

103

PETROLOGY AND GEOCHEMISTRY OF QUARTZ -
TOURMALINE VEIN ALTERATION OF A GRANODIORITE,
HEYSON TOWNSHIP, RED LAKE, ONTARIO

Petrology and Geochemistry of Quartz-Tourmaline Vein
Alteration of a Granodiorite, Heyson Township, Red Lake, Ontario

by
Wayne J. Gignac

Submitted to the Department of Geology
in Partial Fulfilment of the Requirements
for the Degree
Bachelor of Science

McMaster University

April 1, 1983

Bachelor of Science (1983)
(Geology)

McMaster University
Hamilton, Ontario

Title: Petrology and Geochemistry of Quartz-Tourmaline Vein
Alteration of a Granodiorite, Heyson Township,
Red Lake, Ontario.

Author: Wayne J. Gignac

Supervisor: Dr. James H. Crocket

Number of Pages: 76, viii

Abstract

The Buffalo Mine, located in Heyson Township, Red Lake, consists of quartz-tourmaline veins in a grandiorite. An alteration halo, consisting of andesine feldspar, quartz, calcite, with minor tourmaline, zircon, and opaques, is seen surrounding the veins. Opaque minerals consists of pyrite and hematite. Possible Na - overgrowths of the plagioclase are seen, as well as complete destruction of the mafic minerals.

Geochemistry shows that the wall-rock alteration involves the breakdown of Si, Al, Fe, Mg, Na, and K. Si and Al remain fairly constant, while Na and Ca increase and Fe, Mg, and K decrease in abundance. There has been a sufficient input of CO₂ to precipitate calcite, as well as enough sulfur to form pyrite.

The initial hydrothermal solutions were high temperature NaCl solutions, enriched in boron and containing some CO₂. The fluids were likely oxidizing and had a neutral pH.

Acknowledgements

I would like to thank Dr. Tony Andrews of the Ontario Geological Survey for initially suggesting the topic, for guidance in the field, and for subsequent advice on how to proceed with the problem. I am also grateful to Dr. J. H. Crockett who acted as my supervisor.

The many others to whom I would like to express my appreciation include Mr. L. Zwicker for thin section preparation, Mr. O. Mudroch for XRF whole rock analysis, and Mr. J. Whorwood for photographic assistance.

Many thanks go to Lyndor Office Services for the typing of this thesis.

I would like to thank Andy Fyon who gave freely of his time and experience. His advice was greatly appreciated.

Finally, I would like to thank Cathy Mathews who was the driving force behind completion of this thesis. Many thanks for the hours of debates and encouragement.

TABLE OF CONTENTS

| | Page |
|--------------------------------|------|
| Scope and Contents | ii |
| Abstract | iii |
| Acknowledgements | iv |
| Table of Contents | v |
| List of Figures | vi |
| List of Tables | vii |
| | |
| Chapter I - Introduction | |
| 1.1 Location and Accessibility | 1 |
| 1.2 Previous Work | 1 |
| 1.3 Mine History | 6 |
| 1.4 Statement of Problem | 6 |
| | |
| Chapter II - General Geology | |
| 2.1 Red Lake Area | 8 |
| 2.2 Buffalo Mine | 11 |
| | |
| Chapter III - Petrography | |
| 3.1 Introduction | 22 |
| 3.2 Vein Mineralogy | 22 |
| 3.3 Unaltered Granodiorite | 26 |
| 3.3.1 Essential Minerals | 26 |
| 3.3.1.1 Feldspar | 26 |
| 3.3.1.2 Quartz | 26 |
| 3.3.1.3 Biotite | 28 |
| 3.3.1.4 Chlorite | 28 |
| 3.3.2 Accessory Minerals | 28 |
| 3.3.2.1 Opaques | 28 |
| 3.3.2.2 Carbonate | 35 |
| 3.3.2.3 Zirzon | 35 |
| 3.4 Altered Granodiorite | 35 |
| 3.4.1. Essential Minerals | 35 |
| 3.4.1.1 Feldspar | 35 |
| 3.4.1.2 Quartz | 36 |
| 3.4.1.3 Carbonate | 36 |
| 3.4.2 Accessory Minerals | 44 |
| 3.4.2.1 Tourmaline | 44 |
| 3.4.2.2 Biotite | 44 |
| 3.4.2.3 Opaques | 49 |
| 3.4.2.4 Zircon | 42 |
| | |
| Chapter IV - Geochemistry | |
| 4.1 Introduction | 56 |
| 4.2 Wall Rock Alteration | 56 |

| | |
|---------------------------------------|----|
| Chapter V - Nature of the Vein Fluids | |
| 5.1 Composition | 71 |
| Chapter VI - Conclusions | |
| 6.1 Summary of Alteration | 74 |
| Bibliography | 75 |

LIST OF FIGURES

| | | |
|------|--|----|
| 1.1 | Location of Heyson Township | 2 |
| 1.2 | Location of Buffalo Mine | 4 |
| 2.1 | Major Volcanic Sequences, Red Lake | 9 |
| 2.2 | Schematic of Buffalo Mine | 12 |
| 2.3 | Photograph of Veins at Buffalo Mine | 14 |
| 2.4 | Photograph of Veins at Buffalo Mine | 14 |
| 2.5 | Photograph of Veins at Buffalo Mine | 16 |
| 2.6 | Photograph of Veins at Buffalo Mine | 16 |
| 2.7 | Sample One - Vein & Alteration Halo | 19 |
| 2.8 | Sample Three - Vein & Alteration Halo | 19 |
| 2.9 | Sample Six - Vein & Alteration Halo | 21 |
| 2.10 | Sample Four - "Fresh", Unaltered Granodiorite | 21 |
| | Photomicrograph of Vein | |
| 3.1 | Quartz-Tourmaline at Granodiorite Contact | 24 |
| 3.2 | Tourmaline | 24 |
| | Photomicrograph of Unaltered Granodiorite | |
| 3.3 | Plagioclase with carbonate alteration | 29 |
| 3.4 | Pseudo-mosaic quartz | 29 |
| 3.5 | Altered Biotite | 31 |
| 3.6 | Altered Biotite | 31 |
| 3.7 | Interstitial Habit of Biotite | 33 |
| 3.8 | Interstitial Habit of Biotite | 33 |
| 3.9 | Opaque (Pyrite) | 38 |
| | Photomicrograph of Altered Granodiorite | |
| 3.10 | Deformation of Andesine | 38 |
| 3.11 | Carbonate alteration of Andesine | 40 |
| 3.12 | Possible Overgrowth of Andesine | 40 |
| 3.13 | Mosaic Quartz | 42 |
| 3.14 | Mosaic Quartz | 42 |
| 3.15 | Mosaic Quartz | 45 |
| 3.16 | Carbonate Environment | 45 |
| 3.17 | Carbonate Environment | 47 |
| 3.18 | Carbonate Veinlets | 47 |
| 3.19 | Extensively Altered Biotite | 50 |
| 3.20 | Extensively Altered Biotite | 50 |
| 3.21 | Fragmented Hematite | 52 |
| 3.22 | Pyrite containing Biotite Inclusions | 52 |
| 3.23 | Zircon Cluster | 54 |
| 3.24 | Zircon Cluster | 54 |
| 4.1 | Gains and Losses of Major Oxides | 61 |
| 4.2 | Variation Diagram for Altered/Unaltered Granodiorite | 65 |
| 4.3 | Variation Diagram for Altered/Unaltered Granodiorite | 65 |
| 4.4 | Variation Diagram for Altered/Unaltered Granodiorite | 67 |
| 4.5 | Variation Diagram for Samples 6A, 6B, 6C | 67 |
| 4.6 | Variation Diagram for Samples 6A, 6B, 6C | 69 |
| 4.7 | Variation Diagram for Samples 6A, 6B, 6C | 69 |

LIST OF TABLES

| | | |
|-----|---|----|
| 3.1 | Petrology of Unaltered Granodiorite | 27 |
| 3.2 | Petrology of Altered Granodiorite | 37 |
| 4.1 | Composition of Fresh and Altered Granodiorite | 57 |
| 4.2 | C.I.P.W. Norms | 58 |
| 4.3 | Average Chemical Compositions | 59 |
| 4.4 | Relative Gains and Losses of Oxides | 60 |

Chapter I

Introduction

1.1 Location and Accessibility

The study area is the Buffalo Mine, located in the northern portion of Heyson Township, which is in the southern section of the Red Lake area. The Buffalo Mine is just south of the Dome stock, north of Snib Lake and west of Highway 618, approximately 3 km from the intersection with Highway 105. Figure 1.1 shows the general relation of Heyson Township to the Red Lake area, and figure 1.2 shows the location of the Buffalo mine in Heyson Township.

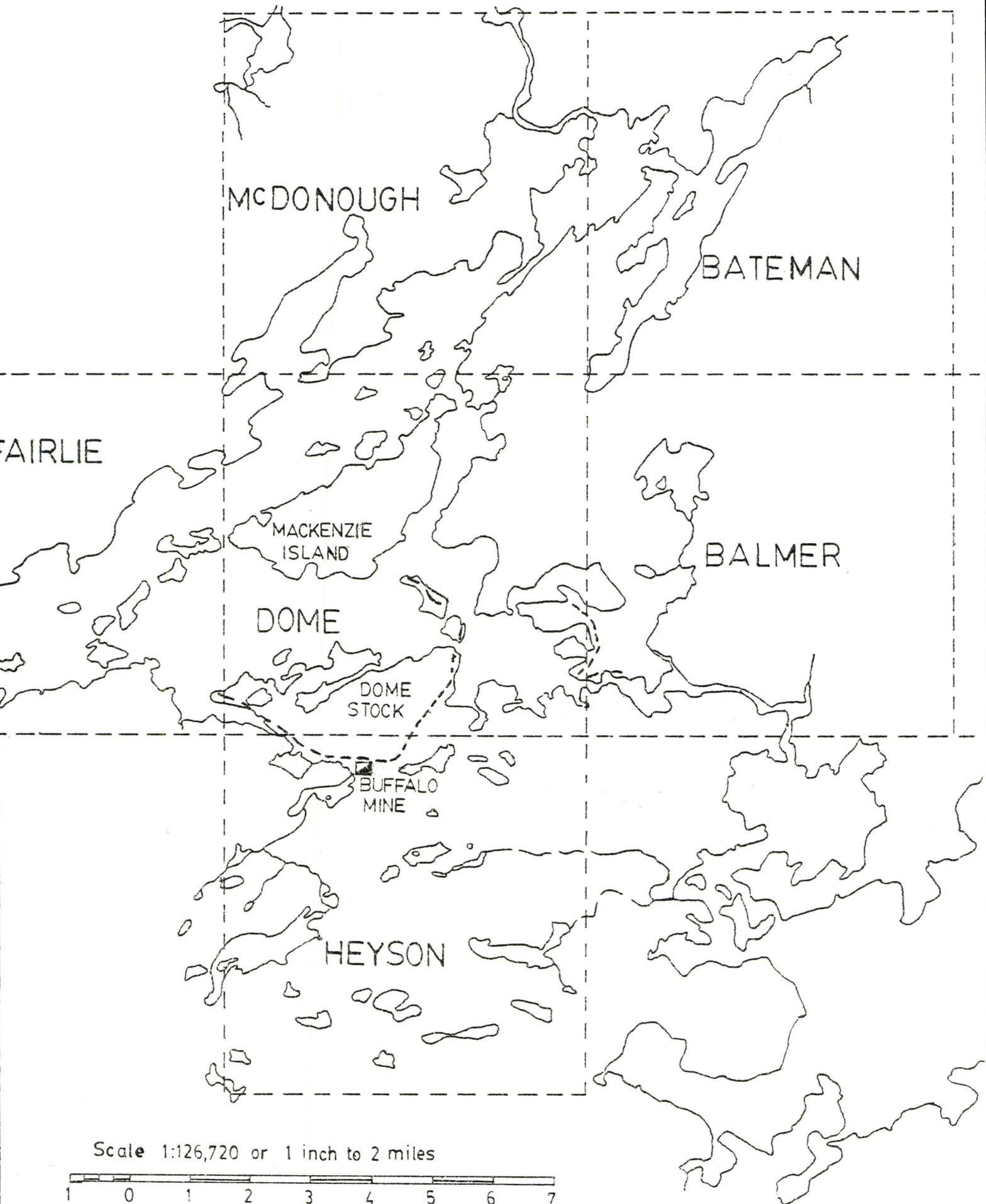
The Buffalo Mine, is accessible by logging roads either from Highway 618 (approximately 3 km from the intersection of Highway 618 and 104) or from St. Paul's Bay (Red Lake). From the highway, it is a 0.9 km hike to the mine, and from St. Paul's Bay, 2.7 km.

1.2 Previous Work

In 1883 Robert Bell of the Geological Survey of Canada, first visited Red Lake and mentioned the presence of Huronian type rocks containing what he termed 'some interesting minerals'. The first geological work was done in 1893 by D. B. Dowling of the Geological Survey of Canada, who studied the belts of sedimentary and volcanic rocks and the surrounding granites and granite gneisses. The Ontario Department of Mines became active in 1922 when E. L. Bruce visited the area and stated that recorded mineral finds were not of economic importance, but that the region did have prospecting possibilities. With the discovery

Figure 1.1

Relationship of Heyson Township to the
Red Lake Area.
(Ontario Geological Survey, Map No. 35c,
Red Lake Gold Area)



MCDONOUGH

BATEMAN

FAIRLIE

MACKENZIE
ISLAND

BALMER

DOME

DOME
STOCK

BUFFALO
MINE

HEYSON

Scale 1:126,720 or 1 inch to 2 miles

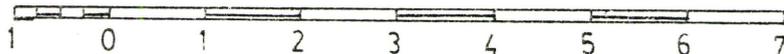
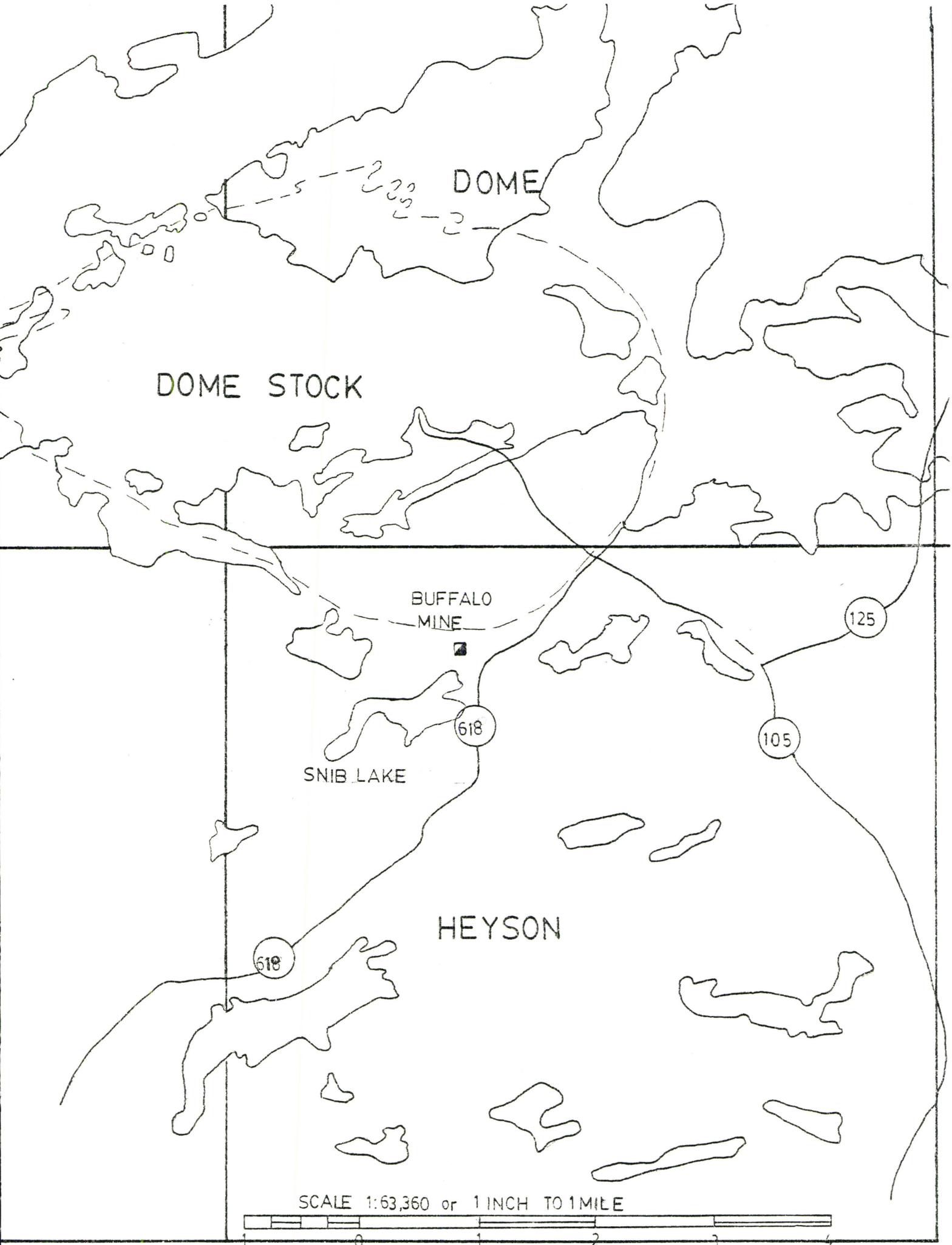


Figure 1.2

Location of Buffalo Mine in Heyson
Township
(Ontario Department of Mines,
Preliminary Geological Map No. P.338,
S. A. Ferguson, 1966)



DOMESTOCK

DOMESTOCK

BUFFALO
MINE

SNIB LAKE

HEYSON

SCALE 1:63,360 or 1 INCH TO 1 MILE



of gold-heavy veins, the Ontario Department of Mines' interest was sparked and in 1926, J. E. Hawley and E. L. Bruce carried out a detailed geological examination of the area. With the increase in gold prices in 1933, the Department commissioned M. R. Hurst to make a survey of the mineral occurrences. This was published in 1936 and was followed in 1940 by mapping and a report by H. C. Horwood.

Regional geological mapping was carried out by H. C. Horwood in 1940 on Heyson Township. The northern part of Heyson Township was later mapped in detail by S. A. Ferguson in 1963 and a report was published in 1968.

1.3 Mine History

The Buffalo property comprises 26 patented claims and has been explored at irregular intervals since 1926. Gold mineralization was discovered by diamond drilling and in the period 1945-1948 a vertical shaft was sunk to 60 m., and 185 m. of drifting and crosscutting was completed. In October, 1980, Wilanour Resources optioned the Buffalo Property and developed an open pit in 1981 to mine the gold. The Buffalo pit is approximately 120 m. long by 40 m. wide, by 10 to 12 m. deep. In the spring of 1982, the mine was allowed to flood. Later the entrance was blocked by waste rock and the pit partially filled in with waste rock and overburden.

1.4 Statement of Problem

A series of quartz-tourmaline veins in a sheared granodiorite occur at the Buffalo mine. A prominent alteration

halo is seen around the veins, in the granodiorite. During the summer of 1982, while working for the Ontario Geological Survey, the author collected samples of the vein, altered granodiorite, and unaltered granodiorite for the purpose of studying the petrological and geochemical alteration of the granodiorite associated with the veins. Twenty thin sections and three polished thin sections were prepared, and seven whole rock analysis were carried out to aid in this investigation.

Chapter II

General Geology

2.1 Red Lake Area

The Red Lake greenstone belt forms part of the Uchi subprovince of the Superior Province. The volcanic stratigraphy may be divided into two sequences (Pirie, 1980). The lower mafic sequence is comprised of a thick succession of mafic to ultramafic metavolcanics, intercolated with felsic metavolcanics and metasediments. An overlying-alkaline sequence is comprised of substantial thicknesses of felsic to intermediate volcanic rocks, with minor metasedimentary units throughout the succession. The entire volcanic assemblage was deformed by the emplacement of granitoid batholiths bordering the volcanic belt, and later by the intrusion of the granitoid Dome stock in the centre of the belt. The major volcanic sequences in the Red Lake area are shown in figure 2.1. Except close to the main batholiths and in the vicinity of the Campbell Red Lake and Dickenson Mines, most of the volcanic sequence has undergone only low grade, greenschist facies metamorphism.

Heyson township is mostly comprised of the upper calc-alkaline sequence. The lower mafic sequence occurs in the northwest corner of the township. The Dome stock was intruded in the northern part of Heyson Township between St. Paul's Bays and Highway 618 (figure 1.2, 2.1).

Figure 2.1

Major Volcanic Sequences, Red Lake
(Pirie, 1980)



GRAVES CALC-ALKALIC SEQUENCE

RED LAKE AREA
VOLCANIC SEQUENCES

BALL
CALC-ALKALIC
SEQUENCE

LOWER MAFIC SEQUENCE
(THOLEIITIC to KOMATIITIC)

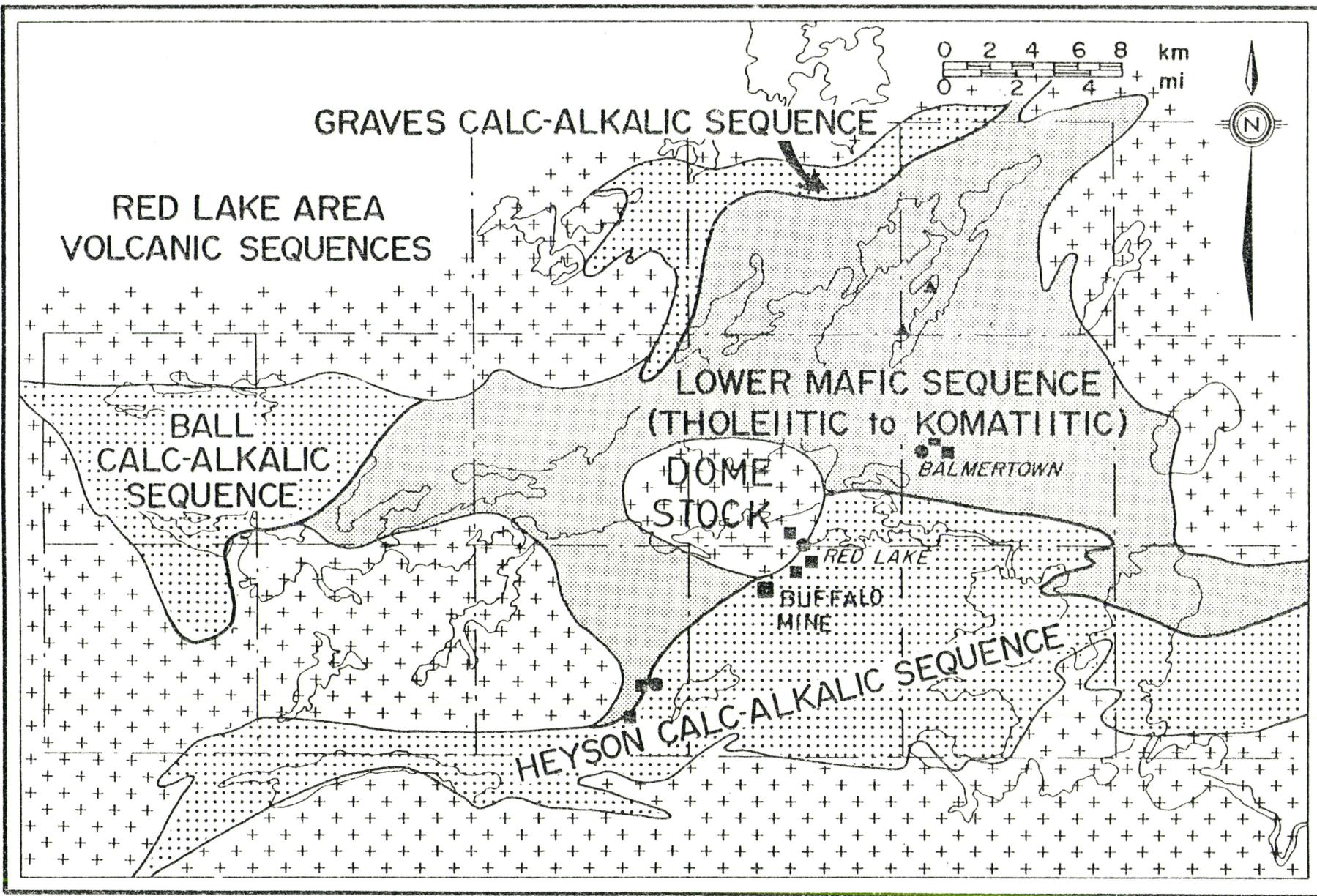
DOME
STOCK

BALMERTOWN

RED LAKE

BUFFALO
MINE

HEYSON CALC-ALKALIC SEQUENCE



2.2 Buffalo Mine

The Buffalo pit (M. Durocher, 1981) is located along the contact between the Dome stock and the volcanic rocks of the upper calc-alkaline sequence. A schematic diagram (figure 2.2) illustrates the relationships among the various rock units in and around the mine. The contact between the Dome granodiorite stock and the volcanic rocks is sharp, and dips steeply to the south. The granodiorite dyke which hosts the Buffalo mine is separate from the Dome stock by a thin band of silicified mafic volcanics. In addition to the ore-bearing granodiorite dyke, there are several small, irregular dykes of granodiorite. There is some question as to whether the gold-bearing granodiorite dyke is actually part of the Dome stock or actually a dyke in the volcanic country rocks and not genetically related to the Dome stock.

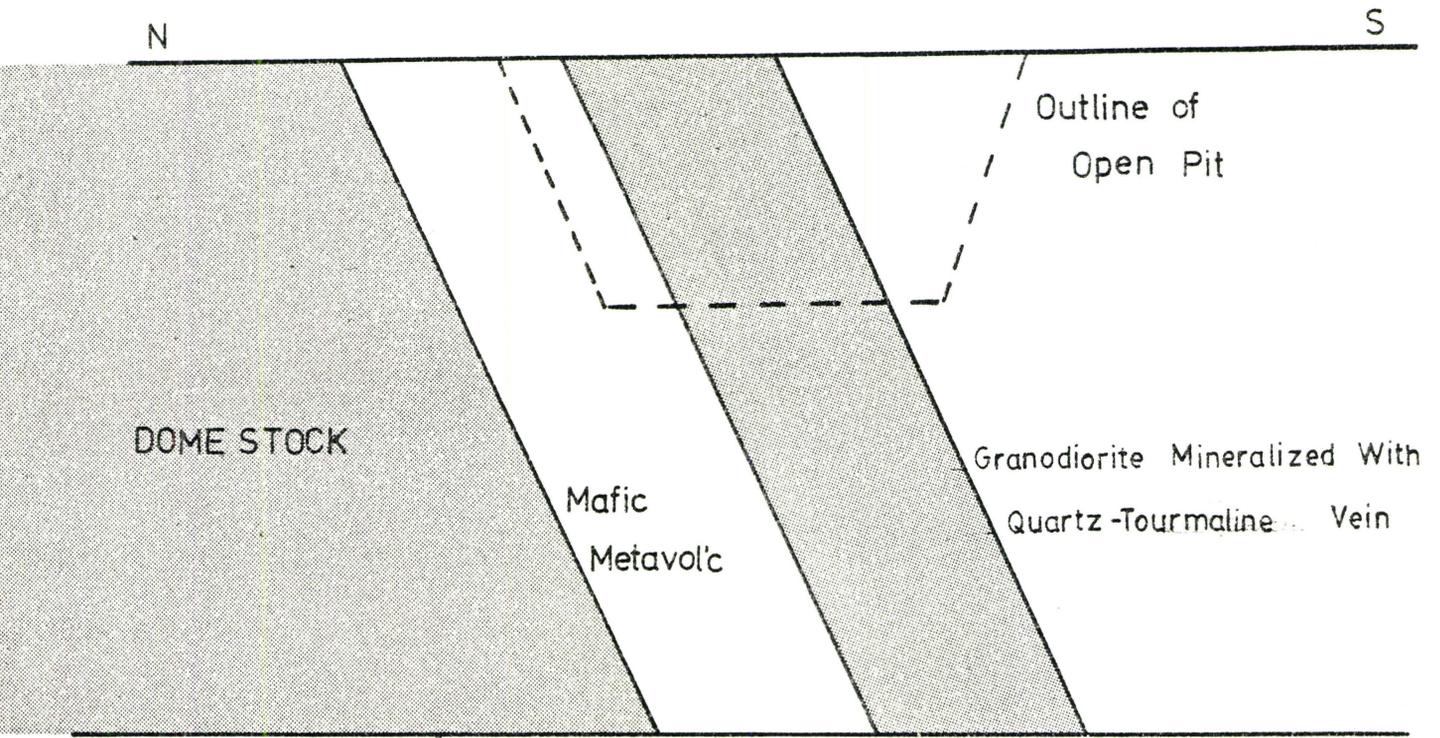
The granodiorite dyke of the Buffalo pit is a grey coloured, medium grained rock, with a well-developed secondary foliation. The granodiorite contains variably spaced quartz-tourmaline veins striking 120° and dipping 80° S.W. The veins vary in width from 1 cm. to 10 cm. and the strike length of individual veins varies between 2 and 30 m, but is generally less than 15 m. The down dip extent of the veins is roughly the same as the strike length. Figures 2.3 through 2.6 are photographs of the veined granodiorite at the Buffalo mine. Here one can see the long linear extent of the veins, the quartz-rich cores, and the alterations halo surrounding the veins, in the granodiorite. The veins are well zoned with tourmaline-rich margins and quartz-rich cores. The proportions of tourmaline

Figure 2.2

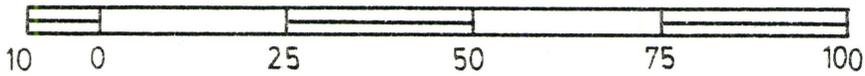
Schematic Drawing showing relationship of
rock units at the Buffalo Mine.

(After Durocher, 1981)

FIGURE 2.2



Scale 1cm to 30 m



FOOTNOTE:

All Samples Were Collected From a Mine Dump

Figure 2.3

Quartz-Tourmaline Vein in Granodiorite,
Buffalo Mine.

Figure 2.4

Quartz-Tourmaline Vein in Granodiorite,
Buffalo Mine



Figure 2.5

Quartz-Tourmaline Vein in Granodiorite,
Buffalo Mine. Lens cap is 6 cm in diameter.

Figure 2.6

Quartz-Tourmaline Vein in Granodiorite,
Buffalo Mine



and quartz vary depending on the width of the vein. As the vein decreases in width, the amount of tourmaline increases and quartz decreases. These proportions may vary, however, within individual veins. Some of the veins appear to have been emplaced after the foliation was developed and are undeformed whereas others are foliated and appear to have been emplaced during the development of the foliation. Figures 2.7 through 2.10 are photographs of representative samples. Figures 2.7 and 2.8 are samples one and three, respectively, and show the quartz-tourmaline vein, surrounded by the pink alteration halo, gradually moving out into grey granodiorite. Figure 2.9 is a photograph of sample six, which shows the same relationship as samples one and three. Marked on the sample is the location of samples 6A, 6B, 6C, which were used for XRF whole rock analysis. Figure 2.10 is a photograph of sample four, which is representative of the "fresh", unaltered granodiorite.

Figure 2.7

Sample 1 - showing vein and alteration Halo

Figure 2.8

Sample 3 - showing vein and alteration Halo

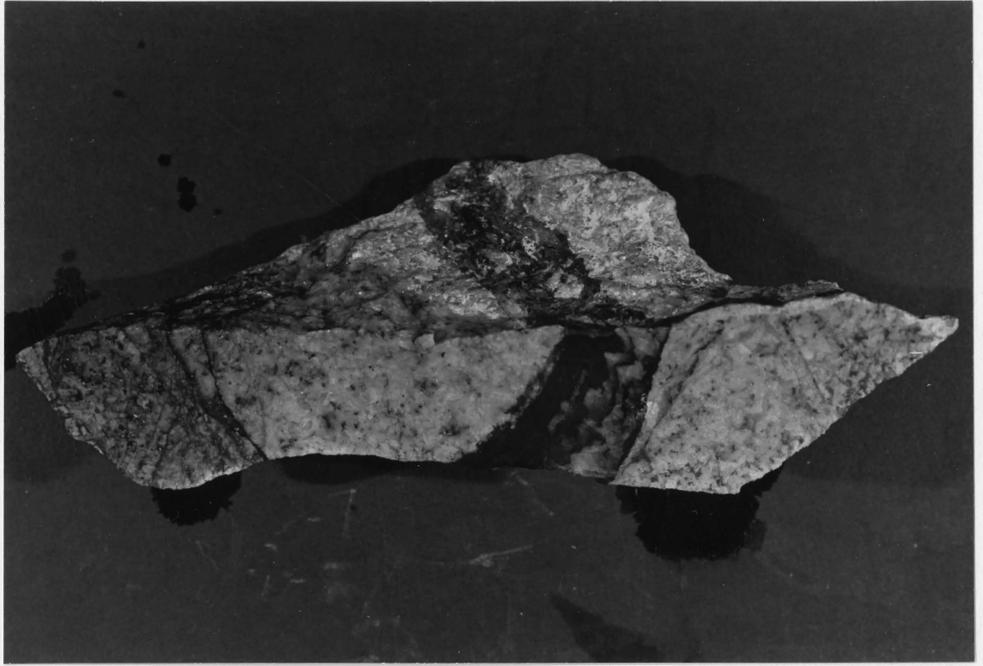
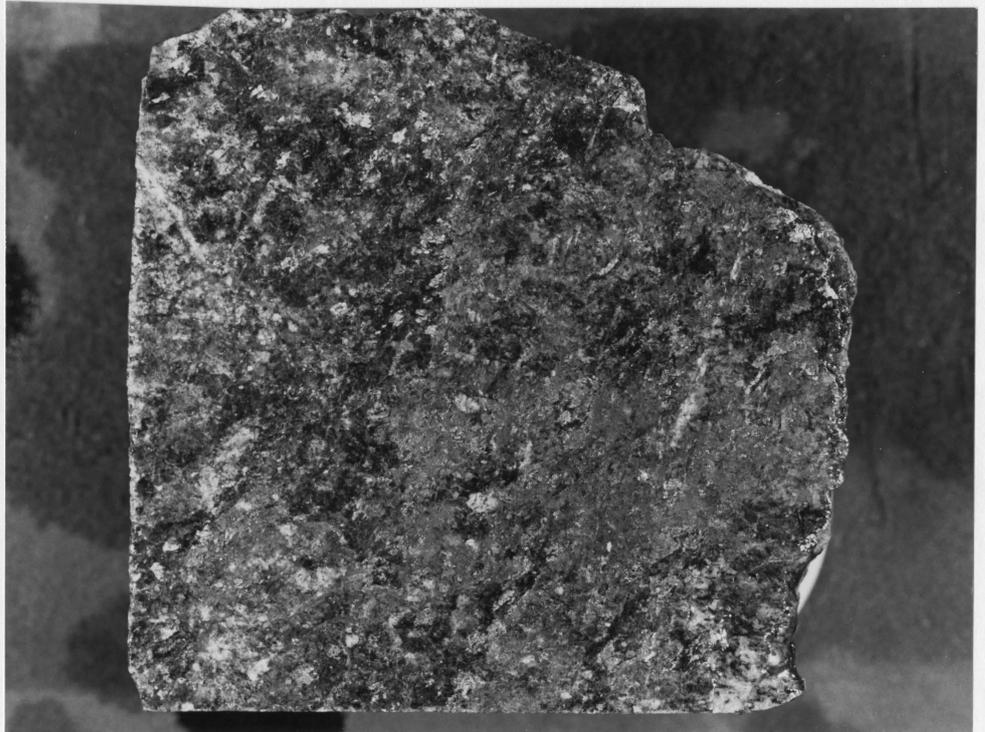


Figure 2.9

Sample 6 - XRF samples 6A, 6B, 6C are
marked on sample.

Figure 2.10

Sample 4 - "fresh", unaltered granodiorite



Chapter III

Petrography

3.1 Introduction

There are pronounced colour and mineralogical changes in the granodiorite in the immediate vicinity of the quartz-tourmaline veins. These changes are illustrated in figures 2.7 through 2.9. The alteration halo usually has a width of about twice that of the vein and is symmetrically developed on both sides of the vein. The halo is salmon-pink in colour due to the presence of hematite. The principal minerals present in the alteration zone are quartz, plagioclase, and minor amounts of mafic material. This intense alteration passes gradually into normal, grey granodiorite with significantly more mafic minerals.

Two to eight centimeter pods of disseminated pyrite are seen in the veins. Pyrite decreases in size and abundance to one to two percent in the granodiorite. Occasionally irregular blebs of chalcopyrite also occur along fracture surfaces and visible gold is seen in some of the veins.

3.2 Vein Mineralogy

Veins are made up of quartz and tourmaline in varying proportions (figure 3.1). The tourmaline rich areas consist of large aggregates made up of small, individual, subhedral, columnar grains. These large aggregates show subparallel alignment of individual grains possibly due to flow (figure 3.2).

Birefringence varies among the grains. Small grains have a yellow-brown centre and clear edges, whereas larger grains show blue interiors with pink exteriors and yellow-brown to white edges. This is probably due to varying thickness in the tourmaline grains.

The quartz grains are fairly large in size (2-4 mm). Their extinction varies from total extinction (cut perpendicular to C-axis) to normal extinction (cut parallel to C-axis). Most grains, however, have been cut perpendicular or almost perpendicular to the C-axis. Extinction is usually undulatory. Bubble trains are also seen in the quartz and show a random orientation.

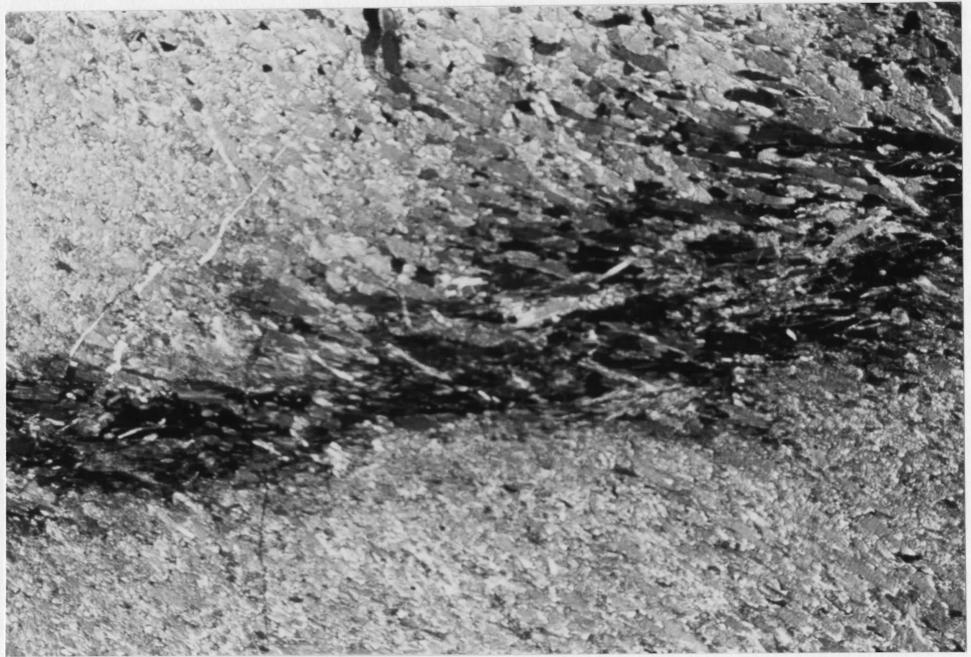
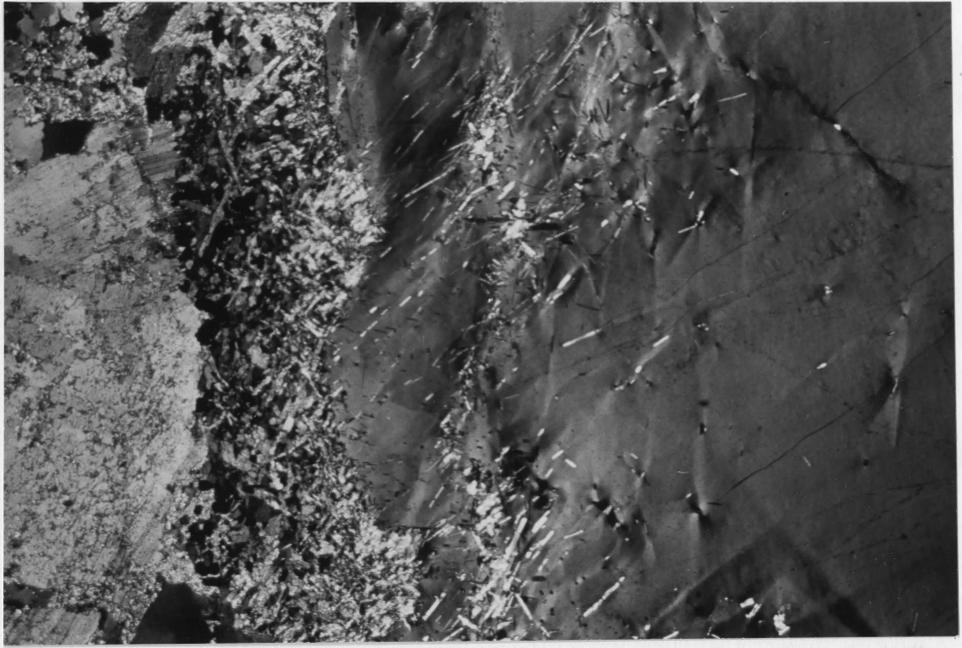
There is some evidence that suggests that the tourmaline may have been injected into the veins after the quartz instead of co-precipitating with the quartz. For instance, the proportion of quartz in the veins increases with width of the vein (i.e. small veins are almost pure tourmaline). The tourmaline, itself is found on the margins of the veins with the quartz in the centre (figures 2.7 through 2.9) In sample six (figure 2.9), a pure tourmaline stringer is seen coming off of the main quartz-tourmaline vein. In this section, fractures which cut the quartz, are filled with tourmaline. These lines of evidence help support the following hypothesis. The quartz was initially formed as veins. Subsequent stress cause the reopening of the quartz veins (which is easiest along the quartz/host rock contact) and the opening of new fractures. Boron rich fluids passed through these fractures, forming tourmaline veins.

Figure 3.1

Photomicrograph showing quartz-tourmaline vein on edge of granodiorite. Note tourmaline on margin. (Mag. 25x)

Figure 3.2

Photomicrograph of tourmaline in vein. (Mag. 25x)



3.3 Unaltered Granodiorite

The unaltered granodiorite is represented by samples four and five (figure 2.10). Table 3.1 lists the representative minerals with their approximate modal abundance, grain size, grain shape, and characteristic features.

3.3.1 Essential Minerals

3.3.1.1. Feldspar

The main constituent of the unaltered granodiorite is feldspar. Because the Red Lake area has undergone low grade metamorphism, and because the granodiorite has been influenced by the vein filling fluids, the differentiation between plagioclase and potash feldspar was difficult, and necessitated the identification of the potash feldspars by sodium cobaltinitrate etching.

The composition of the plagioclase was calculated from Michel-Levy's method and was determined to be andesine (An_{38} to An_{44}). Some doubt may be cast on the accuracy of this determination due to the altered state of the plagioclase. The potash feldspar was identified as orthoclase. Carbonate has attacked the andesine grains, causing pitting with a uniform distribution of carbonate speckes (figure 3.3). The orthoclase is less altered by the carbonate.

3.3.1.2 Quartz

A few large quartz grains are seen with clusters of fine grained quartz surrounding the larger grain. The clusters

Table 3.1 Petrology of Unaltered Granodiorite

| Mineral | Approximate Modal Abundance | Grain Size (mm) | Grain Shape | Granodiorite Characteristic Features |
|------------------|-----------------------------|-----------------|-------------|---|
| Andesine | 43% | 0.05-1 | Anhedra1 | A few grains show relict twinning. |
| Orthoclase | 2% | 6.1 | Subhedra1 | Twins more abundant than in andesine. |
| Quartz | 25% | 6.01-0.3 | Anhedra1 | Shows pseudomosaic texture with sutured contacts. |
| Biotite | 20% | 0.1 | Anhedra1 | Occurs in 1 mm clusters. |
| Chlorite | 5% | 0.5 | Anhedra1 | Alteration product of biotite. |
| Opagues (pyrite) | 1% | 0.1-0.25 | Anhedra1 | Associated with biotite. |
| Calcite | 5% | 0.01 | Anhedra1 | Alteration produced in andesine. |
| Zircon | Trace | 0.01 | Euhedra1 | Associated with biotite. |

show weakly developed mosaic texture and all contacts are sutured (figure 3.4). Few of the quartz grains in the pseudo-mosaic quartz are in contact. Various minerals fill the interstices between the grains. The quartz grains usually have undulatory extinction, large numbers of fluid inclusions, little alteration, and few subgrains.

3.3.1.3. Biotite

Biotite is also present in the granodiorite, appearing as pleochroic green to very dark green in colour. The biotite has been extensively replaced by chlorite and other minerals. (figures 3.5, 3.6) Its appearance is very ragged and the grains are widely dispersed in the slide. The biotite occurs in clusters of about 1 mm and seems to be located interstitially between the quartz and feldspar grains (figures 3.7, 3.8).

3.3.1.4 Chlorite

Chlorite is also present and is the alterations product of the biotite. The chlorite has a colourless to pale green pleochroic colour and is almost completely black at extinction. The chlorite is always associated with the biotite clusters and, in some cases, appears to be pseudomorphous after biotite. (figure 3.5,3.6).

3.3.2. Accessories

3.3.2.1. Opaques

The opaques are found in association with the biotite. They are anhedral in shape and occur in small clusters (fig. 3.9).

Figure 3.3

Photomicrograph of unaltered granodiorite showing plagioclase with carbonate alteration. (Mag. 63x)

Figure 3.4

Photomicrograph of unaltered granodiorite showing pseudo-mosaic quartz with sutured contacts. (Mag. 63x)

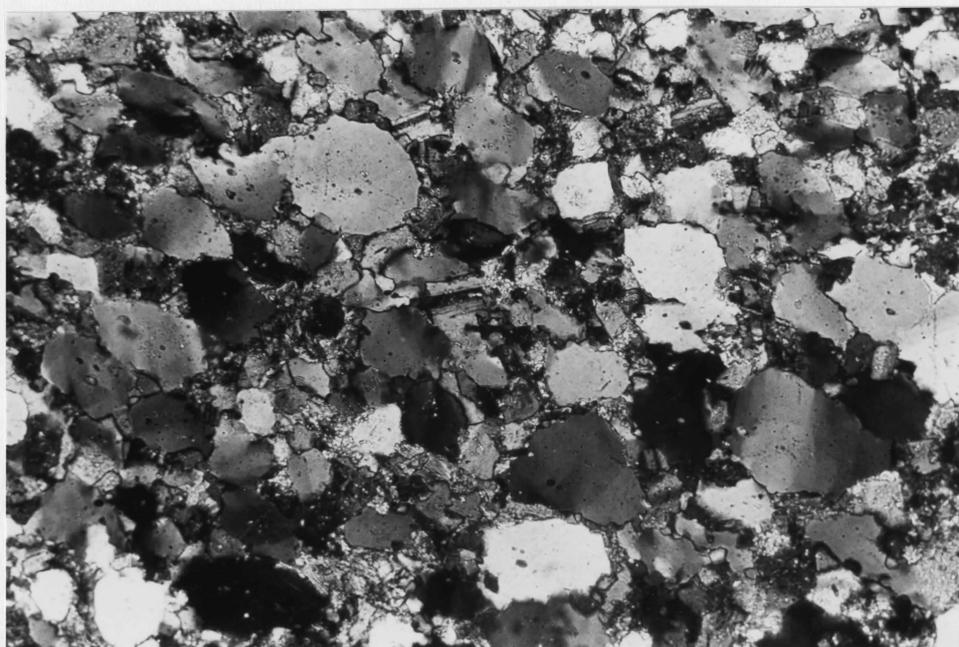


Figure 3.5

Photomicrograph of unaltered granodiorite showing altered biotite. Note Zircon in photo (Mag. 160 x).

Figure 3.6

Photomicrograph of unaltered granodiorite showing altered biotite. (Mag. 160 x).

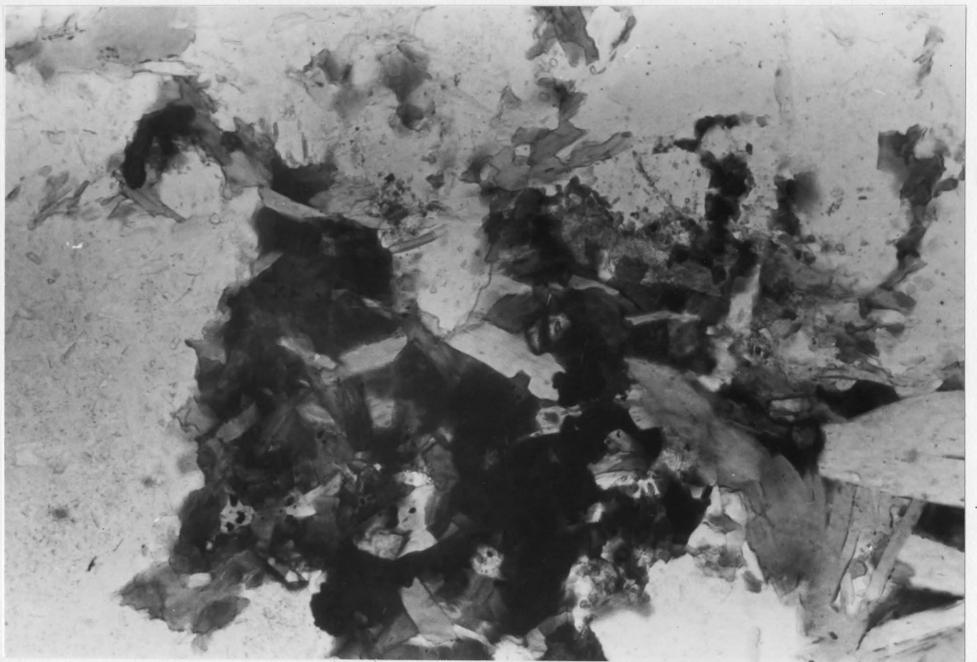
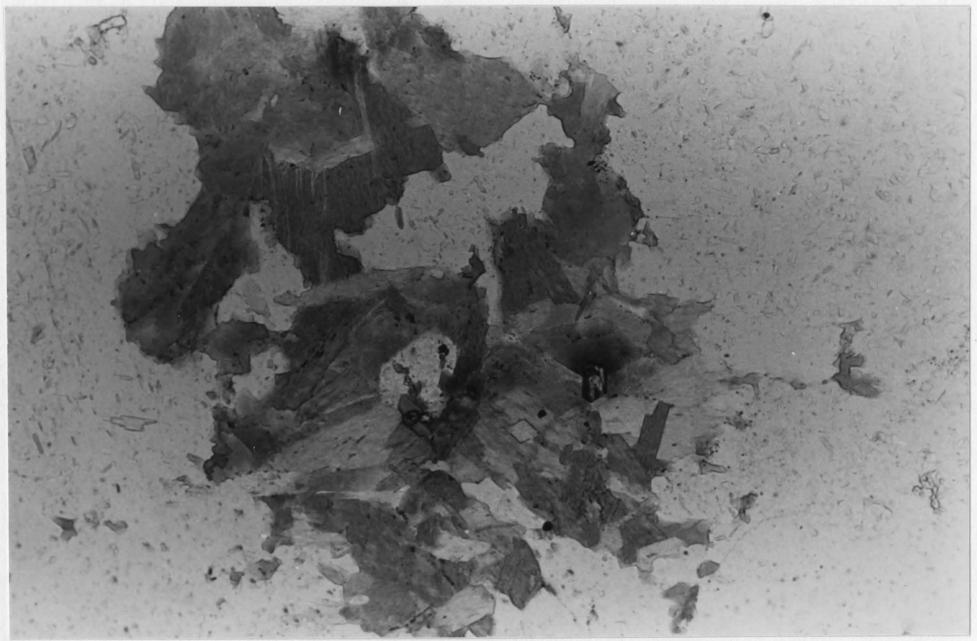
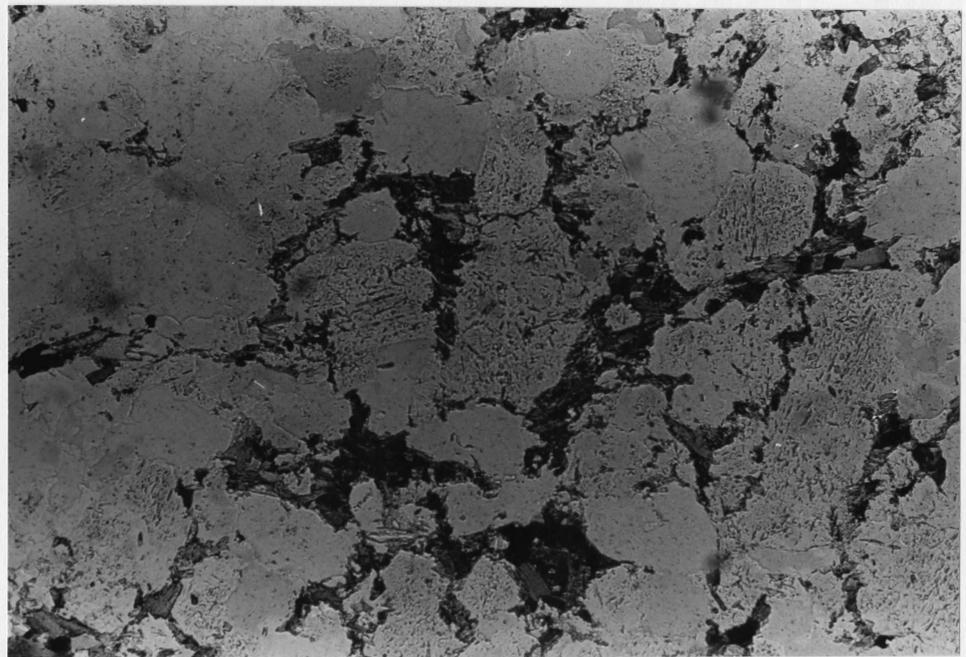
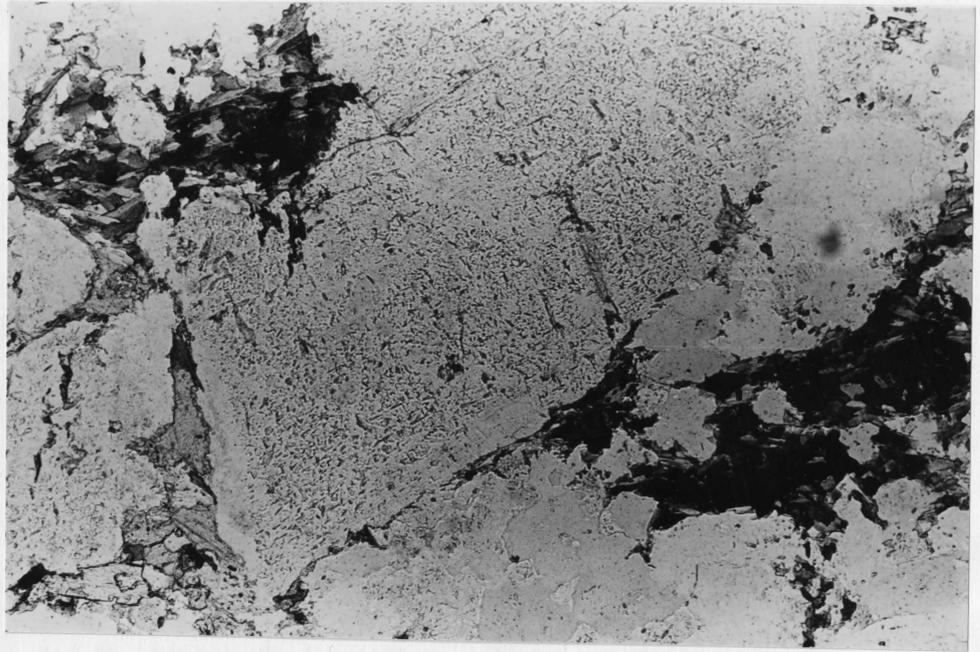


Figure 3.7

Photomicrograph of unaltered granodiorite showing interstitial habit of biotite. (Mag. 63 x)

Figure 3.8

Photomicrograph of unaltered granodiorite showing interstitial habit of biotite. (Mag. 63 x).



The opaques are probably pyrite.

3.3.2.2. Carbonate

The carbonate has been identified by X-ray diffraction (XRD) as calcite and is seen as small specks, altering the andesine. A few very small poals (less than 0.1 mm) of calcite are seen interstitially.

3.3.2.3. Zircon

A very small (less than 0.01 mm), euhedral zircon is sometimes seen associated with the biotite. (figure 3.5).

3.4 Altered Granodiorite

The altered granodiorite is represented by samples 1, 3, and 6A. (Figures 2.7,2.8,2.9 respectively). The essential minerals are plagioclase, quartz, and carbonate. The representative minerals found in the altered granodiorite along with their approximate modal abundance, grain size, grain shape, and characteristic features are listed in table 3.2.

3.4.1 Essential Minerals

3.4.1.1. Feldspar

The main constituent of the altered granodiorite is again feldspar. However, all the feldspar is plagioclase and potash feldspar is absent. The composition of the plagioclase is again andesine (An_{38} to An_{44}). Deformation is evident in the andesine and is suggested by bent, fractured,

and curved twins (figure 3.10). The andesine has been highly carbonatized, with the carbonate seen in the andesine grains as specks, blebs and veinlets, some cutting through the entire grain (figure 3.11). The carbonate alteration is greater in the centre of the grains, with a cleaner rim of andesine around the outer edge of the grain (figure 3.12). This could represent a possible overgrowth on the andesine grains.

3.4.1.2. Quartz

The carbonate alteration has not been as severe on the quartz grains. Most grains do show some carbonate inclusions, but these are very small in number when compared to the plagioclase. Half of the total quartz occurs as large (1 mm) single grains and the other half as fine grained clusters, presenting a mosaic texture. The contacts between the mosaic quartz and the larger quartz grains, and with the grains in the mosaic texture all show sutured boundaries (figure 3.13, 3.14). The mosaic quartz is also very compact, with no inclusions of other minerals between the grains (figure 3.15).

3.4.1.3. Carbonate

The carbonate in this sample is calcite, which was determined by x-ray diffraction (XRD). The calcite has been introduced into the alteration zone as an extensive carbonate alteration. The calcite occurs interstitially, between the quartz and andesine grains and seems to occur as flows cutting through series of grains (figure 3.16, 3.17). Closer to the

Table 3.2

Petrology of Altered Granodiorite

| Mineral | Approximate Modal Abundance | Grain Size (mm) | Grain Shape | Granodiorite Characteristic Features |
|------------|-----------------------------|-----------------|-------------|--|
| Andesine | 50% | 0.3-2 | Anhedra1 | Fractured with deformed twins. Possible over-growth. |
| Quartz | 30% | 0.1-1 | Anhedra1 | Mosaic texture with sutured boundaries. |
| Calcite | 20% | Various | Anhedra1 | Interstitial to, and altering Plagioclase. |
| Tourmaline | Trace | 0.1 | Subhedra1 | Associated with Pyrite. |
| Biotite | Trace | 0.1 | Subhedra1 | Very altered. |
| Opagues | 3% | | | |
| 1)Pyrite | | 1 | Subhedra1 | Biotite inclusions. |
| 2)Hematite | | 0.1-0.5 | Anhedra1 | Associated with interstitial carbonate. |
| Zircons | Trace | 0.05 | Euhedra1 | Associated with Pyrite. |

Figure 3.9

Photomicrograph of unaltered granodiorite showing opaques, probably pyrite.
(Mag. 63x)

Figure 3.10

Photomicrograph of altered granodiorite showing deformation of the andesine.
(Mag. 25X)

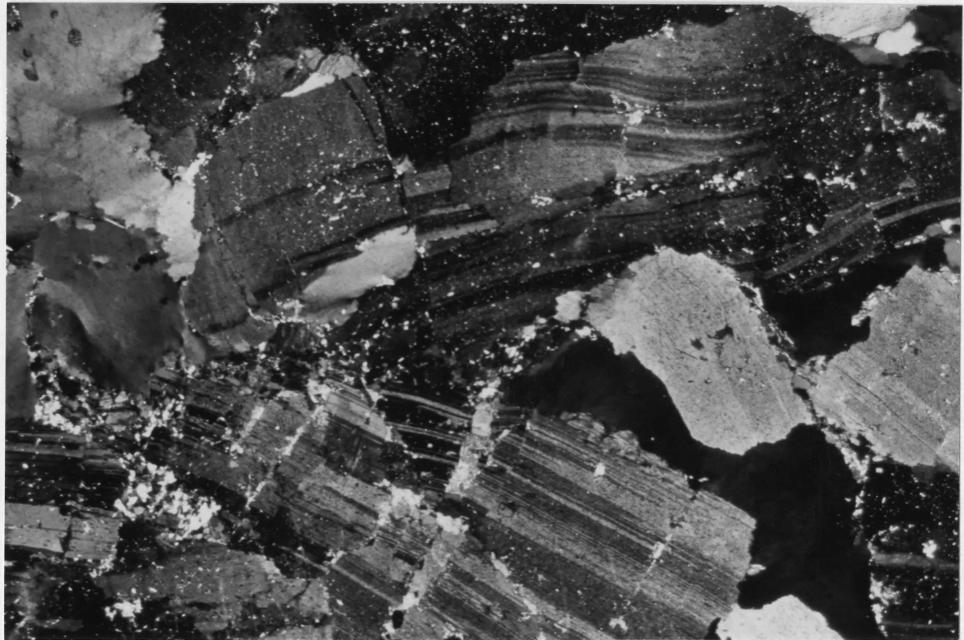
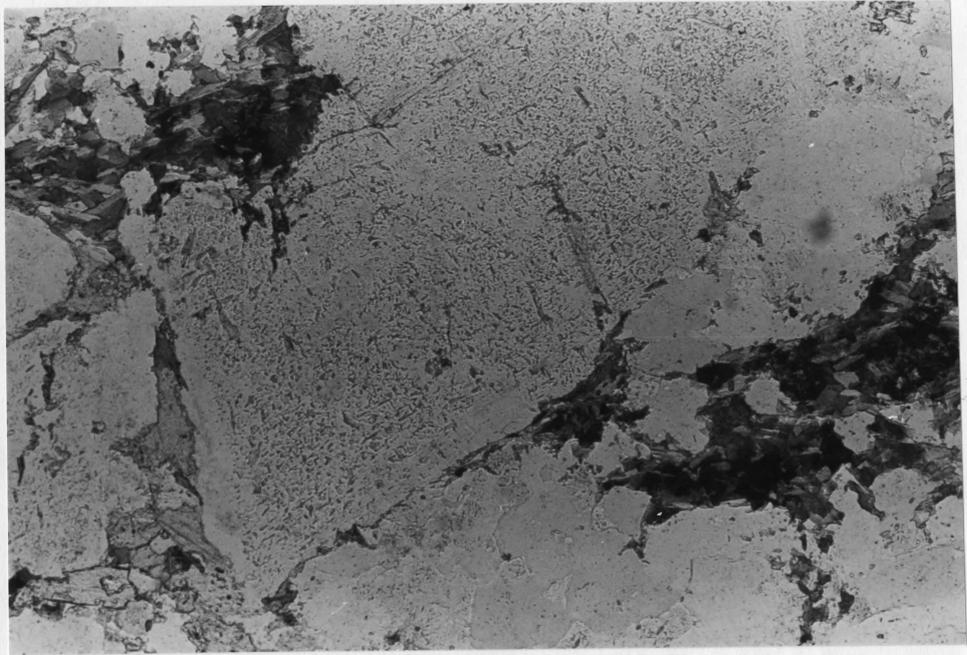


Figure 3.11

Photomicrograph of altered granodiorite showing carbonate alteration of the andesine.
(Mag. 63x)

Figure 3.12

Photomicrograph of altered granodiorite showing carbonate alteration in centre of andesine grain, with a clean, outer rim. Possible overgrowth of the andesine.
(Mag. 63x)

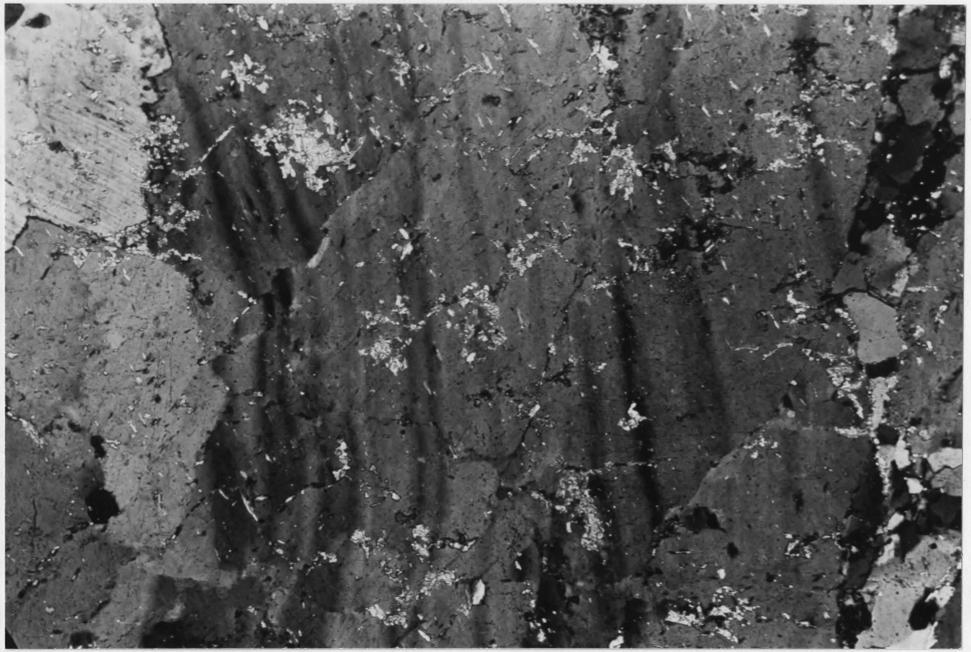
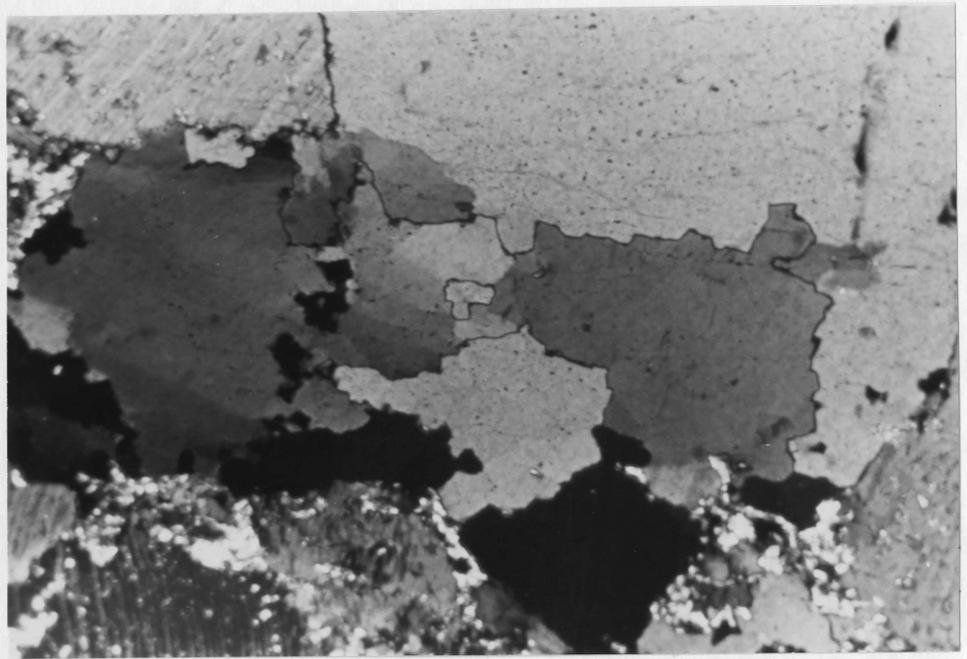
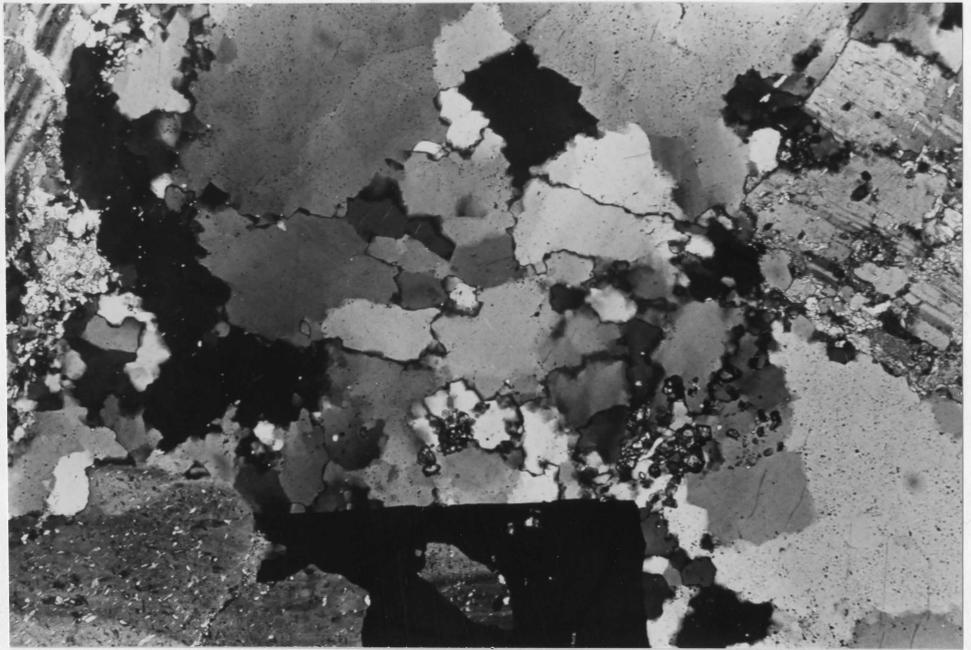


Figure 3.13

Photomicrograph of altered granodiorite showing mosaic quartz with sutured boundaries.
(Mag. 63x)

Figure 3.14

Photomicrograph of altered granodiorite showing mosaic quartz with sutured boundaries.
(Mag. 63x)



quartz-tourmaline vein, the calcite has a larger grain size and occurs as thin veinlets, along the edges of the grains (figure 3.18). Calcite is also found in the plagioclase grains as specks and blebs, and is seen filling cracks and fissures in various other grains (figure 3.11, 3.12)

3.4.2 Accessories

3.4.2.1. Tourmaline

Only a trace of tourmaline was seen in the altered granodiorite and is very fine grained and altered. The tourmaline is associated with the interstitial carbonate and occur in greatest abundance when associated with the opaques. It is also seen as small inclusions in pyrite grains. As would be expected, their size and abundance decreases away from the vein.

3.4.2.2 Biotite

Mafic minerals are very rare in this alteration zone. Only a trace of biotite was observed. Biotite has a very altered appearance, resembling a fibrous matte (sericitic look) (figures 3.19, 3.20) and it appears as if the biotite has been completely recrystallized. The remnant grains of biotite are always seen associated with pyrite. No chlorite is seen in the altered granodiorite.

Figure 3.15

Photomicrograph of altered granodiorite showing tightly packed mosaic quartz with no inclusions of other minerals between the quartz grains.
(Mag. 63x)

Figure 3.16

Photomicrograph of altered granodiorite showing the environment of the carbonate.
(Mag. 25x)

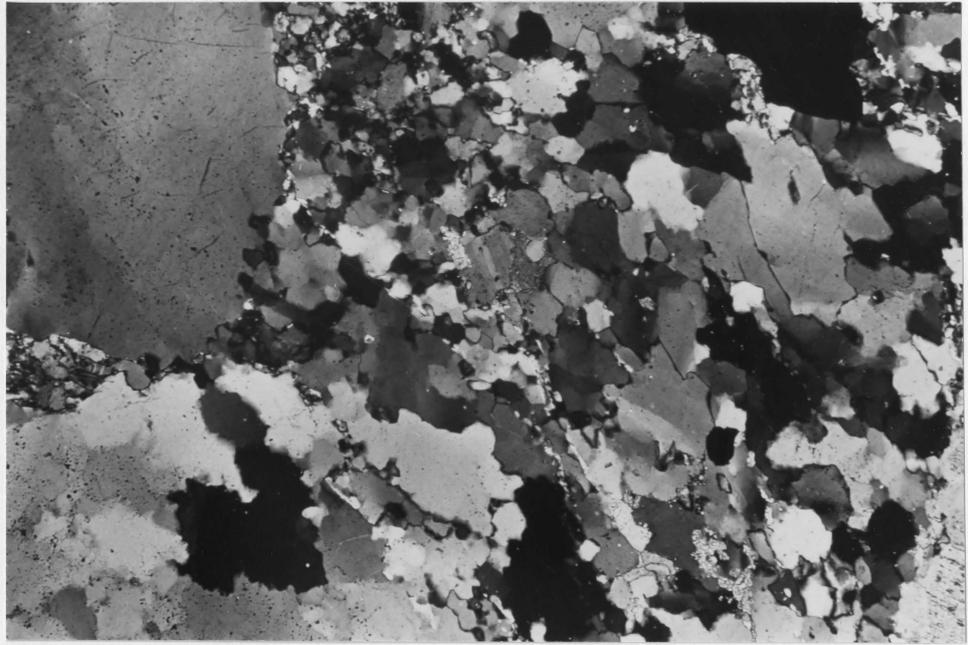
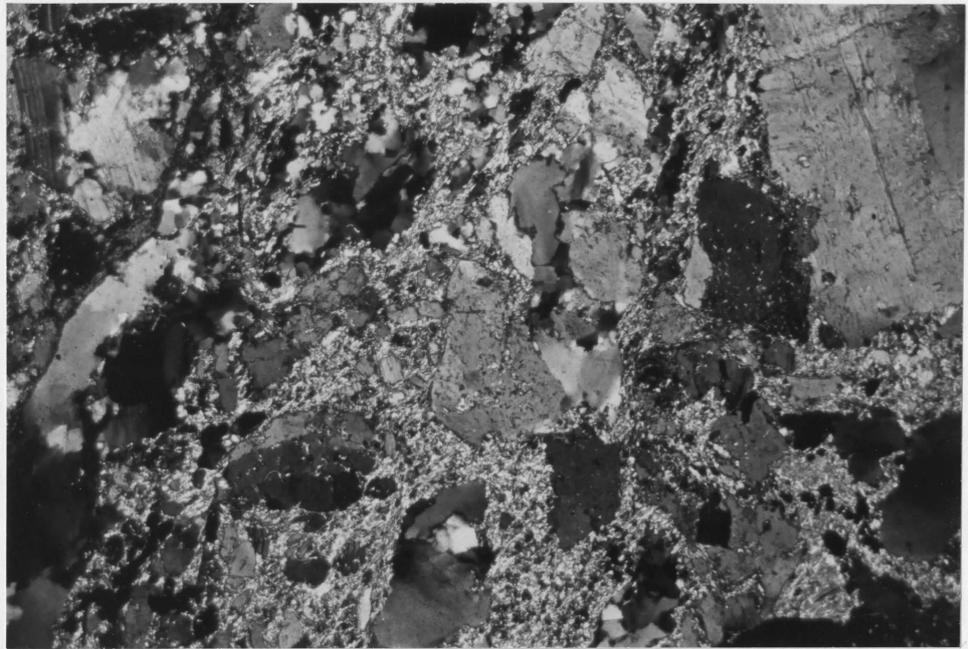


Figure 3.17

Photomicrograph of altered granodiorite showing the environment of the carbonate. (Mag. 25x)

Figure 3.18

Photomicrograph of altered granodiorite showing carbonate as thin veinlets along grain edges. (Mag. 25x)



3.4.2.3 Opaques

The opaques consist of hematite and pyrite. The hematite is found in the interstitial carbonate and is usually drawn out, as if fragments of an original grain (figure 3.21). The pyrite is seen between quartz and andesine grains and contains biotite inclusions (figure 3.19, 3.20, 3.22). The abundance and size of both hematite and pyrite decrease away from the quartz-tourmaline vein.

3.4.2.4 Zircons

Euhedral, tetragonal-shaped zircons are associated with the pyrite and usually occur in small clusters (figure 3.23, 3.24). The zircons are not associated with the hematite.

Figure 3.19

Photomicrograph of altered granodiorite
showing extensively altered biotite.
(Mag. 160 x)

Figure 3.20

Photomicrograph of altered granodiorite
showing extensively altered biotite.
(Mag. 65 x)

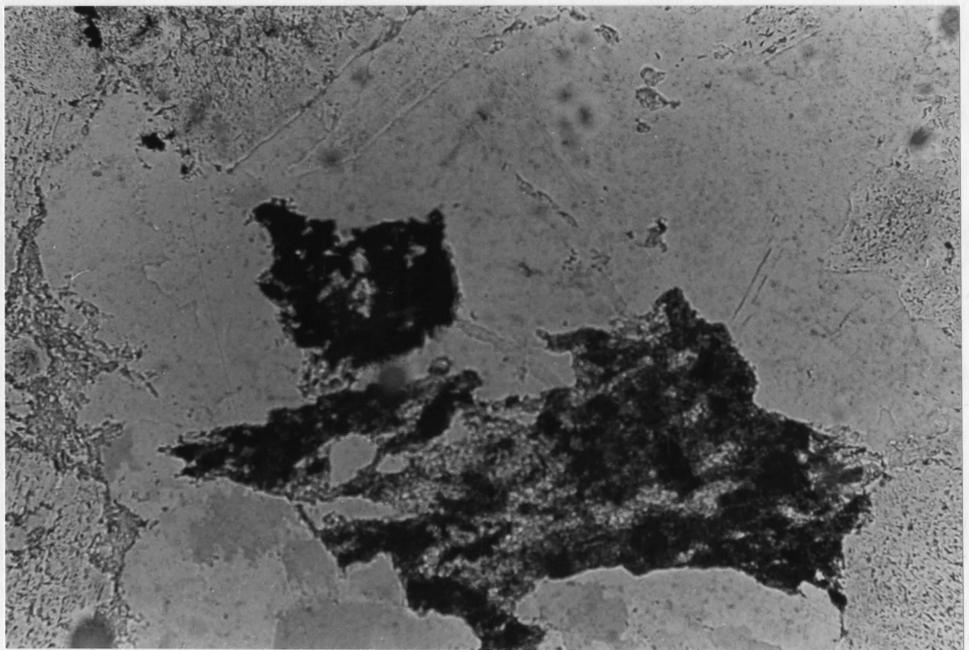
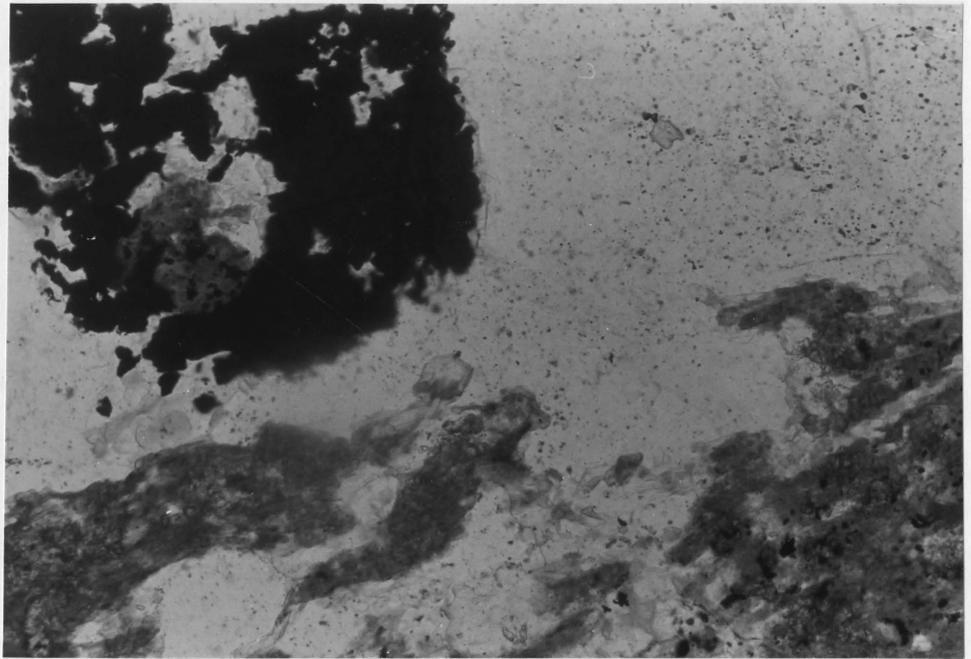


Figure 3.21

Photomicrograph of altered granodiorite
showing fragmented hematite.
(Mag 65x)

Figure 3.22

Photomicrograph of altered granodiorite
showing pyrite containing biotite inclusions.
(Mag. 160x)

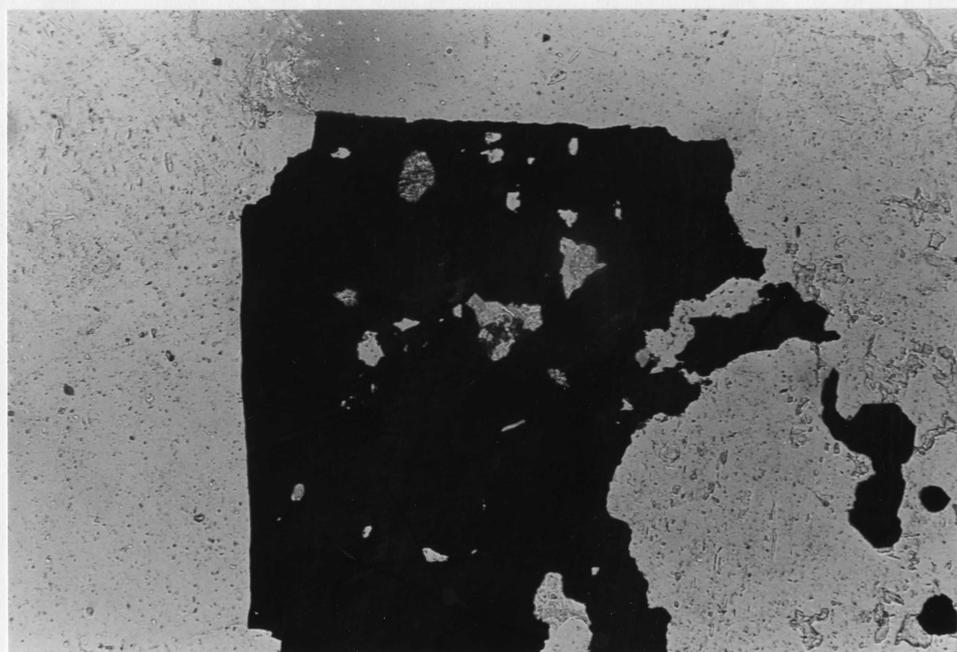
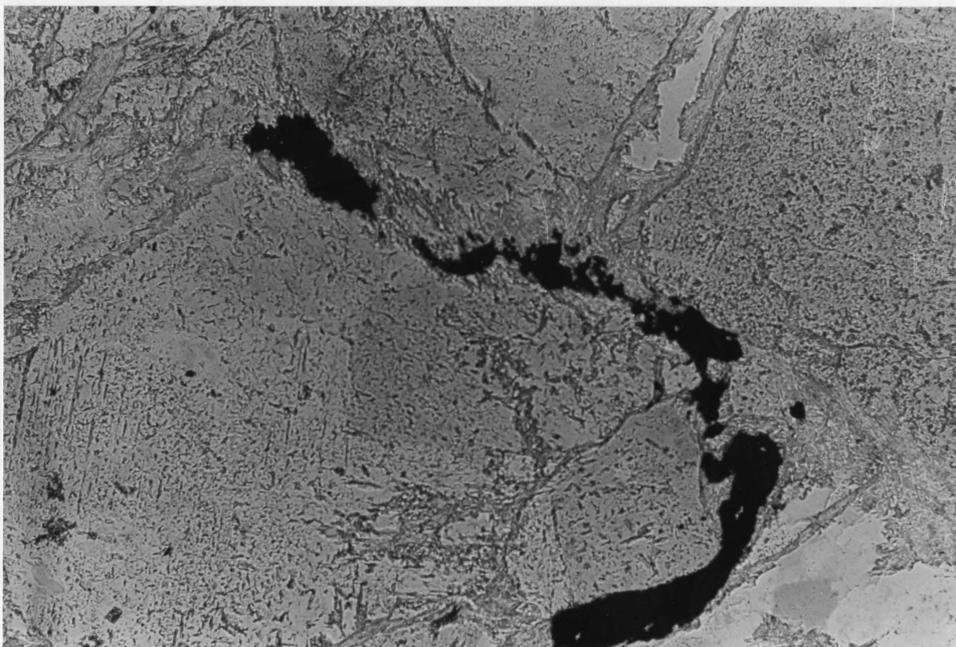
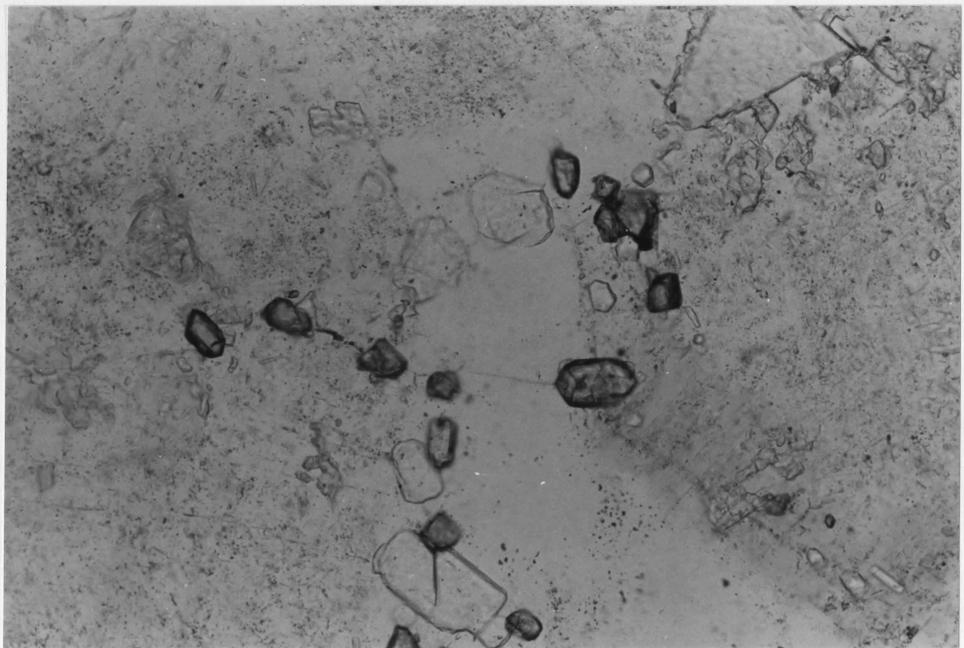
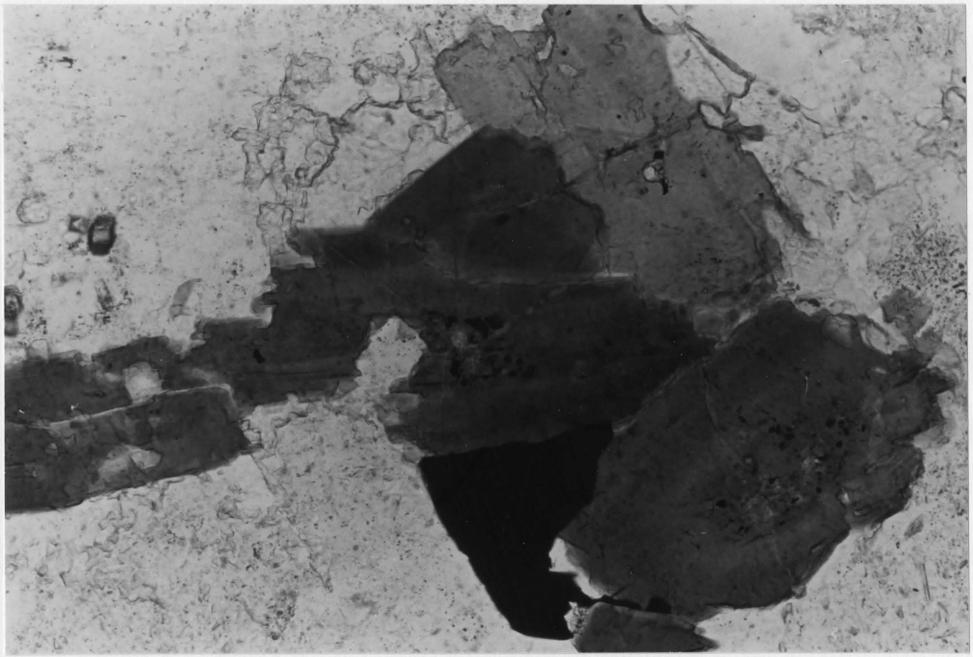


Figure 3.23

Photomicrograph of altered granodiorite
showing zircon clusters.
(Mag. 65x)

Figure 3.24

Photomicrograph of altered granodiorite
showing zircon clusters.
(Mag. 160x)



CHAPTER IV

Geochemistry

4.1 Introduction

A Philips, Model 1450 AHP, semi-automatic, sequential, x-ray fluorescence spectrometer was used for whole rock element analysis. A 6:1 mixture of flux (lithium tetraborate and lithium metaborate) to rock powder was fused in a platinum-gold crucible for 3-5 minutes at 1200°C, to prepare pellets for major element, whole rock analysis. The major elements Si, Al, total Fe, Mg, Ca, Na, K, P, Mn, Ti were analysed using a Cr X-ray tube.

The data for all the samples are listed in table 4.1, and their C.I.P.W. Norms are presented in table 4.2. Included with these analyses, for comparison, are the average major element compositions for a granodiorite (Nockolds, 1954).

4.2 Wall Rock Alteration

The composition of the wall rock is important in determining the degree of alteration. For instance, mafic rocks are more susceptible than felsic rocks to hydrothermal alteration. Other important factors include the degree of shearing or fracturing, the composition of the hydrothermal solutions, and the prevailing pressure and temperature.

Figure 4.1 is a plot of the relative gains and losses of the major oxides as compared to the unaltered granodiorite. The average composition of the unaltered granodiorite (samples 4 and 5) was subtracted from the average composition of the altered granodiorite (samples 2, 3, and 6A), thus giving a positive value for a gain in an oxide, and a negative value for a loss (see tables 4.3

Table 4.1
Composition Of Fresh
Altered Granodiorite

| | 2a | 2b | 3a | 3b | 4 | 5 | 6A | 6B | 6C | Average Granodiorite Composition |
|--------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------------------------------------|
| SiO ₂ | 70.59 | 70.65 | 67.79 | 68.48 | 72.60 | 69.97 | 73.01 | 67.64 | 68.99 | 66.88 |
| Al ₂ O ₃ | 13.72 | 13.78 | 14.25 | 14.44 | 12.30 | 13.29 | 11.41 | 15.65 | 14.71 | 15.66 |
| Fe ₂ O ₃ | 1.08 | 1.10 | 1.83 | 1.84 | 3.47 | 3.76 | 2.08 | 2.43 | 2.79 | 3.92 |
| MgO | 0.40 | 0.16 | 0.42 | 0.21 | 1.35 | 1.86 | 1.11 | 1.09 | 0.92 | 1.57 |
| CaO | 2.72 | 2.80 | 3.23 | 3.32 | 1.43 | 1.38 | 3.30 | 2.15 | 1.70 | 3.56 |
| Na ₂ O | 8.02 | 8.03 | 8.23 | 7.44 | 4.97 | 4.60 | 5.81 | 5.25 | 4.53 | 3.84 |
| K ₂ O | 0.77 | 0.80 | 0.90 | 0.91 | 1.64 | 2.19 | 0.65 | 2.72 | 2.93 | 3.07 |
| TiO ₂ | 0.51 | 0.53 | 0.52 | 0.53 | 0.23 | 0.25 | 0.41 | 0.44 | 0.36 | 0.57 |
| MnO | 0.09 | 0.09 | 0.11 | 0.11 | 0.08 | 0.07 | 0.12 | 0.09 | 0.08 | 0.07 |
| P ₂ O ₅ | 0.13 | 0.12 | 0.13 | 0.13 | 0.04 | 0.04 | 0.15 | 0.10 | 0.09 | 0.21 |
| LOI | 1.95 | | 2.59 | | 1.89 | 2.52 | 1.95 | 2.42 | 2.77 | |
| C | 2.52 | | 2.77 | | 1.39 | 0.77 | 2.73 | 0.80 | | |
| S | 0.38 | | 0.76 | | 0.16 | 0.11 | 1.42 | 0.64 | | |

Footnotes to Table 4.1

- 1) Analysis by XRF with normalization to 100% including L.O.I.
- 2) Sample Description
 2,3 - altered Granodiorite taken adjacent to vein - (Highly altered)
 4,5 - unaltered Granodiorite with no affiliation to vein (no apparent alteration)
 6A,B,C, - samples moving away from vein i.e./ 6A alteration 6C (see figure 2.9)
- 3) a,b. are duplicate samples. A,B, and C are different samples from the same hand sample.
- 4) One would expect C+5 L.O.I., which is not the case for samples 2,3, and 6A which are the highly altered samples.

Table 4.2 C.I.P.W. Norms

| | 2 | 3 | 4 | 5 | 6A | 6B | 6C |
|--------------|--------|---------|---------|---------|---------|--------|--------|
| Calcite | 3.968 | 4.944 | 2.474 | 1.797 | 5.310 | 1.862 | 2.997 |
| Na-Carbonate | .772 | .329 | | | | | |
| Apatite | .299 | .301 | .095 | .095 | .348 | .236 | .211 |
| Ilmenite | .190 | .235 | .446 | .486 | .523 | .836 | .695 |
| Sphene | .996 | .972 | | | .333 | .333 | |
| Orthoclase | 4.515 | 5.260 | 9.722 | 13.214 | 3.794 | 16.341 | 17.540 |
| Magnesite | .830 | .878 | .637 | | .770 | | .590 |
| Albite | 63.061 | 67.733 | 42.267 | 40.185 | 48.783 | 45.152 | 39.212 |
| Anorthite | | | | 1.709 | | 5.131 | |
| Corundum | .433 | .063 | 2.393 | 2.701 | 1.151 | 2.266 | 4.064 |
| Magnetite | | | 2.562 | 2.603 | | .417 | 1.914 |
| Hematite | 1.993 | 2.019 | | | 1.915 | 1.689 | .570 |
| Quartz | 23.944 | 17.268 | 35.624 | 30.887 | 35.246 | 23.313 | 30.581 |
| Hypersthene | | | 3.783 | 1.830 | 1.830 | 2.754 | 1.626 |
| Enstatite | | | 2.626 | 4.724 | 1.830 | 2.754 | 1.626 |
| Ferrosillite | | | 1.156 | 1.602 | | | |
| Sum | 100 | 100.002 | 100.003 | 100.003 | 100.003 | 99.998 | 100 |

Footnotes to Table 4.2

- 1) Convention of Irving and Baragar (1971) was used to apportion iron between FeO and Fe₂O₃.

$$\text{ie/ } \% \text{ Fe}_2\text{O}_3 = \% \text{ TiO}_2 + 1.5$$

$$\% \text{ Fe O} = (\% \text{ Fe}_2\text{O}_2 = \text{TiO}_2 - 1.5) \times 0.8998$$

- 2) Sample Description
see table 4.1

Table 4.3 Average Chemical Compositions

| | Altered Granodiorite | Unaltered Granodiorite |
|--------------------------------|----------------------|------------------------|
| SiO ₂ | 70.10 | 71.29 |
| Al ₂ O ₃ | 13.52 | 12.80 |
| Fe ₂ O ₃ | 1.59 | 3.62 |
| MgO | 0.46 | 1.61 |
| Na ₂ O | 7.51 | 4.82 |
| K ₂ O | 0.81 | 1.92 |
| TiO ₂ | 0.50 | 0.24 |
| MnO | 0.10 | 0.08 |
| P ₂ O ₅ | 0.13 | 0.04 |
| L. O. I. | 2.16 | 2.21 |
| C. | 2.67 | 1.08 |
| S. | 0.85 | 0.14 |

Footnotes to Table 4.3

1) Altered granodiorite is average of samples 2, 3, and 6A.

Unaltered granodiorite is average of samples 4, and 5.

Table 4.4 Relative Gains and Losses of Oxides in Altered
Granodiorite

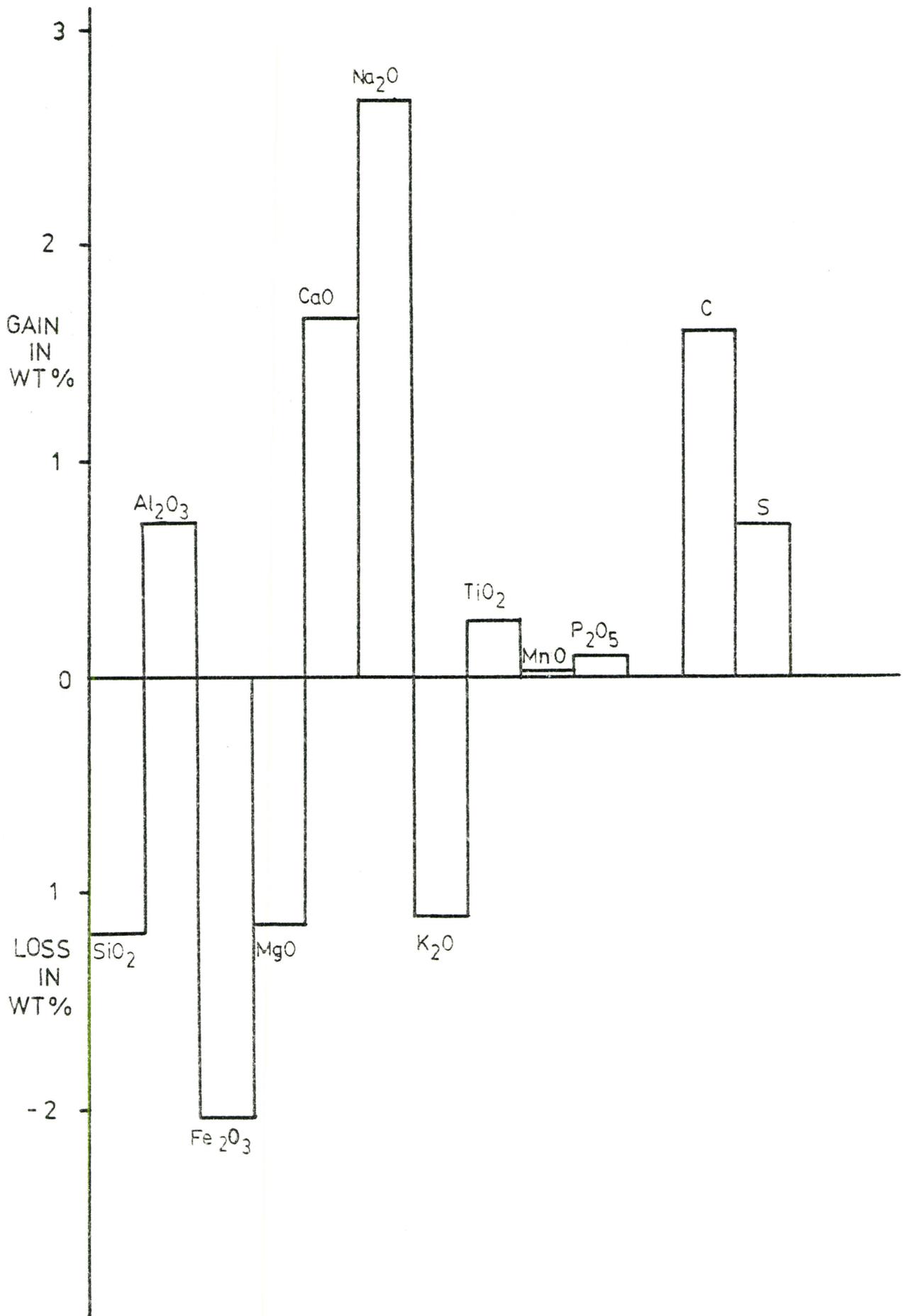
| | |
|--------------------------------|-------|
| SiO ₂ | -1.19 |
| Al ₂ O ₃ | +0.72 |
| Fe ₂ O ₃ | -2.03 |
| MgO | -1.15 |
| CaO | +1.66 |
| Na ₂ O | +2.69 |
| K ₂ O | -1.11 |
| TiO ₂ | +0.26 |
| MnO | +0.02 |
| P ₂ O ₅ | +0.09 |
| L.O.I. | -0.05 |
| C | +1.59 |
| S. | +0.71 |

Footnote to Table 4.4

- 1) Gains and Losses were Calculated by subtracting the average unaltered granodiorite composition from the average altered granodiorite composition.
- 2) Negative = Loss
Positive = Gain

Figure 4.1

Graph showing gains and losses of the major oxides as compared to the unaltered granodiorite.



and 4.4). Figure 4.2 through 4.4 are variation diagrams showing the increase and decrease of the major elements with distance from the vein. using the average of samples 2, 3, and 6A as the altered granodiorite and the average of samples 4 and 5 as the unaltered granodiorite. To show compositional variations in a profile away from quartz-tourmaline veins, through altered rock into fresh granodiorite, data for samples 6A, 6B, 6C were plotted as a function of approximate sample distance from the vein on figures 4.5 through 4.7. The major oxide composition for average granodiorite (Table 4.1) was also plotted for comparison.

According to Gresens (1967), the actual gains and losses that occur in metasomatic alterations cannot be obtained without a knowledge of the relationship between compositional changes and volume changes that accompany the process. In a metasomatic alteration of rock A (fresh) to rock B (altered)

$$x = a \left(fv \left(\frac{g^B}{g^A} \right) C_1^B - C_1^A \right)$$

where x = total amount of material lost or gained

fv = volume factor (V^B/V^A)

a = amount of each mineral

gn = specific gravity of mineral n

C_n^z = weight fraction of component n in mineral z

In the calculation of the gains and losses (table 4.4 and figure 4.1), a volume factor of one was assumed and the specific gravity ratio (g^b/g^A) was found to be equal to one. The gains and losses of the oxides, found by subtracting the fresh granodiorite composition from the altered granodiorite composition are, therefore, absolute gains and losses.

Figure 4.2

Variation diagram of oxides SiO_2 and Al_2O_3
for averaged altered and unaltered granodiorite
(AGC = average granodiorite composition, Nockolds, 1954)

Figure 4.3

Variation diagram of oxides Na_2O , CaO , C , and S
for averaged altered and unaltered granodiorite
(AGC = average granodiorite composition, Nockolds, 1954)

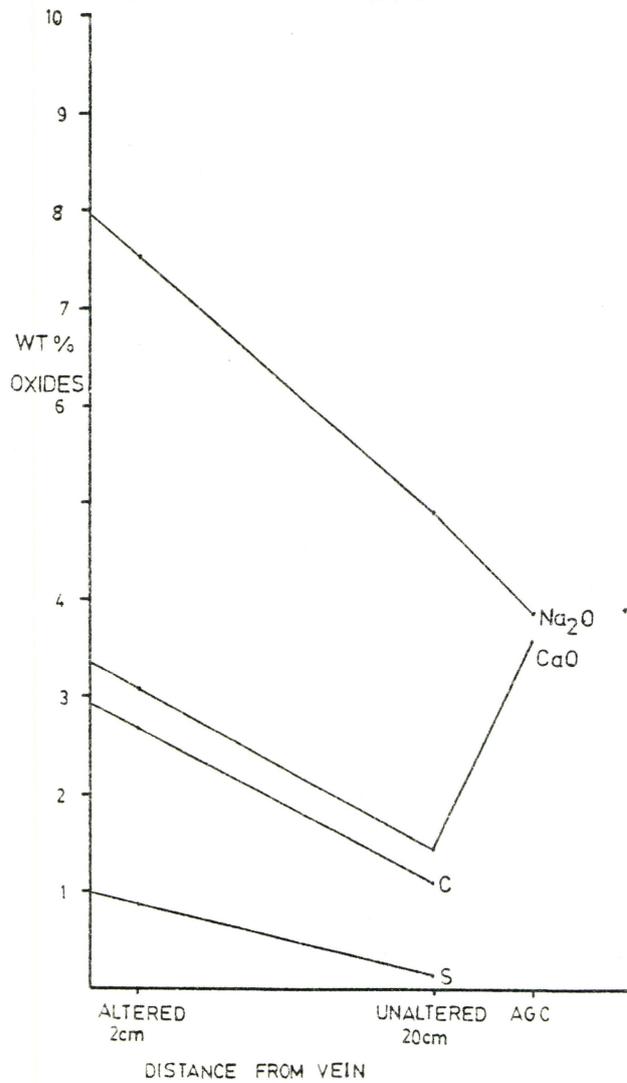
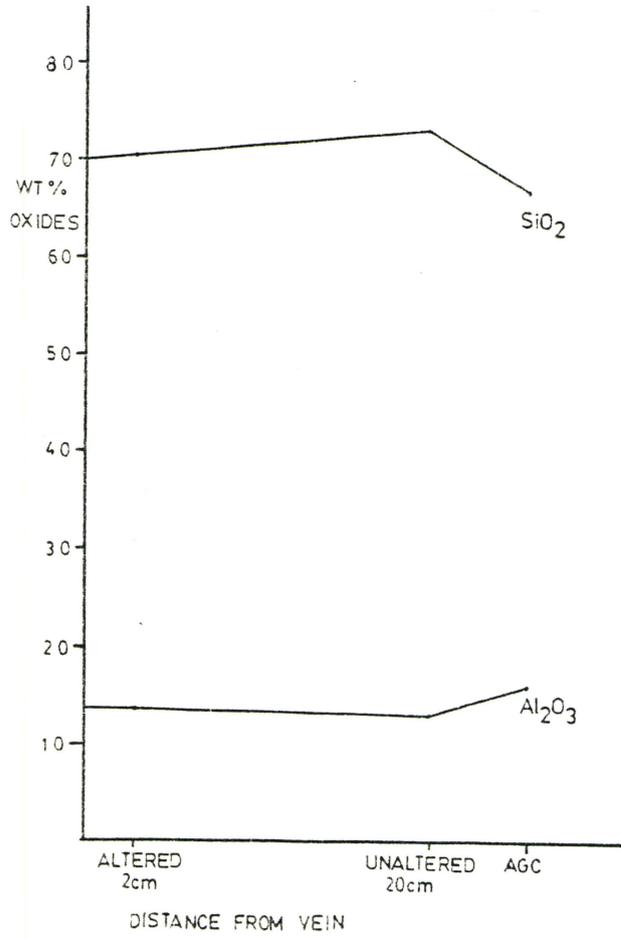


Figure 4.4

Variation diagram of oxides Fe_2O_3 , K_2O , MgO and TiO_2 for averaged altered and unaltered granodiorite (AGC - average granodiorite composition, Nuckolds, 1954)

Figure 4.5

Variation diagrams of oxides SiO_2 and Al_2O_3 for Samples 6A, 6B, and 6C. (AGC = average granodiorite composition, Nuckolds, 1954)

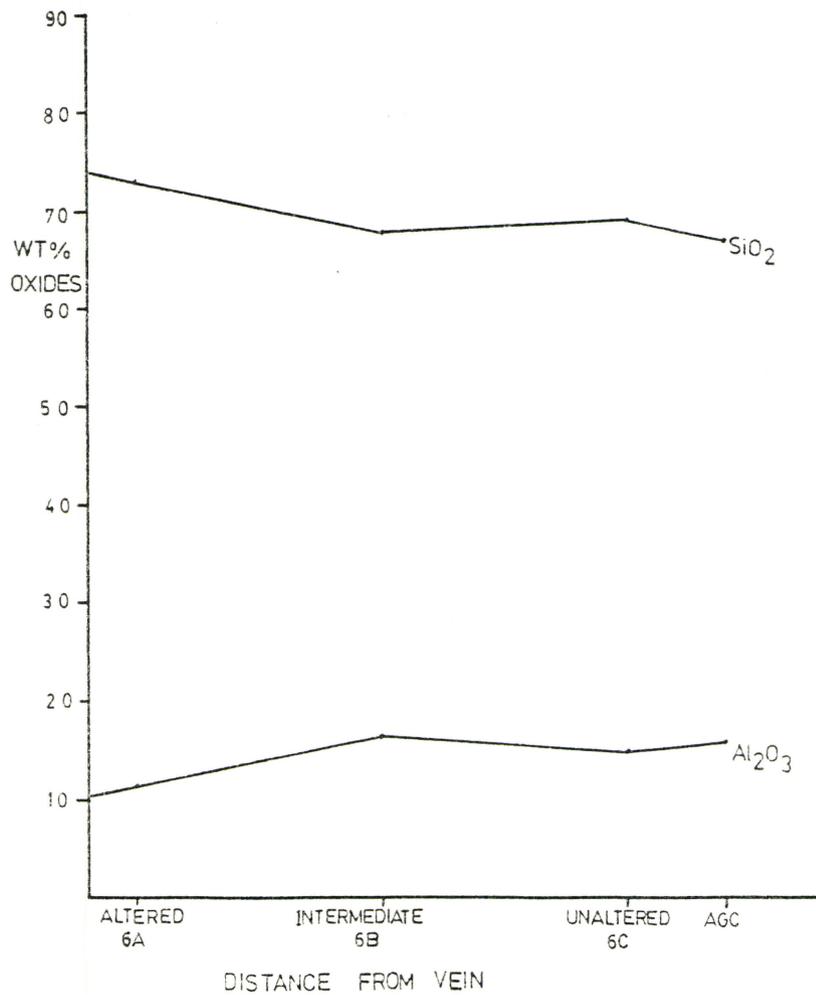
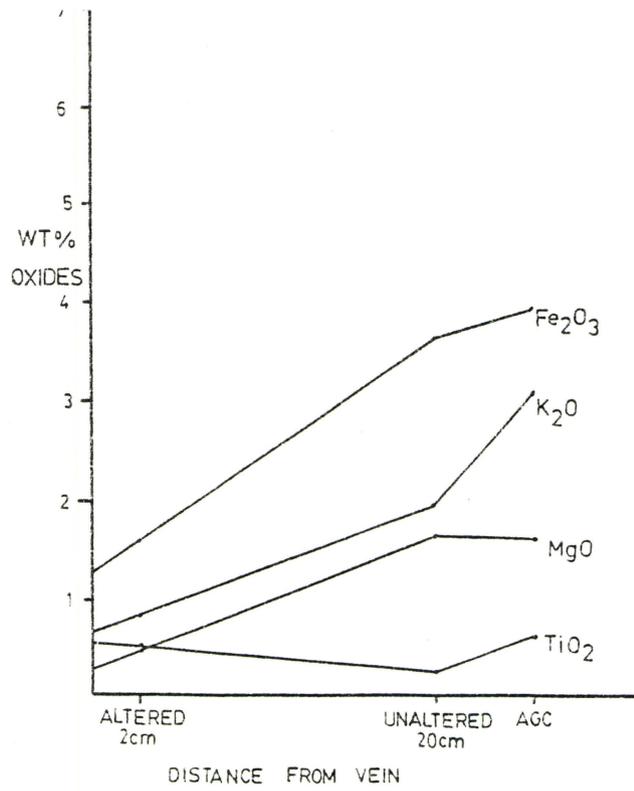


Figure 4.6

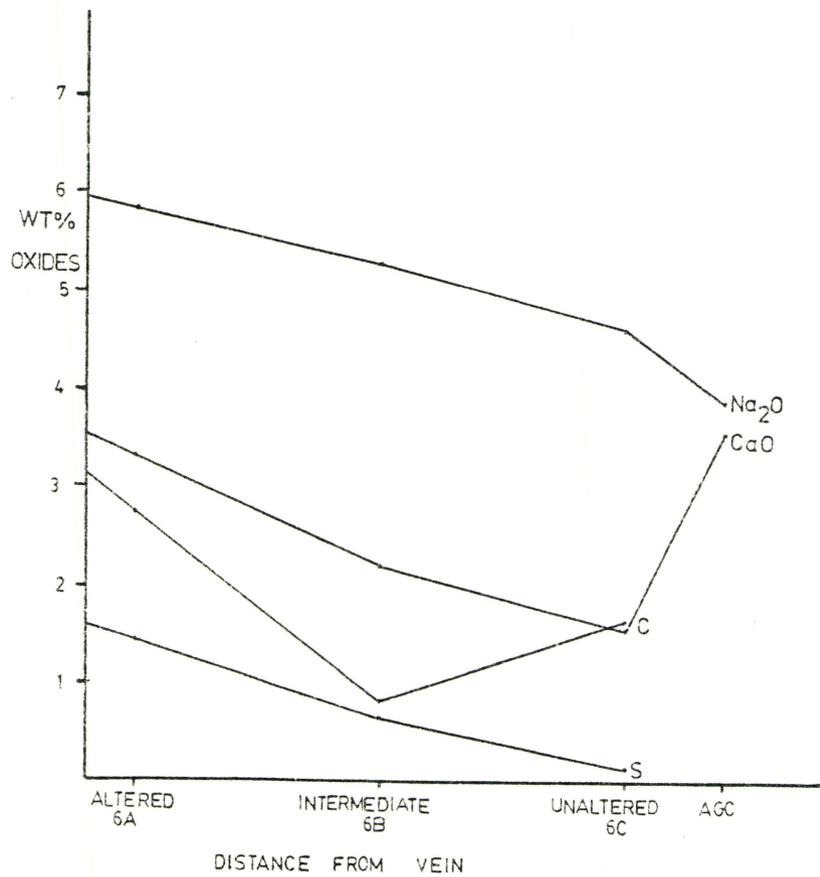
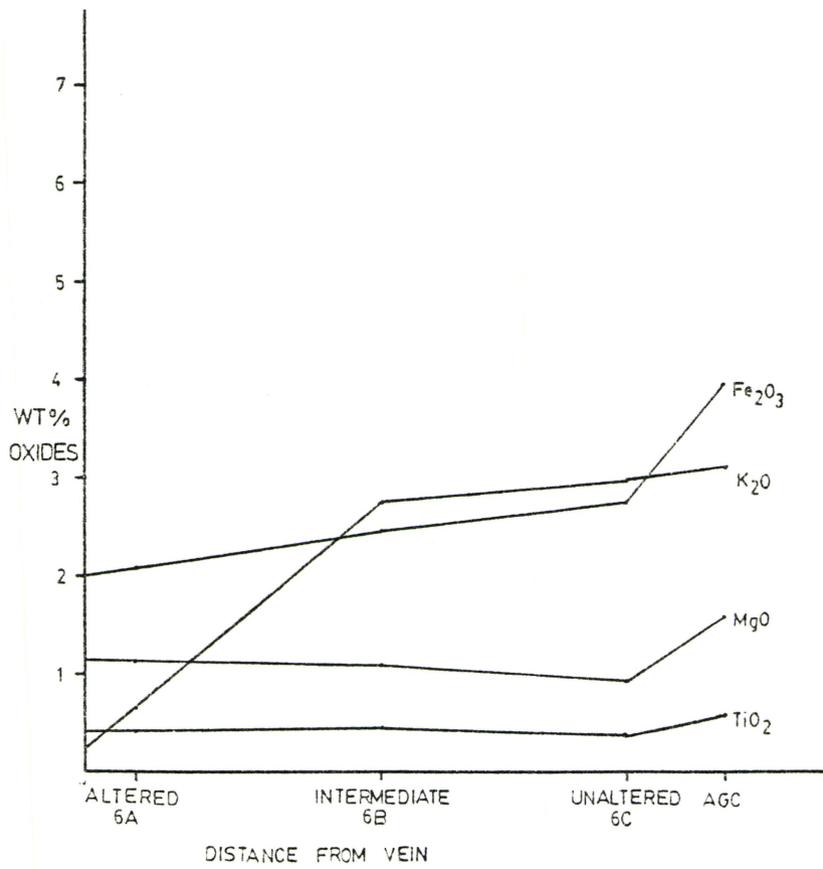
Variation diagram of Na_2O , CaO , C, and S for samples 6A, 6B, and 6C.

(AGC = average granodiorite composition, Nockolds, 1954).

Figure 4.7

Variation diagram of Fe_2O_3 , K_2O , MgO , and TiO_2 for samples 6A, 6B, and 6C.

(AGC = average granodiorite composition, Nockolds, 1954)



From a study of the variation diagrams (figures 4.2 through 4.7), certain trends become evident:

- a) The wall-rock alteration involves the breakdown of silicate minerals with the release of Si, Al, Fe, Mg, Ca, Na, and K.
- b) The relative amounts of Si and Al remain fairly constant, showing only a slight decrease in Si (1.19%) and a slight increase in Al (0.72%).
- c) All altered samples show an increase in Ca and Na, and a depletion in Fe, K, Mg, when compared to the unaltered granodiorite. These trends are reflected in the mineralogy. Only plagioclase feldspar of andesine composition is seen near the vein. Potash feldspars are absent. Mafic minerals are also absent near the vein. The biotite and chlorite have broken down, releasing K, Mg, Fe^{2+} , and Fe^{3+} .
- d) There is an increase of C (as CO_2) towards the vein. This influx of CO_2 is responsible for the partial replacement of plagioclase by carbonate (calcite).
- e) There is a sufficient increase in S, as the vein is approached, for the formation of pyrite. The necessary iron is probably derived from the breakdown of mafic minerals.
- f) The alteration halo exhibits pervasive oxidation of iron (hematite) giving the characteristic reddish-pink colour.

CHAPTER V

Nature of the Vein Fluids

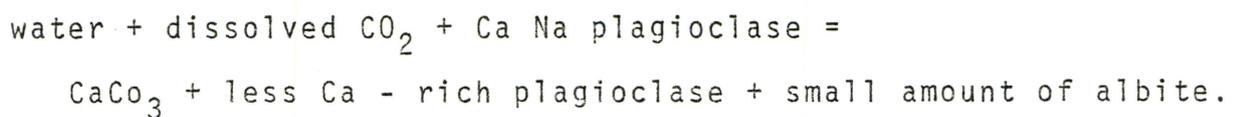
5.1 Composition

Many petrological and chemical changes occur in the granodiorite host rock as the quartz-tourmaline vein is approached. These changes, or alterations, are dependent on the temperature, pressure, and composition of the vein-forming fluids. The nature of these hydrothermal solutions can only be inferred from present day hydrothermal activity and the stability field of the various mineral assemblages formed.

A summary of the petrological and chemical changes from the unaltered to the altered granodiorite is as follows:

- a) The carbonate alteration of the plagioclase is restricted to the centres of grains, with a cleaner rim of plagioclase along the outer edge of the grain. The grain size of the plagioclase increases towards the vein, as does the sodium content. This may represent a sodium albite overgrowth. Carbon dioxide from the fluids may have reacted with the calcium in the plagioclase, forming calcite. The fluids, which the geochemistry shows are enriched in sodium, may have added a cleaner, outer rim to the calcium-rich plagioclase. This phenomena, however, could also be explained by zoning of plagioclase, with a calcium-rich core and a sodium-rich outer rim, except no zoned plagioclase is seen in the fresh granodiorite.
- b) The carbonate occurs as an alteration product in plagioclase and as an interstitial accessory mineral. Towards the vein, the calcite increases in grain size and abundance. The

chemistry shows that carbon (as CO_2) and calcium increase towards the vein. Assuming that the enrichment is not due to a migration from a depleted area, the CO_2 and calcium must have been added from the fluids. The vein fluids have broken down mafic silicates and the plagioclase in the host rock. This released Ca which has reacted with vein fluid carbonate to form calcite. A possible reaction for calcite formation is:



- c) The mafic minerals are completely destroyed by the fluids. The crystal structure of the biotite has been destroyed and chlorite is no longer present. This reaction is supported by the geochemical data, which shows a depletion in iron, magnesium, and potassium in the near vein wall rock.
- d) The abundance and size of magnetite and pyrite increase towards the vein, suggesting that the vein fluids either carried the iron or the sulfur. The rock alteration probably released iron from mafic minerals so that only the sulfur was derived from the vein fluids. The vein fluids were also sufficiently oxidizing to fix some of the iron as an oxide.
- e) The vein itself, is composed of tourmaline; therefore, the fluids must have been enriched in boron.
- f) The vein fluids must have been oxidizing to form hematite, in the altered host rock. Hematite and pyrite are seen co-existing in the alteration halo and according to Garrels and Quist (1965, figure 7.20), when hematite and pyrite co-exist, the fluids have a neutral pH and a low Eh.

The initial mineralizing fluids, therefore, were probably high temperature, NaCl solutions, enriched in boron, and containing some CO₂. The fluids were likely oxidizing and had a neutral pH.

CHAPTER VI

Conclusions

6.1 Summary of Alteration

The progressive alteration of the felsic rocks by the high temperature, NaCl hydrothermal solutions can be visualized as follows:

- 1) Alteration is recognized by the introduction of soda and the destruction of mafic minerals.
- 2) The fluids caused oxidation of iron (hematite) and alteration of plagioclase by calcite.

This alteration was caused by high temperature, enriched fluids, containing NaCl solutions and some CO₂.

6.2 Future Work

In the future, a link between alteration and ore deposition should be sought, for the purpose of exploration. Firstly, collection of samples from numerous other quartz-tourmaline veins in felsic rocks is needed. Such locations could include the Sigma Mine near Val D'or, Quebec.

A comparison of extensive petrological and geochemical data should be carried out to determine similarities and differences in the alteration assemblages, composition of mineralizing fluids, and ore mineralogy. Secondly, a link between the alterations, fluids, and ore should be determined, along with a hypothesis of formation. Once this is found, exploration is as simple as finding other localities with similar characteristics.

BIBLIOGRAPHY

1. Augustithis, S. S. (1973)
Atlas of the Textural Patterns of Granite, Gneisses
and Associated Rock Types, American Elsevier
Publishing Co. Inc., 378. p.
2. Bishop, E. G. (1948)
Report of the Property of Buffalo Red Lake Mines Ltd.
3. Deer, Howie, and Zussman (1980)
An Introduction to the Rock Forming Minerals,
John Wiley & Sons Ltd., 528 p.
4. Durocher, Marcel (1981)
Confidential Report of the Buffalo Mine, Property Visit.
5. Durocher, Marcel (1982)
Confidential Report of the Buffalo Mine, Property Visit.
6. Ferguson, S. A. (1968)
Geology of the Northern Part of Heyson Township
District of Kenora, Ontario Department of Mines
Geological Report 56, 54 p.
7. Garrels, R. M., and Christ, C. L. (1965)
Solutions, Minerals, and Equilibria, Freeman, Cooper,
and Company, California, 450 p.
8. Gresens, R. L. (1967)
Composition - Volume Relationships of Metasomatism;
Chemical Geology, Vol. 2, p 47-65.
9. Gorman, B. E., Kerrich, R., and Fyfe, W. S., (1981)
Geochemistry and Field Relations of Lode Gold Deposits
in Felsic Igneous Intrusions - Porphyries of the Timmins
District, Grant 56, Part A, p. 108-124 in Geoscience
Research Grant Program, Summary of Research 1980-1981,
edited by E. G. Pye, Ontario Geological Survey, Miscellaneous
Paper 98, 340 p.
10. Hodgson, G. S., and MacGeehan, P. J. (1981)
Gold Ore Formation at the Campbell and Dickenson
Mines, Red Lake Area, Grant 11, p. 132-143 in Geoscience
Research Grant Program, Summary of Research 1980-1981,
edited by E. G. Pye, Ontario Geological Survey,
Miscellaneous Paper 98, 340 p.
11. Horwood, H. C. (1940)
Geology and Mineral Deposits of the Red Lake Area,
Ontario Department of Mines, Annual Report, Vol.
49, Pt. 2, 231 p.

12. Kerr, Paul F. (1977)
Optical Mineralogy, McGraw-Hill, Inc., 492 p.
13. Kerrich, R., Gorman, B. E., and Fyfe, W. S. (1980)
Geochemistry and Field Relations of Lode Gold Deposits in Felsic Igneous Intrusion; Grant 56, p. 136-143 in Geoscience Research Grant Program, Summary of Research, 1979-1980, edited by E. G. Pye, Ontario Geological Survey, M. P.93, 362 p.
14. Nockolds, S. R. (1954)
Average Chemical Composition of Some Igneous Rocks; Bulletin of the Geological Society of America, Vol. 65, p. 1007-1032.
15. Nockolds, S. R. , Knox, R. W., O. B., and Chinner, G.A. (1978)
Petrology for Students, University Press, New York, 435 p.
16. Pirie, J. (1979)
Heyson Township Area District of Kenora, Patricia Portion: p 8-11 in Summary of Field Work, 1979, by the Ontario Geological Survey, edited by W. G. Milne, O. L. White, R. B. Barlow, and C. R. Kustra, Ontario Geological Survey, Miscellaneous Paper 90, 245 p.
17. Pirie, J. (1981)
Regional Geological Setting of Gold Deposits in the Red Lake Area, Northwestern Ontario p. 71-93 in Genesis of Archean, Volcanic - Hosted Gold Deposits, Symposium Held at University of Waterloo, March 7, 1980, Ontario Geological Survey, MP 97,
18. Spry, Alan (1976)
Metamorphic Textures. Pergamon Press Ltd., Canada 350 p.
19. Stephenson, J. F. (1971)
Gold Deposits of the Rice Lake - Beresford Lake Greenstone Belt, Southeastern Manitoba, p. 337-374. in Manitoba Mines Branch Pub. 71-1, Report 16.
20. Studemeister, P. A., Kerrich, R., and Fyfe, W. S. (1981)
Geochemistry and Field Relations of Lode Gold Deposits in Felsic Igneous Intrusions - The Gutcher Lake Stock; Grant 56 Part 13, p. 267-292 in Geoscience Research Grant Program, Summary of Research 1980-1981, edited by E. G. Pye, Ontario Geological Survey, Miscellaneous Paper 98, 340 p.