A Geochemical Evaluation of the Alteration Zone at the Norbec Mine, Noranda, Quebec: Bulk Chemical Composition, Mass and Volume Change, Flux of Elements

by

Noëlle Shriver

A thesis submitted to the Faculty of
Graduate Studies and Research
in partial fulfilment of the requirements
for the degree of Master of Sciences

Department of Geological Sciences
McGill University, Montréal, Quebec
Submitted June, 1992

Short Title for M.Sc Thesis of Noëlle Shriver-Dept. of Geological Sciences:

GEOCHEMISTRY OF THE ALTERATION ZONE AT THE NORBEC MINE, NORANDA, QUEBEC

ABSTRACT

A funnel-shaped alteration pipe in Archean tholeiitic to transitional rhyolite and andesite underlying massive Zn-Cu sulphide ore at the Norbec mine in northwestern Quebec was outlined from drill core samples. Geochemical parameters, including mass changes and mobile element ratios were used with normative alteration mineralogy and thin section petrography to determine the extent of the alteration. The alteration was initially characterised by a peripheral zone of sericite-chlorite-quartz and a central chlorite-quartz zone. Isochemical metamorphism of the alteration pipe within the contact aureole of the Lac Dufault stock has converted these assemblages to cordierite-anthophyllite-biotite bearing rocks.

The delineated pipe has a mass of 42.2 million tonnes and a volume of 13 x 10^6 m^3. Volume increase is 7% to 12% relative to the unaltered rhyolitic and andesitic rocks. The bulk chemical composition of the alteration pipe was calculated using "weighting" procedures and "volumes of influence" for samples and drill hole intersections. Net mobile mass change (the chemical flux) for the pipe was $+5.8 \times 10^6$ tonnes. Inclusion of the massive ore lens yields a flux of $+9.6 \times 10^6$ tonnes for the entire hydrothermal system. The largest additions to the system were (in 10^6 tonnes): FeO (+4.2), SiO_2 (+3.8), S (+1.8), K_2O (+0.55), and MgO (+0.5); the only major depletions were Na_2O (-1.4), and Ca (-0.44). Addition of Cu, Zn, Au, and Ag accounted for 3.4% of the total element flux.

Bulk oxygen isotope data for the altered rhyolite suggest that the Norbec deposit formed at temperatures between 200°C and 300°C, with highest temperatures in the central chloritic zone of the alteration pipe. Calculations using SiO_2, K and Fe solubilities in typical sea-floor hydrothermal fluids suggest that water/rock ratios of 250 to 900 were necessary to introduce the added mobile elements to the alteration pipe.

RESUME

Une cheminée d'altération en entonnoir dans des rhyolites et andesites tholéiitiques à transitionelles d'âge archéen en-dessous de minérai sulfuré massif de Zn et Cu à la mine Norbec dans le nord-ouest de Québec a été delimitée avec des carottes de forage. Des paramètres géochimiques, incluant des changements de masse et des rapports d'éléments mobiles ont été utilisés avec la minéralogie d'altération normative et la petrographie de lame mince dans le but de déterminer l'étendue de l'altération. L'altération a initialement été characterisépar une zone périphérique de séricite-chlorite-quartz et une zone centrale de chlorite-quartz. Un métamorphisme isochimique de la cheminée d'altération à l'interieur de l'auréole de contact du stock Lac Dufault a converti ces zones à des roches composées de cordierite-anthophyllite-biotite

La cheminée délimitée à une masse de 42.2 millions de tonnes et un volume de 13 x 10^6 m^3 Le volume augmente d 7% à 12% relatif aux rhyolites et andesites non-alterés. La composition chimique entiere de la cheminée d'altération a été calculée utilisant des procédés de "pesage" et "volumes d'influence" sur les échantillons et les intersections de forage Le changement net de masse mobile (flux chimique) pour la cheminée était +5.8 x 10^6 tonnes. L'inclusion de la lentille de minerai donne un flux de +9.6 x 10^6 tonnes pour le sytème hydrothermale entier Les plus hautes additions au système étaient (x 10^6): FeO (+4.2), SiO^2 (+3.8), S(+1.8), K^2O (+0.55) et MgO (+0.5); les seules baisses majeures étaient Na^2O (-1.4) et Ca (-0.44) L'addition de Cu, Zn Au et Ag consistaient de 3.4% du flux d'élément total.

Les données d'isotopes d'oxygène pour la rhyolite alterée suggèrent que le gîte de Norbec a été formé à des températures entre 200 à 300 C avec les températures les plus élevées dans la zone centrale chloritique de la cheminée d'altération. Des calcules utilisant les solubilités de SiO_2, K et Fe dans des fluides hydothermales de fond marin suggèrent que des rapport eau/roche de 250 à 900 étaient nécessaire pour introduire les élements mobiles à la cheminée d'altération.

ACKNOWLEDGEMENTS

I would like to express my gratitude to my thesis supervisor Dr. Wallie MacLean for his encouragement, ideas and criticisms and helping me to keep my confidence through the many phases of this project. I would also like to thank my thesis co-advisor Dr. Tim Barrett for his meticulous editing, fresh ideas and for always providing that reference or article I needed.

I am very grateful to Sergio Cattalani and Peter Bambic for collecting and preparing the first batch of samples used in the study so that I could start the research promptly on arriving at McGill. I also wish to express my appreciation to Gérard Riverin of Minnova Inc. for allowing us accessability to the Norbec core and mine records and the MERQ for providing support for the first year of this study.

I am greatly appreciative of the technical support I have received from; George Panagiotidis for preparing thin sections; Tariq Ahmedali for the x-ray fluorescence and LECO induction furnace analyses; Eric Hoffman from Actilab for INAA and LECO analyses, and the staff at Centre de Réchérches Minérales in Ste. Foy, Quebec for X-ray fluorescence and neutron activation analyses. I would like to thank Dr Larry Hoy for performing oxygen isotope determinations and helping to interpret the data, and Gary Nassif for translating the abstract. I am greatly indebted to Steeve McCauley for all of his computer assistance and appreciate the help of Jeff Best in putting together the final copies.

Lastly, I would like to express my appreciation to my friends at McGill who gave me encouragement as well as diversion from my thesis; and of course Wüj.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

GENERAL STATEMENT

Recent published geological work on the Norbec Cu-Zn massive sulphide deposit in the Noranda district, Quebec has been limited to brief reviews in survey articles on ore deposits in the area (e.g. Purdie 1967, Chartrand and Cattalani 1990). With improved understanding of major and trace element geochemistry and its applications, the hydrothermal alteration pipe associated with the ore zone was studied thoroughly using the immobile element methods outlined by MacLean (1990). Focus in the present study was on the Waite Rhyolite which stratigraphically underlies the Norbec deposit and has been affected most by the associated hydrothermal alteration. The Waite Rhyolite also forms the footwall to the nearby Vauze and Waite orebodies.

Hydrothermal alteration is concentrated around the pipe-like feeder zone to the overlying orebody. Fluid temperatures estimated from oxygen isotope systematics reached 200° to 300°, and water/rock ratios were as high as ~900, estimated from SiO_2, K and Fe flux. Intense leaching and fixation of elements produced alteration mineral assemblages consistent with other massive sulphide deposits in Archean terranes. These alteration assemblages have been subjected to contact metamorphism by the nearby Lac Dufault granodiorite to an anthophyllite-cordierite-biotite assemblage. Metamorphism was apparently isochemical and the geochemical analyses represent the original bulk composition of the hydrothermally altered rocks.

From this geochemical study at the Norbec Mine, the degree of alteration was evaluated and elemental mass gains and losses were calculated for individual samples. The mass change calculations were further used to define the outline of the alteration zone and to estimate closely its bulk chemical composition. The total mass and volume changes that the host volcanic units were subjected to during alteration were then calculated and total flux of each analyzed element was determined for the hydrothermal system.

PURPOSE AND METHODOLOGY

The research was part of an ongoing project initiated by the Ministère de l'Énergie et des Ressources du Québec (MERQ) to systematically re-evaluate the geology of closed mines as well as those presently operating in the Noranda area The objectives of the research were to apply recently developed geochemical techniques to major and trace element data for the host rocks to the Norbec orebody in order to determine the nature of the original rocks and to quantify the effects of hydrothermal alteration. Processing of the chemical data allowed the volume, size, mass and bulk chemical composition of the alteration zone to be determined, and the resulting volumetric and mass changes to be estimated. The chemical flux of mobile components which resulted in the formation of the alteration zone and overlying orebody was calculated and compared with similar data from the Horne mine (MacLean and Hoy 1991), the largest massive sulphide ore deposit in the Noranda district. These objectives were realised using the following procedures:

1) Samples were taken from drill core for eleven exploration drill holes that were stored at the Norbec mine site, to best obtain a group of altered and unaltered samples of the host rock units. The sampling program was somewhat hindered by lost sections of core and vandalized core boxes at outlying storage facilities.

2) Samples were cut into three portions; the first as a representative sample, the second for thin section, and the third (1 to 3cm) to be crushed and powdered for geochemical analyses.

3) 95 samples were chemically analyzed for major and trace elements using X-ray fluorescence spectrometric methods. Glass beads were used to analyze the major elements, and pressed powder pellets for trace elements (Ga, Rb, Sr, Y, Zr and Nb). A subset of samples was analyzed for REE by INAA; Cu, Zn, Pb and Ag by ICP; and S and CO_2 by the LECO method.

4) Fractionation lines were generated using incompatible element monitors for the freshest samples from the data set and supplementary samples from the nearby Ansil and Waite mine areas. Alteration lines and precursor compositions for the Waite Rhyolite and Waite Andesite were determined.

5) Mass changes were calculated using the techniques outlined by MacLean and Kranidiotis (1987) and MacLean (1990), and were used with cation normative

alteration mineral estimations to outline the extent of the alteration zone in the Waite Rhyolite. The outline of this part of the altered zone was extrapolated into the Waite Andesite and the total volume and tonnage of altered rock were calculated. The volume of the original rhyolite and andesite represented by the alteration zone were computed using immobile element relations.

6) Bulk chemical composition and net mass change were determined for the mobile elements in each unit, and the total flux of components in the hydrothermal system was calculated

7) The flux values for the Norbec system were compared with those estimated for the Horne mine (MacLean and Hoy 1991, and unpublished data of MacLean).

8) Oxygen isotope values (obtained by L. Hoy, University of Montréal) were compared with calculated values to estimate the temperature of formation of the alteration mineral assemblages

9) Water/rock ratios were estimated using the solubility of silica, K and Fe in hydrothermal fluids and the total bulk mass change of these components in the alteration pipe.

PREVIOUS WORK

The Noranda area has been the focus of base metal exploration since the discovery of the Horne Mine in 1920 (Spence 1967). The overall volcanic sequence comprises alternating andesite and rhyolite flows with minor pyroclastics.

This environment was favourable to the generation of "Noranda Type" volcanogenic massive sulphide deposits. To date, more than 90 million tonnes of ore containing copper, zinc, gold and silver have been extracted from the area, and several deposits have been recently discovered (e.g. Ansil and Mobrun mines).

The Norbec deposit was discovered in 1961 during an exploration drilling campaign by a partnership between Lake Dufault Mines Limited and Falconbridge Nickel Mines Limited. The objective of the campaign was to intersect the contact between the Waite Rhyolite and overlying Amulet Andesite, as this was considered a favourable horizon for base metal massive sulphide mineralization as seen at the Waite deposits to the west. The campaign was successful and the Norbec mine went into production in October of 1964 and operated until 1976. The exploited zones consisted of a principle stratiform massive Cu-Zn lens and a mineralized stockwork zone. A total of 4.3 million tonnes of ore were mined at 2.8% Cu, 4.7% Zn, 43 g/t Ag, and 0.9 g/t Au (Chartrand and Cattalani 1990). During the period of operation, the ore mineralogy and textures were studied by A.E Johnson as part of a Ph.D. project (1966). Geochemical studies of the deposit and surrounding rocks formed the basis of a Ph.D study by H.C. Sakrison (1967) and a M Sc project by I. Pirie (1980).

LOCATION AND ACCESS

The Norbec deposit is 15 kilometres north of Rouyn-Noranda, Quebec (Fig. 1). The Noranda area is situated on the southern margin of the Abitibi Greenstone Belt which straddles the Ontario-Quebec border.

The mine is accessible via Quebec highway 101 North from Rouyn-Noranda which is connected to the Norbec property by a paved private road. Presently, the mine is closed but the offices and mill are still in use by Minnova Incorporated.

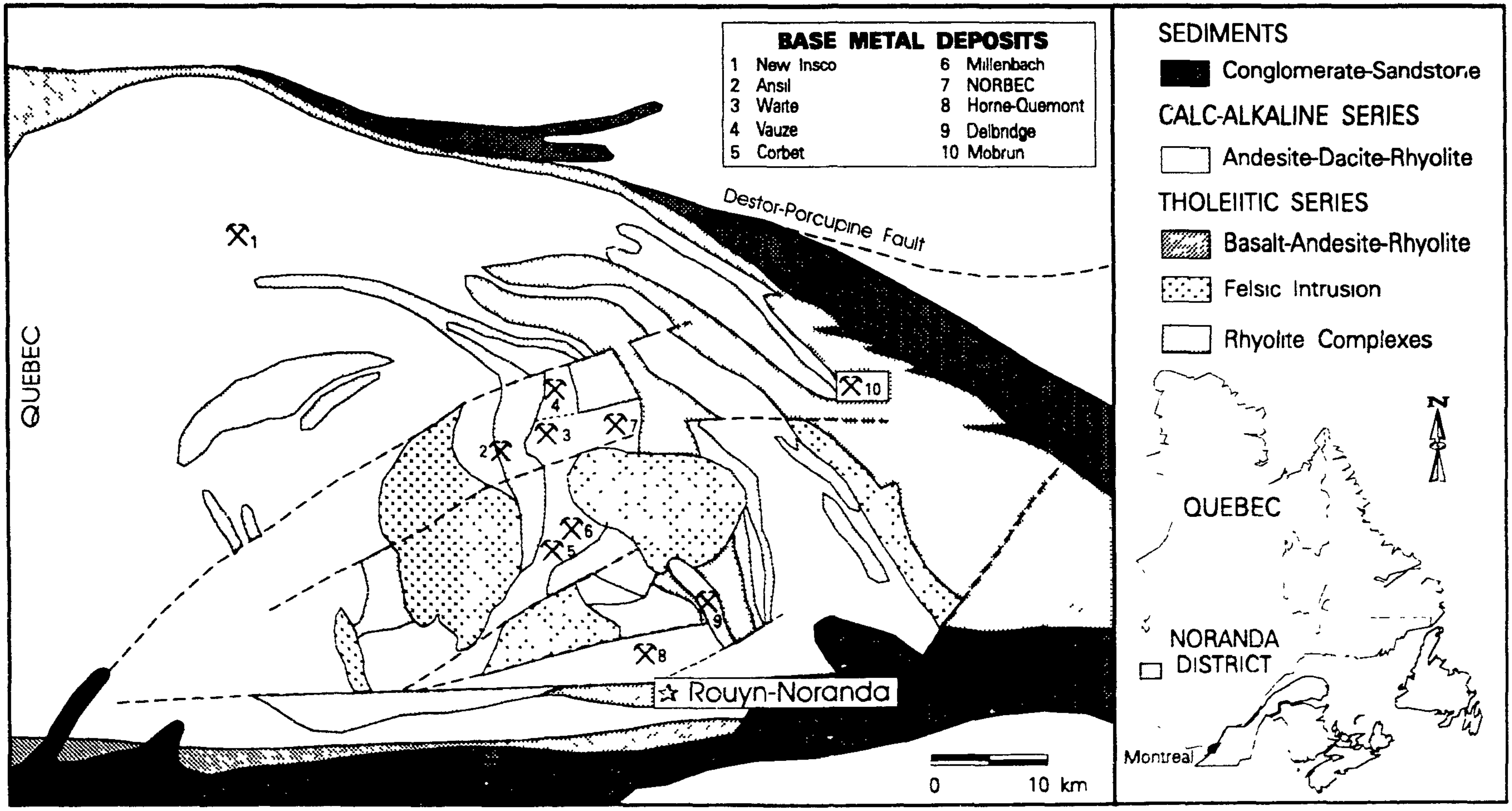

Figure 1 Location map of the Blake River Group in the province of Quebec and the base metal deposits of the Noranda district Adapted from Gelinas et al 1977 1984

CHAPTER 2: GEOLOGY

REGIONAL GEOLOGY

The volcanic stratigraphy hosting the base metal deposits of the Noranda camp is part of the Blake River Group (BRG) in the Archean Abitibi Greenstone Belt. The BRG is lensoidal in shape and straddles the Ontario-Quebec border extending from Timmins in the west, to Cadillac in the east (Goodwin 1977), and is bounded by the Destor-Porcupine Fault to the north and the Larder Lake-Cadillac Fault to the south (Fig. 1). The BRG hosts gold and massive sulphide deposits in the Timmins and Noranda areas, and significant gold deposits in the Kirkland Lake and Larder Lake districts. The BRG was folded during the Kenoran Orogeny to produce an overall configuration of an east trending syncline (Goodwin, 1977). The rocks have been regionally metamorphosed to prehnite-pumpellyite and greenschist facies (Jolly 1977). Where late-stage felsic plutons intrude the volcanic stratigraphy, lower amphibolite facies hornfels metamorphism has stabilized biotite, garnet, cordierite, hornblende, actinolite and anthophyllite. A spotted "dalmationite" rock of biotite, cordierite and anthophyllite has formed where the contact metamorphism has affected chlorite and sericite-rich rocks in the alteration zones beneath the massive sulphide deposits. Extensive diorite sills and dikes have also intruded the BRG, filling faults which may have large vertical displacements (e.g. the Dufresnoy sill).

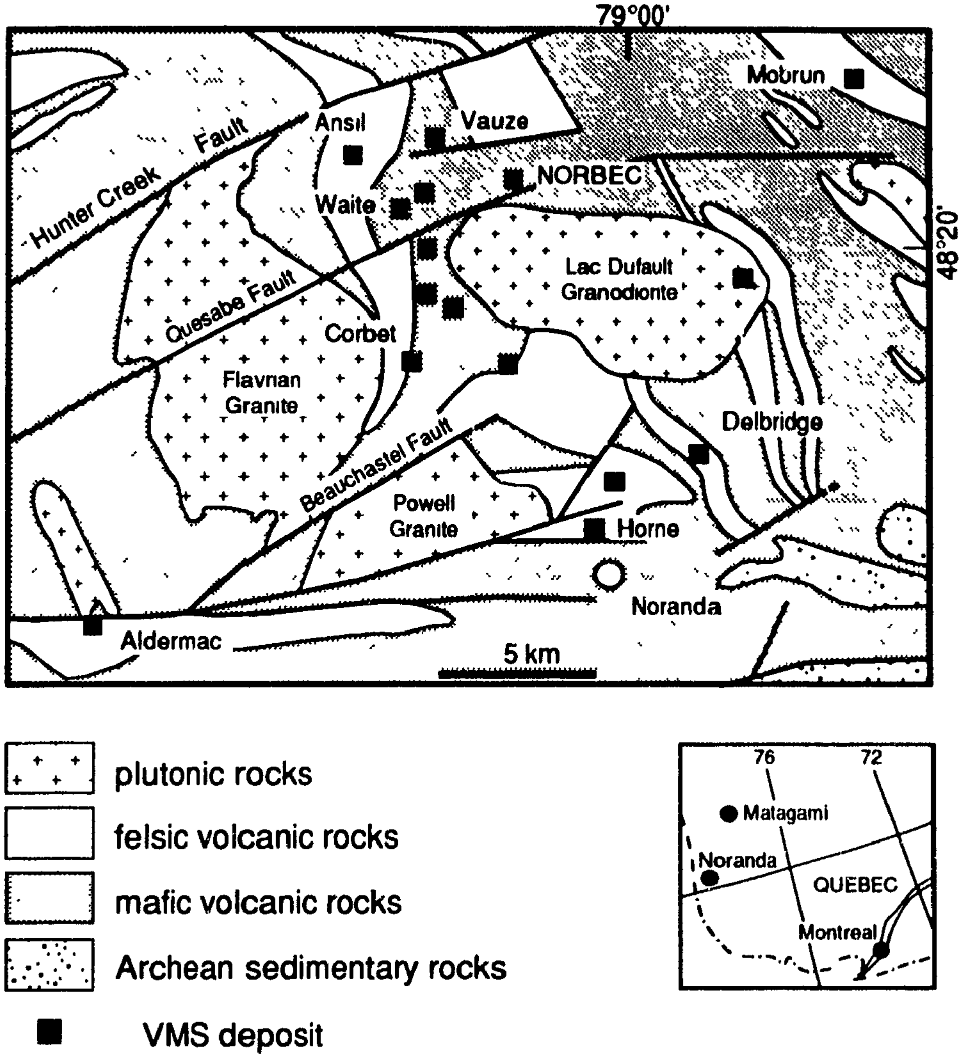

Figure 2: Location of the Norbec mine in the Central Mine Sequence, showing the general geology of the Noranda area and volcanogenic massive sulphide (VMS) deposits   Named massiv esulphide deposits are referred to in the text. Adapted from Barrett et al. (1992).

The Blake River Group is divided into four sub-groups by Goodwin (1977) according to age and chemical variations: Bowman, Garrison, Misema and Noranda. The Noranda sub-group hosts the majority of the base metal mines in the central Noranda district (Fig. 2). This sub-group is composed of sheet-like to tabular flows of basalts, andesite and rhyolite having an upward progression from tholeiitic to calc-alkaline affinities (Goodwin 1977). The sub-group has been further subdivided into five zones by Spence and de Rosen-Spence (1975) to represent primarily the major occurrences of rhyolitic formations (Fig. 3). Most of the base metal deposits, including the Norbec Mine, occur at the end of the third zone named, appropriately, the Mine Zone Gélinas et al. (1977, 1984) also sub-divided the BRG stratigraphy in the Noranda district into a series of sub-groups composed of tholeiite, calc-alkaline or mixed affinity formations.

The mafic volcanic rocks of the Noranda sub-group are pillowed to massive and occur as extensive sheets traceable for several kilometres and up to 800 metres thick. The mafic rocks range in composition from basalt to dacite with a mean in the andesite field. The rhyolites are generally tabular and up to 200 metres thick, but may also occur as domes several hundreds of metres thick. The lava flows are massive to brecciated. Pyroclastic rocks account for less than 1% of the volcanism in the Noranda sub-group (Spence 1975). The presence of pillowed andesite lava and the scarcity of sub-aerial pyroclastic material implies a subaqueous environment during the formation of the Noranda sub-group. This is further supported by the existence of volcanogenic massive sulphide deposits that form at modern submarine discharge sites of large seawater-dominated fluid circulation systems.

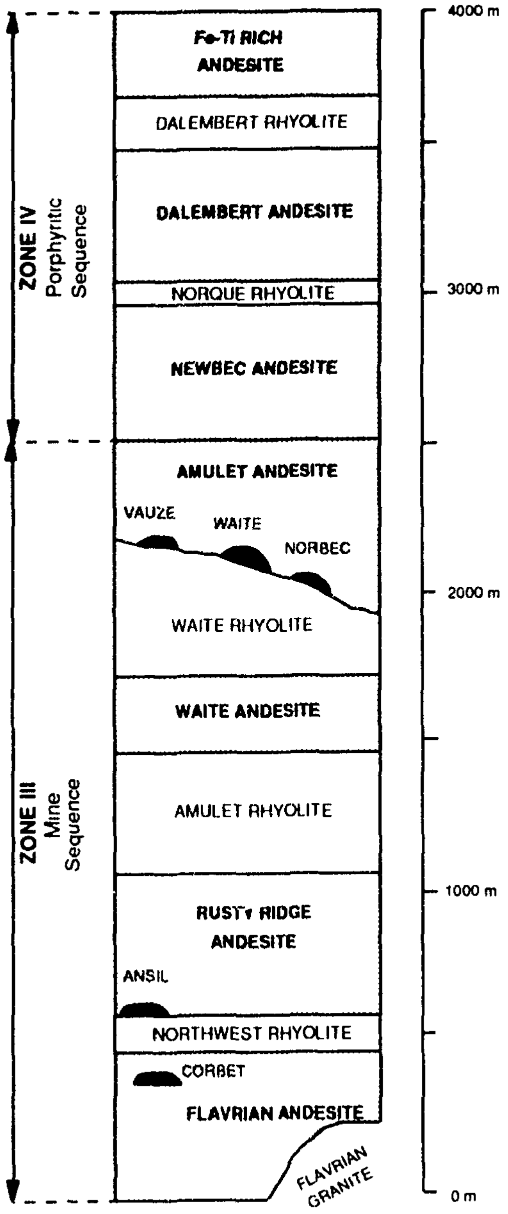

Figure 3 General stratigraphic section of the Central Mine Sequence and overlying Porphyritic Sequence showing the location of massive sulphide deposits referred to in the text Adapted from Spence and de Rosen-Spence (1975) and de Rosen-Spence (1976).

MINE GEOLOGY

The Norbec Mine lies at the contact of the Waite Rhyolite and the stratigraphically overlying Amulet Andesite (Fig. 3). Alteration extends below the ore horizon through the rhyolite and into the underlying Waite Andesite. Alteration is not seen in the hangingwall Amulet Andesite, indicating that hydrothermal processes ceased before its extrusion. A thin (<5m) tuffite bed is closely associated with the ore horizon and is found elsewhere on the Norbec property at the Amulet Andesite / Waite Rhyolite contact. This section of stratigraphy is present at the neighbouring Waite Mine to the west, but has been displaced by a normal fault occupied by the 500m thick Dufresnoy gabbro-diorite dyke (Fig. 4) The Norbec stratigraphy has been intruded by several late stage dykes and sills that crosscut the alteration zone, and in some instances, the massive sulphide orebody. These intrusives range in composition from felsic to gabbroic, and are generally less than 10m thick (Fig. 4).

Waite Andesite

The Waite Andesite stratigraphically underlies the Waite Rhyolite at the Norbec mine. In this area its thickness is greater than 770m (Purdie, 1967). The unit is composed of pillowed and massive flows that are variably feldspar porphyritic, with a medium grained groundmass of acicular feldspar, interstitial mafic minerals and quartz. Both pillowed and massive units are variably amygdaloidal with fillings of quartz, epidote and calcite. In the vicinity of the mine,

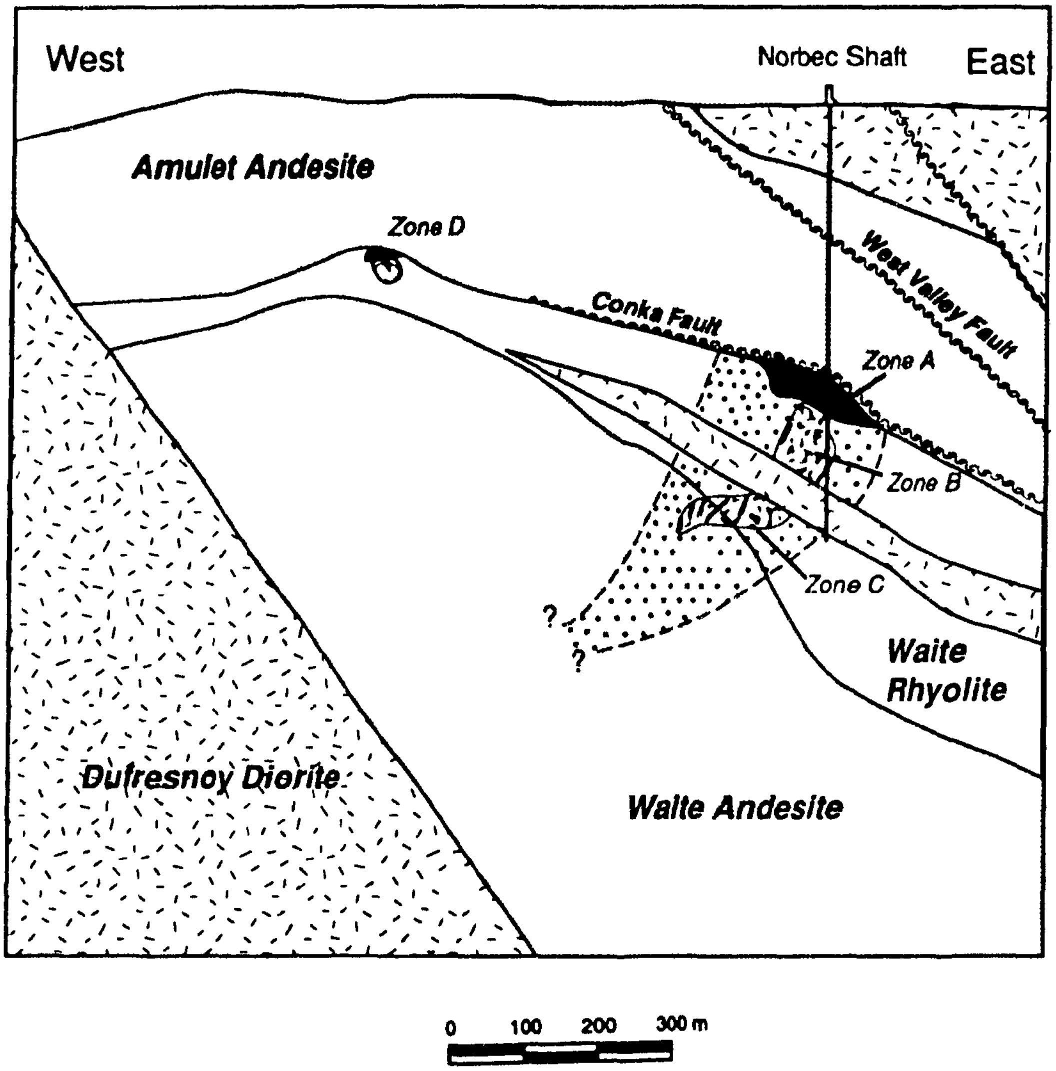

Figure 4 Vertical east-west section showing a schematic outline of the main Norbec ore lens and associated stringer ore, and the satellite Zone D orebody. Dotted lines represent the suggested outline of the alteration zone, stippled units are diorite sills. Adapted from Bancroft and Atkinson (1987).

the Waite Andesite has been moderately to strongly affected by hydrothermal alteration that formed a sericite-chlorite assemblage which was later metamorphosed to cordierite-anthophyllite-biotite.

Waite Rhyolite

The Waite Rhyolite stratigraphically underlies the Amulet Andesite and the Norbec massive A Zone, and hosts the stringer B and C Zone ore. The unit is ~200 metres thick in the mine area and thickens to the east to 300 metres or more. The rhyolite is generally massive, but in the vicinity of the mine it consists of ~25% breccia units and minor bedded tuff. In this area the rhyolite is strongly altered. Least altered samples were obtained only from drill holes more than 1km from the mine.

Fresh Waite Rhyolite is generally porphyritic with albitic phenocrysts up to 2mm across; quartz phenocrysts are absent. Occasionally, albite phenocrysts are broken in the tuffaceous units. Quartz albite spherulites were rarely observed; they were presumably derived from devitrification of glassy parts of the rhyolite. The rhyolite groundmass is a fine grained mosaic of quartz and albite with minor chlorite and sericite. Altered and metamorphosed Waite Rhyolite is composed of an assemblage of quartz-biotite-anthophyllite-pinite-chlorite-sericite-garnet with rare relict albite phenocrysts. Generally, these metamorphosed altered rocks are coarse grained and contain disseminated and stringer-type pyrite and chalcopyrite.

The Norbec Orebody

The Norbec orebody lies ~400 metres below surface and consists of a main stratabound lens (A Zone) with an underlying discordant stringer ore zone (B and C Zones) (Fig 3). The main ore lens measures 200m by 120m, attaining a maximum thickness of 45m. The feeder pipe extends downward more than 500m at an angle of 80° to the southwest, with a diameter in the Waite Rhyolite of ~120m. The stringer and disseminated ore in Zone B and C is concentrated in the centre of the alteration pipe and extends 75m below the massive sulphides in the A Zone. A 50m diorite sill cuts the stringer zone 110m below the massive ore lens. A smaller satellite massive ore lens (D Zone) occurs 600m southwest of the main orebody on the same stratigraphic horizon, but was not mined.

The Norbec deposit comprised over 4.3 million tonnes of massive sulphide and stringer ore grading 4.7% Zn, 2.8% Cu, 43 g/tonne Ag and 0.9 g/tonne Au; this includes mined ore and a small amount of reserves. The mineralogy of the massive ore was estimated by Johnson (1966) to be 30% pyrite, 20% sphalerite, 15% chalcopyrite and 11% pyrrhotite, with accessory magnetite and trace galena. Silicates (mainly quartz, with minor chlorite and sericite) and carbonate account for 20% of the massive ore horizon and are generally interstitial to the sulphides. The ore and gangue minerals have been largely recrystallized during contact metamorphism. Chalcopyrite is concentrated in the lower portion of the massive ore lens and in the underlying stringer B Zone ore. Sphalerite is concentrated higher up and near the margins of the massive sulphide pile, and as a disseminated peripheral halo to the copper-rich stringer B Zone. Layered sphalerite-pyrite-pyrrhotite ores occur at the top of the massive ore lens (Sakrison 1967), whereas the rest of the orebody is generally structureless except for later shearing. The B Zone is generally composed of altered rhyolite with chalcopyrite stringers that decrease in abundance and size with depth.

The Contact Tuff

The Norbec orebody is on the same stratigraphic horizon as the Contact Tuff and the massive ore lens grades into the tuff at its margins The tuffite is associated with at least six massive sulphide deposits and is generally continuous throughout the Central Noranda district. It is a heterogeneous and thinly banded unit consisting of fine layers of tuff with cherty layers containing up to 20% sulphides. Pyrite and pyrrhotite are the most common sulphides, but chalcopyrite and sphalerite may also be present. The Contact Tuff varies in thickness from a few centimetres to 5m near the Norbec orebody (Sakrison 1967). The tuffite has a sharp contact with the overlying andesite but is generally gradational with the underlying Waite Rhyolite (Sakrison 1967). In some areas, intense shearing has occurred along the tuff-rhyolite contact and has strongly tectonized the tuffite.

Amulet Andesite

The Amulet Andesite stratigraphically overlies the Norbec orebody. The unit attains a thickness of 800 metres and outcrops in the mine area. It is pillowed to massive, commonly amygdaloidal, generally plagioclase porphyritic, and is intruded by diorite and diabase dikes. Outside the alteration zone, the andesite consists of albite-hornblende-epidote-chlorite-quartz. The plagioclase phenocrysts are tabular to thin and elongate up to 5mm.

STRUCTURE AND METAMORPHISM

The Norbec deposit is within a fault bounded block with a surface area of approximately 5km^2 defined by the Vauze Creek Fault to the north, the Waite Fault to the south, and a fault occupied by the Dufresnoy Diorite to the west (Bancroft and Atkinson 1987). Smaller sills and faults to the east of the deposit may define this margin of the block. The stratigraphy within the block strikes 330° and dips 20° to the scutheast. The deposit itself is relatively undeformed, although two small thrust faults intersect the orebody at low angles. The Conka Fault slices off the top 15m of the orebody and has ~30m of displacement to the east, while the Norka fault intersects the northwest margin of the massive sulphides with little displacement (Purdie, 1967).

The regional metamorphic grade is in the prehnite-pumpellyite to greenschist facies, which stabilizes prehnite, pumpellyite, albite, actinolite, chlorite, sericite and epidote. The late-stage Lac Dufault granodiorite pluton to the south has metamorphosed the rocks within a 1km contact aureole to the hornblende hornfels facies, stabilizing biotite, actinolite-hornblende, andalusite, garnet, cordierite and anthophyllite. The contact metamorphism has increased the grain size of the rocks to an average of 1 to 5mm, but retrograde reactions have altered the cordierite to a fine-grained mixture of chlorite and sericite called pinite, which has pseudomorphed the roundish grains. In the alteration zone, pinite pseudomorphs of cordierite in a groundmass of anthophyllite and biotite give the rocks a spotted texture referred to as "dalmationite". Dalmationite is present in much of the Waite Rhyolite at Norbec, and also in the underlying Waite Andesite, and has been reported at other mines within the contact aureole of the Lac Dufault granodiorite (e.g. Millenbach, Riverin and Hodgsen 1980, Knuckey et al. 1982a; Vauze, Lickus 1965; Amulet, Hall 1982; Corbet, Knuckey et al. 1982b). Strongly metamorphosed VMS deposits at Montauban in the Grenville Province also contain dalmationite which is indicative of syngenetic chlorite-sericite alteration zones (Bernier et al. 1987). Hall (1982), and Riverin and Hodgsen (1980) have studied deposits within the contact aureole of the Lac Dufault stock and consider the metamorphic process to have been isochemical.

CHAPTER 3: GEOCHEMISTRY AND ALTERATION

INTRODUCTION

Samples of the three main lithologies hosting the Norbec orebody and associated tuffite, dykes and sills were taken from eleven drill holes throughout the area of the deposit (Fig. 5). The samples were used for petrographic studies, geochemical calculations, and for the determination of the normative alteration mineral assemblage. Freshest samples of the host stratigraphy to the orebody were selected further away from the alteration pipe, and used to construct fractionation lines for the major and trace elements. These formed the basis for determining the composition of the precursors to the altered samples. Mass changes and normative mineral assemblages were used to determine the extent of the alteration zone beneath the massive orebody. The bulk chemical composition and mass change in the alteration zone were determined, and the total volumetric change resulting from alteration was calculated.

ANALYTICAL TECHNIQUES

Samples were crushed with a jaw crusher followed by grinding to -200 mesh. The rock powders were chemically analyzed at the Centre de Récherches Minérales in Sainte-Foy, Québec and at the Geochemical Laboratories of McGill

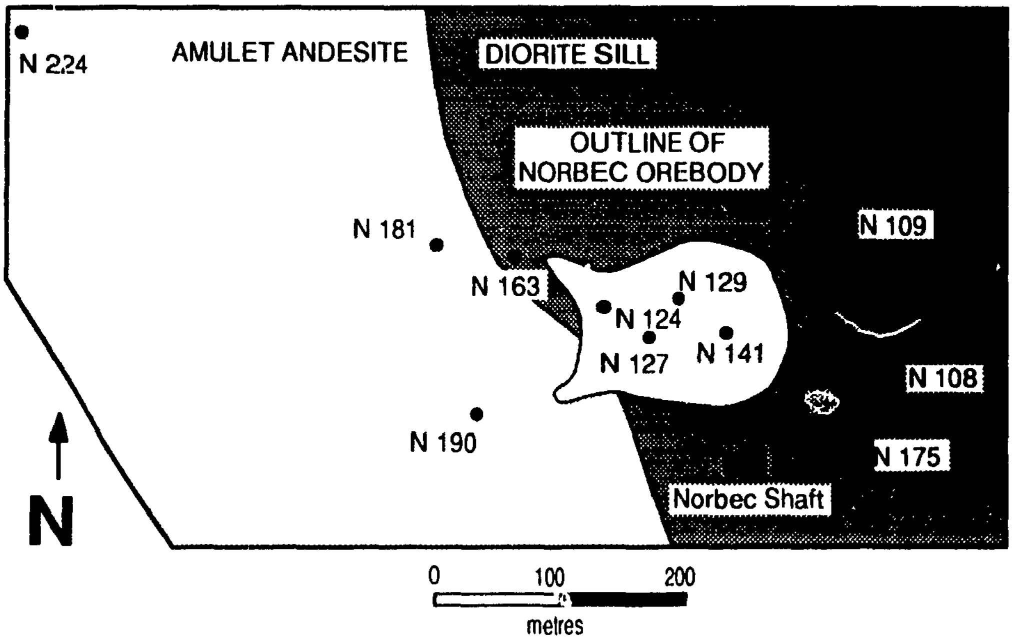

Figure 5. Surface projection of the Norbec orebody and location of surface diamond drill holes used in this study Surface mine geology is shown

University, Montreal, Quebec. Major elements were determined by X-ray fluorescence (XRF) using fused beads prepared from the rock powders. The trace elements Rb, Sr, Y, Zr and Nb were analyzed by XRF using pressed pellets of the rock powders. Detection limits for the major elements was 0.01% and 5ppm for the trace elements. Copper and zinc analyses along with several CO_2 and sulphur analyses were carried out by Activation Laboratories Ltd. in Ancaster, Ontario. Other CO_2 and SO_3 analyses were carried out by the Geochemical Laboratories of McGill University. The LECO method was used to determine the concentrations of these elements with detection limits of 0.02% for CO_2, and 10 ppm for SO_3. Rare earth element concentrations were determined using neutron activation analyses at the Centre de Récherches Minérales on representative samples of the volcanic rocks associated with the Norbec orebody. Dr. L. Hoy carried out oxygen isotope analyses on 23 samples of the fresh and altered units at the Geotop Laboratory at the University of Montreal.

GEOCHEMICAL CLASSIFICATION OF STRATIGRAPHY

Host Volcanic Rocks

Least altered volcanic rocks in the mine stratigraphy (Table 1) belong to a low-K bimodal suite common to Archean greenstone belts (Fig. 6). Mafic volcanic rocks, termed andesites in the Noranda district, cover a compositional range from basalt to andesite, whereas the felsic volcanic rocks have a much narrower range within the rhyolite field. The Amulet Andesite varies from basalt to basaltic-andesite on a K_2O versus SiO_2 classification plot, suggesting some inhomogeneity (Fig. 6).

	Amulet Andesite		**Waite Rhyolite**	**Waite Andesite**
DDH	N181-1010	N129-1222	N175-1543	N224 992
wt%				
SiO_2	54 70	51 00	75 02	58 90
TiO_2	1 63	1 21	0 27	1 26
Al_2O_3	16 10	16 70	11 87	14 60
FeO	8 89	9 86	3 11	9 14
MnO	0 21	0 38	0 02	0 24
MgO	4 84	4 69	0 12	3 99
CaO	7 77	10 70	1 00	5 34
Na_2O	4 95	3 90	6 01	4 53
K_2O	0 29	0 27	0 52	0 43
P_2O_5	0 30	0 10	0 02	0 17
LOI	0 80	1 75	1 77	0 78
SUM	100 48	100 56	99 73	99 38
ppm				
Ga	15	16	15	
Nb	6	5	17	7
Rb	6	10	17	13
Sr	220	140	38	120
Y	23	17	52	28
Zr	110	84	273	120

Table 1 Chemical composition of some representative least altered samples of volcanic host rocks at the Norbec Mine

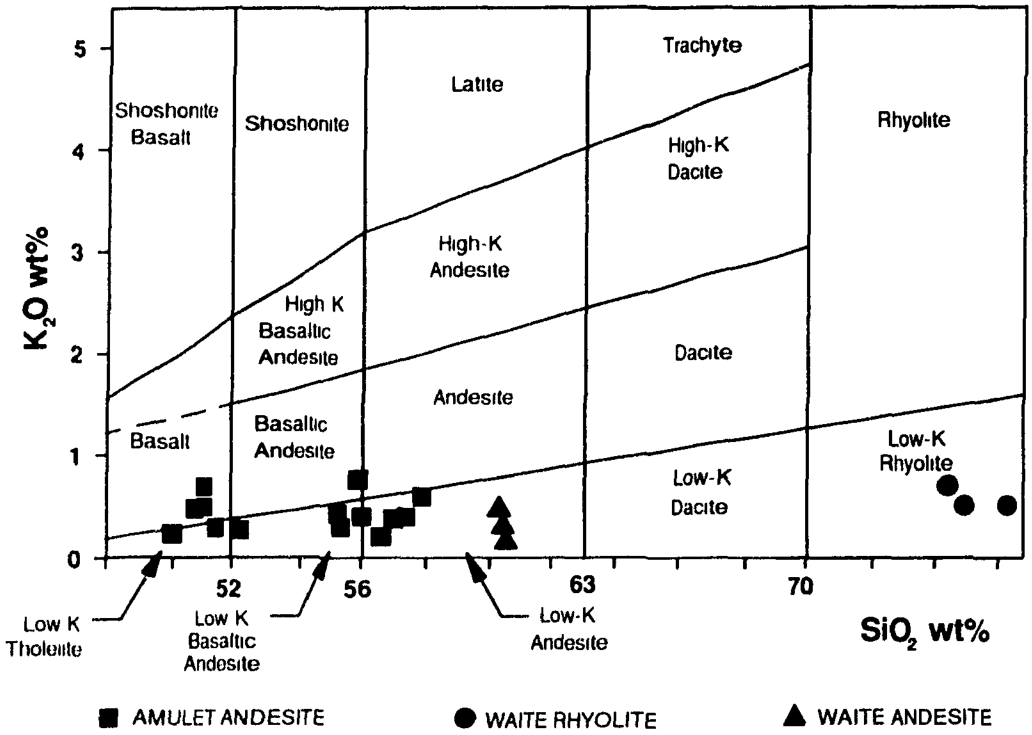

Figure 6: Diagram of K2O versus SiO2 showing the fields of volcanic lithologies, after Peccerillo and Taylor (1976). Only least altered samples are indicated.

The Waite Rhyolite is generally mineralogically homogeneous below the orebody although its morphology changes from flows to breccia Geochemically, the least altered rhyolite has low Ti and highly concentrated high field strength (HFS) elements (Nb, Zr, Y). Hydrothermally altered rhyolite generally shows enrichment in silica, potassium and magnesium, loss of sodium and frequently loss of calcium. Least altered samples were selected on the basis of a $K_2O/(K_2O+Na_2O)<20$ (sericitization index) along with SiO_2 and LOI values typifying a rhyolite. The Waite Andesite is a chemically homogeneous andesite unit, but is variably plagioclase porphyritic.

The geochemistry of the Main Contact Tuff is variable, generally ranging in composition between the Amulet Andesite and the Waite Rhyolite (Appendix I), but not falling on fractionation lines. The tuffite is characterized by low sodium, high potassium and high LOI, with the bulk of the LOI due to sulphur

A number of HFS elements (Zr, Y, Nb, REE) exhibit regular concentration from mafic to felsic units due to their incompatibility during magma differentiation This phenomenon is characteristic of suites of tholeiitic magmatic affinity, and allows the HFS elements to be used to establish fractionation profiles. In calc-alkaline suites, HFS elements are generally compatible and cannot be used to generate fractionation lines.

The three volcanic formations hosting the Norbec orebody and alteration pipe have very similar flat REE profiles (Fig. 7) with La_N/Yb_N ratios of 1.15 to 1.25, and incompatible element Zr/Y ratios of 4 to 6. These data characterize the rocks as having affinities that are tholeiitic to transitional (between tholeiite and calc-alkaline) (Bonavia and MacLean 1986, Lesher et al. 1986, MacLean and Barrett in review). Because the HFS elements are consistently incompatible from basalt to rhyolite in the Norbec rocks (Cattalani et al. 1992), it is possible to use them to establish fractionation lines, alteration lines, and calculate mass changes.

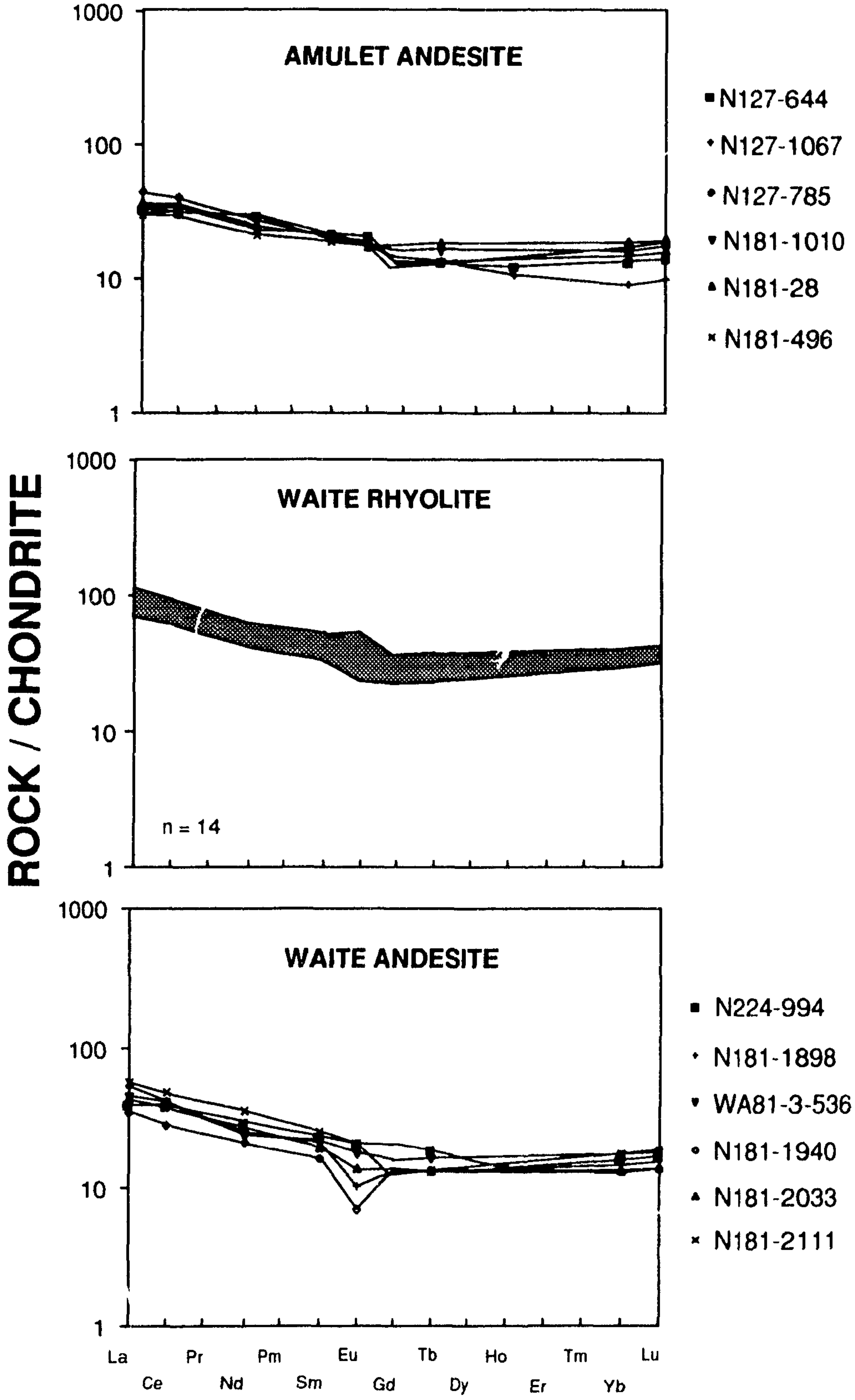

Figure 7 Plots of rare earth element distributions normalised to chondrite (Evensen et al 1978) for least altered samples of Amulet Andesite, Waite Rhyolite, and Waite Andesite.

PRECURSOR COMPOSITIONS OF THE HOST ROCKS

Hydrothermal alteration associated with the Norbec orebody is strongest in the Waite Rhyolite, but also affects the underlying Waite Andesite. The dominant pre-metamorphic normative alteration mineralogy (albite, quartz, sericite, chlorite) is similar to that of other Noranda-type volcanogenic massive sulphide deposits. There is no evidence of petrologic or compositional zoning that would signify mass transfer of material within or across the contact metamorphic aureole.

The mass changes and chemical flux that occurred during the alteration process are the differences between the chemical compositions of the original (least altered) volcanic units and the reconstructed composition of the alteration zone. The determination of the precursor composition and resulting mass change of a unit depends upon the immobility of elements which are used as a fractionation monitor for the suite. Immobility can be shown with x-y plots of two elements using both fresh and altered samples of a unit. A regression line of $r > 0.90$ for the data set and passing through the origin implies a constant ratio of the elements throughout alteration, and therefore, their immobility in contact with hydrothermal fluids.

Fractionation Trends

Fractionation lines for the Mine Sequence (Fig. 3) were established using least altered samples from the Norbec area, and supplementary data from the nearby Ansil Mine, Corbet Mine, and a deep drill hole (WA 81-3) located 5km west of Norbec. The incompatible HFS element Zr was used as a monitor of fractionation; other incompatible elements (e.g. Y, Nb, Hf) may be used, but Zr is more abundant and most accurately analyzed. The fractionation monitor is paired with a compatible immobile element such as Al or Ti to produce well constrained fractionation trends at high angles to alteration lines; this allows mass changes to be subsequently calculated (MacLean 1990, MacLean and Barrett in review). For the Norbec data, Al_2O_3-Zr produced a well defined fractionation line with r = 0.96 (Fig. 8A), and was used as the basis to calculate mass changes. The high regression coefficient for the line indicates that these units were derived by fractionation from a single magma chamber.

Alteration Line

Samples of Waite Rhyolite within the alteration zone produce a highly correlated (r = 0.98) alteration line that intersects the Al_2O_3-Zr fractionation line and passes near the origin (Fig. 8B). This verifies that Al and Zr were immobile during alteration (MacLean and Kranidiotis 1987). The regression line produced by TiO_2 versus Zr (r = 0.96) demonstrates that Ti also was immobile in this hydrothermal system, and confirms the immobility of Zr. The high degree of correlation of data to the regression line also demonstrates that the Waite Rhyolite was initially homogeneous. The altered samples project to a very narrow sector of the fractionation line that coincides with the locations of the three least altered samples of rhyolite.

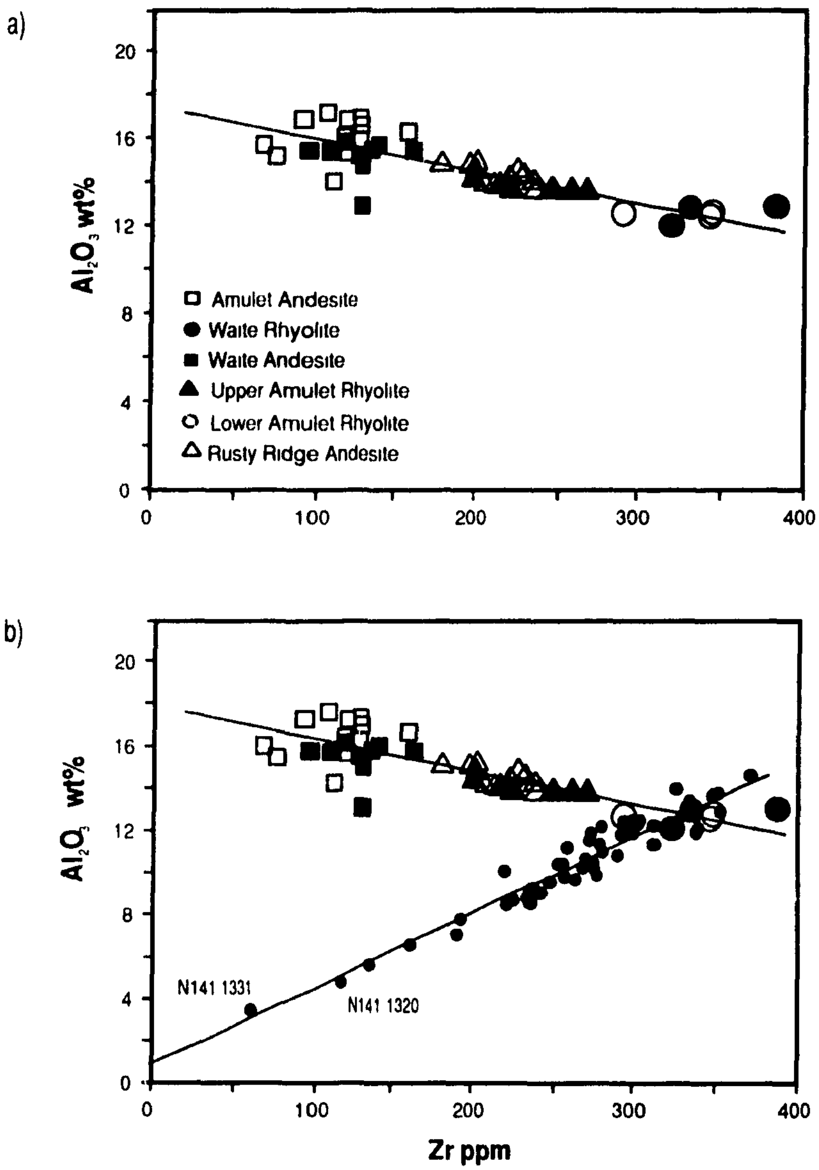

Figure 8 a) Al2O3 versus Zr fractionation trend in the least-altered rocks from the Norbec, Waite, and Ansil areas, using Zr as a fractionation monitor. Equation of the regression line is y=-0.16x+18, r=0.96, n=45. Several stratigraphic units of the Central mine Sequence are represented.

b) Intersection of the alteration line of the Waite Rhyolite (small closed circles) with the fractionation line in a). Altered samples of the Waite Rhyolite forms a linear trend that extends from near the origin through the precursor rhyolite composition. Equation of the line is y=0.037x+0.80, r=0.98, n=48

Immobile elements have been residually concentrated in altered samples that plot above the Al_2O_3-Zr fractionation line, owing to the loss of mobile components during alteration (MacLean 1990). Mass loss commonly occurs during chloritization and sericitization, which often results in the leaching of silica, Na and Ca. Samples plotting below the fractionation line have experienced mass addition resulting from silicification and mineralization, which has diluted the concentration of the immobile elements at a constant ratio. For example, sample N141-1331 on Figure 8B is from the stringer ore zone and has the lowest Zr content (61 ppm). It plots on the alteration regression line defined by the Waite Rhyolite data set. The immobile elements in this sample have been diluted by the addition of silica and sulphides. By contrast, elements that are mobile during alteration plot randomly against Zr with very low or negative r-values

Precursor Composition

The intersection of alteration and fractionation lines derived from an immobile element pair yields the composition of the precursor of the altered volcanic unit (Fig. 8B); high r-values for these lines indicate an initially narrow compositional range. Least altered samples of the Waite Rhyolite (n=3) plot at the intersection of the alteration and fractionation lines, and were averaged to approximate the original bulk composition. The composition of the Waite Andesite was also estimated by this method. These precursor compositions (Table 2) were used to compute mass changes during the alteration process

	Waite Rhyolite	**Waite Andesite**
SiO_2	76 18	59 76
TiO_2	0 29	1 27
Al_2O_3	12 25	14 79
FeO	3 80	9 25
MnO	0 04	0 24
MgO	0 51	4 05
CaO	0 51	5 42
Na_2O	5 75	4 58
K_2O	0 63	0 43
P_2O_5	0 03	0 17
SUM	100	100
Zr	313	120

Table 2 Precursor compositions of the hosting volcanic rocks used in mass change calculations THe precursor composition of the Waite Rhyolite was determined from the intersection of the alteration line with the fractionation line (Fig 8A), and the average of the least altered samples (n=3) The precursor composition of the Waite Rhyolite was determined by averaging the least altered samples (n=10)

MASS CHANGES

Geochemical studies of alteration zones associated with volcanogenic massive sulphide deposits in the Abitibi Greenstone Belt (Phelps Dodge, MacLean and Kranidiotis 1987; Horne, Cattalani et al. 1990, MacLean and Hoy 1991; Ansil, Barrett et al. 1991; Delbridge, Barrett et al. 1992a; Corbet, Barrett et al. 1992b) indicate that Al, Ti, Zr, Nb and Yb are immobile during hydrothermal alteration. Mass change calculations (Fig. 9) are based on the differences in concentration of immobile elements between an altered sample and its precursor (Table 2). In Figure 9, the immobile elements in the altered samples are normalized to their original proportions, and the contents of the mobile elements are readjusted by the same factor to obtain the "reconstructed composition" (RC) (Appendix II):

$$R\,C = \left(Zr_{fresh} / Zr_{altered} \right) \;X\; \text{wt\% of } Oxide_{altered} \qquad \text{Equation 1}$$

These reconstructed compositions reflect the actual mass of the altered rocks.

Mass Changes = Precursor Composition - RC   Equation 2

The differences between reconstructed and precursor compositions constitute the mass changes incurred during alteration and show the additions and depletions of mobile elements (Table 3) .

	Precursor wt%	**Altered sample N141-1320**	**R C**	**Mass Change**
SiO_2	76.18	55.26	126.8	50.6
TiO_2	0.29	0.12	0.28	0.0
Al_2O_3	12.25	5.66	13.0	0.7
FeO	3.80	22.34	51.3	47.5
MnO	0.04	0.09	0.21	0.2
MgO	0.51	2.61	6.0	5.5
CaO	0.51	0.49	1.1	0.6
Na_2O	5.75	0.22	0.5	5.2
K_2O	0.63	0.04	0.09	-0.5
P_2O_5	0.03	0.02	0.05	0.0
Cu	0.00	2.29	5.3	5.3
Zn	0.00	1.39	3.2	3.2
S	0.00	7.20	16.5	16.5
CO_2	0.00	2.26	5.2	5.2
SUM	100.00	100.00	229.4	129.4
Zrppm	313	136	313	0

E F = 313 / 136 = 2.29

Table 3 An example of mass changes in the Waite Rhyolite beneath the Norbec orebody. The precursor composition is from Table 2. R C is the reconstructed composition, and E F is the enrichment factor = $Zr_{fresh}/Zr_{altered}$

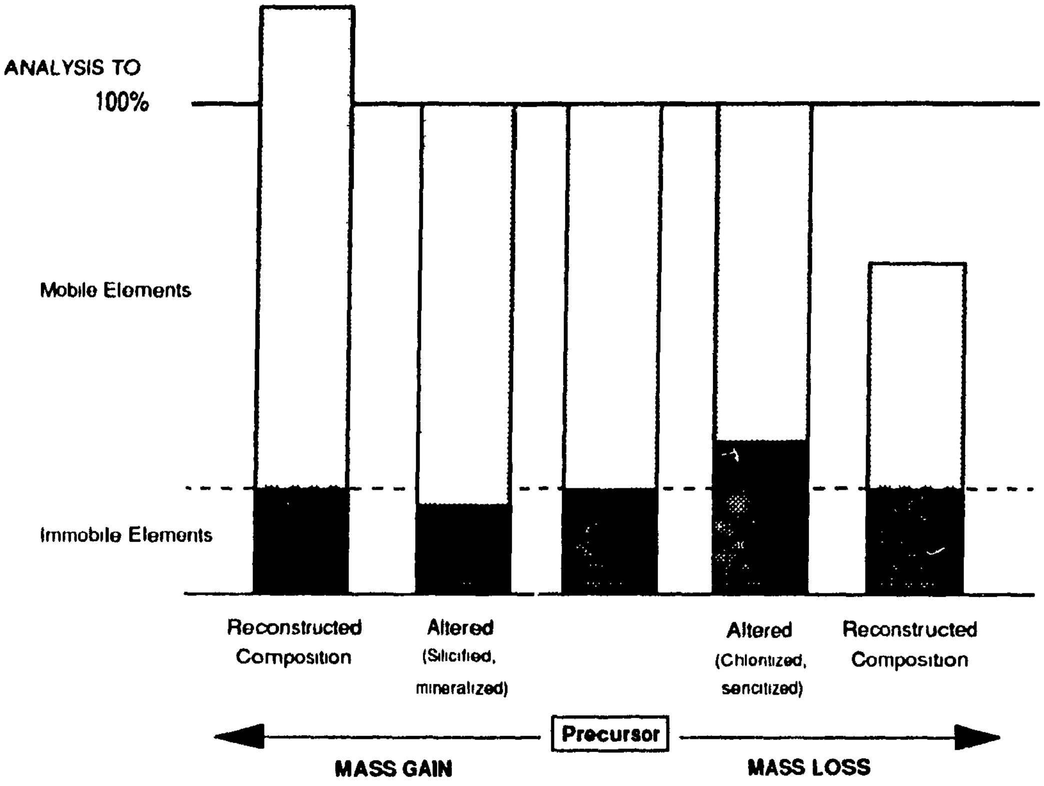

Figure 9· Schematic diagram illustrating the method used to calculate mass changes for an altered rock. The middle column represents the unaltered (precursor) rock with a geochemical composition normalised to 100% (less LOI). The columns to the left and right of the precursor represent chemical analyses of the altered rocks which have gained or lost mobile elements (grey zone). The outer two columns represent reconstructed composition of the altered rocks after normalizing the immobile elements (dark zone) to their original contents Modified from MacLean (1990).

Immobile elements and mass changes can be used to measure the severity of alteration. From initial inspection, sample N141-1320 (Table 3) from below the orebody has SiO_2 (55.26 wt%) and Zr (136 ppm) values more typical of a basalt than a rhyolite. However, TiO_2 and Al_2O_3 are very low (0.12 wt% and 5.66 wt%, respectively) and position this sample on the alteration line of the Waite Rhyolite (Fig. 8B). The reconstructed composition (Table 3) reveals that the sample has had large additions of S (as sulphides), silica, Fe and Mg, while Na and K have been removed. These changes are typical of the centre of an alteration pipe.

The reconstructed composition and mass changes for the entire alteration zone have been calculated using a combination of data from individual samples. The samples were "weighted" for "volume of influence" and density according to their distribution in the alteration zone, the geometry of which was then outlined in detail to obtain accurate estimates of these parameters (see below)

DELINEATION OF THE ALTERATION ZONE

The extent of alteration below the Norbec orebody was delineated using petrography, normative alteration mineralogy, loss of Na_2O, K_2O/K_2O+Na_2O (sericitization index), loss on ignition and mass changes On initial inspection, samples were considered to lie within the alteration zone if they showed significant bulk chemical change from the precursor composition by factors >1 7 in K_2O, CaO, and MgO; >1.5 in Na_2O and FeO; and >1.1 in SiO_2 and Zr. Samples were designated as "altered" using these chemical parameters and the requirement that at least one-third of the albite was converted to normative sericite and chlorite.

Normative Alteration Mineral Assemblage

Normative minerals (in cation %) were computed to estimate the amounts of hydrothermal alteration minerals formed prior to contact metamorphism (Appendix II). The minerals quartz, albite, sericite, chlorite, epidote, calcite and with relict rutile represent the typical hydrothermal alteration assemblage associated with Noranda-type massive sulphide deposits. Where sulphur analyses were available, sulphide minerals were added to the normative assemblage. The normative alteration mineral assemblage also was used in determining the calculated δO^{18} values. An igneous normative mineral assemblage was determined for the precursor rocks to calculate the volume change during alteration.

Least altered samples of Waite Rhyolite, from beyond the periphery of the alteration pipe, are composed primarily of ~55% normative albite, ~35% quartz and ~10% mafic minerals. These minerals were seen in the thin sections of the unmetamorphosed samples. A vague zoning of normative alteration minerals is apparent in the pipe, with chlorite and sulphides concentrated at the centre and sericite at the periphery. The amount of quartz increases in the alteration zone due to the breakdown of albite to quartz-sericite-chlorite assemblages, and also to a net introduction of silica as calculated from mass changes. This added silica defines a pod, or sub-zone, of altered rhyolite enriched in quartz and stringers of sulphides in the centre of the alteration zone. Other areas of silica enrichment occur primarily at the margin of the pipe in the sericite-quartz zone. The zonation of the alteration minerals encountered at the Norbec mine is, except for the central pod of silica, typical of other deposits in the Noranda district.

VOLUME AND MASS OF THE ALTERATION ZONE

The volume of altered rock was outlined using six diamond drill holes in the core of the pipe, and five holes between the core and periphery. Alteration is most extensive in the Waite Rhyolite just below the orebody, but also extends into the underlying Waite Andesite where it becomes less intense and diffuse with depth. The most complete data coverage is restricted to the rhyolite, as only a few drill holes penetrated the altered Waite Andesite. The Waite Rhyolite is ~200 m thick below the orebody, excluding a 50m thick sill of unaltered and unmineralized diorite in the lower portion of the unit. The sill has been excluded in the calculations of volume and mass.

The upper and lower (-200 m) surfaces of the alteration zone in the rhyolite are approximately oval in outline (Fig. 10A). In three-dimensions, this part of the pipe approximates a frustum of a cone (Fig. 10B). From its dimensions and shape, the zone of altered Waite Rhyolite was divided into a series of prisms and a central polyhedron having a combined volume of 8.08×10^6 m^3 The volume approximated as a frustum of a cone was slightly larger (~10%), but this method does not allow for irregularities in detailed pipe outline. The density of the altered rhyolite averaged 2.85 g/cm^3 ($\sigma = 0.05$) from weight/volume measurements on core samples, and 2.91 g/cm^3 ($\sigma = 0.16$) from normative mineral percentages and mineral densities. The mean of these two density estimates, 2.88 g/cm^3, yielded a mass of altered rhyolite of 23.3 million tonnes.

Due to the lack of holes penetrating the Waite Andesite, sampling of this unit was limited. The lower portion of the alteration zone, therefore, was assumed to have a conical shape (cf. Lydon 1984, 1988; Franklin et al. 1981), extending downward from the base of the altered Waite Rhyolite (Fig. 11). The extrapolated apex of the cone is 550 m below the orebody, including the 50m thick sill. Given the measured density of 2.97 ($\sigma = 0.20$), and a volume of 4.92×10^6 m^3, the mass of altered Waite Andesite is 14.6 million tonnes.

The total volume of the alteration pipe thus is $13.0 \times 10^6 m^3$ with a mass of 37.9 million tonnes. This volume is ~1/500 the size of the Horne mine (Fig. 1:8) alteration zone which was estimated at 5km^3, including the H and #5 ore zones, alteration in the hanging wall, and restored faulted segments (MacLean and Hoy 1991).

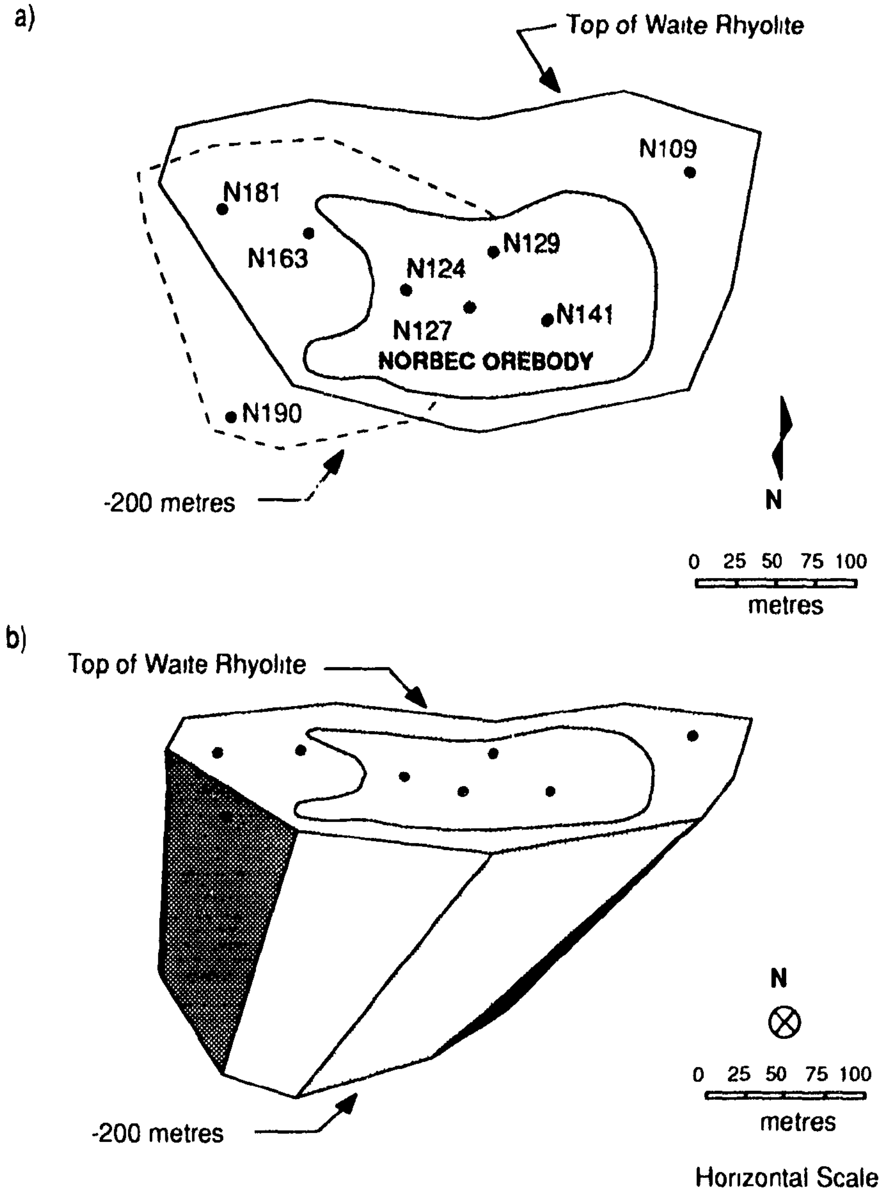

Figure 10. a) Outline of the upper and lower (-200m) extension of the alteration zone within the Waite Rhyolite as delineated from the surface diamond drill holes The outline of the Norbec orebody is on the upper surface Note that the stratigraphy has been returned to horizontal
b) Schematic projection of the alteration zone within the Waite Rhyolite (looking north).

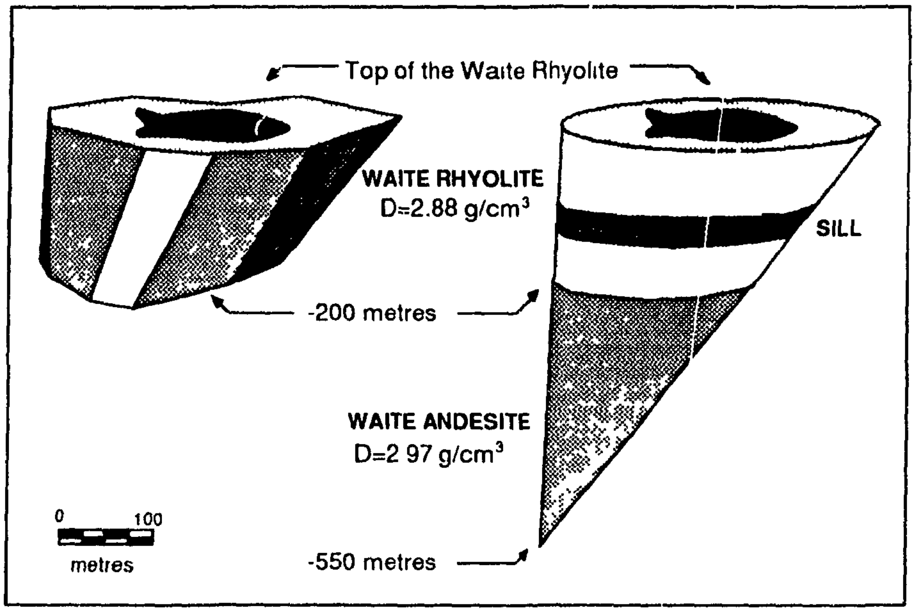

Figure 11: Extrapolation of the alteration pipe into the Waite Andesite based upon the outlined portion of the pipe in the Waite Rhyolite.

BULK CHEMICAL COMPOSITION

Averaging Procedures

The bulk chemical composition of the alteration zone can be estimated by different methods. The simplest, but least precise, is the arithmetic mean of the chemical data, which gives equal importance to clustered and dispersed samples in the alteration zone, but leads to a large margin of error. Other averaging procedures, such as cross-sectional, contouring, geostatistical and kriging, were evaluated. The approach adapted uses a three-dimensional model with volumes of influence for each sample and each drill hole, as in an ore reserve estimation. This procedure compensates for the uneven distribution of the drill holes and samples. Samples were "weighted" for their control length of drill core (midpoints between adjacent sample) to a thickness of 200m to determine the average chemical composition for the altered rhyolite, and to a thickness of 350 m for the Waite Andesite in each drill hole.

$$z_i^* = \left(\frac{d_2 - d_1}{2} \right) (z_i) \qquad \text{Equation 3}$$

$$Z_a = \left(\frac{\sum z_i}{l_a} \right) \qquad \text{Equation 4}$$

where z_i^* is the weighted oxide or trace element i (wt%), $d_2 - d_1$ is difference in depth between the sample locations or top of the rhyolite and bottom of the rhyolite or andesite, z_i is the weight fraction of the oxide or trace element i in the sample, Z is the weighted composition of the unit in the drill hole and l is the length of the drill hole within unit a. The drill holes were then weighted for their volumes of influence in the alteration zone by constructing a polyhedron around each hole using median distance between the holes to constrain their shape. Using these volumes of influence, average reconstructed chemical compositions were calculated for the Waite Rhyolite and Waite Andesite within the confines of the alteration pipe (Table 4) yielding the bulk chemical composition of the alteration zone.

$$Z_a^* = \Sigma (Z_j \times V_j) \qquad \text{Equation 5}$$

$$Z_{total} = (Z_a^* \times V_a^*) + (Z_b^* \times V_b^*) \qquad \text{Equation 6}$$

where Z^* is the bulk chemical composition of the unit, V_j is the volume fraction ("volume of influence") for drill hole j, Z_{total} is the bulk chemical composition of the alteration zone, V_a^* and V_b^* is the volume fraction of unit a and b, respectively. Weighted bulk chemical compositions of chloritic, sericitic or other alteration subzones also can be determined with these techniques when sampling coverage is sufficient.

Net Mass Change

From the bulk chemical data and the immobile element procedures outlined above, the average mass changes were determined for each component (Equation 2) for the entire alteration pipe (Table 4). The altered rhyolite and andesite exhibit significant increases in silica, Fe, Mg and K. Only Na has been removed from both units. Potassium, Rb and Ba behaved similarly (Rb versus K, r = 0.91; Ba versus K, r = 0.80) and increased at constant ratios owing to their incorporation exclusively into sericite. Calcium and Sr were added to the rhyolite, but almost entirely removed from the andesite. Sulphur increased to 1.9 wt% in the Waite Rhyolite, but changed little in the andesite. Base and precious metals were added in small amounts to the Waite Rhyolite, but not to the andesite. Total mass change was twice as high in the rhyolite (+20.5 wt%) as in the andesite (+10.0 wt%) (Table 4). The net mass change in the entire alteration zone (+16.5 wt%) is a weighted average of these two units. The bulk changes include rocks from all the sub-zones of alteration in the pipe including the stringer ore zones. The

	Waite Rhyolite		**Waite Andesite**		**Alteration Zone**		**Average Composition**
	Avg R-C	Mass Δ	Avg RC	Mass Δ	Avg RC	MassΔ	
SiO_2	87.3	11.1	65.3	5.0	78.8	8.8	67.6
TiO_2	0.33	0.04	1.0	-0.12	0.59	-0.02	0.51
Al_2O_3	12.8	0.5	17.7	2.0	14.7	1.1	12.6
FeO	10.2	6.4	15.7	8.0	12.3	7.0	10.6
MnO	0.16	0.12	0.47	0.28	0.28	0.18	0.20
MgO	1.3	0.8	6.3	2.0	3.2	1.3	2.8
CaO	1.8	1.3	0.53	-5.1	1.3	-1.1	1.1
Na_2O	2.3	-3.4	0.76	-3.8	1.7	-3.5	1.5
K_2O	1.9	1.3	2.0	1.7	1.9	1.4	1.6
P_2O_5	0.03	0.00	0.21	0.03	0.03	0.01	0.03
Cu	0.08	0.08	0.00	0.00	0.05	0.05	0.04
Zn	0.35	0.35	0.00	0.00	0.2	0.2	0.17
S	1.9	1.9	0.04	0.04	1.2	1.2	1.0
Sum	120.5	20.5	110.0	10.0	116.5	16.5	100
Rb ppm	38	14	41	31	39	21	33
Sr ppm	56	11	46	-138	52	-46	45
Ba ppm	370	106	490	361	416	203	357
Pb ppm	21	17	20	16	21	17	18
Au ppb	29	28	1.5	-1.6	18	17	15
Ag ppm	4.0	3.9	0.3	0.3	2.6	2.6	2.2
Co ppm	44	38	27	0	37	24	32
E.F.		1.205		1.100		1.165	

Table 4. Average bulk reconstructed composition (RC) and mass changes for the Norbec alteration zone. E.F. is the enrichment factor. In this case E.F. = $\text{Sum}_{(\text{altered})}/\text{Sum}_{(\text{precursor})}$ where the sum of the components in the precursor is equal to 100.

mass additions listed in Table 4 represent net amounts of individual components that were brought into the alteration pipe from an external source via the hydrothermal fluids. Net mass losses are of components leached from the pipe; these probably were exhaled via the hydrothermal fluids onto the seafloor and into the overlying water column.

The addition of 8.8 wt% SiO_2 to the alteration pipe represents a net silicification of the rhyolite and andesite. This is not simply the increase in modal or normative quartz that results from the breakdown of albite to sericite, or to chlorite and quartz. Iron was added in large amounts (7.0% FeO_T), and incorporated into chlorite (with Mg) and sulphides. The introduced K (1.4% K_2O) produced sericite. Calcium was added only to the altered rhyolite and mainly formed calcite. In other similar alteration zones in the Noranda district, Ca has commonly been removed (Horne, MacLean and Hoy 1991; Ansil, Barrett et al. 1991), but in the Delbridge mine (Fig. 1:9) alteration zone, Ca locally was added also, as calcite (Barrett et al. 1992a in review). The increase in Al in the Waite Andesite probably reflects higher primary Al contents due to igneous accumulation of plagioclase in some samples, rather than mass increase. The lower net value of mass change in the andesite indicates that it has experienced a lower degree of chemical alteration, but does not necessarily reflect a lower degree of mineralogical alteration; the unit initially contained large quantities of Fe and Mg that were converted to chlorite (and later cordierite and anthophyllite), whereas these elements were less abundant in the rhyolite precursor and were added in the chlorite-rich zones.

Volumetric Change

The change in volume of the host volcanic rocks during alteration was determined using the principle of Zr immobility which prescribes that the amount of Zr in a volume of altered rock is the same as in the initial volume of the precursor. Each gram of Zr represents a certain volume of fresh rock (Table 5), and using the known amount of Zr in the alteration pipe, and a calculated density of the precursor rock, the original volume of the fresh precursor rock can be calculated.

$$V\,(m^3)_{precursor} = Zr\,(T)_{alteration\ zone} \times \frac{1}{Zr(g)_p} \times \frac{1}{D_p} \qquad \text{Equation 7}$$

Where D_p = density of the precursor, and $Zr\,(g)_p$ = ppm Zr / 10^6. The volume of the unaltered precursor can also be calculated from the known volume of the alteration zone, bulk enrichment factor (E.F.), and the densities of the altered (D_A) and precursor (D_p) rocks.

$$V\,(m^3)_{precursor} = V\,(m^3)_{alteration\ zone} \times \frac{D_A}{D_p} \times \frac{1}{E.F.} \qquad \text{Equation 8}$$

The volume estimates are very close (Table 5), and differ only in that one extra calculated variable (D_A) was utilized in equation 2. The volume of the fresh Waite Rhyolite was 7.21 x 10^6 m^3 giving a 12.1% increase in volume during alteration. Similarly, the fresh Waite Andesite had a volume of 4.6 x 10^6 m^3 with an increase of 7.0% during alteration. The significant volume increase in the Waite Rhyolite during alteration is accounted for by vesicle filling, and by matrix and other open-space filling in the breccia intervals which represent 25% of the rhyolite. In the Waite Andesite, the matrix of pillows and breccias, and vesicular intervals provided the porosity to accommodate the calculated volume increase.

	Waite Rhyolite	**Waite Andesite**
D_p	2 67	2 89
D_A	2 88	2 97
Zr in precursor (ppm)	313	120
Mass of altered rock (T)	23 270 400	14 612 400
$Zr_{alteration\ zone}$ (T)	6044	1594
Enrichment Factor	1 21	1 10
Volume of altered rock (m^3)	8 080 000	4 920 000
Volume of fresh rock (m^3)	7 224 500	4 605 000
Volumetric change	12 1%	7 0%

Table 5 Average volumetric change of the Waite Rhyolite and Waite Andesite after hydrothermal alteration D_p = density of precursor, D_A = density of altered rock

Weighted Flux Calculations

The flux of an element is its total weighted mass change in the alteration system based on wt% and ppm, and expressed as tonnes and kilograms (Table 6). The term "hydrothermal system" includes both the alteration zone and the massive sulphides, as the components of the ore lens are derived from fluid-rock interaction, and then deposited on the sea floor above the alteration pipe. Twenty per cent of the ore lens is a silicate component, mostly chert, but also of tuffaceous origin composed of quartz, chlorite and sericite.

The flux calculations provide a comprehensive display of the effect of a focused flow of ore forming fluids on a small volume of the volcanic units. Some mobile components were introduced and some depleted, while others were redistributed within the alteration zone. The weighting procedures smooth local compositional variations (which may be large as in the case of silica and iron) between samples or sub-zones of the alteration pipe and give a true depiction of the total flux. The flux of metals represented by the orebody was calculated from the average grade of the deposit (Chartrand and Cattalani 1990) Included in Table 6 are the mass change tonnages of fluxed elements in the Waite Rhyolite, Waite Andesite and the orebody. Material added was 7.81 million tonnes, and depleted 1.79 million tonnes, yielding a net flux of 9.6 million tonnes. Net changes in major and trace elements are illustrated on a histogram (Fig 12) and show the separate contributions of the alteration zone and orebody to total flux of each element.

	Waite Rhyolite	**Waite Andesite**	**TOTAL ZONE**	**Orebody**	**TOTAL SYSTEM**
Vol (m^3)	8 080 000	4 920 000	0 13 km^3	1 080 000	0 14 km^1
D (g/cm^3)	2 88	2 97			
Tonnes (MT)	23 270	14 612	37 9	4 3	42 2
FLUX					
SiO_2	2 595 MT	0 723 MT	3 32 MT	0 506 MT	3 81 MT
FeO*	1 492	1 165	2 66	1 561	4 22
MnO	0 280	0 041	0 32	0 010	0 33
MgO	0 188	0 291	0 48	0 018	0 50
CaO	0 302	-0 739	-0 44		0 44
Na_2O	-0 791	-0 552	-1 30	-0 040	1 34
K_2O	0 293	0 254	0 55	0 007	0 55
S	0 433	0 006	0 44	1 346	1 79
Cu	0 019		0 019	0 120	0 14
Zn	0 082		0 081	0 202	0 28
Pb	400 T	234 T	634 T		634 T
Ag	91	4	95	185	285
Rb	330	450	780	10	790
Sr	260	-2020	-1 760	0	1 760
Ba	2470	5270	7 740	74	7 814
Co	880		880		880
Au	640 kg	30 kg	670 kg	3870 kg	4 540 kg
NET FLUX	**4 897 000 T**	**1 193 000 T**	**6.1 MT**	**3 730 000 T**	**9.9 MT**

Table 6 Total mass of element fluxes in the Norbec alteration zone, orebody and the complete hydrothermal system FeO* is total iron as FeO

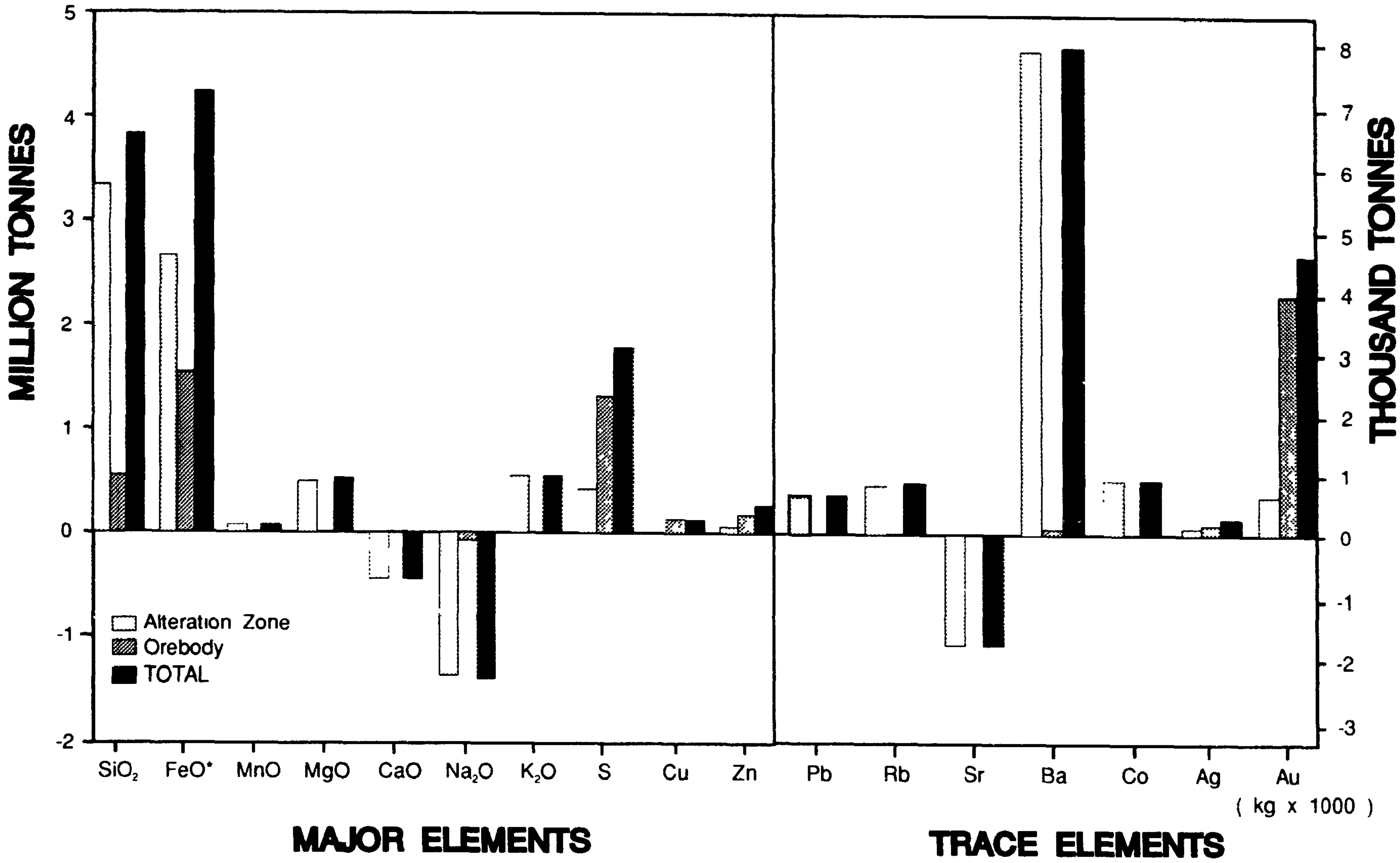

Figure 12: Histogram showing the total flux of each element in the alteration zone, orebody, and sum of both Elements on the left are in millions of tonnes, those on the right are in thousands of tonnes, except for Au which is in thousands of kilograms Elements plotting below the zero line show a net depletion in the hydrothermal system

The total mass of the hydrothermal system (alteration zone plus ore) is 42.2 million tonnes (MT). Ten per cent of this mass is represented by added iron (4.2 MT), 8% by added silica (3.8 MT), followed by additions S (1.8 MT), K_2O (0.55 MT), MgO (0.50 MT), and smaller contributions of other elements. The massive ores account for three-quarters of the added S, and about one-third of the Fe The mass losses in the system were restricted to Na_2O (-1.38 MT), CaO (-0.44 MT), and the geochemically associated Sr (-1760 T). The gain in the economically important metals (Cu and Zn) represent <1% of the total mass of the hydrothermal system, and only 3.4 wt% of the material added. Seventy-five per cent of the Cu and Zn is contained in the massive ore lens, and the remainder in stringer and disseminated sulphides in the alteration pipe. Both Au and Ag are added to the system, mostly to the massive sulphide lens. Lead and Co were not analyzed in the massive ores, but show small net additions in the alteration pipe.

Silica was added to the alteration zone as quartz in veinlets and amygdules, as a matrix in breccia units and in the stringer zone. It appears to have been largely trapped in the alteration zone, as the overlying massive ore and tuffite unit contain <10% added silica. Most of the non-sulphide iron and all of the Mg in the alteration zone was in chlorite prior to metamorphism. As non-sulphide Fe greatly exceeds the Mg, the chlorite was probably an Fe-rich ripidolite. This is supported by the high Fe/Fe+Mg ratios of metamorphic mafic minerals (see Appendix II) which now make up the alteration zone.

Barium showed the largest addition to the system of the non-ore trace elements. Ba has a good correlation with K (r = 0.80) and is inferred to substitute (along with Rb) for K in sericite. In the Kuroko ores of Japan, Ba occurs largely as barite ($BaSO_4$), suggesting a higher oxidation state for the Kuroko hydrothermal fluids than for those that formed the Norbec deposit.

Although Cu and Zn masses are impressive (482 000 T), their flux in the system was only a fraction of that for FeO and silica (Table 5). Copper and Zn masses are similar to added K_2O (550 000 T) and MgO (500 000 T), but much less than leached Na_2O (1 380 000 T). Base metals and Ag (285 T) and Au (4.54 T) were important economic components, but they represent only minor flux products of the system.

Comparison with the Horne Mine

The flux of elements at Norbec was much smaller that at the Horne mine (Fig. 1:8, Table 7), the largest massive sulphide deposit in the Noranda district (Fig. 1). A preliminary estimate of the mass changes for the Horne (MacLean and Hoy 1991, MacLean, unpub. data) includes the very large alteration zone which extended from below the orebody into the hangingwall, and sectors displaced by faulting. The orebody includes the Cu-Au-rich H lenses, and the high tonnage subeconomic Zn-bearing #5 Zone.

	Horne Deposit	Norbec Deposit	Norbec*
MASS $_{(AZ)}$	15 000 MT	37 9 MT	37 9 MT
MASS $_{(ORE)}$	259 MT	4 3 MT	4 3 MT
MASS $_{(Total)}$	15 259 MT	42 2 MT	42 2 MT
ALTERATION ZONE (AZ)			
SiO_2	1 700 MT	3 8 MT	4 3 MT
$FeO_{(AZ)}$	135	2 7	0 34
MgO	-15	0 50	-0 04
CaO	-200	-0 44	-0 50
Na_2O	-335	-1 38	0 84
K_2O	240	0 56	0 60
OREBODY (ORE)			
$FeO_{(ORE)}$	70	1 56	1 16
Cu	1 5	0 14	0 03
Zn	3 6	0 28	0 06
S	120	1 79	1 99
Au	760 T	4 510 kg	12 600 kg

Table 7 Comparison of the actual flux of ore and rock forming elements from the Norbec deposit with the Horne deposit Norbec* is the predicted flux of the system as a scaled down version of the Horne deposit

The Norbec orebody makes up a much larger portion (~10%) of its small focused hydrothermal system than do the Horne orebodies (~2%), which occur within a large and diffuse alteration zone. Although the sizes of the hydrothermal systems are very different, they exhibit some important similarities. Both have gained large quantities of silica, Fe, and K, and both have lost most of their Ca and Na The flux of Mg was different at the two mines, with a gain at Norbec, and loss at the Horne where it was leached during the sericitization process. At the Horne, silicification is mainly in the extensive quartz-sericite alteration zone, whereas, at Norbec, pods of silicification are also present in the chloritic stringer zone. Both orebodies show the same trend of relative metal and sulphur additions. S>Fe>Zn>Cu>Au.

To make a clearer comparison between the two mines, the ratio of element flux to the mass of the hydrothermal system at the Horne can be used to predict element flux in a deposit of the size of Norbec (Table 7). This procedure reasonably predicts the flux of silica, Ca, Na, K in the Norbec alteration zone, but underestimates Fe and Mg due to the proportionately larger chloritic zone at Norbec. Iron and S are closely predicted for the Norbec orebody, but Cu and Zn are lower, and Au higher. Some of these variations can be accounted for by the atypical nature of the Horne among the Noranda deposits, with its very large silica-sericite alteration zone, a small chlorite zone, and Au-rich ore. As more geochemical data are compiled on the alteration zones of these deposits, the flux of elements in each system can be more accurately determined and compared.

OXYGEN ISOTOPES

Oxygen isotopes were measured by L. Hoy of the University of Montréal on the host volcanic rocks of the Norbec deposit. Twenty six whole rock samples were analyzed using the BrF_5 medium method (Clayton and Mayeda 1963) to extract the oxygen. The samples studied were fine-grained metamorphosed volcanic rocks, and, therefore, mineral separates were not obtained. Temperature estimates on these would not be relevant to alteration conditions.

The measured bulk oxygen isotope analyses for the least altered Waite Rhyolite average ~9.7‰ which is on the higher limit of the $\delta^{18}O$ range for the unaltered rhyolites of the Abitibi Greenstone Belt (Taylor 1968, Beaty et al. 1988, Cattalani et al. 1990 and 1992). The altered rhyolites returned values ranging from 5.1 to 10.5‰ with an average of 7‰. The unaltered hangingwall Amulet Andesite samples have measured oxygen isotope values of 6.8 to 9.4‰ and are also at the upper limit of the Abitibi average.

The hydrothermal mineral assemblages of the host volcanic rocks have been metamorphosed within the contact aureole of the Lac Dufault granodiorite to the hornblende hornfels facies. The oxygen isotope values of the original hydrothermal minerals have been affected by this event, but the contact mineral assemblages do not imply a significant migration of fluids (Hall 1982, Riverin and Hodgsen 1980). Metamorphic reactions generally were prograde dehydration followed by retrograde hydration. The total effect of these reactions on the oxygen isotopes of the bulk rock are considered minimal (Valley 1986, Cattalani et al. 1992), and the measured bulk $\delta^{18}O$ indicate the thermal and isotopic conditions during the hydrothermal alteration associated with the formation of the Norbec massive sulphide deposit.

Calculated Oxygen Isotope Values

The $\delta^{18}O$ values of the altered volcanic rocks can be calculated using the methods outlined by MacLean and Hoy (1990) using weight percentages of the alteration minerals and their $\delta^{18}O$ values. The wt % of each alteration mineral was calculated using the normative alteration mineral program outlined in Chapter 3 and Appendix II, and subsequently converted to weight %. The oxygen isotope values of each alteration mineral were assessed using a series of steps: $\delta^{18}O$ values for minerals at several temperatures typical of VMS hydrothermal fluids were determined using experimentally derived equations for quartz (Matsuhisha et al. 1979), chlorite (Wenner and Taylor 1971), muscovite-sericite (O'Neil and Taylor 1969), calcite (O'Neil et al. 1969), zoisite-epidote (Matthews et al. 1983), albite (Bottinga and Javoy 1973), and magnetite (Wenner and Taylor 1971). At Norbec, the mineralizing fluid is estimated to have a $\delta^{18}O \approx 0‰$ (seawater) (L. Hoy in Cattalani et al. 1992). The resulting bulk-rock $\delta^{18}O$ values were calculated for each sample that had a measured $\delta^{18}O$ using the equation:

$$\delta^{18}O_{WR} = \sum \delta^{18}O_i \left[\frac{X_i \bullet Y_i}{\Sigma_i X_i \times Y_i} \right] \qquad \text{Equation 9}$$

(MacLean and Hoy, 1991) where $\delta^{18}O_{WR}$ is the bulk oxygen isotope composition of the altered rock, $\delta^{18}O_i$ is the oxygen isotope composition of mineral i, X_i is the weight fraction of the mineral i relative to all oxygen-bearing minerals, and Y_i is the weight fraction of oxygen in mineral i. Several assumptions were made when using this formula: 1) each mineral formed at a constant temperature, 2) the hydrothermal fluids had a constant temperature, 3) the hydrothermal fluids had a constant $\delta^{18}O$ value (in this case 0‰), 4) the normative mineral program gives an accurate estimation of the original hydrothermal mineral assemblage and, 5) the $\delta^{18}O$ values of the minerals have not been greatly readjusted by contact and regional prograde and retrograde metamorphism. The bulk oxygen isotope values reflect the normative mineral assemblage such that a chlorite-rich rock should have

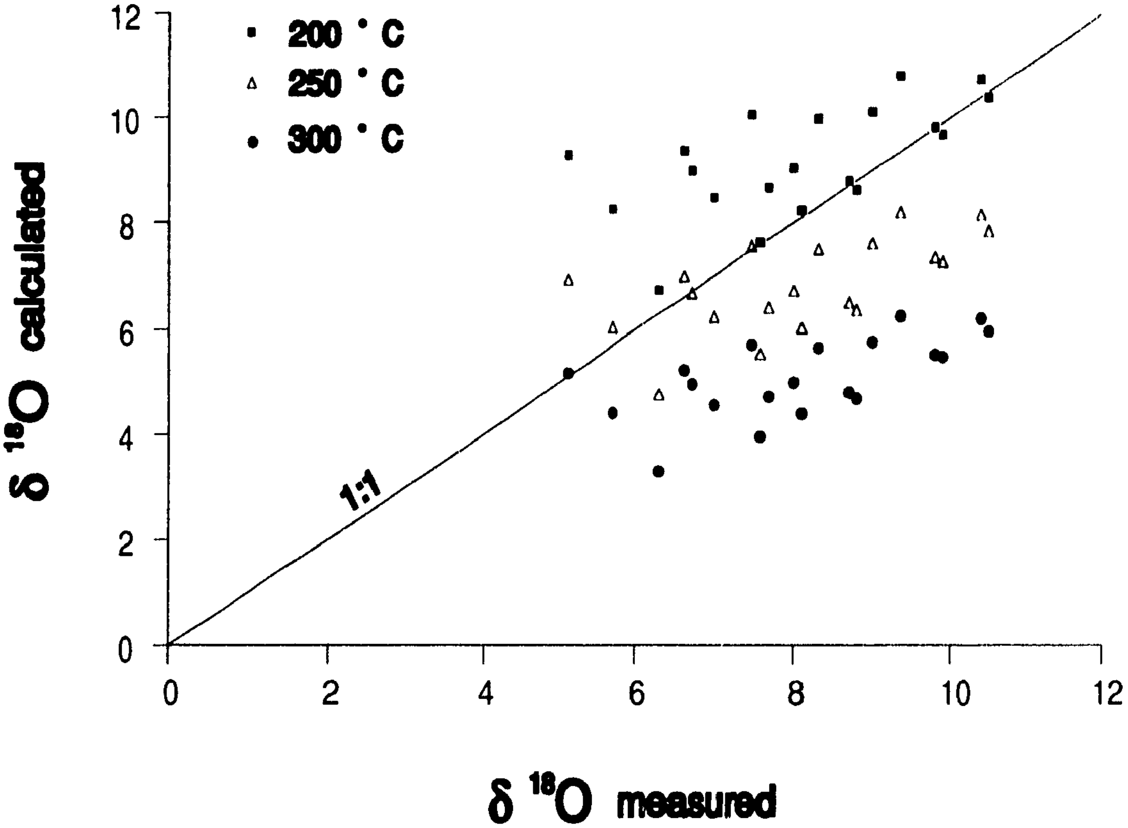

Figure 13. Plot of measured bulk δ ^{18}O values (horizontal axis) against calculated bulk δ ^{18}O values (vertical axis) for the Waite Rhyolite The calculated values were carried out for the measured samples at temperatures of 200°, 250°, and 300° Calculated values were obtained after using Equation 13 and mineral contents were normative estimates Precise predictive capability should result in a 1 1 correlation between the calculated and measured values

a very low $\delta^{18}O$ value (0 - 1‰), while a silicified rock should have a relatively high value (6 -9‰) depending on the temperature of formation.

The calculated values for the rocks analyzed by L. Hoy (Cattalani et al. 1992) show a moderately good correlation with the measured $\delta^{18}O$ values at temperatures between 200° and 250° (Fig. 13). Samples with $\delta^{18}O$ values above 8‰ show the best correlation with the measured values at 200° and, in most cases, (Appendix II:3) represent samples furthest from the deposit with a mineral assemblage of quartz and albite. Samples correlating best with a temperature of 250° are generally composed of quartz-chlorite-(sericite) representing samples proximal to the deposit. The one sample correlating best with the measured values at 300° is composed of quartz and chlorite and is within the stringer zone (Appendix II:3). The calculated and measured values of the oxygen isotopes show that there is a strong correlation between the bulk $\delta^{18}O$ and the alteration mineralogy and all samples have formed at temperatures between 200° and 350°C, typical of VMS deposits in the Noranda area.

CHAPTER 4: DISCUSSION

HOST VOLCANIC UNITS

The stratigraphy in the Norbec area is a bimodal sequence of basalt-andesites and rhyolites. The units define a single fractionation line indicating that the volcanic rocks are part of a fractionated series derived from a single magma chamber. The Waite Rhyolite, which hosts the Norbec deposit, lies at the top of the volcanic sequence and is the most fractionated unit of the series. From discrimination plots, the rocks hosting the Norbec deposit are tholeiitic to transitional in affinity, and are of the low-K series. These compositions are typical of the volcanic suites hosting the Ansil, Corbet, Vauze, and Waite deposits.

The volcanic units of the Blake River Group have been divided into tholeiitic and calc-alkaline affinities by Spence and de Rosen-Spence (1975), Gélinas et al. (1977), Ludden and Gélinas (1984), and Gélinas et al (1984) mainly on the basis of AFM major element discrimination diagrams supplemented by Miyashiro plots. From twenty four samples of debatable freshness, the rocks in the Norbec area were designated as belonging to the Dufault calc-alkaline unit (Gélinas et al, 1977, 1984). Ujike and Goodwin (1987) attempted to define the affinities of individual flows and determined that the Dufault unit comprised a combination of tholeiitic and calc-alkaline flows. Miyashiro plots with Jenson plots (Al-(ΣFe+Ti)-Mg) were used to determine the affinity of variably altered rhyolites and andesites of the

Dufault unit, and were supplemented with $[La/Yb]_N$ ratios. Ujike and Goodwin (1987) determined that the Amulet Andesite, Waite Rhyolite, and Waite Andesite are all of calc-alkaline affinity. However, the major elements used to classify the units in the cited studies are very mobile during hydrothermal alteration and can give erroneous classifications when used in these plots, and careful consideration was not used when determining the freshness of the sample. The light REE also have been shown to be mobile under some hydrothermal conditions (MacLean 1988). In the present study, *fresh* samples were examined in terms of: a) K_2O vs. SiO_2 plot, b) REE plots, c) $[La/Yb]_N$ ratios, d) Zr/Y ratios, and e) fractionation plots. The results indicate that all three volcanic host formations have a tholeiitic to transitional affinity.

The volcanic paleo-environment in the Norbec area has been interpreted as a cauldron of ~20 km in diameter extending from the Hunter Creek Fault to the north to the Horne Creek Fault to the south (Gibson and Watkinson 1990, Péloquin et al. 1990). The cauldron was filled by several cycles of volcanism with each cycle characterised by a thick basal andesitic unit overlain by a series of bimodal andesitic-rhyolitic units. The first cycle of Péloquin et al. (1990) correlates with the third cycle (Mine series) of Spence and de Rosen-Spence (1975) and signals the beginning of the cauldron subsidence defined by the Gibson and Watkinson (1990) interpretation. Goldie (1976, 1979) suggests the Flavrian Pluton represents the shallow underlying magma chamber that was coeval with the Blake River Group volcanic units. Most of the VMS deposits in the cauldron are proximal to the vents

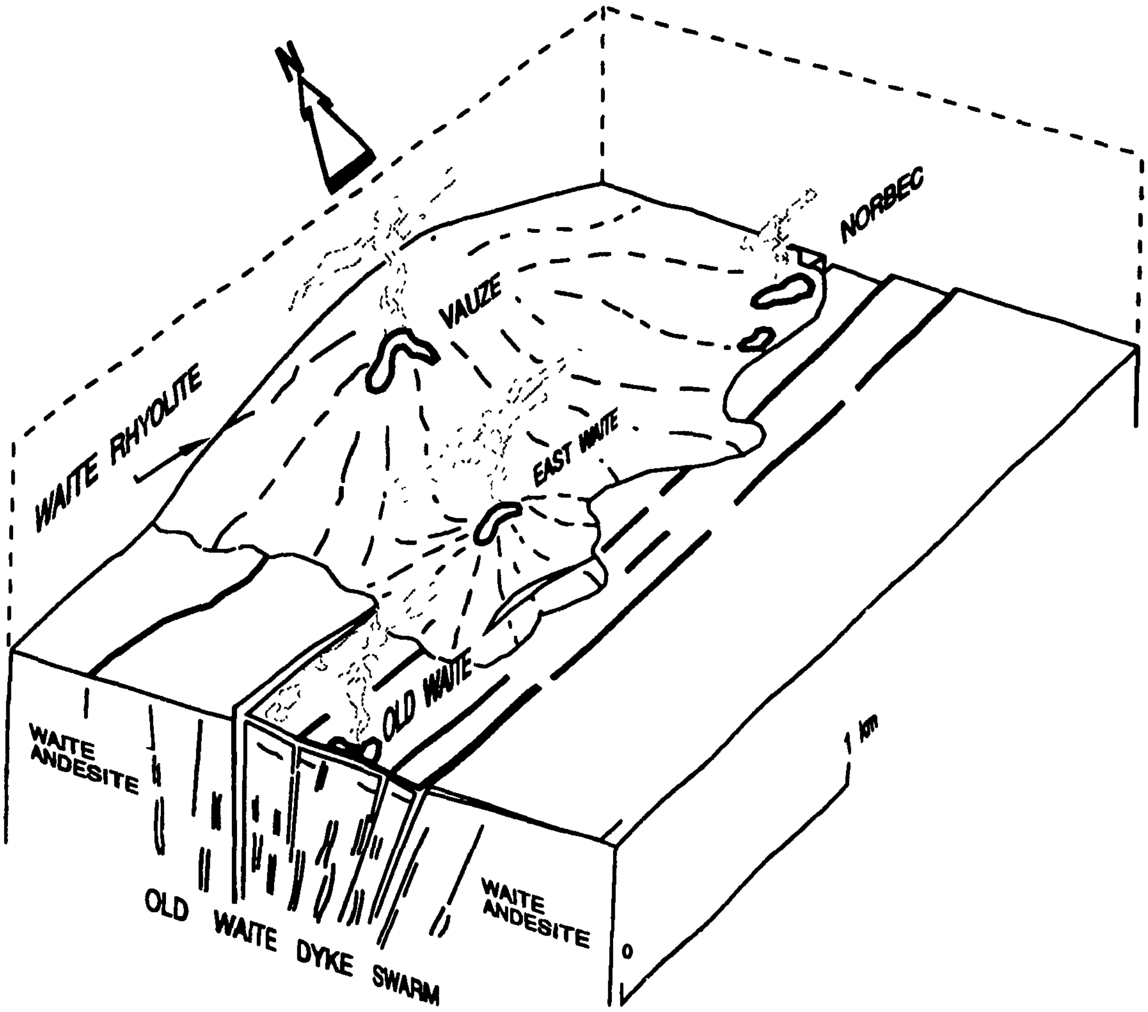

Figure 14: Schematic diagram illustrating an interpretated environment of deposition for the Norbec, Waite, and Vauze orebodies showing the location of VMS deposits along the Old Waite Dyke Swarm Adapted from Gibson and Watkinson (1990)

of rhyolite domes (except the Corbet and Ansil deposits), which are localized along synvolcanic faults and lineaments (Gibson and Watkinson 1990). Gibson and Watkinson (1990) recognized the pronounced alignment of the Waite, Norbec and Newbec deposits along a east-northeast lineament and infer a synvolcanic fissure that was also parallel to the Old Waite Dyke Swarm (Fig. 14). The overlying Amulet Andesite may have been fed from this fissure. The presence of synvolcanic faults allowed the hydrothermal fluids to penetrate and alter extensive areas of the volcanic stratigraphy, and localize the massive sulphide orebodies.

ALTERATION

The rocks hosting the Norbec deposit have been altered to chlorite, sericite and quartz, and later isochemically metamorphosed to cordierite, anthophyllite and biotite. The mass change calculations show that this resulted from a large influx of silica, potassium and iron, and a large loss of sodium and calcium. The original albite has been replaced by quartz and sericite or chlorite depending upon the composition of the hydrothermal fluid.

$$\underset{\text{Albite}}{3\ NaAlSi_3O_8} + K^{+}_{(aq)} + 2H_2O \rightarrow \underset{\text{Sericite}}{KAl_3Si_3O_{10}(OH)_4} + \underset{\text{Quartz}}{6\ SiO_2} + 3\ Na^{+}_{(aq)} \qquad \text{Equation 10}$$

$$\underset{\text{Albite}}{6\ NaAlSi_3O_8} + 3\ Mg^{++}_{(aq)} + 6\ Fe^{+}_{(aq)} + 7\ H_2O \rightarrow \underset{\text{Chlorite}}{Mg_3Fe_6Al_6Si_5O_{20}(OH)_{16}} + \underset{\text{Quartz}}{13\ SiO_2} + 6\ Na_{(aq)} \qquad \text{Equation 11}$$

The absolute amounts of chlorite and sericite formed during hydrothermal alteration were strictly controlled by the initial amount of Al in the rocks (MacLean and

Kranidiotis 1987, MacLean and Hoy 1991). As shown in earlier plots, Al was strongly immobile in the hydrothermal system and its quantity did not change during alteration. The chlorite-rich and sericite-rich rocks formed through residual concentration by the removal of mobile elements.

The metamorphic minerals that now constitute the Norbec alteration zone are primarily cordierite, anthophyllite, biotite with minor amounts of garnet, gahnite and andalusite. These minerals have formed from simple dehydration reactions of the hydrothermal alteration minerals.

$$\underset{\text{Chlorite}}{14\,(FeMg)_9Al_6Si_5O_{22}(OH)_{16}} + 131\,SiO_2 \rightarrow \underset{\text{Cordierite}}{21\,(FeMg)_2Al_4Si_5O_{18}} + \underset{\text{Anthophyllite}}{12\,(FeMg)_7Si_8O_{22}(OH)_2} + 100\,H_2O \qquad \text{Equation 12}$$

$$\underset{\text{Chlorite}}{7\,(FeMg)_9Al_6Si_5O_{20}(OH)_{16}} + \underset{\text{Sericite}}{7\,KAl_3Si_3O_{10}(OH)_2} \rightarrow \underset{\text{Biotite}}{7\,K(FeMg)_3AlSi_3O_{10}(OH)_2} + \underset{\text{Cordierite}}{14\,(FeMg)_2Al_4Si_5O_{18}} + \underset{\text{Anthophyllite}}{2\,(FeMg)_7Si_8O_{22}(OH)_2} + 54\,H_2O$$

Equation 13

These equations show that the dalmationite alteration zone can form by isochemical processes with only water being lost. Further proof that the metamorphic process was not metasomatic is given by the high regression coefficients with the immobile element plots for altered samples in the metamorphosed alteration zone indicating that both transformation mechanisms did not affect the concentrations of these elements or their ratios It is more difficult to determine that the mobile elements were not metasomatically affected by the contact metamorphic event. Several geologic observations indicate that the contact metamorphism did not significantly affect the mobile elements The chemical zoning typical of Noranda-type VMS deposits has been preserved, but may have been homogenized during metasomatism. There is no evidence of veining with metamorphic minerals or an introduction of exotic elements such as F or Cl that could have come from the intrusive stock. A chemical gradient of the mobile elements across the aureole reflecting the soubility or temperature front of the metasomatic fluids is not observed; supporting the isochemical hypothesis.

WATER-ROCK INTERACTION

Several methods can be used to estimate the water to rock ratio needed to produce the alteration mineral assemblages observed in many types of deposits. The calculated mass changes of certain elements provides the data to compute the water/rock ratios for a sample or for the whole alteration zone. The method used in this study was based on the solubility of an element in the hydrothermal fluid and its concentration in the altered rocks. Silica, K and Fe addition to the Waite Rhyolite and the Waite Andesite were used to determine the amount of hydrothermal fluid needed to introduce these elements to the rocks. Several assumptions are made when doing these calculations: 1) the concentrations of these elements are saturated in the fluids, 2) total precipitation of the component occurs during alteration, 3) the hydrothermal alteration occurred as a single event, and 4) the altered rocks had a homogenous morphology. With these assumptions, the estimated water/rock ratios are a minima. For the Norbec deposit, a temperature of 250°C was chosen for the average temperature of the hydrothermal fluids.

The estimated mass additions of SiO_2 to the Waite Rhyolite and Waite Andesite are 11.1 wt% and 5.0 wt% respectively. Aqueous SiO_2 contents in typical hydrothermal fluids at silica saturation at a temperature of 250° are ~400 ppm (Cobble et al. 1982). Therefore, to fix 111 000 ppm SiO_2 (=11.1 wt% SiO_2) in the Waite Rhyolite, the water/rock ratio had to be at least 278, the addition of 50 000 ppm SiO_2 to the Waite Andesite requires a water/rock ratio of 125 There is evidence of quartz in the massive sulphide lens which would suggest that not all of the silica precipitated from the fluid into the footwall alteration pipe (as assumed). This would require that the water/rock ratios were actually higher than those estimated above

The estimated addition of potassium (as K) to the Waite Rhyolite is 1.08 wt% (or 10 800 ppm), and to the Waite Andesite 1.41 wt% (14 100 ppm) Calculations by MacLean and Hoy (1991) indicate that hydrothermal fluids at 250° in the stability field of sericite (muscovite) can carry 2 x 10^{5} g K/g H_2O (20 ppm K). Therefore, the water/rock ratio for the fluid adding K to the Waite Rhyolite is 540, and for the Waite Andesite is 705 These values fall under the same assumptions as mentioned above. The much larger values may be evidence that the fluids were undersaturated in silica

Iron (as Fe) has a solubility of 1000 to 2000 µmoles/kg of H_2O (55.8 to 112 ppm) in fluids discharging from seafloor vents at 250° to 350°C (Von Damm et al. 1985). The Waite Rhyolite has had 4.97 wt% Fe added during alteration, while the

Waite Andesite has had 6.22 wt%. This indicates water/rock ratios of 444 to 890 for the rhyolite, and 555 to 1115 for the andesite. A minimal water/rock ratio of ~250 to ~900 appears necessary to have altered the Waite Rhyolite and Waite Andesite to their average bulk chemical compositions.

COMPARISON WITH OTHER VMS DEPOSITS IN THE NORANDA DISTRICT

A series of geochemical studies have recently been performed on several deposits in the Noranda area (Barrett et al. 1992, 1992a, 1992b, 1991; MacLean and Hoy, 1991; Cattalani et al. 1990). Similar techniques were used to calculate mass changes, oxygen isotope values and water/rock ratios In general, the results are similar to those determined for the Norbec, but each deposit shows individuality. Geochemical evaluation at the Horne copper-gold mine (MacLean and Hoy, 1991) indicates that the deposit formed at temperatures between 275° and 380°C with water/rock ratios in the range of 50 to 300. In this system, silica and K_2O were added and Na_2O and CaO were leached. The Delbridge zinc deposit, located 3 km east of Rouyn-Noranda in a series of rhyolites, formed at temperatures of 175° to 200°C (Barrett et al. 1992a in review). Large mass changes in silica were calculated in the alteration zone, from strongly negative to strongly positive, which resulted in a net bulk mass change near zero. Potassium, Fe and Mg were added to the footwall rhyolites and Na_2O was leached from both the footwall and hangingwall (Barrett et al. 1992a in review). The Ansil Cu-(Zn) mine at the top of the Northwest Rhyolite formed at temperatures of 250° to 300°C with highest temperatures calculated at the paleo-discharge site (Barrett et al 1991). A lower temperature of 200° to 270°C from oxygen isotope geochemistry on mineral separates was determined for the formation of magnetite-rich bodies in the massive ore. The Ansil alteration zone shows the same fluctuations of silica as at the Delbridge and large additions of FeO, MgO and K_2O; Na_2O and CaO are completely removed (Barrett el al. 1991). The Corbet Cu-Zn mine is in the upper portion of the Flavrian Andesite, the lowest andesite of the Mine Sequence Alteration is predominantly chloritic with little silicification or sericitization of the footwall andesites (Barrett et al. 1992b in review). Subsequently, large amounts of silica, CaO and Na_2O were removed from the alteration zone, and considerable FeO and MgO were added. Chlorite geothermometry indicates the hydrothermal alteration occurred from 255° to 293°C, which is corroborated by the $\delta^{18}O$ values that give temperatures of 250° to 300°C (Barrett el al. 1992b in review). The Mobrun Zn-(Cu) mine is in rhyolites of the fifth volcanic cycle of Spence (1967). The hangingwall and footwall rhyolites are sericitized and variably silicified with local patches of chloritization (Barrett el al. 1992). Potassium, FeO and MgO have been added in moderate amounts to the footwall and hangingwall and silica shows mass addition only to the hangingwall. Both rhyolites have CaO, Na_2O leached with silica depletion observed only in the footwall Oxygen isotopes from quartz separates indicate temperatures of formation of the quartz-sericite alteration of ~350°C (Barrett et al. 1992).

CONCLUSIONS

The present research project indicates the usefulness of geochemistry in providing information about stratigraphy, the precursor composition of altered rocks, normative alteration mineral assemblage, and mass changes of mobile elements during hydrothermal alteration. The mass change calculations and normative alteration mineral assemblages outline the alteration envelope, determine its bulk chemical composition and allow calculation of total volume change during alteration. The normative alteration mineral assemblage also is used to estimate the oxygen isotope composition of the altered units. Finally, with the bulk mass change values, water/rock ratios in the Waite Rhyolite and Waite Andesite were estimated.

The Norbec deposit consists of a 37.9 million tonne alteration zone with a volume of 13.0 x 10^6 m^3, and a 4.3 million tonne Cu-Zn orebody with a volume of 1.08 x 10^6 m^3. The volumetric change of the host volcanic units during alteration was a 12.1% increase in the Waite Rhyolite, and 7.0% increase in the Waite Andesite. Ten per cent of the added mass was represented by iron (4.2 MT) which was fixed in chlorite and sulphides. Other significant contributions were SiO_2 (3.8 MT), S (1.8 MT), K_2O (0.55 MT). Oxygen isotope values are compatible with alteration at temperatures from 200°C to 300°C, with distal samples altered at lower temperatures. The estimated water/rock ratios needed to introduce the mobile components to the system range from ~250 to ~900. The parameters that were necessary to produce the Norbec deposit fall within the range of those that produced Noranda type VMS deposits.

The series of geochemical studies carried out on the volcanogenic massive sulphide deposits of the Noranda area show the strong similarity between deposits in temperatures of formation and elemental mass changes. The variations between deposits are generally a result of host rock lithology, mineralization style and variations in alteration mineralogy.

REFERENCES

Bancroft, W L., Atkinson, I. (1987) Internal report of Noranda Exploration Co. Ltd.

Barrett, T.J., Cattalani, S., Hoy, L., Riopel, J., Lafleur, P.-J. (1992) Massive sulfide deposits of the Noranda area, Quebec· IV. The Mobrun mine. Can. J. Earth Sci. (in press)

Barrett, T.J., Cattalani, S., MacLean, W.H. (1992a) Volcanic lithostratigraphy and alteration at the Delbridge massive sulfide deposit, Noranda, Quebec. J. Expl Geochem. (in review)

Barrett, T J , MacLean, W H., Cattalani, S , Hoy, L. (1992b) Massive sulfide deposits of the Noranda area, Quebec: V. The Corbet mine. Can J. Earth Sci (in review)

Barrett, T J., MacLean, W.H., Cattalani, S., Hoy, L., Riverin, G. (1991) Massive sulfide deposits of the Noranda area, Quebec. III. The Ansil mine. Can J. Earth Sci. 28. 1699-1730

Beaty, D.W , Taylor, H.P , Jr. (1988) An oxygen isotope study of the Kidd Creek, Ontario, volcanogenic massive sulphide deposit: Evidence for a high ^{18}O ore fluid Econ Geol. 83. 1-17

Bernier, L , Pouliot, G., MacLean, W.H (1987) Geology and metamorphism of the Montauban North gold zone. a metamorphosed polymetallic exhalative deposit, Grenville Province, Quebec. Econ. Geol. 82: 2076-2090.

Bonavia, F F , MacLean, W.H (1986) Geology and ore enrichment factors at the

Radiore mine, Quebec. Mineral. Deposita 21: 137-146

Bottinga, Y., Javoy, M. (1973) Comments on oxygen isotope geothermometry. Earth Planet. Sci. Lett 5: 250-265

Cattalani, S., MacLean, W.H., Shriver, N., Barrett, T.J , Hoy, L. Géologie et géochimie du gisement de Norbec, district de Noranda, Québec. Ministére de l'Energie et des Ressources du Québec. Report ET (accepted January 1992)

Cattalani, S., Barrett, T.J., MacLean, W.H., Hoy, L., Hubert, C., and Fox, J S. (1990). La métallogénie des sulfures massifs: Les mines Horne et Quemont, district de Noranda, Québec. Ministère de l'Energie et des Ressources du Québec. Rapport ET 90-07

Chartrand, F., Cattalani, S. (1990) Massive sulphide deposits in northwestern Quebec. In: Rive, M , Verpaelst, P , Gagnon, Y., Lulin, J-M , Riverin, G ,Simard, A. (eds.) The Northwestern Quebec Polymetallic Belt· A summary of 60 years of mining exploration The Canadian Institute of Mining and Metallurgy Special Volume 43· 77-91

Clayton, R.N., Mayeda, T K (1963) The use of bromine pentafluoride in the extraction of oxygen from oxides and silicates for isotopic analysis. Geochim. et Cosmochim. Acta 27: 43-52

Cobble, J.W., Murray, R C , Turner, P J., Chen, K. (1982) High-temperature thermodynamic data for species in aqueous solution. Elec Power Research Inst. Rept. Np-2400. 179pp

Deer, W A, Howie, R.A., Zussman, J. (1966) An Introduction to the Rock Forming Minerals. Commonwealth Printing Press Ltd., Hong Kong. 528 pp

de Rosen-Spence, A.F. (1976) Stratigraphy, development and petrogenesis of the Central Noranda volcanic pile, Noranda, Quebec. Ph.D. Thesis, University of Toronto Toronto, Ontario. 166pp

Evensen, N.M., Hamilton, P J., O'Nions, R.K. (1978) The abundances of rare-earth elements in the solar system. Amer. Geophys. Union. 59: p314

Franklin, J.M , Lydon, J W , Sangster, D.F. (1981) Volcanic-associated massive sulphide deposits Econ. Geol., 75th Anniversary Volume: 485-627

Gélinas, L., Brooks, C., Perrault, G , Carignon, J., Trudel, P., Grasso, F. (1977) Chemo-stratigraphic divisions within the Abitibi volcanic belt, Rouyn-Noranda district, Quebec In Barager. W.R A., Coleman, L.C., Hall, J.M. (eds.): Volcanic regimes in Canada. The Geological Association of Canada Special Paper No. 16 265-295

Gélinas, L., Trudel, P., Hubert, C (1984) Chemostratigraphic division of the Blake River Group, Rouyn-Noranda area, Abitibi, Quebec. Can. J. Earth Sci. 21: 220-231

Gibson, H.L , Watkinson, D.H (1990) Volcanogenic massive sulphide deposits of the Noranda cauldron and shield volcano, Quebec. In: Rive, M., Verpaelst, P , Gagnon, Y , Lulin, J-M , Riverin, G., Simard, A. (eds.) The Northwestern Quebec Polymetallic Belt: A summary of 60 years of mining exploration. The Canadian Institute of Mining and Metallurgy Special Volume 43: 119-

Goldie, R.J. (1976) The Flavrian and Powell plutons, Noranda area, Quebec. Ph.D. Thesis, Queen's University, Kingston, Ontario 356 pp

Goldie, R. (1979) Consanguineous Archean intrusive and extrusive rocks, Noranda, Quebec. chemical similarities and differences. Precambrian Research 9: 275-287

Goodwin, A.M. (1977) Archean volcanism in superior province, Canadian shield. In: Barager. W.R.A., Coleman, L C., Hall, J.M. (eds.): Volcanic regimes in Canada. The Geological Association of Canada Special Paper No. 16 205-241

Hall, B.V. (1982) Geochemistry of the alteration pipe at the Amulet Upper A deposit, Noranda, Quebec. Can. J. Earth Sci. 19: 2060-2084

Johnson, A.E. (1966) Mineralogy and textural relationships in the Lake Dufault ores, Northwestern Quebec M Sc. Thesis, University of Western Ontario, London, Ontario

Jolly, W.T (1977) Relations between Archean lavas and intrusive rocks of the Abitibi area, Canada, in light of major element geochemistry. Jour. Petrol. 21: 323-363

Knuckey, M.J., Comba, C D A., Riverin, G (1982a) Structure, metal zoning and alteration at the Millenbach deposit, Noranda, Quebec In: Hutchinson, R.W , Spence, C.D , Franklin, J.M (eds.) Precambrian Sulphide Deposits, H.S. Robinson Memorial Volume Geol. Assoc Canada Spec. Pa. 25: 255-295

Knuckey, M J., WAtkins, J.J (1982b) The geology of the Corbet massive sulphide deposit, Noranda district, Quebec, Canada. In: Hutchinson, R.W., Spence, C.D , Franklin, J.M (eds.) Precambrian Sulphide Deposits, H.S. Robinson Memorial Volume Geol. Assoc. Canada Spec. Pa. 25: 297-317

Lesher, C M , Goodwin, A M , Campbell, I.H., Gorton, M.P. (1986) Trace-element geochemistry of ore-associated and barren, felsic metavolcanic rocks in the Superior province, Canada Can J. Earth Sci. 23: 222-237

Lickus, R.J. (1965) Geology and geochemistry of the ore deposits at the Vauze mine, Noranda district, Quebec. Ph.D. Thesis, University of McGill, Montreal, Quebec 135pp

Ludden, J , Gélinas, L (1982) Archean metavolcanics from the Rouyn-Noranda district, Abitibi Greenstone Belt, Quebec: mobility of trace elements and petrogenetic constraints Can. J. Earth Sci. 19: 2276-2287

Lydon, J W (1984) Volcanogenic massive sulphide deposits. Part 1: a descriptive model. Geoscience Canada 11. 195-202

Lydon, J.W (1988) Volcanogenic massive sulphide deposits. Part 2: genetic models Geoscience Canada 15· 43-65

MacLean, W H. (1988) Rare earth element mobility at constant inter-REE ratios in the alteration zone at the Phelps Dodge massive sulphide deposit, Matagami, Quebec. Mineralium Deposita 23: 231-238

MacLean, W H (1990) Mass change calculations in altered rock series. Mineral. Deposita 25. 44-49

MacLean, W.H., Barrett, T.J. (1992) Lithogeochemical techniques using immobile elements. J. Exploration Geochem (in review)

MacLean, W.H , Hoy L D (1991) Geochemistry of hydrothermally altered rocks at the Horne mine, Noranda, Quebec Econ. Geol 86. 506-528

MacLean, W.H., Kranidiotis, P. (1987) Immobile elements as monitors of mass transfer in hydrothermal alteration: Phelps Dodge massive sulfide deposit, Matagami, Quebec Econ Geol 82· 951-962

Matsuhisha, Y., Goldsmith, J R , Clayton, R N (1979) Oxygen isotope fractionation in the system quartz-albite-anorthite-water Geochim Cosmochim Acta 42 1131-1140

Matthews, A., Goldsmith, J R., Clayton, R N (1983) Oxygen isotope fractionation between zoisite and water. Geochim. Cosmochim. Acta 47. 645-654

O'Neil, J.R , Clayton, R.N., Mayeda, T K (1969) Oxygen isotope fractionation in divalent metal carbonates J Chem Phys 51 5547-5558

O'Neil, J.R., Taylor, H P. Jr. (1969) Oxygen isotope equilibrium between muscovite and water. J. Geophys. Res. 74: 6012-6022

Peccerillo, A , Taylor, S.R. (1976) Geochemistry of Eocene calc-alkaline volcanic rocks from the Kastamonu area, northern Turkey. Cont. Miner. Petrol. 68: 61-81

Péloquin, A.S., Potvin, R., Paradis, S., Laflèche, M.R , Verpaelst, P., Gibson, H.L (1990) The Blake River Group, Rouyn-Noranda area, Quebec: a stratigraphic synthesis In· Rive, M , Verpaelst, P , Gagnon, Y., Lulin, J-M., Riverin, G , Simard, A (eds) The Northwestern Quebec Polymetallic Belt: A summary of 60 years of mining exploration The Canadian Institute of Mining and Metallurgy Special Volume 43: 107-118

Pirie, I (1980) Lithogeochemical dispersion in the area of the Norbec deposit, Noranda, Quebec. M.Sc. thesis, Queens University, Kingston, Ontario. 190pp

Purdie, J.J. (1967) Lake Dufault Mines, Limited. In· Canadian Institute of Mining and Metallurgy Centennial Field Excursion, Northwestern Quebec-Northern Ontario, pp 53-57

Riverin, G , Hodgson, C.J (1980) Wall-rock alteration at the Millenbach Cu-Zn mine, Noranda, Quebec. Econ. Geol. 75· 424-444

Sakrison, H.C. (1967) Geochemical studies of the host rocks of the Lake Dufault mine, Quebec Ph D Thesis, McGill University, Montreal, Quebec. 147pp.

Spence, C.D (1967) The Noranda area. In· Canadian Institute of Mining and Metallurgy Centennial Field Excursion, Northwestern Quebec-Northern Ontario, pp 36-39

Spence, C D., de Rosen-Spence, A.F. (1975) The place of sulphide mineralization in the volcanic sequence at Noranda, Quebec. Econ. Geol. 70: 90-101

Taylor, H.P , Jr. (1968) The oxygen isotope geochemistry of igneous rocks. Contr. Mineral Petrol. 19 1-71

Ujike, O , Goodwin, A M. (1987) Geochemistry and origin of Archean felsic metavolcanic rocks, central Noranda area, Quebec, Canada. Can. J. Earth

Sci. 24 2551-2567

Valley, J.W. (1986). Stable isotope geochemistry of metamorphic rocks In Valley, J.W., Taylor, H.P.,, Jr. and O'Neil, J.R (eds.), Stable Isotopes in High Temperature Geological Processes, Mineralogical Society of America, Reviews in Mineralogy, 16· 445-489.

Von Damm, K.L., Edmond, J.M., Measures, C.I., Grant, B (1985) Chemistry of submarine hydrothermal solutions at Guaymas Basin, Gulf of California. Geochim. et Cosmochim Acta. 49 2221-2237

Wenner, D.B , Taylor, H P Jr (1971) Temperatures of serpentinization of ultramafic rocks based upon $^{18}O/^{16}O$ fractionation between coexisting serpentine and magnetite. Contrib. Mineral. Petrol 32: 165-185

APPENDIX I
GEOCHEMISTRY

SAMPLE PREPARATION

Samples were collected from the core stored at the Norbec mine and from nearby core shacks. Each sample was cut into three parts; one for a representative hand sample, one for making a thin section, and one for geochemical analyses. The portion of the sample reserved for the geochemical analyses was crushed in a Braun jaw crusher and then ground for 60 - 90 seconds in a tungsten carbide ring grinder to a powder of -200 mesh.

ANALYTICAL TECHNIQUES

Thirty grams of the powder were sent to Centre de Récherches Minérales in Sainte-Foy, Québec or to the Geochemical Laboratories of McGill University in Montreal, Quebec for chemical analyses. X-ray fluorescence analyses were carried out on fused beads prepared from the rock powders to determine major element geochemistry The beads were prepared from the fusion of a mixture of 1 gram of powder, 5 grams of lithium tetraborate, 0.3 grams of lithium fluoride, 0.01 gram of ammonium nitrate and 0.015 grams of lithium bromide. Detection limits for the major elements was 0.01%. Pressed powder pellets were made for a more accurate determination of trace element concentrations using X-ray fluorescence. These pellets were made from approximately 8 grams of powder mixed with 1 gram of binding agent and compressed under a pressure of 25 tons/in^2 for one minute. The detection limit for the trace elements was 5ppm.

Copper and Zinc analyses along with several CO_2 and Sulphur analyses were made by Activation Laboratories Ltd., Ancaster, Ontario. Supplementary CO_2 and SO_3 analyses were carried out by the Geochemical Labortories of McGill University. The LECO method using a LECO Analyser was used to determine the concentrations of these elements with detection limits of 0.02% for CO_2, and 10ppm for SO_3. Rare Earth Element (REE) concentrations were determined using neutron activation by the Centre de Récherches Minérales on representative samples of the volcanic rocks associated with the Norbec orebody.

Dr. L.D. Hoy carried out oxygen isotope analyses on 26 samples of the volcanic rocks using standard techniques of gas extractions and mass spectrometry analysis (MacLean and Hoy, 1991) at the Geotop Laboratory at the University of Montreal, Montreal, Quebec.

Table A I.1. Chemical Analyses of Wallrocks at the Norbec Mine

Hole #	Depth feet	SiO_2	TiO_2	Al_2O_3	FeO* as FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Sum	Sum less LOI	Norm Factor	Ga	Nb	Zr	Y	Sr	Rb	Ba	Co	Cu	Zn	CO_2	S
N-108																											
tuff	1597	62.5	0.51	11.2	11.1	0.04	1.50	0.78	0.63	3.05	0.07	6.24	97.64	91.40	1.094		6	122	17	9	84	500	68	1575	7222	0.56	5.95
diorite	1730	55.5	1.65	15.5	10.2	0.18	3.98	6.76	3.58	0.46	0.29	1.53	99.59	98.06	1.020		9	93	22	169	12					0.25	0.01
WR	1915	73.0	0.29	11.9	5.0	0.13		2.11	3.58	3.30	0.03	0.86	100.13	99.27	1.007		17	298	58	140	55	670	1	34	155	0.35	0.02
WR	2010	75.4	0.28	12.0	3.5	0.07	0.17	0.90	5.27	1.37	0.03	0.50	99.53	99.03	1.010		18	296	42	46	26	280	1	20	60	0.38	0.01
WR	2210	70.8	0.33	12.6	5.8	0.11	0.59	2.53	3.75	1.54	0.04	1.57	99.60	98.03	1.020		18	324	52	135	33	520	2	3	110	0.68	0.01
N-109																											
tuff	1567	58.9	0.50	10.6	12.7	0.07	0.79	3.62	1.89	2.26	0.08	4.11	95.54	91.43	1.094		4	123	31	90	67	280	160	3938	16876	1.49	5.72
WR	1607	77.1	0.27	11.2	2.8	0.06	0.24	0.50	4.44	2.48	0.03	0.41	99.52	99.11	1.009		16	278	44	46	37	560	1	17	55	0.3	0.22
WR	1835	76.7	0.27	11.5	2.6	0.05	0.12	0.77	5.03	1.92	0.02	0.41	99.38	98.97	1.010		17	270	35	49	32	440	1	12	52	0.3	0.03
diorite	2010	55.9	1.66	15.4	10.4	0.17	3.90	6.25	4.95	0.50	0.29	0.44	99.90	99.46	1.005		9	94	23	162	15					0.12	0.02
WR	2265	72.0	0.31	12.3	4.7	0.10	0.23	1.51	2.53	4.70	0.04	0.97	99.35	98.38	1.016		16	296	55	78	84	630	2	8	98	0.27	0.01
N-124																											
diorite	62	53.1	1.44	15.7	9.8	0.13	5.17	8.11	2.93	0.66	0.29	1.45	98.79	97.34	1.027	18	7	150	26	320	16						
A A	306	55.0	1.30	16.7	9.0	0.15	4.59	7.23	3.62	0.39	0.16	0.62	98.76	98.14	1.019	17	4	110	24	160	12						
A A	888	49.8	1.29	16.9	9.7	0.13	8.39	7.86	2.20	0.28	0.16	1.67	98.40	96.73	1.034	20	6	97	17	160	9						
WR	1233	76.2	0.22	10.0	3.3	0.18	0.95	3.63	1.44	1.23	0.02	2.33	99.49	97.16	1.029	14	11	260	48	47	37	220	21	31	675		
WR	1236	55.3	0.24	7.9	21.7	0.55	1.85	5.81	0.41	0.35	0.05	4.27	98.43	94.16	1.062		15	195	41	61	6	130	23	159	272	1.2	5.68
WR	1249	56.8	0.24	10.2	18.5	0.68	2.02	7.85	0.26	0.33	0.03	1.90	98.80	96.90	1.032		13	251	47	72	3	50	11	18	336	0.18	1.23
WR	1284	59.5	0.21	9.6	13.3	0.86	4.20	8.61	0.97	0.23	0.02	1.29	98.80	97.51	1.026	16	11	250	55	80	5	68	26	23	430		
WR	1429	73.1	0.23	10.2	10.1	0.05	1.21	0.17	0.16	1.25	0.01	2.84	99.30	96.45	1.037	23	12	260	39	7	25	290	37	704	112		
N-127																											
A A	644	56.6	1.31	15.5	8.2	0.16	4.25	8.02	2.84	0.59	0.15	1.15	98.81	97.66	1.024	16	5	110	24	140	17	100	36	67	30		
A A	785	55.8	0.92	16.5	7.4	0.14	3.94	8.65	4.10	0.35	0.14	1.18	99.14	97.96	1.021	18	5	120	21	210	10	110	32	44	21		
A A	964	51.6	1.29	18.6	7.4	0.20	3.66	9.78	4.22	0.72	0.18	1.28	98.94	97.66	1.024	15	7	100	20	190	20						
A A	1015	48.8	1.31	19.0	8.4	0.24	4.11	10.6	3.56	0.60	0.15	1.92	98.69	96.77	1.033	16	7	100	19	150	16						
A A	1067	47.7	1.27	18.7	9.2	0.27	3.16	13.0	2.24	0.21	0.18	2.06	97.97	95.91	1.043	18	6	99	18	220	7						
A A	1115	45.6	1.19	15.7	8.6	0.26	3.95	8.43	3.71	1.25	0.18	10.0	98.86	88.86	1.125	21	7	88	20	100	39						
WR	1280	69.1	0.31	11.8	9.7	0.07	1.48	0.15	0.26	2.55	0.03	4.02	99.45	95.43	1.048		13	332	56	19	52	280	43	283	1138	0.25	2.69
WR	1300	80.8	0.21	8.7	3.9	0.44	0.93	0.02	0.24	2.10	0.02	2.15	99.48	97.33	1.027		10	231	33	15	41	200	45	705	7104	0.23	1.19
WR	1320	54.3	0.12	5.6	22.0	0.09	2.56	0.48	0.22	0.04	0.02	6.36	91.70	85.34	1.172		3	134	29	18	3	50	140	51494	14828	2.22	7.07
WR	1334	53.0	0.06	3.4	27.0	0.06	1.66	0.14	0.01	0.03	0.02	8.23	93.56	85.33	1.172		3	61	19	16	3	50	410	49778	623	1.2	11.17
WR	1371	75.4	0.12	4.8	10.4	0.06	1.05	0.18	0.02	0.35	0.01	2.62	94.93	92.31	1.083		7	116	20	17	11	110	110	35297	2568	1.22	3.7
WR	1387	68.5	0.15	6.4	14.0	0.04	1.35	0.02	0.01	0.38	0.22	3.22	94.20	90.98	1.099		9	157	29	16	11	50	190	43535	870	0.8	3.83
WR	1422	74.5	0.21	9.2	8.7	0.04	1.24	0.06	0.13	1.00	0.01	2.33	97.39	95.06	1.052	17	12	250	49	7	22	290	43	511	53		
WR	1460	76.3	0.22	8.7	11.5	0.08	1.80	0.06	0.05	0.54	0.01	0.01	99.24	99.23	1.008		16	227	40	17	9	210	39	140	109	0.37	0.21

Hole	Depth	SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	LOI		Sum	Norm	Ga	Nb	Zr	Y	Sr	Rb	Ba	Co	Cu	Zn	CO2	S
WR	1485	76 4	0 21	8 8	9 4	0 07	1 35	0 10	0 12	0 06	0 02	1 97	98 47	96 50	1 036		17	231	44	18	12	340	37	42	52	0 22	0 06
WR	1512	67 3	0 22	9 7	14 2	0 09	2 55	0 07	0 01	0 34	0 01	3 15	97 70	94 55	1 058	22	12	260	44		8	300	69	899	148	0 37	0 06
dyke	1560	57 1	1 59	15 2	11 0	0 15	4 25	6 03	2 82	0 13	0 28	0 17	98 64	98 47	1 016		9	90	24	172	3						
N-129																											
diorite	306	53 9	1 43	15 7	9 1	0 14	5 28	8 14	2 66	0 53	0 30	0 84	98 01	97 17	1 029	21	6	150	28	350	13						
A A	936	55 0	0 98	15 6	7 8	0 17	4 77	7 71	4 81	0 20	0 16	1 13	98 38	97 25	1 028	14	7	120	24	130	8	91	35	12	27		
A A	992	42 0	1 57	21 7	8 9	0 23	5 96	11 0	1 93	1 02	0 21	3 49	97 99	94 50	1 058	24	8	120	22	220	37						
A A	1067	48 0	1 34	15 3	11 4	0 21	7 36	9 65	2 27	0 42	0 12	1 72	97 82	96 10	1 041	14	4	60	18	130	13						
A A	1114	48 3	1 19	18 0	9 2	0 19	3 16	11 3	3 28	0 48	0 15	3 33	98 56	95 23	1 050	20	6	94	16	180	14						
A A	1172 5	47 0	1 31	14 8	9 7	0 28	5 07	10 1	2 87	1 21	0 17	5 25	97 78	92 53	1 081	29	5	81	18	110	31						
A A	1222	51 0	1 21	16 7	8 9	0 38	4 69	10 7	3 90	0 27	0 10	1 75	99 57	97 82	1 022	16	5	84	17	140	10						
WR	1307	65 9	0 31	13 3	8 5	0 46	1 92	3 34	1 54	1 48	0 03	2 28	99 06	96 78	1 033	20	14	340	70	70	41	380	13	40	133		
dyke	1329	44 4	1 27	16 6	11 7	0 69	8 88	9 71	0 21	1 66	0 14	3 11	98 46	95 35	1 049		7	55	11	123	64	222	114	1549	199	0 25	0 16
WR	1357	65 2	0 31	13 4	7 3	0 64	1 77	5 47	2 15	1 65	0 02	1 94	99 80	97 86	1 022	19	13	340	76	110	52	360	16	5	119		
WR	1377	65 6	0 25	10 5	9 1	0 55	1 44	7 46	0 44	0 07	0 04	3 39	98 81	95 42	1 048		18	283	91	168	3	50	18	4	146	1 6	0 17
WR	1414	61 3	0 21	9 3	15 0	0 90	1 13	8 70	0 34	0 33	0 02	0 79	98 07	97 28	1 028	19	10	240	52	69	5	69	28	7	174		
WR	1441	61 0	0 25	9 9	17 5	1 51	2 20	1 41	0 32	0 45	0 03	3 13	97 69	94 56	1 058	16	14	260	43	13	19	84	9	52	435		
WR	1468	53 3	0 27	12 9	22 9	0 21	1 90	0 17	0 21	0 46	0 01	3 58	95 87	92 29	1 084	22	10	300	56	8	13	50	7	26	895		
WR	1583	67 8	0 34	14 2	7 2	0 11	1 78	2 14	0 29	2 94	0 05	2 59	99 41	96 82	1 033	16	15	360	70	20	96	260	8	5	267		
WR	1612	78 4	0 22	8 5	5 4	0 06	0 84	1 52	0 42	1 66	0 02	2 31	99 38	97 07	1 030		12	235	36	34	59	270	28	425	416	0 9	1 11
WR	1632	76 5	0 23	9 7	4 7	0 06	1 21	1 13	2 16	1 83	0 01	0 76	98 32	97 56	1 025	14	12	270	45	51	40	570	24	8	529		
N-141																											
WR	1406	71 8	0.19	7 0	12 5	0 13	2 83	0 77	0 65	0 07	0 01	2 80	98 76	95 96	1 042		11	189	37	13	5	50	65	5915	310	1 47	1 65
WR	1507	59 6	0 33	13 1	15 3	0 21	4.20	0 94	0 68	1 89	0 03	3 17	99 43	96 26	1.039		16	325	74	12	61	260	1	50	778	0 62	0 8
WR	1601	75 4	0.22	10.2	4 3	0 18	0 32	2.87	2 96	1 51	0 02	1 60	99 52	97 92	1 021		13	224	44	54	36	290	1	24	77	1 35	1 5
dyke	1651	56 0	1 67	15 4	9 0	0 28	3 85	6 96	5 28	0 40	0 30	0 70	99 91	99 21	1 008		8	92	23	179	9					0 35	0 01
N-163																											
WR	1109	73 0	0 25	11 3	5 8	0 09	0 88	2 69	2.17	1 36	0 02	1 77	99 26	97 49	1 026		14	258	45	106	45	520	2	70	2034	1 21	1 2
WR	1253	75 4	0 25	10 3	6 6	0 06	0 73	0 25	0 52	2 63	0 01	2 90	99 61	96 71	1 034		14	252	42	6	49	220	1	322	1603	0 27	2 04
diorite	1349	53 6	1 51	14 3	10 6	0.17	6 06	4 30	3.89	0 29	0 22	4 43	99 39	94 96	1 053		7	72	19	85	10					1 99	0 03
WR	1411	69 6	0 28	11.0	10 9	0 15	0 95	0 59	0 52	1 86	0 04	3 13	98 99	95 86	1 043		16	280	51	10	41	200	7	415	331	1 89	1 8
diorite	1487	56 0	1 64	15 4	10 0	0 19	4 67	5 95	4 54	0 41	0 28	0 60	99 63	99 03	1 010		8	94	23	179	12					0 1	0 1
N-175																											
WR	1543	75 0	0 27	11 9	2.8	0 02	0 12	1 00	6 01	0.52	0 02	1.77	99 41	97 64	1 024		17	273	52	38	17	130	4	68	10	0 82	1 69
WR	1639	74 2	0 30	12 4	3.6	0.10	0.42	1 56	5 13	1 66	0 03	0 60	100 01	99 41	1 006		18	295	52	60	24	350	1	13	56	0 4	0 06
WR	1779	74 9	0 30	12.2	3 0	0 07	0 22	1 19	4 22	3 02	0 02	0 61	99 70	99 09	1 009		17	302	43	33	46	450	1	36	67	0 6	0 01
WR	1826	72 8	0.29	12.2	3 7	0 08	0 54	1 66	3 34	2 90	0 03	1 90	99 40	97 50	1 026		16	295	56	23	66	400	1	14	51	1 01	0 07

Hole	Depth	SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI		Sum	Norm	Ga	Nb	Zr	Y	Sr	Rb	Ba	Co	Cu	Zn	CO_2	S
N-181																											
A A	28	54.4	1.30	16.7	10.2	0.17	4.83	6.60	3.82	0.42	0.17	0.55	99.13	98.58	1.014	19	5	120	29	160	13	130	43	2	39		
A A	250	54.2	1.41	15.2	9.7	0.15	4.64	6.14	4.47	0.75	0.29	1.49	98.46	96.97	1.031	18	8	150	29	250	17						
A A	496	55.9	1.32	15.6	9.4	0.15	5.67	5.57	3.34	0.39	0.14	1.20	98.64	97.44	1.026	14	5	110	23	140	14	130	33	36	39		
A A	800	49.8	1.30	17.9	9.0	0.20	4.34	11.5	2.75	0.66	0.15	1.19	98.79	97.60	1.025	18	6	100	17	190	18						
A A	1010	54.7	1.63	16.1	8.0	0.21	4.84	7.77	4.95	0.29	0.30	0.80	99.59	98.79	1.012	15	6	110	23	220	6	85	23	8	23		
A A	1024	55.5	1.30	15.1	9.5	0.09	5.50	2.93	1.11	2.02	0.19	6.19	99.38	93.19	1.073	18	8	120	26	35	59						
WR	1042	83.4	0.21	9.0	0.8	0.02	0.18	0.86	4.19	0.54	0.02	0.71	99.86	99.15	1.009	11	12	240	40	44	17	110	34	14	70		
WR	1065	72.7	0.32	12.8	5.3	0.13	0.51	2.37	2.00	1.68	0.04	1.30	99.06	97.76	1.023		14	348	57	83	47	340	13	31	103	0.35	0.41
WR	1319	73.1	0.31	12.5	4.6	0.05	0.87	0.87	5.16	0.70	0.04	1.32	99.51	98.19	1.018	17	16	370	68	45	19	200	15	13	42		
diorite	1367	55.3	1.51	15.0	9.5	0.13	5.52	5.20	3.60	0.62	0.26	1.70	98.29	96.59	1.035	21	6	98	23	190	16						
diorite	1685	54.9	1.60	15.2	9.7	0.13	3.81	7.04	3.40	0.55	0.29	1.62	98.26	96.64	1.035	19	6	110	25	210	17						
W A	1898	57.4	0.83	15.2	14.0	0.70	4.72	0.52	0.19	1.42	0.18	1.42	96.62	95.20	1.050	19	7	130	23	6	22	310	36	191	312		
W A	1940	56.9	0.78	15.0	15.7	0.21	4.33	0.38	0.04	1.09	0.16	3.05	97.65	94.60	1.057		10	116	19	22	23	450	28	364	60	0.25	0.73
Fpr-Po	2002	51.2	0.85	19.8	8.1	0.12	5.71	9.44	2.49	0.48	0.10	1.23	99.51	98.28	1.017	18	4	60	8	260	15						
W A	2033	58.7	0.80	15.6	8.2	0.48	7.72	0.61	0.79	2.52	0.18	3.79	99.34	95.55	1.047	17	8	130	22	18	53	460	21	7	199		
W A	2111	59.0	0.84	16.1	6.8	0.13	4.39	5.58	4.33	0.18	0.18	1.32	98.87	97.55	1.025	21	7	150	26	240	7	130	32	4	43		
N-190																											
tuff	1028	41.3	1.08	13.2	7.5	0.24	3.62	14.92	0.91	2.22	0.16	14.38	99.48	85.10	1.175		6	80	13	165	57	290	15	12	103	11.76	0.06
WR	1174	73.0	0.30	12.2	4.7	0.13	0.71	3.10	2.43	1.56	0.03	1.23	99.42	98.19	1.018		17	299	56	105	52	260	1	14	161	0.25	0.09
WR	1308	73.0	0.29	11.8	4.7	0.02	0.46	0.60	3.36	3.21	0.03	2.09	99.50	97.41	1.027		16	293	52	74	67	520	2	29	20	0.31	2.29
diorite	1472	55.9	1.67	15.7	10.3	0.16	3.99	6.00	5.51	0.27	0.30	0.13	99.95	99.82	1.002		8	91	23	146	9					0.15	0.01
WR	1623	75.5	0.23	8.6	5.3	0.04	0.09	0.22	1.26	2.27		2.81	96.25	93.44	1.070		13	227	38	6	55	440	2	313	22671	2.7	3
W A	1724	53.7	0.88	16.0	11.3	0.75	7.86	1.21	0.53	2.93	0.19	4.44	99.82	95.38	1.048		7	118	21	40	67	640	19	21	539	0.97	0.7
W A	1841	57.7	0.83	15.5	15.1	0.32	4.74	0.29	0.76	1.50	0.18	2.73	99.64	96.91	1.032		8	115	18	6	27	490	26	70	142	0.29	0.13
N-224																											
A A	43	63.4	1.23	14.0	6.0	0.18	3.16	5.49	4.04	0.38	0.15	0.99	98.98	97.99	1.021	13	6	100	23	110	14						
A A	249	48.9	0.92	14.7	10.4	0.18	7.40	11.0	1.73	0.49	0.08	2.37	98.21	95.84	1.043	17	5	69	21	130	15						
A A	531	48.0	1.29	18.8	8.8	0.19	5.66	9.42	3.03	1.06	0.17	2.43	98.83	96.40	1.037	19	8	100	21	190	32						
WR	779	79.8	0.20	8.9	1.8	0.04	0.48	2.12	1.13	2.21	0.01	3.08	99.70	96.62	1.035	10	11	230	40	17	65	270	21	65	26		
WR	951	77.6	0.21	11.3	2.4	0.05	0.24	0.76	4.69	1.75	0.02	0.75	99.79	99.04	1.010	16	13	310	60	73	38	400	30	29	79		
W A	992	58.9	1.26	14.6	8.2	0.24	3.99	5.34	4.53	0.43	0.17	0.78	98.47	97.69	1.024	15	7	120	28	120	13	120	27	16	59		
rhyolite	1180	71.2	0.29	12.4	4.3	0.06	0.68	5.01	2.05	0.32	0.05	1.14	97.54	96.40	1.037		12	265	48	168	6	130	27	44	29	0.12	0.28
WA81-3																											
W A	274	59.8	1.07	16.2	6.4	0.11	2.75	3.78	7.21	0.24	0.26	0.74	98.60	97.86	1.022	19	9	190	36	64	5	100	31	132	40		
W A	536	56.9	1.13	15.4	8.0	0.15	4.26	6.32	5.01	0.58	0.13	0.54	98.39	97.85	1.022	15	5	120	23	150	10	200	38	50	33		
W A	890	62.6	0.98	14.7	7.0	0.16	2.60	2.90	6.23	0.13	0.32	0.92	98.56	97.64	1.024	22	10	230	45	150	4						
UAR	1120	70.4	0.76	12.5	4.9	0.09	1.54	1.88	5.51	0.10	0.19	0.65	98.48	97.83	1.022	21	11	260	53	64		50	21	5	47		
UAR	1516	76.3	0.17	11.7	3.0	0.04	0.50	0.69	4.88	1.18	0.02	1.31	99.81	98.50	1.015	18	16	320	71	35	29						

Hole	Depth	SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	LOI		Sum	Norm	Ga	Nb	Zr	Y	Sr	Rb	Ba	Co	Cu	Zn	CO2	S
U A P	1870	47 4	0 72	15 8	9 7	0 17	8 78	11 3	1 47	0 37	0 06	2 40	98 19	95 79	1 044	18	3	47	15	130	12						
U A R	2350	59 4	1 02	13 6	10 1	0 29	4 37	1 84	2 61	1 64	0 35	1 70	96 90	95 20	1 050	20	9	190	43	73	23						
L A R	2800	73 4	0 28	11 7	3 9	0 08	0 89	1 23	4 84	0 67	0 04	1 38	98 40	97 02	1 031	17	14	320	63	67	12	320	18	21	49		
L A R	3290	75 9	0 30	11 2	3 6	0 10	1 61	0 53	3 90	0 49	0 04	1 41	99 05	97 64	1 024	15	15	340	63	50	11	50	14	38	205		
L A R	3550	60 2	1 13	14 8	7 3	0 15	4 05	3 50	4 21	0 46	0 20	2 39	98 34	95 95	1 042	19	8	210	39	170	11						
L A R	3570	58 7	1 44	14 8	8 8	0 22	3 55	3 14	5 60	0 20	0 30	1 71	98 46	96 75	1 034	18	7	140	33	150	6						
L A R	3747	74 3	0 29	11 6	4 2	0 07	2 23	0 29	2 70	1 14	0 03	1 97	98 81	96 84	1 033	17	15	330	63	18	20						
R R A	4320	65 6	0 88	13 6	6 9	0 14	3 04	1 31	4 47	0 70	0 23	1 86	98 69	96 83	1 033	21	11	220	49	42	14						
R R A	4611	65 4	0 94	13 9	6 4	0 11	2 12	2 53	5 99	0 12	0 25	1 20	98 96	97 76	1 023	21	11	210	46	100	5						

LEGEND

A A = Amulet Andesite
W R = Waite Rhyolite
W A = Waite Andesite
U A R = Upper Amulet Rhyolite
L A R = Lower Amulet Rhyolite
R R A = Rusty Ridge Andesite

Table A I:2. Rare Earth Element Analyses of the Hosting Volcanic Rocks in ppm.

Hole	Depth feet	La	Ce	Nd	Sm	Eu	Tb	Ho	Yb	Lu
N-127										
A A	644	8.1	20	14	3.2	1.2	0.5	0.7	2.2	0.36
A A	1067	7.7	20	14	3.1	1	0.5	0.6	1.5	0.25
N-129										
A A	992	9.9	26	17	3.9	1.5	0.7	0.7	1.9	0.3
W R	1307	29	73	42	10	2.4	1.8	2.7	7.4	1.2
W R	1357	30	73	42	10	2.6	1.8	2.5	7.1	1.2
W R	1414	18	42	25	6.6	1.7	1.3	1.8	5	0.6
W R	1441	18	44	25	6.5	1.9	1.2	1.6	4.6	0.77
W R	1468	20	53	32	7.4	1.5	1.6	2.1	6	0.98
W R	1583	31	77	45	11	2.4	1.9	2.5	7.1	1.2
W R	1632	18	45	27	6.8	2.5	1.2	1.8	4.6	0.73
N-224										
A A	249	4.4	11	9	2.4	0.9	0.6	0.7	2	0.34
W R	779	16	37	21	5.1	1.1	1	1.3	4.1	0.71
W A	992	9.7	25	14	3.6	1.2	0.7	0.8	2.6	0.43
WA81-3										
W A	274	15	36	21	5.1	1.4	0.9	1	3.1	0.55
W A	536	12	30	18	3.9	1.2	0.7	1	2.1	0.38
U A R	890	18	47	29	7.1	2	1.3	1.8	4.2	0.7
U A R	1516	23	57	33	8.9	1.5	1.8	2.5	7.3	1.3
U A R	2350	17	44	25	6.5	1.5	1.2	1.4	4	0.69
L A R	2800	28	64	36	9.1	2	1.6	2.2	6.4	1.1
L A R	3570	12	29	19	4.9	1.5	0.9	1.2	3.1	0.54
R R A	4320	20	49	29	7	1.3	1.3	1.7	4.4	0.75
		La	**Ce**	**Nd**	**Sm**	**Eu**	**Tb**	**Ho**	**Yb**	**Lu**
chondrite*		**0.245**	**0.638**	**0.474**	**0.154**	**0.058**	**0.0375**	**0.0567**	**0.165**	**0.0254**

*Chondrite abundances from Evensen et al (1978)

Normalized Rare Earth Element Analyses

Hole	Depth feet	La	Ce	Nd	Sm	Eu	Tb	Ho	Yb	Lu	(La/Yb)n
N-127											
A A	644	33.1	31.3	29.5	20.8	20.7	13.3	12.3	13.3	14.2	2.48
A A	1067	31.4	31.3	29.5	20.1	17.2	13.3	10.6	9.1	9.8	3.46
N-129											
A A	992	40.4	40.8	35.9	25.3	25.9	18.7	12.3	11.5	11.8	3.51
W R	1307	118.4	114.4	88.6	64.9	41.4	48.0	47.6	44.8	47.2	2.64
W R	1357	122.4	114.4	88.6	64.9	44.8	48.0	44.1	43.0	47.2	2.85
W R	1414	73.5	65.8	52.7	42.9	29.3	34.7	31.7	30.3	23.6	2.42
W R	1441	73.5	69.0	52.7	42.2	32.8	32.0	28.2	27.9	30.3	2.64
W R	1468	81.6	83.1	67.5	48.1	25.9	42.7	37.0	36.4	38.6	2.24
W R	1583	126.5	120.7	94.9	71.4	41.4	50.7	44.1	43.0	47.2	2.94
W R	1632	73.5	70.5	57.0	44.2	43.1	32.0	31.7	27.9	28.7	2.64
N-224											
A A	249	18.0	17.2	19.0	15.6	15.5	16.0	12.3	12.1	13.4	1.48
W R	779	65.3	58.0	44.3	33.1	19.0	26.7	22.9	24.8	28.0	2.63
W A	992	39.6	39.2	29.5	23.4	20.7	18.7	14.1	15.8	16.9	2.51
WA81-3											
W A	274	61.2	56.4	44.3	33.1	24.1	24.0	17.6	18.8	21.7	3.26
W A	536	49.0	47.0	38.0	25.3	20.7	18.7	17.6	12.7	15.0	3.85
U A R	890	73.5	73.7	61.2	46.1	34.5	34.7	31.7	25.5	27.6	2.89
U A R	1516	93.9	89.3	69.6	57.8	25.9	48.0	44.1	44.2	51.2	2.12
U A R	2350	69.4	69.0	52.7	42.2	25.9	32.0	24.7	24.2	27.2	2.86
L A R	2800	114.3	100.3	75.9	59.1	34.5	42.7	38.8	38.8	43.3	2.95
L A R	3570	49.0	45.5	40.1	31.8	25.9	24.0	21.2	18.8	21.3	2.61
R R A	4320	81.6	76.8	61.2	45.5	22.4	34.7	30.0	26.7	29.5	3.06

AA= Amulet Andesite, WR=Waite Rhyolite, WA=Waite Andesite, UAR=Upper Amulet Rhyolite, LAR=Lower Amulet Rhyolite, RRA=Rusty Ridge Andesite
Samples analysed at the Centre de Recherches Minerales in Ste Foy, Quebec

APPENDIX II

Procedures and Calculations

Mass Change Calculations

The following is an outline of the procedures given in MacLean and Kranidiotis (1987), and MacLean (1990) for calculating the mass changes of elements in a sample. All calculations were carried out on a spreadsheet computer program. At this stage, immobility has been proven for at least two elements (Al_2O_3 and Zr in this case), fractionation and alteration lines have been plotted to determine the precursor composition for the altered unit. With the geochemical analysis of the altered sample, the following was done:

1) normalize the sample to SUM=100 on an LOI, H_2O, CO_2, S free basis with iron as FeO*

2) an Enrichment Factor (E F) was determined for each sample from the equation

$$\text{E F} = \frac{\text{Immobile Element in precursor}}{\text{Immobile Element in altered rock,}}$$

In this case Zr was used as the immobile element.

3) each major element (as an oxide) in the altered sample was multiplied by the E.F estimate to show the Reconstructed Composition of the sample

4) the mass changes are the difference between the Reconstructed Composition and the Precursor and have the units wt%.

Normative Mineral Program

A cation % normative mineral program was designed, using Lotus 123, to determine the normative concentrations of alteration minerals in the altered and fresh samples The program was designed in a similar fashion to the Niggli igneous normative programs. It used the following alteration minerals in the order: leucoxene (TiO_2), albite ($NaAlSi_3O_8$), sericite ($KAl_3Si_3O_8(OH)_2$), apatite ($Ca_5(PO_4)_3(OH)$), chlorite ($(Mg,Mn,Fe)_9Al_6Si_5O_{20}(OH)_{16}$), zoisite ($Ca_2Al_3Si_3O_{12}(OH)$), kaolinite ($Al_2Si_2O_5(OH)$), talc ($Mg_3Si_4O_{10}(OH)_2$), calcite ($CaCO_3$), pyrite ($FeS_2$), and quartz ($SiO_2$). The following procedures were carried out:

1) normalize the sample to SUM=100 on an LOI, H_2O, CO_2, S free basis with $Fe_2O_3^*$ as FeO^*, use only the major oxides and metal analyses above 0.01 wt%

2) divide each oxide or trace metal by its molecular mass based on a single cation (i.e. Al_2O_3 becomes $AlO_{1.5}$) to determine the number of moles of each cation present. Sum this column.

3) calculate the per cent each cation contributes to the sum of the moles. This will determine the cation % used to make the minerals

4) the alteration minerals listed above were made, in the given order, with a cation acting as the limiting factor. (i.e. for Albite, all of the Na_2O was used with an equivalent amounts of Al_2O_3, and three times the concentration of SiO_2). A flow sheet kept a tally of the cations.

5) the sum of the minerals is 100, therefore, the quantity of each is its percentage in the rock.

6) for later calculations, the normative minerals expressed as cation % were changed to weight % by dividing the formula weight of the mineral by the number of cations and then normalized to the sum 100.

Table A II:1. Mass Change calculations for the Waite Rhyolite at the Norbec mine.

WAITE RHYOLITE GEOCHEMICAL DATA - NORMALIZED LOI-FREE

Hole	Depth	SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Zr E.F.	Al E.F.	Ga	Nb	Zr	Y	Sr	Rb
PRECURSOR		76.2	0.29	12.25	3.80	0.04	0.51	0.51	5.75	0.63	0.03					313			
N-108	1915	73.5	0.29	11.98	5.01	0.13	0.00	2.13	3.61	3.32	0.03	1.043	1.023		17	300	58	141	55
	2010	76.2	0.28	12.08	3.57	0.07	0.17	0.91	5.32	1.38	0.03	1.047	1.014		18	299	42	46	26
	2210	72.2	0.34	12.83	5.92	0.11	0.60	2.58	3.83	1.57	0.04	0.947	0.955		18	331	53	138	34
N-109	1607	77.8	0.27	11.31	2.83	0.06	0.24	0.50	4.48	2.50	0.03	1.116	1.083		16	280	44	46	37
	1835	77.5	0.27	11.57	2.65	0.05	0.12	0.78	5.08	1.94	0.02	1.147	1.059		17	273	35	50	32
	2265	73.2	0.32	12.45	4.81	0.10	0.23	1.53	2.57	4.78	0.04	1.040	0.984		16	301	56	79	85
N-124	1233	78.43	0.23	10.29	3.38	0.19	0.98	3.74	1.48	1.27	0.02	1.170	1.190	14	11	268	49	48	38
	1236	58.74	0.25	8.34	23.09	0.58	1.96	6.17	0.44	0.37	0.05	1.511	1.469		16	207	44	65	6
	1249	58.56	0.25	10.57	19.10	0.70	2.08	8.10	0.27	0.34	0.03	1.208	1.159		13	259	49	74	3
	1284	61.02	0.22	9.83	13.66	0.88	4.31	8.83	0.99	0.24	0.02	1.221	1.246	16	11	256	56	82	5
	1429	75.79	0.24	10.57	10.45	0.05	1.25	0.18	0.17	1.30	0.01	1.161	1.158	24	12	270	40	7	26
N-127	1280	72.43	0.32	12.33	10.16	0.07	1.55	0.16	0.27	2.67	0.03	0.900	0.993		14	348	59	20	54
	1300	82.97	0.22	8.95	4.01	0.45	0.96	0.02	0.25	2.16	0.02	1.319	1.369		10	237	34	15	42
	1320	63.59	0.14	6.52	25.75	0.11	3.00	0.56	0.26	0.05	0.02	1.993	1.880		4	157	34	21	4
	1334	62.06	0.07	4.01	31.61	0.07	1.95	0.16	0.01	0.04	0.02	4.379	3.057		4	71	22	19	4
	1371	81.66	0.13	5.15	11.25	0.07	1.14	0.20	0.02	0.38	0.01	2.491	2.381		8	126	22	18	12
	1387	75.24	0.16	6.99	15.38	0.04	1.48	0.02	0.01	0.42	0.24	1.814	1.752		10	173	32	18	12
	1422	78.37	0.22	9.70	9.11	0.04	1.30	0.06	0.14	1.05	0.01	1.190	1.263	18	13	263	52	7	23
	1460	76.93	0.22	8.74	11.55	0.08	1.81	0.06	0.05	0.54	0.01	1.368	1.402		16	229	40	17	9
	1485	79.17	0.22	9.13	9.70	0.07	1.40	0.10	0.12	0.06	0.02	1.308	1.342		18	239	46	19	12
	1512	71.18	0.23	10.30	15.04	0.10	2.70	0.07	0.01	0.36	0.01	1.138	1.189	23	13	275	47	0	8
N-129	1307	68.10	0.32	13.74	8.78	0.48	1.98	3.45	1.59	1.53	0.03	0.891	0.891	21	14	351	72	72	42
	1357	66.62	0.32	13.69	7.41	0.65	1.81	5.59	2.20	1.69	0.02	0.901	0.895	19	13	347	78	112	53
	1377	68.72	0.26	11.04	9.51	0.58	1.51	7.82	0.46	0.07	0.04	1.055	1.110		19	297	95	197	3
	1414	63.01	0.22	9.58	15.45	0.93	1.16	8.94	0.35	0.34	0.02	1.269	1.279	20	10	247	53	71	5
	1441	64.51	0.26	10.50	18.46	1.60	2.33	1.49	0.34	0.48	0.03	1.138	1.167	17	15	275	45	14	20
	1468	57.75	0.29	13.98	24.77	0.23	2.06	0.18	0.23	0.50	0.01	0.963	0.876	24	11	325	61	9	14
	1583	70.02	0.35	14.67	7.41	0.11	1.84	2.21	0.30	3.04	0.05	0.842	0.835	17	15	372	72	21	99
	1612	80.79	0.23	8.77	5.56	0.06	0.87	1.57	0.43	1.71	0.02	1.293	1.397		12	242	37	35	61
	1632	78.42	0.24	9.94	4.84	0.06	1.24	1.16	2.21	1.88	0.01	1.131	1.232	14	12	277	46	52	41
N-141	1406	74.78	0.20	7.31	13.07	0.14	2.95	0.80	0.68	0.07	0.01	1.589	1.677		11	197	39	14	5
	1507	61.91	0.34	13.63	15.86	0.22	4.36	0.98	0.71	1.96	0.03	0.927	0.899		17	338	77	12	63
	1601	76.96	0.22	10.40	4.39	0.18	0.33	2.93	3.02	1.54	0.02	1.368	1.178		13	229	45	55	37
N-163	1109	74.91	0.26	11.54	5.90	0.09	0.90	2.76	2.23	1.40	0.02	1.183	1.062		14	265	46	109	46
	1253	77.91	0.26	10.66	6.82	0.06	0.75	0.26	0.54	2.72	0.01	1.201	1.149		14	261	43	6	51
	1411	72.59	0.29	11.49	11.35	0.16	0.99	0.62	0.54	1.94	0.04	1.072	1.067		17	292	53	10	43
N-181	1042	84.11	0.21	9.03	0.79	0.02	0.18	0.87	4.23	0.54	0.02	1.293	1.357	11	12	242	40	44	17
	1065	74.35	0.33	13.06	5.38	0.13	0.52	2.42	2.05	1.72	0.04	0.879	0.938		14	356	58	85	48
	1319	74.45	0.32	12.73	4.67	0.05	0.89	0.89	5.26	0.71	0.04	0.831	0.962	17	16	377	69	46	19
N-190	1174	74.38	0.31	12.47	4.75	0.13	0.72	3.16	2.47	1.59	0.03	1.028	0.983		17	305	57	107	53
	1308	74.92	0.30	12.12	4.77	0.02	0.47	0.62	3.45	3.30	0.03	1.041	1.010		16	301	53	76	69
	1623	80.81	0.25	9.17	5.62	0.04	0.10	0.24	1.35	2.43	0.00	1.288	1.336		14	243	41	6	59
N-224	779	82.59	0.21	9.17	1.84	0.04	0.50	2.19	1.17	2.29	0.01	1.315	1.336	10	11	238	41	18	67
	951	78.35	0.21	11.41	2.44	0.05	0.24	0.77	4.74	1.77	0.02	1.000	1.074	16	13	313	61	74	38
	1180	73.89	0.30	12.86	4.47	0.06	0.71	5.20	2.13	0.33	0.05	1.139	0.952		12	275	50	174	6

Table A II:1 continued; Mass Changes in the Waite Rhyolite.

Hole	Depth feet	SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	SUM
N-108	1915	0.5	0.01	0.24	1.42	0.10	-0.51	1.71	-1.99	2.84	0.00	4.27
	2010	3.6	0.01	0.40	-0.06	0.03	-0.33	0.44	-0.18	0.82	0.00	4.72
	2210	-7.8	0.03	-0.10	1.80	0.07	0.06	1.93	-2.13	0.86	0.01	-5.30
N-109	1607	10.6	0.01	0.37	-0.65	0.03	-0.24	0.05	-0.75	2.16	0.00	11.59
	1835	12.7	0.02	1.02	-0.76	0.02	-0.37	0.38	0.08	1.60	-0.01	14.73
	2265	-0.1	0.04	0.70	1.20	0.07	-0.27	1.09	-3.07	4.34	0.01	4.03
N-124	1233	15.5	-0.03	-0.21	0.15	0.18	0.63	3.86	-4.02	0.85	-0.01	16.96
	1236	12.6	0.10	0.35	31.10	0.84	2.46	8.82	-5.09	-0.07	0.05	**51.15**
	1249	-5.4	0.01	0.52	19.27	0.81	2.01	9.28	-5.43	-0.22	0.01	20.84
	1284	-1.7	-0.03	-0.24	12.88	1.04	4.75	10.27	-4.54	-0.34	0.00	22.08
	1429	11.8	-0.01	0.03	8.33	0.02	0.95	-0.31	-5.56	0.87	-0.02	16.12
N-127	1280	-11.0	0.00	-1.15	5.34	0.03	0.89	-0.37	-5.50	1.77	0.00	-10.03
	1300	33.2	-0.01	-0.45	1.49	0.56	0.75	-0.48	-5.42	2.22	0.00	31.87
	1320	50.6	-0.01	0.74	47.54	0.17	5.47	0.61	-5.24	-0.54	0.02	**99.33**
	1334	195.6	0.02	5.30	134.60	0.27	8.01	0.21	-5.70	-0.48	0.07	**337.86**
	1371	127.2	0.03	0.57	24.22	0.12	2.32	-0.02	-5.70	0.31	0.00	**149.07**
	1387	60.3	0.01	0.43	24.10	0.04	2.18	-0.47	-5.73	0.13	0.41	**81.37**
	1422	17.1	-0.03	-0.71	7.04	0.01	1.04	-0.43	-5.59	0.62	-0.02	19.02
	1460	29.1	0.01	0.30	12.00	0.07	1.97	-0.43	-5.68	0.11	-0.02	36.82
	1485	27.3	-0.01	-0.31	8.88	0.05	1.32	-0.37	-5.59	-0.55	0.00	30.76
	1512	4.8	-0.03	-0.52	13.32	0.07	2.56	-0.43	-5.74	-0.22	-0.02	13.82
N-129	1307	-15.5	0.00	-0.01	4.02	0.38	1.26	2.56	-4.33	0.73	0.00	-10.91
	1357	-16.2	0.00	0.09	2.88	0.55	1.12	4.53	-3.77	0.89	-0.01	-9.91
	1377	-3.7	-0.01	-0.60	6.23	0.57	1.08	7.74	-5.26	-0.55	0.01	5.54
	1414	3.8	-0.02	-0.10	15.80	1.13	0.96	10.84	-5.31	-0.20	0.00	26.87
	1441	-2.8	0.01	-0.30	17.22	1.78	2.14	1.19	-5.36	-0.09	0.01	13.84
	1468	-20.6	-0.01	1.21	20.05	0.18	1.47	-0.33	-5.53	-0.15	-0.02	-3.71
	1583	-17.2	0.01	0.10	2.44	0.06	1.04	1.35	-5.50	1.93	0.01	-15.82
	1612	28.3	0.00	-0.92	3.39	0.04	0.61	1.51	-5.19	1.58	0.00	29.29
	1632	12.5	-0.02	-1.01	1.68	0.03	0.89	0.80	-3.25	1.49	-0.02	13.09
N-141	1406	42.7	0.02	-0.64	16.97	0.18	4.18	0.77	-4.67	-0.51	-0.01	**58.92**
	1507	-18.8	0.03	0.39	10.91	0.16	3.53	0.40	-5.10	1.19	0.00	-7.29
	1601	29.1	0.02	1.97	2.21	0.21	-0.06	3.50	-1.61	1.48	0.00	**36.83**
N-163	1109	12.4	0.01	1.40	3.18	0.07	0.56	2.75	-3.12	1.02	-0.01	18.27
	1253	17.4	0.02	0.56	4.40	0.03	0.40	-0.20	-5.10	2.64	-0.02	20.12
	1411	1.6	0.02	0.06	8.36	0.13	0.55	0.15	-5.17	1.45	0.01	7.16
N-181	1042	32.6	-0.02	-0.58	-2.78	-0.01	-0.28	0.61	-0.29	0.07	0.00	29.31
	1065	-10.8	0.00	-0.76	0.93	0.08	-0.05	1.62	-3.95	0.88	0.01	-12.08
	1319	-14.4	-0.03	-1.68	0.08	0.00	0.23	0.23	-1.38	-0.04	0.00	-16.94
N-190	1174	0.3	0.02	0.56	1.08	0.10	0.23	2.74	-3.21	1.00	0.00	2.79
	1308	1.8	0.02	0.37	1.17	-0.02	-0.02	0.13	-2.16	2.80	0.00	4.06
	1623	27.9	0.03	-0.43	3.44	0.02	-0.39	-0.21	-4.01	2.50	-0.03	28.84
N-224	779	32.4	-0.02	-0.19	-1.39	0.01	0.14	2.38	-4.21	2.38	-0.02	31.48
	951	2.2	-0.08	-0.84	-1.36	0.01	-0.27	0.26	-1.01	1.14	-0.01	0.00
	1180	7.9	0.05	2.40	1.29	0.03	0.29	5.41	-3.33	-0.25	0.03	13.86

Table A II:1b Mass Change calculations for the Waite Andesite at the Norbec Mine.

WAITE ANDESITE GEOCHEMICAL DATA - NORMALIZED LOI-FREE

Hole	Depth feet	SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Zr corr	Al corr	Ga	Nb	Zr	Y	Sr	Rb
Precursor		60.40	1 08	15 73	7 70	0 19	4 29	5 59	4 54	0 31	0 18					135			
N-181																			
WA	1898	60 3	0 87	15 97	14 75	0 74	4 96	0 55	0 20	1 49	0 19	0 989	1 067	20	7	137	24	6	23
WA	1940	60 2	0 82	15 83	16 59	0 22	4 58	0 40	0 04	1 15	0 17	1 101	0 948		11	123	20	23	24
WA	2033	61 4	0 84	16 33	8 53	0 50	8 08	0 64	0 83	2 64	0.19	0 992	1 843	18	8	136	23	19	55
WA	2111	60 5	0 86	16 50	6 99	0 13	4 50	5 72	4 44	0 18	0.18	0 878	2 249	22	7	154	27	246	7
N-190																			
WA	1724	56 3	0 92	16 81	11 85	0 79	8 24	1 27	0 56	3.07	0 20	1 091	1 328		7	124	22	42	70
WA	1841	59 5	0 86	15.98	15 62	0 33	4 89	0 30	0 78	1 55	0 19	1 138	1 007		8	119	19	6	28
N-224																			
WA	992	60 3	1 29	14 95	8 42	0 25	4 08	5 47	4 64	0 44	0 17	1 099	1 868	15	7	123	29	123	13
WA81-3																			
WA	274	61 1	1 09	16.55	6 58	0 11	2 81	3 86	7 37	0 25	0 27	0 695	2 389	19	9	194	37	65	5
WA	536	58 1	1 15	15 74	8 15	0 15	4 35	6 46	5 12	0 59	0.13	1 101	1 930	15	5	123	24	153	10
WA	890	64.1	1 00	15 06	7.19	0 16	2 66	2 97	6 38	0 13	0 33	0 573	2 188	23	10	236	46	154	4

MASS CHANGES - WAITE ANDESITE ONLY

Hole	Depth	SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	SUM
N-181												
WA		-0 79	-0 22	0 05	6 88	0 54	0 61	-5 05	-4 34	1 16	0 01	-1 15
WA		5 87	-0 17	1 59	10 57	0 05	0 75	-5 15	-4 49	0 96	0 01	10 08
WA		0.56	-0 25	0 47	0 77	0 31	3 73	-4 96	-3 72	2.31	0 01	-0 78
WA		-7 30	-0 32	-1 24	-1 56	-0 07	-0 34	-0 57	-0 64	-0 15	-0 02	-12 21
N-190												
WA		1 04	-0 07	2 61	5 23	0 67	4 70	-4 21	-3 93	3 04	0 04	9 11
WA		7 29	-0 11	2 45	10 07	0 19	1 27	-5 25	-3 65	1 45	0 03	13 75
N-224												
WA		5 86	0 34	0 70	1 55	0 08	0 20	0 42	0 56	0 17	0 01	9 89

Table A II2. Alteration Normative Mineral Assemblage Program for the Waite Rhyolite data set.

DDH		N-108			N-109			N-124					N-127			
Feet		1915	2010	2210	1607	1835	2265	1233	1236	1249	1284	1429	1280	1300	1320	1334
	GMM*															
SiO2	60.09	73.51	76.18	72.18	77.77	77.52	73.17	78.43	58.74	58.56	61.02	75.79	72.43	82.97	63.59	62.06
TiO2	79.88	0.29	0.28	0.34	0.27	0.27	0.32	0.23	0.25	0.25	0.22	0.24	0.32	0.22	0.14	0.07
Al2O3	50.98	11.98	12.08	12.83	11.31	11.57	12.45	10.29	8.34	10.57	9.83	10.57	12.33	8.95	6.52	4.01
Fe2O3	79.85	5.01	3.57	5.92	2.83	2.65	4.81	3.38	23.09	19.10	13.66	10.45	10.16	4.01	25.75	31.61
MnO	70.94	0.13	0.07	0.11	0.06	0.05	0.10	0.19	0.58	0.70	0.88	0.05	0.07	0.45	0.11	0.07
MgO	40.31	0.00	0.17	0.60	0.24	0.12	0.23	0.98	1.96	2.08	4.31	1.25	1.55	0.96	3.00	1.95
CaO	56.08	2.13	0.91	2.58	0.50	0.78	1.53	3.74	6.17	8.10	8.83	0.18	0.16	0.02	0.56	0.16
Na2O	30.99	3.61	5.32	3.83	4.48	5.08	2.57	1.48	0.44	0.27	0.99	0.17	0.27	0.25	0.26	0.01
K2O	47.09	3.32	1.38	1.57	2.50	1.94	4.76	1.27	0.37	0.34	0.24	1.30	2.67	2.16	0.05	0.04
P2O5	70.98	0.03	0.03	0.04	0.03	0.02	0.04	0.02	0.05	0.03	0.02	0.01	0.03	0.02	0.02	0.02
SUM		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
* single cation																
Number of Moles of Cation																
Si		1.2233	1.2677	1.2012	1.2943	1.2900	1.2176	1.3052	0.9775	0.9746	1.0155	1.2612	1.2053	1.3807	1.0583	1.0328
Ti		0.0037	0.0035	0.0042	0.0034	0.0034	0.0039	0.0028	0.0032	0.0031	0.0027	0.0030	0.0041	0.0027	0.0018	0.0009
Al		0.2349	0.2369	0.2517	0.2219	0.2269	0.2442	0.2019	0.1635	0.2073	0.1929	0.2074	0.2419	0.1755	0.1278	0.0786
Fe		0.0697	0.0498	0.0823	0.0393	0.0368	0.0669	0.0471	0.3214	0.2658	0.1901	0.1454	0.1414	0.0559	0.3584	0.4399
Mn		0.0018	0.0010	0.0016	0.0009	0.0007	0.0014	0.0026	0.0082	0.0099	0.0124	0.0007	0.0010	0.0064	0.0015	0.0010
Mg		0.0000	0.0043	0.0149	0.0060	0.0030	0.0058	0.0243	0.0487	0.0517	0.1069	0.0311	0.0385	0.0237	0.0744	0.0483
Ca		0.0379	0.0162	0.0460	0.0090	0.0139	0.0274	0.0666	0.1100	0.1445	0.1575	0.0031	0.0028	0.0004	0.0100	0.0029
Na		0.1164	0.1717	0.1234	0.1446	0.1640	0.0830	0.0478	0.0141	0.0087	0.0321	0.0054	0.0088	0.0080	0.0083	0.0004
K		0.0706	0.0294	0.0334	0.0531	0.0412	0.1015	0.0269	0.0079	0.0072	0.0050	0.0275	0.0567	0.0458	0.0010	0.0007
P		0.0004	0.0004	0.0006	0.0004	0.0003	0.0006	0.0003	0.0007	0.0004	0.0003	0.0001	0.0004	0.0003	0.0003	0.0003
SUM		1.7587	1.7809	1.7594	1.7728	1.7803	1.7523	1.7255	1.6553	1.6731	1.7153	1.6850	1.7010	1.6994	1.6419	1.6059
Cation %																
Si		69.5559	71.1848	68.2742	73.0051	72.4615	69.4850	75.6428	59.0531	58.2500	59.1993	74.8487	70.8612	81.2508	64.4568	64.3152
Ti		0.2079	0.1988	0.2395	0.1924	0.1918	0.2251	0.1643	0.1928	0.1853	0.1572	0.1772	0.2391	0.1590	0.1072	0.0548
Al		13.3590	13.3021	14.3071	12.5147	12.7470	13.9386	11.7008	9.8790	12.3889	11.2466	12.3103	14.2228	10.3301	7.7837	4.8955
Fe		3.9621	2.7936	4.6803	2.2179	2.0695	3.8187	2.7272	19.4157	15.8844	11.0836	8.6318	8.3107	3.2869	21.8310	27.3949
Mn		0.1050	0.0559	0.0899	0.0481	0.0400	0.0818	0.1514	0.4974	0.5912	0.7248	0.0434	0.0608	0.3750	0.0905	0.0617
Mg		0.0000	0.2391	0.8486	0.3389	0.1690	0.3310	1.4058	2.9444	3.0908	6.2293	1.8469	2.2618	1.3949	4.5325	3.0051
Ca		2.1551	0.9100	2.6157	0.5074	0.7793	1.5619	3.8611	6.6468	8.6336	9.1790	0.1865	0.1648	0.0216	0.6109	0.1822
Na		6.6169	9.6422	7.0159	8.1541	9.2119	4.7357	2.7718	0.8488	0.5175	1.8713	0.3177	0.5168	0.4682	0.5067	0.0235
K		4.0140	1.6496	1.8961	2.9973	2.3141	5.7896	1.5581	0.4768	0.4322	0.2920	1.6332	3.3359	2.6964	0.0606	0.0465
P		0.0242	0.0240	0.0327	0.0241	0.0160	0.0327	0.0168	0.0452	0.0261	0.0168	0.0043	0.0260	0.0170	0.0201	0.0206
SUM		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Book-keeping for formation of normative minerals																
Si(Total)		69.5559	71.1848	68.2742	73.0051	72.4615	69.4850	75.6428	59.0531	58.2500	59.1993	74.8487	70.8612	81.2508	64.4568	64.3152
Si(Ab)		49.7052	42.2581	47.2267	48.5429	44.8259	55.2780	67.3275	56.5067	56.6976	53.5853	73.8957	69.3107	79.8461	62.9369	64.2445
Si(Ser)		42.9631	38.5983	41.5383	44.1823	41.2908	46.0751	62.6532	55.0762	55.4009	52.7093	68.9960	59.3029	71.7570	62.7550	64.1051
Si(Chl)		42.9631	38.5983	40.2026	44.1823	41.2908	46.0751	60.2730	48.7432	46.5886	45.6266	63.1504	56.2211	70.2796	56.8423	60.1614
Si(Zoi)		42.9631	38.5983	40.2026	44.1823	41.2908	46.0751	58.8745	48.7432	46.5886	45.6266	63.0722	56.2211	70.2796	56.8423	60.1614
Si(Kaol)		42.9631	38.5983	40.2026	44.1823	41.2908	46.0751	58.8745	48.7432	46.5886	45.6266	63.0722	56.2211	70.2796	56.8423	60.1614
Si(Talc)		42.8232	38.2049	40.2026	43.6663	41.0122	45.5248	58.8745	48.7432	46.5886	45.6266	63.0722	56.2211	70.2796	56.8423	60.1614
Si(Qtz)		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Book-keeping for formation of normative minerals

Al(Total)	13 3590	13 3021	14.3071	12 5147	12 7470	13 9386	11.7008	9 8790	12 3889	11 2466	12 3103	14 2228	10 3301	7 7837	4 8955
Al(Ab)	6 7421	3 6599	7 2913	4 3606	3.5351	9.2029	8 9290	9 0302	11 8714	9 3753	11 9927	13 7059	9 8619	7 2770	4 8719
Al(Ser)	0 0000	0 0000	1 6029	0 0000	0.0000	0 0300	4 2548	7.5996	10 5747	8 4992	7 0929	3 6981	1 7728	7 0952	4.7324
Al(Mg-Chl)	0 0000	0 0000	0 9772	0 0000	0 0000	0 0000	3.2167	5 3051	8 1200	3 8632	5 8328	2 1497	0.5928	4 0131	2 6879
Al(Fe-Chl)	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	1 3985	0 0000	0 0000	0 0000	0 0782	0 0000	0 0000	0 0000	0 0000
Al(Zoi)	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000
Al(Kaol)	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000
Fe(Total)	3 9621	2 7936	4 6803	2 2179	2 0695	3 8187	2 7272	19 4157	15 8844	11 0836	8 6318	8 3107	3 2869	21 8310	27 3949
Fe(Chl)	3 9621	2 7936	3 2144	2 2179	2 0695	3 8187	0 0000	11 4582	3 7043	5 2888	0 0000	5 0862	2 3977	15 8112	23 3631
Fe(Py)	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0.0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000
Ca(Total)	2 1551	0 9100	2 6157	0 5074	0 7793	1 5619	3 8611	6 6468	8 6336	9 1790	0 1865	0 1648	0 0216	0 6109	0 1822
Ca(Ap)	2 1147	0 8700	2.5612	0 4673	0 7526	1 5074	3 8331	6 5714	8 5902	9 1510	0 1793	0 1214	0 0000	0 5773	0 1479
Ca(Zoi)	2 1147	0 8700	2 5612	0 4673	0 7526	1 5074	2 9008	6 5714	8 5902	9 1510	0 1272	0 1214	0 0000	0 5773	0 1479
Ca(Cc)	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000
Mg+Mn (Tot)	0.1050	0 2951	0 9385	0 3870	0 2090	0 4127	1 5572	3 4418	3 6820	6 9541	1 8903	2 3226	1 7700	4 6231	3 0668
Mg+Mn(Chl)	0 1050	0 2951	0 0000	0 3870	0 2090	0 4127	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000
Mg+Mn(Talc)	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000
Mg-Chlorite	0 0000	0 0000	2 0856	0 0000	0 0000	0 0000	3 4604	7 6485	8 1823	15 4535	4 2006	5 1613	3 9332	10 2734	6 8152
Fe Chlorite	0 0000	0 0000	3 2575	0 0000	0 0000	0 0000	6 0605	17 6835	27 0668	12 8772	19 1818	7 1656	1 9761	13 3771	8 9596
Chlorite TOTAL	0 0000	0 0000	5 3431	0 0000	0 0000	0 0000	9 5209	25 3321	35 2491	28 3307	23 3824	12 3269	5 9093	23 6506	15 7748
Fe/Mg	0 0000	0 0000	1 5619	0 0000	0 0000	0 0000	1 7514	2 3120	3 3080	0 8333	4 5665	1 3883	0 5024	1 3021	1 3146
MINERAL %															
Leucoxene TiO2	0.2079	0 1988	0 2395	0 1924	0 1918	0 2251	0 1643	0 1928	0 1853	0 1572	0 1772	0 2391	0 1590	0 1072	0 0548
Albite NaAlSi3O8	33 0844	48 2111	35 0793	40 7704	46 0593	23 6783	13 8588	4 2440	2 5873	9 3 67	1 5883	2 5842	2 3412	2 5333	0 1177
Sericite KAl3Si3O10(OH)2	15 7316	8 5397	13 2728	10 1747	8 2486	21 4734	10 9066	3 3379	3 0256	2 0441	11 4327	23 3516	18 8745	0 4244	0 3254
Apatite Ca5(PO4)3(OH)	0 0646	0 0639	0 0871	0 0641	0 0426	0 0872	0 0448	0 1205	0 0695	0 0449	0 0116	0 0694	0 0345	0 0536	0 0548
Chlorite (Mg Mn Fe)9Al6Si5O20(OH)16	0 0000	0 0000	5 3431	0 0000	0 0000	0 0000	9 5209	25 3321	35 2491	28 3307	23 3824	12 3269	5 9093	23 6506	15 7748
Zoisite Ca2Al3Si3O12(OH)	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	3 7293	0 0000	0 0000	0 0000	0 2086	0 0000	0 0000	0 0000	0 0000
Kaolinite Al2Si2O5(OH)	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000
Talc Mg3Si4O10(OH)2	0 2449	0 6885	0 0000	0 9030	0 4876	0 9631	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000
Calcite CaCO3	2 1147	0 8700	2 5612	0 4673	0 7526	1 5074	2 9008	6 5714	8 5902	9 1510	0 1272	0 1214	0 0000	0 5773	0 1479
Pyrite FeS2	3 9621	2 7936	3 2144	2 2179	2 0695	3 8187	0 0000	11 4582	3 7043	5 2888	0 0000	5 0862	2 3977	15 8112	23 3631
Quartz SiO2	42 8232	38 2049	40 2026	43 6663	41 0122	45 5248	58 8745	48 7432	46 5886	45 6266	63 0722	56 2211	70 2796	56 8423	60 1614
TOTAL	98 23	99 57	100 00	98 46	98 86	97 28	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00

* if sum is less than 100 K is probably in orthoclase rather than in sericite

Table A II2. Alteration Normative Mineral Assemblage Program for the Waite Rhyolite data set.

DDH	N-127						N-129							N-129		N-141
Feet	**1371**	**1387**	**1422**	**1460**	**1485**	**1512**	**1307**	**1357**	**1377**	**1414**	**1441**	**1468**	**1583**	**1612**	**1632**	**1406**
SiO2	81 66	75 24	78 37	76 93	79 17	71 18	68 10	66 62	68 72	63 01	64 51	57 75	70 02	80 79	78 42	74 78
TiO2	0 13	0 16	0 22	0 22	0 22	0 23	0 32	0 32	0 26	0 22	0 26	0 29	0 35	0 23	0 24	0 20
Al2O3	5 15	6 99	9 70	8 74	9 13	10 30	13 74	13 69	11 04	9 58	10 50	13 98	14 67	8 77	9 94	7 31
Fe2O3	11 25	15 38	9 11	11 55	9 70	15 04	8 78	7 41	9 51	15 45	18 46	24 77	7 41	5 56	4 84	13 07
MnO	0 07	0 04	0 04	0 08	0 07	0 10	0 48	0 65	0 58	0 93	1 60	0 23	0 11	0 06	0 06	0 14
MgO	1 14	1 48	1 30	1 81	1 40	2 70	1 98	1 81	1 51	1 16	2 33	2 06	1 84	0 87	1 24	2 95
CaO	0 20	0 02	0 06	0 06	0 10	0 07	3 45	5 59	7 82	8 94	1 49	0 18	2 21	1 57	1 16	0 80
Na2O	0 02	0 01	0 14	0 05	0 12	0 01	1.59	2 20	0 46	0 35	0 34	0 23	0 30	0 43	2 21	0 68
K2O	0 38	0 42	1 05	0 54	0 06	0 36	1 53	1 69	0 07	0 34	0 48	0 50	3 04	1 71	1 88	0 07
P2O5	0 01	0 24	0 01	0 01	0 02	0 01	0 03	0 02	0 04	0 02	0 03	0 01	0 05	0 02	0 01	0 01
SUM	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00
* single cation																
Number of Moles of Cation																
Si	1 3590	1 2521	1 3042	1 2803	1 3175	1 1846	1 1332	1 1087	1 1435	1 0487	1 0735	0 9611	1 1653	1 3444	1 3050	1 2445
Ti	0 0016	0 0021	0 0028	0 0028	0 0027	0 0029	0 0040	0 0040	0 0033	0 0027	0 0033	0 0037	0 0044	0 0028	0 0030	0 0025
Al	0 1009	0 1371	0 1902	0 1714	0 1791	0 2021	0 2696	0 2686	0 2165	0 1879	0 2060	0 2742	0 2877	0 1720	0 1950	0 1433
Fe	0 1566	0 2141	0 1268	0 1607	0 1350	0 2093	0 1222	0 1032	0 1323	0 2150	0 2570	0 3447	0 1031	0 0774	0 0674	0 1819
Mn	0 0009	0.0006	0 0006	0 0011	0 0010	0 0013	0 0067	0 0092	0 0081	0 0130	0 0225	0 0032	0 0016	0 0009	0 0009	0 0019
Mg	0 0282	0 0368	0 0324	0 0450	0 0347	0 0669	0 0492	0 0449	0 0374	0 0288	0 0577	0 0511	0 0456	0 0215	0 0308	0 0732
Ca	0 0035	0 0004	0 0011	0 0011	0 0018	0 0013	0 0615	0 0997	0 1394	0 1595	0 0266	0 0033	0 0394	0 0279	0 0207	0 0143
Na	0 0007	0 0004	0 0044	0 0016	0 0040	0 0002	0 0513	0 0709	0 0149	0 0113	0 0109	0 0073	0 0097	0 0140	0 0714	0 0219
K	0 0081	0 0089	0 0223	0 0116	0 0013	0 0076	0 0325	0 0358	0 0016	0 0072	0 0101	0 0106	0 0645	0 0363	0 0398	0 0015
P	0 0002	0 0034	0 0001	0 0001	0 0003	0 0001	0 0004	0 0003	0 0006	0 0003	0 0004	0 0002	0 0007	0 0003	0 0001	0 0001
SUM	1 6597	1 6559	1 6849	1 6757	1 6775	1 6765	1 7307	1 7452	1 6976	1 6744	1 6681	1 6593	1 7220	1 6975	1 7341	1 6851
Cation %																
Si	81 8832	75 6170	77 4062	76 4039	78 5399	70 6613	65 4770	63 5307	67 3624	62 6279	64 3567	57 9211	67 6727	79 2012	75 2543	73 8537
Ti	0 0981	0 1247	0 1641	0 1656	0 1624	0 1738	0 2317	0 2272	0 1932	0 1614	0 1984	0 2207	0 2553	0 1671	0 1702	0 1471
Al	6 0818	8.2814	11 2915	10 2279	10 6752	12 0539	15 5761	15 3902	12 7510	11 2234	12 3485	16 5235	16 7061	10 1306	11 2472	8 5037
Fe	9 4354	12 9299	7 5234	9 5898	8 0473	12 4865	7 0598	5 9114	7 7945	12 8423	15 4058	20 7760	5 9877	4 5611	3 8873	10 7935
Mn	0 0552	0.0374	0 0352	0 0678	0 0610	0 0800	0 3871	0.5282	0 4786	0 7789	1 3494	0 1933	0 0930	0 0513	0 0500	0 1133
Mg	1 7003	2.2232	1 9206	2 6855	2 0688	3 9911	2 8438	2.5710	2 2053	1 7210	3 4600	3 0779	2 6485	1 2647	1 7744	4 3418
Ca	0.2095	0 0237	0 0668	0 0643	0 1102	0 0788	3 5559	5 7111	8 2119	9 5240	1 5940	0 1979	2 2887	1 6449	1 1911	0 8491
Na	0 0421	0 0214	0 2619	0 0970	0 2392	0 0102	2 9669	4 0621	0 8765	0 6735	0 6546	0 4425	0 5613	0 8225	4 1201	1 2971
K	0 4852	0 5357	1 3258	0 6897	0 0787	0 4555	1 8765	2 0516	0 0918	0 4302	0 6058	0 6379	3 7446	2 1394	2 2972	0 0919
P	0 0092	0 2057	0 0044	0 0085	0 0174	0 0089	0 0252	0 0165	0 0348	0 0173	0 0268	0 0092	0 0422	0 0171	0 0083	0 0087
SUM	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00
Book-keeping for fomation of normative minerals																
Si(Total)	81 8832	75 6170	77 4062	76 4039	78 5399	70 6613	65 4770	63 5307	67 3624	62 6279	64 3567	57 9211	67 6727	79 2012	75 2543	73 8537
Si(Ab)	81 7568	75 5527	76 6205	76 1128	77 8223	70 6307	56 5763	51 3443	64 7329	60 6073	62 3928	56 5936	65 9889	76 7337	62 8941	69 9623
Si(Ser)	80 3014	73 9457	72 6430	74 0438	77 5862	69 2642	50 9469	45 1895	64 4576	59 3166	60 5753	54 6800	54 7551	70 3156	56 0026	69 6865
Si(Chl)	76 4812	68 4015	67 3768	67 3256	71 9323	60 3665	45 2299	40 8785	58 6363	51 6006	52 3449	42 8739	50 6626	67 9072	55 8062	63 9108
Si(Zoi)	76 4812	68 4015	67 2876	67 3256	71 8106	60 3665	45 1106	40 8785	54 0227	51 6006	52 3449	42 8739	50 6626	67 9072	55 8062	63 9108
Si(Kaol)	76 4812	68 4015	66 6441	67 3256	68 5171	60 3665	45 1106	40 8785	54 0227	51 6006	52 3449	42 8739	50 6626	67 9072	55 8062	63 9108
Si(Talc)	76 4812	68 4015	66 6441	67 3256	68 5171	60 3665	45 1106	40 8785	54 0227	51 6006	52 3449	42 8739	50 6626	67 9072	53 8449	63 9108
Si(Qtz)	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0.0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000	0 0000

Book-keeping for fomation of normative minerals

Al(Total)	6.0818	8.2814	11.2915	10.2279	10.6752	12.0539	15.5761	15.3902	12.7510	11.2234	12.3485	16.5235	16.7061	10.1306	11.2472	8.5037
Al(Ab)	6.0397	8.2600	11.0296	10.1308	10.4360	12.0437	12.6091	11.3280	11.8745	10.5499	11.6939	16.0810	16.1448	9.3081	7.1271	7.2066
Al(Ser)	4.5842	6.6530	7.0521	8.0619	10.1999	10.6771	6.9798	5.1732	11.5992	9.2592	9.8764	14.1673	4.9110	2.8900	0.2356	6.9308
Al(Mg-Chl)	3.4139	5.1459	5.7482	6.2263	8.7800	7.9630	4.8258	3.1071	9.8099	7.5927	6.6701	11.9865	3.0834	2.0127	0.0000	3.9608
Al(Fe-Chl)	0.0000	0.0000	0.7327	0.0000	3.4152	0.0000	0.1193	0.0000	4.6136	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Al(Zoi)	0.0000	0.0000	0.6435	0.0000	3.2935	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Al(Kaol)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Fe(Total)	9.4354	12.9299	7.5234	9.5898	8.0473	12.4865	7.0598	5.9114	7.7945	12.8423	15.4058	20.7760	5.9877	4.5611	3.8873	10.7935
Fe(Chl)	4.3146	5.2110	0.0000	0.2503	0.0000	0.5420	0.0000	1.2508	0.0000	1.4533	5.4006	2.7961	1.3626	1.5421	3.8873	4.8524
Fe(Py)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ca(Total)	0.2095	0.0237	0.0668	0.0643	0.1102	0.0788	3.5559	5.7111	8.2119	9.5240	1.5940	0.1979	2.2887	1.6449	1.1911	0.8491
Ca(Ap)	0.1942	0.0000	0.0595	0.0502	0.0811	0.0639	3.5138	5.6836	8.1540	9.4952	1.5493	0.1826	2.2183	1.6164	1.1772	0.8346
Ca(Zoi)	0.1942	0.0000	0.0595	0.0502	0.0811	0.0639	3.4343	5.6836	5.0783	9.4952	1.5493	0.1826	2.2183	1.6164	1.1772	0.8346
Ca(Cc)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mg+Mn (Tot)	1.7555	2.2606	1.9558	2.7533	2.1298	4.0712	3.2309	3.0992	2.6839	2.4998	4.8094	3.2712	2.7415	1.3160	1.8244	4.4551
Mg+Mn(Chl)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.4710	0.0000
Mg+Mn(Talc)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mg-Chlorite	3.9011	5.0235	4.3462	6.1185	4.7328	9.0471	7.1798	6.8871	5.9642	5.5552	10.6876	7.2693	6.0921	2.9244	0.7853	9.9002
Fe-Chlorite	11.3798	17.1531	16.7186	20.7544	17.8828	26.5434	15.6885	10.3569	17.3212	25.3089	22.2338	39.9552	10.2780	6.7090	0.0000	13.2025
Chlorite TOTAL	15.2808	22.1766	21.0648	26.8729	22.6156	35.5904	22.8683	17.2440	23.2854	30.8641	32.9214	47.2245	16.3701	9.6334	0.7853	23.1027
Fe/Mg	2.9171	3.4146	3.8467	3.3921	3.7785	2.9339	2.1851	1.5038	2.9042	4.5559	2.0803	5.4964	1.6871	2.2941	0.0000	1.3336

MINERAL %

Leucoxene TiO_2	0.0981	0.1247	0.1641	0.1656	0.1624	0.1738	0.2317	0.2272	0.1932	0.1614	0.1984	0.2207	0.2553	0.1671	0.1702	0.1471
Albite $NaAlSi_3O_8$	0.2106	0.1071	1.3095	0.4852	1.1960	0.0509	14.8346	20.3107	4.3824	3.3677	3.2731	2.2125	2.8063	4.1125	20.6003	6.4857
Sericite $KAl_3Si_3O_{10}(OH)_2$	3.3961	3.7497	9.2809	4.8276	0.5510	3.1887	13.1352	14.3612	0.6424	3.0116	4.2408	4.4652	26.2121	14.9756	16.0802	0.6435
Apatite $Ca_5(PO_4)_3(OH)$	0.0245	0.0379	0.0117	0.0226	0.0464	0.0237	0.0673	0.0440	0.0928	0.0461	0.0715	0.0245	0.1127	0.0456	0.0222	0.0232
Chlorite $(Mg,Mn,Fe)_9Al_6Si_5O_{20}(OH)_{16}$	15.2808	22.1766	21.0648	26.8729	22.6156	35.5904	22.8683	17.2440	23.2854	30.8641	32.9214	47.2245	16.3701	9.6334	0.7853	23.1027
Zoisite $Ca_2Al_3Si_3O_{12}(OH)$	0.0000	0.0000	0.2379	0.0000	0.3246	0.0000	0.3181	0.0000	12.3028	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Kaolinite $Al_2Si_2O_5(OH)$	0.0000	0.0000	1.2869	0.0000	6.5869	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Talc $Mg_3Si_4O_{10}(OH)_2$	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.4323	0.0000
Calcite $CaCO_3$	0.1942	0.0000	0.0595	0.0502	0.0811	0.0639	3.4343	5.6836	5.0783	9.4952	1.5493	0.1826	2.2183	1.6164	1.1772	0.8346
Pyrite FeS_2	4.3146	5.2110	0.0000	0.2503	0.0000	0.5420	0.0000	1.2508	0.0000	1.4533	5.4006	2.7961	1.3626	1.5421	3.8873	4.8524
Quartz SiO_2	76.4812	68.4015	66.6441	67.3256	68.5171	60.3665	45.1106	40.8785	54.0227	51.6006	52.3449	42.8739	50.6626	67.9072	53.8449	63.9108
TOTAL	100.00	99.81	100.06	100.00	100.08	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

* if sum is less than 100, K is probably in orthoclase rather than in sericite

Table A II:2. Alteration Normative Mineral Assemblage Program for the Waite Rhyolite data set.

DDH	N-141	N-163			N-181			N-190			N-224			
Feet	**1507**	**1601**	**1109**	**1253**	**1411**	**1042**	**1065**	**1319**	**1174**	**1308**	**1623**	**779**	**951**	**1180**
SiO2	61 91	76 96	74 31	77 91	72 59	84 11	74 35	74 45	74 38	74 92	80 81	82 59	78 35	73 89
TiO2	0 34	0 22	0 26	0 26	0 29	0 21	0 33	0 32	0 31	0 30	0 25	0 21	0 21	0 30
Al2O3	13 63	10 40	11 54	10 66	11 49	9 03	13 06	12 73	12 47	12 12	9 17	9 17	11 41	12 86
Fe2O3	15 86	4 39	5 90	6 82	11 35	0 79	5 38	4 67	4 75	4 77	5 62	1 84	2 44	4 47
MnO	0 22	0 18	0 09	0 06	0 16	0 02	0 13	0 05	0 13	0 02	0 04	0 04	0 05	0 06
MgO	4 36	0 33	0 90	0 75	0 99	0 18	0 52	0 89	0 72	0 47	0 10	0 50	0 24	0 71
CaO	0 98	2 93	2 76	0 26	0 62	0 87	2 42	0 89	3 16	0 62	0 24	2 19	0 77	5 20
Na2O	0 71	3 02	2 23	0 54	0 54	4 23	2 05	5 26	2 47	3 45	1 35	1 17	4 74	2 13
K2O	1 96	1 54	1 40	2 72	1 94	0 54	1 72	0 71	1 59	3 30	2 43	2 29	1 77	0 33
P2O5	0 03	0 02	0 02	0 01	0 04	0 02	0 04	0 04	0 03	0 03	0 00	0 01	0 02	0 05
SUM	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00
* single cation														
Number of Moles of Cation														
Si	1 0302	1 2808	1 2466	1 2966	1 2079	1 3998	1 2373	1 2389	1 2377	1 2468	1 3448	1 3745	1 3039	1 2296
Ti	0 0043	0 0028	0 0032	0 0032	0 0037	0 0027	0 0041	0 0040	0 0038	0 0037	0 0031	0 0026	0 0027	0 0038
Al	0 2674	0 2039	0 2264	0 2091	0 2253	0 1771	0 2562	0 2497	0 2445	0 2378	0 1799	0 1799	0 2238	0 2523
Fe	0 2208	0 0611	0 0821	0 0950	0 1580	0 0110	0 0748	0 0651	0 0661	0 0664	0 0782	0 0255	0 0340	0 0622
Mn	0 0031	0 0026	0 0013	0 0009	0 0022	0 0003	0 0019	0 0007	0 0019	0 0003	0 0006	0 0006	0 0007	0 0009
Mg	0 1082	0 0081	0 0224	0 0187	0 0246	0 0045	0 0129	0 0220	0 0179	0 0117	0 0024	0 0123	0 0060	0 0175
Ca	0 0174	0 0523	0 0492	0 0046	0 0110	0 0155	0 0432	0 0158	0 0563	0 0110	0 0042	0 0391	0 0137	0 0927
Na	0 0228	0 0975	0 0718	0 0174	0 0175	0 1364	0 0660	0 1696	0 0799	0 1113	0 0435	0 0377	0 1528	0 0686
K	0 0417	0 0327	0 0296	0 0578	0 0412	0 0116	0 0365	0 0151	0 0337	0 0700	0 0516	0 0486	0 0375	0 0070
P	0 0004	0 0003	0 0003	0 0001	0 0006	0 0003	0 0006	0 0006	0 0004	0 0004	0 0000	0 0001	0 0003	0 0007
SUM	1 7163	1 7422	1 7329	1 7034	1 6919	1 7589	1 7336	1 7814	1 7423	1 7595	1 7083	1 7209	1 7754	1 7354
Cation %														
Si	60 0251	73 5156	71 9382	76 1189	71 3946	79 5806	71 3711	69 5465	71 0421	70 8615	78 7229	79 8695	73 4428	70 8560
Ti	0 2501	0 1614	0 1853	0 1900	0 2161	0 1507	0 2364	0 2219	0 2195	0 2118	0 1804	0 1506	0 1495	0 2170
Al	15 5774	11 7055	13 0621	12 2764	13 3159	10 0662	14 7809	14 0175	14 0345	13 5163	10 5312	10 4524	12 6057	14 5391
Fe	12 8639	3 5082	4 7370	5 5761	9 3365	0 6249	4 3166	3 6521	3 7912	3 7760	4 5775	1 4841	1 9163	3 5865
Mn	0 1792	0 1487	0 0751	0 0513	0 1304	0 0162	0 1081	0 0403	0 1071	0 0164	0 0353	0 0339	0 0401	0 0506
Mg	6 3066	0 4653	1.2922	1 0993	1 4531	0 2560	0 7466	1 2339	1 0296	0 6658	0 1399	0 7162	0 3386	1 0084
Ca	1 0146	3 0000	2 8393	0 2706	0 6487	0 8793	2 4937	0 8869	3 2312	0 6242	0 2458	2 2736	0 7707	5 3401
Na	1 3282	5 5990	4 1448	1 0186	1 0346	7 7524	3 8082	9 5189	4 5835	6 3260	2 5471	2 1930	8 6068	3 9541
K	2 4294	1 8797	1 7095	3 3903	2 4354	0 6575	2 1052	0 8498	1 9365	3 9773	3 0199	2 8226	2 1135	0 4062
P	0 0256	0 0165	0 0167	0 0086	0 0347	0 0162	0 0333	0 0322	0 0247	0 0247	0 0000	0 0042	0 0160	0 0421
SUM	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00
Book-keeping for fomation of normative minerals														
Si(Total)	60 0251	73 5156	71 9382	76 1189	71 3946	79 5806	71 3711	69 5465	71 0421	70 8615	78 7229	79 8695	73 4428	70 8560
Si(Ab)	56 0406	56 7186	59 5039	73 0632	68 2909	56 3234	59 9465	40 9897	57 2914	51 8836	71 0815	73 2905	47 6224	58 9937
Si(Ser)	48 7525	51 0795	54 3754	62 8922	60 9847	54 3509	53 6310	38 4402	51 4820	44 6932	63 0974	65 0312	43 6235	57 7751
Si(Chl)	42 9515	50 6900	51 2180	61 9865	56 8387	54 0665	50 7581	36 8160	48 7443	44 6932	63 0974	65 0312	43 6235	55 1944
Si(Zoi)	42 9515	50 6900	51 2180	61 9865	56 8387	54 0665	49 5484	36 8160	48 3880	44 6932	63 0974	65 0312	43 6235	46 9249
Si(Kaol)	42 9515	50 6900	51 2180	61 9865	56 8387	54 0665	49 5484	36 8160	48 3880	44 6932	63 0974	65 0312	43 6235	48 9249
Si(Talc)	42 9515	50 6900	51 2180	61 9865	56 8387	54 0665	49 5484	36 8160	48 3880	43 7835	62 8638	64 0311	43 1186	48 9249
Si(Qtz)	*0 0000*	*0 0000*	*0 0000*	*0 0000*	*0 0000*	*0 0000*	*0 0000*	*0 0000*	*0 0000*	*0 0000*	*0 0000*	*0 0000*	*0 0000*	*0 0000*

Book-keeping for fomation of normative minerals

Al(Total)	15.5774	11.7055	13.0621	12.2764	13.3159	10.0662	14.7809	14.0175	14.0345	13.5163	10.5312	10.4524	12.6057	14.5391
Al(Ab)	14.2493	6.1065	8.9173	11.2578	12.2813	2.3138	10.9727	4.4986	9.4510	7.1904	7.9841	8.2594	3.9990	10.5850
Al(Ser)	6.9611	0.4674	3.7888	1.0869	4.9752	0.3413	4.6572	1.9491	3.6416	0.0000	0.0000	0.0000	0.0000	9.3664
Al(Mg-Chl)	2.6373	0.0580	2.8773	0.3198	3.9195	0.1598	4.0874	1.0996	2.8838	0.0000	0.0000	0.0000	0.0000	8.6605
Al(Fe-Chl)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.2096	0.0000	0.3563	0.0000	0.0000	0.0000	0.0000	6.2595
Al(Zoi)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Al(Kaol)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Fe(Total)	12.8639	3.5082	4.7370	5.5761	9.3365	0.6249	4.3166	3.6521	3.7912	3.7760	4.5775	1.4841	1.9163	3.5865
Fe(Chl)	8.9080	3.4212	0.4210	5.0964	3.4572	0.3851	0.0000	2.0027	0.0000	3.7760	4.5775	1.4841	1.9163	0.0000
Fe(Py)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ca(Total)	1.0146	3.0000	2.8393	0.2706	0.6487	0.8793	2.4937	0.8869	3.2312	0.6242	0.2458	2.2736	0.7707	5.3401
Ca(Ap)	0.9719	2.9724	2.8115	0.2564	0.5908	0.8524	2.4383	0.8332	3.1901	0.5831	0.2458	2.2665	0.7440	5.2699
Ca(Zoi)	0.9719	2.9724	2.8115	0.2564	0.5908	0.8524	1.6319	0.8332	2.9525	0.5831	0.2458	2.2665	0.7440	1.0902
Ca(Cc)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mg+Mn (Tot)	6.4858	0.6141	1.3673	1.1507	1.5835	0.2722	0.8547	1.2742	1.1367	0.6823	0.1752	0.7501	0.3787	1.0589
Mg+Mn(Chl)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.6823	0.1752	0.7501	0.3787	0.0000
Mg+Mn(Talc)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mg Chlorite	14.4129	1.3646	3.0384	2.5570	3.5188	0.6049	1.8993	2.8315	2.5260	0.0000	0.0000	0.0000	0.0000	2.3531
Fe-Chlorite	8.7909	0.1932	9.5910	1.0660	13.0651	0.5327	9.5924	3.6655	8.4249	0.0000	0.0000	0.0000	0.0000	7.9699
Chlorite TOTAL	23.2038	1.5578	12.6294	3.6230	16.5839	1.1376	11.4917	6.4969	10.9509	0.0000	0.0000	0.0000	0.0000	10.3231
Fe/Mg	0.6099	0.1416	3.1566	0.4169	3.7129	0.8806	5.0504	1.2946	3.3352	0.0000	0.0000	0.0000	0.0000	3.3870
MINERAL %														
Leucoxene TiO2	0.2501	0.1614	0.1853	0.1900	0.2161	0.1507	0.2364	0.2219	0.2195	0.2118	0.1804	0.1506	0.1495	0.2170
Albite NaAlSi3O8	6.6408	27.9950	20.7238	5.0929	5.1729	38.7620	19.0409	47.5947	22.9177	31.6298	12.7355	10.9650	43.0329	19.7705
Sericite KAl3Si3O10(OH)2	17.0056	13.1579	11.9665	23.7321	17.0477	4.6026	14.7363	5.9488	13.5553	16.7775	18.6296	19.2719	9.3309	2.8434
Apatite Ca5(PO4)3(OH)	0.0682	0.0440	0.0445	0.0228	0.0927	0.0431	0.0887	0.0859	0.0659	0.0658	0.0000	0.0113	0.0427	0.1123
Chlorite (Mg,Mn Fe)9Al6Si5O20(OH)16	23.2038	1.5578	12.6294	3.6230	16.5839	1.1376	11.4917	6.4969	10.9509	0.0000	0.0000	0.0000	0.0000	10.3231
Zoisite Ca2Al3Si3O12(OH)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.2257	0.0000	0.9501	0.0000	0.0000	0.0000	0.0000	16.7187
Kaolinite Al2Si2O5(OH)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Talc Mg3Si4O10(OH)2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.5919	0.4088	1.7502	0.8836	0.0000
Calcite CaCO3	0.9719	2.9724	2.8115	0.2564	0.5908	0.8524	1.6319	0.8332	2.9525	0.5831	0.2458	2.2665	0.7440	1.0902
Pyrite FeS2	8.9080	3.4212	0.4210	5.0964	3.4572	0.3851	0.0000	2.0027	0.0000	3.7760	4.5775	1.4841	1.9163	0.0000
Quartz SiO2	42.9515	50.6900	51.2180	61.9865	56.8387	54.0665	49.5484	36.8160	48.3880	43.7835	62.8638	64.0311	43.1186	48.9249
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	98.42	99.64	99.93	99.22	100.00

* if sum is less than 100 K is probably in orthoclase rather than in sericite

Table A II · 3 Oxygen Isotope calculations for the Waite Rhyolite at the Norbec mine

Hole	N-124					N-127									
Depth (m)	375.82	376.74	380.70	391.37	435.56	390.15	396.24	402.34	406.61	417.89	422.76	433.43	445.01	452.63	460.86
Depth (ft)	1233	1236	1249	1284	1429	1280	1300	1320	1334	1371	1387	1422	1460	1485	1512
SiO2	76.20	55.3	56.75	59.50	73.10	69.12	80.75	54.27	52.96	75.38	68.45	74.50	76.34	76.40	67.30
TiO2	0.22	0.24	0.24	0.2	0.23	0.31	0.2	0.12	0.06	0.12	0.15	0.2	0.22	0.21	0.22
Al2O3	10.00	7.85	10.24	9.59	10.20	[illegible]	8.71	5.56	3.42	4.75	6.36	9.22	8.67	8.81	9.74
FeO	3.28	21.74	18.50	13.32	10.08	9.69	3.9	21.97	26.97	10.38	13.99	8.66	11.45	9.36	14.22
MnO	0.18	0.55	0.68	0.86	0.05	0.07	0.04	0.09	0.06	0.06	0.04	0.04	0.08	0.07	0.09
MgO	0.95	1.95	2.02	4.20	1.21	1.48	0.93	2.56	1.66	1.05	1.35	1.24	1.80	1.35	2.55
CaO	3.63	5.31	7.85	8.61	0.17	0.15	0.02	0.48	0.14	0.18	0.02	0.06	0.06	0.10	0.07
Na2O	1.44	0.41	0.26	0.97	0.16	0.26	0.24	0.22	0.00	0.02	0.00	0.13	0.05	0.12	
K2O	1.23	0.35	0.33	0.23	1.25	2.55	2.10	0.04	0.03	0.35	0.38	1.00	0.54	0.60	0.34
P2O5	0.02	0.05	0.05	0.02	0.00	0.03	0.02	0.02	0.02	0.01	0.02	0.01	0.01	0.02	0.01
CO2		1.20	0.18			0.25	0.23	2.22	1.20	1.22	0.80		0.37	0.22	
S		5.68	1.23			2.69	1.19	7.07	11.17	3.70	3.83		0.21	0.06	
Total	97.15	95.36	97.10	97.51	96.45	95.68	97.16	87.55	86.52	93.52	91.56	95.07	99.59	97.26	94.54
LOI	2.33	4.27	1.9	1.29	2.84	4	2	6	8	3	3	2	0	2	3
FeO*	3.65	24.16	20.56	14.80	11.20	10.77	4.34	24.42	29.97	11.54	15.55	9.62	12.73	10.40	15.80
# CATIONS	**1.6765**	**1.7631**	**1.6641**	**1.6727**	**1.6253**	**1.7129**	**1.6907**	**1.6721**	**1.7456**	**1.6752**	**1.6409**	**1.6018**	**1.6777**	**1.6373**	**1.5849**
Cation %															
Si	75.64	52.21	56.76	59.20	74.85	67.16	79.49	54.02	50.49	74.89	69.42	77.41	75.73	77.66	70.67
Ti	0.16	0.17	0.18	0.16	0.18	0.23	0.16	0.09	0.04	0.09	0.11	0.16	0.16	0.16	0.17
Al	11.70	8.73	12.07	11.25	12.31	13.48	10.11	6.52	3.84	5.56	7.60	11.29	10.14	10.55	12.05
Fe	2.73	17.16	15.47	11.08	8.63	7.87	3.21	18.29	21.50	8.63	11.87	7.52	9.50	7.95	12.48
Mn	0.15	0.44	0.58	0.72	0.04	0.06	0.03	0.08	0.05	0.05	0.03	0.04	0.07	0.06	0.08
Mg	1.41	2.60	3.01	6.23	1.85	2.14	1.36	3.80	2.36	1.56	2.04	1.92	2.66	2.05	3.99
Ca	3.86	5.88	8.41	9.18	0.19	0.16	0.02	0.51	0.14	0.19	0.02	0.07	0.06	0.11	0.08
Na	2.77	0.75	0.50	1.87	0.32	0.49	0.46	0.42	0.00	0.04	0.00	0.26	0.10	0.24	0.00
K	1.56	0.42	0.42	0.29	1.63	3.16	2.64	0.05	0.04	0.44	0.49	1.33	0.68	0.78	0.46
P	0.02	0.04	0.04	0.02	0.00	0.02	0.02	0.02	0.02	0.01	0.02	0.01	0.01	0.02	0.01
S	0.00	10.05	2.31	0.00	0.00	4.90	2.20	13.19	19.96	6.89	7.28	0.00	0.38	0.12	0.00
C	0.00	1.55	0.25	0.00	0.00	0.33	0.31	3.02	1.56	1.65	1.11	0.00	0.50	0.31	0.00
SUM	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Cation Min. Norms															
Apatite	0.04	0.11	0.11	0.04	0.00	0.07	0.04	0.04	0.04	0.02	0.05	0.02	0.02	0.05	0.02
Quartz	58.88	43.10	45.40	45.63	63.08	53.29	68.76	47.64	47.27	69.95	62.84	66.64	65.73	67.74	60.40
Albite	13.86	3.75	2.52	9.36	1.59	2.45	2.29	2.12	0.00	0.19	0.00	1.31	0.48	1.18	0.00
Sericite	10.90	2.95	2.95	2.04	11.43	22.13	18.46	0.36	0.26	3.11	3.44	9.28	4.78	5.45	3.19
Chlorite	9.52	22.39	34.34	28.33	23.38	11.69	5.78	19.82	12.44	13.97	20.42	21.06	26.63	22.22	35.63
Zois(Ep)	3.73	0.00	0.00	0.00	0.21	0.00	0.03	0.00	0.00	0.00	-0.03	0.21	0.00	0.32	0.00
Kaolinite	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.02	1.31	0.00	2.39	0.00
Pyrite	0.00	15.07	3.46	0.00	0.00	7.35	3.29	19.78	29.93	10.33	10.92	0.00	0.58	0.18	0.00
Carbonate	2.90	7.36	8.59	9.15	0.13	0.66	0.62	6.03	3.12	1.36	2.22	0.00	0.21	0.00	0.06
Magnetite	0.00	5.10	2.45	5.29	0.00	2.15	0.60	4.12	6.88	0.00	0.00	0.00	0.00	0.00	0.53
Rutile	0.16	0.17	0.18	0.16	0.18	0.23	0.16	0.09	0.04	0.09	0.11	0.16	0.16	0.16	0.17
Graphite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.98	0.00	0.00	0.40	0.31	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Weight of Oxygen-bearing Cation in Normative Minerals

Hole				**N-124**					**N-127**									
Depth (ft)				**1233**	**1236**	**1249**	**1284**	**1429**	**1280**	**1300**	**1320**	**1334**	**1371**	**1387**	**1422**	**1460**	**1485**	**1512**
Ap				3	7	7	3	0	4	3	3	3	1	3	1	1	3	1
Qz				3538	2590	2728	2742	3790	3202	4132	2862	2841	4203	3776	4005	4010	4071	3629
Ab				727	197	132	491	83	128	120	111	0	10	0	69	25	62	0
Ser				620	168	168	116	650	1259	1050	20	15	177	196	528	272	310	181
Chl				597	1405	2155	1778	1467	733	363	1244	781	877	1282	1322	1671	1394	2236
Zo				212	0	0	0	12	0	2	0	0	0	2	12	0	18	0
Carb				145	368	430	458	7	33	31	302	156	68	111	0	10	0	3
Mt				0	394	189	408	0	166	47	318	531	0	0	0	0	0	41
Rt				13	14	15	13	15	19	13	7	4	7	9	13	13	13	14
Total				5856	5142	5824	6008	6024	5545	5757	4868	4330	5344	5376	5950	6004	5871	6106
wt % Norms	**wt frac Ox**																	
Ap	0 413			0 05	0 13	0 12	0 05	0 00	0 07	0 05	0 06	0 06	0 03	0 05	0 02	0 02	0 05	0 02
Qz	0 533			60 42	50 36	46 84	45 63	62 92	57 75	71 77	58 81	65 60	78 66	70 25	67 31	66 79	69 33	59 44
Ab	0 488			12 41	3 83	2 27	8 17	1 38	2 32	2 09	2 29	0 00	0 19	0 00	1 15	0 42	1 06	0 00
Ser	0 482			10 60	3 26	2 88	1 94	10 80	22 71	18 25	0 42	0 34	3 31	3 64	8 87	4 53	5 28	2 97
Chl	0 459			10 20	27 33	37 00	29 59	24 35	13 23	6 30	25 55	18 04	16 41	23 84	22 21	27 84	23 75	36 61
Zo	0 458			3 62	0 00	0 00	0 00	0 20	0 00	0 03	0 00	0 00	0 00	0 03	0 20	0 00	0 31	0 00
Carb	0 48			2 48	7 16	7 38	7 62	0 11	0 60	0 54	6 20	3 61	1 27	2 06	0 00	0 17	0 00	0 05
Mt	0 276			0 00	7 66	3 25	6 79	0 00	3 00	0 81	6 53	12 27	0 00	0 01	0 00	0 00	0 00	0 66
Rt	0 391			0 23	0 27	0 25	0 21	0 24	0 33	0 22	0 15	0 08	0 14	0 17	0 23	0 22	0 22	0 23
Total				100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00
	D-18 Ox Calculations																	
Wt% Ox	**200 C**	**250 C**	**300 C**															
Qz	11 58	8 86	6 83	32 20	26 84	24 97	24 32	33 53	30 78	38 25	31 34	34 97	41 93	37 44	35 88	35 60	36 95	31 68
Ab	10 28	7 74	5 83	6 06	1 87	1 11	3 99	0 67	1 13	1 02	1 12	0 00	0 09	0 00	0 56	0 20	0 52	0 00
Ser	6 74	4 81	3 36	5 11	1 57	1 39	0 93	5 20	10 94	8 80	0 20	0 16	1 59	1 76	4 28	2 19	2 54	1 43
Chl	2 27	1	0 05	4 68	12 54	16 98	13 58	11 18	6 07	2 89	11 73	8 28	7 53	10 94	10 20	12 78	10 90	16 81
Zo	1 05	0 65	0 35	1 66	0 00	0 00	0 00	0 09	0 00	0 01	0 00	0 00	0 00	0 01	0 09	0 00	0 14	0 00
Carb	9 03	6 77	5 07	1 19	3 44	3 54	3 66	0 05	0 29	0 26	2 98	1 73	0 61	0 99	0 00	0 08	0 00	0 03
Mt	6 96	6 85	6 78	0 00	2 11	0 90	1 87	0 00	0 83	0 22	1 80	3 39	0 00	0 00	0 00	0 00	0 00	0 18
Wt% Ox Tot	less Apatite & Rutile			50 90	48 38	48 89	48 36	50 74	50 04	51 43	49 17	48 53	51 75	51 12	51 00	50 85	51 06	50 13
Wt % Ox Tot				51 01	48 54	49 04	48 46	50 83	50 20	51 54	49 25	48 59	51 82	51 21	51 10	50 95	51 16	50 23
D 18 Ox Calc	200 degrees			9 68	7 97	7 65	7 85	8 99	9 04	10 11	8 48	8 59	10 04	9 37	9 28	9 02	9 31	8 25
D 18 Ox Calc	250 degrees			7 28	5 8	5 55	5 71	6 68	6 72	7 63	6 24	6 33	7 56	7 00	6 92	6 70	6 95	6 05
D 18 Ox Calc	300 degrees			5 49	4 20	3 98	4 12	4 95	4 99	5 77	4 57	4 65	5 71	5 23	5 16	4 97	5 18	4 41
D 18 Ox Meas				9 9				6 7	8	9	7		7 5	6 6	5 1			5 7
Book-keeping for Norm analyses																		
Calcite				0 00	3 09	0 49	0 00	0 00	0 23	0 00	0 97	0 23	0 36	0 00	0 00	0 10	0 00	0 00
FeCarb				0 00	0 00	0 00	0 00	0 00	0 43	0 62	5 07	2 89	1 00	2 22	0 00	0 11	0 00	0 00
Excess Carb				2 90	4 26	8 10	9 15	0 13	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 06
Ca Ap				3 83	5 81	8 34	9 15	0 19	0 12	0 01	0 48	0 12	0 18	0 01	0 05	0 05	0 08	0 06
Al Ab+ser				4 25	6 72	10 30	8 50	7 09	3 51	1 74	5 95	3 73	4 19	6 13	7 05	7 99	7 98	10 69
Si Ab+Ser				62 66	48 69	53 98	52 71	69 00	56 21	70 20	52 59	50 38	73 44	67 95	72 64	73 39	74 61	69 31
Fe Py				2 73	12 14	14 32	11 08	8 63	5 43	2 12	11 70	11 52	5 18	8 23	7 52	9 3[illegible]	7 89	12 4[illegible]
Mg Mn Ch				3 46	6 76	7 97	15 45	4 20	4 89	3 11	8 61	5 35	3 57	4 6	4 35	6 06	4 68	9 05
FeCh				6 06	15 63	26 37	12 87	19 18	6 79	2 68	[illegible]	7 09	7 41	15 8	16 71	20 57	17 54	26 58
Si MgCh				61 79	47 00	51 99	48 85	67 95	54 98	69 43	50 44	49 05	72 55	66 90	71 56	71 87	73 44	67 04
Al MgCh				3 22	4 69	7 91	3 86	5 83	2 04	0 80	3 36	2 13	3 12	4 74	5 75	6 17	6 58	7 97
Si FeCh				60 28	43 10	45 40	45 63	63 16	53 29	68 76	47 64	47 27	69 95	62 84	67 38	66 73	69 06	60 40
Al FeCh				1 40	0 00	0 00	0 00	0 08	0 00	0 00	0 00	0 00	0 00	0 00	0 73	0 00	1 32	0 00
Mg Mn Ch				0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
Fe Ch				0 00	5 10	2 45	5 29	0 00	2 37	0 9	6 65	8 33	0 50	[illegible]	0 00	0 05	0 00	0 53
Al Zo				0 00	0 00	0 00	0 00	0 00	0 00	0 0	0 00	0 00	0 00	0 0	0 66	0 00	1 20	0 00
Si Zo				59 88	43 10	45 40	45 63	63 08	53 29	68 77	47 64	47 27	69 95	62 85	67 30	66 73	68 94	60 40
Ca Zo				2 90	5 81	8 34	9 15	0 13	0 12	0 00	0 48	0 12	0 18	0 00	0 00	0 05	0 00	0 06
Ca Ca				2 90	4 26	8 10	9 15	0 13	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 06
C Ca				0	0 00	0 00	0 00	0 00	0 22	0 01	2 53	1 45	1 48	[illegible]	0 00	0 45	0 31	0 00

Table A II . 3.

Hole	**N-129**										**N-141**			**N-108**			**N-109**		
Depth (m)	**398 38**	**405 08**	**413 62**	**419 71**	**430 99**	**439.22**	**447 45**	**432.50**	**491 34**	**497 44**	**428 55**	**459 34**	**487 99**	**583 70**	**612 66**	**673.62**	**489.82**	**559 31**	**690 38**
Depth (ft)	**1307**	**1329**	**1357**	**1377**	**1414**	**1441**	**1468**	**1583**	**1612**	**1632**	**1406**	**1507**	**1601**	**1915**	**2010**	**2210**	**1607**	**1835**	**2265**
SiO2	65 9	44	65 2	65 57	61 3	61	53 3	67 8	78 42	76 5	71 76	59 59	75 36	72 97	75 44	70 76	77 08	76 72	71 96
TiO2	0 31	1 26	0 31	0 25	0 21	0 25	0 27	0 34	0 22	0 23	0 19	0 33	0 22	0 29	0 28	0 33	0 27	0 27	0 3
Al2O3	13 3	16 46	13 4	10 53	9 32	9 93	12 9	14 2	8 514	9 7	7 0	13 12	10 18	11 89	96	12 58	11 21	11 45	12 25
FeO	8 49	11 61	7 25	9 07	5 03	7 46	22 86	7 17	5 40	4 72	2 56	15 29	4 30	4 98	3 55	5 80	2 81	2 63	4 73
MnO	0 46	0 68	0 64	0 55	0 9	1 51	0 21	0 11	0 06	0 06	0 13	0 21	0 18	0 13	0 07	0 11	0 06	0 05	0 1
MgO	1 92	6 79	1 77	1 44	1 13	2 2	1 9	1 78	0 84	1 21	2 83	4 2	0 32		0 17	0 59	0 24	0 12	0 23
CaO	3 34	9 61	5 47	7 46	8 7	1 41	0 17	2 14	1 52	1 13	0 77	0 94	2 87	2 11	0 9	2 53	0 5	0 77	1 51
Na2O	1 54	0 21	2 15	0 44	0 34	0 32	0 21	0 29	0 42	2 16	0 65	0 68	2 96	3 58	5 27	3 75	4 44	5 03	2 53
K2O	1 48	1 66	1 65	0 07	0 33	0 45	0 46	2 94	1 66	1 83	0 07	1 89	1 51	3 3	1 37	1 54	2 48	1 92	4 1
P2O5	0 03	0 14	0 02	0 04	0 02	0 03	0 01	0 05	0 02	0 01	0 01	0 03	0 02	0 03	0 03	0 04	0 03	0 02	0 04
CO2		0 25		1 6					0 9		1 47	0 12	1 35	0 35	0 38	0 53	0 3	0 3	0 27
S		0 16		0 168					1		1 65	0 8	1 5	0 02	0 01	0 01	0 22	0 03	0 01
Total	96 77	94 67	97 86	97 02	97 28	94 56	92 29	96 82	97 97	97 55	97 45	96 30	99 27	99 63	99 42	98 71	99 42	99 28	98 65
LOI	2 28	3 1	1 94	3 39	0 79	3 13	3 58	2 59	2 31	0 76	2 8	3 17	1 6	0 86	0 5	1 57	0 41	0 41	0 97
FeO*	9 44	12 9	8 06	10 08	16 7	19 4	25 4	7 97	6	5 25	13 96	16 99	4 78	5 53	3 94	6 45	3 12	2 92	5 26
# CATIONS	**1 6750**	**1 6862**	**1 7079**	**1 6615**	**1 6289**	**1 5774**	**1 5314**	**1 6673**	**1 7030**	**1 6918**	**1 7022**	**1 6915**	**1 7835**	**1 7546**	**1 7727**	**1 7406**	**1 7709**	**1 7699**	**1 7305**
Cation %																			
Si	65 48	43 43	63 53	65 68	62 63	64 36	57 93	67 68	76 64	75 26	70 16	58 63	70 32	69 21	70 82	67 66	72 44	72 14	69 23
Ti	0 23	0 94	0 23	0 19	0 16	0 20	0 22	0 26	0 16	0 17	0 14	0 24	0 15	0 21	0 20	0 24	0 19	0 19	0 22
Al	15 58	19 15	15 39	12 43	11 22	12 35	16 52	16 71	9 81	11 25	8 08	15 21	11 20	13 29	13 23	14 18	12 42	12 69	13 89
Fe	7 06	9 58	5 91	7 60	12 84	15 40	20 77	5 99	4 41	3 89	10 27	12 58	3 36	3 95	2 78	4 64	2 21	2 07	3 81
Mn	0 39	0 57	0 53	0 47	0 78	1 35	0 19	0 09	0 05	0 05	0 11	0 18	0 14	0 10	0 06	0 09	0 05	0 04	0 08
Mg	2 84	12 93	2 57	2 15	1 72	3 46	3 08	2 65	1 22	1 77	4 12	6 16	0 45	0 00	0 24	0 84	0 34	0 17	0 33
Ca	3 56	10 16	5 71	8 01	9 52	1 59	0 20	2 29	1 59	1 19	0 81	0 99	2 87	2 14	0 91	2 59	0 50	0 78	1 56
Na	2 97	0 40	4 06	0 85	0 67	0 65	0 44	0 56	0 80	4 12	1 23	1 30	5 36	6 58	9 59	6 95	8 09	9 17	4 72
K	1 88	2 09	2 05	0 09	0 43	0 61	0 64	3 74	2 07	2 30	0 09	2 37	1 80	3 99	1 64	1 88	2 97	2 30	5 77
P	0 03	0 12	0 02	0 03	0 02	0 03	0 01	0 04	0 02	0 01	0 01	0 02	0 02	0 02	0 02	0 03	0 02	0 02	0 03
S	0 00	0 30	0 00	0 32	0 00	0 00	0 00	0 00	2 03	0 00	3 02	1 48	2 62	0 04	0 02	0 02	0 39	0 05	0 02
C	0 00	0 34	0 00	2 19	0 00	0 00	0 00	0 00	1 20	0 00	1 96	0 83	1 72	0 45	0 49	0 89	0 38	0 39	0 35
SUM	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00
Cation Min Norm																			
Apatite	0 07	0 31	0 04	0 09	0 05	0 07	0 02	0 11	0 04	0 02	0 02	0 07	0 04	0 06	0 06	0 05	0 06	0 04	0 09
Quartz	45 11	25 56	40 88	52 66	51 60	52 35	42 88	50 67	65 71	55 81	60 72	41 96	48 49	41 88	38 19	39 84	43 08	40 55	44 55
Albite	14 83	2 01	20 31	4 27	3 37	3 27	2 21	2 81	3 98	20 60	6 16	6 49	26 78	32 92	47 96	34 76	40 45	45 85	23 59
Sericite	13 13	14 63	14 36	0 63	3 01	4 24	4 46	26 21	14 49	16 08	0 61	16 61	12 58	27 95	11 49	13 15	20 81	16 12	40 37
Chlorite	22 87	41 58	17 25	22 35	30 86	32 92	47 22	16 37	9 34	0 79	21 94	22 67	1 49	17 57	4 27	5 30	15 31	11 30	27 11
Zois(Ep)	0 32	0 00	0 00	12 28	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
Kaolinite	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
Pyrite	0 00	0 44	0 00	0 47	0 00	0 00	0 00	0 00	3 05	0 00	4 53	2 21	3 93	0 05	0 03	0 03	0 58	0 08	0 03
Carbonate	3 43	10 30	5 68	7 07	9 50	1 55	0 18	2 22	2 76	1 18	3 92	1 78	4 56	2 56	1 35	3 43	0 85	1 13	1 86
Magnetite	0 00	4 22	1 25	0 00	1 45	5 40	2 79	1 36	0 47	3 89	1 95	7 98	1 96	3 93	2 77	3 18	2 01	2 04	3 80
Rutile	0 23	0 94	0 23	0 19	0 16	0 20	0 22	0 26	0 16	0 17	0 14	0 24	0 15	0 21	0 20	0 24	0 19	0 19	0 22
Graphite	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
Total	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	98 53	100 00	100 00	100 00	91 99	97 78	100 00	92 72	94 71	87 39

Weight of Oxyge

Hole	**N-129**									**N-141**			**N-108**			**N-109**			
Depth (ft)	**1307**	**1329**	**1357**	**1377**	**1414**	**1441**	**1468**	**1583**	**1612**	**1632**	**1406**	**1507**	**1601**	**1915**	**2010**	**2210**	**1607**	**1835**	**2265**
Ap	4	19	3	6	3	4	2	7	3	1	1	4	3	4	4	5	4	3	5
Qz	2711	1536	2457	3164	3101	3146	2577	3045	3948	3354	3648	2521	2914	2516	2295	2394	2588	2436	2677
Ab	778	105	1065	224	177	172	116	147	209	1080	323	340	1405	1727	2516	1823	2122	2405	1237
Ser	747	833	817	36	171	241	254	1491	824	915	35	945	716	1591	654	748	1184	917	2297
Chl	1435	2609	1082	1402	1937	2066	2963	1027	586	49	1377	1422	94	1103	268	332	961	709	1701
Zo	18	0	0	697	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carb	172	516	284	354	475	78	9	111	138	59	196	89	228	128	68	171	42	57	93
Mt	0	326	96	0	112	417	216	105	36	300	150	616	151	303	214	245	155	157	293
Rt	19	77	19	15	13	16	18	21	13	14	11	20	13	17	16	19	16	16	18
Total	5884	6021	5823	5898	5989	6139	6154	5954	5758	5772	5743	5958	5523	5183	5498	5739	5151	5282	4920
wt % Norms																			
Ap	0.07	0.32	0.05	0.10	0.05	0.07	0.02	0.12	0.05	0.02	0.02	0.07	0.05	0.08	0.07	0.09	0.08	0.05	0.11
Qz	46.07	25.51	42.19	53.64	51.78	51.24	41.87	51.13	68.57	58.10	63.53	42.32	52.76	48.55	41.74	41.71	50.25	46.13	54.41
Ab	13.22	1.75	18.29	3.80	2.95	2.80	1.89	2.47	3.62	18.72	5.63	5.71	25.43	33.31	45.76	31.77	41.19	45.53	25.15
Ser	12.70	13.83	14.03	0.60	2.86	3.93	4.13	25.04	14.32	15.85	0.61	15.86	12.96	30.69	11.89	13.04	22.99	17.37	46.69
Chl	24.38	43.34	18.58	23.78	32.34	33.65	48.15	17.26	10.18	0.86	23.98	23.87	1.69	21.28	4.88	5.79	18.66	13.43	34.58
Zo	0.31	0.00	0.00	11.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carb	2.92	8.57	4.88	6.00	7.94	1.26	0.15	1.86	2.40	1.02	3.42	1.50	4.14	2.47	1.23	2.99	0.82	1.07	1.89
Mt	0.00	5.41	1.66	0.00	1.87	6.79	3.50	1.76	0.63	5.20	2.62	10.33	2.74	5.85	3.89	4.27	3.02	2.98	5.96
Rt	0.32	1.27	0.32	0.26	0.22	0.26	0.29	0.35	0.23	0.24	0.20	0.34	0.23	0.33	0.29	0.34	0.30	0.30	0.37
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Wt% Ox																			
Qz	24.56	13.60	22.49	28.59	27.60	27.31	22.32	27.25	36.55	30.97	33.86	22.56	28.12	25.88	22.25	22.23	26.78	24.59	29.00
Ab	6.45	0.85	8.93	1.85	1.44	1.36	0.92	1.21	1.77	9.13	2.75	2.79	12.41	16.26	22.33	15.50	20.10	22.22	12.27
Ser	6.12	6.67	6.76	0.29	1.38	1.89	1.99	12.07	6.90	7.64	0.29	7.64	6.25	14.79	5.73	6.28	11.08	8.37	22.50
Chl	11.19	19.89	8.53	10.91	14.84	15.44	22.10	7.92	4.67	0.39	11.01	10.96	0.78	9.77	2.24	2.66	8.56	6.16	15.87
Zo	0.14	0.00	0.00	5.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carb	1.40	4.11	2.34	2.88	3.8	0.61	0.07	0.90	1.15	0.49	1.64	0.72	1.98	1.19	0.59	1.43	0.40	0.52	0.91
Mt	0.00	1.49	0.46	0.00	0.52	97	0.97	0.49	0.17	1.43	0.72	2.85	0.76	1.61	1.07	1.18	0.83	0.82	1.64
Wt% Ox Tot	49.87	46.61	49.51	49.94	49.58	48.49	48.36	49.83	51.22	50.06	50.27	47.52	50.30	49.96	49.73	49.29	50.63	50.35	50.46
Wt % Ox Tot	50.02	47.24	49.65	50.09	49.69	48.63	48.49	50.02	51.33	50.16	50.36	47.68	50.41	50.12	49.88	49.46	50.78	50.49	50.65
D 18 Ox Calc	8.63	6.07	8.79	8.13	8.23	7.64	6.73	8.67	9.91	9.97	9.09	7.43	10.13	10.88	10.43	9.53	11.25	11.01	11.38
D 18 Ox Calc	6.37	4.22	6.51	6.07	6.04	5.53	4.76	6.41	7.46	7.51	6.76	5.36	7.64	8.28	7.88	7.13	8.58	8.38	8.70
D 18 Ox Calc	4.68	2.83	4.80	4.49	4.40	3.96	3.30	4.72	5.62	5.66	5.02	3.81	5.77	6.32	5.97	5.33	6.58	5.40	6.70
D 18 Ox Meas	8.8		8.7		8	7.6	6.3	7.7		8.3									
Book-keeping fo																			
Calcite	0.00	0.67	0.00	4.35	0.00	0.00	0.00	0.00	2.40	0.00	59	67	3.44	0.91	0.97	78	0.77	0.77	[illegible]
FeCarb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Excess Carb	3.43	9.63	5.68	2.69	9.50	55	0.15	2.22	0.36	15	0.00	0.12	1.12	1.65	0.38	1.65	0.08	0.36	1.15
Ca Ab	3.51	9.97	5.68	7.95	9.50	55	0.18	2.22	1.56	8	0.79	0.95	2.84	2.10	0.87	2.54	0.46	0.75	1.50
Al Ab+se	6.98	12.47	5.17	11.13	9.26	9.88	14.17	4.9	2.80	0.24	6.58	6.80	0.45	5.27	1.28	1.59	4.59	3.39	8.13
Si Ab+Ser	50.45	35.95	45.19	62.85	59.32	60.58	54.66	54.76	68.74	56.0	66.20	47.62	48.86	37.48	37.12	41.16	39.25	37.72	37.77
Fe Py	7.06	9.43	5.91	7.44	12.84	5.40	20.77	5.99	3.40	3.89	8.76	11.84	2.04	3.93	2.77	4.63	2.01	2.04	3.80
Mg Mn Ch	7.18	30.2	6.89	5.82	5.56	0.69	7.27	6.09	2.83	0.79	9.41	14.08	1.31	17.57	4.27	2.07	15.3	11.30	27.11
FeCh	15.68	1.58	10.36	6.53	25.3	22.23	39.95	10.28	6.5	0.00	12.54	8.59	0.19	0.00	0.00	3.23	0.00	0.00	0.00
Si MgCh	49.16	28.45	43.47	61.39	57.93	57.91	52.87	53.24	67.33	55.81	63.85	44.10	48.54	41.88	38.19	40.65	43.08	40.55	44.55
Al MgCh	4.83	3.47	3.11	9.56	7.59	6.67	11.99	3.08	1.95	0.00	3.75	2.58	0.06	0.00	0.00	0.97	0.00	0.00	0.00
Si FeCh	45.23	25.56	42.88	57.26	51.60	52.35	42.86	50.67	65.71	55.81	60.72	41.96	48.49	41.88	38.19	39.84	43.08	40.55	44.55
Al FeCh	0.12	0.00	0.00	4.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mg Mn Ch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.47	0.00	0.00	0.00	5.01	2.22	0.00	7.28	5.29	12.6
Fe Ch	0.00	4.22	25	0.00	1.45	5.40	2.79	36	0.47	3.89	3.12	7.95	96	3.93	2.77	3.18	2.0	2.04	3.80
Al Zo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si Zo	45.1	25.56	42.88	52.66	51.60	52.35	42.86	50.67	65.71	55.81	50.72	41.96	48.49	41.88	38.19	39.84	43.08	40.55	44.55
Ca Zo	3.43	9.97	5.66	4.56	9.50	55	1.18	2.22	56	18	0.79	0.95	2.84	2.10	0.87	2.54	0.46	0.75	1.50
Ca Ca	3.43	9.63	5.68	2.69	9.50	1.55	0.18	2.22	0.36	5	0.00	0.12	12	65	0.38	1.65	0.08	0.36	5
C Ca	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table A II 3

Hole	N-163			N-175				N-190			N-181			N-224	
Depth (m)	338 03	381 92	430 08	470 31	499 57	542 25	556 57	357.84	398 68	494 70	316 56	323 55	400 71	236 66	288 91
Depth (ft)	1109	1253	1411	1543	1639	1779	1826	1174	1308	1623	1042	1065	1319	779	951
SiO_2	73 03	75 35	69 58	75 02	74 9	74 86	72 8	73 03	72 98	75 5	83 4	72 66	73	79 8	77 6
TiO_2	0 25	0 25	0 28	0 27	0 3	0 3	0 29	0 3	0 29	0 23	0 21	0 32	0 31	0 2	0 21
Al_2O_3	1 25	10 3	0	1 87	12 38	12 24	12 16	12 24	1 81	8 57	8 95	2 77	12 5	8 86	11 3
FeO	5 76	6 8	0 90	2 80	3 64	2 95	3 7	4 67	4 66	5 25	0 78	5 25	4 59	1 77	2 42
MnO	0 09	0 06	0 5	0 02	0 1	0 07	0 08	0 13	0 02	0 04	0 02	0 13	0 05	0 04	0 05
MgO	0 88	0 73	0 95	0 12	0 42	0 22	0 54	0 7	0 46	0 09	0 18	0 51	0 87	0 48	0 24
CaO	2 69	0 25	0 59	[illegible]	1 56	1 9	1 66	3 1	0 6	0 22	0 86	2 37	0 87	2 12	0 76
Na_2O	2 17	0 52	0 52	6 01	5 13	4 22	3 34	2 43	3 36	1 26	4 19	2	5 16	1 13	4 69
K_2O	1 36	2 63	1 86	0 52	1 66	3 02	2 9	1 56	3 21	2 27	0 51	1 68	0 7	2 21	1 75
P_2O_5	0 02	0 01	0 04	0 02	0 03	0 02	0 03	0 03	0 03		0 02	0 04	0 04		0 02
CO_2	1 21	0 27	1 89	0 82	0 4	0 6	0 1	0 25	0 31	2 7		0 35			
S	1 2	2 04	1 8	1 69	0 06	0 01	0 07	0 09	2 29	3		0 41			
Total	98 71	96 99	97 77	98 47	99 81	99 69	98 52	98 45	97 73	96 14	99 15	98 10	98 19	96 61	99 04
LOI	1 77	2 9	3 3	1 77	0 6	0 61	1 9	1 23	2 09	2 81	0 71	1 3	1 32	3 08	0 75
FeO*	6 4	7 35	12 11	3 11	4 05	3 28	4 12	5 19	5 18	5 84	0 87	5 84	5 1	1 97	2 69
# CATIONS	**1 7545**	**1 7174**	**1 7212**	**1.8214**	**1 7838**	**1 7730**	**1 7444**	**1 7194**	**1 7920**	**1 7513**	**1 7441**	**1 7155**	**1 7493**	**1 6627**	**1 7584**
Cation %															
Si	69 27	73 02	67 28	68 55	69 22	70 27	69 46	70 69	67 76	71 76	79 58	70 51	69 55	79 87	73 44
Ti	0 18	0 18	0 20	0 19	0 21	0 21	0 21	0 22	0 20	0 16	0 5	0 23	0 22	0 15	0 15
Al	12 58	11 78	12 55	12 78	13 61	13 54	13 67	13 96	12 92	9 60	10 07	14 60	14 02	10 45	12 60
Fe	4 57	5 36	8 81	2 14	2 84	2 32	2 96	3 78	3 62	4 18	0 62	4 26	3 65	1 48	1 92
Mn	0 07	0 05	0 12	0 02	0 08	0 06	0 06	0 11	0 02	0 03	0 02	0 11	0 04	0 03	0 04
Mg	1 24	1 05	1 37	0 16	0 58	0 31	0 77	1 02	0 64	0 13	0 26	0 74	1 23	0 72	0 34
Ca	2 73	0 26	0 61	0 98	1 56	1 20	1 70	3 21	0 60	0 22	0 88	2 46	0 89	2 27	0 77
Na	3 99	0 98	0 97	10 65	9 28	7 66	6 18	4 56	6 05	2 32	7 75	3 76	9 52	2 19	8 61
K	1 65	3 25	2 29	0 61	1 98	3 62	3 53	1 93	3 80	2 75	0 66	2 08	0 85	2 82	2 11
P	0 02	0 01	0 03	0 02	0 02	0 02	0 02	0 02	0 02	0 00	0 02	0 03	0 03	0 00	0 02
S	2 13	3 70	3 26	2 89	0 10	0 02	0 13	0 16	3 98	5 34	0 00	0 75	0 00	0 00	0 00
C	1 57	0 36	2 49	1 02	0 51	0 77	1 32	0 33	0 39	3 50	0 00	0 46	0 00	0 00	0 00
SUM	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00
Cation Min Norr															
Apatite	0 04	0 02	0 09	0 04	0 06	0 04	0 06	0 07	0 06	0 00	0 04	0 09	0 09	0 00	0 04
Quartz	49 25	59 47	53 56	34 52	36 78	40 54	42 91	48 14	41 98	57 35	54 07	48 91	36 82	65 00	43 24
Albite	19 95	4 89	4 87	53 24	46 40	38 40	30 89	22 80	30 24	11 61	38 76	18 81	47 59	10 96	43 03
Sericite	11 52	22 76	16 06	4 24	13 83	25 32	24 71	13 48	26 61	19 26	4 60	14 56	5 95	19 75	14 79
Chlorite	10 71	3 48	15 63	1 06	-5 31	16 63	10 32	10 73	15 11	3 26	1 14	10 52	6 50	0 69	7 80
Zois(Ep)	1 16	0 00	0 00	0 00	0 00	0 00	0 00	1 08	0 00	0 00	0 00	3 85	0 00	0 00	0 00
Kaolinite	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
Pyrite	3 20	5 56	4 89	4 34	0 16	0 03	0 19	0 24	5 98	8 01	0 05	1 12	0 00	0 00	0 00
Carbonate	3 98	0 71	4 39	2 05	2 03	1 94	2 97	3 24	0 95	3 46	0 85	1 91	0 83	2 27	0 74
Magnetite	0 00	2 93	0 00	0 33	2 79	2 31	2 90	0 00	1 63	0 00	0 39	0 00	2 00	1 48	1 92
Rutile	0 18	0 18	0 20	0 19	0 21	0 21	0 21	0 22	0 20	0 16	0 15	0 23	0 22	0 15	0 15
Graphite	0 00	0 00	0 30	0 00	0 00	0 00	0 00	0 00	0 00	1 77	0 00	0 00	0 00	0 00	0 00
Total	100 00	100 00	100 00	100 00	96 95	92 15	94 53	100 00	92 55	98 37	100 00	100 00	100 00	98 94	96 11

Weight of Oxyge															
Hole	**N-163**		**N-175**					**N-190**			**N-181**			**N-224**	
Depth (ft)	**1109**	**1253**	**1411**	**1543**	**1639**	**1779**	**1826**	**1174**	**1308**	**1623**	**1042**	**1065**	**1319**	**779**	**951**
Ap	3	1	5	3	4	3	4	4	4	0	3	5	5	0	3
Qz	2959	3573	3219	2075	2210	2436	2579	2893	2523	3446	3249	2939	2213	3906	2598
Ab	1047	256	256	2792	2434	2014	1620	1196	1586	609	2033	987	2496	575	2257
Ser	656	1295	914	241	787	1440	1406	767	1514	1096	262	828	338	1124	842
Chl	672	218	981	66	334	1044	647	673	948	205	71	660	408	43	490
Zo	66	0	0	0	0	0	0	61	0	0	0	219	0	0	0
Carb	199	36	220	102	102	97	149	162	48	173	43	96	42	114	37
Mt	0	226	0	25	215	178	223	0	126	0	30	0	155	115	148
Rt	15	15	17	15	17	17	17	18	17	13	12	19	18	12	12
Total	5616	5621	5611	5320	5435	5142	5351	5774	4869	5133	5703	5753	5675	5802	5407
wt % Norms															
Ap	0.05	0.02	0.10	0.05	0.07	0.05	0.07	0.07	0.08	0.00	0.05	0.09	0.09	0.00	0.05
Qz	52.69	63.57	57.36	39.00	40.66	47.37	48.19	50.10	51.81	67.14	56.97	51.09	38.99	67.32	48.05
Ab	18.64	4.56	4.56	52.49	44.77	39.17	30.28	20.71	32.58	11.86	35.65	17.15	43.99	9.91	41.74
Ser	11.67	23.04	16.29	4.54	14.48	28.01	26.28	13.29	31.10	21.36	4.59	14.40	5.96	19.37	15.57
Chl	11.96	3.88	17.48	1.25	6.14	20.29	12.10	11.66	19.47	3.99	1.25	11.48	7.18	0.75	9.06
Zo	1.18	0.00	0.00	0.00	0.00	0.00	0.00	1.06	0.00	0.00	0.00	3.80	0.00	0.00	0.00
Carb	3.55	0.64	3.92	1.92	1.87	89	2.78	2.80	0.98	3.37	0.75	1.66	0.73	1.96	0.69
Mt	0.00	4.03	0.00	0.47	3.96	3.46	4.18	0.00	2.58	0.00	0.52	0.00	2.72	1.97	2.73
Rt	0.26	0.27	0.30	0.29	0.32	0.34	0.32	0.31	0.34	0.26	0.22	0.33	0.32	0.21	0.23
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Wt% Ox															
Qz	28.09	33.88	30.58	20.78	21.67	25.25	25.69	26.70	27.62	35.79	30.37	27.23	20.78	35.88	25.61
Ab	9.09	2.22	2.22	25.61	21.85	19.11	14.78	10.11	15.90	5.79	17.40	8.37	21.47	4.84	20.37
Ser	5.63	11.10	7.85	2.19	6.98	13.50	12.66	6.40	14.99	10.29	2.21	6.94	2.87	9.34	7.50
Chl	5.49	1.78	8.02	0.57	2.82	9.31	5.55	5.35	8.94	1.83	0.57	5.27	3.30	0.34	4.16
Zo	0.54	0.00	0.00	0.00	0.00	0.00	0.00	0.49	0.00	0.00	0.00	1.74	0.00	0.00	0.00
Carb	1.70	0.31	1.68	0.92	0.90	0.91	1.33	1.35	0.47	1.62	0.36	0.80	0.35	0.94	0.33
Mt	0.00	1.11	0.00	0.13	1.09	0.96	1.15	0.00	0.71	0.00	0.14	0.00	0.75	0.54	0.75
Wt% Ox Tot	50.54	50.41	50.55	50.21	49.68	50.41	50.06	50.40	50.75	51.65	51.06	50.34	49.53	51.20	50.41
Wt % Ox Tot	50.66	50.52	50.71	50.34	49.83	50.57	50.22	50.55	50.92	51.76	51.16	50.51	49.69	51.28	50.52
D 18 Ox Calc	9.60	9.70	9.20	10.50	10.40	[illegible]	10.51	9.55	11.10	10.72	10.75	9.32	9.82	10.39	10.81
D 18 Ox Calc	7.20	7.28	6.86	7.94	7.86	8.47	7.96	7.15	8.46	8.14	8.16	6.98	7.36	7.86	8.20
D 18 Ox Calc	5.40	5.47	5.11	6.02	5.96	6.48	6.05	5.36	6.48	6.21	6.21	5.22	5.52	5.97	6.25
D 18 Ox Meas											10.4		9.8	0.5	9.35
Book-keeping fo															
Calcite	3.13	0.49	[illegible]	1.91	1.02	1.54	2.63	0.66	0.79	0.45	0.00	0.93	0.00	0.00	0.00
FeCarb	0.00	0.22	3.28	0.14	0.00	0.00	0.00	0.00	0.00	3.01	0.00	0.00	0.00	0.00	0.00
Excess Carb	0.85	0.00	0.00	0.00	[illegible]	0.40	0.34	2.57	0.16	0.00	0.85	0.98	0.83	2.27	0.74
Ca Abt	2.71	0.25	0.56	0.95	1.52	[illegible]	1.66	3.17	0.56	0.22	0.85	2.41	0.83	2.27	0.74
Al Ab+Ser	3.65	1.04	4.69	0.32	1.59	4.99	3.09	3.62	-4.53	0.98	0.34	4.60	1.95	0.21	2.34
Si Ab+Ser	52.36	60.33	57.47	34.79	35.45	36.38	40.33	51.23	38.20	56.54	54.35	52.99	38.44	64.83	41.29
Fe Py	3.50	3.51	[illegible]	0.69	2.79	2.31	2.90	3.70	1.63	1.50	0.62	3.89	3.65	1.48	1.92
Mg-Mn Ch	2.93	2.45	3.32	0.40	5.31	16.63	10.32	2.51	15.11	3.26	0.60	1.88	2.83	0.69	7.80
FeCh	7.78	1.03	12.31	0.66	0.00	0.00	0.00	8.22	0.00	0.00	0.53	8.65	3.66	0.00	0.00
Si MgCh	51.63	59.72	56.64	34.69	36.78	40.54	42.9	50.60	41.98	57.35	54.20	52.52	37.74	65.00	43.24
Al MgCh	2.77	0.31	3.69	0.20	0.00	0.00	0.00	2.87	0.00	0.00	0.16	4.04	1.10	0.00	0.00
Si FeCh	49.69	59.47	53.56	34.52	36.75	40.54	42.91	48.54	41.98	57.35	54.07	50.36	36.82	65.00	43.24
Al FeCh	0.44	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.00	44	0.00	0.00	0.00
Mg-Mn Ch	0.00	0.00	0.00	0.00	3.25	7.85	5.47	0.00	7.45	1.63	0.00	0.00	0.00	1.06	3.89
FeCh	0.00	3.05	1.64	0.40	2.79	2.31	2.90	0.00	63	1.50	0.39	0.00	2.00	48	92
Al Zo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si Zo	49.25	59.47	53.56	34.52	36.79	40.54	42.91	48.14	41.98	57.35	54.07	48.91	36.82	65.00	43.24
Ca Zo	2.42	0.25	0.56	0.95	1.52	[illegible]	1.66	2.90	0.56	0.22	0.85	1.45	0.83	2.27	0.74
Ca Ca	0.85	0.00	0.00	0.00	[illegible]	0.40	0.34	2.57	0.16	0.00	0.85	0.98	0.83	2.27	0.74
C Ca	0.00	0.11	1.34	0.07	0.00	0.00	0.00	0.00	0.00	3.25	0.00	0.00	[illegible]	0.00	0.00

APPENDIX III

Calculation of the Original Volume of the Hosting Volcanic Rock to the Norbec Deposit and Net Volume Change

	Precursor W Rhyolite	Precursor W Andesite
SiO2	76 18	59 76
TiO2	0 29	1 27
Al2O3	12 25	14 79
FeO	3 8	9 25
MnO	0 04	0 24
MgO	0 51	4 05
CaO	0 51	5 42
Na2O	5 75	4 58
K2O	0 63	0 43
P2O5	0 03	0 17
SUM	100	100

Igneous Normative Mineral Program Niggli-type cation% norm
a) divide by the molecular mass of each oxide on a single cation basis to
to determine the cation %

CATIONS	Rhyolite	Andesite	CATION %	Rhyolite	Andesite
Si	1 2680	0 9947		70 97	55 57
Ti	0 0036	0 0159		0 20	0 89
Al	0 2403	0 2901		13 45	16 21
Fe	0 0529	0 1287		2 96	7 19
Mn	0 0006	0 0034		0 03	0 19
Mg	0 0127	0 1005		0 71	5 61
Ca	0 0091	0 0966		0 51	5 40
Na	0 1856	0 1478		10 39	8 26
K	0 0134	0 0091		0 75	0 51
P	0 0005	0 0031		0 03	0 17
SUM	1 7866	1 7900		100 00	100 00

Normative Mineral Flow Sheet Chlorite added for extra Al

Si	70 97	55 57	Fe,Mg,Mn	3 70	13 00
Si Ab	39 81	30 79	Fe-Ilm	3 50	12 11
Si Or	37 56	29 26	Fe-Chl	1 46	12 11
Si An	36 60	21 82	Fe-Cpx	1 46	10 61
Si Chl	35 47	21 82	Fe-Opx	0 00	0 00
Si Cpx	35 47	18 82			
Si Opx	34 01	8 21			
Ca	0 51	5 40	Al	13 45	16 21
Ca Ap	0 48	5 22	Al Ab	3 06	7 95
Ca An	0 00	1 50	Al Or	2 31	7 44
Ca Cpx	0 00	0 00	Al-An	1 36	0 00
			Al-Chl	0 00	0 00

Normative Minerals

Apatite	0 05	0 29
Ilmenite	0 41	1 78
Albite	51 94	41 30
Orthoclase	3 74	2 55
Anorthite	2 39	18 60
Chlorite	4 53	0 00
Clino px	0 00	6 00
Ortho px	2 92	21 21
Quartz	34 01	8 21
Sum	100	100

Change cation % norm to weight % norm to determine volume and density of the precursors Amt of norm mineral * (Formula weight/# of cations)

	Rhyolite	Andesite
Apatite	3 16	17 86
Ilmenite	31 23	136 53
Albite	2724 39	2165 93
Orthoclase	208 39	141 97
Anorthite	132 76	1034 67
Chlorite	284 02	0 00
Clino px	0 00	348 51
Ortho px	169 62	1232 15
Quartz	2043 84	493 64
Sum	5597 40	5571 26

Normalized Weight % of normative minerals for the precursors

Apatite	0 06	0 32
Ilmenite	0 56	2 45
Albite	48 67	38 88
Orthoclase	3 72	2 55
Anorthite	2 37	18 57
Chlorite	5 07	0 00
Clino px	0 00	6 26
Ortho-px	3 03	22 12
Quartz	36 51	8 86
Sum	100 00	100 00

The volume each mineral occupies in cm3 per 100 grams of rock Specific gravity is 100/vol Median composition of chlorite used

	Rhyolite	Andesite
Apatite	0 02	0 10
Ilmenite	0 12	0 52
Albite	18 58	14 84
Orthoclase	1 45	0 99
Anorthite	0 86	6 73
Chlorite	1 70	0 00
Clino-px	0 00	1 84
Ortho-px	0 85	6 18
Quartz	13 78	3 34
Sum cm3	37 35	34 54
Avg S G	2 677	2 895

Densities used from D H Z *	
Apatite	3 15
Ilmenite	4 7
Albite	2 62
Orthoclase	2 57
Anorthite	2 76
Chlorite med	2 98
Clino-px	3 4
Ortho-px	3 58
Quartz	2 65

* Deer, Howie and Zussman

Determining the original volume of hosting volcanic rocks
Given data from previous calculations

	Altered WR	Altered WA
Volume m3	8080000	4920000
Tonnes	23270400	14612400
E F	1 205	1 100
S G Fresh	2 68	2 89
S G Altered	2 88	2 97
Zr Fresh	313	120
Vol (cm3) 100g of Fresh	37 35	34 54

METHOD I

a) Weight of Zr in the Altered units
=tonnes of altered rock * Zr(ppm) in precursor / 1000000 / E F

	WR	WA
Zr tonnes	6044 51	1594 08

b) volume (m3) of 100g of precursor represented by 1 gram of Zr
i e for the Waite Rhyolite, 313 ppm = 0 0313 g in 100g of rock

	WR	WA
m3 fresh	0 00120	0 00289

c) Resulting volume of precursor hosting volcanic rocks
=tonnes Zr in altered rocks * vol of rock represented by 1g Zr

	WR	WA
Vol m3	7224445	4605563

d) % volume change

	WR	WA
%	11 84	6 83

METHOD II

a) Enrichment factor is also the mass change factor

	WR	WA
E F	1 205	1 11

b) the density factor is S G (alt) / S G (fresh)

	WR	WA
S G factor	1 075	1 028

c) volume is related to mass by the density, therefore
the volume change between fresh and altered rock is the E F/S G factor

	WR	WA
vol chnge	1 121	1 080
%	12 13	8 01

AVERAGE OF BOTH METHODS:

WR	WA
11 99	7 42

APPENDiX IV
DETERMINATION OF OREBODY COMPONENTS

STATISTICS OF THE NORBEC OREBODY
MASS = 4 3 MT or 4 300 000 T
GRADE = 2 8% Cu, 4 7% Zn, 43 g/t Ag, and 0 9 g/t Au

Mass of ore minerals		Copper (T)	Zinc (T)	Iron (T)	Sulphur (T)	Ag (T)	Au (T)
Cu as CuFeS2	2 8% Cu =	120 400		105 827	121 094		
Zn as ZnS	4 7% Zn =		202 100		99 092		
Ag as Ag	43 ppm Ag =					185	
Au as Au	0 9 ppm Au =						3.87
TOTAL MASS OF ORE ELEMENTS		120 400	202 100	105 827	220 186	185	3.87

TOTAL MASS OF ORE MINERALS 648 701 87 TONNES
TOTAL MASS OF REMAINING GANGUE MINERALS 3 651 298 13 TONNES

GANGUE MINERALS
The gangue minerals of the orebody are 30% pyrite, 11% pyrrhotite, 4% magnetite, and 20% silicates. Therefore, there is 46 2% pyrite, 16 97% pyrrhotite, 6 1% magnetite, and 30.8% silicates in the remaining mass of gangue minerals

Opaque gangue minerals

			Fe (T)	Sulphur (T)
46 2%	FeS2	GMM=119 85	786 095	900 804
16 97%	FeS	GMM=87 85	394 082	225 544
6 1%	Fe3O4	GMM=77 18	222 729	
TOTAL MASS OF OPAQUES			1 402 906 T	1 126 348 T

Silicate Gangue Minerals
Silicate minerals from tuffite and chert components account for 30 8% of the gangue.
Of the 30 8%, 24 6% is quartz, 4 6% is chlorite, and 1 5% is sericite

	SiO2 (T)	MgO (T)	MnO (T)	FeO (T)	AlO1.5 (T)	KO0 5 (T)
24 6% SiO2	898 219					
4 6% Mg3MnFe5Al6Si5O20(OH)16						
0 48% MgO		17 551				
0 28% MnO			10 292			
1 43% FeO				52 144		
1 22% AlO1 5					44 407	
1 19% SiO2	43 550					
1 5% KAl3Si3O10(OH)2						6 788
0 19% KO0 5						
0 60% AlO1 5					22 041	
0 71% SiO2	25 940					
TOTAL	967 710	17 551	10 292	52 144	66 448	6 788

	SiO2 (T)	MgO (T)	MnO (T)	FeO (T)	AlO1 5 (T)	KO0.5 (T)	Sulphur (T)
Total Gangue	967 710	17 551	10 292	1 455 050	66 448	6 788	1 126 348

Assume that the tuff component was the same as the Waite Rhyolite with 60% Albite and 40% Quartz, and that Aluminum was immobile during alteration to chlorite and sericite
60% NaAlSi3O8
AlO1 5 = 19 47% of Ab = 66 448 T Therefore, Albite has a mass of 341 284 T
NaO0 5 = 11 83% of Ab = 40 374 T
SiO2 = 68 70% of Ab = 234 470 T

Total mass of Albite is 60% of the tuff and quartz accounts for the remaining 40%, therefore·
SiO2 = 227 523 T

In a mass change context, the major oxides have been added or depleted this way·

SiO2	+505 717 T
AlO1 5	0
FeO	+521 444 T
MnO	+102 292 T
MgO	+17 551 T
NaO0 5	-40 374 T
KO0 5	+6 788 T