GEOCHEMICAL AND STABLE ISOTOPE STUDIES OF GOLD BEARING GRANITOIDS IN THE MURCHISON SCHIST BELT NORTH EASTERN TRANSVAAL

SEAN WAUGH KEDDA

A Dissertation Submitted to the Faculty of Science
University of the Witwatersrand, Johannesburg
for the Degree of Master of Science

Johannesburg, 1992

DECLARATION

I declare that this dissertation is my own, unaided work.
It is being submitted for the degree of Master of Science from the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

Sean Keadle

(Name of candidate)

23 day of September 1992

ABSTRACT

Gold-antimony mineralization within the Murchison schist belt is intimately related to intrusive granodiorites which have intruded sporadically along major structural discontinuities. The most important of these, the Antimony Line, appears to have been intruded at depth by a granodiorite of batholithic dimensions. Some of these intrusions exhibit varying degrees of sodium metasomatism and gold mineralization within their cupula zones, resulting in the formation of albitites. Mineralization within the intrusions is characterised by a Be-Mo-Sb-Au-W-B-S paragenesis, precipitated mainly between 250 °C and 350°C. Light stable isotope and fluid inclusion data indicate fluid homogeneity on a regional scale, with evidence of phase separation on a local scale. Regional sea water alteration is precluded as a source of the carbonate in the mineralizing event and an external, juvenile source for the mineralizing fluids is proposed. The Antimony Line mineralization shows distinct isotopic similarities to the mineralization in the albitized intrusions. This study indicates that the granodiorite intrusions, and their albitized cupolas, are genetically linked to hydrothermal activity and mineralization within the Antimony Line.

TABLE OF CONTENTS

Chapter 4
GEOCHEMISTRY

Chapter 5
STABLE ISOTOPE GEOCHEMISTRY

Acknowledgements

I would like to thank Golden Dumps Limited for all their assistance while I was completing this project, especially for the accommodation at GEM and for access to their mines. Phelps Dodge (Pty) Ltd and Anglovaal (Pty) Ltd are also thanked for permitting access to the core from the Malati Store and Minerva mine, respectively. I would like to thank Lyn Witfield for all her assistance with the diagrams and I would also like to express my gratitude to Carl Anhausser and EGRU for their financial assistance. Finally, I would like to thank Mary-Anne for all her help and support during this period.

List of Figures

List of Plates

List of Tables

CHAPTER 1
Introduction

1.0 Introductory Statement

The Archaean Murchison Range is well known as a major producer of antimony and gold and contains the largest antimony producing mine in the world. The southern margin of the belt also produced significant quantities of emeralds which are associated with small intrusive felsic bodies and associated pegmatites and also contains several small to medium size quartz-lode gold deposits, which often show a close relationship to the late intrusive Archaean granitoids (Van Eeden *et al.*, 1939 and Vearncombe *et al.*, in press). The Murchison schist belt has been intruded by numerous syn- to post-kinematic intrusions, predominantly of granodiorite composition, especially along the major linear structural discontinuity known as the "Antimony Line". The presence of albite rich, granite-like bodies, commonly spatially related to antimony-gold mineralization, is a distinctive feature of the Murchison schist belt (Boese, 1964). These albite rich rocks have previously been referred to as albitites by Pearton (1980), who proposed a metamorphic lateral secretion process for their origin. The granodiorite intrusions themselves are often found to be affected by varying degrees of sodium metasomatism (albitization) within the cupula zones and are sporadically mineralized with auriferous pyrite and minor antimony and molybdenite. These albitites of the Murchison schist belt have formed the basis of this study. The albitized granodiorites have a variable chemical nature as a result of hydrothermal alteration, and are referred to as "granitoids" in the general sense for the purpose of this study.

The hydrothermal alteration is characterised by sodium alteration, resulting in the formation of and replacement by albite of pre-existing magmatic minerals and the systematic leaching of quartz. Pyrite mineralization, with minor arsenopyrite, gold, antimony, molybdenite, tetrahedrite, chalcopyrite, tourmaline and beryl, occurs sporadically disseminated within the albitized bodies. Auriferous pyrite bodies are occasionally developed along the contact with the intrusions and these may contain spectacular gold grades. The objectives of this investigation are to document and interpret the petrography, geochemistry, light stable isotopes and the fluid characteristics responsible for albitization and mineralization, within three granodiorite intrusions selected for detailed study. Another major objective was to test the idea that the albite rich rocks of the Murchison schist belt are the product of sodium alteration of the granodiorite intrusions rather than of lateral secretion processes.

Boese (1964), proposed the name "beresite" for albite-rich granitic-like bodies which are common in the Murchison schist belt. The term "beresites" is commonly used by U.S.S.R geologists for granitic rocks which have been heavily sericitized, albitized and impregnated with pyrite. Generally the rocks are enriched in K, Ca and CO_2 and depleted in Na and Mg. Troger (1935), described a beresite as "an aplitic muscovite granite in which orthoclase has been autometasomatically altered to muscovite". The rocks in question in the Murchison schist belt comprise up to 90% albite, with the remainder consisting of minor quartz, orthoclase, *occasional* muscovite and disseminated auriferous pyrite and are enriched in Na. On the basis of the disparity between beresites and the rocks of the Murchison schist belt Pearton (1980), proposed the term "albitite" to describe these albite-rich rocks. An *albitite* is defined as a porphyritic igneous rock consisting predominantly of albite (Gary *et al.*, 1974). The name albitite is commonly used for the rock type in the U.S.S.R and eastern Europe. The process of *albitization* represents the development of albite at the expense of pre-existing feldspars, by the introduction of sodium and removal of potassium by aqueous fluids, it may also be referred to as sodium silicate alteration (Siems, 1984). In this study the term albitite is used to described altered parental granitoid material consisting of more than 70% albite.

The relevant terminology applied to late magmatic alteration is defined for clarity. *Deuteric* reactions refer specifically to reactions between primary magmatic minerals and water rich solutions that separate from the same body of magma at a late stage in the cooling history. These reactions thus apply to alteration of an igneous rock by its own residual fluids (Tyrrell 1926), and do not apply to alteration of a secondary nature which may be related to solutions of an extraneous nature. As the process of albitization is essentially an open system at lower temperatures, the deuterically derived fluids may be affected by fluids of an extraneous origin.

The Archaean Murchison schist belt is situated in the north-eastern Transvaal, between the Drakensburg escarpment to the east, and the Kruger National Park to the west (Figure. 1.1), 190 kilometres north of the well known Barberton greenstone belt. The schist belt takes the form of an isoclinally folded, narrow, elongated sequence of volcanic and sedimentary rocks which have been intruded by Archaean granites and gneisses. The schist belt is approximately 140 km long and has a maximum width of 15 km near the town of Leydsdorp (Figure 1.2). The east-north-east striking belt partially defines a major crustal east-north-east trending lineament (the Murchison lineament) which extends across most of the Transvaal.

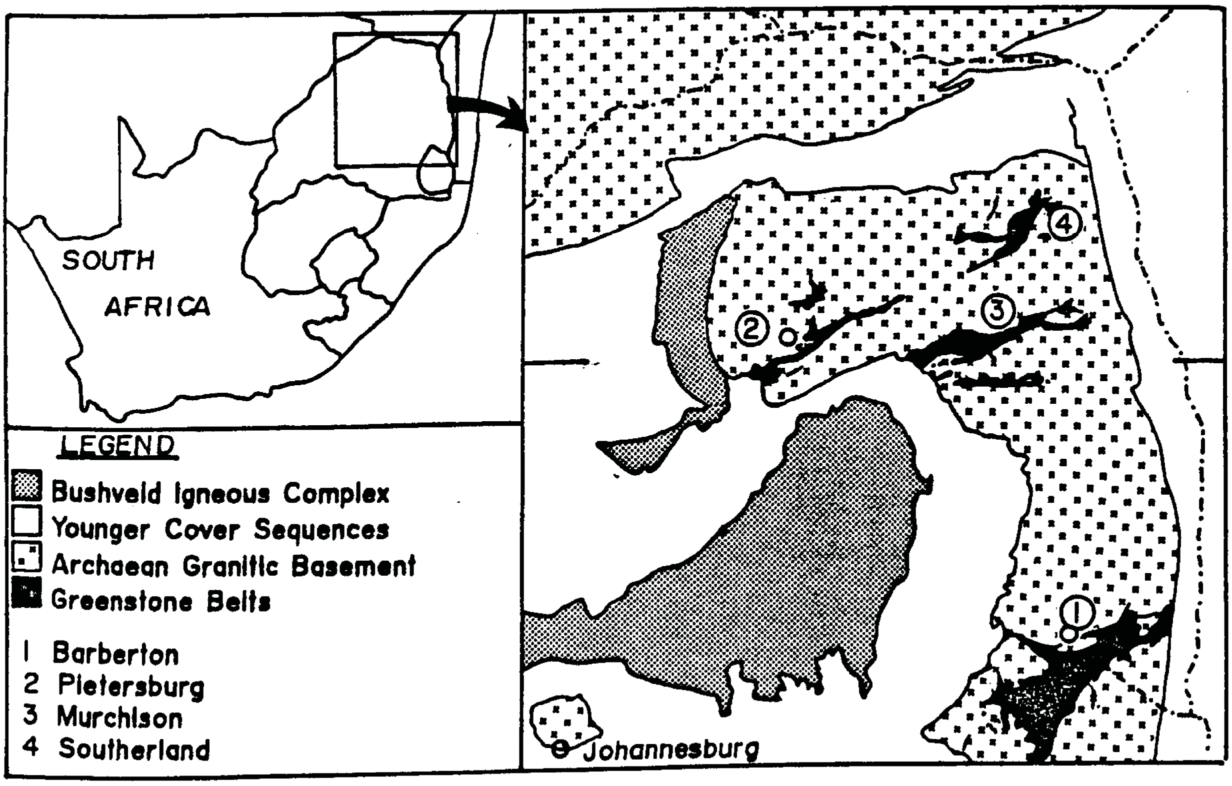

Figure 1.1. The location of the Murchison schist belt relative to other Archaean greenstone belts

The location of the three granitoids under consideration is shown in Figure 1.2. The Malati Store mine is 15 km along the Letaba road from the Consolidated Murchison Mine, near the old Mulati Post Office. This intrusion is situated on the Antimony Line, approximately two kilometre east of Antimony Kop. The cupola zone is exposed within a quarry and is presently being exploited for its gold content. The intrusion has been drilled by Phelps Dodge (Ltd) to evaluate its economic potential. This evaluation provided fresh material for this study, as well as providing information on the dimensions of the intrusion.

The Discovery Shaft intrusion is situated within the Gravelotte Emerald Mine (GEM) in the Discovery open-cast emerald mine (Figure 1.2). The body is only partially exposed on the surface but is well exposed within the Discovery Shaft gold mine which was developed to exploit a spatially related auriferous pyritic schist. Material for this study was provided from underground development and exploration diamond drilling.

The Minerva Mine intrusion is situated 15 km along the Harmony road from Gravelotte town. The intrusion is poorly exposed on the surface and its actual dimensions are not well constrained due to thick soil cover. A surface drilling program by Anglo Vaal (Ltd) designed to examine the Minerva mine at depth, intersected two granitoids. One of these granitoids consists of a hydrothermally altered albite rich rock which contains disseminated auriferous pyrite. The other is an unaltered garnet-muscovite bearing granodiorite.

1.2. Geography

1.2.1. Topography

The geographical features of the study area has been well documented by Wellington (1955). The Murchison schist belt forms a prominent topographic feature in the generally low, undulating Transvaal lowveld. The central Murchison schist belt is highly conspicuous due to the presence of resistant quartz-carbonate rocks, quartzites and ironstones. These lose their significance towards the east where they form low, isolated koppies.

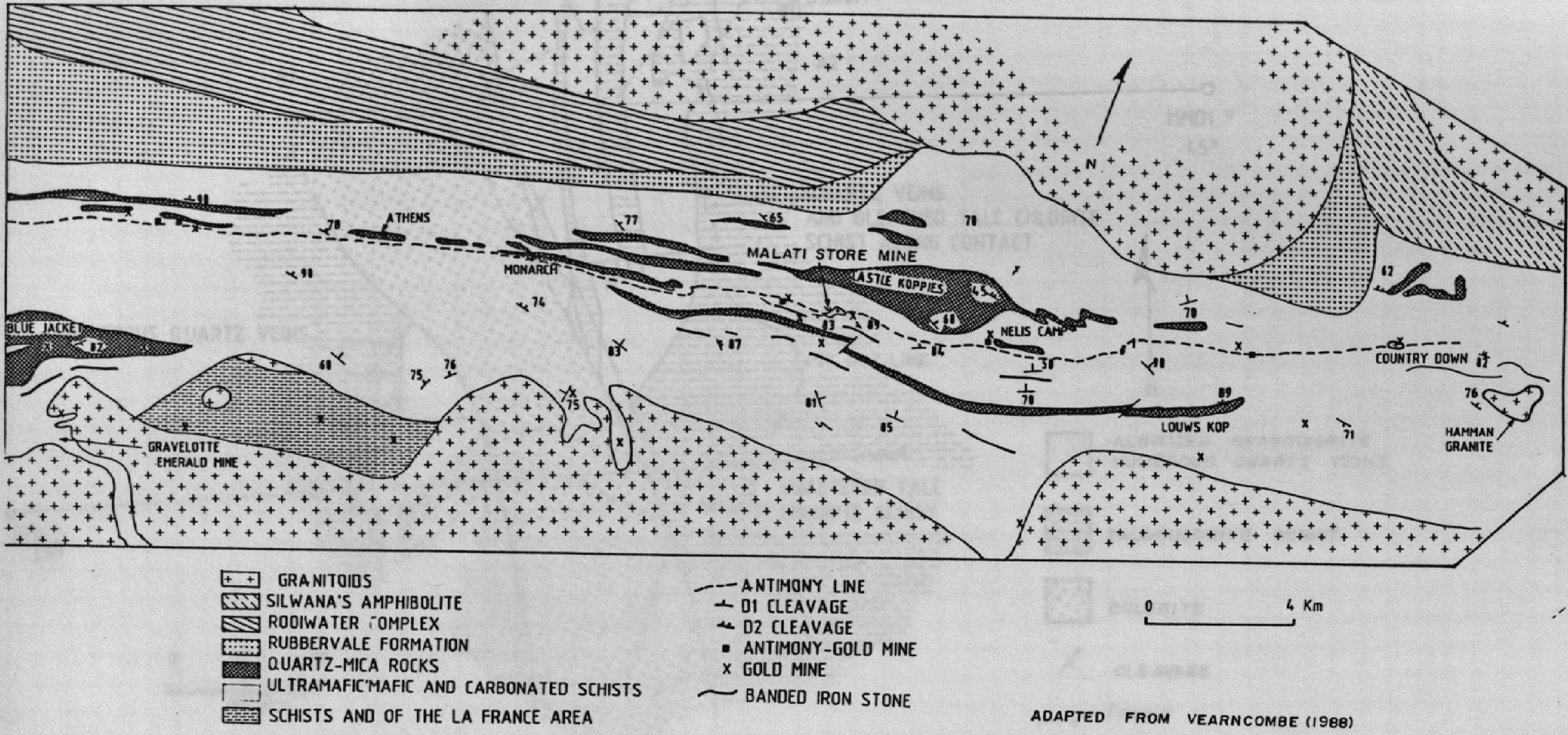

Figure 2.1. GEOLOGICAL MAP OF THE EASTERN PORTION OF THE ANTIMONY LINE

SHOWING THE LOCATION OF THE MALATI STORE MINE AND GEM.

The most prominent feature in the area is the Antimony Line, formed from the resistant quartz-carbonate rocks which dominate this linear feature. From the central portion of the schist belt, toward the east, two separate quartzite ridges are prominent - the Castle Koppies Bar, to the north of the Antimony Line, and the Louws Kop Bar, to the south.

The Mulati river is the major tributary of the area and drains into the Selati River which is the major regional outlet (Figure. 1.2) This river is usually flowing and provides water to most of the Murchison mines and the town of Gravelotte.

1.2.2. Climate

The study area is located in the Lowveld and is typified by a warm climate, varying from a maximum in January of 38°C to a mean minimum of 17°C in July. Rain generally occurs between November and March and is usually highly erratic and torrential. Summers are usually hot and humid, while the winters are generally cool and dry.

1.2.3. Vegetation

Rapid changes in the vegetation occur over the area, largely determined by the soil type, which often accumulates to a thickness, of 6 meters or more in low lying areas. Mopani veld is the dominant species in the low lying areas, especially over the surrounding granitoids.

1.3. Historical Review

Although the present day mineral exploitation is orientated toward the extraction of antimony, with gold as a by-product, the earliest exploitation of minerals was for copper by the ancients who exploited the deposits of the "Copper-Zinc Line". Modern geological exploration commenced when Button and Sutherland travelled north from the Transvaal in search of the metal in 1869 and found alluvial gold in the Selati river (Baines, 1877). On returning to the area in June 1870, they named the hills of the area as the Murchison Range, after Sir Roderick T. Murchison, a geologist who had predicted that gold would be found in the area after the discovery of alluvial gold in the Oliphants river, 30 km south of the Murchison Range.

In the wake of subsequent promising discoveries at Eersteling (1871), Pilgrims Rest (1872) and Kaapsehoop (1874), the Murchison Range did not receive much attention until later when poor results in other goldfields forced diggers to look further afield. In 1888, "French Bob" of Barberton fame, started what was to be known as the Leydsdorp gold rush which resulted in numerous claims being pegged, many of them indiscriminately. In October 1888, the ground held by the government was proclaimed a public gold field and the town of Leydsdorp was established in 1890, named after Dr. Laydes, then State Secretary.

The gold rush was short lived, due to numerous problems, including poor mining practice, malaria, lack of financial backing and the lack of surface water (the nearest being the Selati River, 8 km to the south). By 1891 only 45 of the original 6000 claims were being worked, although several larger mining syndicates did operate viable, usually by mining various reefs simultaneously.

Stibnite bearing reefs along the Antimony Line were originally worked for their gold content, but the antimony minerals rendered the ore difficult to process, resulting in only minor exploitation. A small amount of antimony was produced as a by-product of gold extraction in the early 1900's. The post World War I years saw development in the mining of antimony and further technical developments in the 1920's and 30's allowed more efficient extraction of both gold and antimony. The strategic importance of antimony was fully realized at the onset of Word War II, resulting in rapid expansion of antimony production, and the formation of the Consolidated Murchison Gold Fields and Development Company, which was concerned with producing antimony, with gold as a by-product. By the 1950's the antimony concentrate production amounted to 13 195 tons and gold production to 339 kg. Peak antimony concentrate production occurred in 1969 and has been declining since then. Recently, the rising price of gold and unstable antimony prices has enhanced the value of gold as a by-product and its production has steadily increased.

The history of emerald production in the Murchison Range has been thoroughly discussed by Van Eeden *et al.* (1939) and Sinkankas (1981). The first find occurred in 1927, at Somerset Hill (BVB Ranch), resulting in the formation of the Beryl Mining Company. The present day Cobra Emerald Mine (GEM) was discovered in 1929. Numerous small workings were opened but most had discontinued operations by 1939. The main production was from the Somerset mine and Cobra mine. In early 1970

Discovery quarry was opened to the south of the main Cobra mine. The BVB mine was worked until 1978, but has received little attention since then. In 1985, Golden Dumps (Proprietary) Ltd was responsible for management of the Cobra North and South and Discovery mines, the only major producing mines. In 1987 emerald operations were discontinued, due to decreasing reserves and declining quality of the gem stones.

1.3.1. Discovery Shaft Gold Mine

The Discovery Shaft mine is a recent somewhat unexpected find, although there are records of there having been gold workings at the adjacent Beryl Kop (± 1 km to the East (van Eeden *et al.*, 1939). In early August 1984, samples of gossanous material from the west of Discovery quarry, produced highly encouraging results. From October 1985, the drilling and sampling program was intensified, resulting in the development of the Discovery Shaft, sunk from the 5 level bench in the Discovery pit to exploit the auriferous pyritic schist by Golden Dumps (Pty) Ltd in April 1986. Ore evaluation delineated 25 500 tons of ore at an average grade of 13.5 g/t to approximately 150 m (Cobra Emerald Mines Limited, 1986). The auriferous pyritic schist was largely exhausted in April, 1990. Gold mining at GEM was also initiated 3 km to the north-west of the Cobra and Discovery pits at the Blue Jacket mine where there is an auriferous east-west striking quartz-carbonate vein within quartz-chlorite schists. Presently the Discovery Shaft mine is being tributed with the shaft pillars being extracted.

1.3.2. Malati Store Mine

This mine is also been known as Malati Pump, Malati Quarry, Malati Store and Castle Koppies Pump mine. For the purpose of this investigation the deposit will be referred to as Malati Store mine. This deposit is presently being exploited on a small scale for its gold content which averages 3 g/t (Present owner, per. com. and Phelps Dodge (Pty) Ltd). The mining operation utilizes a five stamp mill and is extracting weathered material, including minor quantities of apparently supergene material which facilitates the extraction of the refractory gold. However, problems are being encountered due to the refractory nature of the unweathered ore. The body was previously developed by the Murchison Exploration and Mining Company between 1934 and 1938. Van Eeden *et al.* (1939) notes that a complicated underground system had been developed to exploit the body to a depth of 75 feet but that underground developments were flooded during their visit. The deposit was referred to as a leucocratic feldspar-quartz- carbonate granite, with pyrite crystals. They noted that the gold was apparently associated with the pyrite and that the values were erratic. The Malati Mining Company leased the deposit from 1970 to 1983 with limited success. Problems included variable grade and the refractory nature of the fresh ore. The large slimes dams, however, suggest that a fairly large tonnage of material was processed from the underground operation. The shaft is presently flooded and inaccessible. Phelps Dodge (Pty) Ltd recently drilled the prospect to evaluate the intrusion. However, due to low, erratic grades and mineral right problems the option was discontinued.

1.3.3. Minerva Gold Mine

Also known as Griffen Mine, this mine was discovered in 1903 and was initially known as the Lawrence claims. It was mined by the Griffen Gold Mining Company from 1908 to 1913, mined again from 1934 to the late 1930's by the Mopani Gold Mine Limited and finally mined in the mid-50's by the Duchen Gold Mining Company. The latter exploited the deposit on a fairly large scale. Extensive underground workings have been developed, resulting in extensive surface dumps which are presently being reprocessed. The mine was recently re-evaluated by Anglo Vaal (Limited) , who presently hold the underground mineral rights. Van Eeden *et al.* (1939), described the deposit as comprising reefs situated within hornblende schists, chlorite schists and talc schists located on the southern-eastern side of a green quartzitic bar. They noted that a granitic intrusion was located close to the deposit and suggested that the effect of the granite to produce the mineralization of a high-temperature type was evident. Pyrite is the dominant mineral, but arsenopyrite and pyrrhotite do occur in varying amounts. This deposit was probably the most successful gold mining venture in the Murchison schist belt, outside the Antimony Line.

1.4 Geology of The Murchison Range and Related Areas

The Archaean Murchison schist belt (Jeppe, 1893; Mellor, 1906; Hall, 1912; Van Eeden *et al.*, 1939; Viljoen *et al.*, 1978) is the second largest greenstone or schist belt in the Kaapvaal Craton. The belt is flanked to the north and south by intrusive Archaean granitoids and to the west it is overlain by the early Proterozoic sediments and volcanics of the Wolkberg Group, considered by SACS (1980) to be part of the Transvaal Sequence. To the east, the belt breaks up into enclaves between granitoids and is unconformably overlain by the upper Palaeozoic and Mesozoic rocks of the Karoo sequence (Figure 1.2).

The term "schist belt", as proposed by Hall (1912), Van Eeden *et al.* (1939) and Vearncombe (1988), is used rather than "greenstone belt" (Anhaeusser *et al.*, 1969; Pearton and Viljoen, 1986), although it may have been a greenstone succession prior to tectonisim and metamorphism (Vearncombe, 1988). Although well preserved mafic volcanic rocks are present, they occur amongst other mafic rocks which lack evidence of volcanic origin. The ultramafic to mafic volcanic pile exhibit low grade metamorphism, and vast tracts of greenstone without pervasive deformation such as those which characterise the classic greenstone successions of Barberton (Anhaeusser, 1983) are lacking.

The rocks comprising the schist belt are usually pervasively and intensely deformed such that the predominant rock types are meta-schists, with the primary minerals and structure only occasionally visible. These schists show complex folding and are generally east-north-east striking and steeply dipping, with a low metamorphic grade (Hall, 1912; Van Eeden *et al.*, 1939; Minnitt, 1975; Muff and Saager 1979; Viljoen *et al.*, 1978; Pearton, 1978, 1979, 1980; SACS, 1980) from mid-greenschist to upper amphibolite facies. The Murchison granite greenstone terrain can be broadly divided into four units (Barton, 1984):-

(1) greenstone/schist belt remnants,

(2) Rooiwater Complex,

(3) leucocratic tonalitic, trondhjemitic and granodiorites gneisses surrounding the belt,

(4) late-stage granitic plutons.

The geology of the Murchison Range is dominated by the "Antimony Line", an east-north-east trending linear structure, showing intense deformation relative to the surrounding rocks (Nutt *et al.*, 1988) of some 50-250 m width and extending 55 km from Horse Shoe in the west, beyond Gravelotte, to the Caledonian Camp in the east. The term "Antimony Line" was first used by Wilson-Moore (1896), and has remained in use since that time. It refers to a zone of talcose and carbonate rocks along the southern flank of the Antimony Bar which hosts antimony-gold mineralization. Along the strike are sporadically developed concentrations of antimony, with associated gold and tungsten mineralization. Mineralization, with few exceptions, is located within thickened quartz-carbonate masses in the talc-rich assemblage, also commonly associated with fuchsite zones. The mining centres along the "line" are known as "complexes" (Pearton and Viljoen, 1986). Locally, quartz-chlorite schist and quartz-muscovite schists are included within the above rock types, and in some areas slightly mineralized carbonate rocks are developed north of the Antimony Bar. Thus, in a broad sense, the Antimony Line preserves a variety of rock types within a zone of intense carbonate development. There is disagreement in the literature concerning the origin of the mineralization in the Antimony Line and particularly whether it represents a syngenetic sequence of deposits (Ileri, 1973; Minnitt, 1975; Muff, 1976; Muff and Saager, 1979) or an epigenetic set of deposits (Hall, 1912; Van Eeden *et al.* 1939; Boocock *et al.*, 1984; Pearton and Viljoen 1986; Vearncombe and Van Reenen, 1986). In the epigenetic argument, the source of the mineralizing fluids could have been the surrounding granitoids (Hall, 1912; Van Eeden *et al.* 1939) or from the surrounding schists of the schist belt (Pearton, 1980; Boocock *et al.*, 1984; Pearton and Viljoen, 1986; Vearncombe, 1988). Recent works interpret the Antimony Line to represent a zone of intense shear deformation along which mineralized hydrothermal, CO_2-H_2O rich fluids migrated resulting in vein-type epigenetic antimony-gold mineralization (Vearncombe, 1988).

The first geological publication on the Murchison area was by Hall (1912) who recognized the presence of sedimentary successions. He noted that the acid and basic schists were derived from igneous rocks and that the schists were intruded by the so called "older granite". The first comprehensive account of the geology of the Murchison schist belt was provided by Van Eeden *et al.* (1939), who proposed that the range be divided into three divisions of the Swaziland System. Other early workers correlated the Murchison belt with the sequence from the Barberton area. However this correlation is based on lithologies and on the basic assumption that all the greenstone remnants within the Craton were part of a single crustal unit. Viljoen *et al.* (1978), have since revised the stratigraphic nomenclature pertaining to the Murchison Range and this revision formed the basis for subsequent classification by SACS, (1980) (Figure 1.3) which assumes a northward younging sequence. However, this stratigraphy is contradicted by observed changes in younging around tight to isoclinal folds (Graham, 1974; Minnitt, 1975; Boocock *et al.*, 1984) as well as a contradictory southward younging for both the felsic volcanic rocks of the Rubbervale formation (Taylor, 1981; Maiden, 1984) and the Rooiwater complex (Vearncombe *et al.*, 1986, 1987). Due to these structural complications, Vearncombe *et al.* (1988), proposed that the Murchison schist belt be described in terms of five domains defined by their lithological, metamorphic and structural characteristics. The domains are:-

1) Silwana's amphibolite
2) Rooiwater complex
3) Rubbervale formation
4) Murchison ultramafic, mafic, carbonated and metasedimentary schists
5) La France Schists

In some cases, these coincide with previous stratigraphic formations and the original names (SACS, 1980; Van Eeden *et al.*, 1939) and have been retained. The boundaries of these domains are usually tectonic breaks along which intrusive granitoids may occur. The domains are described from north to south with no necessary stratigraphic significance.

For the purpose of description, the geology of the Murchison schist belt is described using the classification as proposed by SACS (1980). The complete succession comprises the Gravelotte Group which is divided up according to the scheme shown in Figure 1.3. However the sequence of stratigraphic succession can not be unequivocally stated due to the structural uncertainties that exist in this schist belt.

Formation	Lithology	Approx. Thickness (m)	Remarks
Rubbervale	Felsic porphyritic tuffs, mafic porphyritic and subordinate lavas and sills	3500	
Mac Kop	Quartzite, grits, with intercalated chlorite schists, minor sericite schists and conglomerates	1500	Intrusive sepentinite bodies
Weigel	Quartz-chlorite schists (magnesiopelites), quartzite "bars", quartz-muscovite schists and a variety of carbonate rocks Banded iron formations Mafic lavas including Mg-and Fe-rich varieties and alkali tholeiites Talc-chlorite schists (altered ultramafic lava)	3500	Castle Koppies bar Chloritoid bar Spitzkop bar Antimony bar **Antimony Line** Louwskop bar
La France	Conglomerates, grits, quartzite, chlorite schists(high-alumina metamorphic minerals)	2000	
Leydsdorp	Mafic lavas (metatholeiitic) with interlayered banded ironstone formations, quartz-chlorite schists and quartz-porphyries. Variously carbonated	3000	
Mulati	Mafic lavas (Basaltic komatiites, metatholeiitic) lesser ultramafic lava (peridotitic komatiites) and felsic tuffs.	Unknown	

Figure 1.3. The lithostratigraphy of the Gravelotte Group after SACS (1980).

1.4.1. Mulati Formation

This sequence is generally composed of an assemblage of mafic, often komatiitic, basalts and ultra-basic rocks which occupy the southern flank of the Murchison Range. It also constitutes the many xenoliths and the masses of greenstone material which are well developed in the granites to the south of the schist belt. In relatively well preserved areas, such as the central portion of the schist belt, two phases can be recognised. The lower phase comprises an assemblage of komatiites and komatiitic basalts. Interlaid with the komatiites are metatholeiite (including possibly pre-contemporaneous sills; Pearton and Viljoen, 1986) together with minor felsic tuffs. Tholeiitic material dominates the upper volcanic phase with minor komatiitic basalt flows occur near the top of the sequence, while biotite rich tuffwacke are well represented at the base (Pearton and Viljoen, 1986). Tremolite-actinolite schists occurring frequently along the contact with younger intrusive granitoids as apparently metamorphic aureoles.

1.4.2. Leydsdorp Formation

This formation consists of massive and schistose tholeiitic, magnesium tholeiitic and minor komatiitic volcanic rocks. These rocks overlie the Mulati Formation and are well exposed in the Leydsdorp syncline, where they are defined by the Spitzkop silicious "bar", southwest of Gravelotte. The volcanic rocks are extensively carbonated, especially along regional shear zones. The rocks of the Leydsdorp Formation are restricted to the western and eastern portions of the Murchison range and are not present in the central portion (Figure 1.2). It has been suggested that the Selkirk member of the Weigel Formation (see later) is correlated to the Leydsdorp Formation and occupies a tight anticlinal fold structure, but this can not be substantiated (Pearton and Viljoen, 1986).

1.4.3. La France Formation

This formation comprises grits, quartzites, conglomerates and chlorite schists and is characterised by the presence of high grade alumina-rich metamorphic minerals. Garnet and kyanite occur in distinct zonal patterns within the quartz-sericite schists (SACS, 1980). The presence of these high grade metamorphic minerals may be due to granitic intrusions affecting only a minor part of the La France Formation.

1.4.4. Weigel Formation

The Weigel Formation occupies the central core of the Murchison Range and consists of quartz-chlorite schist, quartzite, quartz-muscovite schist, minor banded iron formations and conglomerate units, as well as mafic (tholeiitic) lavas and talc-chlorite schists in association with talcose and silicified rocks. The latter units constitute the Antimony Line and contain the antimony-gold mineralization.

The formation is divided into three easily recognizable lithological units: The lower unit is composed predominantly of a variety of quartz-chlorite schists units in which two prominent quartz-muscovite schist units occur, namely the Louws Kop Bar and the Antimony Bar (Van Eeden *et al.*, 1939). Primary textures in these rocks have been largely erased by dynamic metamorphism resulting in large tracts of schistose material. The Antimony Line is developed along the southern flank of the Antimony Bar and occurs as a broadly stratiform zone of talcose and quartz-carbonate rocks. Numerous banded iron-stones and sparse metatholeiites occur interlaid within the quartz-chlorite schists.

The central unit is known as the Selkirk metabasalt Member and consists of a variety of mafic lavas. Both magnesium metabasalts and metatholeiite varieties have been identified (Pearton and Viljoen, 1986). Variolitic textures and the occasional pillow structures indicate younging to the north.

The upper unit of the Weigel Formation is a monotonous sequence of quartz-muscovite schists. The Chloritoid Bar and the Castle Koppies Bar (Figure 2.2) (Van Eeden *et al.*, 1939) represent two prominent quartzite horizons with this unit. The Chloritoid Bar is unusual in that it is made up of a series of quartz-muscovite schists and chloritoid-quartz schists and quartzites, with associated black carbonaceous shale, polymictic conglomerates and ferruginous horizons. Negligible muscovite occurs in the chloritoid-bearing rocks, while iron oxides are ubiquitous throughout most of the horizons. The Castle Koppies Bar contains minor horizons of massive quartzite and coarse, clastic ferruginous horizons.

1.4.5. Mac Kop Formation.

The Mac Kop Formation occurs on the eastern portion of the Murchison schist belt in the southern bifurcation known as the Bawa schist belt, approximately 14 km north of the Phalaborwa Township (Minnitt, 1975). It consists of quartzite, quartz-sericite schist feldspathic sandstone, minor conglomerate and chlorite schist. The formation was considered by Minnitt (1975) to represent a younger sedimentary assemblage, unrelated to the Weigel Formation sediments and probably derived mainly from erosion of the surrounding granitic terrain.

1.4.6. Rubbervale Formation

This unit occurs between the Weigel Formation and the Rooiwater Complex and is composed of a series of volcanic rocks which are quite distinct from any of the rocks to the south. The formation is composed of porphyroclastic schists derived from subvolcanic quartz feldspar porphyries and schists which were themselves derived from locally bedded felsic tuffs, lavas and agglomerates. Along the southern flank of the Rubbervale formation, silicified tuffs and lavas are exposed along a discontinuous line along which several zinc-copper deposits occur, known as the "Cu-Zn Line" (Viljoen *et al.*, 1978; Taylor, 1981; Maiden, 1984). The schists are succeeded to the south by komatiitic basalts, feldspathic amphibolite, (possibly representing a major sill) with isolated feldspar porphyries lenses. In the west, rhyolite, felsic volcanic schists and mineralized tuffaceous porphyry are overlain by greywacke which youngs to the south. The formation is pervasively deformed and metamorphosed to green schist facies.

1.4.7. Rooiwater Complex

Originally named by Kent (Van Eeden *et al.*, 1939), the Rooiwater meta-complex is a thick layered, differentiated body which has intruded along the northern flank of the Murchison and is composed largely of gabbroic rock (Vearncombe *et al.*, 1986, 1987). It has an intrusive contact with the Rubbervale formation but has been intruded by the surrounding granitoids (Maiden, 1984). The pre-deformational relationship between the Rooiwater complex and the Rubbervale Formation is complicated by the structural contrast between the largely undeformed Rooiwater complex and the pervasively deformed Rubbervale formation schists. The intrusive complex consists of a younger Free State Diorite Suite (the Hornblende Granite of Van Eeden *et al.*, 1939) and an older Novengilla Gabbro Suite, both of which have been metamorphosed to amphibolite facies (Vearncombe, 1988). Much of the suite is undeformed and is south-facing. Radiometric age determination on a sample from the Free State Diorite Suite gave a minimum age of 2961 ± 75 MA (Burger and Walraven, 1975 - 1976).

The Novengilla Gabbro Suite has undergone magmatic differentiation and varies in composition from amphibolite to feldspathic amphibolite. Within the amphibolites there are two major vanadium-bearing titaniferous magnetite bands. The bands average 9 m in thickness and dip to the south-east at 65° (de Beer *et al.*, 1984; de Beer, 1985). In addition, magnetite is disseminated throughout the amphibolite in close proximity to the magnetite bands.

1.5. Intrusive Rocks

The tectonic relationships between the granitoids and the Murchison sequence is uncertain (Barton, 1984). Late stage granitoid plutons intrude the gneissic terrain as well as the Murchison sequence. The vast tracts of granite (*senso lato*) occurring in the northern Transvaal and surrounding the Murchison Range are considered by Barton and Van Reenen (1987) to have been emplaced during the Limpopo orogeny. Work done by Barton (unpubl. data) shows the granitoids to be trondhjemitic to dioritic in composition. Dating by whole rock Rb-Sr methods on certain granitoids gave consistent ages of 2.7-2.65 Ga (Barton and Van Reenen, 1987), although this does not necessarily indicate the emplacement age of the plutons. Two varieties of granitoid rocks occur around and within the Murchison schist belt, namely tonalitic and trondhjemitic gneisses, as well as late stage granitoid plutons and their associated pegmatite and aplite contact phases. The 1984 Geological Map of South Africa (Scale 1:1 000 000) shows the Murchison schist belt to be largely surrounded by tonalitic and trondhjemitic gneisses of the 3500 Ma Goudplaats gneiss. A second group of unnamed gneisses extends south-eastward from

Tzaneen and borders the north-western margin of the belt.

1.5.1 Tonalitic and Trondhjemitic Gneisses

The tonalitic and trondhjemitic rocks surrounding the Murchison Range are heterogeneous, migmatitic and banded gneisses, composed predominantly of oligoclase/andesine with lesser amounts of microcline, quartz, biotite and hornblende. Apatite, zircon and magnetite occur as accessory minerals and garnet has developed locally. The differences among the types of gneisses are easily demonstrated by their variable Sr and Pb isotopic signatures (Vearncombe *et al.*, in press). The tonalitic and trondhjemitic gneisses north of the belt show different Rb-Sr isotopic characteristics to those south of the belt. Barton (unpubl. data) also suggests that the gneisses on the southern side of the schist belt are akin to those developed in the Barberton terrain further south and that the gneisses to the north of the belt have characteristics similar to those of the Goudplaats gneiss, although the younger age of some of the gneisses makes direct correlation impossible. The genetic and structural relationships between the gneisses and the schist belt lithologies are uncertain. In the immediate vicinity of the Murchison schist belt, the gneisses occur as xenoliths and macroxenoliths within a sequence of later granitoid plutons. The gneisses generally do not occur in direct contact with the schist belt (Vearncombe *et al.*, in press).

1.5.2 Late Stage Plutons

Numerous, small, late-stage intrusive granitoids are exposed along the margins of, and within, the schist belt. At present, two sets of age data for these plutons are available. The older age approximately 2750 Ga age obtained was from a carbonated granite, exposed in the Gravelotte Emerald Mine (Barton, 1984). This age, however may not represent the age of intrusion, as it is likely that the isotopes were affected by the carbonate alteration. The younger age from late stage plutons in the area which are generally unaltered and only locally deformed and which yield consistent whole rock Rb-Sr ages of 2650 ± 30 Ga (Barton, 1984). These plutons are composed of variable proportions of quartz, microcline and, usually, oligoclase, with variable amounts of biotite and hornblende. Apatite, zircon, garnet and magnetite are common accessory minerals. The plutons generally range from granite to granodiorite, except for the Maranda pluton which is an alkali-feldspar granite (Vearncombe, *et al.*, in prep.). However this study suggests that the unusual chemical nature of the Maranda pluton is in fact due to alkaline metasomatism, similar to that observed in the Malati Store and Discovery Shaft intrusions. These late plutons are corundum normative and are peraluminous (i.e.

$Al_2O_3/(K_2O + Na_2O + CaO) > 1.1$). Vearncombe *et al.* (In press) suggest that these common characteristics indicate that all of these units might be genetically related, perhaps forming a single batholith, encompassing the Murchison schist belt.

Vearncombe *et al.* (1988; In press), noted that the Antimony Line is intimately associated with a series of granitoid bodies, of which the Maranda granite is the western most intrusion (Figure 1.2). The Antimony Line does in fact represent a prominent geophysical discontinuity extending from the Maranda granite in the west, to the Baderoukwe granite to the east. A series of geophysical sounding and gravity profiles (de Beer *et al.*, 1984;de Beer, 1985), show that granitoid bodies are near-surface, beneath, or in close proximity to, the Antimony Line (Figure 1.4). The intrusive bodies which are observed on surface, such as the Malati Store intrusion, are thought to connect at depth to a larger intrusion that is intrusive in to the major structural discontinuity represented by the Antimony Line (Figure 1.4). Small granodiorite bodies (Vearncombe, 1988), termed "beresites" (Boese, 1964), or albitites (Pearton, 1980), are also common along the Antimony Line. They comprise albite, white mica, quartz, rutile, and, locally, pyrite and occasionally tourmaline. This study suggests that these albite-rich bodies are the product of sodium alteration of high level portions of the underlying granodiorite intrusion.

Minor stibnite mineralization is recorded in the Maranda granitoid, near its eastern contact with the Antimony Line and berthierite and stibnite occur in the quartz-rich margins of the granodiorite near the Alpha-Gravelotte ore body. Vearncombe (1988), described another granitoid at the Old Gravelotte mine, where a granodiorite body is intrusive into the ore zone. Underground exposure suggests that the granodiorite post-dates the D1 cleavage. Other granitoid material occur as thin veins in the vicinity of the Monarch mine, usually cutting the D1 cleavage. Pyritic zones near the margins of the granodiorite at Old Gravelotte mine are spatially related to both the margins and to internal brittle fracture zones and have quartz veins, containing pyrite, pyrrhotite, arsenopyrite, and gold mineralization. Vearncombe *et al.* (1988) and Boocock *et al.* (1988), rule out the theory that the source of the fluids related to the Antimony Line is due to the intrusive granitoids, because they appear to post-date the D1 cleavage and they do not contain economic antimony mineralization. However this study will show that there is evidence that the granodiorites intruded an active tectonic environment.