

3.3. Silicate Mineralogy

3.3.1. Albitized Intrusions

The three albitized intrusions studied have broadly similar silicate mineralogy, although differences occur as a result of the degree of albitization within the intrusions. The degree of albitization may vary greatly within a single intrusion, especially in the Discovery Shaft intrusion. On average, the Minerva Mine intrusion is the least altered and contains moderately altered mafic minerals, including primary biotite and hornblende, with only minor albite replacement. The Discovery Shaft intrusion contains only remnant mafic minerals, with the alkali feldspars being partially replaced by albite. The Malati Store intrusion exhibits the greatest degree of albitization, where the mineralogy is dominated by replacement albite.

The unaltered Willie pluton consists of a mosaic of approximately equal amounts of equigranular orthoclase, plagioclase and quartz with minor microcline. Large porphyritic orthoclase crystals occur and commonly show internal zoning as well as inclusions of albite, quartz and muscovite. Microperthite, as well as granophyric textures, occur within the alkali feldspars. Minor amounts of hornblende, biotite, magnetite and sericite also occur. Minor sericitization and kaolinitization of the alkali feldspars has occurred and, occasionally, small amounts of replacement albite are observed as a fine rim of albite around the alkali feldspars. The biotite and hornblende show minor chloritization. There is little or no indication of major hydrothermal activity occurring within the Willie pluton. The occasional chloritization of the biotite and sericitization of the feldspars, as observed in the Willie pluton, are considered to represent ordinary late deuteric effects which are not related to albitization.

Within the albitized intrusions, biotite and hornblende destruction occurred early in the hydrothermal history, being replaced by chlorite, carbonate and minor irregular epidote. The intense chloritization of mafic minerals results in the exsolution of fine rutile aggregates occurs along cleavage planes (Plate 3.16).

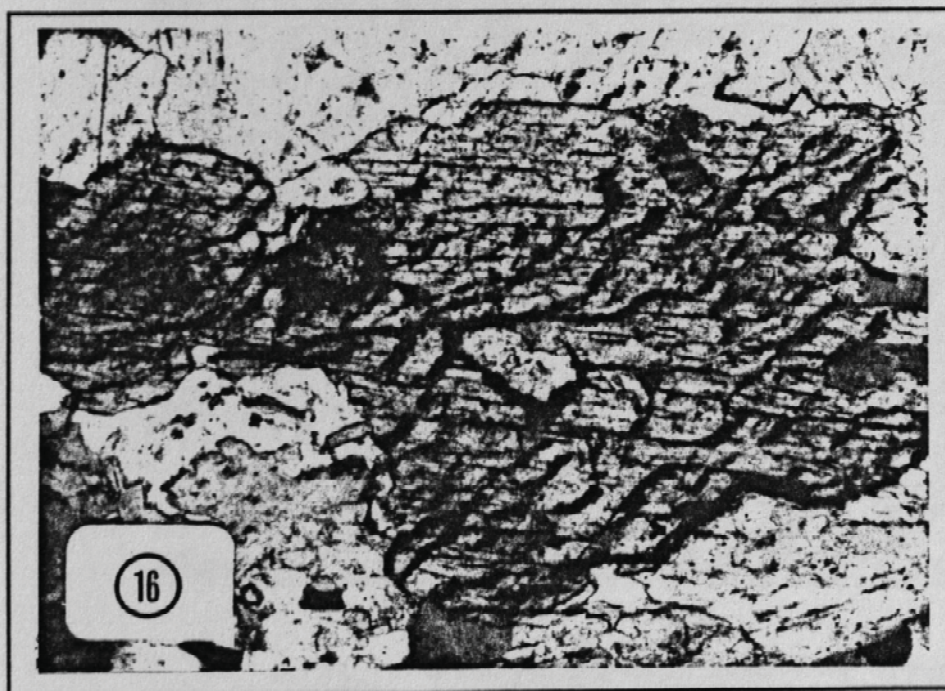


Plate 3.16. Replacement of hornblende by chlorite and fine grained carbonate. Note exsolution of fine rutile along cleavage planes. Discovery Shaft intrusion. (X200).

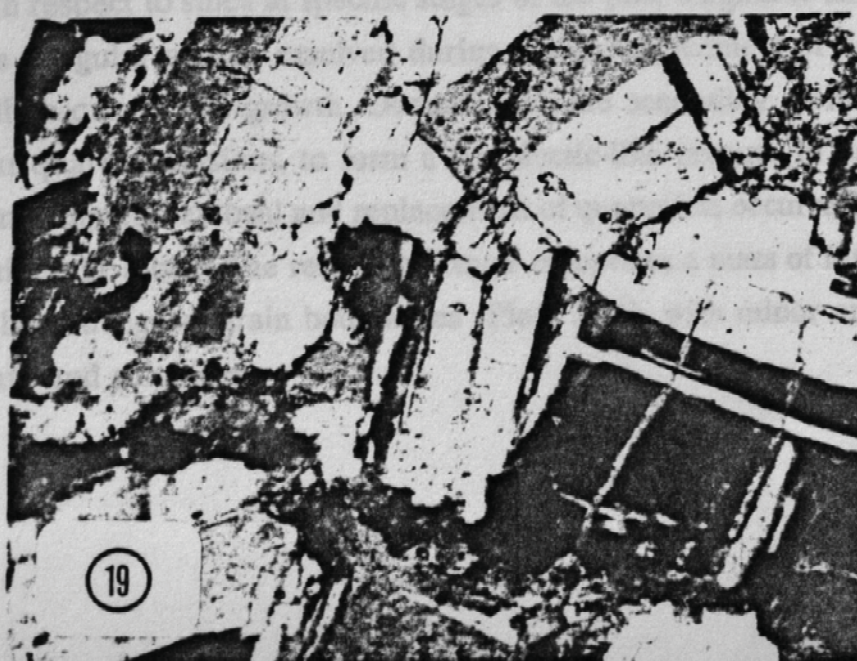
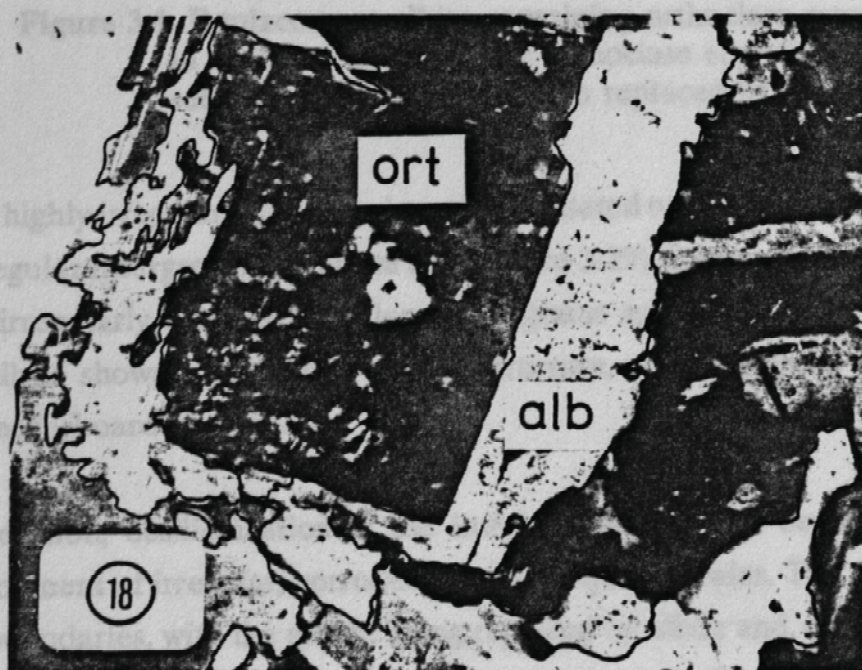
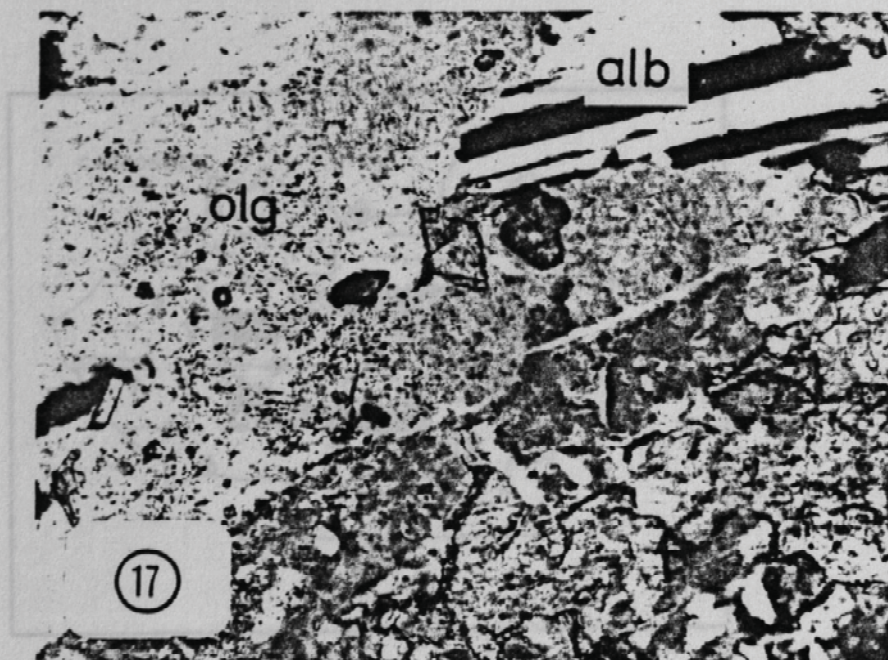
The initial stages of albitization resulted in the replacement of alkali feldspars by irregular overgrowths of white, inclusion free albite. The alkali feldspars also break down to fine-orientated sericite, minor epidote and chlorite and irregular quartz grains. Initially, the albitization appears to be isochemical, with the redistribution of elements from the alkali feldspars into albite, quartz, sericite and chlorite. With increased alteration there is an influx of sodium and rapid removal of potassium (See Chapter 4.), resulting in the destruction of sericite to a fine-grained albite-quartz-carbonate intergrowth and the growth of large albite laths, at the expense of feldspars and quartz. The irregular quartz precipitated during the early alteration was also replaced by albite. Magmatic plagioclase (oligoclase) was also gradually corroded and replaced by laths of albite and carbonate (Plate 3.17), initially along cleavage planes.

The replacement of the alkali feldspar by albite results in highly irregular grain boundaries between the albite, orthoclase and quartz. The replacement albite often contains irregular remnant cores of orthoclase and quartz in optical continuity (Plate 3.18 and Figure 3.1). The albite grains are initially highly irregular and intergrown with remnant orthoclase, quartz and exsolved quartz, but become more euhedral with greater degrees of replacement.

Plate 3.17. The replacement of oligoclase by albite (alb) and carbonate.
Discovery Shaft intrusion. (X100).

Plate 3.18. The replacement of orthoclase (ort) by albite (alb).
Discovery Shaft intrusion. (X100).

Plate 3.19. Albitite consisting of an irregular intergrowth of albite.
Ferroan-dolomite occurs along grain boundaries and stress cracks.
Opaque mineral is pyrite. Malati Store intrusion. (X100).



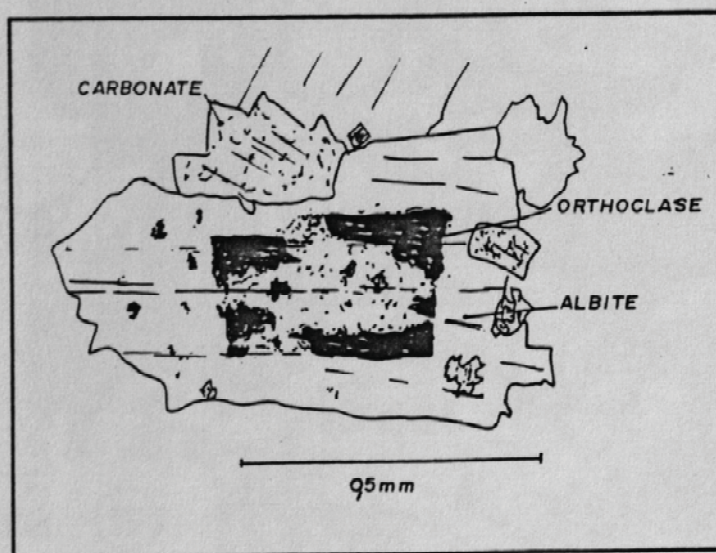


Figure 3.1. Replacement albite containing orthoclase remnants, in optical continuity. The orthoclase contains numerous sericite grains which are also replaced by albite.

The albite contains highly irregular and inconsistently orientated twinning and commonly occurs as highly irregular intergrowths of albite laths (Plate 3.19). Large albite laths may contain numerous irregularly oriented, smaller albite grains as well as rutile needles. Occasionally, the albite shows a distinctive mosaic structure, with combined twinning, giving rise to a "checkerboard" texture.

With increased alteration, desilicification of the intrusion occurs. The desilicification results in the development of irregular, corroded magmatic quartz grains. The corrosion begins along joint boundaries, with the quartz being replaced by albite and, occasionally, carbonate (Plate 3.20). This indicates that the fluids involved in the alteration were undersaturated with respect to silica at specific stages of the post-magmatic history. The replacement of the irregular quartz, exsolved during albite replacement of orthoclase, results in a fine albite-quartz intergrowth. Occasionally, the secondary albite contains numerous, irregular quartz inclusions, to form a symplectic-like texture. In portions of the Malati intrusion complete removal and replacement of quartz has occurred, resulting in virtually monomineralic albite. The resulting texture comprises a mass of interlocking albite laths which have irregular grain boundaries (Plate 3.21), with minor amounts of interstitial carbonate and sulphides.

Plate 3.20. Replacement of magmatic quartz by albite, showing remnant quartz in optical continuity. Discovery Shaft intrusion. (X200)

Plate 3.21. Albitite composed of >95% albite, with minor carbonate and sulphides. Malati Store intrusion. (X100)

Plate 3.22. Late actinolite growth. Opaque mineral is fine pyrite films along stress cracks and grain boundaries. Discovery Shaft intrusion. (X100)

Only rarely does the replacement albite show evidence of post-crystallization stress although fine fractures related to the brecciation event do occur and are filled with late quartz, carbonate or pyrite. The remnant magmatic quartz and feldspars commonly show extreme undulose extinction and the plagioclase may exhibit deformed twin lamellae.

The approximate composition of the replacement albite is estimated to be $Ab_{95}-Ab_{98}$ using the Michel-Levey statistical method (Heinrich, 1965) The original plagioclase was oligoclase (Ab_{70}).

Staining techniques did not reveal the presence of paragonite, or any of its low temperature breakdown products. The $Na_2O-Al_2O_3-SiO_2-H_2O$ stability curves, indicate that the $M_{NaCl}:M_{HCl}$ was therefore high, in excess of 10^4 (Figure 3.2) at temperatures $\pm 300^\circ C$ (Siems, 1984) estimated from microthermometry data.

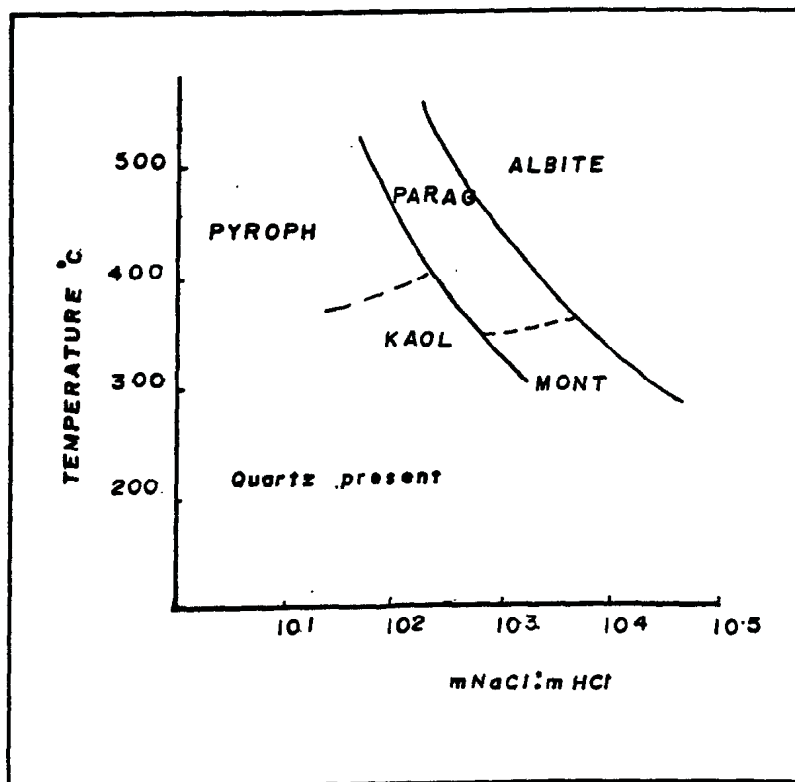


Figure 3.2. $Na_2O-Al_2O_3-SiO_2-H_2O$ stability curves.
Adapted from Seims (1984)

Carbonate is a ubiquitous mineral and was precipitated over a large portion of the alteration history, occurring both as an early euhedral phase within sulphide and as a late anhedral phase along grain boundaries and cracks. The late carbonate replaces both albite and residual quartz along grain boundaries and cracks. Staining techniques, using alizarin red S and potassium ferricyanide, indicate that the carbonate is predominantly ferroan-dolomite. Small amounts of calcite occur as late, cross-cutting veinlets within the sheared intrusion contacts. Purple fluorite occurs as fine cubic crystals in late veins, associated with quartz sericite veins. Biotite, in contact with fluorite, shows radiogenic damage. Other accessory minerals in the intrusions include apatite, monazite, epidote, zircon and beryl. Beryl is common, as small, euhedral, randomly orientated crystals within the albite matrix. Occasional large, irregular blows of quartz with fine grained beryl and scheelite occur within the albitites.

The chlorite content of the intrusions is variable, ranging from trace to zones of monomineralic chlorite along the contacts. Original mafic biotite is replaced by chlorite which with increased albitization and desilicification, is replaced by fine grained carbonate, epidote and albite. Late hydrothermal growth of chlorite is associated with the late sericite alteration, commonly occurring as fine quartz-chlorite veins. The sheared contact of the Discovery Shaft intrusion contains a high proportion of orientated chlorite.

The quartz stockwork of the intrusions is paragenetically late and is considered to be the final stage of the alteration sequence. This final stage resulted in intense, pervasive and vein-related silicification which is manifested as quartz rims developed around relic quartz grains albite and as fine irregular veins. Brecciation resulted in the micro-fracturing of the albite grains commonly along cleavage planes. These cracks are usually filled with quartz and, occasionally, carbonate. The quartz stockwork occurs as an equigranular mosaic with only minor carbonate and sericite developed along grain boundaries. There is evidence in the Discovery Shaft intrusion and to a lesser extent in the Malati Store intrusion, for late potassic alteration over-printing the early sodium metasomatism. This resulted in the development of sericite, biotite and the replacement of albite along grain boundaries by highly irregular alkali feldspar. Late, fine-grained muscovite-quartz $\pm$ chlorite veins cross cut the intrusions. Small amounts of actinolite occur as radiating crystals within the Discovery Shaft intrusion, commonly along the sheared contact (Plate 3.22). Biotite along the sheared contact of the intrusion overgrows the hydrothermal albite as well as the actinolite.

3.4. Discovery Shaft Ore Zone

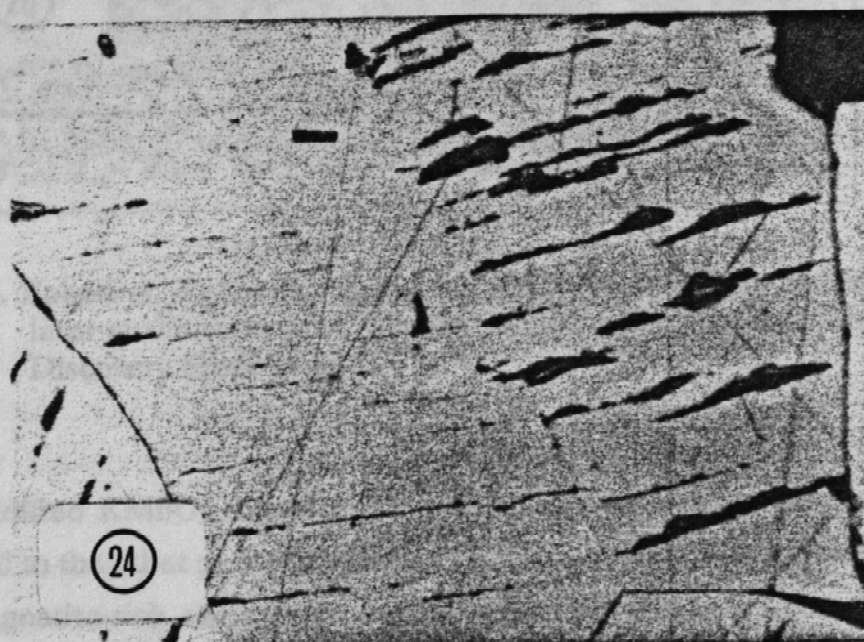
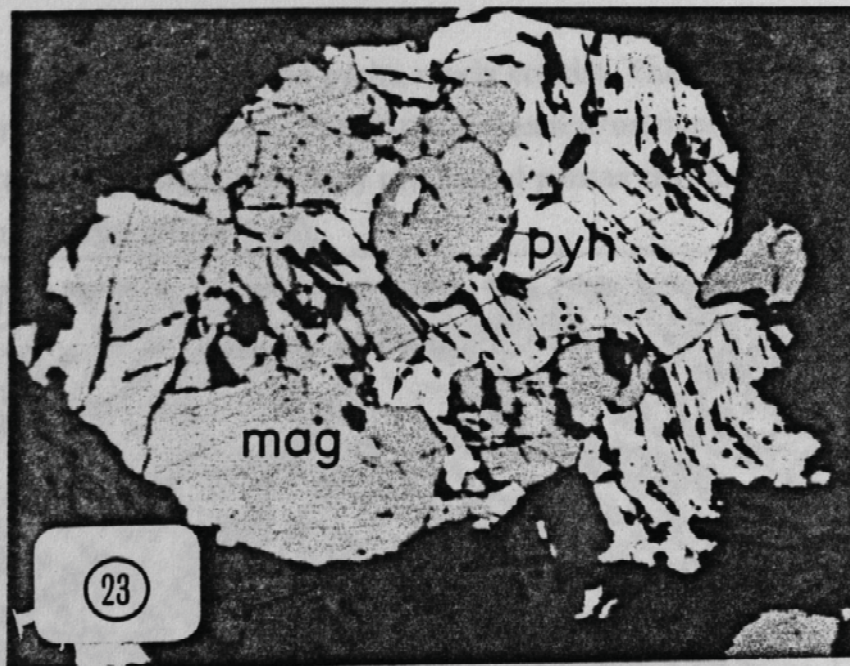
The ore zone at Discovery Shaft consists of discontinuous lenses of pyrite-pyrrhotite and magnetite with minor amounts of chalcopyrite, molybdenite, stibnite and rare cinnabar. The pyrrhotite-rich zones show a close interrelationship with magnetite, commonly including the magnetite and, apparently, replacing it in many cases (Plate 3.23). The granular pyrrhotite has a well developed cleavage (Plate 3.24). Pyrrhotite and pyrite exhibit complex textural relationships suggestive of fluctuating sulphur contents and / or fO_2 of the mineralizing fluid. The magnetite layers consist of fine ($< 50 \mu\text{m}$), irregular to rounded grains which rarely show internal structure or exsolution of other Fe-Ti phases. Occasionally, grains contain exsolution lamellae (Plate 3.25). The small size of the lamellae prevents positive identification, but they are likely to be ilmenite or haematite, however no haematite was positively identified in the ore zone.

Pyrite is the dominant sulphide within the ore zone and occurs as large (up to 3 mm) anhedral to subhedral grains, commonly with an inclusion rich core. NAA indicates that the pyrite is auriferous and may contain either submicroscopic gold or dissolved gold. Liberation in hydrofluoric acid indicates that the grain morphology is distinctly different from that of the intrusions and consists of un-striated cubic forms with only occasional octahedral modifications. The grains may be elongated with attenuated edges and are occasionally shattered. The elongation direction is usually sub-parallel to the fabric of the rock. There appears to be at least three phases of pyrite mineralization. An early diagenetic metamorphic phase followed by a dominant euhedral phase containing numerous inclusion including gold and, a late inclusion free anhedral phase. Staining of the pyrites by acidified KMnO_4 generally indicates that they are internally structureless which does not support fluctuations in the sulphur content of the fluid. The staining also indicates that the pyrites are generally of low arsenic content. The contact between pyrite-rich layers and magnetite-rich zones is usually sharp and not suggestive of magnetite replacement by pyrite.

Plate 3.23. Magnetite apparently being replaced by pyrrhotite.
Discovery Shaft ore zone. (X200).

Plate 3.24. Granular pyrrhotite grain showing well-developed cleavage.
Discovery Shaft ore zone (X200).

Plate 3.25. Euhedral magnetite grain showing exsolution of a unidentified mineral.
Discovery Shaft ore zone. (X500).



However it is noted that magnetite and pyrite rarely coexist. The magnetite rich zones do not contain pyrite and visa versa. The early diagenetic/metamorphic pyrite phase occurs as small (<0.5 mm), cubic, randomly orientated pyrites that may occasionally be enclosed within later pyrite (Plate 3.26).



Plate 3.26. Euhedral, digenetic / metamorphic pyrite occurring within later auriferous pyrite. Sample stained with acidified KMnO_4 . Discovery Shaft 11-level

Staining with acidified KMnO_4 suggests that this pyrite phase has a very low arsenic content compared to the other pyrite phases. This pyrite is present along the entire strike of the pyrite-magnetite-rich shear zone, including the un-mineralized zones, and is interpreted as being either of diagenetic origin or a preexisting pyrite-rich lithology. Further along strike from the ore zone the lithology is composed predominantly of fine magnetite with recrystallized quartz rich zones and occasional zones of the small euhedral diagenetic pyrite. The physical features of this horizon supports the idea that it represents a highly sheared banded ironstone. The gold grade of this zone is negligible. The large auriferous euhedral phase post-dates the major shearing as indicated by the presence of actinolite trails within the grains. This phase overgrows and includes the diagenetic pyrite and contains an inclusion-rich core comprising mainly of silicates and carbonates with minor amounts of pyrrhotite, chalcopyrite, rutile, rare magnetite and, occasionally gold. Pyrrhotite-rich zones are commonly rich in chalcopyrite, very little

chalcopyrite occurs within the pyrite rich zones. The relationship between the pyrite and pyrrhotite rich zones is not clear. There may be a decrease in pyrrhotite away from the intrusion contact. Gold as noted, is predominantly associated with pyrite, commonly within the inclusion rich core of the euhedral pyrite as small ellipsoid inclusions. However, there is evidence of minor fracture-filling gold along cracks within shattered pyrites especially in severely sheared zones (Figure 3.3).

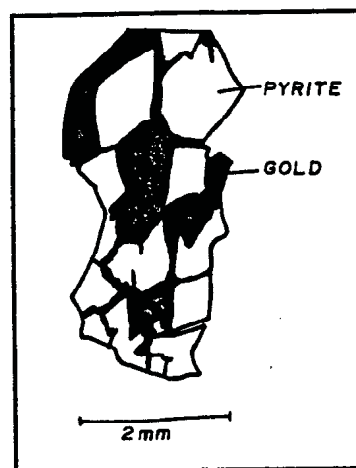


Figure 3.3. Fracture filling in shattered pyrite.
Discovery Shaft ore zone. 11-Level

This euhedral phase is overgrown by a late euhedral, relatively inclusion-free phase. Later stress has resulted in the deformation and shattering of the pyrite grains and the development of quartz pressure shadows. The quartz-rich layers are commonly sheared and folded. Other minerals observed in the ore zone include molybdenite, cinnabar, stibnite, arsenopyrite, beryl, fluorite and tetrahedrite.

The silicate assemblage in the Discovery Shaft ore zone consists of banded, talc-chlorite-actinolite, with minor biotite- and quartz-rich layers. This crude layering is commonly folded and is defined by discontinuous quartz, magnetite lenses and the segregation of actinolite, talc and chlorite. This distinct mineralogical layering may reflect a primary mineralogical layering in the original host rock. The actinolite is often replaced by late talc and carbonate. A late, randomly orientated, biotite and sericite assemblage overgrows the actinolite-chlorite assemblage, again indicating late potassic alteration.

3.5. Conclusions

The mineralogy of the intrusions examined is consistent with the notion that the albite-rich bodies (albitites) have formed as a result of sodium metasomatism of an original granodiorite intrusion. This resulted in the replacement of the original magmatic minerals by albite and the subsequent leaching of silica and potassium. The fluids involved in the alteration were thus enriched in Na^+ and depleted in K^+ and silica. Limited late potassic alteration has occurred within the intrusions, apparently related to late fluids migrating along the contact. Figure 3.4. shows a proposed mineralogical paragenetic sequence for the intrusions. The alteration sequence of alteration events can be summarized as:-

1. Unaltered granodiorite
2. Early chlorite-sericite alteration of deuteric nature (propylitisation) - not necessarily related to main stage albitization (observed in most granodiorite intrusions examined)
3. Main stage albitization, carbonation, sulphidation and desilicification
4. Late silicification and sericitization

No magnetite is present within the albitized intrusions. This may be because it has completely replaced by sulphides or, possibly carbonates, in the alteration process. The sulphide mineralogy of the albitized intrusions is dominated by hydrothermal pyrite, which contains gold as visible inclusions and as microscopic particles, suggesting simultaneous precipitation. The sulphide mineralization occurred late in the hydrothermal alteration of the intrusions as it commonly post-dates the albite replacement.

Along with arsenic rich pyrite, the Malati Store intrusion is mineralized with arsenopyrite and minor antimony- and mercury-bearing minerals. By comparison, the Discovery Store and Minerva mine intrusions are arsenic-poor, with only rare antimony and mercury minerals, although they have higher chalcopyrite and molybdenite contents. The Ti-enrichment in the altered intrusions (See Chapter 4.1), is due to the introduction and precipitation of hydrothermal ilmenite and rutile. Haematite was not stable during albitization and during the replacement of ilmenite by rutile. This suggests that the $f\text{O}_2$ conditions were low, ie. below haematite stability, during the albitization process.

The alteration of magmatic mafic minerals resulted in the liberation of a fine grained rutile aggregate along cleavage planes. With increased albitization, the oriented rutile aggregate was enclosed within a fine grained carbonate and albite matrix. The rutile has been replaced by sphene in the Discovery Shaft and Minerva Mine intrusions.

The ore zone at Discovery Shaft contains pre-existing diagenetic/metamorphic sulphides, as well as magnetite and quartz and is considered to represent a sheared banded ironstone. Sulphide-gold mineralization occurred after major shearing and is interpreted to be due to the interaction between the sheared iron rich lithology and auriferous fluids which migrated into the country rock from the Discovery Shaft granodiorite intrusion. Sulphidation reactions may have caused destabilizing of the gold sulphur complex, resulting in the precipitation of auriferous pyrite. Minor upgrading of the deposits has occurred due to later shearing.

The nature of the sequence of alteration is similar to the model proposed by Smirnov (1976), which genetically relates sodium alteration and potassic alteration emplaced spatially in and around the parent intrusion. The relative intensities and volumes of either potassic or sodic alteration are a function of the composition of the parent rock type, where sodium rich parental rocks are associated with larger proportions of sodium metasomatism. In this regard, the potassic and sodium alteration that is common to GEM and to portions of the Antimony line, may be genetically related. Albitization of the granitoids would result in the liberation of fluids rich in potassium (Chapter 4) that would migrate to higher levels resulting in potassic alteration resulting the spatially related potassic and sodium alteration.

CHAPTER 4

Geochemistry

4.0. Introduction.

The albite-rich rocks of the Murchison schist belt may be attributed either to hydrothermal alteration associated with magmatic intrusives (this study), or to a process of lateral secretion (Pearson, 1980). In order to test the possibility that the albite-rich rocks or "albitites" might be related to the suite of intrusive granodiorite intrusions which surround and intrude the Murchison schist belt, the geochemistry of these rocks has been compared to that of unaltered granodiorites and tonalites found in the vicinity. Major, trace and REE analyses of the albite rich rocks were carried out and the trace element content of the pyrite from both altered intrusions and related pyritic schists was determined. This geochemical data is used to show that the albitites of the Murchison schist belt are directly related to intrusive granodiorites, similar to that of the Willie pluton (Fig. 1.2). They are, furthermore, the product of endogranitic subsolidus alteration which resulted in varying degrees of albitization and sulphidation in the cupola zone. It is also suggested that the fluids responsible for albitization are closely related to albite pegmatites which are linked to emerald mineralization in the region.

Due to a lack of data on the granitoid suite which intrudes and surrounds the Murchison schist belt, the granodiorite/tonalite and albite porphyry rocks of the Barberton greenstone belt have also been used for comparison with the altered albite-rich rocks of this study. Numerous geochemical studies have been conducted on the granitoids of the Barberton area (Condie and Hunter, 1976; Glickson, 1976; Viljoen and Viljoen, 1961) (Table 4.1.1). In addition, data on unaltered intrusives from several trondhjemitic intrusions in the eastern portion of the Murchison schist belt is available from Minnitt (1975). Vearncombe *et al.* (unpubl. data) shows analysis of several granodiorites from the Murchison area, while the albitites of Pearson (1980) have also been used for comparison in this study (Table 4.1.1)

Unaltered Granodiorites from the Murchison Area														
Sample	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	LOI	Total	Na ₂ O/K ₂ O
13	71.04	0.08	15.87	0.91	0.79	0.05	0.67	0.38	7.91	2.56	0.23	0.95	101.24	3.09
14	74.82	0.06	13.93	0.52	0.86	0	0.27	0.99	4.11	4.35	0.21	0.35	100.17	0.44
15	74.27	0.06	13.77	0.87	0.68	0	0.21	0.83	3.03	5.47	0.18	0.40	99.49	0.55
16	72.73	0.30	13.12	2.03	1.11	0	0.67	1.72	2.50	4.79	0.30	0.31	99.58	0.52
17	70.50	0.34	15.99	0.52	1.83	0.04	1.01	2.32	4.81	2.24	0.16	0.72	100.07	2.15
18	72.27	0.15	14.52	1.57	0.94	0.12	0.80	2.78	4.44	1.58	0.28	0.28	99.79	2.81
GC2	67.76	0.01	19.20	0.32	1.23	0.02	0.62	2.76	5.69	0.81	0.09	0.59	99.82	7.02
GC2	73.31	0.20	14.37	0.18	0.87	0.03	0.29	0.93	4.14	4.68	0.06	0.56	99.85	0.88
RM15	75.22	0.06	15.04	0.18	0.38	0.01	0.14	1.84	3.50	2.74	0.04	0.62	99.76	1.88

Barberton Tonalites and Albite Porphyries														
Sample	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	LOI	Total	Na ₂ O/K ₂ O
106	70.63	0.24	14.96	0.39	1.26	0.03	1.06	1.08	5.37	1.55	0.06	0.79	98.73	3.46
117	68.93	0.30	16.21	0.76	1.56	0.03	3.69	3.69	5.16	0.82	0.09	1.29	99.88	8.32
118	70.63	0.31	15.29	0.73	1.52	*	3.34	3.34	4.95	1.15	0.01	0.84	99.52	4.30
KPV	64.60	0.51	15.40	4.84	-	*	4.33	4.33	4.72	1.55	*	-	98.53	3.05
NEL	71.00	0.27	14.70	2.15	-	*	2.67	2.67	5.63	1.85	*	-	99.07	3.04
STB	71.10	0.23	15.00	1.62	-	*	2.32	2.32	6.48	1.67	*	-	99.16	3.88
THP	71.30	0.27	14.00	2.49	-	*	2.57	2.57	5.74	1.50	*	-	99.03	3.84
VPS	68.84	0.30	14.60	0.26	1.51	0.05	2.80	2.80	5.12	1.67	0.11	3.62	99.69	3.07
98	67.79	0.50	16.02	0.97	0.86	0.03	0.78	0.78	5.70	1.40	0.19	2.13	99.79	4.07
100	67.49	0.50	15.97	2.16	2.44	0.05	3.03	3.03	5.39	1.56	0.19	1.26	99.74	3.46

"Albitites" of the Murchison Area														
Sample	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	LOI	Total	Na ₂ O/K ₂ O
SC4	65.87	0.16	17.15	0.44	0.62	0.04	1.15	1.67	7.44	1.04	0.02	3.42	99.02	7.15
SC5	71.06	0.16	16.15	0.20	0.29	0.06	0.90	0.81	5.00	2.28	0.01	2.55	99.46	2.19
M10	67.40	0.29	14.60	2.24	-	*	1.40	1.40	5.20	1.80	0.09	4.40	98.82	2.89
RC32	67.10	2.93	16.20	1.28	-	*	2.63	2.63	6.40	0.84	0.52	0.62	101.25	10
MR22	70.13	0.02	15.20	0.66	1.15	0.30	2.04	2.04	4.60	1.69	0.07	3.14	99.80	2.43

- 13 - Maranda pluton (Barton, unpubl. data)
 14 - Average of 3 analysis of the Willie pluton (Barton, unpubl. data)
 15 - Average of 3 analysis of the Lekkersmaak pluton (Barton, unpubl. data)
 16 - Average of 3 analysis of the Mashishimela pluton (Barton, unpubl. data)
 17 - Average of 2 analysis of the Bouderskwa pluton (Minnitt, 1975)
 18 - Average of 3 analysis of an unnamed pluton, Letaba Ranch (Barton, unpubl. data)
 GC2 - Leucocratic trondhjemite, Letaba granite, Witkop-Shiny section (Minnitt, 1975)
 GC5 - Late intrusive adamellite granitoid plug, Mac Kop, Bawa Schiet belt (Minnitt, 1975)
 RM15 - Quartz-feldspar porphyry, Witkop-Shiny section (Minnitt, 1975)
 106 - "Ancient tonalite" (Glickson, 1976) * Not detected
 117 - "Ancient tonalite" (Glickson, 1976) - Not analyses
 118 - "Ancient tonalite" (Glickson, 1976)
 KPV - Kaap Valley tonalite (Condle and Hunter, 1976)
 NEL - Nelshoofte tonalite (Condle and Hunter, 1976)
 STB - Stolzburg tonalite (Condle and Hunter, 1976)
 THP - Theespruit tonalite (Condle and Hunter, 1976)
 VPS - Widespread feldspar porphyry intrusive, Komati Formation (Viljoen and Viljoen, 1989)
 98 - Middle Marker porphyry (Glickson, 1976)
 100 - Middle Marker porphyry (Glickson, 1976)
 SC4 - "Beresite" from borehole JLS.1 at Monarch North (150 feet) (Pearson, 1980)
 SC5 - "Beresite" from borehole JLS.1 at Monarch North (190 feet) (Pearson, 1980)
 M10 - Leuco mica-granite from Duchon mine dump (Viljoen and Van Vuren, unpubl. data)
 RC32 - Massive resistant albite lens from Free State Koppies/Antimony Kop area (Pearson, 1980)
 MR22 - "Beresite" from Gravelotte mine. Borehole GS. 39 (Pearson, 1980)

Table 4.1.1. MAJOR ELEMENT DATA USED FOR GEOCHEMICAL COMPARISONS

4.1. Major Elements Analysis

The major element data for the Discovery Shaft and Malati Store intrusions are presented in Tables 4.1.2 and 4.1.3. Table 4.1.4 contains the major element analysis for various granitoids and related rocks, including samples from the unaltered Willie Pluton (JUD.3 and JUD.5) and from the unaltered intrusion at the Minerva mine (MIN.2) (Fig.1.2). Also included are samples of felsic material and albite pegmatites from the Cobra and Discovery pits at GEM. Two samples (DUC.1 and DUC.2) were collected from the Duchon mine dumps to compare with the data of Pearton (1980), who regarded this intrusion to be an example of a laterally-secreted albitite. Albite-rich intrusives from the emerald occurrence at BVB were also analysed for comparison with the pegmatites at GEM. An occurrence of tonalitic gneiss from the vicinity of the BVB emerald mine was also sampled (BVB.2).

4.1.1. De La Roche Multi-Cationic Parameters

Most major-element studies on granitic rocks have made use of the bivariate oxide-percent versus silica-percent plots of Harker (1909) or of the oxide-percent versus Larsen-index plots (Larsen, 1938) to evaluate petrogenetic hypotheses. The inadequacies of oxide-percent bivariate diagrams and their misinterpretation in the case of hydrothermally altered rocks have been discussed by Pearce (1969). As with other classification systems, only the "leucocratic components" are considered. This is unsatisfactory, particularly with rocks of intermediate to basic compositions. An alternative approach in the discrimination of various granitoid series is to use cationic/molecular values, which express whole rock chemistry as cationic parameters in terms of mineralogical components. This concept has been extensively used by de la Roche (1964) and de la Roche and Leterrier (1973) and has been recommended more recently by Pitcher (1979) and Batchelor (1985). The calculation of the R1-R2 parameters used in this plot is shown below where,

$$R1 = 4Si - 11(Na + K) - 2(Fe + Ti)$$

$$R2 = 6Ca + 2Mg + Al$$

Malati Store Intrusive (MSI)																
Element	MM1.94	MM1.142	MM2.64	MM2.66	MM2.72	MM3.164. 5	MM3.166. 5	MM3.169. 3	MM4.18 4	MM4.187. 7	MM4.197	MUL.1	MUL.21	MUL.2.66	MUL.2.66	Average
SiO ₂	68.24	58.29	66.25	67.59	66.03	66.56	66.56	67.79	59	62.68	66.03	63.77	66.36	67.00	66.90	64.67
TiO ₂	0.43	0.54	0.50	0.56	0.49	0.42	0.28	0.43	0.43	0.50	0.52	0.87	0.42	0.48	0.47	0.49
Al ₂ O ₃	13.57	14.08	13.93	12.64	13.71	13.48	15.50	12.37	14.21	15.33	14.57	14.17	12.75	14.01	13.70	13.87
Fe ₂ O ₃	3.55	5.57	4.18	4.81	4.13	4.90	2.96	4.29	3.90	4.09	5.90	4.49	4.52	4.25	4.93	4.42
MnO	0.06	0.11	0.05	0.06	0.06	0.05	0.06	0.16	0.08	0.08	0.10	0.06	0.03	0.04	0.05	0.07
MgO	0.87	1.53	0.94	1.00	0.87	0.82	0.80	1.84	0.84	0.88	1.59	0.79	0.83	0.97	0.60	1.00
CaO	1.82	4.65	1.80	1.68	1.79	1.54	1.59	1.17	1.87	2.01	4.04	2.75	1.82	1.82	1.65	2.13
Na ₂ O	7.54	7.88	7.97	7.13	8.26	7.93	9.26	5.27	8.65	8.71	8.40	8.69	8.24	8.16	8.80	8.06
K ₂ O	0.20	0.18	0.19	0.22	0.19	0.15	0.03	0.55	0.13	0.13	0.16	0.16	0.12	0.22	0.10	0.18
P ₂ O ₅	0.10	0.06	0.06	0.04	0.04	0.11	0.06	0.14	0.08	0.11	0.22	0.14	0.09	0.34	0.03	0.11
LOI	3.54	7.02	4.29	4.52	4.16	3.77	3.17	5.99	11.25	5.00	6.72	4.57	6.59	1.31	1.69	4.91
Total	99.90	99.83	100.14	100.27	99.73	99.74	100.27	101.89	100.15	99.50	100.23	99.26	100.77	100.95	98.92	100.11
Na ₂ O/K ₂ O	38.64	41.76	41.27	31.97	43.26	53.23	280.67	9.51	65.53	64.99	51.88	54.31	68.67	37.97	88.00	64.76

Table 4.1.2. MAJOR ELEMENT ANALYSES FOR THE MALATI STORE INTRUSION (MSI) (Wt. %)

Discovery Shaft Intrusion (DSI)														
Element	KE51.8G	KE21.G	KE21.B	KE51.7	KE51.2	BH186.180	KE51.1	KE18.5	11.7	11.11	KE54	11.10	DFS.BER	Average
SiO ₂	69.59	68.14	73.87	66.54	71.61	61.44	74.60	69.66	68.50	67.26	70.45	68.16	70.60	69.26
TiO ₂	0.27	0.36	0.29	0.32	0.28	0.86	0.26	0.33	0.34	0.28	0.31	0.37	0.35	0.35
Al ₂ O ₃	16.28	16.69	13.51	17.59	14.23	17.34	13.13	14.62	15.65	16.89	16.89	16.64	13.70	15.55
Fe ₂ O ₃	1.78	2.05	1.53	1.68	1.81	4.98	1.96	2.53	2.14	1.99	1.58	2.10	3.17	2.25
MnO	0.03	0.03	0.04	0.03	0.04	0.06	0.04	0.03	0.05	0.03	0.03	0.02	0.01	0.03
MgO	0.81	1.22	0.79	0.85	0.89	2.45	0.89	1.54	1.13	1.23	0.89	1.39	0.80	1.13
CaO	1.69	1.49	1.45	1.63	1.96	0.96	1.98	1.34	2.13	1.28	1.12	1.09	1.36	1.49
Na ₂ O	8.62	7.41	7.61	9.70	6.04	8.97	5.55	7.83	6.01	9.02	7.68	9.13	7.90	7.80
K ₂ O	0.13	1.40	0.20	0.22	1.34	0.48	1.15	0.30	1.98	0.28	0.30	0.35	0.32	0.65
P ₂ O ₅	0.11	0.39	0.27	0.15	0.29	0.37	0.17	0.14	0.46	0.07	0.21	0.11	0.11	0.22
LOI	1.59	1.71	1.31	1.64	1.32	2.41	1.21	1.68	1.64	1.57	1.30	1.39	1.20	1.54
Total	100.97	100.61	100.87	100.35	99.72	100.28	100.30	100.46	100.01	99.91	100.76	100.76	99.51	100.35
Na ₂ O/K ₂ O	67.88	5.30	37.84	44.10	4.50	19.36	4.82	25.93	3.03	30.69	25.60	25.86	24.69	24.58

Table 4.1.3. MAJOR ELEMENT ANALYSES FOR DISCOVERY SHAFT INTRUSIONS (DSI) (Wt.%)

Element	Unaltered Granodiorites (ALG)			Discovery "Foliated" (DFS)			Cobra PK Albite Pegmatites (ABP)			Minerve Mine Intrusion (MMI)		Duchon Mine Intrusion (DMI)		Albitas from BVB (BVB)		Tensitic grades from BVB (TON)
	JUD.3	MIN.2	JUD.5	DISP.2	DISP.3	D2	COB.2	COB.1	COB.3	MIN.1	MIN.4	DUC.1	DUC.2	BVB.1	JUD.2	
SiO ₂	73.80	74.44	73.95	83.50	88.73	82.57	89.76	72.51	67.34	67.79	69.45	69.40	68.70	62.75	76.07	74.89
TiO ₂	0.25	0.01	0.15	0.82	0.32	0.83	0.05	0.28	0.01	0.16	0.11	0.28	0.28	0.06	0.05	0.22
Al ₂ O ₃	14.51	14.71	14.31	16.31	16.85	16.08	16.25	14.39	16.68	14.67	16.13	14.01	14.23	21.69	14.00	14.41
Fe ₂ O ₃	1.27	0.54	1.51	4.37	1.71	4.63	1.23	1.90	1.01	0.76	1.36	3.89	3.61	0.84	0.58	1.15
MnO	0.02	0.06	0.01	0.05	0.02	0.06	0.02	0.02	0.01	0.07	0.05	0.03	0.02	0.03	0.01	0.03
MgO	0.28	0.01	0.24	2.25	0.71	2.49	0.31	0.76	0.45	0.37	0.78	1.20	1.10	0.87	0.06	0.27
CaO	0.67	0.96	0.74	3.45	2.76	4.84	1.32	0.74	0.78	1.01	1.77	2.56	2.60	3.27	0.52	1.16
Na ₂ O	5.14	5.14	4.58	6.82	7.56	5.53	8.45	6.44	10.21	6.27	6.63	4.40	3.90	9.56	7.80	6.94
K ₂ O	4.01	3.41	4.18	1.20	0.46	1.31	0.17	0.34	0.25	0.08	0.11	1.84	1.99	0.47	0.57	0.58
P ₂ O ₅	0.48	0.03	0.31	0.35	0.04	0.14	0.02	0.06	0.02	0.05	0.03	0.08	0.07	0.03	0.07	0.32
LOI	0.55	0.29	0.35	1.84	0.86	2.10	3.23	2.30	2.25	2.18	2.39	3.88	4.01	0.35	0.32	0.38
Total	100.36	99.59	100.31	100.97	100.15	100.14	98.58	99.74	100.10	98.77	95.13	101.54	100.51	100.14	100.01	100.85
Na ₂ O/K ₂ O	1.28	1.51	1.09	5.68	16.47	4.22	49.71	18.93	40.84	76.43	59.20	2.39	1.86	20.16	13.69	10.25

Table 4.1.4. MAJOR ELEMENT ANALYSES FOR VARIOUS GRANITOIDS FROM THE MURCHISON SCHIST BELT (Wt.%)

The theory of the diagram lay-out and its comparison to other techniques is described by de la Roche *et al.* (1980). The R1-R2 parameters are plotted on a chemical variation diagram which includes a mineralogical network and indicates the degree of silica saturation. The major advantage of this bivariate chemical variation diagram is that it takes into account all the major chemical elements and is independent of norm calculations and the implicit models of crystallization adopted when calculating the norm.

The de la Roche values for the samples in this study are presented in Tables 4.1.5 and 4.1.6. The samples examined exhibit a wide range of R1 values (721 - 2623) and a narrow range of R2 values (496 - 591). Figure 4.1.1 is a plot of R1 versus R2 for the granitoid rocks of this study and various unaltered granodiorites / tonalities from the Murchison and Barberton areas (Vearncombe *et al.* unpubl data; Glickson, 1976; Condie and Hunter, 1976). The samples from the Malati Store, Minerva Mine and the Discovery Shaft intrusions show that there is a continuous progression of decreasing R1 values from the field defined by the unaltered granodiorites, towards the theoretical R1 value, of albite. There is a slight increase in the R2 value as the R1 value decreases, which may be attributed to the increase in the Ca-content of the rock due to the accompanying carbonate alteration. This plot confirms the petrographic work of this study which suggested that the Malati Store intrusion is the most severely albitized intrusion.

The Discovery Shaft intrusion samples also exhibit a wide range of R1 values from unaltered granodiorite through to compositions close to that of albite. The petrographic study also indicates that there are varying degrees of alteration within the intrusion. The R1-R2 diagram (Figure 4.1.1) also includes the "albitites" of Pearton, (1980). These samples plot along the trend as defined by the samples of this study. Pearton (1980) described sample M10 from the Duchon mine intrusion as an albitite (Table 4.1.1), however, this sample plots within the field of unaltered granodiorites and has a similar composition to other unaltered granodiorites which intrude the Murchison schist belt. There is no indication petrographically or geochemically that this intrusion exhibits alteration in the form of albitization. The Maranda granite (Barton, unpubl. data) plots within the field of altered samples as defined by this study. Barton, (unpubl. data) notes that this intrusion exhibits varying degrees of alteration and is unique in that its chemical composition is that of an alkali granite. The intrusion is also occasionally mineralized, and its atypical chemistry is thus due to albitization similar to that which has affected the other intrusions described above. The Maranda intrusion forms the western limit of the Antimony Line and is interpreted to have intruded this major structural discontinuity.

This reinforces the idea that a number of granodiorites have intruded into the Antimony Line, and possibly other major structural discontinuities, and have undergone varying degrees of albitization and mineralization in their cupola zones.

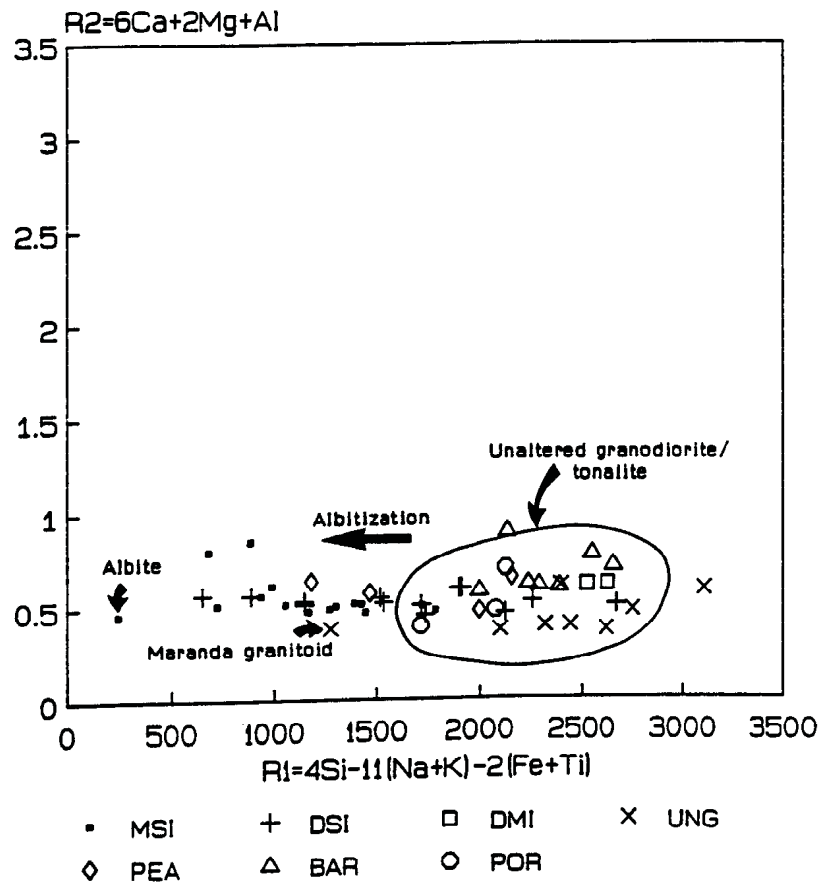


Figure 4.1.1. R1-R2 plot of granitoids from the Murchison and Barberton areas.

- MSI - Malati Store intrusion
- DSI - Discovery Shaft intrusion
- DMI - Duchen Mine intrusion
- UNG - Unaltered granodiorites
- PEA - "Albitites" of Pearton (1980)
- BAR - TTG's from the Barberton area (Condie and Hunter, 1976)
- POR - Barberton albite porphyries (Glickson, 1976)
- BAR - Barberton TTG's (Glickson, 1976; Condie and Hunter, 1976)
- POR - Barberton porphyries (Glickson, 1976)

Figure 4.1.2. is an R1-R2 plot of the granitoid rocks from this study, as well as of samples from the Barberton greenstone belt, and includes the rock classification of de la Roche *et al.* (1980).

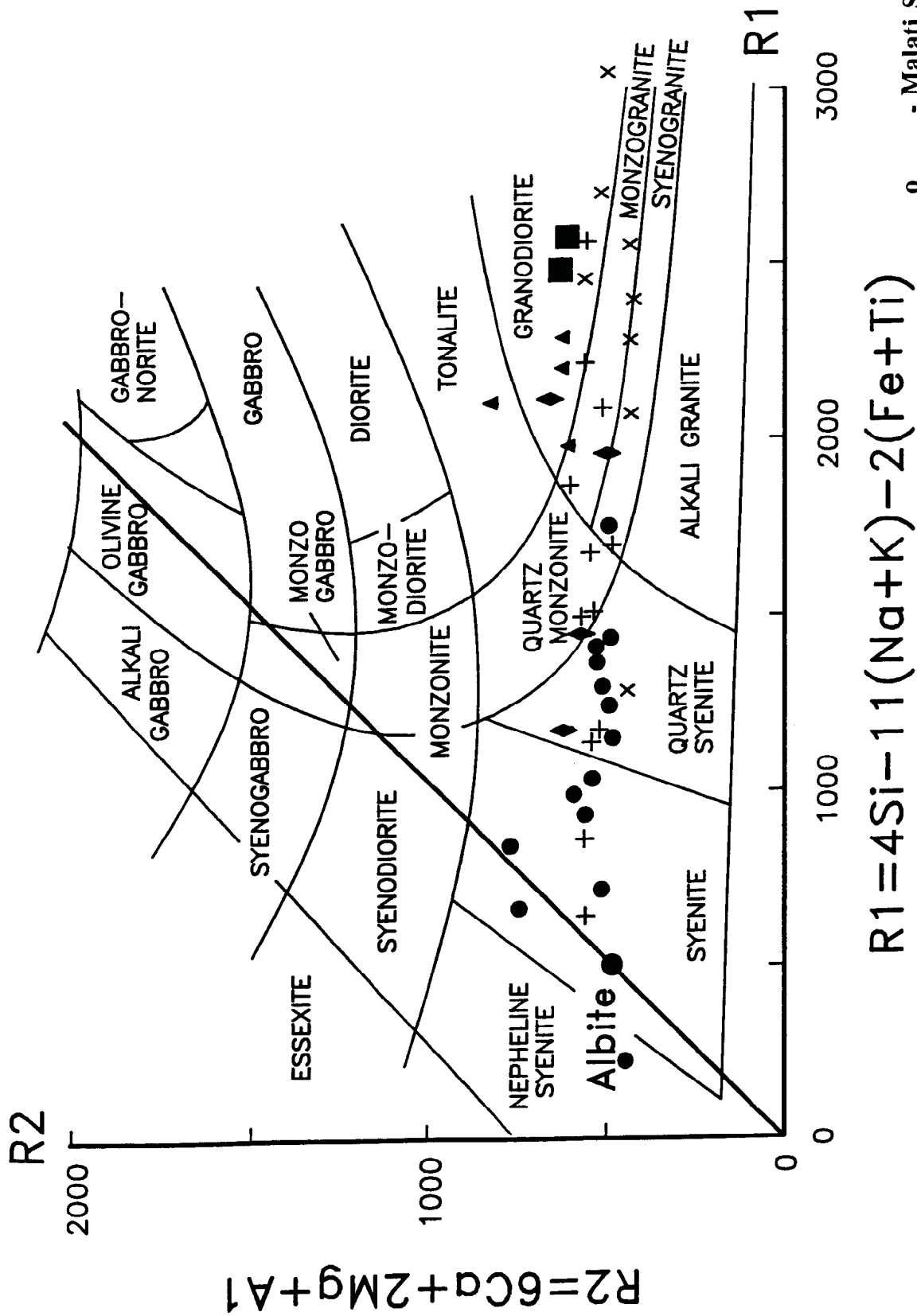


Figure 4.1.2. De la Roche R1-R2 diagram showing the R1-R2 values for the albitized granitoids and unaltered granitoids of the Murchison schist belt. Barberton granitoids included for comparison.

It is evident from the diagram that samples from the Barberton area and the unaltered samples analyses from the Murchison schist belt occur within the granodiorite / monzogranite field. There is, however, a continuous progression to lower R1 values with increasing alteration into fields defined by quartz-syenites and syenites, a trend which indicates the decrease in the silica content due to desilicification of the intrusions during alteration.

4.1.2. CIPW Normative Calculations.

The normative mineral contents of the samples were calculated using a computer programme. Tables 4.1.5. and 4.1.6. contains the results of the normative element composition as calculated by this program. As expected from petrographic studies, albite and quartz are the dominant minerals within the albitites. Anorthite is only a minor component in the Discovery Shaft and Malati Store intrusions. All the unaltered rocks are corundum normative and have peraluminous indices > 1.0 (average = 1.10), a feature noted by Barton (unpubl. data) to be characteristic of the intrusions from this area. There appears to be a slight decrease in the peraluminous index in the altered intrusions (Malati Store, average = 0.88 and Discovery Shaft, average = 0.96). A portion of the Discovery Shaft samples are corundum normative, as would be expected in this variably altered intrusion. The normative orthoclase content is low in the albitized intrusions but attains values of up to 22% in the unaltered granodiorites. The normative albite content of the Malati Store intrusion is high (average = 74%), confirming the petrographic descriptions from this study that the body is composed predominantly of albite. The Discovery Shaft intrusion has a lower normative albite content, with an average of 69%. In comparison, the average normative albite content of the unaltered granodiorites is 44%. The Discovery Shaft intrusion shows a wider range in the normative albite content, due to the varying degrees of alteration within the intrusion. The normative quartz content of the intrusions is variable, ranging from 7 % in the highly altered rocks to 29% in the unaltered samples, indicating desilicification with increased albitization. The Malati Store intrusion has an average normative quartz content of 14% and the Discovery Shaft intrusion 17%. The unaltered granodiorites have an average normative quartz content of 28%.

Malati Store Intrusion (MSI)										
Sample	Quartz	Ortho.	Albite	Anorth.	Corund.	Apatite	Biotite	R1	R2	Peralum. Index
MM1.94	21.02	0	69.29	2.85	0	0.21	1.94	1720.2	504.1	0.92
MM1.142	9.97	0	74.66	2.57	0	0.18	1.89	882.5	849.6	0.75
MM2.64	17.16	0	73.37	1.71	0	0.13	1.84	1419.9	512.5	0.90
MM2.65	15.93	0	66.46	1.90	0	0.09	2.16	1762.9	477.3	0.90
MM2.72	15.96	0	75.64	0	0	0.09	1.84	1303.8	503.8	0.86
MM3.184.5	10.76	0	73.20	0.76	0	0.24	1.46	1448.0	469.9	0.90
MM3.185.5	11.17	0	62.92	0.64	0	0.13	0.28	1056.0	513.9	0.98
MM3.189.3	30.08	0	50.54	3.62	2.17	0.31	5.55	2396.2	459.1	1.16
MM4.184	7.76	0	83.78	0	0	0.18	1.34	721.1	510.6	0.86
MM4.187.7	9.66	0	80.52	2.42	0	0.24	1.27	935.8	559.4	0.91
MM4.197	7.21	0	78.71	1.65	0	0.46	1.56	661.4	799.9	0.77
MUL1	10.96	0	77.92	0	0	0.30	1.54	969.2	611.4	0.80
MUL21	15.02	0	71.84	0	0	0.20	1.18	1274.6	486.0	0.81
MM2.65/72	10.23	0	74.01	0.96	0	0.72	2.10	1394.1	517.7	0.88
MUL.BER	13.02	0	74.83	0	0	0.06	0.65	1171.5	475.0	0.83
Average	13.73	0	73.85	1.26	0.14	0.34	1.79	1276.5	549.8	0.88
Discovery Shaft Intrusion (DSI)										
Sample	Quartz	Ortho.	Albite	Anorth.	Corund.	Apatite	Biotite	R1	R2	Peralum. Index
KE51.6G	14.70	0	77.51	2.62	0	0.23	1.23	1536.2	521.12	0.93
KE21.G	16.30	4.03	65.57	3.54	1.80	0.60	0	1516.7	547.3	1.08
KE21.8	25.36	0	67.56	2.09	0	0.56	1.87	2124.2	456.3	0.93
KE51.7	5.02	0	64.69	3.70	0	0.31	2.02	885.2	561.6	0.97
KE81.2	26.54	4.61	54.74	6.42	0.57	0.61	5.40	2256.0	522.3	1.04
BH186.180	2.60	0	79.56	0	2.25	0.76	4.30	652.3	564.4	1.06
KE81.1	32.23	3.80	50.14	7.56	0	0.36	4.50	2762.14	503.5	1.03
KE18.5	16.59	0	69.97	3.84	0	0.29	2.82	1716.45	506.6	0.99
11.7	20.24	7.66	54.45	9.47	0.20	0	6.50	1902.11	591.3	0.93
11.11	8.79	0	79.48	4.65	0	0.14	2.69	1151.39	529.3	0.90
KE44	20.17	0	67.80	3.05	3.1	0.43	2.79	1846.32	495.3	0.77
11.10	9.32	0	79.65	3.29	0	0.22	3.21	1153.24	511.9	0.93
DIS.BER	21.06	0	71.23	0.96	0	0.23	3.03	1732.96	453.9	0.91
Average	16.84	1.55	69.40	3.94	0.60	0.38	3.16	1633.79	520.6	0.96

Table 4.1.5. CIPW NORMATIVE MINERAL CONTENT AND R1-R2 PARAMETERS FOR THE MALATI STORE AND DISCOVERY SHAFT INTRUSIONS

	Quartz	Ortho.	Albite	Anorth.	Corund.	Apatite	Biote	R1	R2	Peralum. Index
Unaltered Granodiorite (ULG)										
JUD.3	25.96	22.20	45.95	0	1.86	1.1	2.23	2100.7	369.20	1.07
MIN.2	26.06	19.74	46.21	2.84	1.67	0.61	0.68	2321.0	361.25	1.11
JUD.5	26.64	23.23	41.07	1.13	2.04	0.65	2.13	2267.2	372.32	1.11
Average	27.56	21.72	44.41	1.32	1.86	0.75	1.68	2267.2	377.6	1.10
Discovery "Felsites" (DFS)										
DISP.2	11.80	0	60.78	10.27	0	0.73	11.20	1366.2	801.2	0.77
DISP.3	16.12	0	66.90	10.80	0	0.06	4.24	1734.3	663.2	0.76
D2	14.65	0	50.01	15.29	0	0.29	12.50	1760.6	966.5	0.65
Average	14.26	0	59.23	12.12	0	0.37	9.31	1630.5	810.9	0.73
Cobra Pt Albite Pegmatites (ABP)										
COB.2	16.27	0	76.42	3.20	0	0	1.62	1573.6	456.9	0.97
COB.1	26.76	4.77	56.60	2.26	1.60	0.12	4.77	2373.5	399.2	1.11
Minerva Mine Intrusion (MMI)										
MIN.1	36.48	0	57.64	0.75	0	0.11	0.77	2911.4	375.3	0.88
MIN.4	45.57	0	39.57	0	0	0.06	1.06	2626.2	368.0	0.54
Duchen Mine Intrusion (DMI)										
DUC.1	30.31	5.30	40.76	11.56	0.75	0.17	9.21	2520.5	606.0	1.14
DUC.2	32.30	6.73	36.76	12.11	1.30	0.15	8.50	2623.3	607.4	1.20
Albitites from BVB (BVB)										
BVB.1	0	0.20	79.54	14.22	0	0.06	3.92	651.7	816.5	1.08
JUD.2	25.26	2.80	69.01	1.46	0	0.06	0.63	2147.1	333.5	0.96
Tonalitic Gneiss from BVB (TON)										
BVB.2	27.94	2.55	61.63	2.67	1.29	0.66	2.27	2326.4	420.7	1.06

Table 4.1.6. CIPW NORMATIVE MINERAL CONTENT AND R1-R2 PARAMETERS FOR VARIOUS MURCHISON GRANITOIDES