

Geology and Geochemistry of the Eagle Bay Assemblage in the Johnson Lake area,
Kootenay Terrane, South-Central British Columbia

By

Sean L. Bailey
B.Sc. Memorial University, 1999

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

In the department of Earth and Ocean Sciences

We accept this thesis as conforming
to the required standard


Dr. S. Paradis, Supervisor (Geological Survey of Canada)


Dr. S.T. Johnston, Supervisor (Department of Earth and Ocean Sciences)


Dr. D. Canil, Departmental Member (Department of Earth and Ocean Sciences)


Dr. R. Thompson, External Member (Geological Survey of Canada)

© Sean Lee Bailey, 2002
University of Victoria

All rights reserved. This thesis may not be reproduced in whole or in part, by photocopy
or other means, without the permission of the author.

QE187

B277

Supervisor: Dr. Suzanne Paradis

ABSTRACT

1: 20,000 scale geological mapping of the Eagle Bay Assemblage was conducted in the Johnson Lake area in southern British Columbia to document lithologies that host economically important base and precious metal deposits. The Eagle Bay Assemblage consists of polydeformed, greenschist metamorphic grade rocks derived from volcanic, intrusive and sedimentary protoliths, and is assigned to the pericratonic Kootenay Terrane of the Canadian Cordillera.

Lower Cambrian (and older?) metamorphosed bedded chert, siliciclastic, mafic volcanic/ volcanoclastic rocks and limestone structurally overlie Devonian-Mississippian felsic, intermediate and mafic volcanic/volcanoclastic and siliciclastic rocks. Geological units and structures trend northwest, and dip east. The geometries are controlled predominantly by Jurassic west-verging folding and thrusting. Folds are tight to isoclinal with overturned limbs, have synmetamorphic axial planar cleavage and developed synchronously with thrust faulting. Fault geometries can be explained by treating the thrusts as a series of ramps and flats. Thrust flats trend northwest and dip moderately east concordant with stratigraphic layers. Ramps trend north, dip steeply east and cut across stratigraphic layers.

Late Devonian felsic to intermediate volcanic rocks and subvolcanic intrusions have calc-alkalic whole rock geochemistry and are assigned to a volcanic arc tectonic setting. Structurally overlying these rocks are alkalic intermediate to felsic rocks that yield a 36064.6 Ma U-Pb zircon age. These rocks are interpreted to have formed during

ripping of the volcanic arc. Mafic volcanic rocks overlying the Rea and Sam^atosum deposits are of uncertain age and have an ocean island basalt (OIB) rift type chemistry. Mafic volcanic rocks of known Lower Paleozoic age have OIB and mid ocean ridge basalt (MORB) type chemistry and are remnants of a continental margin rift. Late Devonian rocks host volcanogenic massive sulphide (VMS; Rea, K7, Homestake) and quartz-carbonate-sulphide vein (Samatosum) deposits. The Homestake massive barite/sulphide deposit is hosted within altered felsic volcanic rocks of unit 6. The Rea and Samatosum deposits occur within a fault repeated altered argillite and quartz-wacke that is truncated to the south. However this zone continues northwest of the map area and may host undiscovered massive sulphide deposits.

Examiners:

[REDACTED]
Dr. S. Paradis, Supervisor (Geological Survey of Canada)

[REDACTED]
Dr. S.T. Johnston, Supervisor (Department of Earth and Ocean Sciences)

[REDACTED]
Dr. D. Canil, Departmental Member (Department of Earth and Ocean Sciences)

[REDACTED]
Dr. R. Thompson, External Examiner (Geological Survey of Canada)

TABLE OF CONTENTS

ABSTRACT.....	ii
TABLE OF CONTENTS.....	iv
LIST OF TABLES.....	vi
LIST OF FIGURES.....	vii
ACKNOWLEDGEMENTS.....	xi
CHAPTER 1: INTRODUCTION.....	1
OVERVIEW.....	1
DESCRIPTION OF THE STUDY AREA	2
PREVIOUS WORK.....	4
REGIONAL GEOLOGY	6
REGIONAL STRUCTURE AND METAMORPHISM	8
REFERENCES.....	11
 CHAPTER 2: STRATIGRAPHY AND STRUCTURE OF METASEDIMENTARY, METAVOLCANIC AND INTRUSIVE ROCKS FROM THE JOHNSON LAKE AREA, SOUTHERN BRITISH COLUMBIA.....	 13
ABSTRACT.....	13
INTRODUCTION.....	14
LOCAL STRATIGRAPHIC UNITS	18
Volcanic and Sedimentary rocks	18
Unit 1: Bedded chert and metapelite	18
Unit 2: Mafic volcanic rocks.....	22
Unit 3a: Mafic volcanic/volcaniclastic rocks	22
Unit 3b: Limestone.....	23
Unit 4: Mafic volcanic/volcaniclastic rocks	23
Unit 5: Siliciclastic rocks	24
Unit 6: Felsic and intermediate volcanic rocks	25
Unit 7, 8: Argillite, quartz-wacke, and quartz lithic pebble conglomerate.....	26
Unit 9: Felsic and intermediate volcanic rocks	26
Unit 10: Argillite, quartz-wacke.....	28
Intrusive Rocks.....	29
Late Devonian granite, granodiorite, and diorite.....	29
Hornblende diorite	30
REGIONAL STRATIGRAPHIC CORRELATIONS.....	30
STRUCTURE	34
Shafer Lake syncline	42
Haggard Creek fault	42
Samatosum Creek and Samatosum Mountain faults	43
East-West trending faults	43
DISCUSSION	43
CONCLUSIONS.....	48
ACKNOWLEDGEMENTS	49
REFERENCES.....	50
 CHAPTER 3: GEOCHEMISTRY, GEOCHRONOLOGY, AND TECTONIC SETTING OF METAVOLCANIC ROCKS FROM THE EAGLE BAY ASSEMBLAGE, JOHNSON LAKE AREA, SOUTHERN BRITISH COLUMBIA, CANADA.....	 54

ABSTRACT	54
INTRODUCTION	55
GEOLOGY	59
Volcanic Rocks	62
Unit 2: Mafic volcanic rocks	62
Unit 3a: Mafic volcanic/volcaniclastic rocks	62
Unit 4: Mafic volcanic/ volcaniclastic rocks	63
Unit 6: Felsic and intermediate volcanic rocks	64
Unit 9: Felsic to intermediate volcanic rocks	64
Devonian felsic to intermediate intrusive rocks	65
WHOLE ROCK GEOCHEMISTRY	65
RESULTS	66
Mafic volcanic rocks	66
Felsic to Intermediate volcanic rocks	76
U-Pb ZIRCON GEOCHRONOLOGY	86
U-Pb geochronology results	86
NEODYMIUM ISOTOPES	87
Neodymium isotope results	87
DISCUSSION	92
Petrogenesis and tectonic setting of Lower Paleozoic rocks	92
Petrogenesis and tectonic setting of Middle Paleozoic rocks	95
CONCLUSIONS	97
ACKNOWLEDGEMENTS	97
REFERENCES	98
 CHAPTER 4: MINERAL OCCURRENCES	 104
INTRODUCTION	104
SULPHIDE OCCURRENCES	104
Samatsum (B.C. Minfile 082M 244)	105
Rea (B.C. Minfile 082M 191)	114
K7 (B.C. Minfile 082M 277)	117
Homestake (B.C. Minfile 082M 25)	119
Agate (B.C. Minfile 82M 53)	120
Stake (B.C. Minfile 082M 107)	120
Twin Mountain (B.C. Minfile 082M 20)	120
Acacia (B.C. Minfile 082M 75)	121
SULPHUR ISOTOPES	121
DISCUSSION	124
CONCLUSIONS	130
REFERENCES	130
 CHAPTER 5: CONCLUSIONS	 134
STRATIGRAPHY	134
STRUCTURE	134
GEOCHEMISTRY	135
MINERAL OCCURRENCES	136
TECTONIC SETTING	137
REFERENCES	138

Appendix I:	1: 20 000 scale geological map and sections (in pocket), hand sample and thin section descriptions.....	139
Appendix II:	Lithogeochemical data, limits of detection.....	152
Appendix III:	Isotope data.....	184
Appendix IV:	Digital Appendices, CD ROM	

LIST OF TABLES

CHAPTER 2

Table 2.1: Summary of isotopic age dates from rocks of the Eagle Bay Assemblage, and Kootenay Terrane	27
Table 2.2: Summary of structural events in the Eagle Bay Assemblage, after Schiarizza and Preto, (1987) and this study.	41

CHAPTER 3

Table 3.1. Whole rock major and trace element analyses for mafic volcanic rocks, Johnson Lake Area, B.C., Canada.	68
Table 3.2. Whole rock major and trace element analyses for felsic volcanic rocks, Johnson Lake Area, B.C., Canada.	70
Table 3.3. Whole rock major and trace element analyses of mafic-intermediate volcanic rocks, unit 6, Johnson Lake area, B.C. Canada	72
Table 3.4: Summary of characteristics of VMS districts.....	78
Table 3.5: Results of U-Pb zircon analyses for sample SLB99-31, quartz feldspar porphyritic rhyolite of unit 9, Johnson Lake B.C.	88
Table 3.6: Neodymium isotopic data for Johnson Lake volcanic and sedimentary rocks. Isotopes are reported as ratios to ^{144}Nd . ϵNd was calculated based on the T Ma ages listed, Nd correction = Nd static S54, uncertainty is reported as 2 standard errors. Unit 4 ϵNd T values calculated for both Devonian and Lower Cambrian ages.....	90

CHAPTER 4

Table 4.1: Grade and tonnage summaries of deposits/significant showings in the Johnson Lake area (after Carmichael, 1991; Pirie, 1989).	106
Table 4.2: Hydrothermal alteration minerals of the Samatosum deposit, B.C.	114

LIST OF FIGURES

CHAPTER 1

Figure 1.1: Location of the study area, within the Kootenay Terrane of British Columbia, modified after Wheeler and McFeely (1991). 3

Figure 1.2: Terrane map of the northern Cordillera after Monger (1993), **JFR**= Juan de Fuca Ridge, **Pac**= Pacific ocean, unpatterned areas are ocean floor or extensive areas of plutonic rock or post accretionary cover. The morphological belt boundaries are outlined, **F**= Foreland belt, **O**= Omineca crystalline belt, **Int**= Intermontane belt, **C**= coast belt, **Ins**= Insular belt. 7

Figure 1.3: Geology of the Johnson Lake area, modified after Schiarizza and Preto (1987), present study area is outlined. 9

CHAPTER 2

Figure 2.1: Simplified geological map of Southeastern British Columbia, modified after Wheeler and McFeely (1991). Mineral deposits indicated are Rea (R), Homestake (H), Harper Creek (HC), Goldstream (G), and True Blue (TB). The study area (see Fig. 2.2) is outlined by the rectangle surrounding the Rea and Homestake deposits. 15

Figure 2.2: Simplified geological map of the Johnson Lake area. 16

Figure 2.3: Stratigraphic section of geological units in the Johnson Lake Area, after this study and Schiarizza and Preto (1987). See map legend for unit designations. 19

Figure 2.4: Photo's of rock units and textures, Johnson Lake area, A.) "Banded chert", microcrystalline quartz, chert bands are 2-4 cm wide, unit 1. B.) Metre size pillows in mafic metavolcanic of unit 4. C.) Intercalated black and grey phyllite Unit 10. D.) Rip up clasts of black phyllite in sandstone of unit 10. E.) Coarse-grained Devonian intrusive. F.) Hornblende diorite dike. 20

Figure 2.5: Photomicrographs of textures in rocks from the Johnson Lake area A.) Microcrystalline quartz(chert), sample SLB99-11 (unit 1) B.) Epidote (pseudomorphs of plagioclase?) Crystals in fine grained actinolite, chlorite, opaque matrix, sample SLB99-09 (unit 2). C.) Oolites in limestone of unit 3b. D.) Deformed igneous plagioclase grain unit 4, fabric defined by chlorite, actinolite and opaques. E.) Embayed quartz crystal in quartz sericite carbonate matrix, unit 9, sample SLB99-137. F.) Saussauritized plagioclase grain in unit 9, sample SLB99-137. All photos taken in cross polarized transmitting light. 21

Figure 2.6: Regional Stratigraphic correlation chart, Neoproterozoic to Paleozoic volcanic-sedimentary packages of the Omineca belt, Southern British Columbia, after Schiarizza and Preto (1987). 32

Figure 2.7: NE-SW cross-sections of the Johnson Lake area, no vertical exaggeration. 35

Figure 2.8: Structural domains and stereo plots of poles to planes and lineations. S_0 = compositional layering, S_2 = penetrative foliation, $L_2 = S_0 / S_2$ intersection lineation + F_2 minor fold hinge lines. Great circles plotted are the average orientation of that plane, average orientations of the L_2 lineations are also given. 36

Figure 2.9: Sketch of F_1 isoclinal folds refolded and transposed by F_2 isoclinal folds in Cambrian limestone intercalated with unit 1. S_1 is assumed to be the axial planar cleavage to F_1 (has been transposed and overprinted by S_2), F_2 axial planes dip 45-60 degrees east, S_2 is the penetrative cleavage/foliation that is axial planar to F_2 , S_0 refers to bedding or compositional layering. 37

Figure 2.10: Sketch of S_2 "penetrative foliation" folded by S_3 giving rise to "crenulation cleavage", L_3 lineation is defined by the intersection of S_2 and S_3 , (i.e. crenulation fold hinges)..... 38

Figure 2.11: Schematic sketch of F_2 isoclinal folds folded by broad open F_3 folds, axial planes to F_2 trend NW, dip 45-60 degrees east and have a penetrative cleavage/ foliation defined by sericite, chlorite, actinolite (synmetamorphic), F_3 folds trend NE, dip 80-90 degrees south and have a crenulation cleavage defined by open folds of S_2 . F_2 is Jurassic-Cretaceous, F_3 is Cretaceous or younger..... 38

Figure 2.12: Photos of macroscopic rock structures in the Johnson Lake area A.) Recumbent isoclinal fold in quartzite of unit 5 B.) Sheared fragments in S_2 plane, unit 4. C.) Kink bands folding the S_2 fabric, unit 4. D.) S-fold viewed down-plunge, pelitic schist of unit 1 E.) Isoclinal F_1 refolded by tight F_2 folds limestone interbeds of unit 1. F.) Quartz veins in chlorite schist that are isoclinally folded by the foliation (S_2). 40

Figure 2.13: Geological map near the Samatosum Creek fault, Line A-B is the trace of the fault plane solution in Figure 2.14. 44

Figure 2.14: Fault plane solution for the Samatosum Creek fault, viewing east. Limestone contact used as a marker horizon pitch of the limestone in the fault plane is 28 degrees, restoration of the marker suggests either sinistral strike-slip, thrust fault (East block up), or combination sinistral-thrust fault.....45

CHAPTER 3

Figure 3.1: Simplified geological map of Southeastern British Columbia, modified after Wheeler and Mcfeely (1991). Mineral deposits indicated are Rea (R), Homestake (H), Harper Creek (HC), Goldstream (G), and True Blue (TB). The study area (see Fig. 2) is outlined by the rectangle surrounding the Rea and Homestake deposits. 56

Figure 3.2: Simplified geological map of the Johnson Lake area, B.C. 57

Figure 3.3: Stratigraphic section of geological units in the Johnson Lake area, after this study and Schiarizza and Preto (1987). See map (Fig. 3.2) legend for unit designations. 60

Figure 3.4: Immobile HFSE discrimination plots for mafic volcanic rocks from the Johnson Lake Area. A.) Nb/Y-Zr/TiO₂ plot of Winchester and Floyd, (1977). B.) Y/Ti- Zr/Ti plot after Barrett and MacLean (1999). C.) Nb/Yb-Th/Yb after Pearce and Peate (1995). D.) Nb/Yb- Zr/Yb after Pearce (1983) N-MORB, E-MORB and OIB values from Sun and McDonough (1989)..... 73

Figure 3.5: Primitive mantle normalized multielement plots for mafic volcanic rocks from the Johnson Lake area, elements are arranged in order of decreasing incompatibility in a mantle source region. A.) Unit 2 mafic volcanic rocks have an N-MORB type pattern. B.) Mafic volcanic rocks from unit 3a have an OIB type geochemical pattern. C.) Mafic volcanic rocks from unit 4 have an OIB basalt pattern. Normalization values after Sun and McDonough (1989)..... 74

Figure 3.6: Chondrite normalized rare earth element (REE) diagrams. Elements are arranged from left to right in order of LREE's to HREE's. A.) Unit 2 mafic rocks have an N-MORB type pattern. B.) Unit 3a mafic volcanic rocks have an OIB type geochemical pattern. C.) Unit 4 mafic volcanic rocks have OIB basalt type patterns. Average OIB, N-MORB, E-MORB, and chondrite normalization values after Sun and McDonough (1989). 75

Figure 3.7: Tectonic discrimination diagrams for mafic and intermediate volcanic rocks from the Johnson Lake area. A.) Zr-Th-Nb ternary diagram of Wood (1980). B.) V/Ti diagram of Shervais (1982). C.) Nb-Zr-Y diagram of Meschede (1986).....77

Figure 3.8: Major and trace element lithogeochemistry of felsic rocks from the Johnson Lake area, A.) Zr/TiO₂, Nb/Y plot of Winchester and Floyd (1977) B.) SiO₂, Zr/TiO₂ plot of Winchester and Floyd, 1977. C.) Shand's Index after Maniar and Piccoli (1989), showing the predominantly peraluminous affinity of units 6 and 9. D-F trace element ratios D.) (Zr/Yb) / (Ti/Yb) E.) (Zr/Yb) / (Sc/Yb) F.) (Th/Yb) / (Nb/Yb). FL= Finlayson Lake district, Yukon- Kudz Ze Kayah unit after Piercey et al., 2000; 2001. BT = Bathurst district, New Brunswick, Flat Landing Brook and Nepisiguit Falls formations, after Lentz (1998). MW= Mount Windsor Subprovince, Australia, Puddler Creek Formation, after Stoltz (1995). 81

Figure 3.9: Trace element plots for felsic rocks in the Johnson Lake area. A.) Zr/Nb ratios and B.) Hf/Nb ratios showing separate differentiation trends for units 6 and 9. C.) Primitive mantle normalized multielement plot, note the differences in Zr, Hf and V between units 6 and 9. D.) Chondrite normalized REE plot, note the negative Eu anomaly and the relative abundances of HREE's. Normalization values after Sun and McDonough (1989). 82

Figure 3.10: A.) Primitive mantle normalized multielement diagram for rocks of unit 6, note the negative Nb and Ti anomalies B.) Chondrite normalized REE diagram for rocks of unit 6. 83

Figure 3.11: Tectonic discrimination diagrams of felsic volcanic and plutonic rocks from the Johnson Lake area. A.) Nb/Y granite discrimination diagram of Pearce et al, (1984), all samples plot near the boundary between the arc to within plate granites B.) Rb/Nb+Y granite discrimination diagram of Pearce et al. (1984). 85

Figure 3.12: U-Pb Concordia diagram of zircon fractions 2-5 from sample SLB99-031, a quartz feldspar porphyritic flow of unit 9, all fractions are discordant, linear regression defines an upper intercept coinciding with an age of 360.6±4.7Ma. 89

Figure 3.13: Whole rock Nd (ppm) plotted against εNd values for units of this study. Global data for MORB and shale after Faure (1986). 91

Figure 3.14: ¹⁴⁷Sm/¹⁴⁴Nd vs initial εNd values for rocks of the Johnson Lake area, Kootenay Terrane, B.C. Fields for the western Canadian shield and Devonian to Jurassic Miogeocline after Boghossian et al. (1996). Fields for pericratonic terrane sedimentary rocks and depleted mantle after Patchett and Gehrels (1998). 91

Figure 3.15: Schematic cross sections illustrating Paleozoic tectonic settings of the western North American continental margin in Southern B.C. not to scale. A.) Schematic cross section of Late Neoproterozoic to Cambrian continental margin undergoing extension, OIB=ocean island basalt (alkalic), MORB=mid ocean ridge basalt (tholeiite). B.) Devonian subduction of a shallow dipping oceanic plate under North American margin, and associated volcanic arc. C.) Steepening in the angle of subduction in the oceanic plate leads to tension in the overriding North American plate forming a back-arc basin (Modified after van Staal et al., 1991). 94

CHAPTER 4

Figure 4.1: Simplified geological map of the Samatosum deposit, B.C. 107

Figure 4.2: Cross section A-A' through the Samatosum deposit viewing to the northwest, modified from B. Friesen, (1991), Minnova Inc. 108

Figure 4.3: A.) Samatosum deposit, open pit viewed toward the Southwest, showing contact between mafic fragmental (hangingwall) and metasedimentary rocks (footwall), the cross fault is a late top down to the south normal fault. B.) Steeply dipping sulphide bearing quartz vein in sericite-pyrite-quartz altered metasedimentary rocks. C.) Contrast in alteration styles in fissile schist (metasedimentary rocks), dominantly Fe-carbonate (siderite, ankerite) sericite-pyrite-quartz alteration overlying sericite-pyrite-quartz alteration. 109

Figure 4.4: Alteration and mineralization at the Samatosum deposit; A.) Quartz-pyrite alteration of metasedimentary rocks. B.) Quartz-carbonate vein containing coarse sulphides. C.) Isoclinally folded quartz veins in metasedimentary rocks near contact with metavolcanic rocks. D.) Quartz-carbonate veins with coarse pyrite, sphalerite, galena, chalcopyrite, and tetrahedrite-tennantite..... 110

Figure 4.5: Photomicrographs of sulphide textures observed with reflecting light microscopy of polished thin sections from the Samatosum deposit. A.) Resorbed anhedral pyrite crystals in a matrix of tetrahedrite, Samatosum quartz vein ore. B.) Subhedral tetrahedrite within a matrix of coarse galena and sphalerite, there is a chalcopyrite rim separating sphalerite and tetrahedrite. C.) Coarse sphalerite with fine-grained chalcopyrite, cubic pyrite crystals, anhedral galena with tetrahedrite inclusions. Sulphide abbreviations are: gln=galena, py=pyrite, cpy=chalcopyrite, sph=sphalerite, tet=tetrahedrite..... 112

Figure 4.6: Cross section through the RG8 sulphide - barite lens, Rea deposit, after Hoy and Gouthier (1986)..... 115

Figure 4.7: Polished thin section photomicrographs (reflected light microscopy) of sulphide occurrences in the Johnson Lake area. A.) Colloform texture: replacement of pyrite by galena, Rea deposit. B.) Fine-grained intergrowth of anhedral sulphide crystals, Rea deposit. C.) Fine-grained sphalerite inclusions in coarse pyrite, Rea deposit. D.) Coarse barite from the Homestake deposit with carbonate and sericite taken in cross polarized transmitted light. E.) Reflected light photo of D, fine grained disseminated sulphides, Homestake deposit. F.) Coarse inclusions of anhedral pyrite and sphalerite in galena (Twin Mountain occurrence). Sulphide abbreviations are: gln=galena, py=pyrite, cpy=chalcopyrite, sph=sphalerite, tet=tetrahedrite, ba=barite. 118

Figure 4.8: Sulphur isotope data from sulphide deposits in the Johnson Lake area, sulphide phases analyzed include pyrite, sphalerite, galena, tetrahedrite, chalcopyrite; the sulphate phase is barite..... 123

Figure 4.9: VMS model for the Homestake deposit, (modified after Goodfellow, 2002). Heat derived from the volcanics, and subvolcanic intrusion leads to a hydrothermal circulation cell, fluids are seawater and magmatic derived fluids. Venting of these fluids onto the seafloor along fault controlled conduits leads to the precipitation of massive barite/sulphide deposits. The underlying siliciclastic sequence may have provided a good reservoir/ permeable unit from which metals are partially derived, the relatively impermeable overlying rocks would help to focus fluid flow along structures. 127

Figure 4.10: Hydrothermal model of the Rea deposit (and Samatosum syngenetic mineralization). Heat derived from the volcanics, results in the development of hydrothermal circulation during late stages of alkalic mafic volcanism, fluids are seawater and magmatic derived fluids. Venting of these fluids onto the seafloor along fault controlled conduits lead to the precipitation of massive barite/sulphide deposits (modified after Goodfellow, 2002)..... 129

ACKNOWLEDGEMENTS

The following people are thanked for contributions to this thesis. Jim and Barb Lewko provided excellent accommodations at Johnson Lake resort during field work. Lithogeochemical analyses were carried out at the GSC under the supervision of Peter Belanger, radiogenic isotope analyses were carried out at the University of Alberta under the supervision of Robert Creaser and Larry Heaman. Discussion with the following individuals is gratefully acknowledged: Paul Schiarizza, Trygve Höy, Ray Lett (B.C. Geological Survey), Bob Friesen (Consultant), Victor Preto (Consultant), Ken Daughtry (Consultant), Bob Thompson (GSC), Tim Termunde (Eagle Plains Resources), Maurice Colpron (Yukon Geology Program), Neil Banerjee, Brent Carbo, Kimberly Scully, Lawrence Winter, Stephen Piercey (Laurentian University), Charles Doyle (UVIC) and Andy Okulitch (GSC). Jennifer Porter and Morgan Soley provided excellent field assistance. This project was funded by the Geological Survey of Canada Ancient Pacific NATMAP project (S. Paradis), University of Victoria Graduate Fellowship and an NSERC grant (S. T. Johnston). Parm Dhesi, Roger Macleod, Claudia Saheb and Richard Franklin provided invaluable GIS assistance. Special thanks to Gloria, Ruben, Dave, and Paul for discussions on everything from carbon isotopes in fatty acids to dirt (a.k.a. quaternary geology) and elastic thickness of the lithosphere. Their great sense of humour kept me in good spirits when I needed it most. Finally, thanks to my family for their constant support and encouragement.

CHAPTER 1: INTRODUCTION

OVERVIEW

The purpose of this research was to investigate rocks of the Eagle Bay Assemblage in the Johnson Lake area that host massive sulphide deposits. The Eagle Bay Assemblage consists of Paleozoic, polydeformed greenschist metamorphic grade rocks, assigned to the Kootenay Terrane (Schiarizza and Preto, 1987). Geological mapping, geochemistry, and geochronology was utilized to characterize these rocks. The primary goals of this project were to: (1) Produce a 1: 20 000 scale geological map and cross sections (appendix I); (2) Characterize volcanic rocks, and elucidate tectonic settings using geological mapping and geochemistry; (3) Constrain the ages of some of the volcanic rocks using U-Pb zircon geochronology; and (4) Examine the stratigraphic and structural controls on mineralization pertaining to the Samatosum and Rea deposits. The primary results of this research are presented in chapters 2 and 3, written as stand alone contributions consistent with peer reviewed journal articles. Chapter 2 summarizes the stratigraphy and structural geology of the Johnson Lake area while chapter 3 examines the geochemistry, geochronology, and tectonic setting. Chapter 4 describes the significant sulphide occurrences in the region.

The study area is located 80 km north Kamloops (Fig. 1.1), within NTS map sheet 82M/04 and has geographical co-ordinates 119 54' 00" to 119 42' 00" degrees longitude, and 51 11' 00" to 51 04' 00" degrees latitude. This region has been the focus of extensive exploration efforts by prospectors, and junior and senior mining companies. The last major stage of exploration in the area followed the discovery of the Rea massive sulphide

deposit in 1983. This culminated in the discovery of the Samatosum silver deposit, which was mined from 1989 to 1992.

In addition to its economic potential for base and precious metal deposits, rocks in the study area provide insight into the Paleozoic through Tertiary tectonic evolution of the North American continental margin. Lithogeochemical and radiogenic isotope studies provide insight into paleotectonic settings of volcanic rocks in the area. Geological structures in the region provide information on deformation events that have occurred along the North American margin spanning the Paleozoic to Cenozoic Era's.

This research was conducted in conjunction with the Ancient Pacific Margin NATMAP project. The Ancient Pacific Margin NATMAP project investigates the pericratonic terranes of the Canadian Cordillera in British Columbia and Yukon. These terranes consist predominantly of Paleozoic volcanic, sedimentary and intrusive rocks, which are thought to have formed on or close to the western margin of the North American Continent (Price et al., 1985; Nelson, 1997; Nelson et al., 2000). The NATMAP project consists of multidisciplinary studies (bedrock mapping, mineral deposit, geochemical and isotope studies; quaternary mapping, till and stream sediment geochemistry) and is a collaboration between universities, B.C. and Yukon geological surveys, the Geological Survey of Canada and industry.

DESCRIPTION OF THE STUDY AREA

The region is dominated by generally north to northwest trending valleys, ridges and plateaus. Elevations in the area range from 450 metres at Adams Lake to 1900 metres at the highest point on Samatosum Mountain. The vegetation consists of a dense cover of

coniferous trees including Red cedar, Western Hemlock, and Douglas Spruce along with lesser deciduous trees. Undergrowth consists of a variety of moss, ferns and flowering plants. Extensive logging activities have resulted in numerous clear-cuts linked by roads, which have increased bedrock exposure and accessibility. Sinmax Valley near Squam Bay on Adams Lake has been developed for agricultural use.

Bedrock is overlain by variable amounts of glacial till, and postglacial soil. On the Samatsum Plateau, glacial till has a thickness in exploration trenches of

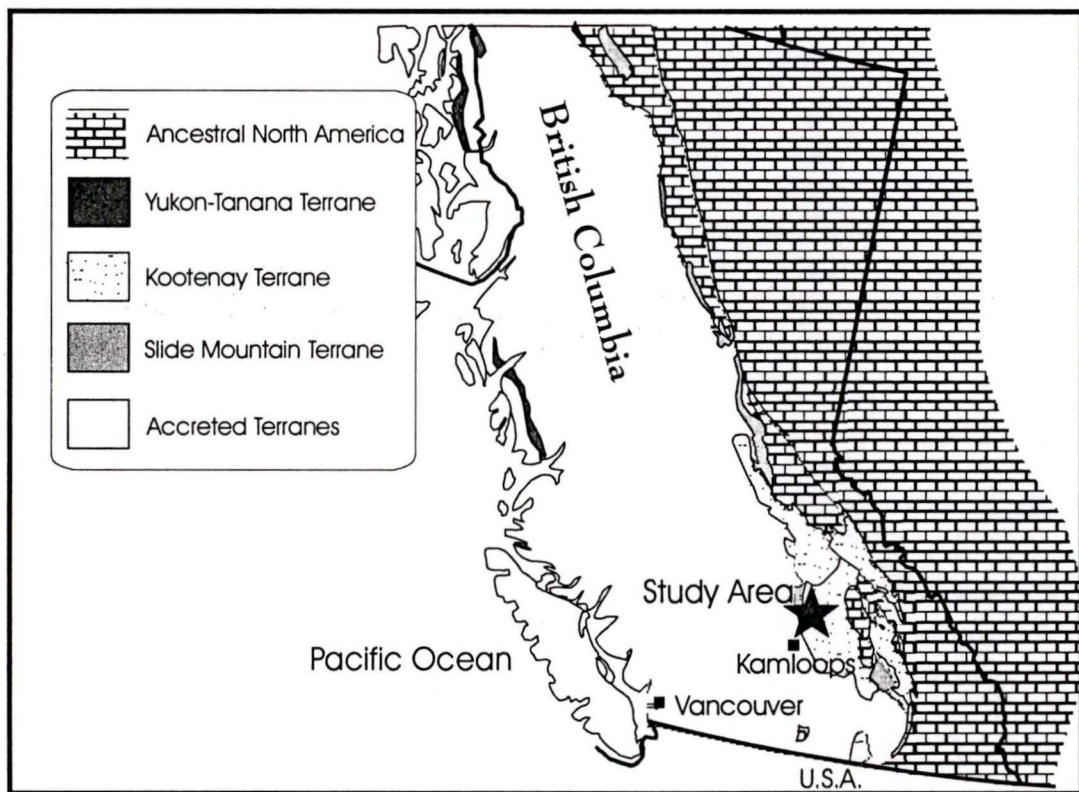


Figure 1.1: Location of the study area, within the Kootenay Terrane of British Columbia, modified after Wheeler and McFeely (1991).

7 metres (Oliver and Marr, 1987). Glacial deposits covering the map area result from the last glacial period (Fraser glaciation; Bobrowsky et al., 1997; Dixon-Warren et al., 1997a; 1997b); regional ice flow direction was toward the south-southeast (Fulton and Smith, 1986).

PREVIOUS WORK

Initial geological investigations of the Adams Lake area were conducted by Selwyn (1872), Jones, (1959), and Campbell (1963). More recent regional geological studies include 1:250 000 scale mapping by Okulitch (1979) and 1:100 000 scale mapping by Schiarizza and Preto (1987).

Gouthier (1986) analyzed lead isotopes of galena samples from various syngenetic massive sulphide occurrences in the Eagle Bay Assemblage in an attempt to define model lead ages. Her work led to the recognition of Cambrian, Devonian-Mississippian, and Triassic model lead ages. The Homestake and Rea syngenetic sulphide deposits were found to have Devonian-Mississippian Pb isotope model ages on galena in agreement with U-Pb zircon dates published by Schiarizza and Preto (1987). Furthermore, she noted that several of the stratiform deposits within unit EBG defined by Schiarizza and Preto (1987) had Triassic model lead ages, and suggested that the host rocks may be as young as Triassic.

Hoy and Gouthier (1986) interpreted units in the area of the Rea deposit to be inverted based on bedding/cleavage relationships, and top indicators. Hoy (1987) interpreted the volcanic sequences hosting the Rea and Homestake massive sulphide deposits to have formed in a rifted volcanic arc based on whole rock geochemical data. The interpretation was based on an incomplete set of geochemical elements, and limited sampling sites. Hoy's (1987) interpretation is being retested using a larger more diverse sample set and modern analytical techniques presented in this study.

More recent studies include a surficial geology study by Dixon-Warren (1997a, b.), a till geochemistry study by Bobrowsky et al. (1997) and regional stream water

geochemistry by Lett et al. (1998). Mineral exploration in the region has been intermittent and focused primarily on precious (Au, Ag) and base metal (Zn, Cu, Pb) occurrences. Prospecting since the turn of the century has turned up a number of sulphide deposits and showings including Homestake, Rea, Samatosum, K7, Twin Mountain, Agate, and Acacia (refer to map in appendix I).

The Rea deposit was discovered in 1983 by prospectors A. Hilton and R. Nicholl. It was optioned by Rea Gold Corporation and subsequently sold to Corporation Falconbridge Copper. The polymetallic nature of the deposit, and especially the high contents of associated gold made this a particularly attractive exploration target. The Rea discovery led to a staking rush in the region. Subsequent exploration by Corporation Falconbridge Copper led to the discovery of the "Silver Zone". The "Silver Zone" consisted of high-grade silver hosted in quartz-carbonate veins, associated with quartz-sericite-carbonate-pyrite alteration. This led to the establishment of the Samatosum open pit and underground mine that operated from 1989 until 1992.

Exploration was conducted from 1987 to 1989 by Esso Minerals Canada on the Kamad claims that included the Twin Mountain and Acacia showings, and the Homestake deposit (see map in appendix I). This led to the recognition of a southerly continuation of the alteration and mineralized zone hosting the Rea deposit. Till sampling, geophysics, and diamond drilling subsequently led to the discovery of stratiform mineralization (Zn, Pb, Cu, Au, Ag) referred to as the K7 deposit. These claims were later optioned by Homestake Canada Ltd. Exploration work conducted included trenching, electromagnetic geophysics surveys, and diamond drilling. Work conducted by Esso Minerals and Homestake Canada Ltd are summarized by Oliver and

Marr (1987), Heberlein (1988), Heberlein et al. (1989), Carmichael and Bozek (1990), and Carmichael (1991) in company and assessment reports.

REGIONAL GEOLOGY

The Eagle Bay Assemblage is assigned to the pericratonic Kootenay Terrane of British Columbia, within the Omineca Crystalline Belt, one of five morphological belts of the Canadian Cordillera (Schiarizza and Preto, 1987; Wheeler and McFeely, 1991; Monger, 1993; Fig. 1.2). The Omineca crystalline belt refers to variably deformed and metamorphosed rocks of continental affinity that are exposed east of Mesozoic arc and back arc sequences (Intermontane Belt) and west of deformed Paleozoic continental margin sedimentary rocks (Foreland Belt) in British Columbia. The Kootenay Terrane and correlative rocks of the Yukon-Tanana Terrane to the north comprise dominantly Paleozoic metasedimentary and metavolcanic rocks deposited on the distal western edge of ancestral North America (Schiarizza and Preto, 1987; Gabrielse et al., 1991). Major rock successions of the Kootenay Terrane include the Lardeau Group, the Eagle Bay Assemblage, eastern assemblages of the Late Paleozoic Milford Group, and equivalent rocks within the Shuswap metamorphic complex (Höy, 1999).

The Eagle Bay Assemblage, described by Schiarizza and Preto (1987) consists of Lower Cambrian to Mississippian metasedimentary and metavolcanic rocks that are intruded by Late Devonian foliated granite/diorite and Jurassic-Cretaceous granodiorite and quartz monzonite of the Raft and Baldy batholiths, and overlain by tertiary basalt. The regional geology defined by Schiarizza and Preto (1987) in the Johnson Lake area, is

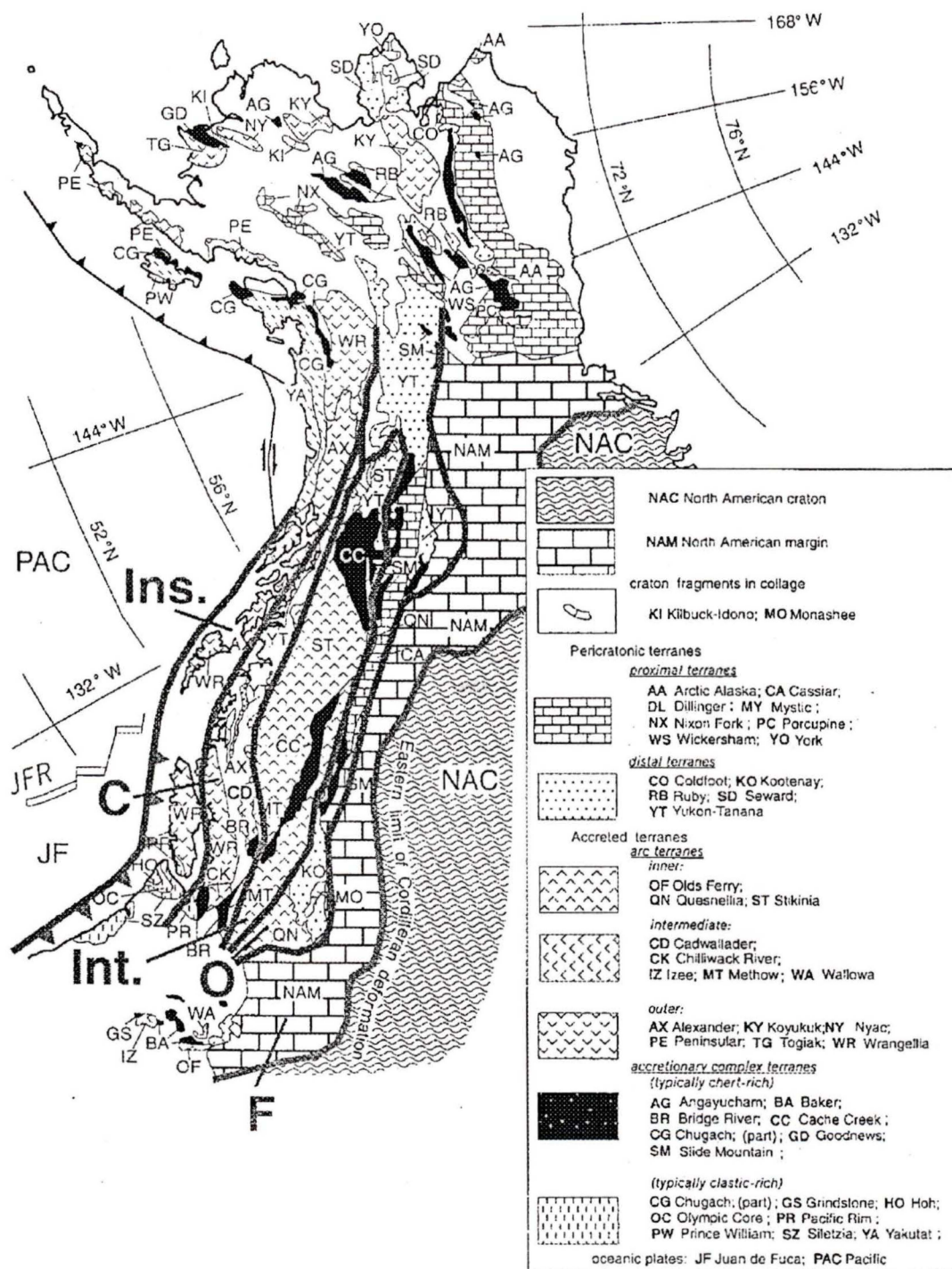


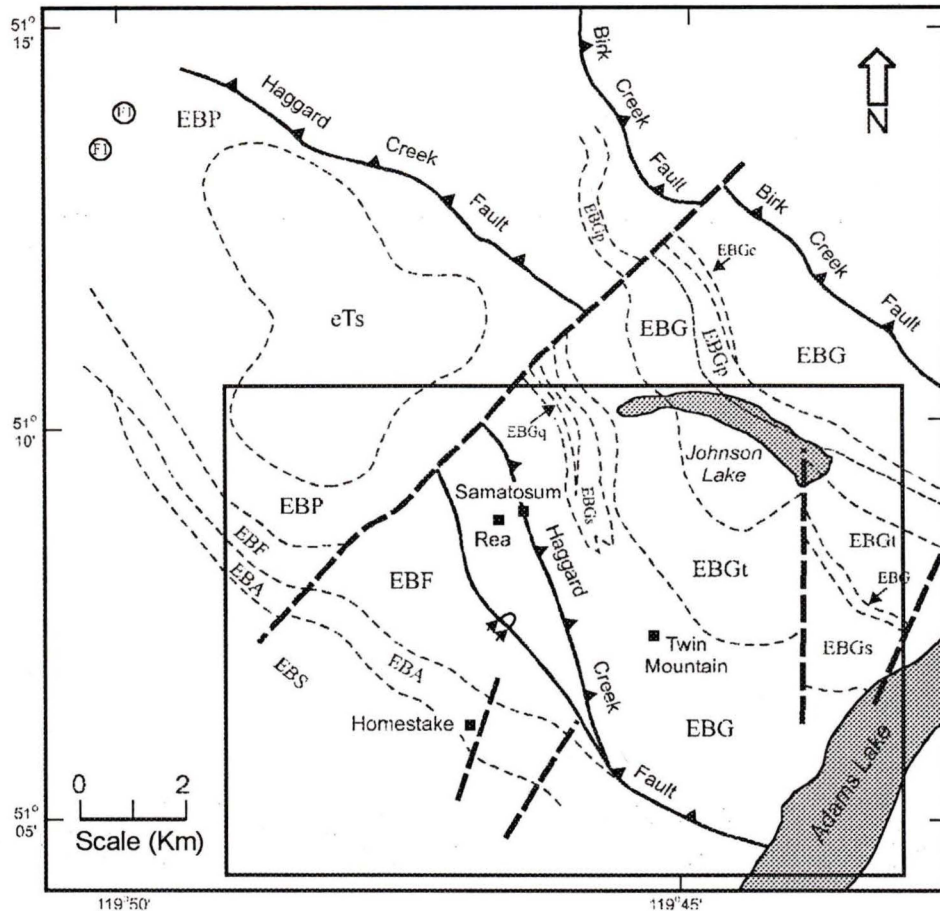
Figure 1.2: Terrane map of the northern Cordillera after Monger (1993), **JFR**= Juan de Fuca Ridge, **Pac**= Pacific ocean, unpatterned areas are ocean floor or extensive areas of plutonic rock or post accretionary cover. The morphological belt boundaries are outlined, **F**= Foreland belt, **O**= Omineca crystalline belt, **Int**= Intermontane belt, **C**= coast belt, **Ins**= Insular belt.

summarized in Fig. 1.3. Near Johnson Lake, these rocks consist of Lower Cambrian (and older?) clastic metasedimentary rocks (units EBH and EBQ), mafic metavolcanic rocks and limestone (unit EBG). These rocks structurally overlie Devonian-Mississippian mafic, intermediate and felsic metavolcanic and metasedimentary rocks (units EBA and EBF, respectively), and metaclastic rocks (unit EBP).

Numerous mineral occurrences of the Eagle Bay Assemblage, including the Rea, Homestake, Samatosum and Twin Mountain deposits are hosted by mafic to felsic metavolcanic and metasedimentary rocks of units EBA, EBF, and EBG (Fig. 1.3). Geological mapping by Schiarizza and Preto (1987), Hoy and Gouthier (1986), and this study indicate that units EBA, EBF, and EBP of Schiarizza and Preto (1987) are apparently right-way-up regionally but locally overturned (Fig. 1.3). These units are structurally overlain by mafic metavolcanic rocks of EBG and the Tshinakin Limestone member (Schiarizza and Preto, 1987). The apparent juxtaposition of older (Cambrian) rocks over younger (Devonian) rocks led Schiarizza and Preto (1987) to infer the presence of a major thrust fault, which they referred to as the Haggard Creek Thrust Fault. The Samatosum and Rea deposits are located near the inferred trace of this fault, and controversy exists over which package(s) of rocks host the deposits and whether or not a major thrust fault even exists.

REGIONAL STRUCTURE AND METAMORPHISM

Rocks of the Eagle Bay Assemblage have been subjected to multiple episodes of deformation. Early phases of deformation include inferred syndepositional extensional



LEGEND

- Geological contacts
- Overturned syndine
- Thrust fault
- Fault
- Conodont fossil locality; Mississippian
- Mineral occurrence

EOCENE

- eTs** Kamloops Group:
Andesite and basalt

EAGLE BAY ASSEMBLAGE

MISSISSIPPIAN

- EBP** Phyllite, sandstone, grit, minor conglomerate, limestone and metavolcanic rocks

DEVONIAN and/or MISSISSIPPIAN

- EBF** Feldspathic phyllite and schist derived from intermediate tuff and volcanic breccia

DEVONIAN

- EBA** Chlorite - sericite - quartz phyllite and schist derived from felsic to intermediate volcanic rocks
- EBS** Grey-green phyllite and schist derived from sandstone, argillite, quartz pebble conglomerate,

LOWER CAMBRIAN

- EBG** Calcareous chlorite schist and greenstone derived from mafic volcanic rocks; EBGc - marble
EBGt - Tshinakian limestone; EBGs - phyllite, limestone, quartzite; EBGq - quartzite;
EBGp - phyllite and limestone

Figure 1.3: Geology of the Johnson Lake area, modified after Schiarizza and Preto (1987), present study area is outlined.

faulting of Cambrian and Devonian-Mississippian age associated with rift type volcanism and basin filling sediments (Hoy, 1999). Rocks of the Fennel Formation (west of the study area) are included in the Slide Mountain Terrane. These rocks are interpreted to represent the remnants of a Mississippian-Permian marginal ocean basin developed on the outer western edge of the North American continent (Nelson, 1997) that were subsequently thrust east over rocks of the Kootenay Terrane during the Triassic-Jurassic (Schiarizza and Preto, 1987).

The style of folding in the Eagle Bay Assemblage is synmetamorphic, tight to isoclinal folds with overturned limbs and associated penetrative axial planar cleavage (Schiarizza and Preto, 1987). The folds and cleavage are associated with west verging thrust faults of probable Jurassic age (Schiarizza and Preto, 1987; Okulitch, 1989). The Jurassic event has been attributed to accretion of the Intermontane Belt to the western North American margin (Fig. 1.3; Monger, 1993). The metamorphic grade of the Eagle Bay Assemblage is generally lower to upper greenschist, however in the northeastern portion of the Eagle Bay Assemblage the metamorphic grade increases to amphibolite grade (Schiarizza and Preto, 1987).

Near the Cretaceous Raft and Baldy batholiths, 20 kilometres north of the study area, folds and faults have trends parallel to the contacts of the intrusions, suggesting that these are syn-intrusive structures (Schiarizza and Preto, 1987). The area also contains Eocene brittle faults that strike north to northeast coinciding with basaltic volcanism (unit eTs of Schiarizza and Preto, 1987).

REFERENCES

- Bobrowsky P.T., Leboe, E.R., Dixon-Warren, A., Ledwon, A., MacDougall, D., Sibbick, S.
1997: Till geochemistry of the Adams Lake Plateau-North Barriere lake Area; British Columbia Ministry of Employment and Investment, open file 1997-9, 263 pages.
- Campbell, R.B.
1963: Adams Lake Map-area, British Columbia, Geological Survey of Canada, Map 48-1963.
- Carmichael, R.G.
1991: 1990 Final Report on the Kamad Claims, Homestake Canada Ltd. Internal Report.
- Carmichael, R.G., and Bozek, J.
1990: 1989 Final Report on the Kamad Claims, Homestake Canada Ltd. Internal Report.
- Colpron, M. and Price, R.A.
1995: Tectonic significance of the Kootenay Terrane, Southeastern Canadian Cordillera: an alternative model. *Geology*, v. 23, pages 25-28.
- Dixon-Warren, A. Bobrowsky, P.T., Leboe, E.R. and Ledwon, A.
1997a: Eagle Bay Project: Surficial Geology of the Adams Lake Plateau (82M/04) and North Barriere Lake Map area; in *Geological Fieldwork 1996*, Lefebure, D.V., McMillian, W.J. and McArthur, G. Editors, B.C. Ministry of Employment and Investment, paper 1997-1, p. 405-411.
- Dixon-Warren, A. Bobrowsky, P.T., Leboe, E.R. and Ledwon, A.
1997b: Terrain Geology map of the Adams Plateau area, NTS 82M/04, scale 1:50 000; British Columbia Ministry of Employment and Investment, open file 1997-7.
- Fulton, R.J. and Smith, G.W.
1986: Surficial Geology Seymour Arm, British Columbia; Geological Survey of Canada, Map 1609A, 1:250 000.
- Gabrielse, H., Monger, J.W.H., Wheeler, J.O., Yorath, C.J.
1991: Morphological Belts, tectonic assemblages, and terranes, in *Geology of the Cordilleran Orogen in Canada*, Chapter 2: Tectonic Framework, H. Gabrielse and C.J. Yorath eds. *Geological Survey of Canada*, *Geology of North America* v.2, 844 pages.
- Gouthier, F.
1986: Galena lead isotope study of mineral deposits in the Eagle Bay Formation, Southeastern British Columbia. Unpublished M.Sc. Thesis, University of British Columbia, 152 pages.
- Heberlein, D.R.
1988: 1987 Final Report, Esso Minerals Canada.
- Heberlein, D.R. Marr, J.M., Oliver, J.C.
1989: 1988 Kamad Final Report, Esso Minerals Canada.
- Höy, T. and Goutier, F.
1986: Rea Gold (Hilton) and Homestake volcanogenic sulphide – barite deposits, southeastern British Columbia (82M/4W); in *Geological Fieldwork 1985*; British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1986-1.
- Höy, T.
1987: Alteration, Chemistry and tectonic setting of Volcanogenic massive sulphide–barite deposits at Rea Gold and Homestake Southeastern British Columbia in *Exploration in British Columbia 1986*, British Columbia Ministry of Energy, Mines and Petroleum Resources, p. B7-B19.

- Höy, T.
1999: Massive sulphide deposits of the Eagle Bay Assemblage, Adams Plateau, south-central British Columbia (082M 3, 4); *in* Geological Fieldwork 1998; British Columbia Ministry of Energy and Mines, Paper 1999-1, p. 223-245.
- Jones, A.G.
1959: Vernon Map-Area, British Columbia, Geological survey of Canada, Memoir 296, 186 pages.
- Lett, R.E., Sibbick, S., Runnells, J.
1998: Regional Stream Water Geochemistry of the Adams Lake-North Barriere Lake Area, British Columbia (NTS 82M/04 82M/05), British Columbia Ministry of Employment and Investment, open file 1998-9.
- Monger, J.W.H.
1993: Canadian cordilleran tectonics, from geosynclines to crustal collage, Canadian Journal of Earth Sciences. v. 30, pages 209-231.
- Nelson, J.L.
1997: Last seen Heading south: extensions of the Yukon Tanana terrane into Northern British Columbia; *in* Geological Fieldwork 1996, D.V. Lefebure, W.J. McMillan and J.G. McArthur, editors, B.C. ministry of employment and investment editors, Geological Survey Branch, paper 1997-1, pages 145-156.
- Nelson, J.L., Mihalynuk, M.J., Murphy, D.C., Colpron, M., Roots, C.F., Mortensen, J.K., Friedman, R.M.
2000: Ancient Pacific Margin Part II: A preliminary comparison of potential VMS hosting successions of the Yukon Tanana Terrane, from Finlayson Lake district to Northern British Columbia; *in* Geological Fieldwork 1999, B.C. Ministry of Energy and Mines, Paper 2000-1, pages 19-25.
- Okulitch, A.V.
1979: Lithology, stratigraphy, structure and mineral occurrences of the Thompson-Shuswap-Okanagan area, British Columbia; Geological Survey of Canada, open file 637.
- Okulitch, A.V.
1989: Revised Stratigraphy in the Thompson-Shuswap-Okanagan area, Southern British Columbia, Current Research, report 89-1E, Geological Survey of Canada, pages 51-60.
- Oliver, J.C., and Marr, J.M.
1987: 1986 Final Report, Kamad Claims; Esso Minerals Canada, Technical Report.
- Price, R.A., Monger, J.W.H., and Roddick, J.A.
1985: Cordilleran Cross Section, Calgary to Vancouver; *in* Field guides to Geology and Mineral Deposits in the Southern Canadian Cordillera, D.J. Templeman-Kluit, Editor, *Geological Society of America*, Cordilleran Section Meeting, Vancouver, May, 1985, pages 3.2-3.85.
- Schiarizza, P. and Preto, V.A.
1987: Geology of the Adams Plateau-Clearwater-Vavenby area; British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1987-2.
- Selwyn, A.R.C.
1872: Journal and Report of Preliminary Explorations in British Columbia, Geological Survey of Canada, Report of Progress, 1871-1872, pages 16-72.
- Wheeler, J.O. and McFeely, P.
1991: Tectonic Assemblage Map of the Canadian Cordillera and Adjacent Parts of the United States of America; Geological Survey of Canada. Map 1712A, Scale 1: 2 000 000.

CHAPTER 2: STRATIGRAPHY AND STRUCTURE OF THE EAGLE BAY ASSEMBLAGE IN THE JOHNSON LAKE AREA, SOUTHERN BRITISH COLUMBIA

ABSTRACT

1: 20,000 scale geological mapping was conducted in the Johnson Lake area to examine stratigraphic sequences that host economically important base and precious-metal deposits. The Eagle Bay Assemblage consists of polydeformed, greenschist metamorphic grade rocks derived from volcanic, intrusive and sedimentary protoliths, and is assigned to the pericratonic Kootenay Terrane of the Canadian Cordillera.

Lower Paleozoic (and older?) mafic volcanic and volcanoclastic rocks, limestone, and siliciclastic rocks structurally overlie Devonian-Mississippian felsic, intermediate, mafic volcanic and intrusive rocks, and siliciclastic rocks. Age constraints include a 360 ± 4.6 Ma U-Pb zircon age on felsic volcanic rocks and correlation of a thick limestone with the archaeocyathid bearing Lower Cambrian Tshinakin Limestone (Schiarrizza and Preto, 1987). The limestone is intercalated with mafic volcanic/volcanoclastic rocks and siliciclastic rocks, suggesting a Lower Paleozoic age for these rocks.

Geological units and structures are northwest trending. The geometries were dominantly controlled by southwest-verging folding and thrusting of Jurassic age. Folds are tight to isoclinal with overturned limbs; they have axial planar cleavage defined by schistosity and developed synchronous with thrust faulting. Fault geometries can be explained by treating the thrusts as a series of ramps and flats. Thrust flats trend northwest and dip moderately northeast concordant with stratigraphic layers, whereas ramps trend north and dip steeply east.

These rocks host volcanogenic massive sulphide (Rea, K7, Homestake) and quartz-carbonate vein silver (Samatosum) deposits. Host rocks to the Homestake massive barite-sulphide deposit are altered felsic volcanic rocks of unit 6. The Rea and Samatosum deposits occur in fault-repeated altered argillite and quartz-wacke of unit 7 that is truncated structurally to the south. However, these rocks continue along strike to the northwest and may have future exploration potential.

INTRODUCTION

This paper presents the results of 1:20,000 scale geological mapping conducted in the Johnson Lake area to investigate rock packages that host economically important massive sulphide deposits. The Johnson Lake area is located 80 km north of the city of Kamloops in British Columbia (Fig. 2.1, inset), and is bounded by latitudes $51^{\circ} 04' 00''$ to $51^{\circ} 11' 00''$, longitudes $119^{\circ} 42' 00''$ to $119^{\circ} 54' 00''$ (Fig. 2.2) and is in NTS map sheet 82M/04. Rocks of this study form part of the Eagle Bay Assemblage (Jones, 1959; Schiarizza and Preto, 1987), and are assigned to the Kootenay Terrane of the Omineca Crystalline Belt (Fig. 2.1; Wheeler and McFeely, 1991). The Eagle Bay Assemblage consists of Paleozoic sedimentary and volcanic rocks that developed on the distal North American continental margin and have been intruded by Devonian and Cretaceous granites.

The structure and stratigraphy of the Eagle Bay Assemblage has been elucidated by regional (1:100,000 scale) mapping by Schiarizza and Preto (1987) that divided the Eagle Bay Assemblage into four rock packages bound by east-dipping southwest-verging thrust faults. The Haggard Creek fault is the westerly and structurally lowest of these thrust faults and is interpreted to place Lower Paleozoic and older rocks, onto Middle Paleozoic rocks (Schiarizza and Preto, 1987).

The primary goal of this study was to map (1:20 000 scale) the distribution of lithologies and structures, in an area known to host massive sulphide deposits. This paper draws attention to the presence of a southwest-verging fold and thrust belt. The following questions are addressed: (1) What are the depositional environments of the supracrustal rocks cropping out in the study area? (2) What is the association between folding and

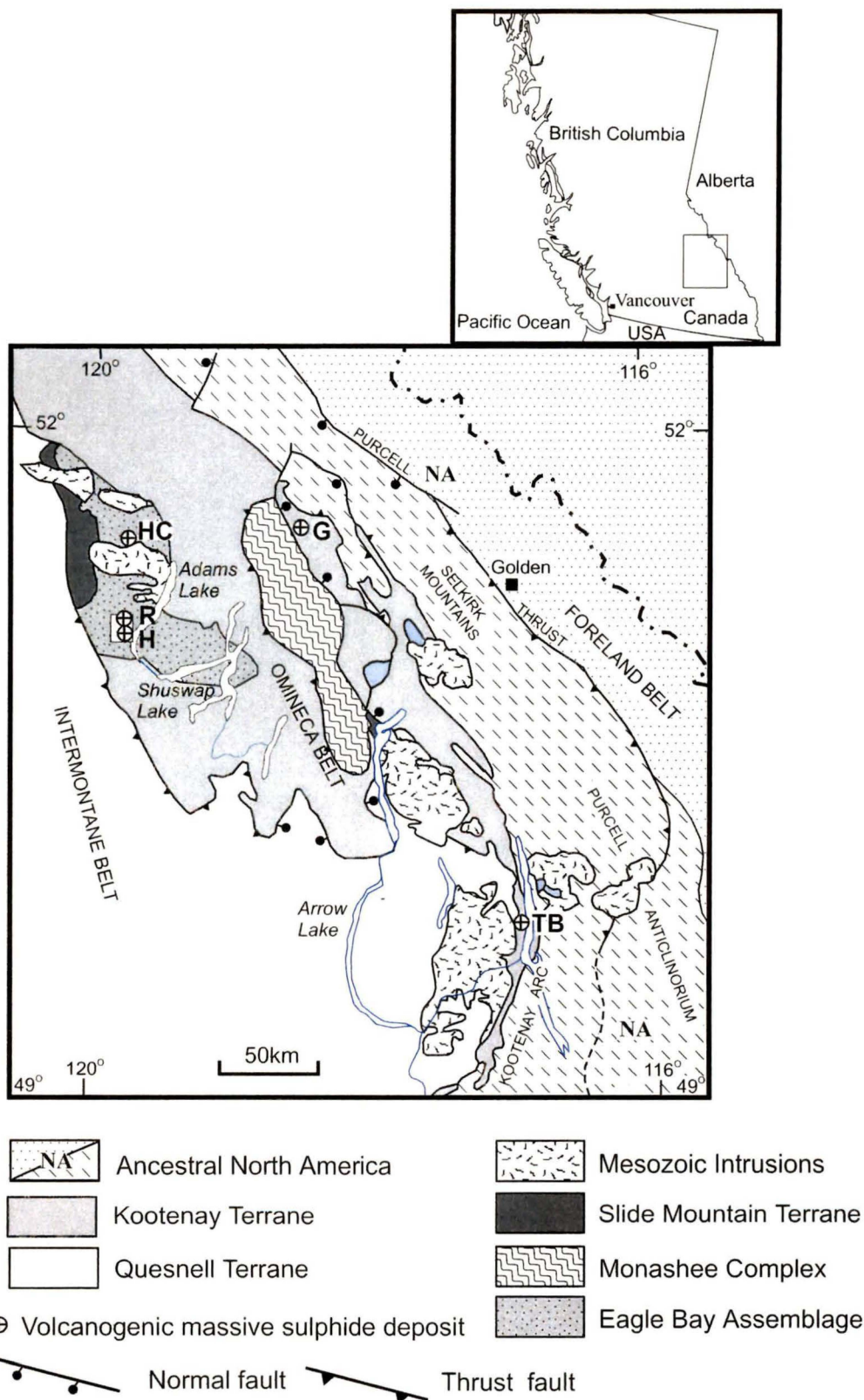


Figure 2.1: Simplified geological map of Southeastern British Columbia, modified after Wheeler and Mcfeely (1991). Mineral deposits indicated are Rea (R), Homestake (H), Harper Creek (HC), Goldstream (G), and True Blue (TB). The study area (see Fig. 2) is outlined by the rectangle surrounding the Rea and Homestake deposits.

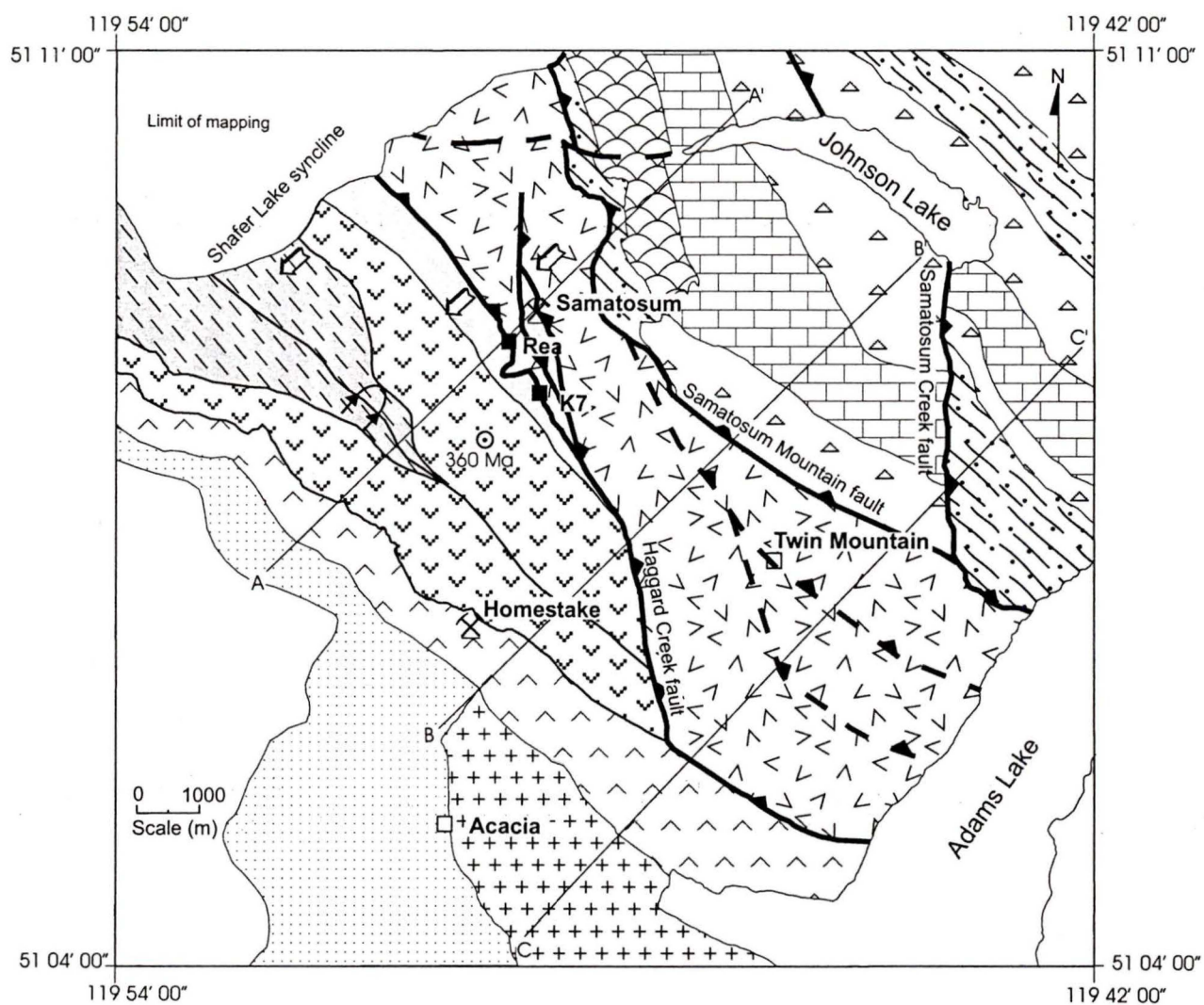


Figure 2.2: Simplified geological map of the Johnson Lake area

Legend

Intrusive Rocks

Devonian



Felsic to intermediate intrusive rocks: quartz-feldspar-sericite-ankerite schist derived from foliated granodiorite to diorite

Layered Rocks

Devonian- Mississippian



10

Metasedimentary rocks: Phyllite, and quartz-sericite schist derived from argillite to quartz wacke, sandstone, and minor pebble conglomerate.



9

Felsic metavolcanic rocks: Quartz-sericite schist derived from quartz-feldspar phyric rhyolite, and quartz-feldspar crystal lithic tuff, lapilli to bomb-size pyroclastics. Lesser mafic to intermediate metavolcanic rocks,



7,8

Metasedimentary rocks: Phyllite, and quartz-sericite schist derived from argillite to quartz wacke, sandstone, and pebble conglomerate.



6

Felsic to intermediate metavolcanic rocks: quartz-feldspar-sericite-ankerite schist derived from rhyolite, rhyodacite, dacite.



5

Metasedimentary rocks: Dominantly fine to coarse grained quartzite, quartz pebble lithic conglomerate, minor phyllite, quartz sericite ankerite schist, chlorite schist, and marble.

Lower Cambrian and older



4

Mafic metavolcanic/volcaniclastic rocks: Calcareous chlorite schist derived from flows, fragmentals, tuffs



3b

Limestone: White weathering, finely crystalline, white to grey marble and dolostone



3a

Mafic metavolcanic/volcaniclastic rocks: Calcareous chlorite schist derived from mafic flows, fragmentals, tuff, interbedded limestone and metapelites



2

Mafic volcanic rocks: Light green, calcareous chlorite schist and greenstone derived from pillows, pillow breccias and feldspathic crystal tuffs.



1

Metasedimentary rocks: Phyllite derived from shale and siltstone, banded chert, minor white-grey marble



Fault (undefined)



Thrust fault



Overturned syncline



Top indicator



U-Pb Zircon date



Past producer



Developed prospect



Prospect



Geological cross section

faulting and how do these structures control the distribution of units? (3) What are the characteristics of each phase of deformation, and how many phases can be recognized?

LOCAL STRATIGRAPHIC UNITS

The Johnson Lake area is underlain by polydeformed lower to middle greenschist metamorphic grade rocks of volcanic, intrusive and sedimentary origin. The rocks encountered in the map area belong to units EBG, EBF, EBA, EBP, EBS and Dgn defined by Schiarizza and Preto (1987; Fig. 2.3). These units have been further subdivided in the present study (Figs. 2.2; 2.3). A stratigraphic section (Fig. 2.3) summarizes units in the map area including thicknesses, relative ages, and relationships of the units. Reported thicknesses are structural as all units in the map area have been modified by deformation, and estimated thicknesses are from fold limbs.

Volcanic and Sedimentary rocks

Unit 1: Bedded chert and metapelite

Bedded chert and metapelite crops out in two northwest striking belts in the eastern portion of the map area with a combined thickness of 300 metres. The chert is grey-white to black in color, locally graphitic, and contains 2-4 cm thick beds composed of microcrystalline quartz (Figs. 2.4a; 2.5a). Chert is intercalated with grey to black siliceous and calcareous phyllite to schist derived from pelite. The mineral assemblage consists of abundant fine-grained muscovite, carbonate, chlorite, iron-oxides and quartz. Unit 1 structurally overlies unit 4, except in the central part of the map where it is cut out by a thrust fault (Fig. 2.2). Unit 1 is overlain by unit 2 and is of probable Lower Cambrian age as it contains limestone interbeds.

Eagle Bay Assemblage stratigraphic units in the Johnson Lake area

Regional Eagle Bay Assemblage stratigraphic units (not to scale) after Schiarizza and Preto (1987)

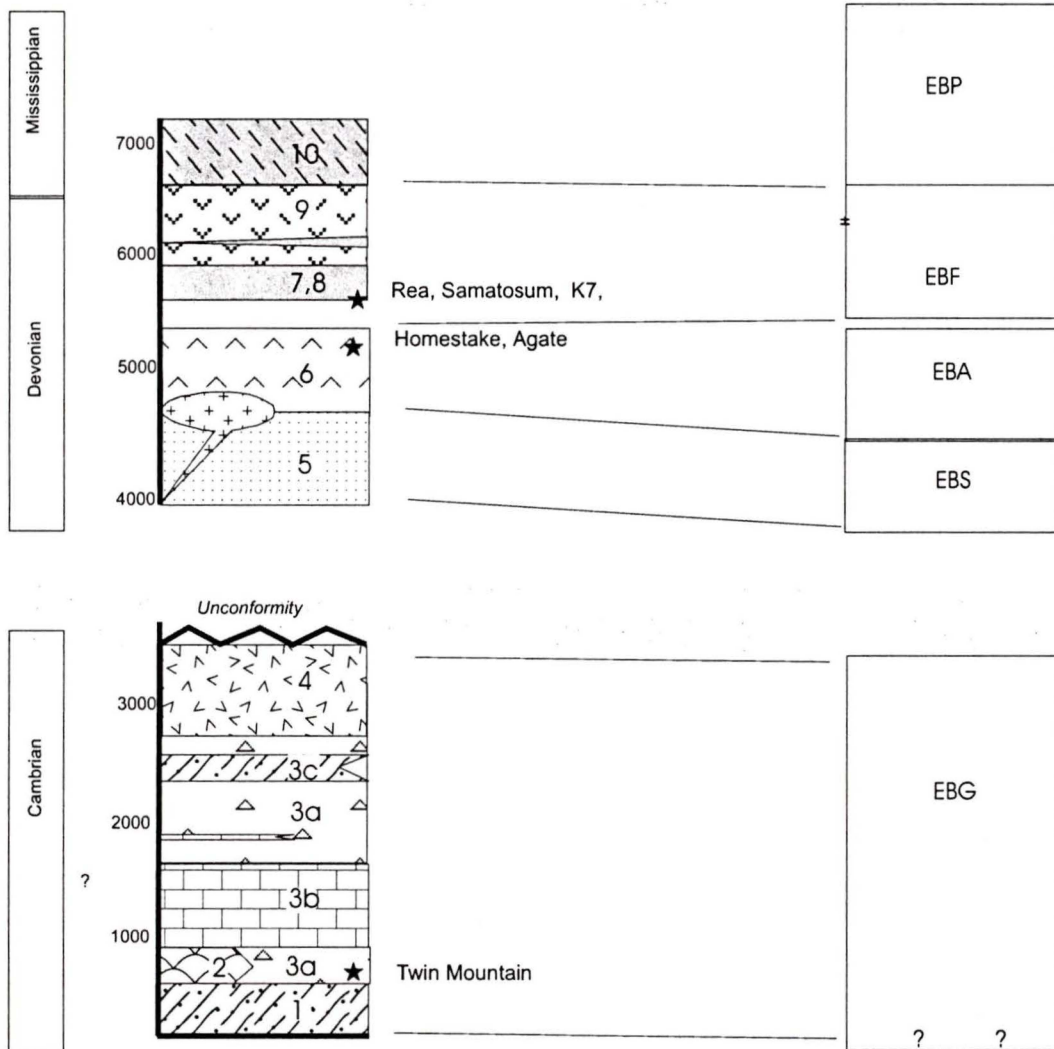


Figure 2.3: Stratigraphic section of geological units in the Johnson Lake area, after this study and Schiarizza and Preto (1987). See Fig. 2.2 legend for unit designations.

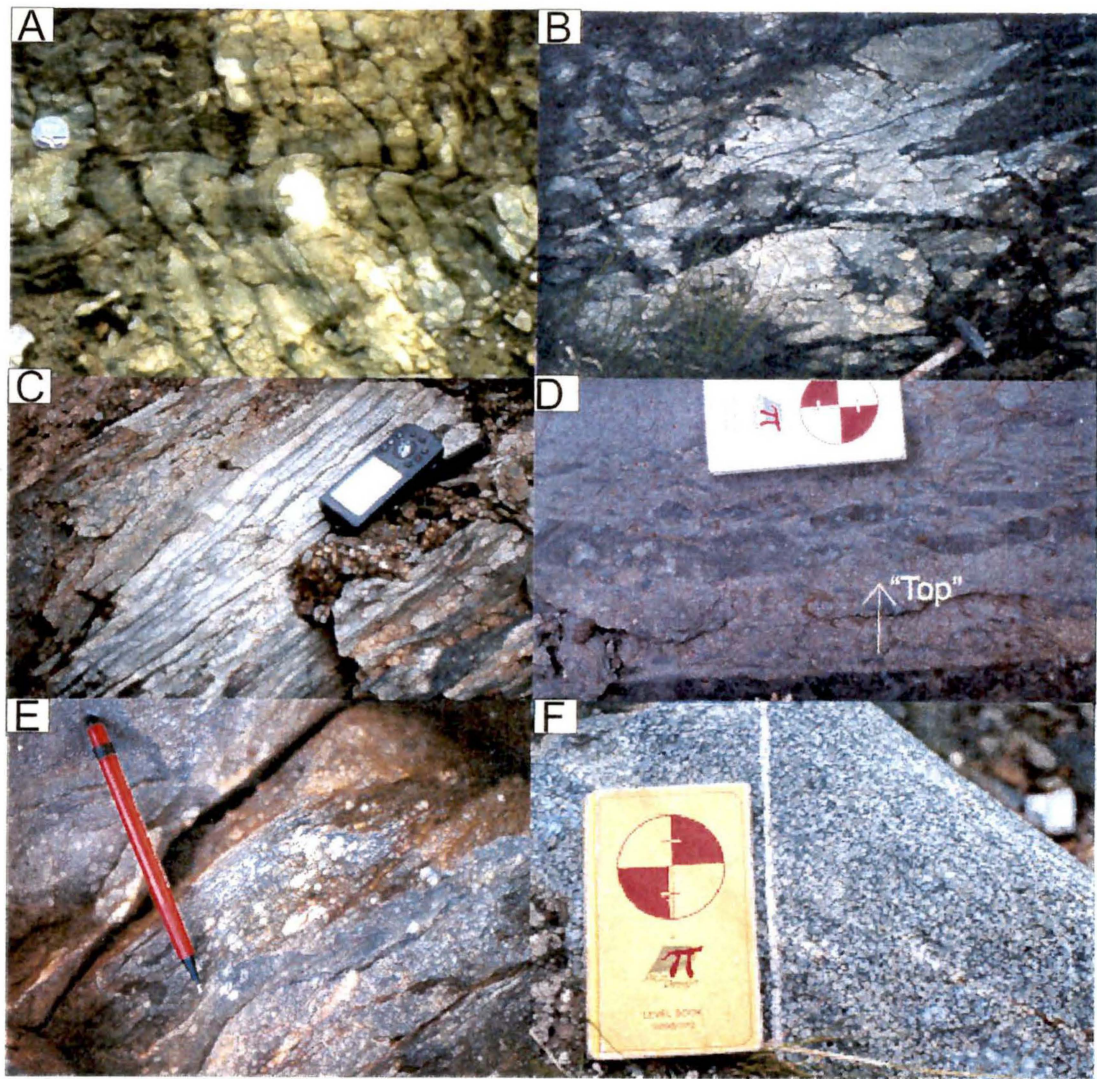


Figure 2.4: Photo's of rock units and textures, Johnson Lake area, A.) "Banded chert", microcrystalline quartz, chert bands are 2-4 cm wide, unit 1. B.) Metre size pillows in mafic metavolcanic of unit 4. C.) Intercalated black and grey phyllite Unit 10. D.) Rip up clasts of black phyllite in sandstone of unit 10. E.) Coarse grained Devonian intrusive. F.) Hornblende diorite dike

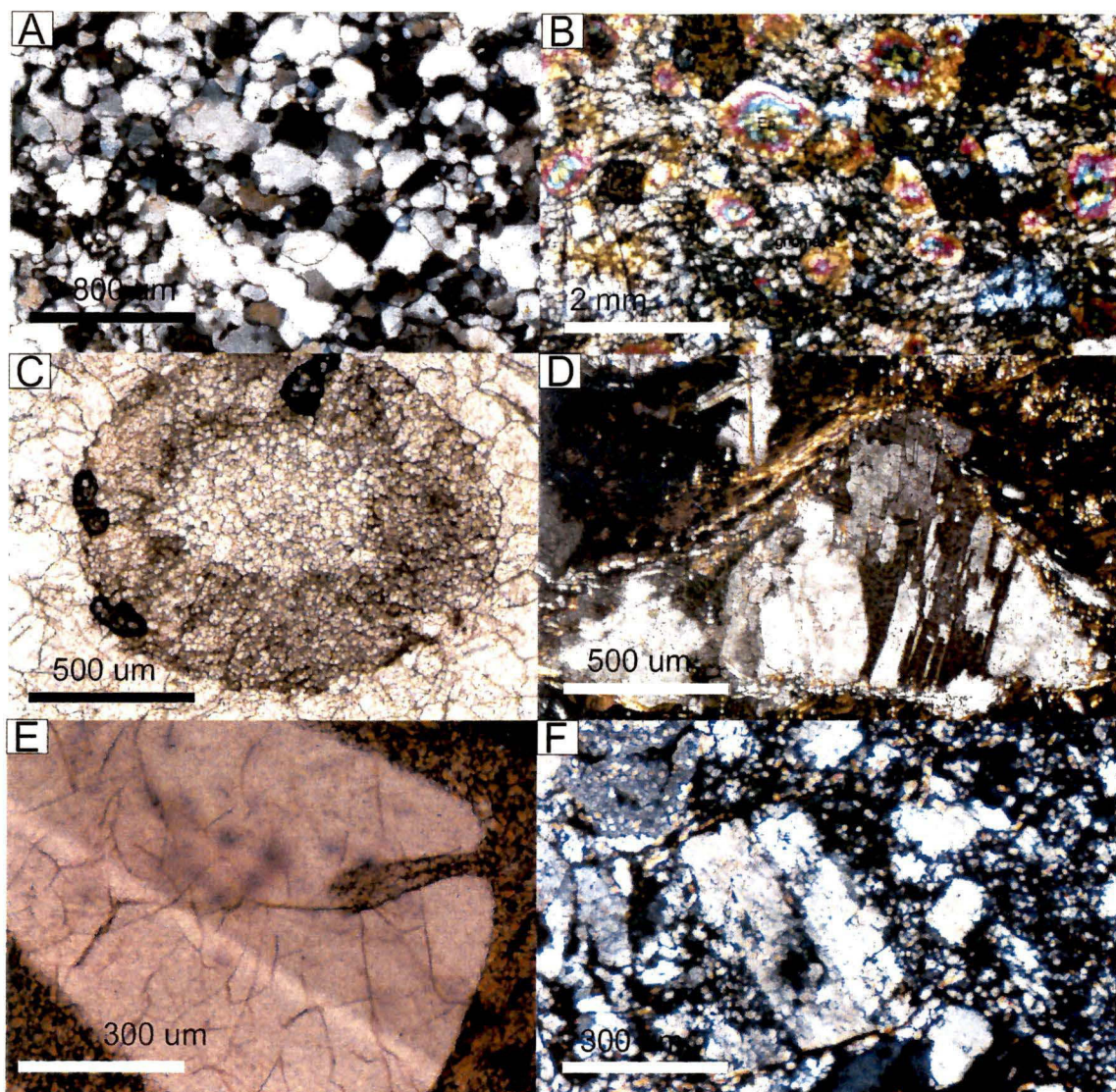


Figure 2.5: Photomicrographs of textures in rocks from the Johnson Lake area A.) Microcrystalline quartz (chert), sample SLB99-11 (unit 1) B.) Epidote (pseudomorphs of plagioclase?) Crystals in fine grained actinolite, chlorite, opaque matrix, sample SLB99-09 (unit 2). C.) Oolites in limestone of unit 3b. D.) Deformed igneous plagioclase grain unit 4, fabric defined by chlorite, actinolite and opaques. E.) Embayed quartz crystal in quartz sericite carbonate matrix, unit 9, sample SLB99-137. F.) Saussuritized plagioclase grain in unit 9, sample SLB99-137. All photos taken in cross polarized transmitting light.

Unit 2: Mafic volcanic rocks

Rocks assigned to unit 2 crop out in the northeast part of the map area, and have a thickness of 600m. This unit is composed of greenstone and chlorite schist derived from pillows, pillow breccias and feldspathic crystal tuffs. Pillows locally exceed one metre or more in length. The metavolcanic rocks have a light green color due to abundant epidote, and generally have a white or grey weathered surface. The mineral assemblage consists of epidote, chlorite, actinolite, Fe-oxides, carbonate, and quartz (Fig. 2.5b.) Metatuffs contain epidote crystals less than 1 mm in length that are pseudomorphs after plagioclase. These rocks contain veinlets of quartz, carbonate, fibrous amphibole, and octahedral magnetite crystals. Unit 2 stratigraphically overlies unit 1, underlies the limestone (unit 3b) (Fig. 2.2) and is of probable Lower Cambrian age.

Unit 3a: Mafic volcanic/volcaniclastic rocks

Unit 3a consists of 1.5- 3 km of structurally thickened mafic volcanic and volcaniclastic rocks, and includes fragmental, massive and tuffaceous facies. This unit has an approximate thickness of 700m beneath the limestone (unit 3b), occurs intermittently above it and continues east of the map area. Fragmental facies have bleached lapilli to bomb-sized greenstone clasts, which contain chlorite, quartz and calcite amygdules. The matrix has a foliation defined by chlorite and actinolite that wrap around plagioclase phenocrysts. Fine-grained, fissile, calcareous chlorite schist is derived from mafic tuffs, while rocks that are more competent are derived from mafic flows. Mafic volcaniclastic rocks have thin intercalated limestone beds suggesting that they were deposited coevally with unit 3b.

Unit 3b: Limestone

The Limestone is 600-700 metres thick, strikes northwest along the eastern portion of the map area (Fig. 2.3) and is best exposed in the cliffs above Johnson Lake. It consists dominantly of finely crystalline white to grey limestone with minor dolostone, and has a buff white to grey weathered surface. The limestone is commonly massive, but laminations defined by light and dark compositional bands are locally present. Sericitic bands suggest clay input into the carbonate depositional environment. The limestone typically consists of fine to medium grained calcite, with no primary textures preserved. However, the presence of rare oolites in thin section (Fig. 2.5c) suggests a shallow marine depositional environment (King and Chafetz, 1983; Morse and Mackenzie, 1990)

Unit 3b has been correlated to the archaeocyathid bearing Lower Cambrian Tshinakin Limestone from Vavenby (Schiarizza and Preto, 1987; Hughes 2001). Unit 3b limestone is in conformable contact with the underlying and overlying greenschist and metasedimentary rocks, both of which contain interbedded limestone layers tens of centimetres to tens of metres in thickness. These layers typically preserve bedding features and macroscopic folds.

Unit 4: Mafic volcanic/volcaniclastic rocks

Unit 4 consists of a 1 to 4 kilometre structurally thickened sequence of calcareous chlorite-sericite-quartz schist and chlorite schist of uncertain age derived from mafic volcanic rocks that outcrop in the central portion of the map area. Protoliths include abundant volcaniclastic rocks, rare mafic massive flows, pillowed flows (Fig. 2.4b), and flow breccias. The most common rock type is lapilli-tuff with 4-5 centimetre long mafic volcanic fragments. Individual fragmental layers mapped at a 1: 20 000 scale are

designated as unit 4b on the map in appendix I. The lapilli are typically bleached and of similar composition to the matrix. Locally, the fragments are up to bomb-size. Fine-grained chlorite schist is abundant throughout unit 4. Massive flows contain calcite and quartz amygdules. Pillows are up to one metre in diameter, have quartz and calcite amygdules, an outer fine-grained, non-vesicular rim, and have been flattened into the penetrative foliation plane. Mineral assemblages consist of chlorite, actinolite, plagioclase, siderite, ankerite, calcite, iron oxides, pyrite, epidote, and quartz. Most of the minerals are metamorphic, however rare igneous plagioclase crystals are flattened in the S_2 foliation plane (Fig. 2.5d).

Cobble conglomerate forms thin discontinuous layers exposed in the cliffs on the eastern side of Sinmax Valley (see map in appendix I). The cobble conglomerate consists of slightly rounded pebble to cobble size clasts in a calcareous chlorite schist matrix that is intraformational in unit 4. Clasts of grey to white quartzite (with well rounded quartz grains up to 1 mm in size), limestone, and chlorite schist are present. This conglomerate was interpreted by Schiarizza and Preto (1987) to mark the trace of the Haggard Creek fault along the base of unit EBG.

Unit 5: Siliciclastic rocks

This unit consists of undivided metasedimentary rocks that outcrop in the western part of the map area and were included in unit EBS of Schiarizza and Preto (1987). Rock types include quartzite, sericite-quartz schist, quartz-sericite chlorite-schist, phyllite, and quartz lithic pebble conglomerate. The quartzites are derived from mature quartz sandstones, with well rounded quartz grains up to 1 mm in size that form up to 50% of the rock. The schist is fine-grained and fissile. Black graphitic phyllite is derived from

argillite containing minor sandstone layers. The quartz lithic pebble conglomerate contains lithic fragments of quartzite, chert, vein quartz, and phyllite. These conglomerates have yielded Proterozoic and Archean zircons (Table 2.1). These rocks are intruded by and are older than Devonian foliated granodiorite-diorite. Unit 5 is intercalated with and conformably overlain by quartz-sericite schist of unit 6 (Schiarrizza and Preto, 1987).

Unit 6: Felsic and intermediate volcanic rocks

Unit 6 consists of a 1000 metre structurally thickened sequence of white to yellow, rusty weathering, quartz-sericite-carbonate, and quartz-sericite-chlorite-carbonate schist with minor black phyllite and chert. Unit 6 rocks crop out in the western part of the map area and strike northwest (see map in appendix I). Most primary textures have been obliterated by pervasive sericite, chlorite, quartz, carbonate, and pyrite alteration related to volcanogenic massive sulphide/ barite deposits. Rare preserved embayed quartz crystals and plagioclase phenocrysts suggest felsic to intermediate volcanic protoliths.

Correlative unit EBA rocks (on the east side of Adams Lake) have yielded a U-Pb zircon age of 387 Ma (Schiarrizza and Preto, 1987). However, these analyses were carried out during the early development of the Radiogenic Isotope Lab at the University of British Columbia and the ages may be suspect (P. Schiarrizza, per comm, 2000). On the east side of Adams Lake, felsic dykes of unit EBA that cross cut structurally overlying greenschist and greenstone have been dated by U-Pb zircon techniques at 357 Ma (T. Höy and R. Friedman, per comm, 2001).

Unit 7, 8: Argillite, quartz-wacke, and quartz lithic pebble conglomerate

Unit 7 (see map in appendix I) consists of black to grey phyllite and quartz-sericite schist derived from fine-grained argillite and quartz wacke, whereas unit 8 is dominantly quartz lithic pebble conglomerate. These units have been grouped for the purpose of this paper but are distinguished on the 1: 20 000 scale map in appendix I because unit 8 forms an excellent marker unit that can be traced 6 kilometres along strike. Near the Samatosum and Rea deposits the metasedimentary rocks are part of a structurally complex sequence called the "Mine Series". The Samatosum and Rea deposits are located within the metasedimentary rocks near the contact with structurally overlying mafic volcanic rocks of unit 4. Here, the metasedimentary rocks are highly strained and altered (i.e., sericitized $\pm$ clay, silicified, and carbonatized) and consist of carbonaceous black phyllite, sericitized yellow phyllite containing chert layers, and pyrite-rich silicified grey phyllite. Graded bedding and rip-up clasts provide consistent stratigraphic tops toward the west, and indicate that units 7 and 8 are overturned.

Quartz-lithic pebble conglomerate of unit 8 structurally overlies unit 9 on the overturned limb of the Shafer Lake syncline (i.e. lies stratigraphically beneath unit 9). Pebble conglomerate can be traced for 6 kilometres along strike, and thickens from 50m in the south to over 200m in the north. The conglomerate contains clasts (up to 3 centimetres in length) of chert, chlorite schist, and vein quartz, and shows graded bedding with quartz-wacke and argillite.

Unit 9: Felsic and intermediate volcanic rocks

This unit consists of an 800-1000 metre thick sequence of rhyodacite, dacite and andesite flows and volcanoclastic rocks that crop out on the eastern and western limbs of

the Shafer Lake syncline (Fig. 2.2). Volcanic rocks on the eastern limb have a felsic composition, whereas those on the western limb have an intermediate composition, and

Table 2.1: Summary of isotopic age dates from rocks of the Eagle Bay Assemblage, and Kootenay Terrane

<i>Unit /Location</i>	<i>Isotope system, mineral</i>	<i>Interpreted origin</i>	<i>Age</i>	<i>Reference</i>
Regional thermal event (Omineca belt)	K-Ar (mica, zircon fission tracks)	metamorphic	Eocene (45-52 Ma)	Parrish et al. (1988)
Baldy and Raft Batholiths	Ar-Ar, muscovite	Igneous, Cooling age	Cretaceous (96-100 Ma)	Wanless et al. (1966; 1967)
Regional metamorphism (Trinity Hills)	K-Ar (muscovite, biotite, hornblende)	metamorphic	Cretaceous-Jurassic (126-154 Ma)	Mathews, W.H. (1981)
EBF (unit 7) Ore veins, Samatosum Mtn	Ar-Ar, muscovite	metamorphic? metasomatic?	Jurassic (185-190 Ma)	Clark and Williams-Jones, (1991)
Unit 9, (EBF) Samatosum Mtn	U-Pb zircon	Igneous crystallization	Devonian (360.6 $\pm$ 4.7Ma)	This thesis
Unit 9, (EBF) Samatosum Mtn	U-Pb zircon	xenocryst	Neoproterozoic (750.4 $\pm$ 158.4 Ma)	This thesis
EBA dikes, Adams Lake. (correlates to Unit 6 this study)	U-Pb zircon	Igneous Cooling age?	Mississippian (357 Ma)	T. HÖy and R. Friedman (2001) Per comm
EBA, Adams Lake	U-Pb zircon	Igneous crystallization	Devonian (387 Ma)	Schiarizza and Preto (1987)
Unit 5 (EBS)	U-Pb zircon	detrital	Paleoproterozoic (1817,1878 Ma) Archean (2672, 2678 Ma)	This thesis

both are intercalated with minor argillite to quartz wacke. The felsic volcanic/volcaniclastic rocks consist of white weathering, beige quartz-sericite schist derived from quartz-feldspar porphyritic (Figs. 2.5e-f) rhyodacite to dacite, quartz-feldspar-crystal-lithic tuffs and pyroclastic rocks. Fragmental volcanic rocks contain 5-

15cm long felsic fragments that are flattened and stretched in the penetrative foliation plane. The felsic volcanic rocks are structurally overlain (stratigraphically underlain) to the east by quartz lithic pebble conglomerate of unit 8. At the stratigraphic top the felsic rocks are interbedded with and conformably overlain by black argillite, and quartz-wacke of unit 10. Broken crystals of quartz and feldspar are common in the felsic volcanic rocks; quartz crystals may be embayed, and feldspar crystals are partially replaced by sericite and carbonate. Fissile quartz sericite schists are interpreted as crystal ash tuffs, whereas the more competent schists are interpreted as flows, or dikes. A U-Pb zircon date of 360.6 ± 4.7 Ma is interpreted to be the age of deposition for the volcanic protolith (Bailey et al., in prep; Table 2.1).

Unit 9 on the western limb of the Shafer Lake syncline is dominated by chlorite schist derived from intermediate volcanoclastic rocks. Common rock types include fine-grained, fissile, calcareous chlorite schist interpreted as having been derived from mafic to intermediate crystal tuff, and agglomerate. Locally, fragments of felsic volcanic rocks account for 65 to 80 % of the rock. The calcareous chlorite schist is fissile, plagioclase porphyritic, and contains siderite, ankerite, and minor sericite. Plagioclase feldspar phenocrysts have largely been replaced by sericite and carbonate.

Unit 10: Argillite, quartz-wacke

Unit 10 consists of argillite, quartz-wacke and minor pebble conglomerate that stratigraphically overlies unit 9, and is exposed in the core of the Shafer Lake syncline. Black to grey argillite layers are intercalated with grey to beige quartz-wacke (Fig. 2.4c). Local sedimentary top indicators include rip up clasts (Fig. 2.4d), and scour and fill

structures. This unit is graphitic, and fine-grained; grains in the quartz wackes are less than 0.5mm in diameter. Disseminated pyrite grains up to 1 mm in diameter are common and result in rusty weathering of the argillite. The fine-grained, pyritic and graphitic nature of these rocks indicates that they formed in an anoxic basin environment. Limestone beds of unit EBP of Schiarizza and Preto (1987) crop out north of the study area have yielded Mississippian conodonts (Schiarizza and Preto, 1987) and are correlative with unit 10.

Intrusive Rocks

Late Devonian granite, granodiorite, and diorite

This unit is composed of fine to coarse-grained, quartz-sericite schist and quartz-sericite-chlorite schist, derived from granite, granodiorite, and diorite. It forms a sill in the southwestern corner of the map area, intruding volcanic and sedimentary rocks of units 5 and 6 (Fig. 2.2). The margins of the intrusion are fine-grained and resemble unit 6, while coarser phases with a better preservation of igneous textures are found in the interior of the intrusion (Fig. 2.4e). Intergrowths of quartz and feldspar resembling granophyric texture are found in the felsic intrusive rocks suggesting a shallow emplacement level. Similarities in composition, and the shallow emplacement at the base of unit 6 suggest that these rocks are an intrusive equivalent to "Late Devonian" volcanic rocks of unit 6.

Hornblende diorite

Hornblende diorite of unknown age intrudes rocks of unit 4 in several localities (see map in appendix I). Contacts of the diorite are parallel to the foliation, and this intrusion predates the regional isoclinal folding and foliation development. The diorite is typically coarse-grained (Fig. 2.4f) and consists of plagioclase (50% anorthite composition), chlorite, hornblende, and zoned augite crystals.

REGIONAL STRATIGRAPHIC CORRELATIONS

Stratigraphic correlation between the units in this study and those of the Eagle Bay Assemblage defined by Schiarizza and Preto (1987) are shown in Fig. 2.3. Eagle Bay Assemblage rocks have been further correlated with rocks in other parts of the Kootenay Terrane in southern British Columbia (Fig. 2.6; Read and Wheeler, 1976; Okulitch, 1979; 1989; Struik, 1982; 1985; Schiarizza and Preto, 1987). This section will present stratigraphic correlations of rocks from the Eagle Bay Assemblage with those of southern British Columbia and Yukon Territory (Finlayson Lake district). These correlations are important in evaluating the tectonic evolution of the western North American continental margin and for mineral exploration.

The Eagle Bay Assemblage is composed of Upper Neoproterozoic to Middle Paleozoic greenschist grade metamorphosed sedimentary and volcanic/intrusive rocks (Price et al., 1985; Schiarizza and Preto, 1987). The rocks lie westward of autochthonous Paleozoic miogeoclinal successions of North America (Foreland belt), and east of accreted volcanic arc and back-arc basin rocks (Intermontane belt). Devonian-Mississippian rocks of the Kootenay Terrane may be correlative with rocks of the Yukon-

Tanana Terrane in the Yukon Territory and Northern British Columbia (Schiarizza and Preto, 1987; Colpron and Price, 1995; Nelson, 1997; Nelson et al., 2000).

Geological mapping, geochronology, and whole rock geochemical analysis by Murphy and Piercey (1999), and Piercey et al. (2000; 2001) in the Finlayson Lake district of Yukon has resulted in the recognition of rocks that are remnants of Late Devonian to Mississippian primitive to mature arcs and back arc basins. These rocks host the Wolverine, Fyre Lake, GP4F, and Kudzu Ze Kayah volcanogenic massive sulphide deposits. Similar metamorphosed volcanic and sedimentary sequences have been recognized in the Little Salmon Lake and Little Kalzas areas in Yukon (Colpron, 1999), the Big Salmon Complex in B.C. (Mihalynuk et al., 2000), the Dorsey Terrane (Nelson, 1997; Nelson et al., 2000), and Klinkit-Swift River Assemblages (Roots et al., 2000) of British Columbia and southern Yukon.

In southern British Columbia, correlations have been made between rocks of the Eagle Bay Assemblage, Vernon area, Kootenay Arc, Barkerville and Cariboo terranes (Fig. 2.6). Okulitch (1979, 1989) and Schiarizza and Preto (1987) correlate the Eagle Bay Assemblage to rocks in the Kootenay Arc and Vernon area. The Hamill and Horsethief Creek Group in the Kootenay Arc are metamorphosed siliciclastic assemblages that are similar to units EBQ and EBH of the Eagle Bay Assemblage (Fig. 2.6) respectively. All of the aforementioned units consist of quartz arenite, wacke, siltstone and argillite, considered to be part of an Upper Neoproterozoic to Lower Cambrian siliciclastic sequence (Read and Wheeler, 1976; Schiarizza and Preto, 1987). Schiarizza and Preto (1987), and Okulitch (1979; 1989) considered the basal portion of the Silver Creek Formation in the Vernon area to be correlative with units EBH, EBQ, and EBG (Fig. 2.6).

Schiarizza and Preto (1987) correlated rocks of Units EBG (units 1 to 3) with the Lardeau Group and the archaeocyathid bearing Tshinakin Limestone (correlated to unit 3b) with the archaeocyathid bearing Lower Cambrian Badshot Formation in the Kootenay Arc. The presence of siliciclastic rocks interbedded with chlorite schist in the Hamill Group and unit EBH suggest that both of these units are gradational upwards into chlorite schist and greenstone of the Lardeau Group and unit EBG.

In the Vernon area, rocks of the Silver Creek Formation were previously correlated to units EBH and EBQ of the Eagle Bay Assemblage (Okulitch, 1979, 1989; Schiarizza and Preto, 1987), and Lower Paleozoic rocks of the Kootenay Arc (Read and Wheeler, 1976). However, the Silver Creek Formation is cut by late Devonian granite and potentially underlain by Devonian quartzite suggesting that this unit may be as young as Devonian (Erdmer et al., 1999, 2001; R.I. Thompson per comm, 2002). The Sicamous and Tsalcom formations are correlated to mid Paleozoic units EBS (unit 5) and EBM of the Eagle bay Assemblage and Kootenay Arc (Okulitch, 1989). Okulitch (1989) suggested that clastic metasedimentary rocks of unit EBP (unit 10), be correlated to the Milford Group in the Kootenay Arc based on lithology and fossil similarities as described by Read and Wheeler (1976) and Klepacki (1983). The Milford Group has yielded Mississippian conodonts (Orchard, 1985) while the stratigraphic top of unit EBP has yielded Upper Mississippian conodont fossils (Schiarizza and Preto, 1987) suggesting age equivalence.

In the Barkerville Terrane, rocks of the Snowshow Group described by Struik (1986; 1988) and Ferri (2001) may be in part correlative to those found in the Eagle Bay Assemblage. Ferri (2001) suggests that the Keithly, Harveys Ridge, Downey, Agnes,

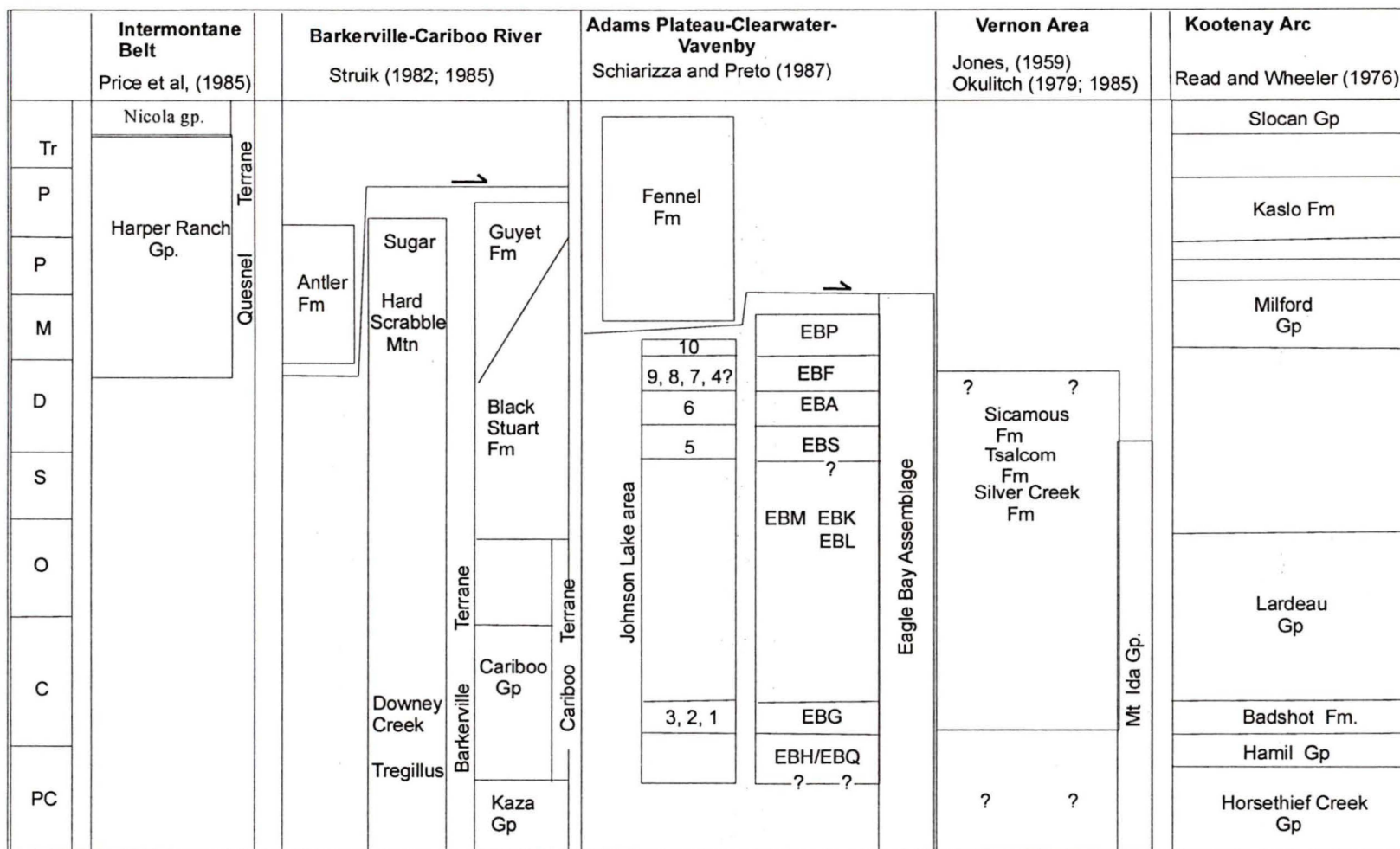


Figure 2.6: Regional Stratigraphic correlation chart, Neoproterozoic to Paleozoic volcanic-sedimentary packages of the Omineca belt, Southern British Columbia, after Schiarizza and Preto (1987).

Goosepeak, Eagle Nest and Bralco Limestone successions are correlative to units EBH, EBQ, and EBG of Schiarizza and Preto (1987). Ferri (2001) further suggests that the Ramos succession could be correlative with Devonian-Mississippian volcanic rocks (units EBA, EBF) of the Eagle Bay Assemblage.

STRUCTURE

The regional strike of the units in the Johnson Lake area is northwest with layers dipping 30 to 60 degrees to the east (Figs. 2.2, 2.7). Ductile and brittle deformation events of Lower Paleozoic to Eocene are recognized within the region (Schiarizza and Preto, 1987). The presence of rift related geological units and associated syngenetic sulphide deposits suggest that lower and middle Paleozoic extensional faults are present. However, the earliest recognizable macroscopic structures in the Johnson Lake area are Jurassic-Cretaceous folds and thrusts (D_2) that overprint pre-existing structures and control the distribution of geological units. This deformation predates intrusion of Late Cretaceous granitoids of the Raft and Baldy batholiths north of the study area. Isotopic age dating of regional metamorphism in the Kootenay Terrane has yielded Jurassic-Cretaceous ages (Table 2.1; Mathews, 1981). Unpublished Ar-Ar muscovite dates (Table 2.1; Clark and Williams-Jones, 1991) from the Johnson Lake area are interpreted to be the age of regional metamorphism and the D_2 event.

The study area has been divided into three structural domains (Fig. 2.8) based on regional structures and orientation of structural measurements at the outcrop scale. Four planar fabrics (S_0 , S_1 , S_2 , S_3) are recognized in the area (Figs 2.9-2.11). S_0 is primary bedding recognized in volcanic and sedimentary rocks by laminations, beds, and

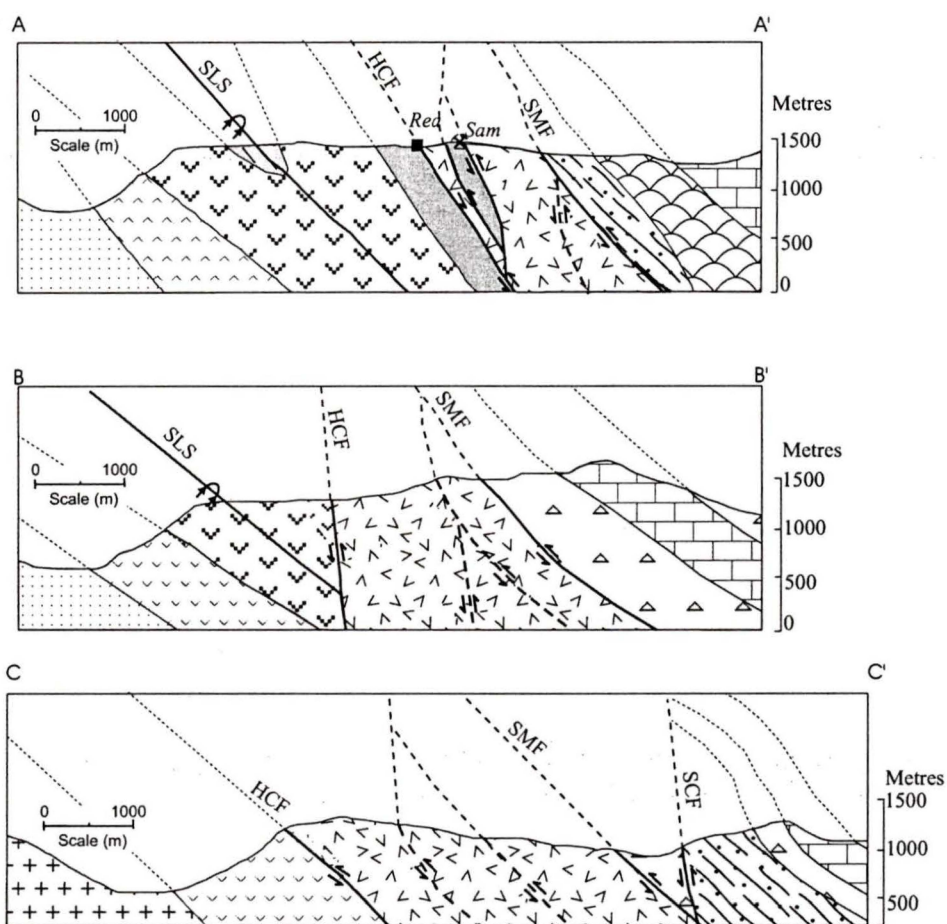


Figure 2.7: NE-SW cross sections of the Johnson Lake area, no vertical exaggeration, see Fig. 2.2 for lines of section. Repetition across the Rea and Samatosum (Sam) zones accommodated by a thrust fault duplex. SLS-Shafer Lake syncline, HCF- Haggard Creek fault, SMF-Samatosum Mountain fault, SCF- Samatosum Creek fault.

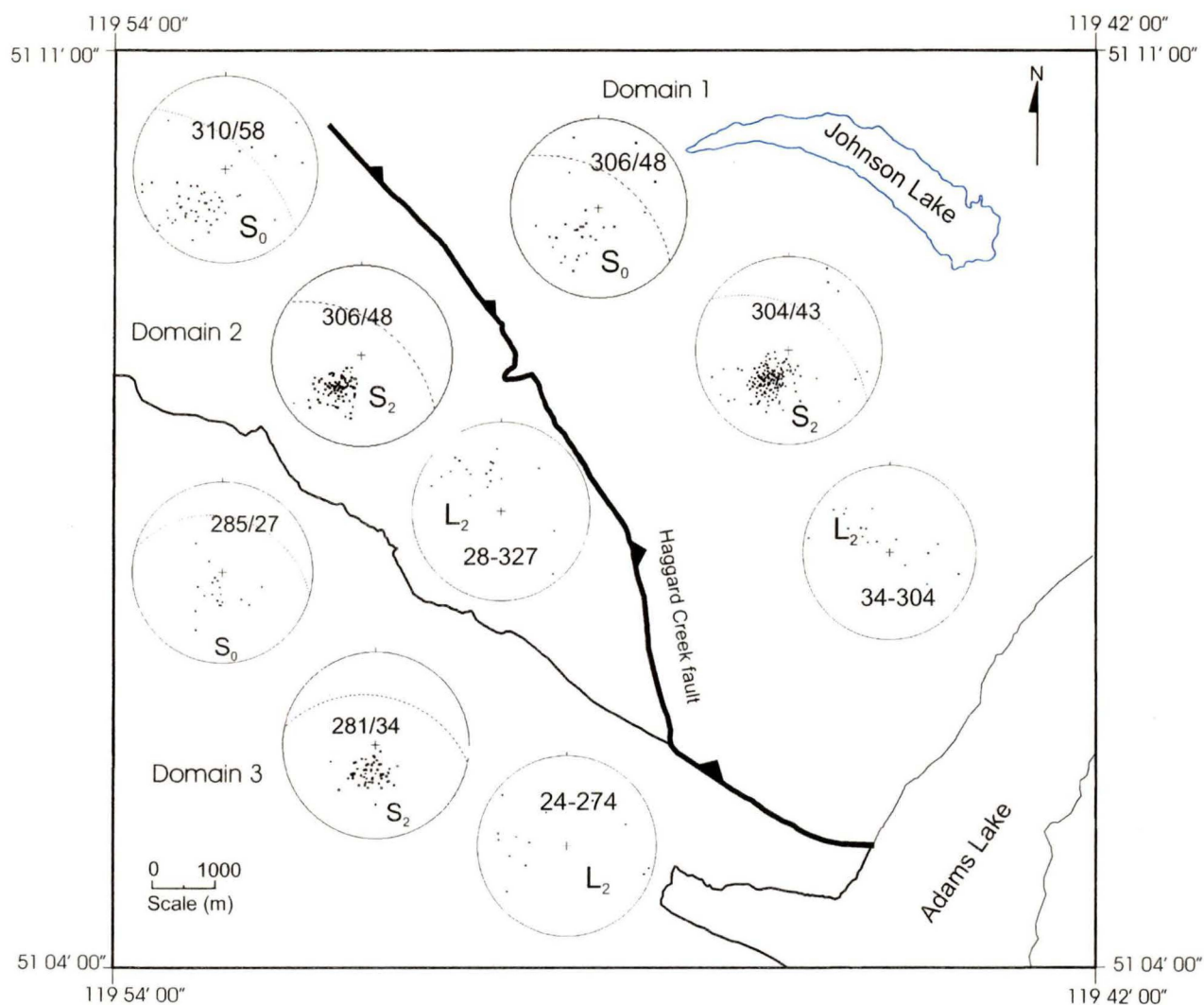


Figure 2.8: Structural domains and stereo plots of poles to planes and lineations. S_0 = compositional layering, S_2 = penetrative foliation, L_2 = S_0 / S_2 intersection lineation + F_2 minor fold hinge lines. Great circles plotted are the average orientation of that plane, average orientations of the L_2 lineations are also given.

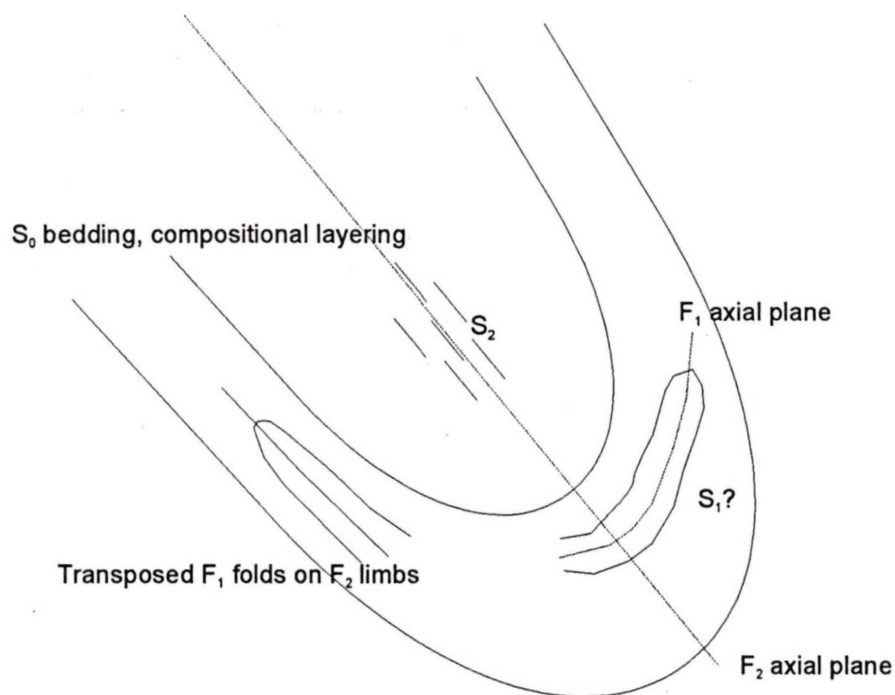


Figure 2.9: Sketch of F_1 isoclinal folds refolded and transposed by F_2 isoclinal folds in Cambrian limestone intercalated with unit 1. S_1 is assumed to be the axial planar cleavage to F_1 (has been transposed and overprinted by S_2), F_2 axial planes dip 45-60 degrees east, S_2 is the penetrative cleavage/foliation that is axial planar to F_2 , S_0 refers to bedding/compositional layering.

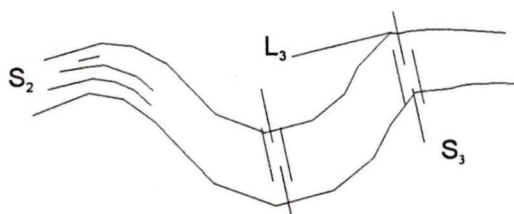


Figure 2.10: Sketch of S_2 "penetrative foliation" folded by S_3 giving rise to "crenulation cleavage", L_3 lineation is defined by the intersection of S_2 and S_3 , (i.e. crenulation fold hinges)

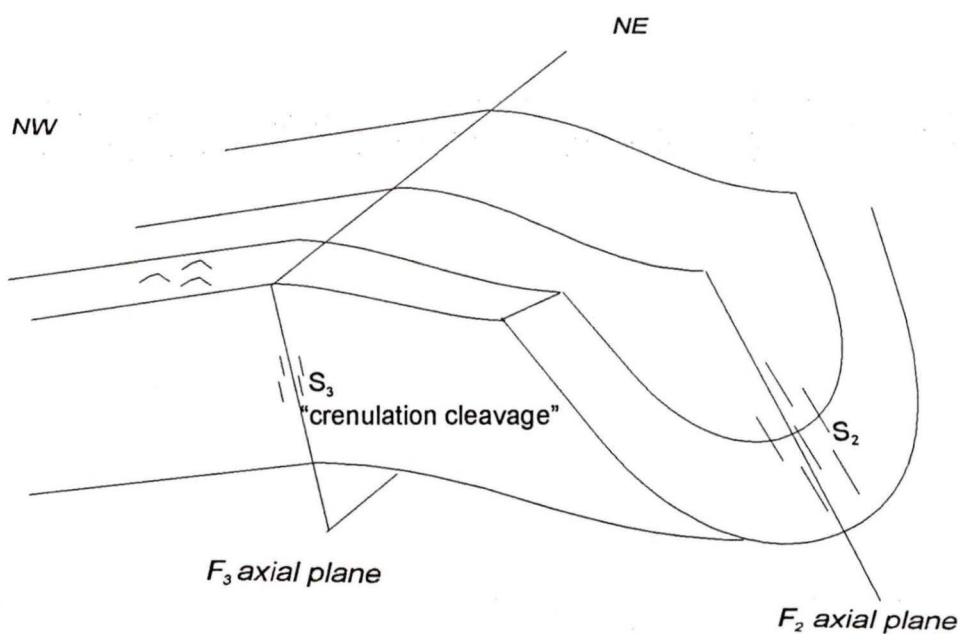


Figure 2.11: Schematic sketch of F_2 isoclinal folds folded by broad open F_3 folds, axial planes to the F_2 trend NW, dip 45-60 degrees east and have a foliation defined by sericite, chlorite, actinolite (synmetamorphic), F_3 folds trend NE, dip 80-90 degrees south and have a crenulation cleavage defined by open folds of S_2 . F_2 is Jurassic-Cretaceous, F_3 is Cretaceous or younger

compositional layers. S_1 is the axial planar cleavage of tight to isoclinal folds (F_1) recognized in Lower Cambrian rocks (Fig. 2.8). S_2 is the regional penetrative foliation defined by the alignment of sericite, chlorite, actinolite and biotite. The S_2 foliation is axial planar to F_2 folds, indicating that F_2 is synmetamorphic (Figs. 2.8; 2.12). S_2 transposes earlier planar elements (S_0 , S_1 , veins, etc.) and dips moderately east. The S_2 foliation is folded by a northeast striking, steeply dipping cleavage (S_3) that is axial planar to broad, open northeast trending folds (Figs. 2.9-2.10). This cleavage is perpendicular to F_2 , and is defined by crenulation and kink bands of the S_2 foliation (Figs. 2.9; 2.12). L_2 is the S_0 / S_2 intersection lineation and is parallel to the hinge lines of F_2 minor folds (Fig. 2.12); L_2 and F_2 have been combined in the stereo plots (Fig. 2.8).

Domain 1 is the eastern part of the map area that encompasses Lower Paleozoic rocks. Bedding in this domain dips eastward and is coplanar with the S_2 foliation. L_2 lineations are NW to SE plunging and distributed along a great circle girdle. Domain 2 encompasses the central part of the map area. Bedding (S_0) and S_2 trend northwest. The L_2 lineation plunges shallowly northwest. S_0 is steeper than S_2 (Fig. 2.8) indicating that bedding is overturned and is consistent with sedimentary top indications including graded beds, rip up clasts, and scour and fill structures (see appendix I). Domain 3 is the western part of the map area (Fig. 2.8) and is characterized by east-west striking S_0 and S_2 , and predominantly east trending L_2 . Bedding has a shallower dip than the foliation, suggesting that it is upright.

Thin limestone beds in unit 1 have isoclinal folds (F_1) that are refolded by coaxial tight to isoclinal F_2 folds (Fig. 2.8e). This relationship was seen in a single outcrop location, and was not evident in rocks of known Devonian-Mississippian age.

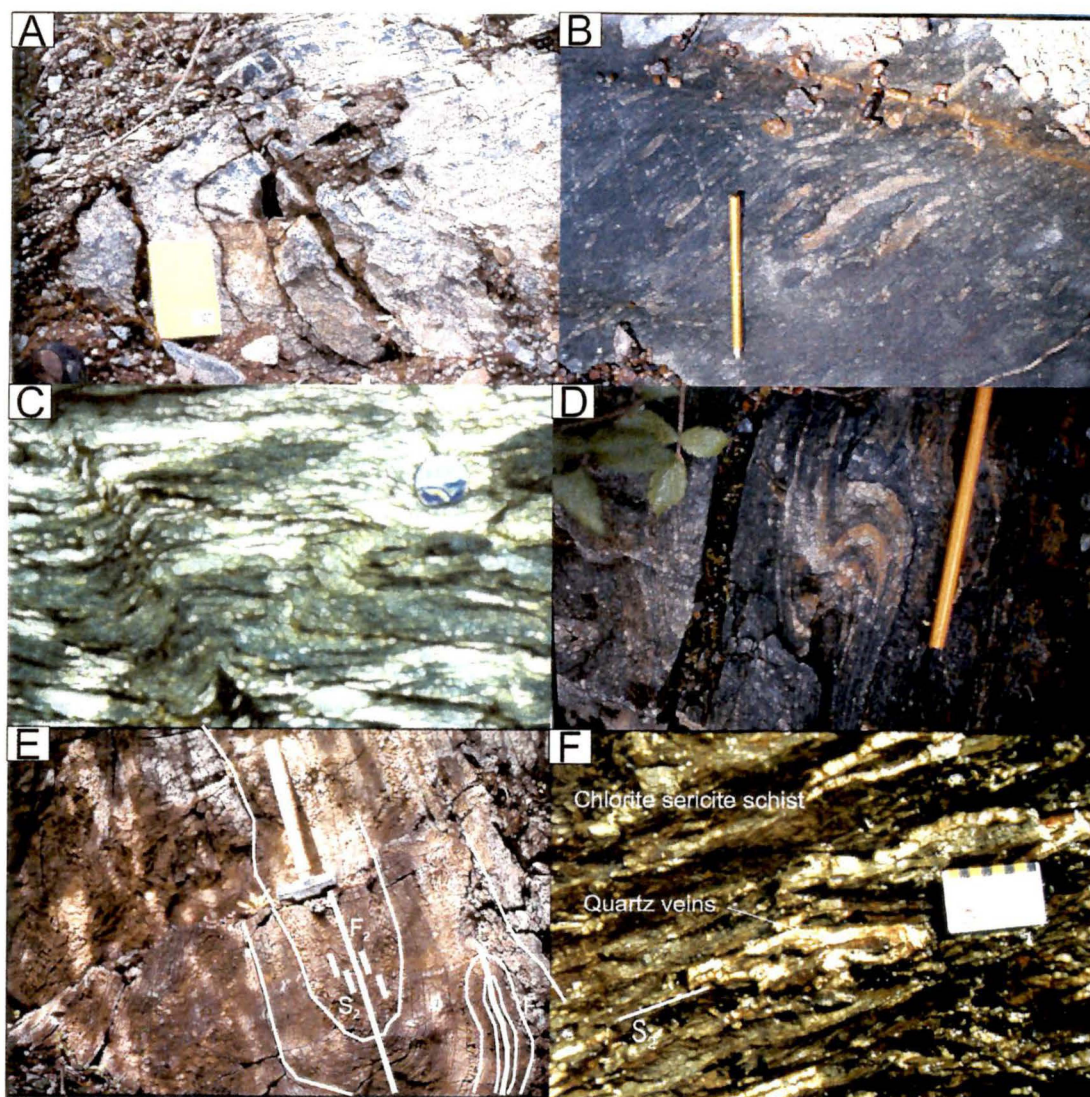


Figure 2.12: Photos of macroscopic rock structures in the Johnson Lake area A.) Recumbant isoclinal fold in quartzite of unit 5 B.) Sheared fragments in S_2 plane, unit 4. C.) Kink bands folding the S_2 fabric, unit 4. D.) S-fold viewed down-plunge, pelitic schist of unit 1 E.) Isoclinal F_1 refolded by tight F_2 folds limestone interbeds of unit 1. F.) Quartz veins in chlorite schist that are isoclinally folded by the foliation (S_2).

Refolded F_1 folds may be related to the rheology of the limestone and progressive Jurassic-Cretaceous folding and thrusting. Fragments in greenschist, cobble conglomerate (unit 4), and quartz-lithic pebble conglomerate (unit 8) (Fig. 2.8) have prolate ellipsoid shapes. These fragments typically have aspect ratios of 3-6 to 1. The foliations in some of these clasts are not concordant with the penetrative fabric of the rock suggesting that the clasts were derived from previously deformed rocks.

F_2 is the dominant fold phase in the Johnson Lake area and controls the regional northwest strike of geological units. Bedding cleavage intersections, minor folds and the east dipping S_2 cleavage indicate that F_2 is southwest-verging (Fig. 2.8). The S_2 cleavage

Table 2.2: Summary of structural events in the Eagle Bay Assemblage, after Schiarizza and Preto, (1987) and this study.

Age	Cambrian	Devonian-Mississippian (D_1 ?)	Jurassic to Early Cretaceous (D_2)	Cretaceous	Tertiary (D_3)
Macroscopic folds	None recognized	None recognized	NW trending overturned tight to isoclinal, (F_1 and F_2)	E-W trending along Raft and Baldy batholiths	NE trending open folds (F_3)
faults	Extensional (presumed)	Extensional (presumed)	West directed thrust faults. NE striking extensional or tear faults?	E-W trending along Raft and Baldy batholiths.	NE striking normal; east-northeast trending strike slip faults.
Cleavage/foliation	None recognized	None recognized	Penetrative foliation (S_2), slaty cleavage and schistosity	kinks and crenulations?	kinks and crenulations? (S_3 ?)
Associated magmatism	Alkalic to subalkalic basalt (OIB and N-MORB)	Calc alkaline rhyolite, rhyodacite, dacite, and andesite;	Granite, granodiorite	Granite, granodiorite	Quartz feldspar porphyry, basalt and lamprophyre dikes

is axial planar to F_2 folds and defined by a metamorphic foliation, suggesting that the F_2 folds are synmetamorphic. The rocks have been subjected to lower to middle greenschist grade metamorphism and lack evidence of higher-grade metamorphism.

Shafer Lake syncline

The Shafer Lake syncline is a northwest trending, shallowly northwest plunging, tight syncline (Figs. 2.2; 2.7) within structural domain 2. The fold axial plane dips 30- 40 degrees eastward parallel to the axial planar cleavage. The eastern limb consists of argillite, quartz wacke, quartz-lithic pebble conglomerate and quartz-feldspar porphyritic rhyodacite. Bedding-cleavage relationships and sedimentary top indicators suggest that this is a steeply east-dipping, overturned limb of a southwest-verging syncline. The western limb is upright based on the map pattern and bedding cleavage relationships.

Haggard Creek fault

The Haggard Creek fault (HCF) strikes northwest through the center of the map area and emplaces Lower Paleozoic rocks on Devonian-Mississippian rocks. The HCF dips moderately to steeply east, and cuts the axial trace of the Shafer Lake syncline in the central part of the map (Figs. 2.2; 2.7), thus postdates F_2 . However, regionally the HCF shares the same strike as F_2 axial planes and S_2 and is likely a late, upright thrust fault related to D_2 . Footwall and hangingwall units cannot be matched across the HCF, thus the HCF is a thrust fault of regional extent (Schiarizza and Preto, 1987).

An inverted "sliver" of unit 7 hosts the Samatosum deposit and is exposed east of the Rea deposit (Fig. 2.2). This sliver is entirely bound within northeast-dipping faults.

These faults are interpreted to be late splays of the HCF forming a thrust duplex with less than 3 km of displacement (Fig. 2.7).

Samatosum Creek and Samatosum Mountain faults

The Samatosum Creek fault (SCF) is a steeply east dipping fault that strikes north and offsets rocks of units 1-3 (see map in appendix I). Unit 3b limestone is vertically offset on this fault by 2.6 km of dip slip motion (Figs. 2.13-2.14). The Samatosum Mountain fault (SMF) is an assumed thrust fault that dips 30-45 degrees eastward, has a northwest strike that is concordant with bedding, and emplaces units 1 to 3 over unit 4 (Figs. 2.2, 2.3). Unit 1 is present in the hangingwall of the SCF but is cut out by the SMF suggesting that the SMF is younger. The Samatosum Creek and Samatosum Mountain faults merge near Adams Lake suggesting that these are splays off a common thrust fault.

East-West trending faults

Small offsets in the strike of units are explained by the presence of east to northeast striking faults (see map, appendix I). These fault offsets include dextral strike-slip and top-down to the south normal fault displacement. For example at the Samatosum mine, a late east striking, top-down to the south normal fault displaces the ore zone.

DISCUSSION

Early to Middle Paleozoic rocks of the study area provide a record of the evolution of a distal continental margin to an active convergent margin. Lower Paleozoic rocks record deep marine (fine-grained pelite and chert, pillowed basalt) to shallow

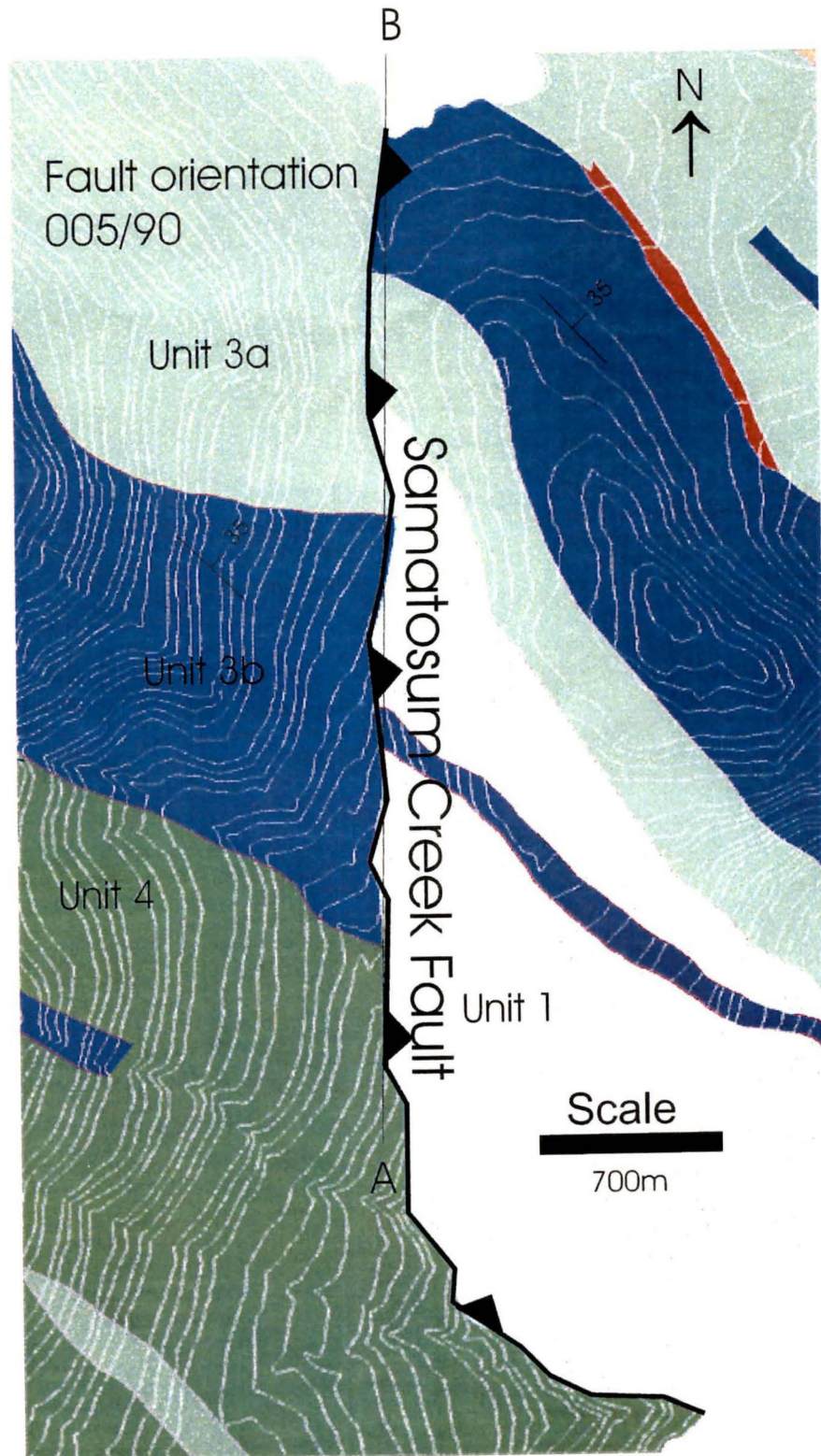


Figure 2.13: Geological map near the Samatsum Creek fault, Line A-B is the trace of the fault plane solution in Figure 2.14

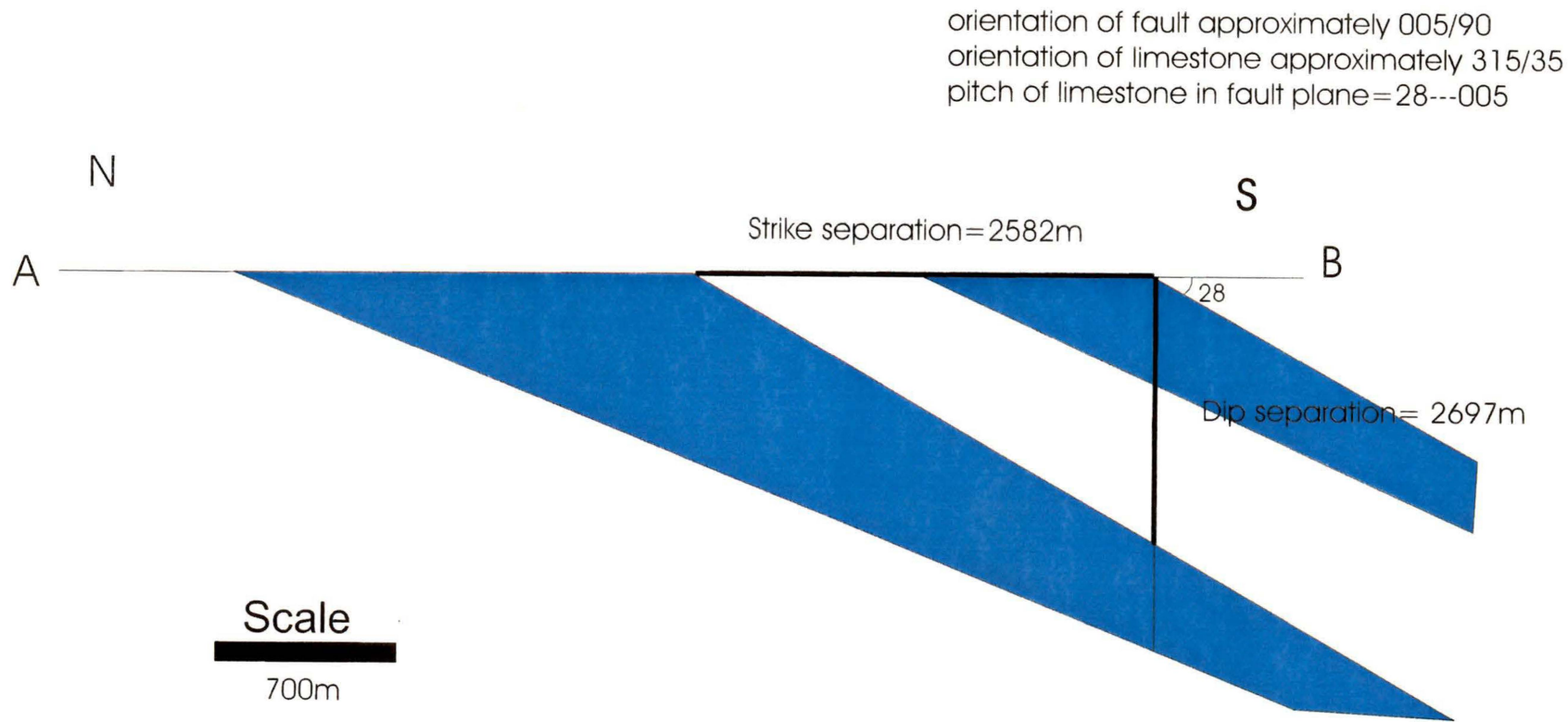


Figure 2.14: Fault plane solution for the Samatosum Creek fault, viewing east. Limestone contact used as a marker horizon
 pitch of the limestone in the fault plane is 28 degrees, restoration of the marker suggests either sinistral strike slip, thrust fault
 (East block up), or combination sinistral thrust fault.

marine (oolitic limestone) deposition along a distal continental margin. Mafic volcanic/volcaniclastic rocks occur at multiple intervals in the Lower Paleozoic sequence. This magmatism may be attributable to episodic extension of the continental margin (Devlin and Bond, 1988; Lickorish and Simony, 1995; Bailey et al., in prep).

Devonian sedimentary rocks (unit 5) contain mature quartz sandstone, and quartz lithic pebble conglomerate with a quartzite matrix indicating a shallow marine depositional environment. The quartz sandstones yield Archean and Early Proterozoic zircons (Table 2.1) suggesting proximity to a direct or recycled cratonic source. These rocks pass conformably up into Devonian felsic volcanic/volcaniclastic rocks at the base of unit 6. Thus, felsic volcanism commenced in shallow marine conditions marking the transition from passive continental margin to an convergent margin.

Unit 6 is overlain by felsic to intermediate volcanic and volcaniclastic rocks of unit 9. Argillite to quartz-wacke is intercalated with both units 6 and 9. These sedimentary lithologies, coupled with sedimentary structures such as rip up clasts, and scour and fill structures, suggest that units 7,8 and 10 are turbidite sequences. This sedimentary part of the Middle Paleozoic succession records a transition from shallow to deep marine environments during Late Devonian to Early Mississippian. This reflects the formation of an ensialic basin in response to rifting within an overall convergent margin setting (Bailey et al., in prep).

Massive sulphide deposits occur at two stratigraphic levels. The Homestake massive barite/sulphide deposit is hosted in Devonian felsic volcanic rocks of unit 6. The Rea, Samatosum, and K7 deposits are hosted in silicified and sericitized metasedimentary of unit 7 (Fig. 2.2). The Rea and Homestake deposits have Devonian model lead ages

(Gouthier, 1986) in agreement with Late Devonian U-Pb zircon ages for their hostrocks (Table 2.1, and references therein). All presently known VMS deposits occur stratigraphically beneath unit 9 (≈ 360 Ma). The abundance of preserved feldspar phenocrysts and lack of pervasive alteration in felsic volcanic rocks of unit 9 indicates that local VMS hydrothermal systems had ceased prior to volcanic deposition of unit 9.

Paleozoic rocks in the study area are polydeformed. Three phases of folding have affected the rocks. Outcrop scale F_1 folds are refolded by F_2 and are likely part of progressive folding. Northwest trending and plunging F_2 folds control the strike of units in the Johnson Lake area. An example is the Shafer Lake syncline; a tight, overturned F_2 syncline with an east-dipping axial plane. Bedding/cleavage relationships, fold asymmetry, and top indicators indicate that F_2 is southwest verging. Broad trending folds (F_3) do not appreciably affect the geometry of the area, but tend to gently warp the limbs of F_2 folds and create a crenulation cleavage (S_3).

Thrust faults have a ramp and flat type geometry, such as exhibited by the Haggard Creek and Samatosum Creek faults whereby thrust flats are parallel to the regional strike of the geological units and ramps cut across the units (Fig. 2.7). The Haggard Creek fault cuts the Shafer Lake syncline and therefore postdates F_2 . However, thrust faults, S_2 and F_2 axial planes parallel suggesting that these structures are part of a common compressional event (D_2), with the thrust faults developing during the late stages of shortening. These faults truncate the Rea and Samatosum hostrocks (unit 7). Thrust splays of the Haggard Creek fault emplace a "sliver" of unit 7 within unit 4, and define a thrust duplex. The Rea zone is truncated by a thrust to the south yet continues along strike, and is open to exploration toward the north.

The regional foliation (S_2) is axial planar to F_2 , and suggests that the D_2 event was synmetamorphic. Metamorphism in the Eagle Bay assemblage is constrained by Jurassic-Cretaceous Ar-Ar sericite dates (Clark and Williams-Jones, 1991). Jurassic to Early Cretaceous metamorphic isotopic dates have been obtained in other parts of the Omineca belt (Mathews, 1981) suggesting that this is also the age of metamorphism and deformation in the Eagle Bay Assemblage (Schiarizza and Preto, 1987). Thus, Paleozoic rocks in the Johnson Lake area were deformed during the development of a Jurassic-Cretaceous, southwest-verging fold and thrust belt.

CONCLUSIONS

Lower Paleozoic rocks consist of greenschist grade metamorphosed mafic volcanic/volcaniclastic rocks, limestone, pelite and chert. The limestone was deposited in a shallow submarine environment while the chert and pelite formed in a deeper marine environment. Mafic volcanic and volcaniclastic rocks were (potentially) erupted in both shallow and deep marine environments.

Devonian-Mississippian rocks consist of a volcano-sedimentary sequence. The volcanic rocks consist of felsic intermediate and mafic volcanic and volcaniclastic rocks, including flow, crystal-ash tuff, and lapilli tuff facies. Sedimentary rocks consist of quartzite, argillite and quartz pebble conglomerate deposited under shallow marine conditions, and argillite, quartz wacke, and quartz lithic pebble conglomerate deposited under deeper marine conditions. VMS deposits are hosted by altered felsic volcanic rocks of unit 6 and altered argillite of unit 7.

Three phases of folding are recognized. F_1 isoclinal folds are recognized in Lower Paleozoic limestone. F_2 forms tight to isoclinal, northwest trending folds that have a synmetamorphic axial planar cleavage, and F_3 forms broad open folds. F_2 developed synchronous with thrust faults during Jurassic-Cretaceous folding and thrusting and controls the regional strike and distribution of the units. The Shafer Lake syncline is an overturned F_2 syncline in the footwall to the Haggard Creek fault. This fold and thrust geometry reflects a primary southwest-verging fold and thrust belt.

ACKNOWLEDGEMENTS

The following people are thanked for contributions to this manuscript. Jim and Barb Lewko at Johnson Lake Resort provided excellent accommodations. Discussion with the following individuals is gratefully acknowledged: Paul Schiarizza, Trygve Höy, Jim Logan (B.C. geological survey), Bob Friesen (Consultant), Victor Preto (Consultant), Ken Daughtry (Consultant), Bob Thompson (GSC), and Noah Hughes. Jennifer Porter and Morgan Soley provided excellent field assistance. This project was funded by the Geological Survey of Canada Ancient Pacific Natmap Project (Paradis), University of Victoria Graduate Fellowship and an NSERC grant (Johnston). This manuscript has benefited from reviews by Dr. Charles Doyle.

This paper presents part of the senior authors M.Sc. Thesis submitted to the University of Victoria. A 1:20,000 scale geological map will also be published as an open file by the Geological Survey of Canada. Additional publications have been produced summarizing the regional stratigraphy, structure, geochemistry, and mineral occurrences (Bailey et al., in preparation, 2001; 2000).

REFERENCES

- Bailey, S.L., Johnston, S.T., Paradis, S.
In preparation: Geochemistry, Geochronology, and Tectonic setting of metavolcanic rocks from the Eagle Bay Assemblage, Johnson Lake area, Southern British Columbia, Canada.
- Bailey, S.L., Paradis, S., Johnston, S.T.
 2000: Geological setting of the Devonian-Mississippian, Rea and Samatsum VMS deposits of the Eagle Bay Assemblage, Adams Lake area, south central British Columbia; *in Geological Fieldwork 1999*, B.C. Ministry of Energy and Mines, Paper 2000-1, p. 287-296.
- Bailey, S.L., Paradis, S., Johnston, S.T.
 2001: New insights into metavolcanic successions and geochemistry of the Eagle Bay Assemblage, South Central British Columbia; Geological Survey of Canada, Current Research 2001-A8, 13 p.
- Clark, J.R., and Williams-Jones, A.E.
 1991: Samatsum Research Project, Unpublished reports to Minnova Inc, McGill University.
- Colpron, M. and Price, R.A.
 1995: Tectonic significance of the Kootenay Terrane, Southeastern Canadian Cordillera: an alternative model. *Geology*, v. 23, p. 25-28.
- Colpron, M.
 1999: Glenlyon Project: preliminary stratigraphy and structure of Yukon-Tanana Terrane, Little Kalzas lake area, central Yukon, *in Yukon Exploration and Geology 1998*; Exploration and Geological Services Division, Indian and Northern Affairs Canada, p. 63-72.
- Devlin, W.J., Bond, G.C.
 1988: The initiation of the early Paleozoic Cordilleran miogeocline; evidence from the uppermost Proterozoic-Lower Cambrian Hamill Group of southeastern British Columbia. *Canadian Journal of Earth Sciences* v.25, no. 1, p. 1-19.
- Erdmer, P., Thompson, R.I., Daughtry, K.L.
 1999: Pericratonic Paleozoic succession in Vernon and Ashcroft map areas, British Columbia. Current Research, Cordillera and Pacific margin/ Interior Plains and Arctic Canada, Geological Survey of Canada, p. 205-213.
- Erdmer, P., Heaman, L., Creaser, R.A., Thompson, R.I., Daughtry, K.L.
 2001: Eocambrian granite clasts in southern British Columbia shed light on Cordilleran hinterland crust *in Canadian Journal of Earth Sciences*, v.38, no. 7 pages 1007-1016.
- Ferri, F.
 2001: Geological setting of the Frank Creek massive sulphide occurrence near Caribou Lake, East-Central British Columbia (93A/11, 14) *in Geological Fieldwork 2000*, paper 2001-1, p. 31-50.
- Hughes, N.D.
 2001: Tectonic Significance of the Early Cambrian (and older?) Eagle Bay Assemblage, Vavenby Area, south-central British Columbia, unpublished M.Sc. Thesis, University of Montana, U.S.A.
- Jones, A.G.
 1959: Vernon Map-Area, British Columbia, Geological survey of Canada, Memoir 296, 186 p.
- King, D.T. Jr., Chafetz H.S.

- 1983: Tidal-flat to shallow-shelf deposits in the Cap Mountain Limestone Member of the Riley Formation, Upper Cambrian of central Texas, *Journal of Sedimentary Petrology*. V.53, no. 1, p. 261-273. 1983.
- Klepacki, D.W.
1983: Stratigraphic and Structural relations of the Milford Kaslo and Slocan Groups, Roseberry Quadrangle, Lardeau Map Area, British Columbia; *in* Current Research, Part A, Geological Survey of Canada, Paper 83-1A, p. 229-233.
- Lickorish, W.H., Simony P.S.
1995: Evidence for late rifting of the Cordilleran margin outlined by stratigraphic division of the Lower Cambrian Gog Group, Rocky Mountain main ranges, British Columbia and Alberta. *Canadian Journal of Earth Sciences* v. 32, no. 7, p. 860-874.
- Mathews, W.H.
1981: Early Cenozoic resetting of Potassium-Argon dates and geothermal history of the North Okanagan area, British Columbia; *Canadian journal of Earth Sciences*, v. 18, p. 1310-1319.
- Mihalynuk, M.J., Nelson J., Roots, C.F., Friedman, R.M., de Keijzer, M.
2000: Ancient Pacific Margin Part III: Regional Geology and Mineralization of the Big Salmon Complex (NTS 104N/9E, 16 & 104O/12,13,14W), *in* Geological Fieldwork 1999, B.C. Ministry of Energy and Mines, Paper 2000-1, p. 27-45.
- Morse, J.W., Mackenzie, F.T.
1990: Geochemistry of sedimentary carbonates; *in* Developments in Sedimentology. V.48, Elsevier, 707 p.
- Murphy, D. and Piercey, S.J.
1999: Finlayson Project: Geological Evolution of the Yukon-Tanana Terrane and it's relationship to Campbell River Range belt, Northern Wolverine Lake Map area, Southeastern Yukon, *in* Yukon Exploration and Geology 1998; Exploration and Geological Services Division, Indian and Northern Affairs Canada, p. 47-62.
- Nelson, J.L.
1997: Last seen Heading south: extensions of the Yukon Tanana terrane into Northern British Columbia; *in* Geological Fieldwork 1996, D.V. Lefebure, W.J. McMillan and J.G. McArthur, editors, B.C. ministry of employment and investment editors, Geological Survey Branch, paper 1997-1, p. 145-156.
- Nelson, J.L., Mihalynuk, M.J., Murphy, D.C., Colpron, M., Roots, C.F., Mortensen, J.K., Friedman, R.M.
2000: Ancient Pacific Margin Part II: A preliminary comparison of potential VMS hosting successions of the Yukon Tanana Terrane, from Finlayson Lake district to Northern British Columbia; *in* Geological Fieldwork 1999, B.C. Ministry of Energy and Mines, Paper 2000-1, p. 19-25.
- Okulitch, A.V.
1979: Lithology, stratigraphy, structure and mineral occurrences of the Thompson-Shuswap-Okanagan area, British Columbia; Geological Survey of Canada, open file 637.
- Okulitch, A.V.
1989: Revised Stratigraphy in the Thompson-Shuswap-Okanagan area, Southern British Columbia, Current Research, report 89-1E, Geological survey of Canada, p. 51-60.
- Orchard, M.J.
1985: Carboniferous, Permian, and Triassic Conodonts from the Central Kootenay Arc, British Columbia: Constraints on the age of the Milford, Kaslo and Slocan Groups; *in* Current Research, Part A, Geological Survey of Canada, Paper 85-1A, p. 287-300.

- Parrish, R.R., Carr, S.D., Parkinson, D.L.
1988: Eocene extensional tectonics and geochronology of the southern Omineca belt, British Columbia and Washington, *Tectonics*, v.7, p.181-212.
- Piercey, S.J. Paradis S., Murphy D.C., Mortensen J.K.
2001: Geochemistry and paleotectonic setting of felsic volcanic rocks in the Finlayson Lake volcanic-hosted massive sulphide (VHMS) district, Yukon, Canada, *Economic Geology*, in press.
- Piercey, S.J., Murphy, D.C., Mortensen, J.K., and Paradis, S.,
2000: Arc rifting and ensialic back-arc basin magmatism in the northern Canadian cordillera: evidence from the Yukon-Tanana terrane, Finlayson lake region, Yukon: in *Slave-Northern Cordilleran Lithospheric Experiment (SNORCLE)-Lithoprobe Report 72*, p. 129-138.
- Price, R.A., Monger, J.W.H., and Roddick, J.A.
1985: Cordilleran Cross Section, Calgary to Vancouver; in *Field guides to Geology and Mineral Deposits in the Southern Canadian Cordillera*, D.J. Templeman-Kluit, Editor, *Geological Society of America*, Cordilleran Section Meeting, Vancouver, May, 1985, p. 3.2-3.85.
- Read, P.B., and Wheeler, J.O.
1976: Geology, Lardeau West Half, British Columbia, Geological Survey of Canada, open file 432.
- Roots, C.F., de Keijzer, M. Nelson J.L., and Mihalynuk, M.G.
2000: Revision mapping of the Yukon Tanana and equivalent terranes in Northern B.C. and Southern Yukon between 131° and 133°; in *current research 2000-A*; Geological Survey of Canada.
- Schiarizza, P. and Preto, V.A.
1987: Geology of the Adams Plateau-Clearwater-Vavenby area; British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1987-2.
- Struik, L.C.
1982: Bedrock Geology of Cariboo Lake (93/A/14), Spectacle Lake (93H/13), Swift river (93A/13) and Wells (93H/14) Map Areas, Central British Columbia, Geological Survey of Canada, Open File 858.
- Struik, L.C.
1985: Thrust and strike slip faults bounding tectonostratigraphic terranes, Central British Columbia, in *Field Guides to Geology and Mineral Deposits of the Southern Canadian Cordillera*, D.J. Templeman Kluit, Editor, *Geological Society of America*, Cordilleran Section, p. 14.1-14.8.
- Struik, L.C.
1986: Imbricated terranes of the Cariboo gold belt with correlations and implications for tectonics in Southeastern British Columbia, in *Canadian Journal of Earth Sciences*, v.23, p. 1047-1061.
- Struik, L.C.
1988: Structural Geology of the Cariboo gold mining district, east-central B.C. Geological Survey, memoir, 421, 100 p.
- Wanless, R.K., Stevens, R.D., Lachance, G.R., and Rimsaite, J.Y.H.
1966: Age determinations and geological studies Part 1- isotopic ages, Report 5, Geological Survey of Canada, paper 65-17.
- Wanless, R.K., Stevens, R.D., Lachance, G.R., and Edmonds, C.M.
1967: Age determinations and geological studies, K-Ar isotopic ages, Report 7, Geological Survey of Canada, paper 66-17.

Wheeler, J.O. and McFeely, P.

1991: Tectonic Assemblage Map of the Canadian Cordillera and Adjacent Parts of the United States of America; Geological Survey of Canada. Map 1712A, Scale 1: 2 000 000.

CHAPTER 3: GEOCHEMISTRY, GEOCHRONOLOGY, AND TECTONIC SETTING OF METAVOLCANIC ROCKS FROM THE EAGLE BAY ASSEMBLAGE, JOHNSON LAKE AREA, SOUTHERN BRITISH COLUMBIA, CANADA

ABSTRACT

This paper presents an assessment of the lithogeochemical and Sm-Nd isotopic characteristics of metavolcanic rocks from the Eagle Bay Assemblage, Kootenay Terrane, in the Johnson Lake area. Geochemical and age constraints on these rocks provide a framework for recognizing volcanic rocks and tectono-stratigraphic settings in the Canadian Cordillera that are favorable to host massive sulphide deposits. The volcanic rocks have experienced hydrothermal alteration and lower to middle greenschist grade metamorphism, therefore immobile elements (e.g. Ti, Zr, Nb, Y, REE's) are used to characterize the volcanic precursors. Lower Paleozoic (and older?) mafic volcanic/volcaniclastic, limestone, and siliciclastic rocks structurally overlie Devonian-Mississippian felsic, intermediate, and mafic volcanic/intrusive and siliciclastic rocks in the Johnson Lake area. New age constraints from this study include a 360 ± 4.6 Ma U-Pb zircon age on felsic volcanic rocks of unit 9. The volcanic rocks are divided into: (1) Three suites of mafic volcanic rocks that include mid-ocean ridge basalt (MORB) and ocean island basalt (OIB) of probable Cambrian age (unit 2 and 3a respectively), and OIB of uncertain age (unit 4). (2) Calc-alkaline and alkaline Devonian-Mississippian intermediate to felsic volcanic rocks. ϵ_{Nd} values of +3 to +5 indicate that OIB mafic rocks of units 3a and 4 are derived from recycled crust, whereas Devonian-Mississippian felsic to intermediate volcanic rocks of unit 9 have ϵ_{Nd} values of -1 to -2.6 suggesting that they are derived predominantly from Late Neoproterozoic continental crust. The rocks in the Johnson Lake area are remnants of Lower and Middle Paleozoic rift related volcanism. Lower Cambrian (OIB) alkalic basalts record rifting on the outer North American continental margin and are associated with sediment-hosted massive sulphide deposits. Devonian-Mississippian intermediate and felsic volcanic rocks formed in a rifted volcanic arc environment and host volcanogenic massive sulphide deposits.

INTRODUCTION

This paper presents lithogeochemical, neodymium isotope, and U-Pb zircon geochronology data of volcanic rocks in the Johnson Lake area of south-central British Columbia (Figs. 3.1 and 3.2). These rocks host volcanogenic massive sulphide (VMS) and quartz-carbonate vein-hosted silver deposits including the past producing Homestake and Samatosum mines, and the Rea and K7 deposits (Fig. 3.2). These deposits are hosted in volcanic and sedimentary rocks of similar age to the Finlayson Lake (VMS) district in the Yukon Territory (Piercey et al., 2001; Murphy and Piercey, 1999). This study examines the petrogenesis of volcanic rocks of the Johnson Lake area, and provides critical constraints on the Paleozoic tectonic evolution of the western North American continental margin. The geochemical data provides insight into the local and regional scale volcanic and tectonic controls on massive sulphide mineralization.

Paleozoic tectonism of the North American Continental margin in the Canadian Cordillera is recorded in the Kootenay Terrane in southern British Columbia (Fig. 3.1), and the Yukon-Tanana Terrane in northern British Columbia and Yukon Territory (Monger and Price, 1979; Mortensen, 1992; Monger, 1993; Colpron and Price, 1995; Nelson, 1997; Nelson et al., 2000). The Kootenay and Yukon-Tanana terranes are composed of variably deformed and metamorphosed rocks derived from sedimentary, volcanic and intrusive protoliths of dominantly Paleozoic age (Price et al., 1985; Gabrielse et al., 1991; Colpron and Price, 1995; Mihalynuk et al., 1999; Colpron, 2001). These terranes separate North American continental margin strata to the east (Foreland Belt) from volcanic-sedimentary terranes to the west (Intermontane Belt; Fig. 3.1) that were considered to be allocthonous relative to the Foreland Belt (Monger, 1993).

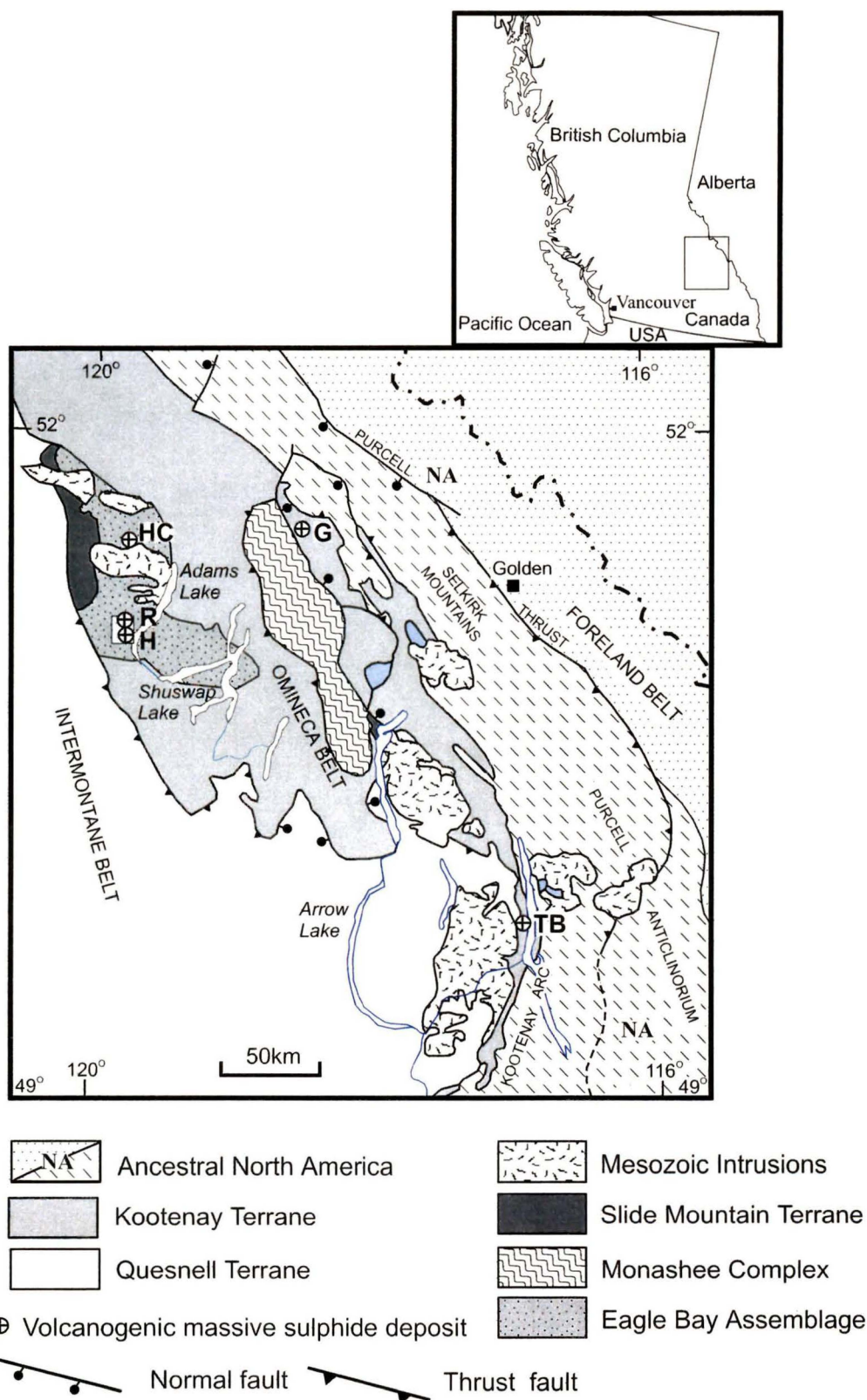


Figure 3.1: Simplified geological map of Southeastern British Columbia, modified after Wheeler and McFeely (1991). Mineral deposits indicated are Rea (R), Homestake (H), Harper Creek (HC), Goldstream (G), and True Blue (TB). The study area (see Fig. 3.2) is outlined by the rectangle surrounding the Rea and Homestake deposits.

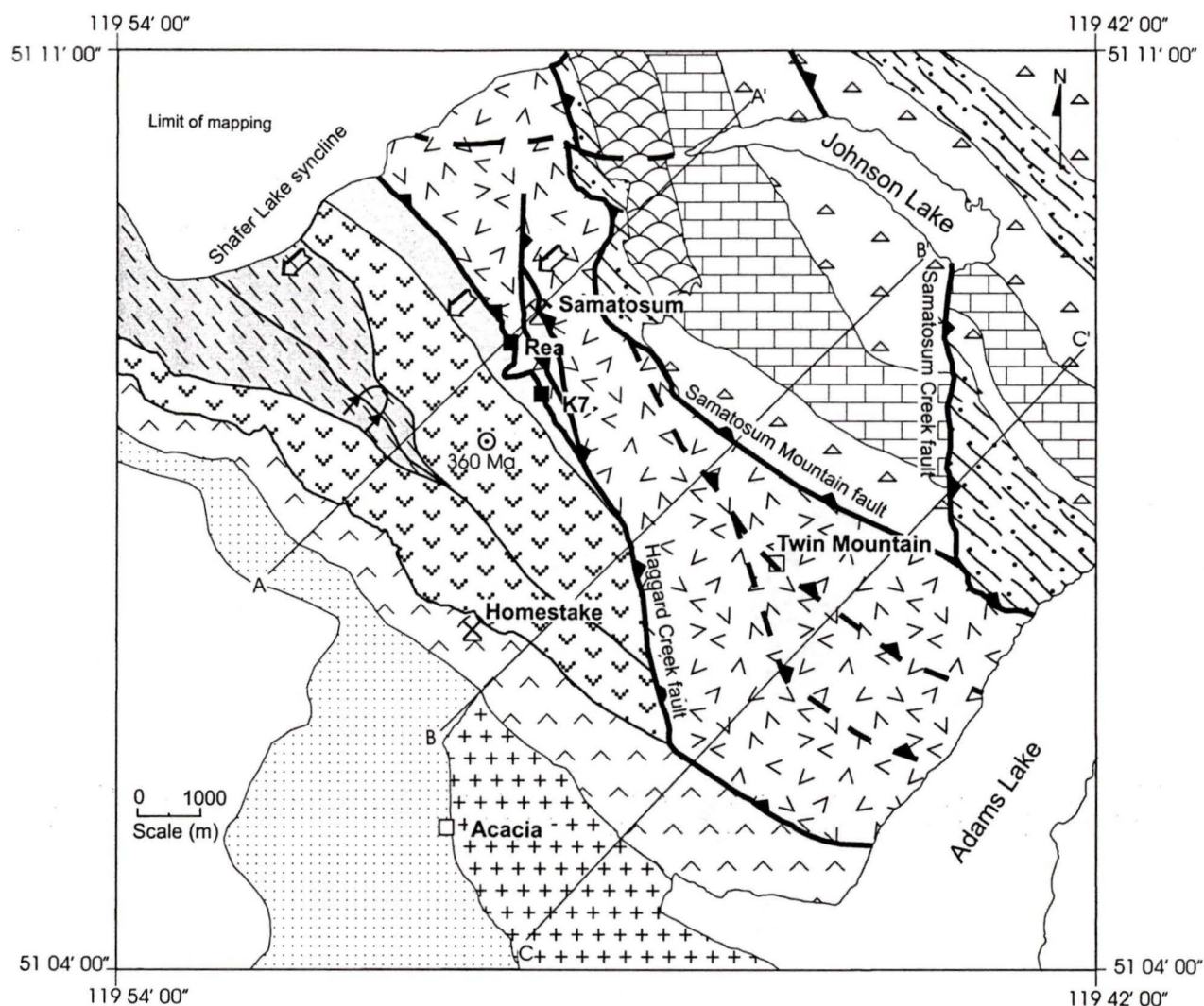


Figure 3.2: Simplified geological map of the Johnson Lake area

Legend

Intrusive Rocks

Devonian



Felsic to intermediate intrusive rocks: quartz-feldspar-sericite-ankerite schist derived from foliated granodiorite to diorite

Layered Rocks

Devonian- Mississippian



10

Metasedimentary rocks: Phyllite, and quartz-sericite schist derived from argillite to quartz wacke, sandstone, and minor pebble conglomerate.



9

Felsic metavolcanic rocks: Quartz-sericite schist derived from quartz-feldspar phryic rhyolite, and quartz-feldspar crystal lithic tuff, lapilli to bomb-size pyroclastics. Lesser mafic to intermediate metavolcanic rocks,



7,8

Metasedimentary rocks: Phyllite, and quartz-sericite schist derived from argillite to quartz wacke, sandstone, and pebble conglomerate.



6

Felsic to intermediate metavolcanic rocks: quartz-feldspar-sericite-ankerite schist derived from rhyolite, rhyodacite, dacite.



5

Metasedimentary rocks: Dominantly fine to coarse grained quartzite, quartz pebble lithic conglomerate, minor phyllite, quartz sericite ankerite schist, chlorite schist, and marble.

Lower Cambrian and older



4

Mafic metavolcanic/volcaniclastic rocks: Calcareous chlorite schist derived from flows, fragmentals, tuffs



3b

Limestone: White weathering, finely crystalline, white to grey marble and dolostone



3a

Mafic metavolcanic/volcaniclastic rocks: Calcareous chlorite schist derived from mafic flows, fragmentals, tuff, interbedded limestone and metapelites



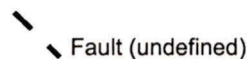
2

Mafic volcanic rocks: Light green, calcareous chlorite schist and greenstone derived from pillows, pillow breccias and feldspathic crystal tuffs.



1

Metasedimentary rocks: Phyllite derived from shale and siltstone, banded chert, minor white-grey marble



Fault (undefined)



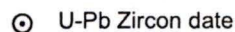
Thrust fault



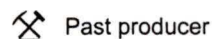
Overturned syncline



Top indicator



U-Pb Zircon date



Past producer



Developed prospect



Prospect

GEOLOGY

The study area is underlain by Lower Cambrian to Mississippian metasedimentary and metavolcanic rocks assigned to the Eagle Bay Assemblage (Jones, 1959; Schiarizza and Preto, 1987; Okulitch, 1979). The Eagle Bay Assemblage structurally underlies Devonian-Permian oceanic rocks of the Fennel Formation to the west and may be stratigraphically linked to it (Schiarizza and Preto, 1987). The Fennel Formation consists of mid-ocean ridge basalt (MORB), gabbro, chert, siliciclastic and lesser felsic volcanic rocks that developed in a marginal basin west to the North American Continental Margin. This ophiolitic assemblage was subsequently thrust eastward over the Eagle Bay Assemblage prior to the Middle Jurassic (Schiarizza and Preto, 1987). The Eagle Bay Assemblage lies west of other Lower Paleozoic to Neoproterozoic successions of the Kootenay Terrane and high-grade metamorphic rocks of the Monashee Complex (Fig. 3.1).

The study area is divisible into an east-dipping Devonian-Mississippian sequence, and a structurally overlying, east-dipping panel of Lower Paleozoic rocks (Fig. 3.2). The contact between lower and middle Paleozoic rocks is a southwest verging thrust fault termed the Haggard Creek Fault (Schiarizza and Preto, 1987). The Lower Paleozoic succession (units 1 to 3; Figs. 3.2 and 3.3) consists of mafic metavolcanic and volcanoclastic rocks, limestone and metapelites interpreted to be stratigraphically upright and eastward younging (Schiarizza and Preto, 1987). Age constraints are based on correlation with rocks along strike that include the Lower Cambrian archaeocyathid bearing Tshinakin Limestone (Schiarizza and Preto, 1987). Mafic volcanic and volcanoclastic rocks (unit 4) in the structural hangingwall of the Samatosum and Rea

Eagle Bay Assemblage stratigraphic units in the Johnson Lake area

Regional Eagle Bay Assemblage stratigraphic units (not to scale) after Schiarizza and Preto (1987)

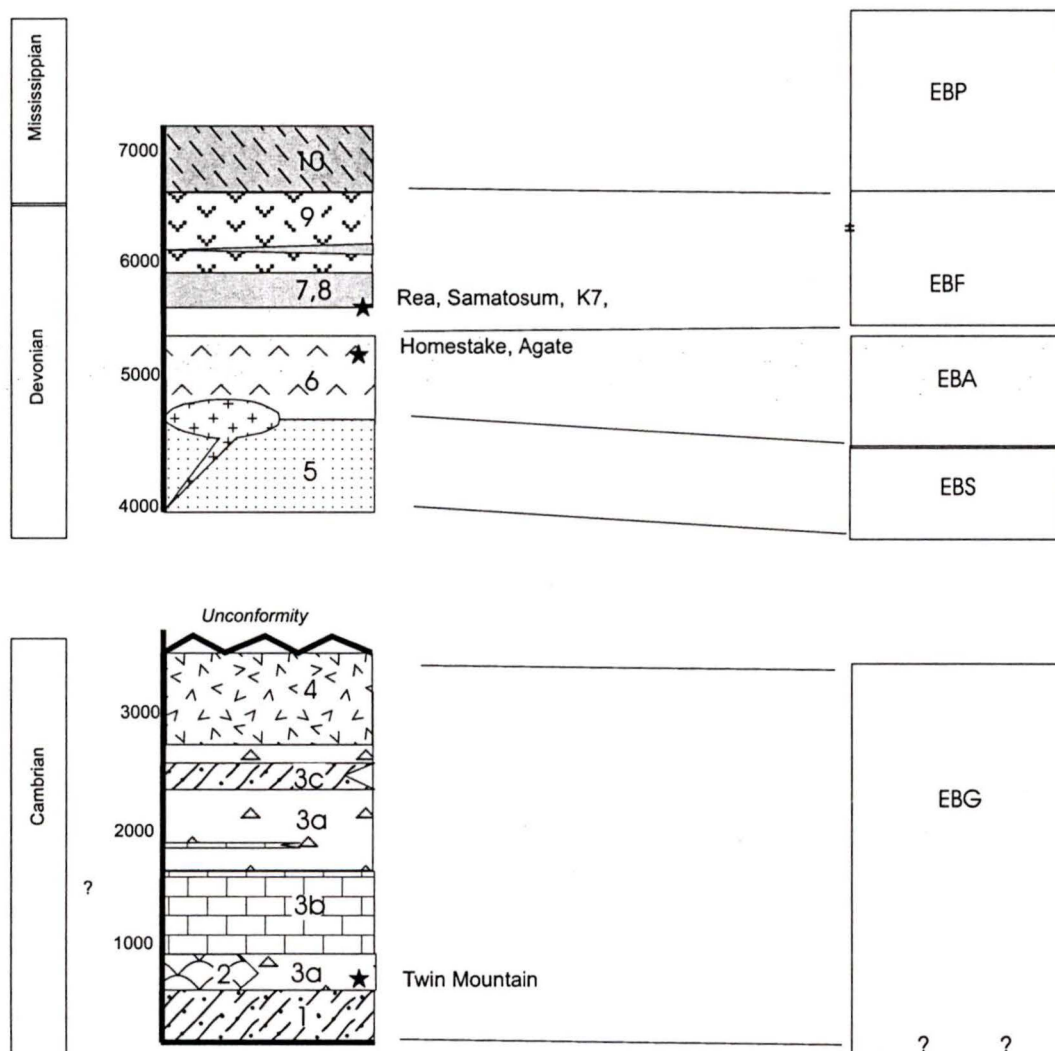


Figure 3.3: Stratigraphic section of geological units in the Johnson Lake area, after this study and Schiarizza and Preto, (1987). See Fig. 3.2 legend for unit designations.

deposits are of uncertain age. These were previously grouped with Lower Paleozoic rocks (Schiarizza and Preto, 1987), but may be part of a Devonian-Mississippian sequence in the footwall of a regional thrust fault (Höy and Gouthier, 1986; Bailey et al., 2000, in preparation;).

Rocks of known Devonian-Mississippian age consist of felsic volcanic, intrusive, and sedimentary rocks of units 5 to 10 (Figs 3.2 and 3.3). Ages are constrained by U-Pb zircon dating of 357-360 Ma on the felsic volcanic rocks of units 6 and 9 (Schiarizza and Preto, 1987; this study). The felsic rocks are intercalated with and overlain by argillite, greywacke, and quartz-lithic pebble conglomerate that are interpreted to be turbidite sequences (Höy and Gouthier, 1986; Schiarizza and Preto, 1987).

The dominant phase of folding in the study area consists of northwest trending, southwest verging, overturned tight to isoclinal folds with a synmetamorphic, penetrative, axial planar cleavage. Isoclinal folds developed synchronously with southwest-directed thrust faults and together constitute a west verging fold and thrust belt of Jurassic age (Schiarizza and Preto, 1987; Bailey et al., in preparation). The rocks are further dissected by north to northeast trending Eocene brittle faults, and warped by northeast trending open folds (Schiarizza and Preto, 1987).

The following unit descriptions will focus on volcanic and intrusive rocks. All of the Paleozoic rocks have undergone lower to middle greenschist facies metamorphism. However, macroscopic, petrographic and geochemical characteristics allow for identification of protoliths. Hence, protolith names will be used to refer to the units herein.

Volcanic Rocks

Unit 2: Mafic volcanic rocks

This unit consists of a 700 metre thick sequence of mafic volcanic rocks derived from pillows, pillow breccias and crystal tuffs that overlie metasedimentary rocks of unit 1 and underlie limestone of unit 3b. Unit 2 mafic volcanic rocks commonly have a white or grey weathered surface, and a light green color due to abundant epidote and locally contain veinlets of quartz-carbonate, fibrous amphibole, and octahedral magnetite crystals. The mineral assemblage consists primarily of chlorite, actinolite, epidote, Fe-oxides, carbonate, and quartz.

Unit 3a: Mafic volcanic/volcaniclastic rocks

Unit 3a consists of 1.5-3 km of structurally thickened mafic volcanic and volcaniclastic rocks and includes fragmental, tuffaceous and massive facies. Rocks grouped in unit 3a outcrop stratigraphically below and above the Tschinakin Limestone (Figs. 3.2, 3.3). This unit has an approximate thickness of 700m beneath the Tschinakin Limestone, occurs intermittently above it and continues east of the map area.

Fragmental facies included bleached lapilli to bomb-sized greenstone that are variably foliated and contain chlorite, quartz and calcite amygdules. The matrix has a foliation defined by chlorite, actinolite and octahedral magnetite. Fine-grained, fissile, calcareous chlorite schist is derived from mafic tuffs, while more competent rocks are derived from mafic volcanic flows.

Unit 4: Mafic volcanic/ volcaniclastic rocks

Unit 4 consists of approximately 1-3 km of structurally thickened, calcareous chlorite-sericite-quartz schist and chlorite schist of uncertain age derived from mafic volcanic and volcaniclastic rocks, that outcrop in the central portion of the map area (Fig. 3.2). Primary igneous textures and outcrop-scale volcanic features are preserved and suggest that these rocks were volcaniclastic rocks (fragmental and tuffaceous), massive and pillowed basalt flows. The most common rocks are lapilli-tuff with an average fragment size of 4-5 centimetres. The lapilli are bleached, fine-grained or amygdular and are derived from other volcanic facies within unit 4. The massive flows have weakly developed foliation and contain calcite and quartz amygdules. Amygdaloidal pillows are up to one metre in diameter, display a fine-grained, non-vesicular rim, and are flattened within the penetrative foliation plane. The mineral assemblage consists of chlorite, actinolite, plagioclase, siderite, ankerite, calcite, iron oxides, $\pm$ pyrite, epidote, and quartz. Most of the minerals are metamorphic, however, rare deformed igneous plagioclase crystals are present.

Mafic volcanic rocks of unit 4 are intercalated with and overlain by altered and mineralized metasedimentary rocks observed in exploration trenches and drill core at the Rea deposit (Höy and Gouthier, 1986). Thus, the contact between unit 4 and unit 7 of this study was interpreted to be stratigraphic (Höy and Gouthier, 1986; Fig. 3.2), and created a conundrum in the interpretation of this boundary as a regional thrust fault as suggested by Schiarizza and Preto (1987). Furthermore, to the east of Adams lake, this contact is cut by felsic dikes of Mississippian age (357 Ma; T. Höy and R. Freidman, per comm. 2001),

suggesting that these units have been in contact since the mid Paleozoic and were not structurally juxtaposed during Jurassic folding and thrusting.

Unit 6: Felsic and intermediate volcanic rocks

Unit 6 consists of yellow, rusty-weathered, fissile, quartz-sericite-carbonate, and chlorite-sericite-carbonate-quartz schists that have a structural thickness of 300 to 1000 metres. Unit 6 overlies sedimentary rocks of unit 5 and underlies felsic to intermediate volcanic rocks of unit 9. Much of the primary mineralogy in this unit has been replaced by extensive quartz-sericite-chlorite-pyrite alteration, rendering the identification of precursor lithologies difficult. Rare preserved embayed quartz and albite phenocrysts suggest felsic to intermediate protoliths.

Unit 6 hosts polymetallic massive sulphide occurrences (including the Homestake deposit, and the Agate and Stake showings). These mineral occurrences have extensive associated zones of chert, fissile quartz-sericite-pyrite schist, and quartz-chlorite-sericite schist reflecting alteration associated with massive barite/sulphide mineralization.

Unit 9: Felsic to intermediate volcanic rocks

Unit 9 consists of a 500 to 1000 metre structurally thickened sequence of white weathering, beige quartz-sericite schist derived from quartz-feldspar porphyritic rhyodacite, quartz-feldspar-crystal-lithic tuffs and volcanoclastic rocks. Unit 9 is both underlain and overlain by black phyllite, quartz wacke and quartz lithic pebble conglomerate. Volcanoclastic rocks may contain fragments 5 to 15 centimetres in length that are flattened and stretched into the penetrative foliation plane. The mineral

assemblage consists of quartz, sericite, plagioclase, siderite, ankerite, and fine-grained disseminated pyrite. Microtextural features include the presence of embayed quartz crystals, and albite crystals partially replaced by sericite and carbonate.

Unit 9 also contains intermediate to mafic volcanic rocks on the western limb of the Shafer Lake syncline (Fig. 3.2). These rocks include agglomerate with fragments up to 30 centimetres in length, and fine-grained, fissile calcareous chlorite schist. The schist is plagioclase porphyritic and contains siderite, ankerite and minor sericite.

Devonian felsic to intermediate intrusive rocks

This unit consists of fine to coarse-grained quartz-sericite schist and quartz-sericite-chlorite schist, derived from an intrusion of felsic to intermediate composition. This intrusion has a sill like morphology in the western part of the map area and intrudes units 5 and 6. The rocks are primarily composed of quartz, sericite, chlorite, albite, Fe-carbonates, and opaques (pyrite and Fe oxides), with accessory zircon and apatite. Rocks on the margins of the intrusion are typically fine-grained, whereas in the interior quartz and feldspar display a granophyric textural intergrowth indicating a shallow level of emplacement. This intrusion is a subvolcanic equivalent to unit 6.

WHOLE ROCK GEOCHEMISTRY

A variety of geochemical analyses were performed during this study to test correlations of units and unravel the petrogenesis of the volcanic, volcanoclastic, and intrusive rocks. Powdered whole rock samples were analyzed for major, minor and trace element compositions using fused bead x-ray fluorescence (XRF), acid dissolution

inductively coupled plasma mass spectrometry (ICP-MS) and inductively coupled plasma emission spectrometry (ICP-ES) techniques at the Geological Survey of Canada's (GSC) analytical lab. Further details on the analytical methods, detection limits, precision and standards are given in appendix II and the GSC analytical chemistry lab website:

http://www.nrcan.gc.ca/gsc/mrd/labs/chem_e.html.

Due to the metamorphism and alteration, major element classifications for the metavolcanic rocks are suspect. Diagrams utilizing high field strength elements (HFSE; Zr, Nb, Y, Ti, Hf, Ta) are used to classify the rocks as these elements typically behave in an immobile fashion during low to moderate alteration and greenschist facies metamorphism (Jenner, 1996; MacLean and Barrett, 1993; Barrett and MacLean, 1999). Normalized trace element diagrams were also used to provide information about source regions for magmatism and identify rocks of similar magmatic affinity. The remainder of the elements, including the major elements and the large ion lithophile elements (LILE) tend to show various degrees of mobility.

RESULTS

Major and trace element geochemical data for the volcanic rocks in the Johnson Lake area are reported in Tables 3.1 to 3.3 and in Figures 3.4 to 3.11. Element abundances and ratios are mentioned if they are diagnostic of a particular unit, rock type, or tectonic setting.

Mafic volcanic rocks

Unit 2 mafic volcanic rocks plot within the subalkaline basalt fields in the Nb/Y-Zr/TiO₂ diagram of Winchester and Floyd (1977) (Fig. 3.4a) and the tholeiitic field in the

Y/Ti-Zr/Ti diagram (Fig. 4b) of Barrett and MacLean (1999). These rocks have low Nb/Yb (0.3-0.7), Zr/Yb (8-15), and Th/Yb (0.2-0.5) ratios similar to N-MORB (Figs. 3.4c, 3.4d) reflecting low HFSE and Th concentrations (Fig. 3.5; Table 3.1). Light rare earth elements (LREE) are depleted relative to the heavy rare earth elements (HREE) and have patterns similar to normal mid-ocean ridge basalts (N-MORB) on the primitive mantle normalized plot (Fig. 3.5a) and chondrite normalized REE plot (Fig. 3.6a). The REE patterns reflect derivation of unit 2 mafic volcanic rocks from a LREE and HFSE depleted mantle source.

Unit 3a has SiO₂ within typical basalt values of 45-53 wt%. The TiO₂ (1.8-3.2 wt%) and P₂O₅ (0.2-0.5 wt%) concentrations are higher than in unit 2 (Table 3.1). Unit 3a has Nb/Y (0.67-1.0), and Zr/TiO₂ (52-94) ratios within the typical range for alkalic basalts (Winchester and Floyd, 1977) (Fig. 3.4a). These rocks have high Nb/Yb (5-11), Zr/Yb (50-90), and Th/Yb (0.4-0.8) ratios that are similar to OIB (Figs. 3.4c-d) reflecting higher HFSE and Th concentrations than unit 2 (Fig. 3.5; Table 3.1). Unit 3a has enrichment in highly incompatible elements (Th-Ti; Fig. 3.5b), compared to less incompatible elements. The REE pattern (Fig. 3.6b) is similar to OIB (Sun and McDonough, 1989).

Unit 4 mafic volcanic rocks have Nb/Y (0.7-2) and Zr/TiO₂ (0.002-0.006) within the range for alkalic basalt (Fig. 3.4a). The Nb/Yb, Zr/Yb, and Th/Yb ratios are similar to OIB (Figs. 3.4c-d) reflecting higher HFSE and Th concentrations than unit 2 (Fig. 3.5; Table 3.1). The primitive mantle normalized plot of unit 4 (Fig. 3.5c) closely resembles unit 3a (Fig. 3.5b) and shows enrichment in the highly incompatible elements compared to the less incompatible elements. This pattern is similar to OIB. In the Zr-Th-Nb

Table 3.1. Whole rock major and trace element analyses for mafic volcanic rocks, Johnson Lake Area, B.C., Canada

Sample Name	SB99-09	SB99-17B	SB99-48	SB99-17C	SB99-39	PS78-253	DF-132.1	DF-132.2	SP00-40	SP00-41	SB99-107B	SB00-216B
Unit#	2	2	2	2	2	3a	3a	3a	3a	3a	3a	3a
rock type												
SiO ₂ (wt%)	47.8	49.4	49.3	45.4	48.1	50.5	52.9	52.8	51.8	43.3	51.3	51.4
TiO ₂	0.7	0.7	1.3	1.0	0.9	2.0	2.5	2.5	1.8	2.1	2.0	3.2
Al ₂ O ₃	17.2	16.6	15.0	19.2	16.8	15.3	13.3	13.3	13.1	12.9	15.8	19.1
Fe ₂ O ₃	2.7	4.9	3.7	1.7	2.9	3.9	3.4	3.7	12.6	13.7	12.9	0.0
FeO	5.7	5.4	7.7	10.9	6.2	5.8	6.3	6.1	0.0	0.0	2.4	0.0
MnO	0.2	0.2	0.2	0.3	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.2
MgO	7.8	7.0	8.6	12.6	9.4	6.8	5.6	5.6	6.6	10.4	5.0	7.6
CaO	13.1	13.6	11.6	5.4	13.8	10.8	11.4	11.5	9.7	14.6	5.0	14.8
Na ₂ O	3.1	2.0	2.5	2.8	1.5	4.4	3.6	3.6	3.7	2.0	3.3	2.8
K ₂ O	1.5	0.0	0.1	0.8	0.2	0.1	0.4	0.4	0.1	0.5	1.7	0.4
P ₂ O ₅	0.1	0.0	0.1	0.1	0.1	0.2	0.3	0.3	0.2	0.2	0.5	0.4
H ₂ O ^T	4.1	3.1	3.5	6.4	3.4	3.2	2.5	2.5	2.5	3.8	3.1	3.9
CO ₂ ^T	5.8	0.3	0.3	0.4	0.1	2.3	2.3	2.3	0.1	3.9	1.9	1.2
Cr (ppm)	464	491	321	627	512	144	174	176	348	478	447	222
Ni	150	159	69	244	167	69	71	71	150	308	438	117
Co	44	49	32	64	41	42	38	38	44	71	63	63
Sc	38	43	47	56	43	36	30	29	32	32	32	50
V	250	259	330	332	338	316	297	295	310	288	141	479
Cu	174	15	52	72	69	86	119	120	69	74	0	119
Pb	0	4	0	0	0	2	2	2	3	3	0	2
Zn	64	60	88	91	54	111	101	101	122	113	89	147
Sn	0.0	0.6	0.6	0.6	0.7	4.2	4.2	4.2	2.7	1.4	1.4	2.4
Mo	0.0	0.0	0.0	0.0	0.0	0.1	1.1	1.0	0.3	0.0	0.0	0.7
Sb	0.2	0.9	0.4	0.0	0.5	0.3	0.6	0.5	0.2	1.2	0.0	0.2
Te	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.1	0.0	0.0	0.0	0.0
K	12211	340	423	6417	1370	864	3620	3618	1172	4517	14269	3536
Rb	25	0	2	18	3	1	7	6	1	12	33	10
Cs	1.9	0.1	0.1	0.6	0.1	0.1	0.6	0.6	0.1	1.1	0.9	0.8
Ba	340	68	47	254	80	42	135	93	59	160	333	122
Sr	43	249	45	81	77	250	260	259	605	533	144	256
Ga	13	14	17	19	24	18	19	18	21	19	15	35
Ta	0.05	0.05	0.15	0.07	0.07	0.82	1.77	1.87	0.86	1.28	1.04	1.83
Nb	0.7	0.7	2.1	0.8	0.9	14.6	30.1	29.1	14.1	20.3	18.8	29.2
Hf	0.7	0.8	1.1	1.0	0.8	2.7	3.7	3.7	1.9	3.1	3.6	5.0
Zr	22	20	39	33	26	104	187	187	121	117	188	207
Y	18	20	34	26	28	22	29	28	27	25	19	44
Th	0.1	0.0	0.1	0.1	0.1	0.7	1.9	1.8	0.9	1.2	1.1	1.6
U	0.1	0.0	0.0	0.0	0.0	0.2	0.8	0.8	0.3	0.3	0.2	0.7
La	0.5	0.8	2.3	1.0	1.8	10.4	19.7	19.7	12.1	16.0	11.5	25.6
Ce	1.8	2.9	7.4	3.3	5.4	28.1	44.6	44.6	30.2	37.3	31.3	54.8
Pr	0.4	0.6	1.3	0.7	1.0	4.1	6.3	6.1	4.2	4.9	4.0	7.2
Nd	2.3	3.4	7.8	4.2	5.4	17.7	27.0	27.0	21.2	22.4	17.7	32.9
Sm	1.1	1.4	2.8	1.8	2.0	4.3	6.5	6.4	5.3	5.3	4.2	8.2
Eu	0.5	0.6	1.0	0.6	1.0	1.6	2.2	2.2	1.9	1.7	1.0	2.8
Gd	1.8	2.5	4.2	3.1	3.0	4.4	6.5	6.5	5.9	5.4	4.0	8.9
Tb	0.4	0.5	0.8	0.6	0.6	0.7	1.0	1.0	0.9	0.8	0.6	1.3
Dy	2.6	3.3	4.9	4.1	3.9	4.1	5.6	5.4	5.3	4.7	3.8	8.0
Ho	0.6	0.7	1.1	0.9	0.9	0.8	1.1	1.1	1.0	0.9	0.8	1.6
Er	1.8	2.2	3.1	2.5	2.6	2.0	2.8	2.7	2.6	2.3	1.9	3.9
Tm	0.3	0.3	0.5	0.4	0.4	0.3	0.4	0.4	0.3	0.3	0.3	0.6
Yb	1.9	2.3	3.1	2.6	2.7	1.7	2.5	2.4	2.1	1.9	1.8	3.4
Lu	0.3	0.3	0.5	0.4	0.4	0.3	0.4	0.4	0.3	0.3	0.3	0.5
Al ₂ O ₃ /TiO ₂	23.1	23.1	11.2	20.1	19.6	7.7	5.2	5.3	7.3	6.3	8.0	5.9
Zr/Y	1.2	1.0	1.2	1.2	0.9	4.8	6.4	6.7	4.4	4.8	10.0	4.7
Zr/Nb	31.2	30.3	19.0	41.3	27.8	7.1	6.2	6.4	8.6	5.8	10.0	7.1
Zr/Hf	32.3	26.3	34.5	32.6	30.9	38.5	50.0	50.0	63.2	37.9	51.4	41.5
Nb/Y	0.0	0.0	0.1	0.0	0.0	0.7	1.0	1.0	0.5	0.8	1.0	0.7
Zr/TiO ₂	29.4	28.6	29.2	34.5	30.1	52.1	73.8	74.1	67.0	57.0	94.7	64.1
Th/Nb	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Nb/Nb*	0.8	0.8	0.9	0.8	0.5	1.2	1.2	1.2	1.0	1.1	1.2	1.0
Ce _N /Yb _N	0.3	0.4	0.7	0.3	0.6	4.7	5.0	5.2	4.0	5.4	4.9	4.5
La _N /Yb _N	0.2	0.3	0.5	0.3	0.5	4.5	5.7	5.9	4.1	6.0	4.6	5.4

unit designations after Bailey et al. in preparation, samples from the Eagle Bay Assemblage, Kootenay Terrane, B.C.

unit 2; calcareous greenstone to chlorite schist derived from epidote rich mafic flows and pillows

unit 3a; calcareous chlorite schist derived from mafic volcanic to volcanoclastic rocks

unit 4; calcareous chlorite schist derived from mafic volcanic to volcanoclastic rocks

* Nb/Nb* = 2(Nb/Nbpm)/(Th/Thpm + La/Lapm) where pm = primitive mantle normalization values of Sun and McDonough (1989).

Table 3.1 (cont). Whole rock major and trace element analyses for mafic volcanic rocks, Johnson Lake Area, B.C., Canada

Sample Name	SB99-98B	SB99-193	SB99-45	SB99-42	SB99-05	SB99-22C	SB99-61	SB00-394	SB00-417	SB00-473	SB00-474	SB00-558
Unit#	4	4	4	4	4	4	4	4	4	4	4	4
rock type												
SiO ₂ (wt%)	49.8	46.2	49.8	45.5	55.8	43.1	51.6	56.5	51.0	57.1	43.9	55.6
TiO ₂	2.7	1.9	1.9	1.7	1.4	1.2	1.3	2.2	2.3	2.5	2.8	2.1
Al ₂ O ₃	16.4	16.0	13.6	14.5	10.9	11.5	12.2	21.0	15.0	16.4	16.2	16.1
Fe ₂ O ₃	18.1	1.5	1.9	1.3	2.2	1.0	1.6	0.0	0.0	0.0	0.0	0.0
FeO	1.4	9.4	10.2	11.7	6.5	6.5	6.1	0.0	0.0	0.0	0.0	0.0
MnO	0.1	0.1	0.2	0.2	0.1	0.2	0.1	0.2	0.2	0.2	0.2	0.1
MgO	3.6	7.2	14.2	13.5	9.3	6.7	6.6	10.7	11.1	9.6	9.9	12.0
CaO	1.9	13.3	7.5	9.7	9.4	26.5	16.3	3.0	17.6	8.7	23.3	11.0
Na ₂ O	0.1	3.1	0.2	1.2	3.5	2.9	3.7	6.1	2.4	4.6	2.6	2.8
K ₂ O	5.6	1.1	0.4	0.6	0.7	0.3	0.3	0.1	0.0	0.4	0.5	0.0
P ₂ O ₅	0.3	0.3	0.2	0.2	0.2	0.2	0.1	0.3	0.4	0.5	0.5	0.3
H ₂ O ^T	3.5	4.5	5.5	5.0	3.5	3.1	3.1	5.4	5.0	4.5	4.8	0.0
CO ₂ ^T	0.0	8.6	9.2	11.6	4.6	16.0	9.3	1.2	8.6	1.8	12.5	5.7
Cr (ppm)	780	256	506	713	476	501	420	321	719	232	765	715
Ni	531	83	327	387	259	222	187	201	451	92	351	433
Co	36	35	52	80	54	44	41	72	79	51	81	74
Sc	36	27	30	29	19	21	22	36	30	38	33	31
V	282	234	241	249	185	158	163	338	284	311	314	251
Cu	98	153	84	127	109	41	53	135	150	153	150	0
Pb	2	0	9	2	3	2	2	1	7	2	6	3
Zn	81	92	226	123	63	54	61	133	168	142	176	127
Sn	1.3	1.2	1.4	0.8	1.8	1.0	1.1	0.0	0.0	2.4	0.0	3.0
Mo	0.2	0.0	0.0	0.4	0.4	0.0	0.0	0.0	0.0	1.5	0.3	0.0
Sb	0.6	0.0	1.3	1.3	0.3	1.0	0.0	0.2	2.0	0.7	1.4	2.4
Te	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
K	46353	9388	3204	5039	5802	2590	2540	515	324	3628	4317	249
Rb	143	23	12	15	22	6	4	1	0	5	14	0
Cs	4.5	0.9	0.3	0.3	5.6	0.2	0.1	0.2	0.3	0.2	0.6	0.1
Ba	1639	317	363	703	215	274	170	150	2234	243	289	96054
Sr	20	210	177	132	206	523	384	75	328	376	607	1626
Ga	24	19	18	18	11	11	14	26	21	24	27	21
Ta	1.6	1.1	1.4	1.0	0.9	0.6	0.9	1.6	1.6	1.7	2.3	1.5
Nb	27.7	21.5	23.4	19.1	16.1	13.7	15.9	28.7	27.6	29.1	40.5	25.1
Hf	3.1	2.1	1.8	1.7	1.5	1.4	1.6	2.9	2.6	2.4	4.0	3.0
Zr	123	89	71	74	58	60	63	104	92	134	145	117
Y	25	17	18	17	13	14	12	22	21	25	27	21
Th	1.7	1.2	1.3	1.0	0.8	0.6	0.9	1.7	2.1	1.8	2.9	1.4
U	0.5	0.4	0.4	0.3	0.2	0.2	0.3	0.5	0.5	0.5	1.0	0.6
La	14.3	15.8	12.9	13.1	10.8	6.4	8.6	15.0	21.0	19.4	26.0	16.3
Ce	31.8	33.9	28.1	28.6	22.6	13.7	19.3	31.2	44.7	42.5	56.4	36.9
Pr	4.7	4.3	3.5	3.6	2.9	1.9	2.4	4.2	5.8	5.3	7.2	4.6
Nd	20.5	18.1	15.2	16.7	12.9	8.6	10.3	17.5	25.0	24.3	31.8	20.7
Sm	5.4	4.0	3.3	3.5	3.1	2.4	2.5	4.6	5.5	5.8	6.9	4.6
Eu	1.8	1.4	1.0	1.3	1.2	0.9	0.9	1.6	1.8	2.1	2.3	1.4
Gd	5.8	3.6	3.4	3.3	3.2	2.7	2.8	5.2	5.9	6.3	7.1	4.7
Tb	0.9	0.6	0.6	0.5	0.5	0.4	0.5	0.8	0.8	0.9	1.1	0.7
Dy	4.9	3.2	3.2	2.9	2.7	2.4	2.5	5.0	4.9	4.9	5.6	3.7
Ho	0.9	0.6	0.6	0.6	0.5	0.5	0.5	0.9	0.9	0.9	1.0	0.7
Er	2.3	1.5	1.5	1.4	1.2	1.2	1.1	2.4	2.2	2.1	2.3	1.8
Tm	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3
Yb	1.7	1.4	1.3	1.3	1.0	1.2	1.0	1.9	1.6	1.6	1.9	1.6
Lu	0.3	0.2	0.2	0.2	0.1	0.2	0.1	0.3	0.2	0.2	0.3	0.3
Al ₂ O ₃ /TiO ₂	6.1	8.3	7.2	8.7	8.0	9.7	9.6	9.4	6.4	6.6	5.8	7.7
Zr/Y	5.0	5.3	4.1	4.4	4.5	4.4	5.1	4.6	4.4	5.2	5.3	5.6
Zr/Nb	4.4	4.2	3.0	3.9	3.6	4.4	4.0	3.6	3.3	4.6	3.6	4.6
Zr/Hf	40.0	41.6	40.7	44.3	38.6	43.6	40.0	36.1	35.0	55.0	35.7	39.5
Nb/Y	1.1	1.3	1.3	1.1	1.3	1.0	1.3	1.3	1.3	1.1	1.5	1.2
Zr/TiO ₂	46.0	46.8	37.9	44.3	42.9	50.5	50.0	46.4	39.3	53.7	51.5	56.0
Th/Nb	0.1	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1
Nb/Nb*	1.3	1.1	1.4	1.3	1.3	1.7	1.4	1.4	1.0	1.2	1.1	1.3
Ce _N /Yb _N	5.1	6.9	6.1	6.1	6.6	3.2	5.4	4.6	7.9	7.5	8.3	6.3
La _N /Yb _N	5.9	8.4	7.2	7.2	8.1	3.8	6.3	5.7	9.6	8.8	9.9	7.2

unit designations after Bailey et al. *in preparation*, samples from the Eagle Bay Assemblage, Kootenay Terrane, B.C.

unit 2; calcareous greenstone to chlorite schist derived from epidote rich massive basalt, pillow breccia.

unit 3a; calcareous chlorite schist derived from fragmental to massive basalt

unit 4; calcareous chlorite schist to greenstone, derived from fragmental to massive basalt

* Nb/Nb* = 2(Nb/Nbpm)/(Th/Thpm + La/Lapm) where pm = primitive mantle normalization values of Sun and McDonough (1989).

Table 3.2. Whole rock major and trace element analyses for felsic volcanic rocks, Johnson Lake Area, B.C., Canada

Sample Name	HS00-03	HS00-05	HS00-06	HS00-07	HS00-08	HS00-11	B99-31	B99-142D	B99-146	B99-163	B99-166
Unit #	6	6	6	6	6	6	9	9	9	9	9
Rock Type	fv	fv	fv	fv	fv	fv	fv	fv	fv	fv	fv
SiO ₂ (wt%)	65.6	76.9	69.4	74.9	61.3	65.9	70.6	68.3	69.7	63.5	67.6
TiO ₂	0.5	0.3	0.3	0.4	0.5	0.3	0.3	0.3	0.3	0.4	0.5
Al ₂ O ₃	11.9	12.7	15.0	14.9	12.9	15.3	13.7	16.6	16.6	17.8	14.5
Fe ₂ O ₃	2.5	2.2	3.5	0.4	4.0	1.0	1.2	2.4	1.3	3.1	3.6
FeO	0.9	0.1	0.9	0.1	1.0	2.9	1.5	1.6	1.4	2.1	2.0
MnO	0.4	0.0	0.1	0.0	0.5	0.1	0.1	0.1	0.0	0.1	0.1
MgO	2.6	0.9	0.6	0.9	2.7	0.8	0.8	1.1	0.8	1.9	1.2
CaO	3.1	0.0	1.7	0.1	3.0	3.9	5.2	2.8	0.3	1.0	4.7
Na ₂ O	0.6	0.2	3.3	0.2	0.2	3.0	3.5	2.3	7.7	6.7	3.4
K ₂ O	3.3	4.4	2.0	4.9	4.1	2.5	3.2	4.3	1.7	3.2	2.1
P ₂ O ₅	0.1	0.1	0.1	0.0	0.1	0.1	0.2	0.2	0.2	0.3	0.1
H ₂ O ^T	0.0	2.1	2.7	2.4	0.0	2.1	1.4	2.2	0.9	1.6	2.5
CO ₂ ^T	5.0	0.2	1.4	0.1	5.1	3.0	4.1	2.4	0.1	0.0	3.9
Cr (ppm)	0.0	10.0	0.0	17.0	12.0	0.0	12.6	18.8	15.1	14.4	51.9
Co	0.0	0.0	0.0	0.0	8.0	0.0	0.0	9.4	0.0	9.3	11.6
Sc	7.1	7.1	6.9	10.0	8.9	7.1	6.4	8.3	4.5	6.9	16.9
V	12	12	15	18	18	17	66	93	58	93	117
Cu	18	0	0	0	96	15	0	13	0	0	15
Pb	25	205	3	50	1909	4	4	4	3	2	2
Zn	105	116	66	72	2730	94	20	43	36	82	38
Sn	3	5	2	3	2	2	1	1	1	1	1
Sb	0.4	0.9	0.3	2.1	1.3	0.7	0.2	0.4	0.0	0.2	0.0
Rb	100	160	61	180	130	68	86	177	36	144	76
Cs	1.6	1.9	1.6	2.0	1.6	1.3	2.7	5.6	3.4	7.7	2.8
Ba	680	1100	1200	3100	1000	710	851	3548	713	989	3280
Sr	140	32	200	29	110	220	252	100	139	223	150
Tl	0.8	1.2	0.3	1.7	1.0	0.6	0.5	0.9	0.2	0.7	0.4
Ga	15.0	16.0	17.0	18.0	17.0	18.0	13.7	18.8	16.1	20.6	15.9
Ta	0.9	0.9	0.6	1.2	1.0	0.6	1.3	1.1	1.2	1.3	0.7
Nb	15.0	15.0	9.6	18.0	15.0	8.9	16.8	17.7	19.1	20.6	10.4
Hf	6.3	6.0	3.8	7.3	6.1	4.4	3.7	3.8	3.7	4.9	3.1
Zr	240	220	160	270	240	170	137	136	120	165	138
Y	30	35	22	35	37	31	23	20	15	30	18
Th	16	14	4	17	15	5	23	26	24	31	10
U	4.8	3.8	1.2	5.1	4.8	1.5	1.3	5.6	3.6	6.4	1.8
La	47.0	57.0	23.0	60.0	53.0	28.0	64.1	75.1	41.2	65.9	32.8
Ce	90.0	110.0	50.0	110.0	99.0	58.0	115.6	146.1	77.3	123.6	61.4
Pr	10.0	12.0	5.9	13.0	11.0	7.1	12.6	15.7	8.7	14.4	6.9
Nd	39.0	44.0	23.0	48.0	42.0	29.0	44.1	56.3	31.1	53.6	24.3
Sm	7.5	8.3	4.8	9.0	8.2	5.6	8.1	9.2	4.9	8.6	4.6
Eu	1.3	1.6	1.0	1.3	1.6	1.1	1.7	2.1	1.2	2.4	1.2
Gd	6.4	6.9	4.2	7.3	7.5	5.1	5.8	6.4	3.4	6.7	3.7
Tb	0.9	1.1	0.6	1.1	1.2	0.9	0.8	0.8	0.5	1.0	0.6
Dy	5.2	5.7	3.7	6.3	6.4	5.0	4.0	3.5	2.4	4.7	3.0
Ho	1.0	1.1	0.7	1.2	1.2	1.0	0.7	0.6	0.5	0.8	0.6
Er	2.7	2.8	2.1	3.0	3.1	2.8	1.7	1.7	1.2	2.2	1.6
Tm	0.4	0.4	0.4	0.5	0.5	0.5	0.3	0.3	0.2	0.3	0.2
Yb	3.1	2.8	2.6	3.2	3.3	3.2	1.7	1.7	1.4	2.1	1.6
Lu	0.5	0.4	0.4	0.5	0.5	0.5	0.3	0.3	0.2	0.4	0.3
Zr/Y	8.0	6.3	7.3	7.7	6.5	5.5	5.9	6.8	8.0	5.5	7.6
Zr/Hf	38.1	36.7	42.1	37.0	39.3	38.6	37.1	36.1	32.4	33.3	44.8
Hf/Nb	0.4	0.4	0.4	0.4	0.4	0.5	0.2	0.2	0.2	0.2	0.3
Zr/TiO ₂	452.8	628.6	592.6	613.6	444.4	653.8	519.5	406.2	414.1	380.7	260.0
Zr/Nb	16.0	14.7	16.7	15.0	16.0	19.1	8.1	7.6	6.3	8.0	13.3
Nb/Y	0.5	0.4	0.4	0.5	0.4	0.3	0.7	0.9	1.3	0.7	0.6
Nb/Ta	16.1	16.9	16.3	15.0	15.3	15.9	13.3	15.5	15.8	15.4	14.2
Sc/Yb	2.3	2.5	2.7	3.1	2.7	2.2	3.8	5.0	3.2	3.3	10.7
TiO ₂ /Yb	0.2	0.1	0.1	0.1	0.2	0.1	0.2	0.2	0.2	0.2	0.3
Zr/Yb	77.4	78.6	61.5	84.4	72.7	53.1	81.3	81.3	85.7	80.0	86.7

unit designations after Bailey et al. *in preparation*, samples from the Eagle Bay Assemblage, Kootenay Terrane, B.C.
unit 6; quartz sericite schist derived from felsic volcanic rocks, Dev int; quartz sericite schist derived from granodiorite
unit 9; quartz feldspar porphyritic rhyolite to trachyandesite, fv=felsic volcanic rocks, gd= granodiorite,

Table 3.2 (cont). Whole rock major and trace element analyses for felsic volcanic rocks, Johnson ake Area, B.C., Canada

Sample Name	B99-192	B99-33	B99-192B	B99-146C	B99-86	B99-94	B00-656	B00-660	B00-630	B00-635
Unit #	9	9	9	9	9	9	Dev int	Dev int	Dev int	Dev int
Rock Type	fv	fv	fv	fv	fv	fv	gd	gd	gd	gd
SiO ₂ (wt%)	66.2	67.6	67.1	62.7	68.3	66.5	75.9	74.4	63.0	73.8
TiO ₂	0.4	0.3	0.3	0.6	0.4	0.3	0.2	0.2	0.4	0.4
Al ₂ O ₃	16.5	16.6	13.9	17.1	18.5	17.0	15.6	15.1	18.5	15.9
Fe ₂ O ₃	1.4	2.1	1.3	5.0	1.8	3.2	0.0	0.0	0.0	0.0
FeO	3.8	0.7	2.3	2.4	2.1	1.3	0.0	0.0	0.0	0.0
MnO	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.4	0.0
MgO	1.3	0.7	1.0	1.9	1.2	1.6	0.7	1.5	4.2	1.0
CaO	4.1	2.7	8.3	2.1	0.5	1.1	0.1	2.7	6.0	1.2
Na ₂ O	3.4	3.3	2.8	3.7	0.1	4.2	4.0	3.3	2.0	4.2
K ₂ O	2.8	5.6	2.8	4.1	6.7	4.6	3.4	2.7	5.5	3.4
P ₂ O ₅	0.2	0.3	0.2	0.3	0.3	0.3	0.1	0.1	0.1	0.1
H ₂ O ^T	2.4	1.7	1.8	2.6	3.0	2.0	1.8	1.8	2.5	1.9
CO ₂ ^T	2.9	1.8	5.9	1.7	0.6	0.6	0.2	2.4	7.7	0.9
Cr (ppm)	14.7	16.6	17.2	17.6	18.7	13.3	0.0	0.0	0.0	0.0
Co	0.0	0.0	5.4	11.4	27.0	0.0	0.0	0.0	0.0	5.3
Sc	6.5	5.5	6.6	16.6	6.7	6.8	5.6	2.5	7.9	8.4
V	71	67	67	180	104	90	10	22	43	24
Cu	0	0	0	0	18	0	18	17	12	21
Pb	3	18	4	3	201	2	3	12	94	2
Zn	63	50	42	84	193	62	28	129	220	26
Sn	1	3	1	1	2	1	2	2	14	2
Sb	0.2	0.3	0.0	0.5	1.7	0.6	0.3	0.0	0.3	0.0
Rb	75	166	78	166	176	153	84	58	159	106
Cs	2.5	3.3	2.9	6.4	5.5	12.3	1.8	1.3	3.6	2.2
Ba	1675	1556	967	1761	1246	1634	1248	588	1133	1481
Sr	215	143	337	188	20	75	57	139	170	127
Tl	0.4	0.6	0.4	0.8	1.9	0.8	0.4	0.4	0.7	0.4
Ga	17.8	18.7	16.1	18.7	20.8	22.5	18.7	17.1	23.8	20.1
Ta	1.4	1.3	0.9	0.5	1.3	1.6	1.8	0.9	1.8	1.7
Nb	20.9	22.8	15.0	11.4	19.7	25.5	21.8	7.6	26.0	23.3
Hf	4.0	5.2	3.3	3.5	4.5	5.3	9.9	4.1	10.3	9.6
Zr	147	187	118	155	166	163	302	171	317	360
Y	20	27	19	23	35	32	30	12	33	31
Th	28	30	26	12	31	32	30	26	32	29
U	1.4	5.5	2.0	3.0	10.3	5.1	6.4	2.8	6.9	7.5
La	84.8	81.9	82.7	52.8	92.4	113.4	78.0	52.4	35.1	76.1
Ce	157.1	155.6	150.4	101.5	176.5	214.5	145.6	74.8	79.3	148.1
Pr	17.8	17.6	17.2	11.4	18.7	22.5	14.6	6.1	10.0	15.9
Nd	60.7	61.2	58.0	43.5	69.6	82.7	47.8	19.2	40.8	56.0
Sm	9.6	9.9	9.5	7.5	12.5	13.3	7.6	2.7	8.3	9.4
Eu	2.3	2.3	2.4	1.9	3.3	3.1	1.1	0.5	1.4	1.4
Gd	6.3	7.1	6.6	5.4	12.5	9.1	6.0	2.1	6.7	7.2
Tb	0.8	0.9	0.8	0.8	1.6	1.1	0.9	0.3	0.9	1.0
Dy	3.7	4.6	3.5	3.8	6.5	5.4	4.7	1.8	4.9	5.1
Ho	0.6	0.8	0.6	0.7	1.0	0.9	1.0	0.4	1.0	1.0
Er	1.5	2.1	1.5	2.0	2.4	2.3	2.7	1.0	2.8	2.7
Tm	0.2	0.3	0.2	0.3	0.4	0.4	0.4	0.2	0.5	0.4
Yb	1.5	2.0	1.4	1.9	2.3	2.3	3.2	1.2	3.4	3.4
Lu	0.3	0.3	0.2	0.3	0.4	0.4	0.5	0.2	0.6	0.5
Zr/Y	7.4	6.9	6.1	6.8	4.7	5.2	10.0	14.5	9.7	11.7
Zr/Hf	36.8	36.0	35.5	44.1	37.2	30.8	30.5	42.1	30.8	37.4
Hf/Nb	0.2	0.2	0.2	0.3	0.2	0.2	0.5	0.5	0.4	0.4
Zr/TiO ₂	411.8	562.2	423.6	242.1	432.6	470.9	1261.7	1069.1	847.9	998.8
Zr/Nb	7.0	8.2	7.9	13.6	8.4	6.4	13.8	22.5	12.2	15.5
Nb/Y	1.1	0.8	0.8	0.5	0.6	0.8	0.7	0.6	0.8	0.8
Nb/Ta	15.4	16.9	15.9	22.4	14.6	15.6	12.4	8.9	14.4	13.8
Sc/Yb	4.4	2.8	4.7	8.9	3.0	2.9	1.7	2.1	2.3	2.5
TiO ₂ /Yb	0.2	0.2	0.2	0.3	0.2	0.1	0.1	0.1	0.1	0.1
Zr/Yb	100.00	94.74	84.62	83.33	72.73	69.57	93.55	145.45	93.33	106.25

unit designations after Bailey et al. *in preparation*, samples from the Eagle Bay Assemblage, Kootenay Terrane, B.C. unit 6; quartz sericite schist derived from felsic volcanic rocks, Dev int; quartz sericite schist derived from granodiorite unit 9; quartz feldspar porphyritic rhyolite to trachyandesite, fv=felsic volcanic rocks, gd= granodiorite,

Table 3.3: Whole rock major and trace element analysis of mafic-intermediate volcanics, unit 6, Johnson Lake area, B.C. Canada

SAMPLE_NO	DF80-122	PS78-194	PS78-199	VP80-042	SP00-019e	SP00-024	SP00-029	HSP-00-015	SLB00-627	SLB00-628
Unit [#]	6	6	6	6	6	6	6	6	6	6
SiO ₂ (wt%)	50.8	59.1	47.0	57.3	53.4	53.3	55.8	53.2	54.6	50.1
TiO ₂	1.5	0.6	0.8	0.6	0.6	0.6	0.5	0.5	0.6	0.7
Al ₂ O ₃	12.6	17.0	15.3	15.0	17.5	16.8	14.8	15.8	17.7	16.2
Fe ₂ O ₃	0.9	4.6	1.6	0.8	8.5	9.0	5.4	6.6	6.1	8.9
FEO	8.7	2.5	5.5	5.4	0.0	0.0	0.0	0.0	2.7	6.7
MNO	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1
MGO	9.9	1.9	2.9	3.1	12.1	3.6	3.2	1.5	2.1	2.6
CAO	5.0	3.9	11.0	3.5	0.1	5.1	6.7	5.8	4.2	8.6
NA ₂ O	2.0	4.4	2.7	3.3	0.1	3.9	2.0	6.0	3.8	2.8
K ₂ O	0.0	1.7	1.2	2.9	2.1	1.4	1.8	1.6	2.6	0.8
P ₂ O ₅	0.24	0.13	0.21	0.17	0.10	0.20	0.14	0.20	0.27	0.28
H ₂ OT	5.3	2.6	3.3	2.2	6.8	3.6	2.4	1.3	2.4	3.6
CO ₂ T	3.7	3.1	9.7	6.1	0.6	3.9	8.8	7.7	6.4	6.5
CR (ppm)	480	27	30	92	64	19	48	5	8	8
Ni	308	9	11	9	5	5	21	5	8	8
Co	52	16	25	13	9	22	9	13	7	23
Sc	19.0	26.0	24.0	19.0	29.0	23.0	17.0	17.0	23.0	22.0
V	165	189	192	107	175	162	120	102	150	144
Cu	62	9	118	55	21	5	10	29	8	18
Pb	14	10	5	12	4	5	13	8	13	7
Zn	131	139	65	112	233	154	85	80	217	86
Sn	4.0	4.0	4.0	10.0	1.8	0.8	2.1	1.5	1.0	1.0
Mo	0.2	0.1	0.1	1.3	1.7	0.0	0.0	0.0	0.1	0.1
St	0.0	0.0	0.0	0.5	0.4	0.0	0.0	0.7	0.0	0.1
Sb	0.2	0.8	1.8	0.5	0.3	1.6	0.7	0.4	0.6	0.9
Te	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1
Rb	0.3	60.0	36.0	68.0	48.0	40.0	67.0	50.0	82.0	18.0
Cs	0.1	1.6	1.6	2.1	0.8	1.1	1.4	0.7	1.9	0.6
Ba	26	920	550	1300	540	710	1100	3500	710	480
Sr	380	260	480	200	5	220	660	370	230	350
Ga	16.0	15.0	15.0	17.0	17.0	18.0	15.0	18.0	21.0	18.0
Ta	1.3	0.3	0.3	0.9	0.5	0.4	0.7	0.4	0.5	0.4
Nb	23.0	4.8	4.6	18.0	7.8	6.6	11.0	6.9	9.1	8.3
Hf	2.6	1.9	2.1	4.8	2.5	1.9	2.5	2.4	3.4	3.0
Zr	100	67	81	190	89	100	130	120	150	130
Y	17	16	18	38	24	22	16	22	29	29
Th	2.5	3.3	3.5	14.0	5.4	2.1	8.3	2.5	2.0	1.5
U	0.6	1.2	1.0	3.4	2.1	0.7	1.4	0.9	0.8	0.7
La	17.0	11.0	19.0	42.0	22.0	16.0	28.0	18.0	19.0	19.0
Ce	37.0	23.0	42.0	97.0	40.0	35.0	53.0	40.0	48.0	47.0
Pr	4.4	2.9	5.5	13.0	4.8	4.5	5.9	5.2	6.2	6.3
Nd	18.0	11.0	22.0	51.0	19.0	19.0	22.0	21.0	27.0	27.0
Sm	4.3	2.6	4.8	10.0	3.5	4.1	3.9	4.3	5.6	5.8
Eu	1.4	0.7	1.4	1.5	0.8	1.1	1.0	1.0	1.3	1.5
Gd	4.4	2.7	4.3	8.6	3.6	4.0	3.2	4.1	5.5	5.6
Tb	0.7	0.4	0.6	1.2	0.6	0.6	0.5	0.6	0.8	0.9
Dy	3.6	2.7	3.4	6.9	3.5	3.6	2.6	3.8	4.6	4.9
Ho	0.7	0.6	0.7	1.3	0.7	0.7	0.5	0.7	0.9	0.9
Er	1.6	1.6	1.7	3.6	2.0	1.9	1.3	2.2	2.6	2.6
Tm	0.2	0.3	0.3	0.5	0.3	0.3	0.2	0.4	0.4	0.4
Yb	1.2	1.7	1.7	3.4	1.9	2.0	1.3	2.1	2.8	2.7
Lu	0.2	0.3	0.3	0.5	0.3	0.3	0.2	0.4	0.4	0.4
Zr/Y	5.9	4.2	4.5	5.0	3.7	4.5	8.1	5.5	5.2	4.5
Zr/Hf	38.5	35.3	38.6	39.6	35.6	52.6	52.0	50.0	44.1	43.3
Hf/Nb	0.1	0.4	0.5	0.3	0.3	0.3	0.2	0.3	0.4	0.4
Zr/TiO ₂	66.7	113.6	102.5	322.0	153.4	156.3	260.0	222.2	241.9	188.4
Zr/Nb	4.3	14.0	17.6	10.6	11.4	15.2	11.8	17.4	16.5	15.7
Nb/Y	1.4	0.3	0.3	0.5	0.3	0.3	0.7	0.3	0.3	0.3
Nb/Ta	17.7	16.0	16.4	20.7	14.4	17.4	16.7	18.2	18.6	18.9
Sc/Yb	15.8	15.3	14.1	5.6	15.3	11.5	13.1	8.1	8.2	8.1
TiO ₂ /Yb	1.3	0.3	0.5	0.2	0.3	0.3	0.4	0.3	0.2	0.3
Zr/Yb	83.3	39.4	47.6	55.9	46.8	50.0	100.0	57.1	53.6	48.1

[#] unit designations after Bailey et al. *in preparation*, samples from the Eagle Bay Assemblage, Kootenay Terrane, B.C.

rock types are calcareous quartz sericite chlorite schist derived from intermediate-mafic volcanic rocks

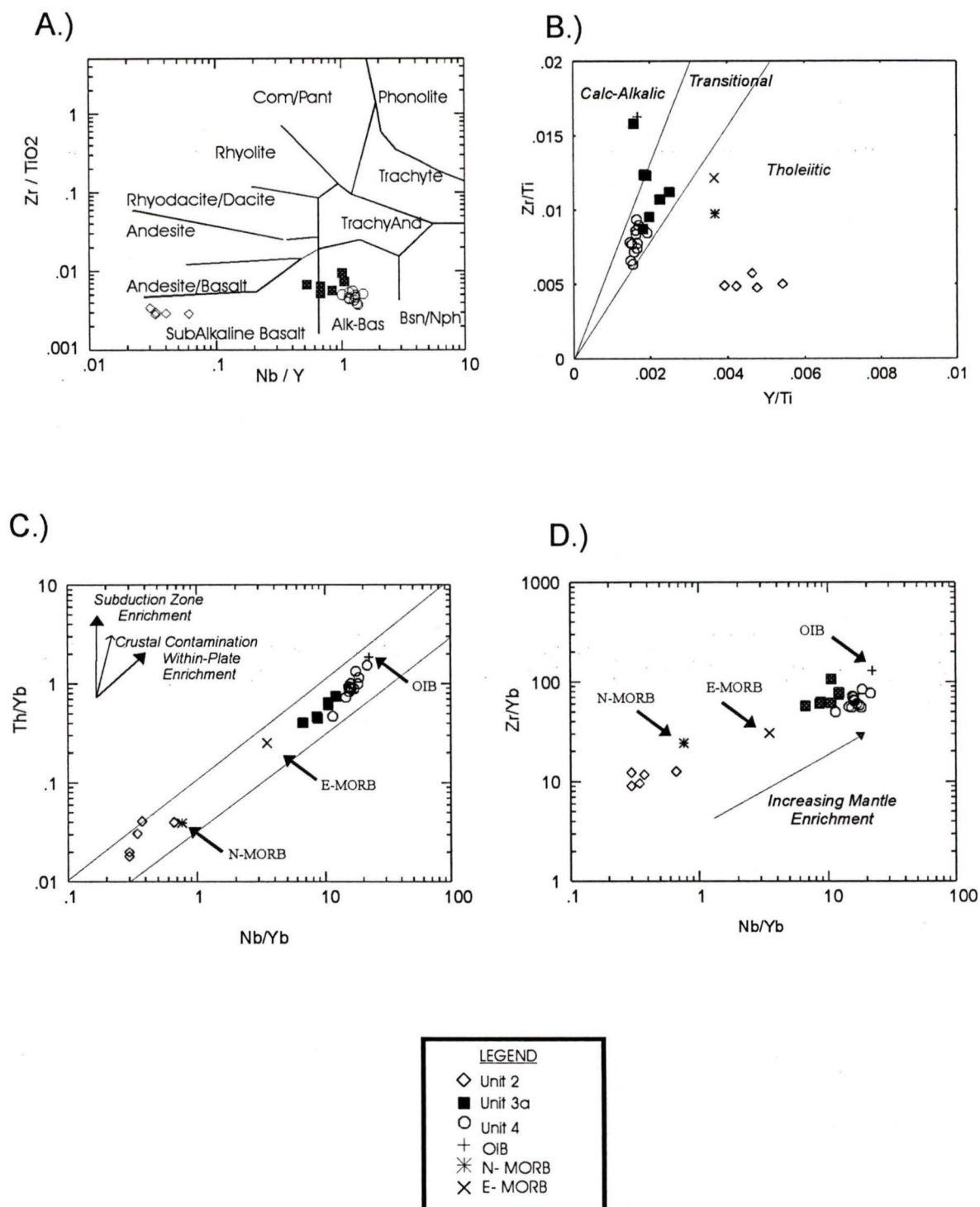


Figure 3.4: Immobile HFSE discrimination plots for mafic volcanic rocks from the Johnson Lake Area. A.) Nb/Y - Zr/TiO_2 plot of Winchester and Floyd, (1977). B.) Y/Ti - Zr/Ti plot after Barrett and Maclean (1999). C.) Nb/Yb - Th/Yb after Pearce and Peate (1995). D.) Nb/Yb - Zr/Yb after Pearce (1983) N-MORB, E-MORB and OIB values from Sun and McDonough (1989).

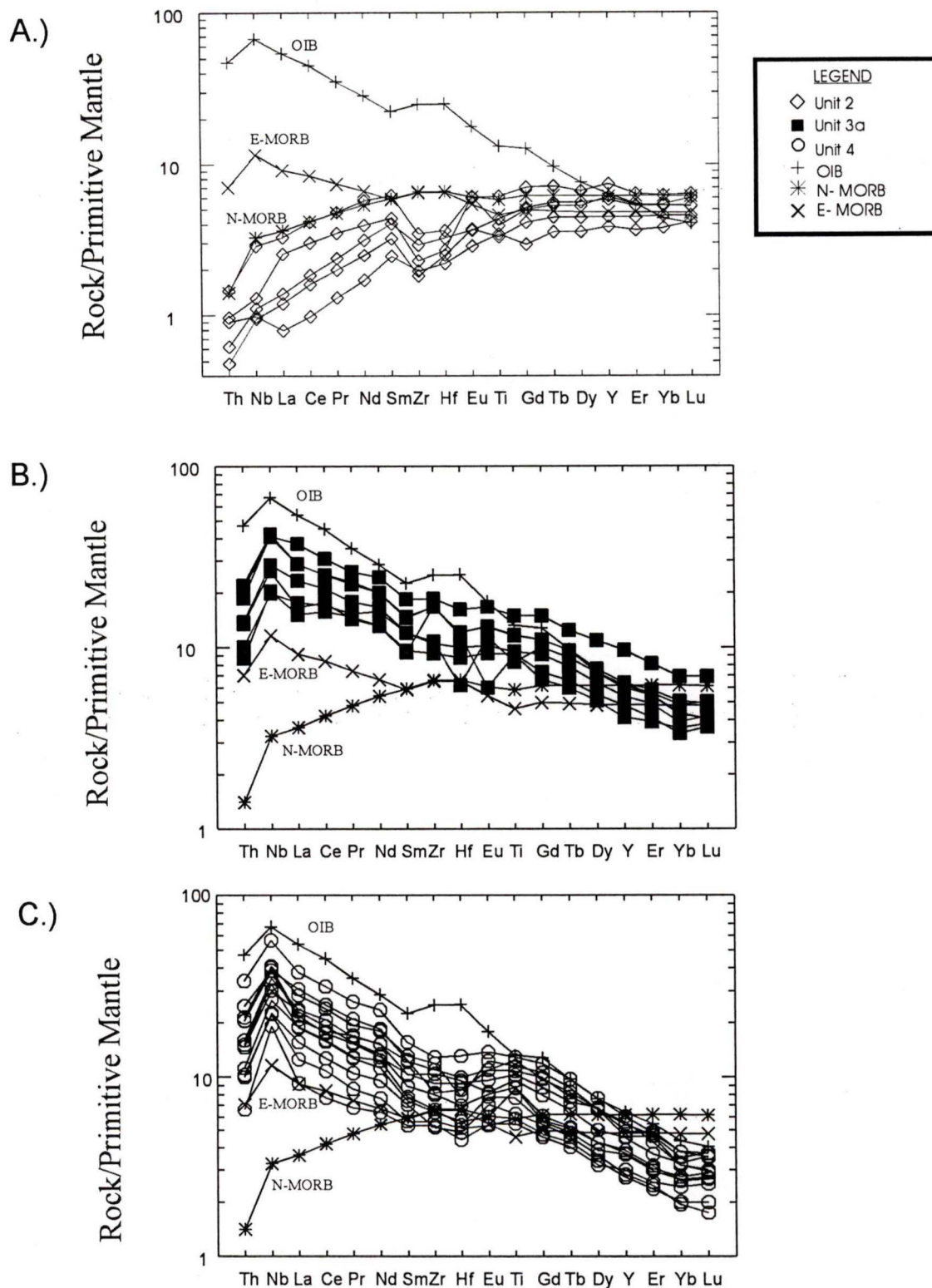


Figure 3.5: Primitive mantle normalized multi-element plots for mafic volcanic rocks from the Johnson Lake area, elements are arranged in order of decreasing incompatibility in a mantle source region. A.) Unit 2 mafic volcanic rocks have an N-MORB type pattern. B.) Mafic volcanic rocks from unit 3a have an OIB type geochemical pattern. C.) Mafic volcanic rocks from unit 4 have an OIB basalt pattern. Normalization values after Sun and McDonough (1989).

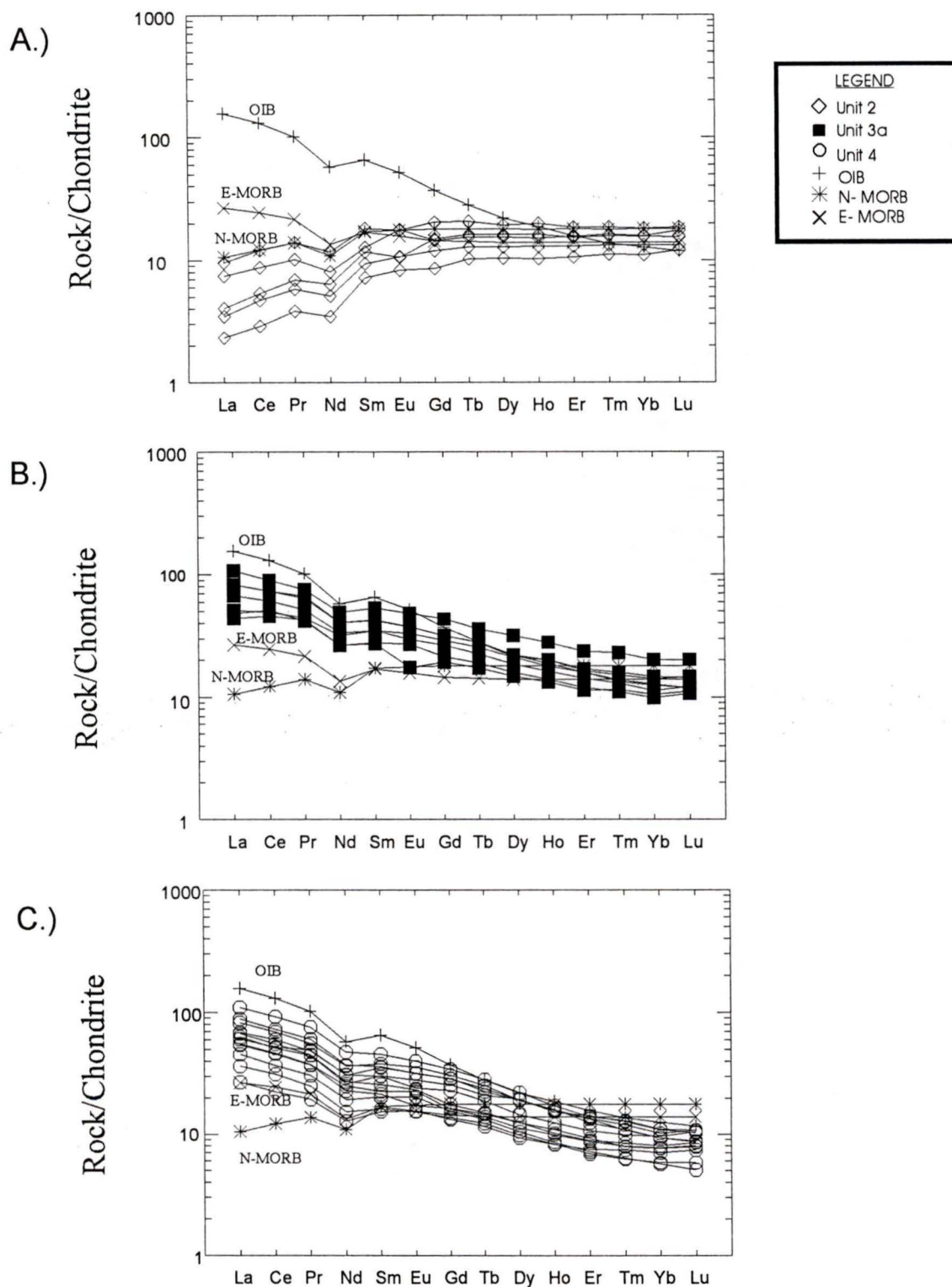


Figure 3.6: Chondrite normalized rare earth element (REE) diagrams. Elements are arranged from left to right in order of LREE's to HREE's. A.) Unit 2 mafic rocks have an N-MORB type pattern. B.) Unit 3a mafic volcanic rocks have an OIB type geochemical pattern. C.) Unit 4 mafic volcanic rocks have OIB basalt type patterns. Average OIB, N-MORB, E-MORB, and chondrite normalization values after Sun and McDonough (1989).

tectonic discrimination diagram of Wood (1980) (Fig. 3.7a), unit 2 basalts plot in the MORB field and unit 3a and 4 basalts plot in the “within plate” field. Unit 2 basalts plot along the boundary between arc and ocean floor basalts in the Ti/V discrimination diagram (Fig. 3.7b) of Shervais (1982) whereas unit 3a and unit 4 straddle the MORB, BABB and alkaline basalt fields. Unit 2 samples plot near the N-MORB field in the Nb-Zr-Y discrimination diagram (Fig. 3.7c) of Meschede (1986), whereas units 3a and 4 plot in the within plate alkalic to tholeiite fields.

Felsic to Intermediate volcanic rocks

The systematics of felsic volcanic whole rock geochemistry differs from that of mafic volcanic geochemistry. There has been less emphasis on characterizing felsic volcanic rocks based on trace element characteristics than for mafic rocks. Constraints on the tectonic setting of felsic volcanic rocks are often based on combined geochemistry, lithological associations and metallogeny. This section examines the geochemical characteristics of the felsic volcanic rocks in the Johnson Lake area and compares them to felsic rocks in the Finlayson Lake district of the Yukon-Tanana Terrane, Yukon (Piercey et al., 2001), Bathurst mining district of New Brunswick (Lentz 1998; van Staal et al. 1991), and Mount Windsor Subprovince, Australia (Stoltz, 1995). Felsic volcanic rocks in the Finlayson Lake district hosts the Kudz Ze Kayah, Wolverine, and GP4F volcanogenic massive sulphide (VMS) deposits. In the Bathurst district, felsic volcanic rocks of the Tetagouche Group host the Ordovician Brunswick VMS deposits. In the

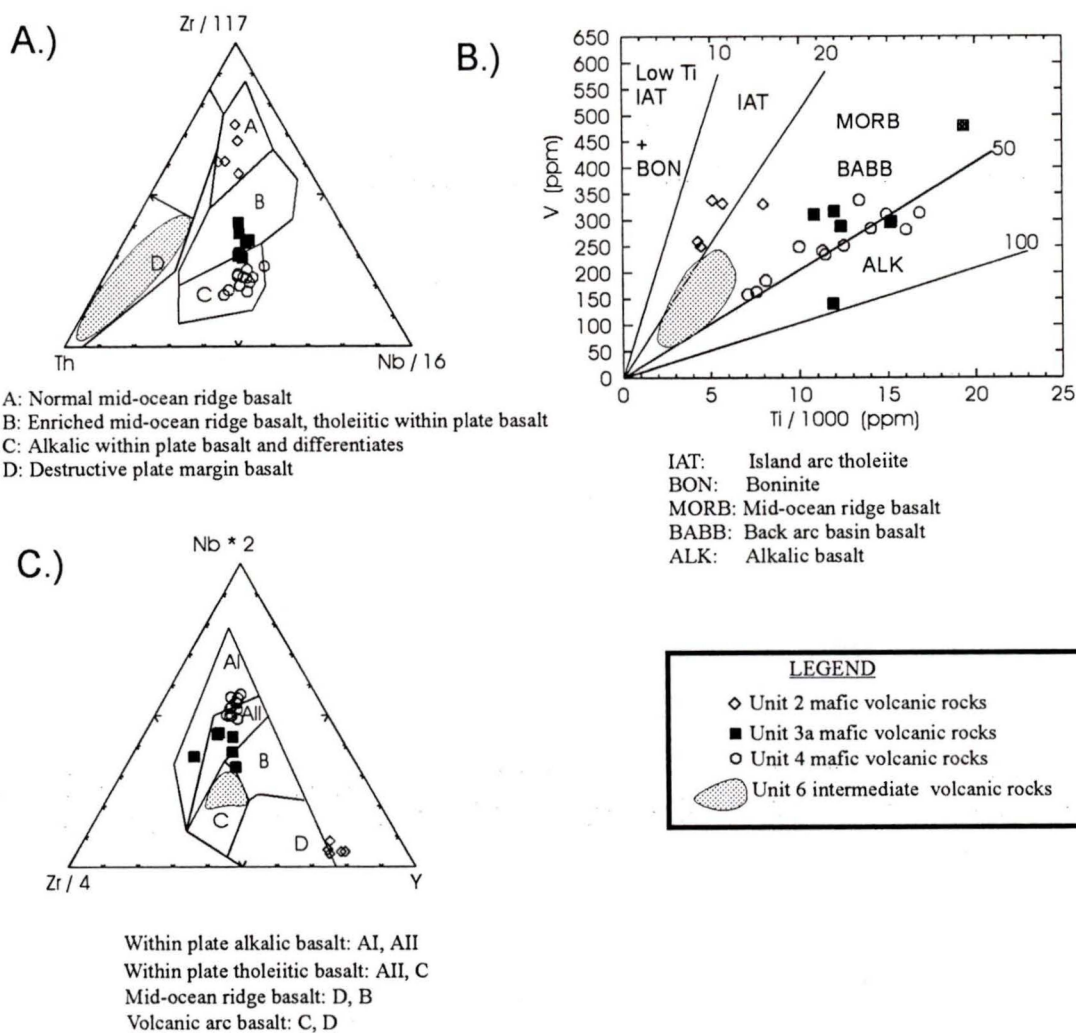


Figure 3.7: Tectonic discrimination diagrams for mafic and intermediate volcanic rocks from the Johnson Lake area. A.) Zr-Th-Nb ternary diagram of Wood (1980). B.) V/Ti diagram of Shervais (1982). C.) Nb-Zr-Y diagram of Meschede (1986).

Mount Windsor district of Australia, VMS deposits occur at the contact between rhyodacite of the Mount Windsor Formation and dacite of the Trooper Creek Formation (Stoltz, 1995). The Mount Windsor Subprovince hosts VMS deposits including the 6.6 Mt Thalanga deposit (Paulick et al., 2001). A summary of characteristics of these areas, plus those of the Okinawa Trough incipient back-arc basin is presented in Table 3.4. Sulphide deposits in the Jade hydrothermal field of the Okinawa trough have been suggested to be modern analogues for the “Kuroko” class of deposits (Halbach et al. 1989).

Table 3.4: Summary of characteristics of VMS districts.

Characteristic	Eagle Bay Assemblage (B.C.)[#]	Finlayson Lake District (YT)[*]	Bathurst (NB)^{##}	Mt. Windsor Subprovince (AUS)^{**}	Okinawa trough (Japan)^{###}
Age	Devonian-Mississippian	Devonian-Mississippian	Ordovician	Cambrian-Ordovician	Quaternary
Volcanic lithologies	Calc-alkaline rhyodacite, andesite-dacite, post mineralization alkalic rhyodacite-andesite, alkalic basalt?	Calc-alkaline rhyolite-rhyodacite, boninite, alkalic basalt	Calc-alkaline felsic volcanic rocks. Alkalic basalt	Calc-alkaline felsic to intermediate volcanic rocks	Bimodal volcanic rocks, rhyolite-rhyodacite, alkalic basalt.
Sedimentary lithologies	Quartzite, limestone argillites, quartz wacke, pebble conglomerate, chert,	Argillite, chert pebble conglomerate.	Quartzite, argillite, greywacke	Quartzite, argillite, greywacke	Silty clay, thick Pleistocene argillite quartz wacke
Deposit types associated	Felsic and mafic volcanic and sedimentary-hosted massive sulphide, quartz-carbonate vein hosted Ag.	Felsic and mafic volcanic and sedimentary hosted massive sulphide	Felsic volcanic and sedimentary hosted massive sulphide	sedimentary hosted massive sulphide	Volcanic associated massive sulphide
Tectonic setting	Rifted volcanic arc, continental back arc basin	Rifted volcanic arc, continental back arc basin	continental back arc basin	continental back arc basin.	Incipient continental back arc basin.

[#] data after Schiarizza and Preto, (1987), Hoy and Gouthier (1986) Bailey et al. (2000, 2001)

^{*} data from Hunt, (1998); Piercey et al.,(2000, 2001); Murphy and Piercey, (1999)

^{##} data after Lentz, (1996, 1998); Goodfellow, (2002); van Staal et al., (1991)

^{**} data after Berry et al. (1992); Stoltz, (1995)

^{###} data after Halbach et al. (1989), Shinjo et al. (1999, 2000)

Geochemical data for intermediate to felsic rocks of the Johnson Lake area are presented in Tables 3.2-3.3 and Figures 3.8-3.12. Unit 6 consists predominantly of felsic volcanic rocks and minor volumes of intermediate-mafic volcanic rocks. Unit 6 felsic rocks plot in the rhyodacite/dacite field in the Nb/Y-Zr/TiO₂ and Zr/TiO₂-SiO₂ diagram of Winchester and Floyd (1977) and the intermediate rocks plot mainly as andesite (Figs. 3.8a-b).

Trace element ratios show the relationships between the various units and provide constraints on magmatic affinity. Intermediate to felsic rocks of the Johnson Lake area form distinct clusters on the Zr/Yb- Ti/Yb (Fig. 3.8d), Zr/Yb- Sc/Yb (Fig. 3.8e) and Th/Yb- Nb/Yb (Fig. 3.8f) diagrams (after Piercey et al., 2001). Rhyodacite and andesite of unit 6 have similar Zr/Nb (12-22) and Hf/Nb (0.4-0.5) ratios (Figs. 3.9a-b) suggesting that these rocks are derived from a common magmatic source (MacLean and Barrett, 1993).

In the primitive mantle normalized plot (Fig. 3.9c) all of the felsic rocks display prominent negative Nb and Ti anomalies. Unit 6 rhyodacite has enrichment in Zr and Hf, depletion in V, and higher abundances of REE's, especially HREE's compared to unit 9 (Fig. 3.9d). Unit 6 also has a negative Eu anomaly relative to Sm and Gd (Fig. 3.9d). Unit 6 andesites have lower concentrations of incompatible elements (Th-Lu,) except Al, Sc, and V, which are enriched relative to the rhyodacites of unit 6 (Fig. 3.10a). The andesites have a negative Nb and Ti anomaly (Fig. 3.10a) considered to be the "arc geochemical signature" for mafic to intermediate volcanic rocks (Jenner, 1996). The shape of the REE (Fig. 3.10b) patterns of rhyodacites and andesites are similar. However, the andesites have slightly lower concentrations of REE's and lack the prevalent negative Eu anomaly

present in the rhyodacite. Andesite of unit 6 plot in volcanic arc fields in mafic tectonic discrimination diagrams (Figs. 3.7a-c).

Devonian felsic to intermediate intrusive rocks have SiO_2 ranging from 62 to 75 wt% and plot within the rhyodacite/dacite field in the Nb/Y-Zr/TiO₂ (Fig. 3.8a) and Zr/TiO₂ - SiO₂ (Fig. 3.8b) diagrams of Winchester and Floyd (1977). The Sc/Yb ratios are < 3.2 (Fig. 3.8e), and Zr/Yb ratio's range from 93 to 145 (Fig. 3.8d-e). Zr/Hf ratios range from 30 to 42 (Table 3.2), and the Nb/Y ratios range from 0.65 to 0.72 (Fig. 3.8a). The Zr/Nb ratios range from 12 to 22 (Fig. 3.9a), and Hf/Nb ratios are 0.4-0.5 (Fig. 3.9b) similar to unit 6 volcanic rocks.

Normalized multielement patterns (Fig. 3.9c-d) of Devonian intrusive rocks show similar trends to unit 6, including enrichments of Zr and Hf, depletion of V, and higher abundances of MREE's and HREE's than unit 9 (Fig. 3.9d).

In the Nb/Y-Zr/TiO₂ diagram (Fig. 3.8a) of Winchester and Floyd (1977), unit 9 samples plot in the trachyandesite field. In the SiO₂ - Zr/TiO₂ diagram (Fig. 3.8b) of Winchester and Floyd (1977), these rocks plot in the rhyodacite field with SiO₂ ranging from 62 to 70 wt%. Characteristic trace element ratios include Ti/Yb > 0.15 (Fig. 3.8d), Nb/Yb ranging from 6.4 to 16 (Fig. 3.8f), Th/Yb > 6.6 (Fig. 3.8f), Sc/Yb ratios > 2.5 (Fig. 3.8e) and Zr/Yb ratios (Fig. 3.8e) ranging from 75-100. Unit 9 has Zr/Hf ratios ranging from 32 to 44 (Table 3.2), Nb/Y ratios > 0.7, Zr/Nb ratios of 7 (Fig. 3.9a) and Hf/Nb ratios of 0.2 (Fig. 3.9b). In the normalized multielement plot (Fig. 3.9c), unit 9 displays a negative Nb and Ti anomaly relative to Th-La and Eu-Gd respectively. Unit 9 has lower

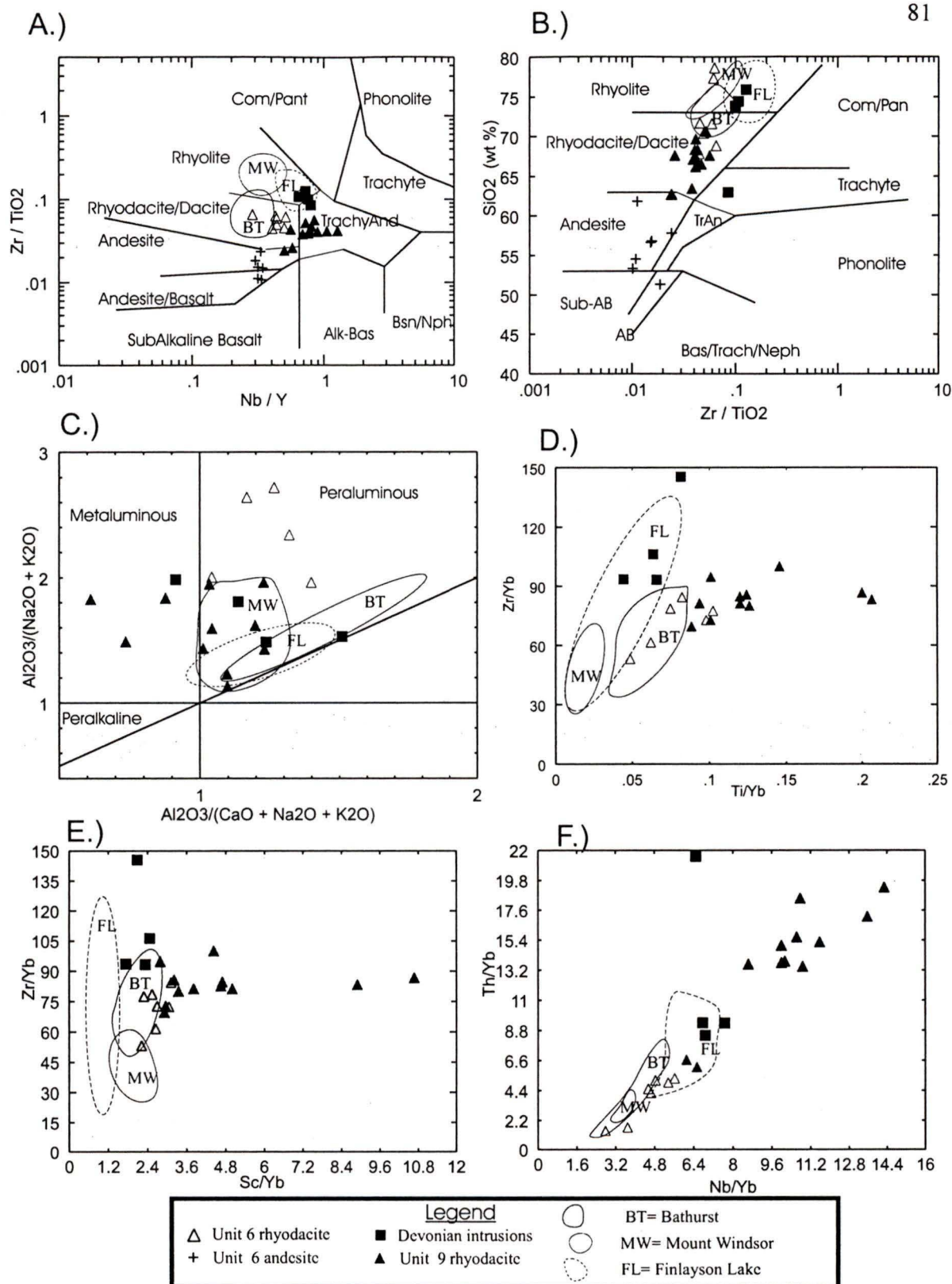


Figure 3.8: Major and trace element lithogeochemistry of felsic rocks from the Johnson Lake area, A.) Zr/TiO_2 , Nb/Y plot of Winchester and Floyd (1977) B.) SiO_2 , Zr/TiO_2 plot of Winchester and Floyd (1977). C.) Shand's Index after Maniar and Piccoli (1989), showing the predominantly peraluminous affinity of units 6 and 9. D-F trace element ratios D.) $(Zr/Yb) / (Ti/Yb)$ E.) $(Zr/Yb) / (Sc/Yb)$ F.) $(Th/Yb) / (Nb/Yb)$. FL= Finlayson Lake district, Yukon- Kudz Ze Kayah unit after Piercey et al., 2000; 2001. BT = Bathurst district, New Brunswick, Flat Landing Brook and Nepisiguit Falls formations, after Lentz et al. (1998). MW= Mount Windsor Subprovince, Australia, Puddler Creek Formation, after Stoltz (1995).

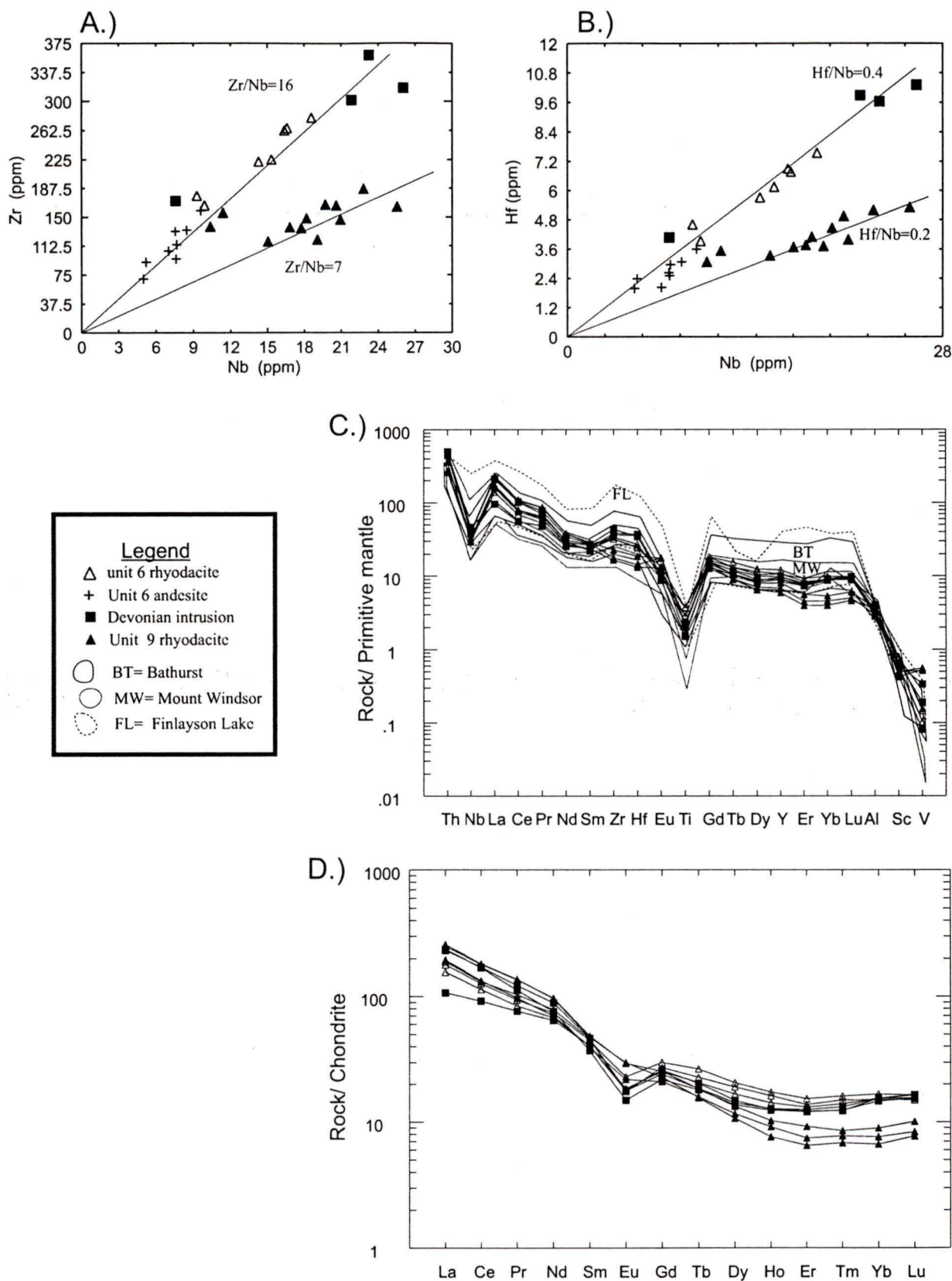


Figure 3.9: Trace element plots for felsic rocks in the Johnson Lake area. A.) Zr/Nb ratios and B.) Hf/Nb ratios showing separate differentiation trends for units 6 and 9. C.) Primitive mantle normalized multi-element plot, note the differences in Zr, Hf and V between units 6 and 9. D.) Chondrite normalized REE plot, note the negative Eu anomaly and the relative abundances of HREE's. Normalization values after Sun and McDonough (1989).

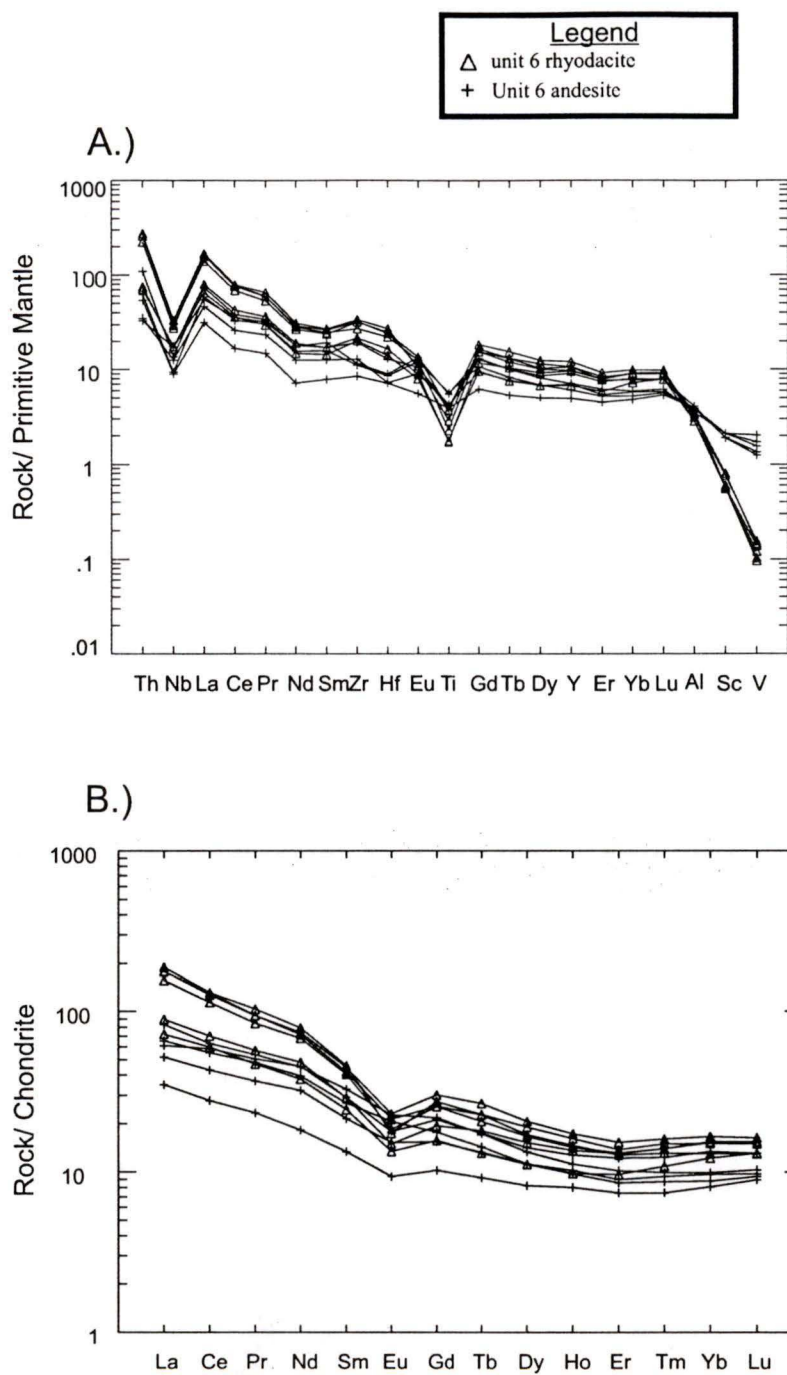


Figure 3.10: A.) Primitive mantle normalized multi-element diagram for rocks of unit 6, note the negative Nb and Ti anomalies B.) Chondrite normalized REE diagram for rocks of unit 6.

Zr, Hf, and HREE's abundances (Fig. 3.9c-d) than unit 6, and slightly higher concentrations in V (Table 3.1).

The use of geochemistry for tectonic discrimination of felsic volcanic rocks has not been as extensively studied as for mafic rocks, because granite compositions are often complicated by variations in the composition of crustal sources, degree of partial melting, contamination, fractional crystallization, and volatile fugacities (Pearce et al., 1984; Whalen et al., 1987; Christiansen and Keith, 1996). However, tectonic settings are relatively well defined for the Finlayson Lake (Piercey et al. 2000; 2001), Bathurst (Lentz, 1998; van Staal et al., 1991) and Mount Windsor districts (Stoltz, 1995). Comparisons with the felsic lithogeochemistry of these VMS districts may elucidate the tectonic setting recorded in felsic rocks of the Johnson Lake area.

Felsic rocks associated with VMS mineralization in each of these districts plot in the rhyodacite/dacite to rhyolite fields (Fig. 3.8a-b), and within the peraluminous field in Figure 3.8c. In the Nb/Y (Fig. 3.11a) and Rb/Y+Nb (Fig. 3.11b) diagrams, felsic rocks from the Johnson Lake area and Mount Windsor Subprovince straddle the "volcanic arc granite field". Rocks from the Finlayson Lake and Bathurst districts plot inside the "within plate (A-type) granite field". On the primitive mantle normalized multielement plot (Fig. 3.9c), broad trends common to these rocks include the presence of negative Nb and Ti anomalies and high concentrations in the HFSE's, Th, and REE's. Rocks of unit 6 have similar multielement patterns (including relative concentrations of Zr, Hf, HREE's, and low V) to the Kudz Ze Kayah unit in the Finlayson Lake district, and Flat Landing Brook and Nepisiguit Falls formations in the Bathurst district.

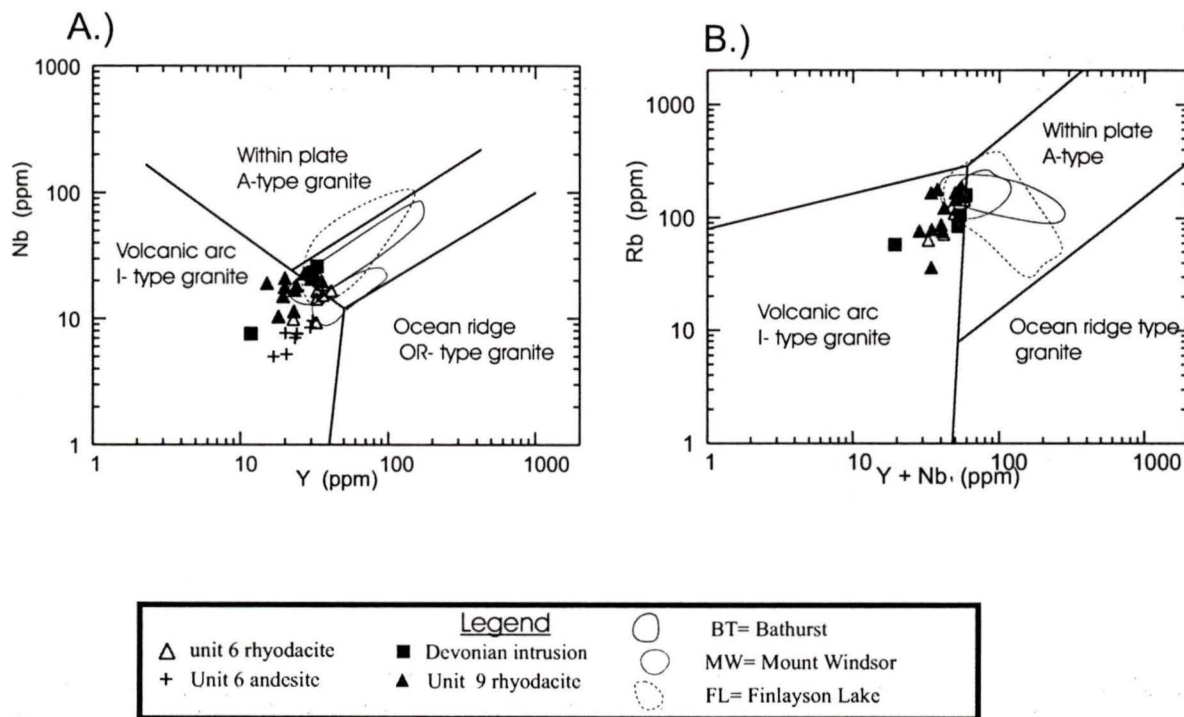


Figure 3.11: Tectonic discrimination diagrams of felsic volcanic and plutonic rocks from the Johnson Lake area. A.) Nb/Y granite discrimination diagram of Pearce et al, (1984), all samples plot near the boundary between the arc to within plate granites B.) Rb, Nb+Y granite discrimination diagram of Pearce et al. (1984).

U-Pb ZIRCON GEOCHRONOLOGY

Samples for U-Pb geochronology were prepared and analyzed at the University of Alberta geochronology laboratory following standard procedures (Heaman and Machado, 1992; Heaman and Lecheminant, 1993). Approximately 3-4 kg of quartz feldspar porphyry (unit 9) was crushed with a steel jaw crusher and powdered to <300µm using a Bico disk mill. Heavy mineral fractions were collected using a Wilfley table and zircons isolated using standard magnetic and heavy mineral fraction separation techniques. Five zircon fractions were recovered from a quartz-feldspar phyric flow of unit 9 (sample SLB99-31). The zircons were dissolved in concentrated HNO₃, HCL and HF acids, and purified U and Pb aliquots isolated using anion exchange chromatography. The isotopic compositions of U and Pb were determined on a VG 354 mass spectrometer. All ages are calculated using the decay constants: $^{238}\text{U} - 1.55125 \times 10^{-10} \text{ yr}^{-1}$ and $^{235}\text{U} - 9.8485 \times 10^{-10} \text{ yr}^{-1}$ determined by Jaffey et al (1971) and uncertainties reported at two standard errors. Further details on the U-Pb analytical methods, zircon fractions and data are included in appendix II.

U-Pb geochronology results

Five populations of zircons were identified with a stereoscope and subsequently hand picked for analyses. These fractions are summarized in Table 3.5 and consist of the following populations: 1.) A single, colourless, slightly resorbed zircon prism, with a possible tip overgrowth interpreted to be a xenocryst, 2.) tan coloured euhedral prisms with a length to width ratio ranging from 2:1 to equant, 3.) tan euhedral zircons that are

slightly resorbed, 4.) angular tan zircon fragment and, 5.) angular, transparent, tan zircon fragments.

The U-Pb results for the five fractions of zircon are presented in Table 3.5 and on a Concordia diagram (Fig. 3.12). The fractions are discordant indicating that some Pb may have been lost during deformation and metamorphism. Linear regression of fractions 2, 3 and 5 yields an age of $360 \pm 4.7\text{Ma}$, which is interpreted to be the crystallization age of unit 9. Discordance of fraction 4 is likely due to poor dissolution of the zircon grain. Fraction one was is a single resorbed zircon prism interpreted to be a xenocryst. This fraction was highly discordant due to lead loss.

NEODYMIUM ISOTOPES

Nine samples from the Johnson Lake area were submitted to the University of Alberta Isotope Research Facilities for Sm-Nd isotope analyses following the methods of Creaser et al. (1997). This was completed in an attempt to evaluate source regions of metavolcanic and metasedimentary rocks. Whole rock powders were dissolved in concentrated HF and HNO₃, and spiked with a mixture of ¹⁵⁰Nd and ¹⁴⁹Sm of known isotopic ratio. The samples were converted to chloride complexes and the rare earth elements separated by means of conventional cation exchange chromatography. The chromatography process isolated Sm and Nd into two separate fractions that were subsequently analyzed on a Thermal Ionization Mass Spectrometer (TIMS).

Neodymium isotope results

Ratios of ¹⁴⁷Sm/¹⁴⁴Nd and ¹⁴³Nd/¹⁴⁴Nd, analytical uncertainty, Sm-Nd concentrations and the calculations of ϵNd_T are summarized in Table 3.6 and figures 3.13

Table 3.5: Results of U-Pb zircon analyses for sample SLB99-31, quartz feldspar porphyritic rhyolite of unit 9, Johnson Lake B.C.

	Description	Weight (μg)	Concentration (ppm)				TCPb (pg)	$^{206}\text{Pb}/^{204}\text{Pb}$	Atomic Ratios $\pm 2\text{s error}$			Apparent age $\pm 2\text{s error}$ (Ma)			% Dis.
			U	Pb	Th	Th/U			$^{206}\text{Pb}/^{238}\text{U}$	$^{207}\text{Pb}/^{235}\text{U}$	$^{207}\text{Pb}/^{206}\text{Pb}$	$^{206}\text{Pb}/^{238}\text{U}$	$^{207}\text{Pb}/^{235}\text{U}$	$^{207}\text{Pb}/^{206}\text{Pb}$	
1	1 resorbed prism col possible tip overgrowth	3.7 ± 1.6	171	10	20	0.1	17	95	0.0336 ± 4	0.297 ± 24	0.0643 ± 49	212.8 ± 2.4	264.4 ± 19.0	750.4 ± 158.4	72.8
2	9 prisms (2:1 to equant) tan eu sl res	3.7 ± 1.8	879	55	547	0.6	10	1159	0.0555 ± 2	0.411 ± 3	0.0538 ± 3	348.4 ± 1.4	348.1 ± 1.4	361.6 ± 10.6	3.8
3	15 prisms (2:1) tan eu sl res	2.6 ± 0.6	1348	82	943	0.7	6	2035	0.0543 ± 2	0.402 ± 2	0.0537 ± 2	340.8 ± 1.4	340.8 ± 1.4	358.6 ± 8.0	5.1
4	1 angular piece tan	1.0 ± 0.2	1227	78	806	0.7	8	548	0.0551 ± 3	0.399 ± 6	0.0525 ± 7	345.7 ± 1.6	340.7 ± 4.4	306.7 ± 31.0	-13.0
5	11 angular tan trans frags n/incl	13.3 ± 0.5	964.93	59.98	727.5	0.8	16	2789	0.0547 ± 3	0.405 ± 2	0.0538 ± 1	343.0 ± 0.8	345.3 ± 0.8	360.7 ± 2.5	5.0

Abbreviations: eu=euhedral, sl res=slightly resorbed, trans=transparent, col=coloured, Ug=micrograms, U=uranium, Th= Thorium, Pb=lead, Dis= dissolution, ppm= parts per million.

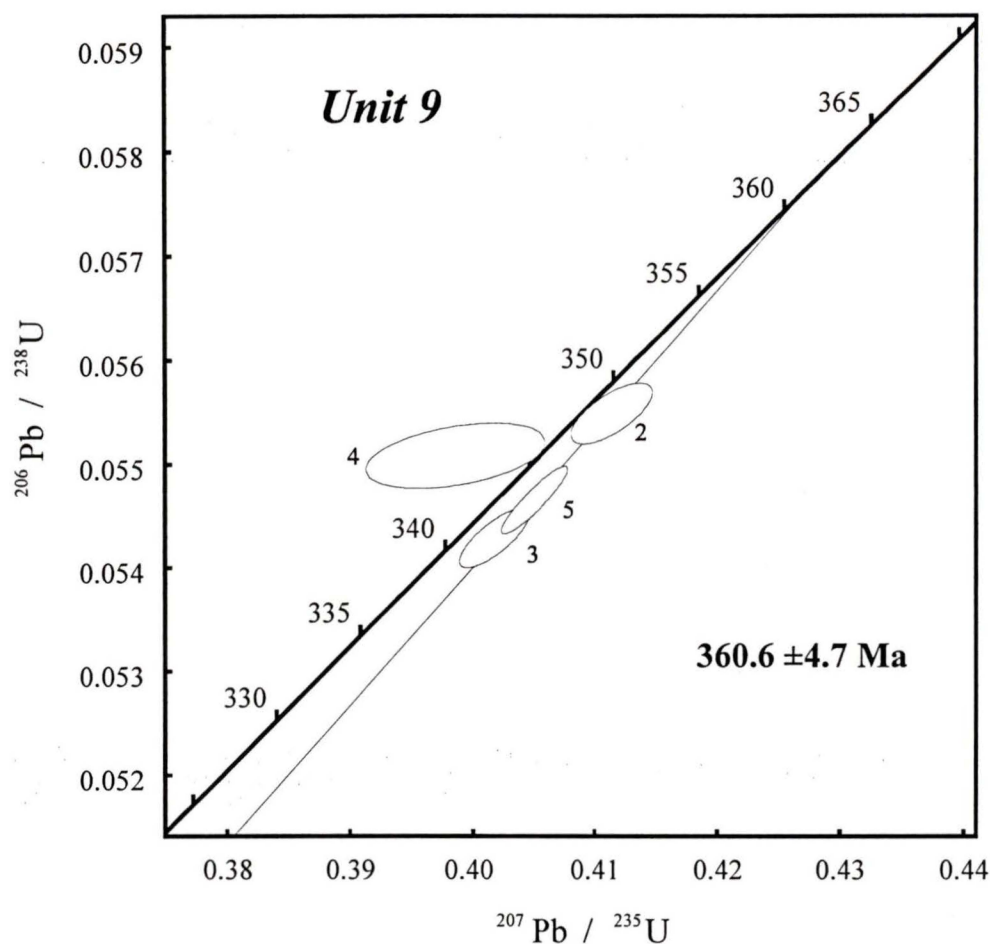


Figure 3.12: U-Pb Concordia diagram of zircon fractions 2-5 from sample SLB99-031, a quartz feldspar porphyritic flow of unit 9, all fractions are discordant, linear regression defines an upper intercept coinciding with an age of 360.6 ± 4.7 Ma.

and 3.14. ϵ_{Nd_T} is an expression of the deviation in the samarium and neodymium isotope ratios from that of a chondritic uniform reservoir (CHUR) at a given time (T) in the earth's history.

Table 3.6: Neodymium isotopic data for Johnson Lake volcanic and sedimentary rocks. Isotopes are reported as ratios to ^{144}Nd . ϵNd was calculated based on the T Ma ages listed, Nd correction = Nd static S54, uncertainty is reported as 2 standard errors. Unit 4 ϵNd T values calculated for both Devonian and Lower Cambrian ages.

Sample	unit	Sm ppm	Nd ppm	$^{147}\text{Sm}/^{144}\text{Nd}$	$^{143}\text{Nd}/^{144}\text{Nd}$	uncert.	TDM	ϵNd T	T Ma	Sm/Nd
B99-6A	4	2.83	11.66	0.14654243	0.512679971	0.000013	1.10	+3.30	360	0.24
								+4.33	540	
B99-6B	4	4.66	20.52	0.137261445	0.512714113	0.000007	0.90	+3.40	360	0.23
								+4.65	540	
B99-09	2	0.81	1.73	0.282931331	0.513350506	0.000009	0.41	+8.34	540	0.47
B99-61	3a	2.34	9.39	0.150529246	0.512765559	0.000007	0.96	+5.71	540	0.25
B99-108	3a	1.79	7.11	0.152670563	0.512785983	0.000007	0.94	+5.34	540	0.25
B00-165	10	4.63	25.37	0.110301002	0.512143422	0.000007	1.50	-5.68	360	0.18
B99-182	9	12.14	74.73	0.098210459	0.512353467	0.000010	1.07	-1.02	360	0.16
B99-33	9	9.54	57.60	0.100143666	0.512277483	0.000009	1.19	-2.60	360	0.17
B99-86	9	13.37	72.95	0.110840804	0.512335705	0.000009	1.22	-1.95	360	0.18

Mafic volcanic rocks of unit 2 have a ϵNd_{540} value of +8.34 and low concentration of Nd (1.73 ppm), similar to average Cambrian MORB (Fig. 3.13). Mafic volcanic rocks of unit 3a have ϵNd_{540} of +5.3-5.7, whereas mafic volcanic rocks of unit 4 have lower ϵNd_{360} values (+3.3 to +3.4) than unit 3a (Table 3.6; Fig. 3.13). Felsic volcanic rocks of unit 9 have ϵNd_{360} ranging from -1.02 to -2.6 and relatively high concentrations of Nd (60-70ppm). Unit 10 argillites have an ϵNd_{360} value of -5.7 and are within sedimentary rock values common to the pericratonic terranes (Patchett and Gehrels, 1998) and the Devonian to Jurassic miogeocline (Boghossian et al., 1996; Fig. 3.14).

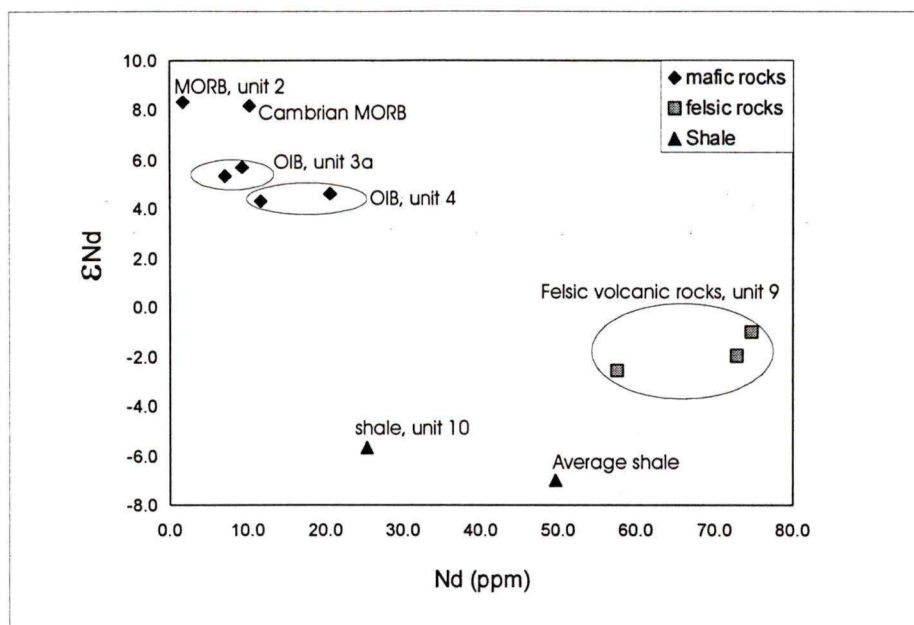


Figure 3.13: Whole rock Nd (ppm) plotted against ϵ_{Nd} values for units of this study. Global data for MORB and shale after Faure (1986).

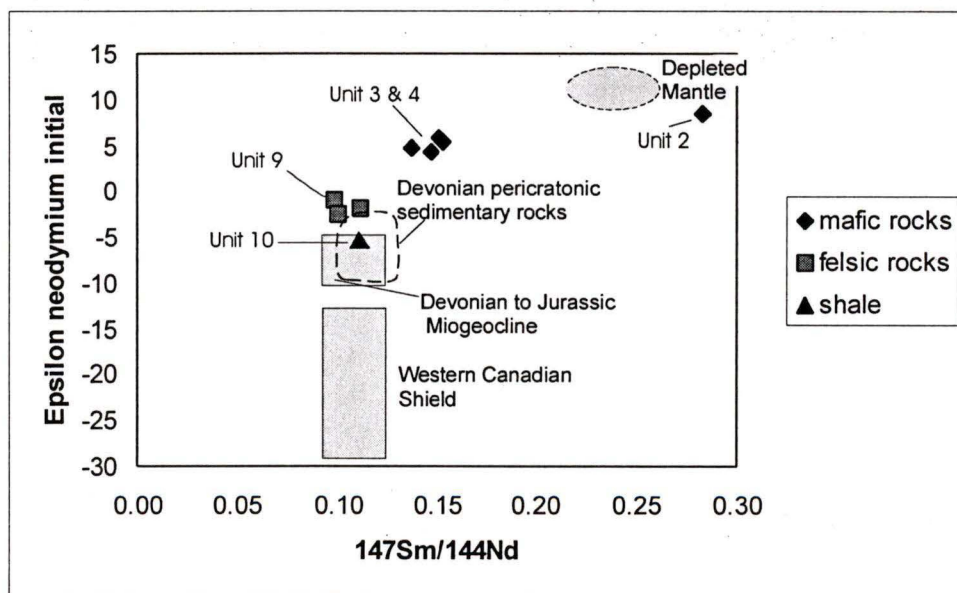


Figure 3.14: $^{147}\text{Sm}/^{144}\text{Nd}$ vs initial ϵ_{Nd} values for rocks of the Johnson Lake area, Kootenay Terrane, B.C. Fields for the western Canadian shield and Devonian to Jurassic Miogeocline after Boghossian et al. (1996). Fields for pericratonic terrane sedimentary rocks and depleted mantle after Patchett and Gehrels (1998).

DISCUSSION

Combined lithological, lithogeochemical, neodymium isotope and geochronology data provide constraints on the paleotectonic environments of both Lower Cambrian and Devonian-Mississippian volcanic and plutonic rocks in the Johnson Lake area.

Identifying the geochemical characteristics of igneous rocks associated with sulphide deposits has important implications for future exploration both locally and in other parts of the pericratonic terranes such as Finlayson District of Yukon Tanana Terrane. The petrogenesis, paleotectonic environments, and style of mineralization recognized in the Johnson Lake area are summarized in the following section.

Petrogenesis and tectonic setting of Lower Paleozoic rocks

Mafic rocks of unit 2 have typical N-MORB geochemical characteristics including LREE depletion relative to HREE, and generally low HFSE contents (Figs. 3.4-3.7). These rocks are interpreted as a phase of MORB volcanism within a dominantly alkalic mafic volcanic succession (Bailey et al., 2001). ϵNd_{540} values of +8 in unit 2 mafic volcanic rocks are similar to Cambrian MORB's elsewhere in the Canadian Cordillera (Fig. 3.13). Unit 3a alkalic mafic volcanic rocks have OIB type geochemical characteristics (Figs. 3.5b, 3.6b, 3.7a-c). The ϵNd_{540} values of +5.3 to +5.7 are lower than unit 2 (+8) and higher than unit 4 (+3.3 to +3.4). There are similarities in the geochemical signatures of alkalic basalts of unit 3a and unit 4, including the primitive mantle normalized multielement and chondrite normalized REE patterns (Figs. 3.5, 3.6). However, there are subtle differences in the trace element compositions of these rocks.

Unit 3a has higher concentrations of immobile elements, and REE's (Figs. 3.5, 3.6).

There are also subtle differences in the La/Yb, Nb/Y, Zr/Nb, and Zr/Y ratios (Table 3.1).

Two possible magmatic and tectonic relationships exist between volcanic rocks of unit 3a and unit 4: (1) Unit 3a and unit 4 are either products of different alkalic basaltic eruption events that occurred during the Lower Cambrian and Devonian periods respectively, and were juxtaposed during Jurassic folding and thrusting; or (2) unit 3a and unit 4 are part of the same Lower Cambrian volcanic event that consisted of dominantly alkalic basalt with minor MORB type volcanism (unit 2). In the case of the second interpretation, slight differences in the geochemical patterns between the two units may reflect chemical evolution of the magma or mixing of different source regions.

Alkalic basalts (within plate basalts) are typical volcanic rocks found in intracontinental rifts and continental arc rifts (van Staal et al., 1991, Piercey et al., 2000). East of Adams Lake, alkalic basalts correlative to unit 3a are intercalated with calc-silicate schist (correlative to unit 1) that host stratiform Pb-Zn deposits (Hoy, 1999). Thus, the alkalic nature of the mafic volcanic rocks, and association with sedimentary rocks that host stratiform Pb-Zn deposits suggest deposition in an intracontinental rift basin. This tectonic interpretation is in accordance with the interpretation of Hoy (1999). Lower Cambrian rifting is also recorded in siliciclastic sedimentary rocks of the Cordilleran miogeocline by synsedimentary faults and sedimentary deposition leading to growth strata, and increased feldspar content in sandstones from uplifted blocks (Devlin and Bond, 1988; Likorish and Simony, 1995).

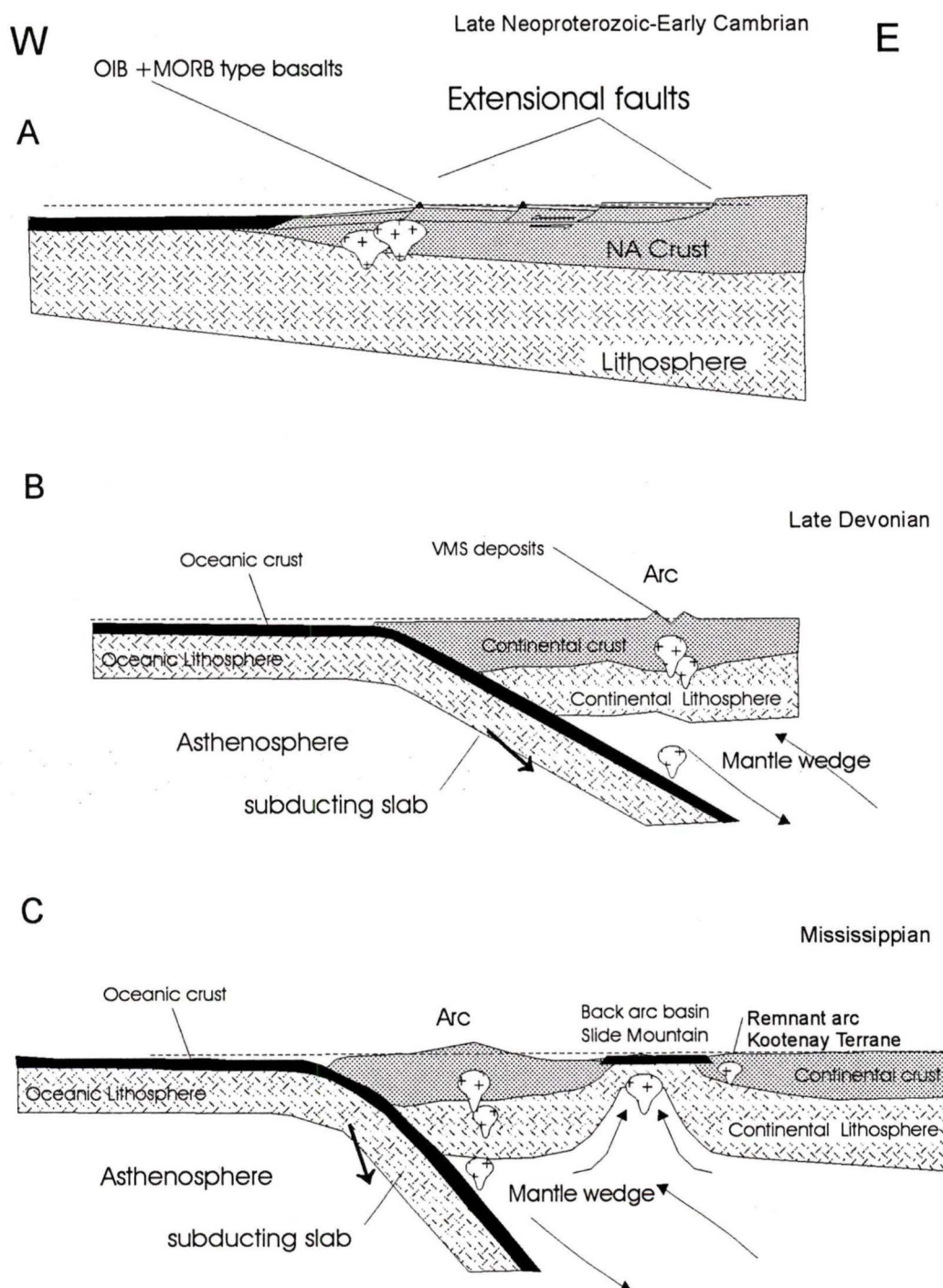


Figure 3.15: Schematic cross sections illustrating Paleozoic tectonic settings of the western North American continental margin in Southern B.C. not to scale. A.) Schematic cross section of Late Neoproterozoic to Cambrian continental margin undergoing extension, OIB=ocean island basalt (alkalic), MORB=mid ocean ridge basalt (tholeiite). B.) Devonian subduction of a shallow dipping oceanic plate under North American margin, and associated volcanic arc. C.) Steepening in the angle of subduction in the oceanic plate leads to tension in the overriding North American plate forming a back-arc basin (Modified after van Staal et al., 1991).

Petrogenesis and tectonic setting of Middle Paleozoic rocks

Intermediate volcanic rocks of unit 6 have geochemical characteristics that suggest formation in a volcanic arc environment. These characteristics include negative Nb and Ti anomalies on the normalized multielement diagram (Fig. 3.10), and the calc-alkalic nature of the rocks (Fig. 3.7). Ratios of immobile and incompatible elements are often preserved during prograde greenschist metamorphism and are characteristic of a source region (Barrett and MacLean, 1993). Thus, the similar Zr/Nb and Hf/Nb ratios of the felsic and intermediate rocks of unit 6 suggest that these rocks formed from a common source region during Late Devonian arc volcanism.

The geochemical signatures of the felsic rocks of unit 6 are similar to those of the Finlayson Lake district in Yukon Territory, Bathurst district of New Brunswick, and the Mount Windsor Subprovince of Australia (Table 3.4). The felsic VMS hosting sequences of the Finlayson Lake district formed in a back arc basin (Piercey et al., 2000; 2001). An ensialic back arc basin setting is proposed for the volcanism and associated mineralization in the Bathurst district (van Staal et al., 1991). In the Mount Windsor Subprovince a rifted continental volcanic arc setting was proposed for the volcanic rocks and associated sulphide deposits (Stoltz, 1995). Although the tectonic models differ between these regions, the VMS related felsic volcanic rocks have some common geochemical features. These features include multielement patterns that show enrichments in Zr, HF relative to Sm and Eu (Fig. 3.9c), negative Nb and Ti anomalies relative to Th and La (Fig. 3.9c), and flat patterns in the HREE's (Fig. 3.9c-d). A negative Eu anomaly relative to Sm and Gd in unit 6 (Figs. 3.9c-d, 3.10a-b) may be explained by

hydrothermal alteration related to VMS formation. Eu is typically mobile during high temperature hydrothermal alteration (Gena et al., 2001; Kikawada et al., 2001).

Unit 9 consists of rhyodacite to dacite that has no known associated sulphide mineralization, and may be the youngest stage of felsic volcanism in the Johnson Lake area. The felsic volcanic rocks are alkalic (Fig. 3.8a), and have lower concentrations of Zr, Hf and HREE's than unit 6 (Fig. 3.8). Unit 9 yield ≈ 360 Ma zircons interpreted as the crystallization age of these rocks. The ϵNd_{360} values of the felsic rocks (-1 to -3) are somewhat juvenile and the model ages of <1.5 Ga are consistent with a Proterozoic continental crustal component. Argillite of unit 10 has yielded an ϵNd_{360} value of -5.7, which overlaps fields for the miogeocline and pericratonic terranes (Fig. 3.14) and is consistent with sediments derived from mixed juvenile and evolved crustal sources.

We interpret the volcanic rocks of unit 6 to record calc-alkaline continental arc magmatism built on siliciclastic rocks (unit 5) of the North American continental margin (unit 5) (Fig. 3.15b). Rifting of this arc and attenuation of continental crust (Fig. 3.15C) led to the development of a basin and was accompanied by alkalic volcanism (unit 9). The ages of felsic continental arc volcanism (357-360Ma) are equivalent to those in the Finlayson Lake area (Piercey et al., 2001), and Little Salmon complex (Colpron, 2001) in the Yukon Tanana Terrane. The similar lithologies and ages suggest that a Devonian-Mississippian continental arc setting extended along a significant portion of the ancient pacific margin and rifting of the continental arc was important in the formation of VMS deposits.

CONCLUSIONS

The rocks of the Johnson Lake area record a complex history of extension, sedimentary deposition, volcanism, and deformation in the North American continental margin that spans from Lower Paleozoic to the Tertiary periods. Stratabound sulphide deposits are associated with Lower and Middle Paleozoic rift related rocks.

Lower Paleozoic rocks consist of alkalic basalts, carbonate and siliciclastic sequences that formed in an intracontinental rift basin (Höy 1999; Bailey et al., 2001). Devonian to Early Mississippian intermediate and felsic volcanic rocks in the Johnson Lake area are remnants of a Middle Paleozoic rifted arc setting, recording a period of extensional tectonism in the North American plate within an overall convergent margin setting. Calc-alkaline felsic volcanic rocks of unit 6 host the Homestake massive barite/sulphide deposit and have similar geochemical attributes to felsic rocks from Finlayson Lake, Bathurst and the Mount Windsor Subprovince including enrichments in Zr, Hf and HREE's.

ACKNOWLEDGEMENTS

The following people are thanked for contributions to this manuscript. Jim and Barb Lewko at Johnson Lake resort provided excellent accommodations. Geochemical analyses were carried out at the GSC under the supervision of Peter Belanger. Discussion with the following individuals is gratefully acknowledged: Paul Schiarizza, Trygve Höy, Ray Lett (B.C. Geological Survey), Bob Friesen (Consultant), Victor Preto (Consultant), Ken Daughtry (Consultant), Bob Thompson (GSC), and Tim Termunde (Eagle Plains Resources). Jennifer Porter and Morgan Soley provided excellent field assistance. This

project was funded by the Geological Survey of Canada Ancient Pacific Natmap Project (Paradis), University of Victoria Graduate Fellowship and an NSERC grant (Johnston).

This manuscript has benefited from reviews by Lawrence Winter, and Stephen Piercey.

This paper presents part of the senior authors M.Sc. Thesis submitted to the University of Victoria. A 1:20, 000 scale geological map will also be published as an open file by the Geological Survey of Canada. Additional publications have been produced summarizing the regional stratigraphy, structure, and mineral occurrences (Bailey et al., 2000, 2001, in preparation).

REFERENCES

- Bailey, S.L., Paradis, S., Johnston, S.T.
2000: Geological setting of the Devonian-Mississippian, Rea and Samatsum VMS deposits of the Eagle Bay Assemblage, Adams Lake area, south central British Columbia; *in* Geological Fieldwork 1999, B.C. Ministry of Energy and Mines, Paper 2000-1, p. 287-296.
- Bailey, S.L., Paradis, S., Johnston, S.T.
2001: New insights into metavolcanic successions and geochemistry of the Eagle Bay Assemblage, South Central British Columbia; Geological Survey of Canada, Current Research 2001-A8, 13 p.
- Bailey, S.L., Paradis, S., Johnston, S.T.
In preparation: Stratigraphy and Structure of the Eagle Bay Assemblage in the Johnson Lake Area, Southern British Columbia.
- Barrett, T.J., MacLean, W.H.
1993: Chemostratigraphy and hydrothermal alteration in exploration for VHMS deposits in greenstones and younger volcanic rocks, *in* Lentz, D.R., ed, alteration and alteration processes associated with ore forming systems: Geological association of Canada, Short Course notes, v.11, p.433-467.
- Barrett, T.J., MacLean, W.H.
1999: Volcanic sequences, lithogeochemistry, and Hydrothermal alteration in some bimodal volcanic-associated massive sulphide systems: *in* Barrie, C.T., and Hannington, M.D. eds., Volcanic-Associated massive sulphide deposits: Processes and examples in modern and ancient Environments, Reviews in Economic Geology, v.8, p. 101-131.
- Berry, R.F., Huston, D.L. Stoltz, A.J., Hill, A.P., Beams, S.D., Kuronen, U., and Taube, A.,
1992: Stratigraphy, structure, and volcanic hosted massive sulphide mineralization of the Mount Windsor Subprovince, North Queensland Australia, *in* Economic Geology, v. 87, p. 739-763.
- Boghossian, N.D., Patchett, P.J., Ross, G.M., and Gehrels, G.E.

- 1996: Nd isotopes and the source of sediments in the miogeocline of the Canadian Cordillera; *Journal of Geology*, v. 104, p. 259-277.
- Christiansen, E.H., Keith, J.D.
 1996: Trace element systematics in silicic magmas: A metallogenic perspective; in *Trace Element Geochemistry of Volcanic Rocks: Applications for Massive Sulphide Exploration*, Wyman D.A. (ed.); Geological Association of Canada, Short Course notes, v. 12, p. 115-151.
- Colpron, M. and Price, R.A.
 1995: Tectonic significance of the Kootenay Terrane, Southeastern Canadian Cordillera: an alternative model. *Geology*, volume 23, p. 25-28.
- Colpron, M.
 2001: Geochemical characterization of Carboniferous volcanic successions from Yukon Tanana Terrane, Glenlyon map area (105L), central Yukon, in *Yukon Exploration and Geology 1998*; Exploration and Geological Services Division, Indian and Northern Affairs Canada, p. 63-72.
- Creaser, R.A., Erdmer, P., Stevens, R.A., Grant, S.L.
 1997: Tectonic affinity of Nisutlin and Anvil assemblage strata, from the Teslin tectonic zone, northern Canadian Cordillera: constraints from neodymium isotope and geochemical evidence, *Tectonics*, v.16, p. 107-121.
- Devlin, W.J., Bond, G.C.
 1988: The initiation of the early Paleozoic Cordilleran miogeocline; evidence from the uppermost Proterozoic-Lower Cambrian Hamill Group of southeastern British Columbia. *Canadian Journal of Earth Sciences* v.25, no. 1, p. 1-19.
- Faure, G.
 1986: *Principles of Isotope Geology*, 2nd edition; John Wiley and Sons. United States of America.
- Gabrielse, H., Monger, J.W.H., Wheeler, J.O., Yorath, C.J.
 1991: Morphological Belts, tectonic assemblages, and terranes, in *Geology of the Cordilleran Orogen in Canada*, Chapter 2: Tectonic Framework, H. Gabrielse and C.J. Yorath eds. *Geological Survey of Canada*, *Geology of North America* v.2, 844 pages.
- Gena, K., Mizuta, T., Ishiyama, D., Urabe, T.
 2001: Acid-sulphate type alteration and mineralization in the Desmos Caldera, Manus back-arc basin, Papua New Guinea. *Resource Geology* v. 51, no. 1, p. 31-44.
- Goodfellow, W.D.
 2002: Current Understanding of the origin of massive sulphide deposits in the Bathurst mining camp, northern New Brunswick, in *The Gangue*, issue 72, p. 1-10.
- Goodfellow, W.D., Lydon, J.W., Turner, R.J.W.
 1993: Geology and genesis of stratiform sediment hosted (SEDEX) zinc-lead-silver deposits, in *Kirkham, R.v., Sinclair, W.D., Thorpe, R.I., and Duke, J.M., eds Mineral Deposit Modeling*; Geological Association of Canada, Special paper 40, p. 201-251.
- Halbach, P., Nakamura, K., Wahsner, M., Lange, J., Sakai, H., Kaeslitz, L., Hansen, R.D., Yamano, M., Post, J., Prause, B., Seifert, R., Michaelis, W., Teichmann, F., Kinoshita, M., Maerten, A., Ishibashi, J., Czerwinski, S., Blum, N.
 1989: Probable modern analogue of kuroko-type massive sulphide deposits in the Okinawa Trough back-arc basin, *Nature* v.338 P. 496-499.

Heaman, L.M., and Machado, N.

1992: Timing and origin of mid-continent rift alkaline magmatism, North America: evidence from the Coldwell Complex. *Contributions to Mineralogy and Petrology*, v. 110, p. 289-303.

Heaman, L.M., and Lecheminant, A.N.

1993: Paragenesis and U-Pb systematics of baddeleyite (ZrO₂). *Chemical Geology*, vol 110, p. 95-126.

Höy, T.

1999: Massive sulphide deposits of the Eagle Bay Assemblage, Adams Plateau, south-central British Columbia (082M 3, 4); *in Geological Fieldwork 1998*; British Columbia Ministry of Energy and Mines, Paper 1999-1, p. 223-245.

Höy, T. and Goutier, F.

1986: Rea Gold (Hilton) and Homestake volcanogenic sulphide – barite deposits, southeastern British Columbia (82M/4W); *in Geological Fieldwork 1985*; British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1986-1.

Hunt, J.A.

1998: Recent Discoveries of volcanic associated massive sulphide deposits in the Yukon; *in Canadian Institute of Mining and Metallurgy Bulletin*, v. 90, p.56-65.

Irvine, T.N. and Barager, W.R.A.

1971: A guide to the chemical classification of the common volcanic rocks; *Canadian Journal of Earth Sciences*, v.8, p. 523-548.

Jaffey, A.H. Flynn, K.F., Glendenin, L.E., Bentley, W.C. Essling, A.M.

1971: Precision measurements of half-lives and specific activities of ²³⁵U and ²³⁸U; *in Physics reviews*, C.4, p. 1889-1906.

Jenner, G.A.

1996: Trace element geochemistry of igneous rocks: Geochemical nomenclature and analytical geochemistry; *in Trace Element Geochemistry of Volcanic Rocks: Applications for Massive Sulphide Exploration*, Wyman D.A. (ed.); Geological Association of Canada, Short Course notes, v. 12, p. 51-77.

Jones, A.G.

1959: Vernon Map Area, British Columbia, Geological Survey of Canada, memoir 296, 186 p..

Kikawada, Y., Ossaka, T., Oi, T., Honda, T.

2001: Experimental studies on the mobility of lanthanides accompanying alteration of andesite by acidic hot spring water. *Chemical Geology*, v. 176; P. 137-149.

Lentz, D.R.

1996: Trace-element systematics of felsic volcanic rocks associated with massive sulphide deposits in the Bathurst Mining Camp: Petrogenetic, tectonic and chemostratigraphic implications for VHMS exploration; *in Trace Element Geochemistry of Volcanic Rocks: Applications for Massive Sulphide Exploration*, Wyman, D.A. (ed.); Geological Association of Canada, Short Course Notes, v. 12, p. 359-402.

Lentz, D.R.

1998: Petrogenetic evolution of felsic volcanic sequences associated with Phanerozoic volcanic-hosted massive sulphide systems: the role of extensional geodynamics; *in Ore Geology Reviews*, v.

Lickorish, W.H., Simony P.S.

- 1995: Evidence for late rifting of the Cordilleran margin outlined by stratigraphic division of the Lower Cambrian Gog Group, Rocky Mountain main ranges, British Columbia and Alberta. *Canadian Journal of Earth Sciences* v. 32, no. 7, p. 860-874.
- Maniar, P.D. and Piccoli, P.M.
1989: Tectonic discrimination of Granitoids: *Geological Society of America Bulletin*, v.101, p. 635-643.
- MacLean, W.H., Barrett, T.J.
1993: Lithogeochemical techniques using immobile elements, *Journal of Geochemical Exploration*, v. 48, p. 109-133.
- Meschede, P.M.
1986: A method of discriminating between different types of mid-ocean ridge basalts and continental tholeiite with the Nb-Zr-Y diagram; *Chemical Geology*, v. 56, p. 207-218.
- Mihalynuk, M.J., Nelson J., Roots, C.F., Friedman, R.M., de Keijzer, M.
1999: Ancient Pacific Margin Part III: Regional Geology and Mineralization of the Big Salmon Complex (NTS 104N/9E, 16 & 104O/12,13,14W), in *Geological Fieldwork 1999*, British Columbia Ministry of Energy and Mines, Paper 2000-1, p. 27-45.
- Monger, J.W.H.
1993: Canadian cordilleran tectonics, from geosynclines to crustal collage, *Canadian Journal of Earth Sciences*. v. 30, p. 209-231
- Monger, J.W.H. and Price, R.A.
1979: Geodynamic Evolution of the Canadian Cordillera, progress and problems, *Canadian Journal of Earth Sciences*. v. 16, p. 770-791.
- Mortensen, J.K.
1992: Pre-mid-Mesozoic tectonic evolution of the Yukon Tanana Terrane, Yukon and Alaska: *Tectonics* v.11, p.836-853.
- Murphy, D. and Piercey, S.J.
1999: Finlayson Project: Geological Evolution of the Yukon-Tanana Terrane and it's relationship to Campbell River Range belt, Northern Wolverine Lake Map area, Southeastern Yukon, in *Yukon Exploration and Geology 1998*; Exploration and Geological Services Division, Indian and Northern Affairs Canada, p. 47-62.
- Nelson, J.L.
1997: Last seen Heading south: extensions of the Yukon Tanana terrane into Northern British Columbia; in *Geological Fieldwork 1996*, D.v. Lefebure, W.J. McMillan and J.G. Mcarthur, editors, B.C. ministry of employment and investment editors, Geological Survey Branch, paper 1997-1, p. 145-156.
- Nelson, J.L., Mihalynuk, M.J., Murphy, D.C., Colpron, M., Roots, C.F., Mortensen, J.K., Friedman, R.M.
2000: Ancient Pacific Margin Part II: A preliminary comparison of potential VMS hosting successions of the Yukon Tanana Terrane, from Finlayson Lake district to Northern British Columbia; in *Geological Fieldwork 1999*, B.C. Ministry of Energy and Mines, Paper 2000-1, p. 19-25.
- Okulitch, A.V.
1979: Lithology, stratigraphy, structure and mineral occurrences of the Thompson-Shuswap-Okanagan area, British Columbia; *Geological Survey of Canada*, open file 637.
- Paulick, H., Herrmann, W., Gemmell, J.B.

- 2001: Alteration of felsic volcanic rocks hosting the Thalanga massive sulphide deposit (Northern Queensland Australia) and geochemical proximity indicators to ore, in *Economic Geology*, v.96, p. 1175-1200.
- Patchett, P.J., Gehrels, G.E.
1998: Continental influence on Canadian Cordilleran Terranes from Nd isotope study, and significance for crustal growth processes. *Journal of Geology*, v.106, p. 269-280.
- Pearce, J.A.
1983. Role of sub-continental lithosphere in magma genesis at active continental Margins. In *Continental Basalts and Mantle Xenoliths*. Edited by C.J. Hawkesworth and M.J. Norry. Shivan, Nantwich, U.K., p.230-249.
- Pearce, J.A., Harris, N.B.W., and Tindle, A.G.
1984: Trace element discrimination diagrams for the tectonic interpretation of granitic rocks; *Journal of Petrology*, v. 25, p. 956-983.
- Pearce, J.A., and Peate, D.W.
1995: Tectonic implications of the composition of volcanic arc magmas: *Annual Reviews in Earth and Planetary Science*, v. 23, p. 251-285.
- Piercey, S.J., Murphy, D.C., Mortensen, J.K., and Paradis, S.,
2000: Arc rifting and ensialic back-arc basin magmatism in the northern Canadian cordillera: evidence from the Yukon-Tanana terrane, Finlayson Lake region, Yukon: in *Slave-Northern Cordilleran Lithospheric Experiment (SNORCLE)-Lithoprobe Report 72*, p. 129-138.
- Piercey, S.J., Paradis S., Murphy D.C., Mortensen J.K.
2001: Geochemistry and paleotectonic setting of felsic volcanic rocks in the Finlayson Lake volcanic-hosted massive sulphide (VHMS) district, Yukon, Canada, *Economic Geology*.
- Price, R.A., Monger, J.W.H., and Roddick, J.A.
1985: Cordilleran Cross Section, Calgary to Vancouver; in *Field guides to Geology and Mineral Deposits in the Southern Canadian Cordillera*, D.J. Templeman-Kluit, Editor, *Geological Society of America*, Cordilleran Section Meeting, Vancouver, May, 1985, p. 3.2-3.85.
- Schiarizza, P. and Preto, V.A.
1987: Geology of the Adams Plateau-Clearwater-Vavenby area; British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1987-2.
- Shervais, J.W.
1982: Ti-V plots and the petrogenesis of modern and ophiolitic lavas; *Earth and Planetary Science Letters*, v. 59, p. 101-118.
- Shinjo, R., Chung, S-L., Kato, Y., and Kimura, M.
1999: Geochemical and Sr-Nd isotopic characteristics of volcanic rocks from the Okinawa trough and Ryuku arc: implications for the evolution of a young, intracontinental back arc basin: *Journal of Geophysical Research*, v. 104, #B5, p. 10591-10608.
- Shinjo, R., and Kato, Y.
2000: Geochemical constraints on the origin of bimodal volcanism at the Okinawa trough, an incipient back arc basin, in *Lithos*, v. 54, p. 117-137.
- Stoltz, A.J.

- 1995: Geochemistry of the Mount Windsor Volcanic rocks: implications for the tectonic setting of Cambro-ordovician volcanic-hosted massive sulphide mineralization in Northeastern Australia: *Economic Geology*, volume 90, p. 1080-1097.
- Sun, S. and McDonough, W.F.
1989: Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes; *in* *Magmatism in the Ocean Basins*, Saunders, A.D. and Norry, M.J. (ed.); Geological Society Special Publication 42, p. 313-345.
- van Staal, C.R., Winchester, J.A., Bedard, J.H.
1991: Geochemical Variations in Middle Ordovician volcanic rocks of the northern Miramichi Highlands and their tectonic significance; *in* *Canadian Journal of Earth Sciences*, volume 28, p. 1031-1049.
- Whalen, J.B., Currie, K.L., Chappell, B.W.
1987: A type granites: geochemical characteristics, discrimination and petrogenesis; *in* *Contributions to mineralogy and petrology*, v. 95, p. 407-419.
- Wheeler, J.O. and McFeely, P.
1991: Tectonic Assemblage Map of the Canadian Cordillera and Adjacent Parts of the United States of America; Geological Survey of Canada. Map 1712A, Scale 1: 2 000 000.
- Winchester, J.A. and Floyd, P.A.
1977: Geochemical discrimination of different magma series and their differentiation products using immobile elements; *Chemical Geology*, v. 20, p. 325-343.
- Wood, D.A.
1980: The application of a Th-Hf-Ta diagram to problems of tectonomagmatic classification and to establishing the nature of crustal contamination of basaltic lavas of the British Tertiary volcanic province; *Earth and Planetary Science Letters*, v. 50, p. 11-30.

CHAPTER 4: MINERAL OCCURRENCES

INTRODUCTION

Prospectors and exploration companies have long recognized the Eagle Bay Assemblage as a favorable region to host sulphide deposits. Several significant sulphide deposits including Samatosum, Rea, and Homestake have been discovered in the map area over the last century (see map in pocket, appendix 1). This chapter focuses on describing and comparing the main mineral occurrences. The Samatosum and Rea (+K7) deposits differ in mineralization styles yet have similar host lithologies and they have been suggested to be structural repetitions of the same zone (Pirie, 1989). The Homestake deposit is hosted at a different stratigraphic level and has a different mineralization style than the Rea deposit. Sulphur isotope ratios were measured on sulphide and sulphate minerals from several of the mineral occurrences, and these results are presented here. This chapter also presents ideas surrounding the genesis of these massive sulphide deposits by comparing them to modern and ancient analogues.

SULPHIDE OCCURRENCES

Massive sulphide deposits discovered in the map area during the past century (Höy and Gouthier, 1986; Oliver and Marr, 1987; Pirie, 1989; Carmichael, 1991) include syngenetic massive barite/sulphides and epigenetic quartz-carbonate-sulphide veins. Most of the occurrences are base metal sulphides, but may contain significant concentrations of gold and silver which make them particularly attractive exploration targets. These sulphide deposits are hosted in rocks of similar age, lithologies, environments, and tectonic settings to VMS deposits (e.g. Wolverine, Kudz Ze Kayah, GP4F, Fire Lake) in the Finlayson Lake district of Yukon (Murphy and Piercey, 1999; Piercey et al., 2001).

Grades and tonnages of the significant sulphide occurrences in the Johnson Lake area are listed in Table 4.1. Known deposits are of low tonnage, yet have relatively high silver and gold values. Past producers are the Samatosum and Homestake deposits. The Samatosum deposit was examined during this study and will be described in detail. Several of these occurrences are old workings/ adits that are no longer accessible. Therefore, descriptions of the occurrences presented here are from industry and government reports, and British Columbia mineral inventory file.

Table 4.1: Grade and tonnage summaries of deposits/significant showings in the Johnson Lake area (after Carmichael, 1991; Pirie, 1989).

Deposit	Tonnage (Mt)	Au (g/t)	Ag (g/t)	Cu (wt%)	Pb (wt %)	Zn (wt%)
Samatosum	634, 984	1.6	833	1.1	1.4	3.0
Rea	376, 000	6.1	69.4	0.33	2.2	2.3
K7	375, 000	4.0	55	0.5	4.8	6.1
Twin	4.1 m	12.8	108	0.2	1.5	0.6
Drill holes	2.7 m	8.6	259	0.6	2.8	3.2
Homestake	250, 000	0.5	202	0.3	1.2	2.2

Mt= metric tonnes, *g/t*= grams per tonne, *wt%*= weight percent

Samatosum (B.C. Minfile 082M 244)

The Samatosum deposit was discovered in 1986, and is located 2.5 km southwest of Johnson Lake and 500 metres northeast of the Rea deposit. The Samatosum deposit contained 634,984 tonnes of ore grading 1,035 grams/tonne Ag, 1.2% Cu, 1.7% Pb, 3.6% Zn, 1.9 grams/ tonne Au (Pirie, 1989) and was mined by Minnova Minerals Inc. (previously Corporation Falconbridge Copper, presently Inmet Mining Corporation) from 1989 to 1992. The Samatosum deposit is hosted by altered and deformed metasedimentary rocks close to the contact with structurally overlying mafic volcanoclastic rocks (Figs. 4.1; 4.2; 4.3a; 4.3b). Structural evidence (see chapter 2)

indicates that the hostrocks are inverted and that the deposit is on the overturned eastern limb of the Shafer Lake syncline (see map and sections, appendix 1).

Exploration companies refer to the hostrocks as the "Mine Series" which is a metasedimentary succession consisting of carbonaceous black argillite, sericitized yellowish argillite containing chert lenses (Figs. 4.3b, 4.4a) and pyrite-rich silicified greyish argillite (Figs. 4.3b-c). Pervasive quartz-sericite-pyrite-carbonate alteration is most intense along the metasediment-metavolcanic contact. The protolith of these rocks is difficult to determine because of intense alteration, deformation, and mineralization. However, the rocks can be traced along strike where they become black phyllite likely derived from argillite to quartz wacke.

Mafic volcanoclastic rocks structurally overlying the sediments (Figs. 4.2; 4.3a) are commonly fine-grained to lapilli tuffs, with minor massive to pillowed flows. The contact between the mafic volcanic rocks and the altered sedimentary rocks trends northwest and dips moderately to steeply to the east. Folded and brecciated mineralized quartz veins crosscut metasedimentary rocks and metavolcanic rocks near the deposit (Figs. 4.3b; 4.4a). The degree of alteration appears to be less in mafic volcanic rocks accounting for the better preservation of primary textures. However, pervasive sericite-pyrite-quartz $\pm$ fuchsite-carbonate alteration is seen several hundred metres into the structural hangingwall of the deposit (the highest degrees of alteration are up to 30 metres from the contact with metasedimentary rocks). The penetrative foliation is related to the Jurassic fold and thrust event. Earlier structures have been transposed and overprinted by this event, for example, many of the quartz veins are transposed, or isoclinally folded.

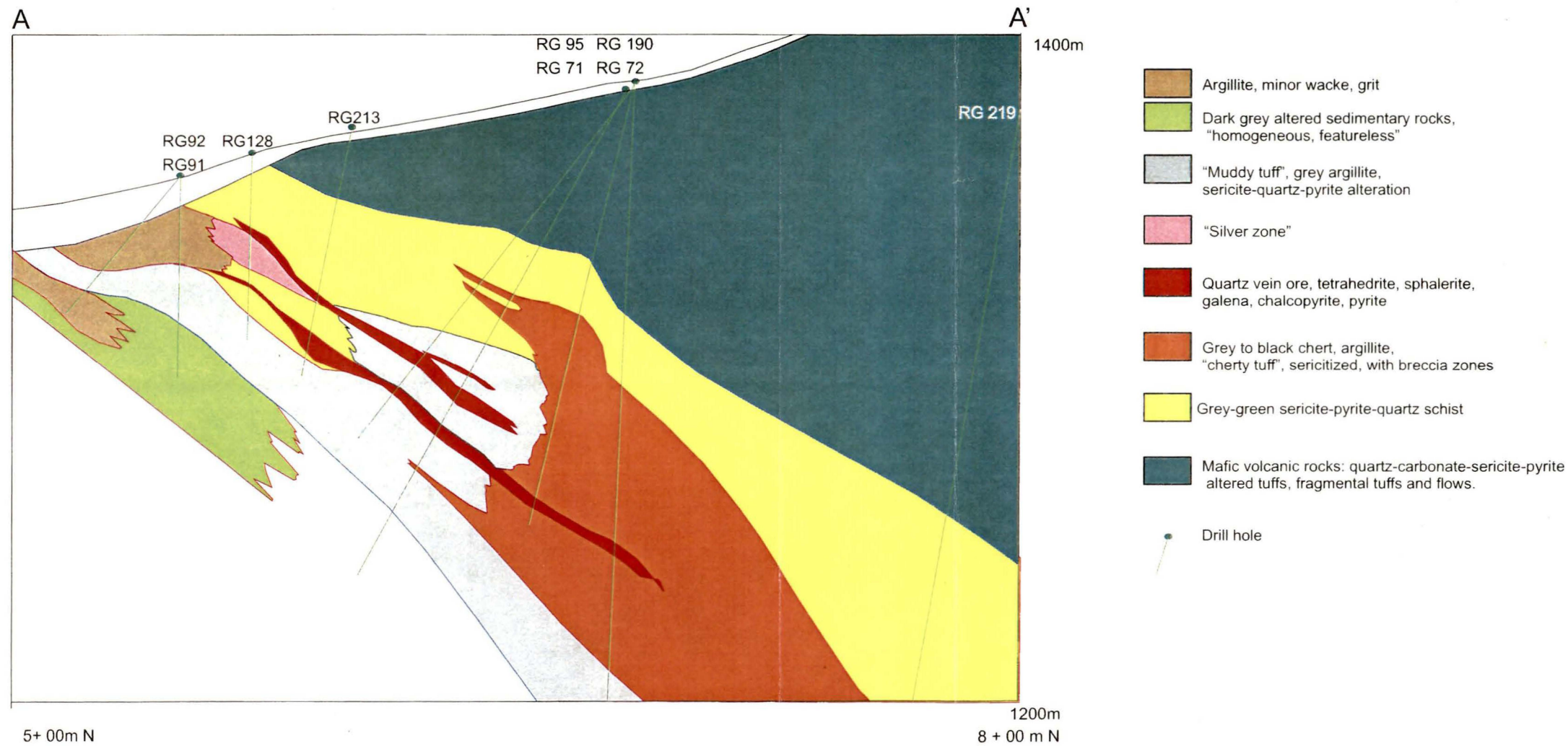


Fig. 4.2: Cross section A-A' through the Samatosum deposit viewing to the northwest, modified from B. Friesen, (1991), Minnova Inc.

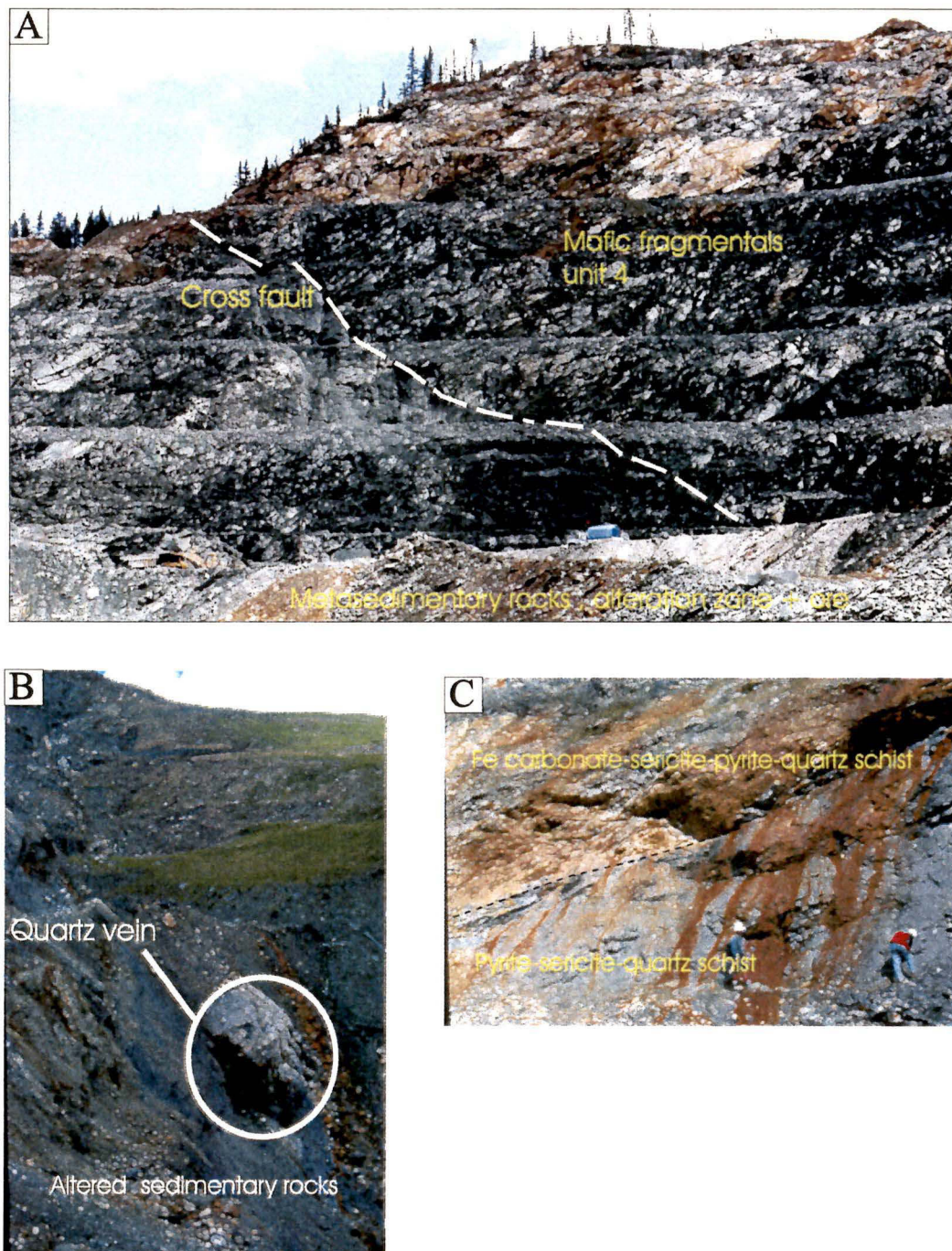


Figure 4.3: A.) Samatosum deposit, open pit viewed toward the Southwest, showing contact between mafic fragmentals (hangingwall) and metasedimentary rocks (footwall), the cross fault is a late top down to the south normal fault. B.) Steeply dipping sulphide bearing quartz vein in sericite-pyrite-quartz altered metasedimentary rocks. C.) Contrast in alteration styles in fissile schist (metasedimentary rocks), dominantly Fe carbonate (siderite, ankerite) sericite-pyrite-quartz alteration overlying sericite-pyrite-quartz alteration.

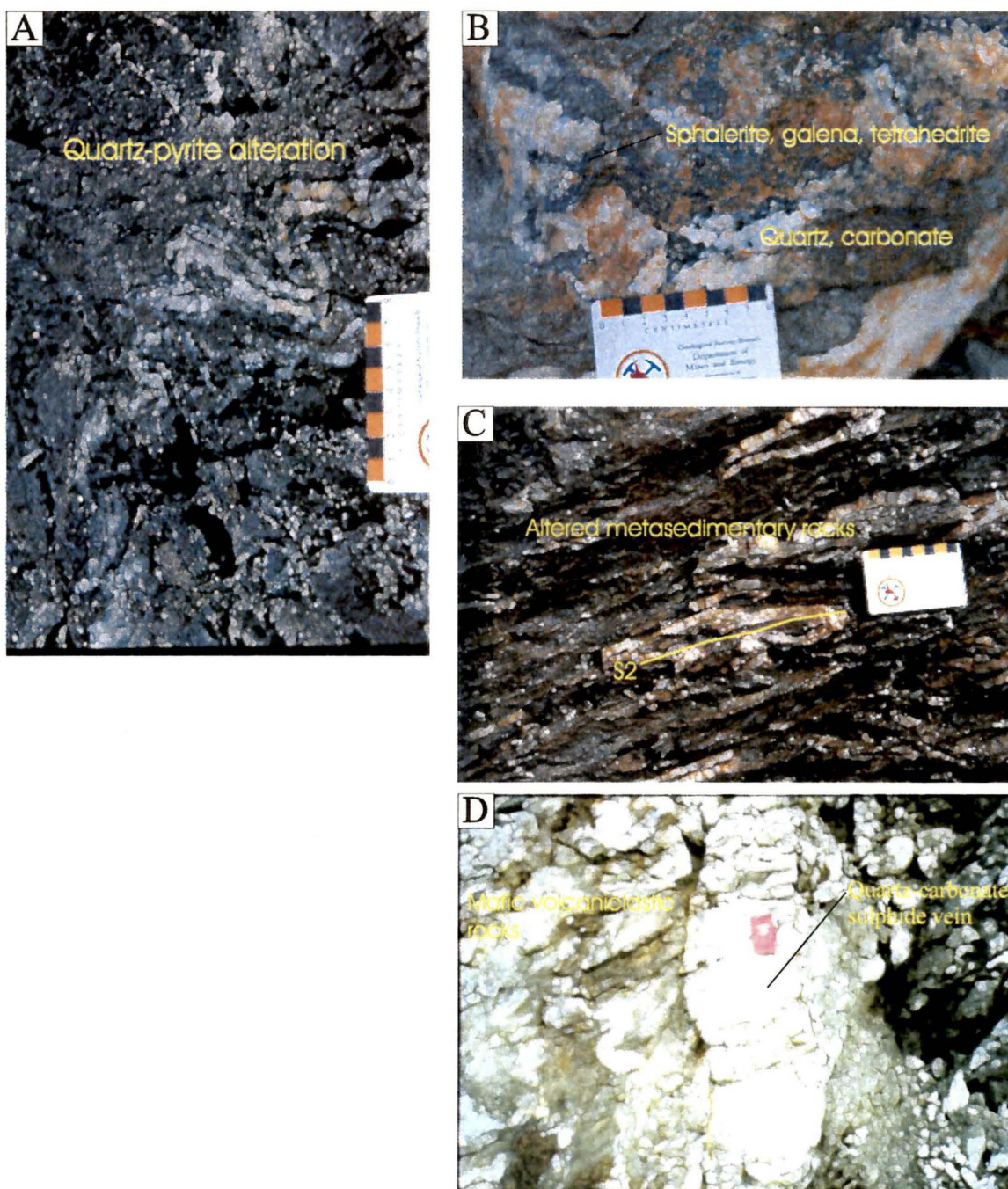


Figure 4.4: Alteration and mineralization at the Samatosum deposit; A.) Quartz-pyrite alteration of metasedimentary rocks. B.) Quartz-carbonate vein containing coarse sulphides. C.) Isoclinally folded quartz veins in metasedimentary rocks near contact with metavolcanic rocks. D.) Quartz-carbonate veins with coarse pyrite, sphalerite, galena, chalcopyrite, and tetrahedrite-tennantite.

Shallow (30 degree) east dipping thrust faults cut the mineralization and may be late thrust faults in the Jurassic fold and thrust event. A late structure (post-Jurassic) identified at the mine site is the cross fault (Figs. 4.1; 4.3a). This is an east trending top down to the south normal fault that cuts the mine sequence (and penetrative foliation), and has minor displacement (15 metres).

Syngenetic and epigenetic mineralization styles are identified at Samatosum. These include; thin fine-grained sulphide bands in a pyritic chert envelope (syngenetic), coarse sulphides in quartz-carbonate veins (epigenetic), and disseminated sulphides in sericitic schist (syngenetic/epigenetic?). Mineralization consists of tetrahedrite, sphalerite, galena, pyrite, chalcopyrite (Figs. 4.4b; 4.5), minor electrum, bournonite, gersdorffite, chalcocite, arsenopyrite, and covellite (Pirie, 1989). Tetrahedrite is the primary silver-bearing mineral (Pirie, 1989) and occurs as coarse-grained, steely blue-black masses in quartz veins (Fig 4.4b). Tetrahedrite typically replaces, or occurs as inclusions in sphalerite, chalcopyrite, pyrite, and galena (Fig. 4.5).

The alteration assemblage at Samatosum is summarized in Table 4.2. Quartz is the dominant alteration mineral associated with the sulphide mineralization, and has coarse and fine-grained, white to grey varieties. Pyrite is also a ubiquitous alteration mineral, and has several morphologies including, resorbed-anhedral, octahedral, and cubic pyrite crystals. Pyrite may be disseminated, in veinlets, or in quartz and carbonate veins. Chlorite, sericite and carbonates are abundant and typically very fine-grained. Most of the alteration assemblage is aligned in the penetrative foliation plane suggesting that alteration minerals recrystallized during metamorphism. However, pyrite crystals

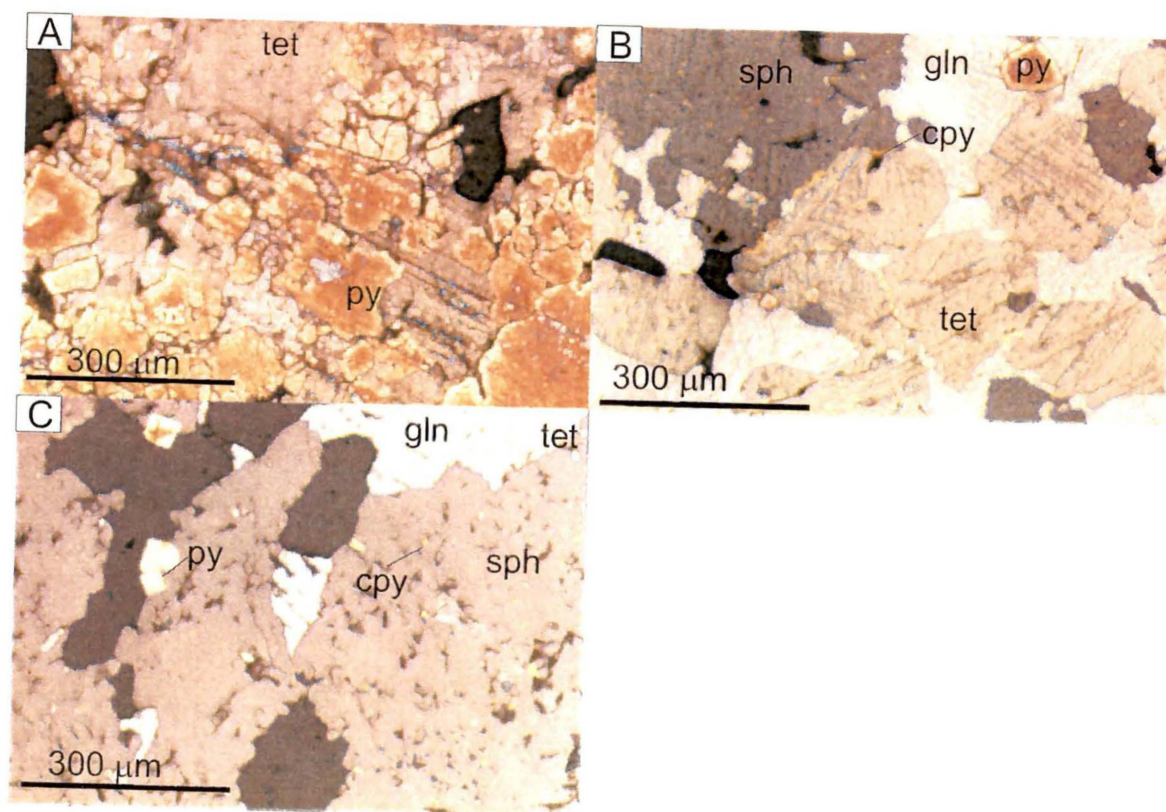


Figure 4.5: Photomicrographs of sulphide textures observed with reflecting light microscopy of polished thin sections from the Samatosum deposit. A.) Resorbed anhedral pyrite crystals in a matrix of tetrahedrite, Samatosum quartz vein ore. B.) Subhedral tetrahedrite within a matrix of coarse galena and sphalerite, there is a chalcopyrite rim separating sphalerite and tetrahedrite. C.) Coarse sphalerite with fine grained chalcopyrite, cubic pyrite crystals, anhedral galena with tetrahedrite inclusions. Sulphide abbreviations are: gln=galena, py=pyrite, cpy=chalcopyrite, sph=sphalerite, tet=tetrahedrite.

may have quartz pressure shadows, indicating that alteration predates metamorphism.

Alteration phases are typically fine-grained and are listed in Table 4.2. Siderite is the dominant iron carbonate mineral (Pirie, 1989) whereas fuchsite is typically associated

Table 4.2: Hydrothermal alteration minerals of the Samatosum deposit, B.C.

Mineral	Maximum grain size	Shape/ occurrence	Associated minerals
quartz	30 mm	Anhed, veins, amygdules, ubiquitous	All phases
sericite	1mm	Subhed flakes, ubiquitous	Qtz, chl, py,
chlorite	1mm	Subhed flakes	Qtz, cal, sid, ank,
pyrite	1 mm	Euhed, cubic to octahedral, disseminated, anhedral resorbed, veins	Qtz, ser, chl, cal, ank, sid, sph, tet-tenn, cpy, gln
fuchsite	1 mm	Subhed flakes	Qtz, ser, chl, carb, py
calcite	20-40 mm	Euhed-subhed-anhed, veins, amygdules	Qtz, ser, chl, ank, sid, py, sph, tet-tenn, cpy, gln
siderite	1-2 mm	Euhed-subhed-anhed, veins, amygdules	Qtz, ser, chl, cal, ank, py, sph, tet-tenn, cpy, gln
ankerite	1-2 mm	Euhed-subhed-anhed, veins, amygdules	Qtz, ser, chl, cal, sid, sph, py, tet-tenn, cpy, gln
albite	10 mm	Subhed, veins	Qtz, cal, py,
sphalerite	20-30 mm	Anhed, subhed	Qtz, ser, chl, cal, ank, py, sid, tet-tenn, cpy, gln
chalcopyrite	1-2 mm	Anhed,	Qtz, cal, ank, py, sid, sph, tet-tenn, cpy, gln
tetrahedrite/tennantite	4-5 cm	Anhed, subhed	Qtz, ser, chl, cal, ank, py, sid, sph, tet-tenn, cpy, gln
galena	1 cm	Anhed- euhed, cubic	Qtz, ser, chl, cal, ank, py, sid, sph, tet-tenn, cpy

Abbreviations: alb = albite, ank = ankerite, cal = calcite, cpy = chalcopyrite, chl = chlorite, gln = galena, py = pyrite, qtz = quartz, sid = siderite, sph = sphalerite, tet = tetrahedrite, tenn = tennantite, anhed = anhedral, subhed = subhedral, euhed = euhedral, grdms = groundmass.

only with alteration mineral assemblages of mafic volcanic rocks. Fine-grained tourmaline was identified by Minnova Inc geologists (Pirie, 1989), but was not observed during this study.

Veins have variable orientations in the deposit. Pyritic quartz veins are isoclinally folded in the structural hangingwall to the deposit (Fig. 4.4c). Vertical quartz veins with pyrite, chalcopyrite, sphalerite, galena and tetrahedrite cut through the mafic volcanic rocks in the structural hangingwall of the deposit (Fig. 4.4d). It is uncertain whether these veins cut across the metasedimentary contact and continue into the footwall of the

deposit. These steep veins do not appear to be significantly deformed by F_2 . However, quartz veins on the margins of these steep veins are folded (Fig. 4.4d), and have axial planes of orientation similar to the S_2 fabric. Late calcite veins containing sphalerite and galena cross cut all earlier fabrics and structures.

Clark and Williams-Jones (1991) dated the mineralized veins using Ar-Ar techniques on sericite. They concluded that the mineralized veins were 185-190 Ma (Early Jurassic). This argues against a VMS stockwork interpretation of the veins, and may reflect Early Jurassic remobilization of syngenetic sulphide mineralization. However, there are no closely constrained metamorphic ages on these rocks and these ages could result from metamorphic "resetting" of the sericite. There is no definitive age on the Samatosum deposit. Pirie (1989) commented that "lead isotope analysis suggests that the lead in veins is the same as syngenetic lead and is Devonian". The stratigraphic sequence and presence of syngenetic mineralization is similar to the Rea deposit suggesting that the earliest mineralization is Devonian.

Rea (B.C. Minfile 082M 191)

The Rea deposit was discovered in 1983 by prospectors A. Hilton and R. Nicholl, and later optioned to Corporation Falconbridge Copper (presently Inmet Mining Corporation). Subsequent exploration revealed two massive sulphide lenses termed the discovery zone. The southern lens (RG8; Fig. 4.6) has a surface strike of 75 metres with a downdip extension of 80 metres whereas the northern lens (L100) has a surface strike of 50 metres and a down dip extension of at least 120 metres (Höy and Goutier, 1986). Combined reserves for the two massive sulphide lenses totaled 376,000 tonnes grading

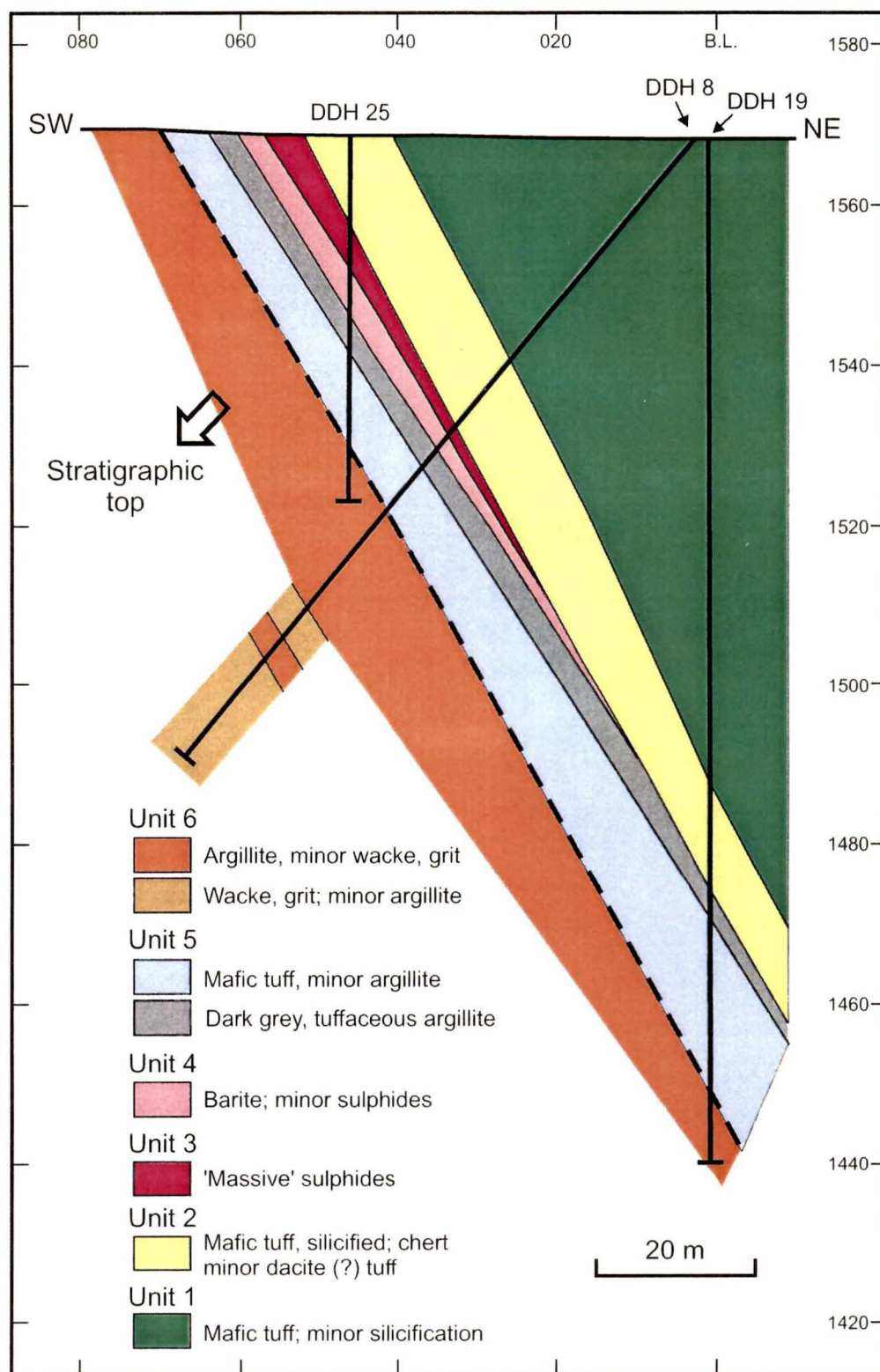


Figure 4.6: Cross section through the RG8 sulphide - barite lens, Rea deposit, after Hoy and Gouthier (1986).

0.33 percent copper, 2.2 percent lead, 2.3 percent zinc, 6.1 grams per tonne gold, and 69.4 grams per tonne silver (Northern Miner – November 30, 1987).

The exploration site has been reclaimed and only a few exposures in trenches remain. However, Rea is described in considerable detail by White (1985), Höy and Goutier (1986), and Höy (1987). The deposit is situated on the overturned eastern limb of the Shafer Lake syncline and is thus inverted (Fig. 4.6). The stratigraphic footwall of the deposit consists of metamorphosed mafic tuffs (Unit 4) and chert that show sericite-quartz-carbonate alteration of a mafic volcanic precursor. Mafic volcanic rocks (unit 4) in the hangingwall to the Samatosum and Rea deposits have identical ocean island basalt type chemistry (Bailey et al., 2002a; in preparation). The two massive sulphide lenses, one of which contains a barite cap (RG8), are stratigraphically above this zone and overlain by a thin mafic tuff (Höy and Goutier, 1986). Mafic tuffs are then stratigraphically overlain by argillites and minor tuffs, that grade into quartz-lithic pebble conglomerate. The Rea zone extends along strike for seven kilometres and hosts at least five volcanogenic massive sulphide lenses (Carmichael, 1991).

Sulphides include pyrite, sphalerite, galena, arsenopyrite, chalcopyrite, and tetrahedrite/tennantite. These are fine to medium grained with banded to brecciated texture. Colloform pyrite and sphalerite are observed in the massive sulphides and are evidence of open space replacement of sulphides (Fig. 4.7). Chalcopyrite inclusions occur within the sphalerite are similar to the “chalcopyrite disease” texture commonly recognized in volcanogenic massive sulphide deposits (Nagase and Kojima, 1997). Gangue consists mainly of quartz, sericite and carbonate. Gold and silver are associated

with massive sulphide and barite, gold occurs within the structure of arsenopyrite, whereas silver is mainly in tetrahedrite/tennantite.

K7 (B.C. Minfile 082M 277)

K7 is located 2 km southeast of, and along strike from the Rea deposit (see map, appendix 1). K7 consists of two massive sulphide lenses that were discovered by Esso Minerals Ltd. in a 1988 drill program (Carmichael, 1991) and later optioned to Kamad Silver Corporation. The sulphide lenses have a combined 375 000 tonnes grading; 4.0 g/t Au, 55 g/t Ag, 0.5% Cu, 4.8% Pb, 6.1% Pb (Table 4.1; Carmichael, 1991). Subsequent work by Kamad Silver included diamond drilling and downhole pulse EM geophysics.

The geological units and mineralization style are identical to the Rea deposit. The structural hangingwall to the deposit consists of calcareous mafic volcanic and volcanoclastic rocks. The mineralization is hosted in an altered sedimentary rock succession. This includes pervasive sericite-pyrite-quartz alteration and the presence of a “pyritic, sericitic and graphitic chert” zone (Carmichael, 1991). The mineralization consists of a fine to medium grained assemblage of banded, massive to disseminated pyrite, sphalerite, galena, and chalcopyrite in a siliceous gangue found near the contact with overlying mafic volcanoclastic rocks.

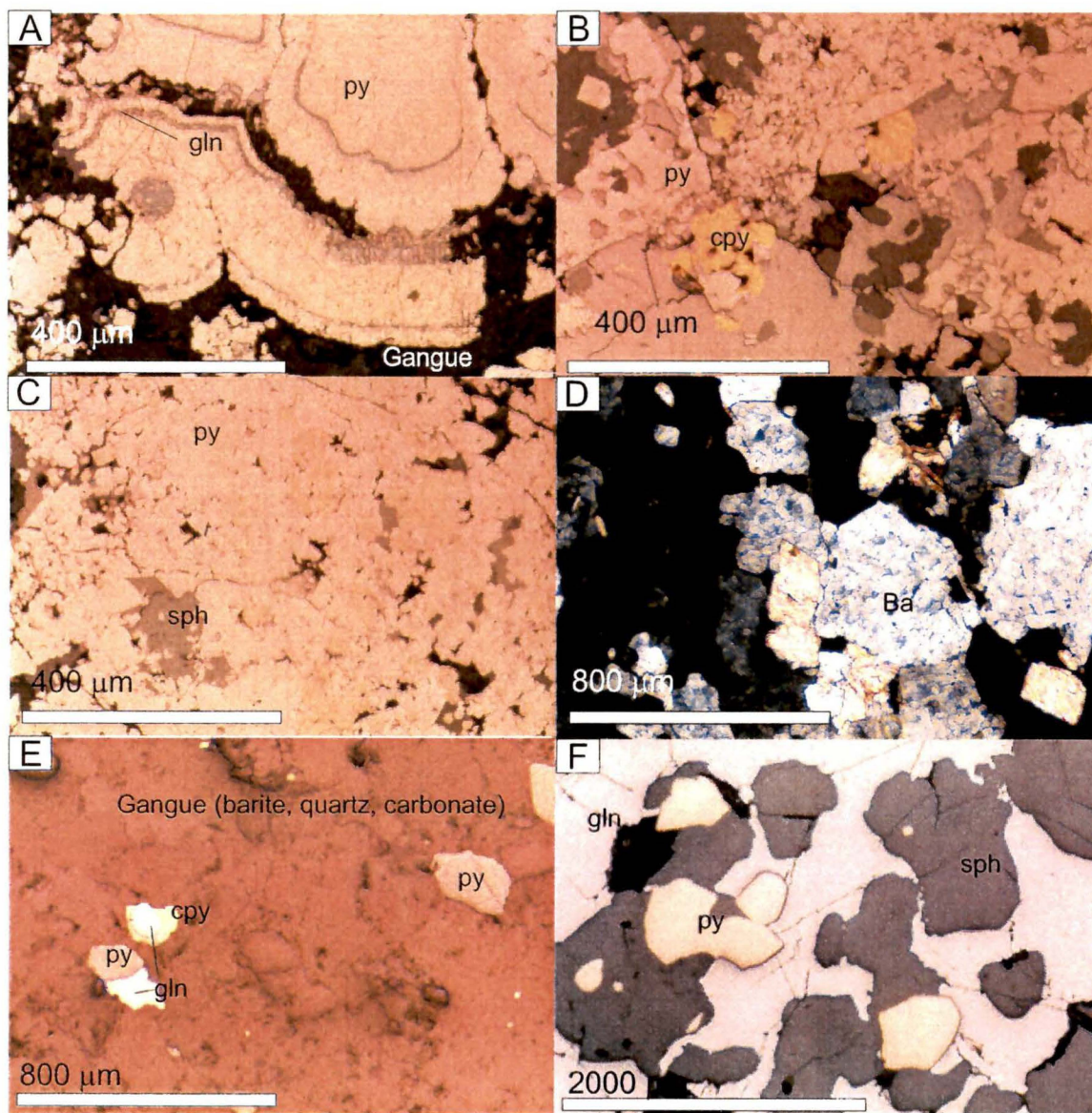


Figure 4.7: Polished thin section photomicrographs (reflected light microscopy) of sulphide occurrences in the Johnson Lake area. A.) Colloform texture: replacement of pyrite by galena. Rea deposit. B.) Fine grained intergrowth of anhedra sulphide crystals, Rea deposit. C.) Fine grained sphalerite inclusions in coarse pyrite, Rea deposit. D.) Coarse barite from the Homestake deposit with carbonate and sericite taken in transmitted light, cross polar. E.) Reflected light photo of D, fine grained disseminated sulphides, Homestake deposit. F.) Coarse inclusions of anhedra pyrite and sphalerite in galena (Twin Mountain occurrence). Sulphide abbreviations are: gln=galena, py=pyrite, cpy=chalcopyrite, sph=sphalerite, tet=tetrahedrite, ba=barite.

Homestake (B.C. Minfile 082M 25)

The Homestake deposit outcrops on the cliffs on the north side of Sinmax creek (see map, appendix 1). The mineralization consists of massive barite/sulphide hosted in fissile sericite-quartz-carbonate $\pm$ pyrite $\pm$ chlorite schist and phyllite of unit 6 (Höy and Gouthier, 1986). The deposit is overlain by a sequence of ankeritic phyllite, argillite and tuffaceous chlorite schist (Höy and Gouthier, 1986). Present reserve estimates are listed in Table 4.1 (after Carmichael, 1991). Thin chert and argillite beds are intercalated with quartz sericite schist. Foliation and compositional layering dip at moderate angles to the east, and the deposit is interpreted to be in an upright sequence of Unit EBA (unit 6 this study) of Schiarizza and Preto (1987). Massive sulphide/barite overlie a thick sequence of sericite-quartz-pyrite alteration, and further substantiates the upright interpretation for this package of rocks. Pervasive alteration near the Homestake deposit has obliterated all primary textures. However, phenocrysts of plagioclase and broken and embayed quartz crystals are present along strike, suggesting that the schists have felsic volcanic protoliths.

The mineralization consists of at least three tabular bodies (Höy and Gouthier, 1986). The lower zone is massive barite containing several percent, fine-grained disseminated sulphides (Fig. 4.7 including; pyrite, sphalerite, galena, and tetrahedrite-tennantite (Fig. 4.7). The upper zone consists of thin sulphide lenses up to 1 metre in thickness, interspersed with quartz sericite schist, and cut by quartz veins. The sulphide minerals consist of pyrite, galena, sphalerite, tetrahedrite, chalcopyrite, argentite, native silver, and traces of native silver and gold (Höy and Gouthier, 1986).

Agate (B.C. Minfile 82M 53)

The Agate prospect lies on the shoreline of Adams Lake in Squam Bay (see map, appendix 1). Agate consists of quartz veins containing pyrite, sphalerite, galena and chalcopyrite mineralization over a strike length of 800m in quartz-sericite-pyrite-schist hostrocks. Work on the Agate occurrence dates back to the turn of the century, when an adit was constructed to follow the mineralization downdip (see minfile reports).

Stake (B.C. Minfile 082M 107)

The Stake showing is located 2 kilometres north-northwest of the Homestake mine. It consists of pyrite, sphalerite and galena hosted in sericite-quartz schist of unit 6. This showing was not visited during the present study, but is listed in the British Columbia mineral inventory file. Minnova Minerals Inc. tested this zone with two drill holes in 1989; no significant mineralization was intersected (B. Friesen, per comm 2000).

Twin Mountain (B.C. Minfile 082M 20)

The Twin Mountain occurrence consists of galena, sphalerite, chalcopyrite, and pyrite mineralization in carbonate-quartz veins, and sulphide-barite lenses. Hostrocks consist of sericitized and silicified schists derived from mafic volcanic flows and volcanoclastic rocks. The property was explored by Camoose Mines Ltd during the 1950's, and was reexamined during the 1980's by Corporation Falconbridge Copper. Drilling intersected 2.37 metres assaying 10.6 grams per tonne gold, 335.3 grams per tonne silver, 3.13 percent zinc, 2.74 percent lead and 0.55 percent copper (George Cross

Newsletter #237, 1987). Galena was the dominant sulphide mineral found in quartz-carbonate veins during this study and has inclusions of sphalerite and pyrite (Fig. 4.7).

Acacia (B.C. Minfile 082M 75)

The Acacia showing is located in the western part of the map area (appendix 1) and consists of coarse red to brown sphalerite in quartz veins. The hostrocks are east trending, south dipping fissile sericite-quartz-chlorite-carbonate-biotite schist. This occurrence is hosted within a metasedimentary/metavolcanic succession along the north margin of a Devonian intrusion (see map appendix 1). Three adits were constructed in the early 1900's to follow the mineralization down dip. The mineralization was described in mineral inventory file reports as banded sulphides. This could not be substantiated in the field; the mineralization seen in the tailings from the adits consisted of coarse sphalerite hosted in milky white quartz veins.

SULPHUR ISOTOPES

Sulphur isotope compositions were measured on sulphide and sulphate minerals to evaluate sulphur sources and characteristics of sulphide occurrences in the Eagle Bay Assemblage (see appendix IV) and compare them to known values for Kuroko-type VMS deposits. Sulphide and sulphate minerals were hand picked from crushed rock samples, and powdered with a ceramic pestle and mortar. Powdered sulphide samples were mixed with vanadium pentoxide and combusted on a CE elemental analyzer followed by gas chromatographic separation of the SO₂ gas. Sulphates were combusted with copper oxide at 1100 °C and SO₂ cryogenically separated. The sulphur isotopes of the SO₂ gas were

subsequently measured on a VG SIRA 12 mass spectrometer. A detailed description of the techniques used in this study is given in appendix IV and are slightly modified from techniques described by Rees and Holt (1991), and Sasaki et al. (1979). The isotopes are referenced to Cañon Diablo troilite and reported as $\delta^{34}\text{S}\text{‰}$ based on the equation (Ohmoto et al, 1982):

$$\delta^{34}\text{S}\text{‰} = \{(R_i/R_{\text{cdt}}) - 1\} \times 1000$$

where

$R_i = {}^{34}\text{S}/{}^{32}\text{S}$ of the sample

$R_{\text{cdt}} = {}^{34}\text{S}/{}^{32}\text{S}$ of standard (Canon Diablo troilite)

Barite from the Homestake ($\delta^{34}\text{S}\text{‰} \approx 35$) and Rea deposits ($\delta^{34}\text{S}\text{‰} \approx 21$) has a $\delta^{34}\text{S}$ signature reflecting mixing of hydrothermal sulphate with seawater sulphate (Ohmoto et al, 1982). Secular curves of $\delta^{34}\text{S}$ for barite (anoxic bottom water conditions) during Late Devonian-Early Mississippian in the Cordillera are determined from the Selwyn Basin and range from +30 to +45 ‰ (Goodfellow, 1987; Shanks et al., 1987). Global values for $\delta^{34}\text{S}$ determined from marine evaporates ranges from +20 $\approx$ +26‰ during Late Devonian-Early Mississippian (Claypool et al., 1980).

The $\delta^{34}\text{S}$ of the sulphide phases range from +2.7 to +6.2 ‰ at the Rea deposit. Sulphides could not be sampled from the massive sulphide lense at the Homestake deposit as it is not exposed at surface, however, pyrite from quartz veins return a $\delta^{34}\text{S}$ value of +7 ‰ (Fig. 4.8). Pyrite, chalcopyrite, and tetrahedrite from epigenetic veins in the Samatosum deposit have $\delta^{34}\text{S}$ values ranging from 4.9 to 8.3 ‰. Sphalerite in quartz veins at the Acacia occurrence has $\delta^{34}\text{S}$ of 1.9-2.1 ‰. Cubic to subhedral pyrite from black phyllite of unit 10 has $\delta^{34}\text{S}$ values ranging from -8.5 to -19 ‰ interpreted to be either diagenetic or metamorphic in origin.

In summary, most of the mineral occurrences have sulphides within the range for Kuroko-type deposits, and barite (if present) derived from a mixed hydrothermal and seawater sulphate source. Coarse vein sulphides from the Samatosum deposit have slightly higher $\delta^{34}\text{S}$ values than the Rea deposit (Fig. 4.8).

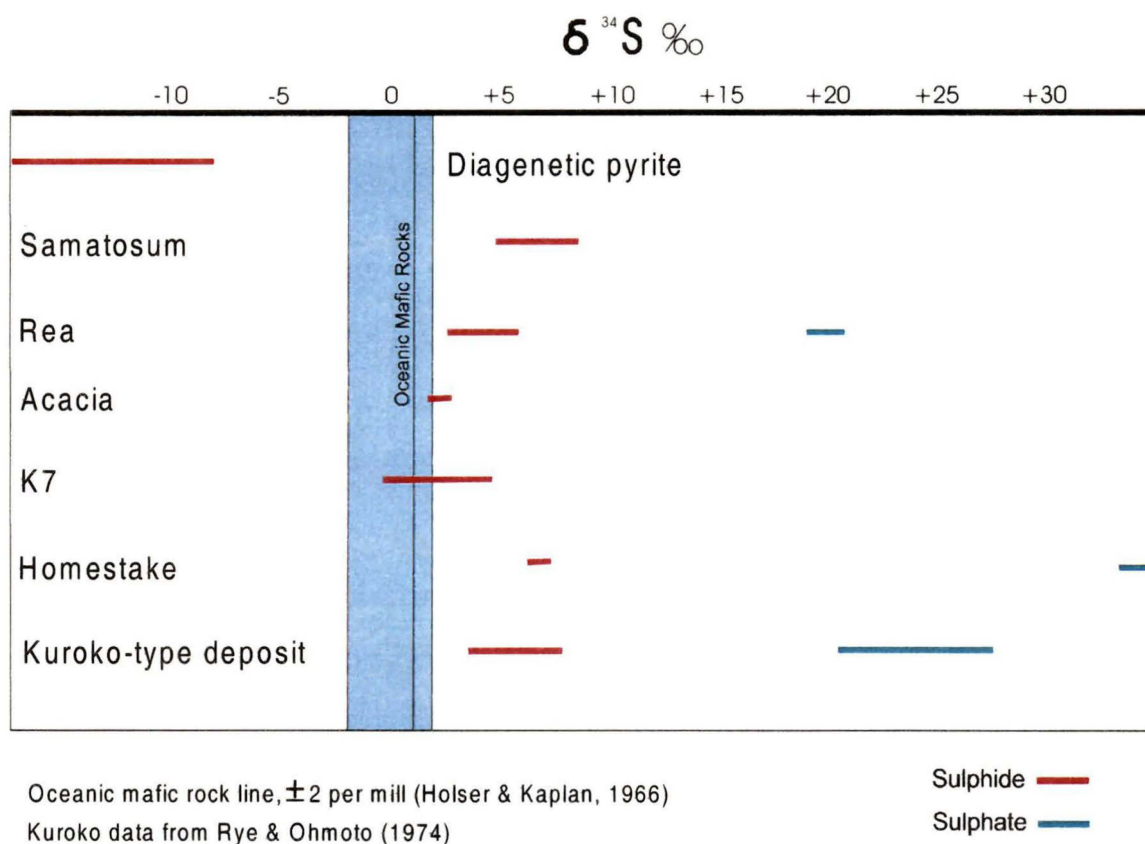


Figure 4.8: Sulphur isotope data from sulphide deposits in the Johnson Lake area, sulphide phases analyzed include pyrite, sphalerite, galena, tetrahedrite, chalcopryrite; the sulphate phase is barite.

DISCUSSION

The stratigraphic and structural setting of the metasedimentary and metavolcanic rocks of the Eagle Bay Assemblage in the Johnson Lake area has important implications for understanding the genesis of the sulphide mineralization. Volcanogenic massive sulphides are hosted in at least two stratigraphic levels of approximately Late Devonian (357-360 Ma) age.

The Rea deposit was interpreted to be part of the Devonian-Mississippian volcanic-sedimentary sequence (Höy and Gouthier 1986). Mafic tuffs (unit 4) in the footwall were correlated to mafic tuffs in the hangingwall of the Rea deposit, and the contact with stratigraphically overlying argillite interpreted to be conformable (Höy and Gouthier 1986). This interpretation of the sequence contrasts with inference of a regional thrust fault along this contact by Schiarizza and Preto (1987). The mafic tuffs in the hangingwall to the Rea deposit have the same geochemical signature as those in the hangingwall to the Samatosum deposit (Bailey et al., in preparation, see map appendix I). Unlike Rea, there are no mafic tuffs in the immediate structural footwall to the Samatosum deposit. It was suggested that the "Silver zone" hosting the Samatosum deposit was a structural repetition of the Rea zone (Pirie, 1989).

Isoclinally folded quartz and carbonate veins and pervasive sericite-quartz-carbonate-pyrite alteration in the structural hanging wall in both the Rea and Samatosum deposits formed prior to metamorphism and F_2 . This alteration may be related to stratiform (VMS) mineralization in the metasedimentary rocks. This indicates a stratigraphic rather than structural relationship for the eastern contact of units 4 and 7. There are no distinctive fault rocks present in this zone (i.e. fault breccia, mylonites) that

can point to a large displacement along this contact. Repetition of the Rea and Samatosum hostrocks (western contact) can be explained by the presence of a steep east-dipping fault. This fault emplaces younger units over older units in this region and may be either an overturned thrust fault or a steep upright thrust fault.

The Samatosum deposit is more complex than the Rea deposit as it includes both syngenetic and epigenetic styles of mineralization. The age of this mineralization is uncertain, and may be either Devonian (Pirie, 1989), or Early Jurassic (Clark and Williams-Jones, 1991). Late sulphide bearing carbonate veins cross-cut Jurassic structures and are evidence of remobilization of preexisting mineralization. Samatosum ore veins belong to one of two potential models (1) A stockwork zone underlying a VMS system or (2) Early Jurassic mesothermal veins overprinting pre-existing VMS type mineralization.

The Homestake and Rea deposits are considered to be volcanogenic massive sulphide deposits (Höy and Gouthier 1986, Höy, 1999). However, the facies of the hostrocks present and the morphology of the deposits indicate that the depositional environments are different between these deposits. Contrary to the argillite and alkalic mafic volcanic succession at Rea, Homestake is hosted within a calc-alkaline felsic volcanic succession. The morphology of the deposits differs considerably; Homestake is a massive barite deposit with minor sulphide lenses, while Rea consists of sheet-like deposits of massive sulphide, with or without a barite cap. These characteristics suggest that these deposits formed at different stratigraphic levels.

U-Pb zircon ages bracket the age of felsic volcanism above and below the mineralization to be within the 357-360 Ma range (Schiarrizza and Preto, 1987, Bailey et

al., in preparation). These ages are similar to ages of felsic rocks and inferred mineralization ages within the Finlayson lake district of the Yukon Territory. Similarities in regional lithologies, tectonic setting and mineral deposits (see chapter 3) between these areas suggests that arc rifting was an important metallogenic event during the 357-360 Ma time frame that extended over a large portion of the ancient Pacific margin.

There is a fundamental change in the depositional environment from Late Devonian to Early Mississippian in the Johnson Lake area. The Late Devonian volcanic rocks of unit 6 are built on a dominantly shallow submarine passive margin siliciclastic sequence. However, this depositional environment changes to deep marine turbidite sedimentation of unit 10 in the Mississippian.

A model for the formation of the Homestake deposit is illustrated in Figure 4.9. Homestake is hosted in a felsic volcanic pile overlying a siliciclastic sequence consisting of quartzite, black phyllite, quartz sericite schist, and quartz-lithic pebble conglomerate. The presence of thick siliciclastic sequences in the stratigraphic footwall to massive sulphide deposits are recognized in other VMS districts such as Bathurst (Goodfellow, 2002; van Staal et al., 1991). Siliciclastic rocks are thought to play an intricate role in mineralization by acting as a porous, permeable reservoir that allows abundant fluid circulation, and a broad source region for metals (Goodfellow, 2002).

The mineralization at Homestake consists primarily of massive barite with minor massive sulphide bands and is similar to shallow submarine VMS deposits described by Shanks et al. (1987) and Hannington (1995). The closest ancient analogue is the Brewer gold deposit in Carolina; a massive barite deposit containing elevated gold and silver values, hosted in a Neoproterozoic calc-alkaline volcanic arc complex (Foley et al.,

2001). Modern analogues are “white smoker” hydrothermal vents (<250 degrees temperature) that produce primarily barite with minor sulphide deposits. Such deposits are recognized in the Kita-Bayonnaise Calderas of the Izu-Bonin Arc (Iizasa et al., 1992) and Palinuro Seamount in the Tyrrhennian Sea (Minnitti and Bonavia, 1984).

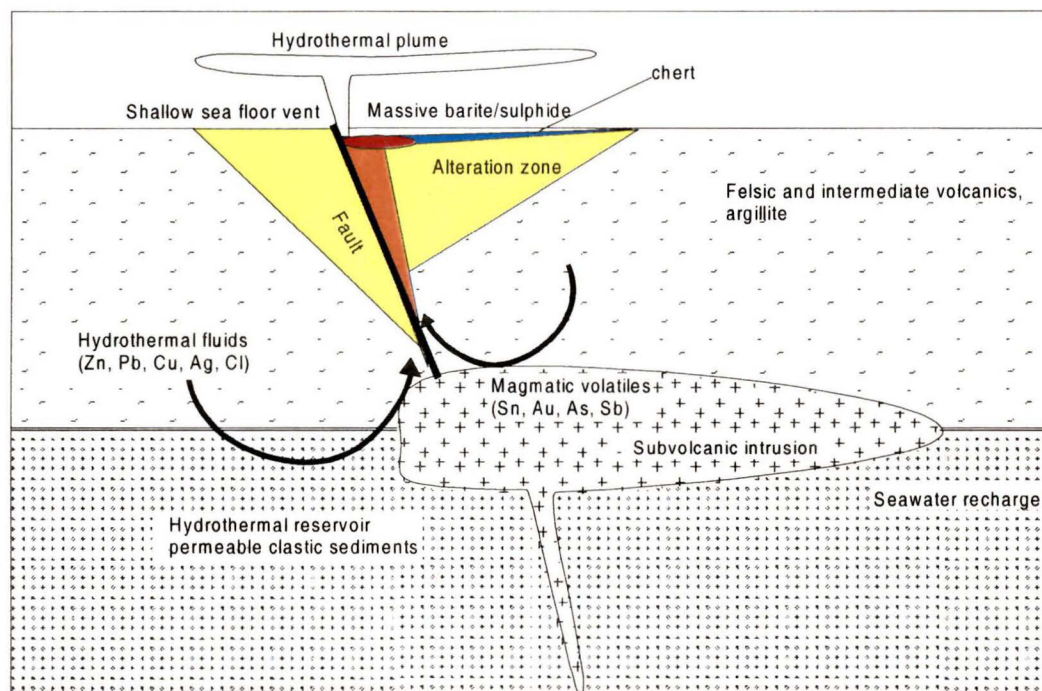


Figure 4.9: VMS model for the Homestake deposit, (modified after Goodfellow, 2002). Heat derived from the volcanics, and subvolcanic intrusion leads to a hydrothermal circulation cell, fluids are seawater and magmatic derived fluids. Venting of these fluids onto the seafloor along fault controlled conduits leads to the precipitation of massive barite/sulphide deposits. The underlying siliciclastic sequence may have provided a good reservoir/ permeable unit from which metals are partially derived, the relatively impermeable overlying rocks would help to focus fluid flow along structures.

A model for the formation of the Rea deposit is illustrated in Figure 4.10. Rea is hosted in an altered turbidite sequence stratigraphically above an alkalic mafic volcanic/volcaniclastic sequence. Höy and Goutier (1986) suggested that the mineralization was coeval with the waning stages of alkalic mafic volcanism. The presence of dominantly fine-grained argillite to quartz wacke suggests that this deposit formed at depths considerably deeper than Homestake. Modern continental marginal

basins may be up to 2000 metres in depth, such as the Okinawa trough behind the Ryuku arc of Japan (Halbach et al, 1989; 1993).

The Rea deposit consists of a massive sulphide deposit with a barite cap. It has low copper values and enrichment in As, Sb, and Hg. The sulphide minerals of the Rea deposit, and associated elements are similar to Kuroko-type massive sulphide deposits (Ohmoto et al., 1983; Halbach et al., 1993; Franklin, 1993), although the morphology of the deposit is analogous to Besshi type massive sulphides (sediment hosted, sheet-like deposit; Mitchell and Bell, 1973; Slack, 1993). Thus, the Rea deposit may be considered to be a hybrid deposit type between these two end member models.

A modern analogue of the Kuroko-type deposits is currently forming in the Jade hydrothermal field (Halbach et al., 1989; 1993). The broad rock associations and deposit types in this portion of the Okinawa trough are similar to the Johnson lake area and may be an analogous depositional environment and tectonic setting (See chapter 3). The Jade hydrothermal field occurs at a fault intersection within a caldera in the Okinawa trough. The tectonic setting is an incipient back arc basin developing behind the Ryuku arc. The Okinawa trough is floored by oceanic crust at its southern extent. However, it is underlain by a sliver of continental crust rifted from the Eurasian continental margin at its northern extent in the region of the Jade hydrothermal field. The magmatism in this zone is bimodal, consisting of felsic volcanic rocks and alkalic basalt. Sediments are derived both from the Eurasian continent and from the Ryuku and Japanese arc systems. There are accumulations of 300 metres of Pleistocene argillite to quartz wacke in the basin. Massive sulphide samples recovered from the Jade Hydrothermal Field described by Halbach et al. (1993) have mineral assemblages including barite as the dominant sulphate

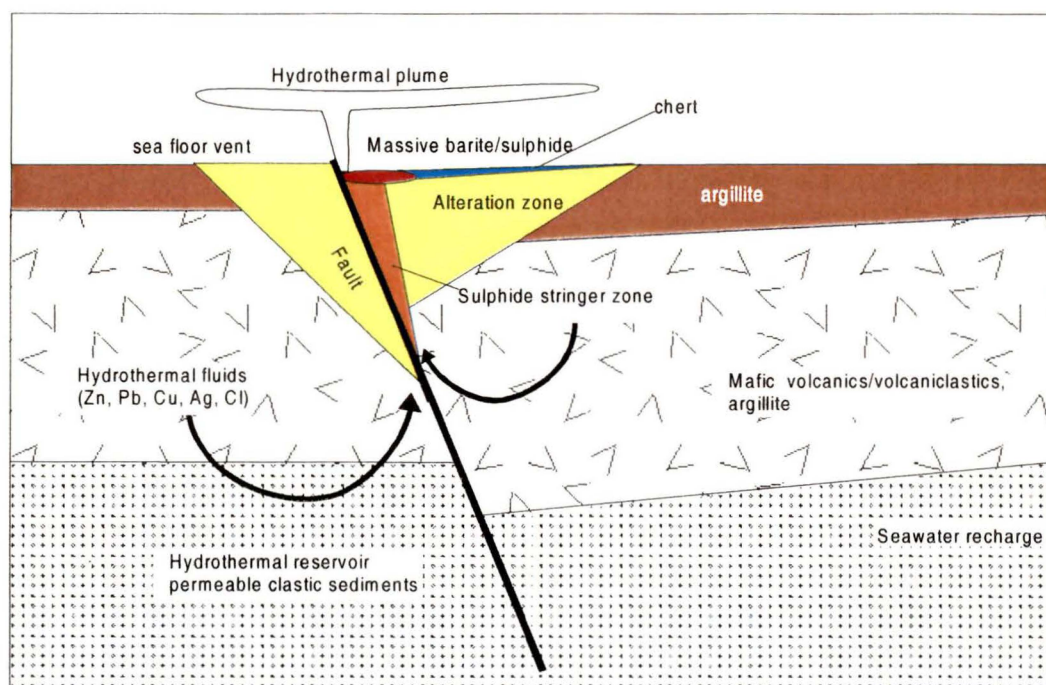


Figure 4.10: Hydrothermal model of the Rea deposit (and Samatosum syngenetic mineralization). Heat derived from the volcanics, results in the development of hydrothermal circulation during late stages of alkalic mafic volcanism, fluids are seawater and magmatic derived fluids. Venting of these fluids onto the seafloor along fault controlled conduits lead to the precipitation of massive barite/sulphide deposits (modified after Goodfellow, 2002).

mineral, and laminated sulphides consisting of pyrite, sphalerite, galena, chalcopryrite, tetrahedrite-tennantite and realgar.

Rea and Samatosum have geochemical signatures consisting of high concentrations of As, Sb, Hg, Au and Ag (Bobrowsky et al., 1997; Lett et al., 1998; also see geochemical analysis appendix II). These signatures are interpreted to reflect input from magmatic volatiles (Goodfellow, 2002), and/or low temperature aqueous complexing of the epithermal suite of elements (As, Sb, Hg; Hannington, 1995). Rea could also potentially be interpreted as a lateral equivalent of the Homestake deposit, formed on the flanks of the volcanic complex in a deeper sedimentary dominated environment.

CONCLUSIONS

The Samatosum and Rea deposits are contained in a similar overturned sequence of greenschist metamorphic grade sericitized, silicified and carbonaceous argillites that are structurally overlain by mafic volcanoclastic rocks and flows. Lead isotopes from the Rea deposit suggest a Late Devonian age (Goutier, 1986), supporting the speculation (Höy and Gouthier, 1986; Pirie, 1989) that hostrocks to the Rea and Samatosum deposits belong to the Devonian-Mississippian succession of the Eagle Bay Assemblage.

Mineralization styles reflect both shallow submarine massive-barite formed in a submerged volcanic arc (Homestake) and polymetallic massive sulphide/barite deposits (Rea, Samatosum) that formed during rifting of a volcanic arc. The Samatosum deposit consists of both syngenetic and epigenetic styles of mineralization. The age of the syngenetic mineralization is Devonian, whereas epigenetic mineralization is pre-Middle Jurassic, and may reflect either (1) Early Jurassic remobilization of pre-existing sulphide mineralization or (2) A Devonian VMS stockwork.

REFERENCES

- Bailey, S.L., Paradis, S., Johnston, S.T.
In preparation: Geology of the Johnson Lake Area: 1: 20, 000 scale map, Geological Survey of Canada, Open File # 1234.
- Bailey, S.L., Johnston, S.T., Paradis, S.
In preparation: Stratigraphy and Structure of the Eagle Bay Assemblage In the Johnson Lake Area, Southern British Columbia.
- Bailey, S.L., Johnston, S.T., Paradis, S.
In preparation: Geochemistry, Geochronology, and Tectonic setting of metavolcanic rocks from the Eagle Bay Assemblage, Johnson Lake area, Southern British Columbia, Canada.
- Bobrowsky P.T., Leboe, E.R., Dixon-Warren, A., Ledwon, A., MacDougall, D., Sibbick, S.
 1997: Till geochemistry of the Adams Lake Plateau-North Barriere lake Area; British Columbia Ministry of Employment and Investment, open file 1997-9, 263 p.
- Carmichael, R.G.

- 1991: 1990 Final Report on the Kamad Claims, Homestake Canada Ltd. Internal Report.
- Clark, J.R, and Williams-Jones, A.E.
 1991: Samatosum Research Project, Unpublished reports to Minnova Inc, McGill University.
- Claypool, C.E., Hosler, W.T., Saki, I.R., and Zak, I.
 1980: The age curves for sulphur and oxygen isotopes in marine sulphate and their mutual interpretation; *Chemical Geology*, v. 28, pages 199-260.
- Foley, N., Ayuso, R.A., Seal, R.
 2001: Remnant colloform pyrite at the Haile gold deposit, South Carolina; a textural key to genesis; *Economic Geology*, v.96, No. 4, Pages 891-902.
- Franklin, J.M.
 1993: Volcanic Associated massive sulphide deposits; *Kirkham, R.V., Sinclair, W.D., Thorpe, R.I., and Duke, J.M., eds. Mineral Deposit Modeling: Geological Association of Canada, Special paper 40*, p. 315-334.
- Friesen, B.
 1991: Unpublished cross sections, Samatosum mine, 1: 250 and 1: 500 scale, Minnova Inc.
- The George Cross Newsletter #237, 1987.
- Goodfellow, W.D.
 1987: Anoxic stratified oceans as a source of sulfur in sediment-hosted stratiform Zn-Pb deposits (Selwyn Basin, Yukon, Canada); *Chemical Geology*, v. 65, pages 359-382.
- Goodfellow, W.D.
 2002: Current Understanding of the origin of massive sulphide deposits in the Bathurst mining camp, northern New Brunswick, in *The Gangue*, issue 72, pages 1-10.
- Gouthier, F.
 1986: Galena lead isotope study of mineral deposits in the Eagle Bay Formation, Southeastern British Columbia. Unpublished M.Sc. Thesis, University of British Columbia, 152 pages.
- Halbach, P., Pracejus, B.
 1993: Geology and Mineralogy of Massive Sulphide Ores from the Central Okinawa Trough, Japan, *Economic Geology*, v. 88, pages 2210-2225.
- Halbach, P., Nakamura, K., Wahsner, M., Lange, J., Sakai, H., Kaeseltz, L., Hansen, R.D., Yamano, M., Post, J., Prause, B., Seifert, R., Michaelis, W., Teichmann, F., Kinoshita, M., Maerten, A., Ishibashi, J., Czerwinski, S., Blum, N.
 1989: Probable modern analogue of kuroko-type massive sulphide deposits in the Okinawa Trough back-arc basin, *Nature* V.338 Pages 496-499.
- Hannington, M.
 1995: Gold rich Volcanogenic massive sulphide deposits, in *Current mineral deposit models of the Canadian Cordillera*. British Columbia Geological Survey, Short Course.
- Holser, W.T., Kaplan, I.R.
 1966: Isotope geochemistry of sedimentary sulfates, *Chemical Geology*. V.1 no.2, pages 93-135.

Höy, T. and Goutier, F.

- 1986: Rea Gold (Hilton) and Homestake volcanogenic sulphide – barite deposits, southeastern British Columbia (82M/4W); in *Geological Fieldwork 1985*; British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1986-1.

Höy, T.

- 1987: Alteration, chemistry and tectonic setting of volcanogenic massive sulphide–barite deposits at Rea Gold and Homestake Southeastern British Columbia in *Exploration in British Columbia 1986*, British Columbia Ministry of Energy, Mines and Petroleum Resources, pages B7-B19.

Höy, T.

- 1999: Massive sulphide deposits of the Eagle Bay Assemblage, Adams Plateau, south-central British Columbia (082M 3, 4); in *Geological Fieldwork 1998*; British Columbia Ministry of Energy and Mines, Paper 1999-1, p. 223-245.

Iizasa, K., Yuasa, M., Yokota-S

- 1992: Mineralogy and geochemistry of volcanogenic sulfides from the Myojinsho submarine caldera, the Shichito-Iwojima Ridge, Izu-Ogasawara Arc, northwestern Pacific; *Marine Geology*, v.108; 1, pages 39-57.

Lett, R.E., Sibbick, S., Runnells, J.

- 1998: Regional Stream Water Geochemistry of the Adams Lake-North Barriere Lake Area, British Columbia (NTS 82M/04 82M/05), British Columbia Ministry of Employment and Investment, open file 1998-9.

Minniti, M. Bonavia, F.F.

- 1984: Copper-ore grade hydrothermal mineralization discovered in a seamount in the Tyrrhenian Sea (Mediterranean): Is the mineralization related to porphyry coppers or to base metal lodes? *Marine Geology*, v.59, pages 271-282.

Mitchell, A.H. and Bell, J.D.

- 1973: Island Arc evolution and related mineral deposits; *Journal of Geology*, v.81, pages 381-405.

Murphy, D. and Piercey, S.J.

- 1999: Finlayson Project: Geological Evolution of the Yukon-Tanana Terrane and it's relationship to Campbell River Range belt, Northern Wolverine Lake Map area, Southeastern Yukon, in *Yukon Exploration and Geology 1998*; Exploration and Geological Services Division, Indian and Northern Affairs Canada, pages 47-62.

Nagase T., and Kojima, S.

- 1997: An SEM examination of the chalcopyrite disease texture and it's genetic implication; *Mineralogical magazine*, v. 61, No 404, pages 89-98.

Ohmoto, H., and Lasaga, A.C.

- 1982: Kinetics of reactions between aqueous sulphates and sulphides in hydrothermal systems: *Geochimica et Cosmochimica Acta* v. 46, pages 1727-1745.

Ohmoto, H., Mizukami, M., Drummond, S.E., Eldridge, C.S., Pisutha-Arnond, v. and Lenagh, T.C.

- 1983: Chemical processes of Kuroko formation; in Ohmoto, H., and Skinner, B.J., eds., *Kuroko and related volcanogenic massive sulphide deposits*; *Economic Geology, Monograph 5*, pages 570-604.

Oliver, J.C., and Marr, J.M.

- 1987: 1986 Final Report, Kamad Claims; Esso Minerals Canada, Technical Report.

Piercey, S.J. Paradis S., Murphy D.C., Mortensen J.K.

2001: Geochemistry and paleotectonic setting of felsic volcanic rocks in the Finlayson Lake volcanic-hosted massive sulphide (VHMS) district, Yukon, Canada, *Economic Geology* v. 96, pages 1877-1906.

Pirie, I. (1989): The Samatsum Deposit; *The Northern Miner Magazine*, June 1989, p. 15-18.

Rees, C.E., Holt, B.D.

1991: The isotopic analysis of sulphur and oxygen: in *Stable isotopes in the assessment of natural and anthropogenic sulphur in the environment*, H.R. Krouse and V.A. Grinenko (eds.). New York, Wiley, pages 43-64.

Rye, R.O., Ohmoto, H.

1974: Sulfur and Carbon Isotopes and Ore Genesis: A Review, in *Stable Isotopes as Applied to Problems of Ore Deposits*, *Economic Geology*, V. 69; 6, pages 826-842.

Sasaki, A., Arikawa, Y. Folinsbee, R.E.,

1979: Kiba reagent method of sulphur extraction applied to isotope work. *Bulletin, Geological Survey of Japan*, v. 30, pages 1347-1353.

Schiarizza, P. and Preto, V.A.

1987: Geology of the Adams Plateau-Clearwater-Vavenby area; British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1987-2.

Shanks, W.C., III, Woodruff, L.G., Jilson, G.A., Jenninngs, D.S., Modene, J.S. and Ryan, B.D.,

1987: Sulphur and lead isotope studies of stratiform Zn-Pb-Ag deposits, Anvil Range Yukon: Basinal brine exhalation and anoxic bottom water mixing; *Economic Geology*, v.82, pages 600-634.

Slack, J.F.

1993: Descriptive and grade-tonnage models for Besshi-type massive sulphide deposits. *Kirkham, R.V., Sinclair, W.D., Thorpe, R.I., and Duke, J.M., eds Mineral Deposit Modeling: Geological Association of Canada, Special paper 40, p. 343-371.*

van Staal, C.R., Winchester, J.A., Bedard, J.H.

1991: Geochemical Variations in Middle Ordovician volcanic rocks of the northern Miramichi Highlands and their tectonic significance; in *Canadian Journal of Earth Sciences*, v. 28, pages 1031-1049.

White, G.P.E.

1985: Hilton Massive Sulphide discovery (Rea Gold), Johnson Creek- Adams Lake Area (82M/4W), B.C. Ministry of Energy, Mines and Petroleum resources, *Geological Fieldwork*, paper 1985-1, pages 77-83.

CHAPTER 5: CONCLUSIONS

STRATIGRAPHY

Lower Paleozoic rocks consist of alkalic (with minor subalkaline) basalts, carbonate and siliciclastic rocks that formed in an intracontinental rift basin (Höy 1999; Bailey et al., 2001) in shallow and deep marine conditions. The age constraints are based on correlation of this package with rocks near Vavenby (30 km north of the study area) that contain the archaeocyathid bearing (Lower Cambrian) Tshinakin Limestone (Schiarizza and Preto, 1987). These rocks structurally overlie a Middle Paleozoic sequence along the Haggard Creek thrust fault.

The Middle Paleozoic sequence consists of siliciclastic rocks, calc-alkaline and alkaline felsic to intermediate volcanic rocks and subvolcanic intrusions. A Late Devonian age for felsic volcanic rocks is indicated by U-Pb zircon geochronology. Argillite, quartz wacke, and quartz pebble conglomerate are Devonian to Mississippian turbidite deposits, exposed on the overturned limb and in the core of the Shafer lake syncline and mark the transition from a volcanic dominated to a sedimentary basin.

STRUCTURE

Lower Paleozoic rocks are structurally emplaced over Middle Paleozoic rocks along the Haggard Creek fault. The Shafer lake syncline strikes and plunges northwest, and is an overturned syncline in the footwall to the Haggard Creek fault. The Samatosum zone is a structural repetition of the Rea zone and occurs as a “thrust sliver” within late splays off the Haggard Creek fault. The Haggard Creek fault cuts the Shafer Lake

syncline, thus postdates it. Thrust faults follow ramp and flat geometries, north-striking faults cut across stratigraphy (ramp) whereas northwest striking thrust faults are parallel to the regional stratigraphy (flat). Regionally, the thrust flats are parallel to stratigraphy indicating that they follow bedding plane weaknesses. Furthermore, the thrusts share strike with the axial planes to F2 folds indicating that the Haggard Creek, Samatosum Mountain, and Samatosum Creek faults are late faults in an overall Jurassic-Cretaceous fold and thrust belt.

GEOCHEMISTRY

Lower Cambrian mafic volcanic rocks have both MORB (unit 2) and OIB (unit 3a) type geochemical signatures. The MORB type rocks have ϵNd_{540} signatures indicating a juvenile mantle source region (+8). OIB rocks have a slightly less positive ϵNd_{540} signature (+4-+5) indicating that these rocks were derived from a recycled crustal component.

Felsic and intermediate volcanic rocks of unit 6 have a calc-alkaline geochemical signature, with marked enrichments in HFSE and HREE compared to unit 9. Negative Eu anomalies in this unit may be attributed to high temperature alteration of felsic volcanic rocks during alteration related to massive sulphide genesis. These rocks also have marked negative Nb and Ti anomalies similar to volcanic arc magmas (Jenner, 1996). Unit 6 is intruded by granite-granodiorite of identical geochemical signature. Felsic and intermediate volcanic rocks of unit 9 are more alkalic than unit 6 based on Nb/Y values (>0.7), and have no known mineralization associated with them. The ϵNd values in these

rocks are less juvenile (-1 to -2.6) and coupled with the presence of a Late Neoproterozoic zircon xenocryst indicate derivation from or contamination by Late Neoproterozoic continental crust.

MINERAL OCCURRENCES

The contact between unit 4 and unit 7 along the Rea and Samatosum zones is likely stratigraphic because; (1) At Rea the metasedimentary rocks are intercalated with mafic tuffs correlated to overlying mafic tuffs and volcanic/volcaniclastic rocks. (2) The mineralization at Rea includes fine grained stratiform banded sulphides in a siliceous gangue, similar textures are identified at Samatosum suggesting a component of syngenetic mineralization. (3) A pervasive alteration “envelope” of sericite, pyrite, quartz, carbonate, and fuchsite is developed in the mafic volcaniclastic rocks structurally overlying the Samatosum and Rea deposits, potentially of the same age as the syngenetic mineralization.

Mineralization styles reflect both shallow submarine massive barite developed in a submerged volcanic arc (Homestake) setting and polymetallic massive sulphide/barite deposits (Rea, Samatosum) that formed in a deeper marine environment during rifting of the volcanic arc. The Samatosum deposit has both syngenetic and epigenetic styles of mineralization. The age of the epigenetic mineralization determined from Ar-Ar sericite ages is pre-Middle Jurassic, and likely reflects upgrading and remobilization of pre existing mineralization.

Sulphur isotopes from these deposits share similarities to the Kuroko-type deposits. This includes a mixed hydrothermal fluid, seawater sulphate source and

sulphides with $\delta^{34}\text{S}$ values ranging from -1 to $+8$ ‰. Samatsum has higher $\delta^{34}\text{S}$ values than the Rea deposit (4-8‰) that may reflect remobilization of mineralization and addition of sulphur from metasomatic fluids.

TECTONIC SETTING

Lower Paleozoic rocks in the Johnson lake area are the remnants of an intracontinental rift basin. Evidence for this includes: 1.) Eruption of a thick sequence of alkalic basalt on shallow marine siliciclastic sequences (2) This eruption was periodic with intervening sedimentary depositional events, including deposition of a thick carbonate sequence in a shallow marine environment, and deposition of subalkaline basalt, chert and pelite in a deep marine environment and (3) The formation of sedimentary exhalative (SEDEX) deposits.

Devonian to Early Mississippian intermediate and felsic volcanic rocks in the Johnson lake area are the metamorphosed and polydeformed remnants of a Middle Paleozoic rifted volcanic arc, and provide a record of extensional tectonics in the western North American Plate margin in an overall convergent margin setting. Calc-alkaline felsic volcanic hostrocks to the Homestake deposit and have similar geochemical attributes to felsic volcanic rocks that host VMS deposits in Finlayson Lake, Bathurst and the Mt. Windsor Subprovince.

The evidence for a rifted volcanic arc includes: (1) A transition from calc-alkalic to alkalic volcanism (2) A change in sedimentation style from quartzite, limestone, pebble conglomerate, and shale typical of a passive continental margin sedimentary sequence to argillite, quartz wacke and pebble conglomerate typical of deep marine

turbidites; and (3) The transition from shallow submarine volcanogenic massive barite deposits to deeper marine volcanogenic massive sulphide deposits.

REFERENCES

Bailey, S.L., Paradis, S., Johnston, S.T.

2001: New insights into metavolcanic successions and geochemistry of the Eagle Bay Assemblage, South Central British Columbia; Geological Survey of Canada, Current Research 2001-A8, 13 p.

Höy, T.

1999: Massive sulphide deposits of the Eagle Bay Assemblage, Adams Plateau, south-central British Columbia (082M 3, 4); *in* Geological Fieldwork 1998; British Columbia Ministry of Energy and Mines, Paper 1999-1, p. 223-245.

Jenner, G.A.

1996: Trace element geochemistry of igneous rocks: Geochemical nomenclature and analytical geochemistry; *in* Trace Element Geochemistry of Volcanic Rocks: Applications for Massive Sulphide Exploration, Wyman D.A. (ed.); Geological Association of Canada, Short Course notes, v. 12, p. 51-77.

Schiarizza, P. and Preto, V.A.

1987: Geology of the Adams Plateau-Clearwater-Vavenby area; British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1987-2.

APPENDIX I

**Geological Descriptions
Petrographic Descriptions
Maps and Sections**



Johnson Lake area: thin section descriptions

Thin section:
SLB99-05

Unit: 4

Location:
Johnson Lake Area

Mineral assemblage:
calcite+ Fe carbonates 40%
chlorite 20%
plagioclase 25%
Fe Oxides/ opaques 11%
biotite 2%
accessories (allanite, epidote) 2%

Description:

Fine grained metabasite, foliation defined by chlorite and biotite, main foliation is crenulated, biotite occurs within and cross cuts the foliation thus is late tectonic to post tectonic. Plagioclase and chlorite aggregates are remnant phenocrysts, porphyroblasts, or amygdules. Plagioclase phenocrysts are anhedral and contain carlsbad twins, occur as single crystals or in aggregates. Allanite and epidote inclusions in chlorite.

Rock name/protolith: calcareous chlorite schist, derived from a mafic volcanic flow (amygdular texture)

Thin section:
SLB99-06a

Unit: 4

Location:
Johnson Lake Area

Mineral assemblage:
Plagioclase 50%
chlorite 20%
opaques and accessories (Fe oxides, allanite, epidote) 15-20%
Carbonates 5%
actinolite 2-5%
quartz 1%

Description:

This sample is a fragment from a flow breccia, the matrix is chlorite schist, amygdules of quartz, calcite, and chlorite. Plagioclase seems to be recrystallized, radiating around amygdule, or as laths in matrix

Rock name/protolith: Amygdular porphyritic metabasalt

Thin section:
SLB99-06b

Unit: 4

Location:
Johnson Lake Area

Mineral assemblage:
chlorite 45%
Plagioclase 40%

opaques (Fe oxides, leucoxene) 5%
allanite and epidote 10%

Description:

chlorite schist, foliation is defined by chlorite, leucoxene and wraps around plagioclase crystals (plagioclase contains twinning/exsolution lamellae, igneous origin) plagioclase crystals are transposed into S_2 .

Rock name/protolith: chlorite schist derived from mafic volcanic

Thin section:

Unit: 2

SLB99-09

Location:

Johnson Lake Area

Mineral assemblage:

Epidote <50%

Chlorite 25%

Carbonates 5%

Quartz 20%

opaques Fe-Ti oxides 1-2%

Description:

Heterogeneous rock. Coarse grained epidote porphyroblasts (may be pseudomorph of plagioclase) in a fine grained matrix of chlorite carbonate and opaques. Quartz present in veins and veinlets. Poorly developed foliation defined by chlorite/opaques.

Rock name/protolith: calcareous greenschist

Thin section:

Unit: 1b

SLB99-11

Location:

Johnson Lake Area

Mineral assemblage:

Quartz 97%

Hematite 2%

Chlorite 1%

Description:

Fine grained (microcrystalline) assemblage of quartz, minor hematite staining and chlorite present.

Rock name/protolith: chert

Thin section:

Unit: 2

SLB99-17b

Location:

Johnson Lake Area

Mineral assemblage:

Actinolite 65%

Epidote 30%

Carbonate 5%

Description: Fine to medium grained rock with poorly developed foliation defined by actinolite, epidote is zoned from core to rim. Epidote appears to be overgrowing fibrous actinolite, thus is paragenetically late.

Rock name/protolith: actinolite-epidote schist derived from mafic flow or intrusive.

Thin section:

SLB99-17C

Unit: 2**Location:**

Johnson Lake Area

Mineral assemblage:

Chlorite 45

Plagioclase 30%

Opaques 10%

Sericite 5%

Carbonate 10%

Description:

Rock contains up to 11% MgO, occurs along a contact between sediments and pillow lava, matrix is fine grained chlorite, plagioclase, and opaques. Chlorite and opaques dominantly define the foliation and wrap around coarse (.5mm) euhedral plagioclase crystals.

Rock name/protolith: Chlorite-plagioclase schist

Thin section:

SLB99-21

Unit: 4**Location:**

Johnson Lake Area

Mineral assemblage:

Chlorite 50%

Plagioclase 15%

Opaques (Fe oxides + leucoxene) 10%

Actinolite 10%

Carbonate 10%

epidote 5%

Description:

Heterogeneous chlorite schist derived from crystal tuff, composed of a fine grained assemblage of chlorite, actinolite, epidote, opaques with coarser anhedral plagioclase, bands of chlorite and epidote are isoclinally folded, S_2 is the axial plane to these folds. Calcite veinlets are parallel to and cross-cut the foliation (yet appears to be slightly folded by it. Calcite alteration likely syn- to post tectonic).

Rock name/protolith: Calcareous Chlorite-plagioclase schist

Thin section: Unit: 4
SLB99-22b

Location:
Johnson Lake Area

Mineral assemblage:

Quartz 65%
Sericite 35%

Description:

Fine grained assemblage of anhedral quartz and sericite, strongly foliation defined by sericite and quartz, matrix quartz is fine grained, veinlet quartz is coarse grained. This rock appears to be an alteration product, no primary textures present.

Rock name/protolith: quartz sericite schist, alteration zone

Thin section: Unit: 4
SLB99-22c

Location:
Johnson Lake Area

Mineral assemblage:

Carbonates 70%
Quartz 15%
Chlorite 10%
Opaques + accessories (allanite) 5%

Description:

Fine grained Calcareous-chlorite-quartz-schist, calcite is coarser grained, chlorite defines the foliation.

Rock name/protolith: Calcareous-chlorite-quartz-schist

Thin section: Unit: 4
SLB99-22d,

Location:
Johnson Lake Area

Mineral assemblage:

Actinolite 50%
Opaques 25%
Plagioclase 10%
Sericite 10%
Chlorite 5%

Description:

Fine grained metasedimentary, appears banded, this is an oriented TS, was looking for graded bedding but none could be unambiguously distinguished, the banding results from compositional differences, there is a C-S fabric developed, dextral shear sense.

Rock name/protolith: actinolite schist, pelite

Thin section: SLB99-24 **Unit:** 7

Location:
Johnson Lake Area

Mineral assemblage:
Quartz 95%
Sericitic, chlorite opaques 5%

Description:
Microcrystalline quartz, no detrital grains of quartz or Fe oxides can be discerned in this rock, in outcrop it lacks bedding. Triple grain boundaries between quartz grains suggest recrystallization, some grains have undulose extinction indicating post crystallization strain. Foliation is defined by sericite, chlorite and Fe oxides which occur along fractures and quartz grain boundaries. Fluid inclusions are abundant, elongate and may record an earlier fabric than defined by sericite, chlorite, opaques. This rock is likely an exhalative chert unit, not a sedimentary chert.

Rock name/protolith: chert

Thin section: SLB99-26 **Unit:** 7

Location:
Johnson Lake Area

Mineral assemblage:
Quartz 55%
Matrix 30%
Lithics 15%

Description:
A coarse grained psammitic schist, quartz grains are up to 1-2mm and are flattened in to the foliation plane, lithic fragments include chert fragments, phyllite, the foliation wraps around euhedral pyrite crystals (pyrite is pre-early tectonic). Matrix is composed of fine grained phyllosilicates (sericite, chlorite), quartz, opaques.

Rock name/protolith: "grits", quartz-lithic phyllite, "quartz lithic sandstone (turbidite)"

Thin section: SLB99-27 **Unit:** 7 alteration

Location:
Johnson Lake Area

Mineral assemblage:

carbonate	65%
Sericite	10%
Fe oxides	10%
Quartz	5%
pyrite	5%
muscovite	5%

Description: dominantly carbonate, some Fe carbonates are present (rusty-yellow weathering handsample, oxide rims on carbonate grains) the foliation is defined by carbonates, sericite and bands of oxides. Pyrite grains have been being corroded and partially replaced by quartz. The foliation wraps around the pyrite grains, and there are quartz grains growing in pressure shadows, thus these are either early tectonic or pre-tectonic in origin.

Rock name/protolith: calcareous-sericite-quartz schist

Thin section:**Unit: 9**

SLB99-30

Location:

Johnson Lake Area

Mineral assemblage:

Quartz	fine grained 25%
	Coarse grained 15%
Sericite	25%
Feldspar	15%
Carbonates	8%
Accessories and opaques	7%
Chlorite	5%

Description:

Quartz sericite schist, fine grained matrix of quartz and sericite, with coarser quartz in porphyroblasts and veinlets, and plagioclase phenocrysts/porphyroblasts. Foliation defined by matrix, chlorite, and wraps around phenocrysts of plagioclase.

Rock name/protolith: Quartz sericite schist, derived from rhyodacitic crystal tuff

Thin section:**Unit: 9**

SLB99-31

Location:

Johnson Lake Area

Mineral assemblage:

Carbonate	15%
Matrix (sericite, quartz, opaques)	40%
Plagioclase phenocrysts	20%
Sanidine phenocrysts	5%
Feldspar (type?) porphyroblasts	10%
Quartz	10%

Description:

.5mm feldspar grains within a matrix of fine grained quartz and sericite. Several feldspar types are present in this sample, subhedral zoned albite and possibly sanidine, there are definitely albite twins present along with carlsbad twinning, these are remnant igneous phenocrysts. Poikilobasts of plagioclase? overprint the fabric. Euhedral carbonate grow at the expense of igneous feldspar. This sample produced zircons yielding a 360 Ma age.

Rock name/protolith: ankerite-quartz-sericite schist, derived from plagioclase porphyritic rhyodacite.

Thin section: Unit: 7
SLB99-32

Location:
Johnson Lake Area

Mineral assemblage:

Quartz 60%
Sericite 25%
Fe oxide 15%

Description:

Foliation defined by sericite and deformed quartz grains, the matrix is fine grained sericite and quartz, quartz grains are single crystals, not aggregates of grains, may be derived from volcanic source.

Rock name/protolith: quartz sericite schist , metapelite (greywacke protolith)

Thin section: Unit: 9
SLB99-33

Location:
Johnson Lake Area

Mineral assemblage:

Carbonate	15%
Matrix (sericite, quartz, opaques)	40%
Plagioclase phenocrysts	20%
Sanidine phenocrysts	5%
Feldspar (type?) porphyroblasts	10%
Quartz	10%

Description:

Much like SLB99-31, Foliation defined by sericite and quartz grains, the matrix is fine grained sericite and quartz, plagioclase phenocrysts present, quartz crystals are partially embayed. Euhedral Fe carbonate crystals have been partially dissolved and oxidized, form rusty weathering crystals. Feldspars have been largely replaced by sericite and carbonate.

Rock name/protolith: quartz sericite schist , metapelite (greywacke protolith)

Thin section: Unit: 3b
SLB99-98

Location:

Johnson Lake Area

Mineral assemblage:

Calcite 95%

Sericite 4 %

Quartz 1%

Description:

Granoblastic assemblage of calcite, grain size <100 um, minor sericite and quartz, S₂ defined by planar alignment of sericite, 1 mm diameter oolites present, sparry calcite cores, with micritic rims within a coarser calcite matrix.

Rock name/protolith: limestone/ marble

Thin section:

SLB00-216B

Unit: 3a**Location:**

Johnson Lake Area

Mineral assemblage: actinolite 40%, epidote, 10%, opaques 30%, chlorite 5%, plagioclase 2-5%, sericite, 10%.

Description: fine grained actinolite schist, S₂ is defined by actinolite, sericite, chlorite, lappili tuff, lapilli have similar composition to matrix, except slightly more epidote

Rock name/protolith: actinolite schist/ mafic lappili tuff

Thin section:

HSB00-03

Unit: 6 "Homestake schist"**Location:**

Johnson Lake Area

Mineral assemblage: quartz 30%, sericite 30% feldspar 15 ? %, carbonate 10% pyrite 3-4%

Description: fine grained assemblage, alternating quartz feldspar layers with sericite rich layers, anhedral grains of Qtz, Ser, Fsp. Intergrown quartz and feldspar crystals, pyrite is euhedral, carbonates subhedral to euhedral, foliation is defined by sericite (at least 2 generations) and wraps around all of the alteration phases.

Rock name/protolith: felsic volcanic, crystal ash tuff?

Thin section:

HSB00-05

Unit: 6 "Homestake schist"**Location:**

Johnson Lake Area

Mineral assemblage: quartz 45 %, sericite 35 %, carbonate 15%, pyrite 3-4%, biotite, 2%

Description: fine grained assemblage, alternating quartz feldspar layers with sericite rich layers, anhedral grains of Qtz, ser, fsp, pyrite is subhedral and partially resorbed, carbonates subhedral to euhedral, foliation is defined by sericite and wraps around all of the alteration phases.

Rock name/protolith: felsic volcanic, crystal ash tuff?

Thin section: Unit: 6 "Homestake schist"
HSB00-06

Location:
Johnson Lake Area

Mineral assemblage: quartz 35 %, Feldspar 35% sericite 20 %, opaques and accessories 10%

Description: fine grained assemblage, euhedral to anhedral (simple twinning present) albite or Ksp grains in a fine grained matrix of Qtz and sericite, these are partially sericite altered, grains up to 0.7 mm in length. anhedral grains of Qtz, ser, the opaque is a rusty brown weathering mineral likely hematite, and appears to represent oxidation possibly of Fe carbonate.

Rock name/protolith: felsic volcanic, crystal ash tuff?

Thin section: Unit: 6 "Homestake schist"
HSB00-07

Location:
Johnson Lake Area

Mineral assemblage: quartz 30%, sericite 30% feldspar 15 ? %, carbonate 10% pyrite 3-4%

Description: fine grained assemblage, alternating quartz feldspar layers with sericite rich layers, anhedral grains of Qtz, ser, fsp. Intergrown quartz and feldspar crystals, pyrite is euhedral, carbonates subhedral to euhedral, foliation is defined by sericite (at least 2 generations) and wraps around all of the alteration phases.

Rock name/protolith: felsic volcanic, crystal ash tuff?

Thin section: Unit: 6 "Homestake schist"
HSB00-08

Location:
Johnson Lake Area

Mineral assemblage: quartz 30%, sericite 30% feldspar 25 %, carbonate 10% pyrite 3-4%

Description: fine grained assemblage, alternating quartz feldspar layers with sericite rich layers, anhedral grains of Qtz, ser, fsp. Intergrown quartz and feldspar crystals, pyrite is euhedral to subhedral, carbonates subhedral to euhedral, foliation is defined by sericite, deformed plagioclase, quartz.

Rock name/protolith: quartz sericite schist/ felsic volcanic, crystal ash tuff?

Thin section:
HSB00-11

Unit: 6 "Homestake schist"

Location:
Johnson Lake Area, B.C.

Mineral assemblage: quartz 30%, sericite 20 % feldspar 25 %, carbonate 20%, biotite 5%

Description: fine grained assemblage, alternating quartz feldspar layers with sericite rich layers, anhedral grains of Qtz, ser, fsp. Intergrown quartz and feldspar crystals, pyrite is euhedral to subhedral, carbonates subhedral to euhedral, foliation is defined by sericite, deformed plagioclase, quartz.

Rock name/protolith: quartz sericite schist/ felsic volcanic, crystal ash tuff?

Polished Thin section:
HSB00-10.1

Unit: massive barite, homestake deposit

Location:
Johnson Lake Area, B.C.

Mineral assemblage: barite <75%, carbonate, 10%, quartz < 10%, sericite 2-3%, sulphides 5%,

Description: (1-2 mm) barite crystals intergrown with medium (1-2 mm) grained carbonate and quartz grains, fine grained sulphides (0.2-0.3mm), fine grained sericite. Sulphides consist of pyrite, sphalerite, galena +/- tetrahedrite, typically anhedral grains, there are a few subhedral (dodecahedral or octahedral?) crystals of tetrahedrite or galena present suggesting replacement of sphalerite or pyrite.

Rock name/protolith: massive barite

Thin section:
HSB00-10.2

Unit: Homestake deposit

Location:
Johnson Lake Area, B.C.

Mineral assemblage: barite <40%, carbonate <30 %, quartz < 10%, sericite 2-3%, sulphides 20 %,

Description: (1-2 mm) barite crystals intergrown with medium (1-2 mm) grained carbonate and quartz grains, coarse sulphides fine grained sericite. Sulphides consist of pyrite, sphalerite, galena +/- tetrahedrite, typically anhedral grains, there are a few subhedral (cubic to octahedral) pyrite grains, these are replaced by sphalerite and galena progressively, galena replaces anhedral sphalerite, some late stage pyrite growth as these contain inclusions of galena. 1-2 mm crystals of sulphides.

Rock name/protolith: massive barite

Thin section:
Sam-1

Unit: Samatsum deposit

Location:

Johnson Lake Area

Mineral assemblage: Fe carbonates 66%,sericite 15%, quartz 10%, pyrite 7 %
chlorite 2%,

Description: fine grained carbonate-sericite schist, carbonate is fine grained, subhedral-euhedral, pyrite are slightly resorbed, subhedral to euhedral.

Rock name/protolith: pelite alteration

Thin section:**Unit:** Samatosum deposit

Sam-25

Location:

Johnson Lake Area

Mineral assemblage: graphite Fe carbonates quartz, chlorite, feldspar, biotite, sericite

Description: feldspar and quartz + carbonate veins 1-6 mm wide, feldspars are twinned and intergrown with quartz and carbonate. Biotite cross cuts alteration "late stage paragenesis, all other minerals transposed into the foliation. circular aggregates of qtz-feldspar, chlorite which may represent an amygdale.

Rock name/protolith: pelite/vein alteration

Polished Thin section:**Unit:** Samatosum deposit

Sam-29

Location:

Johnson Lake Area

Mineral assemblage: quartz, sericite, opaques (50% pyrite, sphalerite, galena, tetrahedrite)

Description: siliceous ore, quartz .3 to .8mm in length, anhedral-subhedral, with some comb textures, pyrite is subhedral to euhedral, consisting of cubic and octahedral crystals. Sphalerite has inclusions of pyrite, galena rimming and replacing sphalerite, tetrahedrite rimming and replacing galena. Most of the sulphide grains are anhedral except pyrite. Paragenesis appears to be py-sp-ga-tet.

Rock name/protolith: siliceous ore

Polished Thin section:**Unit:** Samatosum deposit

Sam-30

Location:

Johnson Lake Area

Mineral assemblage: quartz, sericite (gangue 55%), sulphides (45% pyrite, sphalerite, galena, tetrahedrite)

Description: carbonate veins with quartz and sericite (+ fuchsite) hosting sulphide mineralization, pyrite is replaced by sphalerite and galena with intergrowths and inclusions in each other suggesting contemporaneous deposition. Sericite/fuchsite and barite inclusions in sphalerite. Sp contains chalcopryrite disease suggesting high T replacement, sulphides have anhedral crystals with wispy intergrowths and inclusions.

Rock name/protolith: quartz-carbonate vein mineralization

Thin section:
Sam-35

Unit: Samatosum deposit

Location:
Johnson Lake Area

Mineral assemblage: graphite Fe carbonates 66%, sericite 15%, quartz 10%, pyrite 7 % chlorite 2%,

Description: foliated quartzite with graphite, subhedral to euhedral pyrite is partially resorbed, pre to synkinematic.

Rock name/protolith: pelite alteration

Thin section Descriptions Samatosum deposit

Table : Hydrothermal alteration minerals at the Samatosum deposit, B.C.

Mineral	abundance	Maximum grain size	Shape/ occurrence	Associated minerals
quartz	> 25%	3 cm	Anhed, veins, amygdules, ubiquitous	All phases
sericite	> 10%	1mm	Subhed flakes, ubiquitous	Qtz, chl, py,
chlorite	< 10%	1mm	Subhed flakes	Qtz, cal, sid, ank,
pyrite	> 10%	1 mm	Euhed, cubic to octahedral, disseminated, veins	Qtz, ser, chl, cal, ank, sid, sp, tet-tenn, cpy, ga
calcite	< 10%	2-4 cm	Euhed-subhed-anhed, veins, amygdules.	Qtz, ser, chl, ank, sid, py, sp, tet-tenn, cpy, ga
siderite	> 10%?	1-2 mm	Euhed-subhed-anhed, veins, amygdules	Qtz, ser, chl, cal, ank, py, sp, tet-tenn, cpy, ga
ankerite	> 10%?	1-2 mm	Euhed-subhed-anhed, veins, amygdules	Qtz, ser, chl, cal, sid, sp, py, tet-tenn, cpy, ga
albite	< 1%	10 mm	Subhed, veins	Qtz, cal, py,
sphalerite	< 1%	2-3 cm	Anhed, subhed	Qtz, ser, chl, cal, ank, py, sid, tet-tenn, cpy, ga
chalcopryrite	< 1%	1-2 mm	Anhed,	Qtz, cal, ank, py, sid, sp, tet-tenn, cpy, ga
tetrahedrite/tennantite	< 1%	4-5 cm	Anhed, subhed	Qtz, ser, chl, cal, ank, py sid, sp, tet-tenn, cpy, ga
galena	< 1%	1 cm	Anhed- euhed, cubic	Qtz, ser, chl, cal, ank, py sid, sp, tet-tenn, cpy

Abbreviations: alb = albite, anhed = anhedral, ank = ankerite, cal = calcite, cpy = chalcopryrite, chl = chlorite, ep = epidote, euhed = euhedral, ga = galena, grdms = groundmass, Ksp = k feldspar, plag = plagioclase, py = pyrite, qtz = quartz, sid = siderite, sp = sphalerite, subhed = subhedral, tet = tetrahedrite, tenn = tennantite.

APPENDIX II

**Lithogeochemical Data
Limits of Determination**

Analytical methods and Limits of Determination

Sampling Protocol

Rock samples were collected from outcrops during this study with emphasis on collecting least altered and metamorphosed samples. Alteration visible in the field consisted of visible, quartz, and calcite veining, and sericite, Fe-carbonate, and pyrite alteration; this is evidence for mobility of the major elements. Most samples show some degree of alteration and/or metamorphism and carbonate appears to be ubiquitous in rocks throughout the study area. The freshest samples possible were collected in the field, when necessary the weathered surfaces were trimmed with a diamond rock saw. Rock samples were crushed for geochemical analysis to 1.5 cm with a steel jaw crusher and pulverized in a Bico ceramic disc grinder. The powder was reduced to <100 μm fraction in a ceramic ball mill suitable for ICP or XRF sample preparation.

Major and Trace Element Analysis

Samples were submitted to the Geological Survey of Canada's analytical Chemistry Laboratories in Ottawa for whole rock major and trace element analysis. Major element concentrations were determined using XRF fused disk method and trace element concentrations determined using ICP-MS acid digestion, lithium-metaborate flux techniques. 12 samples were analyzed for trace elements by acid digestion ICPMS techniques at the University of Victoria. There are differences in the technique between the labs; the technique used at the University of Victoria is described below.

The ICP-MS preparation and analysis essentially follows that of Jenner et al. (1990) and is summarized as follows. Approximately 0.100 grams of sample were weighed into teflon screw top containers. 1-2 ml of concentrated HF and 1-2 ml of

concentrated HNO_3 were added and the containers capped and placed on a hot plate for three days to allow digestion to occur. The caps were then removed and the solution allowed to evaporate in a fume hood. The sample was then dissolved in 2 ml of 8N HNO_3 and again allowed to evaporate. Finally 2.5 ml of HNO_3 was added and the samples capped and allowed to sit overnight on the hot plate. This solution was transferred to 250 ml sample bottles and diluted with deionized water such that the mass of the solution was 100 g. 0.3 g of solution was then transferred to test tubes and equal amounts of 2% HNO_3 added. A second solution of sample plus spike were also prepared, and three standards were run per sample submitted. The samples were analyzed on the VG PQ 2S ICP-MS at the University of Victoria.

The method used at the Geological Survey of Canada laboratories is similar to the standard method with the following modifications. The acid dissolution is accomplished using hydrofluoric, perchloric and nitric acid. Residue was fluxed with lithium metaborate and subsequently redissolved to achieve nearly complete dissolution of the samples.

GSC Analytical methods and Limits of Determination

The analytical limits of determination are as reported by the Analytical Chemistry Laboratories of the Geological Survey of Canada, for the various elements and analytical methods (from the GSC analytical chemistry lab website http://www.nrcan.gc.ca/gsc/mrd/labs/chem_e.html.)

1. Major elements (X-ray fluorescence) (METHOD XRF-100)

Analysis is completed by fused disk wavelength dispersive X-ray Fluorescence. This method is not suitable for samples containing greater than 5% S or significant amounts of barite, percent levels of copper or lead or for samples for which insufficient quantities are available for producing a fused disk major element determinations for these samples are completed using the ICPES-100 package. When ICP-ES and ICP-MS are also requested, Ba, Nb, Rb, Sr and Zr values may be obtained using these techniques.

Analyte	Calibration range (%)	Limit of determination (%)
SiO ₂	0 - 100	0.50
TiO ₂	0 - 3	0.02
Al ₂ O ₃	0 - 60	0.40
Cr ₂ O ₃	0 - 4	0.02
Fe ₂ O ₃ total	0 - 90	0.10
MnO	0 - 1	0.01
MgO	0 - 50	0.10
CaO	0 - 35	0.10
Na ₂ O	0 - 10	0.50
K ₂ O	0 - 15	0.05
P ₂ O ₅	0 - 1	0.02
Ba	0 - 0.30	0.002
Nb	0 - 0.04	0.003
Rb	0 - 0.06	0.002
Sr	0 - 0.20	0.002
Zr	0 - 0.20	0.002

Sample required: 1.0 g. If XRF-100 and L.O.I. are requested together (METHOD XRF-110), an additional 0.5 g sample is required.

2. Major elements (ICP-ES) (METHOD ICPES-100)

Analysis is completed by fusing the sample with a mixed lithium metaborate - lithium tetraborate flux, dissolution of the fusion melt followed by analysis by ICP emission spectrometry. This method is suitable for samples containing greater than 5% S or significant amounts of barite, percent levels of copper or lead or samples for which sufficient quantities are not available for the determination of major elements by XRF. If required, the determination of Rb, Sr, Nb and Zr by ICP spectrometry is available on request. This method can also be applied to samples smaller than 0.5 g when necessary.

Analyte	Limit of determination (%)	Analyte	Limit of determination (%)
SiO ₂	0.5	CaO	0.01
TiO ₂	0.02	Na ₂ O	0.03
Al ₂ O ₃	0.2	K ₂ O	0.05
Cr ₂ O ₃	0.02	P ₂ O ₅	0.01
Fe ₂ O ₃	0.06	Ba	0.003
MnO	0.01	Loss on Ignition	0.1
MgO	0.04		

Sample required: 0.5 g

3. Supplementary whole rock determinations (volatiles)

Ferrous Iron is determined using the Wilson Method (titrimetric). H₂O (total), CO₂ (total) and S are determined using combustion followed by infra-red spectrometry, CO₂ (carbonate carbon) is determined by acid evolution followed by infrared spectrometry and C (total non-carbonate carbon) is calculated. Loss on ignition is determined by gravimetry at 900 C.

Parameter	Sample required	Limit of determination, %	Method
FeO	0.2g	0.2	METHOD CHEM-100
H ₂ O _{total}	0.5g	0.1	METHOD CHEM-110
CO _{2total}	0.5g	0.1	METHOD CHEM-120
CO ₂	0.5g	0.1	METHOD CHEM-130
S _{total}	0.5g	0.02	METHOD CHEM-140

4. Trace elements

Determinations are based on the **total** dissolution of the sample using nitric, perchloric and hydrofluoric acids followed by a lithium metaborate fusion of any residual material. For ICPE-110 package analysis is done using ICP emission spectrometry. For ICPMS-100 and ICPMS-110 packages, analysis is done using ICP mass spectrometry. Elements listed in ICPE-110 may be determined by ICPMS-100 or ICPMS-110 at our discretion when analyte concentrations are too low for determination by ICP-ES.

Trace elements 1 (ICP emission spectrometry) METHOD ICPMS-110			
Element	Limit of determination (ppm)	Element	Limit of determination (ppm)
Ag	5	Pb	10
Ba	10	Sc	0.5
Be	0.5	Sr	5
Co	5	V	5
Cr	10	Y	5
Cu	10	Yb	0.5
La	10	Zn	5
Ni	10	Zr	10
Mo	5		

Sample required: 1.0 g

Trace elements 2 (ICP mass spectrometry): Rare-earth elements + Y METHOD ICPMS-100			
Element	Limit of determination (ppm)	Element	Limit of determination (ppm)
Ce	0.1	Nd	0.1
Dy	0.02	Pr	0.02
Er	0.02	Sm	0.02
Eu	0.02	Tb	0.02

Gd	0.02	Tm	0.02
Ho	0.02	Y	0.02
La	0.1	Yb	0.05
Lu	0.02		
Trace elements 2 (ICP mass spectrometry): Other trace elements METHOD ICPMS-110			
Element	Limit of determination (ppm)	Element	Limit of determination (ppm)
Ag	0.1	Pb	2
Bi	0.5	Rb	0.05
Cd	0.2	Sn*	0.5
Cs	0.02	Ta	0.2
Ga	0.1	Th	0.02
Hf	0.05	Tl	0.02
In	0.05	U	0.02
Mo	0.2	Zr	0.5
Nb	0.05		

* on demand

Sample required: 1.0 g

Analytical Precision

Throughout the course of this study duplicate samples were included to test analytical precision. In addition random samples were run as part of GSC policy. The results of these analyses are reported along with samples (see digital appendice). Samples analyzed in this study have similar matrices to rocks from the Finlayson Lake district analyzed by Piercey et al., 2001; 2000, and Piercey, 2001. The analytical precision reported by Piercey is summarized below.

Summary of precision, accuracy, and related data for repeat analyses of felsic international reference materials (Piercey et al. 2001)

	P98-KZK2 n=10	Min ¹	Max ¹	%RSD ¹	2σ ¹	P-1 n=5	Min ¹	Max ¹	%RSD ¹	2σ ¹	MDRU Values	RD ¹
SiO ₂	74.64	74.10	75.60	0.68	0.34	70.96	70.70	71.10	0.25	0.17	69.81	1.65
TiO ₂	0.30	0.29	0.31	2.47	0.00	0.38	0.37	0.38	1.30	0.00	0.40	6.77
Al ₂ O ₃	12.14	12.00	12.30	0.89	0.07	14.10	14.00	14.20	0.45	0.06	14.38	1.98
Fe ₂ O ₃ T	2.12	1.90	2.30	5.36	0.08	3.90	3.90	3.90	0.00	0.00	3.80	2.73
Fe ₂ O ₃	0.83	0.60	1.00	13.97	0.08	1.28	1.20	1.50	9.11	0.12	-	-
FeO	1.16	1.00	1.30	7.27	0.06	2.34	2.20	2.40	3.42	0.08	-	-
MnO	0.02	0.01	0.02	28.41	0.00	0.08	0.07	0.08	5.13	0.00	0.09	14.43
MgO	0.86	0.79	0.92	4.79	0.03	1.11	1.10	1.12	0.67	0.01	1.10	0.95
CaO	0.20	0.16	0.24	13.22	0.02	3.49	3.47	3.52	0.49	0.02	3.59	2.83
Na ₂ O	1.19	1.10	1.20	2.66	0.02	3.80	3.80	3.80	0.00	0.00	4.04	5.83
K ₂ O	6.80	6.50	6.87	1.69	0.08	2.12	2.11	2.13	0.35	0.01	2.04	4.06
P ₂ O ₅	0.09	0.09	0.09	0.00	0.00	0.08	0.08	0.08	0.00	0.00	0.09	10.73
H ₂ O	0.99	0.90	1.00	3.37	0.02	0.62	0.60	0.70	6.45	0.04	-	-
CO ₂	0.10	0.10	0.10	0.00	0.00	0.10	0.10	0.10	0.00	0.00	-	-
Total	99.34	98.00	100.20	0.65	0.43	100.56	100.20	100.80	0.22	0.22	99.95	0.61
Cr (ppm)	71	65	75	4.44	2.11	149	140	155	3.43	5.11	133.77	11.54
Ni	-	<10	<10	-	-	-	<10	<10	-	-	1.65	-
Co	7	<5	9	40.41	1.89	6	6	7	6.45	0.40	7.48	17.11
Sc	4.9	4.6	5.1	3.26	0.11	11.0	11.0	11.0	-	-	10.46	5.12
V	13	10	16	21.13	1.82	58	58	59	0.69	0.40	59.72	2.55
Cu	-	<10	<10	-	-	16	10	21	35.48	5.50	4.67	232.14
Pb	11	10	12	7.69	0.55	10	9	13	14.41	1.47	3.78	170.00
Zn	35	30	44	11.59	2.71	44	43	45	2.03	0.89	46.55	5.47
Bi	0.5	0.5	0.5	-	-	0.3	0.2	0.5	33.53	0.11	-	-
Cd	-	<0.2	<0.2	-	-	-	<0.2	<0.2	-	-	-	-
In	-	<0.05	<0.05	-	-	0.1	0.1	0.1	-	-	-	-
Sn	4.3	3.7	4.6	7.32	0.21	2.4	1.8	4.1	36.16	0.88	5.00	51.20
Mo	1.1	1.0	1.5	14.56	0.11	0.5	0.4	0.6	14.39	0.07	0.89	41.50
Sb	-	<0.20	<0.20	-	-	0.3	0.2	0.3	17.68	0.05	0.35	22.89
Ag	0.3	0.1	0.5	94.28	0.19	0.3	0.3	0.3	-	-	0.17	78.57
Rb	207	190	220	3.98	5.49	50	47	56	6.22	3.14	48.00	5.00
Cs	1.2	1.1	1.3	6.03	0.05	1.2	1.1	1.4	8.03	0.10	1.22	0.27
Ba	559	510	600	4.25	15.84	724	710	730	1.10	8.00	708.00	2.26
Sr	26	20	34	23.27	4.02	256	250	260	1.91	4.90	217.50	17.70
Tl	0.8	0.1	1.0	32.30	0.17	0.3	0.3	0.3	5.17	0.02	-	-
Th	22.9	21.0	25.0	6.33	0.97	4.4	4.2	4.8	4.88	0.21	4.02	9.05
U	6.4	5.9	6.9	4.74	0.20	1.5	1.4	1.6	5.06	0.07	1.56	5.28
Ga	19	18	20	4.30	0.54	15	14	17	7.30	1.10	24.00	37.50
Ta	1.7	1.5	1.8	5.89	0.06	0.3	0.3	0.3	4.87	0.01	0.50	39.60
Nb	24.4	23.0	25.0	3.46	0.56	3.8	3.6	4.1	4.55	0.17	5.96	36.59
Hf	5.7	5.4	6.1	4.75	0.18	3.8	3.6	4.0	3.61	0.14	3.55	6.02
Zr	207	190	230	8.26	11.39	126	110	140	8.09	10.20	115.00	9.57
Y	32	31	34	2.60	0.56	23	22	24	3.28	0.75	13.52	68.66
La	40.9	38.0	43.0	3.54	0.97	13.2	13.0	14.0	3.03	0.40	13.58	2.80
Ce	105.7	97.0	110.0	5.32	3.75	28.0	26.0	30.0	4.52	1.26	27.06	3.47
Pr	10.3	9.3	11.0	6.21	0.43	3.4	3.2	3.5	3.04	0.10	-	-
Sm	7.1	6.2	7.8	5.99	0.28	2.9	2.8	3.1	3.99	0.12	2.65	10.27
Nd	35.3	33.0	37.0	4.64	1.09	13.0	12.0	14.0	4.87	0.63	12.22	6.38
Eu	0.5	0.5	0.6	5.21	0.02	0.8	0.7	0.8	4.05	0.03	0.83	6.07
Gd	6.1	5.5	6.6	5.33	0.22	3.1	3.0	3.3	3.14	0.10	-	-
Tb	1.0	0.9	1.1	5.61	0.04	0.5	0.5	0.6	3.71	0.02	0.37	40.32
Dy	6.1	5.4	6.7	5.89	0.24	3.3	3.1	3.5	4.48	0.15	-	-
Ho	1.2	1.1	1.3	4.77	0.04	0.7	0.7	0.8	5.09	0.04	-	-
Er	3.3	3.1	3.6	5.21	0.11	2.1	2.0	2.2	4.26	0.09	-	-
Tm	0.5	0.5	0.6	5.73	0.02	0.4	0.3	0.4	3.61	0.01	-	-
Yb	3.6	3.4	3.7	2.74	0.06	2.5	2.3	2.7	6.08	0.15	2.16	13.89
Lu	0.5	0.5	0.6	5.63	0.02	0.4	0.4	0.4	1.98	0.01	0.35	16.63

Notes: 1 - Min - minimum value; Max = maximum value; %RSD = percent relative standard deviation

2s = error of the mean at 95% confidence level; RD = relative difference; LOD = limit of detection

Summary of precision, accuracy, and related data for repeat analyses of felsic international reference materials
(Piercey et al. 2001)

	WP-1 n=5	Min ¹	Max ¹	%RSD ¹	2 σ ¹	MDRU Values	RD ¹	LOD ¹
SiO ₂	65.06	64.90	65.20	0.18	0.12	64.04	1.59	0.50
TiO ₂	0.50	0.49	0.50	0.80	0.00	0.52	3.95	0.02
Al ₂ O ₃	16.38	16.30	16.50	0.60	0.10	16.51	0.80	0.40
Fe ₂ O ₃ T	4.52	4.50	4.60	0.88	0.04	4.39	2.85	0.10
Fe ₂ O ₃	1.70	1.50	1.90	8.32	0.14	-	-	-
FeO	2.56	2.40	2.70	3.98	0.10	-	-	0.20
MnO	0.08	0.08	0.08	0.00	0.00	0.09	12.97	0.01
MgO	2.70	2.68	2.71	0.41	0.01	2.64	2.23	0.10
CaO	5.05	5.02	5.08	0.38	0.02	5.12	1.30	0.10
Na ₂ O	4.30	4.30	4.30	0.00	0.00	4.40	2.32	0.50
K ₂ O	1.64	1.63	1.66	0.67	0.01	1.59	3.22	0.05
P ₂ O ₅	0.18	0.17	0.18	2.25	0.00	0.18	1.32	0.02
H ₂ O	0.30	0.30	0.30	0.00	0.00	-	-	0.10
CO ₂	0.10	0.10	0.10	0.00	0.00	-	-	0.10
Total	100.62	100.40	100.90	0.20	0.20	-	-	-
Cr (ppm)	79	74	82	3.35	2.64	69.54	13.32	10.00
Ni	45	43	46	2.60	1.17	36.12	24.05	10.00
Co	12	10	13	8.30	0.98	12.54	5.89	5.00
Sc	10.0	10.0	10.0	0.00	0.00	9.26	7.99	0.50
V	82	80	84	1.65	1.36	83.00	0.72	5.00
Cu	16	15	18	6.05	0.98	10.05	61.19	10.00
Pb	7	7	8	5.56	0.40	3.27	120.24	2.00
Zn	59	57	60	2.31	1.36	58.23	0.63	10.00
Bi	0.6	0.4	0.8	29.99	0.17	-	-	0.20
Cd	-	<0.2	<0.2	-	-	-	-	0.20
In	<0.1	<0.1	<0.1	-	-	-	-	0.05
Sn	1.6	1.1	2.2	23.13	0.37	6.00	73.67	0.50
Mo	0.9	0.8	0.9	5.70	0.05	0.92	6.83	0.20
Sb	-	<0.2	<0.2	-	-	0.27	-	0.20
Ag	0.2	0.1	0.2	33.33	0.05	0.23	35.34	0.10
Rb	23	22	24	2.75	0.63	22.00	4.55	0.05
Cs	0.5	0.4	0.5	2.43	0.01	0.81	44.55	0.02
Ba	582	550	610	3.98	23.15	607.00	4.12	10.00
Sr	724	720	730	0.68	4.90	737.00	1.76	5.00
Tl	0.2	0.1	0.2	8.43	0.01	-	-	0.02
Th	2.1	2.0	2.2	3.60	0.07	1.91	9.03	0.02
U	0.8	0.8	0.9	4.71	0.04	0.85	2.56	0.02
Ga	19	18	20	4.71	0.89	29.00	34.48	0.10
Ta	0.22	0.21	0.24	5.36	0.01	0.50	55.20	0.20
Nb	4.04	3.9	4.2	3.36	0.14	6.56	38.37	0.05
Hf	3.3	3.0	3.4	4.82	0.16	3.14	5.61	0.05
Zr	112	110	120	3.57	4.00	136.00	17.65	0.50
Y	15	14	16	4.92	0.75	8.67	75.38	0.02
La	13.6	13.0	14.0	3.60	0.49	13.83	1.64	0.10
Ce	29.8	29.0	30.0	1.34	0.40	28.37	5.03	0.10
Pr	3.8	3.7	3.9	1.96	0.07	-	-	0.02
Sm	3.2	3.1	3.4	3.95	0.13	2.84	12.58	0.10
Nd	15.6	15.0	16.0	3.14	0.49	13.72	13.74	0.02
Eu	0.9	0.8	0.9	3.28	0.03	0.95	5.72	0.02
Gd	2.9	2.8	3.0	2.60	0.07	-	-	0.02
Tb	0.4	0.4	0.5	3.89	0.02	0.29	47.11	0.02
Dy	2.4	2.3	2.6	4.92	0.12	-	-	0.02
Ho	0.5	0.5	0.5	2.11	0.01	-	-	0.02
Er	1.3	1.2	1.4	5.67	0.07	-	-	0.02
Tm	0.2	0.2	0.2	1.89	0.00	-	-	0.02
Yb	1.4	1.4	1.4	0.00	0.00	1.27	10.30	0.05
Lu	0.2	0.2	0.2	2.75	0.01	0.20	14.12	0.02

Whole rock major and trace element data, 1999 field season, Johnson lake area.

LAB_NO	118 DUP	119 DUP	120 DUP	121 DUP	122 DUP	88	103	102	92	93	117
SAMPLE_N	99-057-118(L	99-057-119(L	99-057-120(L	99-057-121(L	99-057-122(L	REA	SAM-1	SAM-10	SAM-11	SAM-12	SAM-125B
Unit	33 alteration					4 (EBG)	4 (EBG)	4 (EBG)	4 (EBG)	4 (EBG)	33 alteration
SiO2	63.70	58.50	44.30	60.30	3.40	5.50	36.20	12.40	73.90	33.40	35.00
TiO2	0.51	0.53	3.19	0.23	0.09	0.08	1.96	0.19	0.48	1.30	0.67
Al2O3	13.70	15.80	16.10	12.80	1.30	1.70	14.40	9.80	12.40	18.80	8.10
Fe2O3T	5.50	6.60	17.30	2.80	9.49	20.10	14.30	7.10	4.70	13.90	7.20
Fe2O3	3.30	2.30	4.60	0.50	-999.00	-999.00	1.10	1.00	-999.00	1.50	2.00
FeO	2.0	3.9	11.4	2.1	-999.0	-999.0	11.9	5.5	-999.0	11.2	4.7
MnO	0.10	0.11	0.11	0.07	0.51	0.01	0.14	1.65	0.05	0.30	0.15
MgO	1.19	3.58	7.03	0.95	5.57	0.04	13.55	14.91	2.07	13.08	4.25
CaO	4.48	6.44	2.94	7.79	9.80	0.06	5.65	19.67	0.26	4.81	18.82
Na2O	3.20	3.50	2.30	3.30	0.23	0.18	0.20	0.10	0.20	0.10	3.40
K2O	2.03	0.98	1.36	3.04	0.32	0.12	0.76	1.64	2.83	1.71	0.52
H2OT	2.4	2.8	5.5	1.2	-999.0	-999.0	6.7	2.8	-999.0	7.1	0.9
CO2T	3.9	1.9	1.7	7.2	16.0	0.1	7.8	30.4	0.4	7.0	21.5
P2O5	0.13	0.41	0.56	0.18	0.02	0.02	0.26	0.08	0.06	0.18	0.08
ST	-0.02	-0.02	-0.02	0.17	15.80	23.50	0.15	0.93	1.59	0.68	0.25
BA	3100	420	780	830	647	220000	700	1100	2000	790	200
TOTAL	100.9	100.9	101.2	100.0	99.7	81.9	101.0	101.3	99.2	101.3	100.4
LOI	-999.0	-999.0	-999.0	-999.0	3.4	13.7	-999.0	30.6	3.3	-999.0	21.2
AG	-0.1	-0.1	-0.1	-0.1	178.0	182.0	-0.1	0.1	-0.1	-0.1	-0.1
BE	1.5	2.5	1.2	1.9	-0.5	-0.5	0.5	0.6	1.3	0.6	-0.5
BI	-0.2	-0.2	-0.2	-0.2	0.3	1.3	0.4	0.6	0.4	-0.2	-0.2
CD	-0.2	-0.2	-0.2	-0.2	280.0	170.0	-0.2	-0.2	-0.2	-0.2	-0.2
CO	10	14	61	-5	53	-5	67	17	6	35	35
CR	48	14	37	13	63	41	713	29	76	329	332
CS	2.50	1.30	1.70	2.70	0.21	0.21	0.54	0.74	1.40	0.57	0.43
CU	12	11	171	-10	1590	4620	120	11	-10	-10	43
GA	15.00	16.00	22.00	14.00	2.80	22.00	21.00	13.00	16.00	19.00	9.90
HF	2.90	3.20	3.80	3.60	0.15	0.33	2.60	0.80	1.90	2.20	0.91
IN	-0.05	-0.05	0.09	-0.05	1.90	1.50	-0.05	-0.05	0.05	-0.05	-0.05
MO	-0.2	-0.2	-0.2	0.8	-0.2	544.0	0.5	0.5	-0.2	0.4	0.3
NB	9.60	13.00	31.00	15.00	1.00	1.30	28.00	3.80	9.40	10.00	5.90
NI	-10	-10	80	-10	219	247	419	30	34	167	221
PB	3	13	7	8	300000	20500	6	59	5	5	13
RB	73.00	29.00	42.00	86.00	8.90	5.10	23.00	51.00	110.00	48.00	16.00
SB	-0.2	0.5	2.1	-0.2	220.0	1570.0	3.5	0.7	1.3	1.4	0.5
SC	16.0	14.0	45.0	6.9	4.3	1.9	30.0	8.9	13.0	33.0	13.0
SN	1.2	0.8	1.4	0.8	1.3	270.0	0.7	0.7	1.9	2.1	-0.5
SR	142	1040	79	441	109	931	101	230	38	104	212
TA	0.74	0.76	1.80	1.10	0.07	0.07	1.70	0.27	0.62	0.61	0.34
TE	-0.2	-0.2	-0.2	-0.2	15.0	5.9	-0.2	-0.2	-0.2	-0.2	-0.2
TH	9.60	16.00	2.00	24.00	0.10	0.41	1.50	5.70	9.00	0.80	0.36
TL	0.42	0.14	0.48	0.50	0.29	97.00	0.23	1.00	1.80	0.79	0.19
U	1.70	4.00	0.49	1.30	0.05	51.00	0.41	1.10	1.00	0.92	0.10
V	113	171	485	74	20	284	267	61	58	259	96
ZN	35	65	109	19	68600	58000	183	137	66	251	33
ZR	140.0	150.0	190.0	140.0	4.7	13.0	110.0	30.0	65.0	91.0	36.0
CE	60.0	92.0	58.0	120.0	5.9	15.0	37.0	83.0	73.0	23.0	11.0
DY	3.00	4.10	4.90	4.40	1.20	1.70	2.90	1.90	1.80	4.20	1.90
ER	1.50	1.70	2.00	1.80	0.50	0.90	1.40	0.76	0.88	2.10	0.88
EU	1.00	1.80	2.20	1.80	1.10	2.30	1.10	0.87	0.45	0.55	0.68
GD	3.40	6.20	6.60	6.50	1.50	1.80	3.70	3.30	2.70	4.10	2.00
HO	0.55	0.69	0.87	0.76	0.20	0.35	0.54	0.31	0.34	0.80	0.35
LA	32.0	44.0	27.0	66.0	3.0	9.0	17.0	41.0	29.0	10.0	4.7
LU	0.25	0.26	0.25	0.30	0.06	0.13	0.21	0.11	0.17	0.28	0.12
ND	24.0	44.0	35.0	47.0	3.7	5.8	20.0	27.0	23.0	14.0	6.7
PR	6.30	11.00	7.60	13.00	0.76	1.60	4.50	7.40	6.40	3.00	1.40
SM	4.00	7.80	7.00	8.50	1.10	1.40	4.10	4.80	4.10	3.50	1.80
TB	0.51	0.80	0.91	0.88	0.22	0.30	0.52	0.42	0.37	0.69	0.32
TM	0.23	0.27	0.29	0.29	0.07	0.14	0.22	0.12	0.16	0.32	0.13
Y	16.00	22.00	24.00	24.00	6.50	14.00	17.00	9.90	9.70	24.00	9.70
YB	1.60	1.60	1.60	1.80	0.37	0.83	1.40	0.74	1.00	1.90	0.80

LAB_NO	94	114	101	109	110	105	95	100	104	107	108
SAMPLE_N	SAM-13	SAM-15	SAM-18	SAM-19	SAM-2	SAM-20	SAM-21	SAM-22	SAM-24.2	SAM-25	SAM-27
Unit	4 (EBG)	4 (EBG)	4 (EBG)	4 (EBG)	4 (EBG)	33 alteration	33 alteration	33 alteration	4 (EBG)	4 (EBG)	4 (EBG)
SIO2	46.30	47.90	43.10	45.50	45.80	10.90	43.70	3.30	40.10	36.40	73.70
TIO2	0.98	1.15	1.27	1.13	2.29	0.35	1.26	0.09	1.18	0.80	0.67
AL2O3	9.40	11.20	13.00	10.80	11.20	5.30	14.60	1.30	11.70	8.80	14.20
FE2O3T	8.10	7.70	11.30	6.40	10.50	5.80	4.10	9.60	9.30	9.70	3.60
FE2O3	-999.00	0.60	-999.00	0.40	-999.00	0.20	0.20	-999.00	1.00	1.80	0.30
FEO	-999.0	6.4	-999.0	5.4	-999.0	5.0	3.5	-999.0	7.4	7.1	3.0
MNO	0.31	0.22	0.19	0.26	0.18	0.84	0.32	0.52	0.20	0.26	0.02
MGO	8.46	8.86	7.46	7.91	11.22	6.78	5.45	5.75	9.34	8.60	1.97
CAO	8.46	6.61	5.77	11.88	5.99	34.88	9.32	9.80	13.28	17.00	0.11
NA2O	0.10	3.60	4.42	3.00	1.00	0.10	2.70	0.22	2.40	2.50	0.20
K2O	1.67	0.03	0.10	0.04	0.31	0.26	3.44	0.31	0.02	0.12	3.46
H2OT	-999.0	2.9	-999.0	3.4	-999.0	2.7	1.5	-999.0	4.8	4.0	2.8
CO2T	12.3	9.5	6.0	10.4	7.0	30.5	13.9	15.9	9.5	12.0	0.1
P2O5	0.10	0.14	0.15	0.10	0.92	0.05	0.13	0.01	0.11	0.10	0.08
ST	3.02	0.96	5.87	0.23	1.40	0.51	0.46	15.60	0.16	-0.02	0.11
BA	4300	42	76	45	310	150	4600	644	110	2600	1000
TOTAL	99.9	100.2	98.8	100.6	97.8	98.4	101.1	94.7	101.3	100.0	100.9
LOI	14.5	-999.0	10.4	13.2	11.1	25.9	14.4	3.0	-999.0	13.3	-999.0
AG	0.3	-0.1	0.2	-0.1	-0.1	2.4	0.3	178.0	-0.1	-0.1	-0.1
BE	0.5	-0.5	-0.5	-0.5	-0.5	-0.5	1.5	-0.5	-0.5	-0.5	1.4
BI	-0.2	-0.2	-0.2	-0.2	-0.2	0.3	-0.2	0.3	0.2	0.2	0.4
CD	-0.2	-0.2	-0.2	-0.2	-0.2	7.9	-0.2	280.0	-0.2	-0.2	-0.2
CO	48	36	46	44	55	12	41	52	52	44	17
CR	507	500	507	472	306	158	620	68	554	364	80
CS	0.85	0.10	0.10	0.12	0.18	0.68	1.90	0.23	0.11	12.00	1.90
CU	147	40	56	68	55	749	89	1580	75	73	26
GA	9.90	12.00	15.00	12.00	15.00	9.40	16.00	2.60	14.00	12.00	23.00
HF	1.10	1.70	1.60	1.50	4.90	0.49	1.60	0.13	1.50	1.20	2.70
IN	-0.05	-0.05	-0.05	-0.05	-0.05	0.12	-0.05	2.10	-0.05	0.08	-0.05
MO	0.5	0.4	-0.2	-0.2	4.6	-0.2	0.5	-0.2	0.3	-0.2	-0.2
NB	10.00	15.00	15.00	14.00	76.00	4.00	14.00	1.20	14.00	11.00	13.00
NI	316	164	210	226	255	102	141	211	255	199	31
PB	19	5	107	15	6	3890	10	250000	3	3	5
RB	54.00	0.25	2.50	0.83	8.70	9.00	110.00	8.80	0.09	6.70	120.00
SB	2.9	1.6	2.8	0.9	1.5	2.7	2.2	220.0	0.8	1.3	1.3
SC	19.0	19.0	27.0	21.0	23.0	13.0	23.0	4.3	24.0	17.0	17.0
SN	0.6	0.9	0.5	0.6	1.3	0.5	0.8	1.4	0.7	0.8	2.3
SR	256	117	106	191	125	462	143	111	213	299	30
TA	0.60	0.86	0.81	0.78	4.20	0.23	0.87	0.06	0.82	0.62	1.00
TE	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	14.0	-0.2	-0.2	-0.2
TH	0.55	0.92	0.83	0.85	4.70	0.23	0.97	0.11	0.75	0.60	13.00
TL	0.71	-0.02	0.03	0.02	0.09	0.11	1.10	0.30	-0.02	0.09	1.30
U	0.57	0.63	0.23	0.15	1.30	0.07	0.26	0.04	0.16	0.12	1.80
V	147	178	214	170	200	96	193	20	177	160	60
ZN	94	68	124	108	165	1530	36	69900	61	54	70
ZR	42.0	67.0	62.0	59.0	210.0	20.0	61.0	4.9	60.0	48.0	99.0
CE	8.2	23.0	17.0	23.0	120.0	17.0	17.0	5.9	16.0	13.0	96.0
DY	1.50	4.10	2.30	3.40	4.90	4.30	2.30	1.10	3.20	2.40	2.60
ER	0.71	1.80	1.20	1.50	2.30	1.90	1.10	0.47	1.60	1.40	1.40
EU	0.73	1.10	0.69	1.00	2.80	1.50	0.93	1.00	1.10	0.75	1.00
GD	1.80	3.60	2.80	3.60	6.90	4.30	2.70	1.40	3.60	2.40	3.70
HO	0.29	0.76	0.44	0.61	0.89	0.76	0.43	0.19	0.61	0.49	0.50
LA	3.5	11.0	7.4	11.0	54.0	8.3	7.6	3.1	6.4	5.9	40.0
LU	0.10	0.20	0.18	0.24	0.31	0.21	0.15	0.05	0.25	0.23	0.26
ND	5.1	13.0	9.5	13.0	53.0	11.0	10.0	3.6	11.0	8.0	33.0
PR	1.10	2.90	2.20	2.90	13.00	2.20	2.20	0.75	2.30	1.70	9.00
SM	1.50	3.00	2.40	3.10	8.90	3.30	2.50	1.00	3.00	2.10	5.80
TB	0.29	0.65	0.40	0.57	0.90	0.72	0.41	0.20	0.54	0.38	0.50
TM	0.11	0.25	0.18	0.24	0.35	0.27	0.17	0.06	0.24	0.21	0.24
Y	8.20	20.00	12.00	18.00	23.00	24.00	13.00	6.40	17.00	15.00	13.00
YB	0.62	1.40	1.20	1.50	2.00	1.60	1.00	0.35	1.50	1.40	1.70

LAB_NO	106	96	72	111	97	98	99	116	89	112	90
SAMPLE_N	SAM-28	SAM-29	SAM-29M	SAM-3	SAM-32	SAM-36	SAM-37	SAM-38	SAM-4	SAM-5	SAM-6
Unit	33 alteration	33 alteration	33 alteration	4 (EBG)	33 alteration	33 alteration	33 alteration	33 alteration	33 alteration	4 (EBG)	4 (EBG)
SiO2	73.90	41.80	38.10	41.10	53.80	48.40	41.90	28.60	72.40	40.80	38.40
TiO2	0.25	0.94	0.11	1.06	3.44	1.37	1.47	1.08	0.54	1.28	1.23
Al2O3	7.00	9.30	1.70	11.50	14.50	13.80	14.00	9.70	11.30	13.60	11.80
Fe2O3T	9.23	9.70	20.40	5.50	12.80	9.40	12.80	10.60	3.70	10.30	9.00
Fe2O3	-999.00	0.60	-999.00	-999.00	-999.00	1.30	1.30	-999.00	-999.00	0.90	-999.00
FEO	-999.0	8.2	-999.0	-999.0	-999.0	7.3	10.3	-999.0	-999.0	8.4	-999.0
MNO	-0.01	0.16	0.01	0.28	0.01	0.13	0.14	0.38	0.09	0.24	0.40
MGO	0.23	11.17	0.09	7.13	0.77	9.00	10.65	9.61	2.49	10.75	7.16
CAO	0.13	9.74	0.10	11.32	0.91	6.19	5.30	13.51	1.55	7.16	10.10
NA2O	0.16	0.70	0.05	0.20	0.29	4.20	2.90	0.20	0.10	0.10	0.40
K2O	1.71	0.54	0.39	3.09	3.83	0.08	0.05	2.36	2.88	1.73	2.81
H2OT	-999.0	3.6	-999.0	-999.0	-999.0	4.8	4.9	-999.0	2.2	4.8	-999.0
CO2T	0.1	14.2	0.3	16.6	-0.1	3.8	7.4	20.3	3.2	10.5	15.3
P2O5	0.02	0.10	0.04	0.42	0.60	0.16	0.18	0.11	0.09	0.16	0.05
ST	7.61	0.08	24.30	1.23	10.10	0.08	0.15	4.02	0.71	0.48	3.20
BA	5050	1100	1770	2400	2800	1400	71	1200	1400	980	950
TOTAL	101.0	101.3	104.1	99.8	101.5	101.0	100.7	100.6	101.5	101.1	100.1
LOI	5.8	16.7	13.1	17.6	8.5	-999.0	-999.0	21.1	-999.0	14.0	16.9
AG	3.4	0.1	1170.0	-0.1	1.8	-0.1	-0.1	-0.1	-0.1	-0.1	0.4
BE	-0.5	-0.5	-0.5	0.9	2.0	-0.5	-0.5	0.6	1.2	-0.5	1.0
BI	-0.2	0.3	-0.2	0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
CD	2.4	-0.2	350.0	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	0.3
CO	7	63	-5	48	59	50	60	77	15	48	41
CR	51	457	38	458	28	615	613	456	76	528	495
CS	0.84	0.26	0.28	1.40	1.50	4.80	0.09	1.20	1.40	0.83	1.40
CU	80	107	30100	19	62	131	118	76	20	31	67
GA	11.00	13.00	21.00	16.00	22.00	13.00	18.00	12.00	15.00	18.00	15.00
HF	1.10	1.20	0.40	1.50	6.80	1.50	1.80	1.10	2.10	1.70	1.60
IN	-0.05	0.06	0.08	-0.05	-0.05	-0.05	0.06	-0.05	-0.05	-0.05	-0.05
MO	0.8	0.4	29.0	0.4	2.9	-0.2	-0.2	-0.2	0.5	-0.2	0.5
NB	3.80	11.00	1.90	13.00	30.00	14.00	17.00	11.00	9.50	14.00	14.00
NI	-10	303	36	152	36	300	309	381	52	303	159
PB	374	-1	44800	15	98	1	2	27	37	16	146
RB	55.00	17.00	11.00	110.00	0.00	2.90	0.92	69.00	88.00	62.00	95.00
SB	70.0	0.7	15300.0	2.1	25.0	0.8	1.0	2.3	2.7	1.1	4.2
SC	13.0	20.0	3.9	22.0	25.0	26.0	24.0	27.0	13.0	23.0	23.0
SN	2.3	0.9	11.0	0.6	1.9	1.3	2.7	-0.5	1.7	0.9	0.8
SR	23	148	-10	206	93	168	97	176	47	133	196
TA	0.27	0.67	0.11	0.78	2.00	0.91	0.99	0.70	0.66	0.88	0.81
TE	0.5	-0.2	22.0	-0.2	0.5	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
TH	2.10	0.71	1.10	0.77	1.70	0.80	0.98	0.70	7.50	0.85	0.82
TL	11.00	0.18	120.00	1.20	2.70	0.03	-0.02	0.65	1.40	0.65	1.20
U	2.60	0.15	1.70	0.22	2.00	0.18	0.24	0.22	1.30	0.22	0.30
V	83	146	41	188	288	187	246	189	74	189	187
ZN	776	67	107000	40	34	60	118	95	83	261	263
ZR	43.0	47.0	15.0	62.0	285.0	57.0	75.0	44.0	76.0	68.0	65.0
CE	13.0	18.0	43.0	18.0	62.0	17.0	22.0	30.0	58.0	15.0	17.0
DY	0.95	2.30	0.56	3.30	9.20	3.30	2.80	4.60	2.50	1.60	2.50
ER	0.44	0.99	0.23	1.50	3.60	1.60	1.30	2.10	1.20	0.85	1.30
EU	0.53	0.95	0.73	0.75	2.40	1.00	1.00	1.20	0.48	0.58	0.53
GD	1.30	2.70	1.00	3.50	11.00	3.50	3.20	4.70	2.60	2.20	2.50
HO	0.17	0.39	0.10	0.62	1.60	0.63	0.50	0.84	0.47	0.30	0.50
LA	4.0	8.3	25.0	7.5	22.0	6.7	9.9	14.0	26.0	6.5	7.0
LU	0.07	0.14	0.04	0.22	0.32	0.21	0.19	0.26	0.21	0.16	0.20
ND	9.2	10.0	14.0	11.0	36.0	11.0	12.0	17.0	20.0	8.3	9.4
PR	2.00	2.30	3.90	2.30	7.80	2.30	2.70	3.80	5.50	1.80	2.20
SM	1.90	2.60	1.60	3.00	9.70	3.10	3.00	4.10	3.50	2.10	2.40
TB	0.16	0.42	0.13	0.56	1.80	0.55	0.49	0.76	0.43	0.31	0.40
TM	0.07	0.15	0.03	0.23	0.47	0.24	0.20	0.30	0.21	0.13	0.21
Y	4.90	12.00	2.80	18.00	42.00	18.00	15.00	25.00	14.00	8.60	15.00
YB	0.45	0.87	0.21	1.30	2.40	1.50	1.30	1.80	1.40	0.92	1.30

LAB_NO	91	113	115	71	42	30	26	66	14	41	64
SAMPLE_N	SAM-7	SAM-8	SAM-9	SAM-ALT 12	SLB99-05	SLB99-09	SLB99-101	SLB99-104	SLB99-106	SLB99-107B	SLB99-107C
Unit	4 (EBG)	33 alteration	33 alteration	33 alteration	4 (EBG)	2 (EBG)	4 (EBG)	4 (EBG)		11 4 (EBG)	4 (EBG)
SIO2	39.90	63.10	75.20	54.60	51.90	43.60	43.40	57.70	49.90	49.20	44.00
TIO2	1.87	0.77	0.50	0.70	1.26	0.68	1.55	2.45	1.25	1.90	2.66
AL2O3	17.90	17.80	5.20	16.30	10.10	15.70	15.20	14.30	16.70	15.20	16.90
FE2O3T	17.60	6.80	4.20	10.20	8.70	8.30	13.40	11.90	10.60	14.90	13.40
FE2O3	16.10	1.10	-999.00	-999.00	2.00	2.50	6.50	3.70	2.00	12.40	7.70
FEO	1.3	5.1	-999.0	-999.0	6.0	5.2	6.2	7.4	7.7	2.3	5.1
MNO	0.08	0.10	0.17	0.67	0.13	0.16	0.08	0.09	0.15	0.09	0.20
MGO	14.72	3.16	3.63	4.03	8.69	7.14	9.61	4.67	7.69	4.80	6.90
CAO	0.44	0.13	3.39	0.14	8.78	11.95	5.80	1.81	5.56	4.77	9.98
NA2O	0.00	0.10	0.00	0.30	3.30	2.80	0.10	0.00	4.60	3.20	2.40
K2O	0.74	4.19	0.69	4.24	0.65	1.34	1.98	1.39	0.80	1.65	0.02
H2OT	8.9	3.9	-999.0	-999.0	3.5	4.1	5.9	6.1	3.7	3.1	4.4
CO2T	0.2	0.2	6.3	5.5	4.6	5.8	4.3	1.1	0.7	1.9	0.1
P2O5	0.18	0.09	0.95	0.07	0.18	0.05	0.20	0.30	0.13	0.46	0.74
ST	0.14	0.85	1.07	2.89	0.06	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02
BA	480	2400	910	2100	200	310	350	1100	390	320	54
TOTAL	102.6	100.9	101.6	99.9	101.3	101.2	101.0	101.3	101.0	101.1	101.2
LOI	-999.0	-999.0	5.5	9.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0
AG	-0.1	-0.1	0.2	-0.1	-0.1	-0.1	-0.1	-0.1	0.1	-0.1	-0.1
BE	-0.5	2.1	-0.5	1.7	1.1	-0.5	0.6	1.2	0.5	1.0	1.7
BI	-0.2	0.5	0.5	0.4	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
CD	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
CO	59	17	30	32	50	40	70	40	43	60	49
CR	757	103	199	85	443	423	869	630	405	429	109
CS	0.39	2.00	0.47	2.50	5.20	1.70	1.80	1.30	0.31	0.90	0.18
CU	18	13	23	24	101	159	-10	49	77	-10	-10
GA	25.00	25.00	7.30	23.00	10.00	12.00	16.00	20.00	16.00	14.00	23.00
HF	2.50	3.00	1.20	2.70	1.40	0.62	1.30	3.40	1.20	3.50	3.90
IN	-0.05	0.06	-0.05	0.13	0.07	-0.05	0.07	0.05	0.05	0.05	0.10
MO	-0.2	0.3	5.1	-0.2	0.4	-0.2	-0.2	-0.2	-0.2	-0.2	1.1
NB	21.00	14.00	6.30	15.00	15.00	0.64	14.00	32.00	10.00	18.00	48.00
NI	399	50	122	56	241	137	392	156	99	420	84
PB	7	9	82	7	3	-1	-1	-1	-1	-1	5
RB	23.00	120.00	21.00	140.00	20.00	23.00	42.00	32.00	9.80	32.00	0.24
SB	1.1	2.0	5.7	2.0	0.3	0.2	0.8	0.3	0.4	-0.2	-0.2
SC	27.0	20.0	9.0	17.0	18.0	35.0	36.0	28.0	33.0	31.0	20.0
SN	0.6	2.3	0.7	3.7	1.7	-0.5	0.9	1.1	0.7	1.3	2.3
SR	-10	15	115	49	192	39	83	43	295	138	805
TA	1.30	1.00	0.40	0.90	0.80	0.05	0.64	1.70	0.51	1.00	2.30
TE	-0.2	-0.2	1.5	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
TH	1.10	14.00	3.00	11.00	0.79	0.07	0.79	1.60	0.50	1.10	3.00
TL	0.24	1.20	0.43	2.50	0.11	0.09	0.12	0.14	0.02	0.09	-0.02
U	0.35	1.80	9.80	1.50	0.20	0.07	0.23	0.76	0.14	0.20	0.76
V	282	92	132	77	172	228	266	237	202	135	206
ZN	324	92	123	131	59	58	118	106	83	85	99
ZR	99.0	110.0	49.0	120.0	54.0	20.0	56.0	150.0	45.0	180.0	270.0
CE	22.0	110.0	26.0	94.0	21.0	1.6	17.0	39.0	16.0	30.0	94.0
DY	2.80	4.30	5.40	4.50	2.50	2.40	2.10	4.50	2.60	3.60	5.70
ER	1.50	2.10	2.30	2.30	1.10	1.60	0.99	2.30	1.30	1.80	2.10
EU	0.58	0.75	0.68	0.97	1.10	0.44	0.87	0.87	0.79	0.97	3.30
GD	3.00	4.90	5.90	5.10	3.00	1.60	2.60	4.60	2.80	3.80	8.80
HO	0.55	0.79	0.98	0.87	0.45	0.53	0.38	0.90	0.50	0.72	0.95
LA	9.7	46.0	11.0	34.0	10.0	0.5	7.4	18.0	7.0	11.0	43.0
LU	0.25	0.32	0.27	0.35	0.12	0.28	0.18	0.28	0.15	0.27	0.21
ND	13.0	38.0	14.0	33.0	12.0	2.1	10.0	19.0	9.7	17.0	50.0
PR	2.80	10.00	3.10	8.90	2.70	0.33	2.30	4.70	2.20	3.80	12.00
SM	3.00	5.80	4.00	5.70	2.90	1.00	2.60	4.30	2.50	4.00	9.90
TB	0.46	0.74	0.96	0.82	0.46	0.35	0.40	0.74	0.45	0.62	1.20
TM	0.24	0.32	0.33	0.36	0.15	0.26	0.16	0.33	0.17	0.28	0.27
Y	16.00	23.00	29.00	25.00	12.00	16.00	10.00	27.00	14.00	18.00	27.00
YB	1.50	2.00	1.80	2.30	0.89	1.70	1.00	1.80	1.00	1.70	1.40

LAB_NO	57	63	31	65	54	62	70	61	76	51	59
SAMPLE_N	SLB99-108	SLB99-109	SLB99-11	SLB99-111	SLB99-114	SLB99-115	SLB99-11B	SLB99-121	SLB99-125	SLB99-129	SLB99-137
Unit	4 (EBG)	4 EBG	1b (EBGs)	4 (EBG)	4 (EBG)	4 (EBG)	4 (EBG)	4 (EBG)	4 (EBG)	4 (EBG)	9 (EBF)
SIO2	39.50	45.10	95.70	36.80	40.40	46.70	39.00	41.00	44.90	45.20	61.70
TIO2	0.94	1.45	0.07	1.08	1.58	1.34	0.82	1.08	2.21	2.03	0.56
AL2O3	9.50	13.40	2.20	10.00	13.00	12.50	7.00	11.00	14.80	17.00	14.10
FE2O3T	7.00	13.60	0.80	8.40	12.90	8.30	6.20	7.70	11.70	8.90	6.90
FE2O3	-999.00	1.80	0.00	1.50	3.60	1.10	0.30	0.60	2.20	-999.00	0.80
FEO	-999.0	10.6	0.7	6.2	8.4	6.4	5.3	6.4	8.5	-999.0	5.5
MNO	0.11	0.18	0.02	0.16	0.14	0.13	0.19	0.13	0.17	0.07	0.06
MGO	4.11	14.26	0.33	6.08	8.17	4.70	6.12	5.97	12.03	14.53	4.58
CAO	20.05	4.73	0.03	20.26	13.32	11.28	20.50	11.69	3.51	0.03	2.19
NA2O	3.00	2.90	0.60	2.60	2.80	4.20	0.90	3.20	2.20	4.40	5.10
K2O	0.73	0.10	0.22	0.21	0.16	0.06	0.11	1.17	0.02	0.05	0.47
H2OT	2.1	6.2	0.4	3.0	4.1	3.0	3.2	1.4	6.1	-999.0	2.6
CO2T	13.6	0.4	0.1	12.4	5.5	8.9	15.8	16.8	4.3	0.1	2.9
P2O5	0.12	0.16	0.03	0.12	0.25	0.15	0.06	0.16	0.30	0.15	0.12
ST	-0.02	0.13	-0.02	-0.02	0.04	0.14	-0.02	0.14	0.17	1.63	-0.02
BA	190	22	49	190	98	79	98	240	90	-20	630
TOTAL	100.9	101.5	100.5	100.4	101.6	100.8	99.4	100.8	101.5	94.3	100.8
LOI	11.8	-999.0	-999.0	11.3	-999.0	-999.0	15.4	17.3	-999.0	6.7	-999.0
AG	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	0.2	-0.1	-0.1	-0.1
BE	0.5	0.6	-0.5	-0.5	0.5	-0.5	-0.5	-0.5	-0.5	0.9	1.1
BI	-0.2	-0.2	0.5	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	0.4	-0.2
CD	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
CO	28	72	-5	39	61	41	20	37	53	7	14
CR	405	846	26	390	590	358	359	372	552	816	69
CS	0.48	0.12	0.13	0.17	0.10	0.06	0.09	0.53	0.09	0.07	0.58
CU	52	106	-10	79	75	81	-10	50	89	44	12
GA	9.00	17.00	2.20	12.00	19.00	12.00	8.50	12.00	18.00	20.00	15.00
HF	1.20	1.80	0.34	1.40	1.70	1.60	0.93	1.50	2.80	1.60	2.90
IN	-0.05	-0.05	-0.05	0.06	0.06	0.07	-0.05	0.06	0.10	0.05	-0.05
MO	-0.2	0.7	0.3	0.6	-0.2	-0.2	-0.2	-0.2	0.4	0.3	-0.2
NB	8.70	12.00	1.80	14.00	20.00	11.00	8.80	12.00	28.00	21.00	12.00
NI	189	418	11	181	368	197	66	157	314	209	10
PB	-1	-1	13	-1	2	4	2	3	4	107	20
RB	15.00	0.63	6.20	4.10	1.80	0.85	2.80	36.00	0.14	0.19	15.00
SB	0.5	0.4	-0.2	0.4	0.4	1.1	-0.2	1.8	1.4	2.9	-0.2
SC	21.0	24.0	2.7	18.0	23.0	22.0	14.0	17.0	27.0	31.0	22.0
SN	-0.5	1.2	-0.5	1.3	0.8	0.5	-0.5	0.9	1.5	1.1	0.7
SR	303	27	-10	335	362	177	604	132	51	112	123
TA	0.45	0.70	0.10	0.71	1.10	0.61	0.47	0.68	1.60	1.20	0.83
TE	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	0.6	-0.2
TH	0.48	0.73	3.00	0.73	1.10	0.60	0.52	0.72	1.50	0.94	6.30
TL	0.04	-0.02	0.03	0.02	-0.02	0.02	-0.02	0.49	0.03	0.02	0.09
U	0.32	0.22	0.58	0.23	0.30	0.40	0.12	0.22	0.42	0.25	1.50
V	167	210	12	145	232	172	120	127	241	308	119
ZN	39	95	16	59	90	70	38	39	106	507	75
ZR	49.0	73.0	13.0	57.0	67.0	61.0	33.0	62.0	110.0	70.0	130.0
CE	13.0	18.0	18.0	18.0	30.0	17.0	9.8	16.0	47.0	22.0	35.0
DY	2.00	3.10	0.49	2.40	3.20	2.50	1.80	2.40	4.00	3.50	2.30
ER	1.10	1.50	0.22	1.10	1.50	1.20	0.85	1.10	1.80	1.90	1.30
EU	0.67	1.20	0.18	0.84	1.40	1.00	0.75	0.99	1.90	0.92	0.73
GD	2.20	3.30	0.68	2.70	4.00	2.90	2.00	2.90	5.40	3.40	2.60
HO	0.42	0.59	0.08	0.46	0.60	0.47	0.34	0.45	0.75	0.72	0.47
LA	5.7	7.8	6.4	7.8	14.0	7.4	4.5	7.0	21.0	9.6	17.0
LU	0.15	0.19	0.04	0.14	0.18	0.15	0.10	0.14	0.23	0.23	0.23
ND	7.7	11.0	5.0	9.7	16.0	9.7	6.0	9.5	26.0	13.0	16.0
PR	1.70	2.40	1.40	2.20	3.60	2.20	1.30	2.00	6.00	2.70	3.90
SM	1.90	2.90	0.85	2.50	3.60	2.60	1.60	2.50	5.90	3.00	2.90
TB	0.36	0.54	0.10	0.42	0.59	0.45	0.33	0.43	0.78	0.58	0.40
TM	0.16	0.22	0.04	0.17	0.21	0.17	0.12	0.16	0.25	0.27	0.21
Y	12.00	17.00	1.90	13.00	17.00	13.00	10.00	13.00	20.00	21.00	14.00
YB	0.98	1.30	0.23	0.98	1.20	0.98	0.74	0.95	1.50	1.60	1.40

LAB_NO	7	73	60	69	75	5	39	49	68	12	11
SAMPLE_N	SLB99-138D	SLB99-139	SLB99-140	SLB99-141	SLB99-142D	SLB99-146	SLB99-146C	SLB99-151	SLB99-152	SLB99-153	SLB99-161
Unit	4 (EBG)	Sam horizon	4 (EBG)	Sam horizon	9b (EBF)	9b (EBF)	9b (EBF)	9b (EBF)	9b (EBF)	9b (EBF)	9b (EBF)
SIO2	27.30	44.00	44.40	89.60	65.50	69.40	60.50	61.70	50.40	56.10	59.90
TIO2	0.53	1.40	3.20	0.19	0.32	0.29	0.62	0.49	0.52	0.58	0.58
AL2O3	4.60	15.00	16.30	5.40	15.90	16.50	16.50	15.30	14.90	16.40	17.10
FE2O3T	9.70	12.10	17.20	2.00	4.00	2.80	7.40	7.20	6.70	8.40	7.40
FE2O3	1.00	1.30	4.50	2.00	2.30	1.30	4.80	1.60	0.70	2.80	2.80
FEO	7.8	9.7	11.4	-0.2	1.5	1.4	2.3	5.1	5.4	5.0	4.1
MNO	0.35	0.13	0.11	0.00	0.07	0.01	0.10	0.13	0.20	0.11	0.07
MGO	10.31	8.36	7.06	0.26	1.03	0.79	1.85	3.30	3.20	3.86	3.52
CAO	18.46	5.05	2.96	0.00	2.67	0.27	1.98	2.00	9.36	5.08	0.70
NA2O	0.40	3.90	2.30	0.10	2.20	7.70	3.60	4.90	5.60	4.90	6.60
K2O	0.71	0.13	1.38	1.46	4.14	1.73	3.94	1.56	1.02	1.77	2.26
H2OT	1.4	4.2	5.6	1.2	2.2	0.9	2.6	2.8	2.3	2.6	2.4
CO2T	27.3	7.5	1.7	0.2	2.4	0.1	1.7	1.4	6.8	1.3	0.2
P2O5	0.13	0.17	0.57	0.06	0.20	0.20	0.32	0.26	0.33	0.51	0.45
ST	0.04	0.04	-0.02	-0.02	0.29	-0.02	-0.02	-0.02	0.06	-0.02	-0.02
BA	240	160	800	390	3400	710	1700	1600	1600	570	1200
TOTAL	100.4	101.0	101.6	100.6	101.1	100.7	101.0	100.8	100.9	101.1	100.9
LOI	27.3	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0
AG	0.1	0.4	-0.1	0.3	-0.1	-0.1	0.1	-0.1	-0.1	-0.1	-0.1
BE	-0.5	-0.5	1.3	0.6	4.1	2.4	3.0	2.1	2.0	2.1	2.3
BI	-0.2	-0.2	-0.2	0.3	-0.2	0.3	-0.2	-0.2	-0.2	-0.2	-0.2
CD	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
CO	23	42	58	-5	9	-5	11	17	17	16	17
CR	188	272	40	45	18	15	17	18	66	34	14
CS	0.48	0.10	1.70	0.93	5.40	3.40	6.20	2.60	0.91	3.00	7.90
CU	37	92	169	16	12	-10	-10	10	79	27	15
GA	5.60	18.00	21.00	7.40	18.00	16.00	18.00	17.00	15.00	17.00	17.00
HF	0.77	1.30	4.30	0.84	3.60	3.70	3.40	3.20	3.90	3.60	3.60
IN	-0.05	0.10	0.10	-0.05	-0.05	-0.05	-0.05	0.06	-0.05	-0.05	-0.05
MO	0.3	-0.2	-0.2	0.3	0.4	-0.2	-0.2	-0.2	0.4	0.5	-0.2
NB	12.00	15.00	31.00	3.80	17.00	19.00	11.00	12.00	13.00	16.00	15.00
NI	127	157	80	-10	-10	-10	-10	-10	13	12	-10
PB	2	25	5	9	4	3	3	2	8	11	8
RB	19.00	3.30	40.00	44.00	170.00	36.00	160.00	47.00	23.00	50.00	73.00
SB	0.3	7.5	1.9	2.2	0.4	-0.2	0.5	0.2	-0.2	0.6	0.3
SC	10.0	25.0	46.0	6.9	8.0	4.5	16.0	14.0	16.0	23.0	14.0
SN	-0.5	1.3	1.6	0.8	1.0	0.8	1.0	1.0	0.9	1.0	1.1
SR	198	115	80	32	96	138	181	276	1030	937	278
TA	0.55	0.79	1.70	0.25	1.10	1.20	0.49	0.68	0.69	0.77	0.63
TE	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
TH	0.68	0.80	2.00	6.00	25.00	24.00	12.00	14.00	18.00	21.00	20.00
TL	0.34	0.13	0.51	0.72	0.84	0.22	0.79	0.23	0.22	0.24	0.41
U	0.19	0.18	0.53	0.35	5.40	3.60	2.90	4.00	4.60	6.00	4.00
V	103	195	487	25	89	58	174	151	136	201	147
ZN	40	145	112	15	41	36	81	68	54	64	98
ZR	33.0	54.0	190.0	32.0	130.0	120.0	150.0	140.0	150.0	170.0	140.0
CE	11.0	19.0	57.0	25.0	140.0	77.0	98.0	130.0	100.0	200.0	170.0
DY	2.00	2.50	5.20	0.52	3.40	2.40	3.70	3.70	3.50	5.20	4.40
ER	0.78	1.10	2.20	0.25	1.60	1.20	1.90	1.70	1.60	2.00	1.90
EU	0.83	1.00	2.40	0.19	2.00	1.20	1.80	2.00	1.90	3.30	2.60
GD	2.30	2.80	6.80	0.83	6.10	3.40	5.20	6.20	6.00	9.40	7.20
HO	0.34	0.46	0.90	0.09	0.60	0.45	0.70	0.65	0.62	0.87	0.80
LA	5.9	8.2	26.0	11.0	72.0	41.0	51.0	66.0	50.0	110.0	91.0
LU	0.08	0.15	0.26	0.06	0.27	0.23	0.30	0.26	0.23	0.26	0.31
ND	6.0	11.0	34.0	8.3	54.0	31.0	42.0	52.0	46.0	84.0	68.0
PR	1.40	2.50	7.50	2.30	15.00	8.70	11.00	14.00	12.00	23.00	19.00
SM	1.80	2.70	7.30	1.30	8.80	4.90	7.20	8.40	8.10	14.00	11.00
TB	0.36	0.46	0.95	0.10	0.75	0.48	0.74	0.78	0.75	1.20	0.95
TM	0.10	0.17	0.30	0.04	0.25	0.20	0.28	0.25	0.23	0.27	0.29
Y	9.90	13.00	25.00	2.30	19.00	15.00	22.00	20.00	20.00	27.00	25.00
YB	0.55	0.98	1.80	0.33	1.60	1.40	1.80	1.60	1.40	1.60	1.90

LAB_NO	10	20	16	21	40	13	15	43	45	19	18
SAMPLE_N	SLB99-163	SLB99-166	SLB99-166B	SLB99-166C	SLB99-168	SLB99-171	SLB99-179	SLB99-17B	SLB99-17C	SLB99-182	SLB99-187
Unit	9 (EBF)	9b (EBF)	9b (EBF)	9b (EBF)	9b (EBF)	9b (EBF)	9b (EBF)	2 (EBG)	2 (EBG)	9b (EBF)	9b (EBF)
SIO2	61.60	63.90	39.60	42.30	58.50	51.30	50.30	48.20	42.90	54.30	67.50
TIO2	0.42	0.50	1.90	1.15	0.54	1.92	0.76	0.70	0.90	0.74	0.35
AL2O3	17.30	13.70	11.50	11.40	15.70	15.60	19.30	16.20	18.10	17.60	14.90
FE2O3T	5.20	5.50	11.40	7.60	6.70	11.10	10.20	10.70	13.10	9.00	3.10
FE2O3	3.00	3.40	2.00	2.00	2.20	7.00	3.70	4.80	1.60	2.20	2.00
FEO	2.0	1.9	8.5	5.0	4.0	3.7	5.8	5.3	10.3	6.1	1.0
MNO	0.05	0.10	0.18	0.18	0.11	0.13	0.11	0.16	0.25	0.09	0.03
MGO	1.85	1.16	11.38	6.03	3.57	3.91	6.03	6.88	11.91	4.50	0.96
CAO	0.95	4.48	8.14	10.52	6.40	4.42	3.11	13.31	5.06	2.82	3.26
NA2O	6.50	3.20	2.00	1.20	3.50	7.00	2.60	2.00	2.60	3.90	0.90
K2O	3.10	2.03	0.03	2.34	0.98	0.62	3.61	0.04	0.73	2.70	5.42
H2OT	1.6	2.5	4.5	2.4	2.9	2.3	4.6	3.1	6.4	4.0	2.2
CO2T	-999.0	3.9	-999.0	15.5	1.9	3.1	0.1	0.3	0.4	1.7	2.4
P2O5	0.29	0.13	0.24	0.17	0.41	0.38	0.45	0.04	0.05	0.52	0.22
ST	0.26	-0.02	0.14	0.27	-0.02	-0.02	-0.02	-0.02	-0.02	0.02	-0.02
BA	960	3100	42	780	380	240	2000	66	240	1600	1500
TOTAL	99.1	101.3	90.2	100.6	100.8	101.4	100.9	101.2	101.3	101.5	101.3
LOI	1.7	-999.0	14.5	16.5	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0
AG	-0.1	-0.1	-0.1	-0.1	0.1	-0.1	-0.1	-0.1	-0.1	0.1	-0.1
BE	3.7	1.4	-0.5	-0.5	2.5	0.5	5.1	-0.5	0.5	4.2	2.7
BI	-0.2	0.2	-0.2	-0.2	0.3	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
CD	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
CO	9	11	61	26	13	26	22	48	60	18	6
CR	14	49	491	167	16	122	27	479	592	43	15
CS	7.50	2.60	0.05	1.60	1.40	1.20	6.00	0.05	0.61	3.80	5.70
CU	-10	14	56	57	11	89	82	15	68	54	-10
GA	20.00	15.00	14.00	13.00	16.00	12.00	23.00	14.00	18.00	19.00	16.00
HF	4.80	2.90	1.70	1.20	3.10	3.00	4.80	0.76	0.95	3.90	3.60
IN	-0.05	-0.05	-0.05	-0.05	-0.05	0.06	-0.05	-0.05	0.06	0.05	-0.05
MO	-0.2	0.2	-0.2	-0.2	0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
NB	20.00	9.80	24.00	13.00	14.00	43.00	17.00	0.66	0.75	17.00	19.00
NI	-10	-10	292	68	-10	77	-10	155	230	12	-10
PB	2	2	5	4	12	2	12	4	-1	11	2
RB	140.00	72.00	0.33	51.00	29.00	17.00	120.00	0.37	17.00	100.00	170.00
SB	0.2	-0.2	0.6	0.2	0.6	0.5	0.5	0.9	-0.2	0.3	0.3
SC	6.7	16.0	22.0	20.0	14.0	21.0	28.0	42.0	53.0	24.0	7.7
SN	1.4	1.4	1.2	-0.5	0.9	2.0	2.1	0.6	0.6	1.1	0.9
SR	216	142	87	95	1020	157	777	243	76	369	127
TA	1.30	0.69	1.30	0.63	0.73	2.30	1.00	0.05	0.07	0.78	1.20
TE	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
TH	30.00	9.20	1.10	0.71	15.00	2.40	20.00	0.04	0.05	32.00	25.00
TL	0.68	0.41	-0.02	0.59	0.14	0.07	0.43	-0.02	0.09	0.39	0.83
U	6.20	1.70	0.29	0.20	3.90	0.60	5.80	0.02	-0.02	5.90	1.90
V	90	111	189	156	172	162	303	253	313	238	89
ZN	80	36	104	42	67	60	86	59	86	75	25
ZR	160.0	130.0	71.0	52.0	140.0	140.0	180.0	20.0	31.0	160.0	120.0
CE	120.0	58.0	32.0	20.0	93.0	41.0	180.0	2.8	3.1	190.0	140.0
DY	4.60	2.80	2.90	2.30	4.10	3.60	5.70	3.20	3.90	4.90	3.40
ER	2.10	1.50	1.20	1.10	1.70	1.70	2.30	2.10	2.40	1.90	1.50
EU	2.30	1.10	1.30	1.00	1.90	1.30	3.20	0.61	0.58	3.00	2.10
GD	6.50	3.50	3.70	2.80	6.30	4.00	9.60	2.40	2.90	8.20	5.50
HO	0.82	0.55	0.52	0.41	0.68	0.70	0.99	0.72	0.87	0.84	0.58
LA	64.0	31.0	14.0	8.8	45.0	18.0	96.0	0.8	0.9	114.0	79.0
LU	0.34	0.26	0.15	0.13	0.27	0.23	0.33	0.33	0.37	0.24	0.26
ND	52.0	23.0	18.0	11.0	44.0	21.0	75.0	3.3	4.0	75.0	55.0
PR	14.00	6.50	4.20	2.60	11.00	5.20	21.00	0.54	0.62	21.00	16.00
SM	8.30	4.30	3.70	2.80	8.00	4.20	13.00	1.40	1.70	12.00	8.50
TB	0.94	0.53	0.53	0.42	0.82	0.62	1.20	0.47	0.57	1.10	0.72
TM	0.32	0.23	0.17	0.14	0.26	0.24	0.32	0.33	0.38	0.27	0.22
Y	29.00	17.00	15.00	13.00	23.00	19.00	29.00	20.00	25.00	26.00	19.00
YB	2.00	1.50	1.00	0.85	1.60	1.40	2.00	2.20	2.50	1.50	1.50

LAB_NO	23	36	17	86	77	53	56	78	79	80	81
SAMPLE_N	SLB99-192	SLB99-192B	SLB99-193	SLB99-198	SLB99-200	SLB99-204	SLB99-21	SLB99-214	SLB99-215	SLB99-216	SLB99-217
Unit	9 (EBF)	9 (EBF)	4 (EBG)	4 (EBG)	4 (EBG)	10 4 (EBG)		duplicate slb99	duplicate slb99	duplicate slb99	duplicate slb99
SiO2	63.20	62.50	40.80	23.10	37.30	19.20	46.80	77.40	44.00	60.80	36.50
TiO2	0.34	0.26	1.69	0.65	2.12	0.06	1.92	1.09	1.44	0.23	1.29
AL2O3	15.80	12.90	14.10	8.00	14.30	0.70	15.50	11.10	10.70	13.10	12.40
FE2O3T	5.30	3.50	10.50	10.60	14.00	7.70	12.40	2.40	8.60	2.80	8.20
FE2O3	1.30	1.20	1.30	-999.00	1.60	0.00	2.50	2.00	-999.00	0.50	1.10
FEO	3.6	2.1	8.3	-999.0	11.2	6.9	8.9	0.4	-999.0	2.1	6.4
MNO	0.05	0.08	0.13	0.30	0.13	0.15	0.13	0.00	0.25	0.07	0.11
MGO	1.22	0.96	6.34	12.24	17.74	11.94	8.00	1.28	8.45	0.98	3.85
CAO	3.95	7.70	11.79	16.87	3.56	24.55	7.16	0.01	8.60	7.86	18.03
NA2O	3.20	2.60	2.70	0.10	0.20	0.20	3.20	0.60	0.50	3.30	3.10
K2O	2.63	2.57	1.00	1.15	0.02	0.11	0.95	4.40	1.40	3.08	1.11
H2OT	2.4	1.8	4.5	-999.0	8.1	0.2	4.5	1.9	-999.0	1.2	3.1
CO2T	2.9	5.9	8.6	25.0	4.1	36.2	1.4	-0.1	13.0	7.1	13.6
P2O5	0.21	0.21	0.23	0.12	0.65	0.05	0.25	0.01	0.41	0.19	0.21
ST	-0.02	-0.02	0.02	1.00	-0.02	0.04	-0.02	0.17	2.50	0.18	0.09
BA	1600	900	280	390	-20	63	450	970	910	840	260
TOTAL	101.0	100.9	101.5	99.2	101.1	100.4	101.4	100.5	100.0	100.8	101.0
LOI	-999.0	-999.0	-999.0	25.5	-999.0	33.5	-999.0	-999.0	15.3	-999.0	-999.0
AG	-0.1	-0.1	0.1	1.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
BE	2.1	2.4	-0.5	-0.5	1.1	-0.5	1.0	1.3	0.8	1.8	0.5
BI	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
CD	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
CO	-5	-5	31	31	58	5	43	-5	33	-5	28
CR	14	16	226	144	531	27	170	382	417	15	192
CS	2.40	2.70	0.77	0.52	0.04	0.15	0.33	1.80	1.30	2.50	0.54
CU	-10	-10	135	205	92	-10	85	-10	51	-10	85
GA	17.00	15.00	17.00	9.60	23.00	0.70	18.00	15.00	13.00	13.00	17.00
HF	3.80	3.10	1.90	0.85	3.90	0.41	1.80	1.20	2.80	3.40	1.70
IN	-0.05	-0.05	0.07	0.06	0.06	-0.05	0.09	-0.05	0.06	-0.05	0.06
MO	-0.2	0.3	-0.2	-0.2	-0.2	-0.2	0.2	1.2	0.2	1.0	0.5
NB	20.00	14.00	19.00	6.80	62.00	1.10	26.00	8.10	43.00	15.00	16.00
NI	-10	-10	73	63	306	62	82	65	195	-10	62
PB	3	4	-1	12	-1	18	1	-1	35	6	1
RB	72.00	73.00	20.00	28.00	-0.05	4.20	15.00	110.00	47.00	83.00	22.00
SB	0.2	-0.2	-0.2	3.0	1.1	0.2	-0.2	1.0	5.4	0.4	0.5
SC	6.2	6.1	24.0	20.0	24.0	1.5	27.0	14.0	18.0	6.8	24.0
SN	0.9	0.8	1.1	-0.5	0.9	-0.5	1.1	0.9	1.2	0.9	0.8
SR	205	314	186	236	87	409	225	13	235	445	371
TA	1.30	0.88	0.99	0.37	3.00	0.07	1.30	0.44	2.00	1.10	0.90
TE	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
TH	27.00	24.00	1.10	0.49	4.00	0.79	1.30	0.28	2.80	23.00	0.92
TL	0.38	0.38	0.15	0.27	-0.02	0.04	0.03	0.40	0.66	0.48	0.12
U	1.30	1.90	0.33	0.20	1.10	0.52	0.35	1.20	0.78	1.20	0.30
V	68	62	207	126	211	11	243	194	160	75	210
ZN	60	39	81	47	115	61	88	15	120	21	62
ZR	140.0	110.0	79.0	33.0	200.0	18.0	66.0	49.0	140.0	140.0	73.0
CE	150.0	140.0	30.0	20.0	78.0	12.0	35.0	5.3	55.0	120.0	26.0
DY	3.50	3.30	2.80	5.30	3.80	1.90	3.70	0.60	3.40	4.40	3.30
ER	1.40	1.40	1.30	2.20	1.50	0.92	1.70	0.38	1.40	1.80	1.40
EU	2.20	2.20	1.20	2.50	2.20	0.73	1.40	0.05	0.99	2.00	1.20
GD	6.00	6.10	3.20	5.70	5.70	2.20	4.60	0.54	4.50	6.70	3.70
HO	0.56	0.57	0.51	0.92	0.65	0.37	0.68	0.13	0.62	0.75	0.57
LA	81.0	77.0	14.0	8.9	39.0	6.3	16.0	2.4	27.0	66.0	12.0
LU	0.25	0.23	0.19	0.21	0.15	0.10	0.19	0.06	0.16	0.29	0.19
ND	58.0	54.0	16.0	13.0	37.0	6.5	18.0	2.9	25.0	46.0	14.0
PR	17.00	16.00	3.80	2.80	9.10	1.50	4.20	0.67	6.20	13.00	3.30
SM	9.20	8.80	3.50	4.70	7.00	1.80	4.30	0.61	4.90	8.80	3.70
TB	0.74	0.74	0.50	0.95	0.77	0.34	0.68	0.09	0.67	0.89	0.56
TM	0.23	0.21	0.19	0.29	0.19	0.13	0.24	0.06	0.19	0.28	0.21
Y	19.00	18.00	15.00	28.00	17.00	15.00	19.00	3.90	17.00	23.00	17.00
YB	1.40	1.30	1.20	1.60	1.10	0.73	1.30	0.37	1.10	1.80	1.30

LAB_NO	82	58	87	44	8	83	47	84	29	3	52
SAMPLE_N	SLB99-218	SLB99-22	SLB99-22B	SLB99-22C	SLB99-26	SLB99-27	SLB99-30	SLB99-31	SLB99-33	SLB99-35	SLB99-37
Unit	duplicate slb99 4 (EBG)	4 (EBG)	4 (EBG)	4 (EBG)	4 (EBG)	33 alteration	9 (EBF)	9 (EBF)	9 (EBF)	4 (EBG)	4 (EBG)
SIO2	44.50	34.10	86.00	34.60	77.40	47.10	57.60	67.20	65.20	36.40	43.90
TIO2	1.02	1.22	0.62	0.95	0.39	1.82	0.61	0.25	0.32	1.23	0.85
AL2O3	10.50	12.50	6.80	9.20	8.40	13.10	15.40	13.00	16.00	11.00	7.60
FE2O3T	8.80	9.70	1.50	6.60	8.50	7.80	7.70	2.70	2.80	7.10	5.10
FE2O3	1.20	1.60	1.20	0.80	0.80	-999.00	1.00	1.10	2.00	0.90	0.40
FEO	6.9	7.3	0.3	5.2	7.0	-999.00	6.1	1.4	0.7	5.6	4.2
MNO	0.20	0.13	0.00	0.17	0.03	0.18	0.08	0.05	0.05	0.16	0.20
MGO	9.31	6.88	0.78	5.41	2.48	7.76	5.29	0.72	0.70	3.21	4.03
CAO	12.47	15.51	0.03	21.25	0.18	6.48	3.16	4.91	2.57	20.58	19.35
NA2O	3.60	2.50	0.60	2.30	0.10	0.60	4.90	3.30	3.20	3.70	2.40
K2O	0.10	1.09	2.63	0.25	0.73	1.73	0.76	3.05	5.44	0.32	0.20
H2OT	3.7	4.4	1.1	3.1	3.1	-999.00	3.5	1.4	1.7	2.5	2.2
CO2T	7.4	12.1	0.1	16.0	0.7	9.8	2.5	4.1	1.8	15.1	14.4
P2O5	0.12	0.18	0.01	0.12	0.08	0.51	0.12	0.16	0.25	0.21	0.18
ST	-0.02	-0.02	0.11	-0.02	0.03	1.80	0.06	0.16	-0.02	0.16	0.07
BA	1600	240	590	220	540	1100	890	810	1500	97	130
TOTAL	101.2	99.7	100.3	99.6	101.4	98.9	101.1	101.0	100.2	101.3	100.0
LOI	-999.0	14.5	-999.0	14.4	-999.0	12.6	-999.0	-999.0	-999.0	12.8	11.6
AG	-0.1	-0.1	-0.1	-0.1	0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
BE	0.5	0.5	0.6	-0.5	0.5	1.1	1.1	1.9	4.1	-0.5	-0.5
BI	-0.2	-0.2	-0.2	-0.2	0.2	-0.2	-0.2	-0.2	-0.2	0.3	-0.2
CD	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	0.2
CO	47	55	-5	35	-5	39	19	-5	-5	23	26
CR	443	574	223	402	97	513	122	12	16	176	323
CS	6.20	0.89	1.00	0.18	0.37	1.50	1.20	2.60	3.20	0.18	0.17
CU	80	81	-10	33	46	45	22	-10	-10	63	43
GA	9.90	14.00	8.80	9.00	10.00	15.00	16.00	13.00	18.00	12.00	8.80
HF	1.20	1.60	0.75	1.10	5.40	3.40	3.30	3.50	5.00	1.40	1.20
IN	-0.05	0.08	-0.05	0.07	-0.05	0.05	0.06	-0.05	-0.05	-0.05	-0.05
MO	0.4	-0.2	0.8	-0.2	0.4	-0.2	0.2	0.5	0.3	0.3	-0.2
NB	12.00	11.00	4.70	11.00	9.00	52.00	12.00	16.00	22.00	14.00	12.00
NI	231	203	38	178	60	205	11	-10	-10	55	131
PB	1	1	8	2	8	21	12	4	17	-1	3
RB	3.40	26.00	54.00	5.10	25.00	58.00	35.00	82.00	160.00	5.30	2.10
SB	1.7	0.9	0.8	0.8	1.7	4.6	0.3	0.2	0.3	0.3	0.2
SC	21.0	24.0	8.9	17.0	9.0	22.0	26.0	6.1	5.3	19.0	13.0
SN	0.6	1.0	-0.5	0.8	0.7	2.0	1.3	0.8	2.7	0.8	0.5
SR	206	419	-10	420	33	216	220	240	138	409	626
TA	0.67	0.55	0.26	0.51	0.53	2.70	0.86	1.20	1.30	0.69	0.60
TE	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
TH	0.60	0.54	0.15	0.45	12.00	3.50	6.60	22.00	29.00	0.80	0.67
TL	0.02	0.10	0.25	0.02	0.50	0.74	0.19	0.49	0.56	0.03	-0.02
U	0.13	1.90	0.67	0.20	2.30	0.90	2.00	1.20	5.30	0.27	0.20
V	180	195	114	127	112	190	159	63	65	146	86
ZN	54	74	8	43	203	126	77	19	48	51	34
ZR	46.0	60.0	28.0	48.0	200.0	170.0	130.0	130.0	180.0	59.0	53.0
CE	15.0	17.0	1.5	11.0	63.0	59.0	36.0	110.0	150.0	24.0	20.0
DY	2.60	2.80	0.35	1.90	3.00	3.50	2.60	3.80	4.40	2.40	2.20
ER	1.20	1.40	0.21	0.99	1.70	1.40	1.60	1.60	2.00	1.10	1.10
EU	0.80	1.10	-0.02	0.73	0.80	1.10	0.71	1.60	2.20	1.10	0.56
GD	2.60	3.10	0.23	2.20	3.30	5.00	2.80	5.50	6.80	3.00	2.60
HO	0.49	0.53	0.07	0.37	0.61	0.61	0.57	0.67	0.76	0.43	0.43
LA	6.6	7.3	0.7	5.1	32.0	30.0	18.0	61.0	79.0	11.0	9.0
LU	0.17	0.16	0.03	0.15	0.27	0.19	0.29	0.27	0.33	0.16	0.14
ND	8.6	9.7	0.8	6.9	27.0	27.0	15.0	42.0	59.0	13.0	11.0
PR	1.90	2.20	0.21	1.50	7.50	7.00	4.00	12.00	17.00	3.10	2.40
SM	2.30	2.70	0.22	1.90	4.30	6.00	3.00	7.70	9.50	3.00	2.50
TB	0.42	0.49	0.05	0.35	0.53	0.69	0.44	0.75	0.88	0.45	0.41
TM	0.19	0.19	0.03	0.15	0.27	0.21	0.27	0.26	0.29	0.16	0.16
Y	14.00	15.00	2.20	11.00	19.00	17.00	16.00	22.00	26.00	12.00	12.00
YB	1.10	1.10	0.22	0.96	1.70	1.20	1.80	1.60	1.90	0.95	1.00

LAB_NO	25	32	22	34	37	6	74	50	4	48	33
SAMPLE_N	SLB99-39	SLB99-42	SLB99-45	SLB99-48	SLB99-50	SLB99-54	SLB99-56	SLB99-58	SLB99-59	SLB99-61	SLB99-67C
Unit	4 (EBG)	4 (EBG)	Alt zone at Sa	2 (EBG)	1a (EBGs)	4 (EBG)	3 (EBG)	4 (EBG)	4 (EBG)	4 (EBG)	4 (EBG)
SIO2	46.70	38.20	42.50	48.10	61.20	45.60	0.30	42.40	39.30	45.50	41.70
TIO2	0.83	1.40	1.61	1.30	0.95	3.04	0.00	1.26	1.03	1.12	1.00
AL2O3	16.30	12.20	11.60	14.60	13.60	12.50	0.10	14.80	9.90	10.80	10.50
FE2O3T	9.40	12.00	11.30	12.00	6.90	15.50	0.10	12.10	8.80	7.40	10.20
FE2O3	2.80	1.10	1.60	3.60	0.70	1.20	0.00	1.80	1.60	1.40	0.40
FEO	6.0	9.8	8.7	7.5	5.6	12.9	-0.2	9.3	6.5	5.4	8.9
MNO	0.14	0.14	0.19	0.20	0.11	0.67	0.00	0.17	0.13	0.12	0.34
MGO	9.16	11.32	12.10	8.42	4.72	4.65	2.06	7.65	5.81	5.78	5.53
CAO	13.43	8.12	6.38	11.27	2.93	7.18	55.19	10.75	18.78	14.42	15.02
NA2O	1.50	1.00	0.20	2.40	2.40	3.20	0.00	3.70	3.70	3.30	1.50
K2O	0.16	0.51	0.33	0.05	2.26	0.04	0.04	0.07	0.11	0.27	0.21
H2OT	3.4	5.0	5.5	3.5	3.7	4.0	0.1	4.3	3.0	3.1	4.2
CO2T	0.1	11.6	9.2	0.3	3.5	4.6	41.6	4.7	11.7	9.3	11.6
P2O5	0.05	0.18	0.20	0.11	0.17	0.68	0.01	0.10	0.11	0.12	0.13
ST	-0.02	0.11	0.92	-0.02	-0.02	0.03	-0.02	0.02	-0.02	-0.02	-0.02
BA	78	590	310	46	370	45	-20	67	190	150	52
TOTAL	100.8	100.9	101.1	101.5	101.9	100.4	99.5	101.1	101.7	100.8	101.2
LOI	-999.0	15.1	-999.0	-999.0	-999.0	-999.0	28.7	-999.0	10.2	-999.0	12.3
AG	-0.1	-0.1	-0.1	0.1	-0.1	-0.1	-0.1	0.1	-0.1	-0.1	-0.1
BE	-0.5	0.5	-0.5	-0.5	1.5	1.8	-0.5	-0.5	-0.5	-0.5	-0.5
BI	-0.2	-0.2	-0.2	-0.2	0.3	-0.2	-0.2	-0.2	-0.2	-0.2	0.3
CD	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	0.3
CO	40	67	44	31	18	33	-5	73	44	36	35
CR	497	599	432	313	150	38	10	788	503	371	128
CS	0.11	0.26	0.25	0.11	3.30	0.14	0.03	0.09	0.06	0.08	0.18
CU	67	107	72	51	31	236	-10	68	40	47	78
GA	23.00	15.00	15.00	17.00	17.00	23.00	0.20	13.00	10.00	12.00	13.00
HF	0.81	1.40	1.50	1.10	6.20	5.40	-0.05	1.30	0.95	1.40	1.60
IN	0.09	0.05	-0.05	0.07	0.07	0.12	-0.05	0.18	0.05	-0.05	0.09
MO	-0.2	0.3	-0.2	-0.2	0.2	0.7	-0.2	0.4	0.2	-0.2	0.3
NB	0.90	16.00	20.00	2.00	16.00	31.00	0.28	7.50	8.00	14.00	3.20
NI	162	325	279	67	64	35	-10	448	292	165	50
PB	-1	2	8	-1	6	4	1	-1	-1	2	4
RB	2.70	13.00	10.00	1.60	76.00	0.51	0.51	0.79	0.67	3.30	5.60
SB	0.5	1.1	1.1	0.4	0.5	-0.2	0.3	0.3	0.3	-0.2	0.2
SC	42.0	24.0	26.0	46.0	19.0	32.0	-0.5	28.0	20.0	19.0	28.0
SN	0.7	0.7	1.2	0.6	2.1	2.1	-0.5	0.8	1.2	1.0	0.8
SR	75	111	151	44	65	291	137	152	209	339	259
TA	0.07	0.82	1.20	0.15	0.98	1.70	-0.05	0.42	0.38	0.76	0.20
TE	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
TH	0.08	0.80	1.10	0.12	10.00	1.90	0.04	0.44	0.45	0.77	0.79
TL	-0.02	0.10	0.22	-0.02	0.43	-0.02	-0.02	-0.02	-0.02	-0.02	0.03
U	0.04	0.21	0.31	0.04	1.90	0.60	0.29	0.43	0.19	0.23	0.50
V	328	209	206	322	128	390	-5	223	167	144	250
ZN	52	103	193	86	81	146	-5	88	69	54	78
ZR	25.0	62.0	61.0	38.0	220.0	250.0	0.9	46.0	35.0	56.0	66.0
CE	5.2	24.0	24.0	7.2	78.0	64.0	0.4	9.5	11.0	17.0	9.0
DY	3.80	2.40	2.70	4.80	4.50	8.40	0.05	2.60	2.10	2.20	4.80
ER	2.50	1.20	1.30	3.00	2.40	3.80	0.03	1.30	1.00	1.00	3.10
EU	1.00	1.10	0.86	1.00	1.40	2.80	-0.02	0.72	0.64	0.79	0.90
GD	2.90	2.80	2.90	4.10	5.50	9.60	0.05	2.50	2.10	2.50	4.10
HO	0.83	0.47	0.53	1.10	0.91	1.50	-0.02	0.52	0.41	0.41	1.10
LA	1.7	11.0	11.0	2.2	38.0	27.0	0.3	3.9	4.9	7.6	3.3
LU	0.43	0.17	0.17	0.46	0.44	0.49	-0.02	0.17	0.12	0.13	0.53
ND	5.2	14.0	13.0	7.6	37.0	41.0	0.2	6.9	7.0	9.1	6.8
PR	0.94	3.00	3.00	1.30	9.20	9.50	0.10	1.40	1.60	2.10	1.20
SM	1.90	2.90	2.80	2.70	6.80	9.50	0.06	2.10	1.70	2.20	2.50
TB	0.56	0.44	0.47	0.76	0.84	1.50	-0.02	0.45	0.35	0.41	0.78
TM	0.40	0.17	0.17	0.46	0.39	0.56	-0.02	0.19	0.14	0.14	0.46
Y	27.00	14.00	15.00	33.00	26.00	46.00	0.36	14.00	12.00	11.00	33.00
YB	2.60	1.10	1.10	3.00	2.70	3.20	0.03	1.20	0.85	0.87	3.20

LAB_NO	2	9	24	35	27	46	55	85	28	67	38
SAMPLE_N	SLB99-6A	SLB99-6B	SLB99-78	SLB99-81	SLB99-82	SLB99-86	SLB99-89	SLB99-90	SLB99-91	SLB99-94	SLB99-97
Unit	4 (EBG)	4 (EBG)	9 (EBF)	9 (EBF)	9 (EBF)	9 (EBF)	4 (EBG)	Rea horizon	4 (EBG)	9 (EBF)	9 (EBF)
SIO2	49.40	43.40	54.70	44.20	10.70	65.80	42.10	74.50	53.80	65.10	91.30
TIO2	1.19	1.91	0.41	1.88	0.05	0.37	2.05	1.15	1.74	0.34	0.20
AL2O3	11.00	13.60	17.40	12.90	1.50	17.80	13.90	16.40	18.00	16.60	4.90
FE2O3T	8.00	13.90	4.00	9.90	9.50	3.90	12.10	0.60	10.10	4.50	1.00
FE2O3	1.50	1.90	-999.00	1.50	0.40	1.70	1.80	-999.00	2.00	3.10	0.80
FEO	5.8	10.8	-999.0	7.6	8.2	2.0	9.3	-999.0	7.3	1.3	0.2
MNO	0.15	0.16	0.06	0.21	0.30	0.11	0.14	0.00	0.09	0.05	0.00
MGO	7.99	13.17	2.15	12.95	12.37	1.19	11.68	0.47	6.20	1.53	0.22
CAO	11.59	5.81	5.29	4.05	26.67	0.49	5.07	0.01	0.68	1.04	0.00
NA2O	4.90	2.90	2.80	3.00	0.20	0.10	2.80	0.60	4.00	4.10	0.30
K2O	0.09	0.14	3.75	0.02	0.30	6.47	0.03	3.97	0.98	4.49	1.13
H2OT	2.3	6.2	1.8	5.2	0.5	3.0	5.6	2.3	4.8	2.0	1.0
CO2T	5.0	1.2	7.2	6.7	38.9	0.6	6.2	0.1	0.6	0.6	0.1
P2O5	0.18	0.28	0.20	0.57	0.02	0.29	0.64	0.02	0.22	0.26	0.01
ST	-0.02	-0.02	0.99	0.07	-0.02	0.39	-0.02	0.06	0.62	-0.02	0.03
BA	190	110	1000	21	300	1200	100	4600	570	1600	620
TOTAL	101.2	101.6	100.9	100.9	100.2	100.5	101.3	100.7	101.1	100.7	100.2
LOI	-999.0	-999.0	-999.0	-999.0	35.9	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0
AG	-0.1	-0.1	-0.1	-0.1	-0.1	0.4	-0.1	0.4	-0.1	-0.1	0.6
BE	0.8	0.5	5.4	0.9	-0.5	2.9	1.1	-0.5	-0.5	4.9	-0.5
BI	-0.2	0.2	0.4	-0.2	0.2	1.7	-0.2	-0.2	-0.2	-0.2	0.4
CD	-0.2	-0.2	-0.2	-0.2	-0.2	0.7	-0.2	-0.2	-0.2	-0.2	-0.2
CO	31	63	7	44	8	26	57	-5	38	-5	-5
CR	380	722	13	435	23	18	501	31	254	13	37
CS	0.10	0.15	2.90	0.04	0.28	5.30	0.06	3.80	0.71	12.00	1.30
CU	118	98	35	57	-10	17	62	-10	74	-10	-10
GA	8.90	20.00	20.00	17.00	3.00	20.00	17.00	17.00	20.00	22.00	7.30
HF	1.40	2.00	5.50	2.90	0.61	4.30	3.70	3.70	2.30	5.20	0.89
IN	-0.05	0.06	-0.05	0.06	-0.05	-0.05	0.07	-0.05	0.05	0.06	-0.05
MO	0.5	-0.2	0.6	-0.2	-0.2	1.3	-0.2	1.6	0.2	-0.2	0.4
NB	16.00	24.00	20.00	55.00	1.00	19.00	59.00	19.00	19.00	25.00	4.20
NI	176	387	-10	213	-10	-10	265	-10	102	-10	-10
PB	4	-1	18	2	11	194	2	45	2	2	88
RB	0.58	2.40	130.00	0.08	11.00	170.00	0.43	140.00	27.00	150.00	38.00
SB	0.7	0.6	2.3	0.5	-0.2	1.6	0.9	4.5	0.6	0.6	6.2
SC	19.0	24.0	8.8	21.0	25.0	6.5	23.0	22.0	26.0	6.7	5.6
SN	0.6	1.4	1.1	1.1	-0.5	1.8	1.2	1.5	1.1	1.4	2.8
SR	206	113	364	102	342	19	144	97	59	73	29
TA	0.74	1.20	1.30	2.60	0.06	1.30	2.90	1.20	1.10	1.60	0.25
TE	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
TH	0.83	1.40	30.00	3.50	0.64	30.00	3.80	7.30	1.20	31.00	3.60
TL	-0.02	-0.02	0.80	-0.02	0.12	1.80	-0.02	3.20	0.49	0.83	0.91
U	0.20	0.30	6.90	0.87	0.96	9.90	1.00	2.10	0.33	5.00	0.56
V	151	228	98	180	113	100	207	188	237	88	31
ZN	51	103	30	69	127	186	99	7	87	61	9
ZR	56.0	85.0	210.0	160.0	32.0	160.0	190.0	120.0	93.0	160.0	33.0
CE	20.0	36.0	150.0	66.0	10.0	170.0	71.0	50.0	28.0	210.0	36.0
DY	2.50	3.40	4.80	3.00	1.70	6.30	3.70	5.50	2.10	5.30	0.48
ER	1.20	1.50	2.30	1.20	0.96	2.30	1.60	3.00	1.20	2.30	0.22
EU	0.97	1.50	2.40	1.70	0.55	3.20	2.00	0.90	0.88	3.00	0.14
GD	2.70	4.20	7.00	4.20	1.80	12.00	5.20	4.70	2.60	8.90	0.80
HO	0.46	0.64	0.91	0.52	0.35	1.00	0.66	1.10	0.44	0.92	0.08
LA	9.9	17.0	80.0	33.0	5.4	89.0	37.0	25.0	14.0	111.0	15.0
LU	0.15	0.17	0.40	0.16	0.18	0.35	0.19	0.44	0.18	0.37	0.05
ND	11.0	20.0	60.0	31.0	5.8	67.0	32.0	22.0	15.0	81.0	11.0
PR	2.60	4.60	17.00	7.80	1.40	18.00	8.00	6.00	3.60	22.00	2.90
SM	2.60	4.20	10.00	5.00	1.60	12.00	5.80	4.60	3.10	13.00	1.50
TB	0.44	0.63	0.97	0.61	0.29	1.50	0.73	0.86	0.37	1.10	0.11
TM	0.17	0.21	0.37	0.17	0.16	0.34	0.23	0.48	0.16	0.36	0.04
Y	15.00	19.00	31.00	16.00	12.00	34.00	19.00	35.00	11.00	31.00	2.40
YB	0.99	1.20	2.40	0.99	1.00	2.20	1.30	2.90	1.10	2.30	0.29

LAB_NO	1
SAMPLE_N	SLB99-98B
Unit	4 (EBG)
SIO2	48.60
TIO2	2.61
AL2O3	16.00
FE2O3T	19.20
FE2O3	17.70
FEO	1.4
MNO	0.05
MGO	3.51
CAO	1.85
NA2O	0.10
K2O	5.45
H2OT	3.5
CO2T	-0.1
P2O5	0.33
ST	-0.02
BA	1600
TOTAL	101.4
LOI	-999.0
AG	-0.1
BE	1.2
BI	-0.2
CD	-0.2
CO	35
CR	761
CS	4.40
CU	96
GA	23.00
HF	3.00
IN	0.08
MO	0.2
NB	27.00
NI	518
PB	2
RB	140.00
SB	0.6
SC	35.0
SN	1.3
SR	20
TA	1.60
TE	-0.2
TH	1.70
TL	0.44
U	0.46
V	275
ZN	79
ZR	120.0
CE	31.0
DY	4.80
ER	2.20
EU	1.80
GD	5.70
HO	0.88
LA	14.0
LU	0.27
ND	20.0
PR	4.60
SM	5.30
TB	0.87
TM	0.30
Y	24.00
YB	1.70

Whole rock trace element data, Johnson lake area, ICP-MS results from University of Victoria ICP-MS Lab.

SAMPLE_NO	SLB99 101	SLB99 101*	SLB99 168	slb99 168 dup	SLB99 168*	SLB99 107B	SLB99 107B*	SLB99 204	SLB99 204*	SLB99 89
Rock Type	CS	CS	PCS	PCS	PCS	CS	CS	MD	MD	MFV
Li (ppm)	0.00	62.22	0.00	0.00	21.17	0.00	20.90	0.00	5.86	0.00
Be	0.60	1.00	2.50	2.50	2.52	1.00	1.34	0.00	0.67	1.10
Sc	36.00	37.92	14.00	14.00	14.27	31.00	33.90	1.50	3.11	23.00
V	266.00	285.44	172.00	171.00	176.91	135.00	149.86	11.00	11.29	207.00
Rb	42.00	44.13	29.00	29.00	26.40	32.00	32.24	4.20	3.87	0.43
Sr	83.00	90.35	1020.00	1040.00	1089.21	138.00	155.77	409.00	435.14	144.00
Y	10.00	8.35	23.00	22.00	19.97	18.00	15.11	15.00	10.61	19.00
Zr	56.00	58.55	140.00	150.00	142.59	180.00	76.79	18.00	13.30	190.00
Nb	14.00	16.17	14.00	13.00	15.99	18.00	21.11	1.10	2.51	59.00
Mo	0.00	0.19	0.20	0.00	0.18	0.00	0.49	0.00	0.20	0.00
Cs	1.80	1.83	1.40	1.30	1.26	0.90	1.00	0.15	0.00	0.06
Ba	350.00	367.53	380.00	420.00	412.41	320.00	307.34	63.00	53.96	100.00
La	7.40	7.51	45.00	44.00	43.63	11.00	10.55	6.30	6.64	37.00
Ce	17.00	17.16	93.00	92.00	94.11	30.00	29.73	12.00	12.79	71.00
Pr	2.30	2.45	11.00	11.00	11.44	3.80	3.87	1.50	1.68	8.00
Nd	10.00	10.81	44.00	44.00	44.47	17.00	16.33	6.50	6.91	32.00
Sm	2.60	2.70	8.00	7.80	8.00	4.00	3.94	1.80	1.82	5.80
Eu	0.87	0.79	1.90	1.80	1.88	0.97	0.96	0.73	0.63	2.00
Gd	2.60	2.81	6.30	6.20	7.27	3.80	4.12	2.20	2.13	5.20
Tb	0.40	0.38	0.82	0.80	0.84	0.62	0.63	0.34	0.28	0.73
Dy	2.10	2.23	4.10	4.10	4.40	3.60	3.60	1.90	1.69	3.70
Ho	0.38	0.36	0.68	0.69	0.75	0.72	0.66	0.37	0.27	0.66
Er	0.99	1.20	1.70	1.70	2.03	1.80	1.93	0.92	0.91	1.60
Tm	0.16	0.23	0.26	0.27	0.26	0.28	0.36	0.13	0.17	0.23
Yb	1.00	1.07	1.60	1.60	1.74	1.70	1.41	0.73	0.57	1.30
Lu	0.18	0.17	0.27	0.26	0.30	0.27	0.20	0.10	0.08	0.19
Hf	1.30	1.57	3.10	3.20	3.58	3.50	1.98	0.41	0.28	3.70
Ta	0.64	0.78	0.73	0.76	0.82	1.00	1.05	0.07	0.07	2.90
Tl	0.12	0.00	0.14	0.14	0.00	0.09	0.22	0.04	0.00	0.00
Pb	0.00	0.00	12.00	13.00	13.42	0.00	1.88	18.00	19.32	2.00
Bi	0.00	0.11	0.30	0.00	0.00	0.00	0.19	0.00	0.12	0.00
Th	0.79	1.00	15.00	16.00	17.01	1.10	1.24	0.79	0.96	3.80
U	0.23	0.31	3.90	4.00	4.10	0.20	0.29	0.52	0.59	1.00
P	0.00	732.33	0.00	0.00	1501.78	0.00	1687.16	0.00	199.45	0.00
Ti	0.00	7493.97	0.00	0.00	2752.87	0.00	9171.01	0.00	273.34	0.00
Cr	869.00	680.70	16.00	14.00	5.33	429.00	326.93	27.00	11.69	501.00
Co	70.00	55.70	13.00	14.00	11.68	60.00	45.20	5.00	5.24	57.00
Ni	392.00	312.31	0.00	0.00	3.72	420.00	325.98	62.00	50.59	265.00
Cu	0.00	0.00	11.00	11.00	5.51	0.00	0.00	0.00	1.66	62.00
Zn	118.00	95.69	67.00	65.00	55.88	85.00	61.63	61.00	47.36	99.00
As	0.00	0.42	0.00	0.00	1.23	0.00	1.21	0.00	0.53	0.00
Se	0.00	1.76	0.00	0.00	3.06	0.00	2.40	0.00	0.46	0.00
Ag	0.00	0.17	0.10	0.00	0.46	0.00	0.18	0.00	0.04	0.00
Cd	0.00	0.00	0.00	0.00	0.20	0.00	0.21	0.00	0.00	0.00
Sn	0.90	0.64	0.90	0.80	0.80	1.30	0.77	0.00	0.00	1.20
Sb	0.80	0.67	0.60	0.50	0.54	0.00	0.02	0.20	0.14	0.90
W	0.00	0.00	0.00	0.00	1.18	0.00	0.00	0.00	0.00	0.00
Hg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

CS=chlorite schist, PCS= plagioclase porphyritic (porphyroblastic) chlorite schist, MD= mafic dyke

MFV= metafelsic volcanic/volcaniclastic, QSS= quartz sericite schist, SCS= sericite chlorite schist,

MMFB= metamafic flow breccia, BF= black phyllite

*= samples analyzed at University of Victoria ICP lab

other samples analyzed at GSC ottawa chemical laboratories

dup= duplicate sample

SAMPLE_	SLB99 89*	SLB99 140	slb99 140 dup	SLB99 140*	SLB99 139	SLB99 139*	SLB99 139* dup	SLB99 22B	SLB99 22B*
Rock Type	MFV	PCS	PCS	PCS	SCS	SCS	SCS	QSS	QSS
Li (ppm)	60.56	0.00	0.00	59.49	0.00	50.80	71.10	0.00	6.84
Be	1.32	1.30	1.20	1.43	0.00	0.00	0.00	0.60	1.09
Sc	23.33	46.00	45.00	46.66	25.00	19.66	26.74	8.90	9.33
V	220.95	487.00	485.00	519.91	195.00	157.78	215.81	114.00	120.27
Rb	0.00	40.00	42.00	39.59	3.30	2.30	3.10	54.00	53.80
Sr	154.54	80.00	79.00	84.12	115.00	94.23	126.15	0.00	10.04
Y	9.97	25.00	24.00	10.80	13.00	2.88	3.66	2.20	1.91
Zr	102.05	190.00	190.00	50.41	54.00	6.97	15.83	28.00	29.41
Nb	64.80	31.00	31.00	38.48	15.00	10.96	19.07	4.70	5.74
Mo	0.05	0.00	0.00	0.06	0.00	0.04	0.05	0.80	0.89
Cs	0.00	1.70	1.70	1.66	0.10	0.00	0.00	1.00	1.23
Ba	73.83	800.00	780.00	767.19	160.00	152.75	144.68	590.00	593.79
La	36.67	26.00	27.00	25.50	8.20	6.85	7.13	0.70	0.85
Ce	72.17	57.00	58.00	57.36	19.00	15.84	16.46	1.50	1.33
Pr	8.52	7.50	7.60	7.65	2.50	2.47	2.15	0.21	0.38
Nd	33.09	34.00	35.00	33.35	11.00	10.20	9.60	0.80	0.93
Sm	5.98	7.30	7.00	6.81	2.70	2.01	1.86	0.22	0.00
Eu	1.82	2.40	2.20	2.08	1.00	0.38	0.47	0.00	0.00
Gd	5.57	6.80	6.60	6.02	2.80	1.37	1.50	0.23	0.00
Tb	0.59	0.95	0.91	0.64	0.46	0.12	0.14	0.05	0.00
Dy	5.31	5.20	4.90	3.10	2.50	0.75	0.87	0.35	0.33
Ho	0.38	0.90	0.87	0.44	0.46	0.00	0.00	0.07	0.00
Er	1.15	2.20	2.00	1.18	1.10	0.28	0.39	0.21	0.41
Tm	0.20	0.30	0.29	0.22	0.17	0.00	0.00	0.03	0.20
Yb	0.60	1.80	1.60	0.72	0.98	0.00	0.19	0.22	0.19
Lu	0.09	0.26	0.25	0.11	0.15	0.02	0.06	0.03	0.02
Hf	1.64	4.30	3.80	1.27	1.30	0.17	0.43	0.75	0.80
Ta	3.20	1.70	1.80	2.01	0.79	0.68	0.81	0.26	0.28
Tl	0.00	0.51	0.48	0.52	0.13	0.00	0.00	0.25	0.39
Pb	0.00	5.00	7.00	2.86	25.00	0.00	0.00	8.00	0.00
Bi	0.10	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.20
Th	4.12	2.00	2.00	2.09	0.80	0.76	0.78	0.15	0.35
U	0.98	0.53	0.49	0.48	0.18	0.13	0.00	0.67	0.89
P	2266.43	0.00	0.00	1962.42	0.00	674.87	645.07	0.00	24.37
Ti	9343.85	0.00	0.00	0.00	0.00	5706.92	6416.29	0.00	2972.10
Cr	385.95	40.00	37.00	23.19	272.00	213.36	195.88	223.00	150.80
Co	43.95	58.00	61.00	44.35	42.00	33.18	31.57	0.00	1.24
Ni	213.44	80.00	80.00	65.27	157.00	129.68	121.35	38.00	26.55
Cu	37.12	169.00	171.00	113.71	92.00	56.94	54.76	0.00	0.00
Zn	77.69	112.00	109.00	81.50	145.00	95.20	90.54	8.00	2.46
As	0.53	0.00	0.00	1.39	0.00	28.95	27.14	0.00	1.34
Se	2.19	0.00	0.00	2.58	0.00	0.99	1.02	0.00	1.17
Ag	0.34	0.00	0.00	0.18	0.40	0.08	0.09	0.00	0.09
Cd	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sn	0.97	1.60	1.40	0.98	1.30	0.43	0.54	0.00	0.26
Sb	0.77	1.90	2.10	1.69	7.50	0.77	0.99	0.80	0.56
W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

SAMPLE_NO	SAM 38	SAM 38*	SLB99 42	SLB99 42*	K89-49 11	SLB99 165	LIMIT OF DET; dilution = 0.646 G/K BCR-2 this ru	
Rock Type	MMFB	MMFB	MMFB	MMFB	BF			
Li (ppm)	0.00	18.76	0.00	65.38	122.35	31.57	1.35	8.53
Be	0.60	0.69	0.50	0.78	0.84	2.01	0.15	1.91
Sc	27.00	27.99	24.00	25.68	23.76	16.66	0.22	34.35
V	189.00	196.58	209.00	228.91	243.32	187.08	0.41	445.27
Rb	69.00	69.86	13.00	14.02	25.10	91.42	0.63	48.60
Sr	176.00	202.77	111.00	127.69	17.32	86.89	2.18	354.36
Y	25.00	7.58	14.00	5.17	6.22	13.68	0.09	33.69
Zr	44.00	29.53	62.00	27.18	73.75	112.92	0.16	197.88
Nb	11.00	13.77	16.00	17.67	7.35	17.24	0.05	16.40
Mo	0.00	0.18	0.30	0.32	0.45	1.59	0.02	251.21
Cs	1.20	1.27	0.26	0.00	0.84	3.63	0.27	1.16
Ba	1200.00	1296.62	590.00	625.02	545.75	769.81	0.85	692.41
La	14.00	13.89	11.00	8.05	11.89	43.33	0.09	24.97
Ce	30.00	29.71	24.00	17.67	29.07	81.29	0.24	53.82
Pr	3.80	3.93	3.00	2.37	3.68	9.05	0.09	6.87
Nd	17.00	17.50	14.00	9.21	14.80	33.61	0.35	29.55
Sm	4.10	3.98	2.90	2.22	3.03	5.39	0.30	6.58
Eu	1.20	1.19	1.10	0.75	0.41	1.19	0.21	2.00
Gd	4.70	3.49	2.80	2.13	2.67	4.84	0.32	7.54
Tb	0.76	0.40	0.44	0.24	0.27	0.50	0.05	1.11
Dy	4.60	1.83	2.40	1.26	1.39	2.83	0.08	6.52
Ho	0.84	0.31	0.47	0.17	0.24	0.49	0.08	1.31
Er	2.10	0.82	1.20	0.70	0.76	1.61	0.09	3.79
Tm	0.30	0.11	0.17	0.13	0.12	0.22	0.08	0.53
Yb	1.80	0.77	1.10	0.51	0.90	1.48	0.10	3.25
Lu	0.26	0.19	0.17	0.08	0.19	0.24	0.01	0.55
Hf	1.10	0.87	1.40	0.75	2.08	3.16	0.17	5.44
Ta	0.70	0.71	0.82	0.84	0.35	0.96	0.00	0.86
Tl	0.65	0.62	0.10	0.00	0.64	0.34	0.19	0.38
Pb	27.00	17.27	2.00	0.00	254.39	3.18	1.73	11.70
Bi	0.00	0.00	0.00	0.00	0.25	0.00	0.06	0.11
Th	0.70	0.83	0.80	0.83	4.59	10.07	0.03	6.18
U	0.22	0.20	0.21	0.22	1.47	2.46	0.09	1.64
P	0.00	417.84	0.00	718.51	566.28	469.24	22.55	1540.37
Ti	0.00	5410.71	0.00	6739.52	3657.71	3634.18	0.77	12506.33
Cr	456.00	413.71	599.00	495.11	20.03	72.21	0.45	18.13
Co	77.00	61.24	67.00	57.32	19.34	12.35	0.02	33.04
Ni	381.00	318.65	325.00	274.11	17.05	28.49	0.19	12.23
Cu	76.00	54.91	107.00	75.17	21.55	25.67	0.04	3.91
Zn	95.00	82.18	103.00	88.07	144.01	69.49	0.18	107.61
As	0.00	82.38	0.00	2.35	106.12	6.34	0.03	0.98
Se	0.00	1.82	0.00	1.21	3.18	3.31	0.44	3.63
Ag	0.00	0.26	0.00	0.15	1.08	0.47	0.01	0.57
Cd	0.00	0.28	0.00	0.00	0.20	0.19	0.13	0.47
Sn	0.00	0.43	0.70	0.46	4.16	1.53	0.16	1.67
Sb	2.30	2.47	1.10	0.97	13.83	0.41	0.00	0.28
W	0.00	4.14	0.00	1.41	2.12	23.40	0.25	0.46
Hg	0.00	0.00	0.00	0.00	0.00	0.00	0.51	0.00

Appendix 2: Whole rock major and trace element data, 2000 field season, Johnson lake area

LAB_NO	1	2	3	4	5	6	7	8	9	10	11	12
SAMPLE_NO	MSS00-020	MSS00-023	HSB00-03	HSB00-04	HSB00-05	HSB00-06	HSB00-07	HSB00-08	HSB00-10.1	HSB00-11	ACB00-01	ACB00-02
SIO2	27.00	69.40	65.60	51.70	76.90	69.40	74.90	61.30	3.00	65.90	45.50	47.00
TIO2	0.09	0.66	0.53	0.58	0.35	0.27	0.44	0.54	-0.02	0.26	1.35	3.57
AL2O3	0.10	15.00	11.90	17.20	12.70	15.00	14.90	12.90	0.20	15.30	11.00	13.00
FE2O3T	1.10	5.40	3.40	8.30	2.30	4.50	0.50	5.00	0.20	4.20	8.60	14.90
FE2O3	0.00	2.51	-999.00	3.18	2.19	3.50	0.39	-999.00	-999.00	0.98	0.82	2.33
FEO	1.0	2.6	-999.0	4.6	0.1	0.9	0.1	-999.0	-999.0	2.9	7.0	11.3
MNO	0.06	0.08	0.40	0.13	0.00	0.05	0.00	0.49	0.04	0.10	0.20	0.24
MGO	13.95	1.65	2.59	2.41	0.87	0.65	0.92	2.73	1.22	0.80	6.16	8.13
CAO	21.91	0.14	3.13	6.41	0.00	1.69	0.07	3.00	1.35	3.88	8.68	5.07
NA2O	0.00	3.70	0.60	2.30	0.20	3.30	0.20	0.20	-0.03	3.00	4.20	2.70
K2O	0.01	2.40	3.25	3.39	4.39	2.05	4.86	4.08	0.07	2.49	0.04	1.80
H2OT	0.2	2.7	-999.0	3.5	2.1	2.7	2.4	-999.0	0.1	2.1	2.2	4.5
CO2T	34.0	0.5	5.0	4.5	0.2	1.4	0.1	5.1	2.0	3.0	11.9	0.5
P2O5	0.02	0.10	0.08	0.49	0.06	0.11	0.03	0.09	-0.01	0.11	0.22	0.73
ST	-0.02	-0.02	1.10	-0.02	0.08	-0.02	0.28	1.54	9.60	-0.02	-0.02	-0.02
BA	-20	560	680	1300	1100	1200	3100	1000	452000	710	-20	960
TOTAL	98.4	101.3	97.6	100.5	100.0	101.1	99.6	96.8	65.6	100.9	99.3	100.9
LOI	29.8	-999.0	6.2	-999.0	-999.0	-999.0	-999.0	6.6	1.4	-999.0	13.1	-999.0
ST_IC	66	76	-10000	83	763	52	2748	-10000	-10000	61	60	214
AG	-0.1	0.2	-0.1	0.2	0.2	-0.1	0.2	0.5	25.0	0.2	0.2	-0.1
BE	-0.5	1.5	2.3	2.7	2.4	1.5	2.4	2.6	-0.5	1.6	-0.5	2.9
BI	-0.2	-0.2	-0.2	-0.2	0.3	-0.2	-0.2	0.3	-0.2	-0.2	-0.2	-0.2
CD	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	8.6	32.0	-0.2	-0.2	-0.2
CL	-100	-100	174	-100	-100	-100	-100	247	-100	-100	-100	-100
CO	-5	30	-5	15	-5	-5	-5	8	-5	-5	31	49
CR	-10	73	-10	-10	10	-10	17	12	-10	-10	361	505
CS	-0.02	2.00	1.60	2.10	1.90	1.60	2.00	1.60	0.06	1.30	0.05	18.00
CU	-10	42	18	20	-10	-10	-10	96	963	15	48	-10
F	50	527	1323	882	1492	651	1785	981	51	480	501	1702
GA	-0.10	18.00	15.00	20.00	16.00	17.00	18.00	17.00	2.10	18.00	14.00	25.00
HF	0.04	3.10	6.30	3.80	6.00	3.80	7.30	6.10	0.13	4.40	2.50	9.40
IN	-0.05	0.07	-0.05	0.09	-0.05	-0.05	-0.05	0.11	0.05	0.13	-0.05	0.08
MO	-0.2	2.5	2.4	1.3	3.6	-0.2	0.5	2.5	16.0	-0.2	0.2	0.9
NB	0.06	13.00	15.00	13.00	15.00	9.60	18.00	15.00	0.23	8.90	21.00	85.00
NI	-10	55	-10	-10	-10	-10	-10	-10	-10	-10	175	298
PB	-1	14	25	7	205	3	50	1909	7054	4	17	2
RB	0.12	69.00	100.00	120.00	160.00	61.00	180.00	130.00	2.50	68.00	0.76	79.00
SB	-0.2	0.3	0.4	2.1	0.9	0.3	2.1	1.3	71.0	0.7	0.4	0.9
SC	-0.5	17.0	7.1	15.0	7.1	6.9	10.0	8.9	-0.5	7.1	18.0	19.0
SN	-2.0	4.0	3.0	-2.0	5.0	2.0	3.0	2.0	-2.0	2.0	-2.0	4.0
SR	91	17	140	300	32	200	29	110	3713	220	410	150
TA	-0.05	0.90	0.93	0.62	0.89	0.59	1.20	0.98	0.02	0.56	1.20	5.30
TE	-0.2	-0.2	0.2	-0.2	0.2	-0.2	0.3	0.3	0.3	-0.2	-0.2	0.3
TH	0.03	14.00	16.00	15.00	14.00	4.40	17.00	15.00	0.12	4.60	2.30	7.40
TL	-0.02	0.37	0.83	1.30	1.20	0.34	1.70	1.00	0.09	0.60	-0.02	0.94
U	0.12	1.60	4.80	3.30	3.80	1.20	5.10	4.80	1.50	1.50	0.61	1.80
V	10	82	12	165	12	15	18	18	-5	17	149	246
ZN	62	92	105	103	116	66	72	2730	14000	94	104	331
ZR	0.9	110.0	240.0	170.0	220.0	160.0	270.0	240.0	4.4	170.0	99.0	360.0
CE	0.6	94.0	90.0	140.0	110.0	50.0	110.0	99.0	1.4	58.0	38.0	160.0
DY	0.11	3.30	5.20	5.00	5.70	3.70	6.30	6.40	0.04	5.00	3.60	7.30
ER	0.05	1.60	2.70	2.10	2.80	2.10	3.00	3.10	0.02	2.80	1.50	2.50
EU	0.02	1.00	1.30	2.60	1.60	1.00	1.30	1.60	0.04	1.10	1.40	3.80
GD	0.13	3.90	6.40	8.60	6.90	4.20	7.30	7.50	0.09	5.10	4.30	11.00
HO	0.03	0.66	1.00	0.88	1.10	0.73	1.20	1.20	-0.02	1.00	0.66	1.20
LA	0.3	38.0	47.0	74.0	57.0	23.0	60.0	53.0	0.7	28.0	19.0	78.0
LU	-0.02	0.27	0.48	0.33	0.43	0.43	0.49	0.50	-0.02	0.49	0.18	0.27
ND	0.3	29.0	39.0	62.0	44.0	23.0	48.0	42.0	0.7	29.0	19.0	76.0
PR	0.08	8.00	10.00	16.00	12.00	5.90	13.00	11.00	0.16	7.10	4.50	18.00
SM	0.12	5.10	7.50	11.00	8.30	4.80	9.00	8.20	0.12	5.60	4.30	14.00
TB	0.02	0.61	0.94	1.10	1.10	0.63	1.10	1.20	-0.02	0.86	0.68	1.50
TM	-0.02	0.26	0.45	0.33	0.45	0.37	0.51	0.51	-0.02	0.47	0.21	0.34
Y	0.97	17.00	30.00	26.00	35.00	22.00	35.00	37.00	0.23	31.00	18.00	34.00
YB	0.05	1.80	3.10	2.10	2.80	2.60	3.20	3.30	-0.02	3.20	1.30	1.90

Appendix II: Whole rock major and trace element data, 2000 field season, Johnson lake area

LAB_NO	1	2	3	4	5	6	7	8	9	10	11
SAMPLE_NO	MSS00-020	MSS00-023	HSB00-03	HSB00-04	HSB00-05	HSB00-06	HSB00-07	HSB00-08	HSB00-10.1	HSB00-11	ACB00-01
SiO2	27.00	69.40	65.60	51.70	76.90	69.40	74.90	61.30	3.00	65.90	45.50
TiO2	0.09	0.66	0.53	0.58	0.35	0.27	0.44	0.54	-0.02	0.26	1.35
Al2O3	0.10	15.00	11.90	17.20	12.70	15.00	14.90	12.90	0.20	15.30	11.00
Fe2O3T	1.10	5.40	3.40	8.30	2.30	4.50	0.50	5.00	0.20	4.20	8.60
Fe2O3	0.00	2.51	-999.00	3.18	2.19	3.50	0.39	-999.00	-999.00	0.98	0.82
FEO	1.0	2.6	-999.0	4.6	0.1	0.9	0.1	-999.0	-999.0	2.9	7.0
MNO	0.06	0.08	0.40	0.13	0.00	0.05	0.00	0.49	0.04	0.10	0.20
MGO	13.95	1.65	2.59	2.41	0.87	0.65	0.92	2.73	1.22	0.80	6.16
CAO	21.91	0.14	3.13	6.41	0.00	1.69	0.07	3.00	1.35	3.88	8.68
NA2O	0.00	3.70	0.60	2.30	0.20	3.30	0.20	0.20	-0.03	3.00	4.20
K2O	0.01	2.40	3.25	3.39	4.39	2.05	4.86	4.08	0.07	2.49	0.04
H2OT	0.2	2.7	-999.0	3.5	2.1	2.7	2.4	-999.0	0.1	2.1	2.2
CO2T	34.0	0.5	5.0	4.5	0.2	1.4	0.1	5.1	2.0	3.0	11.9
P2O5	0.02	0.10	0.08	0.49	0.06	0.11	0.03	0.09	-0.01	0.11	0.22
ST	-0.02	-0.02	1.10	-0.02	0.08	-0.02	0.28	1.54	9.60	-0.02	-0.02
BA	-20	560	680	1300	1100	1200	3100	1000	452000	710	-20
TOTAL	98.4	101.3	97.6	100.5	100.0	101.1	99.6	96.8	65.6	100.9	99.3
LOI	29.8	-999.0	6.2	-999.0	-999.0	-999.0	-999.0	6.6	1.4	-999.0	13.1
ST_IC	66	76	-10000	83	763	52	2748	-10000	-10000	61	60
AG	-0.1	0.2	-0.1	0.2	0.2	-0.1	0.2	0.5	25.0	0.2	0.2
BE	-0.5	1.5	2.3	2.7	2.4	1.5	2.4	2.6	-0.5	1.6	-0.5
BI	-0.2	-0.2	-0.2	-0.2	0.3	-0.2	-0.2	0.3	-0.2	-0.2	-0.2
CD	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	8.6	32.0	-0.2	-0.2
CL	-100	-100	174	-100	-100	-100	-100	247	-100	-100	-100
CO	-5	30	-5	15	-5	-5	-5	8	-5	-5	31
CR	-10	73	-10	-10	10	-10	17	12	-10	-10	361
CS	-0.02	2.00	1.60	2.10	1.90	1.60	2.00	1.60	0.06	1.30	0.05
CU	-10	42	18	20	-10	-10	-10	96	963	15	48
F	50	527	1323	882	1492	651	1785	981	51	480	501
GA	-0.10	18.00	15.00	20.00	16.00	17.00	18.00	17.00	2.10	18.00	14.00
HF	0.04	3.10	6.30	3.80	6.00	3.80	7.30	6.10	0.13	4.40	2.50
IN	-0.05	0.07	-0.05	0.09	-0.05	-0.05	-0.05	0.11	0.05	0.13	-0.05
MO	-0.2	2.5	2.4	1.3	3.6	-0.2	0.5	2.5	16.0	-0.2	0.2
NB	0.06	13.00	15.00	13.00	15.00	9.60	18.00	15.00	0.23	8.90	21.00
NI	-10	55	-10	-10	-10	-10	-10	-10	-10	-10	175
PB	-1	14	25	7	205	3	50	1909	7054	4	17
RB	0.12	69.00	100.00	120.00	160.00	61.00	180.00	130.00	2.50	68.00	0.76
SB	-0.2	0.3	0.4	2.1	0.9	0.3	2.1	1.3	71.0	0.7	0.4
SC	-0.5	17.0	7.1	15.0	7.1	6.9	10.0	8.9	-0.5	7.1	18.0
SN	-2.0	4.0	3.0	-2.0	5.0	2.0	3.0	2.0	-2.0	2.0	-2.0
SR	91	17	140	300	32	200	29	110	3713	220	410
TA	-0.05	0.90	0.93	0.62	0.89	0.59	1.20	0.98	0.02	0.56	1.20
TE	-0.2	-0.2	0.2	-0.2	0.2	-0.2	0.3	0.3	0.3	-0.2	-0.2
TH	0.03	14.00	16.00	15.00	14.00	4.40	17.00	15.00	0.12	4.60	2.30
TL	-0.02	0.37	0.83	1.30	1.20	0.34	1.70	1.00	0.09	0.60	-0.02
U	0.12	1.60	4.80	3.30	3.80	1.20	5.10	4.80	1.50	1.50	0.61
V	10	82	12	165	12	15	18	18	-5	17	149
ZN	62	92	105	103	116	66	72	2730	14000	94	104
ZR	0.9	110.0	240.0	170.0	220.0	160.0	270.0	240.0	4.4	170.0	99.0
CE	0.6	94.0	90.0	140.0	110.0	50.0	110.0	99.0	1.4	58.0	38.0
DY	0.11	3.30	5.20	5.00	5.70	3.70	6.30	6.40	0.04	5.00	3.60
ER	0.05	1.60	2.70	2.10	2.80	2.10	3.00	3.10	0.02	2.80	1.50
EU	0.02	1.00	1.30	2.60	1.60	1.00	1.30	1.60	0.04	1.10	1.40
GD	0.13	3.90	6.40	8.60	6.90	4.20	7.30	7.50	0.09	5.10	4.30
HO	0.03	0.66	1.00	0.88	1.10	0.73	1.20	1.20	-0.02	1.00	0.66
LA	0.3	38.0	47.0	74.0	57.0	23.0	60.0	53.0	0.7	28.0	19.0
LU	-0.02	0.27	0.48	0.33	0.43	0.43	0.49	0.50	-0.02	0.49	0.18
ND	0.3	29.0	39.0	62.0	44.0	23.0	48.0	42.0	0.7	29.0	19.0
PR	0.08	8.00	10.00	16.00	12.00	5.90	13.00	11.00	0.16	7.10	4.50
SM	0.12	5.10	7.50	11.00	8.30	4.80	9.00	8.20	0.12	5.60	4.30
TB	0.02	0.61	0.94	1.10	1.10	0.63	1.10	1.20	-0.02	0.86	0.68
TM	-0.02	0.26	0.45	0.33	0.45	0.37	0.51	0.51	-0.02	0.47	0.21
Y	0.97	17.00	30.00	26.00	35.00	22.00	35.00	37.00	0.23	31.00	18.00
YB	0.05	1.80	3.10	2.10	2.80	2.60	3.20	3.30	-0.02	3.20	1.30

LAB_NO	12	13	14	15	16	17	18	19	20 dup	21	22
SAMPLE_N	ACB00-02	SLB00-216B	SLB00-218	SLB00-256	SLB00-269B	SLB00-270	SLB00-285	SLB00-286	SLB00-309	SLB00-313	SLB00-319.1
SIO2	47.00	42.20	46.20	39.60	95.50	49.30	44.90	1.30	56.10	37.80	41.30
TIO2	3.57	2.65	1.46	1.35	0.07	1.58	2.94	-0.02	0.33	2.18	3.57
AL2O3	13.00	15.70	12.80	12.90	1.80	17.00	14.50	-0.20	13.50	7.70	14.40
FE2O3T	14.90	14.80	11.20	11.70	1.10	13.60	15.20	0.11	3.20	9.10	12.60
FE2O3	2.33	5.24	1.86	0.91	0.99	1.81	4.30	0.11	1.20	1.76	2.93
FEO	11.3	8.6	8.4	9.7	0.1	10.6	9.8	0.0	1.8	6.6	8.7
MNO	0.24	0.20	0.18	0.15	0.02	0.18	0.18	0.02	0.15	0.16	0.13
MGO	8.13	6.25	10.31	9.39	0.21	3.66	6.64	16.90	0.89	7.77	4.91
CAO	5.07	12.11	10.38	10.59	0.09	3.75	6.00	34.50	10.15	11.93	7.36
NA2O	2.70	2.30	2.50	1.90	0.00	5.90	3.10	0.05	3.20	0.10	5.10
K2O	1.80	0.35	0.28	0.20	0.51	0.41	0.71	-0.05	2.59	2.01	0.09
H2OT	4.5	3.9	3.9	5.6	0.6	3.8	4.6	0.2	1.9	2.0	3.2
CO2T	0.5	1.2	2.4	8.4	0.3	1.6	2.3	46.1	8.0	18.6	7.2
P2O5	0.73	0.31	0.16	0.18	0.02	1.25	0.69	-0.01	0.14	0.32	1.91
ST	-0.02	-0.02	0.02	-0.02	-0.02	-0.02	-0.02	-0.02	0.09	0.14	0.06
BA	960	100	85	400	91	510	160	-20	1800	180	44
TOTAL	100.9	101.0	100.9	100.9	100.2	100.9	100.6	99.2	100.2	99.2	100.8
LOI	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	36.1	-999.0	18.9	-999.0
ST_IC	214	181	206	71	81	112	51	59	798	1586	626
AG	-0.1	-0.1	-0.1	0.2	-0.1	-0.1	0.2	-0.1	0.1	-0.1	0.1
BE	2.9	0.8	-0.5	-0.5	-0.5	3.1	1.2	-0.5	1.2	1.2	1.6
BI	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
CD	-0.2	-0.2	-0.2	-0.2	0.4	0.2	-0.2	-0.2	-0.2	-0.2	-0.2
CL	-100	-100	-100	-100	-100	-100	-100	167	140	-100	-100
CO	49	52	51	58	-5	13	38	-5	-5	40	32
CR	505	182	821	547	24	-10	11	21	22	422	13
CS	18.00	0.63	0.13	0.37	0.93	2.50	0.56	-0.02	2.30	1.40	0.13
CU	-10	98	59	75	21	10	-10	-10	11	39	35
F	1702	570	404	731	163	1170	1133	114	510	768	1441
GA	25.00	29.00	13.00	17.00	2.40	34.00	16.00	-0.10	16.00	13.00	27.00
HF	9.40	4.10	2.20	2.50	0.51	9.80	5.30	0.09	3.40	4.80	15.00
IN	0.08	0.10	0.06	0.08	-0.05	0.14	0.08	-0.05	-0.05	0.06	0.12
MO	0.9	0.6	0.6	-0.2	0.4	1.4	0.4	-0.2	0.3	1.9	2.2
NB	85.00	24.00	11.00	11.00	1.30	71.00	42.00	0.22	8.20	33.00	92.00
NI	298	96	210	285	15	-10	24	-10	-10	312	24
PB	2	2	1	1	-1	3	2	1	4	4	3
RB	79.00	8.20	4.60	3.80	16.00	9.10	12.00	0.12	68.00	68.00	1.90
SB	0.9	0.2	0.3	0.2	0.3	0.2	0.3	-0.2	0.3	-0.2	0.3
SC	19.0	41.0	35.0	30.0	2.3	13.0	10.0	-0.5	20.0	17.0	21.0
SN	4.0	2.0	-2.0	4.0	-2.0	4.0	2.0	4.0	-2.0	2.0	3.0
SR	150	210	130	290	-10	150	170	131	450	450	590
TA	5.30	1.50	0.69	0.66	0.07	3.80	2.50	0.04	0.62	1.80	5.60
TE	0.3	-0.2	0.2	0.3	-0.2	-0.2	0.2	0.2	0.2	0.2	-0.2
TH	7.40	1.30	0.57	0.70	1.00	4.40	1.90	0.07	6.70	3.40	11.00
TL	0.94	0.05	-0.02	-0.02	0.13	0.09	0.03	-0.02	0.35	0.35	0.02
U	1.80	0.59	0.19	0.20	0.51	2.50	0.68	1.30	2.80	0.76	2.20
V	246	393	236	238	13	13	105	9	90	165	182
ZN	331	121	101	92	48	204	124	64	56	109	170
ZR	360.0	170.0	80.0	100.0	19.0	600.0	260.0	4.4	140.0	200.0	600.0
CE	160.0	45.0	19.0	20.0	7.9	160.0	77.0	1.8	55.0	79.0	240.0
DY	7.30	6.60	3.70	5.00	0.53	10.00	6.90	0.38	4.70	4.80	14.00
ER	2.50	3.20	1.70	2.40	0.30	3.90	2.70	0.33	2.80	2.00	5.60
EU	3.80	2.30	1.10	2.20	0.14	5.00	3.40	0.04	0.93	2.30	7.10
GD	11.00	7.30	3.90	5.20	0.58	15.00	9.60	0.29	4.50	6.40	21.00
HO	1.20	1.30	0.71	0.95	0.11	1.80	1.20	0.10	0.96	0.81	2.30
LA	78.0	21.0	8.1	7.5	3.2	71.0	31.0	0.9	29.0	38.0	106.0
LU	0.27	0.42	0.23	0.28	0.05	0.44	0.33	0.05	0.54	0.22	0.52
ND	76.0	27.0	13.0	16.0	2.8	89.0	46.0	0.8	23.0	39.0	120.0
PR	18.00	5.90	2.70	3.20	0.74	21.00	10.00	0.18	6.20	9.80	30.00
SM	14.00	6.70	3.40	4.60	0.58	18.00	10.00	0.19	4.50	7.50	24.00
TB	1.50	1.10	0.61	0.88	0.08	2.10	1.30	0.05	0.76	0.85	2.60
TM	0.34	0.48	0.26	0.36	0.05	0.53	0.37	0.05	0.48	0.25	0.64
Y	34.00	36.00	20.00	28.00	3.00	50.00	34.00	6.70	31.00	20.00	56.00
YB	1.90	2.80	1.50	2.00	0.31	3.10	2.20	0.31	3.50	1.40	3.60

LAB_NO	23	24	25	26	27	28	29	30	31	32	33
SAMPLE_NO	SLB00-355	SLB00-358	SLB00-367	SLB00-378	SLB00-394	SLB00-397	SLB00-417	SLB00-426	SLB00-430	SLB00-473	SLB00-474
SiO2	66.20	67.60	52.40	50.20	45.30	54.30	38.80	45.10	46.30	47.00	30.40
TiO2	0.25	0.36	1.05	1.24	1.79	0.60	1.78	1.91	0.98	2.05	1.94
Al2O3	14.70	14.80	15.00	15.00	16.80	15.70	11.40	16.10	14.60	13.50	11.20
Fe2O3T	2.80	4.00	11.20	11.90	15.20	8.10	11.90	11.70	10.00	13.00	11.30
Fe2O3	2.24	1.11	1.41	2.00	3.75	0.98	2.45	2.14	2.66	2.21	0.85
FeO	0.5	2.6	8.8	8.9	10.3	6.4	8.5	8.6	6.6	9.7	9.4
MNO	0.16	0.05	0.16	0.18	0.14	0.13	0.16	0.10	0.14	0.16	0.14
MGO	0.68	0.97	7.69	7.83	8.59	2.03	8.42	8.75	9.91	7.91	6.86
CAO	3.74	2.29	5.92	7.44	2.40	7.21	13.39	5.37	10.94	7.17	16.15
Na2O	4.80	4.10	4.90	3.80	4.90	2.50	1.80	4.60	3.00	3.80	1.80
K2O	2.41	2.89	0.06	0.06	0.05	1.72	0.03	0.20	0.10	0.36	0.36
H2OT	1.5	1.7	3.5	3.8	5.4	3.5	5.0	5.0	3.6	4.5	4.8
CO2T	3.2	2.1	0.3	0.5	1.2	5.4	8.6	2.9	1.8	1.8	12.5
P2O5	0.07	0.09	0.11	0.11	0.21	0.23	0.33	0.23	0.10	0.42	0.34
ST	0.12	0.02	-0.02	-0.02	0.02	-0.02	0.05	0.03	-0.02	0.05	-0.02
BA	890	1200	57	52	120	390	1700	70	97	200	200
TOTAL	100.5	100.7	101.2	101.2	100.8	100.8	100.8	100.9	100.7	100.5	96.8
LOI	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	14.5
ST_IC	1317	215	84	68	155	120	495	345	96	449	156
AG	0.2	0.1	0.2	0.3	0.2	0.5	0.2	-0.1	-0.1	-0.1	0.2
BE	1.6	2.0	0.5	0.7	0.6	0.6	0.6	0.5	-0.5	0.9	-0.5
BI	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
CD	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
CL	-100	-100	-100	-100	-100	-100	115	-100	-100	-100	-100
CO	-5	6	39	44	58	60	60	48	48	42	56
CR	-10	-10	284	616	257	274	547	222	821	191	529
CS	1.50	1.10	0.11	0.16	0.14	0.14	0.21	0.19	0.04	0.19	0.40
CU	-10	-10	-10	-10	108	116	114	137	137	126	104
F	719	740	738	321	412	925	764	621	307	621	516
GA	15.00	17.00	23.00	19.00	21.00	21.00	16.00	21.00	15.00	20.00	19.00
HF	9.80	8.60	1.40	1.50	2.30	2.40	2.00	1.40	1.40	2.00	2.80
IN	-0.05	-0.05	0.09	0.07	0.07	0.22	0.06	0.07	0.06	0.09	0.06
MO	-0.2	0.3	0.6	0.4	-0.2	-0.2	-0.2	0.3	-0.2	1.2	0.2
NB	8.80	16.00	7.10	7.40	23.00	22.00	21.00	24.00	8.50	24.00	28.00
NI	-10	-10	71	81	161	172	343	110	129	76	243
PB	2	2	5	3	1	1	5	2	3	2	4
PB	2	2	5	3	1	1	5	2	3	2	4
RB	51.00	81.00	0.78	0.68	0.48	0.59	0.35	2.60	0.52	4.20	10.00
SB	-0.2	-0.2	0.3	0.2	0.2	0.2	1.5	-0.2	0.2	0.6	1.0
SC	7.2	7.5	24.0	26.0	29.0	30.0	23.0	30.0	44.0	31.0	23.0
SN	-2.0	2.0	-2.0	-2.0	-2.0	2.0	-2.0	-2.0	-2.0	2.0	-2.0
SR	130	170	340	340	60	390	250	130	280	310	420
TA	0.63	1.10	0.43	0.39	1.30	1.20	1.20	1.20	0.52	1.40	1.60
TE	-0.2	0.3	-0.2	-0.2	0.2	0.2	-0.2	-0.2	-0.2	-0.2	-0.2
TH	18.00	20.00	1.10	1.00	1.40	1.50	1.60	1.50	0.51	1.50	2.00
TL	0.26	0.27	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	0.02	0.06
U	2.50	6.40	0.23	0.22	0.39	0.38	0.39	0.31	0.14	0.39	0.69
V	21	25	173	172	271	287	216	239	197	256	217
ZN	30	45	118	123	107	114	128	103	92	117	122
ZR	340.0	280.0	39.0	41.0	83.0	100.0	70.0	49.0	50.0	110.0	100.0
CE	27.0	100.0	20.0	16.0	25.0	24.0	34.0	33.0	12.0	35.0	39.0
DY	2.60	5.80	4.70	3.50	4.00	3.70	3.70	4.00	2.20	4.00	3.90
ER	1.60	3.40	2.60	1.70	1.90	1.90	1.70	1.80	1.10	1.70	1.60
EU	0.69	1.10	1.60	1.20	1.30	1.20	1.40	1.50	0.79	1.70	1.60
GD	2.90	6.50	5.00	3.70	4.20	3.90	4.50	4.50	2.50	5.20	4.90
HO	0.52	1.10	0.94	0.65	0.70	0.68	0.68	0.71	0.41	0.75	0.68
LA	15.0	57.0	9.2	7.1	12.0	11.0	16.0	16.0	5.1	16.0	18.0
LU	0.30	0.53	0.30	0.20	0.21	0.21	0.17	0.19	0.13	0.18	0.19
ND	12.0	41.0	13.0	10.0	14.0	14.0	19.0	18.0	7.6	20.0	22.0
PR	3.10	12.00	2.70	2.20	3.40	3.30	4.40	4.20	1.60	4.40	5.00
SM	2.80	7.50	4.00	3.00	3.70	3.40	4.20	4.30	2.10	4.80	4.80
TB	0.41	0.94	0.75	0.55	0.63	0.58	0.64	0.66	0.39	0.78	0.73
TM	0.23	0.50	0.34	0.23	0.26	0.26	0.21	0.22	0.15	0.23	0.23
Y	14.00	30.00	23.00	16.00	18.00	17.00	16.00	17.00	12.00	21.00	19.00
YB	1.60	3.20	2.00	1.40	1.50	1.40	1.20	1.30	0.90	1.30	1.30

LAB_NO	34	35	36	37	38	39	40 dup	41	42	43	44
SAMPLE_N	SLB00-480	SLB00-492	SLB00-502	SLB00-506	SLB00-544	SLB00-553	SLB00-558	SLB00-559	SLB00-570	SLB00-576	SLB00-588
SIO2	39.00	57.20	48.50	50.80	46.60	47.10	37.60	54.00	48.10	44.70	74.90
TIO2	1.01	0.41	2.40	1.97	1.24	2.13	1.41	1.40	1.56	1.56	0.14
AL2O3	12.00	17.60	12.60	13.20	16.90	13.50	10.90	13.40	14.90	16.20	13.60
FE2O3T	11.00	4.30	13.70	10.90	11.20	11.40	9.90	9.90	12.00	12.50	1.60
FE2O3	1.21	1.41	2.14	2.89	3.08	2.73	-999.00	-999.00	2.55	1.49	1.38
FEO	8.8	2.6	10.4	7.2	7.3	7.8	-999.0	-999.0	8.5	9.9	0.2
MNO	0.18	0.08	0.20	0.12	0.15	0.16	0.08	0.03	0.18	0.12	0.01
MGO	9.34	1.58	8.65	7.78	8.25	11.51	8.13	9.15	7.73	8.51	0.38
CAO	12.65	5.23	8.94	7.16	8.92	8.36	7.44	0.45	7.05	5.22	1.01
NA2O	1.70	4.80	3.20	2.90	3.60	2.80	1.90	2.60	4.40	4.20	3.40
K2O	0.02	3.03	0.15	2.45	0.35	0.07	0.02	0.39	0.51	0.04	2.78
H2OT	5.3	2.3	3.4	3.1	3.8	4.5	-999.0	-999.0	3.7	5.2	1.4
CO2T	9.1	4.0	0.2	0.4	0.8	0.2	5.7	0.2	1.5	3.1	0.8
P2O5	0.10	0.29	0.28	0.64	0.17	0.42	0.19	0.11	0.18	0.16	0.04
ST	-0.02	0.02	0.05	0.05	-0.02	-0.02	1.71	4.65	-0.02	-0.02	-0.02
BA	31	1100	50	1400	400	73	65000	3200	240	130	740
TOTAL	100.4	100.5	101.0	100.7	101.2	101.2	85.0	96.2	100.8	100.4	100.1
LOI	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	9.3	6.3	-999.0	-999.0	-999.0
ST_IC	77	168	472	477	131	98	-10000	-10000	164	127	94
AG	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	0.1
BE	-0.5	4.7	0.7	2.5	0.5	1.3	0.5	0.9	0.7	0.5	1.9
BI	-0.2	0.7	-0.2	-0.2	-0.2	-0.2	-0.2	2.5	-0.2	-0.2	-0.2
CD	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
CL	157	103	-100	-100	-100	-100	150	-100	113	-100	-100
CO	59	6	50	45	44	51	50	50	45	50	-5
CR	547	-10	396	334	291	437	484	617	320	318	-10
CS	0.07	3.70	0.07	1.50	1.00	0.06	0.07	0.75	0.31	0.18	3.10
CU	78	28	51	45	129	77	-10	49	113	138	-10
F	415	1324	476	1030	330	584	746	1381	324	566	402
GA	14.00	20.00	15.00	25.00	19.00	14.00	14.00	19.00	18.00	20.00	15.00
HF	1.50	5.00	3.40	4.70	1.80	3.20	2.00	1.60	1.70	1.50	3.80
IN	-0.05	-0.05	0.09	0.07	-0.05	-0.05	0.18	0.08	0.06	0.06	-0.05
MO	-0.2	0.6	0.2	0.4	-0.2	-0.2	-0.2	3.0	-0.2	-0.2	0.3
NB	5.40	21.00	20.00	27.00	13.00	35.00	17.00	7.60	13.00	15.00	9.70
NI	347	-10	196	227	153	223	293	401	105	159	-10
PB	1	9	1	6	1	5	2	3	-1	2	2
RB	0.10	89.00	1.20	41.00	6.00	0.35	0.32	13.00	6.60	0.42	86.00
SB	0.3	0.5	0.2	0.2	0.3	1.2	1.6	2.0	0.4	0.2	0.3
SC	31.0	9.3	34.0	11.0	28.0	23.0	21.0	27.0	35.0	30.0	2.1
SN	-2.0	-2.0	-2.0	3.0	4.0	2.0	2.0	2.0	-2.0	-2.0	2.0
SR	290	250	200	950	410	290	1100	110	420	140	45
TA	0.33	1.50	1.30	1.60	0.81	2.20	0.99	0.47	0.78	0.90	0.89
TE	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	0.6	-0.2	-0.2	-0.2
TH	0.43	32.00	1.20	1.90	0.81	2.30	0.92	0.42	0.77	0.90	21.00
TL	-0.02	0.51	-0.02	0.10	0.03	-0.02	-0.02	0.17	0.03	-0.02	0.52
U	0.19	11.00	0.39	0.46	0.23	0.60	0.41	0.50	0.19	0.23	3.90
V	245	102	293	138	192	178	170	239	239	244	10
ZN	91	58	116	171	99	96	86	29	112	101	25
ZR	59.0	200.0	160.0	210.0	63.0	160.0	79.0	56.0	56.0	51.0	150.0
CE	13.0	190.0	37.0	78.0	22.0	48.0	25.0	14.0	23.0	20.0	71.0
DY	3.40	5.00	5.70	4.10	3.20	4.10	2.50	1.70	3.30	3.20	1.90
ER	2.00	2.00	2.80	1.20	1.50	1.90	1.20	0.85	1.50	1.50	1.20
EU	0.94	2.80	1.80	2.80	1.20	1.80	0.94	0.61	1.20	1.10	0.50
GD	3.10	8.30	6.40	7.70	3.60	5.30	3.20	2.00	3.80	3.50	2.30
HO	0.73	0.82	1.10	0.63	0.62	0.76	0.48	0.34	0.63	0.59	0.38
LA	4.9	100.0	15.0	35.0	9.6	22.0	11.0	5.7	9.7	8.5	43.0
LU	0.25	0.29	0.34	0.10	0.19	0.24	0.18	0.13	0.18	0.19	0.25
ND	9.0	74.0	23.0	47.0	13.0	26.0	14.0	9.3	13.0	11.0	20.0
PR	1.80	21.00	5.10	10.00	2.80	5.80	3.10	2.00	2.90	2.50	6.60
SM	2.50	12.00	5.90	9.80	3.20	5.40	3.10	2.20	3.60	3.00	3.00
TB	0.56	1.00	1.00	0.97	0.58	0.80	0.48	0.33	0.60	0.57	0.36
TM	0.27	0.29	0.38	0.14	0.23	0.27	0.17	0.12	0.21	0.22	0.20
Y	21.00	27.00	32.00	17.00	17.00	22.00	14.00	9.10	17.00	17.00	14.00
YB	1.80	2.00	2.40	0.72	1.40	1.70	1.10	0.83	1.30	1.40	1.50

LAB_NO	45	46	47	48	49	50	51	52	53	54	55
SAMPLE_N	SLB00-627	SLB00-628	SLB00-629	SLB00-630	SLB00-632	SLB00-635	SLB00-646	SLB00-647	SLB00-651	SLB00-656	SLB00-660
SIO2	54.60	50.10	59.80	55.60	59.90	69.80	31.30	44.60	53.10	73.00	69.60
TIO2	0.62	0.69	0.32	0.33	1.10	0.34	1.49	1.70	2.07	0.23	0.15
AL2O3	17.70	16.20	13.50	16.30	20.10	15.00	11.20	14.50	15.60	15.00	14.10
FE2O3T	6.10	8.90	3.80	2.60	6.40	3.10	11.10	13.40	9.90	2.10	2.40
FE2O3	3.10	1.45	0.80	0.71	1.73	1.65	1.54	3.39	1.34	1.43	0.29
FEO	2.7	6.7	2.7	1.7	4.2	1.3	8.6	9.0	7.7	0.6	1.9
MNO	0.11	0.14	0.15	0.32	0.02	0.03	0.13	0.15	0.11	0.03	0.07
MGO	2.05	2.61	2.63	3.73	1.72	0.95	10.39	7.82	4.94	0.70	1.39
CAO	4.24	8.58	5.19	5.29	0.34	1.12	7.97	4.80	3.46	0.07	2.54
NA2O	3.80	2.80	3.20	1.80	4.90	4.00	0.30	2.00	5.50	3.80	3.10
K2O	2.57	0.75	2.94	4.85	2.26	3.25	3.42	0.27	0.91	3.29	2.49
H2OT	2.4	3.6	2.2	2.5	3.8	1.9	2.0	5.5	3.5	1.8	1.8
CO2T	6.4	6.5	6.5	7.7	0.2	0.9	21.4	7.1	2.2	0.2	2.4
P2O5	0.27	0.28	0.08	0.08	0.29	0.07	0.38	0.24	0.45	0.05	0.10
ST	0.04	0.11	0.64	-0.02	0.45	-0.02	0.54	-0.02	0.02	-0.02	0.02
BA	710	480	1200	1000	510	1400	370	83	380	1200	550
TOTAL	100.6	100.5	100.6	100.8	100.9	100.4	100.5	101.2	100.8	100.2	100.0
LOI	-999.0	-999.0	-999.0	-999.0	-999.0	-999.0	20.8	-999.0	-999.0	-999.0	-999.0
ST_IC	417	1134	5814	96	4377	94	5174	108	206	70	226
AG	-0.1	-0.1	0.4	0.2	0.5	0.1	0.6	1.1	0.2	0.2	-0.1
BE	1.6	0.9	2.5	2.9	1.8	2.8	0.9	0.6	1.5	2.2	2.4
BI	-0.2	-0.2	0.3	0.3	-0.2	-0.2	0.5	-0.2	-0.2	-0.2	-0.2
CD	-0.2	-0.2	-0.2	0.5	-0.2	-0.2	0.3	-0.2	-0.2	-0.2	0.3
CL	-100	143	171	148	-100	-100	198	106	100	-100	-100
CO	7	23	6	-5	5	5	62	61	31	-5	-5
CR	-10	-10	12	-10	49	-10	547	616	64	-10	-10
CS	1.90	0.56	3.20	3.20	1.20	2.10	1.60	0.21	4.90	1.70	1.20
CU	-10	18	-10	11	59	20	143	29	92	17	16
F	1000	694	1014	1486	876	1027	1229	1058	736	1003	516
GA	21.00	18.00	17.00	21.00	19.00	19.00	15.00	17.00	24.00	18.00	16.00
HF	3.40	3.00	8.20	9.10	4.70	9.10	1.90	2.40	4.90	9.50	3.80
IN	0.07	0.05	0.05	0.11	-0.05	-0.05	0.16	0.06	0.06	-0.05	-0.05
MO	-0.2	-0.2	-0.2	-0.2	1.4	-0.2	0.9	-0.2	0.5	0.3	-0.2
NB	9.10	8.30	10.00	23.00	13.00	22.00	24.00	19.00	25.00	21.00	7.10
NI	-10	-10	-10	-10	10	-10	295	453	61	-10	-10
PB	13	7	6	83	4	2	346	19	3	3	11
RB	82.00	18.00	79.00	140.00	68.00	100.00	100.00	6.60	24.00	81.00	54.00
SB	0.6	0.9	0.3	0.3	-0.2	-0.2	0.8	0.7	0.4	0.3	-0.2
SC	23.0	22.0	17.0	7.0	19.0	7.9	19.0	28.0	18.0	5.4	2.3
SN	-2.0	-2.0	4.0	12.0	5.0	2.0	2.0	-2.0	2.0	2.0	2.0
SR	230	350	170	150	190	120	220	180	250	55	130
TA	0.49	0.44	1.00	1.60	0.77	1.60	1.50	1.10	1.40	1.70	0.80
TE	-0.2	-0.2	-0.2	-0.2	-0.2	0.2	0.7	-0.2	-0.2	-0.2	-0.2
TH	2.00	1.50	20.00	28.00	11.00	27.00	1.70	1.30	6.20	29.00	24.00
TL	0.77	0.18	0.39	0.65	0.45	0.40	0.47	0.04	0.15	0.40	0.33
U	0.79	0.67	4.30	6.10	4.30	7.10	0.44	0.60	1.30	6.20	2.60
V	150	144	125	38	174	23	172	198	166	10	21
ZN	217	86	95	194	62	25	157	229	96	27	121
ZR	150.0	130.0	260.0	280.0	180.0	340.0	82.0	92.0	210.0	290.0	160.0
CE	48.0	47.0	63.0	70.0	17.0	140.0	43.0	25.0	85.0	140.0	70.0
DY	4.60	4.90	6.00	4.30	2.40	4.80	2.70	3.70	5.60	4.50	1.70
ER	2.60	2.60	3.50	2.50	1.70	2.60	1.10	1.80	2.30	2.60	0.95
EU	1.30	1.50	1.10	1.20	0.45	1.30	1.20	1.10	2.80	1.10	0.43
GD	5.50	5.60	6.60	5.90	2.10	6.80	3.90	3.90	8.00	5.80	2.00
HO	0.93	0.93	1.30	0.87	0.57	0.92	0.47	0.71	0.97	0.92	0.37
LA	19.0	19.0	29.0	31.0	7.0	72.0	19.0	11.0	41.0	75.0	49.0
LU	0.42	0.42	0.61	0.49	0.34	0.52	0.12	0.21	0.25	0.50	0.16
ND	27.0	27.0	31.0	36.0	6.5	53.0	23.0	15.0	41.0	46.0	18.0
PR	6.20	6.30	7.60	8.80	1.60	15.00	5.10	3.30	9.70	14.00	5.70
SM	5.60	5.80	6.90	7.30	1.60	8.90	4.30	3.40	8.80	7.30	2.50
TB	0.82	0.87	1.10	0.81	0.39	0.96	0.55	0.62	1.20	0.86	0.32
TM	0.41	0.41	0.60	0.41	0.28	0.41	0.15	0.25	0.31	0.42	0.16
Y	29.00	29.00	41.00	29.00	18.00	29.00	13.00	20.00	28.00	29.00	11.00
YB	2.80	2.70	4.00	3.00	2.10	3.20	0.85	1.60	1.90	3.10	1.10

LAB_NO	56 dup	57 dup
SAMPLE_N	00-059-056 (lab #20)	00-059-057 (lab #40)
SiO2	55.40	38.30
TiO2	0.33	1.46
Al2O3	13.50	11.10
Fe2O3T	3.20	10.10
Fe2O3	1.20	-999.00
FEO	1.8	-999.0
MNO	0.16	0.16
MGO	0.92	8.35
CAO	10.38	7.73
NA2O	3.20	1.90
K2O	2.64	0.02
H2OT	2.0	-999.0
CO2T	7.9	5.7
P2O5	0.13	0.20
ST	0.08	1.75
BA	1800	67000
TOTAL	99.7	86.8
LOI	-999.0	8.8
ST_IC	950	-1000
AG	0.1	-0.1
BE	1.3	0.5
BI	-0.2	-0.2
CD	-0.2	-0.2
CL	151	139
CO	-5	49
CR	24	475
CS	2.40	0.07
CU	11	-10
F	518	574
GA	17.00	15.00
HF	3.70	2.00
IN	-0.05	-0.05
MO	0.3	-0.2
NB	8.40	17.00
NI	-10	284
PB	4	2
RB	71.00	0.29
SB	0.3	1.8
SC	22.0	20.0
SN	-2.0	2.0
SR	420	1100
TA	0.68	0.98
TE	-0.2	-0.2
TH	7.40	0.91
TL	0.36	-0.02
U	3.00	0.41
V	97	166
ZN	61	79
ZR	150.0	81.0
CE	56.0	25.0
DY	4.80	2.60
ER	3.00	1.30
EU	0.97	0.96
GD	4.70	3.10
HO	1.00	0.49
LA	29.0	11.0
LU	0.57	0.18
ND	23.0	14.0
PR	6.20	3.20
SM	4.70	3.10
TB	0.81	0.49
TM	0.49	0.18
Y	32.00	14.00
YB	3.70	1.20

REFERENCES

- Jenner, G.A., Longerich, H.P., Jackson, S.E., and Fryer, B.J.
1990: ICP-MS a powerful tool for high precision trace-element analysis in earth sciences: evidence from selected U.S.G.S. reference samples; *Chemical Geology*, V. 83, p. 133-148.
- Longerich, H.P.
1995: Analysis of pressed pellets of geological samples using wavelength-dispersive X-Ray fluorescence spectrometry; *X-Ray Spectrometry*, V. 24.
- Piercey, S.J. Paradis S., Murphy D.C., Mortensen J.K.
2001: Geochemistry and paleotectonic setting of felsic volcanic rocks in the Finlayson Lake volcanic-hosted massive sulphide (VHMS) district, Yukon, Canada, *Economic Geology* V. 96, pages 1877-1906.
- Piercey, S.J., Murphy, D.C., Mortensen, J.K., and Paradis, S.,
2000: Arc rifting and ensialic back-arc basin magmatism in the northern Canadian cordillera: evidence from the Yukon-Tanana terrane, Finlayson lake region, Yukon: in *Slave-Northern Cordilleran Lithospheric Experiment (SNORCLE)-Lithoprobe Report 72*, p. 129-138.

APPENDIX III

**U-Pb Zircon Analysis
Neodymium Isotopes
Sulphur Isotopes**

Methods

The following section is a summary of the techniques involved in obtaining the isotope data presented herein. It summarizes the methods used, sample preparations, and analytical equipment.

U-Pb Geochronology

A total of five samples from the Eagle Bay Assemblage were submitted for U-Pb zircon geochronology at the University of Alberta Isotope Research Facilities in an attempt to determine crystallization ages of metafelsic to metamafic volcanics. The procedure follows that of Heaman and Lecheminant (1993) and Heaman and Machado (1992).

Samples were crushed in a jaw crusher and then reduced to 30-40 μm size using hardened steel disks on a Reuland P000 grinder. Heavy minerals were separated from light fractions using a wilfley table. The samples were sieved and fractions smaller than 210 μm were washed with ethanol and dried. A Frantz magnetic barrier separator was then used to separate magnetic from non-magnetic minerals. The remaining heavy minerals were then separated in methylene iodide (MI). Five distinct zircon types were recognized under a stereo microscope and picked for multi and single grain analysis. Zircons were dissolved in teflon screw top containers using concentrated HF and concentrated HNO_3 and placed on a hot plate for 7 days. The samples were loaded onto Nd filaments and analyzed for ^{235}U , ^{238}U , ^{206}Pb and ^{207}Pb on a VG354 mass spectrometer.

Neodymium isotope analysis

A total of nine samples from the Eagle Bay Assemblage were submitted to the University of Alberta Isotope Research Facilities for neodymium isotope analysis. Procedures follow those outlined by Creaser et al. (1997). This study was done to determine source region variability of metavolcanic and metasedimentary sequences in the Johnson Lake area.

Samples were jaw crushed and then pulverized using a silica bowl (except sample SLB99-165 was pulverized in a tungsten carbide bowl). 100 ug of powder were weighed into 120 ml screw top teflon bombs and a sample spike added to each sample. The spike consisted of the rare isotopes of ^{150}Nd and ^{149}Sm dissolved in 1N HNO_3 . 5 ml of concentrated HF acid and 2 ml of concentrated HNO_3 acid were added and samples placed on a hot plate for 7 days to allow complete acid digestion to occur. 10 ml of 6N HCl were added and the sample capped and placed on the hot plate for 24 hours. The sample was then dried and 6ml of 0.75N HCl added. The sample was then capped, placed on a hot plate overnight and then cooled and transferred to a 15 ml polypropylene centrifuge tube.

These samples were then passed through a DEP (Di-ethylhexyl phosphate) chromatographic column and washed with varying concentrations of HCl to separate the Sm and Nd. These samples were allowed to evaporate and then HNO_3 was added to each sample. Nd samples were loaded onto rhenium filaments using a syringe and tubing. Sm samples were loaded onto tantalum filaments, along with an activator (this controls the flow of isotopes to the mass spectrometer). The filament was heated and the sample allowed to dry. One standard was analyzed per turret (twenty samples). The samples

were converted to nitrates and measurements completed using a thermal ionization mass spectrometer.

The following detailed description of the method is written communication from Dr.

Robert Creaser, University of Alberta.

“The powdered samples provided were totally spiked with a mixed tracer solution of $^{150}\text{Nd}+^{149}\text{Sm}$. The spiked samples were then dissolved in $\text{HF}+\text{HNO}_3$ (5:1 volume) at 160C in Teflon PFA vessels for a minimum of 96 hours, followed by evaporation in HEPA filtered air. The dried fluoride residues were converted to chlorides by reaction with 6N HCl for 24 hours and evaporation. The dried chloride residues were taken up in dilute HCl for chromatography. The bulk REE fraction was separated using conventional cation exchange chromatography using AG50-W8 resin (200-400 mesh) in both HCl and HNO_3 media. Nd and Sm were subsequently separated from the remaining REE using LN-Spec resin in dilute HCl media. Processing blanks are less than 400 picograms of either Nd or Sm and are irrelevant compared with the amounts of Nd and Sm analyzed here.

Dried Nd and Sm fractions were converted to nitrates and analyzed by Thermal Ionization Mass Spectrometry using a Micromass Sector54 mass spectrometer. During the course of this study, repeat analyses of the Geological Survey of Japan Nd isotopic standard “Shin Etsu” were carried out to monitor instrument performance, precision and accuracy of isotopic analysis. Nine analyses of the Shin Etsu standard defined an average $^{143}\text{Nd}/^{144}\text{Nd}$ value of 0.512102 ± 0.000009 (1SD). The Nd isotope data presented for this study are corrected relative to a value of Shin Etsu of 0.512107, which is equivalent to a value of 0.511850 for the La Jolla Nd isotopic standard. The mixed, fractionated Nd isotopic ratios for samples were corrected for mass fractionation using a value of $^{146}\text{Nd}/^{144}\text{Nd} = 0.7219$, and the spike stripped off the natural isotopic composition using in-house algorithms.”

Sulfur Isotopes

Sulfur isotope analysis was carried out at the Stable Isotope Laboratory at Carlton University following modified techniques of Rees and Holt (1991) and Sasaki et al., (1979). Sulfur has four stable isotopes, the two most common are ^{32}S (95.02%) and ^{34}S (4.21%), the ratio between these common sulphur isotopes are commonly used in geochemistry (Rollinson, 1993). Sulfur isotope ratios vary depending on the genetic

source of the sulfur. In this study, sulfur isotopes will be a useful aid in characterizing fluid chemistry that resulted in mineralization. For example, barite commonly forms in hydrothermal vents by bonding between Ba^{2+} derived from vented fluids and SO_3^{2-} , derived from seawater and hydrothermal fluid. Seawater sulphate has a $\delta^{34}\text{S}$ of generally +16 to +25, while sulphide derived from venting fluids generally have a low $\delta^{34}\text{S}$ positive value (+4 to +10), and magmatic sulphides have a value near $\delta^{34}\text{S}$.

Samples of mineralized rock were crushed, and using a stereoscope and tweezers sulfide minerals were separated individually. These were powdered and weighed into foil capsules in amounts ranging from 0.14 mg to 0.36 mg depending on the specific sulphide mineral analyzed, along with 0.10 mg of vanadium pentoxide (V_2O_5). These were combusted to form SO_2 gas, which was analyzed for sulfur isotope ratios using a VG SIRA mass spectrometer. Powdered sulphide samples were mixed with vanadium pentoxide and combusted on a CE elemental analyzer followed by gas chromatographic separation of the SO_2 gas. Sulphates were combusted with copper oxide at 1100 °C and SO_2 cryogenically separated. The sulphur isotopes of the SO_2 gas were subsequently measured on a VG SIRA 12 mass spectrometer. The isotopes are referenced to Cañon Diablo troilite and reported as $\delta^{34}\text{S}\%$ based on the equation (Ohmoto et al, 1982):

$$\delta^{34}\text{S}\% = \{ (R_i/R_{\text{cdt}}) - 1 \} \times 1000$$

where

R_i = $^{34}\text{S}/^{32}\text{S}$ of the sample

R_{cdt} = $^{34}\text{S}/^{32}\text{S}$ of standard (Canon Diablo troilite)

Table A-3.1: U-Pb Results for the Ancient Continental Margin Project, Johnson Lake, B.C.

Sample SLB99-31, igneous zircons														
Description	Weight (μg)	Concentration (ppm)				TCPb (pg)	Atomic Ratios $\pm 2\text{s error}$				Apparent age $\pm 2\text{s error (Ma)}$			
		U	Pb	Th	Th/U		$^{206}\text{Pb}/^{204}\text{Pb}$	$^{206}\text{Pb}/^{238}\text{U}$	$^{207}\text{Pb}/^{235}\text{U}$	$^{207}\text{Pb}/^{206}\text{Pb}$	$^{206}\text{Pb}/^{238}\text{U}$	$^{207}\text{Pb}/^{235}\text{U}$	$^{207}\text{Pb}/^{206}\text{Pb}$	% Dis.
1 2 resorbed prism col possible tip overgrowth NM4	3.7 $\pm$ 1.10	1498.7	93.88	1111	1.0	10.08	2758.3	0.0336 $\pm$ 5	0.297 $\pm$ 25	0.0643 $\pm$ 50	212.8 $\pm$ 2.5	264.4 $\pm$ 19.	750.4 $\pm$ 158.	-31.0
2 10 prisms (2:1 to equant) tan eu sl res M4	3.7 $\pm$ 1.12	1692.3	106.2	1278	1.1	9.65	3236	0.0555 $\pm$ 3	0.411 $\pm$ 4	0.0538 $\pm$ 4	348.4 $\pm$ 1.5	348.1 $\pm$ 1.5	361.6 $\pm$ 10.7	-46.2
3 16 prisms (2:1) tan eu NM4 sl res	2.6 $\pm$ 0.7	1885.9	118.5	1446	1.3	9.22	3713.7	0.0543 $\pm$ 3	0.402 $\pm$ 3	0.0537 $\pm$ 3	340.8 $\pm$ 1.4	340.8 $\pm$ 1.4	358.6 $\pm$ 8.1	-61.4
4 2 angular piece tan NM4	1.0 $\pm$ 0.3	2079.5	130.8	1613	1.4	8.79	4191.4	0.0551 $\pm$ 4	0.399 $\pm$ 7	0.0525 $\pm$ 8	345.7 $\pm$ 1.7	340.7 $\pm$ 4.5	306.7 $\pm$ 31.1	-76.7
5 12 angular tan trans frags n/incl 4NM	13.3 $\pm$ 0.6	2273.1	143.1	1781	1.6	8	4669.1	0.0547 $\pm$ 4	0.405 $\pm$ 3	0.0538 $\pm$ 2	343.0 $\pm$ 0.9	345.3 $\pm$ 0.9	360.7 $\pm$ 2.6	-91.9

* col : colorless eq : equant euh : euhedral incl : inclusions irreg : irregular # NM : degrees of non-magnetic fraction pk : pink pr : prism sm : small trans : transparent
z : zircon (#) : grain count

All errors reported to 1 sigma.

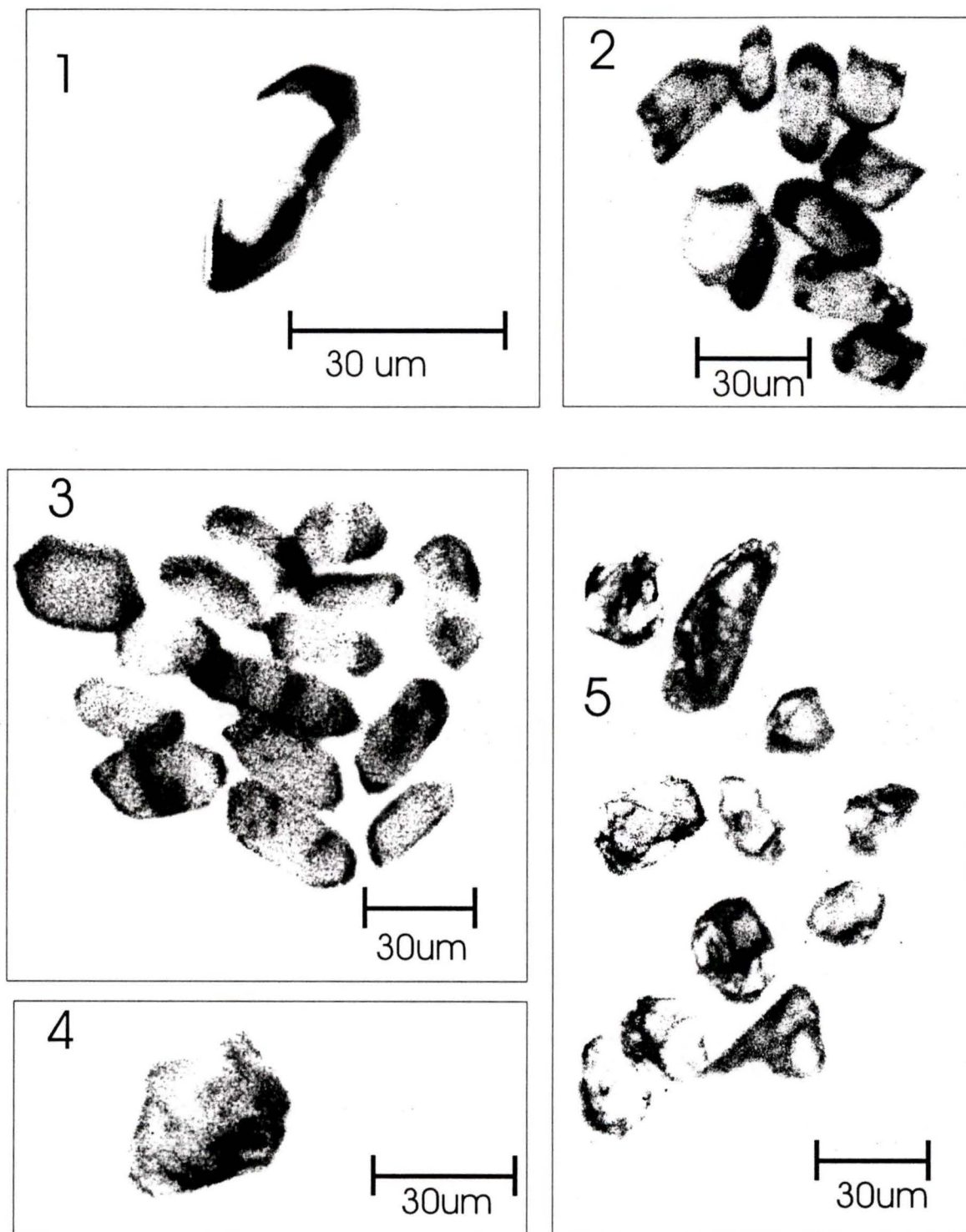


Figure A-3.1: Sample SLB99-31 zircon populations: 1.) Resorbed colourless zircon. 2.) 9 tan coloured slightly resorbed elongate to equant zircon prisms. 3.) 15 tan coloured, euhedral zircon prisms. 4.) Angular piece of tan coloured zircon. 5.) 11 angular tan transparent zircon fragments.

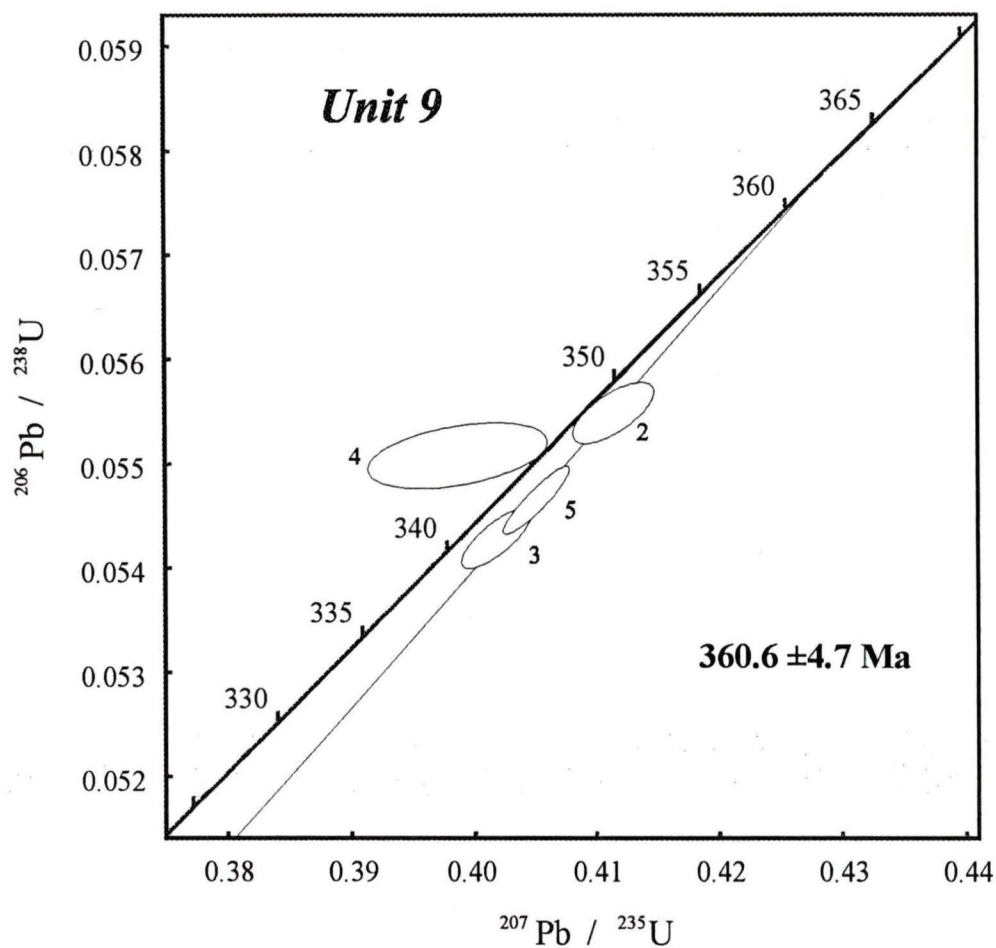


Figure A-3.2: U-Pb Concordia diagram of zircon fractions 2-5 from sample SLB99-031, a quartz feldspar porphyritic flow of unit 9, all fractions are discordant, linear regression defines an upper intercept of U-Pb ratios coinciding with an age of $360.6 \pm 4.7 \text{ Ma}$.

TableA-3.2: U-Pb zircon results from the Johnson Lake area

Description *	Weight (μg)	U (ppm)	Th (ppm)	Pb (ppm)	Th/U	TCPb (pg)	Model Ages (Ma)								%Disc
							²⁰⁶ Pb/ ²⁰⁴ Pb	²⁰⁶ Pb/ ²³⁸ U	²⁰⁷ Pb/ ²³⁵ U	²⁰⁷ Pb/ ²⁰⁶ Pb	²⁰⁶ Pb/ ²³⁸ U	²⁰⁷ Pb/ ²³⁵ U	²⁰⁷ Pb/ ²⁰⁶ Pb		
SLB00-670															
1 z, sm eq dk pk trans clustered incl 0NM (1)	9	203	145	62	0.71	5	6497	0.26458±50	4.052±9	0.11108±7	1513.2±2.6	1644.8±1.7	1817.2±1.1	18.8	
2 z, sm eq pk trans 0NM (1)	11	86	96	44	1.12	4	5278	0.39213±70	9.851±20	0.18220±11	2132.7±3.3	2420.9±1.9	2673.0±1.0	23.7	
3 z, sm 1:1 rounded tip pk trans 0NM (1)	10	92	11	26	0.12	3	5177	0.28762±56	4.546±10	0.11464±9	1629.6±2.8	1736.5±1.8	1874.2±1.3	14.8	
4 z, rounded 2:1 pr cluster/incl/center 0NM (1)	10	95	143	63	1.50	4	7582	0.47811±94	12.051±26	0.18280±11	2519.0±4.1	2608.4±2.0	2678.5±1.0	7.2	
SLB00-656															
1 z, col pr incl 0NM (18)	20	229	101	11	0.44	10	1312	0.04624±9	0.3433±9	0.05384±10	291.4±0.5	299.6±1.7	364.2±4.1	20.4	
2 z, tiny col pr least of incl 0NM (15)	12	314	131	19	0.42	43	263	0.04639±35	0.3567±10	0.05576±146	292.3±2.2	309.7±7.7	443.0±57.1	34.8	
SLB00-420															
1 z, tiny col eq 10NM (12)	12	398	40	28	0.10	13	1541	0.06848±13	0.7631±16	0.08082±8	427.0±0.8	575.79±0.9	1217.1±2.0	67.1	
2 z, larger col irreg 10NM (6)	16	246	81	21	0.33	6	3236	0.08459±12	0.7595±13	0.06512±6	523.5±0.7	573.7±0.7	778.2±1.9	34.1	
3 z, lg tan euh 10NM (1)	7	174	93	12	0.53	16	270	0.05219±9	0.3956±32	0.05497±43	328.0±0.5	338.4±2.3	410.9±17.2	20.7	

* col : colorless dk : dark eq : equant euh : euhedral incl : inclusions irreg : irregular # NM : degrees of non-magnetic fraction pk : pink pr : prism sm : small trans : transparent
z : zircon (#) : grain count

All errors reported to 1 sigma.

Table A-3.3: Geochronology compilation, Kootenay Terrane southern British Columbia

mineral	closing T	Age	description
zircon	850	360	igneous zircon, felsic volcanics of EBA this study
		235	Amphibolite Gneiss, Shushwap river, (Okulitch, 1979)
hornblend	500	155	biotite schist, metamorphic, Trinity Hills, (Mathews, 198
		100	
		185	sericite, Samatosum deposit ore veins (Clark and Jones
		190	sericite, Rea deposit Clark and Jones(1991)
		166	sericite, regional metamorphism, Jones and Clark, 1991
muscovite	250	49	biotite schist, Mathews, 1981
biotite	300	45	biotite schist, Mathews, 1981

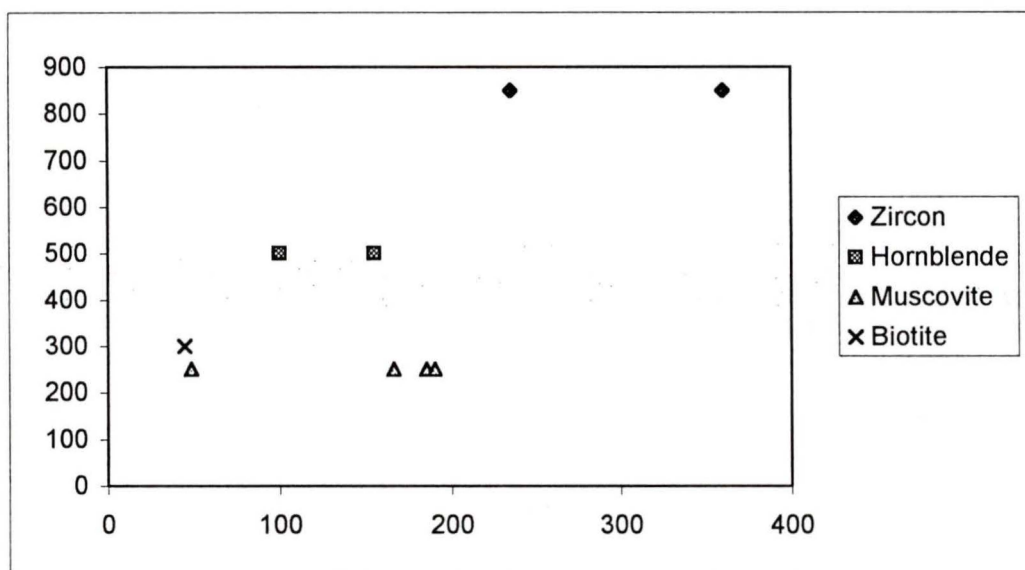
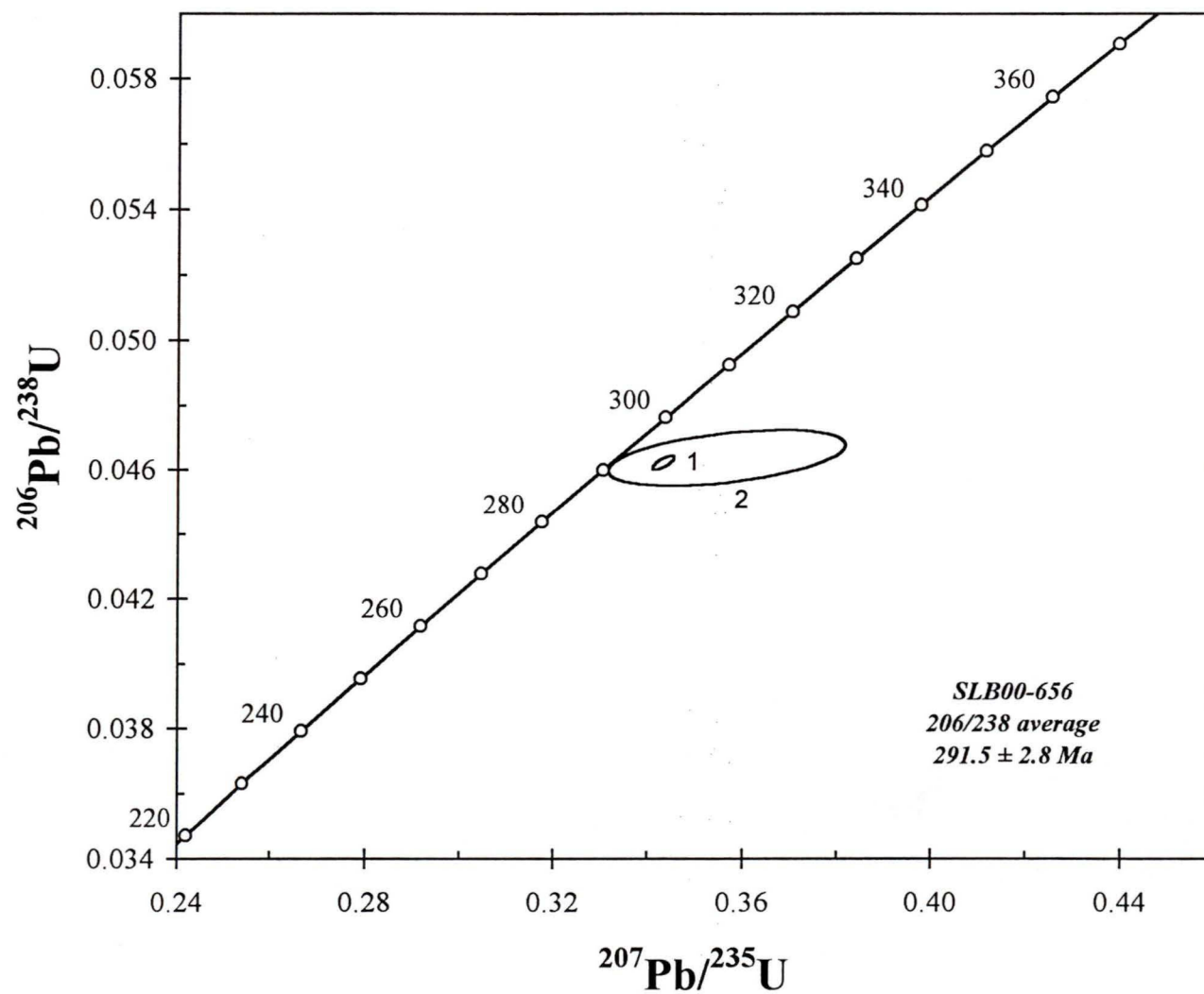
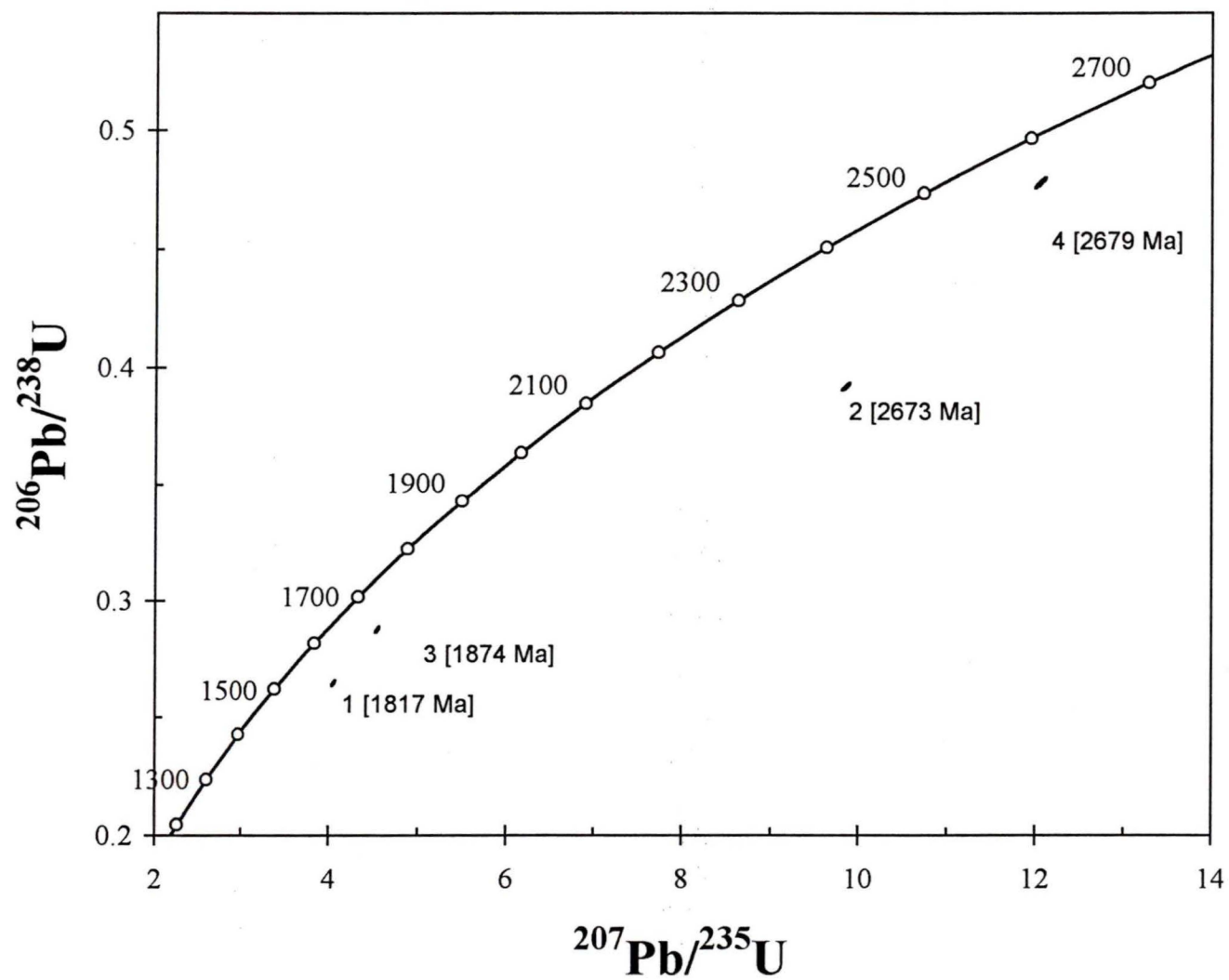


Figure A-3.4: Isotopic age of the mineral sample versus closure temperature for isotopic studies completed in the Kootenay Terrane (see Table A-3.3),





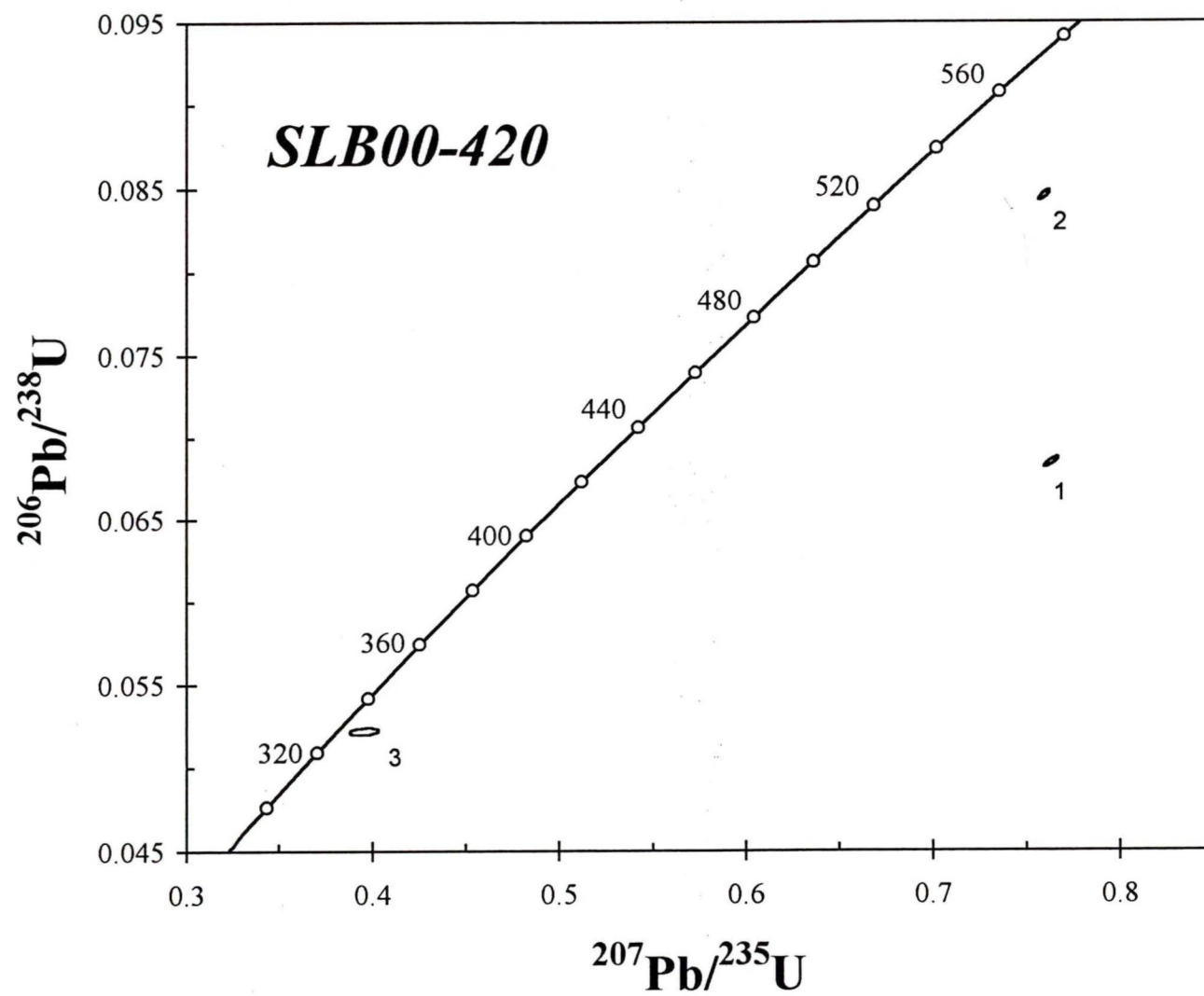


Table A-3.4: Neodymium isotopic data for Johnson Lake volcanic and sedimentary rocks, isotopes are reported as ratios to ^{144}Nd . ϵNd was calculated based on the T Ma ages listed, Nd correction = Nd static S54, uncertainty is reported as 2 standard errors. Unit 4 ϵNd T values calculated for both Devonian and Lower Cambrian ages.

Sample	unit	Sm ppm	Nd ppm	$^{147}\text{Sm}/^{144}\text{Nd}$	$^{143}\text{Nd}/^{144}\text{Nd}$	uncert.	TDM	ϵNd T	T Ma	Sm/Nd
B99-6A	4	2.83	11.66	0.14654243	0.512679971	0.000013	1.10	+3.30	360	0.24
								+4.33	540	
B99-6B	4	4.66	20.52	0.137261445	0.512714113	0.000007	0.90	+3.40	360	0.23
								+4.65	540	
B99-09	2	0.81	1.73	0.282931331	0.513350506	0.000009	0.41	+8.34	540	0.47
B99-61	3a	2.34	9.39	0.150529246	0.512765559	0.000007	0.96	+5.71	540	0.25
B99-108	3a	1.79	7.11	0.152670563	0.512785983	0.000007	0.94	+5.34	540	0.25
B00-165	10	4.63	25.37	0.110301002	0.512143422	0.000007	1.50	-5.68	360	0.18
B99-182	9	12.14	74.73	0.098210459	0.512353467	0.000010	1.07	-1.02	360	0.16
B99-33	9	9.54	57.60	0.100143666	0.512277483	0.000009	1.19	-2.60	360	0.17
B99-86	9	13.37	72.95	0.110840804	0.512335705	0.000009	1.22	-1.95	360	0.18

Table A-3.5: Sulphur Isotope data, sulphide and sulphate minerals from the Johnson Lake area

Lab No.	Sample No.	Mineral	% Mineral	$\delta^{34}\text{S}_{\text{CDT}}$	Comments
B01-018-001	Sam 29 (Samatosum)	py,sp ga	50 ?	8.3	fine grained massive sulphide sample
B01-018-002	Sam 24 (Samatosum)	py	100	6.1	coarse disseminated sulphide
B01-018-003	Sam 13 (Samatosum)	py	100	4.9	coarse disseminated sulphide
B01-018-004	Sam seds (Samatosum)	py	100	6.4	coarse disseminated sulphide
B01-018-005	Bf 01 (Samatosum)	py	100	6.5	Qtz vein ore zone, coarse pyrite
B01-018-006	Bf 01 (Samatosum)	tet	100	6.1	Qtz vein ore zone, coarse tetrahedrite
B01-018-007	BF 02 (Samatosum)	cpy	100	7.4	Qtz vein ore zone, coarse chalcopyrite
B01-018-008	BF 02 (Samatosum)	tet	100	7.2	Qtz vein ore zone, coarse tetrahedrite
B01-018-009	Rainbow	po	100	4.6	massive sulphide sample
B01-018-010	spar	py sp ga	70	2.3	fine grained massive sulphide sample
B01-018-011	lucky coon	sp	100	4.1	medium grained spalerite, lucky coon deposit
B01-018-012	Enargite	ga	100	-2.4	fine grained massive sulphide sample
B01-018-013	Acacia 03	py	100	2.1	coarse pyrite from a quartz vein, Acacia showing
B01-018-014	ACB03 vein (Acacia)	sp	100	1.9	coarse black-reddish sphalerite from a quartz vein, Acacia showing
B01-018-015	Rose Black sphalerite	sp	100	11.7	coarse grained black sphalerite from the Rose showing
B01-018-016	Rea massive Sulphide	py, sp ga	50	4.7	fine grained massive sulphide sample
B01-018-017	Rea unit 3.1	py	100	2.7	coarse pyrite from massive sulphide, Rea deposit
B01-018-018	Rea unit 3.1	cpy	100	6.2	coarse chalcopyrite from massive sulphide, Rea deposit
B01-018-019	HSB-03 (Homestake)	py	100	cancel	from alteration zone, Homestake deposit
B01-018-020	homestake vein	py	100	7.1	coarse pyrite, qtz-py-ser alteration Homestake deposit
B01-018-021	slb99-53B (regional)	py	100	-8.5	coarse disseminated sulphide
B01-018-022	SLB00-298	py	100	-19.0	coarse cubic pyrite from Mississippian black shale (EBP)
B01-018-023	Kam 24-2 (Kamad)	py	100	-0.4	coarse disseminated sulphide
repeat				-0.1	coarse disseminated sulphide
B01-018-024	K89-67-4 (Kamad)	py	100	4.1	coarse disseminated sulphide
repeat				4.3	
B01-018-025	Rea massive Barite	ba	90?	21.2	fine grained, some SiO ₂
B01-018-026	Homestake massive barite	ba	100?	35.0	Eagle Bay Assemblage (EBA), minor SiO ₂

Submitted: February 06, 2001.

Completed: June 12, 2001.

REFERENCES

- Creaser, R.A., Erdmer, P., Stevens, R.A., Grant, S.L.
 1997: Tectonic affinity of Nisutlin and Anvil assemblage strata, from the Teslin tectonic zone, northern Canadian Cordillera: constraints from neodymium isotope and geochemical evidence, *Tectonics*, v.16, pages 107-121.
- Heaman, L.M., and Lecheminant, A.N.
 1993: Paragenesis and U-Pb systematics of baddeleyite (ZrO₂). *Chemical Geology*, vol 110, pages 95-126.
- Heaman, L.M., and Machado, N.
 1992: Timing and origin of mid-continent rift alkaline magmatism, North America: evidence from the Coldwell Complex. *Contributions to Mineralogy and Petrology*, v. 110, pages 289-303.
- Ohmoto, H., and Lasaga, A.C.
 1982: Kinetics of reactions between aqueous sulphates and sulphides in hydrothermal systems: *Geochimica et Cosmochimica Acta* v. 46, pages 1727-1745.
- Rees, C.E., Holt, B.D.
 1991: The isotopic analysis of sulphur and oxygen: in *Stable isotopes in the assessment of natural and anthropogenic sulphur in the environment*, H.R. Krouse and V.A. Grinenko (eds.). New York, Wiley, pages 43-64.
- Rollinson, H.
 1993: *Using Geochemical Data: Evaluation, Presentation, Interpretation*; Longman Group Ltd., 352 p.
- Sasaki, A., Arikawa, Y., Folinsbee, R.E.,
 1979: Kiba reagent method of sulphur extraction applied to isotope work. *Bulletin, Geological Survey of Japan*, v. 30, pages 1347-1353.

Appendix IV: Digital Appendices (CD ROM)

Appendix I

“Autocadmap” folder: A 1: 20 000 scale map and Cross sections drafted in Autocad[®] version R14, are included, this is a preliminary version of the 1: 20 000 scale map generated in Arcinfo[®], point data entered in Fieldlog (Version 14) has been included as DBF (IV) files and excel (version 2000) files.

“Samples”: hand sample descriptions and stations including GPS points are included as excel files, and includes structure data.

<i>File</i>	<i>Size</i>	<i>Type</i>
AppendixIpageformat	83 KB	.DOC (ms word V2000)
Baileycarcinfomap...	10.8 MB	.DWG (autocad R14)
Folder/Baileyproject	5.62 MB	.DBF (DBF IV)
Folder /Samples	432 KB	.XLS (ms excel V2000)

Appendix II

Lithogeochemistry data for 1999 and 2000 season samples, methods, precision and accuracy, limits of detection.

<i>File</i>	<i>Size</i>	<i>Type</i>
AppendixIIpageformat	198KB	.DOC

Appendix III

U-Pb zircon, neodymium and sulphur isotope methods and data, photos of zircon fractions, concordia plots.

<i>File</i>	<i>Size</i>	<i>Type</i>
IsotopeMethods	45KB	.DOC
Figa-3.2	61KB	.DOC
Tablea-3.4	35KB	.DOC
Tablea-3-1	55KB	.XLS
Tablea-3-2	167KB	.XLS
Tablea-3-3	15.5KB	.XLS
Tablea-3-5	18KB	.XLS
Geochroncompilation	15.5KB	.XLS
s-isotope1	20.5KB	.XLS
Zircons2	2.9MB	.CDR (coreldrawV8)
Concordiaplot	146KB	.CDR

VITA

Surname: Bailey

Given Names: Sean Lee

Place of Birth: St. John's, Newfoundland, Canada

Educational Institutions Attended:

University of Victoria	1999 to 2002
Memorial University of Newfoundland	1994 to 1999

Degrees Awarded:

B.Sc. (Honours)	Memorial University	1999
-----------------	---------------------	------

Honours and Awards

University of Victoria Graduate Fellowship	1999-2001
--	-----------

Publications

Bailey, S.L., Paradis, S., Johnston, S.T.

2000: Geologic setting of the Devonian-Mississippian, Rea and Samatsum VMS deposits of the Eagle Bay Assemblage, Adams Lake area, south central British Columbia; *in* Geological Fieldwork 1999, B.C. Ministry of Energy and Mines, Paper 2000-1, p.287-296.

Bailey, S.L., Paradis, S., Johnston, S.T.

2001: New insights into metavolcanic successions and geochemistry of the Eagle Bay Assemblage, South Central British Columbia; Geological Survey of Canada, Current Research 2001-A8, 13 pages.

In preparation:

Bailey, S.L., Paradis, S., Johnston, S.T.

Geology of the Johnson Lake Area British Columbia, open file# 1234 geological map and cross sections Scale 1:20, 000.

Bailey, S.L., Johnston, S.T., Paradis, S.,

Stratigraphy and Structure of the Eagle Bay Assemblage in the Johnson Lake area, Southern British Columbia.

Bailey, S.L., Paradis, S., Johnston, S.T.

Geochemistry and Geochronology of metavolcanic rocks in the Eagle Bay Assemblage, Johnson lake Area, Southern British Columbia, Canada.

UNIVERSITY OF VICTORIA PARTIAL COPYRIGHT LICENSE

I hereby grant the right to lend my thesis to users of the University of Victoria Library, and to make single copies for such users or in response to a request from the Library of any other university, or similar institution, on it's behalf or for one of it's users. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by me or a member of the University designated by me. It is understood that copying or publication of this thesis for financial gain by the University of Victoria shall not be allowed without my written permission.

Title of Thesis:

Geology and Geochemistry of the Eagle Bay Assemblage in the Johnson Lake Area,
Kootenay Terrane, South-Central British Columbia.

Author



Sean Lee Bailey

June 10, 2002