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RARE-ELEMENT PEGMATITES ALONG THE
NORTHERN FLANK OF THE BARBERTON
GREENSTONE BELT, SOUTH AFRICA**

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by

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ABSTRACT

Pegmatites are relatively well-developed in the structurally complex, north-central portion of the Barberton greenstone belt. Detailed study of these pegmatites in the extensive underground workings of the New Consort Gold Mines has shown that they are intensely deformed and have been emplaced into a variety of structural features that formed during a protracted D_2 event along the northern flanks of the belt. Chemical studies have identified the pegmatite suite as belonging to the lithium-cesium-tantalum-enriched rare-element class. The pegmatites are internally zoned and also show a pronounced regional fractionation trend from K-feldspar-albite, through albite-spodumene to albite variants. Geochemical arguments, together with whole-rock Rb-Sr and garnet Sm-Nd isotopic studies, suggest that the 3105 Ma old Nelspruit batholith, immediately to the north of the Barberton greenstone belt, is the most likely source magma for the pegmatites. The pegmatites are often highly altered with albitization and silicification occurring endogenously and Li and K metasomatism taking place along the margins of the intrusions and in veins. Fluid inclusion microthermometry indicates that carbonic and high-salinity aqueous inclusions were active during the sub-solidus evolution of the bodies. It is believed that mineralization processes at Consort were long-lived and were stimulated, at least in part, by intrusion of the Nelspruit batholith and the associated magmatic and volatile egress that was associated with this event.

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THE NATURE AND STRUCTURAL SETTING OF RARE-ELEMENT PEGMATITES ALONG THE NORTHERN FLANK OF THE BARBERTON GREENSTONE BELT, SOUTH AFRICA

INTRODUCTION

Although pegmatites are relatively uncommon in the Barberton greenstone belt (BGB), they represent an important component of the strongly attenuated, stucturally complex, north-central portion of the belt (Hall, 1918; Hearn, 1943; Viljoen, 1964; Anhaeusser, 1969; Voges, 1986). Despite the fact that this area has been intensely studied and explored, and has also been exploited for gold for over a century, the contained pegmatites have never been studied in detail. The New Consort Gold Mines (NCGM), mined since 1884, have exposed several generations of pegmatite in extensive underground workings and, consequently, have been selected as the site of a detailed study of these rocks (Figure 1). The object of the present paper is to report on: 1. the nature and geological setting of the pegmatites; 2. their structural setting relative to the tectonic framework of the northern portion of the BGB; 3. the mineralogical and chemical characteristics of the pegmatites; 4. preliminary Rb-Sr and Sm-Nd isotopic data and to speculate on the origin of the pegmatites. Brief consideration will also be given to the role that the pegmatites, and their parental magma, might have played in the generation of gold mineralization in the region.

REGIONAL GEOLOGICAL SETTING

Stratigraphy

The NCGM occurs at the eastern end of a major E-W trending apophysis of the BGB known as the Jamestown schist belt (JSB). The JSB has been described by early workers in terms of a relatively well-ordered stratigraphic succession (Anhaeusser, 1964, 1969, 1972; Viljoen, 1964) in which most of the rock units form part of the Onverwacht Group. In more recent studies, however, the JSB has also been referred to as an ophiolite complex (De Wit *et al.*, 1987).

To the north of the study area the Nelspruit batholith (NB) intrudes mafic and ultramafic schists correlated with the Theespruit Formation of the Onverwacht Group. These schists are overlain by metasediments and metavolcanics of the Fig Tree Group. Sediments of the Moodies Group overly the lower Fig Tree and Onverwacht Groups. The Kaap Valley Tonalite (KVT) intrudes the latter rocks along the southern flank of the JSB (Figure 1).

Chronological relationships in the region are reasonably well-constrained since the advent of U-Pb single zircon dating. The volcanic rocks of the Onverwacht Group are bracketed in age between 3480Ma and 3440Ma (Armstrong *et al.*, 1990; Kröner *et al.*, 1991). The deposition of the Fig Tree Group volcanic and clastic rocks occurred over a time span of approximately 35Ma from 3259±5Ma to 3225±3Ma (Kröner *et al.*, 1991; Kamo *et al.*, 1990). This implies that there is a hiatus of approximately 200Ma between the end of

Onverwacht volcanism and the onset of Fig Tree deposition (Kamo *et al.*, 1990; Kamo and Davis, 1991; Kröner, 1990). The transition between Fig Tree and Moodies sedimentation is coeval with the emplacement of the KVT at 3227 ± 1 Ma (Kamo and Davis, 1991; Armstrong *et al.*, 1990). The termination of Moodies sedimentation is at present uncertain but is earlier than ca.3080 Ma, the age of the Salisbury Kop pluton which intrudes the upper Moodies sediments in the eastern portion of the BGB (Heubeck *et al.*, 1992).

Structure

Most of the recent structural work in the BGB has focussed on the southern and central portions of the belt (De Wit, 1982; De Wit *et al.*, 1983, 1987; Lamb, 1984; Paris, 1984; Lowe *et al.*, 1985; De Ronde, 1991). The earliest phase of deformation recognised in the BGB pre-dates Moodies deposition. Early, low-angle thrusts resulting in the formation of nappe structures, recumbent folds and overturned stratigraphy, form the D_1 deformational event (De Wit, 1982; De Wit *et al.*, 1983; Tomkinson and King, 1991). Early D_1 deformation probably occurred between ca.3440-3450 Ma at the same time as the emplacement of major TTG (tonalite-trondhjemite-granodiorite) plutonism along the southern portion of the BGB (Armstrong *et al.*, 1990).

The second deformational phase represents the major tectonic event in the BGB and resulted in isoclinal folds with axes trending E-W or NE-SW, and associated high angle reverse faults (Tomkinson and King, 1991). The major regional trend of the BGB formed during this phase of deformation. Kamo *et al.* (1990) and De Ronde (1991) have constrained the age of D_2 deformation at between 3229 ± 3 Ma and 3216+2/-1 Ma. Deposition of the Fig Tree and Moodies Groups occurred over the same period as the D_2 deformation, while additional TTG plutonism is also recorded by the Kaap Valley Tonalite (ca. 3227Ma) and the Dalmein pluton (ca. 3216Ma) during the same period (Tegtmeyer and Kröner, 1987; De Wit *et al.*, 1987; Armstrong *et al.*, 1990; Kamo *et al.*, 1990; Kröner, 1990).

Post-D_2 deformation in the BGB occurs as refolding of D_2 structures in the southern part of the belt (Lamb, 1984; Paris, 1984). A major period of igneous activity occurred both to the north and south of the BGB at 3105 Ma and is represented by the Nelspruit batholith ($3106^{+2}/_{-3}$Ma), the Mpuluzi batholith ($3107^{+4}/_{-3}$Ma), the Boesmanskop syeno-granite complex ($3106^{+6}/_{-7}$Ma) and the Stentor pluton ($3106^{+6}/_{-7}$Ma) (Kamo *et al.*, 1990; Kamo and Davis, 1991). Late-stage granitoid plutonism occurred in three distinct episodes in the Barberton region, namely at 3.07 Ga, at 2.84 Ga and at 2.72 Ga (Robb *et al.*, 1993). Late-stage strike-slip faulting and reactivation have also been recorded in the northern part of the BGB (Robertson, 1989), but the timing of this event is uncertain. It should be noted that correlation of deformation events in different parts of the BGB is problematical, and events may be diachronous. Tomkinson and King (1991), for example, have suggested that the D_1 event in the present study area may be represented by the D_2 event of the central and southern portions of the belt.

Granites

Two major granite bodies occur to the north and south of the study area. The KVT pluton (Figure 1) is 3227 ± 1 Ma old (Kamo, 1991) and is composed of homogeneous
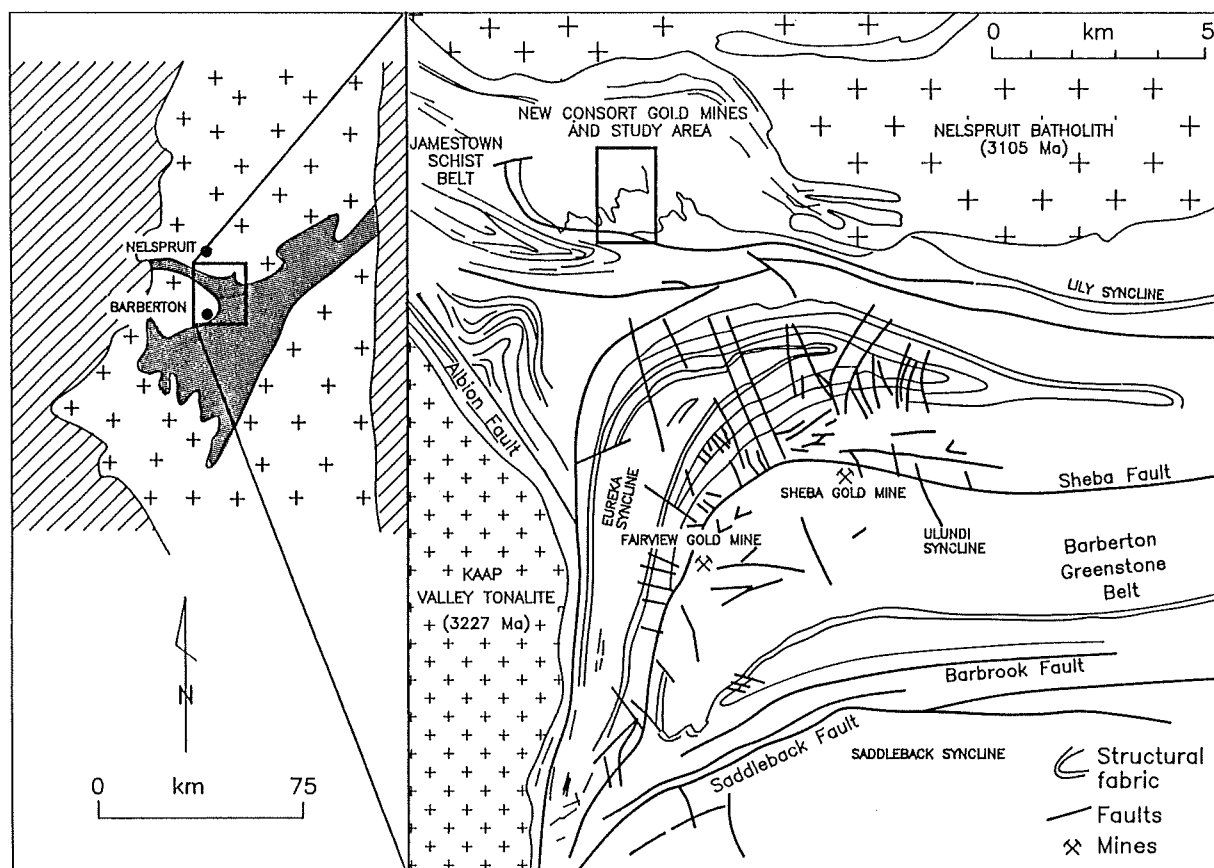
Figure 1: Locality map showing the position of the New Consort Gold Mine area in relation to the complexly deformed north-central portion of the Barberton greenstone belt (modified after Anhaeusser, 1976).

hornblende and hornblende+biotite tonalite. It is weakly foliated and its contact with the surrounding greenstone material is generally sheared with little or no evidence of magmatic intrusion. No pegmatitic phase has been observed in the tonalite.

The Nelspruit batholith has been dated at 3105+2/-3 Ma (Kamo, 1991) and comprises a large composite body of massive, porphyritic granodiorite-adamellite, medium-grained granodioritic bodies and K-rich gneisses and migmatites. Numerous, but volumetrically minor, pegmatitic phases occur throughout the batholith. The southern contact of the Nelspruit batholith, especially in the vicinity of the study area, comprises numerous large pegmatite bodies and is often intensely sheared (Viljoen, 1964).

GEOLOGICAL SETTING OF PEGMATITES AT THE NCGM

Stratigraphy

A simplified stratigraphic column of the NCGM area is shown in Figure 2. Although the units shown are presented in a psuedo-stratigraphic sense it is likely that structural juxtaposition of rock types has occurred. The most common footwall rocks in the mine area
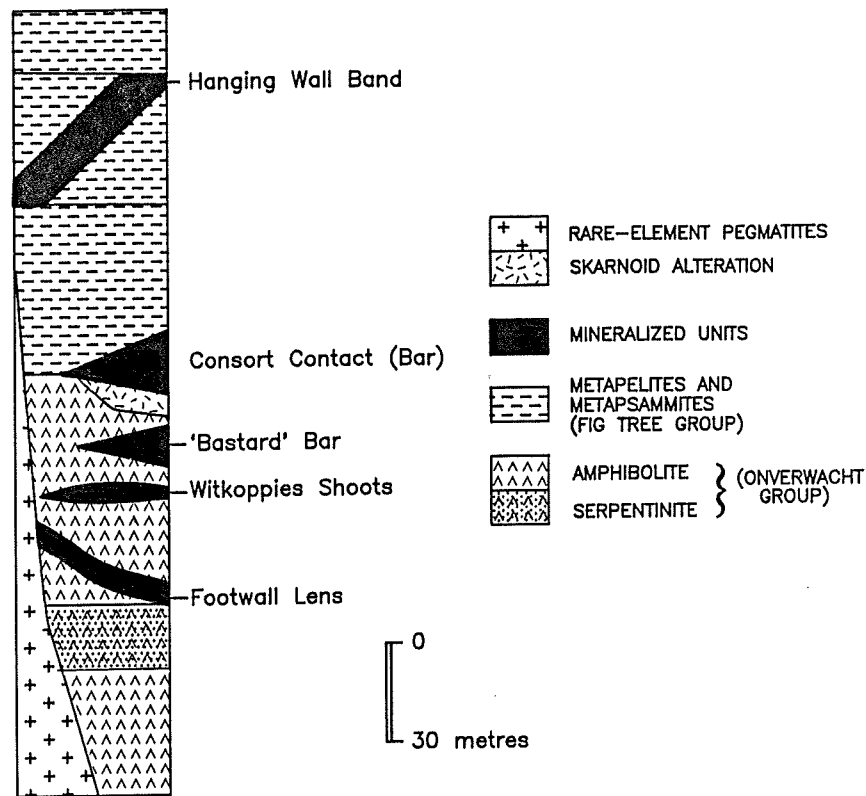
Figure 2: Simplified stratigraphic column showing relevant rock types in the New Consort Gold Mine study area.

juxtaposition of rock types has occurred. The most common footwall rocks in the mine area are tremolite and tremolite-albite amphibolites. The amphibolites are massive, dark-green to black, fine-grained rocks which occasionally also contain phlogopite. Blue-grey serpentinites comprising serpentine, chlorite, talc, carbonate, magnetite and frequent asbestos veinlets also occur in the footwall of the NCGM.

The main ore-horizon or Consort Bar is a thick (average 4m but may reach up to 25m) siliceous mylonitic unit consisting mainly of quartz and biotite (Tomkinson and Lombard, 1990). Lesser amounts of albite, tourmaline, rutile, amphibole, and fuchsite are found in this unit. Where mineralization occurs within the Consort Bar, arsenopyrite, pyrrhotite and gold accompany the typical silicate assemblage.

The hanging wall rocks to the Consort Bar are metapelites and metapsammites. In the north these metasediments comprise mainly quartz-biotite-muscovite-cummingtonite-garnet schists (Tomkinson and Lombard, 1990), while in the southern part of the NCGM the schists consist of quartz, biotite, garnet, andalusite and occasionally muscovite. A foliation is produced by the alignment of phyllosilicates within the quartz-biotite schists of the Consort Bar and almandine-spessartine garnets form distinctive layers within the schists (Voges, 1986).

Other less abundant rock types also occur within the workings of the NCGM. Bodies of albite-muscovite-biotite-microcline schist intrude the footwall amphibolites in places. Textural and mineralogical evidence suggest that the original rock were small granitic intrusions related to the Witkoppies Shoots (Tomkinson and Lombard, 1990). Mineralization also occurs in a lenticular unit termed the "Bastard Bar" just below the Consort Contact, while the "Hanging wall Band" also occurs in the overlying metasediments (Figure 2). Skarnoid assemblages comprising pyroxene (diopside-hedenbergite), amphibole (actinolite-tremolite), idocrase, colourless garnet, scapolite, bytownite and scheelite (Tomkinson and Lombard, 1990) are also found closely associated with the Consort Contact and the Footwall Lens ore shoots.

Structure

Three deformational events have been recognized in the northern part of the BGB. The earliest phase of deformation resulted in recumbent isoclinal folds and associated tectonic slides (Tomkinson and Lombard, 1990). The D_1 event was accompanied by a S_1 fabric which occurred at a very low angle to the original bedding in the host rocks at the NCGM. The S_1 fabric develops as a schistosity in the amphibolites and as a spaced cleavage in the metasediments. The Consort Bar has been interpreted as a D_1 related tectonite (Figure 3).

The second deformational event (D_2) has had a major effect in the NCGM area. This phase of deformation resulted in major N-S to NE-SW trending and near vertical dipping shear zones. The inflection of the Consort Bar between the Top Section and 3 Shaft synclines (Figure 3) is caused by the D_2 Shires Shear Zone (SSZ). The SSZ is approximately 300 to 350 m wide, dips sub-vertically and consists of an anastomosing network of individual shear zones (Tomkinson, 1988). The individual shear zones vary from 1 cm to 5 m in thickness depending on the host rock in which they form. In the amphibolite and serpentinite units the shears can be up to 5 m thick , whereas in the metasediments they are narrow and generally only 1 to 10 cm wide. Individual shears may dip either east or west, although the shear system as a whole dips steeply to the east. Folds are common in the SSZ with the earlier S_1 fabric forming sheath folds in the shear zone. Shear bands, rotated porphyroclasts in pegmatites, asymmetric boudinaging of pegmatites, and strong sub-vertical stretching lineations have been used as kinematic indicators in the SSZ. Stereographic projections of the mylonitic S_2 fabric in the pegmatites, as well as mineral lineations and fold axes within the SSZ are plotted as insets A and B in Figure 3. The kinematic indicators suggest a west block up, with a minor sinistral movement component to the NW-SE trending shear zone. The stress field for the Shires system suggests that compression occurred in a NW-SE orientation. A later reactivation in the SSZ produced local shears with a dominantly dextral strike slip component and a west block down dip slip component. Zones of intense fabric development and carbonate alteration have been found to accompany the SSZ. Several fabrics are developed with these shear zones and are termed the S_2 fabric. In the amphibolite the second cleavage (S_2) occurs as a spaced cleavage on the margins of the shear zone. Within the shear, however, the fabric becomes pervasive. The S_2 fabric also occurs as mylonitic banding in the pegmatites which intrude the SSZ. Overprinting of the S_2 fabric on the S_1 fabric can result in the complete elimination of the earlier fabric. Several other NW-SE trending D_2 shears also occur in the NCGM and these include the Ivaura and Main Reef (MR) faults (Figure 3). The MR and the Ivaura faults dip at 60-70° and
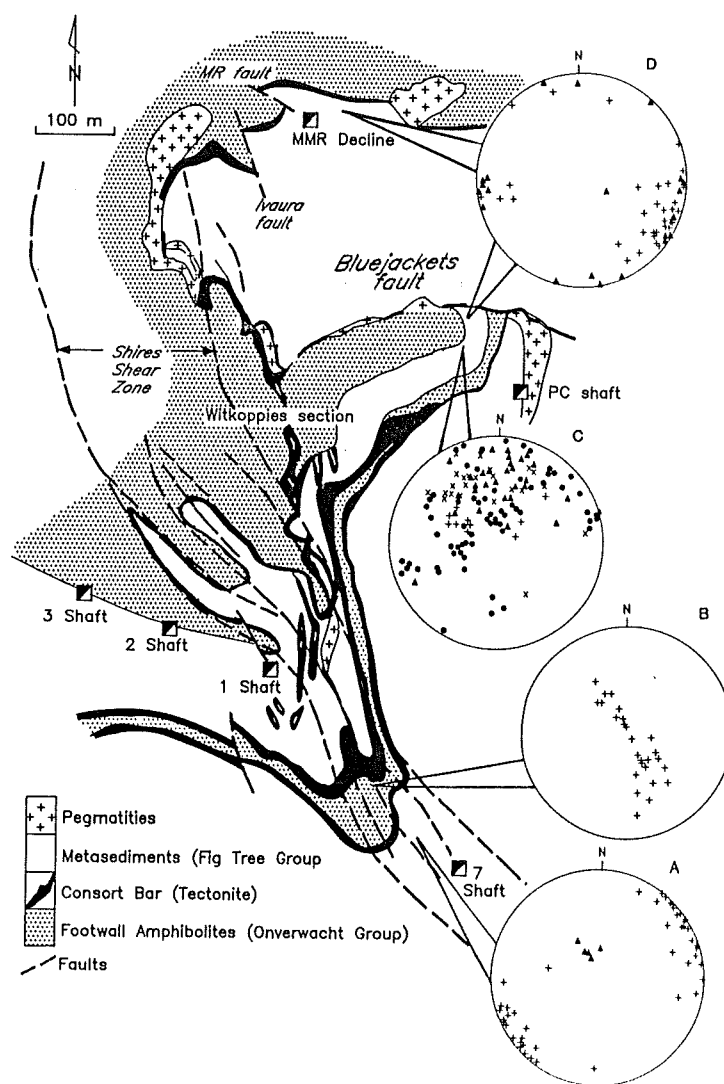
Figure 3: Surface structural plan of the New Consort Gold Mine study area showing some of the major features discussed in the text. Inset A shows poles to the S_2 fabric in Shires pegmatites (crosses) and mineral lineations (triangles); Inset B shows the orientation of fold axes in the SSZ; Inset C shows the diverse orientation of poles to shears encountered in four different levels in the Bluejackets fault zone; Inset D shows poles to the fabric in the MR3 (crosses) and MR5 (triangles) pegmatites.

50-70° to the southwest respectively (Hearn, 1943). Mineralization has been deformed by the D_2 event.

The D_3 deformational event in the region is broadly represented at the NCGM by the Bluejackets fault zone (Figure 3). These faults form a 20 - 50m wide network of normal displacements which dip towards the south and southwest at shallow to moderate angles (Tomkinson and Lombard, 1990). The Bluejackets faults occur as discrete fault planes in the metasediments, and as wider, more ductile zones, in the amphibolites. A pronounced fabric (S_3) which is more localized than the earlier S_1 and S_2 fabrics, accompanies D_3 and is

related only to the Bluejackets fault zone. The S_3 fabric is typically a composite fabric (Figure 3; inset C) that consists of anastomosing shear bands inside the main faults and S-C fabrics on the margins. This fabric (S_3) is parallel to the Bluejackets fault zone and therefore also dips shallowly to the south.

Metamorphism

Three metamorphic events are presently recognized in the NCGM area. The early metamorphic event (M_1) reached mid-greenschist facies and was associated with the D_1 deformational event. Consequently, it pre-dates the intrusion of the Consort pegmatites. The last metamorphic event (M_3) is associated locally with the late D_3 deformational event, and post-dates pegmatite intrusion. The highest grade of metamorphism was associated with the M_2 event, and attained low- to mid-amphibolite facies grade. A well-defined contact metamorphic aureole which decreases in intensity towards the south has also been recognized along the northern flank of the Jamestown Schist Belt (Viljoen, 1964; Anhaeusser and Viljoen, 1965; Anhaeusser, 1969). Recent work suggests that this metamorphic aureole also increases in intensity within the deeper portions of the NCGM, and towards the north. The D_2-related SSZ deforms the early M_2 assemblages, reducing them to talc-chlorite phyllonites. Later splays of tremolite overgrow the associated S_2 fabric suggesting that the D_2 event at the NCGM occurred simultaneously with the M_2 metamorphism, but that the metamorphism continued after the deformation had ceased.

The Consort pegmatites generally occur within the metamorphic aureole of the M_2 event. As with the majority of rare element pegmatites around the world, the Consort pegmatites also occur within upper-greenschist to lower-amphibolite metamorphic terranes. The pegmatites intrude into D_2 structures (see later) that became inactive while metamorphism was ongoing. Metamorphism continued after deformation and pegmatite emplacement, suggesting that the magmatic body which created the contact metamorphism of the greenstone belt was present during pegmatite emplacement. This implies that the parental magma responsible for the pegmatite formation also caused the M_2 metamorphism, and should occur to the north or northeast of the NCGM.

Mineralization

Three distinctive types of gold mineralization have been recognised at the NCGM (Tomkinson and Lombard, 1990), referred to as the Consort Contact, the Footwall Lens and the Witkoppies Shoots. The Consort Contact mineralization is amphibolite hosted and lies immediately below the Consort Bar. In some places the Bar itself may be mineralized. The dominant sulphide associated with this style of mineralization is arsenopyrite. Arsenopyrite generally occurs as fine needles but occasionally may occur as coarse-grained blocky crystals. Other sulphides associated with the arsenopyrite are pyrrhotite and chalcopyrite. The majority of the gold is free milling (60-80%) and is often located on the grain boundaries of other sulphide minerals in this assemblage. The Consort Contact shoots are typically 2 to 3 m thick with a strike length of about 24 to 40 m. Some of the major ore shoots tend to plunge southeast, but some shoots plunge in a southwesterly direction. The ore shoots are thought to be controlled by NE-SW trending shear zones. The orientation of these steeply

dipping shear zones is locally modified when they intersect different lithologies. The change in orientation results in the dilation of the shear zones allowing the further influx of mineralizing fluids. The Consort Contact style of mineralization is the most important in the NCGM. These ore shoots generally exhibit the highest grades, but are limited by their small strike lengths and dip extensions.

The Footwall Lens Shoots are found between the footwall amphibolites and a serpentinite body, below the Consort Bar. Arsenopyrite is again the dominant sulphide, occurring as coarse blocky crystals in the ore zone. Other sulphides in these ore-shoots are loëllingite, along with variable amounts of pyrrhotite and chalcopyrite. Loëllingite can locally form up to 70% of the ore minerals in the Footwall Lens Shoots and 90% of the gold occurs on sulphide and silicate grain boundaries. The albite-rich amphibolite of the Footwall Lens is the host rock to this style of mineralization. The Footwall Lens ore shoots are thought to be controlled by the same NW-SE trending shear zones as the Consort Contact Shoots.

The Witkoppies Shoots are hosted in porphyritic schists interpreted as early high-level granite intrusions. This ore is thought to predate the earliest phase of deformation (D_1) and Tomkinson and Lombard (1990) have suggested that the Witkoppies mineralization formed during or shortly after the intrusion of the granite porphyries. The main sulphides in these shoots are pyrite, pyrrhotite and sphalerite, which are accompanied by free milling gold.

STRUCTURAL SETTING OF PEGMATITES AT THE NCGM

Innumerable pegmatite bodies occur in the working areas of the NCGM. Many of these have similiar structural characteristics and can be grouped together. Three major groupings, namely the pegmatite veins, the Shires pegmatites and the MR pegmatites account for the majority of the pegmatites in the area. The MMR and the PC pegmatites are two large bodies which warrant separate description below.

Pegmatite veins are found in several localities throughout the working areas of the NCGM and two types have been recognized. The one set parallels, but overprints the S_1/S_0 fabric while the other set cross cuts the S_1 fabric at a high angle. Pegmatite veins cut gold mineralization in the SI 19 stope of the MMR section of NCGM. Elsewhere pegmatite veins are observed to have been incorporated and deformed by the D_2 deformation in the SSZ. D_3 related Bluejackets structures also displace and deform pegmatite veins in several localities. The pegmatite veins were, therefore, intruded during the D_2 deformation event.

The Shires pegmatites are confined within the SSZ and trend in a NW-SE direction. The majority of these pegmatites exhibit a mylonitic fabric which has itself been transposed during later deformation. Some of the pegmatites show a mineral growth lineation suggesting that they were emplaced during the deformation. The mylonitic fabric has been ascribed to the S_2 fabric of the D_2 related SSZ. Kinematic indicators from the pegmatites indicate an oblique sense of movement showing a west block up motion with a minor sinistral component for the SSZ. D_3 related Bluejackets faulting clearly cuts and displaces the SSZ and the Shires pegmatites. Ore shoots in the 7 Shaft section parallel the SSZ and the Shires pegmatites suggesting that they have been incorporated into this D_2 structure.

A set of five pegmatite bodies trending NE-SW have been termed the Main Reef (MR) pegmatites and are labelled MR2 to MR6 with increasing depth in the mine. These pegmatites cut the Consort Bar (S_1 fabric) and associated gold mineralization, and intrude the footwall amphibolites but do not penetrate far into the hanging wall metasediments. The MR pegmatites appear to have intruded into kink-like folds that deform the Consort Bar. The fold axes of the kink folds plunge moderately to the southwest. Of all the mine lithologies affected by the kink folding, the less competent, more fissile footwall amphibolites appear to have been the most amenable to pegmatite intrusion. The relationship between the SSZ and the MR pegmatites is not seen, but the final increments of movement on the D_2 related Ivaura fault zone cut the MR3 pegmatite. The MR pegmatites have also been displaced by D_3 Bluejackets faulting and in certain localities appear to have been transported as phacoidal blocks into the Bluejackets fault zone. The MR pegmatites were also, therefore, emplaced pre-D_3 and are probably syn-D_2.

The Maid Main Reef (MMR) pegmatite occurs in the MMR section of the NCGM. Several Bluejackets faults occur in the vicinity of this body. This faulting obscures the original orientation and intrusive position of the MMR pegmatite, but indicates that they pre-date the D_3 deformational event. The mylonitic fabric in the MMR pegmatite is similar to that of the Shires pegmatites, suggesting that it may be related to the Shires pegmatite intrusive event and hence the D_2 deformation.

The Prince Consort (PC) pegmatite, which occurs in the PC Bottom section of the mine, has a dyke-like aspect and trends north-south. The pegmatite cuts the S_1/S_0 host rock fabric at a high angle, and occurs in the footwall amphibolites as well as in the hanging wall metasediments. The fabric in the PC pegmatite parallels the fault-bound contact of the pegmatite. Late movement on the Consort Bar displaces the PC pegmatite causing an approximate east-west fabric to overprint the major north-south trending fabric. The PC pegmatite is cut by the final increments of motion on the D_2 related MMR fault suggesting that it, like all the other pegmatites, is syn-D_2 deformation.

In very few instances was it possible to observe the various pegmatite types in contact with one another, and where such relationships do occur they are equivocal. It is clear from the evidence above that the various pegmatites have been emplaced post-D_1 and pre-D_3 deformation. The exploitation of the early D_2 structures by the pegmatites, and their subsequent deformation by later D_2 structures, indicate that all these pegmatites are syn-D_2 deformation, but were emplaced during a relatively long-lived event. It is, therefore, likely that the Consort pegmatite suite represents a single, but extended, pegmatite intrusive event, and that structural differences between the pegmatites are due to the nature and ductility of the features and host-rocks into which they were emplaced.

MINERALOGY OF RARE-ELEMENT PEGMATITES

The pegmatites at the NCGM can be divided into three sub-types on the basis of their mineralogy and zonation. The three mineralogical sub-types identified are; albite pegmatites, albite-spodumene pegmatites and K-feldspar-albite pegmatites. This classification, based on Cerny (1990), recognizes pegmatite types on the basis of mineralogy, zonation and textures, and ignores the effects of deformation and later alteration.

K-feldspar-albite pegmatites

Typical mineral constituents of the K-feldspar-albite pegmatites are quartz, plagioclase, K-feldspar and muscovite with lesser amounts of garnet, tourmaline, zircon, sericite, sulphides and oxides. In the K-feldspar-albite pegmatites three major zones asymetrically distributed around the core zone are identified. An outer quartz-albite zone [1] forms on the edges of the pegmatite bodies and is best developed where the MR pegmatites are found in the vicinity of the Consort Bar contact. The zone is homogeneous, grey in colour and consists predominantly of quartz and plagioclase, with variable muscovite, K-feldspar and garnet. This zone is similar to the quartz-albite zones of the other two pegmatite types. It constitutes approximately 20-30% of the pegmatite, but this can vary markedly. Most K-feldspar-albite pegmatites contain a quartz-albite zone [1].

A quartz-albite-K-feldspar zone [1a] sometimes occurs as a transition from zone [1] to the intermediate zone [2]. Zone 1a comprises quartz, plagioclase, K-feldspar, muscovite, and variable amounts of garnet. K-feldspar is often perthitic and occasionally exhibits a graphic texture. Muscovite is relatively abundant in zone 1a. The transitional zone is found in most of the K-feldspar-albite pegmatites and constitutes up to 40% of the pegmatite.

Zone 2, comprising graphic-textured quartz-K-feldspar, usually forms after zone [1] or zone [1a]. Muscovite, plagioclase and garnet occur as minor phases and are typical zone [2] assemblages. The graphic quartz-K-feldspar zone can occupy between 10 and 30% of the K-feldspar-albite pegmatites.

Blocky quartz-K-feldspar and blocky quartz-feldspar-muscovite-garnet zones form the inner portions of the K-feldspar-albite pegmatites. Large euhedral crystals form in a matrix of quartz-rich material. The inner zone typically forms less than 5% of the pegmatite, and may also be absent.

Albite-spodumene pegmatites

Albite-spodumene pegmatites comprise quartz, albite and spodumene, with lesser amounts of K-feldspar, muscovite and garnet. The distribution of spodumene varies as a function of the internal zonation within these pegmatites. Accessory phases that have been identified include tourmaline, ixiolite, gahnite, zircon, sericite, holmquistite, sulphides and oxides. Several different zones have been recognized in the albite-spodumene pegmatites. The quartz-albite zone [1] forms the outer edge of the albite-spodumene pegmatites. This zone has in places been found towards the centre of the pegmatite, such as in the 7 Shaft area, but this may only be due to the transposition and folding of the pegmatite body. Zone [1] can be coarse to fine grained, exhibiting features similar to the saccharoidal quartz-albite zone [2] of the albite pegmatites. Spodumene can occur in this zone but generally increases inwards towards the next zone. The quartz-albite zone constitutes between 10 to 40% of the albite-spodumene pegmatites, and is found in most pegmatites of this sub-type.

The quartz-albite-spodumene zone [2] generally occurs inwards from the quartz-albite zone [1]. Zone [2] is usually medium- to fine-grained, but occasionally becomes coarse-grained. Accessory phases of this zone are muscovite, garnet, ixiolite and gahnite. The

albite-spodumene zone constitutes a large volume of the pegmatites and occurs in most, if not all of the albite-spodumene pegmatites.

The albite-quartz-K-feldspar-spodumene zone [2a] is a variant of zone [2] and these two zones grade into one another. The zone shows similar features to the quartz-albite-spodumene zone [2], but differs in the abundance of K-feldspar. Accessory phases are similar to those in the quartz-albite-spodumene zone [2], although abundances may vary. Zone [2a] also occurs in most of the albite-spodumene pegmatites.

The quartz-spodumene zone [2b] is another variation of zone [2]. This zone is a coarse- to very coarse-grained and forms towards the centre of the pegmatite. Quartz and spodumene are the major mineral phases in this zone, with minor amounts of feldspar and muscovite. Zone [2b] forms less than 5% of the pegmatite, and does not occur within all the albite-spodumene pegmatites. Spodumene occurs as discrete primary grains and is the only lithium aluminosilicate phase to have been observed in the pegmatites.

Albite pegmatites

The albite pegmatites vary from dark grey to grey-white in colour with variations being due to zonation. The dominant mineral assemblage of this sub-type is albite and quartz, with variable amounts of minor muscovite and K-feldspar. Other accessory phases are biotite, garnet, tourmaline, zircon, ixiolite, oxides, sulphides and sericite. Some of these phases, such as sericite, are later alteration phases of the pegmatites. K-feldspar commonly occurs as a dark grey to black mineral, showing perthitic textures. Several zones have been identified in the albite pegmatites.

A symplectic quartz-albite zone [1] occurs on the edges of the albite pegmatites. This zone consists predominantly of symplectic-textured quartz and albite. Muscovite occasionally occurs as a minor component and often grows perpendicularly to the pegmatite contact. Zone [1] is generally less than 5cm wide and makes up less than 5% of the pegmatite volume. This zone is found in most albite pegmatites at the NCGM.

The saccharoidal quartz-albite zone [2] occurs inwards from zone [1], particularly in the pegmatite veins, and occurs as a fine-grained "sugary" textured, dark grey, phase. The main minerals in this zone are quartz and albite, which exhibit an equigranular texture. Muscovite, K-feldspar and garnet occur in variable amounts as accessory phases within the zone. In some pegmatite veins albite may be dominant, forming an almost pure albite-rich rock. Zone [2] occurs in all albite pegmatites, constituting the major zone.

A quartz-albite-K-feldspar zone [2a] forms a transitional zone between [2] and [3]. The inner zone [3] is weakly developed and is marked by a dominance of K-feldspar. The amount of muscovite in zone [2a] tends to increase with increasing K-feldspar, whereas garnet is unevenly distributed throughout the zone. In most cases zone [2a] constitutes less than 5% of the pegmatite veins, and is not always present in the zonal sequence. In certain cases it can totally substitute for zone [2].

TABLE 1

MAJOR AND TRACE ELEMENT ANALYSES OF PEGMATITE SUB-TYPES AT NCGM

-12-

	K-Feldspar-Albite Sub-type						Albite-Spodumene Sub-type				Albite Sub-type			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SiO_2	76.70	77.80	77.20	75.40	74.63	73.83	74.40	74.90	73.60	77.30	72.60	74.00	69.30	67.70
Al_2O_3	14.20	13.90	13.20	14.70	14.58	14.82	15.60	15.70	16.80	16.10	17.30	15.80	16.70	19.00
Fe_2O_3	.90	.67	.53	.92	.96	.45	.59	1.14	.61	.75	.65	.38	.38	.54
MnO	.10	.08	.04	.08	.02	.02	.14	.10	.10	.10	.10	.02	.04	.02
wt% MgO	.03	.06	.17	.15	.40	.33	.01	.51	.08	.01	.39	.19	3.17	.80
CaO	.27	.26	.25	.31	.37	.21	.33	.46	.23	.17	.37	.44	.51	.80
Na_2O	4.70	3.20	3.60	3.20	4.39	3.07	4.40	3.40	3.80	3.00	4.00	6.00	5.90	8.90
K_2O	2.47	2.82	4.18	4.62	3.82	7.92	3.02	2.32	3.64	1.49	3.02	1.46	.65	.11
P_2O_5	.03	.03	.03	.02	.07	.08	.14	.10	.09	.06	.33	.33	.33	.47
L.O.I.	.37	.61	.32	.28	.68	.30	.41	.48	.35	.38	.50	.45	1.54	.82
TOTALS	99.77	99.43	99.52	99.68	99.91	101.02	99.04	99.11	99.24	99.36	99.26	99.07	98.52	99.16
Rb	606	583	776	548	295	605	1788	1377	1812	981	3521	1539	1167	334
Sr	29	21	40	23	17	15	46	37	51	24	75	35	72	74
ppm Zr	16	16	ND	ND	22	18	ND	12	ND	11	15	21	14	ND
Y	15	10	10	15	27	26	ND	ND	ND	ND	ND	ND	ND	ND
Nb	45	31	43	30	29	11	47	63	36	55	47	45	46	48
Li	34	36	18	10	10	3	606	1225	1439	2290	948	40	668	21
Ti	57	91	ND	57	60	60	57	137	17	57	114	99	160	103
Sn	14	15	19	10	-	-	43	47	22	49	145	83	76	17
Cs	20	48	20	26	-	-	49	76	85	118	305	108	1179	283
Ta	20	20	20	20	-	-	68	70	20	39	159	141	75	250
Be	10	10	17	10	-	-	20	27	39	28	23	36	22	10

Columns
1-4 : MR pegmatites (MR 2, 3, 5, 6)
5-6 : PC pegmatite
7-10 : Shires (shear zone) pegmatites
11-14 : Pegmatite veins

ND : not detected

Structural setting of mineralogical sub-types

Albite pegmatites occur only as pegmatite veins in the MMR and Witkoppies sections of the NCGM. A few albite pegmatites are also found within the SSZ. Generally the albite pegmatites occur as small veins and not as large extensive bodies. The Shires pegmatites and the MMR pegmatite body are all the albite-spodumene variety. Albite-spodumene pegmatites, therefore, generally occur in well-defined shear zones as large bodies, but can also form as small vein-like intrusions. K-feldspar-albite pegmatites occur mainly as large lenticular bodies and are represented by the MR pegmatites and the PC pegmatite body. Apparent differences between the MR and PC pegmatites are due to differences in the degree of deformation. Pegmatite veins which occur in the PC section of the NCGM are also represented by the K-feldspar-albite sub-type.

CHEMICAL CHARACTERISTICS OF RARE-ELEMENT PEGMATITES

Rare-element pegmatites are classified into two groups (Cerny, 1991). The first, designated LCT (i.e. lithium, cesium, tantalum rich) is enriched in Li, Cs, Rb, Be, Sn, B, P and F, have $Nb \leq Ta$ and are depleted in Ti, Zr, Y and REE. LCT pegmatites are common world-wide, are internally zoned, and usually exhibit regional zonation about a parent granite which is metaluminous-to-peraluminous and syn- to late-orogenic. The second group, designated NYF (niobium, yttrium, fluorine rich) is enriched in Y, REE, Ti, Zr, Be, U, Th and F, have $Nb > Ta$ and very low P, B and rare alkali contents. The NYF pegmatites are associated with anorogenic or post-orogenic granites which tend to be metaluminous or peralkaline. Within each of the groups, however, it is possible to find extreme variations in the degree of fractionation, which reflect zonation and crustal inheritance (Cerny, 1989).

A representative selection of chemical analyses from all the NCGM pegmatite sub-types is presented in Table 1. Major elements tend to reflect the dominant mineralogy of the pegmatite sub-type. Most of the pegmatites, however, are characterized by high SiO_2 (generally > 73 wt.% except for the albite pegmatites) and very low TiO_2 and CaO contents (generally < 150ppm and 0.5 wt.% respectively). K_2O/Na_2O ratios vary as a function of the variable proportion of microcline and albite which is due both to internal zonation and a regional fractionation trend emanating from the parental magma source.

Lithium contents tend to be low (3-40 ppm) in the K-feldspar-albite pegmatites but increase markedly (40-950 ppm) in the more fractionated albite pegmatites. The albite-spodumene pegmatites have Li contents ranging between 600-2300 ppm. Cs contents show a progressive increase with fractionation and range from 20-50 ppm in the K-feldspar-albite pegmatites to 100-1200 ppm in the most fractionated albite variety. Y and Zr contents are very low in all three pegmatite sub-types. These characteristics clearly indicate that the NCGM pegmatites belong to the LCT rather than the NYF category, a feature which is also in accord with their regional characteristics. Unlike most LCT pegmatites, however, Nb and Ta contents are generally low in all the pegmatite sub-types (Nb 25-60 ppm; Ta 20-250 ppm) and Nb/Ta ratios are ≥ 1 in the less differentiated varieties and only follow the stereotype in the albite pegmatites where Nb/Ta is typically 0.2-0.6.

Fractionation trends

Trace element abundances and ratios (K/Rb, Ba/Rb, Rb/Cs, Al/Ga, Rb/Sr etc) are useful indicators of fractionation trends in pegmatites (Cerny 1989; Goad and Cerny, 1981; Shearer *et al.*, 1987; Cerny *et al.*, 1985; Simmons *et al.*, 1987). Although there is a wide variation of element abundances and ratios within individual NCGM pegmatites, there are clear patterns which emerge between the various mineralogical sub-types.

K/Rb ratios are the most consistent of the fractionation indicators in this study and exhibit the least variation within individual pegmatite sub-types. Although K and Rb vary in abundance, the individual pegmatite sub-types are characterized by remarkably consistent K/Rb ratios (Figure 4). Variations in K and Rb abundances within pegmatite bodies are clearly a function of mineral zonation. The zonation in the pegmatites indicates that in situ fractional crystallization has been in effect during cooling of the pegmatitic magma. Fractional crystallization should result in a decrease in the K/Rb ratio towards the most highly fractionated inner portion of the pegmatite. However, this is generally not the case, and K/Rb ratios remain remarkably constant within individual sub-types, suggesting that the earlier-formed outer zones of the pegmatites have re-equilibrated with the residual magma and its attendant vapour phase. Thus, irrespective of internal zonation, pegmatite sub-types appear to reflect a consistent K/Rb ratio that is characteristic of a particular degree of fractionation from a single parental magma. It is suggested that the remarkable consistency observed in K/Rb ratios may be due to the high activity of the pegmatite fluid phase which is responsible for homogenizing mobile trace element ratios.

The most highly fractionated pegmatites, in terms of K/Rb, K/Cs and Rb/Cs, appear to be the albite pegmatites which occur as pegmatite veins in the MMR and Witkoppies sections. The least fractionated are the K-feldspar-albite pegmatites, with the albite-spodumene variety occupying an intermediate position.

The Shires pegmatites, which belong to the albite-spodumene and, to a lesser extent, the albite sub-type, exhibit average K/Rb ratios of around 15. These low values indicate high degrees of fractionation. The K/Rb ratio remains remarkably consistent within these pegmatites which, given the well-defined zonation and extensive albitization, points to pervasive trace element re-equilibration. Other fractionation indicators such as Mg/Li, K/Cs, Rb/Cs, and K/Li ratios also remain relatively constant and confirm that the Shires pegmatites are highly fractionated. Albite pegmatites, particularly in the Witkoppies and MMR sections of NCGM, are the most highly fractionated in the study area and tend to have lower K/Rb ratios than the albite-spodumene pegmatites from the SSZ.

The K-feldspar-albite sub-type is well represented by the MR pegmatites which have higher K/Rb ratios (around 40) and are less fractionated than the Shires pegmatites. Although there is limited data available on the other MR pegmatites a weak fractionation trend is observed in passing from the MR6 pegmatite through to the MR2 pegmatite (Table 1). The lowest K/Rb ratio and highest degree of fractionation are seen in the M2 pegmatite with the K/Rb ratio increasing progressively through the MR3 and MR5 bodies to the MR6 pegmatite which exhibits the lowest degree of fractionation. Fractionation levels within the MR pegmatites, therefore, seem to increase towards the present day surface and in a
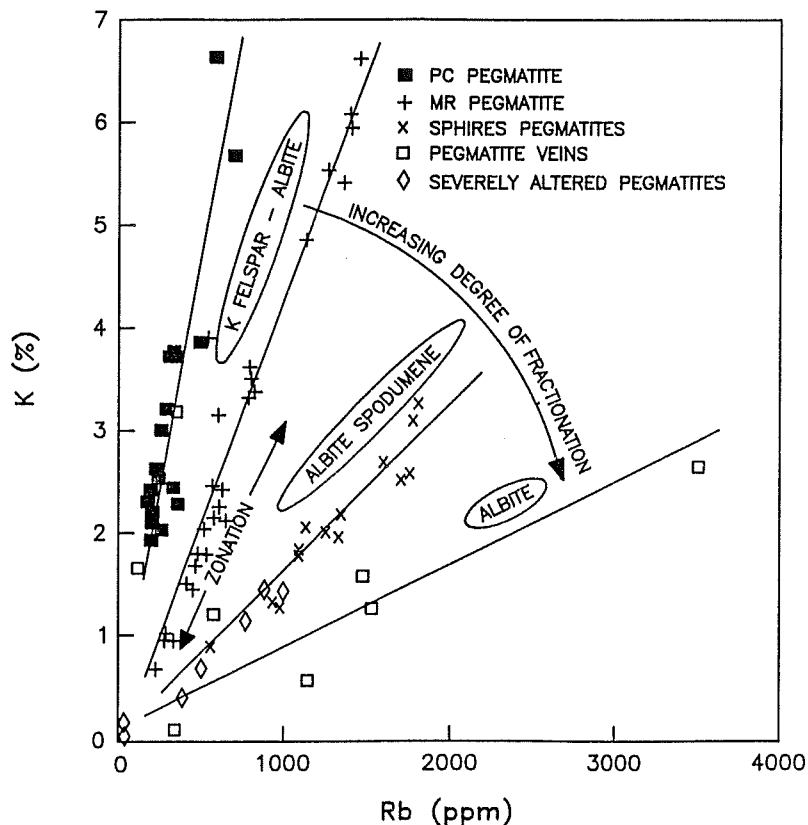
Figure 4: K-Rb plot of the different pegmatite types in the New Consort Gold Mine study area. Fractionation, giving rise to the pattern of regional zonation, is marked by the trend towards lower K/Rb ratios in going from K-feldspar-albite, through albite-spodumene to albite pegmatites. Variations of K and Rb along the constant K/Rb trend lines reflect internal pegmatite zonation.

westward direction.

The PC pegmatite seems to show the largest degree of scatter in K/Rb ratios and also the lowest degree of fractionation in the NCGM area. The most fractionated samples occur towards the coarse, crystalline centre of this body, while the less fractionated portions occur on the margins of the pegmatite. Although there is a general increase in fractionation towards the centre, the inner and outer portions are clearly defined by their K/Rb ratios of approximately 70 and 100 respectively. This trend of decreasing K/Rb ratios inwards suggests that there has been only limited re-equilibration in the pegmatite, which also accords with its low degree of fractionation and, possibly, limited fluid interaction.

In summary, the K-feldspar-albite pegmatites show the lowest degrees of fractionation, and occur in the lower levels of the mine, and towards the east. Progression to higher degrees of fractionation is reflected in the albite-spodumene pegmatites found at higher elevations within the mine workings. The albite-spodumene pegmatites are found in the SSZ ,and on the surface westwards of the SSZ. The albite pegmatites occur as pegmatite veins mainly in the upper levels of the mine, and occasionally above the Bluejackets fault

zone. K/Rb ratios generally confirm that fractionation increases towards the west of the mine workings and from the deeper sections of the mine towards the surface. The regional fractionation trends at NCGM indicate that the source of pegmatitic magma may have been below and to the northeast of the present lowest levels of the mine. In this case the less fractionated K-feldspar-albite pegmatites would occur preferentially in the deeper, northeasterly portions of the mine, with the more highly fractionated albite-spodumene and albite pegmatites appearing at shallower levels and in the southwesterly portions of the NCGM. This scheme is also in accordance with observations that the metamorphic grade in the area increases towards the north and northeast in the region, and that pegmatites become more voluminous with depth.

Pegmatite chemistry in relation to NB and KVT

The NB and KVT exhibit markedly differing crystallization histories which are pertinent in considerations relating to the suitability of either of the two bodies as a magma source for the NCGM pegmatites. The homogeneous tonalite of the KVT exhibits a very restricted range of compatible and incompatible trace element contents and is believed to have crystallized in an equilibrium mode (Robb *et al.*, 1986). In contrast, the NB shows pronounced trace element variations which reflect in situ crystal fractionation related to filter pressing and more rapid cooling of the batholith margins relative to the core (McCarthy and Robb, 1978). A K versus Rb plot of data from the NB, KVT and NCGM pegmatites (Figure 5) shows that the NB and NCGM define a co-linear trend that could be interpreted as a single liquid-line-of-descent. This implies that the pegmatites could be the fractionated equivalents of the NB. By contrast, the KVT data is chemically unrelated to the NCGM pegmatites and could not have given rise to the formation of the latter. This observation is also supported by the fact that the KVT has few, if any, pegmatites associated with it.

ALTERATION

A relationship exists between the intensity of alteration and the degree of fractionation of the NCGM pegmatites. The more highly fractionated albite-spodumene and albite pegmatites are more pervasively albitized and have undergone a greater degree of silicification than the K-feldspar-albite pegmatites, suggesting that the more highly fractionated pegmatites have equilibrated more effectively with a larger volume of hydrothermal fluid.

Alteration of the rare-element pegmatites in the study area is dominated by Na, K, Si and Li metasomatism which results in albitization, silicification, holmquistite and biotite formation and the development of a mica selvage. Tourmalinization is also seen on the edges of the pegmatites indicating the presence of boron-rich fluids. Albitization and silicification occur within the confines of the pegmatite bodies, usually in wide zones several tens of centimetres in extent. By contrast, K-metasomatism is focussed along the edges of the pegmatite bodies and is represented by a micaceous selvage and sericitization of the marginal zones. This alteration does not pervade large portions within the pegmatites. Two reasons can be suggested for these observations. Firstly, the K-metasomatism post-dated Na-metasomatism and occurred under subsolidus conditions, which may have had the effect of
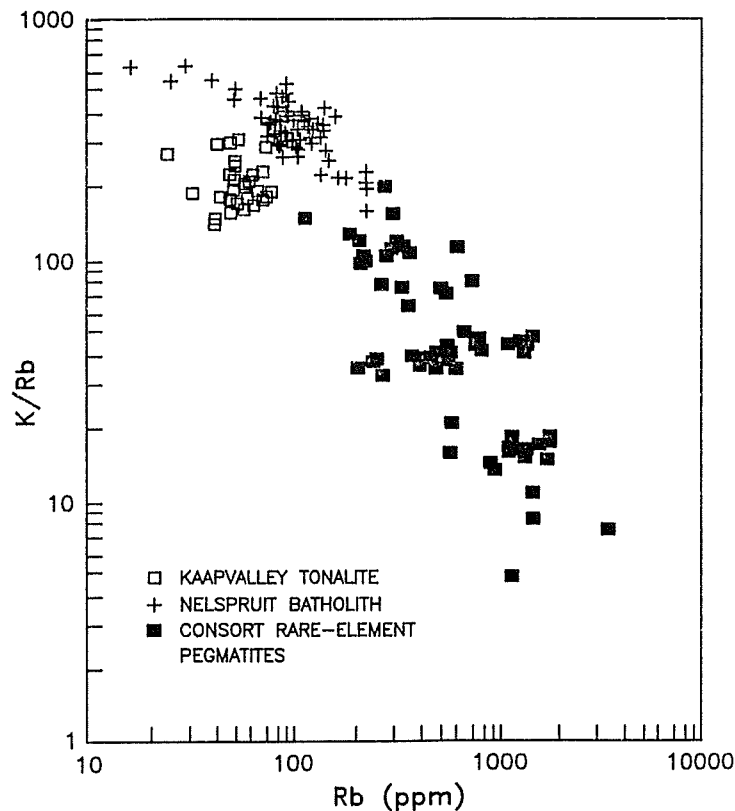
Figure 5: Plot of K/Rb versus Rb for data from the Kaap Valley Tonalite, the Nelspruit batholith and the New Consort Gold Mine pegmatites. The Nelspruit batholith and New Consort data form a co-linear trend suggesting a single liquid-line-of-descent. This trend is compatible with the suggestion of a genetic link between the Nelspruit batholith and the New Consort pegmatites.

limiting fluid flow to the outer limits of the pegmatite bodies. Similar features were reported by London and Burt (1982a) who showed that albitization becomes less prominent at the expense of sericitization later in the pegmatite evolutionary history. Secondly, the relative solubilities of K and Na probably dictate the distance that the two elements can be transported in a fluid system and, hence, determines the nature of alteration zonation. Biotite selvages around pegmatite bodies have been noted to contain anomalous concentrations of gold.

Late alteration includes quartz-feldspar-carbonate-holmquistite veins that cross-cut the pegmatites and late sericitization on the edges of all the pegmatite sub-types.

Fluid inclusion characteristics

Fluid inclusion studies on the rare-element pegmatites at the NCGM proved difficult since the inclusions were very small, having presumably been affected by the intense deformation prevailing in the host rocks. Large, primary inclusions were not observed and

data was only obtained from secondary fluid inclusion trails trapped during the sub-solidus history of the pegmatites. Three different fluid populations have been recognized:

1. Type I H_2O-CO_2; these inclusions were generally 20-30 microns in diameter and occur in broad trails that cut grain boundaries. CO_2 has mean melting and homogenization temperatures of -57.8°C and +6.5°C respectively, implying a CH_4 content of around 6 mole% and a density of 0.95 g.cm^{-3}. Clathrate melting of the inclusions (mean +9.0°C) indicated a low salinity (2 wt.%eNaCl) while global homogenization was usually preceded by decrepitation at ≥210°C (Figure 6a).

2. Type II low-salinity aqueous; these are a minor population in the NCGM pegmatites and occur as small irregular inclusions within late trails. The inclusions exhibit mean melting temperatures of -5.5°C (and salinities of around 6 wt.%eNaCl) and homogenization temperatures of 230°C (Figure 6b and c). Initial melting temperatures were difficult to determine but available data suggests an event at around -16.5°C; and

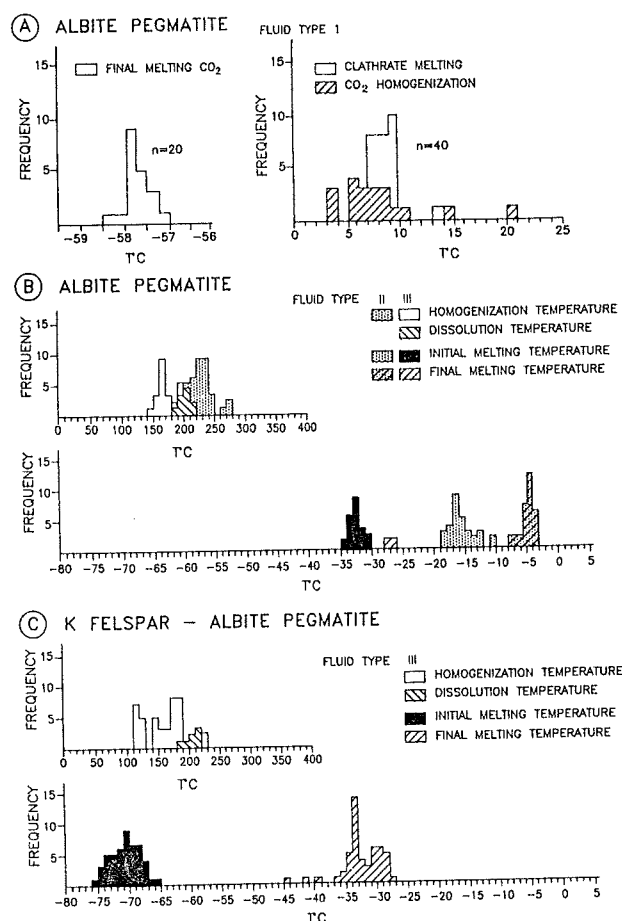*Figure 6: Fluid inclusion microthermometry data for the New Consort Gold Mine pegmatites:*
A. data for H_2O-CO_2 inclusions from pegmatite veins in the PC section. B. data
for Type II and III aqueous inclusions from pegmatite veins in the PC section.
C. data for Type III aqueous inclusions in the PC pegmatite body.

3. Type III high-salinity aqueous; these inclusions represent the most common fluid population in the NCGM pegmatites. Many of the inclusions were large (>50 microns) and often contained a single isotropic daughter crystal, or several daughter phases. Initial melting temperatures of these inclusions indicated a mean of -69°C for the PC pegmatite and -33°C for the pegmatite veins. This suggests that these fluids are complex and probably represented by the systems $H_2O-NaCl \pm MgCl_2 \pm CaCl_2$. Final melting generally occurred between -27 and -35°C. Dissolution of single daughter crystals suggested salinities of around 30 wt.%eNaCl, while (L→V) homogenization temperatures were in the range 110 to 280°C (Figure 6b and c).

It is noteworthy that all three fluid populations are only observed in relatively undeformed samples; furthermore, microthermometry data became increasingly inconsistent with progressive deformation and alteration, suggesting that inclusions were subjected to leakage and volume distortions. Fluid inclusion studies of the Tanco rare-element pegmatite in Manitoba revealed similiar aqueous and H_2O-CO_2 populations, interpreted as reflecting the magmatic-hydrothermal transition of that particular body (London, 1986). Isochoral trends and ranges for the three NCGM fluid populations are plotted in Figure 8, where they are used in the construction of a P-T cooling path for the latter.

ISOTOPE CHARACTERISTICS

Allsopp *et al.* (1968) carried out Rb-Sr isotopic analyses on whole rock samples as well as muscovite, feldspar and spodumene separates from the rare-element pegmatites at the NCGM. This study indicated a "most reliable" age of 3000±30Ma which, is re-calculated to 2940±30Ma with the new decay constant. Allsopp *et al.* (1968) also suggested that assimilation of Consort Bar material by the pegmatites introduced anomalous Sr into the system resulting in the large errors within the data.

During the present study the NCGM pegmatites were re-analysed for their Rb-Sr isotopic ratios. Samples were taken of a Shires pegmatite, the MR3 and PC pegmatites and a K-feldspar-albite vein. These data (Harris *et al.*, in prep.) yield an errorchron with a slope equivalent to 3081 ± 54 Ma and initial ratio of 0.7280 ± 0.0260. When regressed together with the Allsopp *et al.* (1968) data an age of 3040 ± 39 Ma is obtained.

Sm-Nd isotopic analyses were also carried out on garnet separates from samples of the PC pegmatite. These garnets are characterized by extremely high $^{143}Nd/^{144}Nd$ ratios (Harris *et al.*, in prep.) which, when plotted on a Nd evolution diagram, yield model ages that are essentially independent of a reference reservoir or crustal pre-history at 3,1 ± 0,05Ga.

The isotope data from the present study suggest that the NCGM pegmatites were probably formed between about 3080 ± 50Ma (a "minimum" provided by the Rb-Sr whole rock data) and 3100 ± 50Ma (a "maximum" provided by the Sm-Nd garnet model age). The two major granite bodies that occur to the south and north of the study area are the 3227 Ma KVT and the 3105 Ma NB. These ages indicate that the NCGM pegmatites are more likely to have been derived from the Nelspruit event, a suggestion that is supported by the

liquid-line-of-descent argument presented above and the fact that the NB contains abundant pegmatitic phases while the KVT is devoid of such rock types.

DISCUSSION AND CONCLUSIONS

Origin of the pegmatites

The study area is characterized by a complex, varied suite of pegmatites that by and large have been intensely deformed. Structural studies indicate that the pegmatites were emplaced subsequent to the earliest phase of deformation but prior to late deformation identified in the mine area as the Bluejackets Fault zone. Emplacement therefore coincided with an intermediate or D_2 period of deformation which may also have been associated with gold mineralization in the region. The pegmatites belong to the LCT rare-element class which are usually associated with meta- or peraluminous syn- to late-orogenic granitoids. The pegmatites are internally zoned and also exhibit a well-defined regional fractionation trend which generally identifies less fractionated pegmatite types with increasing depth and towards the northeast of the study area.

Chemical trends indicate that the NCGM pegmatites could be the highly fractionated equivalents of the NB, with the two data sets defining a single apparent liquid-line-of-descent. Chemical characteristics of the KVT, on the other hand, are distinctly different from the NCGM-NB trend. Whole rock Rb-Sr and Sm-Nd model ages suggest that the pegmatites are between ca. 3.08 and 3.10 Ga old, constraints which are supported by what is known of the timing of deformational events and the emplacement of pegmatites relative to those deformation events. All the above characteristics are consistent with derivation of the NCGM pegmatites from a source magma represented by the 3105 Ma old NB. The other major granitoid body in the vicinity of the study area, the 3227 Ma old KVT, is too old, and is petrogenetically and chemically unsuitable as a source magma for the NCGM rare-element pegmatites. A summary of the deformation events envisaged in the study area and the various stages of granitoid emplacement is presented in Table 2.

A schematic model showing the main elements pertaining to the origin of the NCGM pegmatites is shown in Figure 7. The southern, pegmatite-rich margin of the NB is shown dipping steeply to the south, below the mine workings. Volatile-rich apophyses of the granite intrude upwards along suitable structural pathways, such as the SSZ and the MR fractures. K-feldspar-albite pegmatites are intruded mainly into the MR structures and also as major pegmatite dykes (the MMR and PC bodies) in the lower levels of the mine workings. The MR pegmatites become progressively more fractionated upwards in the MR zone, from MR5 to MR2. Smaller, more highly differentiated pegmatite bodies and veins concentrated further away from the source magma, especially in the major SSZ structure. Deformation in this zone appears to have been longer-lived and of a more ductile nature, which accounts for some of the differences in the nature of the pegmatites from one part of the mine to another.

TABLE 2

RELATIONSHIP BETWEEN DEFORMATION AND MAGMATIC EVENTS
PERTINENT TO THE STUDY AREA

	DEFORMATION AND MAGMATIC EVENTS	DEFORMATION STYLE/AGES
D_1	-Formation of the Consort Bar tectonite -Duplication and folding of the Consort Bar	Recumbent isoclinal folding and associated tectonic slides
	-Formation of early synclines and associated faults in northern BGB	
	Kaap Valley Tonalite emplacement	3227Ma
	-Continued deformation of early structures and associated faults in northern BGB -Arcuation of the Eureka syncline	Compressive deformation in NW-SE direction
	Fairview porphyry emplacement	3126Ma
D_2	-Beginning of major gold mineralization	
	Nelspruit Batholith emplacement	3105Ma
	-SSZ formation or reactivation with dominantly west block up and minor sinistral displacement -Intrusion and deformation of the Consort pegmatites -End of major gold mineralization	Compressive deformation in approximate NW-SE direction
	-Final movement on Ivaura, MR and MMR fault zones, exhibiting a strong horizontal component. -Late dextral west block down movement on shears in the SSZ.	Continued D_2 deformation or reactivation of D_2 structures by D_3 deformation
D_3	-Bluejackets fault development. -Displacement of gold mineralization, the SSZ and the Consort pegmatites	Normal faulting with horse and rider structures developed

SW   NE

NCGM MINE AREA

SURFACE

MR2

MR1
STRUCTURE

Albite

SHIRES SHEAR ZONE

K-Felspar-
albite

MR5

Albite-
Spodumene
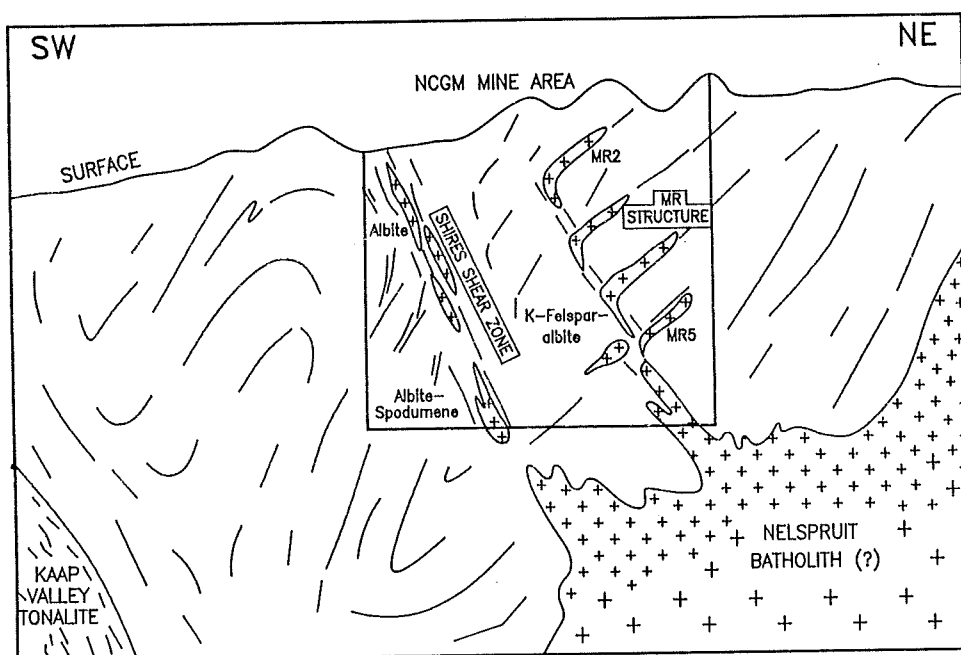
NELSPRUIT
BATHOLITH (?)

KAAP
VALLEY
TONALITE

Figure 7: Schematic model for the emplacement of the various pegmatite types at the New Consort Gold Mine. The pegmatites become less fractionated with depth and towards the northeast. The Nelsprut batholith is believed to be the most likely candidate for the pegmatite source magma. Pegmatite characteristics are largely determined by the nature of the deformational feature into which they were emplaced, and also the relative timing of emplacement during the prolonged D_2 event.

Sub-solidus evolution of the pegmatites

The primary mineral phases present in the NCGM pegmatites are useful in constraining the conditions under which they were formed. Studies on lithium-aluminosilicate minerals have constrained the P-T stability fields of some of the minerals occurring in rare element pegmatites (London and Burt, 1982b; London, 1984; 1987 and Lagache and Sebastian, 1991). Spodumene, for example, is stable at temperatures of 475-700°C and since primary spodumene occurs in at least one sub-type of the Consort pegmatites, and is not simply a replacement of petalite, it must have crystallized in this temperature range and at pressures of 250-400MPa. The break down of muscovite and quartz (Kerrick, 1972) defines an upper temperature limit for pegmatite crystallization since muscovite is a primary component of all the Consort pegmatites. Hence, crystallization of the NCGM pegmatites probably occurred below the granite solidus and in the presence of significant volatile phases. Jahns (1982) showed that the pegmatite solidus for high water contents occurs at temperatures well below that of the granite solidus. High concentrations of B, F, P along with Li, Na, K, Rb and Cs also serve to depress both liquidus and solidus temperatures down to values of between 650 °C (liquidus) and 500 °C (solidus) (London, 1986; 1987). This range also coincides with the stability ranges of the mineral phases described above for the Consort pegmatites.

Fluid inclusions in the Consort pegmatites are secondary, with most primary inclusions apparently being destroyed by severe deformation, particularly in the SSZ. Alteration, caused by the interaction of pegmatitic fluids with earlier formed liquidus phases, took place both during and after deformation. P-T conditions recorded by fluid inclusion data, therefore, represent late stages in the evolution of the pegmatites. London (1986a), for example, has shown that similar late fluids represent the magmatic-hydrothermal transition in the Tanco pegmatite, during which time sub-solidus alteration took place. Isochores of the different fluid inclusion types, together with error ranges for microthermometric data, are plotted in Figure 8. During the late-stage evolution of the Consort pegmatites P-T conditions must have been such that, at least during some period, they intersected these fluid inclusion isochores. Additional constraints on the sub-solidus evolution of the pegmatites is provided by the absence of eucryptite, in the Consort pegmatites. Eucryptite is an alteration product of petalite and its absence implies that fluids were no longer active under conditions of eucryptite stability, below about 200°C and 200MPa.
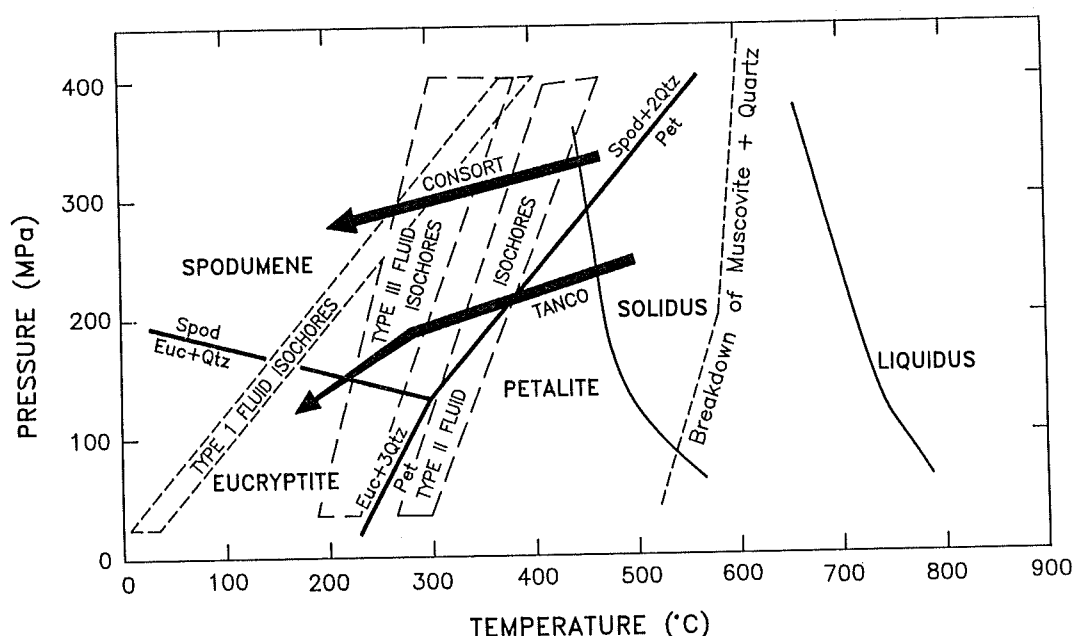

Figure 8: P-T diagram showing the sub-solidus cooling path envisaged for the New Consort Gold Mine pegmatites, compared to the path for the Tanco pegmatite in Manitoba (after London, 1986). Fluid inclusion isochores were calculated using the programme FLINCOR (Brown, 1989). Phase data for lithium aluminosilicates is after London (1984). Breakdown of quartz + muscovite after Kerrick (1971).

The above observations allow the construction of a generalized cooling path in P-T space for the NCGM pegmatites (Figure 8). Sub-solidus cooling in the presence of a vapour phase probably commenced below ca. 500°C at pressures in excess of 300 MPa (3 kb) since spodumene and not petalite is the dominant lithium aluminosilicate phase. Subsequent cooling could not have been accompanied by pronounced decompression since late formation of eucryptite is not observed (Figure 8). This contrasts markedly with the Tanco pegmatite in Manitoba, for example, where the sub-solidus evolution commenced in the stability field

of petalite, at lower pressures than the prevailing conditions at NCGM. Late hydrothermal activity at Tanco appears to have been accompanied by a drop in pressure and took place in the stability field of eucryptite at pressures ≤ 100 MPa (Figure 8).

Relationship between pegmatites and gold mineralization

Rare-element pegmatites are typically not characterized by sulphide mineralization and anomalous enrichments of gold. At NCGM the MR pegmatites cut across the Consort Bar and the major stratiform arsenopyrite-gold mineralization associated with it. It is, therefore, unlikely that pegmatite intrusion is directly responsible in the first instance for gold mineralization in the area. However, the NCGM mineralization is characterized by a complex paragenetic sequence, a major component of which is the unusual but extensively developed pyroxene-amphibole-garnet-scapolite-bytownite-scheelite skarnoid-type alteration which, in places, is intimately associated with and is gradational into, zones of mineralization. Furthermore, biotite selvages around pegmatites are often anomalously enriched in gold. These observations indicate that the NCGM paragenesis was significantly influenced by granitoid emplacement and the fluids derived therefrom. Although the age of mineralization is not known at NCGM, it is pertinent to note that at the nearby Fairview Mine mineralization has been bracketed between 3080 ± 18 and 3126 ± 21 Ma (De Ronde *et al.*, 1991). If mineralization at Fairview and NCGM is broadly coeval, then it is clear that ore forming processes and granite/pegmatite emplacement must have overlapped to a fair degree. The precise role that magmatic fluids have played in gold mineralization along the northern flank of the BGB is, however, a topic which still requires detailed study.

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REFERENCES

Allsopp, H.L., Ulrych, T.J. and **Nicolaysen, L.O.** (1968). Dating some significant events in the history of the Swaziland System by the Rb-Sr isochron method. Can. J. Earth Sci., **5**, 605-619.

Anhaeusser, C.R. (1964). The geology of the Lily syncline and portion of the Eureka syncline between Sheba Siding and Louws Creek Station, Barberton Mountain Land. M.Sc. thesis (unpubl.), Univ. Witwatersrand, Johannesburg, 138pp.

Anhaeusser, C.R. (1969). The stratigraphy, structure and gold mineralization of the Jamestown and Sheba Hills areas of the Barberton Mountain Land. Ph.D. thesis (unpubl.), Univ. Witwatersrand, Johannesburg, 332pp.

Anhaeusser, C.R. (1972). The geology of the Jamestown Hills area of the Barberton Mountain Land, South Africa. Trans. geol. Soc. S. Afr., **75**(3), p.225-263.

Anhaeusser, C.R. (1976). The nature and distribution of Archaesn gold mineralization in southern Africa. Minerals Sci. Engng., **8** (1), 46-84.

Anhaeusser, C.R. and Viljoen, M.J. (1965). The base of the Swaziland System in the Barberton-Noordkaap-Louw's Creek area, Barberton Mountain Land. Inform. Circ. Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg, **25**, 32pp.

Armstrong, T.A., Compston, W., De Wit, M.J. and Williams, I.S. (1990). The stratigraphy of the 3.5 - 3.2Ga Barberton greenstone belt revisited; a single zircon ion microprobe study. Earth Planet. Sci. Lett. **101**, 90-106.

Brown, P.E. (1989). FLINCOR: A fluid inclusion data reduction and exploration programme. Abstr. 2nd Biennial PACROFI Meeting, Toronto, Canada, pp.14.

Cerny, P. (1989). Contrasting geochemistry of two pegmatite fields in Manitoba: products of juvenile Aphebian crust and polycyclic Archaean evolution. Precambrian Res., **45**, 215-234.

Cerny, P., Meintzer, R.E. and Anderson, A.J. (1985). Extreme fractionation in granitic pegmatites: selected examples of data and mechanisms. Can. Min., **23**, 381-421.

De Ronde, C.E.J. (1991). Structural and geochronological relationships and fluid-rock interaction in the central part of the 3.2 - 3.5Ga Barberton Greenstone Belt, South Africa. Ph.D. thesis (unpubl.), Univ. Toronto, Toronto, 370pp.

De Ronde, C.E.J., Kamo, S., Davis, D.W., de Wit, M.J. and Spooner, E.T.C. (1991). Field, geochemical and U-Pb isotopic constraints from hypabyssal felsic intrusions within the Barberton Greenstone Belt, South Africa: Implications for tectonics and the timing of gold mineralization. Precambrian Res., **49**, 261-280.

De Wit, M.J. (1982). Gliding and overthrust nappe tectonics in the Barberton Greenstone Belt. J. Struct. Geol., **4**, 117-136.

De Wit, M.J., Fripp, R.E.P. and Stanistreet, I.G. (1983). Tectonic and stratigraphic implications of new field observations along the southern part of the Barberton Greenstone Belt. Spec. Publ. Geol. Soc. S. Afr., **9**, 21-29.

De Wit, M.J., Hart, R.A. and Hart, R.J. (1987). The Jamestown Ophiolite Complex, Barberton Mountain Belt: a section through 3.5Ga oceanic crust. J. Afr. Earth Sci., **6**, 681-730.

Goad, B.E. and Cerny, P. (1981). Peraluminous pegmatitic granites and their pegmatite aureoles in the Winnipeg River district, southeastern Manitoba. Can. Mineral., **19**, 177-194.

Hall, A.L. (1918). The geology of the Barberton gold mining district. Mem. geol. Surv. S. Afr.,**9**, 347pp.

Hearn, M.G. (1943). A study of the working properties of the chief gold producer of the Barberton District, Eastern Transvaal. D.Sc. thesis (unpubl.), Univ. Witwatersrand, Johannesburg, 201pp.

Heubeck, C., Wendt, J.I., Toulkeridis, T., Kröner, A. and Lowe, D.R. (1992). Timing of deformation of the Archaean Barberton Greenstone Belt, South Africa: constraints from zircon dating of the Salisbury Kop pluton. J. Geol. Soc. S. Afr. (in press).

Jahns, R.H. (1982). Internal evolution of granitic pegmatites. *In*: Granitic Pegmatites in Science and Industry. Min. Assoc. Can. Short Course Handbook **8**, 293-346.

Kamo, S., Davis, D.W. and de Wit, M.J. (1990). U-Pb geochronology of Archean plutonism in the Barberton region, South Africa: 800 m.y. of crustal evolution. Abstr.Geol. Soc. Austr., **27**, 53.

Kamo, S. and Davis, D.W. (1991). A review of geochronology from the Barberton Mountain Land, 59-69. *In*: L.D. Ashwal (Ed.), Two Cratons and an Orogen - Excursion Guidebook and Review Articles for a Field Workshop through Selected Archaean Terranes of Swaziland, South Africa and Zimbabwe. IGCP Project 280, Dept. Geology, Univ. Witwatersrand, Johannesburg, 312pp.

Kerrick, D.M. (1971). Experimental determination of muscovite + quartz stability with $P_{H20} < P_{TOTAL}$. Amer. J. Sci., **272**, 946-958.

Kröner, A. (1990). Single zircon dating constraining the maximum age of the Barberton greenstone belt, southern Africa. J. Geophys. Res., **93**, 15329-15337.

Kröner, A., Byerly, G.R. and Lowe, D.R. (1991a). Chronology of early Archaean granite-greenstone evolution in the Barberton Mountain Land, South Africa, based on precise dating of single zircon evaporation. Earth Planet. Sci., Lett. **103**, 41-54.

Lagache, M. and Sebastian, A. (1991). Experimental study of Li-rich granitic pegmatites: Part II. Spodumene + albite + quartz equilibrium. Am. Mineral., **76**, 611-616.

Lamb, S.M. (1984). Structures and sedimentology on the eastern margin of the Archaean Barberton greenstone belt, northwest Swaziland. Ph.D. thesis (unpubl.), Univ. Cambridge, 178pp.

London, D. (1984). Experimental phase equilibria in the system $LiAlSiO_4\text{-}SiO_2\text{-}H_2O$: a petrogenetic grid for lithium-rich pegmatites. Am. Mineral., **69**, 995-1004.

London, D. (1986). Magmatic-hydrothermal transition in the Tanco rare-element pegmatite: evidence from fluid inclusions and phase equilibria experiments. Am. Mineral., **71**, 376-395.

London, D. (1987). Internal differentiation of rare-element pegmatites: effects of boron, phosphorus and fluorine. Geochim. Cosmochim. Acta, **51**, 403-420.

London, D. and Burt, D.M. (1982a). Alteration of spodumene, montebrasite and lithophilite in pegmatites of the White Picacho district, Arizona. Am. Mineral., **67**, 970113.

London, D. and Burt, D.M. (1982b). Lithium minerals in pegmatites. *In*: Granitic Pegmatites in Science and Industry. Mineral. Assoc. Can. Short Course Handbook **8**, 99-113.

McCarthy, T.S. and Robb, L.J. (1978). On the relationship between cumulus mineralogy and trace and alkali chemistry in an Archaean granite from the Barberton region, South Africa. Geochim. Cosmochim. Acta., **42**, 21-26.

Lowe, D.R., Byerly, G.R., Ranson, B.L. and Nocita, B.W. (1985). Stratigraphic and sedimentological evidence bearing on structural repetition in early Archean rocks of the Barberton greenstone belt, South Africa. Precambrian Res., **27**, 165-186.

Moller, P. (1989). REE(Y), Nb and Ta enrichment in pegmatites and carbonatite-alkalic rock complexes. *In*: Moller, P., Cerny, P. and Saupe, F. (Eds.), Lanthanides, Tantalum and Niobium. Springer-Verlag, Berlin, 103-144.

Paris, I. (1984). The geology of the farms Josefsdal, Dunbar and part of Diepgezet in the Barberton greenstone belt. Ph.D. thesis, (unpubl.), Univ. Witwatersrand, Johannesburg, 258pp.

Robertson, M.J. (1989). The structural geology and gold mineralization of the Main Reef Complex at Sheba Gold Mine, Barberton greenstone belt. M.Sc. dissertation, (unpubl.), Univ. Witwatersrand, Johannesburg, 127pp.

Robb, L.J., Barton, J.M., Kable, E.J.D. and Wallace, R.C. (1986). Geology, geochemistry and isotopic characteristics of the Archaean Kaap Valley pluton, Barberton Mountain Land, South Africa. Precambrian Res., **31**, 1-36.

Robb, L.J., Meyer, F.M., Kröner, A., Trumbull, R.B., Reimold, W.U., de Bruiyn, H., Walraven, F. and Toulkeridis, T. (1993). Late stage granite plutons in the Barberton region and Swaziland: an update. Ext. Abstr. 16th Int. Coll. African Geology, Mbabane, Swaziland.

Shearer, C.K., Papike, J.J. and Laul, J.C. (1987). Mineralogical and chemical evolution of a rare-element granite-pegmatite system: Harney Peak Batholith, Black Hills, South Dakota, Geochim. Cosmochim. Acta, **51**, 473-486.

Simmons, Wm. B., Lee, M.T. and Brewster, R.H. (1987). Geochemistry and evolution of the South Platte granite-pegmatite system, Jefferson County, Colorado. Geochim. Cosmochim. Acta, **51**, 455-471.

Tegtmeyer, A.R. and **Kröner, A.** (1987). U-Pb zircon ages bearing on the nature of early Archean tonalite-trondhjemite gneiss plutons in the Barberton Mountain Land. Precambrian Res., **36**, 1-20.

Tomkinson, M.J. (1988). The Shires shear zone: New Consort Gold Mine, magma injection into an anastomosing heterogeneous shear system. *In:* Deformation and mineralization in the Archaean of South Africa. Abstracts and guide book, Barberton Mountain Land Branch Geol. Soc. S. Afr., 63pp.

Tomkinson, M.J. and **Lombard, A.** (1990). Structure, metamorphism, and mineralization in the New Consort Gold Mines, Barberton greenstone belt, South Africa. *In:* Glover, J.E. and Ho, S.E. (Eds.), Third International Archaean Symposium, Perth, 1990. Ext. Abstrs. Volume, Geoconferences (W.A.) Inc., Perth, 377-379.

Tomkinson, M.J. and **King, V.J.** (1991). The tectonics of the Barberton greenstone belt: an overview. 69-83. *In:* L.D. Ashwal (Ed.), Two Cratons and an Orogen - Excursion Guidebook and Review Articles for a Field Workshop through Selected Archaean Terranes of Swaziland, South Africa and Zimbabwe. IGCP Project 280, Dept. Geology, Univ. Witwatersrand, Johannesburg, 312pp.

Viljoen, M.J. (1964). The geology of the Lily syncline and portion of the Eureka syncline between the Consort Mine and Joes Luck Siding, Barberton Mountain Land. M.Sc. thesis (unpubl.), Univ. Witwatersrand, Johannesburg, 203pp.

Voges, F.D. (1986). The New Consort Gold Mine, Barberton Greenstone Belt, 163-168. *In:* Anhaeusser, C.R. and Maske, S. (Eds.), Mineral Deposits of Southern Africa, I. Geol. Soc. S. Afr., 1020pp.

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