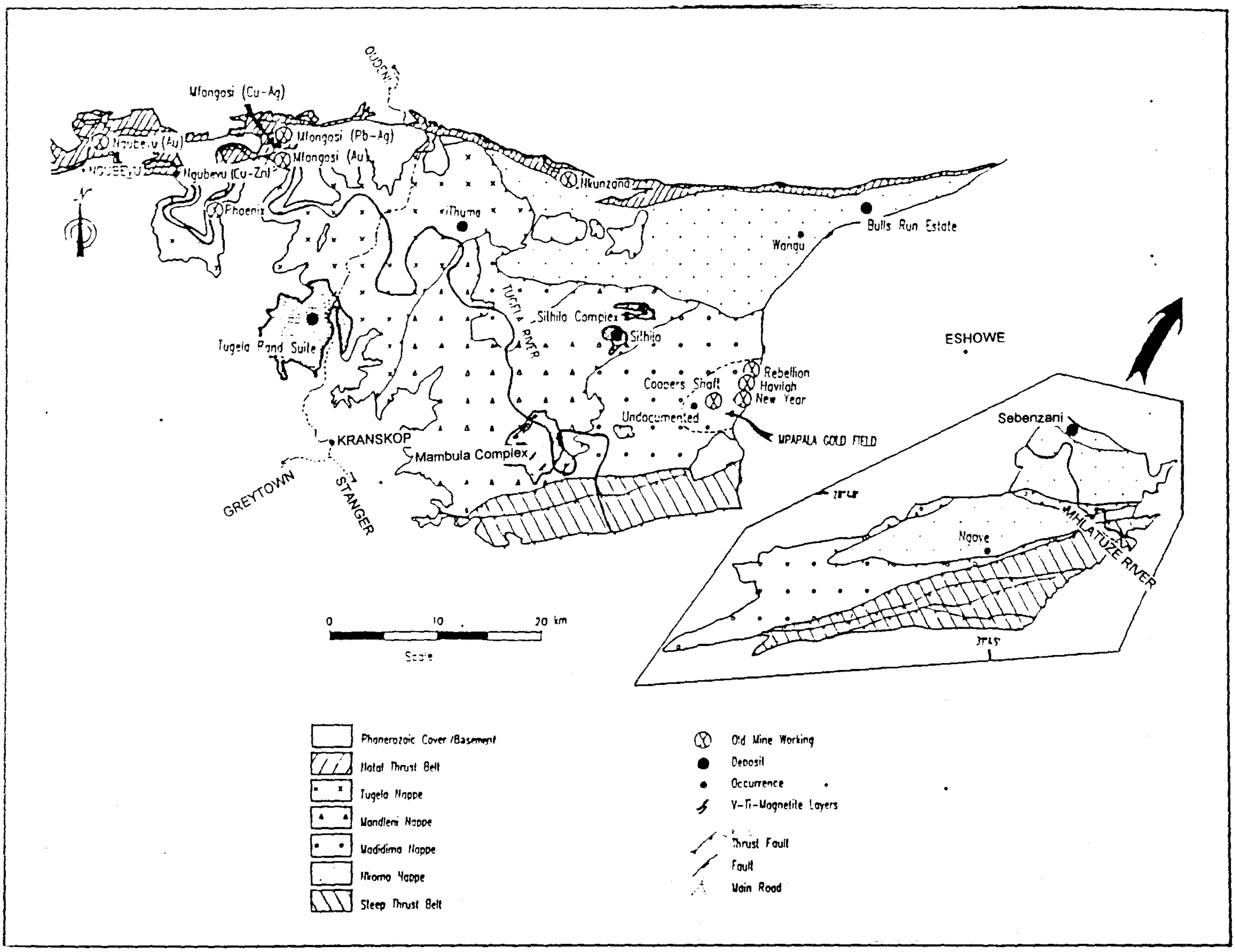


Fig. 4.2: Metalliferous mineral deposits within the Tugela Terrane (after Thomas et al., 1990a).

4.1.1. **Shear Zone-hosted Lode Gold Deposits**

This type of gold mineralisation in the NMP is unique to the Tugela Terrane, although shear zone-hosted gold deposits associated with quartz veins also occur in the Mzumbe Terrane. Shear zone-hosted lode-gold is present within the imbricate thrust front adjacent to the Kaapvaal Craton and in the amphibolitic nappe zone to the south. See chapter five for the genesis of these gold deposits.

THRUST FRONT

4.1.1.1. **Ngubevu Goldfield**

Numerous small occurrences were prospected around the early 1900's in this goldfield, of which four became small mines (Table 4.1). The goldfield is situated in the westernmost part of the Natal Thrust Front (Figs. 4.2 and 4.3). All the gold in the area occurs within quartz veins hosted mainly in interlayered greenschist facies mafic lavas and schistose meta-pelites of the Mfongosi Group, with associated locally developed graphitic schist horizons. These epigenetic gold-rich quartz veins and stringers (up to 7 g/t) are confined to west-striking zones of intense shearing and carbonate alteration (Thomas et al, 1990a). Later-stage, undeformed carbonate-bearing quartz veins are very poorly mineralised, with values of around 20 ppb only.

The graphitic schist horizons contain zones, up to several metres in thickness, of intense carbonate alteration, associated quartz and sericite and abundant fine-grained tourmaline (up to 20% of the rock). According to Thomas et al. (1990a), the presence of such "tourmalinites" has important implications with regards to the genesis of the deposits, as they are often associated with, and genetically related to, stratabound base metal sulphide, gold, tin and tungsten deposits as a result of submarine exhalative processes. These processes could have possibly formed the protores from which at least some of the epigenetic gold mineralisation is derived.

Thomas et al. (1990a) recognised the following sequence of events important to the genesis of the mineralisation at Ngubevu:

1. an early phase of barren quartz veins;
2. intense shearing, probably associated with northward-directed thrusting, which deformed the early veins;

3. mineralising hydrothermal fluids, which were channelled through shear zones, depositing gold in quartz veins during the metamorphic event that was synchronous with, or possibly post-dated the last major deformation; and
4. the late generation of virtually barren carbonate-rich veining that is related to late-stage influx of CO_2-rich fluids along shear zones, resulting in extensive carbonate alteration.

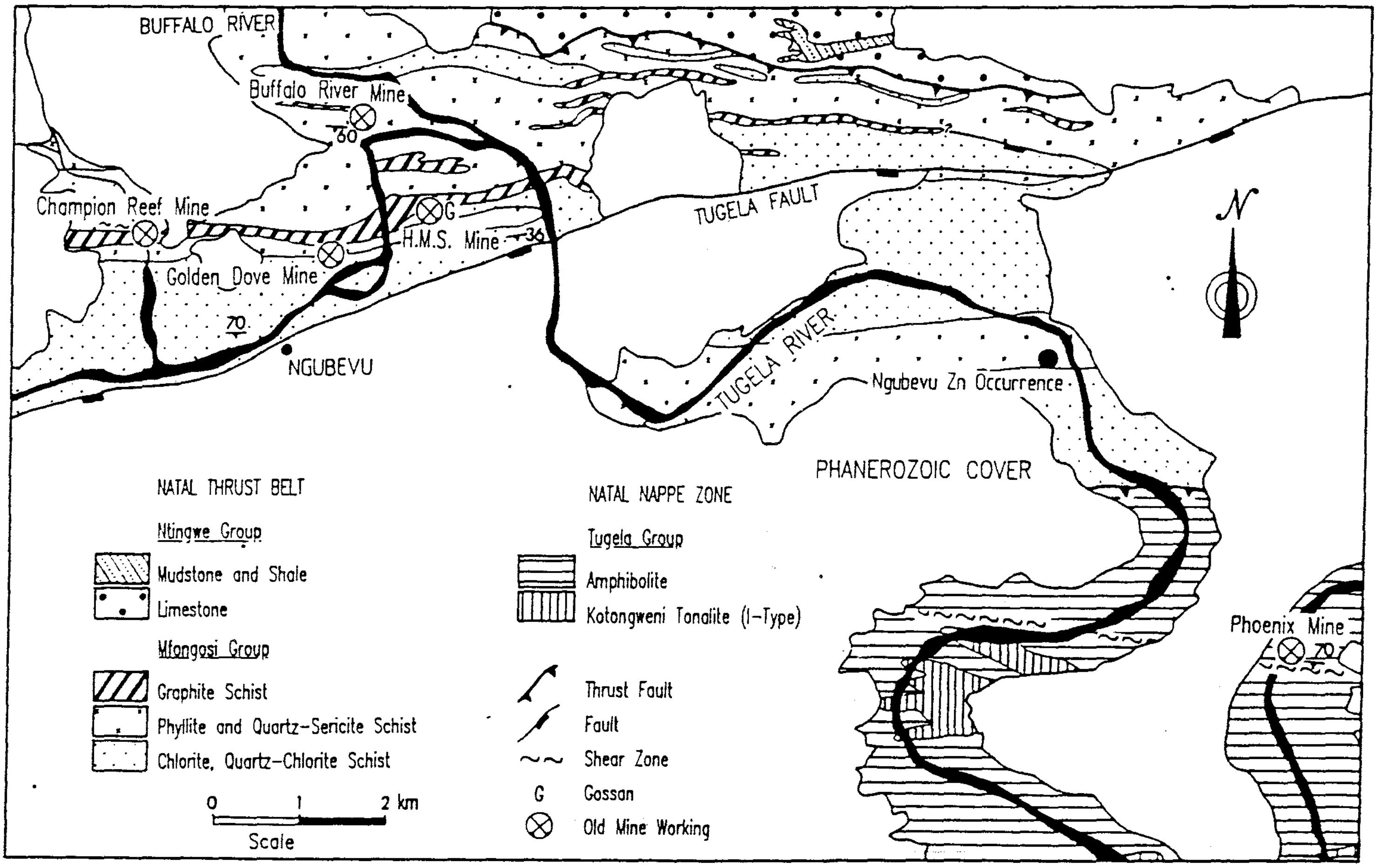


Fig. 4.3: Geology of the western part of the Natal Thrust Front showing the Ngubevu Mineral Occurrences (after Thomas et al., 1990a).

Table 4.1: Characteristics of the Ngubevu Gold Deposits

Mine Name	Mfongosi Group Lithology	Mineralisation/Alteration	Structure of Orebody	Known Grade
H.M.S.	Quartz sericite schist Quartz chlorite schist	Gold in quartz veinlets with disseminated pyrite. Some carbonate alteration. Pervasive silicification.	Silicified shear zone dipping 63°S	Highest of 5.2 g/t.
Champion Reef	Quartz sericite schist, associated graphite schist (tourmaline-rich).	Minor Au-bearing quartz veins in the shear. Minor pyrite. Intense late-stage sericite-calcite alteration. Propylitic alteration around shear (epidote-albite-chlorite-sericite)	4m-wide shear zone dipping 60°S	5.4 g/t over 1.2 m (Hatch, 1910)
Golden Dove	Chlorite and quartz-chlorite schist (metalavas)	Au in fine quartz veinlets. Chlorite-calcite-sericite-pyrite alteration in shear zone. Alteration halo not mineralised. Late carbonatization.	Shear zone dips 55°S.	Quartz Stringer: 7.1ppm Shear zone rock: 45 ppm
Buffalo River	Quartz-sericite schist and phyllite	Au associated with pyrite in gossanous enclaves in quartz veins with Cu, Pb, and Zn and Ni sulphides. Sideritic alteration.	Steep south dipping 70 cm thick mineralised veins	Gossanous enclave: 1.6 ppm Au; 2.23% Cu; 811ppm Ni; 2ppm Ag.

Table after Thomas et al. (1990a)

4.1.1.2. Mfongosi Gold Mine

The mine is situated 20 km east of Ngubevu (Fig. 4.2) on the north bank of the Tugela River. The mineralisation occurs in thin quartz stringers developed along the steep southerly dipping foliation of the Mfongosi chlorite schist host rocks (Thomas et al., 1990a). In 1909, about 1.3 kg of gold was produced from "Ayers Reef" - a steep, west-pitching, poorly defined orebody up to 1.1 m thick, at an average grade of 5.2 g/t (Du Toit, 1931).

4.1.1.3. Nkunzana Gold Mine

These mine workings are situated on both the east and west banks of the Nkunzana River, about 40 km NW of Eshowe (Figs. 4.2 and 4.4). Up to 1922, when the two workings were abandoned, about 25 kg of gold at an average grade of 3.17 g/t was produced (Du Toit, 1931). The mineralisation is hosted in sericite and chlorite schists of the Mfongosi Group. The intensely sheared schists display steep, southerly dipping, c- and s-planar fabrics, with steeply plunging stretching lineations and fold closures. The mineralisation is clearly largely controlled by the lineation (Bullen et al., 1994).

According to old mine plans and sections (Fig. 4.4), the auriferous lodes are steeply plunging, pencil-like bodies that were mined 70 m downplunge to the level of the Nkunzana River. Recent sampling of the adits by Thomas et al. (1990a) has shown that elevated precious and base metal contents are localised within a ferruginous, highly oxidised reef zone. This zone is recognised principally on its ferruginous nature. The following maximum values were recorded over 1 m intersections: Au (4.4 ppm); Ag (0.9 ppm); Cu (235 ppm); Pb (1260 ppm); Zn (370 ppm) and As (333 ppm). In addition, Ba, Y, Rb, and Co are enriched across the auriferous zone, relative to the surrounding schists. Sampling also revealed that the eastern workings have a Cu-As signature, whereas the western workings are distinguished by a Pb-As-Zn association. Previous researchers have found no correlation between gold mineralisation and the intensity of quartz vein development at Nkunzana.

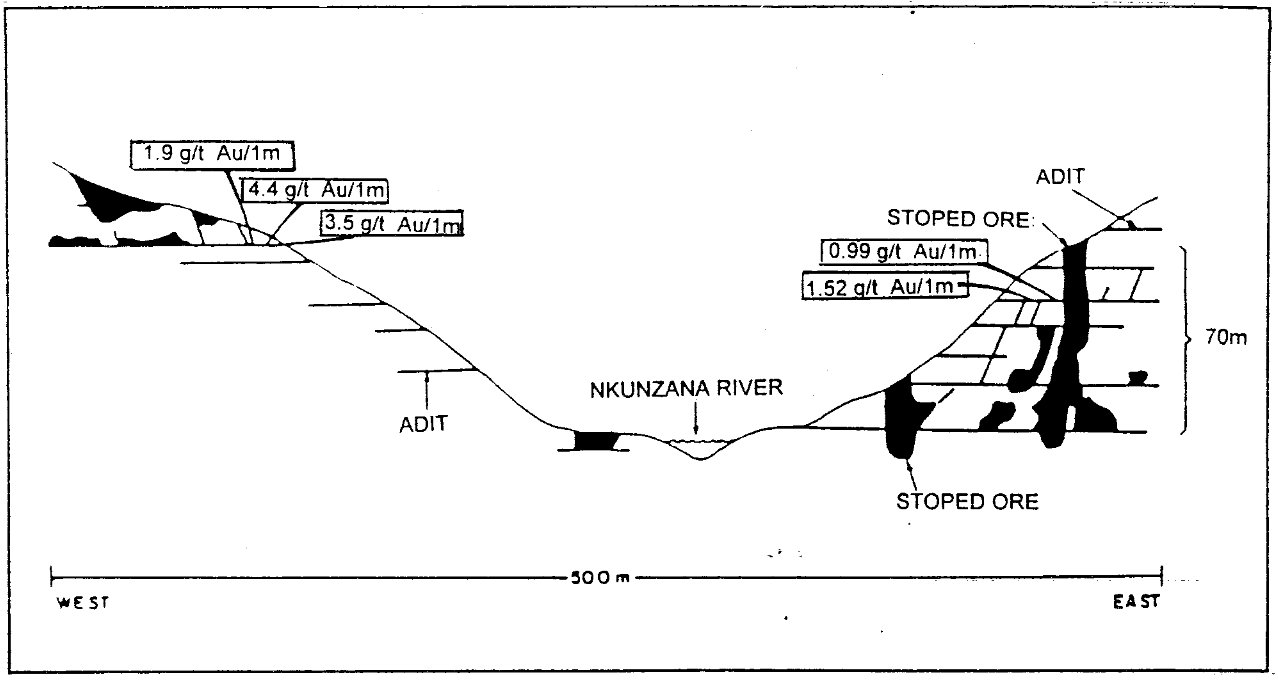


Fig. 4.4: Schematic cross-section through the Nkunzana Mine workings showing the grades achieved at various intervals (obtained from the Government Mining Engineer, Johannesburg, by Thomas et al., 1990a)

NAPPE ZONE

4.1.1.4. **Phoenix Mine (Tugela Nappe)**

This mine is located in the extremely inaccessible "Umvoti Goldfield" which is situated on the Tugela River, some 12 km east-southeast of Ngubevu (Fig. 4.2) on Reserve No.19 7638. Old workings consisted of 4 adits driven into a hillside, where 90 tons of ore were milled in 1907 at an average grade of 8.4 g/t (Hatch, 1910). Mineralisation is hosted within a west-striking shear zone which is about 3 m wide. The shear zone occurs in medium-grained actinolite-clinozoisite-sericite metagabbro of the Tugela Group and dips at 65°S. A grade of 5.49 g/t gold over 60 cm, along a 50 m strike length, and patches of high grade mineralisation were reported by Hatch (1910). Significant gold mineralisation is confined to relatively undeformed quartz veins (up to 75 cm thick) within this shear zone, where the metagabbro is retrogressed to a chlorite-biotite schist.

Theart (1987) recommended a detailed exploration programme in this area to locate possible extensions to the known mineralisation. The best grade obtained was from a pyrite-bearing quartz vein, which gave a value of 6 g/t over a width of 70 cm. Although recent investigations have revealed good grades in places, the workings have remained abandoned.

4.1.1.5. **Mpapala Goldfield (Madidima Nappe)**

This goldfield is situated about 22 km west of Eshowe in the "Mbongolwana Flats" (Fig. 4.2) on Reserve No.21 7638. Four old workings (Rebellion Reef, New Year, Havilah and Cooper's Shaft) have been worked here in the early 1900's (Table 4.2).

The gold occurs disseminated in quartz veins in amphibolites of the Silambo Formation of the Tugela Group and in a later, sheared aplitic dyke. Schurink (1986) reported anomalously high Au, Ag, Cu, Pb and As values. The quartz veins lie within narrow shear zones, one of which is continuous from the Rebellion to the New Year workings, a distance of over 2 kms. Thomas et al. (1990a) concluded that the Au in the Mpapala Goldfield is clearly of hydrothermal, epigenetic origin, similar to that at Ngubevu. Evans (1988) considered the potential for finding mineralisation at depth in the area to be very promising, as all the old workings were discovered because they outcropped or occurred near the surface. His recent sampling of some of the old workings indicated encouraging results (Table 4.2). However, detailed geological studies (mapping, trenching, geochemistry, geophysics, magnetic survey, resistivity and drilling) by Schurink (1986) on the old Rebellion Reef Mine revealed that the quartz veins have limited strike lengths and pinch out with depth. Diamond drilling and trenching revealed K-metasomatism and epidotization as dominant alteration patterns, with traces of calcite and chlorite also evident. Pyrite and magnetite were evident in most samples, with minor chalcopyrite. In addition to these workings, Thomas et al. (1990a) reported a new occurrence in the area (Fig.4.2), with a grab sample grading at > 9 g/t. No further work is reported to have been done in the area.

Table 4.2: Characteristics of the Mpapala Goldfield Workings

Working	Tons Crushed	Grade (g/t)	Known Extent of Orebody	Maximum Width of Orebody	Orientation of Orebody	Recent grab sample Assay (Evans, 1988)
Rebellion	508	1.7	16.8 m strike; 15.9 m depth	1.7 m	045/80 SE	4.5 g/t Au; 580 ppm Cu; 58 ppm Zn
Havilah	189	6.9	Strike unknown; 19.8 m depth	1.5 m	037/vertical	N/a
New Year	436	5.2	Strike unknown; 11.0 m depth	5.5 m	037/vertical	3.2 g/t Au; 4140 ppm Cu; 5100 ppm Pb
Cooper's Shaft	1	40.5	450 m strike; 7.6 m depth	2.0 m	045/85 SE	N/a

Data from Thomas et al. (1990a) and Evans (1988).

4.1.2. Gold-bearing Massive to Semi-massive Sulphides

4.1.2.1. i'Thuma Volcanogenic Sulphide Deposit

Stratiform, sulphide-rich volcanogenic rocks were discovered in the i'Thuma River area (Figs.4.2 and 4.5) in the early 1980's on Reserve No.19 7638. According to Thomas et al. (1990a), the orebody consists of a ~ 2 m thick, fuchsitic, ferruginous, sulphide-rich unit with sheared margins in Tugela Group host rocks. Mineralisation is associated with two lithologies: 1) amphibolitic metalavas and 2) pelitic/psammitic metasediments. The orebody has been folded into a major, northeast-plunging, tight-to-isoclinal F_1 antiform, with both limbs dipping northwest at about 40°. Shearing is most intense at the sulphide/host-rock interface due to the competency contrast, with the intensity of shearing decreasing towards the core of the sulphide unit. Sulphides include pyrite (10-50%), with minor galena and sphalerite. Average gold and silver grades reported were 1.25 g/t and 27 g/t respectively, with elevated contents of Cu (0.3%), Pb (0.32%), Zn (0.18%) and Ba (0.43%), over a width of 1 m and along a 120 m strike length in the sulphide zone. Enhanced Ag and Au values were also obtained from the sheared sulphide rock and immediately adjacent host rocks.

The mica schist footwall contains abundant, concordant pyrite-chalcopyrite segregations up to several centimetres in length, along with a number of thin, phlogopite-rich, sulphide veinlets and magnetite quartzite layers. This horizon, which also contains minor Au, tourmaline and andalusite, has been interpreted as a feeder zone for the overlying exhalative-type mineralisation (De Klerk, 1991). Silica was introduced by premetamorphic, exhalative, mineralizing fluids, and formed medium-grained veins and segregations associated with the sulphides. The observed biotite-chlorite-phlogopite-calcite-andalusite alteration is attributed to the effect of hydrothermal fluids passing through the footwall schist unit. The feeder zone sulphides record values of up to 230 ppb gold, which indicates that the mineralising fluids were also gold-bearing. This implies that the Au mineralisation is syngenetic in origin and not the result of a late epigenetic event. Remobilisation and further concentration during shearing however, could also have occurred.

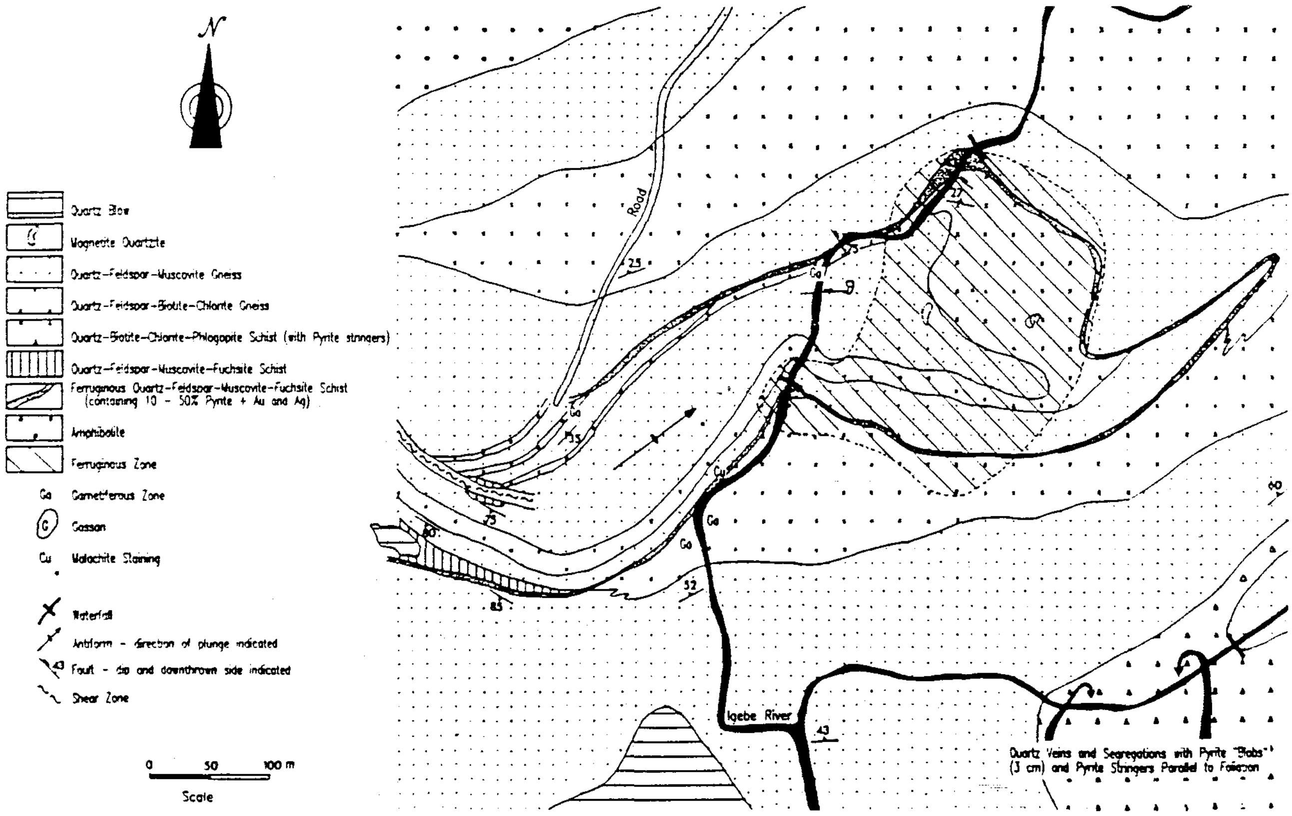


Fig. 4.5: Geology of the area surrounding the i'Thuma massive-semimassive sulphide body (after Thomas et al., 1990a)

Thomas et al.(1990a) related the i'Thuma deposit to other volcanogenic massive sulphide deposits (e.g. the Australian deposits described by Large et al., (1989)), based on paragenetic associations, where the Pb-Zn-Ag-Au association occurs in the massive to semi-massive sulphide body, with a footwall stringer zone consisting of pyrite and chalcopyrite only. These authors therefore proposed that the i'Thuma River mineralisation represents an example of a syngenetic, sediment-hosted, volcanogenic, submarine exhalative, auriferous massive sulphide deposit, the first of its kind to be recognised in the NMP. The marginal grades and lack of infrastructure have thus far counted against the economic viability of this deposit.

4.1.3. **Base Metal and other Mineralisation**

4.1.3.1. **Ngubevu Cu-Zn Mineralisation**

Several shear zone-hosted Cu-Zn showings were identified 6 km east of the Ngubevu Goldfield (Figs. 4.2 and 4.3), hosted in deformed, southerly dipping, quartz-mica schists and chlorite-epidote schists with quartz-calcite veins containing coarse-grained pyrite. Brown (1988a) noted relic textures in the rocks and suggested that the Mfongosi schists at this locality could represent highly deformed metalavas and tuffs and that the mineralisation was of submarine volcanogenic exhalative type, with a chloritised and carbonatised stringer zone to the south, and a stratigraphically higher, Cu-Zn sulphide zone to the north. Sampling of gossanous outcrops indicated grades of up to 0.85% Cu and 1% Zn (Thomas et al., 1990a).

4.1.3.2. **Mfongosi Pb-Ag Workings**

These workings, reported to be situated 2 km north of the Mfongosi gold mine (Fig.4.2), could not be located by Thomas et al. (1990a). Mfongosi chlorite schists host the mineralisation which is associated with a 1.7 m thick south-dipping quartz vein in a shear zone.

The orebody appears to be zoned, with Cu sulphides concentrated towards the hanging wall and pyrrhotite towards the footwall. However argentiferous galena was disseminated throughout (Hedges, 1909).

4.1.3.3. **Mfongosi Cu-Ag Occurrence**

This occurrence is situated 1 km northwest of the confluence of the Mfongosi and Tugela Rivers (Fig. 4.2). Deformed mineralised granitoid in the form of concordant lenses (up to 5 m wide and 3 m thick) intrude the chlorite schists, magnetite quartzites and limestones of the

Mfongosi Group. Grab samples analyzed from these extremely sodic granitoids revealed values of up to 1.6% Cu and 9 ppm Ag (Thomas et al., 1990a). The mineralisation here is thought to be related to the intrusion of cupriferous sodic granite veins and dykes.

4.1.3.4. Magmatic Ores

A number of east-west trending ultramafic bodies occur in the nappe zone of the Tugela Terrane (Figs. 4.2 and 4.6), of which only the Sithilo Complex, Tugela Rand Complex and Ntulwane serpentinite body appear to have been explored. The latter two deposits did not encourage further investigation after initial analyses indicated low Cr_2O_3 values and low Cr/Fe ratios (Wuth and Archer, 1986). The most relevant deposits will be described below.

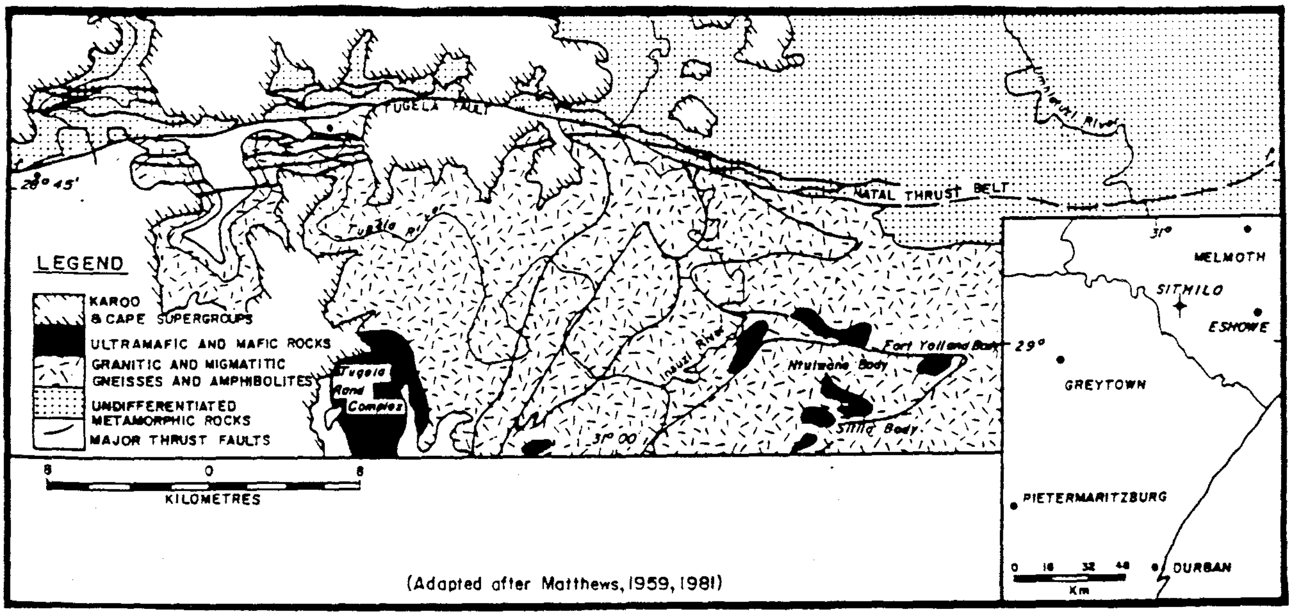


Fig.4.6: Geological setting of the ultramafic bodies within the Tugela Terrane (after Wuth and Archer, 1986).

4.1.3.4.1. Sithilo Complex: Chrome

The Sithilo Complex, which consists essentially of serpentinised dunite, is located on Reserve No.21 7638, some 27 km west of Eshowe, where it intrudes amphibolites of the Tugela Group. It is one of the larger ultramafic bodies in the area, with a strike length of approximately 3 km and width varying from 0.5 to 1 km. According to early Mining Reports on the Natal Colony, attention was first focused on this deposit in 1904 because of the discovery of good quality chrysotile asbestos veins. However, it was only in the early 1950's that exploration at Sithilo revealed four, low-alumina chromite orebodies and during 1952-53 approximately 2000 tons of high-grade chromitite concentrates were produced from four adits driven into the northeastern flank of Sithilo Hill (Wuth and Archer, 1986).

The bulk of the Sithilo body is made up of dunite and olivine peridotite which have locally developed primary cumulate textures. Much of the economically exploited chromite mineralisation is hosted in dunite. Chromite occurs as numerous isolated pods, stringers and irregular stockworks, or may be disseminated. In three of the old workings the chromitite occurs as lenticular bodies, whereas the fourth working is a 15 m diameter, SE-pitching pipe-like chromitite body. The present setting of the chromite lenses is due to tectonic influence, as they are aligned *en echelon* and parallel to shears. Initial concentration however, was attributed to primary magmatic differentiation within the oceanic crust which initially localised and concentrated the mineralisation. Later faulting further limited the extent of the chromite orebodies.

Wuth and Archer (1986) found that in terms of lithology, structure and tectonic setting, the Sithilo body shows affinities with the ultramafic portions of typical chromite-bearing, alpine-type ultramafic complexes around the world, even though it has an incomplete ophiolite sequence (i.e. in the absence of pillow basalts, sheeted dykes and upper gabbros). In addition the textural and compositional character of the chromite is considered sufficient evidence to classify the mineralisation at Sithilo as a Precambrian equivalent of the considerably younger, alpine-type ophiolitic podiform chromite deposits such as those found in Turkey, Cyprus and the Phillippines.

Comparison of ore grades from Sithilo with other alpine-type deposits shows a close correspondence, apart from the lower alumina contents (less than 5% Al_2O_3) at Sithilo. Grades within the four workings range from 9 to 50% Cr_2O_3 while Cr/Fe ratios are typically 1 in the lower grade ores, up to 3.3 in the highest grade ores. Between 1977 and 1979 the deposit was intensely explored by ETC Mines Limited. However, no work has been reported since.

4.1.3.4.2. **The Tugela Rand Layered Suite: Chrome**

This suite is located on the farm Tugela Rand 1974, some10 km north of Kranskop and forms a well-layered association of mafic and ultramafic rocks which intrude the amphibolitic gneisses of the Tugela Nappe (Figs. 4.2 and 4.6). According to Wilson (1990), the Tugela Rand Layered Suite formed as a result of repeated, and sometimes continuous, emplacement of magma into a chamber which at the same time was undergoing crystallisation, while subsequent deformation altered the original sheet-like form of the intrusion. The deformation caused layering in the northern part of the body to have a shallow dip towards the south, while the southern part of the intrusion is more vertical and overturned (Eales et al., 1988).

Chromite occurs as impersistent layers associated with wehrlites and serpentinites and varies from massive chromite to disseminated layers. These irregular chromite orebodies were of limited size and too low grade to warrant exploitation. Thomas et al. (1990a) reported disseminated Cu, Ni and Co sulphides within the lowermost pyroxenitic and peridotitic rocks of the suite. Peak values of 0.12% Cu, 0.25% Ni and 0.027% Co over 3.1 m were obtained from diamond drilling in the northeastern part of the complex (Versfeld, 1981).

4.1.3.4.3. **Sebenzani Cu-Ni Sulphides**

An aerial magnetic anomaly and the occurrence of gossans in the Sebenzani area , some 8 km west of Empangeni, led to an intensive exploration programme for mineralisation here (Schutte and Schurink, 1986). The occurrence is situated south of the Natal Thrust Front, in the Nkomo Nappe (Fig.4.2), in amphibolites, talc schists and actinolite schists with intrusive gabbros and serpentinites. Sulphide minerals include pyrrhotite, pyrite and chalcopyrite.

Drilling of anomalous areas revealed sulphide intersections in all boreholes, with the following maximum values recorded over 5 m: Cu (0.6%), Ni (0.8%) and Co (1149 ppm). In addition, Schutte and Schurink (1986) noted that platinum group metals occur in association with the sulphides. Knoetze (1988, cited in Thomas et al., 1990a) suggested that this occurrence was also an ophiolite-type deposit, similar to the Sithilo body. They considered the potential for economic Cu-Ni mineralisation as excellent and further exploration in the area was encouraged.

4.1.3.4.4. **Mambula Complex : Iron, Titanium and Vanadium**

The Mambula layered mafic complex, on Tugela Location 4674, outcrops over an area of 25 km^2 some 20 km east of Kranskop (Fig. 4.2), near the confluence of the Tugela and Mambula Rivers. These titaniferous iron ores were first recognised and described by Du Toit (1918) and later by Wagner (1928).

The Mambula Complex intrudes amphibolites of the Tugela Group. A broad saucer or funnel-like shape is envisaged for the body due to radially dipping contacts of the layering (Schulze-Hulbe, 1979). The complex is made up of medium-grained gabbro with lesser amounts of norite, websterite, anorthosite and vanadium-rich titaniferous magnetite layers. At least six magnetite-rich layers from 1 to 5 m in thickness are recognised. Poor exposures however, prevent estimates of their extent or lateral continuity. These ores consist of up to 90% V-Ti-magnetite, ilmenite and pleonaste, with trace amounts of the sulphides pyrrhotite, pentlandite, cubanite, chalcopyrite and pyrite also recorded. Ore reserves, estimated by Luyt (1976), are thought to be in the region of 22 Mt at an average grade of 45.92% Fe, 11.53% TiO_2 and 0.56% V_2O_5. According to a detailed mineralogical assessment by Reynolds (1986), it was found that due to the relatively coarse grain size of the ores, the presence of abundant granular ilmenite and simple grain boundary relationships, the ores will be amenable to beneficiation. This would yield an ilmenite concentrate (50.4 to 53% TiO_2) and a Ti-poor magnetite concentrate (3 - 8% TiO_2) containing approximately 1.1% V_2O_5. The ores were found to be rarely pure and generally contain between 10 and 30 volume % of silicate minerals, largely plagioclase and clinopyroxene with lesser amounts of hypersthene.

According to Reynolds (1986), the ores formed during the later stages of the fractional crystallisation sequence responsible for the formation of the complex. The more felsic and Fe-rich nature of this complex suggests that it represents a stratigraphically higher level of a layered complex than the Tugela Rand Layered Suite (TRLS). Like the TRLS, the Mambula Complex was also affected by the tectonics and metamorphism during the NMP tectonic event. The complex was subject to amphibolite facies metamorphism (which modified the texture of the Fe-Ti oxide ores) and northward-directed thrusting.

The economic potential of the deposit is considered to be limited due to its remote locality, small size and moderately low TiO_2 and V_2O_5 contents. In addition, vast resources of these commodities occur in the Bushveld Complex, which can more economically supply the requirements of these commodities in the foreseeable future. Latest exploration attempts here concentrated on Ni and PGM mineralisation, especially after investigations by STK (Steenekamp, 1990) revealed a potentially mineralised troctolite unit in the northern part of the Complex. However, reconnaissance exploration (Anglo American Report, 1992) indicated no significant base or precious metal mineralisation and all prospecting here was abandoned.

4.1.4. **Alkaline Complexes**

The Wangu, Ngoye and Bull's Run alkaline/peralkaline gneiss occurrences near the northeastern margin of the NMP (Fig.4.2) constitute the remnants of a tectonised and metamorphosed alkaline magmatic province. Subeconomic quantities of the various elements typically associated with alkaline and A-type granite complexes were noted at each of these localities (Scogings, 1989a). The potential mineralisation in these bodies was investigated by Scogings (1983, 1986, 1988a, 1989a) and Scogings and Forster (1989). Exploitation potential for these deposits currently appear to be poor. Refer to Chapter Two for lithological descriptions.

4.1.4.1. **Wangu Granitoid Gneiss**

Scogings (1989a) suggests that the Wangu gneisses represent deformed A-type peralkaline microgranitic or aplitic rocks. These rocks outcrop in the Wangu Hills area, northwest of Eshowe. Analyses of these gneisses have shown marked enrichment in incompatible and large-ion lithophilic elements such as Zn, Nb, Zr, Th, Y and Rb (Scogings, 1988a). Of particular economic interest were samples which showed high concentrations of Nb (614 ppm), Y (514 ppm) and REE (2300 ppm). No discrete REE minerals occur in these rocks, and it was therefore suggested that the incompatible elements may be hosted by sodic minerals such as aegerine-augite (Scogings, 1989a).

The anomalous REE, Zr, Nb and Zn contents in the localised iron-rich highly peralkaline siliceous gneisses within the Wangu gneisses were interpreted by Scogings (1989a) as magmatically concentrated cumulate layers.

4.1.4.2. **Bull's Run Complex**

The Bull's Run Estate 12987 is a farm situated on the north bank of the Mhlatuze River some 24 km north of Eshowe. This Complex is essentially composed of syenite and nepheline-syenite gneisses with minor intrusive phases of carbonatite and peralkaline microsyenite (Scogings and Forster, 1989). These intrusive phases of carbonatite contain, apart from apatite, calcite and biotite, accessory phases such as ilmenite, pyrite, pyrochlore and zircon. Samples of brown carbonate gneisses revealed values of up to 3993 ppm Nb and highly elevated Y, Sr and Ba values. Eluvial and alluvial occurrences of zircon, ilmenite and monazite were also reported by Von Backström (1962) for this body and are described in Table 4.5.

4.1.4.3. **Ngoye Complex**

The Ngoye Complex is an elongate east-west trending body approximately 25 km long and up to 4 km wide located just south of Empangeni (Figs. 4.2 and 4.7). The body is surrounded by felsic and amphibolitic gneisses of the NMP. The southern contact of the Ngoye granite gneiss and surrounding gneissic terrain were found to have potential for Nb, Ta, Sn, W and U mineralisation during an investigation of aeromagnetic and air-radiometric anomalies by the South African Development Trust Corporation (STK) (Scogings, 1983). Magnetite-rich rocks adjacent to the southern margin of the Ngoye body showing these anomalies were sampled and found to have high Nb, U, Th, Y, Zr and rare earths with minor Sn, W and Ta values. A mafic intrusive body also near the southern contact (Fig.4.7) showed very high magnetic values. Targets were delineated using geophysics, soil and rock sampling and trenching to locate sites for drilling.

The target over the mafic body was shown to have high Ni content in soil and rock samples. Pyrrhotite, chalcopyrite and possibly pentlandite were macroscopically identified. Drilling revealed mineralisation restricted to the marginal and contact zones along the southern part of the Ngoye Complex. Magnetite-bearing pegmatites also along the southern contact were found to have elevated concentrations of Sn, W, Ta, Nb and U. However, the mineralised horizons are erratic both in grade and width, as well as having short strike lengths. Widths are generally less than 3 m, averaging 1 m. The two elements with the most consistent high concentrations here are Nb and U_3O_8. Reserves were calculated at 1 158 tonnes per metre depth over a 90 m strike length. Average grades calculated by Scogings (1983) are shown in Table 4.3.

Table 4.3: Mineralisation grades in the southern part of the Ngoye Complex

Element	Sn	W	Ta	Nb	U_3O_8
Grade	13 ppm	60 ppm	46 ppm	1 253 ppm	109 ppm

It was concluded that due to the complex nature of the mineralisation and low market values for the elements with high concentrations, this mineralisation was currently unlikely to have any mining potential. Also, there are abundant reserves of these elements elsewhere in the world to sustain supplies for the foreseeable future.

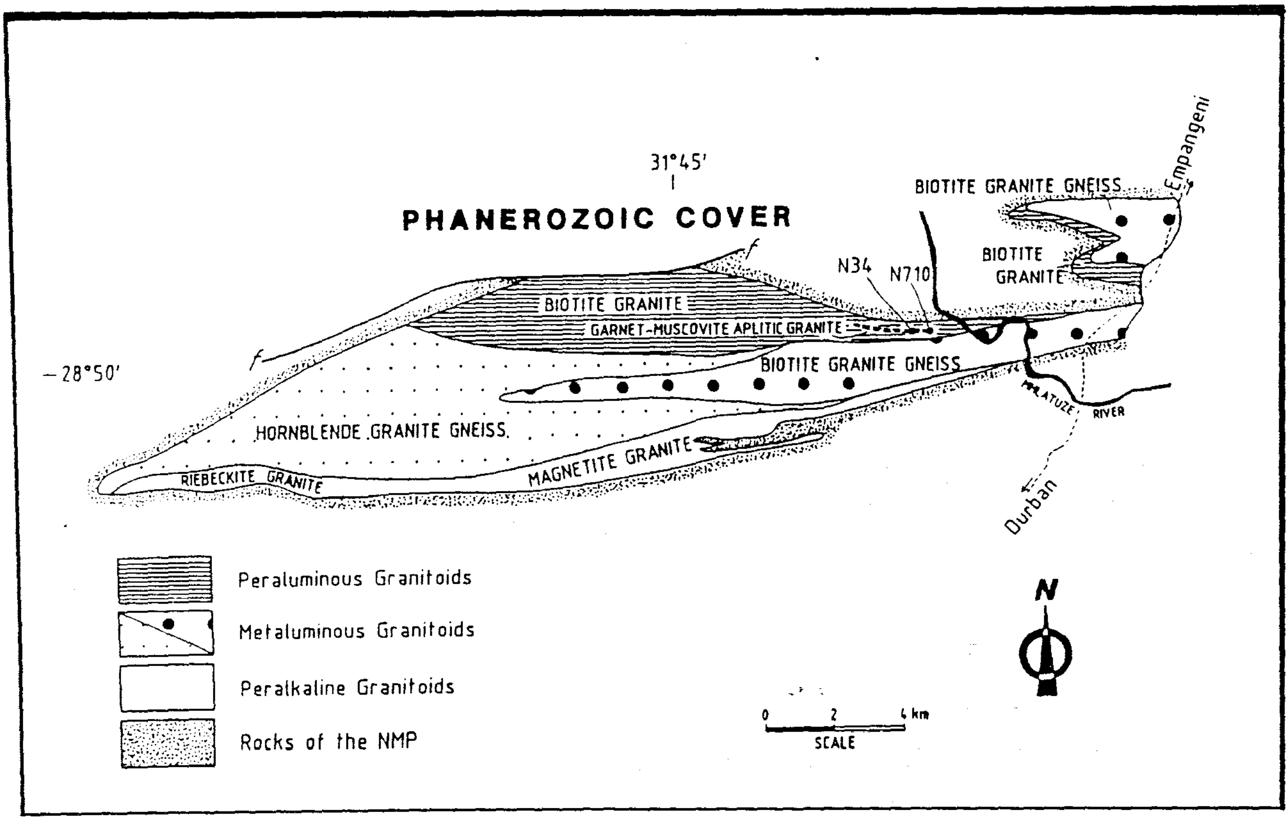


Fig.4.7: Geological Map of the Ngoye Complex showing sample localities (after Bullen et al., 1992)

4.1.5. **Industrial Mineral Deposits**

4.1.5.1. **Bull's Run Complex Mineral Fluxes**

Germiquet (1986a) recognised the Bull's Run Complex (Fig. 4.8) as a possible source of nepheline-based mineral fluxes for use in various industrial applications. Nepheline syenite is a nepheline-feldspar combination widely used as a source of alumina and alkalis for the manufacture of glass and ceramics, as well as for fillers/extenders in the paint, plastics, rubber and adhesive industries. Exploration and beneficiation tests were undertaken by the South African Development Trust Corporation (STK) on the Bull's Run Complex syenites in the late 1980's (Scogings, 1989b). Results indicated the presence of low-iron, glass-grade, nepheline syenite products equivalent to those produced in Canada, Norway and France. Comparisons with commercial nepheline syenite products from these countries are shown in Table 4.4, with sample localities from Bull's Run shown in Fig 4.8.

Preliminary cost studies by Germiquet (1986b) indicated that the venture would be economically viable if product quality is acceptable to the local glass and ceramics industries and if sales of 2000 t/month were achieved.

Table 4.4: Comparison of Bulls Run mineral fluxes with those currently exploited overseas

	D400	D402	D403	B213	A450	Norway	Canada	France
SiO_2	62.40	56.80	55.71	55.70	59.34	55.70	60.30	59.80
Al_2O_3	20.00	23.56	23.45	21.30	23.06	23.90	23.70	20.65
Fe_2O_3	0.12	0.12	0.08	0.32	0.12	0.12	0.07	2.08
CaO	-----	-----	-----	3.55	0.22	1.23	0.30	-----
Na_2O	4.46	9.12	8.69	8.90	8.45	8.20	10.40	8.50
K_2O	10.80	7.54	7.25	5.39	7.75	8.57	5.00	6.25

Data from tables in Scogings (1989b). French sample is a beneficiated phonolite product. -----: Data not determined

The nepheline syenite crops out mainly on the farm Bull's Run Estate and access to the outcrops here is poor. However, initial developers have targeted work on one of the several smaller pluglike nepheline syenite bodies at the more accessible eastern end of the Complex. Potential reserves to a depth of 50 m were considered promising. Development of this site with respect to mining had been hampered due to the fact that this area was to be proclaimed a nature reserve.

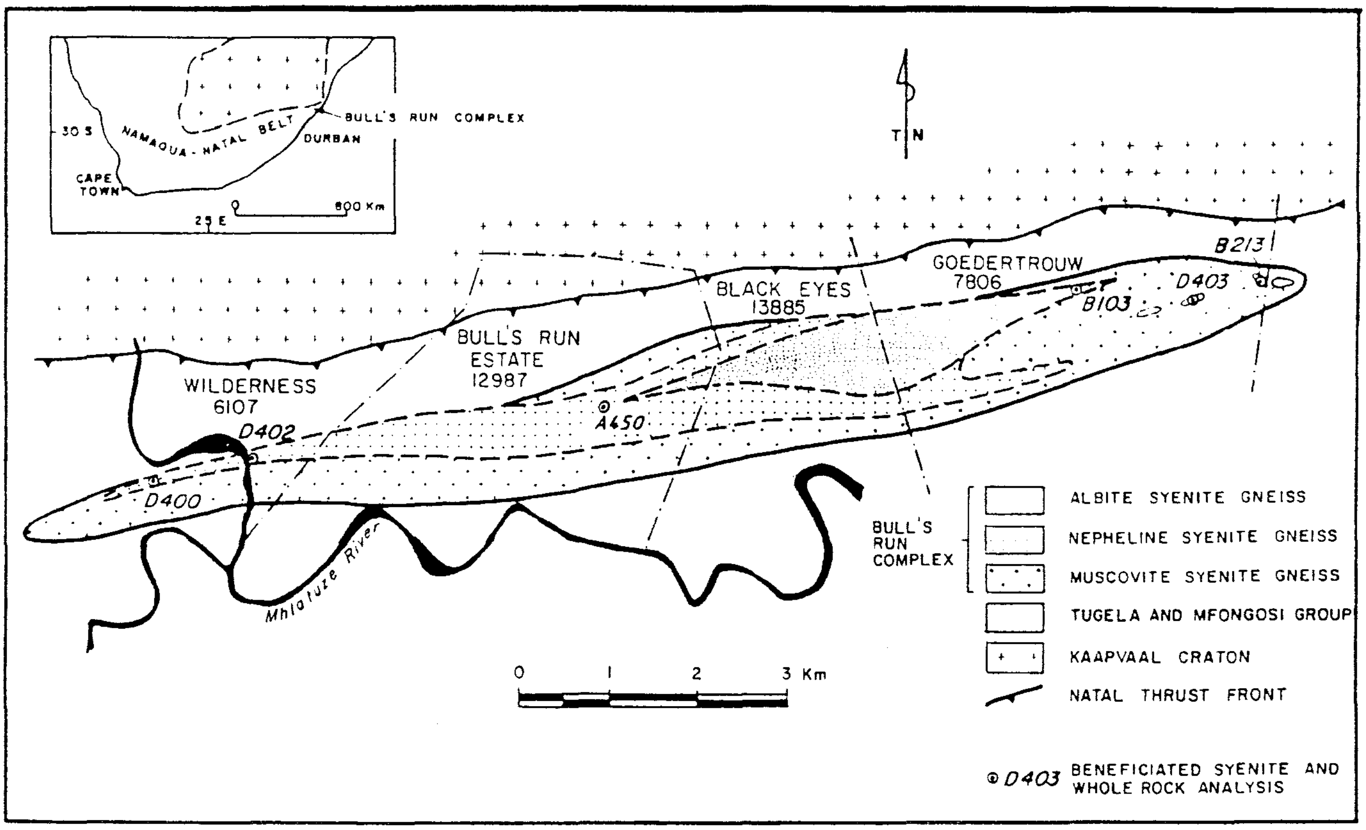


Fig. 4.8: Geology of the Bull's Run Complex showing localities for samples analyzed in Table 4.4 (after Bullen et al., 1992).

4.1.5.2. **Ngoye Complex** (Quartz and feldspar aggregates for the glass industry)

An elongate, intrusive sheet-like outcrop of peraluminous, garnet-muscovite aplitic granite on the northern flank of the Ngoye Complex (Fig. 4.7) on Reserve No.9 7638, was suggested as suitable raw material of low-iron, non-magnetic quartz and feldspar aggregates for the glass industry (Scogings, 1989c). Beneficiation tests conducted by Mintek on two bulk samples of fresh material returned favourable results, with low Fe_2O_3 values important for the glass industry. On the basis of these initial beneficiation results, a more detailed prospecting programme to delineate reserves of suitable material was recommended.

4.1.5.3. Potentially exploitable and Minor Deposits

These deposits, described below and in Table 4.5, are other industrial mineral deposits of the Tugela Terrane (Fig. 4.9). Some of these have been worked in the past, while the others have uncertain potential and require further investigation. The only currently working deposit is a stone aggregate quarry.

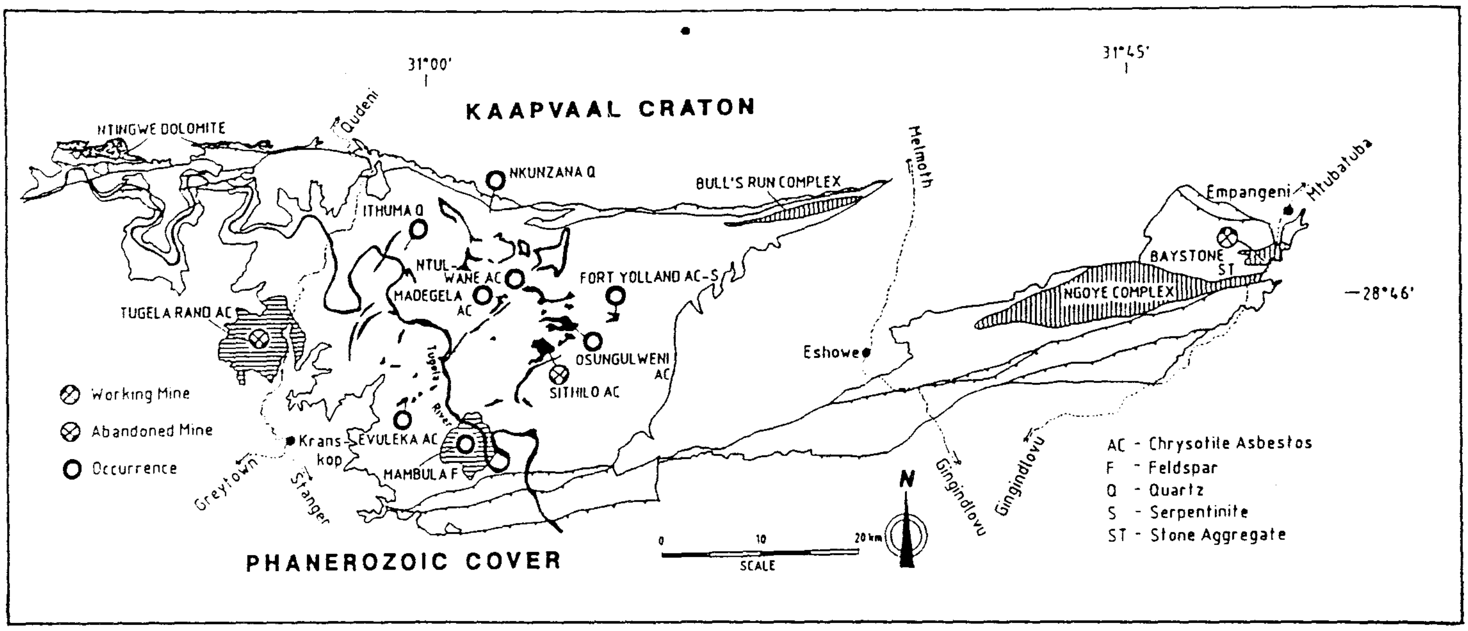


Fig. 4.9: Map of the Tugela Terrane showing industrial mineral occurrences, with talc occurrences shown in black (after Bullen et al., 1992).

Talc

Extensive talc schist occurrences were first reported in the Tugela Valley by Du Toit (1931). More recent investigations by STK (Scogings, 1988b; Van Rensburg and Ahrens, 1989) delineated five potentially exploitable talc bodies in the eastern part of the Tugela Valley in the Middledrift-Sitilo-Khomo area, some 35 km west of Eshowe (Fig.4.9).

Ultramafic igneous intrusives, emplaced as sheets and pods along the soles of thrust planes in the Nappe Zone (Matthews, 1981) were altered to produce the talc bodies. Alteration was attributed to hydration due to retrograde metamorphism. According to Bullen et al. (1992), XRD analysis revealed that the predominant minerals are talc, chlorite and anthophyllite, which led them to propose the following reaction for the formation of the talc:

$$\text{Olivine} + \text{orthopyroxene} + H_2O \rightarrow \text{talc} + \text{chlorite} \pm \text{anthophyllite}$$

Percussion drilling and pitting by STK (Van Rensburg and Ahrens, 1989) indicated that the shape of the talc bodies were highly irregular and discontinuous. Furthermore, the talc is generally off-white and no significant high-grade deposits were found in the area under investigation. The deposits may have future potential though, as samples of the talc proved amenable to a new beneficiation process developed for kaolin deposits by Minemet Industrial Minerals (Bullen et al., 1992).

Table 4.5: Potentially Exploitable and Minor Deposits within the Tugela Terrane

Commodity	**Locality** (Fig 4.9)	**Nature of Mineralisation**	**Host Rocks**	**References**	**Potential Reserves/uses and Comments**
Dolomite	Outcrops north of Tugela River between the Buffalo and Mfongosi Rivers	Average $CaCO_3$ = 50.7%, $MgCO_3$ = 37.3%, SiO_2 = 9%	Chlorite schist	Bullen et al (1992); Mackie (1986); Martini (1987)	Reserves > 100 Mt (estimated) Suited for agricultural lime only because of high magnesia content
Silica	i'Thuma River area	35 m diameter sub-circular quartz 'blow', localised faint iron staining	Mfongosi Group schists and gneisses	Bullen et al. (1992)	High purity silica of potential electronics quality
	1.5 km SSW of old Nkunzana Gold Mine	400 m long outcrop of 1m thick quartz veins	Mfongosi Group schists and gneisses		
Chrysotile Asbestos	Sithilo (Tugela Valley)	12 to 24 asbestos veins, of 120 mm total thickness. Fibre lengths between 6-12 mm	Veins occur adjacent to a microgranite dyke	Bullen et al. (1992)	Previously mined (opencast and underground)
	Tugela Rand (Tugela Valley)	asbestos veins with fibre lengths 3-18 mm	veins developed adjacent to microgranite sills		Poor quality as fibres brittle
Zircon	Bull's Run Complex	Eluvial and alluvial zircon deposits. Crystals up to 6 cm long	In decomposed gneisses	Von Backström (1962); Scogings & Forster (1989)	Grades of up to 0.66% combined ilmenite, zircon and pyrochlore in eluvial soil
Stone Aggregate	Ngoye Complex	Medium-grained biotite-rich gneissic granites	Ngoye Complex granite-gneiss	Bullen et al, (1992)	Aggregate production for local concrete industry

4.2. The Mzumbe Terrane

The Mzumbe Terrane extends from the Lilani-Matigulu Shear Zone in the north, to the Melville Thrust Zone in the south (Fig. 4.10). No published reports of detailed geological mapping or prospecting are available for this area. Late-tectonic rapakivi granites and sulphide-bearing charnockites of the Oribi Gorge Suite constitute more than half the surface area of the region and these appear to be barren. However, the area to the south of Durban has been more comprehensively studied, mainly due to greater mineralisation potential here. The following occurrences have been documented.

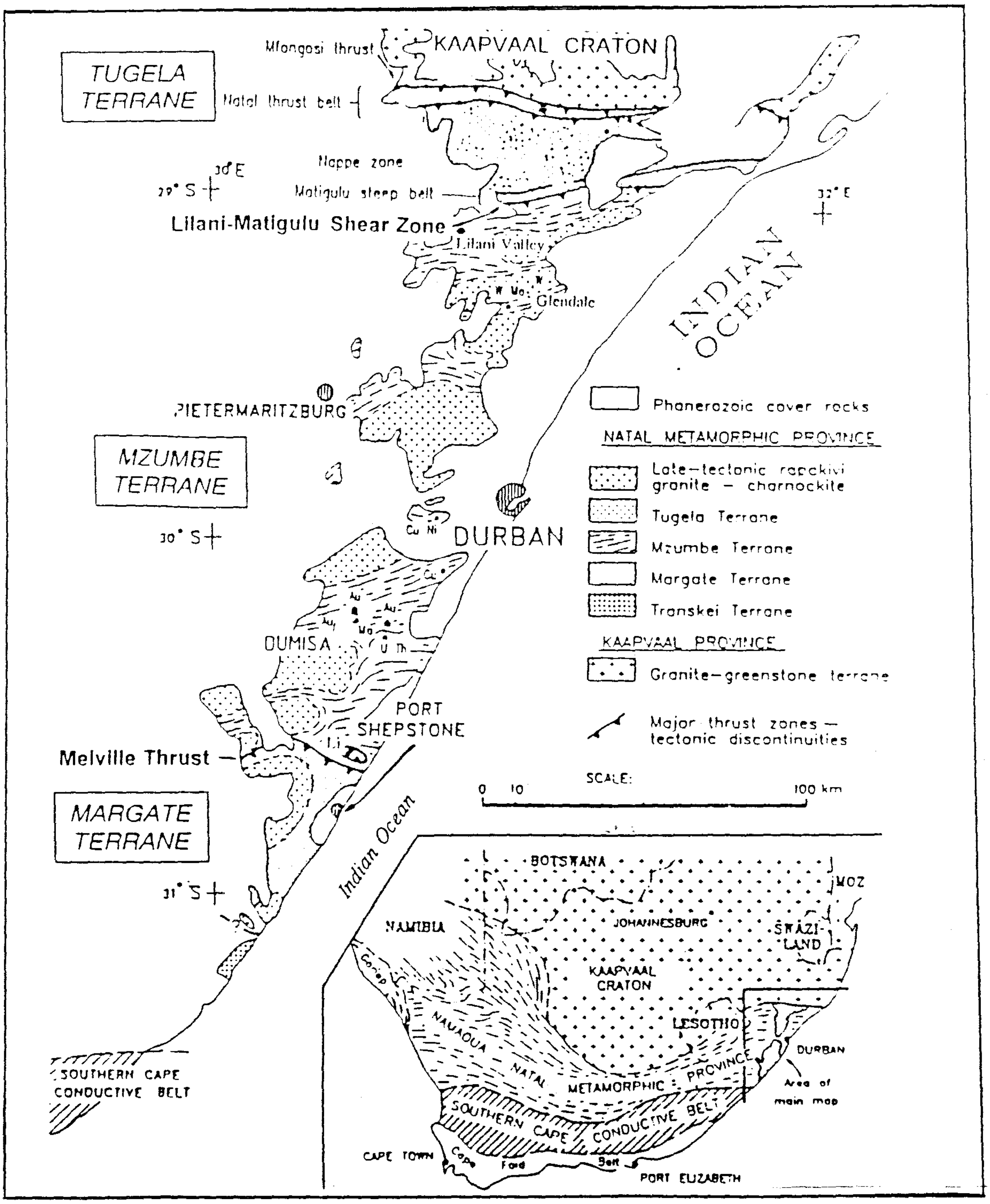


Fig.4.10: Metalliferous Mineral Occurrences in the Mzumbe Terrane (modified after Thomas et al., 1990a).

4.2.1. **Umzinto Goldfield - Shear Zone-Hosted Gold**

These gold deposits are situated in the southern part of the Mzumbe Terrane, to the west of Scottburgh, on the south coast of KwaZulu-Natal. Gold was discovered in auriferous reefs in gneisses near Dumisa Station, in 1887. By 1888, 16 gold prospects had been established in the area (Fig.4.11), some of which became small mines. The bulk of the production came from Dumisa itself. Unsuccessful attempts were made to reopen the Dumisa gold mine in 1987, after a revival of interest in gold following the record gold prices of 1980.

The goldfield was divided into two sectors (Thomas and Gain, 1989), constituting the western or Dumisa sector, and an eastern, Inyangaleza sector. Most recent work was carried out in the western sector, as many of the workings in the Inyangaleza sector are now incorporated into the Vernon Crookes Nature Reserve. The host rocks of the mineralisation in the western sector are highly sheared, leucocratic, syntectonic granite gneisses of the Mzimlilo Suite and fine-grained pink, acid gneisses, of the Ndonyane Formation, a sequence of deformed and metamorphosed acid volcanic and volcaniclastic rocks. The mineralisation in the eastern sector, where ten of the workings were located, is predominantly hosted in the Mzimlilo granites and banded gneisses of the Quha Formation. In all the Umzinto occurrences, the gold, though erratic in grade, appears to have been either disseminated in the sheared host rocks, or locally concentrated in later *en echelon* sulphide-rich quartz vein arrays (Thomas et al., 1990a), the latter containing silver and elevated base metal values (Bullen et al., 1994). Tables 4.6A and 4.6B from Thomas and Gain (1989) summarise details of most of the workings in the Umzinto Goldfield.

Detailed geological and mineralogical analyses were carried out at both the Dumisa and Alfreda Mines (Thomas and Gain, 1989). At Dumisa, gold mineralisation was found sporadically throughout foliations in the shear zones but was generally enriched within, and proximal to, the quartz veins. Some secondary gold enrichment in later brittle, iron-stained fractures may have occurred close to the surface. A mineralogical examination of the ore indicated pyrite as the dominant sulphide, with less abundant cobaltite, marcasite, chalcopyrite, pyrrhotite, molybdenite and covellite. Microscopically, much of the gold is dispersed along silicate and pyrite grain boundaries and fractures. Sampling over a 2 m width revealed grades of up to 6 g/t Au, though the average grades were somewhat lower.

Table 4.6A: Characteristics of the Dumisa Sector Workings (after Thomas and Gain,1989)

Mine/Prospect & Production Period	Mineralisation	Type of Workings	Minimum Recorded Yield	Est. grade (g/t)	Comments
Dumisa (1888-1889)	Gold occurs with sulphides in *en echelon* mm to cm-scale veins associated with intense fabric dipping 45-55°S. Mineralised zone is 9-10 m wide and extends for 10's of metres along strike	Shafts to 30 m depth. Main adit is a drive 100 m along strike	10.42 kg	13.0	More production may have occurred
1903-1914		Further 300 m of driving and shaft sinking. Main adit extended to 160 m with a 12 m cross-cut	31.60 kg	12.3	Figures only up to 1909
Alfreda (1889)	Ferruginous quartz vein arrays and stringers in silicified zone of intense, shallow-dipping shear fabric	2 adits, a winze and numerous trenches over a 400 m strike length	0.15 kg	4.7 49.7	Figures from trial crushing. Production figures not available.
Mimosa (1892)	10-100 mm-wide quartz veins dipping 45°. Gold associated with silver.	3 shafts to 40 m depth, drives at 18 m level. Inclined shaft to 30 m.	1.28 kg	10.3	Yield and grades are minimum values
Other Prospects	Gold-bearing quartz veins and stringers with sulphides. Veins dip southwards.	Trenches and adits	N/A	N/A	No records of production in the literature

Table 4.6B: Characteristics of the Inyangaleza Sector Workings (after Thomas and Gain, 1989)

Mine/Prospect	Mineralisation	Type of Workings	Minimum recorded yield	Est. grade (g/t)	Comments
Happy Thought (Evans, 1984)	Pyrite, pyrrhotite and Au in quartz vein arrays in N-trending banded gneiss	A number of adits and four vertical shafts up to 56 m depth	± 15.5 kg	8.8	Grades up to 15.5 g/t
Golden Butterfly	Associated with blebs of pyrite within a quartz vein hosted in granite. High values localised to a 1.5 m wide quartz blow	Single vertical shaft	93 grams	14.0	Grade from quartz blow on which the shaft was sunk
Other Prospects	Quartz arrays up to 1m width, 70 m strike length, dip steeply to the west. Mineralisation associated with sulphides	Adits and shafts, trenches	± 3.5 kg	± 8.0	Most deposits now occur in a nature reserve

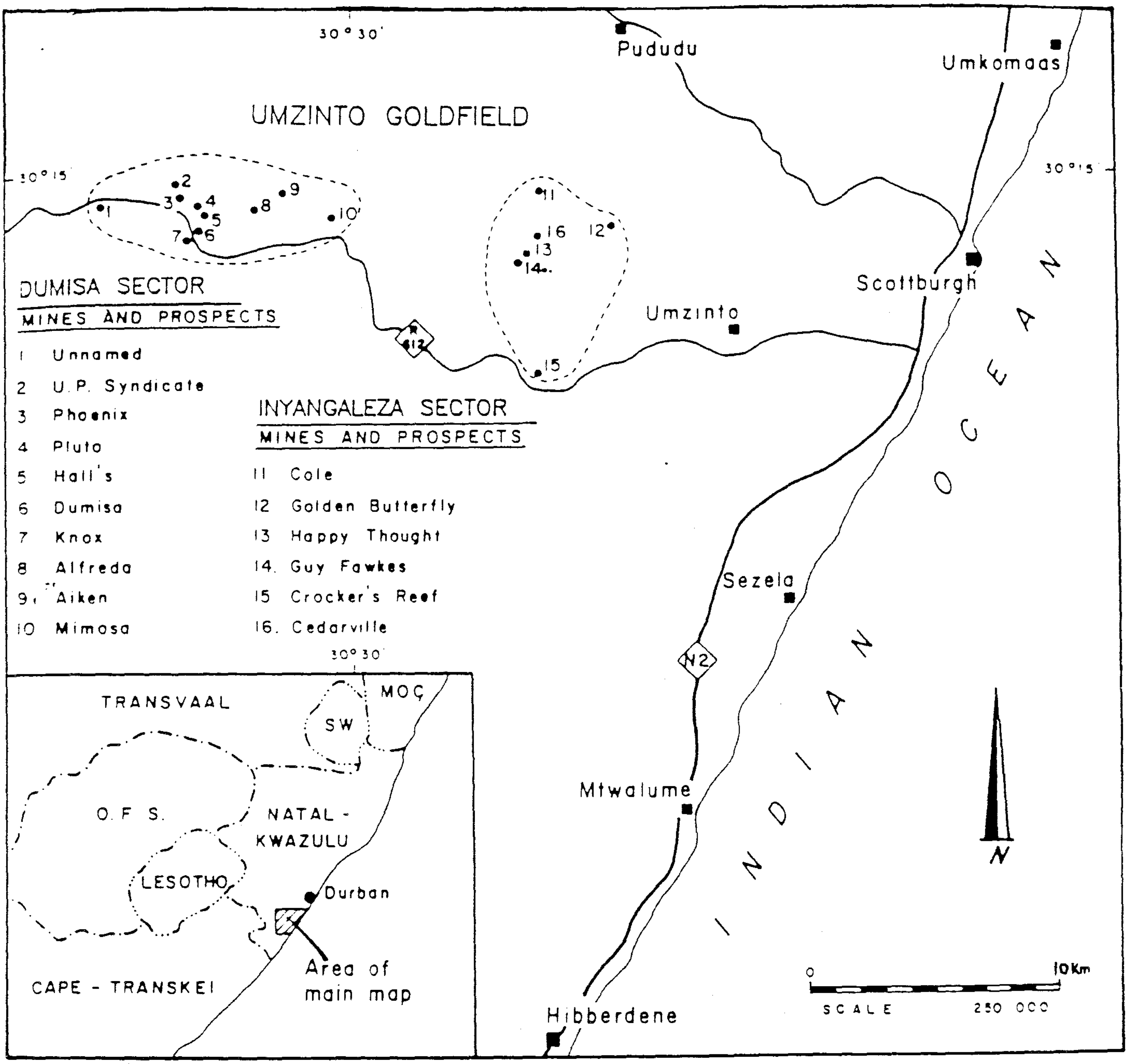


Fig. 4.11:Location of the Umzinto Goldfield Workings in Southern KwaZulu-Natal (after Thomas and Gain, 1989).

Accurate ore reserve calculations were considered impossible by Thomas and Gain (1989) due to the erratic mineralisation patterns. Investigations at Alfreda Mine revealed a close correlation between mineralisation and an intensely silicified, highly foliated, shallow-dipping shear zone. Several phases of silicification are thought to account for the numerous generations of quartz veins and stringers identified. The quartz stringers commonly contain auriferous, gossanous material that is pseudomorphic after sulphides. Recent assays, reported by Thomas and Gain (1989), on channel samples gave a mean value of 5.3 g/t Au at Alfreda.

Mineralisation in high-grade metamorphic rocks such as those encountered here, is far less common than in lower greenschist facies assemblages. Thomas and Gain (1989) drew parallels between the geological setting of Dumisa and the Renco Gold Mine in southern Zimbabwe, which also has fine-grained, erratically distributed mineralisation that defies conventional exploration methods. Similarities were also found in the tectonic settings of the two deposits, with both being related to ductile thrusting, and high-grade metamorphism which produced similar mineral assemblages. There is potential for further gold mineralisation to be discovered in this area, as the sheared host rocks to the mineralisation strike over a distance of 25 km, only a small portion of which has been investigated in detail.

4.2.2. **W-Mo in Ca-rich Gneisses**

4.2.2.1. **Mvoti Valley**

The only known metalliferous occurrences in the Mzumbe Terrane north of Durban, besides the base metal showings at Lilani, are the minor scheelite occurrences in amphibolites, diopside-rich gneisses, and magnetite quartzites. These occurrences are located near Glendale, some 20 km west of Stanger in the Mvoti River Valley (Fig. 4.10), on Umvoti Location 4667. Tungsten mineralisation was first exploited at this locality for use in World War II when a critical shortage of the element was experienced (Stephan, 1977; Scogings, 1984). The old workings consisted of two shallow shafts, and values of up to 1.76% WO_3 were recorded. From the extent of the old workings, which are now partially concealed, it is unlikely that this was ever a significant tungsten producer.

Investigations by Scogings (1984) revealed that the scheelite occurs as white, subhedral grains and stringers in a saccharoidal textured, greyish to dark green, diopside-hornblende gneiss. Examinations under short wave U/V illumination produced a white to blue-white fluorescence, indicating a highly pure product with very little, if any, molybdenum contamination. Grab samples from dumps of the old workings assayed 8 200 ppm W and 55 ppm Mo. Channel sampling undertaken here in 1977 by the Johannesburg Consolidate Investment Company, yielded tungsten contents of 160, 670 and 1 050 ppm WO_3.

Whilst Schutte (1976) and Du Preez (1976) felt that the mineralisation was of pegmatitic origin, Stephan (1977) noted that the scheelite host rocks were bordered on both sides by pegmatites and suggested that the mineralisation resulted from the metasomatic interaction of W-bearing pegmatitic fluids, with the relatively Ca-rich country rock. However, Scogings (1984), found no significant W concentrations in pegmatites in the vicinity of known mineralisation, and, noting that the host rocks to the mineralisation were associated with cherts and magnetite quartzites (possibly of chemical sedimentary origin), he concluded that the Mvoti mineralisation was of syngenetic, stratiform sedimentary-exhalative origin. This was further supported by comparisons of incompatible element profiles (including Ba and Sr) of these Mvoti granites, with tungsten bearing granites from other parts of the world, which showed significant differences.

Exploration along strike to the west of the old workings, revealed low-grade scheelite mineralisation in small isolated pods, but no economically viable deposits were found in the area.

4.2.2.2. **Umzinto**

No *in situ* scheelite mineralisation has yet been located in this area, however alluvial scheelite was reported by Hatch (1910) in the Mpambanyoni River valley west of Umzinto, the mineral being found during gold panning operations. Andreoli and Hart (1985) reported finding a loose stream boulder of calc-silicate gneiss in this general area which contained over 300 ppm W. They suggested that the catchment area of the stream be investigated for scheelite mineralisation. Subsequently, Thomas (1989b) reported the presence of tourmaline-bearing, calc-silicate horizons in the Mpambanyoni River, which could be associated with the above mineralisation.

4.2.3. **Cu-Mo in Granitoids**

In the Mfume area, 30 km south-west of Durban (Fig. 4.10), copper occurs in chalcopyrite which is disseminated within banded gneisses of the Mapumulo Group as well as in secondary malachite (Thomas et al., 1990a). Sampling along an old adit in the area, yielded values of up to 0.78% Cu with trace amounts of Mo.

4.2.4. **Cu-Ni in Ultramafic Rocks**

Anomalous Cu-Ni mineralisation some 35 km west of Durban (Fig.4.10), was found by Schutte (1976) to be the result of silicate nickel within fault bounded serpentinite bodies of limited extent, within gneisses of the Mapumulo Group. The occurrence has no potential as the Cu and Ni are contained within silicate minerals and are not associated with sulphides. Sampling revealed values of between 1 400 and 1 600 ppm Ni, which are considered as background contents for serpentinitic rocks (Burt, 1977).

4.2.5. **U-Th in Pegmatites and Alaskites**

Exploration in the Umzinto area some 60 km southwest of Durban revealed a number of U-Th anomalies (Evans, 1984). Total-count scintillometer surveys of the area established that high readings were associated with alaskites and biotite-bearing pegmatites. Total-rock geochemical sampling by Hart and Barton (1984) indicated U concentrations of up to 900 ppm. However, the high U values obtained were sporadic and the mineralisation patchy. Research by Hart and Barton (1984) showed that surface leaching resulted in substantial U loss from many of the pegmatite and granite samples and there was no evidence of extensive zones of U enrichment at depth. Uranium mineralisation may be redistributed in weathered horizons in high rainfall areas such as this, and drilling would be required to assess the true potential of the area. The recently lost U seems to have been largely reconcentrated in weathered biotite-rich and carbonaceous samples, but high values here are again sporadic. Evans (1984) described a quartz-xenotime rock from the Umzinto area with 53% modal xenotime, which gave a U concentration of 1.26% and Th concentration of 1.88%.

Evans (1984) noted that the distribution of anomalous total-count radiometric readings occurs in close proximity to two major northeast-trending zones of discontinuity within the NMP rocks of the area. He suggested that future exploration for U mineralisation should take into account major structural discontinuities. This observation supports one of the mineralisation models proposed by Andreoli and Hart (1985), where mineralisation in the area was considered to be associated with shear-zone-related polymetallic vein systems. The other model related the mineralisation to pegmatites. Evans (1984) concluded that reinvestigation of this area, in the light of new exploration methods, may lead to the discovery of exploitable uranium mineralisation.

4.2.6. **Base Metal Investigations at Lilani**

A recent prospecting programme for base metals in the Lilani Valley (just south of the Lilani-Matigulu shear zone) of northern KwaZulu-Natal (Fig. 4.10), by a private mining company, revealed a sub-economic Zn-rich massive sulphide deposit (Thomas et al., 1995b). The Mzumbe Terrane has been subject to intense deformation in this area, probably resulting in isolated pockets of mineralisation being spread over wide areas, and at depth, within the shear zone. Although no records are available, the Quha Formation is locally host to base metal mineralisation of unknown grade and outcrops of gossanous material have also been observed in this area. Polished sections from grab samples taken in the area revealed the presence of abundant pyrite, sphalerite and chalcopyrite. Thomas et al. (1994b) reported that the predominantly meta-volcanic Quha Formation gneisses in the northern part of the Mzumbe Terrane, contain pyritic Mn-garnet rich siliceous coticule, which is evidence of exhalative processes having been in operation during their formation. These layers of coticule are up to 30 cm thick and are interlayered with the gneisses. It has been suggested that this formation may be a potential host for Besshi-type Cu-Zn mineralisation (Thomas et al., 1992d; Cornell et al., 1996).

4.2.7. **Industrial Mineral Deposits**

4.2.7.1. **Dimension Stone**

Dimension stone is presently quarried in the Cato Ridge area of the Valley of a Thousand Hills, some 40 km northwest of Durban (Fig. 4.12). The Natal Green Granite Quarry extracts a coarse-grained, porphyritic, greenish-grey, weakly foliated, garnetiferous, charnockitoid phase of the Mgeni pluton of the Oribi Gorge Suite (Bullen et al., 1992). Large exfoliation domes and whalebacks are exploited, as these have widely spaced joints (> 10 m apart) which which allow large unfractured blocks to be recovered. Production, which ceased during the Gulf War, has only recently resumed due to an increased overseas demand for greenish-hued dimension stone. Most of the blocks extracted here are exported through Durban harbour.

A number of granitoid rock types within the NMP are considered suitable for use as dimension stone, the principal ones within the Mzumbe Terrane are described in Table 4.7 and their localities shown in Fig. 4.12, after Bullen et al. (1992). The KwaLembe and Fafa plutons are highly siliceous, sulphide-poor massive charnockite bodies developed within the Oribi Gorge Suite.

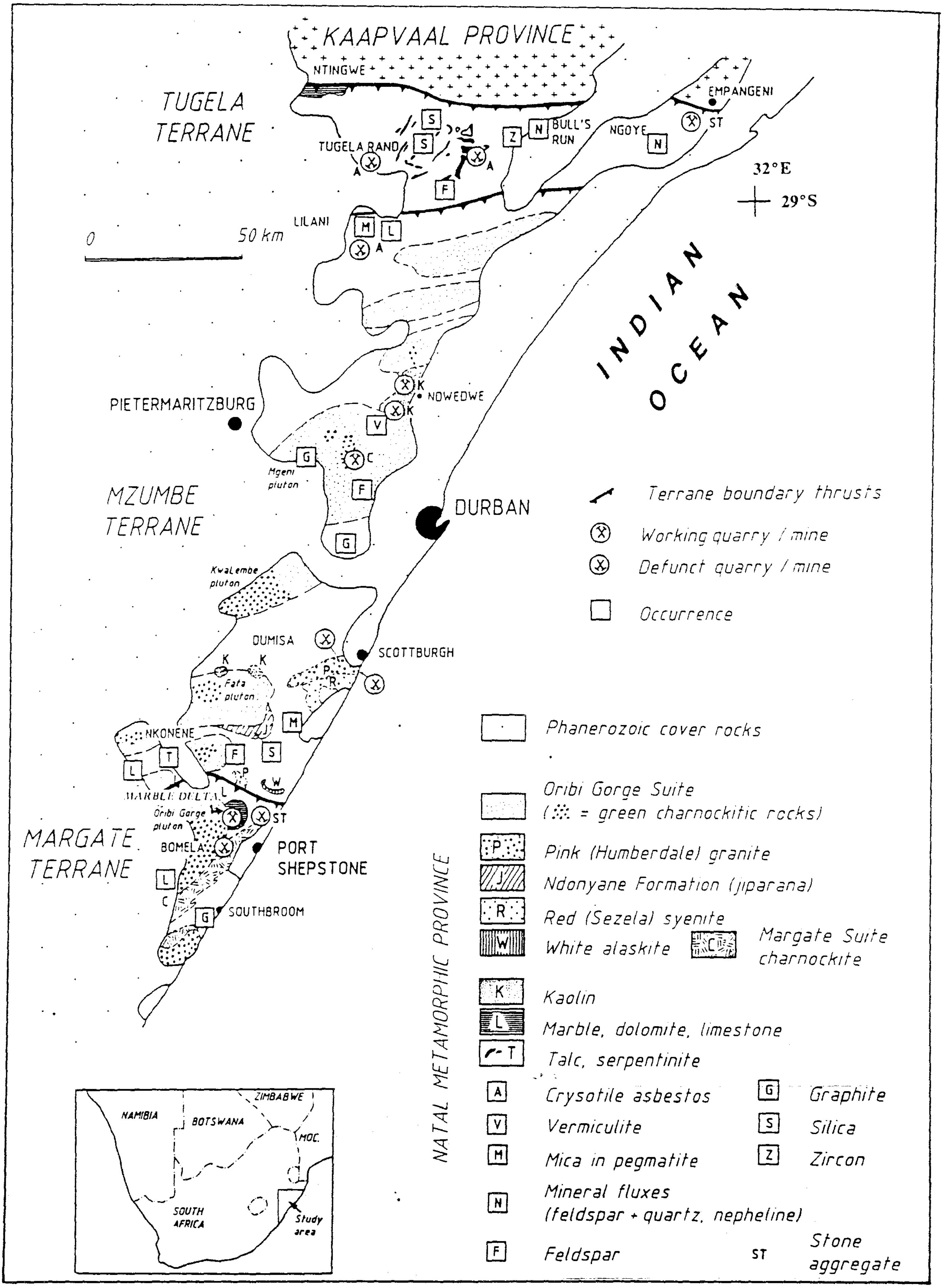


Fig. 4.12: Industrial Mineral Occurrences in the NMP (after Bullen et al., 1992).

Table 4.7: Potential Dimension Stone Lithologies in the Mzumbe Terrane

Host Lithology	Description	Comments
Humberdale Granite (pink)	Medium- to coarse-grained, foliated granite. Up to 1 cm large, pink K-feldspar mesocrysts (Eglington et al., 1991).	Contains zones with unattractive xenoliths and biotite schlieren.
Sezela Suite (red)	Pink to red syenites.	Has large, relatively unfractured outcrops.
Ndonyane Formation	Highly foliated, streaky acid gneisses and migmatites.	May provide an attractive `Juparana'*
Kwalembe and Fafa Plutons	Sulphide-poor, siliceous, massive charnockite plutons of the Oribi Gorge Suite.	Unknown potential.

Data from Bullen et al., (1992).

*Juparana is a Dimension Stone Industry term used to describe a highly foliated, streaky orthogneiss which also contains leucosomes/melanosomes (pers. Comm. R.Thomas, 1998).

4.2.7.2. Kaolin Derived from Proterozoic Granites

Kaolin, derived from weathered granites of the Mzumbe Terrane, occurs at a number of localities in the Inanda-Ndwedwe area, some 30 km north-northwest of Durban (Fig.4.12). The kaolin in this area is associated with residual lateritic weathered profiles which may represent the remnants of an ancient Tertiary land surface (Partridge and Maud, 1987, cited in Bullen et al., 1992). Bullen et al. (1992) reported that, in places, these granitoids may also have been hydrothermally altered. In the area where the best quality kaolin is developed, much of the weathering and hydrothermal activity appears to be associated with post-Natal Group faulting.

Small-scale mining operations e.g. the Snow White Mine (Fig. 4.13), which was mined from 1952 to 1959, selectively exploited the purest, whitest kaolin, while small pits were dug by local tribes, who used the kaolin mainly for medicinal and decorative purposes. Exploitation of the kaolin has been limited to a large extent by the iron staining that resulted from residual lateritic weathering. However, a new beneficiation technique (which is able to remove soluble iron oxide coatings from the clay particles), has been developed by Minemet Industrial Minerals (Bullen et al., 1992), and has resulted has renewed interest in the clay deposits of the Ndwedwe area. Minemet Industrial Minerals currently operate a clay beneficiation plant situated near Inanda. Prospective deposits for this venture include a 5 km long, 300 m wide, steep, southerly dipping aplitic dyke, which contains up to 40% kaolin, and very little unwanted mica. Reserves to a depth of 15 m have been estimated at 10 Mt.

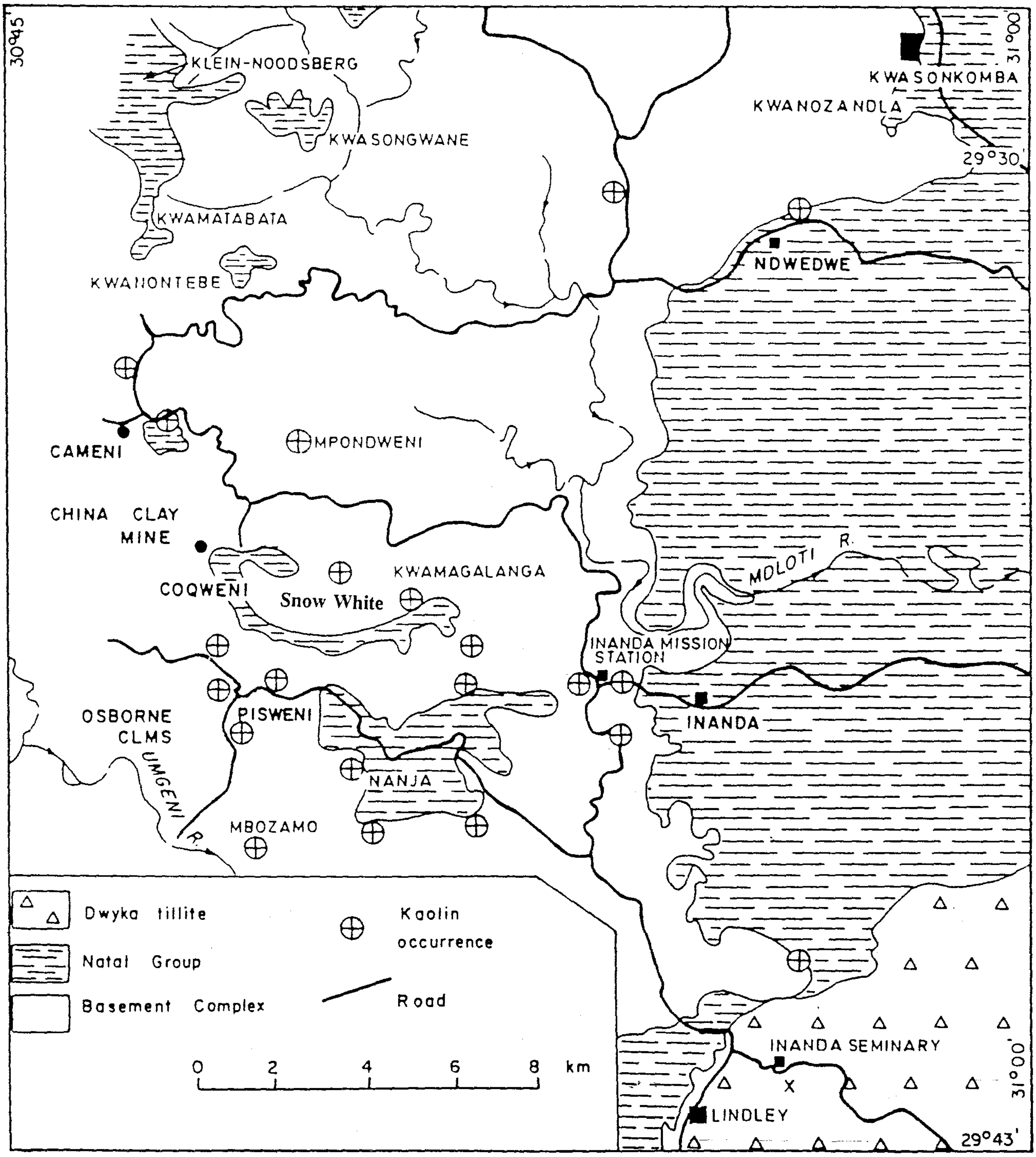


Fig. 4.13: Proterozoic Granite-derived Kaolin occurrences in the Inanda-Ndwedwe area of KwaZulu-Natal (after Heckroodt, 1992).

Mazibuko (1987, cited in Heckroodt, 1992) investigated the clay mineralisation of the Ndwedwe area in detail and two of his analyses of clay, one from the Snow White Mine and the other from Kwa Nozandla (Fig. 4.13), are shown in Table 4.8. The Kwa Nozandla deposit is estimated to spread over 13 000 hectares, to a depth of 80 m, and extensive drilling would be required to prove reserves.

Table 4.8: Properties of two Kaolin Deposits in the Inanda-Ndwedwe Area

Deposit Name	**Kaolinite (%)**	**Quartz (%)**	**Feldspar (%)**
Snow White	30	55	15
Kwa Nozandla	40	50	10

Data from Heckroodt (1992).

Much potential for kaolin mineralisation exists within the NMP, especially in the coarse-grained, porphyritic granitoids of the Oribi Gorge Suite. Bullen et al. (1992) suggest that exploration should be directed towards areas in which faulted, weathered, feldspathic rocks predominate. In addition, areas underlain by Tertiary lateritic weathering profiles may also be targeted, as the known kaolin deposits are formed in these environments. Mazibuko (1987, cited in Heckroodt, 1992) attributed the formation of kaolin in this moist, high rainfall area, to the downward percolation of surface water which leached the feldspar-rich granite. The kaolinisation took place preferentially in a zone between the upper and lower levels of a fluctuating water table, immediately below the contact between the granites and overlying Natal Group sandstones, as well as along faults.

4.2.7.3. **Industrial Mineral Deposits in the Mzumbe Terrane of Uncertain Economic Potential**

Deposits of silica, mica, feldspar, limestone and chrysotile asbestos are also known in the Mzumbe Terrane, but most deposits require further investigations to determine their economic potential. In many cases, the rugged terrane, remote localities and small sizes of deposits has hampered their exploitation. These mineral occurrences are described in Table 4.9, and their locations shown in Fig. 4.12.

Table 4.9: Industrial Mineral Deposits in the Mzumbe Terrane with Uncertain Economic Potential.

Commodity	Locality (Fig.4.12)	Nature of Mineralisation	Host Rocks	References	Comments
Eluvial Feldspar	Valley Trust, 32 km WNW of Durban	Weathered host rocks represent a potential source of low iron, eluvial potassic and sodic feldspar.	Coarse-grained granites of the Oribi Gorge Suite	Bullen et al, (1992)	Extensive reserves exist in this rock type. New beneficiation technique reported by Bullen et al. (1992) may increase potential of the deposits.
Silica	Sangqhu River Valley, 35 km N of Port Shepstone	20 m diameter, subcircular quartz 'blow'	Qtz-fsp gneisses and migmatites	Bullen et al, (1992)	High purity silica of possible electronic quality. Requires precise analyses.
Muscovite	Lilani area, south of Lilani Spa	Qtz-fsp-muscovite-(almandine-tourmaline) pegmatites. Muscovite (±5%) of the rock forms books about 15 by 10 cm in size.	Amphibolitic gneisses	Gevers, (1963); Bullen et al, (1992)	At least 6 pegmatites of possible economic importance occur here
Limestone	Lilani Valley	8 calcitic marble lenses up to 10 m thick and 100 m in length. Average $CaCo_3$ = 84.13%, $MgCo_3$ = 1.75%.	Amphibolites of the Mapumulo Group	Martini, (1987); Thirion (1978); Bullen et al, (1992)	Reserves < 100 000 t Area very inaccessible
Limestone	Mzimkulu River Valley, 45 km NW of Port Shepstone	2 Dolomitic marble beds 3 m thick and 60 m wide. Average CaO = 41.70%, MgO = 10.65%.	Gneisses of the Mapumulo Group	Du Preez (1976); Bullen et al, (1992)	Reserves uncertain. Remote locality.
Chrysotile Asbestos	Lilani Valley	Locally developed thin asbestos veins	Mapumulo Group gneisses	Du Preez (1976)	Previously mined deposit. No potential

4.3. The Margate Terrane

Rocks of the Margate Terrane are exposed south of the Melville Thrust Zone, though its southern boundary is not exposed. This granulite facies terrane has the fewest documented occurrences of metalliferous minerals of the three Terranes in the NMP. However it is host to the substantial, economically exploited Marble Delta limestone deposit near Port Shepstone.

4.3.1. **Tonjeni Au Occurrence**

The Tonjeni area is located 30 km northwest of Port Shepstone (Fig. 4.14), where outcrops of the Turtle Bay Suite (a bimodal gneissic mafic noritoid-felsic enderbite/charnockite association) in the Margate Terrane, have been reported by Thomas et al. (1992a). Random chip sampling of the area (Bekker, 1986) revealed gold concentrations of between 0.10 and 0.17 ppm. According to Bullen et al. (1994) the highest gold concentrations occur in noritic two-pyroxene granulites and melanocratic enderbites which contain up to 5% disseminated sulphides. No records of follow-up investigations are available.

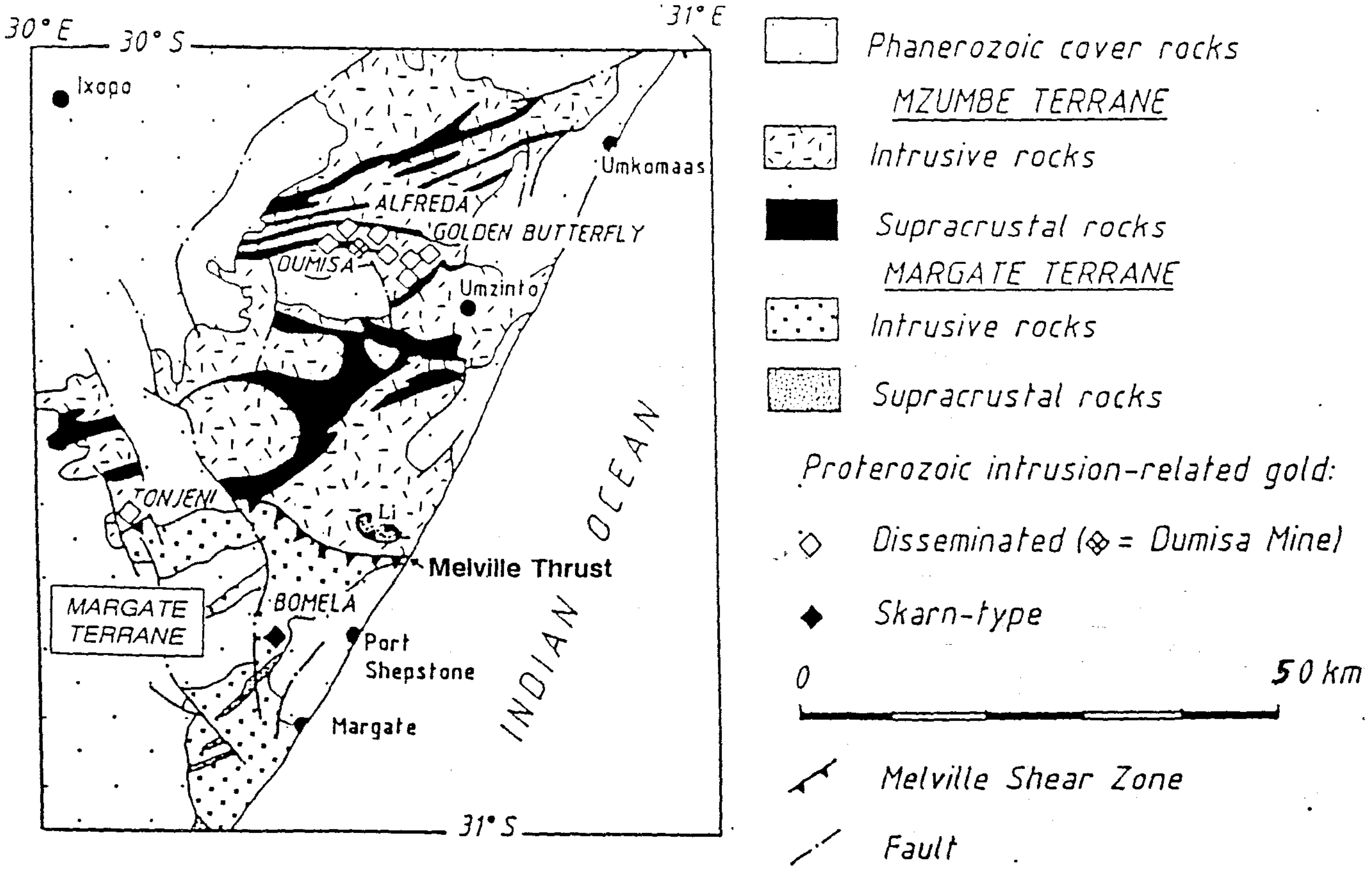


Fig.4.14:Metalliferous Occurrences in the Margate Terrane. Gold Deposits of the Mzumbe Terrane are also shown (after Bullen et al., 1992).

4.3.2. **Bomela Gold**

At Bomela, some 10 km west of Port Shepstone (Fig 4.14), a very low grade skarn-type gold occurrence has been reported (Bekker, 1985a). White, diopside-bearing quartzite enclaves identified within the southeastern marginal zone of the Oribi Gorge porphyritic charnockite, are host to the mineralisation.

Bekker (1985a) considered the metasomatic skarn-type enrichment to be related to the emplacement of the host charnockite host. Field investigations revealed a high percentage of sulphides (mainly pyrite, pyrrhotite, chalcopyrite and niccolite) along microfractures within the rock. Skarn-type alteration was found to predominate within diopside-bearing quartzite enclaves, which host the mineralisation. Initial sampling of the skarn-type rock produced encouraging results (2.10 g/t over ± 7 m), with anomalously high values of Ni, Cu and As. However, follow-up chip sampling at 1 m intervals produced much lower values (highest 0.10 g/t Au). Consequently, the prospect was abandoned.

4.3.3. **Lithium-bearing Pegmatites**

In the Highbury area, some 18 km north of Port Shepstone (Fig. 4.15), a number of spodumene-bearing leucocratic pegmatites have been identified intruding the granulite-grade, mafic gneisses and calc-silicate rocks of the Mucklebraes Formation (Thomas et al., 1994a).

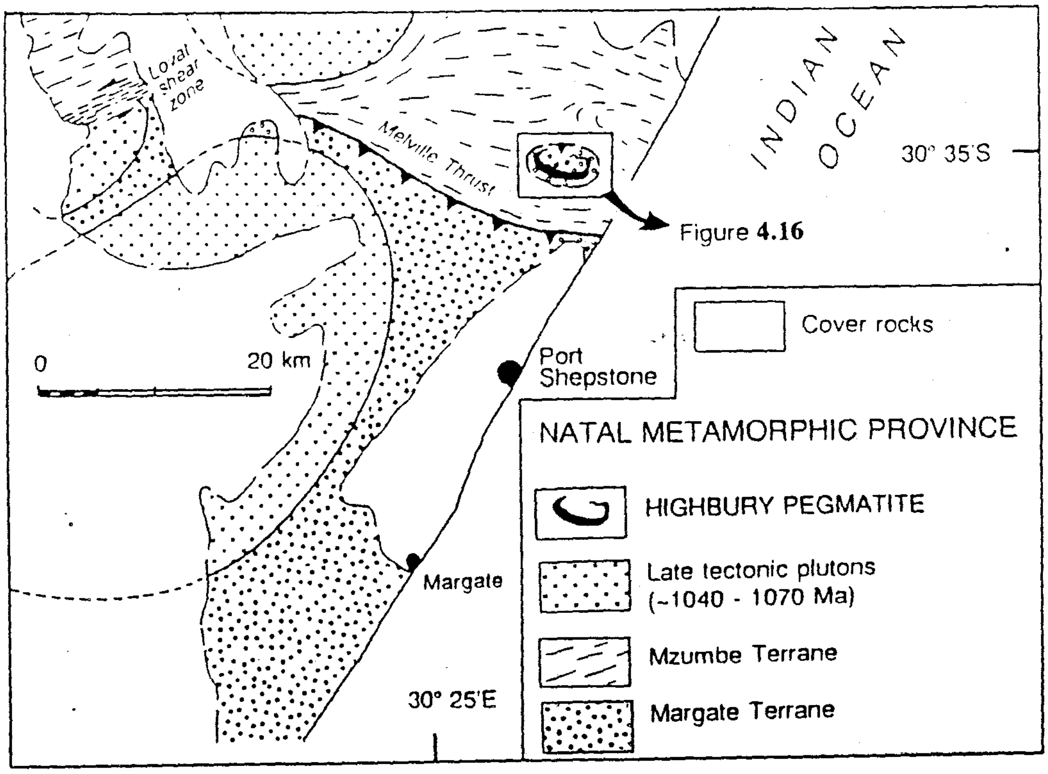


Fig. 4.15: Regional geological setting and location of the Li-bearing Pegmatites (after Thomas et al., 1994a).

A detailed petrographic study and economic evaluation of this occurrence was initiated because of the country's growing lithium requirements, all of which are currently imported. Spodumene is a source of lithium metal which has widespread uses in the electronics, petrochemical, plastics and chemical industries, while Fe-poor spodumene is used in the production of high quality glass and ceramics (Thomas et al., 1994a). The pegmatitic and aplitic rocks which host the mineralisation form a number of subconcordant sill-like bodies that occur in an approximately 150 m thick zone within the Mucklebraes Formation (Fig. 4.16). The Mucklebraes Formation was interpreted by Thomas (1989a) as a small Margate Terrane klippen, within the Mzumbe Terrane. Post-intrusive folding of the klippen into an open east-west-trending periclinal synform, has deformed the aplitic bodies, which occupy the area around the western, southern and eastern limb of the synform, in a broad arc measuring 8 km by 3 km.

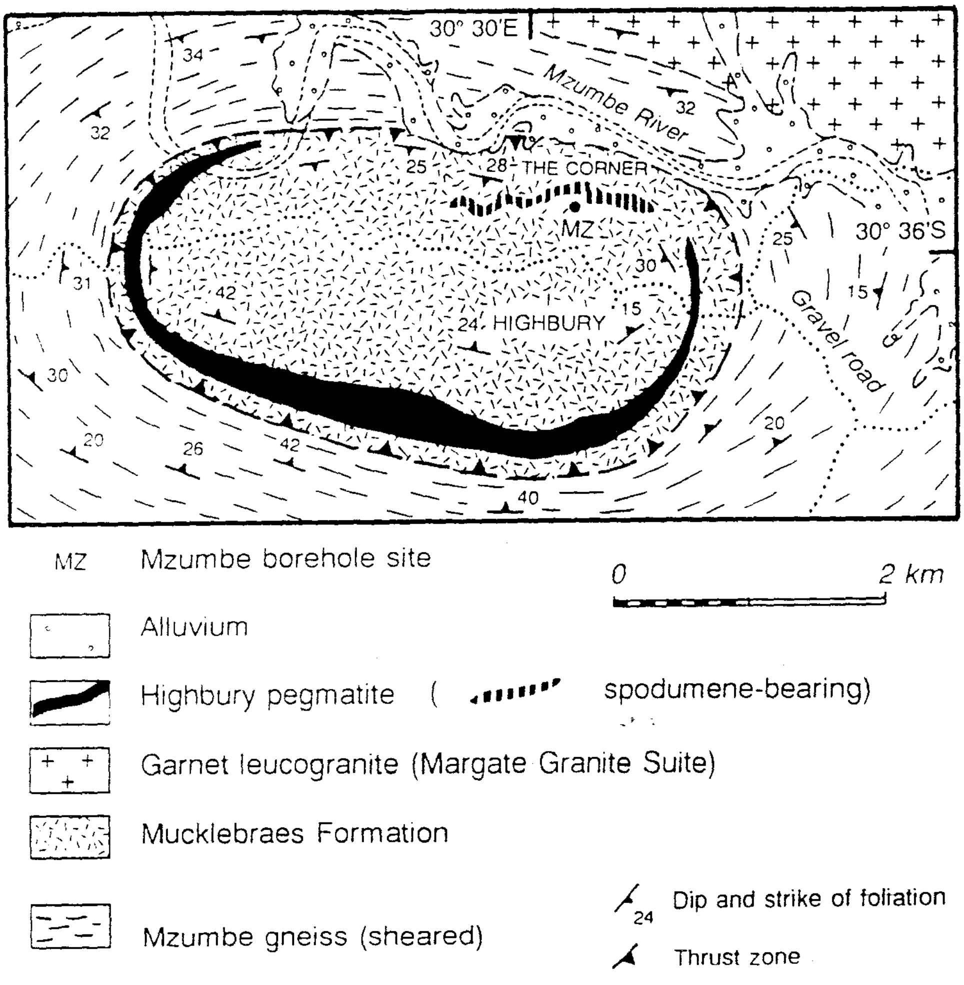


Fig. 4.16: Geology of the Mucklebraes Klippen Structure and Highbury Pegmatite (after Thomas et al., 1994a).

An exploratory borehole was drilled to intersect mineralisation at depth. The spodumene was found to occur within a number of sills but the bulk of the intrusives were barren, garnetiferous aplites, implying that the Li-rich pegmatites may have been the result of lateral fractionation within the intrusive system. Core sampling from this borehole revealed > 23% modal spodumene, which equated to ± 2% Li_2O on average. The spodumene grades decrease with depth and intrusions below 200 m were found to be barren. The Li-rich spodumene occurs predominantly as equant, ovoid to irregular crystals up to 40 cm across, in graphic and symplectic intergrowth with quartz. No discrete spodumene crystals were observed.

Trial beneficiation by flotation carried out by the Council for Geoscience to give a product with > 7% Li_2O was shown to be possible and the different grades available at Highbury would be able to satisfy both the glass and ceramics industries and be an important source of lithium salts. Accurate ore reserves would require further drilling. However indications are that this deposit can be equated in size with other medium sized pegmatite deposits. These factors, coupled with the relatively easy accessibility and close proximity to infrastructure, would no doubt make this deposit economically viable. Potential by-products from exploitation of this deposit include dimension stone (suitably extensive aplitic phases are developed) and feldspar with a high albite content.

4.3.4. **Industrial Mineral Deposits**

4.3.4.1. **Marble: The Marble Delta Limestone Deposits**

Three large quarries in the 'Marble Delta' area (Figs. 4.12 and 4.17), 14 km northwest of Port Shepstone, are currently the largest producers of limestone products in the country. Small-scale quarrying probably started around 1866 (Martini, 1987). These supracrustal, granulite facies dolomitic and calcitic marbles of the Marble Delta Formation (Thomas and Otto, 1991), are highly deformed and extensively intruded by various granitoids and charnockites. The marbles are predominantly white to grey. However minor green, blue and black varieties are also developed due to contact metamorphic effects caused by intrusive charnockitic sheets (Bullen et al., 1992). The marbles are generally considered to be too coarse-grained for use as a dimension stone, with an average grain size of 15 mm (Martini, 1987).

Umzimkulu Lime's two quarries produce a range of carbonate fillers for use in high quality paints, plastics, paper, toothpaste and bread. The dolerite dykes intruding the limestone are also exploited for their high alumina content which is required for certain custom-made products. Annual production of limestone products is of the order of 300 000 to 400 000 tons. Adjacent to the two main quarries, Natal Portland Cement (NPC) mines a less pure calcitic marble from their Simuma Quarry. The marble here contains considerable quantities of Fe and up to 6% MgO. The rock is crushed on site and conveyed a short distance to a large kiln, where klinker is produced for use in NPC's cement plant.

Due to the complex structure and stratigraphy of the region (Fig. 4.17), there are many other potential occurrences of limestone in the vicinity of the existing quarries. These are currently being investigated to increase the lifespan of the operation. Current reserves however, should last well into the next century at the present rate of mining.

4.3.4.2. **Dimension Stone**

At Bomela, near Port Shepstone (Fig. 4.12) a dark green charnockite similar to that mined at Cato Ridge in the Mzumbe Terrane, was quarried on a limited scale in the early 1980's (Bekker, 1982). The deposit was found to be unsuitable for use as dimension stone because of close fracture patterns and the presence of abundant biotite xenoliths. Furthermore, the presence of abundant sulphides in the rocks would affect long term durability and appearance of the polished rock surface. Bullen et al. (1992) related some of these problems to the position of the quarry, which was situated in close proximity to the faulted, fractured, and contaminated southeastern margin of the Oribi Gorge pluton. It is likely that better, less fractured material could exist further from the fault zone. Other potential dimension stone deposits are described in Table 4.10, with localities being shown in Fig. 4.12.

Table 4.10: Potential Dimension Stone Lithologies in the Margate Terrane (after Bullen et al., 1992).

Host Lithology	Description	Comments
Oribi Gorge Pluton	Sulphide-poor, siliceous, massive charnockite pluton of the Oribi Gorge Suite	Unknown potential
Margate Granite Suite	Relatively fine-grained, non-porphyritic charnockites within felsic granites	Extensively developed along the south-eastern margin of the Oribi Gorge Suite
Alaskitic Granite (Mucklebraes Formation)	Almost pure, white alaskitic granite with extensive aplitic phases.	May be mined as a by-product when this deposit is exploited for lithium

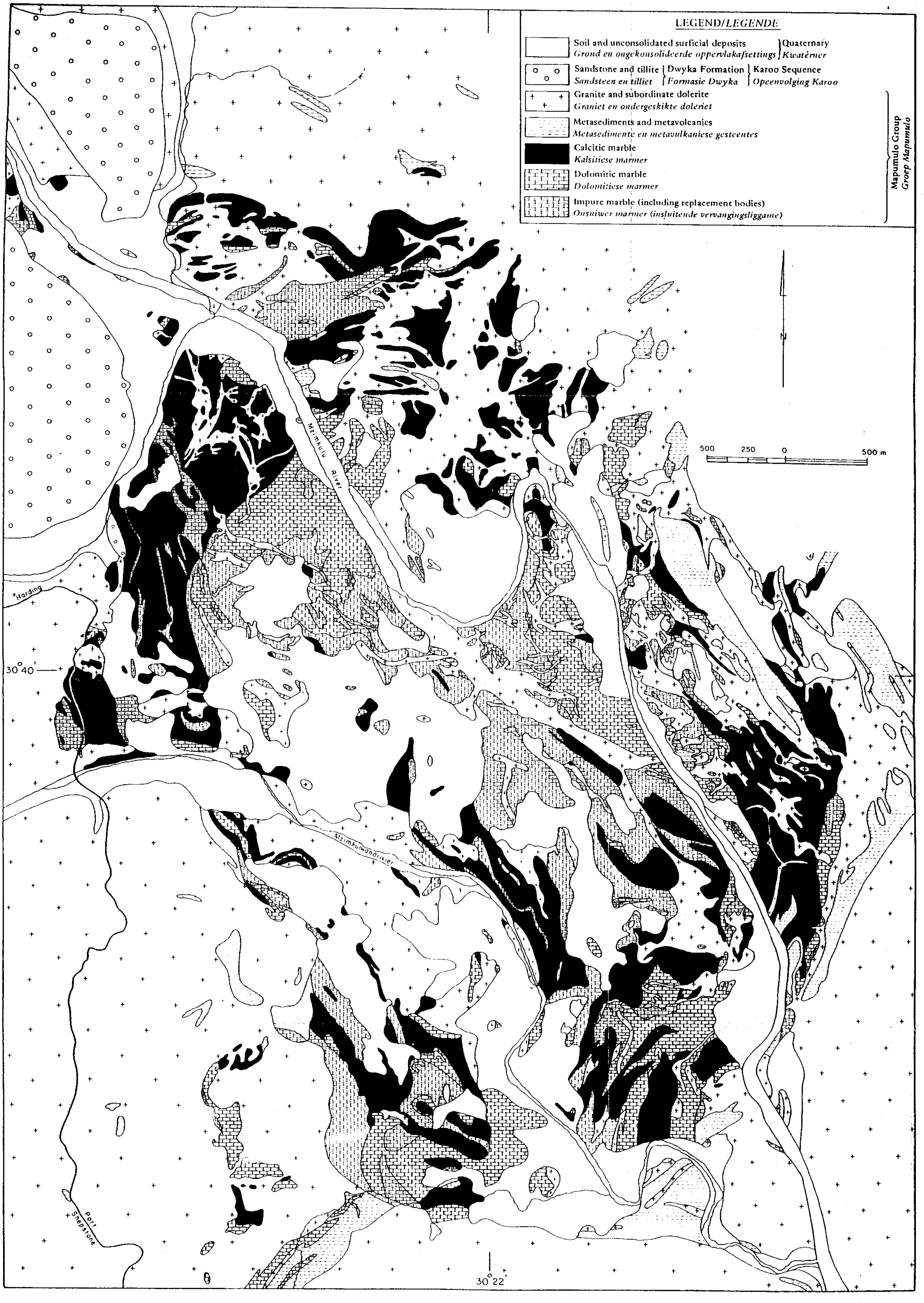


Fig. 4.17: Detailed Geological Map of the Marble Delta Area, Southern KwaZulu-Natal (after Otto, 1977).

4.3.4.3. Industrial Mineral Deposits in the Margate Terrane with Uncertain economic Potential

The deposits are described in Table 4.11, with localities shown in Fig. 4.12. These mineral occurrences are all located close to Port Shepstone, which is well served by road and rail links.

Table 4.11: Industrial Mineral Deposits in the Margate Terrane with Uncertain Economic Potential.

Commodity	Locality	Host Rocks	Nature of Mineralisation	Reference	Remarks
Feldspar	Highbury Pegmatite, N of Port Shepstone (Fig. 4.15)	Pegmatite sills in the Mucklebraes Formation	High albite feldspar	Thomas et al., (1994a)	May be mined as a by-product when lithium is mined here
Graphite	10 km west of Southbroom (Fig. 4.12)	Granulitic gneiss of the Leisure Bay Formation	Steep S-dipping graphite-sillimanite schist layer ± 3 m thick over 350 m strike length	Bekker, (1985b)	Ore reserves to a depth of 300 m > 900 000 t at ± 4.28% graphitic carbon. Uneconomic due to inferior grade
Graphite	Marble Delta (Fig. 4.12)	Limestones of the Marble Delta Group	Local concentrations of graphite of possible biogenic origin	Otto, (1977)	Uneconomic
Stone Aggregate	Umzimkulu Quarry, 8 km NW of Port Shepstone (Fig. 4.12)	Margate Granite Suite	Gneissic garnetiferous leucogranites	Bullen et al., (1992)	Quarry recently ceased production

CHAPTER FIVE

5. Metallogeny of the Precambrian Deposits

Introduction

A variety of mineral deposit styles occur within the Precambrian rocks of the study area. To analyze the genesis of these deposits, it is important that the tectonic evolution of the host terranes be considered, in context with deposits hosted in similar tectonic environments in other terranes. The characteristic features of each mineralisation type are essential to understanding the processes whereby ore deposits form and also in the exploration for these deposits.

Tectonic processes in relation to the genesis of individual deposits in the study area have been hinted at in previous chapters. However, a synthesis of these data and the detailed genesis of some of the important mineralisation styles follows.

5.1. THE ARCHAEAN

5.1.1. Lode Gold Mineralisation

General

Numerous epigenetic, structurally hosted lode gold deposits occur throughout the study area. These deposits are significant in that most of them have been previously mined and/or studied in some detail by various workers. In addition, the only metalliferous deposit currently being mined underground in KwaZulu-Natal is the Klipwal gold mine.

The gold deposits of the Province have special significance as they are typical lode gold deposits, which on a global scale are the second most important producers of the commodity, after placer deposits (Fig. 5.1). In addition, production from lode gold deposits continually show annual increases, whilst production from the Witwatersrand placer deposits are being hampered by numerous difficulties as the mines reach greater depths. Examples of other sources of the metal include Carlin type deposits, volcanogenic massive sulphides, skarns and epithermal systems, in addition to gold being produced as byproducts from mining of other mineral deposits. Only the types of gold deposits present in the study area will be discussed.

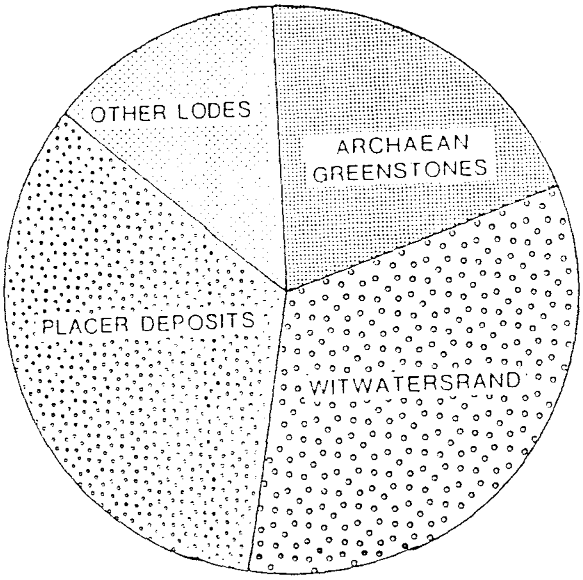


Fig. 5.1: Major sources of world gold production (after Groves and Phillips, 1987). Greenstone production accounts for 20 000t Au. Greenstone lode-gold and other lode-gold deposits now account for a significant proportion of world gold production.

The genesis of lode gold deposits has been widely debated, and an outline of salient factors in their formation is attempted here, to create a better understanding of the deposits in the area under investigation. Many theories have been formulated in an attempt to explain the genesis of lode gold deposits from the Archaean. These theories analyze the sources of the metals and other components in the veins, sources of the mineralising fluids, the means of their mobilisation and transport and the wall rock alteration, and final precipitation of the minerals in the depositional sites. These investigations provide valuable insight into the various factors responsible for the formation of these deposits, and will be discussed later.

Previous literature regarding lode gold deposits concentrated mainly on greenschist grade Archaean deposits as these deposits were the most important gold producers. However, it was recently found that all lode gold deposits within metamorphic terranes of different grades (subgreenschist, amphibolite and granulite grades) and ages (Proterozoic to Cenozoic) have similar characteristics to those found within Archaean terranes, and were all likely to have formed by a similar process (Kerrich and Wyman, 1990; Kerrich, 1993). A refinement of previous theories followed, leading to lode gold deposits of all ages now being viewed as a single class of deposit (or coherent genetic group - Groves, 1993) which formed over a depth range through all metamorphic grades (Fig. 5.2).

This has led to the formulation of the crustal continuum model for lode gold deposits (Groves et al., 1991; Groves, 1993). Evidence gathered by Groves (1993) from structurally controlled lode-gold deposits on a global scale has revealed that these deposits represent a crustal continuum and formed under various crustal regimes over at least a 15 km crustal profile at PT conditions ranging from 180°C at < 1 kb to 700°C at about 5 kb.

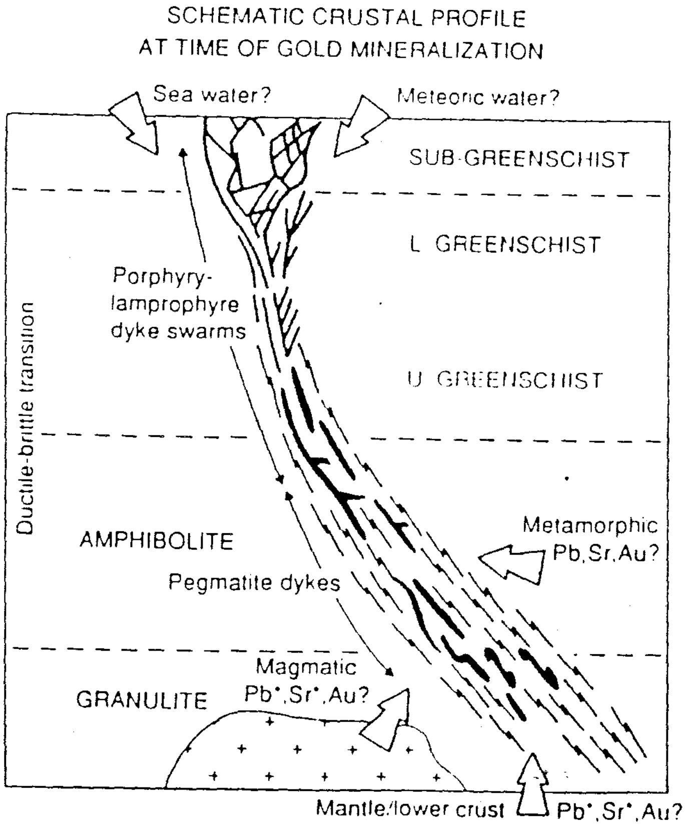


Fig. 5.2: Schematic crustal profile of a hypothetical, continuous hydrothermal system over a crustal range of 25 km. The series of deposits shown here is unlikely to occur in any one area (after Groves, 1993).

The crustal continuum model may be particularly relevant for KwaZulu-Natal, as structurally hosted, epigenetic gold deposits occur within Archaean and Proterozoic host rocks (Tugela and

Mzumbe Terranes). However, although the underlying greenstones are considered a source of the gold, local volcanogenic exhalative processes may also be presumed a source, in light of the tectonic history of these terranes (Thomas et al., 1994b).

5.1.1.1. Genesis of Structurally-hosted Lode Gold Deposits

The basic process whereby lode gold deposits form is clearly understood (Fig. 5.3), and is one where ore-bearing hydrothermal fluids from depth were mobilised and transported due to advection along major structural discontinuities to finally precipitate mineralisation in second-order depositional sites which provide the most favourable geological conditions (structure, host rock composition, fluid chemistry, etc.).

In order to gain a general insight into Archaean lode gold deposits, it is important to analyze the basic mechanisms that lead to the formation of these deposits. These factors may then be used to assist in providing a better understanding the mechanisms involved for the formation of similar deposits found in the study area.

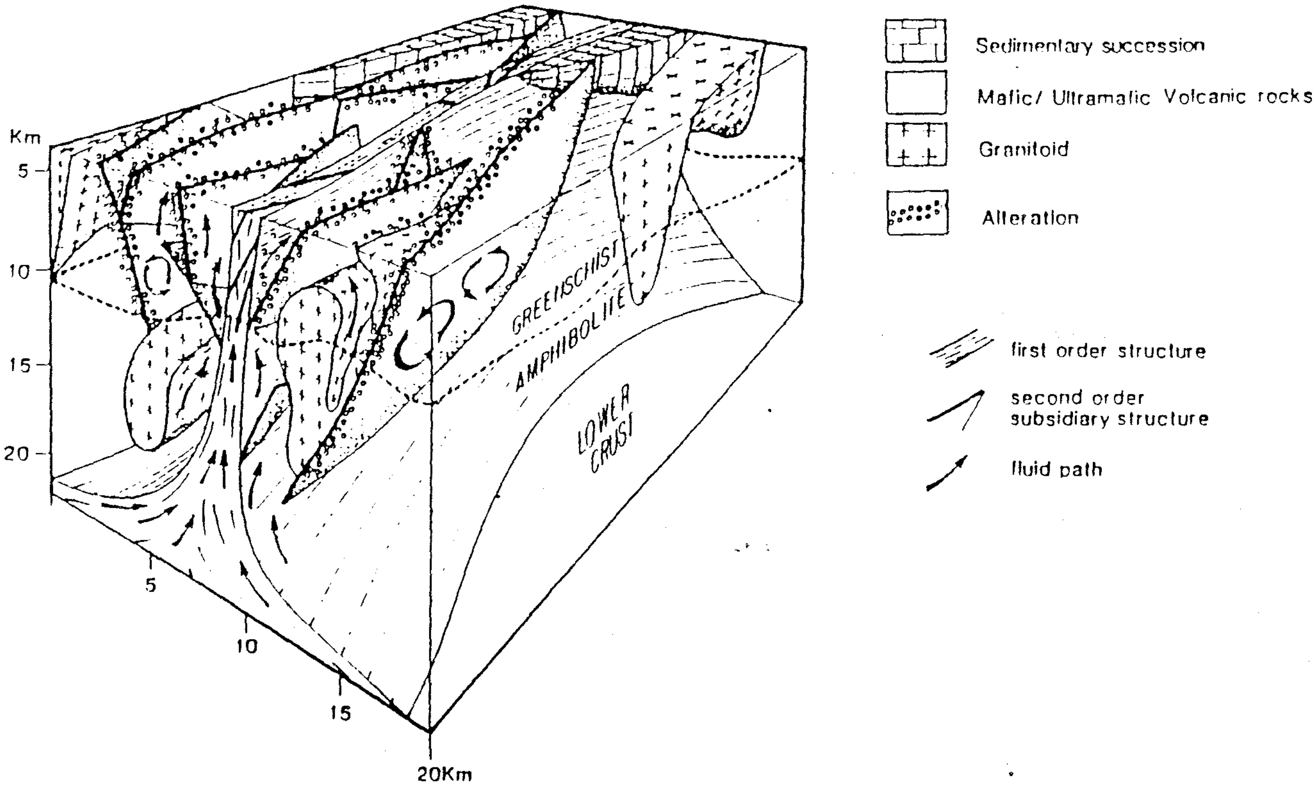


Fig. 5.3: Schematic diagram showing transportation of mineralising fluids through the crust via a major structural discontinuity into second-order subsidiary structures (after Eisenlohr et al., 1989).

A brief overview of the following aspects is considered important to gain a better insight into the genesis of Archaean lode gold deposits. Much of the data represents research from workers in Western Australia and Canada, where such deposits are widespread and more extensively studied. Ongoing research will continue until a model which has broad constraints for all deposits can be presented.

The following parameters are considered essential for a better understanding of the genesis of these epigenetic, structurally-hosted lode-gold deposits:
1] The source of the gold
2] The source of the mineralising fluids and transport
3] Mechanisms of concentration in fluids
4] Structure and wall rock alteration
5] Cause of Au precipitation
6] Timing of the mineralisation

The different models proposed encompass many characteristics of the Archaean lode gold deposits found in the study area, as each model takes into account structurally controlled mineralisation hosted in greenschist facies, volcanic-dominated sequences containing Fe-rich rocks such as basalts, dolerite or BIF.

1] Source of Gold in Archaean Host Rocks

For the formation of any mineral deposit, it is logical to first consider the primary source from which such metals can be attained. Early metallogenic models regarding the source of gold in Archaean deposits centred mainly on theories that involved the leaching of the precious metal from the country rocks by fluids that were mobilised due to a heat source such as granite plutons, or that the plutons themselves were the source of the gold-bearing fluids. That the intrusives generated the heat which caused mobilisation of fluids due to dehydration of country rocks, is also true for many deposits.
Essentially, these earlier theories assumed that all types of country rock were gold-bearing. However, it was pointed out by Keays (1984) that this is not always the case, as only certain rock types contain enough gold to form large gold deposits. Detailed studies by Keays revealed that the initial gold-enriched host rocks were most likely to be from the generation and

emplacement of komatiitic magmas and high-Mg basalts which were derived from relatively high degrees of mantle melting. Keays (1984) suggested that the reason for the enriched precious metal contents of these rocks is due to them becoming S-saturated at a late stage due to their much higher temperatures when compared to most other magmas. As a result, the proportional loss of Au and other chalcophile elements due to scavenging by immiscible sulphide melts was not significant.

Komatiitic magmas are extensively developed in Archaean greenstone terranes because of the higher geothermal gradients that prevailed, and this serves to explain the widespread development of Au deposits in Archaean rocks. Although these magmas had high Au contents when extruded, the Au available from these (i.e. Au not locked up in silicate and oxide phases) to form epigenetic Au deposits (which are due to regional metamorphism and deformation of the volcanic pile) is lost long before ore-forming processes could begin. A study on MORB pillows by Keays and Scott (1976) revealed that the glassy rims of the pillows contain significantly higher concentrations than the interiors. According to Keays and Scott (1976) the loss of this Au could be attributed to the reaction of the hot lavas with seawater, soon after the formation of basaltic pillows, which caused the dissolution of most of the Au (and S) from the pillow interiors. Keays (1984) suggested that this process occurred long before the volcanic piles were subjected to metamorphism and deformation (the ore-forming environment) which culminates in mineral deposits.

To explain the source of mineralisation in various different types of mineral deposits seen at present, an intermediate trap for these precious metals was therefore suggested, to retain the mineralisation until the ore-forming environment was created. Ideal lithologies suggested for this role are interflow chemical sediments, such as BIF. Some BIF lithologies, e.g. in Zimbabwean greenstone belts, are important host rocks to Au mineralisation.
This mineralisation would then be remobilised during subsequent events, which may be related to intrusives which generate heat and create structural conduits along which fluid flow is focused and deposited in their final sites.

According to Keays (1984), ultramafic intrusions form another possible source of Au, especially those enriched in S. These intrusions, in the form of dunite pods and lenses, would not have been affected by seawater metasomatism that initially leached out the Au in the volcanic lavas. However, the source of the metal may also depend on associated lithologies and conditions prevailing at the time of deposit formation. For the lode gold deposits in the Archaean Superior Province of Canada, four genetic models have been proposed to account for the source of the mineralisation (Card et al., 1989). These are briefly described below. In the magmatic-hydrothermal model, it is proposed that the mineralised hydrothermal fluids were derived from ascending magmas generated during Late-Archaean tectonism and metamorphism (Burrows et al., 1986). Likely source magmas include felsic porphyries (Macdonald and Hodgson, 1986, cited in Card et al., 1989) or domal tonalite gneiss-granodiorite quartz monzonite bodies that intruded the lower part of the greenstone belts (Burrows et al., 1986).

Groves and Phillips (1987) proposed the metamorphogenic model where the greenstone belts are considered to be the source of the gold and all the other components of the hydrothermal fluids. Granulitisation of the lower crust as a result of the streaming of CO_2 from the mantle, causing the release of H_2O and the onset of partial melting was proposed by Cameron (1988) and Colvine et al.(1988). These reactions would cause leaching of gold and light intermediate lithophile elements from the lower crust, resulting in gold-bearing H_2O-CO_2-rich fluids.

Finally, volcanogenic origins are also considered likely sources of mineralisation and are thought to have formed by submarine exhalative processes during the waning phases of volcanism (Valliant and Bradbrook, 1986, cited in Card et al., 1989).

2] Source of the Mineralising Fluids and Transport

Fluid inclusion studies do not reveal a unique source of mineralising fluids for lode gold deposits. According to Ho et al. (1985), Groves and Phillips (1987) and Pirajno (1992), fluid inclusion studies from quartz veins related to mineralisation indicate that the fluids are all very similar: being low salinity ($<$ 2 wt. % NaCl equivalent), low density, reduced, near-neutral to slightly alkaline, H_2O-CO_2-CH_4-rich fluids with variable H_2O:CO_2:CH_4 ratios for different deposits. Groves and Phillips (1987) suggested and analyzed several alternatives likely to be the sources of such fluids, including mantle degassing, magmatic fluids from granitoid batholiths and felsic (porphyry) intrusions and metamorphic fluids, while Hutchinson and

Burlington (1984) also suggested recirculated seawater. All these fluid sources have the potential to provide the mineralising fluids, and each deposit may be formed by fluids from different sources.

Previous investigations centred on metamorphic fluids derived from the devolatilisation of greenstones as the predominant source of hydrothermal fluids and solutes in the formation of the major deposits (the metamorphic-replacement model of Groves and Phillips, 1987.)(Fig. 5.3) . This was reasoned because of the low-pressure metamorphism typical in greenstone belt evolution (e.g. Binns et al., 1976, cited by Groves and Phillips, 1987), which implies high geothermal gradients (Groves and Phillips, 1987). According to these authors, this results in positive P-T slopes of most devolatilisation curves at low pressures, implying a restricted temperature interval over which devolatilisation of greenstones occurs. The restricted temperature interval causes most devolatilisation over a relatively small depth, while melting of the greenstone pile is inhibited due to the high geothermal gradient at relatively low pressures. Carbon isotope data indicated that the CO_2 was likely to have been derived from mantle-derived carbonate during mantle-degassing along crustal-scale fault zones. The fluids resulting from the devolatilisation of the greenstones (as a result of grain reactions) extracted Au from the greenstone pile and were channelled along greenstone-scale faults (Fig. 5.4). Au was then deposited in, or adjacent to, fault or shear zones in response to decreased temperature and fluid/wall-rock reactions. Where BIF lithologies are intersected, replacement of Fe oxides by Fe sulphides and gold occurs.

The influence of nearby magmatic intrusions to mineralisation has been cited by many workers in the study area. According to Groves and Phillips (1987), although the intrusions did not contribute significantly to mineralisation, the magma emplacement and mineralisation may have been the result of the same thermal event, with magmas being generated due to melting at deeper crustal levels. These magmas may then have been selectively emplaced along crustal fractures and at the same time, generated the second-order structures where mineralisation is sited.

What is clear is that the ore fluid common to all deposits is deeply sourced and was derived from, or interacted with, granitic rocks below the greenstone belts, while some of the ore-fluid components were also derived from other sources, as indicated by C and O isotope data (Groves, 1993). This is due to the fact that the high-temperature fluids from depth in these crustal-scale hydrothermal systems advected along vertically extensive structures through mid- to lower crustal granitoid-gneiss complexes to the overlying depositional sites. Meteoric and seawater as ore fluid components are suggested for those deposits hosted in brittle structures at shallower crustal levels in very low grade metamorphic settings.

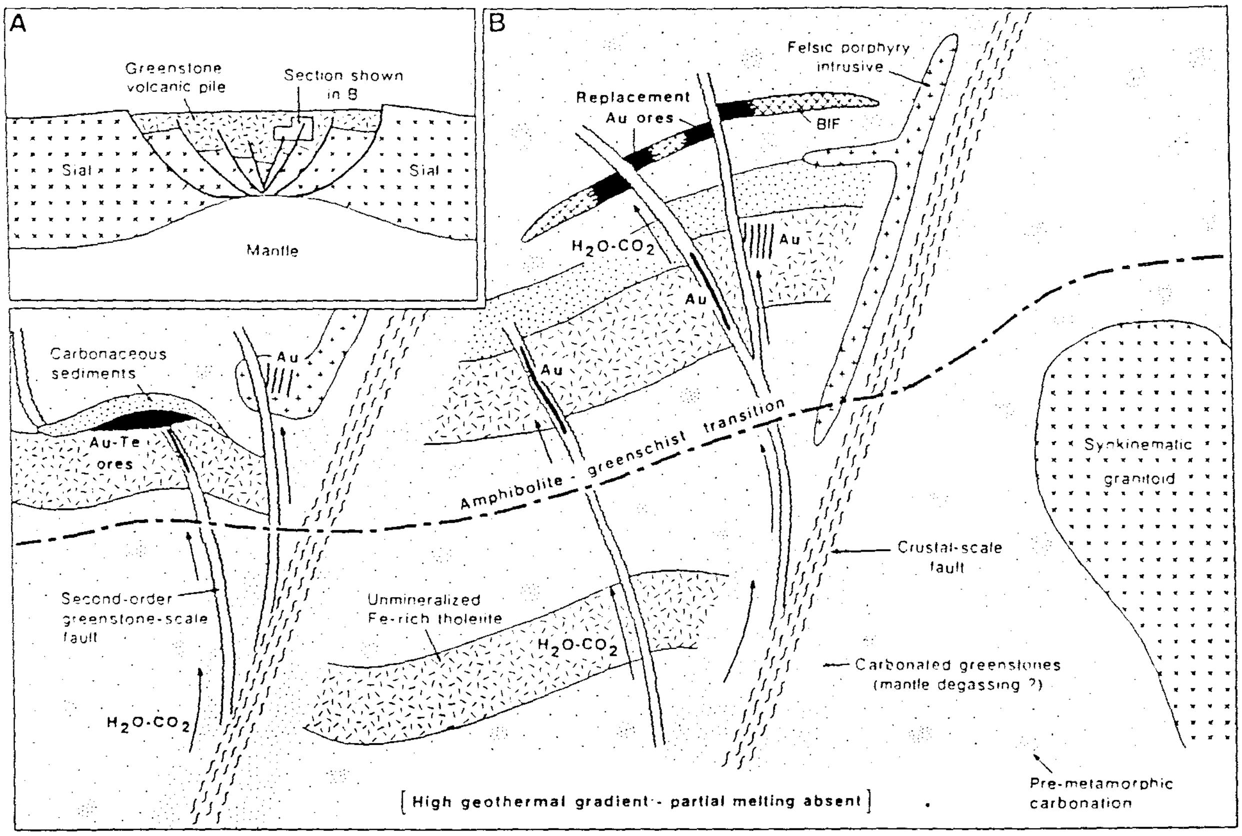


Fig. 5.4: Schematic representation of the metamorphic-replacement model for the generation of Archaean gold deposits (after Groves and Phillips, 1987).

Any steeply inclined plane may constitute the pathway for the migration of fluids. In terms of ore deposition, major structures such as faults, shear zones and thrusts are considered most important channels for the movement and focusing of hydrothermal fluids (Groves and Phillips, 1987; Pirajno, 1992). The channelisation of the fluids and upward migration into the major structures has been attributed to mass transfer processes such as seismic pumping (Sibson et al., 1975), which produced high fluid/rock ratios.

3] Mechanisms of Concentration in fluids (liberation from original state)

For Au to be stable in solution, it must form compounds with other elements in the hydrothermal fluid before being transported. Au in hydrothermal fluids predominantly occurs in the Au^{1+} oxidation state (Seward, 1984), which can form stable complexes with many elements and compounds.

The fluid in which gold concentrates is generally of low salinity, is CO_2-rich, and is likely to be richer in potassium than sodium (Fyfe and Kerrich, 1984). According to Fyfe and Kerrich (1984), gold can form a wide range of complexes with ligands such as the halide ions, sulphur species, carbonyls based on CO, and nitrogen-containing species, along with complex arsenic-derived species which may all be present in hydrothermal solutions. The most common appears to be a reduced sulphur complex such as $HAu(HS)_2$ with which are associated metals such as As, Sb and W, and sulphur which may all have been derived from the volcanic pile and associated sulphide-rich sediments (Groves et al., 1985).

According to Ridley et al. (1996), bisulphide complexes have much greater potential than chloride complexes, with the most significant complexes being $Au(HS)^0$ and $Au(HS)_2^-$. However, according to Romberger (1991, cited in Ridley et al., 1996), gold-chloride complexes become more stable than the bisulphide complexes with increasing temperature.

4] Structure and Wall Rock Alteration

In the case of lode gold deposits it is noted that only a few deposits produce the bulk of the mineralisation, while the others are smaller and have scattered rich pockets of mineralisation. This is due mainly to structural control of the mineralisation system, as at depth vast quantities of mineralised hydrothermal fluids exist. These exploit sites with the most favourable conditions (structure, host rock, fluid chemistry, etc.) for the precipitation of mineralisation, thereby forming deposits of variable sizes and grades. It is also known that these deposits are related to shear- and fracture-zones which suggests that these structures focused fluid flow and acted as conduits for the movement of the ore-bearing fluids. The deposits are known to be of limited lateral extent, but tend to extend to great depths.

There is a distinct association of the lode gold deposits with shearing and large scale fractures which implies that these structures were responsible for focusing fluid flow, and also acted as conduits for the migration of the ore fluids. All the deposits studied indicate an association with structural discontinuities. It is well known that most of the mineralisation is located in brittle-ductile structures subsidiary to the main crustal-scale fractures. Offshoots from the main shear zone at Klipwal gold mine are known to have grades in excess of 200 g/t in some places.

Pirajno (1992), citing Eisenlohr et al. (1989), suggested two reasons for the largely unmineralised first-order structures and the richly mineralised second-order structures.
1] Physico-chemical gradients between the two structures, such as temperature, would be higher in first-order structures, causing migration of mineralised fluids into the second-order structures.
2] The second-order structures were more likely to have interacted with the greenstone source rocks, whereas the crustal-scale first-order structures interacted with a deeper (mantle) source.

On a smaller scale, as noted in deposits at Klipwal (Gold, 1993) and the Melmoth Granite-Greenstone remnant (Bullen, 1990), mineralisation is commonly located towards the centre of shear zones, where shearing was most intense. Also of major importance was the location of mineralisation at the contact between two rock types, with mineralisation invariably hosted in the least competent rock type (Bullen, 1990).

Bonnemaison and Marcoux (1990) proposed a three-stage model for quartz-vein-hosted mineralisation in shear zones. They propose that, for economic concentrations of Au in shear zones, there had to be subsequent phases of deformation and hydrothermal fluid circulation, which lead to enriched concentrations of Au in some preferred sites within the structure. They suggest that gold appears in shear zones at a very early stage in the form of auriferous pyrrhotite (or pyrite, arsenopyrite), and is reconcentrated by deformation and recirculation of hydrothermal fluids in various episodes, when Au may appear in the native state.

Fluid/wall rock interaction is responsible for the distinctive laterally zoned alteration haloes observed in all deposits, while vertical zonation is generally restricted because of heated wall rocks (Groves and Phillips, 1987). According to Groves et al. (1991), wall rock alteration patterns in the ore zone of greenstone successions are typified by ankerite/dolomite-white mica (sericite) and/or biotite±albite, with the alteration characteristically retrograde with respect to peak metamorphism. At lower-amphibolite grade, amphibole-biotite-plagioclase assemblages predominate, while mid-amphibolite to lower granulite-grade assemblages consist mainly of garnet-diopside-biotite-K-feldspar minerals. The S-rich assemblages at low metamorphic grades are dominated by pyrite, with pyrite-pyrrhotite-dominated assemblages and pyrrhotite-arsenopyrite (±loellingite) assemblages developing as metamorphic grades increase (Groves et al., 1991).

These alteration patterns are due to complex mineralogical, chemical and textural changes due to the interaction of the hydrothermal fluids and wall rocks, under evolving physico-chemical conditions (Pirajno, 1992). Alteration patterns may be observed in all hydrothermal deposits, and are related to the activity of K^+ and H^+ ions in the system, which affects the composition of the wall rocks surrounding the hydrothermal system. Dominant mineral assemblages of altered zones are related to specific alteration types, which are useful in locating the source of mineralisation, and hence are an important tool used in exploration. The various types of hydrothermal alteration patterns and associated mineralisation are detailed in Pirajno (1992). Wall rock alteration patterns will largely depend on the composition and metamorphic grade of the rocks with which the fluids interact.

For example, the different mineralogical compositions of the host-rocks at the Harewood and Vira workings of the MGGR are responsible for the variations in wall rock alteration patterns observed at the two deposits (Bullen, 1990). The types of alteration reported from the gold deposits in the study area are mainly argillic, sericitic, silicic, and chloritic haloes surrounding the mineralised quartz veins. Sericitic alteration, also known as phyllic alteration, is characterised by the assemblage quartz-sericite-pyrite (QSP). Argillic alteration is commonly found to be of supergene origin and is mainly due to increased H^+ metasomatism (acid leaching). According to Pirajno (1992), these alteration patterns are characteristic of Archaean shear zone deposits, due to the circulation of hydrothermal fluids rich in H_2O and CO_2. The pattern of alteration found in individual deposits will largely depend on host rock mineral assemblages and their response to metasomatic effects.

5] **Cause of Au Precipitation**

According to Pirajno (1992), precipitation of metals from hydrothermal fluids may be due to a number of factors, such as temperature changes, pressure changes and boiling, reactions between wall rocks and solutions and chemical changes due to mixing of fluids. For the gold deposits, a number of factors are responsible, mainly temperature and pressure decrease, changes in Eh and pH, oxidation of reduced hydrothermal solutions (Hutchinson, 1993) and reactions with wall rocks.

In the metamorphic replacement model of Groves and Phillips (1987), it is suggested that gold deposition mainly occurred in sub-amphibolite facies regimes, under minimum P-T ranges of 1-2 kb and 350-450°, because, according to Seward (1984), solubility of reduced sulphur complexes decreases below ca. 500°C.

As noted earlier, Au is generally transported in hydrothermal fluids with a number of complexing ligands. The type of ligand, however, is important in determining the conditions required for precipitation, as outlined by Seward (1984). For example Au transported as $Au(HS)_2^-$, a simple hydrosulphide complex, could precipitate Au in response to a drop in temperature (due to the ascending fluid or interaction with cooler near-surface water) as well as in response to any process which caused a decrease in the activity of reduced sulphur. The latter process may be caused by boiling, oxidation, dilution and precipitation of metal sulphides. Oxidation of H_2S together with a decrease in pH may also cause Au precipitation. Further, gold transported as a $AuCl_2^-$ (chloride complex) would precipitate gold with a drop in temperature and fluid dilution, which decreases chloride activity.

According to Groves and Phillips (1987), additional factors favouring deposition of gold in Archaean environments include processes whereby sulphidation of wall rocks occurred, simultaneously depositing Fe-sulphides and gold, especially where the fluid pathways intersected Fe-rich rocks such as tholeiites or dolerites. Where fluid/wall rock interaction occurs in less Fe-rich rocks, gold deposits may form due to fluid reduction and/or lowering of pH (Groves and Phillips, 1987).

6] **Timing**

The timing of mineralisation generally post-dated both peak metamorphism and magmatism (e.g. Groves and Phillips, 1987). However rare premetamorphic deposits and some synmetamorphic deposits may also occur (Groves et al., 1991). Mineralisation generally occurred late in the tectonic history of an individual craton (Groves et al., 1989; Ridley et al., 1996). For example, field evidence shows veins crosscutting complexly deformed lithologies and in many cases, wall-rock alteration is generally retrograde with respect to peak metamorphism.

Summary

The above discussion serves to highlight the variety of parameters that are applicable to the formation of lode-gold deposits. Aspects of the genetic models proposed have to be combined for specific deposits, not only in the study area but also on a world scale as individual deposits may contain only a few of the characteristics that are typical of lode-gold mineralisation. There is general agreement that these deposits are epigenetic, but the precise origin of the mineralisation is still equivocal, due mainly to each case-study having a few unique characteristics.

Further research into lode-gold deposits is still required to gain a complete understanding of all the factors responsible for their formation. According to Groves (1993), the poorly understood late tectonic evolution of granitoid-greenstone belts in the Late-Archaean is one of the major factors against resolving the genesis of these lode-gold deposits.

5.1.1.2. LODE-GOLD DEPOSITS IN KWAZULU-NATAL

The lode-gold deposits in KwaZulu-Natal show many of the characteristics common to Archaean gold deposits throughout the world. The gold deposits in the Province have not had much attention in the literature, due mainly to their small size and lack of outcrop. Potential for larger deposits may exist, and if one studies deposits elsewhere and applies similar constraints and models to the terranes in the study area, this potential may be realised. However, a common characteristic of greenstone belts is a restricted number of large deposits being developed, with numerous smaller deposits, largely because the required structural framework had not sufficiently evolved.

In the Archaean rocks of KwaZulu-Natal, lode-gold mineralisation occurs in the Nondweni and Melmoth granite-greenstones, and in the metasediments of the Mozaan Group. To analyze the mineralisation in these different host terranes, models of tectonic evolution proposed for host lithologies must initially be taken into account, followed by the application of some of the parameters discussed earlier in this chapter.

5.1.1.2.1. The Granite-Greenstone Terrane

The lode- gold deposits in the Archaean granite-greenstone terrane of KwaZulu-Natal compare favourably to typical syn-cratonization Archaean lode gold deposits found worldwide (e.g. Bullen et al., 1994; Versfeld, 1988). Studies on the gold deposits of the Nondweni Group greenstones by Versfeld (1988), revealed no relationship between the distribution of gold occurrences and their proximity to exposed intrusive granite contacts. However, along with Bullen (1990), it was suggested that these late-tectonic granitoid intrusions had provided the thermal driving mechanism for mineralising fluids, and may have created the structural pathways necessary for their passage. Mineralisation would then be precipitated from these fluids in structurally and lithologically favourable sites.

Wilson and Versfeld (1994a,b) found the Nondweni Group to have several unique characteristics when compared to the Barberton greenstone belt and other greenstone belts world-wide. Magma compositions and distinctive trace element geochemistry indicate that the source of the Nondweni greenstone magmas as different from those at Barberton, though compositional features that characterise Kaapvaal craton greenstone belts are retained.

According to Wilson and Versfeld (1994a), the development of low-magnesian komatiites, komatiitic andesites and basaltic andesites is indicative of subduction-related volcanism in a continental margin setting. Bullen (1990) also proposed development of the Melmoth greenstones in a subduction-related setting and suggested a possible genetic model for the mineralisation (Fig. 5.5), which may also be broadly applicable to the formation of the structurally-hosted lode gold deposits in the Nondweni greenstones. Versfeld (1988) found no evidence of these gold deposits having been formed by volcanogenic processes and suggested that the gold was derived from leaching of the greenstone pile at depth. The volcanogenic deposits of the Toggekry Formation have no Au-enrichment and are of very limited extent (Versfeld, 1988).

Figure 5.5. (after Bullen, 1990), shows the sequence of events likely to have occurred in the evolution of the greenstone belt and related mineralisation on the southern margin of the Kaapvaal craton.

A - depicts the predeformational, extensional phase, with the greenstones forming in a back-arc basin setting.

B - compression due to closure of the back-arc basin. Intrusion of the trondhjemitic magmas occurred at the same time and were derived from the partial melting of the subducting oceanic plate. Tilting and folding also occurred at this stage, developing axial planar foliation. Minor shear zones are also thought to have developed during this phase.

C - compression and deformation continued, with the formation of a crustal-scale shear zone in response to the intrusion of granodioritic magmas. At this stage, early magmatic fluids were transported through fractures to the shear zone, depositing quartz, silicates and oxides in dilational sites.

D - increased metamorphism at the base of the greenstone pile due to granitoid intrusion generated metamorphic fluids, which reacted with the host rocks. These fluids dissolved Au and were channelled up the shear zone where deposition occurred in dilational sites.

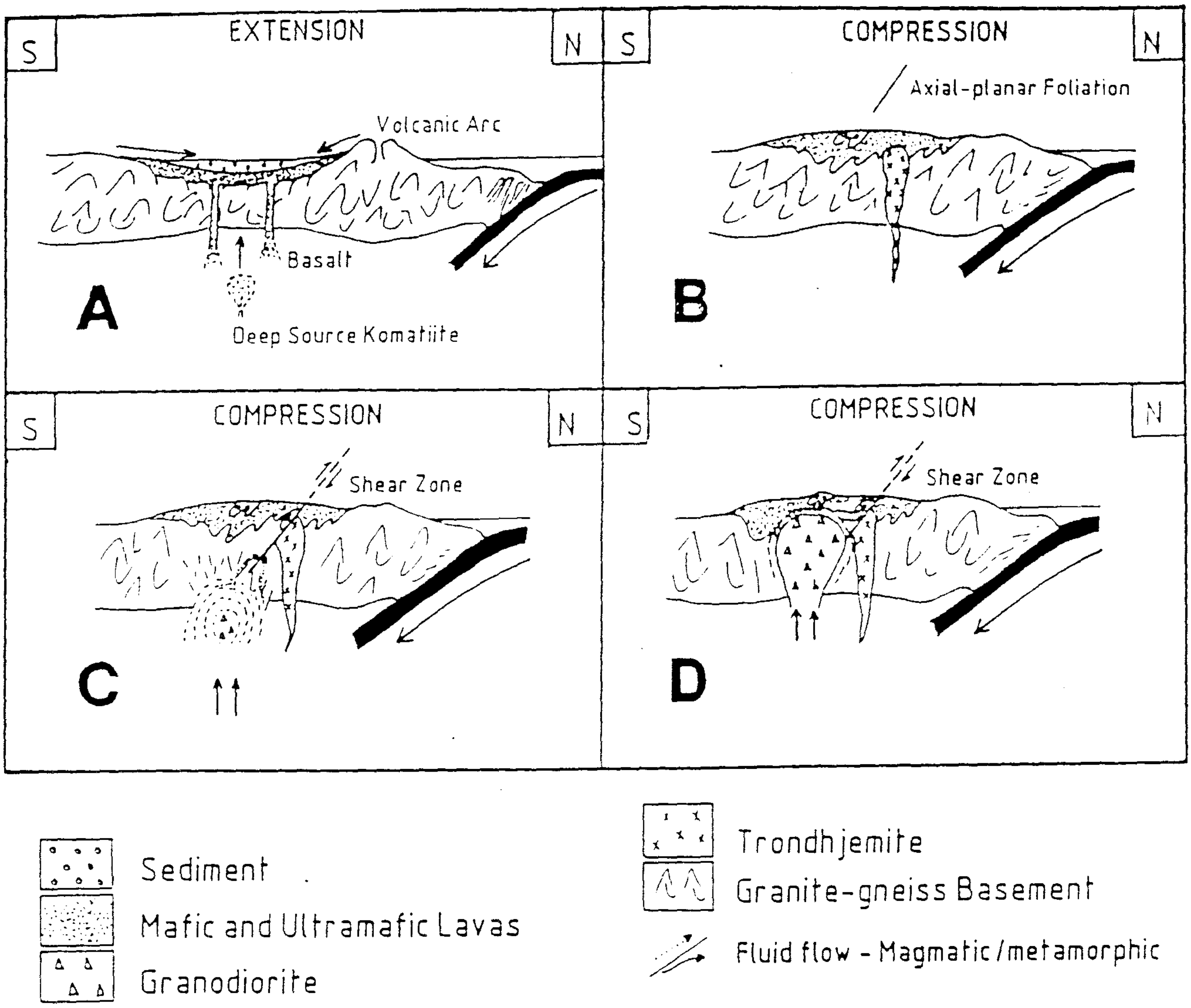


Fig. 5.5: Simplified sketch-map of possible greenstone belt evolution and mineralisation in northern KwaZulu-Natal (modified after Bullen, 1990).

5.1.1.2.2. **Pongola Supergroup Lode-Gold**

These lode gold deposits are hosted in the metasediments of the Mozaan Group and show characteristics typical of mesothermal gold deposits. The deposits here are all related to large-scale shear zones which allowed hydrothermal fluids to be channelled upwards from depth, as in the case of the older greenstone belt-hosted mineralisation.

According to Matthews (1990), the Pongola Supergroup underwent an initial rift phase, mainly in the northern parts, which was accompanied by extensive volcanism, resulting in the extrusion of basalts and andesites, which could have provided the source of some of the mineralisation. Rifting was followed by thermal subsidence, and the deposition of the shallow-water sediments of the Mozaan Group in an epicratonic basin which probably opened southward onto a continental margin. Deformation in the Pongola-Mozaan basin is regionally persistent and is associated with the north-directed thrusting described from many other parts of the Kaapvaal craton (Gold and Von Veh, 1995). This deformation may be responsible for producing the large-scale faults which provided pathways to the mineralisation.

Many of the factors discussed earlier in this chapter with regard to wall rock alteration, transportation and precipitation of mineralisation are likely to apply for the Pongola deposits. However, the primary source of the Au in these deposits is still speculative and requires detailed investigations.

According to Kerrich (1990), mesothermal gold deposits of all ages, from Archaean to Cenozoic, are characterised by similar structural, mineralogical and geochemical characteristics, implying that they are products of a singular, rather than multiple genetic process. Numerous processes have been attributed for their formation, including lateral secretion, exhalative processes, multistage exhalative-remobilisation, tonalite-trondhjemite-granodiorite magma suites, oxidised felsic magmas, lamprophyres, granulitization, meteoric water circulation, metamorphic replacement, metamorphic dehydration, or metamorphism at collisional boundaries (Kerrich, 1990).

Associations of some deposits to specific lithologies, e.g. BIF, and relationships with events, such as magmatism may provide some clues as to the source of the mineralisation. Many of the Pongola Supergroup gold deposits are located near major shear zones, deep seated faults and voluminous late-granitoid plutons, which could have provided the conduits necessary for the passage of mineralising fluids.

5.1.2. **PLACER GOLD**

Placer deposits account for a significant proportion of world gold production, especially the extensive Witwatersrand deposits in South Africa. Production from placer deposits is orders of magnitude greater than for those of even the largest of lode-gold deposits throughout the world. Placer gold occurrences have been documented in the Archaean Pongola Supergroup and Palaeozoic sandstones of the Natal Group and Msikaba Formation. The latter two lithologies have not been well documented in the literature and the exact source of the gold remains unknown.

However, the placer deposits in the Pongola Supergroup have always held interest mainly because of their resemblance and proximity to the richly mineralised lithologies of the Witwatersrand basin. The source of the ore in the Witwatersrand Supergroup is widely debated (e.g. Hutchinson and Viljoen, 1988) and is beyond the scope of this study.

Renewed interest in the similarities between the Witwatersrand and Pongola Supergroup conglomerates followed when U/ Pb dating of single zircons confirmed similar ages for the strata (Beukes and Cairncross, 1991). The Pongola, Witwatersrand, Dominion and Ventersdorp basins are believed to have been developed as a result of extension in the central and southern parts of the Kaapvaal craton, which occurred during the accretion of the granite-greenstone terranes in the western and northern parts (Thomas et al., 1993a). According to Beukes and Cairncross (1991), major horizontal tectonic disruption that is likely to have occurred on the craton between 2700 Ma and 2800 Ma (De Wit and Roering, 1990), juxtaposed the Witwatersrand and Pongola depositional basins, making lateral correlations possible.

Studies by De Wit et al. (1992) revealed that the Witwatersrand basin had undergone at least two depositional cycles during its development. The first cycle, which produced the lower part of the basin, is likely to have formed on a continental platform of a passive continental margin that faced open-ocean conditions to the south and west, with sediments derived mainly from a northern provenance area. The Pongola basin, at the southern margin of the Kaapvaal craton, is of similar age (~ 2 900 Ma) as the lower part (West Rand Group) of the Witwatersrand basin. The southernmost outcrops of the Pongola Supergroup also shows evidence of being part of a passive continental margin facing open ocean to the south (Matthews, 1990). The present distribution and close proximity of the Witwatersrand and Pongola Basins is shown in Fig. 5.6. According to De Wit et al. (1992): "there is general consensus that these basins are erosional remnants of originally much larger sedimentary depositories".

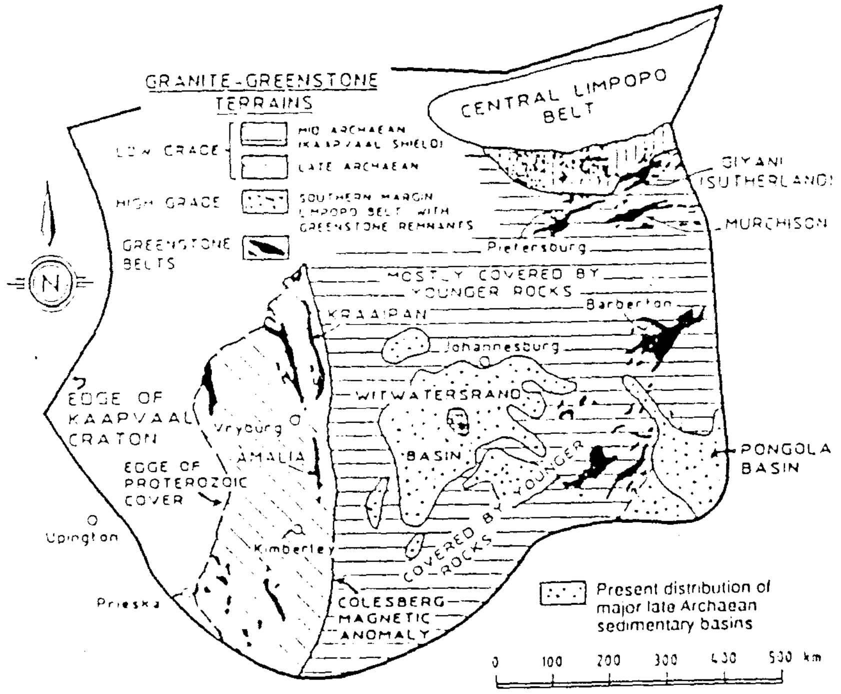
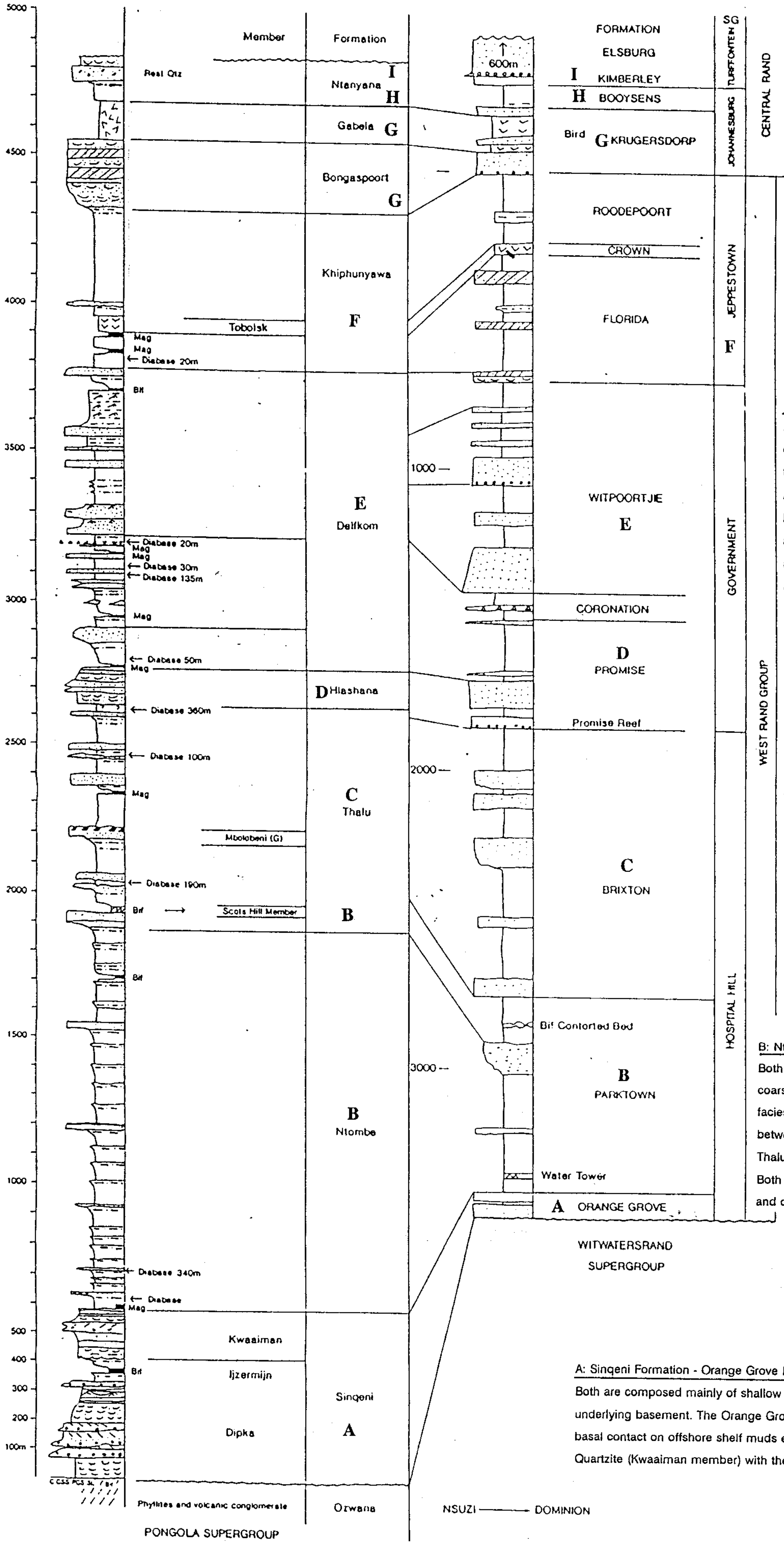


Fig. 5.6: Present-day extents of the Witwatersrand and Pongola Basins on the Kaapvaal Craton (after De Wit et al., 1992).

Beukes and Cairncross (1991) found lithostratigraphic (similar facies types and vertical facies successions) and palaeoenvironmental (similar sedimentation styles and sequence stratigraphic evolution) correlations to exist with the type profile of the Mozaan Group and the profile of the Witwatersrand Supergroup in the Heidelberg - South Rand Goldfield area. These are detailed in Fig 5.7. Refer to Table 2.6 for stratigraphic descriptions of the Mozaan Group.

What has perplexed most workers has always been the lack of economic gold mineralisation in the Pongola Supergroup. Suggestions that the Mozaan auriferous conglomerates were similar to those of the poorly mineralised, lower Witwatersrand, West Rand Group lithologies (Saager et al., 1982; 1986; Weilers, 1990) sufficed as the reason for the lack of economic mineralisation. However, Beukes and Cairncross found that only those conglomerates from the lower part of the Mozaan Group were the focus of the earlier investigations, while the stratigraphically higher Bongaspoort-Ntanyane sedimentary sequence (a possible Central Rand Group equivalent) have received little attention, and should be targeted for future exploration.

Fig. 5.7 (overleaf): Stratigraphic correlations of the Witwatersrand and Pongola Supergroups (after Beukes and Cairncross, 1991).



I: Upper Ntanyana Formation - Kimberley Formation

The upper fluvial and marine quartzites of the Ntanyana Formation may be correlated with the basal part of the Kimberley Formation of the Turffontein Subgroup of the Central Rand Group.

H: Basal Ntanyana Formation - Booysens Shale Unit (Johannesburg Subgrou

The transgressive Booysens Shale unit may be equivalent to the basal transgressive shale of the Ntanyane Formation.

G: Bongaspoort and Gabela Formations - Krugersdorp Formation and Bird la

The fluvial Bongaspoort Quartzite and and Gabela volcanic unit may be correlated with the fluvial Krugersdorp Quartzite and associated Bird Lava of the Johannesburg Subgroup.

F: Khiphunyawa Formation - Jeppestown Subgroup

These units are both major transgressive sequences and are characterised by the presence of amygdaloidal lavas (the Tobolsk and Crown lavas).

E: Delfkom Formation - Witpoortjie Formation

Erosively based fluvial quartzites resting on shelf mudstones characterise both the upper part of the Delfkom Formation and the Witpoortjie Formation.

A diamictite is developed in the Coronation Formation immediately below the Witpoortjie Formation. Diamictites have also been reported at this approximate stratigraphic interval (i.e. four units occur within a stratigraphic interval of 450 m some 2 500 m above the base of the Mozaan Group) by Von Brunn and Gold (1993).

D: Hlashana Formation - Promise Formation

Marine and fluvial deposits of the Hlashana Quartzite correspond to those of the Promise Formation.

C: Thalu Formation - Brixton Formation

Shelf muds and shallow marine quartzites of the Thalu Formation are equated with those of the Brixton Formation.

B: Ntombe Formation and basal part of Thalu Formation - Parktown Shale Formatic

Both units represent major transgressive sequences with stacked coarsening-upward iron-formation-shale-siltstone/shale-quartzite facies successions. A very striking similarity was found to exist between the setting of the Scotts Hill iron-formation member of the Thalu Formation and the Contorted Bed of the Parktown Formation. Both iron-formations are finely laminated, contorted and chert mesobanded, and overlie a coarsening-upward shale-quartzite facies succession

A: Sinqeni Formation - Orange Grove Formation

Both are composed mainly of shallow marine deposits which lie with angular unconformity on underlying basement. The Orange Grove Formation also contains quartzite resting with sharp basal contact on offshore shelf muds equivalent to the basal contact of the upper Sinqeni Quartzite (Kwaaiman member) with the Ijzermin shale member.

When viewed on a broader scale, it is very likely that the two depositaries must have been related in some way as the distance between the southernmost Witwatersrand Supergroup outcrops and those of the Mozaan in the Amsterdam area is only around 110 km. Beukes and Cairncross (1991) concluded that: "It seems highly unlikely that two such similar sequences could develop independently, in approximately the same time interval, such a short distance away from each other on the Kaapvaal Craton." Investigation regarding the Witwatersrand - Pongola correlation continues and is the subject of a recently submitted PhD thesis at the Rand Afrikaans University in Johannesburg (pers comm. N.J.Beukes, 1997).

Versfeld (1988) assumed the source of Au in the Nsuze Group conglomerates (e.g. at Patsoana) to be the Nondweni greenstones, because the conglomerate clasts are dominated by greenstone lithologies. The low grade of mineralisation was attributed to the immature, matrix supported nature of the conglomerates which resulted in lower Au concentration factors.

5.1.3. **Archaean Volcanogenic Massive Sulphide Deposits**

The Toggekry Formation contains mineralisation that exhibits similar features to other Archaean massive sulphide deposits and modern seafloor exhalative massive sulphide deposits (Wilson and Versfeld, 1994a). The sulphide deposits (described in chapter 3) are hosted in reworked felsic tuffs intercalated with sediments. The regional geologic setting envisaged is one of extrusive felsic rocks in a basalt-dominated volcanic environment. As the Toggekry Formation outcrops over a limited area, this eruptive event is attributed to the local development of a major felsic eruptive centre (Versfeld, 1988), after which there was a return to dominantly mafic and ultramafic magmatism. The final location of the mineralisation is structurally controlled, e.g. in closures of folds.

Several similarities exist between these deposits and those of the Murchison greenstone belt in the Northern Province of South Africa, which are also considered to be Archaean volcanic exhalative type deposits (Taylor, 1981, cited in Maiden, 1984). These deposits are of limited size and are confined to a restricted zone within the Rubbervale Formation (Maiden, 1984). The most significant of these, the Maranda J copper-zinc deposit, consists of a small (< 1 Mt) massive sulphide lens overlying a zone of stringer mineralisation. The Rubbervale Formation quartz-sericite-chlorite schists have also been interpreted as metavolcanics (SACS, 1980) and mineralisation has been attributed to hydrothermal activity which leached mineralisation from the volcanic pile (Maiden, 1984).

5.2. THE PROTEROZOIC:NATAL METAMORPHIC PROVINCE

General

The Natal Metamorphic Province (NMP) has been described in detail in chapters two and four of this work. In this section, an attempt is made to illustrate the various genetic types of mineralisation in relation to the tectonic evolution of the NMP.

The NMP forms the Natal sector of the Mesoproterozoic (± 1.1 Ga) Namaqua-Natal Metamorphic Province. The evolution of this high grade tectonic belt has been analyzed by various workers in great detail (e.g. Matthews, 1972; 1990; Thomas and Eglington, 1990; Jacobs et al. 1993; Jacobs and Thomas, 1994; Thomas et al. 1993a; 1994b; 1995b; Cornell et al. 1996). From this research there is general consensus that the evolution of the belt can be related to a complete Wilson Cycle model. This involved an initial phase of extension and rifting that led to fragmentation and the formation of oceanic basins. This early phase was followed by plate convergence, obduction and oblique collisional orogeny.

In the Natal sector, the Tugela Ocean is believed to have formed south of the Kaapvaal Craton, with rising volcanic arcs (later to form the Mzumbe and Margate Terranes) further south (Fig. 5.8). The Tugela Terrane has been interpreted, by Matthews (1972), as an ophiolitic assemblage that was deposited in this oceanic basin. Early northeast-directed thrusting and nappe emplacement, believed to be due to oblique arc-continent collision associated with the closure of the Tugela Ocean, led to the accretion of the three NMP terranes onto the southern margin of the Kaapvaal Craton (Thomas et al., 1994b). Continued convergence is thought to have resulted in collision-induced crustal thickening and later ductile transcurrent shearing (see section 2.2).

5.2.1. Mineralisation and Tectonic Evolution

Four genetic groups of metalliferous deposits have been recognised within the NMP (Thomas et al., 1994b). These are magmatic segregations, volcanogenic exhalative deposits, granite-related deposits and epigenetic precious metals. This metallogeny can be related to the various stages in the tectonic evolution of the NMP. Detailed descriptions of the individual deposits are given in chapter four.

Rifting and sea-floor spreading during the early stages of the development of the NMP (thought to have begun at ~1700 Ma by Thomas et al., (1994b)) are likely to have produced the supracrustal sequences of the Tugela Terrane, which were originally interpreted, by Matthews (1972), as an ophiolite assemblage formed in an oceanic basin to the south of the Kaapvaal Craton. Studies based on events in the entire Namaqua-Natal Province, led Thomas et al., (1994b) to suggest that volcanic arc activity may have been initiated at ~1600 Ma, with arc-related magmatism occurring in back-arc basins between 1200 and 1300 Ma. Mineral deposits associated with the back-arc basin environment include the volcanic exhalative sulphide deposits (which are also found in the Areachap Terrane of the Namaqua sector) and deposits formed as a result of alkali basalt volcanism due to hot-spot activity. Detailed discussions of these deposits follow.

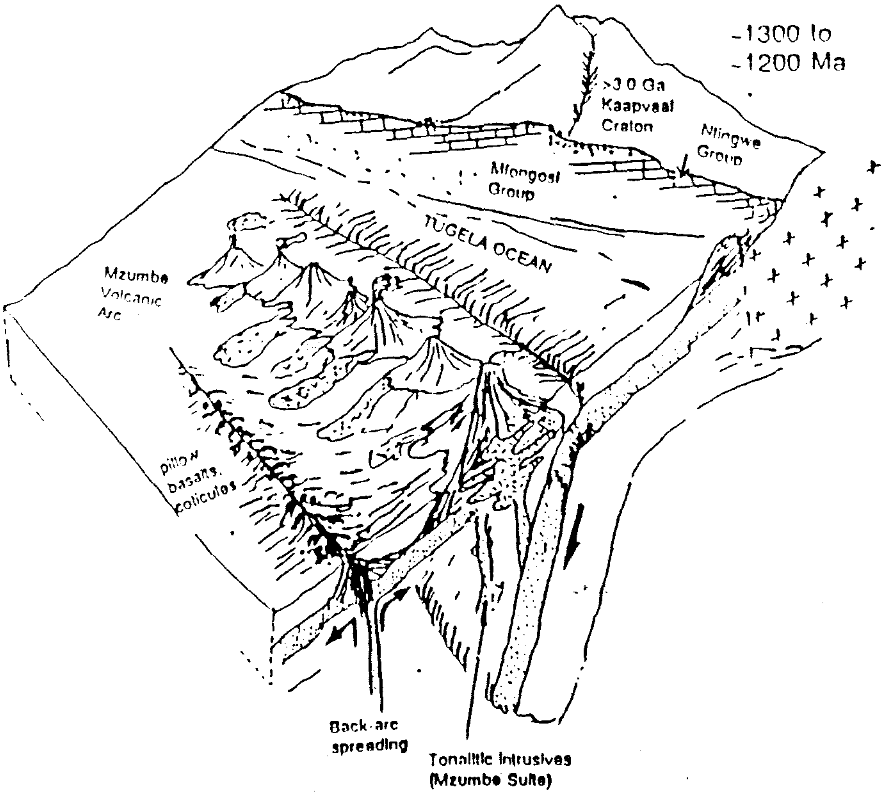


Fig. 5.8: Early stages in the development of the NMP terranes (after Cornell et al., 1996).The southern margin of the craton is considered to have been a long-lived transform fault, that was initiated in the Late Archaean (Matthews, 1990).It is also uncertain how much structural reworking occurred along the southern margin of the craton.

The NMP terranes were later deformed and metamorphosed during north-easterly directed accretion onto the southern margin of the Kaapvaal Craton. Collision-related crustal thickening is then thought to have resulted in the generation of syn- to late-tectonic granitic magmas. Magmatic fluids emanating from these magmas at shallow crustal levels could have resulted in the formation of pegmatites and epithermal vein deposits. Later isostatic adjustments of the terranes may have reactivated major shear zones which provided the conduits for late mineralising fluids which formed precious metal vein deposits (Thomas et al., 1994b).

5.2.1.1. **Magmatic Segregations**

The Tugela Rand Layered Suite (TRLS) and Mambula Complex are considered to be the products of alkali basalt magmatism due to hot-spot activity at ~ 1200 Ma (Wilson, 1990), i.e. prior to the main phase of deformation and metamorphism in the NMP. According to Eales et al. (1988) the geochemistry of the TRLS magmas shows affinities to an alkali basalt with emplacement occurring in an oceanic intraplate-type setting. The Fe-rich Mambula Complex contains similar lithological and textural characteristics to the TRLS and is considered to be a more evolved analogue that resulted from differentiation of a magma of similar overall composition (Eales et al., 1988). The TRLS contains small, irregular, low grade chromite ore bodies. However, recent investigations revealed disseminated Cu, Ni and Co sulphides within the lowermost pyroxenitic and peridotitic rocks (Thomas et al., 1990a). The Mambula Complex contains considerable amounts of Fe-Ti and V mineralisation.

The Sithilo and Sebenzani Complexes are thought to represent a segment of lower oceanic crust that was emplaced along, or adjacent to, thrust zones during obduction of the northern margin of the NMP onto the Kaapvaal craton (Matthews, 1972; Thomas et al., 1990a). Although a complete ophiolite sequence is not developed, Wuth and Archer (1986) considered the Sithilo Complex to be a Precambrian equivalent of the alpine-type, ophiolitic, podiform chromite deposits such as those found in Turkey, Cyprus and the Phillippines. Initial concentration of the chromite is attributed to primary magmatic differentiation within the oceanic crust which initially localised and concentrated the mineralisation (Wuth and Archer, 1986). The minor Cu-Ni occurrences at Sebenzani are also associated with the thrust-related alpine-type serpentinites (Thomas et al., 1994b).

5.2.1.2. Volcanogenic Exhalatives

Volcanogenic massive sulphide deposits found, for example, in Canada and Australia, are significant producers of gold, silver and base metals (Hannington and Scott, 1989; Large et al., 1989).

Volcanogenic exhalative activity in the arc-related environments in which the Tugela and Mzumbe Terranes probably formed is thought to be responsible for the massive sulphide deposits found in these terranes (Thomas et al., 1994b)(Fig. 5.8). Evidence for volcanogenic exhalative activity exists in the form of a submarine-exhalative massive sulphide deposit (the i'Thuma massive sulphides - see section 4.1.2.1) in the Tugela Terrane (Thomas et al., 1990a) and a small (subeconomic) Besshi-type Cu- Zn rich volcanogenic massive sulphide body in gneisses of the Quha Formation in the Lilani Valley (Thomas et al., 1995b). Stratiform tungsten deposits of possible volcanogenic origin (Scogings, 1984) are also reported from northern KwaZulu-Natal in lithologies equated with the Quha Formation.

The origin of the Quha Formation has recently been the subject of a detailed investigation by Cornell et al. (1996). Evidence points to the Quha Formation to have been formed near a back-arc spreading centre (Fig. 5.8) at ~1300 Ma, which is broadly coeval with that of the Copperton Formation in the Areachap Terrane of the Namaqua Province. The latter Terrane was also thought to have formed in a similar environment. A similar structural history (both were accreted onto stable cratonic regions) (Jacobs et al., 1993), as well as lithological and mineralogical similarities are found between the two formations. The Areachap Group has been extensively explored and was found to host two economic Zn-Cu deposits, which were mined, and several other subeconomic prospects.

Although no detailed prospecting has been reported from KwaZulu-Natal, Cornell et al. (1996) report the presence of garnetiferous quartzites or coticules, containing elevated Cu, Ni and Mo values, within the gneisses of the Quha Formation. These coticules are considered to have been formed as cherty chemical sediments in a volcanic-exhalative environment, and may point to the presence of ore-forming environments within the Quha Formation. Cornell et al. (1996) considered it likely that Besshi-type massive sulphide Cu-Zn deposits could be present in the back-arc basin environment where the Quha gneisses originated.

Submarine volcanogenic activity associated with mineral deposit formation on the modern ocean floor can provide important clues as to mineralisation within the ancient terranes (such as the NMP), as they are thought to be products of the same geological and geochemical processes. The following discussion is based on current studies of modern ore-forming processes on the sea floor in various tectonic settings (e.g. mid-ocean ridges and back-arc rifts) as reviewed by Herzig and Hannington (1995), Hannington and Scott (1989) and Large et al. (1989).

In an analogous situation to the early stages of the formation of the NMP terranes, modern sulphide formation within spreading centres in back-arc basins formed volcanic-hosted and sediment-hosted deposits as a consequence of seawater circulation in the volcanic basement. The heat source related to the formation of these deposits includes submarine volcanoes occurring along or close to the axis of oceanic rift zones and intraplate hot-spots and island-arc related seamounts.

Almost identical ore-forming processes are found to occur within various tectonic settings. However, the composition of the underlying volcanic rocks, which vary from mid-ocean ridge basalts to calc-alkaline felsic lavas (such as andesites and rhyolites) causes major variations in the mineral compositions and metal-enrichments in the sulphide deposits formed. According to Herzig and Hannington (1995), polymetallic sulphide mineralisation forming in back-arc environments commonly contains sphalerite as the dominant sulphide, while visible primary gold has also been documented in low-temperature white smoker chimneys from this environment. These environments also contain elevated Ag, Cu and Ba element concentrations, when compared to deposits forming at some mid-ocean ridge deposits.

Ultimately, the concentration of minerals in specific deposits will depend on source-rock geochemistry, which controls the composition of the hydrothermal fluids and their ability to carry gold (Herzig and Hannington, 1995). Other factors, such as temperature, pH and oxygen fugacity control the mineralogical associations in the fluids. Large et al. (1989) concluded that a gold-copper association reflects Au being mobilised as a $AuCl_2^-$ complex from high temperature (above 300°C), low pH (<4.5), moderate to high fO_2, high salinity fluids, while the gold-zinc association implies Au transport as the $Au(HS)_2^-$ complex from lower temperature

(200-250°C), moderate pH (4.5-6), and moderate fO_2 fluids. These associations may be present within different zones within the same deposit, e.g. at i'Thuma, where the Au-Zn association occurs in the upper parts of the deposit, while the footwall stringer zone is characterised by the Au-Cu association (Thomas et al., 1990a).

A typical modern seafloor sulphide deposit is shown in Fig. 5.9. According to Herzig and Hannington (1995), these typically consist of a consolidated basal sulphide mound which

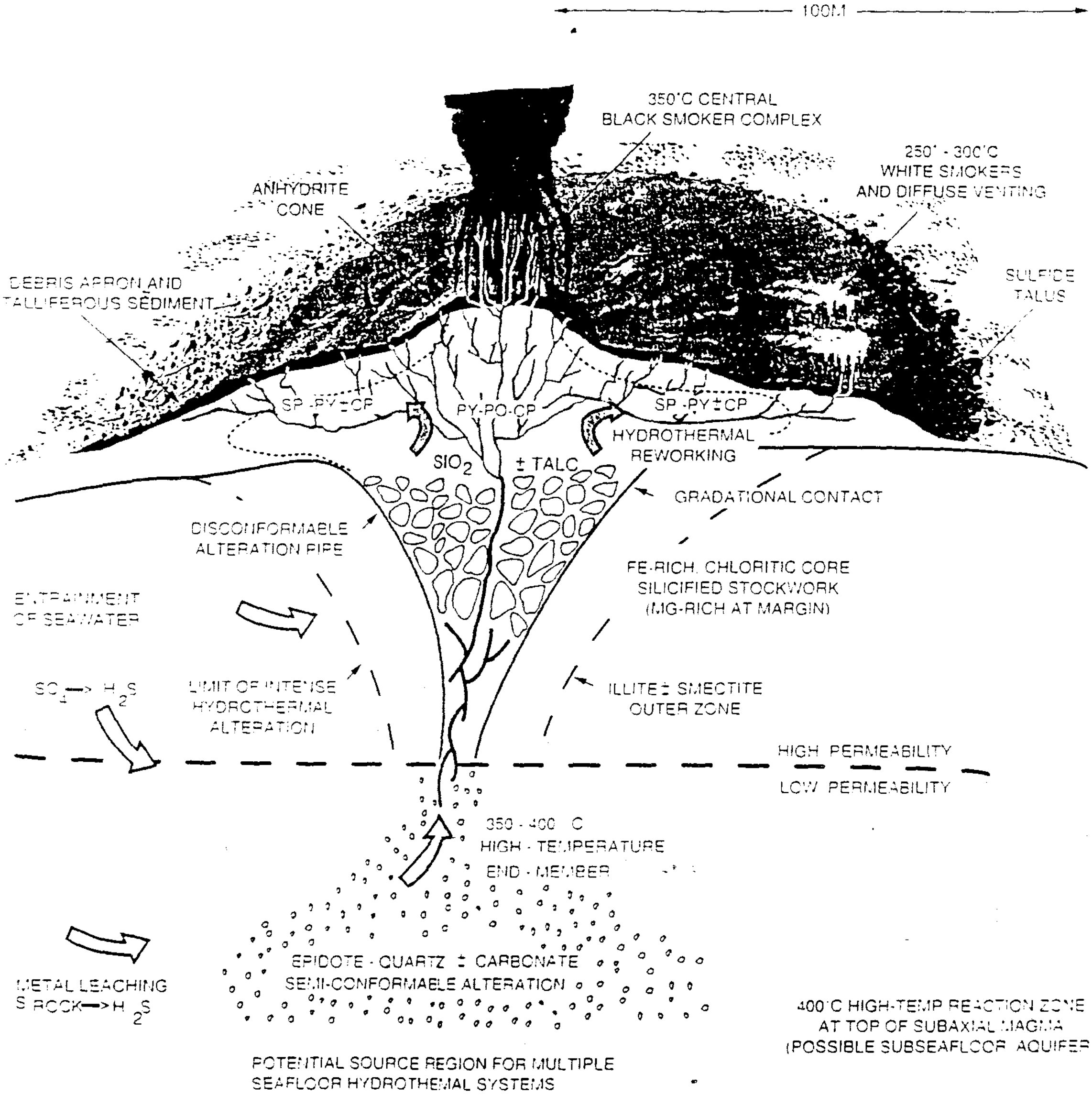


Fig. 4.9: Cross-section of a modern seafloor hydrothermal system, showing the principal components (after Herzig and Hannington, 1995).

overlies a sub-seafloor stockwork. Abundant chimney structures (high-temperature black smokers and lower-temperature white smokers), hydrothermal crusts, metalliferous sediments and accumulations of sulphide talus and debris occur in the upper parts of the deposit. Hydrothermal fluids circulating through the sulphide pile increase the size of the mound, and causes recrystallisation of the sulphide minerals.

5.2.1.3. **Granite-related Deposits**

5.2.1.3.1. **Alkaline Granites**

Sub-economic enrichments of REE, Zr, Nb and Y occur within peralkaline granitic gneisses and carbonatites within the Tugela Terrane (Thomas et al., 1994b). Limited hot-spot activity in the Tugela Ocean led to localised tensional tectonics and resulted in the production of peralkaline granitoids and associated mineralisation (Thomas et al., 1990a). Scogings (1989a) interpreted the peralkaline siliceous gneisses with anomalous REE, Zr, Nb and Zn concentrations, to be magmatically concentrated cumulate layers.

These granites were generated immediately to the south of the Kaapvaal Craton margin in an anorogenic tectonic environment (Scogings, 1986), and were thrusted northward during obduction. This alkaline-type mineralisation is confined to the lowermost structural unit of the nappe zone, the Nkomo Nappe.

5.2.1.3.2. **Li-bearing Pegmatites**

The only economically important pegmatites yet discovered within the NMP are intrusive into the high-grade mafic gneisses of the Mucklebraes Formation (Margate Terrane). These spodumene-rich, leucocratic pegmatites are thought to represent late-stage differentiates of the anhydrous garnet leucogranites and charnockites of the syntectonic Margate Granite Suite, and crystallised from relatively high-temperature, volatile-poor liquids under conditions of low fH_2O and low fO_2 (Thomas et al., 1995b). The lithium is considered to have been scavenged from Li-enriched metasediments of the Margate Terrane during anatexis. The pegmatites crystallised primary petalite which formed symplectic spodumene-quartz intergrowths on near-isobaric cooling (Thomas et al., 1994a).

5.2.1.4. **Epigenetic Deposits**

Epigenetic, quartz vein-hosted gold occurrences have been located within the greenschist facies Tugela Terrane and amphibolite facies Mzumbe Terrane. The final location of the mineralisation in all occurrences is structurally controlled due to the northeast-directed thrusting events, being disseminated in sheared host lithologies and quartz-sulphide vein arrays. Final deposition of the mineralisation thus occurred late in the structural history of the NMP. High grades of metamorphism, due to the intrusion of abundant granitoids in the Mzumbe and Margate Terranes, are considered to have had a detrimental effect on the concentration of mineralisation in the southern parts of the NMP (Thomas et al., 1990a).

The shear-zone-related precious metals in the Tugela Terrane may have been derived from a number of possible sources (Thomas et al., 1990a; 1994b). As the schistose host rocks represent metalavas and passive margin-type sediments that were deposited in the oceanic basin (Tugela Ocean) close to the southern margin of the Kaapvaal Craton, local volcanogenic exhalative processes and the voluminous basic metalavas constitute possible original source rocks for the mineralisation. In addition, the greenstones of the Kaapvaal Craton which underlie the thrust front are thought to be another possible source of gold. Seawater and fluids derived from metamorphic dewatering may have then leached the precious metals from the source rocks before being transported along syntectonic thrust planes during obduction (Thomas et al., 1990a).

Mineralisation in the arc-related Mzumbe Terrane is hosted in amphibolite grade felsic (probably acid volcanic) gneisses of the Ndonyane Formation and associated syntectonic granite gneisses of the Mzimlilo Suite (Thomas and Gain, 1989). The gold in this terrane was mobilized during the NMP accretionary event and concentrated in the shear zones under favourable precipitation conditions (as discussed for the lode gold deposits). The source of the gold in the Mzumbe Terrane is postulated to be the acid igneous gneisses. Mineralisation is associated with sulphides and appears disseminated in the sheared host rocks and in *en echelon* quartz vein arrays that developed within wide, sinistral transcurrent shear zones associated with the major Jolivet Shear.

CHAPTER SIX

6. SUMMARY AND CONCLUSIONS

The mineral deposits within the study area occur in host rocks that range in age from Archaean to Recent. Only the Precambrian deposits have been analyzed as these are most interesting from a metallogenic point of view.

Various styles of mineralisation occur in the study area. The genesis of the mineralisation is generally consistent with models proposed for the evolution of the host terranes. In some cases, the different terranes were found to host similar styles of mineralisation, but with widely varying ages in the mineralising episodes. The ~ 3.6 Ga Archaean granite-greenstone terranes for example, contain structurally-hosted lode-gold mineralisation, in common with the Late Archaean (~ 3 Ga) Pongola Supergroup and the (~ 1.1 Ga) Natal Metamorphic Province (NMP). Volcanogenic massive sulphides are also found in the Archaean Nondweni Group and the NMP. Similar processes are evoked for the formation of the deposits although the host rocks and tectonic evolution paths of the different terranes vary.

A brief summary of the most important genetic types of mineralisation in the various terranes is provided here, to give the reader a broad overview of the Precambrian metallogeny of KwaZulu-Natal. A discussion of the mineral potential of KwaZulu-Natal and a short overview of the benefits of metallogenic mapping follows.

6.1. The Granite-Greenstone Terrane

Numerous small gold deposits have been worked from the Archaean greenstones that outcrop in northern KwaZulu-Natal. These contain many characteristics common to lode-gold deposits found in Archaean granite-greenstone terranes in other parts of the world. The deposits are considered to be intimately linked to nearby late-tectonic intrusive bodies. According to Versfeld (1988) and Bullen (1991), these intrusives are thought to have provided the heat source and created the structures necessary for the passage of deeply-sourced auriferous fluids. These fluids then deposited Au in structurally and lithologically favourable sites. The number and size of mineral deposits in individual terranes is largely considered to be related to the efficiency of this mineralising system.

The Nondweni greenstones also contain volcanic-related massive sulphide deposits rich in Cu-Zn mineralisation. These were formed due to localised sub-aqueous felsic eruptive centres during the evolution of the greenstones. The original deposits were then deformed and are now structurally-hosted.

6.2. **The Pongola Supergroup**

6.2.1. **Placer Deposits**

Showings of gold mineralisation within conglomerates of the Pongola Supergroup have been known since the early parts of the century, however no significant economic mineralisation is evident as yet. The Pongola basin and richly mineralised Witwatersrand basin are of similar age and lie in close-proximity on the Kaapvaal craton, which would suggest that potential rich placer deposits may exist.

6.2.2. **Lode Gold Deposits**

The only working gold mine in KwaZulu-Natal is hosted by the metasediments of the Mozaan Group of the Pongola Supergroup. Numerous other small prospects have also been investigated in the vicinity. These deposits are hosted mainly in quartz veins and show characteristics typical of mesothermal gold deposits. The mineralisation is located adjacent to major structural discontinuities and probably formed under similar conditions to the lode gold deposits found in the granite-greenstones.

6.3. **The Natal Metamorphic Province**

This high-grade tectonomorphic terrane is host to numerous types of mineralisation. The Tugela Terrane in the north contains most of the mineralisation, while the terranes to the south (the Mzumbe and Margate Terranes) are relatively poorly mineralised. The various genetic types of mineralisation correspond to the tectonic evolution model proposed for the NMP (Thomas et al., 1990a). Parts of the Tugela Terrane have been interpreted as an ophiolite complex that accumulated in an oceanic basin to the south of the Kaapvaal craton. This oceanic basin was subject to rifting, sea-floor spreading and limited hot-spot activity. The Mzumbe and Margate terranes have been interpreted as volcanic arcs that developed in response to subduction of the Tugela Ocean. The final location of all the mineralisation within the NMP is structurally controlled, as the terranes have been intensely deformed after their formation.

6.3.1. **Magmatic Segregation Deposits and Ophiolites**

Hot-spot activity in the Tugela Ocean gave rise to alkali basalt magmatism which formed the Tugela Rand and Mambula intrusive complexes. Obduction of the Tugela ophiolites due to north-directed thrusting was accompanied by the emplacement of mineralised alpine-type serpentinites (Sithilo and Sebenzani Complexes) along major structural discontinuities.

6.3.2. **Volcanogenic Exhalations**

Volcanic-arc activity in back-arc basins gave rise to the volcanic exhalative sulphide deposits of the Tugela and Mzumbe Terranes. According to Thomas et al. (1990a), limited sea-floor spreading in the Tugela Ocean gave rise to tholeiitic lavas. Volcanogenic exhalations on the ocean floor close to spreading centres then probably gave rise to the i'Thuma massive to semi-massive sulphide mineralisation. The mineralisation was then thrust northward during the obduction episode to its present location.

The Quha Formation of the Mzumbe Terrane also shows evidence of volcanic exhalative processes and is considered to host Besshi-type massive sulphide Cu-Zn mineralisation. The back-arc basin environment in which the Quha Formation gneisses are considered to have formed and the presence of siliceous coticule point to potential base metal mineralisation. Similarities between the Quha Formation and the Copperton Formation in the Namaqua Metamorphic Province, which has been extensively explored and contains many mineralised prospects, may also encourage further exploration in KwaZulu-Natal.

6.3.3. **Granite-related Deposits**

These consist of peralkaline granitoids which formed in an anorogenic environment in the Tugela Terrane and pegmatite deposits that are related to the collision event. These granitoids contain magmatically concentrated cumulate layers enriched in REE, Zr, Nb and Zn. The rocks were obducted onto the craton and are confined to the lowermost nappe structure.

Spodumene-rich pegmatites derived from the syntectonic Margate Granite Suite contain economic quantities of lithium. Anatectic melting of country rocks rich in lithium are proposed to be the source of the metal.

6.3.4. **Epigenetic Deposits**

Epigenetic, lode gold deposits related to shear zones occur in the Mzumbe and Margate Terranes. The source of metals in the Tugela Terrane have been attributed to the host basic metalavas and underlying greenstone remnants of the Kaapvaal Craton. Interaction with seawater and fluids derived from metamorphic dewatering resulted in leaching of precious metals from the source rocks. These fluids were then carried to their depositional sites by thrusting during obduction. The gold in the Mzumbe Terrane was likely to have been derived from acid igneous intrusives and concentrated in favourable lithological and structural sites by metamorphic and magmatic fluids during deformation.

6.4 THE MINERAL POTENTIAL OF KWAZULU-NATAL

Vast areas of this Province remain unexplored for various reasons, including poor outcrop, deep weathering, inaccessible terrane, population density and poor infrastructure. The following discussion considers areas already known to have mineralisation, and possible extensions to these deposits. The economically important heavy mineral sands deposits are also mentioned.

* The terranes to the north have abundant potential with regards to gold mineralisation.
An ore genesis model proposed by Bullen (1990) for the Melmoth granite greenstones revealed

that other small, shear zone-hosted Au deposits may exist in this remnant and other greenstone inliers in northern KwaZulu-Natal. He suggested that the major shear zone with which these deposits are associated is of considerable extent and should be delineated (westwards) by means of drilling and geophysical methods, in order to locate other shear zones of the same age as those which host the mineralisation. Further, the older workings in the area should be sampled for extensions to the mineralisation at depth. Smaller deposits that still contain mineralisation may prove viable only for small-scale exploitation by private entrepreneurs.

* Many quartz vein hosted prospects in Pongola metasediments have potential for small-scale exploitation. Many of these were sampled by mining companies and found to be uneconomic. However, small-scale exploitation may prove to be viable. In addition, the Klipwal gold mine, which exploits shear zone-hosted gold within the Mozaan Group metasediments, is currently the only working gold mine in KwaZulu-Natal.

* Ongoing research with regards to the Witwatersrand - Pongola lithological correlations are also interesting and some target areas may prove to be of more than academic importance. Recently Beukes and Cairncross (1991) provided detailed correlations of the Mozaan Group and Witwatersrand Supergroup, which contains highly economic placer gold deposits, and found many lithostratigraphic and palaeoenvironmental similarities. These workers suggested that the stratigraphically higher lithologies should be targeted for further economic studies.

* Significant portions of the Natal Metamorphic Province remain unexplored with respect to mineralisation. The Tugela Terrane of the NMP may contain additional massive sulphide deposits similar to those found at i'Thuma. From the proposed tectonic evolution model, there is a possibility that the volcanogenic processes likely to have formed the i'Thuma deposit may have occurred at similar stratigraphic levels and should be examined. The Quha Formation of the Mzumbe Terrane also shows evidence of exhalative processes and should be a target for further exploration. Recent prospecting activity in the Lilani Valley, reported by Thomas et al. (1995b), revealed a sub-economic Zn-rich massive sulphide deposit in the highly deformed gneisses. Other

potential deposits may exist under younger cover. However, these deposits could also have been removed to some extent by erosion or appear to be of limited extent due to extreme structural reworking in some areas.

The NMP terranes contain numerous major structural discontinuities resulting from obduction and thrusting. As most of the mineralisation is structurally controlled, these structures may be host to further mineralisation.

These thrust and shear zones formed channels for the migration of metalliferous fluids from depth, and also for the emplacement of mineralised, alpine-type ultramafic intrusives (Thomas et al., 1990a). Layered intrusions such as the Mambula Complex and Tugela Rand Layered Suite were formed before being thrusted and emplaced at their present locations in the nappe zone. The lower parts of these intrusions may possibly be preserved in other areas within the nappe zone.

* The gold deposits of the Mzumbe Terrane (Umzinto Goldfield) are also considered to have further potential as only a relatively small portion of the shear zone hosting the mineralisation has been explored along strike (Thomas and Gain, 1989). In addition, the poorly exposed Melville Thrust is considered to have potential with regards to metalliferous mineralisation (Thomas et al., 1990a).

* Industrial mineral deposits within the NMP comprise the important Marble Delta limestone deposits in the Margate Terrane, which contains considerable reserves of lime to supply the country's needs for the foreseeable future. Dolomites of the Ntingwe Group of the Tugela Terrane may represent a future resource of lime for local farming projects, while the extensive talc deposits may have potential in the fillers market (Bullen et al., 1992). In addition, the Bull's Run and Ngoye Complexes have abundant reserves of nepheline and feldspar for use in the glass-making industry.

Industrial mineral deposits derived from these older lithologies also provide considerable exploitation potential. Weathered Proterozoic granites of the Mzumbe Terrane have been investigated for their kaolin potential with favourable results. Vast quantities of eluvial feldspar associated with weathered Oribi Gorge Suite Granites are also potentially important (Bullen et al., 1992).

* The most economically exploited mineral deposits currently mined are the heavy mineral sands deposits that occur along the KwaZulu-Natal coastline in the vicinity of Richards Bay in the north. These sands, hosted in lithologies of Recent age, contain economic concentrations of rutile, ilmenite and zircon, from which titanium and zirconium are extracted. Pig iron is a useful byproduct from this operation. The geology and mineralisation of these deposits has been analyzed in Fockema (1986) and Hugo (1993). The mineralisation was found to be derived from many of the older lithologies that are found inland, such as the Karoo dolerites, NMP and the Archaean granite-greenstones, volcanics and sediments. The entire coastline of KwaZulu-Natal is known to contain potential heavy mineral sands deposits.

Further geological research and exploration is required in KwaZulu-Natal to refine the basic theories that already exist. The numerous, albeit small, precious metal deposits (many of which were discovered and worked in the early part of the century) found in the Province certainly points to a mineralised system that was active in the various host terranes. A dedicated exploration programme using every available modern exploration technique will surely mean more economic precious metal discoveries in KwaZulu-Natal.

6.5. THE BENEFITS OF METALLOGENIC MAPPING

Metallogenic maps provide concise information on the mineralisation and depositional environments of the host lithologies in the areas under investigation. Documentation of the field characteristics of various deposits enables possible genetic interpretations of the host terranes to aid in the exploration of potential mineralisation in analogous environments. However, even if genetic interpretations prove to be incorrect, metallogenic maps contain the known characteristics of the mineralisation under investigation and provides a basis for further investigations.

The maps are also useful for land-use information, in that potential areas are not sterilized before exploitation. With the advent of the ORACLE programme, these maps can now be digitally enhanced and customised, and also produced in digital format. Maps may be produced on various scales and specific requirements are easily catered for. However, all the information must first be compiled using the basic metallogenic mapping function, which is documentation of observed geological characteristics.

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