

**ECONOMIC GEOLOGY
RESEARCH UNIT**

University of the Witwatersrand
Johannesburg

THE NATURE OF ARCHAEOAN PEGMATITE
DEPOSITS IN THE NORTH-EASTERN TRANSVAAL

L.J. ROBB and V.M. ROBB

UNIVERSITY OF THE WITWATERSRAND
JOHANNESBURG

THE NATURE OF ARCHAEOAN PEGMATITE
DEPOSITS IN THE NORTH-EASTERN TRANSVAAL

by

L.J. ROBB

(Economic Geology Research Unit, University of the Witwatersrand, Johannesburg)

and

V.M. ROBB

(Anglo American Research Laboratories, Crown Mines, Johannesburg)

ECONOMIC GEOLOGY RESEARCH UNIT
INFORMATION CIRCULAR No. 136

November, 1979

THE NATURE OF ARCHAEOAN PEGMATITE
DEPOSITS IN THE NORTH-EASTERN TRANSVAAL

ABSTRACT

The pegmatites of the North-Eastern Transvaal, which include the Selati Line and Olifants River Mica Field are considered, for the purposes of this paper, to lie within the confines of the Archaeozoic Kaapvaal craton between Mica in the south and the Sutherland greenstone belt in the north. These pegmatites are thought to be igneous in origin and may, in part, be related to the intrusion of the potash-rich Mashishimala Granite which occurs immediately south of the Murchison greenstone belt.

Four principal types of pegmatite deposit are considered to occur in the region, and one of each is described from a select locality in the area; namely the corundum-bearing Bird-Cage Camp prospect, a tantalite-columbite occurrence from the Palakop region, beryl and emerald deposits from the Gravelotte Emerald Mines and an economic deposit of quartz-felspar-muscovite from the Union Mine at Mica.

The granitic pegmatites of the North-Eastern Transvaal are generally considered to be barren, and mineralization, in the case of corundum and emeralds, is the result of interaction between invading pegmatitic fluids and vapours and pre-existing greenstone remnants. In the case, however, of beryl and molybdenum at Gravelotte and beryl and tantalite-columbite at Palakop, the source of mineralization is an albitite pegmatoid, a rock type hitherto little recognized in the region.

* * * * *

THE NATURE OF ARCHAEOAN PEGMATITE
DEPOSITS IN THE NORTH-EASTERN TRANSVAAL

CONTENTS

	<u>Page</u>
I. <u>INTRODUCTION</u>	1
II. <u>CORUNDUM DEPOSITS ASSOCIATED WITH PEGMATITES</u>	4
A. Corundum Deposits at the Bird-Cage Camp	5
B. Genesis of Pegmatite-Related Corundum Deposits	5
III. <u>TANTALITE-COLUMBITE DEPOSITS ASSOCIATED WITH PEGMATITES</u>	7
A. The Palakop Area, Letaba District	7
IV. <u>BERYL AND EMERALD DEPOSITS ASSOCIATED WITH PEGMATITES</u>	9
A. The Gravelotte Emerald Mine	10
V. <u>QUARTZ, FELSPAR AND MUSCOVITE DEPOSITS ASSOCIATED WITH PEGMATITES</u>	10
A. The Union Mine	11
VI. <u>DISCUSSION AND CONCLUSIONS</u>	13
A. The Origin of the Pegmatites in the North-Eastern Transvaal	13
B. Factors Relating to Mineralization in the Pegmatites of the North-Eastern Transvaal	13
<u>ACKNOWLEDGEMENTS</u>	14
<u>REFERENCES</u>	14

* * * * *

THE NATURE OF ARCHAEOAN PEGMATITE
DEPOSITS IN THE NORTH-EASTERN TRANSVAAL

I. INTRODUCTION

The pegmatite fields of the North-Eastern Transvaal are, for the purposes of this paper, considered to lie in the block of country between Pietersburg and the Kruger National Park in the east, and Mica and the Sutherland greenstone belt in the north (Fig. 1), a region which falls within the known confines of the Kaapvaal Craton. This block can be divided into two segments, a southern belt (the Selati Line and Olifants River mica field) where ore-production is currently taking place, and a northern section where pegmatites are known but are either uneconomic or worked out (von Backström, 1973). This paper reviews the nature of pegmatite deposits within the area mentioned above and provides brief descriptions of particular known deposits; three of these deposits are from within the belt of current ore-production and one deposit is from an area where the pegmatites are largely worked out.

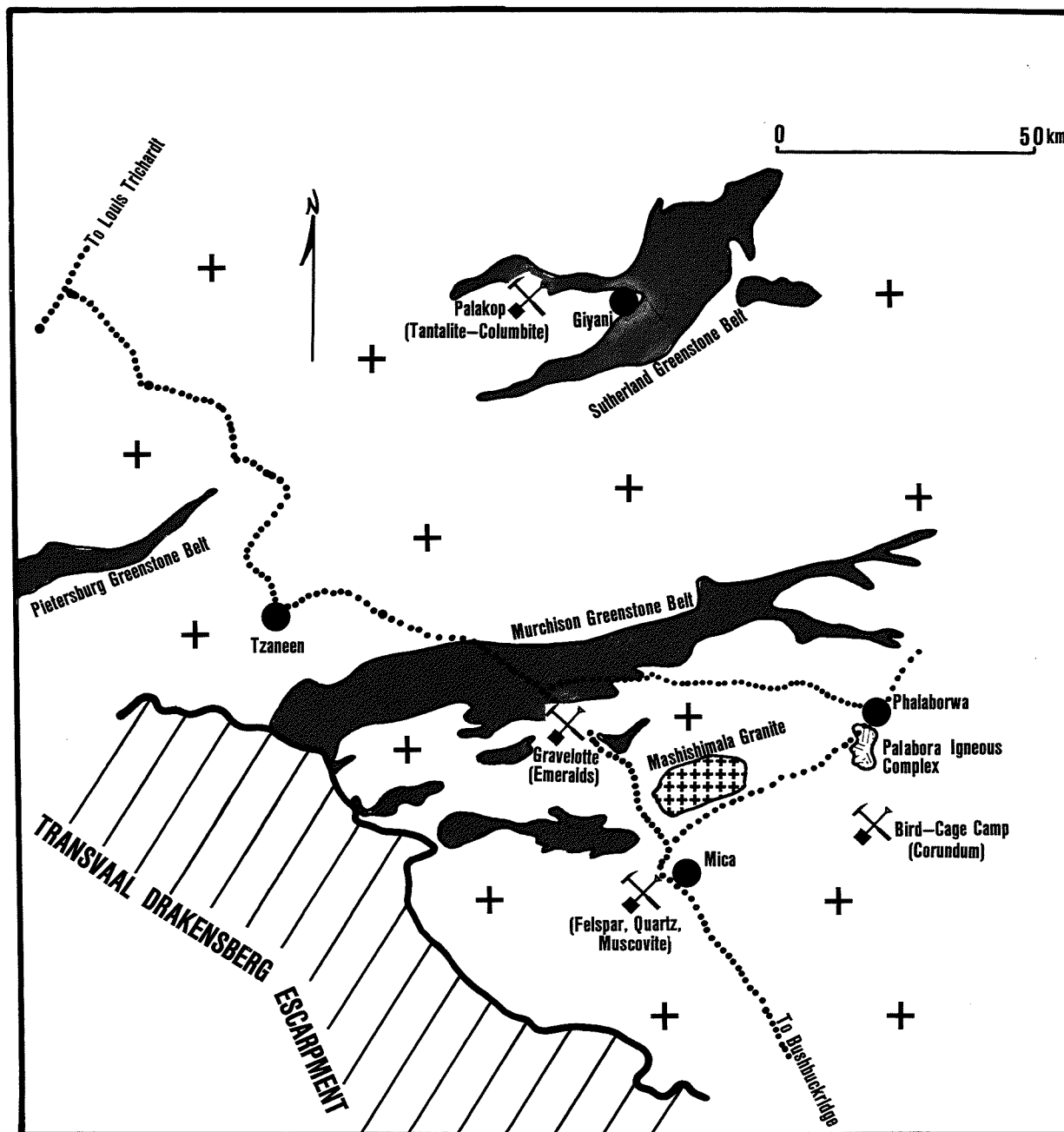


Figure 1 : Schematic map showing the location of the four pegmatite deposits described from the North-Eastern Transvaal pegmatite field.

The southerly pegmatite belt, where most of the mining activity associated with pegmatites is centred, is shown in greater detail in Figure 2. It is seen that this area is dominated by the Mashishimala Granite pluton, a coarse-grained, porphyritic, potash-rich intrusive body (Table 1), the areal extent of which is shown on this diagram to be considerably greater than on previously published maps of the region. Although generally flat and low-lying, the southwestern lobe of the Mashishimala Granite is characterized by a series of tor-like, ENE striking ridges (Fig. 2). It is this topographically distinct lobe that was previously thought to represent the entire outcrop area of the Mashishimala Granite and it is only detailed mapping by geologists of the Palabora Mining Company (and also recently the Geological Survey) that has shown this pluton to be areally more extensive. The region surrounding the Mashishimala Granite consists of tonalitic and trondhjemitic gneisses as well

as innumerable greenstone remnants, the latter comprising mainly talc and talc-chlorite schists, amphibolites and serpentinites. Intrusive into both granite and greenstone are numerous irregularly dispersed pegmatite bodies of varying shape and size. The presence of numerous greenstone remnants in the area is critical, as the formation of pegmatite-related deposits is often associated with the interaction of intruding pegmatitic fluids and vapour with a mafic (greenstone) host. From a review of the available literature in the area it is clear that the majority of economically interesting pegmatites are intrusive into mafic or ultramafic greenstone remnants (Hall, 1920; Kupferberger, 1935; van Eeden et al., 1939; Brandt, 1946; Wilke, 1963; von Backström, 1973).

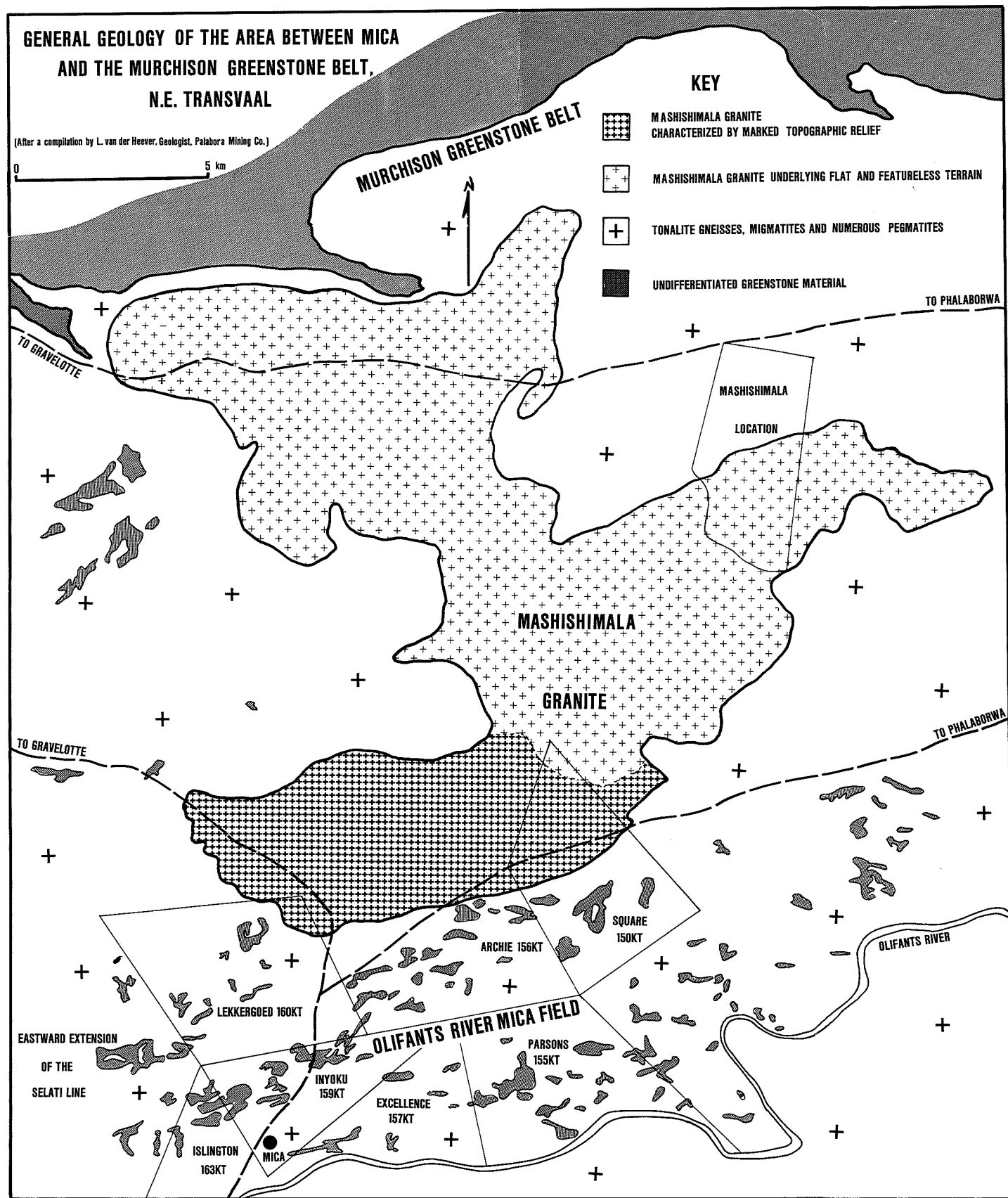


Figure 2 : General geology of the area between Mica and the Murchison greenstone belt, North-Eastern Transvaal.

It is known that pegmatite swarms do not occur in the well-documented Archaean tonalite gneiss-greenstone terranes found, for example, to the southwest of the Barberton greenstone belt (Anhaeusser and Robb, 1978) and it is unlikely, therefore, that the pegmatites are genetically related to these rock types. It is more probable that the pegmatites are a related residual phase of the post-kinematic intrusive, potash-rich Mashishimala Granite that dominates the area (Figure 2), a suggestion that is discussed more fully later in this paper. No age determinations are yet

available for the Mashishimala Granite although a single muscovite age from a pegmatite at Mica has been published. This mineral age of 2040 m.y. (Jamieson and Schriener, 1957) probably does not reflect the actual age of emplacement of the pegmatites in the region.

The pegmatites, particularly those of the southern belt, generally have similar mineralogical characteristics although they may have widely differing shapes (the pegmatites may be podiform, lensoid, sill- or dyke-like, or they may have highly irregular shapes). According to the broad classification of Cameron et al. (1949) the pegmatites of the southern belt can be described as inhomogeneous pegmatites with zonal characteristics. The definition of the zones is, however, variable and the characteristics of individual pegmatites are by no means stereotyped. For example, certain pegmatites from the Palakop area and the Gravelotte Emerald Mine are principally albititic in character and differ from the more widespread granitic (*sensu stricto*) pegmatites. In Figure 3 a cross-section of a sill-like pegmatite exposed in a road-cutting on the main Mica-Gravelotte road displays what are considered to be typical zonation characteristics of pegmatites in the region. This pegmatite, which intrudes highly altered trondhjemite gneiss, consists of an outer zone composed mainly of plagioclase and muscovite, an inner zone of microcline-perthite with lesser amounts of quartz, muscovite and plagioclase and a core zone of massive quartz. Jahns (1955) has stated that, "... quartz masses of this type (i.e. from the core zone) might well represent the last part of the magmatic stage of pegmatite formation" and this, together with the zonal structure of the pegmatite, is considered to provide supporting evidence for a magmatic (as opposed to a replacement or metamorphic) origin for the pegmatites of this region. The presence of an aplitic dykelet, which consists of equigranular microcline, quartz, plagioclase and muscovite, is also illustrated in Figure 3. Again Jahns (1955) has attributed the presence of aplite, together with pegmatite, to the escape of volatile constituents from the latter and its subsequent, more rapid, crystallization within the same single-system magmatic environment. In short, the majority of Archaean pegmatites in the North-Eastern Transvaal generally have textural characteristics indicative of a primary magmatic origin.

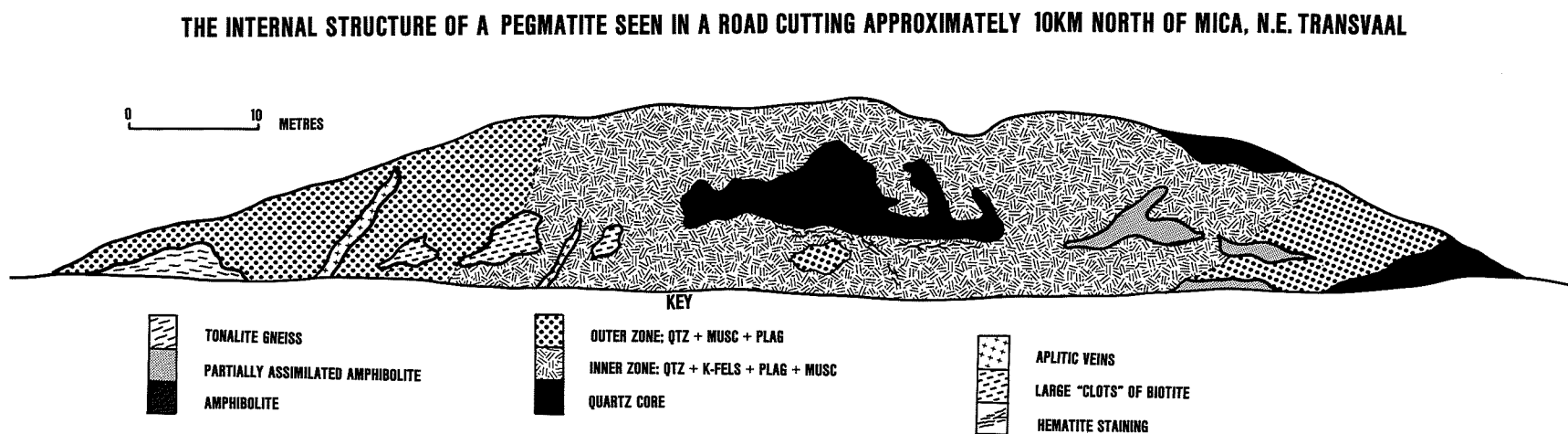


Figure 3 : The internal structure of a pegmatite seen in a road-cutting approximately 10 km north of Mica, North-Eastern Transvaal.

The pegmatite fields of the North-Eastern Transvaal are considered, for descriptive purposes, to contain four principal types of pegmatite-related deposits. These include (i) corundum deposits, (ii) tantalite-columbite deposits, (iii) beryl-emerald deposits and (iv) barren "deposits" of felspar, quartz and muscovite. Noticeably, lithium mineral assemblages, tin minerals, topaz, tungsten and the uranium-thorium-rare earth element mineral assemblages, are either totally absent, are present in only minor sporadic quantities, or have yet to be discovered in this area. The remaining sections of this paper describe specific examples of the four principal types of pegmatite-related deposits in this region.

TABLE 1

MAJOR AND TRACE ELEMENT ANALYSES OF PEGMATITIC, GRANITIC
AND MAFIC ROCK TYPES IN THE NORTH-EASTERN TRANSVAAL

COLUMNS	1	2+	3+	4+	5	6*	7*	8*	9*	10*	11*	12*	13*	14*
SAMPLE NOS.	MARUNDITE	UNION MINE				C 1	C 2	C 4	C 3	C 7	Kub 4	Kub 11	Msh 2	Msh 5
wt.%														
SiO ₂	21,76	67,50	65,20	71,00	70,06	71,56	73,70	73,80	43,20	46,10	66,70	81,10	65,90	71,80
TiO ₂	0,25	0,01	0,01	0,01	0,02	0,21	0,06	0,17	0,34	0,21	0,01	0,01	1,07	0,49
Al ₂ O ₃	61,16	18,00	18,50	18,30	16,67	14,80	14,60	13,80	13,50	8,00	20,10	10,20	13,40	13,00
Fe ₂ O ₃	2,90	0,06	0,06	0,07	0,06	1,78	0,56	1,69	6,70	8,90	1,55	0,30	5,40	3,14
Cr ₂ O ₃	-	-	-	-	-	-	-	-	-	0,40	-	-	-	-
MnO	0,07	0,01	0,01	0,01	0,01	0,01	0,04	0,01	0,05	0,05	0,66	0,01	0,05	0,05
MgO	0,40	0,03	0,01	0,01	0,02	0,50	0,20	0,40	24,10	28,40	0,09	0,10	1,50	0,51
CaO	5,22	0,25	0,40	0,02	0,35	2,05	1,39	0,75	0,14	0,11	0,36	0,73	2,88	1,58
Na ₂ O	2,10	4,50	3,50	10,40	5,21	6,10	7,60	5,20	0,30	0,20	8,80	6,40	4,20	4,00
K ₂ O	0,96	7,50	11,00	2,30	6,75	1,71	0,30	3,00	10,07	0,04	0,11	0,39	3,58	4,45
P ₂ O ₅	0,30	-	-	-	0,01	0,06	0,02	0,02	0,01	0,01	0,03	0,39	0,44	0,15
L.O.I.	4,00	0,40	0,40	0,30	0,50	0,48	0,88	0,56	0,56	6,90	0,53	0,28	0,75	0,55
TOTALS	99,12	98,26	99,09	102,42	99,66	99,26	99,35	99,40	98,97	99,32	98,94	99,91	99,17	99,72
Rb	79	-	-	-	-	50	17	95	610	10	10	19	123	193
Sr	1 345	-	-	-	-	670	260	240	13	10	28	53	450	235
Ba	217	-	-	-	-	260	106	550	790	25	40	30	996	715

(Analysts : + Pegmin, Rand London Corporation : * Bergström and Bakker, Johannesburg)

Column 1 : Average of 9 samples of marundite from Anhaeusser, 1978.

Column 2 : Glass Grade K-felspar.

Column 3 : Select ceramic grade K-felspar.

Column 4 : Plagioclase.

Column 5 : Bulk pegmatite composition; containing 65% K-felspar, 25% plag., 9% qtz., 1% muscovite.

Column 6 : Fine-grained, equigranular tonalitic dyke.

Column 7 : Albitite pegmatoid.

Column 8 : Tonalitic gneiss.

Column 9 : Biotite schist - mineralized zone.

Column 10 : Talc-chlorite schist.

Column 11 : Garnetiferous albitite pegmatoid, Tantalite-Columbite Shaft.

Column 12 : Berylliferous albitite pegmatoid, Kubannek Quarry.

Columns

13 -14 Mashishimala Granite, north of Mica.

Union Mine, Mica.

Cobra Pit, Gravelotte Emerald Mine.

Palakop area.

II. CORUNDUM DEPOSITS ASSOCIATED WITH PEGMATITES

For many years South Africa was the world's leading producer of corundum (Al₂O₃) for use in the manufacture of abrasive products (Kupferberger, 1935), and the pegmatite-related deposits of the Archaean granitic terrane of the North-Eastern Transvaal consistently produced most of this country's corundum. In Table 2 the declining production of corundum in South Africa is demonstrated; a factor undoubtedly linked to the modern employment of ferro-alloy abrasives. Corundum, however, still has a limited usage as a specialized abrasive in the optics industry.

In the pegmatite fields of the North-Eastern Transvaal most corundum deposits occur in the region between Mica and the Murchison greenstone belt, known as the Selati Line. In this area corundum occurs both as primary and eluvial deposits. For the purpose of this paper only the more important primary deposits will be discussed. Primary corundum deposits have been classified by Kupferberger (1935) into three types, namely (i) plumasites (felspar + corundum assemblage), (ii) marundites (margarite + corundum assemblage) and (iii) corundum associated with granitic gneisses and migmatites. Along the Selati Line corundum occurrences are mainly marunditic in character while plumasites predominate in the remainder of the pegmatite fields. Migmatitic and gneissic corundum is generally sporadic and sparse. Two fundamental points characterize the marundite deposits of the Selati Line as well as the plumasites of the remainder of the region; firstly, both these types of deposit are always associated with pegmatites, and secondly, the deposits are invariably found where the pegmatite has intruded mafic or ultramafic greenstone remnants. The following section describes an occurrence of marundite from the Selati Line.

TABLE 2

CORUNDUM PRODUCTION IN THE REPUBLIC OF SOUTH AFRICA

YEAR	PRODUCTION ⁺	VALUE FROM SALES*
1918	3 876	≈52 000
1929	3 627	≈39 000
1938	≈1 200	≈25 000
1953	1 865	87 896
1959	564	33 836
1963	72	3 045
1967	318	18 918
1971	241	19 542
1973	269	20 876

(⁺ Tons

* Rand)

(Data from De Villiers, 1976)

A. Corundum Deposits at the Bird-Cage Camp

The Bird-Cage Camp corundum deposit, which lies north of the Olifants River, approximately 25 km east of Mica, has been described by Hall (1920). The occurrence is considered to represent a typical marundite and one on which a consideration of the genesis of marunditic corundum ore can be made. The Bird-Cage Camp corundum workings consist of a semicircular outcrop of pegmatite intrusive into an amphibolitic greenstone remnant in granitic gneisses (Fig. 4). The amphibolitic country rock is a grey-green, medium-to-coarse-grained massive rock consisting predominantly of euhedral blades of hornblende. The coarse-grained pegmatite material was described by Hall (1920) as being indistinguishable from the mica-bearing pegmatite from the remainder of the Selati Line. As the pegmatite body is narrow (only 9 m at its widest point) it does not show pronounced zoning and can be described as homogeneous, consisting dominantly of quartz and microcline perthite with lesser amounts of plagioclase and muscovite.

The marundite generally occurs along the contact between the pegmatite and host amphibolite. At the Bird-Cage Camp, however, the western limb of the pegmatite (Fig. 4) thins and is entirely replaced by a marunditic 'reef'. The 'reef' is a coarse-grained rock containing hexagonal corundum crystals (often ruby-coloured) together with large whitish plates of the calcium mica known as margarite. The 'reef' also contains sporadic occurrences of biotite and tourmaline. The peripheries of the marundite occurrences are usually rimmed by dark-green, fibrous, talcose material which is considered to represent the silicated alteration product of the host amphibolite (Hall, 1920).

B. Genesis of Pegmatite-Related Corundum Deposits

A consideration of the genesis of pegmatite-related corundum deposits has, in the past, generated considerable controversy, particularly in South African literature. The chemical composition of marundites (i.e. very low SiO₂ and high Al₂O₃; Table 1) immediately implies that the formation of corundum requires either loss of silica or drastic enrichment of alumina from a granite pegmatite system. The earliest investigators referred to a process of "desilication" whereby silica was released from the pegmatite becoming largely manifest in a wall-rock altered talcose zone (Du Toit, 1918; Hall, 1920). These initial considerations were not particularly specific about the processes of desilication but considered that it first resulted in the formation of a plagioclase-corundum assemblage (plumasite) and that later pneumatolytic activity was responsible for the alteration of felspar to margarite and the formation of marunditic reefs.

Some of the drawbacks of these early considerations were that it did not adequately explain the absence of corundum in many instances where pegmatites had intruded mafic greenstone remnants and that, in many cases, no evidence was found of free quartz that should accompany the desilication process. Brandt (1946) presented detailed considerations on the genesis of pegmatite-related corundum deposits whilst objecting to Hall's earlier desilication hypothesis. Brandt maintained that the silicated talcose alteration zone that often accompanies marundite occurrences (Fig. 4) could not possibly contain all the silica that was made available by desilication. Instead he proposed a process of calcification, whereby calcium from the host mafic rocks reacted with silica from the invading pegmatite to produce wollastonite. The presence of wollastonite (CaSiO₃) facilitates a reaction with K-felspar to form the anorthite molecule and the subsequent liberation of potassium is used to form sericite-muscovite (and possibly margarite). These reactions are considered to

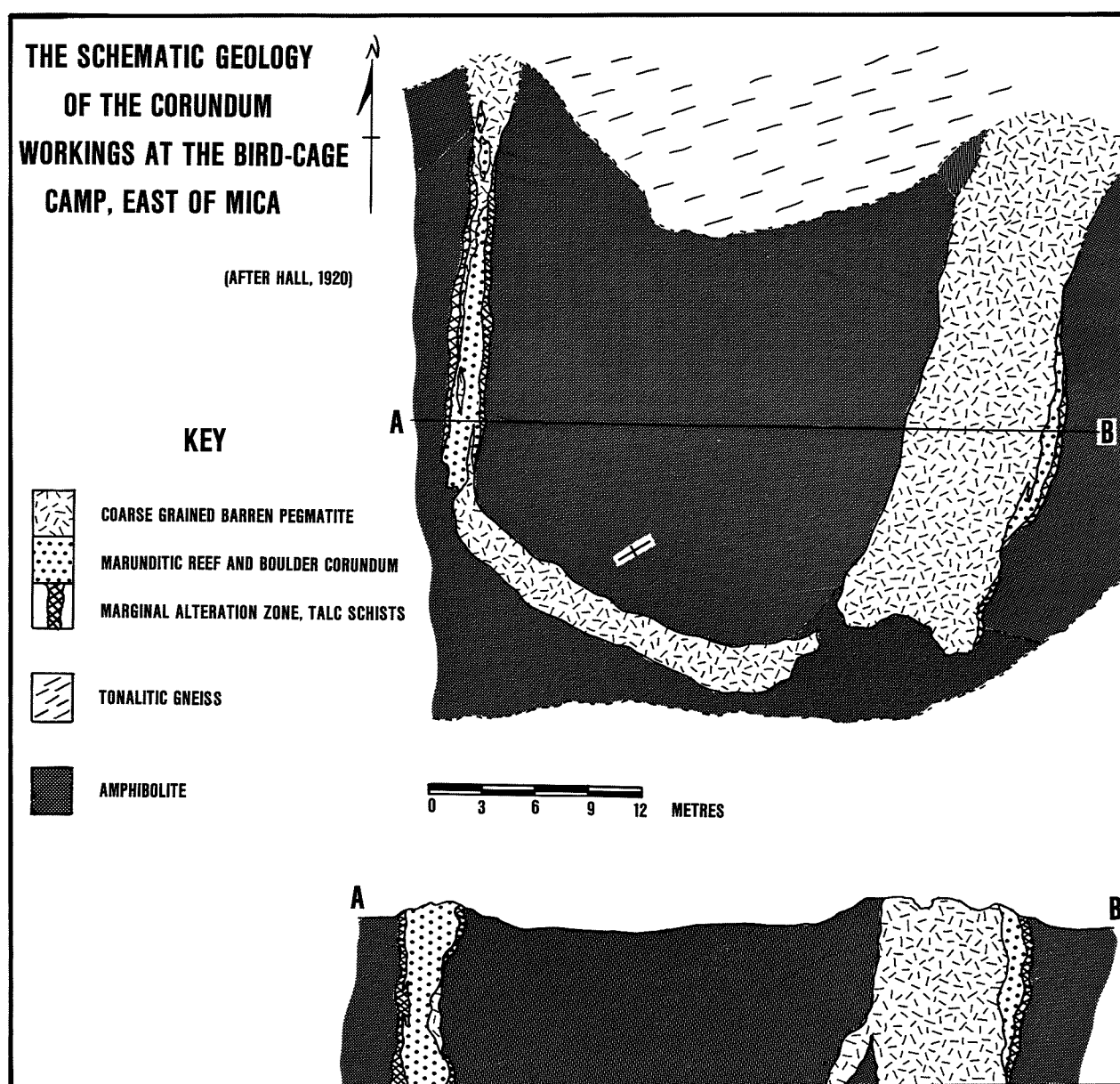


Figure 4 : The schematic geology of the corundum workings at the Bird-Cage Camp, east of Mica.

liberate excess alumina and result in its subsequent crystallization as corundum. Brandt (1946) supported this genetic hypothesis with ample evidence of the calcic alteration of K-felspar to anorthitic plagioclase and of hydrothermal sericitization and formation of muscovite. He also pointed out that corundum is rarely, if ever, found associated with K-felspar.

Recent considerations of marundite have added to the complexities regarding their genesis. Anhaeusser (1978) mapped a marunditic 'reef' southwest of the Barberton greenstone belt and found it to be apparently unassociated with pegmatitic material. It was found here that desilication of aluminous quartz-sericite schists (rock units that form part of the lithology of typical greenstone successions) may have resulted in the supersaturation and subsequent crystallization of corundum at this locality. However, even here, the presence of margarite suggests an intimate reaction with calcium-rich rocks (which are undoubtedly present in the vicinity) along the lines suggested by Brandt (1946).

Clearly the genesis of pegmatite-related corundum is complex and attempts to fit a single model to the innumerable field relations documented is fruitless. Certain characteristics are, however, ubiquitous; (i) most of the 'reefs' are derived from a pegmatitic magma that presumably provided the source of alumina (ii) the pegmatites have invariably intruded mafic greenstone remnants and (iii) the genesis of corundum must be the result of the interaction of pegmatitic magma with its mafic host and the re-arrangement of SiO_2 , CaO , Al_2O_3 and K_2O to form either plumasite or marundite. In conclusion, it is Du Toit (1946) who has perhaps shed the clearest light on understanding why corundum can form in certain situations and not in others that are almost identical, and why plumasite forms in some areas and marundite in others. He suggested that, "the separation of corundum might have been determined by the temperature, not of the pegmatite-magma, but of the

rocks so invaded". The complexities of corundum genesis may, therefore, best be explained by variations in the temperature of the host mafic greenstone remnants, a factor attributable to variations in the depths of intrusion of the invading pegmatite magma. The formation of plumasite and marundite in different areas must also, therefore, be a function of variable pressure, temperature and P_{H_2O} .

III. TANTALITE-COLUMBITE DEPOSITS ASSOCIATED WITH PEGMATITE

The occurrence of tantalite and columbite in the North-Eastern Transvaal pegmatite fields is both minor and sporadic. However, the fact that Ta is an important commodity in specialized steel manufacturing and that both Ta and Nb are vital to certain chemical, electronic and chemical industries stimulates a limited demand for these two elements. South Africa's production of tantalite-columbite has always been very small (of the order of a few tons per annum) but in recent years this figure has dwindled to negligible quantities (Table 3). In past years there has been little or no local demand for Ta-Nb and much of the ore produced has been exported to the United States of America. An international demand for tantalum, for use in specialized electronics industries, has, in very recent years, become evident and it is likely that the demand for this metal will increase.

TABLE 3

TANTALITE-COLUMBITE PRODUCTION IN THE REPUBLIC OF SOUTH AFRICA

YEAR	PRODUCTION ⁺	VALUE FROM SALES*
1953	19	30 230
1955	12	37 200
1961	9	5 408
1963	29	44 080
1965	3	21 900
1967	4,5	31 589
1969	4	3 831
1971	1	-
1973	0,03	-

(⁺ Tons

* Rand)

(Data from Beerman's All Mining Yearbook, 1966 and 1971)

In the Selati Line-Olifants River Mica Field only a few small and sporadic deposits of tantalite-columbite are known. These have been worked by individual prospectors and in the case of Louw's Mine (approximately 20 km southwest of Phalaborwa) a few tons of columbite have recently been extracted in addition to the quartz, feldspar and muscovite which provide the main revenue from the deposit. One of the best known occurrences of tantalite-columbite occurs along the northwestern flank of the Sutherland greenstone belt in the Letaba district (Fig. 1). The Palakop area has been selected as an example of a columbite-tantalite deposit that occurs in association with other economically important minerals.

A. The Palakop Area, Letaba District

The Palakop mining area is situated a few kilometres west of the old Klein Letaba gold mine, which itself is approximately 20 km west of Giyani in Gazankulu. Geologically, Palakop is located on the northernmost of the two east-west trending limbs that outline the broad structure of the Sutherland greenstone belt (Fig. 1).

Palakop itself consists of an isolated, approximately east-west trending hill made up essentially of amphibolitic schists trending $65-80^{\circ}\text{E}$. Intrusive into these schists is a suite of pegmatitic bodies, together with what has been described as a medium-grained pegmatitic granite (Wilke, 1963). In addition, the Palakop region has been intruded by diabase dykes and has also been deformed by large northeast trending shear zones (Fig. 5).

Wilke (1963) identified three separate pegmatite-related deposits in the Palakop region. Firstly, and most important, are the beryl-columbite-tantalite-apatite-bearing pegmatites which generally occur in the central and eastern portions of the map area where the workings known as the Kubannek Quarry are located. Secondly, minor spodumene-bearing pegmatites are located in the western portion of the map area. Approximately 3 km southwest of Palakop is the third type of deposit which consists of a single kyanite-bearing quartz pegmatite. The following description applies particularly to the beryl-columbite-tantalite-apatite pegmatites which predominate in the area shown in Figure 5.

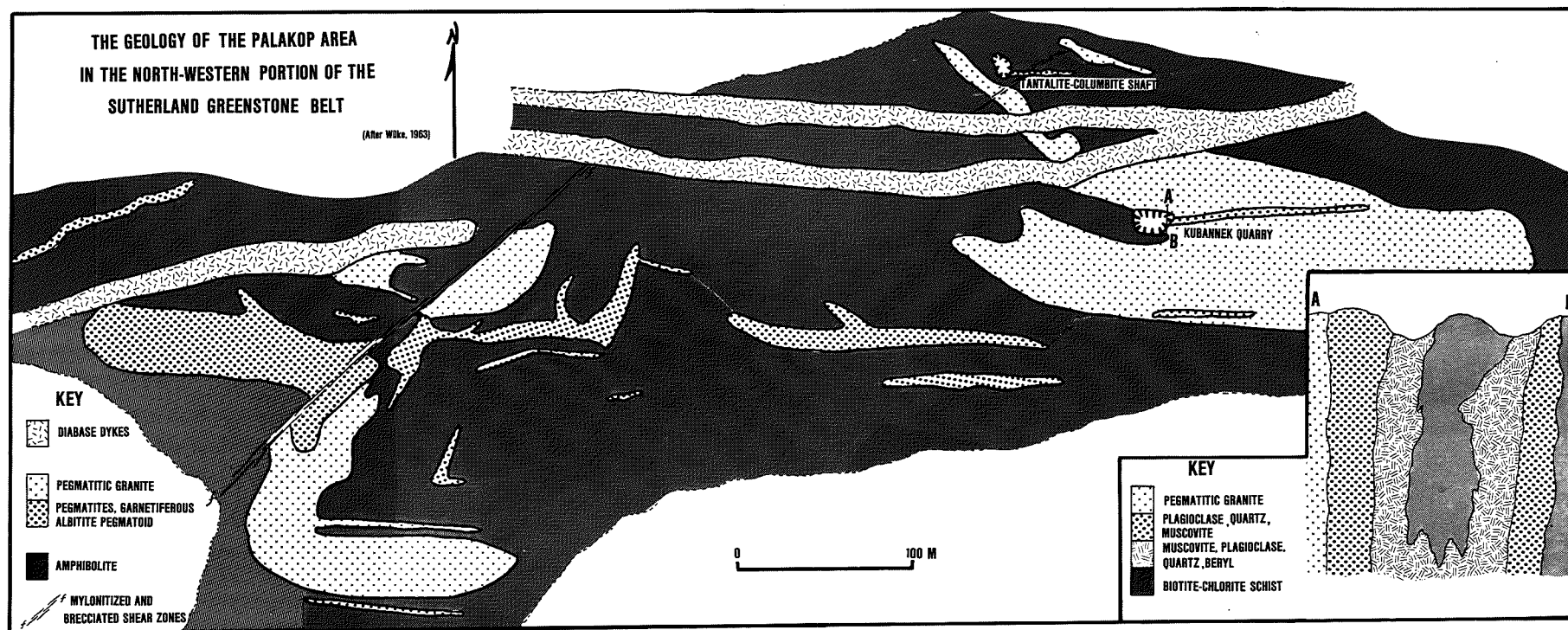


Figure 5 : The geology of the Palakop area in the North-Western portion of the Sutherland greenstone belt.

The beryl-tantalite-columbite pegmatites are best exposed in the Kubannek Quarry where they are distinctly zoned. Figure 5 (inset section A-B) illustrates the eastern face of the quarry (drawn from the authors' observations as well as those of Wilke, 1963) and shows that the zoning is unlike that described for pegmatites of the Selati Line further to the south. The Kubannek pegmatites consist of outer and inner zones and lack the typical quartz-rich core zones that so often characterize the pegmatites of the Selati Line. The outer zone consists of plagioclase, quartz and muscovite and usually displays very distinct contacts with the remainder of the pegmatite. The inner zone, which constitutes the major part of the pegmatite, consists mainly of quartz, plagioclase and muscovite together with disseminated grains of beryl, the latter being generally white in colour. Minor amounts of K-felspar may also be present. The composition of the beryl-bearing inner zone is listed in Table 1, column 12. This zone is seen to have a low $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratio ($\text{K}_2\text{O}/\text{Na}_2\text{O} = 0.06$) which is in marked contrast to the composition of the granitic pegmatite (*sensu stricto*) shown in column 5 of Table 1. The berylliferous zone also has an unusually high SiO_2 and low Al_2O_3 content. Insofar as the Kubannek pegmatites have a composition that is dominated by the presence of albite (and quartz) and are significantly different, therefore, to the more common K-felspar-rich granitic pegmatites, they will be referred to as albitite pegmatoids in order to emphasize this distinction.

Approximately 100 m northwest of the Kubannek Quarry is a small sub-vertical shaft from which tantalite-columbite was extracted (Fig. 5). This shaft was dug into an albitite pegmatoid, approximately 5 m in width, and possessing an unusual mineralogy. The latter is made up essentially of coarse-grained plagioclase laths, and intermittent quartz, together with zones that are rich in tourmaline (dravite) and garnet. Minor amounts of kyanite, muscovite and clinopyroxene are also present. Certain of the samples studied appear to have been tectonized (probably the effect of a nearby shear zone) and contain a plagioclase-quartz-muscovite-epidote-kyanite-garnet-clinopyroxene assemblage. The composition of the garnetiferous albitite pegmatoid that hosts the tantalite-columbite mineralization, is shown in Table 1, column 11. Once again a very low $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratio is evident and the high alumina content is undoubtedly

related to the presence of kyanite and the significant quantities of garnet in the rock. It is apparent from this mineralogy that a metamorphic and/or tectonic overprint has occurred in the area, and it is likely that the influence of metamorphism associated with the Limpopo belt may have extended to this northern section of the Sutherland greenstone belt.

The spodumene-bearing pegmatites of the western portion of the Palakop region are again characterized by distinct zonation. The outer zones consist essentially of quartz, plagioclase, microcline, perthite and muscovite but a distinct core zone is made up of quartz and plagioclase together with coarsely crystalline spodumene. Minor amounts of beryl are also found in the spodumene-bearing pegmatite. The presence of microcline in these spodumene-beryl pegmatites indicates that both granitic pegmatites (*sensu stricto*) and albitite pegmatoids are present in this area.

The pegmatitic granite of the Palakop region appears to contain residual pegmatitic phases of variable composition. Beryl and tantalite-columbite mineralization is frequently associated with a plagioclase-quartz dominated pegmatoid whereas only minor beryl, spodumene and kyanite are associated with more typical granitic pegmatites (*sensu stricto*). The importance of albitite pegmatoids and their association with concentrations of metalliferous elements has not been previously described in the North-Eastern Transvaal and will be discussed more fully in a later section.

All the minerals of commercial interest in the Palakop area are located within the pegmatite and reactions with the surrounding mafic rocks have apparently been minimal. Furthermore, the presence of garnet and, to a lesser extent, tourmaline, is possibly indicative of a metamorphic overprint in the area.

IV. BERYL AND EMERALD DEPOSITS ASSOCIATED WITH PEGMATITES

The single most valuable mineral mined in recent years in the North-Eastern Transvaal pegmatite fields is emerald, the occurrences of which are located in the Gravelotte area along the southern margin of the Murchison greenstone belt. Since 1927 when emeralds were first discovered in the region (van Eeden et al., 1939) a steady production has been forthcoming and the area now boasts the single largest emerald mine (carat production) in the world. This mine, known as the Gravelotte Emerald Mine (G.E.M.), accounted for most of the country's 2549 kg of emeralds produced in 1973 (Table 4) and today still has considerable reserves and expansion possibilities. The Cobra Pit at the Gravelotte Emerald Mine is South Africa's largest emerald working and its geology is described briefly below.

TABLE 4

EMERALD+ PRODUCTION IN THE REPUBLIC OF SOUTH AFRICA

YEAR	PRODUCTION ⁺	VALUE OF EXPORTS*
1963	240	294 000
1965	533	869 000
1967	378	658 940
1969	1 382	462 588
1971	1 986	406 694
1973	2 549	351 000

⁺ Kilograms - where 1 kilogram \approx 4 823 carats

* Rand

[†] These figures include the production of low-grade emeralds for uses other than in the manufacture of jewellery.

(Data from Winterbach, 1976).

A. The Gravelotte Emerald Mine

The Cobra Pit was first described by van Eeden et al. (1939), but since then considerable expansion and development has taken place and the main open-cast workings are now over 100 m deep and recently underground mining operations have also commenced.

The Cobra Pit occurs at the contact between Archaean tonalitic gneisses and talc-chlorite, actinolite and biotite schists occurring within a southeasterly trending off-shoot of the Murchison greenstone belt (Fig. 6). In addition to the tonalitic gneisses, the mafic schists are intruded by two other minor felsic rock types. These include (i) a fine-grained equigranular tonalitic/granodioritic dyke which, unlike the tonalitic gneisses, does not have a pronounced foliation, and (ii) coarse-grained albitite pegmatoids. The fine-grained tonalitic dyke, which appears to be unrelated to mineralization in the pit, is characterized by a quartz-plagioclase-biotite mineral assemblage, and has a typical trondhjemitic composition with a high $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratio (Table 1). The albitite pegmatoids, which are made up of a number of discrete bodies, are intimately linked with the emerald mineralization as well as molybdenite and bismuth. This mineralization relationship applies not only to the Cobra Pit but also to other localities along the southern flank of the Murchison greenstone belt. The albitite pegmatoid is chemically distinct from either the tonalitic gneisses or the fine-grained tonalitic dyke by virtue of its lower Fe + Mg content and much higher $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratio (Table 1; compare columns 6 and 8 with column 7). The albitite pegmatoid is compositionally similar to oceanic plagiogranites, the latter having been regarded as genetically associated with mafic and ultramafic ophiolite complexes (Coleman and Peterman, 1976). Mineralogically the albitite pegmatoid consists mainly of plagioclase feldspar with lesser amounts of quartz and minor muscovite as well as small grains of disseminated beryl. In addition the pegmatoid is in places characterized by large (up to 20 mm²) cubes of pyrite and lesser amounts of chalcopyrite and scattered molybdenite.

The emeralds in the Cobra Pit are confined to a 30-40 m wide zone of essentially monomineralic biotite schist (with only minor actinolite schists) found on the flanks of the albitite pegmatoid. The biotite schists are altered from chlorite and talc-chlorite schists which form the dominant rock-types in the greenstone belt off-shoot. The presence of biotite schists on the margins of the albitite pegmatoid is probably indicative of complex pneumatolytic reactions between it and the enveloping talc-chlorite schists. In order to explain the nature of this reactive process, analyses are presented of both biotite schists found close to the pegmatoid as well as talc-chlorite schists occurring well removed from its influence (Table 1, columns 9 and 10). The most significant effect of the alteration process is a large increase in the K_2O content of the biotite schists, which is counteracted by smaller decreases in their MgO , Fe_2O_3 and SiO_2 contents. The introduction of potash into the pre-existing mafic rocks (potash metasomatism?) has clearly been the main reason for the alteration of talc-chlorite to biotite. It is likely that the transfer of beryllium from the albitite to the surrounding schists, and the subsequent crystallization of emeralds in the biotite-schist, is a process which took place concomitantly with the alteration processes just described. The source of the potash in this alteration process is problematical. It is possible that the depleted potash content of the albitite pegmatoid has resulted from the movement of K_2O from the latter into the marginal schists. If this is the case then the albitite pegmatoid may originally have been a typical granitic pegmatite.

The presence of molybdenite at Cobra has been mentioned by van Eeden et al. (1939) and more recently by Martini (1979) who described the occurrences of molybdenite and bismuth not only at the emerald mine but also on the B.V.B. Ranch 776LT, located approximately 16 km east-northeast of the Cobra Pit area. Molybdenum, generally in the form of molybdenite leaf, occurs in patches, irregularly distributed along the southeastern face of the Cobra Pit at the contact between talc-chlorite schists and tonalitic gneisses. It also occurs scattered throughout the talc-chlorite schists as well as in minor amounts within the albitite pegmatoid. The association of molybdenum with the albitite pegmatoid appears reasonable particularly in the light of recent work which has shown that at low-to-intermediate concentrations of molybdenum this element is preferentially partitioned into plagioclase feldspars rather than into alkali feldspar (Samarkin and Samarkina, 1978). It is likely, therefore, that molybdenum will be located in albititic rocks and plagiogranites rather than in more typical granitic pegmatites.

The maximum grade of molybdenum reported by Martini (1979) is 0.4%, and this, combined with its irregular distribution, makes it an uneconomic mining proposition at present. Besides molybdenite, scattered grains of metallic bismuth and scheelite have also been reported from the Cobra Pit but are not recovered.

V. QUARTZ, FELSPAR AND MUSCOVITE DEPOSITS ASSOCIATED WITH PEGMATITES

In the past minerals such as quartz, plagioclase and alkali feldspars and muscovite were often mined from pegmatites as a by-product of an operation that was principally concerned with the extraction of more valuable minerals. More recently, however, a variety of industries (including the ceramics, glass, paints, electronics and abrasives industries) have provided a considerable demand for high quality quartz, feldspar and muscovite. In addition, an important export market has emerged and as a result a number of pegmatites in the North-Eastern Transvaal are now mined specifically for these three minerals. The following section briefly describes the geology of the Union Mine at Mica (Fig. 1).

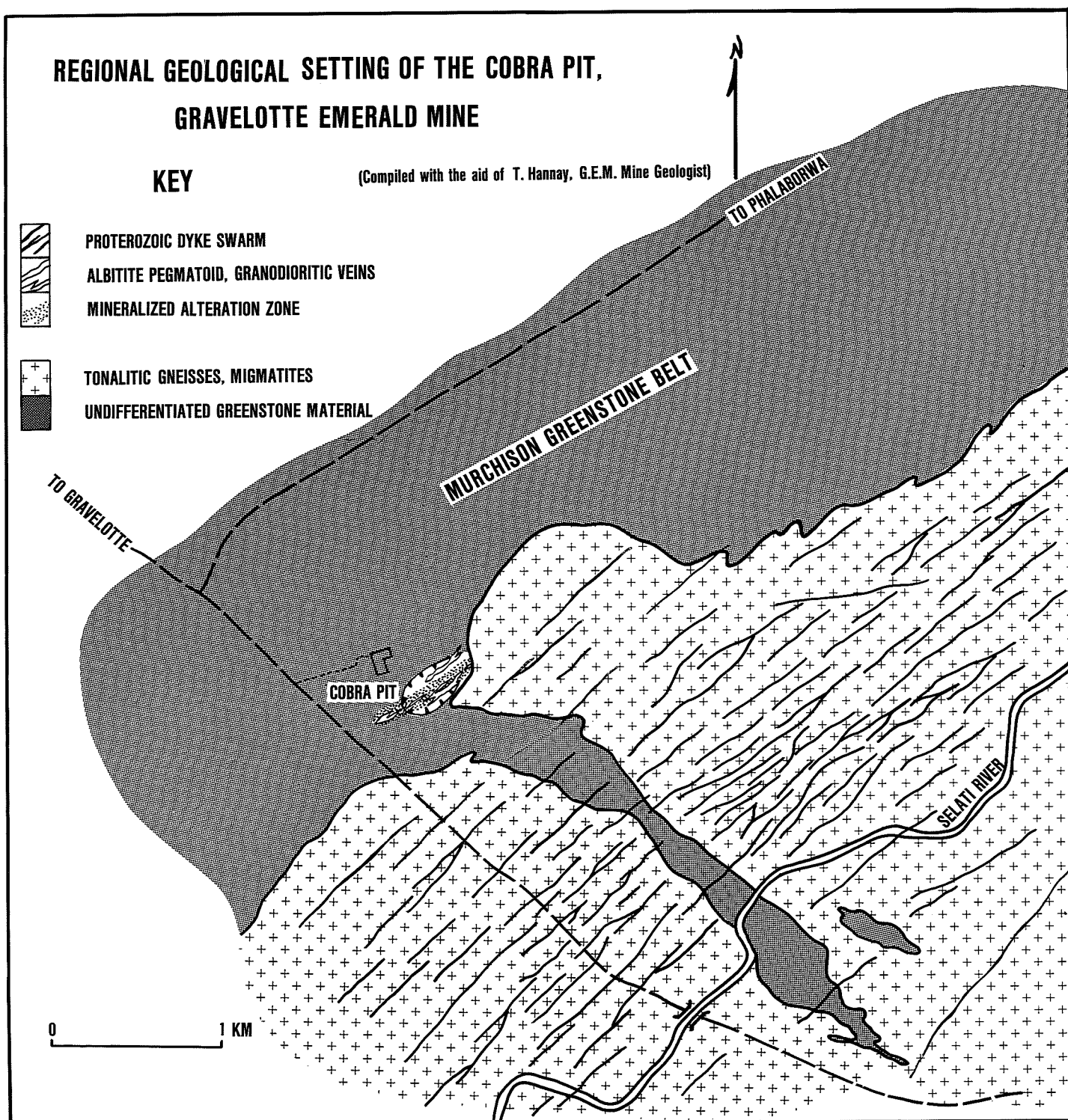


Figure 6 : Regional geological setting of the Cobra Pit, Gravelotte Emerald Mine.

A. The Union Mine

The Union Mine is the largest quartz, felspar and muscovite mine in the area and is situated at Mica, some 40 km southwest of Phalaborwa. The mine is presently an open cast operation and has a total production (for glass and ceramic grade materials) of some 20 000 metric tons a year.

The Union pegmatite, one of the largest in the area, has a roughly circular shape in plan and dips at approximately 30° to the east (Fig. 7). It is intrusive into ENE striking granitic gneisses that contain numerous greenstone remnants, the largest of which outcrops along a portion of the pegmatite-gneiss hangingwall contact (Fig. 7). The pegmatite is heterogeneous and contains well-defined border, wall and core zones. Significantly, the zonation is not symmetrical about the circular pegmatite and the footwall contact shown in the section A-B (Fig. 7) does not have a border zone.

The border zone, where present, consists predominantly of plagioclase and quartz with lesser amounts of disseminated muscovite as well as biotite. It is from this zone that most of the muscovite is extracted. The wall zone which, like the border zone, forms an incomplete annulus around the pegmatite body, consists essentially of plagioclase and quartz with minor amounts of K-felspar. The wall zone of the Union pegmatite also contains a narrow, continuous, shoot of muscovite which dips

at approximately the same angle as that of the pegmatite body as a whole. The core zone, which makes up the bulk of the pegmatite, consists predominantly of microcline perthite and coarse-crystalline quartz. It is from this zone that the bulk of K-felspar (for ceramics) and quartz (for the glass industry) is extracted.

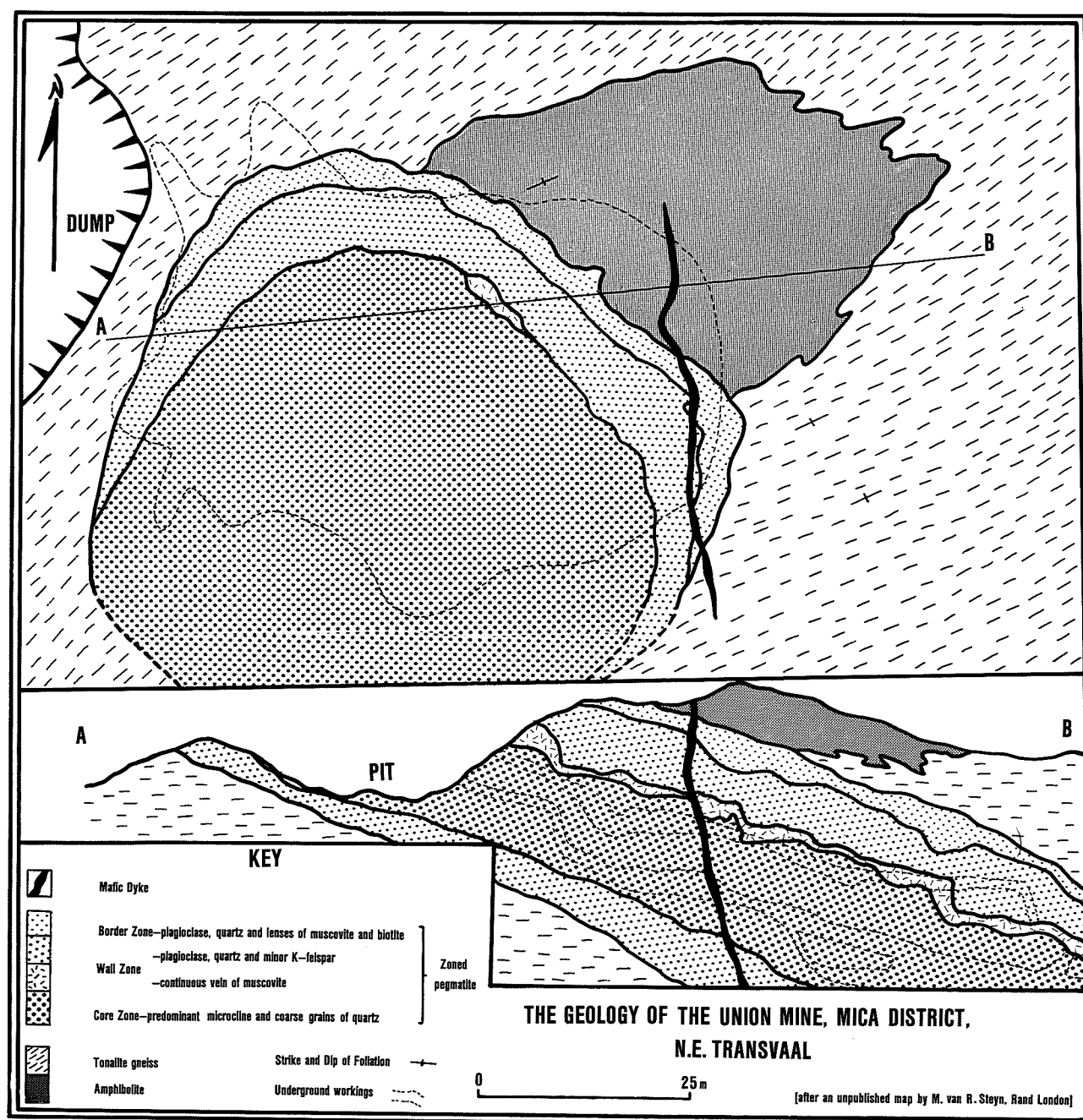


Figure 7 : The geology of the Union Mine, Mica district, North-Eastern Transvaal.

The mineralogy of the Union pegmatite is relatively simple; quartz is generally milky white and relatively free from mineral inclusions and trace impurities. Microcline perthite is characterized by a variety of perthitic textures including patch, film and string perthite. The microcline extracted for the ceramic industry is carefully sorted into various grades, this being largely dependent on the development of exsolved albite and inclusions of quartz and muscovite in the crystals. Select grade K-felspar, used principally in the ceramic industry, requires material with as little exsolved albite as possible so that K_2O contents are high ($> 9,5\% K_2O$) and SiO_2 and Na_2O contents are concomitantly lower. Standard grade ceramic K-felspar and glass grade K-felspar need only contain between $7,5 - 9,5\% K_2O$. A comparison of ceramic and glass grade K-felspar is provided in Table 1. The plagioclase feldspars in the Union pegmatite are generally albite-oligoclase with a Na_2O content of approximately $10,5\%$ (Table 1). Muscovite from the Union Mine is generally unaltered and free from secondary impurities; structures such as reeves (small folds) and staining haloes which tend to make large books of muscovite unfit for commercial use, are limited. Biotite and apatite form minor mineralogical constituents of the pegmatite and have no exploitable significance.

It is of interest to note that the Union pegmatite has many of the characteristics of the mica-bearing pegmatites of the Harts Range, Central Australia, described by Joklik (1955). These pegmatites exhibit a mineral zonation similar to that described for the pegmatites of the North-Eastern Transvaal. Joklik (1955) found that (i) the quality mica is more predominant on the hangingwall than on the footwall side of the pegmatite, (ii) muscovite is invariably less stained when associated with plagioclase than with K-felspar, (iii) the quality of muscovite generally increases with increasing lime content of the associated plagioclase and (iv) muscovite associated with the quartz core is generally of very high quality. In general the conclusions drawn from the Australian deposits are equally applicable to the muscovite-bearing pegmatites in the Mica area.

VI. DISCUSSION AND CONCLUSIONS

A. The Origin of the Pegmatites in the North-Eastern Transvaal.

Questions relating to the origin of the pegmatites in the North-Eastern Transvaal cannot be fully answered in the scope of this paper mainly because no detailed work on this problem has yet been undertaken. Most workers have considered three possible mechanisms for the source of pegmatites (Jahns, 1955). These include *aqueous mechanisms*, such as lateral secretion, *igneous mechanisms*, involving the emplacement of a magma and, *metamorphic mechanisms*, where anatexis, palingenesis or differentiation may have taken place. It has been suggested earlier that the pegmatites described in this paper have characteristics in keeping with an igneous origin, and hence their source must be related to a geological event of similar nature. Furthermore, reference has been made to the large intrusive body of potash-rich Mashishimala Granite occurring to the south of the Murchison greenstone belt (Fig. 2). Very recent work by the Geological Survey of South Africa has shown that the Mashishimala Granite is a composite pluton consisting of up to three discrete phases (J.G. Jantsky, verbal communication, 1979). Where sampled by the authors, this pluton, which has a granodioritic to adamellite composition (Table 1, columns 13 and 14), is characterized by large phenocrysts of microcline microperthite set in a groundmass of plagioclase, quartz and biotite. In terms of composition and mineralogy the Mashishimala Granite is similar to the large batholithic masses of granite that occur to the north and south of the Barberton greenstone belt (e.g. the Nelspruit Porphyritic Granite, and the Lochiel or Hood Granites - Robb, 1978; Anhaeusser and Robb, 1978). These granite bodies invariably have associated with them marginal or transition zones characterized by the pronounced development of pegmatite dykes and veins. It is thus feasible that the Mashishimala Granite or one of its associated phases behaved similarly to the abovementioned granites and was the source of the pegmatite swarms south of the Murchison greenstone belt. This view contrasts with that of Hall (1920) who was of the opinion that the pegmatites were genetically related to the "Old Granite" or tonalitic gneisses and that the Mashishimala Granite was a residual phase of the Palabora Igneous Complex. This alternative is considered unlikely as well-exposed tonalitic and trondhjemitic gneisses to the southwest of the Barberton greenstone belt do not contain related pegmatite phases (Anhaeusser and Robb, 1978) and the residual phases of the Palabora Igneous Complex generally appear to be syenitic and not granitic in composition.

One final point concerns the transition from the Kaapvaal cratonic block into the Limpopo Mobile Belt. Although the deposits described in this paper fall within the cratonic block the occurrence of pegmatites continues well into the Mobile Belt. It is likely that these pegmatites formed in response to the tectonic regime within the Limpopo Belt and their origin may well be related to metamorphic rather than igneous processes.

B. Factors Relating to the Mineralization in the Pegmatites of the North-Eastern Transvaal

Very little consideration has been given in the past as to why some pegmatites may be mineralized and others barren, and why certain economic pegmatites are characterized by a particular mineral assemblage and others by a different assemblage. It has already been mentioned that the pegmatite areas discussed in this paper seem to be lacking in tin, tungsten and uranium-thorium-rare earth mineral assemblages, whereas many of these minerals characteristically occur in pegmatites in the Northwest Cape and in South West Africa/Namibia. The reasons for these discrepancies are undoubtedly related to the degree of concentration of incompatible elements in a residual magma (in the case of an igneous-derived pegmatite) or, alternatively, the availability of the same elements in the source or parent material (in the case of a pegmatite that formed by partial melting in an ultrametamorphic setting). Logan and Van Huyssteen (1976) compared the trace element concentrations in the border-zones of pegmatites from Namaqualand and the North-Eastern Transvaal, and showed that, in general, pegmatites from the latter area were more depleted in incompatible trace elements than those of the former area. They concluded that the Transvaal pegmatites were barren compared with those of Namaqualand. This indicates that mineralization in the "barren" pegmatites of the North-Eastern Transvaal is related to factors *other* than the residual concentration of incompatible elements during crystallization of the magma. The descriptions of the four deposits above provide two clues as to the nature of mineralization associated with these pegmatites. Firstly, all the corundum deposits and certainly all the emerald deposits in the area are formed by processes related to the interaction of invading

pegmatitic magma or vapour phases with pre-existing greenstone remnants. The abundance of xenolithic or remnant greenstone material in the region is evident in Figure 2, and clearly accounts for the widespread occurrences of corundum (marundite) deposits in that area. The mineralization process therefore demands not only the components of the pegmatite itself, but also requires constituents from the greenstones (e.g. calcium, chrome) in order to form the deposits in question. Secondly, mineralization in the Transvaal pegmatites is, in some instances, related to the presence of albitite pegmatoids and not to the more typical granitic pegmatites (*sensu stricto*). In the Cobra Pit at Gravelotte, the beryl (from which the emeralds are derived) and the molybdenum is demonstrably linked to an albitite and at Palakop the tantalite-columbite (as well as beryl) mineralization is also related to a garnetiferous albitite pegmatoid. Although the association of certain elements such as Ta, Nb, Mo and Be with rocks of albitic composition has not previously been reported in the North-Eastern Transvaal, this relationship is not uncommon in other regions. For example, Samarkin and Samarkina (1978) have reported the association of molybdenum with plagioclase-rich rocks in the Soviet Union; Roering (1966) reported the presence of tantalite-columbite and beryl mineralization preferentially concentrated in cleavelandite zones within the Karibib pegmatites in South West Africa; and recently Krynauw (1979) described the association of Sn-Nb-Ta-Mo mineralization with albitites and albitized granites from the Richtersveld suite in Namaqualand. Clearly the search for metallic incompatible elements such as Sn, Ta, Nb, Mo and Be is more likely to be fruitful in the albititic pegmatoid rocks described above than in the more common granitic pegmatites. This implication is one facet of the North-Eastern Transvaal pegmatites that has been generally overlooked.

In conclusion the North-Eastern Transvaal pegmatite field still appears to have a significant economic potential; corundum, though largely obsolete as an abrasive, may yet provide a source of refractory alumina if found in sufficiently large quantities; quartz, feldspar and muscovite are ubiquitous by-products of the region and vital to the needs of the ceramic, glass and other industries; high quality emeralds will always maintain their attractiveness and considerable reserves of these stones remain in the area. Tantalite-columbite and particularly molybdenite are rapidly becoming vital, if not strategic, commodities in advanced technological societies, and it is this avenue which might ultimately provide the best scope for future development in the area.

ACKNOWLEDGEMENTS

The major part of this paper represents a synthesis and collation of the work (mostly unpublished) and help of many people. The authors are very grateful to the following in this regard: J. van Heerden and R. Peattie of the Union Mine, Mica, and Dr. M. van R. Steyn of Rand London Corporation; L.J. Contat and T. Hannay of Gravelotte Emeralds (Pty.) Ltd.; L.J. Gunter and L. van der Heever of Rio Tinto Exploration (Pty.) Ltd., and the Palabora Mining Company; and Dr. J. Martini of the Geological Survey, Pretoria.

Professor C. Roering of the Rand Afrikaans University, Johannesburg, is acknowledged for having read a draft version of this paper. Mrs. W. Job and Miss. H. Long are thanked for drafting and secretarial assistance.

REFERENCES

- Anhaeusser, C.R. (1978). On an Archaean marundite occurrence (corundum-margarite rock) in the Barberton Mountain Land, Eastern Transvaal. *Trans. geol. Soc. S. Afr.*, 81, 211-218.
- Anhaeusser, C.R. and Robb, L.J. (1978). Regional and detailed field and geochemical studies of Archaean trondhjemitic gneisses, migmatites and greenstone xenoliths in the southern part of the Barberton Mountain Land, South Africa. *Inf. Circ. Econ. Geol. Res. Unit*, No. 125, 14 pp.
- Beerman's All Mining Yearbook, (1966 and 1971). Combined Publishers, Johannesburg.
- Brandt, J.W. (1946). Corundum "indicator" basic rocks and associated pegmatites in the Northern Transvaal. *Trans. geol. Soc. S. Afr.*, 49, 51-102.
- Cameron, E.N., Jahns, R.H., McNair, A.H., and Page, L.R. (1949). Internal structure of granitic pegmatites. *Econ. Geol. Monogr.*, 2, 115 pp.
- Coleman, R.G. and Peterman, Z.E. (1975). Oceanic plagiogranites. *J. Geophys. Res.*, 80, 1099-1108.
- De Villiers, S.B. (1976). Corundum. in: Coetzee, C.B. (Ed.), *Mineral Resources of the Republic of South Africa*. Handbook, geol. Surv. S. Afr., 7, 462 pp.
- Du Toit, A.L. (1918). Plumasite (corundum-aplite) and titaniferous magnetite rocks from Natal. *Trans. geol. Soc. S. Afr.*, 21, 53-73.

- Du Toit, A.L. (1946). Discussion on "Corundum "indicator" basic rocks and associated pegmatites in the Northern Transvaal by J.W. Brandt". Trans. geol. Soc. S. Afr., 49, 51-102.
- Hall, A.L. (1920). Corundum in the Northern and Eastern Transvaal. Mem. geol. Surv. S. Afr., 15, 82 pp.
- Jahns, R.H. (1955). The study of pegmatites. in: Bateman, A.M. (Ed.), Econ. Geol. 50th Anniversary Vol., 1130 pp.
- Jamieson, R.T. and Schreiner, G.D.L. (1957). The ages of some African lepidolites determined from the Rb^{87} - Sr^{87} decay. Proc. Roy. Soc., B, 146, 257-269.
- Joklik, G.F. (1955). The mica-bearing pegmatites of the Harts Range, Central Australia. Econ. Geol., 50, 625-649.
- Krynauw, J. (1979). Albitites and associated Sn-Nb-Ta mineralization in the Richtersveld Suite. Abs. Geokongres '79, Univ. of Port Elizabeth, 238-243.
- Kupferburger, W. (1935). Corundum in the Union of South Africa. Bull. geol. Surv. S. Afr., 6, 49 pp.
- Logan, C. and van Huyssteen, E. (1976). The selection of economically mineralized pegmatites according to their border-zone characteristics. N.I.M. Res. Rep. No. 1508.
- Martini, J. (1979). On some molybdenum occurrences associated with emerald deposits in the Gravelotte area, Eastern Transvaal. Unpub. Rep. geol. Surv. S. Afr., 5 pp.
- Robb, L.J. (1978). A general geological description of the Archaean granitic terrane between Nelspruit and Bushbuckridge, Eastern Transvaal. Trans. geol. Soc. S. Afr., 81, 331-338.
- Roering, C. (1966). Aspects of the genesis and crystallization sequence of the Karibib pegmatites, South West Africa. Econ. Geol., 61, 1064-1089.
- Samarkin, G.I. and Samarkina, E.Y. (1978). Molybdenum in the granitic rocks of the principal granite belt of the Southern Urals. Geokimiya, 1, 59-69.
- Van Eeden, O.R., Partridge, F.C., Kent, L.E. and Brandt, J.W. (1939). The mineral deposits of the Murchison Range, east of Leydsdorp. Mem. geol. Surv. S. Afr., 36, 172 pp.
- Von Backström, J.W. (1973). Pegmatite deposits in the Republic of South Africa. A.E.B. Rep. PEL227, 29 pp.
- Wilke, D.P. (1963). Pegmatietvoorkomste te Palakop, Distrik Letaba. Unpub. Rep., geol. Surv. S. Afr., 0073, 4 pp.
- Winterbach, D.J. (1976). Gemstones. in: Coetzee, C.B. (Ed.), *Mineral Resources of the Republic of South Africa*. Handbook, geol. Surv. S. Afr., 7, 462 pp.

* * * * *