MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

National Library
of Canada

Bibliothèque nationale
du Canada

Canadian Theses Service

Service des thèses canadiennes

Ottawa, Canada
K1A 0N4

NOTICE

The quality of this microform is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us an inferior photocopy.

Reproduction in full or in part of this microform is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30, and subsequent amendments.

AVIS

La qualité de cette microforme dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de qualité inférieure.

La reproduction, même partielle, de cette microforme est soumise à la Loi canadienne sur le droit d'auteur, SRC 1970, c. C-30, et ses amendements subséquents.

**STRATIGRAPHIC, STRUCTURAL AND TECTONIC SETTING OF THE
SHASTA Au-Ag DEPOSIT, NORTH-CENTRAL BRITISH COLUMBIA**

by

HENRY MARSDEN, B.Sc.

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

Master of Science

Department of Earth Sciences

Carleton University

Ottawa, Ont.

Date

copyright

1990, Henry Marsden

National Library
of Canada

Bibliothèque nationale
du Canada

Canadian Theses Service Service des thèses canadiennes

Ottawa, Canada
K1A 0N4

The author has granted an irrevocable non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of his/her thesis by any means and in any form or format, making this thesis available to interested persons.

The author retains ownership of the copyright in his/her thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without his/her permission.

L'auteur a accordé une licence irrévocable et non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de sa thèse de quelque manière et sous quelque forme que ce soit pour mettre des exemplaires de cette thèse à la disposition des personnes intéressées.

L'auteur conserve la propriété du droit d'auteur qui protège sa thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

ISBN 0-315-68916-1

Canada

The undersigned recommend to the faculty of Graduate
Studies and Research acceptance of the thesis

Stratigraphic, Structural and Tectonic Setting of the
Shasta Au-Ag Deposit, North-Central British Columbia
submitted by Henry Marsden, B.Sc.

in partial fulfilment of the requirements for
the degree of Master of Science

Thesis Supervisor

Chair, Department of Earth Sciences

Carleton University

November, 1990

Abstract

The Shasta deposit is a precious metal-bearing quartz-carbonate-sulphide stockwork system in the Early to Middle Jurassic Toodoggone volcanic assemblage composed predominantly of dacitic subaerial volcanoclastic rocks that are part of the Hazelton Group in Stikine terrane. The distribution of rock types within the Hazelton Group suggests that the Toodoggone volcanic assemblage was erupted either in a subaerial back-arc setting or in a mature arc above a west-dipping subduction zone. Limited geochemistry shows that the Toodoggone volcanic assemblage is dominated by calc-alkaline, high potassium dacites. The high LILE concentrations and depleted incompatible high field strength elements in these rocks are more characteristic of arc environments than back-arc environments.

The succession mapped within the Toodoggone assemblage can locally be divided into four parts: 1) Late Triassic marine to subaerial basaltic rocks of the Stuhini Group, 2) the dacitic Jock Creek volcanics, 3) the Saunders grey dacite, an Early Bajocian ignimbrite and, 4) the predominantly andesitic Theban member.

The Shasta Au-Ag deposit is spatially related to a dacitic dome within the Jock Creek succession. Telescoped time relationships between the dacite dome and overlying pyroclastic deposits suggest that the dome was an extrusive

flow that continued to grow after the pyroclastic flows were deposited on the flanks of the dome.

The mineralization consists of stockwork-breccia zones that are tabular zones of dilation and incipient strain. The geometry of the two principal zones, the JM and Creek zones, suggests that they are an extensional conjugate fracture set. This geometry predicts that economically significant ore shoots are shallowly plunging rod-shaped features localized at stockwork zone intersections and rolls within the zones.

The stockwork zones are preferentially hosted within pyroclastic rocks along the flank of the dacitic dome. A high original pore fluid content within the pyroclastic deposits may have facilitated structural failure, allowing the development of continuous mineralized fracture systems. The hydrothermal system was probably driven by heat from the dacite dome and its magmatic source.

Acknowledgments

I would like to thank Esso Minerals Canada and Homestake Mineral Development Co. for providing generous support and data for this thesis. I am especially grateful to Ron Britten, who initiated the project and ensured that I was able to carry it through. Some of the mapping, ideas and good company must be credited to Peter Holbek, Peter Thiersch and Margaret MacPherson who have all spent several field seasons working in Shasta camp. Additional financial support for research was provided by the British Columbia Ministry of Mines and Petroleum Resources.

John Moore provided a sound start and excellent advice in the field in both 1988 and 1989. Dick Brown, after educating me in tectonics and structure, has made it possible for me to complete and defend my thesis. Sharon Carr generously provided careful reviewing and advice that greatly improved my earlier efforts. Tony Fowler has given his time to help me with the chemical aspects of this thesis. Maurice Lambert changed my understanding of volcanic processes and inspired a fascination with volcanoes and volcanic rocks.

The thesis would have been very different (and much shorter) if I had not benefited from many long discussions with Derek Thorkelson on the Hazelton Group and island arcs of the world. Derek also provided a Lotus spreadsheet for

the calculation of CIPW norms, NORM*STONER, that saved days of calculator punching.

WORK DONE BY AUTHOR

This thesis is based on five months of mapping, completed between June and September 1988 and 1989. The 1:10,000 mapping was done solely by the author. The 1:2500 map is a compilation based on 1:1000 mapping by the author with significant contributions by Margaret McPherson and Peter Holbek. Additional information from diamond drill core and trench data are based on personal observations by the author but was greatly facilitated by maps and drill logs that were provided by Esso Minerals Canada Ltd. and Homestake Mineral Development Co. Ltd.

Thin-section preparation was done by Jiri Mrazek at the University of Ottawa, all the remaining petrographic work was done by the author.

Sample preparation for the x-ray fluorescence analysis was done by the author but the samples were run at the University of Ottawa by Ron Hartree.

TABLE OF CONTENTS

	Page
ACCEPTANCE SHEET.....	ii
ABSTRACT.....	iii
ACKNOWLEDGEMENTS.....	v
WORK DONE BY AUTHOR.....	vii
TABLE OF CONTENTS.....	viii
LIST OF TABLES.....	xiii
LIST OF FIGURES.....	xv
LIST OF PLATES.....	xvi
LIST OF APPENDICES.....	xvii

CHAPTER I: INTRODUCTION

1.1 Purpose and method of study.....	1
1.2 Location, Access and Topography.....	3
1.3 Previous work.....	4
1.3.1 The Toodoggone volcanics.....	4
1.3.2 The Shasta property.....	6

CHAPTER II: TECTONIC SETTING OF THE TOODOGGONE VOLCANICS

2.1 Introduction.....	10
2.2 Regional Framework.....	11
2.3 Geology of the Hazelton Group.....	16
2.4 Distribution of facies in the Hazelton Group..	25

2.5 Comparison with modern arc systems.....	29
2.6 Discussion.....	34

CHAPTER III: STRATIGRAPHY

3.1 Introduction.....	47
3.2 Stratigraphy and age of the Toodoggone volcanics.....	48
3.3 Age and correlations within the study area....	49
3.4 Stratigraphy of the study area.....	51
3.4.1 Introduction.....	51
3.4.2 Stuhini Group.....	52
3.4.2.1 Pillow basalt and hyaloclastite (unit 1a).....	52
3.4.2.2 Well bedded sandstone, siltstone and conglomerate (unit 1b).....	53
3.4.2.3 Vesicular basalt (unit 1c).....	54
3.4.3 Heterolithic conglomerates (unit 2)....	54
3.4.4 Jock Creek Volcanics.....	55
3.4.4.1 Green lapilli tuff, sediments (unit 3).....	56
3.4.4.2 Dacite dome and epiclastics (units 4a, 4b).....	57
3.4.4.3 Quartz-feldspar lapilli tuffs (unit 5).....	59
3.4.4.4 Laharic deposits (unit 6).....	62

3.4.4.5 Welded chloritic lapilli tuffs	
(unit 7).....	64
3.4.4.6 Laminated crystal ash tuffs	
(unit 8).....	65
3.4.4.7 Hornblende-feldspar phyric tuffs	
breccias and volcanic sediments...	66
3.4.5 Saunders Member.....	67
3.4.5.1 Purple ash and lapilli tuff.....	67
3.4.5.2 Saunders quartz-hornblende-biotite-	
feldspar phyric ignimbrite	
(unit 11a).....	68
3.4.5.3 Crystal lapilli tuff	
(unit 11b).....	69
3.4.5.4 Purple volcanic sandstones	
(unit 11c).....	70
3.4.6 Theban Member.....	71
3.4.6.1 Sub-volcanic feldspar porphyritic	
intrusives (unit 12 int).....	72
3.4.6.2 Volcanic conglomerate and	
siltstone (unit 12a).....	73
3.4.6.3 Pyroxene phyric andesite flows	
and pyroclastic flows (unit 12b)...	74
3.4.7 Quartz-feldspar welded chloritic	
lapilli tuff (unit 13).....	75
3.4.8 Purple lapilli tuff and volcanic	
sandstone (unit 14).....	76

3.4.9 Intrusive rocks.....	76
3.4.9.1 Black Lake stock.....	77
3.4.9.2 JK stock.....	77
3.4.9.3 Miscellaneous dikes.....	79
3.4.10 Alteration.....	79
3.4.10.1 Argillic alteration (i).....	80
3.4.10.2 Advanced argillic alteration (ii).....	81
3.4.10.3 Potassic alteration (iii).....	82

CHAPTER IV: GEOCHEMISTRY

4.1 Introduction.....	97
4.2 Results.....	100
4.2.1 Normative mineralogy.....	100
4.2.2 Major element geochemistry.....	109
4.2.3 Trace element geochemistry.....	111
4.3 Previous analytical work.....	114
4.4 Discussion.....	115

CHAPTER V: STRUCTURE

5.1 Introduction.....	133
5.2 Faults.....	134
5.2.1 Introduction.....	134

5.2.2 Microstructures of the Black Lake and Shasta Faults.....	136
5.3 Mineralized stockwork zones.....	141
5.3.1 Introduction.....	141
5.3.2 Geometry of the mineralized zones.....	142
5.3.3 Lithological controls on the stockwork zones.....	146
CHAPTER VI: SUMMARY AND CONCLUSIONS.....	158
REFERENCES.....	163

LIST OF FIGURES

FIGURE	DESCRIPTION	PAGE
1.1	Location Map, Map area is Figure 3.3.....	8
1.2	Location and access map.....	9
2.1	Terrane map of the Canadian Cordillera. Simplified from Wheeler and McFeely, 1987....	40
2.2	Distribution of the Hazelton Group in north- central British Columbia.....	41
2.3	Time-stratigraphic sections across the Hazelton Group in Stikinia.....	42
2.4	Schematic sections across the Hazelton arc system showing the distribution of volcanic and sedimentary facies.....	43
2.5	Four possible models for the development of the Hazelton arc system.....	44
2.6	Evolution of the Okinawa Trough from the Miocene to the present.....	45
2.7	Two possible scenarios for the Early Jurassic setting of Stikinia.....	46
3.1	Geology Map of the Toodoggone Area. Geology is after Daikow et al. (1985).....	83
3.2	Stratigraphic column for the Toodoggone area.....	84
3.3	Geology Map of the field area. Summarized from Map 1.....	85
3.4	Sections a-a'', b-b', Section locations on Figure 3.3.....	86
3.5	Geology of the Shasta property. Summarized from Map 2, based on 1:1,000 mapping and drillhole data.....	87
3.6	Sections A-A'', B-B''. See Figure 3.5 for section lines.....	88
3.7	Schematic section of facies relationships on the Shasta property.....	89

4.1	Total alkalis versus silica and K ₂ O versus silica diagrams for the study area....	122
4.2	Harker variation diagrams for some major elements.....	123
4.3	Harker variation diagrams for some trace elements.....	125
4.4	AFM diagram (Irvine and Baragar, 1971).....	127
4.5	Jensen Cation plot (Jensen, 1976) and a FeO*/MgO versus silica diagram (Miyashiro, 1974) for the study area.....	128
4.6	MORB normalized variation diagrams for selected units in the study area.....	129
4.7	Tectonic environment trace element diagrams from Pearce and Norry (1979) and Shervais (1982).....	131
4.8	Ti-V tectonic environment discrimination diagram from Shervais (1982).....	132
5.1	A. Equal angle stereogram of faults and slickensides associated with the Shasta fault. B. Equal angle stereogram of the Black Lake fault, associated joints and slip lineation.....	150
5.2	Geometric relationships between the P, Y and R1 surfaces in clay gouge as described by Logan et al., 1979 and Rutter et al., 1986...	151
5.3	A. Equal angle stereogram of poles to veins, joints and orientation of mineralized zones. B. Equal angle stereogram of the main mineralized zones.....	152
5.4	Geometry of the JM and Creek zone intersection.....	153

LIST OF PLATES

PLATE	DESCRIPTION	PAGE
3.1	Isolated pillow basalts of the Stuhini Group.....	90
3.2	Photomicrograph of amygdaloidal margin in pyroxene-feldspar phyric basalt.....	90
3.3	Contorted flow layering in dacite (unit 4a).....	91
3.4	Photomicrograph of dacite (unit 4a).....	91
3.5	Contrast between highly flattened lapilli in welded deposits (right side) and unwelded deposits with subrounded lapilli (unit 5)....	92
3.6	Photomicrograph of pyroclastic flow deposit (unit 5).	92
3.7	Laminated crystal ash tuffs. Subvertical dikes are degassing dikes.....	93
3.8	Photomicrograph of laminated crystal ash tuffs (unit 8).....	94
3.9	Nest of large spherulites(?).....	95
3.10	Highly fractured plagioclase in hot avalanche deposits of unit 9.....	95
3.11	Welding textures and resorbed quartz grain in Saunders ignimbrite (unit 11a).....	96
5.1	Black Lake Fault looking south.....	154
5.2	Shear fabric in the footwall zone of the Black Lake fault zone.....	155
5.3	Shear fabric in the Shasta fault zone.....	156
5.4	Shear fabric in the Shasta fault zone.....	157

LIST OF TABLES

TABLE	DESCRIPTION	PAGE
4.1	Whole Rock Geochemistry.....	101
4.2	Whole Rock Geochemistry Recalculated to 100%.....	104
4.3	Cation & Normative Mineralogy.....	107

LIST OF MAPS

MAP	DESCRIPTION
1	Geological setting of the Shasta property (in pocket).
2	Geology of the Shasta property (in pocket).

LIST OF APPENDICES

APPENDIX	DESCRIPTION	PAGE
I	Summary of petrography and sample locations.....	190
II	Whole rock sample descriptions.....	209
III	Analytical methods and controls.....	219

CHAPTER I INTRODUCTION

1.1 Purpose and methods of study

This thesis is a study of the geologic setting of the Shasta precious metal deposit in north-central British Columbia. The deposit is hosted by dacitic rocks which are units of the Toodoggone volcanic assemblage and form part of the Early Jurassic Hazelton Group. The results of five months of surface mapping and a compilation of diamond drilling by three exploration companies are synthesized into a model that describes the stratigraphic and structural setting of this precious metal stockwork deposit.

It became clear to the author during the course of the study that the tectonic setting of the Hazelton Group was poorly documented, so the scope of the project was expanded to include a synthesis of recent mapping in the Hazelton Group and the tectonic implications of the distribution of various depositional environments observed in the Hazelton rocks.

Chapter I describes the purpose of the thesis and details previous work in the Toodoggone area. Chapter II discusses the tectonic setting of the Hazelton Group. Chapters III and IV are a description of the physical nature, distribution and chemistry of the volcanic rocks exposed within the study area. Chapter V describes the

structural deformation affecting the distribution of these rocks, emphasizing the type of structure that localized precious metal bearing stockwork on the Shasta property. The principal characteristics of the deposit and the main factors that controlled the localization of the mineralization are summarized in Chapter VI.

The work is a contribution to our understanding of the Toodoggone volcanic succession and the genesis of epithermal precious metal deposits, especially the controls that lithology and brittle deformation exert on the localization of mineralized systems. This information can be used to facilitate mineral exploration both on the property and in the surrounding Toodoggone area.

The complex nature of intermediate to acidic volcanism precludes the establishment of a stratigraphy with laterally continuous units. Instead the stratigraphy is defined by grouping mineralogically similar rocks into units composed of genetically related deposits. Each unit may include a diverse array of rock types, representing different transport mechanisms. 1:10,000 scale mapping was used to delineate the position of the Shasta property within the Toodoggone volcanics (Map 1), but 1:1,000 mapping was required to recognize some of the abrupt lateral facies variations that characterize the property area (Map 2). The detailed mapping included the examination and correlation of all drill core obtained from 1983 through 1989. Drill hole

locations and geologic contacts and relationships inferred from drill data are shown on Map 2.

The results of the mapping were synthesized into a geological model by comparing the data with observations from modern volcanic environments and interpreting the geometry of the mineralized zones according to traditional structural theory. Field observations were supplemented with feldspar staining and petrographic work on 70 samples. Sample locations are indicated on Maps 1 and 2, their UTM co-ordinates are listed in Appendix I. Selected samples were analyzed for major and trace elements by X-ray fluorescence. Details of the analytical methods used and the results are discussed in Chapter IV.

1.2 Location, access and topography

The study area is in north-central British Columbia, approximately 300 kilometres north of Smithers (Figure 1.1). The Shasta deposit is accessed by a four-wheel drive road from the Sturdee airstrip, 9 kilometres west of the property, or from Fort St. James via the Cheni Mine Road (Figure 1.2).

The topography of the area is mountainous, but gentle. Moderate slopes lead from the valley bottoms at approximately 1200 metres to broad alpine meadows above 1500 metres. The alpine summits are jagged and rocky, offering

good exposure and relatively easy access along gentle ridges. The climate is drier than in the Coast Ranges and there are no glaciers in the map area. The snowpack is generally light, allowing fieldwork from early June to mid-October. The original forest in the Jock Creek valley was destroyed by a forest fire in the 1950's. The dry south facing slopes are regenerating near streams and seeps, but the rest of these slopes are largely open. North-facing slopes are now overgrown in dense alderbush below 1400 metres; above this elevation the open areas between the burnt pines are covered in a rich display of alpine flowers.

1.3 Previous work

1.3.1 The Toodoggone volcanic assemblage

The Toodoggone volcanic assemblage was informally defined by Carter (1972) who recognized a distinctive, quartz-phyric succession of volcanics within the Early to Middle Jurassic Hazelton Group along the eastern margin of the Bowser Basin. Gabrielse (1977) distinguished the Toodoggone volcanics from the Hazelton volcanics on a 1:250,000 map of the area but did little to further define the nature of either volcanic succession. Tipper and Richards (1976) summarized and interpreted the distribution of the Hazelton Group south and southwest of the Bowser

basin in the Telkwa, Babine, Bait and Sikanni Ranges but paid little attention to the rocks exposed along the eastern margin of the Bowser basin. Exploration companies started work in the area in the late 1960's and in 1969 Kennco discovered the Chapelle deposit. Further work between 1969 and 1974 led to the discovery of significant mineralization on the Chapelle and Lawyers properties. In 1980 DuPont opened the Chapelle (Baker) Mine. Recognition of the economic importance of the Toodoggone district by the British Columbia Ministry of Energy, Mines and Petroleum Resources led to systematic mapping by Schroeter (1981), Panteleyev (1982; 1983) and Daikow (1983; 1984) and subsequent publication of two 1:50,000 maps of the area (Daikow et al., 1985).

Potassium-argon and rubidium-strontium dates from the Toodoggone area have been published by Gabrielse et al. (1980), Daikow (1985) and Cann and Godwin (1980).

Foster (1984) presented petrographic descriptions and geochemical data for some of the Toodoggone volcanic rocks exposed south of the Toodoggone River. Daikow is currently working on a Ph.D. thesis at the University of Western Ontario on the entire Toodoggone succession, in which he will formally define the Toodoggone Formation and three important members (pers. comm, 1988).

1.3.2 The Shasta property

The Shasta property was discovered in 1972, but received little attention until 1984 when Newmont initiated a surface exploration and drilling program. Esso Minerals Canada optioned the property in 1987 and started an aggressive exploration program. By the end of 1988 extensive geological, geochemical and geophysical surveys and over 4000 metres of diamond drilling had delineated eleven mineralized zones and defined geological reserves of 537,000 tonnes of 8.7 grams per tonne gold equivalent (1 gram Au = 70 grams Ag) or 1.02 million tonnes of 5.7 grams Au equivalent per tonne with an average Au:Ag ratio of 1:48. Details of these programs and early descriptions of the property are available only as private company reports by Holbek and Holbek and Thiersch. The geology of the Jock Creek area was generalized in the map produced by Daikow et al. (1985) and Esso encouraged graduate students to work on more detailed mapping within the area and to study the mineralization on the property. Further support in the way of a research grant was offered by the BCMEMPR and this thesis project was initiated in the spring of 1988. Progress reports by Marsden and Moore were published in 1989 and 1990. A related thesis by Peter Thiersch, on the paragenesis and depositional controls of the mineralization, is in progress (Thiersch and Williams-Jones, 1990).

There have been few thesis or other detailed studies of the mineral deposits in the area. The Chapelle (Baker) deposit was described by Barr (1978) and Vulimiri et al. (1983) described the geologic setting and mineralogy of the Lawyers deposit (Cheni Mine). Clark and Williams-Jones have presented papers on the Verenass deposit near Alberts Hump and on age dating efforts in the Toodoggone camp (Clark and Williams-Jones, 1987).

Figure 1.1 : Location Map. Map area is Figure 3.3

Figure 1.2: Location and access map.

CHAPTER II TECTONIC SETTING

2.1 Introduction

The Toodoggone volcanic assemblage is part of the Hazelton Group which consists of Early to Middle Jurassic volcanic and sedimentary rocks exposed throughout northern British Columbia from Bella Coola to the B.C.-Yukon border (Figures 2.1 and 2.2), long established as a predominantly calc-alkaline island arc assemblage of rocks.

The tectonic setting of the Toodoggone volcanic assemblage has not yet been satisfactorily documented. Previous authors working in the area have not described the regional setting of the volcanic assemblage beyond noting that they are part of the Hazelton Group. Tipper and Richards (1976, p. 9) defined the Hazelton Group as "...an eugeosynclinal island-arc and sedimentary assemblage deposited within the Hazelton trough between Early Jurassic (Sinemurian) and Middle Jurassic (Lower Callovian) time." Tipper and Richards (1976) work is based on mapping to the south of the Toodoggone area (Figure 2.2) and they do not include Early to Middle Jurassic volcanic rocks exposed in the Toodoggone, Spatsizi, Telegraph Creek and Iskut River areas. Inclusion of these rocks into a synthesis of the Hazelton Group presents several problems with the simple island arc model as proposed Tipper and Richards (1976).

Unlike any single modern arc system, volcanic rocks of the Hazelton Group span an across arc width of 350 kilometres or greater and can be grouped into two volcanic chains and a central marine basin. The Toodoggone volcanic assemblage is an extensive (1750 km²) subaerial succession dominated by large-volume ignimbrite sheets, deposits characteristic of continental volcanism rather than island arcs.

This chapter presents a discussion of the tectonic implications inherent in the distribution of rock types in the Hazelton Group. This includes a survey of previous studies within the Hazelton Group and then a comparison of the distribution of rock types within the Hazelton Group to that of different depositional environments in modern arc systems. Results of this comparison suggests that the Hazelton Group was emplaced either in a subaerial back-arc setting or as a mature arc above a west-dipping subduction zone.

2.2 Regional Framework

The Early to Middle Jurassic volcanic and sedimentary rocks of the Hazelton Group are exposed in the western Canadian Cordillera of north-central British Columbia (Figures 2.1, 2.2). West of the Rocky Mountain Fold and Thrust Belt, the Canadian Cordillera is composed of numerous suspect terranes (Monger, 1984). Some of these, such as the

Monashee terrane, may be inliers of attenuated North American basement (Parrish and Ross, 1990). Others, such as the Kootenay terrane, are considered to be parautochthonous, pericratonic rocks (Monger and Berg, 1987). In contrast, many of the suspect terranes have oceanic rather than continental characteristics. These terranes, which include Quesnellia, Stikinia and Wrangellia represent, at least in part, Late Paleozoic to Mesozoic island arc terranes. As each terrane is fault bounded, the original distribution of these terranes is not clear. Paleomagnetic and faunal evidence (Monger and Irving, 1980) suggest that some of these terranes spent part of their histories at more southerly latitudes and have since been displaced northwards. Monger (1984) proposed that these suspect terranes can be grouped into two superterranes that were amalgamated and then accreted to North America along sutures within the Coast and Omineca metamorphic and plutonic belts. The timing of accretion is partially recorded by post-accretionary overlap assemblages.

The Jurassic Hazelton Group is the youngest pre-accretionary volcanic and sedimentary assemblage in Stikinia, part of the eastern composite superterrane (Intermontane Superterrane; Monger et al., 1982). This superterrane is composed of the Kootenay, Slide Mountain, Quesnel, Cache Creek and Stikine Terranes (Figure 2.1). As each terrane is fault-bounded, the original distribution of

these tectonic fragments is not clear, but the timing of collisions between tectonic fragments is partially recorded by overlapping sedimentary basins and the age of various thrust faults. Monger (1984) has suggested that the Cache Creek and Quesnel terranes were together by the Late Triassic and were accreted to North America by the Early Jurassic when parts of the Slide Mountain terrane were emplaced onto the North American continental margin. Stikinia and Cache Creek were amalgamated by the Middle Jurassic when rocks of the King Salmon Assemblage and the Cache Creek Group were thrust southwesterly over Stikinia along the King Salmon fault (Figure 2.2).

Stikinia is the largest and most continuous of the suspect terranes, extending from southern British Columbia to the southern Yukon. In northern British Columbia it reaches its maximum width of 350 kilometres, spanning most of the Intermontane Superterrane. Its oldest rocks, the Stikine assemblage, comprise Devonian and upper Paleozoic volcanic and sedimentary strata (Gunning, 1990). However, this assemblage is rather poorly exposed, and Stikinia is more commonly characterized by younger and more widely distributed volcanic and sedimentary rocks of the Late Triassic Stuhini and Lewes River Groups. (Monger and Church, 1977; Anderson and Thorkelson, 1990; Templeman-Kluit, 1979).

The Cache Creek terrane is juxtaposed against much of the east margin of Stikinia. Although parts of Stikinia are

juxtaposed against Cache Creek along major dextral strike slip faults (Gabrielse, 1985) it is generally considered that Cache Creek represents the remnants of an ocean basin (Monger, 1974; Thorstad and Gabrielse, 1986) that separated Stikinia from more inboard regions. Although Monger (1984) cited stratigraphic similarities between Upper Triassic sedimentary rocks on both terranes as evidence for possible Late Triassic amalgamation, other authors (Thorstad and Gabrielse, 1986; Cordey et al., 1987) have presented evidence that the Cache Creek ocean may not have closed until late Early or Middle Jurassic time.

In southern and central British Columbia, the poorly defined margin of Stikinia apparently lies within plutonic and metamorphic rocks of the Coast Plutonic Complex; contact relations with the Insular Superterrane are unclear. Van der Heyden (1990) has suggested that rocks along the western margin of Stikinia were involved in east-vergent thrusting during the Late Jurassic and have been modified by Tertiary extension. In northern British Columbia and the Yukon, recent studies (Hart and Radloff, Mihalynuk and Mountjoy, 1990) have suggested that Stikinia and rocks of the Nisling terrane (Currie, 1990) were juxtaposed in the latest Triassic. Nisling terrane is characterized by rocks of continental character that have yielded Paleozoic dates but may include older rocks (Hansen, 1990; Currie, pers. comm.). Its field relations with Stikinia could be the result of

Late Triassic amalgamation with Stikinia, or Nisling could be a deeper part of the Stikine terrane juxtaposed against higher structural levels (Stuhini-Laberge Groups) along the Tally-Ho shear zone and Llellwyn fault.

The Early Jurassic to Cretaceous history of Stikinia is easier to decipher. Early Jurassic volcanic and sedimentary rocks of the Hazelton Group record subduction beneath the west and possibly east margins of Stikinia. The distribution of the Hazelton Group is partially obscured by a large sedimentary basin, the Bowser Basin. The basin is filled with Middle Jurassic to Upper Cretaceous sediments of the Bowser and Sustut Groups. Conglomerates bearing chert clasts derived from the Cache Creek terrane (Currie, 1984) record the final stages of accretion as the Paleozoic to Jurassic island arc systems of Stikinia were accreted to the continental margin, and rocks from the Cache Creek Ocean were thrust southwestward over Stikinia.

Models for the amalgamation and accretion of the North American Cordillera cannot be based solely on overlapping stratigraphy but instead, must incorporate data relating to the Mesozoic tectonic geometry of Stikinia that eventually led to the accretion of Stikinia to more inboard terranes. The rest of this chapter develops two possible models for the Early Jurassic tectonic setting of Stikinia that persisted until obduction of Cache Creek onto Stikinia.

2.3 Geology of the Hazelton Group

For the following discussion of the distribution of rock types within the Hazelton Group in northern British Columbia, the reader is referred to Figures 2.2 and 2.3, a generalized geology map of northern B.C. and time-stratigraphic sections across northern Stikinia. Localities discussed in the text refer to map areas (Smithers area, Spatsizi area, etc.. .) indicated on Figure 2.2. Individual formations, members and facies are labelled on Figure 2.3. The discussion starts with a definition of the Hazelton Group followed by a review of relationships in the southern part of the belt, in the Smithers, Hazelton, McConnell Creek and Whitesail Lake areas and then in the Iskut River, Telegraph Creek, Cry Lake, Spatsizi and Toodoggone areas.

The Hazelton Group has been defined best by Tipper and Richards (1976) who redefined the Hazelton Group as "...basaltic to rhyolitic volcanic rocks, sedimentary rocks, their tuffaceous equivalents, and minor limestone that were deposited in Early and Middle Jurassic time". Since then, most geologists working in northern British Columbia have adopted that terminology. In the rest of this paper I will use the Hazelton Group to describe all Lower to Middle Jurassic and related sedimentary rocks of Stikinia. This definition includes proximal and basinal sedimentary equivalents of the volcanic successions, but excludes rocks

of contrasting depositional regimes. Under this definition, a sedimentary succession in the Spatsizi that overlies and interfingers with the Early Jurassic Coldfish volcanics (Thorkelson, 1988), and was formally named the Spatsizi Group by Thompson et al. (1986), is included with the Hazelton Group. The name Spatsizi Group should be abandoned. Excluded under the above definition is the Takwahoni Formation, a sedimentary succession deposited north of the Stikine River (Souther, 1971; Bultman, 1979) that lacks extensive volcanic equivalents.

The Hazelton Group unconformably overlies volcanic, sedimentary and plutonic rocks of the Late Triassic Stuhini Group. The basal sequence usually consists of a section of clastic rocks with prominent conglomerates that contain variable amounts of granitoid, limestone and chert clasts in addition to ubiquitous Stuhini Group fragments. The conglomerates have been interpreted as being of Triassic age (Mihalynuk, 1987), Hettangian age (Grove, 1986) and of Sinemurian age (Tipper and Richards, 1976). They are clearly post-Norian and pre-Upper Sinemurian and indicate uplift and erosion before Early Jurassic volcanism.

The following review of the Early Jurassic stratigraphy in northern British Columbia starts with a section across the southern part of the Bowser basin previously described by Tipper and Richards (1976) and then continues clockwise around the perimeter of the Bowser Basin.

Smithers, Hazelton and McConnell Creek areas

Tipper and Richards (1976) recognized three formations within the Hazelton Group, where exposed along the southern edge of the Bowser Basin. These formations are defined on the basis of paleontological ages; the Telkwa Formation is of Sinemurian to lower Pliensbachian age, the Nilkitwa Formation is of lower Pliensbachian to Middle Toarcian age and the Smithers Formation is of late Toarcian to Callovian age. Each of these formations contains a number of facies with very different rock types. The most striking east-west variations are in the Telkwa Formation.

Immediately east of the Coast Plutonic Complex, in the Smithers area, the Telkwa Formation is composed of subaerial basalt to rhyolite of the Howson facies. These rocks grade eastward into the Babine facies where both marine and subaerial volcanics are associated with marine sediments and reefal limestone. In the Hazelton area, the Telkwa Formation is represented by the Kotsine facies, an entirely marine succession of basalts, tuffaceous shale and greywacke over 1500 metres thick.

East of the Kotsine facies, in the McConnell Creek area, is the Bear Lake facies, a second predominantly subaerial facies with basalt to rhyolite similar to the Howson facies. The easternmost Sikanni facies is a subaerial to shallow marine accumulation of conglomeratic and volcanoclastic rocks.

In early Pliensbachian time, the voluminous and widespread volcanism of the Telkwa Formation was succeeded by more restricted and predominantly marine strata of the Nilkitwa Formation. Sedimentary deposition was concentrated in the Nilkitwa depression, a marine trough inherited from the Kotsine facies of the Telkwa Formation (Hazelton area). Within the depression two units of mafic lava were erupted: The upper Pliensbachian to lower Toarcian Carruthers Member and the middle Toarcian Ankwel Member. To the southwest, after a Pliensbachian and early Toarcian hiatus, subaerial deposition in the Smithers area resumed with eruption of the volcanic Red Tuff Member

In the middle to late Toarcian, following Red Tuff and Ankwel activity, emplacement of proximal volcanic rocks ceased and deposition of the Smithers Formation began. Smithers deposition was dominated by marine siltstone and sandstone, some units showing tuffaceous character. Sedimentation transgressed from the Nilkitwa depression to the southwest over the previously terrestrial parts of the Nilkitwa and Telkwa rocks. By late Bajocian time, a shallow sea had been established everywhere in the Smithers-Hazelton area.

Whitesail Lake-Nechako areas

In the Whitesail Lake area, south of the Smithers area, Hazelton-age rocks have been correlated with the Telkwa and

Smithers formations (Daikow and Mihalynuk, 1987; Daikow and Koyanagi, 1988). Like the Howson facies, the Telkwa correlatives in the Whitesail Lake area are subaerially deposited, basaltic to rhyolitic lava and pyroclastic rocks. The rocks correlated with the Smithers Formation differ from those in the type area by the presence of Aalenian to early Bajocian volcanic members.

East of the Whitesail Lake area in the Nechako region, Tipper (1979) showed that the Hazelton Group consists of two broad units. The lower unit comprises chert bearing clastic rocks, interbedded with andesitic to basaltic lava and pyroclastic rocks. The upper unit is a generally marine sequence of rhyolitic to basaltic volcanic rocks intercalated with middle Bajocian sedimentary rocks.

Iskut River-Telegraph Creek areas

North of Smithers, in the Stewart area, mapping by Grove (1986) is being revised (Alldrick, 1987, Britton and Alldrick, 1988; Anderson and Thorkelson, 1990). The nomenclature outlined by Grove (1986) has not been changed but the age range of each formation is still being refined. A basal section of marine clastic rocks, the Lower Unuk River Formation, has yielded Hettangian to Sinemurian fossils (Grove, 1986). The Upper Unuk River Formation, comprising interbedded andesitic flows, sedimentary and

intrusive rocks is of Sinemurian to Pliensbachian age, based both on isotopic dating of the Premier porphyry and paleontological collections. U-Pb zircon dates from the Premier porphyry indicate ages from 195 ± 2.0 Ma. (Alldrick et al, 1987) to 190 ± 2 Ma. (Brown, 1987). These rocks are overlain by the predominantly subaerial Betty Creek Formation. This formation includes andesitic to dacitic volcanic and epiclastic deposits of probable Pliensbachian age. The Mt. Dilworth Formation, a thin but extensive felsic ash flow member, is either of Pliensbachian (Anderson and Thorkelson, 1990) or Toarcian age (Britton and Alldrick, 1988). The most widespread unit in the area is the Salmon River Formation. The formation is dominated by shallow marine sandstone, siltstone and greywacke of Bajocian age but north of Stewart, near the Iskut River, there are profound lateral facies variations with local volcanic units. Lefebvre and Gunning (1989) mapped a sequence of Toarcian sedimentary rocks that are overlain by andesitic volcanic rocks of probable Bajocian age in the Snippaker Mountain area, described later as the Snippaker Mountain facies by Anderson and Thorkelson (1990). To the east the Bajocian section is dominated by marine basalts and interbedded marine sediments and limestones of the Eskay Creek facies, and in the Bowser River map-area the section is dominated by turbiditic tuffs and radiolarian shale of the Troy Ridge facies similar to the Quock Formation of the

Spatsizi Group (Anderson and Thorkelson, 1990).

Further northeast, in the Telegraph Creek map-sheet, Souther (1971) mapped an entirely marine section similar to the marine basalts described by Anderson and Thorkelson (1990) in the eastern Iskut River area. The section includes Hettangian to Toarcian marine sediments and fragmental basalts, Upper Toarcian to Bajocian clastic rocks and over 2000 metres of marine basalt of Bajocian age.

In northwestern Telegraph Creek map-area Brown et al. (1990) mapped a sequence of four Hazelton Group units with strong similarities to the strata in the Iskut River area. Subaerial to marine intermediate to felsic volcanics rocks are associated with sediments bearing Toarcian and Bajocian fossils, suggesting parallels with the Snippaker Mtn. facies in the northern Iskut River area.

Spatsizi and Cry Lake areas

The Hazelton Group is also well exposed along the northwestern margin of the Bowser Basin. Lower to Middle Jurassic sedimentary strata exposed in the Spatsizi area were defined as the Spatsizi Group by Thomson et al. (1986) and they interfinger with the Cold Fish volcanics (Thorkelson, 1988) to the east. Further work has shown that there are three volcanic successions of Sinemurian, Lower Pliensbachian and Toarcian age. The (?) Sinemurian succession consists of mafic and intermediate volcanic rocks

(Thorkelson and Mortensen, unpublished data) that includes biotite bearing ignimbrite similar to those in the Toodoggone area. The Pliensbachian succession comprises bimodal volcanic rocks, limestone and basinal epiclastic strata. The volcanic pile, known informally as the Coldfish formation, is predominantly subaerial and consists of mafic and felsic flows, airfall and ashflow tuffs. The volcanics are conformably overlain by Pliensbachian to Bajocian sediments defined as the Spatsizi Group by Thompson et al. (1986). The conformable to interfingering relationship with underlying volcanics suggests that the term Spatsizi Group should be abandoned or changed to formation status. In the northwestern part of the Spatsizi area Read and Psutka (1990) have mapped volcanics intercalated with Toarcian sedimentary rocks. The volcanics are subaerially deposited trachyandesite lava flows and ashflow tuffs (Thorkelson, pers. comm., 1990).

In the Cry Lake area, north of Spatsizi, the Hazelton Group comprises sedimentary and volcanic rocks of Sinemurian, lower Toarcian and Bajocian age. The Sinemurian section consists of conglomerate with volcanic, granitic, chert and limestone clasts. The Toarcian rocks include intercalated subaerial rhyolitic rocks and marine sediments. The Bajocian section consists of conglomeratic deposits and andesitic breccia.

Toodoggone area

South of the Spatsizi area, Carter (1972) and Gabrielse (1977) mapped a sequence of Jurassic volcanics in the Toodoggone area. Carter (1972) divided the volcanics into a western felsic succession (the Toodoggone volcanics) and an eastern intermediate facies. The western facies has been mapped recently (Daikow et al., 1985) and appears to consist of three laterally extensive members and a number of complex, local volcanic centres. The succession is entirely subaerial and there is no evidence that the marine transgressions that deposited sediments in the Smithers, Hazelton, Iskut River and Spatsizi map-areas affected the Toodoggone area. The Toodoggone volcanics span the Sinemurian and extend as far as the Toarcian and possibly the Bajocian. K-Ar dates from the Addoogatcho Creek and Metsantan members cluster in the Sinemurian and earliest Pliensbachian. A K-Ar sample from a local volcanic centre in the Finlay River area gave a Late Toarcian date. The Saunders Member, a large ignimbrite, has yielded several earliest Bajocian K-Ar dates (Gabrielse et al., 1980; Daikow, 1985). These rocks are overlain by intermediate volcanics of possible Bajocian age (Marsden and Moore, 1990) and Tipper (1976) reported a Bajocian fossil locality from the Toodoggone area.

2.4 Distribution of facies within the Hazelton Group

The distribution of the rock types described above is summarized in a series of time stratigraphic sections across Stikinia in northern British Columbia (Figure 2.3). These can be grouped into three consistent facies that extend northwesterly along the structural grain of the Cordillera. Figure 2.4 is a series of schematic sections that show how these three facies evolved from the Sinemurian to the Bajocian. The western arc facies includes rocks of the Howson and Babine facies in the Smithers area, and rocks exposed in the Iskut River-Telegraph Creek areas to the north. The Howson and Babine facies are dominantly subaerial in the west and become progressively more marine with emergent volcanic edifices and reefal limestone in the Babine Ranges. Similar facies are present in Bajocian rocks of the Salmon River Formation (Iskut River area), while older rocks in this area record the development of an emergent intermediate to felsic volcanic arc in the Pliensbachian. In the Toarcian, the Smithers area remained as a topographic high and was the site of deposition of the predominantly subaerial Red Tuff Member of the Nilkitwa Formation.

The central basin facies in the Hazelton is an entirely marine facies that includes the Kotsine facies of the Telkwa Formation and the central marine facies of the Nilkitwa

Formation. The Nilkitwa Formation is more extensive than the Kotsine facies suggesting considerable marine transgression over the western parts of the Hazelton trough during the Toarcian. This area was still a marine trough in the Bajocian when the Bait Member accumulated in deeper water conditions than adjacent parts of the Smithers Formation. Further north the sections mapped by Souther (1971) in the Telegraph Creek map-area and by Anderson and Thorkelson (1990) in the Bowser River area are also entirely marine although they lack evidence for abundant Toarcian volcanism, instead the dominant local volcanic episode occurred in the Bajocian.

The eastern volcanic facies includes the predominantly subaerial Bear Lake and Sikanni facies of the Telkwa Formation, the volcanics in the Spatsizi area and the Toodoggone volcanics. This facies includes basaltic to felsic volcanics erupted in a variably shallow marine to subaerial setting (Bear Lake, Cold Fish volcanics) or entirely subaerial setting (Toodoggone volcanics) further east.

These three facies define a marine arc edifice on the west, a marine trough in the middle and a subaerial volcanic belt on the east (Figure 2.3, 2.4). Both the eastern and western volcanic facies were intermittently emergent and volcanically active in Sinemurian, Pliensbachian, Toarcian and Bajocian time, whereas the central trough remained

submergent for most of the Early and Middle Jurassic. Only briefly, at the top of the Carruthers Member, did subaerial conditions occur. In general, the sedimentary rocks in the trough are more shaly than those of the eastern and western facies. To convey that this basin was flanked to the east and west by shallower water and subaerial facies, Tipper and Richards (1976) used the term Hazelton trough.

The western arc facies persistently grades from subaerial volcanic facies in the west to deeper water facies on the east (Babine facies, Stewart area and Troy ridge facies in the Iskut River area). This stable marine basin is clearly not an accretionary prism east of the western volcanic chain. The western volcanic chain developed above an east dipping subduction zone.

The eastern arc facies may also grade from an entirely subaerial setting in the Toodoggone area to transitionally marine environments further west in the Spatsizi and McConnell Creek areas.

The ages of the volcanic rocks suggest that there are three main episodes of volcanism. The earliest episode of volcanism was the most widespread; Sinemurian to earliest Pliensbachian eruptive rocks dominate the Telkwa Formation and the Toodoggone volcanics, and Pliensbachian volcanics occur in the Iskut River and Spatsizi areas further north. Toarcian volcanism was much more local, volcanic rocks occurring only in the Smithers, Whitesail Lake, northern

Spatsizi and Toodoggone areas. Bajocian volcanism is recorded in the Whitesail Lake, Iskut River-Telegraph Creek and Toodoggone (?) areas. The waning of volcanism is synchronous with marine transgressions. In late Pliensbachian to Toarcian time marine conditions prevailed in the central basin but subaerial volcanics were erupted in parts of the Smithers area. During the Bajocian, marine rocks were emplaced over the entire map-area except in the Snippaker Mountain (Iskut River) and Toodoggone areas, where subaerial volcanics are exposed. Deeper water facies are exposed in the central basin in the Hazelton area and marine volcanic and sedimentary rocks dominate in the eastern Telegraph Creek Iskut River and Bowser River areas.

The western and eastern arc facies define two volcanic chains that are currently 350 kilometres apart. The amount of extension that occurred during the Early to Middle Jurassic is likely to have been modest; no sheeted dike complexes, large areas of marine basalt, or other indicators of significant extension have been reported. Subsequent shortening of the Hazelton and the overlying sediments in the Bowser Basin has been well documented by Evenchick (in prep.) who estimates an average of 44% shortening across the Bowser Basin, thus the across-trough width of 350 kilometres is a minimum trough width and the two volcanic chains were probably at least 400-450 kilometres apart during the Early Jurassic.

2.5 Comparison with modern arc systems

The most intriguing aspect of the Hazelton arc system is the presence of two subaerial volcanic chains that are a minimum of 350 kilometres apart. Gill (1981) listed the widths of modern arc systems: there are no island arcs over 150 kilometres wide and most of them are less than 50 kilometres wide. Continental arc systems are somewhat wider than island arcs, reaching widths of up to 250 kilometres in the Andes and the Kamchatka Peninsula. These widths represent the distance from the magmatic front to the last volcano in the back-arc area, and volcanism is strongly concentrated in the first 50 kilometres of most arcs. The Kamchatka arc is concentrated into two volcanic chains but, unlike the Hazelton system, the central non-volcanic portion is an axial high, not a trough, and the two chains cover an across-arc width of only 250 kilometres (Hanus and Vanek, 1988).

These observations contrast with the Hazelton arc system. The western volcanic chain, considered alone, has all the characteristics of a single island arc system developed above a east dipping subduction zone. The main magmatic arc is less than 100 kilometres wide and grades into an entirely marine back-arc basin over 150 kilometres wide. What then is the origin of the eastern volcanic chain exposed in the McConnell Creek, Toadoggone and Spatsizi

areas?

An examination of the data on modern arc systems indicate that there are four tectonic settings that could result in a geometry similar to that of the Hazelton trough (Figure 2.5).

(1) An island arc and remnant arc with an intra-arc basin.

(2) Two parallel subduction zones.

(3) An anomalously wide arc related to progressive shallowing of a subducting slab.

(4) An island arc and continental back-arc.

Only the second and fourth examples are consistent with all the features described earlier.

The distribution of volcanic rocks into two volcanic chains is similar to modern arc-back arc systems like the Mariana, West Mariana and Palau-Kyushu arc-remnant arcs. These systems develop when the arc has rifted and part of the original arc migrates away from the active arc system as a result of seafloor spreading in the new back-arc area. This cannot be applied to the Hazelton Trough because in all modern cases the remnant arc is an inactive, subsiding arc whereas both the eastern and western volcanic chains of the Hazelton Group were active throughout a 20 Ma span in the Early Jurassic and the intervening marine basin is as old as both volcanic chains. If the two volcanic chains were formed from two subduction zones and the Telkwa-Stewart chain is a

result of east dipping subduction, then there must have been either a pair of east dipping zones or two inward dipping subduction zones (Figure 2.5). The first possibility is precluded by the absence of an accretionary prism west of the eastern volcanic chain, but the distribution of facies in the Hazelton Group is consistent with two inward dipping subduction zones. The Caribbean is an example of a region with inward dipping subduction zones that both have an active magmatic arc. The Cocos plate is subducting beneath the Central American volcanic chain and the Atlantic plate is subducting beneath the Antilles chain (Brown, 1976). However, these two arcs are over 2,000 kilometres apart, not 350 kilometres like the two volcanic chains in the Hazelton. This model cannot be rejected, as we do not know how far apart the two volcanic chains were originally nor the plate configuration during the Early Jurassic. Although a major fault zone has not been recognized within the Nilkitwa trough, it is also possible that two oppositely dipping systems were separated by a strike slip transform (similar to the Alpine Fault in New Zealand) and were juxtaposed during subsequent accretion. Such a model cannot be favoured because there is no evidence for a large strike-slip system within the central trough facies.

The problem of anomalously wide arc systems has plagued North American geologists since the 1960's when geologists working in the western United States recognized that

intermediate to felsic volcanic rocks were exposed across a width of 1,500 kilometres (for a review see Hamilton, 1988). Mesozoic and Cenozoic arc rocks extend the length of the American Cordillera and extend across widths of 500 kilometres in the Andes. James (1971) and Thorpe et al. (1982) noted that the width of the Andean arc is a result of eastward migration of the magmatic front since Early Jurassic time. Coney and Reynolds (1977) presented some geochronology of volcanic rocks in the western United States and concluded that volcanism migrated eastward from 120 Ma to 45 Ma and then returned westward from 45 to 20 Ma present. They interpreted this migration to indicate gradual shallowing of the subducting slab and eventual slab collapse. This model may be partially correct, but the recent recognition of the importance of extensional tectonics in the western States has led some authors to suggest that the large volcanic fields in Colorado are not related to subduction but to asthenospheric upwelling during extension (Gans et al., 1989). There is no evidence for east-west spatial migration of volcanism through time within the Hazelton Group; therefore changes of slab dip cannot be used to help explain the observed 350 kilometre arc width.

This leaves us with the continental back-arc model as a possible analogy for the Hazelton Group. Most island arc systems are characterized by a variably developed extensional back-arc area (Karig, 1972). Compressional arcs

developing in continental areas may also have a back-arc region. The Southern Volcanic zone in the Andes has extensive plateau basalts behind the main calc-alkaline arc (Munoz and Stern, 1989) and the Tonga-Kermadec arc and the Lau-Havre basin extends onto the New Zealand continental fragment. The arc is manifested in New Zealand as a chain of andesitic volcanoes and the back arc as a large volcanically active graben, the Taupo volcanic zone. Geodetic surveys conducted over a seventy year period show that the area is extending at a rate of 7 ± 4 mm per year and is marked by thin crust, low upper mantle seismic velocities and anomalously high heat flow, all characteristics of back-arc spreading (Cole, 1982; Stern, 1985).

The New Zealand example cannot be used as a direct analogue for the Hazelton system. The New Zealand arc is entirely continental and is located on the immediate edge of the back-arc, and the entire volcanically active area is only 100 kilometres wide. However, the idea can be expanded to other modern back-arc systems. Some back arcs are well developed with 1,000's of kilometres of new oceanic crust distributed around a central spreading centre (for examples, see Karig, 1971). Other back-arcs are less well developed; the conditions that initiate and favour back-arc spreading are not understood and appear to be more complex than the controls on the development of magmatic arcs. Consequently, the width and the locus of spreading in back-arcs is

variable. Some back-arcs develop for several millions of years and then collapse as a response to changes in the subduction vector (Dalziel, 1981). The Okinawa Trough is a modern example of a back arc that has developed in rifted continental crust (Letouzey and Kinimura, 1985). A magmatic arc developed on the margin of the Asian continent in the Oligocene followed by Late Miocene rifting of continental and arc rocks and consequent eastward migration of the active Ryuku arc (Figure 2.6). The basin is currently growing by the creation of new crust along numerous small, offset spreading segments. The Ryuku arc terminates to the south in Taiwan where the Luzon island arc is colliding with the end of the Ryuku arc. This collision has uplifted the area around Taiwan, and Letouzey and Kinimura (1985) propose that indentation of the Luzon arc is resulting in the propagation of faults and extension behind the Ryuku arc. They also indicate that the Miocene volcanic episode was unusually widespread during the initiation of back-arc rifting. The Hazelton trough could be an example of an arc-intra arc-back arc system that only developed to the initial stages of rifting, something between the New Zealand and Okinawa Trough examples cited above.

2.6 Discussion

These observations have some impact on the

interpretation of the tectonics of northern British Columbia. The northern end of the Bowser basin is marked by a roughly east-west trending axial high exposing Late Paleozoic basement rocks and Mesozoic intrusive rocks. This structure has been described as the Stikine arch and is believed to have been an erosional highland both in the latest Triassic (Anderson, 1978) and in the Early Jurassic when sediments were shed northwards into the Whitehorse Trough (Bultman, 1979). The arch is flanked to the northeast by proximal marine sediments of Pliensbachian age (Takwahoni Formation, Tipper, 1978) and correlative rocks of the Laberge Formation (Mihalynuk and Mountjoy, 1990; Hart and Radloff, 1990) further to the north. There is only one reported occurrence of Jurassic volcanics north of the 58th parallel in the Whitehorse trough (Hart and Radloff, 1990). Age correlative rocks of the Laberge Group are entirely sedimentary and observations by Tempelman-Kluit (1978) in the southern Yukon (Laberge map-area) suggest that the Laberge Group represents erosion of a Late Triassic arc, the Lewes River Arc. The Early Jurassic arc-trough-arc geometry described earlier does not extend north of the 58th parallel and the Stikine arch marked a change in the Early Jurassic plate geometry, separating an area of subduction and volcanism from a linear sedimentary basin with little or no volcanic input.

Tempelman-Kluit (1979) has used his arc-forearc

interpretation of the Lewes River and Laberge Groups to suggest that the Cache Creek is a accretionary complex developed by west dipping subduction beneath northern Stikinia. This is supported by presence of eclogite in the Teslin suture and Triassic blueschist in Cache Creek Group rocks exposed to the south (Paterson and Harakal, 1974), although in the absence of evidence concerning the structural vergence in Cache Creek Group rocks, these lines of evidence could equally support the argument that the Cache Creek was a subduction complex for Quesnellia. The Cache Creek is most likely an amalgamation of oppositely dipping accretionary prisms analogous to those resulting from collision currently in progress in the Molluca sea (Silver, 1978).

The end of Hazelton volcanism coincided with the obduction of the Cache Creek terrane. The youngest volcanics in the Hazelton Group are of Bajocian age and the youngest sediments involved in deformation beneath the King Salmon fault are also of Bajocian age. Deformational structures beneath the King Salmon fault are crosscut by 160 Ma (Thorstad and Gabrielse, 1986) and possibly older plutons (Gabrielse, in prep.). The earliest deposits shed from the Cache Creek are of Callovian or Oxfordian age (Evenchick, in prep.).

The combination of these observations suggests one of two possible scenarios (Figure 2.7). Subduction of unknown

polarity during the Late Triassic resulted in eruption of arc related rocks of the Lewes River and Stuhini Groups on the west side of an oceanic basin (Cache Creek). By the latest Triassic subduction had ceased and the Cache Creek Ocean was largely closed. In the Early Jurassic, subduction renewed as either: (1) Subduction initiated west of the Stikine landmass during the Sinemurian. The resultant volcanism built a shallow marine arc along the western margin of the landmass and back-arc volcanics were erupted in local extensional basins both in the marine and subaerial back-arc areas, or (2) the Cache Creek ocean continued to subduct westward beneath Stikinia until the Early Bajocian, building a mature arc in the eastern volcanic chain while the western volcanic chain developed above a subduction zone dipping eastward beneath Stikinia. This latter model is favoured because of the coincidence between overthrusting of Cache Creek and the end of volcanism as well as the arc-type chemical character of the Toadogone volcanics (see Chapter 4).

The origin of the Stikine arch and the Whitehorse trough is enigmatic. Clearly the plate geometry that controlled the evolution of the Hazelton Group did not extend north of the 58th parallel (present coordinates). Clast types and environmental indicators generally suggest that the sediments in the Whitehorse trough were shed from an eroding highland to the west (Bultman, 1979; Hart and

Radloff, 1990). Possible explanations for the change in geometry include: (1) a simple change in the orientation of the plate boundaries and plate vectors north of the Stikine arch resulting in predominantly strike slip boundaries adjacent the Whitehorse trough, and (2) a Late Triassic to Early Jurassic collision between Stikinia and Nisling terrane. Hart and Radloff (1990) suggest that Nisling and Stikinia were juxtaposed across the Tally Ho shear zone by the latest Triassic and Mihalynuk and Mountjoy (1990) report Jurassic sediments resting unconformably on rocks of the Nisling terrane. Currie (pers. comm., 1990) can demonstrate post Early Jurassic deformation within Nisling terrane. These relationships imply that Nisling and Stikinia were juxtaposed by the Late Triassic to Early Jurassic, but do not help decide if Stikinia and Nisling are two amalgamated terranes or upper and lower parts of the same terrane respectively.

By the late Bajocian and early C llovian the entire composite landmass including Slide Mountain, Quesnellia, Cache Creek and Stikinia had been sutured to the North American margin and large basins developed in the foreland of the newly accreted terranes. Deposition in the Bowser and Tantalus basins records erosion of uplifted areas to the east; chert clasts derived from the Triassic Cache Creek Group deposited in shallow marine to subaerial alluvial fans (Eisbacher, 1981; Currie, 1984). The Bowser basin developed

immediately on top of the basinal facies of the Hazelton Group.

Understanding the accretionary processes that built the western Canadian Cordillera may require the conception of processes much more complex than the progressive accretion of continuous linear belts 1000 kilometres long to a linear margin. The Western Pacific is a clear modern analog for the development of subduction along a previously passive continental margin. The processes in this region are very complex and yet offer us many insights into the types of collision and rifting processes that may have built the Canadian Cordillera. Composite landmasses develop from the amalgamation of numerous island arc systems and these masses are separated from the mainland by continually evolving and collapsing marginal basins. The accretion of such a complex to a continental margin is a long-lived and continuous process that overprints time-transgressive structures on top of earlier, more localized rifting and collisional events.

Figure 2.1: Terrane map of the Canadian Cordillera. Simplified from Wheeler and McFeely (1987).

Figure 2.3: Time-stratigraphic sections across the Hazelton Group in Stikinia. Legend for inset map is the same as Figure 2.2.

SINPAURIAN TO PLIENSBACHIAN (194-193 Ma)

PLIENSBACHIAN TO TOARCIAN (198-187 Ma.)

BAJOCIAN (183-176 Ma.)

0 50 100 kilometres

Figure 2.4: Schematic sections across the Hazelton arc system showing the distribution of volcanic and sedimentary facies at three time intervals.

Figure 2.5: Four possible models for the development of the Hazelton arc system. See text for a complete discussion.

Figure 2.6: Evolution of the Okinawa Trough from the Miocene to the present. The Hazelton system may be analogous except that it failed to evolve past the rifting initiation stage. From Letouzey and Kinimura (1985).

Figure 2.7: Two possible scenarios for the Early Jurassic tectonic setting of Stikinia. The geometry of the Late Triassic subduction is largely unconstrained, see text for a full discussion of the two models. Orientation of the terrane on the page does not imply a north-south orientation for Stikinia in the Jurassic.

CHAPTER III STRATIGRAPHY OF THE TOODOGGONE AREA

3.1 Introduction

The geology of the Toodoggone area is displayed in Figure 3.1 and Figure 3.3 is a generalized map of the study area (see Map 1 for more detail). The local facies observed on the Shasta property were mapped at 1:1,000 scale (Figure 3.6. Map 2) and are summarized in a schematic section of the main property area (Figure 3.7).

The unit descriptions are based on field observations and the petrographic study of 64 thin sections. Appendix I summarizes the main features of the petrography. Phenocryst abundance was estimated from thin sections, and in the descriptions to follow the least abundant phenocryst phase is listed first, the most abundant last (Le Bas et al., 1986; IUGS Subcommittee on the Systematics of Igneous Rocks). The average phenocryst sizes reported below were estimated from thin section and are smaller than the apparent grain size recorded during mapping. Volcanic and epiclastic terminology used is consistent with that proposed by Fisher and Schminke (1984) and Smith (1996). The terms pyroclastic flow deposit and welded tuff are used as a general term for any deposit with primary volcanic glass that shows some evidence of compaction and welding. The more specific terms: ash flow, pumice and ash flow, and block and

ash flow refer to the constituent fragments of specific deposits. Wherever possible, the features that were used to discriminate different deposit types are discussed in the text.

3.2 Stratigraphy and age of the Toodoggone assemblage

Daikow et al. (1985) and Daikow (pers. comm., 1985) recognized three widespread members within the Toodoggone volcanic assemblage (see Figure 3.1 and stratigraphic column in Figure 3.2). The oldest member is the Addoogatcho Creek Member, a large ignimbrite sheet dated by K-Ar at 202 ± 7 (hornblende), 200 ± 7 (biotite) and 199 ± 7 Ma (biotite; Daikow, 1985). The middle member, the Metsantan Member, is recognized only in the central part of the map area. It is an andesitic volcanic edifice dated by K-Ar at 197 ± 7 and 200 ± 7 Ma (biotite). The youngest member is the Saunders Member, another ignimbrite that caps the stratigraphy throughout the south-central part of the map-area (Figure 3.1). The Saunders Member is characterized by fresh hornblende and biotite that have given two K-Ar dates of 182 ± 8 and 183 ± 8 Ma (hornblende; Gabrielse et al. 1980).

Mapping during this study has revealed that the Saunders Member is overlain by andesitic volcanic and sedimentary rocks. These rocks are described by Marsden and Moore (1990) as the Theban Member and are correlative with

unit 4 (mafic flow and tuff unit) of Daikow et al. (1985).

The Toodoggone volcanic assemblage also includes numerous minor volcanic centres of uncertain age. Daikow et al. (1985) included most of these volcanics in a very diverse unit, the Toodoggone crystal ash tuffs.

Igneous rocks that intrude the volcanic pile also have Lower Jurassic ages. The Black Lake stock, a medium grained, equigranular, hornblende-biotite bearing granodiorite is exposed at the southwest edge of the present study area (Figure 3.2). It has given two K-Ar whole rock dates of 186 ± 8 and 189 ± 7 Ma. and a biotite date of 200 ± 9 Ma (Gabrielse et al., 1980). Cann and Godwin (1980) report two Rb-Sr whole rock dates from the Kemess Stock exposed to the south of the Finlay River (Figure 3.1) of 190 ± 9 and 191 ± 4 Ma. These intrusive bodies only intrude the Late Triassic Stuhini Group and there is no field evidence for their relationship to the Toodoggone volcanics.

3.3 Age and correlations within the study area

Within the study area, the Stuhini Group is unconformably overlain by the Toodoggone assemblage, part of the Hazelton Group. The stratigraphy is divided into four main divisions: the Stuhini Group, the Jock Creek volcanics, the Saunders Member and the Theban Member. The age, thickness and stratigraphic setting of these rocks is

displayed in Figure 3.2.

The oldest rocks are Late Triassic basalts and marine sediments of the Stuhini Group. These rocks have not been dated within the Toodoggone area but correlative rocks in the McConnell Creek and Tulsequah map areas (Monger and Church, 1977; Monger, 1980) are of late Carnian to early Norian age. The stratigraphy observed during this study is very similar to that described by Monger and Church (1977) in the McConnell Creek area.

The Addoogatcho Creek Member of the Toodoggone assemblage is not present within the study area (Map 1, Figure 3.3) and dacitic volcanoclastics directly overlie conglomerates derived from the Stuhini Group. This succession of dacitic volcanics cannot be assigned to any of the members described above and is described by Marsden and Moore (1990) as the Jock Creek volcanics.

The age of the Jock Creek section is loosely constrained. Daikow et al. (1985) included these rocks in the Toodoggone crystal ash tuffs, a very diverse collection of local volcanic centres. They tentatively assigned a late Bajocian age to these rocks, based on a single K-Ar date of 189 ± 6 Ma from a sample locale south of the Finlay River (Figure 3.1). The Jock Creek section rests unconformably on rocks of probable Late Carnian to Early Norian age and is overlain by the Saunders Member dated by K-Ar from a sample locale within the study area at 182 ± 8 Ma (hornblende). A

sample of hornblende phyric tuff from this study (8HM 11-14, unit 9, UTM N6348600, E622400) located at the top of the Jock Creek section was dated using Ar-Ar by Jim Clark as part of a separate study. Preliminary data indicates a 193.8 ± 2.6 Ma age (Clark, pers. comm., 1990). This would appear to suggest a 10 Ma hiatus prior to emplacement of the Saunders Member but Clark (pers. comm, 1990) also has preliminary Ar-Ar data for the Saunders Member that indicate a 193 Ma age. Until the complete set of data is available the age of these volcanics remains uncertain. The K-Ar ages cited above suggest a Toarcian age whereas the new Ar-Ar data suggests that both the Jock Creek section and the Saunders Member are Pliensbachian. The Theban member overlies the Saunders Member and is of probable post-Toarcian, pre-Bathonian age.

3.4 Stratigraphy of the study area

3.4.1 Introduction

The following description of the stratigraphy of the map area is broken into four main divisions and 18 different units. The number and name of each unit corresponds with those on both maps, the stratigraphic column (Figure 3.2) and Figures 3.3 and 3.5. The general features and external relations of each unit are described first, in order of oldest to youngest, followed by detailed petrographic

descriptions also summarized in Appendix I.

3.4.2 Stuhini Group

The oldest rocks within the study area are basalts and marine sediments of probable Late Triassic age. The basaltic rocks include both marine pillow basalts and subaerial flows. The sections mapped at the head of Paradise Creek (Map 1) consist of marine basalt flows overlain by well bedded turbidity and debris flow deposits. The top of the section consists of marine pillow basalts topped by oxidized, subaerial basalt flows. Some limestone fragments occur within hyaloclastite (UTM N634 '900, E662500) and are fossiliferous with poorly preserved fragments of coral and pyroxene crystals in a carbonate matrix. These features all indicate a marine volcanic edifice that built up to (or near) sea level during the latest Triassic.

3.4.2.1 Pillow basalt and hyaloclastite (unit 1a).

The cliffs exposed in the headwaters of Paradise Creek (Map 1) expose 300 metres of pyroxene-feldspar phyric basalt. The basalt contains 10-40% euhedral augite phenocrysts 1-4 mm in diameter and 25-45 % elongate feldspar lathes 2-4 mm long. Glomeroporphyritic textures are common. All of the flows are amygdaloidal with 5-25% vesicles filled

with pumpellyite, chlorite and zeolite (Plate 3.1).

Massive pillow basalt sections are common and well defined glassy rinds surround each pillow. The complete pillows are gradationally interbedded with hyaloclastite and isolated pillow breccias. The hyaloclastite is recessive, hackly weathering and consists of fragments of chloritized volcanic glass and broken phenocrysts. Irregular resistant masses within the hyaloclastite vary from 1-50 cm in diameter and clearly have chilled margins (Plate 3.2). In some cases the chilled margin is indicated by a concentration of tiny spherical amygdules. These isolated pillows are similar to those described by Carlisle (1963) and probably result from high water-lava ratios causing rapid cooling of submarine lava tongues (Honnorez and Kirst, 1975).

3.4.2.2 Well bedded sandstone, siltstone and volcanic conglomerate (unit 1b).

The pillow basalts of unit 1a are interbedded with at least 50 metres of grey-green marine sedimentary rocks. Thin bedded to laminated siltstone to sandstone is interbedded with grain supported conglomerate. The subangular clasts within the conglomerates are derived from the Stuhini basalts. The fine grained clastic rocks are very well bedded and commonly exhibit graded bedding, soft sediment

deformation and loading structures. This association suggests that these sediments were deposited as debris flows and associated turbidity flows in a marine basin adjacent to an eroding volcanic edifice.

3.4.2.3 Vesicular basalt (unit 1c).

Amygdaloidal, oxidized flows are not exposed within the map area but form part of a section in the Paradise Creek valley located north of the area in Map 1 (UTM N 6343800 E 622100). A 50 metre thick section of amygdaloidal flows comprising individual flows up to 10 metres thick are evident. Each flow base consists of massive chilled basalt and grades upward to amygdaloidal pyroxene-feldspar phyric basalt. The top of each flow is marked by a thin layer of red scoria.

3.4.3 Heterolithic conglomerate (unit 2).

The Stuhini Group basalts are capped by an erosional unconformity marked by several metres of matrix supported conglomerate with both basaltic and granitoid pebbles and cobbles. The granitoid clasts are mostly medium grained equigranular granodiorite. The next 50-80 m of the section consists entirely of a dark maroon conglomerate containing subangular basaltic fragments in a muddy matrix. The

fragments are all derived from the Stuhini Group but are from a diverse array of rock types including massive dark green augite porphyries, reddened amygdaloidal feldspar-augite porphyry and highly altered (carbonatized) fragments. The top of this sequence can be recognized by the presence of a monomictic conglomerate. The clasts in this conglomerate are distinctive because they contain tiny needle shaped relicts of hornblende instead of augite. The hornblende pseudomorphs are outlined by opaque minerals, predominantly hematite, suggesting that these clasts are derived from flows emplaced under oxidizing conditions before erosion and redeposition. The conglomerates were deposited as thin debris flow sheets. The bedding is manifested as a slight decrease in grain size near the top of each flow lobe or sheet and is apparent when viewed from a distance. The lack of interbedded fluvial sediments and the presence of matrix-supported deposits all favour a subaqueous environment of deposition. The oxidized constituents and the presence of rare fossilized wood fragments suggest that the conglomerates were derived from a subaerial source. This unit is very similar to conglomerates in the McConnell Creek map-area (see Figure 2.2) described by Monger and Church (1977).

3.4.4 Jock Creek volcanics

The conglomerates described above are overlain by pyroclastic deposits and a dacite dome that together form the Shasta dome complex (units 3,4 and 5; see Figures 3.5, 3.6 and 3.7). This complex is exposed at the base of a sequence of laharic conglomerates, pyroclastic flow deposits, crystal-rich ash deposits and volcanic breccias described by Marsden and Moore (1990) as the Jock Creek volcanics.

The Shasta dome complex hosts the precious metal mineralization on the Shasta property and consequently was mapped in great detail. Map 2 is a 1: 2,500 compilation map based on 1:1,000 mapping and subsurface information from extensive diamond drilling. Figure 3.5 is a simplified rendition of this map.

3.4.4.1 Green lapilli tuffs and volcanic sediments (units 3a, 3b).

The base of the Jock Creek section is marked by dark green lapilli tuff (unit 3a) and interbedded volcanic sandstone and conglomerate (unit 3b). The pyroclastic flow deposits have highly flattened chloritized lapilli, rare biotite, 10% broken embayed quartz phenocrysts 0.6 mm in diameter and 40% broken euhedral plagioclase crystals 0.7 mm

in diameter that are conspicuously smaller than the mean crystal size in overlying deposits. There is no primary glass preserved and groundmass ash is devitrified to a fine matrix of anhedral quartz and potassic feldspar. The interbedded epiclastic rocks are crystal rich volcanic sandstones or purple and green volcanic conglomerates. These deposits are also characterized by quartz and feldspar crystal fragments derived from the ashflow deposits but tend to be matrix supported with a purple clay rich matrix. Each depositional unit is commonly less than a metre thick and of limited lateral extent; epiclastic and volcanoclastic deposits interfinger. The intimate interfingering of thin ashflow and debris flow deposits suggest that these are distal deposits at the base of a small dacitic volcanic centre.

3.3.4.2 Dacite dome and epiclastics (units 4a, 4b)

The most intriguing aspect of the local geology is a dacite dome (unit 4a) exposed in the northwestern part of Map 1. It has been intersected in many drillholes and its close association with the mineralization has made it the subject of considerable debate among property geologists. The unit is an orange and green weathering rock with conspicuous quartz, biotite and feldspar phenocrysts. Along the margins of the deposit, centimetre scale layering is

observed (Plate 3.3). The strike of the layering is northwesterly, in contrast to the northeasterly strike of bedding in the surrounding geology. Early work on the property suggested that these deposits were crystal-ash tuffs, but several lines of evidence indicate that the layering originated as compositional flow layers in a felsic dome. In thin section the rock consists of 5% embayed quartz 0.6-2.0 mm in diameter, 10-15 % euhedral biotite and hornblende 0.8 to 1.5 mm long and 35% euhedral slightly glomeroporphyritic plagioclase (An 30) in a fine grained matrix of anhedral quartz and potassic feldspar (Plate 3.4). The delicate shapes of the plagioclase phenocrysts contrast with the broken and abraded crystals present in the overlying ash flow and debris flow deposits. Fragments are rare and consist of rounded highly chloritized clasts to 2 cm and very rare pink equigranular granitoid clasts less than 1 cm in diameter. The centimetre scale layering is not evident in thin section and is probably the result of subtle compositional variations. The layering is only prominent along the margin of the dome and is subparallel to the contact between the flow and overlying pyroclastic rocks. The layering is locally contorted into complex folds (Plate 3.3).

The edge of the dacite dome extends northwesterly across the map-area (Map 2, Figure 3.5). West of this boundary the dacite dome is not present and its

stratigraphic position is occupied by a diverse collection of epiclastic deposits less than five metres thick (unit 4b). These deposits include thin bedded volcanic sandstone and laminated purple to green siltstone exposed over a very limited lateral extent, and very coarse breccias. These breccias consist of angular blocks, commonly several metres in diameter, of welded tuff. This tuff is readily distinguished from other pyroclastic deposits on the property by its crowded texture, reddened feldspars and the presence of prominent biotite. The blocks are variably rotated and large interstices between fragments are filled with smaller clasts and a very fine grained clay or sericite. The margins of the blocks and the smaller fragments are all altered (weathered?) to fine grained clay. These deposits may have been tuffs that were extruded on the dacitic dome and were then redeposited as breccias as the dome continued to grow and steepen.

3.3.4.3 Quartz-feldspar lapilli tuffs (units 5a, 5b, 5c)

The dacite dome is flanked and possibly overlain by almost a hundred metres of pyroclastic deposits. The unit is divided into three distinctive facies: carbonaceous ash tuff, a cobble bearing pyroclastic deposit and welded to unwelded lapilli crystal tuffs.

The base of the pyroclastic flows are locally marked by dark green siltstone or ash tuff that is laminated and highly contorted. It is usually less than a metre thick and is intimately associated with one to two metres of a dark grey crystal lapilli tuff that contains numerous charred wood fragments. This deposit is very similar to the hot blast deposits that preceded the deposition of pyroclastic flows during the May, 1980 eruption of Mt. St. Helens (Hoblitt et al., 1981). The second facies overlies, or replaces this deposit and consists of several metres of pyroclastic deposits with 20-60% subrounded cobbles of the underlying dacite flow. These deposits indicate that the dome must have been extrusive and the pyroclastic flows were deposited on top of an irregular flow surface, incorporating rubble from the flow top.

The next 40-50 metres of the section are green welded lapilli crystal tuffs. The deposits contain 15-30% recessive weathering flattened chloritic lapilli, 5% biotite phenocrysts 0.5 mm long, 10-15% broken and embayed quartz phenocrysts and 50% plagioclase 1.0 mm in diameter. The crystals are evenly distributed between the matrix and the chloritic lapilli (Plate 3.6). There is no primary glass preserved and the chloritic lapilli and crystals are set in a fine matrix of anhedral quartz and potassic feldspar. Accessory fragments of a pale brown quartz-feldspar porphyry and green pyroxene-feldspar porphyry constitute less than 5%

of the deposit. These deposits become less welded upsection. Lapilli in the less welded tuffs lack the pointed and cusped ends observed in the welded tuffs (see Plate 3.5) and accessory fragments are more common. This unit is also characterized by pervasive chloritization and finely disseminated pyrite.

These pyroclastic deposits may have been derived either from an adjacent volcanic vent or the dome itself as pyroclastic flows associated with hot rock avalanches and small degassing eruptions from the surface of the dome. Unit 5 shows no evidence of the hot avalanche deposits and talus breccias (Francis et al., 1976; Mellors et al., 1988) that would be associated with eruptive events from a dome and were therefore probably erupted from an adjacent vent.

The area displays some interesting relationships between a dacitic dome and coeval ash flow deposits. The dome has moderately steep flanks that dip 40-50°, and tuffs that were deposited on top of this dome now have a different orientation from all the surrounding volcanoclastic strata. The tuffs could not have been deposited on such a steep slope and must have been tilted into their current orientation by growth of the underlying dome. Modern silicic domes have very steep flow fronts and are characterized by rubbly talus of dacite fragments derived from either the dome itself or related pyroclastic and epiclastic deposits (Mellors et al., 1988; Francis et al., 1976; Rose, 1972;

Swanson et al., 1987). Many of them occur in unstable andesitic craters and are periodically flooded by epiclastic debris from the crater walls and yet the domes continue to grow for periods of years (Mt. St. Helens; Swanson et al., 1987) or even decades (Santiaguito; Rose, 1987). The domes grow both from the extrusion of short stubby lobes of blocky lava and endogenously by accretion of cooling lava to the interior of the dome. Much of the growth of these domes can be attributed to internal expansion, almost half of the volume increase in the Mt. St. Helens dome was by endogenous growth and the margins advanced as fast as 30 metres per day (Swanson et al., 1987). Clearly any deposits lapping onto the flank of dome will be steepened during endogenous growth.

3.4.4.4 Laharic deposits (unit 6).

The Shasta dome complex is overlain by 200 metres of laharic deposits (unit 6) and locally interbedded pyroclastic deposits (unit 7). The laharic deposits rest conformably on the ashflow deposits but also overlap the Shasta dome. Where the gently north-dipping laharic deposits overlie the steep flanks of the dome (Map 1, N6347100, E622900) the sharp contrast in dip results in an apparently unconformable contact.

The transition from the pyroclastic deposits of unit 5

to the sedimentary deposits of unit 6 is marked by several metres of green to purple volcanic siltstone interbedded with thinly bedded volcanic sandstone. The sandstone consists of quartz and feldspar crystal fragments reworked from the underlying ashflow deposits. The laharic deposits are very poorly sorted heterolithic boulder conglomerates. The fragments are predominantly dacitic porphyries and tuff fragments that vary in size from pebbles to giant boulders. Many of the fragments are very strongly oxidized, with rims of bright red hematite. The matrix is a fine green to maroon argillaceous sand with suspended lithic fragments and quartz, hornblende, biotite and plagioclase crystal fragments from 0.5 to 3.0 mm in diameter.

The section is a composite of numerous flow lobes. The individual lobes are often distinctive, with different clast sizes and colours and a variably green to purple matrix. The top of each lobe is commonly marked by thin to medium beds of laminated and cross-laminated volcanic sandstone and siltstone of similar composition to the debris flows. An effort was made to establish a stratigraphy within this unit using surface exposures and diamond drill holes, but individual flow units can rarely be traced across strike for more than 50-100 metres. Unit 6 is clearly a composite of numerous lobes that were deposited in local channels and it lacks a coherent stratigraphy. The volcanic sands are stream worked deposits that mark temporary streams on top of the

flows. This is a characteristic of laharic deposits in other areas (Schminke, 1966). The degree of oxidation within individual flow lobes may reflect the temperature of the debris flows. Hot debris flows were derived from the May, 1980 eruptions at Mt. St. Helens when pyroclastic eruptions incorporated large volumes of snow from the summit cone (Brantley and Waitt, 1988).

The epiclastic deposits of unit 6 onlap and bury the topography of the younger dacite dome and were clearly derived from a different and larger volcanic edifice. Cross bedding orientations in the interbedded sands provide sparse evidence that this edifice was located to the northeast of the Jock Creek area.

3.4.4.5 Welded chloritic lapilli tuff (unit 7)

Grey-green welded pyroclastic flow deposits overlie and are interbedded with the laharic deposits of unit 6. They contain 30-40% highly flattened green pumiceous lapilli, 10% embayed quartz fragments 1.8 mm in diameter and 60% plagioclase (An 40) fragments in a partially devitrified matrix. The green lapilli consist of dark green to brown volcanic glass with highly compacted and welded shapes. The matrix is composed both of welded glassy shards and glass that is devitrified to fine grained quartz and potassic feldspar. Accidental lapilli include pale brown dacite

porphyry fragments and red welded tuff fragments.

The basal few metres of the deposit is unwelded or weakly welded with slightly flattened chloritic lapilli.

3.4.4.6 Laminated crystal ash tuffs (unit 8)

In the central part of the map area (Map 1, Figure 3.3) units 6 and 7 are overlain by 150 metres of well bedded crystal ash tuff. Thin beds a few centimetres thick (Plate 3.7) are defined by differential weathering and subtle colour variations from grey to maroon. The rock contains 5% hornblende 0.6 mm long, 10% resorbed and broken quartz 2 mm in diameter and 60% plagioclase (An₄₀) fragments within a matrix of spherulitic volcanic glass (Plate 3.8). The bedding is outlined by varying proportions of pale to dark red glass. The bedding is crosscut by narrow (2-4 cm) wide subvertical dewatering (or degassing) dikes (Plate 3.7). These dikes contain the same components as the rest of the rock but are fine grained fragments suspended within a silty matrix.

The fine grain size and good sorting of these deposits suggests that they are a thick airfall accumulation, but they are present only in one area and do not appear to have mantled topography, an important characteristic of airfall deposits (Fischer and Schminke, 1984). This suggests that they may be pyroclastic flow or surge deposits of fine

grained material that settled out from an eruption column. There is not enough continuous exposure to observe large scale cross-bedding but the bedding orientations in different outcrops are highly variable.

3.4.4.7 Hornblende-feldspar phyric tuffs, breccias and volcanic sediments (unit 9)

Overlying units 6, 7 and 8 is a 250 metre thick, complex volcanic succession including numerous deposit types. The unit is distinguished from the underlying stratigraphy by the absence of phenocrystic quartz. These rocks contain 15-25% hornblende 1.5-5.0 mm long, and 40-50% plagioclase (An 58) 1.5 to 3.0 mm in diameter. The various subunits include broken flows, volcanic breccias, lapilli tuffs, block and ash flows, debris flows and volcanic sandstones. The broken flows are hornblende-feldspar porphyries that consist of large coherent blocks bounded by small fractures filled with fine silt sized material. These are gradational with dark green tuffs that contain numerous blocks of similar porphyry. The blocks have chilled margins and radial cooling cracks around their rims indicating that they were hot when emplaced in the tuffs. The tuffaceous matrix consists of hornblende and feldspar crystal fragments and devitrified glass with spherulites up to several centimetres in diameter (Plate 3.9). The feldspars are

plagioclase with relict albite twinning that is obscured by patchy extinction, possibly a result of thermal cracking (Plate 3.10). Francis et al. (1976) recognized a gradation from short stubby broken flows through hot avalanche deposits to debris flow deposits in the San Pedro and San Pablo volcanoes in Chile. The hot avalanche deposits are characterized by prismatically jointed angular blocks in a glassy matrix and by the absence of pumiceous lapilli. A hot-rock avalanche from an extrusive lobe on the dome at Mt. St. Helens produced both a coarse avalanche deposit and a pyroclastic flow deposit that was generated either during flow of the hot rock avalanche or by explosive depressurization of a gas rich core within the extrusive lobe (Mellors et al., 1988). The deposits of these pyroclastic flows are similar to those of unit 9 in that they include chilled blocks of dacite and lack the vesicular glassy clasts typical of pumiceous ignimbrites (Wright et al., 1980).

3.4.5 Saunders Member

This unit is a spectacular pyroclastic flow deposit. The base and the top of the unit are both exposed within the map area but a continuous section is not present due to the effects of topography and erosion. The base of the unit is marked by a purple lapilli tuff. It is overlain by a

homogeneous welded tuff that shows little variation in welding or clast composition over a three hundred metre interval. The welded lapilli rich deposits are overlain by welded crystal rich tuffs that are characterized by small fiamme. The top of the unit consists of purple sandstones derived solely from the underlying ashflow deposits.

This succession records the emplacement of a large cooling unit of ignimbrite that is probably an accumulation of many successive pyroclastic eruptions. As this episode of explosive activity waned, the deposits become thinner and less welded and included reworked epiclastic deposits. Eventually explosive volcanism ceased and the ignimbrite deposits are covered by a thin sheet of mudflow and stream deposits derived from adjacent exposed parts of the ignimbrite.

3.4.5.1 Purple ash, lapilli tuff (unit 10)

The base of the Saunders Member between Mt. Shasta and Black Peak is a purple lapilli tuff. The unit is very similar to overlying deposits and contains 10% resorbed quartz fragments 1.0 mm in diameter, 15% oxidized hornblende and biotite 0.8 mm long and 40% plagioclase 1.8 mm in diameter with prominent accessory sphene and apatite. The matrix consists of a very oxidized, maroon devitrified glass in which the welding fabric is preserved.

3.4.5.2 Saunders quartz-hornblende-biotite-feldspar phyric ignimbrite (unit 11a)

Overlying the red lapilli tuff is a 300 metre thick accumulation of welded lapilli crystal tuff. These deposits show very little variation in welding and compaction or mineralogy over the entire interval observed. The unit contains 10-15% resorbed quartz fragments, 15% hornblende and biotite 1.0 mm long and 40% fragments of euhedral oscillatory zoned plagioclase. Accessory minerals include prominent apatite and up to 1% sphene 0.2 to 1.0 mm in diameter. These phenocrystic phases are hosted both by dark grey-green glassy lapilli and a matrix of welded glass shards (Plate 3.11). The lapilli are identical to the matrix except that the phenocrysts are less broken, larger and less crowded. The glass in the lapilli and the welded matrix is either well preserved or partially devitrified to fine grained quartz and potassium feldspar. Accidental fragments of granodiorite and aplite are common. They vary from less than a centimetre to 40 centimetres in diameter.

3.4.5.3 Crystal lapilli tuff (unit 11b)

The ignimbrite described above is overlain by welded crystal tuffs that are well exposed on the south flank of Mt. Todd (Map 1, Figure 3.3). They are distinguished from

the underlying ignimbrite by a lower lapilli and quartz content. Besides these differences they are identical to the ignimbrite and include the prominent sphene crystals and accidental granitoid fragments. In thin section they are very similar and consist of quartz, biotite, hornblende, feldspar and accessory magnetite, apatite, sphene and trace zircon in a matrix of glass shards and small essential lapilli. Some of the deposits are very crystal rich and lack welding textures. They are either volcanic sandstones or unwelded pyroclastic deposits. This unit probably consists of numerous pulses of pyroclastic flows erupted during the waning of a large eruptive event.

3.4.5.4 Purple volcanic sandstone (unit 11c)

The welded crystal tuffs are overlain by purple volcanic sandstones and pebbly sandstone. These deposits are extensively developed east of the Saunders Fault around Mt. Todd (Map 1, Figure 3.3). They include pebbly sandstones with subrounded pebbles of the Saunders ignimbrite and quartz, biotite, hornblende, plagioclase and sphene crystal fragments suspended in a argillaceous red matrix. The low quartz content of the sandstones suggests that they were derived primarily from the upper welded crystal tuff unit (11b). The pebbly sandstones are incised by channels of purple to grey green volcanic sandstone. These deposits are

laminated accumulations of quartz, hornblende and plagioclase with laminations rich in magnetite and sphene.

The widespread distribution of the mud-supported pebbly sandstones suggests that they were deposited as debris flow sheets. These sheets were incised and reworked by stream channels that deposited finely laminated crystal-rich volcanic sands.

The Saunders Member covers an area of approximately 15 by 40 kilometres (Panteleyev, 1983) and is over 300 metres thick, yielding a minimum volume of 180 cubic kilometres. Medium to large volume ignimbrites are common features of the large continental calderas of the southwestern United States (Stephen and Lipman, 1976) and of the ignimbrite shields in the Andes (Guest, 1969, Worner et al., 1988). The Andean ignimbrites, although enormous, are much thinner than the ponded ignimbrites that accumulate in calderas. A source area and associated caldera structure cannot be recognized for the Saunders Member, but its considerable thickness suggest that it was ponded, either within a caldera or a rift valley.

3.4.6 Theban member

Daikow et al. (1985, units 3 and 4) mapped rocks exposed east of the Saunders Fault (Figure 3.1) as the

Lawyers-Metsantan quartzose andesite and a mafic flow and tuff unit. Some of the rocks described by him as the Lawyers-Metsantan andesite are gradational with the underlying Saunders grey dacite and have been assigned to the Saunders Member (units 11 b and 11c) in this study. The rocks mapped as the mafic flow and tuff unit conformably overlie volcanic sandstones of the Saunders Member and are assigned to a new member, the Theban andesites. Well exposed sections are present both on Mount Todd and further north at the northern limit of Map 1.

The Theban member consists of hornblende-pyroxene phyric intrusive rocks, pyroxene phyric flows and epiclastic rocks. The sediments consist of laminated purple to green siltstone and sandstone that is interbedded with volcanic conglomerates derived solely from the hornblende-pyroxene-feldspar phyric intrusive rocks.

3.4.6.1 Sub-volcanic feldspar phyric intrusive rocks (unit 12int).

The Theban member is dominated by medium grained green weathering pyroxene, hornblende and feldspar bearing subvolcanic intrusives. They contain 5% pyroxene 1.0 mm in diameter, 15% hornblende 1.5 mm in diameter and 30% plagioclase (An 55) 2.2 mm in diameter. These rocks intrude the Saunders Member and overlying deposits of the Theban

Member on the east flank of Mt. Todd. They also intrude volcanic conglomerates that consist of cobbles identical to the intrusive rocks.

The contact between the Saunders Member and unit 9 is occupied by a 200 metre thick sill that pinches out on the east side of Mt. Todd where the Saunders Member rests directly on top of unit 9 (Figures 3.3 and 3.4). The actual contact of the sill was not observed and its intrusive nature is inferred from stratigraphic relationships. It is a homogeneous brown to purple porphyry with 10% pyroxene 1.8 mm in diameter, 15% hornblende 0.5 mm in diameter and 25% plagioclase 2.5 mm in diameter. This distinctive mineralogy is identical to small stocks within unit 9 (Map 1, Figure 3.3) and to the subvolcanic intrusive rocks described above. The porphyry hosts two small high grade bornite pods, also a feature of the subvolcanic intrusives of unit 12. If it is correlative with unit 12 then the porphyry is definitely a sill and is younger than the overlying Saunders Member.

3.4.6.2 Volcanic conglomerate and siltstone (unit 12a)

The lower part of the Theban member includes numerous interbeds of volcanic conglomerate and siltstone. These units are dominated by volcanic conglomerates with clasts derived solely from the Theban subvolcanic intrusive rocks

(12int) and finely laminated pastel-colored purple to green volcanic siltstone composed of very small pyroxene and feldspar fragments in a fine argillaceous matrix. They exhibit normal grading and are intimately associated with the conglomerates. They are interpreted as subaqueous debris flow and associated turbidity deposits. The red colour of the sediments and their association with welded ash flow deposits and oxidized flows suggests that they were deposited in a shallow aqueous (lacustrine?) environment.

The complicated telescoped relationship between the intrusive and sedimentary rocks in the Theban Member probably is the result of a tectonically active volcanic environment. Early intrusive rocks must have been rapidly uplifted and eroded prior to eruption of the pyroxene phyric volcanics.

3.4.6.3 Pyroxene phyric andesite flows and tuffs (unit 12b)

The Theban Member is characterized by pyroxene phyric flows. These units vary from medium grained porphyritic rocks with 20% euhedral augite 2.5 mm in diameter and 30% euhedral plagioclase 1.8 mm in diameter to fine grained crowded porphyries with the same mineralogy but an average phenocryst size of about 1 mm. The matrix consists of fine to very fine grained laths of plagioclase and tiny mafics

and opaques.

The flows are interbedded with thin beds of dark green pyroxene plagioclase lapilli tuff and the sediments described below.

3.4.7 Quartz-feldspar welded chloritic lapilli tuff (unit 13)

A large area east of the Saunders Fault and south of Jock Creek (Map 1, Figure 3.3) is underlain by green tuffs with highly flattened chloritic lapilli, white feldspar crystals and minor quartz. These rocks are moderately to strongly epidotized, and are commonly replaced by argillic alteration. Fresh samples contain from 2-10% quartz 0.4-1.2 mm in diameter, 10% hornblende 0.7 mm in diameter and 40% plagioclase (An 40) 1.8 mm in diameter in a matrix of either welded glass shards or devitrified glass (quartz and potassic feldspar). Accessory phases include magnetite, apatite and prominent sphene. Extensive alteration obscures the internal and external relations of this unit, but it locally underlies the Saunders ignimbrite and a purple unit (unit 14) that is composed of both welded tuff and pebbly volcanic sandstone. The simplest interpretation is that units 13 and 14 are part of the Saunders Member, reflect slight depositional variations, and have been affected by strong alteration from hydrothermal systems related to the

underlying and crosscutting intrusive rocks of the JK stock.

3.4.8 Purple lapilli tuff and volcanic sandstone (unit 14)

Overlying the green feldspathic tuff of unit 13 and underlying fresh welded tuff of the Saunders member is a thin unit that consists of both purple welded tuff and purple pebbly volcanic sandstones.

3.4.9 Intrusive rocks

The project area is flanked both on the southwest and northeast by intrusive rocks. The southwest part of the map-area is occupied by the Black Lake stock, a homogeneous coarse grained granodiorite. The stock intruded the Stuhini Group basalts and has yielded K-Ar biotite and hornblende cooling dates of Early Jurassic age. It was emplaced against the Tooodoggone volcanic assemblage by reverse oblique movement (see section 5.3) on the Black Lake fault (Figure 3.1). The northeast margin of the map area is occupied by a more complex intrusive body, the JK stock. This elongate body consists of three distinct varieties. The western margin is a gradational zone of intensive dyking. Tentative timing relationships between the three phases have been

established from local crosscutting relationships. All three intrusive types crosscut the Saunders Member and dikes of the earliest (and most abundant) variety also cut the Theban Member.

3.4.9.1 Black Lake stock

The Black Lake stock is a very homogeneous equigranular granodiorite. It consists of 2-5% fine grained biotite, 15% subhedral hornblende 1.5 mm in diameter, 20% anhedral quartz 1.0-1.5 mm in diameter, 25% anhedral, interstitial orthoclase and 40% euhedral, normally zoned plagioclase with cores of An 35-An 45. Accessory phases include magnetite, apatite and trace zircon.

3.4.9.2 JK stock (units A, B, C)

The JK stock consists of three phases. The oldest, unit A, a medium grained granodiorite, is exposed as remnants within the more extensive hornblende-plagioclase porphyry of unit B. The youngest is an amygdaloidal pyroxene porphyry that forms dikes and a small body south of Jock Creek (Map 1).

Unit A is an equigranular to slightly porphyritic intrusive rock that contains 10% hornblende, 20% anhedral interstitial quartz, 20% anhedral interstitial orthoclase

2

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

and 50% euhedral plagioclase (An 45). It is less common than unit B (see below) and is interpreted to be the remnants of an early intrusive phase that is extensively crosscut and replaced by the younger intrusive rocks. Included with this unit is an unusual intrusive rock exposed at UTM N6349100 E626000 (Map 1). It is a quartz poor (5%), very crowded porphyry with euhedral to subhedral amphibole (riebeckite?) and euhedral plagioclase within fine grained quartz.

Pink weathering porphyritic rocks of unit B are the most abundant variety of the JK stock both within the main intrusive body and as dikes crosscutting the overlying volcanic stratigraphy. They contain 5% embayed quartz crystals 1.0 mm in diameter, 20% hornblende 2.0 mm in diameter and 35% euhedral phenocrysts of plagioclase (An 35?) 3.0 mm in diameter. The matrix consists of variably crystalline quartz and potassic feldspar with accessory apatite, magnetite and zircon. These rocks cut the Theban Member and are cut by unit C .

The youngest variety, unit C, is a dark green, fresh, amygdaloidal pyroxene-bearing intrusive with 20% euhedral augite phenocrysts 2.0 mm in diameter, 50% euhedral plagioclase (An 40) and 2-30% vesicles filled with pumpellyite, calcite and zeolite. It occurs as dikes within the stratigraphy around Diamond Peak (Map 1, Figure 3.3) and also as a small body exposed on the southeastern margin of Map 1.

3.4.9.3 Miscellaneous dikes

There are several fine grained basaltic dikes crosscutting the JK stock. Similar dikes were observed in drill core intersecting the J1 Fault (Map 2). Rhyolitic dikes are fairly common in the vicinity of Mt. Todd (Map 1). These dikes are pink or buff and green with flow banding and shear fabrics. The dikes contain contorted fragments of banded rhyolite within later rhyolite. Dark-coloured lensoidal patches within the rhyolite are seen in thin-section to be dendritic growths of microcrystalline quartz (and potassic feldspar?).

3.4.10 Alteration

There are three main types of hydrothermal alteration within the map area. Argillic alteration (i) is spatially related to the JK stock and the Saunders Fault zone. Advanced argillic alteration (ii) is restricted to narrow zones within argillic alteration in rocks overlying the JK stock. The potassic alteration (iii) on the Shasta property is spatially distinct from the argillic and advanced argillic alteration. Clark and Williams-Jones (1987) suggested that gold mineralization is restricted to hydrothermal events that predate the Saunders Member. While this is probably true for the Shasta property, there is no

evidence that this is a rule for the Toodoggone area. The Saunders Member is extensively altered and argillic alteration in the Theban Member near Mt. Todd hosts quartz-clay veins that carry significant precious metals.

3.4.10.1 Argillic alteration (i)

The most common alteration type consists of argillic alteration zones within much more widespread propylitic epidote-rich alteration. These zones are rusty weathering, yellow to white rocks consisting mostly of quartz, sericite and or clays with disseminated pyrite. Primary textures are mostly obliterated although quartz phenocrysts are preserved and sericite forms pseudomorphs after plagioclase. This type of alteration hosts patches and linear zones of intense silicification and rare veins of carbonate and sericite with fine grained pyrite, chalcopyrite and minor sphalerite (Map 1, UTM N6345800, E625500).

The alteration is concentrated in four areas. The most obvious area is a large gossan covering the area south of Jock Creek and east of Ferricrete Creek (Map 1). Volcanic rocks that overlie the JK stock are variably altered throughout this area. Secondly, the Saunders Fault zone is altered and near the north end of Map 1 the alteration zone expands to cover significant areas up to 1000 m. wide on either side of the fault. A third region of strong alteration is a zone in the northwest corner of the map, the

North Black Gossan. All of these zones were sampled by the author for Esso Minerals Canada Ltd., but did not contain any significant precious metals. The fourth area of alteration is exposed on the steep east face of Mt. Todd (Map 1). This zone hosts a 1 metre wide quartz-carbonate vein carrying chalcopyrite and galena that gave economically significant assays in gold and silver.

3.4.10.2 Advanced argillic alteration (ii)

The argillic alteration in the southeastern part of Map 1 hosts three linear zones of strong silicification with coarsely crystalline alunite. The alunite occurs as late stage veins of platy crystals up to 8 mm across that are pink on the surface and white in drill core. These zones strike approximately 070° and dip 60° to the south. The strongly silicified rock stands up as prominent resistant reefs above the surrounding argillically altered rocks. Alunite is a sulphate mineral that is only stable at very low Ph and high fO_2 (Hemley et al., 1969). These conditions can occur in a vapour condensation zone above a boiling hydrothermal system (Heald et al., 1987; Stoffregen, 1987) or as result of the mixing of magmatic gases with meteoric waters. This combination results in the conversion of magmatic SO_2 to sulphate and can result in large advanced argillic zones in the host rocks around intrusive stocks such as those mapped in the Marysvale, Utah area by

Cunningham et al., (1984). Some of the alunite in the Goldfields, Nevada area is very coarse grained and has an oxygen isotope signature that suggests it originated from meteoric waters involved in weathering of the surrounding sulphide rich rocks (Jensen et al., 1971). The alunite observed in this study is late stage coarse grained and of limited extent suggesting that it may also be supergene in origin.

Advanced argillic alteration that forms above boiling hydrothermal systems may host precious metal mineralization associated with later fluids (eg. Goldfields, Stoffregen, 1987; Round Mountain, Ransome, 1909), but surface sampling and one diamond drill hole by Esso Minerals Canada Ltd. in 1988 failed to indicate any concentration of precious metals in the alteration described above.

3.4.10.3 Potassic alteration (iii)

Strong potassic alteration occurs only on the Shasta property (Figure 3.5). The geometry and mineralogy of these zones is discussed in greater detail in section 5.3. They are linear structures characterized by a distinctive pink coloration reflecting the progressive growth of potassic feldspar. A thorough description of the zones, their paragenesis and mineralogy is presented by Thiersch and Williams-Jones (1990).

Figure 3.1 : Geological map of the Toodoggone area. Geology is modified from Daikow et al. (1985).

Figure 3.4: Sections a-a', b-b', looking east. Section locations shown on Figure 3.3.

Figure 3.5: Geology of the Shasta property. Summarized from Map 2, based on 1:1,000 mapping and drillhole data.

Figure 3.6: Sections A-A'', B-B'', looking east . See Figure 3.5 for section lines.

Figure 3.7: Schematic section of facies relationships on the Shasta property.

Plate 3.1: Isolated pillow basalts of the Stuhini Group. Irregular chilled pillows in hyaloclastite. Sample 9-11-11. UTM N 6345000 E 622500.

Plate 3.2: Photomicrograph of amygdaloidal margin in pyroxene-feldspar phyric basalt. Sample 9-10-16. UTM N 6345500 E 622400. Scale 5x.

Plate 3.3: Contorted flow layering in dacite (unit 4a)

Plate 3.4: Photomicrograph of dacite (unit 4a). Note homogenous, uncrowded texture in contrast to detail of pyroclastic deposits (Plate 3.6). Sample 9-12-6. UTM N 6347600 E 621800. Scale 5x.

Plate 3.5: Contrast between highly flattened lapilli in welded deposits (right side) and unwelded deposits with subrounded lapilli (unit 5).

Plate 3.6: Photomicrograph of pyroclastic flow deposit (unit 5). Note broken crystals and chloritized lapilli (cl). Texture is more crowded than in debris flow deposits and dacite dome (unit 4a). Sample 8-33-8c. UTM N 6346900 E 621850. Scale 5x.

Plate 3.7: Laminated crystal ash tuffs. Subvertical features are degassing dikes.

Plate 3.8: Photomicrograph of laminated crystal ash tuffs (unit 8). Well sorted deposit with crystals and red spherulitic glass (sg). Sample 8-10-10. UTM N 6347850 E 620450. Scale 5x.

Plate 3.9: Nest of large spherulites(?) in unit 9. Individual balls are up to several centimetres across. Straight junctures indicate that these structures grew in place.

Plate 3.10: Highly fractured plagioclase in hot avalanche deposits of unit 9. Fracturing postdates development of albite twinning and may be due to thermal cracking during decrepitation of extruding magma. Sample 8-11-12. UTM N 638750 E 620050. Scale 20x.

Plate 3.11: Welding textures and embayed quartz grain in Saunders ignimrite (unit 11a). Glass (gl) is partially replaced by pumpellyite(?) and chlorite. Sample 8-21-4. UTM N 6348650 E 620850 Scale 5x.

CHAPTER IV: GEOCHEMISTRY

4.1 Introduction

Samples from the study area were analyzed for major and trace elements in order to help classify the local Stuhini and Toodoggone sections and to provide further information on the tectonic setting of the Toodoggone volcanic assemblage. Petrogenetic modelling would require considerable further work and is beyond the scope of this thesis. An effort was made to collect unaltered samples of homogeneous units with no inclusions. See Appendix II for field and petrographic descriptions of the samples.

Samples of pillow basalts and a subvolcanic(?) glomeroporphyritic basalt were collected from the Stuhini Group. These are poor samples for studying the primary composition of magma; the high LOI and scattered values on nearly all plots (see below) stem from pervasive amygdules comprising pumpellyite, chlorite, calcite and zeolites. Results are nonetheless presented in this chapter because abundances of the less mobile elements cluster away from those of the Toodoggone section, emphasizing some differences between these two groups.

The samples from the Toodoggone section include relatively pristine intrusive rocks with very little alteration, samples from the dacite dome (unit 4a), samples

of homogeneous ashflow deposits and andesite flows. Some of the ashflow deposits have a significant proportion of chlorite and calcite replacing volcanic glass, but except for a few samples from unit 5 these samples plot very close to all the better preserved samples from units 7 and 11. Samples of the dacite dome (unit 4) and related pyroclastic deposits of unit 5 are all affected to some degree by chloritic alteration, and the very strong potassium metasomatism that characterizes the mineralized zones suggests that the alkali plots for these samples are probably unreliable.

The X-ray fluorescence analytical procedure and controls are detailed in Appendix III. Standards and duplicate samples were run concurrently and provided a check on the consistency of the analyses (see Appendix III). All major elements show a standard deviation of less than 0.2 wt%. The less abundant oxides (TiO_2 , P_2O_5 , MnO) have a standard deviation of less than 0.04 wt%. The standard deviations for the trace elements are all an order of magnitude smaller than the recorded concentrations. All of the Nb values are below detection limit (10 ppm) except for spurious highs in some standards and samples 7 and 8 (See Tables 4.1 and Appendix III). Loss on ignition (LOI) was determined by heating a 1 gram sample for two hours each at 120°C and 1050°C and determining weight loss. Duplicate determinations are within .05 wt% of each other.

The Toodoggone volcanics are not an easy succession to classify chemically. Pyroclastic flow deposits dominate the extrusive section, and it is difficult to be certain that the samples represent their respective magmas. Pervasive prehnite-pumpellyite facies alteration of the section further obscures the original compositions of the melts erupted as the Toodoggone volcanic assemblage. Basaltic flows were not recognized within the Jurassic section and the majority of the study area is underlain by rocks of dacitic composition. The narrow range of compositions represented by the Toodoggone volcanics restrict the use of empirical discrimination diagrams to distinguish the tectonic setting of the volcanics. Tectonic discrimination diagrams use ratios of immobile incompatible elements from rocks of basaltic composition so that the effects of fractional crystallization are minimal. All of the elements used in these diagrams are compatible with magnetite, amphibole, biotite and zircon, all important minerals in the Toodoggone volcanics.

Even though this work cannot decipher a unique history for the evolution of the Toodoggone volcanics, these rocks clearly have all the chemical characteristics of a mature calc-alkaline arc erupted on a subaerial landmass with a significant crustal thickness (>25 kilometres?).

4.2 Results

4.2.1 Normative mineralogy

The chemical data (Tables 4.1 and 4.2) are presented as CIPW cation norms in Table 4.3. The $\text{FeO}/\text{Fe}_2\text{O}_3$ ratio was not determined analytically and the values in Table 4.2 follow the recommendation of Irvine and Baragar (1971) that $\text{Fe}_2\text{O}_3 = \text{TiO}_2 + 1.5$. The normative calculations were made using a constant ratio of 0.3 for rocks with less than 57 wt% SiO_2 and 0.4 for more silica rich compositions (Le Maitre, 1976). Normative compositions were also calculated using the ratios in Table 4.2; the actual percentages of hypersthene and magnetite change slightly but the normative mineralogy remains essentially the same for a variety of Fe ratios.

The Stuhini Group samples are all olivine and hypersthene normative basalts except for sample 2 (9-10-6) which is slightly nepheline normative. This sample had an anomalously high K_2O value, reflected by the high molecular percent normative orthoclase (18.0%) and normative nepheline (3.90%). The rest of the Stuhini samples are all sodic ($\text{Na}_2\text{O} + 1.5 > \text{K}_2\text{O}$) and metaluminous ($\text{Al}_2\text{O}_3 / \text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O} > 1$).

TABLE 4.1: Whole Rock Geochemistry

	Stuhini Group				Black Lake Stock					Intrusive B					A		C	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Sample No	9-10-12	9-10-6	8-56-16	8-56-12	9-11-3	9-4-13	9-9-13	9-13-7	8-41-8	9-9-14	9-5-9	19	20	21	22	23	24	25
SiO ₂	51.83	49.88	46.72	49.18	63.47	63.47	64.55	63.53	63.68	62.50	51.25	19	20	21	22	23	24	25
Al ₂ O ₃	12.86	16.00	16.16	13.35	16.15	15.83	15.65	15.84	15.33	16.81	17.84	19	20	21	22	23	24	25
FeO*	9.78	11.24	10.38	9.75	5.23	5.20	4.86	5.09	4.92	5.16	10.19	19	20	21	22	23	24	25
FeO	2.46	2.46	2.34	2.43	1.93	1.95	1.97	1.98	1.96	2.04	2.46	19	20	21	22	23	24	25
Fe ₂ O ₃	7.32	8.78	8.04	7.32	3.30	3.25	2.89	3.11	2.96	3.12	7.73	19	20	21	22	23	24	25
MgO	7.27	6.70	6.68	7.44	1.94	1.99	1.71	1.93	1.85	1.79	3.62	19	20	21	22	23	24	25
CaO	8.32	6.31	8.72	7.99	4.71	4.37	3.58	3.96	3.95	4.41	8.30	19	20	21	22	23	24	25
Na ₂ O	3.67	3.02	3.12	3.41	3.41	3.44	4.27	3.52	3.21	4.01	3.43	19	20	21	22	23	24	25
K ₂ O	1.51	3.70	1.03	1.77	3.44	3.37	3.74	3.69	3.57	3.02	1.64	19	20	21	22	23	24	25
TiO ₂	0.96	0.96	0.84	0.93	0.43	0.45	0.47	0.48	0.46	0.54	0.96	19	20	21	22	23	24	25
P ₂ O ₅	0.26	0.25	0.21	0.22	0.22	0.23	0.16	0.18	0.15	0.21	0.39	19	20	21	22	23	24	25
MnO	0.16	0.20	0.13	0.16	0.12	0.11	0.13	0.10	0.14	0.10	0.20	19	20	21	22	23	24	25
S	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	19	20	21	22	23	24	25
Trace elements ppm																		
BA	372	1471	241	692	1345	1439	1508	1390	1745	1570	1302	19	20	21	22	23	24	25
CR	274	93	143	263	60	66	73	48	74	67	42	19	20	21	22	23	24	25
ZR	92	42	34	89	93	88	111	100	103	140	82	19	20	21	22	23	24	25
SR	313	627	448	296	624	671	530	599	572	595	844	19	20	21	22	23	24	25
RB	25	62	16	30	83	82	79	81	71	52	31	19	20	21	22	23	24	25
Y	22	17	13	22	17	18	17	22	18	15	25	19	20	21	22	23	24	25
NB	0	0	0	0	2	0	21	20	0	0	0	19	20	21	22	23	24	25
ZN	74	87	77	76	46	57	66	73	82	46	108	19	20	21	22	23	24	25
NI	83	52	81	73	7	14	38	24	14	18	12	19	20	21	22	23	24	25
V	317	401	365	290	112	108	100	111	132	97	270	19	20	21	22	23	24	25
SUBTOTAL	96.79	98.55	94.13	94.39	99.36	98.71	99.37	98.57	97.55	98.82	98.10	19	20	21	22	23	24	25
LOI	3.21	2.54	5.71	5.63	0.61	0.88	0.85	1.61	1.77	0.78	1.79	19	20	21	22	23	24	25
TOTAL	100.00	101.09	99.84	100.02	99.97	99.59	100.22	100.18	99.32	99.60	99.89	19	20	21	22	23	24	25

Table 4.1 cont...

3	4a Dacite flow											5 Ash flows				
	12	13	14	15	16	17	18	19	20	21	22					
Sample No 89-28	88-08	89-33	9-12-6	8-59-1	28-2	FOXT	9-14-10	88-1	88-14	88-24						
SiO2	59.42	63.12	64.25	63.43	65.70	63.36	63.76	64.74	61.65	63.63	63.54					
Al2O3	16.18	15.55	15.55	15.67	15.31	15.56	15.47	15.72	17.89	15.54	15.27					
FeO*	5.21	3.55	4.21	4.42	3.70	4.17	4.22	3.94	4.04	3.45	3.51					
FeO	1.94	1.85	1.88	1.90	1.86	1.89	1.88	1.86	1.89	1.85	1.82					
Fe2O3	3.27	1.70	2.33	2.52	1.84	2.28	2.34	2.08	2.15	1.60	1.69					
MgO	1.53	1.20	1.53	1.73	1.39	1.54	1.58	1.37	1.55	1.22	1.16					
CaO	4.52	3.10	3.23	2.60	1.92	3.31	2.95	2.15	2.24	3.44	3.49					
Na2O	2.97	2.60	3.56	3.85	3.34	3.26	3.65	4.23	3.29	3.00	2.89					
K2O	3.03	4.37	3.70	3.69	5.67	4.21	3.99	3.93	4.80	4.64	4.27					
TiO2	0.44	0.35	0.38	0.40	0.36	0.39	0.38	0.36	0.39	0.35	0.32					
P2O5	0.14	0.12	0.16	0.17	0.13	0.18	0.15	0.16	0.16	0.12	0.11					
MnO	0.10	0.13	0.11	0.10	0.15	0.12	0.10	0.10	0.14	0.12	0.10					
S	0.00	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01					
Trace elements ppm																
BA	1256	1473	1388	1505	2055	1428	1394	1488	1404	1897	1424					
CR	63	62	45	57	74	53	58	53	52	67	68					
ZR	98	99	95	97	94	90	91	96	116	94	100					
SR	284	244	506	384	268	316	180	554	274	459	353					
RB	107	147	120	103	154	133	135	105	188	144	159					
Y	21	15	16	17	16	15	13	15	14	13	14					
NB	0	0	4	1	0	3	0	4	0	0	0					
ZN	70	68	80	69	71	78	70	80	83	67	63					
NI	66	29	16	8	10	10	14	18	25	11	12					
V	117	43	76	80	61	76	66	71	70	56	43					
SUBTOTAL	93.75	94.35	96.92	96.29	97.95	96.32	96.45	96.95	96.38	95.79	94.89					
LOI	5.88	4.20	3.32	2.92	1.31	3.59	3.76	2.53	3.34	4.21	4.24					
TOTAL	99.63	98.55	100.24	99.21	99.26	99.91	100.21	99.48	99.72	100.00	99.13					

Table 4.1 cont...

7 Ash flows			11 Saunders Member					12 Theban Member					12int
	23	24	25	26	27	28	29	30	31				
Sample No 89-36	8-56-2	8-25-14	8-50-16	9-9-1	9-13-8	9-2-5	9-7-12	9-6-7					
SiO ₂	58.99	60.61	63.90	63.54	61.75	61.20	54.44	54.28	64.44				
Al ₂ O ₃	16.59	16.59	15.80	16.00	15.92	16.05	17.87	17.79	15.44				
FeO*	5.29	5.21	5.13	5.20	5.37	5.66	7.84	8.20	4.45				
FeO	1.97	1.96	1.98	1.99	2.00	2.01	2.28	2.29	1.95				
Fe ₂ O ₃	3.32	3.25	3.15	3.21	3.37	3.65	5.56	5.91	2.50				
MgO	1.74	1.73	1.98	1.85	2.02	1.94	2.37	2.67	1.63				
CaO	4.19	4.18	3.86	4.24	4.22	5.07	6.65	6.21	4.10				
Na ₂ O	4.69	4.26	3.31	3.74	3.46	3.64	4.47	3.86	3.46				
K ₂ O	2.78	3.04	3.51	3.07	3.68	2.90	2.39	3.63	3.80				
TiO ₂	0.47	0.46	0.48	0.49	0.50	0.51	0.78	0.79	0.45				
P ₂ O ₅	0.21	0.21	0.22	0.21	0.19	0.18	0.42	0.38	0.14				
MnO	0.15	0.24	0.12	0.14	0.12	0.15	0.17	0.19	0.13				
S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
Trace elements ppm													
BA	1118	1085	1227	1231	1344	1301	1552	2059	1481				
CR	38	55	54	60	70	56	39	40	92				
ZR	96	89	94	87	95	89	76	75	111				
SR	533	576	581	587	674	615	926	918	513				
RB	76	90	84	69	88	62	39	77	87				
Y	21	21	18	20	21	20	23	26	19				
NB	0	5	2	4	0	0	3	0	3				
ZN	82	98	81	92	75	73	120	116	74				
NI	12	22	24	20	17	8	19	18	20				
V	95	98	99	118	110	126	209	186	106				
SUBTOTAL	95.31	96.74	98.54	98.71	97.48	97.54	97.70	98.29	98.35				
LOI	4.22	3.95	1.51	1.73	1.67	2.29	2.24	2.15	1.17				
TOTAL	99.53	100.69	100.05	100.44	99.15	99.83	99.94	100.44	99.52				

TABLE 4.2: Whole rock chemistry recalculated to 100%

	Stuhini Group				Black Lake Stock				Intrusive B				A		C	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Sample No	9-10-12	9-10-6	8-56-16	8-56-12	9-11-3	9-4-13	9-9-13	9-13-7	8-41-8	9-9-14	9-5-9	17	18	19	20	21
SiO ₂	53.55	50.62	49.63	52.10	63.98	64.30	64.96	64.45	65.28	63.25	52.24	17	18	19	20	21
Al ₂ O ₃	13.29	16.24	17.17	14.14	16.25	16.04	15.75	16.07	15.71	17.01	18.19	22	23	24	25	26
FeO*	10.10	11.41	11.03	10.33	5.26	5.27	4.89	5.16	5.04	5.22	10.39	27	28	29	30	31
FeO	7.61	8.93	8.63	7.94	3.33	3.31	2.92	3.18	3.07	3.18	7.91	32	33	34	35	36
Fe ₂ O ₃	2.49	2.47	2.39	2.49	1.93	1.96	1.97	1.99	1.97	2.05	2.48	37	38	39	40	41
MgO	7.51	6.80	7.10	7.88	1.95	2.02	1.72	1.96	1.90	1.81	3.69	42	43	44	45	46
CaO	8.60	6.40	9.26	8.46	4.74	4.43	3.60	4.02	4.05	4.46	8.46	47	48	49	50	51
Na ₂ O	3.79	3.06	3.31	3.61	3.43	3.48	4.30	3.57	3.29	4.06	3.50	52	53	54	55	56
K ₂ O	1.56	3.75	1.09	1.88	3.46	3.41	3.76	3.74	3.66	3.06	1.67	57	58	59	60	61
TiO ₂	0.99	0.97	0.89	0.99	0.43	0.46	0.47	0.49	0.47	0.55	0.98	62	63	64	65	66
P ₂ O ₅	0.27	0.25	0.22	0.23	0.22	0.23	0.16	0.18	0.15	0.21	0.40	67	68	69	70	71
MnO	0.17	0.20	0.14	0.17	0.12	0.11	0.13	0.10	0.14	0.10	0.20	72	73	74	75	76
S	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	77	78	79	80	81
Trace elements ppm																
BA	384	1493	256	733	1354	1458	1517	1410	1769	1589	1327	82	83	84	85	86
CR	283	94	152	279	60	67	73	49	76	68	43	87	88	89	90	91
ZR	95	43	36	94	94	89	112	101	106	142	84	92	93	94	95	96
SR	323	636	476	314	628	680	533	606	586	602	860	97	98	99	100	101
RB	26	63	17	32	84	83	79	82	73	53	32	102	103	104	105	106
Y	23	17	14	23	17	18	17	22	18	15	25	107	108	109	110	111
NB	0	0	0	0	2	0	21	20	0	0	0	112	113	114	115	116
ZN	76	88	82	81	46	58	66	74	84	47	110	117	118	119	120	121
NI	86	53	86	77	7	14	38	24	14	18	12	122	123	124	125	126
V	328	407	386	307	113	109	101	113	135	96	275	127	128	129	130	131

Table 4.2 cont..

Sample no	3	4a Dacite flow												5 Ash flows				
		12	13	14	15	16	17	18	19	20	21	22						
Sample no	89-28	88-08	89-33	9-12-6	8-59-1	88-2	FOXT	9-14-10	88-1	88-14	88-24							
SiO ₂	63.38	66.90	66.29	65.87	67.07	65.78	66.11	66.78	63.96	66.43	66.96							
Al ₂ O ₃	17.26	16.48	16.04	16.27	15.63	16.15	16.04	16.21	18.56	16.22	16.09							
FeO*	5.56	3.76	4.34	4.59	3.78	4.33	4.38	4.06	4.19	3.60	3.70							
FeO	3.59	1.89	2.45	2.67	1.91	2.42	2.48	2.19	2.29	1.74	1.86							
Fe ₂ O ₃	1.97	1.87	1.89	1.92	1.87	1.90	1.89	1.87	1.90	1.87	1.84							
MgO	1.63	1.27	1.58	1.80	1.42	1.60	1.64	1.41	1.61	1.27	1.22							
CaO	4.82	3.29	3.33	2.70	1.96	3.44	3.06	2.22	2.32	3.59	3.68							
Na ₂ O	3.17	2.76	3.67	4.00	3.41	3.38	3.78	4.36	3.41	3.13	3.05							
K ₂ O	3.23	4.63	3.82	3.83	5.79	4.37	4.14	4.05	4.98	4.84	4.50							
TiO ₂	0.47	0.37	0.39	0.42	0.37	0.40	0.39	0.37	0.40	0.37	0.34							
P ₂ O ₅	0.15	0.13	0.17	0.18	0.13	0.19	0.16	0.17	0.17	0.13	0.12							
MnO	0.11	0.14	0.11	0.10	0.15	0.12	0.10	0.10	0.15	0.13	0.11							
S	0.00	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01							
Trace elements ppm																		
BA	1340	1561	1432	1563	2098	1483	1445	1535	1457	1980	1501							
CR	67	66	46	59	76	55	60	55	54	70	72							
ZR	105	105	98	101	96	93	94	99	120	98	105							
SR	303	259	522	399	274	328	187	571	284	476	372							
RB	114	156	124	107	157	138	140	108	195	150	168							
Y	22	16	17	16	16	16	13	15	15	14	15							
NB	0	0	4	1	0	3	0	4	0	0	0							
ZN	75	72	83	72	72	81	73	83	86	70	66							
NI	70	31	17	8	10	10	15	19	26	11	13							
V	125	46	78	83	62	79	68	73	73	58	45							

Table 4.2 cont..

Sample No	7 Ash flow		11 Saunders Member						12 Theban Member				12int
	23	24	8-56-2	25	26	27	28	29	30	31			
	89-36	8-56-2	8-25-14	8-50-16	9-9-1	9-13-8	9-2-5	9-7-12	9-6-7				
SiO ₂	61.89	62.65	64.85	64.37	63.35	62.75	55.72	55.19	65.56				
Al ₂ O ₃	17.41	17.15	16.03	16.21	16.33	16.46	18.29	18.09	15.71				
FeO*	5.55	5.39	5.21	5.27	5.51	5.80	8.02	8.34	4.53				
FeO	3.56	3.41	3.22	3.27	3.50	3.78	5.73	6.03	2.57				
Fe ₂ O ₃	1.99	1.98	1.99	2.00	2.01	2.02	2.30	2.30	1.96				
MgO	1.83	1.79	2.01	1.87	2.07	1.99	2.43	2.71	1.66				
CaO	4.40	4.32	3.92	4.30	4.33	5.20	6.81	6.31	4.17				
Na ₂ O	4.92	4.40	3.36	3.79	3.55	3.73	4.58	3.92	3.52				
K ₂ O	2.92	3.14	3.56	3.11	3.78	2.97	2.45	3.69	3.87				
TiO ₂	0.49	0.48	0.49	0.50	0.51	0.52	0.80	0.80	0.46				
P ₂ O ₅	0.22	0.22	0.22	0.21	0.19	0.18	0.43	0.39	0.14				
MnO	0.16	0.25	0.12	0.14	0.12	0.15	0.17	0.19	0.13				
S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
Trace elements ppm													
BA	1173	1122	1245	1247	1379	1334	1589	2094	1507				
CR	40	57	55	61	72	57	40	41	94				
ZR	101	92	95	88	97	91	78	76	113				
SR	559	595	590	595	691	631	948	933	522				
RB	80	93	85	70	90	64	40	78	89				
Y	22	22	18	20	22	21	24	26	19				
NB	0	5	2	4	0	0	3	0	3				
ZN	86	101	82	93	77	75	123	118	75				
Ni	13	23	24	20	17	8	19	18	20				
V	100	101	100	120	113	129	214	189	108				

Table 4.3: * CATION NORMATIVE MINERALOGY

SAMPLE	ap	il	or	ab	an	c	mt	di	hy
1.00	0.56	1.37	9.17	33.87	14.55	0.00	2.48	20.91	9.30
2.00	0.53	1.35	18.00	27.24	18.29	0.00	2.80	9.32	0.00
3.00	0.47	1.24	6.44	29.65	28.62	0.00	2.71	12.57	1.82
4.00	0.48	1.36	11.00	32.22	16.72	0.00	2.53	18.79	1.71
5.00	0.47	0.61	20.62	31.06	18.87	0.00	1.63	2.71	8.62
6.00	0.49	0.64	20.33	31.55	18.17	0.00	1.63	1.95	9.14
7.00	0.34	0.66	22.28	38.66	12.59	0.00	1.51	3.41	7.18
8.00	0.38	0.58	22.27	32.28	16.87	0.00	1.60	1.60	8.98
9.00	0.33	0.66	21.85	29.86	17.48	0.00	1.57	1.45	8.89
10.00	0.45	0.76	18.12	36.57	19.24	0.00	1.61	1.27	8.68
11.00	0.84	1.37	9.96	31.66	29.23	0.00	2.59	8.38	15.66
12.00	0.32	0.66	19.30	28.79	23.20	0.15	1.73	0.00	9.31
13.00	0.27	0.52	27.71	25.05	15.66	1.40	1.17	0.00	6.81
14.00	0.35	0.55	22.70	33.19	15.56	0.22	1.34	0.00	8.10
15.00	0.37	0.58	22.71	36.01	12.28	1.16	1.42	0.00	8.86
16.00	0.27	0.52	34.7*	31.14	9.02	0.54	1.18	0.00	7.30
17.00	0.39	0.57	26.01	30.61	15.94	0.06	1.34	0.00	8.15
18.00	0.33	0.55	24.54	34.12	14.22	0.16	1.35	0.00	8.26
19.00	0.35	0.52	23.96	39.20	9.93	1.10	1.25	0.00	7.35
20.00	0.35	0.56	29.48	30.71	10.46	4.07	1.29	0.00	8.04
21.00	0.26	0.51	28.87	28.37	16.03	0.00	1.12	0.89	6.18
22.00	0.25	0.47	26.86	27.63	17.12	0.00	1.15	0.44	6.37
23.00	0.46	0.68	17.16	44.00	16.72	0.00	1.70	2.86	8.32
24.00	0.45	0.66	18.57	39.54	17.74	0.00	1.66	1.82	8.79
25.00	0.47	0.68	21.23	30.43	18.14	0.07	1.62	0.00	10.01
26.00	0.45	0.70	18.50	34.25	18.15	0.00	1.63	1.52	8.93
27.00	0.41	0.72	22.45	32.08	17.59	0.00	1.70	2.20	9.31
28.00	0.39	0.73	17.69	33.74	19.50	0.00	1.44	4.21	9.10
29.00	0.90	1.11	14.45	41.07	22.14	0.00	1.98	7.05	10.80
30.00	0.82	1.02	13.24	37.64	20.29	0.00	2.26	6.46	9.00
31.00	0.28	0.64	23.02	31.86	15.76	0.00	1.40	3.38	6.75

Table 4.3: * CATION NORMATIVE MINERALOGY cont..

SAMPLE	ol	q	ne	Ab	(Mole %)	Fo	Alumina/ Alkali Class	A/CNK	(Mole %)	ANK	Na ₂ O-1. K ₂ O	Fe ₂ O ₃ / FeO used
1	7.78	0.00	0.00	30.04	68.49	metakumin	0.56	1.68	sodic	0.30		
2	18.70	0.00	3.77	35.30	63.06	metakumin	0.77	1.71	potassic	0.30		
3	16.49	0.00	0.00	49.12	64.87	metakumin	0.73	2.59	sodic	0.30		
4	15.18	0.00	0.00	34.16	68.97	metakumin	0.61	1.77	sodic	0.30		
5	0.00	15.42	0.00	37.79	54.49	metakumin	0.90	1.73	potassic	0.40		
6	0.00	16.10	0.00	36.55	55.51	metakumin	0.92	1.70	potassic	0.40		
7	0.00	13.39	0.00	24.56	53.59	metakumin	0.89	1.41	potassic	0.40		
8	0.00	15.33	0.00	34.32	55.67	metakumin	0.93	1.62	potassic	0.40		
9	0.00	17.91	0.00	36.92	55.03	metakumin	0.94	1.68	potassic	0.40		
10	0.00	13.31	0.00	34.47	53.91	metakumin	0.94	1.70	potassic	0.40		
11	0.32	0.00	0.00	48.00	50.68	metakumin	0.79	2.40	sodic	0.30		
12	0.00	16.56	0.00	44.62	48.91	metakumin	0.99	1.98	potassic	0.40		
13	0.00	21.41	0.00	38.47	52.21	peralumin	1.06	1.73	potassic	0.40		
14	0.00	17.98	0.00	31.91	54.16	metakumin	0.99	1.58	potassic	0.40		
15	0.00	16.62	0.00	25.43	56.16	peralumin	1.04	1.52	potassic	0.40		
16	0.00	15.25	0.00	22.46	54.48	peralumin	1.01	1.31	potassic	0.40		
17	0.00	16.94	0.00	34.25	54.57	metakumin	0.98	1.57	potassic	0.40		
18	0.00	16.47	0.00	29.41	55.00	metakumin	0.99	1.50	potassic	0.40		
19	0.00	16.34	0.00	20.21	53.14	peralumin	1.04	1.40	potassic	0.40		
20	0.00	15.04	0.00	25.42	55.37	peralumin	1.22	1.69	potassic	0.40		
21	0.00	17.77	0.00	36.11	53.54	metakumin	0.96	1.56	potassic	0.40		
22	0.00	19.71	0.00	38.26	51.72	metakumin	0.97	1.63	potassic	0.40		
23	0.00	8.11	0.00	27.53	51.51	metakumin	0.90	1.55	sodic	0.40		
24	0.00	10.76	0.00	30.97	50.93	metakumin	0.93	1.61	potassic	0.40		
25	0.00	17.34	0.00	37.34	55.91	metakumin	0.97	1.71	potassic	0.40		
26	0.00	15.88	0.00	34.64	53.76	metakumin	0.93	1.69	potassic	0.40		
27	0.00	13.54	0.00	35.41	55.30	metakumin	0.92	1.65	potassic	0.40		
28	0.00	13.20	0.00	36.62	49.35	metakumin	0.87	1.76	potassic	0.30		
29	0.00	0.50	0.00	35.02	46.75	metakumin	0.81	1.80	sodic	0.30		
30	0.00	9.26	0.00	35.02	50.15	metakumin	0.81	1.80	sodic	0.40		
31	0.00	16.90	0.00	33.10	54.66	metakumin	0.89	1.57	potassic	0.40		

The Toodoggone volcanics are significantly different with normative quartz in all samples except intrusive C (a pyroxene-plagioclase porphyry). They all contain normative hypersthene and orthoclase and some of the more aluminous and less calcic units contain normative diopside and or corundum. Normative plagioclase varies from An 25 to An 48 in intrusive C. The Toodoggone section is predominantly potassic and metaluminous, although nearly all of the A/CNK values are close to 1 and some samples are classified as peraluminous (Table 4.3).

4.2.2 Major element geochemistry

The whole rock analyses are listed in Table 4.1; the same data, recalculated to 100% without LOI, are listed in Table 4.2. The data are all plotted on a total alkalis versus silica diagram (Figure 4.1). The fields in this diagram were defined by the IUGS Commission on Systematics in Petrology (Le Bas et al., 1986). According to this classification scheme the Jock Creek section (units 3,4,5 and 7) and the Saunders Member (unit 11) are all dacites and the Theban Member is a basaltic trachyandesite. The intrusive rocks, including the Black Lake stock, all plot in the same field as the Jock Creek section except for intrusive C, a distinctive pyroxene porphyry. Rocks from the Saunders Member ignimbrite (Unit 11) are slightly less

silicic and alkalic than the Jock Creek section (units 3, 4, 5 and 7).

On a K_2O versus silica diagram (Figure 4.1), the Jock Creek section and the Saunders Member plot as high-potassium dacites while the Theban Member plots as high-potassium andesite and as shoshonite (Pecerillo and Taylor, 1976; Ewart, 1979).

The significance of these classifications is dependent upon the mobility of alkalis and the degree to which they have been changed by alteration. A comparison of Harker variation diagrams for major oxides show that K_2O and Na_2O (Figures 4.1, 4.2) show considerably more scatter than the less mobile elements (MgO , Zr , TiO_2 ; Figure 4.2 and 4.3) and that samples that cluster on a total alkalis versus silica diagram are considerably less clustered on a K_2O versus silica diagram (Figure 4.1); therefore, the variations in K_2O are probably secondary.

The Stuhini sample with 3.06 wt% potassium (sample 2) was the least amygdaloidal and freshest sample obtained from the Stuhini, but because it is the only sample of a glomeroporphyritic feldspar porphyry analysed, it is unclear if the potassium content is primary and representative of a potassic Stuhini suite or not.

The Jock Creek volcanics and the Saunders Member are subalkaline whereas the Theban member is slightly alkaline (Figure 4.1). The entire Toodoggone section plots in the

calc-alkaline fields (Irvine and Baragar, 1971) on an AFM (Figure 4.4) and normative anorthite versus alumina diagram. This distinction between calc-alkaline and tholeiitic may reflect alkali enrichment instead of iron depletion. The Jensen cation plot and FeO^* (total iron)/MgO versus silica plot suggested by Miyashiro (1974) give a more direct depiction of iron enrichment trends (Figure 4.5). The Saunders Member and Jock Creek section plot in the calc-alkaline field and the Theban Member and intrusive C in the tholeiitic field in both of these diagrams (Figure 4.5).

4.2.3 Trace element geochemistry

Trace element data is presented both as XY plots and as spidergrams (variation diagrams normalized to a MORB composition; Sun and McDonough, 1989). The large ion lithophile elements (LILE): K, Rb, Ba and Sr are all enriched relative to a mid-ocean ridge basalt (MORB). The high field strength, incompatible elements: Nb, Zr, Ti and Y are all slightly depleted except for P (Figure 4.6). Two samples from intrusive A yielded high Nb values but these were run concurrently with a standard that gave an anomalously high Nb reading (see Appendix II) and the Nb values for these analyses have been rejected.

The strongly compatible constituents Ni and MgO are all strongly depleted in the more felsic members; the Theban

member and unit C are more depleted than the Stuhini Group. Sr, compatible with plagioclase, is depleted relative to Rb, Ba, and K (Figure 4.6).

Most of the trace elements that are commonly used on tectonic discrimination diagrams are affected by fractionation of magnetite, hornblende and biotite (Pearce and Norry, 1979). These are all important phenocryst phases in the Toodoggone volcanics. Some of the elements, especially Zr, show a slight increase with silica content (Figure 4.3) and were probably not depleted by fractionation. The remaining trace elements show decreasing abundance with increasing silica.

Island arc magmatic rocks show much lower absolute contents of HFSE, especially Ti, Zr and Nb and Ta than MORBs, alkaline ocean basalts and continental flood basalts. Pearce and Norry (1979) present data for island arc and alkalic rift suites that show distinctive fields on Nb, Ti and Y versus Zr diagrams for basaltic rocks. They also present distribution coefficients and analytical data for intermediate through felsic compositions, that allows some of these diagrams to be applied to more differentiated compositions. Crystallization of amphibole will result in a decrease in Y in the residual melt but Zr will remain unaffected until the precipitation of biotite and zircon. These observations help explain the $\log Zr/Y$ versus Zr plot (Figure 4.7). The more mafic rocks of the Stuhini Group, the

Theban member and intrusive C, plot in the island arc field, but Y depletion in the more differentiated intrusives, the Jock Creek section and the Saunders Member, put these rocks in the within plate basalt (WPB) field. A more useful discrimination diagram for felsic rocks is the log Ti versus log Zr plot (Figure 4.7). Titanium is depleted as a result of magnetite, ilmenite and amphibole fractionation, but Zr is not affected unless biotite and zircon become important phases. The more mafic rocks plot in the island arc-MORB overlap field and the felsic rocks show a trend of decreasing Ti, consistent with magnetite fractionation. This trend keeps the more differentiated units in the arc field; within plate basalts would have higher initial Ti and Zr.

Titanium/vanadium plots have also been used to discriminate tectonic environment (Shervais, 1982). The partition coefficients for vanadium increase with increasing oxygen fugacity but the partition coefficients for Ti remain low so that mafic rocks from tholeiitic arcs have Ti/V ratios close to 10, calc-alkaline rocks have ratios from 10-20 and MORBs, alkalic oceanic and continental rocks all have ratios of 20-50 with higher absolute Ti and V in continental environments. The Ti-V plot for samples from the Toodoggone (Figure 4.8) shows a strong Ti-V correlation for the more felsic samples exhibiting a trend typical of that predicted for magnetite fractionation. The more mafic samples plot in the MORB field. This may be an artefact of the limited

sample population that Shervais used to make this diagram. All of the arc analysis used have $\text{TiO}_2 < 0.6$ wt%, whereas Gill (1981) in a compilation of 2500 andesite analysis shows that the average TiO_2 content of an arc andesite is 0.8 wt% and can be as high as 1.3 wt%. These analyses would plot in the MORB field on Figure 4.8

4.3 Previous analytical work

A limited database for the Hazelton volcanics already exists. Tipper and Richards (1976) presented enough major element data to show that the Hazelton volcanics were predominantly calc-alkaline, although the inclusion of dust tuffs and marine clastics in the analysis precludes the use of this data for an overview of the chemistry of the Hazelton Group. Analyses for the Toodoggone were done by Foster (1984) and Daikow (Ph. D. in progress). Foster presented 32 analyses including trace element data for a section exposed near the Toodoggone River. The majority of the samples were from hornblende phyric andesites (Metsantan Member?) that are not exposed in current study area and for Foster's units 19 and 20 that are correlative with the Saunders Member of this study. The samples are very similar to those described above; they are calc-alkaline and moderately potassic. The trace element concentrations are consistent with an arc origin. Foster included two very

potassic analyses that he described as trachytic. The samples were collected in the vicinity of the amethyst gold breccia deposit at Cheni and probably reflect hydrothermal potassium metasomatism. Daikow (pers. comm, 1988) has major element data for the Addogatcho Member, the Metsantan Member and Saunders Member. The Saunders and Addogatcho Members are both moderate to high potassium calc-alkaline dacites, whereas the Metsantan Member is a slightly alkaline andesite similar to the Theban member of this study.

Brown (1987) and Galley (1981) have presented whole rock analyses for the Hazelton Group exposed near Stewart, on the west side of Stikinia. The analyses are very similar to the analyses from the Toodoggone assemblage except that andesitic chemistries predominate and some samples plot in the tholeiitic field, although overall trends on AFM diagrams do not suggest significant iron enrichment with increasing differentiation.

4.4 Discussion

There are several important aspects to the rock chemistry. The majority of the Toodoggone section, with the exception of the Theban member, consists of high potassium dacites. Although high potassium basalts do occur in anomalous arc settings, the vast majority of potassic dacites are erupted in continental arc settings, most

notably in the Andean and Mediterranean arcs and the Tertiary volcanic fields in the western United States and Mexico (Ewart, 1979). These areas all have thicker crust than oceanic island arcs, which tend to be low-K and calc-alkaline with a higher percentage of tholeiitic compositions. Calc-alkaline rocks are generally erupted in mature or continental arcs where the crust is more than 25 kilometres thick (Miyashiro, 1974). Most of the Hazelton Group rocks that have been analysed to date is calc-alkaline and in most areas basaltic rocks are common or andesitic rocks dominate the lower part of the succession. This is typical of island arcs that develop on existing terranes. Volcanism tends to evolve towards more felsic compositions as the arc edifices build to higher levels. The Toodoggone volcanic assemblage differs from the rest of the Hazelton in several ways. The Toodoggone volcanics are entirely subaerial and the earliest eruptive units are large volume dacitic ignimbrites. Dacitic compositions dominate the entire succession with andesites restricted to one area. Similar ignimbrite fields are known in Mexico (Gunderson et al., 1986) and the Central Volcanic Zone of the Andes (Guest, 1969), continental areas with thick crust. The lack of andesitic and mafic eruptive products in the Andes has been attributed to the 70 km of crust in that area, causing ponding of basaltic melts and crustal melting (de Silva, 1989). Whatever the processes involved, the dacitic

chemistry and consistent subaerial environment of deposition of the Toodoggone volcanic assemblage suggests that there was thicker crust beneath the Toodoggone area than any other part of the Hazelton Group. The small number of Stuhini samples analysed, and their contamination by amygdules, precludes an accurate definition of the tectonic setting of the Late Triassic volcanics, but their marine setting, more mafic and less fractionated compositions (higher MgO, Ni, Cr) all indicate a more primitive magma. The crust beneath the Toodoggone area must have been thickened by Late Triassic magmatism and/or tectonism prior to the generation of the Toodoggone volcanic assemblage.

The chemistry of the Toodoggone volcanic assemblage, and probably of the Stuhini Group is similar to modern regions where the volcanics are clearly related to a subducting slab. The high LILE concentrations and HFSE depletion, particularly Nb and Zr, are characteristic of magmas erupted above Wadati-Benioff zones (Pearce, 1982; Gill, 1981). The Toodoggone samples are also enriched in P_2O_5 , a characteristic of some arc environments (Pearce, 1982). The cause of this enrichment is unclear although Kay (1977) notes that it locally correlates with a increase in $^{207}Pb/^{204}Pb$ ratios in arc lavas relative to MORBS. The lead isotopes suggest a sedimentary origin for some of the lead and consequently (?) for elements such as P (Pearce, 1982; Kay, 1977). Although some of the high field strength

elements (eg. Ti, Figure 5.4) may be low as a result of crystal fractionation, other elements (eg. Zr) increase towards more fractionated compositions and the low abundance of these elements relative to MORBS and alkalic continental basalts strongly imply an arc origin for the Jock Creek volcanics, the Saunders Member and associated intrusive rocks of the Black Lake and JK stocks.

Several of the diagrams imply a distinction between the dacitic Jock Creek volcanics and Saunders Member and the more mafic Theban Member and intrusive C. This distinction is based on only three samples and it is unclear to what extent these differences are an effect of fractional crystallization; however the current data imply that the Theban Member is tholeiitic, mildly alkaline and has trace element ratios similar to some MORBs.

If the Toodoggone volcanics were erupted more than 350 kilometres behind a volcanic front (see Chapter II, Tectonic Setting) they are unlikely to have such a strong arc character. The critical question that remains is how the Toodoggone volcanics acquired such a strong arc component. The simplest explanation is to present the Toodoggone volcanics as a mature island arc that developed above a west-dipping subduction zone that was consuming the Cache Creek Ocean. This is not the only possibility, the distribution of rock types within the Hazelton Group and the character of the Toodoggone volcanic assemblage suggest that

they could have been emplaced in a continental back-arc setting (see Figure 2.7 and Chapter II for a full discussion). The chemistry of the Toodoggone volcanic assemblage implies an arc origin, but is not necessarily incompatible with a continental back-arc origin. The sparse data collected from the more mafic members of the Toodoggone volcanics (Theban member, unit 12 and intrusive C) are depleted in the HFSE but are slightly alkalic (Figure 5.1) and have Ti/Zr , Ti/V (Figures 5.8, 5.9) ratios that plot in the MORB field not the island arc field. The chemistry of back-arc and arc magmas is probably controlled by variations in the chemistry of the source regions. The mantle beneath arcs produces melts enriched in LILE elements and depleted in Cr, Ni and incompatible high field strength elements relative to N-type MORB. The combination of depleted compatible and incompatible elements cannot be ascribed to simple fractionation processes. Most authors call for input of LILE from the subducted slab and depletion of incompatible elements as a result of earlier progressive partial melting (or oxidation of the mantle, stabilizing phases that are compatible with HFSE) and crystal fractionation. If back-arc volcanism occurs in an area underlain by a mantle that has been metasomatised by the fluids driven off of a recently subducted slab then magmas produced by partial melting may inherit an arc character even though there is no longer a subducting slab present.

These speculations can be compared to data from modern basaltic rocks erupted in both continental (Stern et al., 1990; Briggs et al., 1990) and marine (Saunders and Tarney, 1984; Weaver et al., 1979; Jenner et al., 1987) back-arc settings. These rocks usually have chemical characteristics that are transitional between island arc and MORB settings. Early rifting is commonly characterized by arc-type chemistries that change to a more MORB character as spreading proceeds in the back-arc basin (Gill, 1987).

Continental back-arcs are usually characterized by alkalic basalt fields with enriched LILE and enriched HFSE, particularly Nb and Ta (Stern et al., 1990). In the southern Andes, calc-alkaline andesitic stratovolcanoes geographically overlap with "back-arc" basaltic scoria cones that have the lower Ba/La and higher Nb and Ta than adjacent stratovolcanoes (Hickey-Vargas et al., 1989). This implies that the chemical differences are more dependent on melting and differentiation processes than variations in the chemistry of the underlying mantle.

The Toodoggone volcanics are enriched in LILE and depleted in Nb, Zr and Ti relative to MORB (Figure 4.6). This is similar to modern arc settings and a chemistry of this type could have resulted from metasomatism and partial melting of the mantle followed by crystal fractionation. Although this does not eliminate the possibility that the

Toodoggone volcanics were emplaced during the early stages of subaerial back-arc rifting and were derived from a part of the mantle that had been metasomatised by Triassic subduction, the simplest explanation of the data collected to date is that the Jock Creek volcanics and the Saunders Member are high-potassium dacites that were erupted above a west-dipping subducting slab. Conclusive evidence that west-dipping subduction of the Cache Creek Ocean beneath Stikinia continued through Hazelton time will have to include the recognition of Jurassic age fauna in oceanic rocks in the Cache Creek Group (see conclusions, chapter 6) and systematic increase in Nb, Ta and La versus the LILE in the Ankwil and Carruthers basalts as well as in the Bajocian basalts of the Telegraph Creek map-area (see Chapter II). Such a study of trace element variations across the entire Hazelton Group is well beyond the scope of this study.

Figure 4.1: Total alkalis versus silica and K_2O versus silica diagrams for the study area. Numbers refer to units discussed in text (Chapter III). Note the clustering of both extrusive and intrusive rocks from the Jock Creek volcanics and the Saunders Member in the dacite field. Greater scatter of data on K_2O versus SiO_2 may reflect alkali mobility during low grade alteration.

1=Stuhini basalt, C=intrusive C, 12=Theban member, $\square$ =Theban intrusive, $\blacksquare$ =Intrusive rocks including Black Lake stock, A and B, $\bullet$ =Jock Creek section, units 3,4,5,7, $\blacktriangle$ =Saunders ignimbrite.

Figure 4.2: Harker variation diagrams for some major elements. Clustering of data for the Toodoggone volcanics (units 4-12 and A,B,C) suggests that the data are reliable except for Na₂O (and K₂O, Fig. 4.1) which have been affected by low grade alteration. Symbols as in Fig. 4.1

Figure 4.2 (cont): Harker variation diagrams for major elements. Symbols as in Figure 4.1.

Figure 4.3: Harker variation diagrams for some trace elements. Zr, Y (note Cr and Ni, not plotted) are less abundant in the more felsic rocks (symbols) than in the Theban Member (unit 12) and intrusive C. Symbols as in Figure 4.1.

Figure 4.3 (cont): Harker variation diagrams for Ti and V. Ti and V are less abundant in the more felsic units (symbols) than the more mafic units. Symbols as in Fig 4.1.

Figure 4.4: AFM diagram (Irvine and Baragar, 1971). The felsic volcanics and intrusives of the Toodoggone volcanics are distinctly calc-alkaline, whereas the Stuhini Group and intrusive C are transitional towards a tholeiitic chemistry.

Figure 4.5: Jensen Cation plot (Jensen, 1976) and a FeO*/MgO versus silica diagram (Miyashiro, 1974) for the study area. Most of the samples are calc-alkaline, except for the Theban Member, intrusive C and the Stuhini Group which plot in the tholeiitic fields.

Figure 4.6: MORB normalized variation diagrams for selected units in the study area. All the data shows LILE enrichment and slight HFSE depletion relative to MORB. Nb values are all below detection limit. Normalizing values used are from Sun and McDonough (1989): Sr: 155 ppm, Rb: 5ppm, K:2100 ppm, Ba: 57 ppm, Nb: 8.3 ppm, Zr: 73 ppm, Ti: 6000 ppm, Y: 22 ppm.

Figure 4.6 (cont): MORB normalized plots of the Toadoggonic volcanics (average values) and the Stuhini Group. Note the consistent LILE enrichment and HFSE element depletion. Scatter in Nb is due to minor variations, all are below analytical detection limits.

Figure 4.7: Tectonic environment discrimination diagrams from Pearce and Norry (1979). Mafic units 12 and C plot in the arc-MORB overlap and MORB fields. Trends defined by data from felsic units are consistent with magnetite $\pm$ biotite and amphibole fractionation; this is also characteristic of arc environments.

Figure 4.8: Tectonic environment discrimination diagram from Shervais (1982). Low V and Ti concentrations in the felsic Toadoggone volcanics may be due to the fractionation of magnetite. Unit 12, the Theban member, plots in the MORB field, whereas the unit 1, the Stuhini group and intrusive C plot in the MORB, Columbia flood basalt overlap, a possible range for back arc chemistries. Symbols as in Figure 4.1.

CHAPTER 5 STRUCTURE

5.1 Introduction

The Toodoggone area is a relatively undeformed part of the Cordillera at the exposed crustal level. There is no evidence of plastic deformation within the study area and the stratigraphy has been offset only along brittle faults developed in the upper crust.

The stratigraphy within the study area (Map 1) is tilted into a gentle north-dipping homocline (see Figures 3.3 and 3.4). This simple structure is only disrupted in the vicinity of major fault zones and adjacent to intrusive bodies. The stratigraphy east of the Saunders Fault in the Mt. Todd area (Map 1) is warped into an open northwest-trending syncline, and sedimentary units within the Theban Member (unit 12) are tilted and disrupted by the numerous small intrusive bodies that characterize this unit. All of the stratigraphy west of the Saunders fault dips gently to the north, except adjacent to the Saunders fault, where panels of unit 3 (UTM N6346000, E624700) are pulled into alignment with the fault zone. The remaining dip variations on Map 1 are due to primary volcanic processes (See Chapter 3).

This chapter concentrates on two aspects of the local

structure. The first section describes the faults mapped at both 1:10,000 and 1:1,000 scale. The fault zones are rarely exposed on surface and they are generally interpreted from sharp offsets of known markers. Since the stratigraphy is generally shallowly north dipping, it is not possible to determine a unique slip vector for most of the faults, and the displacements are designated on Map 1 as relative up and down. Observations of structures in fault gouge from natural and artificial exposures are used to supplement the stratigraphic constraints on fault movement.

The second part of this chapter is a detailed analysis of the structures that host precious metal mineralization on the Shasta property itself. In Chapter VI these observations are integrated into a model that can be used to predict the current location of blind mineralized zones.

5.2 Faults

5.2.1 Introduction

The map area (Map 1, Figure 3.3) is transected by two major faults, the Saunders Fault and the Black Lake Fault. All of these faults are northwest-striking and are downdropped to the west.

The Saunders Fault is manifested within the map area as a broad zone of alteration with numerous fault splays. These

fault splays have been observed in three localities (UTM N6351700, E620000; N6348000, E622900; N6345200, E624700) where they have steep easterly dips. There are no cut off points or microstructures within the fault zone that delineate the sense of movement on the fault within the study area, but Daikow (pers. comm, 1988) has inferred five kilometres of right lateral displacement on the Saunders Fault, where it offsets part of a small stock exposed south of the Finlay River (Figure 3.1). The distribution of local faults (as discussed below) is consistent with this interpretation.

The Black Lake Fault strikes 150° and dips 60° to the west. It juxtaposes a coarse grained intrusive body on the west side against volcanic rocks on the east side, suggesting that the west block is uplifted. Observations within the fault zone are ambiguous but suggest that the Black Lake Fault is a steep reverse fault (see below, section 5.2.2)

Within the map-area (Figure 3.2, Map 1) there are three north striking faults exposed south of the Saunders fault (Figure 3.2, Map 1). All three faults strike between 160° - 190° and have a downdropped east block. The maximum vertical displacement occurs near the Saunders fault and decreases southward, suggesting that these faults nucleated near the Saunders fault and propagated southward. This association suggests that they are minor conjugate faults

that accommodated stress related to larger displacements on the Saunders fault.

Detailed mapping has revealed the presence of two cross-cutting fault sets on the property. They may be subsidiary to those described above. The earliest episode of faulting is a conjugate set of normal or normal oblique faults, the Jock faults and the Shasta fault (Figure 3.5, Map 2). These two faults subtend an angle of 80° (Figure 5.1). The sense of displacement on the Shasta fault can be inferred from several lines of evidence. The fault zone was exposed in an open pit during mining operations allowing observation of gouge textures. Details of the gouge zone (See below, Section 5.2.2) and the north plunging line of intersection between the Jock faults and the Shasta fault (Figure 5.1) all suggest a steep oblique slip vector. The actual slip vector for the Shasta fault probably lies between dip-slip and 65° south.

The surface trace of the Shasta fault is offset by the J1 fault, either as a result of normal dip-slip or right-lateral movement. Other minor faults on the property (see Map 2, Cayley vein area) also exhibit apparent right-lateral offset.

5.2.2 Microstructures of the Black Lake and Shasta Faults

Studies of the deformation of clay gouge (Logan et al.,

1979) and the application of experimental results to natural fault zones by Rutter et al. (1986) have set a firm basis for the use of microtextures in brittle gouge zones as kinematic indicators. Most authors use the terminology of Logan et al. (1979) to describe flattening fabrics (P surfaces) and primary (Y) and secondary (R1) shear surfaces (Figure 5.2). These planes are geometrically analogous to the S, C and shear band planes recognized in plastic sheared tectonites described by Berthe et al. (1979) and Lister and Snoke (1984).

The Black Lake Fault is exposed in a small col just south of the map area (UTM N6344100 E6205000) and the Shasta Fault was exposed during mining of the Creek zone, allowing detailed observations and sampling of the fault zones. Oriented samples of the gouge were collected and soaked in epoxy prior to and during slabbing for thin section preparation.

The Black Lake fault strikes 150° and dips 60° to the west. The fault zone is asymmetrical with 15 centimetres of very fine laminated clay gouge on the hanging wall and 40 centimetres of coarse broken gouge in the footwall (Plate 5.1).

There are numerous fractures in the adjacent wallrock but three fracture sets dominate; $175/90$, $165/72$ SW, $130/35$ SW. The Black Lake stock exposed in the hanging wall is cut by large joints that strike 88° and dip 18° south (Figure

5.1). These prominent joints can be observed from a distance of several kilometres. The very fine grained clay gouge is weakly lineated, measured within the plane of the fault, the lineation pitches 75° toward 330° . Sections cut perpendicular to the strike of the zone and subparallel to the lineation are extremely fine grained and exhibit no optically resolvable textures. Sections cut in the same plane but in the broken footwall zone exhibit highly fractured rock with fragments in a fine grained matrix, both of which are crosscut by three sets of shear fractures (Plate 5.2). The most common orientation is parallel to the shear surface; shear surfaces oriented 65° counterclockwise to this plane are also common. The third shear fracture orientation is a poorly developed plane at 135° counterclockwise from the shear plane. These three planes are equivalent to the Y, P and R1 surfaces (Figure 5.2) described by Logan et al., (1979) in experimentally deformed clay gouge and in natural clay gouge by Rutter et al. (1986). The P surfaces described by these authors are usually not shear surfaces but instead are defined by aligned clay platelets lying in the flattening plane. The Black Lake sample did not develop significant clay gouge matrix and the P surface appears to be defined by early shear surfaces. The sense of movement on most of the shear planes is obscure but several of the Y surfaces exhibit right-lateral shear. The sense of offset is indicated by

bent and fractured feldspar and quartz grains that are pulled into the shear plane (Plate 5.2). The progression from extensively fractured grains to clay gouge is fairly abrupt; the fine grained gouge has undergone extreme grain size reduction and there are no distinctive textures remaining. The grains are deformed both by lattice bending, leading to the development of new grain boundaries, and by brittle failure. Although cataclasis is the dominant deformation process, some large feldspar grains are bent, recrystallised and lie in the flattening plane. The grains have not undergone pressure solution, they do not exhibit extensive polygonization and they lack any rotational fabrics. These predominantly cataclastic features are interpreted to have formed at shallow depths. Dilation during failure is considered to be an important mechanism of fault initiation and propagation (Sibson, 1986). The very low confining pressures at shallow crustal levels allow grains to dilate during failure. The fractured grains tend to show fragmentation and dispersal and do not develop the pressure solution features that are such a prominent feature of rocks in deeper level plastic shear zones.

The consistent right-lateral sense of shear on the Y surfaces, combined with the weak lineation in the clay gouge and the orientation of associated wallrock fractures all suggest that the Black Lake Fault is an oblique reverse fault with a slip vector that pitches within the plane

approximately 75° toward 330° (Figure 5.1).

Oriented samples were also collected from the Shasta Fault. This fault is a zone of clay gouge 40-60 cm wide that strikes 175° and dips 60° west. The walls of the gouge zone are sharp and have fault striations that pitch steeply to the north and south. There are no prominent fracture sets in the wallrock but conjugate faults, the Jock Faults, are oriented $120/50$ NE (Figure 5.2). The fault gouge consists of fragments of quartz and sulphide in a very plastic clay matrix. The clay is clearly foliated and the foliation is locally crenulated into small tight folds with gently south plunging fold axes. Thin sections cut perpendicular to the strike of the fault show isolated quartz and sulphide fragments within fine-grained foliated clay. The clay is cut by numerous anastomosing shears. The orientation of the clay platelets is variable, especially in the vicinity of large grains and where crenulated, but some zones are fairly homogenous and they exhibit two orientations of shear and a planar clay fabric. The two planes are γ surfaces parallel to the plane of shear and R_1 surfaces at 155° counterclockwise from the shear plane. The sense of shear on these surfaces is commonly ambiguous but the consistent orientation of the shear surfaces and the way that they truncate the flattening fabric all suggest a right lateral sense of shear (Plate 5.3). This is consistent with the slip vector suggested by stratigraphic relationships, the

conjugate fault set intersection and the fault striations, all of which suggest that the Shasta Fault is a normal oblique fault with a slip vector that pitches between 65° south and vertical (Figure 5.1).

It is evident from these data that petrographic examination of gouge samples, combined with macroscopic observations, can help to define the sense of shear in brittle fault zones, even at very shallow crustal levels.

5.3 Mineralized stockwork zones

5.3.1 Introduction

The mineralized zones on the Shasta property are multistage quartz-calcite stockwork systems. The precious metal mineralization consists of native gold and silver, electrum and acanthite in association with minor pyrite, sphalerite, galena and chalcopyrite (Thiersch and Williams-Jones, 1990). The mineralization occurs as veinlets and breccia veins less than one metre wide that are lensoidal features within broader (>10 metres) zones of potassic alteration, silicification and veining. The higher grades of mineralization do not correlate with the intensity of alteration or brecciation. Spectacular silver grades are often associated with a late episode of carbonate dominated veining that exhibits restricted alteration haloes characterized by chlorite-epidote and hematite (Thiersch and

Williams-Jones, 1990).

The mineralized zones are not discrete veins, and the diffuse and irregular nature of veining within the zones make initial structural interpretations difficult. The overall distribution of the mineralized zones was initially recognized by using a portable VLF-R system that delineated the altered zones as resistivity highs. Follow-up trenching, drilling and mapping has allowed further definition of the geometry of the mineralized zones.

There is no evidence for stratigraphic displacement across the mineralized zones and the stockwork-breccia zones are tabular zones of dilation and incipient strain. The structural analysis outlined below suggests that the mineralized zones formed within favourable (permeable) host rocks in response to a sub-horizontal tensile or minimum compressive stress.

5.3.2 Geometry of the mineralized zones

The mineralized system has been divided into twelve zones (Map 2, Figure 3.5), although it is now clear that many of the zones are continuous and part of a single hydrothermal-structural system. The JM and Creek zones occur in the central part of the property. These two zones host all of the ore reserves indicated to date. The JM zone strikes 330° and dips 50° northeast. The Creek zone strikes

175° and dips 50° to the west. The two zones subtend an angle of 80° and intersect in a shallowly north plunging line (Figure 5.3). The Creek zone has a strike length of 600 metres, extending from Jock Creek to where it appears to splay into a system of northeast dipping veins known as the Baker zone (Map 2, Figure 3.5). The JM zone has a greater strike length, possibly extending 800 metres from Jock Creek to the Just Over zone. The Rainier and Cayley veins are steeply dipping, south striking vein systems that splay off of the JM zone. The Cayley and Baker zones both break up into a diffuse region of alteration and veining known as the Upper Rainier vein system, where 150° and 120° striking veins dominate. There are two zones subparallel to the JM zone. The JM East zone is 500 metre long stockwork zone that strikes 150°. The Jock zone is an area of alteration and veining dominated by 150° and 110° striking segments that are displaced by the Jock faults (Figure 3.5, Map 2).

Isolated from this complicated system of stockwork zones are the O zone and East zone. The O zone consists of a pair of subparallel zones that strike 310° and dip steeply northeast. The East zone is a mineralized area that strikes northwesterly and is of limited extent.

The orientation of these stockwork zones is relatively consistent. The two principal zone orientations are characterized by the JM and Creek zones that define a conjugate set with a shallowly plunging line of intersection

(Figure 5.3). This suggests that the zones are a record of a subvertical maximum compressive stress (Anderson, 1951). This interpretation is supported by the orientations of veinlets within broad stockwork zones. Figure 5.3 shows that nearly all of the veinlets dip steeper than the bounding walls of the overall zones but have a similar strike (albeit with considerable scatter). Figure 5.4 shows how these veinlets are consistent with extension related to incipient down dip movement along the plane of the zones.

This geometry is not perfectly consistent in all parts of the mineralized system. The most obvious deviations are in the Upper Rainier and Jock zone areas where the 150° striking zones have 110° and 120° striking segments. The Rainier and Cayley veins have a similar strike to the Creek zone but steeper westerly dips, and subtend a shallower angle with the JM zone. These variations are not consistent with Anderson's model (1951) for conjugate fault systems developed in a consistent stress field. This commonly applied model is simplistic in two regards. It assumes that the physical properties of the deforming medium are homogeneous, and it assumes that strain is accommodated in two dimensions. Reches (1978,1983) and Krantz (1988) discuss the effects of a three dimensional stress field. They conclude that orthorhombic fault geometries result, and present some field examples of ideal orthorhombic fault geometry. Conjugate fault sets are a special case of a three

dimensional orthorhombic fault pattern that only occurs when the intermediate and minor strain axes are approximately equal.

The variations observed within the Shasta deposit may record an asymmetrically developed orthorhombic geometry (Figure 5.3). Although it is known that conjugate fault sets often develop asymmetrically, with a master fault and conjugate shear fractures (Hobbs et al., 1976), Krantz (1988) only deals with the ideal case of equally developed conjugate pairs. The orientation of principal strain axes predicted by the orthorhombic model differs from that of the simpler two dimensional system, although both models indicate a subvertical maximum compressive stress for the Shasta stockwork system. The strain axes predicted by an orthorhombic model and the principal stress directions predicted by Anderson (1951) are both indicated on Figure 5.3. The use of strain axes versus stress axes is arbitrary; the principal stress and strain axes are coaxial in a simple, non-rotational system with no volume change. The two models are indicated differently only to indicate that the two different orientations are from two different models.

This geometry could also reflect the development of simple conjugate sets in a shifting stress field. The JM and Creek zone set has the same mineralogy and characteristics as the less well developed southwest striking set suggesting that the two sets developed from the same hydrothermal

system and are roughly coeval.

The geometry of the mineralized zones has several important implications for exploration. Although the grade of the contained mineralization is independent of the intensity of stockworking, economic zones will only be hosted where sufficient extension has occurred to give economically significant widths and strike lengths. These zones would result from: (1) the intersection of two mineralized zones, (2) local rolls within the plane of the zone and (3) as extension veins resulting from minor movement across the mineralized zones. All of these features would be subhorizontal, rod shaped elements that plunge shallowly to the north parallel to the line of intersection of the JM and Creek zones (Figure 5.4). The importance of these controls is obvious in longitudinal sections of the JM and Creek zones that show that the zones pinch out along a shallow north plunging line (proprietary sections, Homestake Mineral Development Co. Ltd.). The sharp cutoff in grade and stockwork intensity in the JM zone also corresponds to a change in lithology and is probably not a simple structural control.

5.3.3 Lithological controls on the stockwork zones

All of the significant mineralization noted to date is

hosted by pyroclastic rocks of unit 5 (Map 2, Figure 3.5). Drilling into the basal stratigraphy beneath well defined veins of the Upper Rainier vein system and the Just Over zone indicates that these zones pinch out in the underlying deposits of unit 3. The dacite dome is altered throughout most of the property and hosts numerous small lensoidal zones and fracture fillings with high precious metal contents, but does not host a significant volume of mineralization anywhere on the property. In the Jock zone area (Figure 3.5), well defined mineralized zones hosted by unit 5 do not continue into the dacitic dome (unit 4). Drilling of the JM zone indicates that it consistently pinches to narrow, poorly mineralized stringers in the dacite. The overlying laharc deposits of unit 7 are locally altered but are not known to contain any mineralization.

The preferential localization of the stockwork zones within the pyroclastic rocks is somewhat surprising. The underlying dacite is a dense competent rock that should host clean, well defined fractures; therefore drilling was initiated within this unit on the belief that drill holes might intersect well defined feeder zones to the diffuse stockwork systems observed on the surface. Instead, the dacite dome underlying the pyroclastic rocks is erratically and poorly mineralized. The lack of well defined feeder zones in the underlying rocks suggests that the mineralizing fluids were largely contained within the pyroclastic rocks

and not funnelled upwards along a major conduit. The pyroclastic rocks were probably considerably more porous than either the dense dacite dome or the clay-rich laharic deposits of unit 7. The porous nature of unit 5 may have localized hydrothermal fluids within this unit, increasing pore pressures and facilitating structural failure. The sudden release of pressure caused by extensional failure would have resulted in the flow of hydrothermal fluid into the newly formed openings and rapid mineral deposition from the depressurized fluids (Sibson, 1987).

The mineralized zones are not only located mainly within unit 5 but they are also preferentially located along the contact between the dacite dome and the pyroclastic rocks. As individual zones diverge from this contact (see the Creek and Rainier-Cayley zones on Map 2) they splay and lose their economic significance. This observation stresses the importance of this contact in the genesis of the mineralization. Perhaps the dacite dome and its magmatic source provided a heat source that drove the hydrothermal system, while the pyroclastic rocks were a preferential aquifer that localized fluid flow and consequent structural failure.

The stockwork zones record an early history of weak extensional strain that clearly pre-dates the faults described above. The hanging wall of the Creek zone is defined by gouge of the Shasta Fault and the gouge contains

milled quartz and pyritic clay gouge from the mineralized zone. The geometry of the mineralized zones is similar to that of the post-mineral faults; both are characterized by sub-horizontal extensional strain with characteristic moderately dipping conjugate structures.

This geometry is difficult to relate to regional structures in the Toodoggone area. This connection is obscured by a lack of timing constraints on most faults. The main northwest striking faults systems (eg. Saunders Fault, Figure 3.1) are probably related to the large right lateral Finlay-Thudaka Fault system in the northern Rocky Mountain trench. These faults have considerable post-Cretaceous movement (Gabrielse, 1985) and are too young to be related to the Early Jurassic mineralization on the Shasta property, but could be temporally related to the post-mineral extensional and strike slip faults described above.

Recognizing Early Jurassic structures is even more difficult. The extensional environment in which the Shasta stockwork zones developed could be related to graben development as suggested by Vulimiri et al. (1983) for the nearby Cheni Mine or could be related to extensional bends in an Early Jurassic strike slip system. Volcanism in island arc, continental arc and back-arc systems is commonly related to either graben or caldera structures and coeval hydrothermal systems are likely in structures associated with either type of environment.

Figure 5.2: Geometric relationships between the P, Y and R1 surfaces in clay gouge as described by Logan et al., 1979 and Rutter et al., 1986.

Figure 5.3: A. Equal angle stereogram of poles to veins, joints and orientation of mineralized zones. Note that the veinlets within individual zones tend to have a similar strike (with considerable scatter) but steeper dips. B. Stereogram of the main mineralized zones. Principal stresses (C_1 , O_2 , O_3) and strains (E_x , E_y , E_z) are predicted from two-dimensional conjugate theory and orthorhombic fault geometry respectively. The use of stress instead of strain for two-dimensional geometry is for the convenience of display only, see text for a full discussion.

Figure 5.4: Geometry of the JM and Creek zone intersection. This model predicts that well developed ore shoots are rod-shaped, north-plunging elements.

Plate 5.1: Black Lake fault. Footwall (above clipboard) is broken and sheared; the hangingwall consists of 15 cm. of very fine clay. Photo looking south. UTM N 6344300 E 620900.

Plate 5.2a: Photomicrograph from the Black Lake fault. Note the orientation of feldspars and horizontal y-shear with right-lateral displacement indicated by bent and broken feldspar in lower right hand corner. P-shear in upper right hand corner. UTM N 6344300 E 620900. Scale 20x.

Plate 5.2b: Photomicrograph of strained and broken quartz grain. Shows right-lateral displacement on P-shear. Scale 50x.

Plate 5.3: Photomicrograph of fabric in the Shasta fault. The bright area in the centre of the plate shows clay platelets oriented in the P-fabric. The lens is bounded by Y-shears. Geometry suggests right-lateral displacement. UTM N 6347250 E 621050. Scale 50x.

Plate 5.4: Photomicrograph of fabric in the Shasta fault. Top plate shows Y-shears and R-shears in plane polarized light. Bottom plate shows Y-shears and P-fabric defined by clay platelets in cross polarized light. Fabric geometry suggests right-lateral displacement. UTM N 6347250 E 621050. Scale 50x.

CHAPTER VI: SUMMARY AND CONCLUSIONS

The Shasta deposit is a precious metal-bearing quartz-carbonate-sulphide stockwork system. The deposit is hosted by the Toodoggone volcanic assemblage, a predominantly dacitic succession of Lower to Middle Jurassic age.

The Toodoggone volcanics are a distinctive subaerial facies of the Hazelton Group. The distribution of rock types within the Hazelton Group suggests that it is not a simple island arc system. The Toodoggone volcanics were erupted either in a subaerial back-arc setting above an east-dipping subduction zone or as a mature magmatic arc above a west-dipping subduction zone that consumed the Cache Creek ocean during Early Jurassic time. The preponderance of Triassic fauna in the Cache Creek and in clasts in the Bowser basin have led to the general conclusion that the Cache Creek ocean had closed by the latest Triassic, but Cordey et al. (1987) recognized Early Jurassic fauna in the southern Cache Creek rocks and work in progress may indicate Jurassic fauna farther north (Cordey, 1990).

The Toodoggone volcanic assemblage is comprised of calc-alkaline, metaluminous to peraluminous high potassium dacites and andesites. The high LILE concentrations and depleted incompatible high field strength element abundances of the Toodoggone volcanic assemblage is typical of an arc environment and is not similar the chemistry of continental

back-arc volcanics in the Andes. The evolved chemistry of the Toadoggon volcanic assemblage, in which explosive dacitic eruptive products are much more abundant than andesitic or basaltic chemistries, is characteristic of areas with a significant crustal thickness, such as continental and mature arc terranes.

The tectonic setting of the Toadoggon volcanics will remain ambiguous until the age of the Cache Creek is settled and a complete geochemical transect across the Hazelton Group is available. If the Toadoggon volcanics and the Telkwa-Stewart volcanic chain are both magmatic arcs developed above inward-dipping subduction zones then the basalts erupted within the Nilkitwa trough and in the Telegraph Creek map-area will be alkalic or MORB-type basalts with higher Ta and Nb and lower Ba/La ratios than in the adjacent arc facies. Tectonic reconstructions of this type are required before we can offer reasonable models for the amalgamation of the western Canadian Cordillera. Understanding the processes that built the Cordillera may require the conception of processes much more complex than the progressive accretion of long linear belts to a linear margin. The key to these complexities is partially recorded by the distribution and type of volcanic and sedimentary rocks exposed within each terrane.

The succession in the study area is divided into four parts: (1) a Late Triassic basement of marine to subaerial

basaltic rocks, (2) the Jock Creek volcanics, comprising a felsic dome and associated ash flow deposits that were buried beneath 200 metres of laharic deposits, ash flows and a complex succession of lapilli tuffs, volcanic breccias and epiclastic rocks, (3) the Saunders Member, an Early Bajocian or Late Pliensbachian ignimbrite and (4) The Theban member, comprising andesitic flows, subvolcanic intrusives, coarse debris flow deposits and fine laminated turbidites. The Toodoggone volcanic assemblage is an exceptionally well preserved part of the Hazelton Group. Primary textures help to distinguish between welded ashflow deposits, unwelded ashflow deposits, laharic deposits, hot avalanche deposits and dome shaped dacitic extrusions. Telescoped relationships between a dacite dome and overlying stratigraphy suggest that the dome was extrusive but that continued to grow after subsequent units were deposited on top of the dome.

The Shasta Au-Ag stockwork deposit is spatially related to a dacitic dome within the Jock Creek volcanics. The stockwork zones are tabular zones of dilation and incipient strain that are part of an extensional conjugate fracture system. This geometry predicts that economically significant ore shoots are shallowly plunging rod-shaped features localized within zone intersections, rolls within the zones and tensional veins.

The location of the mineralized structures was controlled by the stratigraphy. The stockwork zones are

preferentially hosted within pyroclastic rocks along the flank of the dome. The permeability contrast between the dacite dome and the pyroclastic deposits may have localized the hydrothermal system within the pyroclastic rocks. The high pore fluid content within the pyroclastic deposits facilitated structural failure allowing the development of significantly continuous mineralized fracture systems. The hydrothermal system may have been driven by heat from the dacite dome and its magmatic source. This type of model for mineralization in the "epithermal" environment in which the location of structures is controlled by the hydrothermal system differs from the more common model for vein mineralization in deeper level terranes where hydrothermal systems are localized within large structural conduits.

This model can be used to direct regional exploration programs within the Toodoggone area; special attention should be focused on local volcanic centres of Early Jurassic age. Felsic domes may play an important role in the genesis of the mineralizing systems and may be recognized on textural evidence as well as local facies variations. The dacitic rocks have homogeneous porphyritic textures easily recognized in thin section and may have macroscopic flow banding. The margins of the dome may be indicated by dramatic changes in orientation and/or facies in the overlying rocks. The deposits are associated with structurally controlled potassic alteration and are more

subtle than the large gossans that are associated with argillic alteration. Propylitic alteration of the dacitic host rocks includes a change from white to pink plagioclase phenocrysts.

The Shasta property has been carefully covered using a variety of surface exploration techniques; new surface discoveries are unlikely. The model described above and in Chapter V can be used to direct drilling for blind targets. Two areas are obvious exploration targets. (1) The JM and Creek zone intersection is the core of the deposit. This zone is truncated by the Shasta fault and a potentially mineralized area of favourable stratigraphy has been displaced approximately 150 metres down-dip on the Shasta fault. (2) The contact between the dacite dome (unit 4a) and the pyroclastic rocks of unit 5 hosts all of the known mineralization. This contact has only been explored along the strike of the JM zone. Tracing the O zone up to this contact and then tracing the contact eastward to where it is exposed (and mineralized!) above Ferricrete Creek (UTM N6347050 E622750) would test the potential of this contact area. If it is mineralized, then it has the potential to host reserves equal to those already defined in the JM and Creek zones.

REFERENCES

Aldrick, J.D., 1987, Geology and mineral deposits of the Salmon River valley, Stewart area, NTS 104 A and 104 B; British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File Map 1987-22.

Aldrick, J.D., Brown, D.A., Harakal, J.E., Mortensen, J.K. and Armstrong, J.L., 1987, Geochronology of the Stewart mining camp (104B/1); British Columbia Ministry of Energy, Mines and Petroleum Resources, Fieldwork 1986, Paper 1987-1, p. 81-92.

Anderson, E.M., 1951, The Dynamics of Faulting; Oliver and Boyd, London.

Anderson, R.G., 1978, Preliminary report on the Hotailuh batholith: Its distribution, age and contact relationships in the Cry Lake, Spatsizi and Dease Lake map-areas, North-central British Columbia; in Current Research, Part A, Geological Survey of Canada, Paper 78-1A, p. 29-31.

Anderson, R.G., 1984, Late Triassic and Jurassic magmatism along the Stikine Arch and the geology of the Stikine Batholith, north-central British Columbia; in Current research, Part A, Geological Survey of Canada, Paper 84-1A,

p. 67-73.

Anderson, R.G. and Thorkelson, D.J., 1990, Mesozoic stratigraphy and setting for some mineral deposits in Iskut River map area, northwestern British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 90-1E, p. 131-140.

Barr, D.A., 1978, Chapelle gold-silver deposit, British Columbia; Canadian Institute of Mining and Metallurgy Bulletin, v. 72, No. 790, p. 66-79.

Berthe, D., Choukroune, P. and Jegouzo, P., 1979, Orthogneiss, mylonite and non-coaxial deformation of granites; the example of the South Armorican Shear Zone; Journal of Structural Geology, v. 1, p. 31-42.

Brantley, S.R., and Waitt, B.W., 1988, Interrelations among pyroclastic surge, pyroclastic flow, and lahars in Smith Creek valley during first minutes of May, 1980 eruption of Mt. St. Helens, USA; Bulletin of Volcanology, v.50, p. 304-326.

Briggs, R.M., Utting, A.J. and Gibson, I.L., 1990, The origin of alkaline magmas in an intraplate setting near a subduction zone: the Ngatura Basalts, North Island New

Zealand; Journal of Volcanology and Geothermal Research, v. 40, p. 55-70.

Britton, J.M., and Alldrick, D.J., 1988, Sulphurets map area (104A/05W; 104B/08E, 09E); British Columbia Ministry of Energy, Mines and Petroleum Resources, Fieldwork 1987, Paper 1988-1.

Brown, C., 1976, Caribbean gravity field and plate tectonics; GSA Special Paper 169, 79p.

Brown, D.A., 1987, Geological Setting of the Volcanic Hosted Silbak Premier Mine, Northwestern British Columbia (104A/4, B/1); Unpublished M. Sc. thesis, University of British Columbia.

Brown, D.A., Greig, C.J. and Gunning, M.H., 1990, Geology of the Stikine River-Yehiniko Lake area, northwestern B.C.; British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File 1990-1.

Bultman, R.T., 1979, Geology and Tectonic History of the Whitehorse Trough west of Atlin, British Columbia; Unpublished Ph. D. thesis, Yale University.

Cann, R.M., and Godwin, C.I., 1980, Geology and age of the

Kemess porphyry copper-molybdenum deposit, north-central British Columbia; Canadian Institute of Mining and Metallurgy Bulletin, v.73, p.94-99.

Carlisle, D., 1963, Pillow breccias and their aquagene tuffs, Quadra Island, British Columbia; Journal of Geology, v. 71, p. 48-71.

Carter, N.C., 1972, Toodoggone River Area; British Columbia Ministry of Energy, Mines and Petroleum Resources, Geology, Exploration and Mining, 1971, p. 63-70.

Clark, J.R., and Williams-Jones, A.E., 1987, Metallogenic implications of lithotectonic assemblages in the Toodoggone Au-Ag District, North-central British Columbia; Geological Association of Canada, Program with Abstracts, 1987, Volume 12, p. 32.

Cole, J.W., 1982, Tonga-Kermadec-New Zealand; in Thorpe, R.S., ed., Andesites, John Wiley and Sons, New York.

Coney, P.J. and Reynolds, S.J. 1977, Cordilleran Benioff zones; Nature, v. 270, p. 403-406.

Cordey, F., 1990, Radiolarian age determinations from the Canadian Cordillera; in Current Research, Part E, Geological

Survey of Canada, Paper 90-1E, p. 121-126.

Cordey, F., Mortimer, N., De Wever, P., and Monger, J.W.H., 1987, Significance of Jurassic Radiolarians from the Cache Creek Terrane, British Columbia; *Geology*, v. 15, p.1151-1154.

Cunningham, C.G., Rye, R.O., Steven, T.A. and Mehnert, H.H., 1984, Origins and significance of replacement and vein-type alunite deposits in the Marysvale volcanic field, west-central Utah; *Economic Geology* v. 79, p. 50-71.

Currie, L.D., 1984, The Provenance of Chert Clasts in the Ashman Conglomerates of the Northeastern Bowser Basin; unpublished B. SC. thesis, Queen's University, 59 p.

Currie, L.D., 1990, Metamorphic rocks in the Florence Range, Coast Mountains, northwestern British Columbia; in Current Research Part E, Geological Survey of Canada, Paper 90-1E, p. 113-119.

Daikow, L.J., 1983, A comparison of volcanic stratigraphy, structure, and hydrothermal alteration of the Silver Pond (Cloud Creek) and Wrich-Awesome claim groups, Toadoggone River; British Columbia Ministry of Energy, Mines and Petroleum Resources, *Geological Fieldwork 1982*, p. 134-141.

Daikow, L.J., 1984, Geology between the Toodoggone and Chukachida Rivers; British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork 1983, p. 139-145.

Daikow, L.J., 1985, Potassium-argon age determinations from biotite and hornblende in Toodoggone volcanic rocks; British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork 1984, Paper 1985-1, p. 299-300.

Daikow, L.J. and Koyanagi, V., 1988, Stratigraphy and mineral occurrences of Chikamin Mountain and Whitesail Reach map-area; British Columbia Ministry of Energy, Mines and Petroleum Resources Fieldwork 1987, Paper 1988-1, p. 155-168.

Daikow, L.J. and Mihalynuk, M., 1987, Geology of the Whitesail Reach and Troitsa Lake map-areas; British Columbia Ministry of Energy, Mines and Petroleum Resources Fieldwork 1986, Paper 1987-1, p. 171-179.

Daikow, L.J. ,Panteleyev, A. and Schroeter, T.G., 1985, Geology of the Toodoggone River map area, 94E; British Columbia Ministry of Energy Mines and Petroleum Resources Preliminary Map 61.

Dalsiel, I.W.D., 1981, Back-arc extension in the southern Andes: a review and critical reappraisal; Philosophical Transactions of the Royal Society of London, A 300, p. 319-335

de Silva, S.L., 1989, Altiplano-Puna volcanic complex of the central Andes, Geology, v. 17, p. 1102-1106.

deRosen-Spence, A. and Sinclair, A.J., 1988, Lower Jurassic volcanism of the Stikine super-terrane; British Columbia Ministry of Mines, Energy and Petroleum Resources, Fieldwork 1987, Paper 1988-1, p. 211-216.

Dewey, J.F., 1980, Episodicity, sequence and style at convergent plate boundaries; Geological Association of Canada Special Paper 20, p. 553- 573.

Bisbacher, G.H., 1981, Late Mesozoic-paleogene Bowser basin molasse and Cordilleran tectonics, western Canada; in A.D. Miall, (ed.), Sedimentation and Tectonics in Alluvial Basins; Geological Association of Canada Special Paper 23.

Elrich, E.N., 1968, Recent movements and Quaternary volcanic activity within the Kamchatka Territory; Pacific Geology, v. 1, p. 23-39.

Evenchick, C.A., and Green, G.M., 1990, Structural style and stratigraphy of southwest Spatsizi map-area, British Columbia, in Current Research, Part F, Geological Survey of Canada Paper 90-1F, p. 135-144.

Evenchick, C.A., in prep., Geometry, evolution, and tectonic framework of the Skeena Fold Belt, north-central British Columbia.

Ewart, A., 1979, A review of the mineralogy and chemistry of Tertiary-Recent dacitic, latitic, rhyolitic and related salic volcanic rocks; in F. Barker (ed) Trondhjemites, Dacites and Related Rocks, Elsevier, Amsterdam, Oxford, New York.

Fisher, R.V. and Schminke, H-U., 1984, Pyroclastic Rocks; Springer-Verlag, Berlin, Heidelberg, New York and Tokyo, 472 p.

Foster, D.B., 1984, Geology, Petrology and Precious Metal Mineralization, Toodoggone River Area, North Central British Columbia, Unpublished M. Sc. thesis, the University of British Columbia.

Francois, P.W., Roobol, M.J., Walker, G.P.L., Cobbold, P.R. and Coward, M., 1976, The San Pedro and San Pablo volcanoes

of northern Chile and their hot avalanche deposits, Geol. Rundschau, v. 63, p. 357-88.

Gabrielse, H., 1977, Geology of the Toodoggone (NTS 94E) and Ware (NTS 94 F W/2) map-areas, British Columbia; Geological Survey of Canada, Open File 483.

Gabrielse, H., 1985, Major dextral transcurrent displacements along the northern Rocky Mountain Trench and related lineaments in north-central British Columbia; Geological Society of America Bulletin, v. 96, p. 1-14.

Gabrielse, H., in prep., Late Paleozoic and Mesozoic terrane interactions in north-central British Columbia.

Gabrielse, H., Wanless, R.K., Armstrong, R.L., and Erdman, L.R., 1980, Isotopic dating of Early Jurassic volcanism and plutonism in north-central British Columbia; in Current Research, Part E, Geological Survey of Canada, Paper 80-1A, p. 27-32.

Galley, A.G., 1981, Volcanic Stratigraphy and Gold-Silver Occurrences on the Big Missouri Claim Group, Stewart, British Columbia; unpublished M. Sc. thesis, University of Western Ontario.

Gans, P.B., Mahood, G.A., and Schermer, E., 1989, Synextensional magmatism in the Basin and Range Province; A case study from the eastern Great Basin; Geological Society of America Special Paper 233, 53 p.

Gill, J.B., 1981, Orogenic Andesites and Plate Tectonics, Springer-Verlag, Berlin, 390 p.

Gill, J.B., 1987, Early geochemical evolution of an oceanic island arc and backarc: Fiji and the South Fiji basin; Journal of Geology, V. 95, p. 589-615.

Grove, E.W., 1986, Geology and Mineral Deposits of the Stewart Area, British Columbia; British Columbia Ministry of Energy, Mines and Petroleum Resources, Bulletin 58, 219 pp.

Guest, J.E., 1969, Upper Tertiary ignimbrites in the Andean Cordillera of part of the Antofagasta Province, northern Chile; Geological Society of America Bulletin, v. 80, p. 337-362.

Guest, J.E. and Sanchez, J., 1969, A large dacitic lava flow in northern Chile; Bulletin Volcanologique, v. 37, p 778-790.

Gunderson, R., Cameron, K. and Cameron, M., 1986, Mid-Cenozoic high-K calc-alkalic and alkalic volcanism in

eastern Chihuahua, Mexico: Geology and geochemistry of the Benavides-Pozos area; Geological Society of America Bulletin, v. 97, p. 737-753.

Gunning, M.H., 1990, Stratigraphy of the Stikine assemblage, Scud River area, northwest British Columbia (104 G/5, 6); British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork 1989, Paper 1990-1.

Hamilton, W.B., 1988, Plate tectonics and island arcs; Geological Society of America Bulletin, v. 100, p. 1503-1527.

Hansen, V.L., 1990, Yukon-Tanana terrane: A partial acquittal, Geology, v. 18, p. 365-369.

Hanus, V. and Vanek, J., 1985, Structure of Wadati-Benioff zones and volcanism produced by the process of subduction; Tectonophysics, v. 112, p. 51-67.

Hanus, V. and Vanek, J., 1988, Deep structure, volcanism and Wadati-Benioff zone of the northwestern Pacific continental margin; Journal of Geodynamics, v.10, p.24-41.

Hart, C.J.R. and Radloff, J.K., 1990, Geology of Whitehorse, Alligator Lake, Fenwick Creek, Carcross and parts of

Robinson map areas; (105 D/11,6,3,2 and 7), Indian and Northern Affairs Canada, Exploration and Geological Services Division, Yukon Region, Open File report 1990-4.

Hat erton, T. and Dickinson, W.R., 1969, The relationship between andesitic volcanism and seismicity in Indonesia, the Lesser Antilles, and other island arcs; Journal of Geophysical Research, v. ,p. 5301-5310.

Heald, P., Foley, M.K., and Hayba, D.O., 1987, Comparative anatomy of volcanic-hosted epithermal deposits: Acid-sulfate and adularia-sericite types; Economic Geology, v. 82, p. 1-26.

Hemley, J.J., Hostetler, P.B., Gude, A.J. and Mountjoy, W.T., 1969; Some stability relations of alunite; Economic Geology, v. 64, p. 599-612.

Hickey-Vargas, R., Roa, H. M., Escobar, L.L., Frey, F.A., 1989, Geochemical variations in Andean basaltic and silicic lavas from the Villarica-Lanin volcanic chain (39.5°S): an evaluation of source heterogeneity, fractional crystallization and crustal assimilation; Contributions to Mineralogy and Petrology, v. 103, p. 361-386.

Hobbs, B.E, Means, W.D. and Williams, P.F., 1976, An Outline

3

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

of Structural Geology; John Wiley and Sons, New York, Chichester, Brisbane, Toronto, Singapore.

Hoblitt, R.P., Miller, C.D. and Vallence, J.W., 1981, Origin and stratigraphy of the deposit produced by the May 18 directed blast; in P.W. Lipman and D.R. Mullineaux (eds.), The 1980 Eruptions of Mount St. Helens, Washington; United States Geological Survey Professional Paper 1250, p. 401-438.

Honnorez, J. and Kirst, P., 1975, Submarine basaltic volcanism: morphometric parameters for discriminating hyaloclastites from hyalotuffs; Bulletin Volcanologique, v. 39, p. 441-465.

Hutchison, C.S., 1976, Indonesian active arc: K, Sr, and Rb variations with depth to the Benioff zone; Geology, v. 4, p. 407-408.

Irvine, T.N. and Baragar, 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.

James, D.E., 1971, Plate tectonic model for the evolution of the Central Andes; Geological Society of America Bulletin, v p. 3325-3346.

Jenner, G.A., Cavood, P.A., Rautenschlein, M., and White, W.M., 1987, Journal of Volcanology and Geothermal Research, v. 32, p. 209-222.

Jensen, L.S., 1976, A New Cation Plot For Classifying Subalkalic Volcanic Rocks; Miscellaneous Paper 66, Ontario Division of Mines.

Jensen, M.L., Ashley, R.P. and Albers, J.P., 1971, Primary and secondary sulphates at Goldfield Nevada; Economic Geology, v. 66, p. 618-626.

Karig, D.E., 1971, Structural history of the Mariana Arc system; Geological Society of America Bulletin, v. 82, p. 323-344.

Karig, D.E., 1972, Remnant arcs; Geological Society of America Bulletin, v. 83, p. 1057-1068.

Kay, R.W., 1977, Geochemical constraints on the origin of Aleutian magmas; in M. Talwani and W.C. Pitman (eds.), Island Arcs, Deep-sea Trenches and Back-arc Basins, American Geophysical Union, Washington.

Kokelar, P., 1986, Magma-water interactions in subaqueous and emergent basaltic volcanism; Bulletin Volcanologique.,

v. 48, p. 275-289.

Krants, R.W., 1988, Multiple fault sets and three-dimensional strain: theory and application; Journal of Structural Geology, v. 10, No. 3, p. 225-237.

Lefebvre, D. and Gunning, M.H., 1989, Geology of the Bronson Creek area; British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File Map 1989-28.

Le Bas, M.J., Le Maitre, R.W., Streckeisen, A., and Zanettin, B., 1986, A chemical classification of volcanic rocks based on the total alkali-silica diagram; Journal of Petrology, v. 27, p. 745-750.

Le Maitre, R.W., 1976, Some problems of the projection of chemical data into mineralogical classifications; Contributions to Mineralogy and Petrology, v. 56, p. 181-189.

Letousey, J. and Kinimura, M., 1985, Okinawa trough genesis: structure and evolution of a back-arc basin developed in a continent; Marine and Petroleum Geology, v. 2, p. 111-130.

Lipman, P.W., Prostka, H.J. and Christiansen, R.L., 1972, Cenezoic volcanism and plate-tectonic evolution of the

Western United States. I. Early and Middle Cenezoic;
Philosophical Transactions of the Royal Society of London,
A. 271, p. 217-248.

Lister, G.S. and Snoke, A.W., 1984, S-C mylonites; Journal
of Structural Geology, v.6, p. 617-638.

Logan, J.M., Friedman, M., Higgs, W.G., Dengo, C., and
Shimamoto, T., 1979, Experimental studies of simulated fault
gouge and their application to studies of natural fault
zones; in Proceedings of Conference VIII, Analysis of
actual fault zones in bedrock; USGS Open File Report 79-
1239, p. 305-343.

Marsden, H. and Moore, J. M., 1989, The stratigraphic and
structural setting of the Shasta Au-Ag deposit, north-
central British Columbia; British Columbia Ministry of
Energy, Mines and Petroleum Resources Fieldwork 1988, Paper
1989-1, p. 395-407.

Marsden, H. and Moore, J.M., 1990, The stratigraphic and
structural setting of the Shasta Au-Ag deposit, north-
central British Columbia; British Columbia Ministry of
Energy, Mines and Petroleum Resources Fieldwork 1989, Paper
1990-1, p. .

Meijer, A., 1982, Mariana-Volcano Islands; in R.S. Thorpe, (ed.), Andesites: Orogenic Andesites and Related Rocks, John Wiley and Sons, New York, Chichester, Brisbane, Tokyo.

Mellors, R.A., Waitt, R.B., and Swanson, D.A., 1988, Generation of pyroclastic flows and surges by hot-rock avalanches from the dome of Mount St. Helens volcano, USA; Bulletin of Volcanology, v. 50, p. 14-25.

Mihalynuk, M.G., 1987, Metamorphic, Structural and Stratigraphic Evolution of the Telkwa Formation, Zymoetz River Area (103 I/8 and 93L/5), near Terrace, British Columbia; unpublished M. Sc. thesis, University of Calgary.

Mihalynuk, M.G. and Ghent, E.D., 1986, Stratigraphy, deformation and low grade metamorphism of the Telkwa Formation near Terrace, British Columbia; in Current Research, Part B, Geological Survey of Canada Paper 86-1B, p 721-726.

Mihalynuk, M.G., and Mountjoy, K.J., 1990, Geology of the Tagish Lake area (104 M/8,9E); British Columbia Ministry of Energy, Mines and Petroleum Resources, Fieldwork 1989, Paper 1990-1, p. 181-196.

Mihalynuk, M.G. and Rouse, J.M., 1988, Preliminary geology of the Tutshi Lake area, northwestern British Columbia (104M/15); British Columbia Ministry of Energy, Mines and Petroleum Resources Fieldwork 1987, Paper 1988-1.

Miyashiro, A., 1974, Volcanic rock series in island arcs and active continental margins; American Journal of Science, v. 274, p. 321-355.

Monger, J.W.H., 1974, Upper Paleozoic rocks of the Atlin terrane, northwestern British Columbia and south-central Yukon; Geological Survey of Canada Paper 74-47.

Monger, J.W.H., 1980, Upper Triassic stratigraphy, Dease Lake and Tulsequah map-areas, northwestern British Columbia; in Current Research, Part B, Geological Survey of Canada, Paper 80-1B, p. 1-9.

Monger, J.W.H., 1984, Cordilleran tectonics: A Canadian perspective; Bulletin Societe Geologique France, v. 26, p. 255-278.

Monger, J.W.H., and Berg, H.C., 1987, Lithotectonic terrane map of western Canada and southeastern Alaska; United States Geological Survey Miscellaneous Field Studies Map 1874-B.

Monger, J.W.H. and Church, B.M., 1977, Revised stratigraphy of the Takla Group, north-central British Columbia; Canadian Journal of Earth Sciences, v. 14, p. 318-326.

Monger, J.W.H. and Irving, E., 1980, Northward displacement of north-central British Columbia; Nature, v.14, p. 1832-1859.

Monger, J.W.H., Price, R.A. and Tempelman-Kluit, D.J., 1982, Tectonic accretion and the origin of two major metamorphic and plutonic belts in the Canadian Cordillera; Geology, v. 10, p. 70-75.

Munos, B.J., and Stern, C.R., 1989, Alkaline magmatism within the segment 38°-39° of the Plio-Quaternary volcanic belt of the southern South American continental margin; Journal of Geophysical Research, v. 94, p. 4545-4560.

Panteleyev, A., 1982, Toodoggone volcanics south of the Finlay River: British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork 1981, p. 135-141.

Panteleyev, A., 1983, Geology between the Toodoggone and Sturdee Rivers; British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork 1982, p. 143-148.

Parrish, R.R. and Ross, G.M., 1990, Review of the Precambrian basement of the Cordillera; Geological Association of Canada, Program with Abstracts, v. 15, p. A101.

Paterson, I.A. and Harakal, J., 1974, Potassium-argon dating of blue-schists from Pinchi Lake, central British Columbia; Canadian Journal of Earth Sciences, v. 11, p. 1007-1011.

Pearce, J.A., 1982, Trace element characteristics of lavas from destructive plate boundaries; in R.S. Thorpe (ed.) Andesites: Orogenic Andesites and Related Rocks, John Wiley and Sons, Chichester, New York, Brisbane, Tokyo.

Pearce, J.A. and Norry, M.J., 1979, Petrogenetic implications of Ti, Zr, Y and Nb variations in volcanic rocks; Contributions to Mineralogy and Petrology, v. 69, p. 33-47.

Pecerillo, A., and Taylor, S.R., 1976, Geochemistry of Eocene calc-alkaline volcanic rocks from the Kastamonu area, northern Turkey; Contributions to Mineralogy and Petrology, v. 58, p. 63-81.

Ransome, F.L., 1909, Geology and ore deposits of Goldfield,

Nevada; USGS Professional Paper 66, 258 pp.

Read, P.B. and Psutka, J.F., 1990, Geology, Ealua Lake east-half (104 H/13E) and Cullivan Creek (104 H/14) map areas, Geological Survey of Canada, Open File 2241.

Reches, Z., 1978, Faulting of rocks in a three dimensional strain field; Tectonophysics, v. 47, p. 109-129.

Reches, Z., 1983, Faulting of rocks in three dimensional strain fields II. Theoretical analysis; Tectonophysics, v. 95, p. 133-156.

Rose, W.I. Jr., 1972, Santiaguito Volcanic Dome, Guatemala; Geological Society of America Bulletin, v. 83, p. 1413-1434.

Rose, W.I., 1987, Volcanic activity at Santiaguito volcano, 1976-1984; in, J.H. Fink (ed.), The Emplacement of Silicic Domes and Lava Flows, Geological Society of America Special Paper 212, 145 p.

Rose, W.I., Jr., Grant, N.K., Hahn, G.A., Lange, I.M., Powell, J.L., Easter, J. and Degraf, J.M., 1977, The evolution of Santa Maria volcano, Guatemala; Journal of Geology, v. 85, p. 63-87.

Rutter, E.H., Maddock, R.H., Hall, S.H. and White, S.H., 1986, Comparative microstructures of natural and experimentally produced clay bearing fault gouges; Pure and Applied Geophysics, v. 124, No. 1/2, p 3-30.

Saunders, A.D. and Tarney, J., 1984, Geochemical characteristics of back-arc basins, in B.P. Kokelar and M.F. Howells (eds.) Marginal Basin Geology, Blackwell, Oxford.

Schminke, H.-U., 1966, Graded lahars in the type section of the Ellensburg Formation, south-central Washington; Geological Society of America Bulletin, v.78, p. 319-330.

Schroeter, T.G., 1981, Toadogone River; British Columbia Ministry of Energy, Mines and Petroleum Resources Fieldwork 1980, p. 122-133.

Shervais, J.W., 1983, Ti-V plots and the petrogenesis of modern and ophiolitic lavas; Earth and Planetary Science Letters, v. 59, p. 101-118.

Sibson, R.H., 1986, Brecciation processes in fault zones: Inferences from earthquake rupturing; Pure and Applied Geophysics, v. 124, No. 1/2, p. 159-175.

Sibson, R.H., 1987, Earthquake rupturing as a mineralizing

agent in hydrothermal systems; *Geology*, v. 15, p. 701-704.

Silver, E.A., 1978, The Mollucca Sea collision zone, Indonesia; *Journal of Geophysical Research*, v. 83, p. 1681-1691.

Smith, G.A., 1986, Coarse grained non-marine volcanoclastic sediment: terminology and depositional processes; *Geological Society of America Bulletin*, v. 97, p. 1-10.

Souther, J., 1971, Telegraph Creek map-area, *Geological Survey of Canada*, Paper 71-44.

Stern, T.A., 1985, A back-arc basin formed within continental lithosphere: The central volcanic region of New Zealand; *Tectonophysics*, v. 112, p. 385-409.

Stern, T.A., Frey, F.A., Futa, K., Zartman, R. E., Peng, Z. and Kyser, T.K., 1990, Trace-element and Sr, Nd, Pb and O isotopic composition of Pliocene and Quaternary alkali basalts of the Patagonia Plateau lavas of southernmost South America; *Contributions to Mineralogy and Petrology*, v. 104, p. 294-308.

Steven, T.A., and Lipman, P.W., 1976, Calderas of the San Juan volcanic field, southwestern Colorado; *USGS*

Professional Paper 958, 35p.

Stoffregen, R., 1987, Genesis of acid-sulphate alteration and Au-Cu-Ag mineralization at Summitville, Colorado; *Economic Geology*, v. 82, p. 1575-1591.

Sun, S.-S., and McDonough, W.F., 1989, Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes; in A.D. Saunders and M.J. Norry (eds), *Magmatism in the Ocean Basins*; Geological Society Special Publication No. 42, p.313-345.

Swanson, D.A., Dzurisin, D., Holcomb, R.T., Iwatsubo, T.Y., W.W. Chadwick, Jr., Casadavell, T.J., Ewart, J.W., and C.C. Heliker, 1987, Growth of the lava dome at Mt. St. Helens, Washington, (USA), 1981-83; in J.H. Fink (ed.), *The emplacement of Silicic domes and Lava Flows*, Geological Society of America Special Paper 212, 145 p.

Tempelman-Kluit, D., 1978, Reconnaissance geology, Laberge Map-area, Yukon; in *Current Research Part A, Geological Survey of Canada Paper 78-1A*, p. 61-66.

Tempelman-Kluit, D., 1979, Transported cataclastite, ophiolite and granodiorite in the Yukon: Evidence of arc-continent collision; *Geological Survey of Canada, Paper 79-*

14.

Tempelman-Kluit, D., 1980, Highlights of fieldwork in Laberge and Carmacks map-areas, Yukon Territory; in Current Research, Part A, Geological Survey of Canada Paper 80-1A, pp. 357-362.

Thiersch, P. and Williams-Jones, A.E., 1990, Paragenesis and ore controls of the shasta Ag-Au deposit, Tooodoggone River area, British Columbia (94E); British Columbia Ministry of Mines and Petroleum Resources Fieldwork 1989, Paper 1990-1.,

Thomson, R.C., Smith, P.L. and Tipper, H.W., 1986, Lower to Middle Jurassic (Pliensbachian to Bajocian) stratigraphy of the northern Spatsizi area, north-central British Columbia; Canadian Journal of Earth Sciences, v. 23, p. 1963-1973.

Thorkelson, D.J., 1988, Jurassic and Triassic volcanic and sedimentary rocks in the Spatsizi map-area, north-central British Columbia; in Current Research, Part E, Geological Survey of Canada Paper 88-1E, p. 43-48.

Thorpe, R.S., Francis, P.W., Hannill, M. and Baker, M.C.W., 1982, The Andes; in R.S. Thorpe (ed.), Andesites: Orogenic Andesites and Related Rocks, John Wiley and Sons, New York, Chichester, Brisbane, Tokyo.

Thorstad, L.E., and Gabrielse, H., 1986, The Upper Triassic Kutcho Formation, Cassiar Mountains, North-central British Columbia; Geological Survey of Canada, Paper 86-16, 53 p.

Tipper, H.W., 1976, Biostratigraphic study of Mesozoic rocks in Intermontane and Insular Belts of the Canadian Cordillera, British Columbia; in Current Research, Part A, Geological Survey of Canada, Paper 76-1A, p. 57-61.

Tipper, H.W., 1978, Jurassic biostratigraphy, Cry-Lake map area, British Columbia; in Current Research, Part A, Geological Survey of Canada, Paper 78-1A, pp. 25-27.

Tipper, H.W., 1979, Jurassic stratigraphy of the Whitesail lake map area, British Columbia; in Current Research, Part A, Geological Survey of Canada, Paper 79-1, p. 31-32.

Tipper, H.W. and Richards, T.A., 1976, Jurassic stratigraphy and history of north-central British-Columbia; Geological Survey of Canada Bulletin 270, 73 p.

Uyeda, S. and Kanamori, H., 1979, Back-arc opening and the mode of subduction; Journal of Geophysical Research, v. 84, no. B3, p. 1049-1061.

van der Heyden, P., 1990, Eastern Margin of the Coast Belt

in west-central British Columbia; in Current Research, Part E, Geological Survey of Canada Paper 90-1E, p. 171-182.

Vulimiri, M.R., Tegart, P. and Stammers, M.A., 1983, Lawyers Gold-silver Deposits, British Columbia; Canadian Institute of Mining and Metallurgy, Special Volume 37, p. 149-164.

Walker, G.P.L., 1971, Grain size characteristics of pyroclastic deposits, Journal of Geology, v. 79, p. 696-714.

Weaver, S.D., Saunders, A.D., Pankhurst, R.J., and Tarney, J., 1979, A geochemical study of magmatism associated with the initial stages of back-arc spreading; Contributions to Mineralogy and Petrology, v. 68, p. 151-169.

Wheeler, J.O., 1961, Whitehorse Map-area, Yukon Territory (105D); Geological Survey of Canada, Memoir 312, 156 p.

Wheeler, J.O. and McFeely, P., 1987, Tectonic assemblage map of the Canadian Cordillera; Geological Survey of Canada, Open File 1565.

Worner, G., Harmon, R.S., Davidson, J., Moorbath, S., Turner, L., McMillan, N., Nye, C., Lopez-Escobar, I. and Moreno, H., 1988, Geology of the Nevados de Payachata volcanic region (18° S/69°W, N. Chile); Bulletin of

Appendix I:: Petrography and sample locations.

Table 1 Sample locations
Sample No.

	Unit	UTM Northing	UTM Easting
9-11-11	1a	6345000	622500
9-10-16	1a	6345500	622400
9-10-6	1a	6344250	621000
9-10-12	1a	6344250	622850
8-56-16	1a	6344700	621800
8-56-12	1a	6344500	622300
8-49-1	1a	6344500	623850
8-37-13	2	6346450	621650
8-12-3	2	6346400	621600
8-34-14	2	6346350	621600
8-34-15b	2	6346350	621600
8-34-9	3	6346500	621950
8-35-5b	3	6346500	621550
8-35-7	3	6346450	621600
8-35-1b	3	6346550	621350

Sample No.	Unit	UTM Northing	UTM Easting
88-28a	3	6346750	621200
FQXT		6347400	621200
88-02	4a	6347200	621250
88-08	4a	6346900	621150
87-17	4a	6346850	621250
8-8-14	4a	6347550	621400
8-48-11	4a	6347050	622850
89-33	4a	6347600	621800
9-12-6	4a	6347700	622200
8-59-1	4a	6347450	621350
9-14-10	4a	6347200	622750
8-33-8c	4b	6346900	621850
88-28b	4b	6346750	621200
88-1	5	6347300	621200
88-14	5	6347200	621050
88-24	5	6347100	621350

Sample No.	Unit	UTM Northing	UTM Easting
8-32-1	5	6346950	6215650
8-9-1	6	6347650	621200
8-9-8	6	6347650	620900
8-48-7	6	6346950	622650
8-48-16	6	6346200	622650
8-5-1b	6	6347450	620900
8-9-5	7	6347750	620850
89-36	7	6344700	621400
8-56-2	7	6347550	621000
8-10-10	8	6347850	620450
8-10-16	9	6348250	620100
8-11-1b	9	6348100	621250
8-11-12	9	6348750	620050
8-11-12 (Block)	9	6348759	620050
8-24-8	9	6351400	618500
8-5-13	9	6348100	621250

Sample No.	Unit	UTM Northing	UTM Easting
8-25-14	11a	6351500	618200
8-50-16	11a	6349300	619800
9-9-1	11a	6352150	622300
9-13-8	11a	6351200	623700
8-4-1c	11a	6349250	622000
8-21-4	11a	6348650	620850
8-21-4b	11a	5348650	620850
8-45-16	11a	6349550	624000
9-9-9	11b	6351100	623600
8-20-5	11c	6350800	622250
8-19-12	11c	6350500	621800
8-20-10	11c	6350800	621550
8-19-9b	12	6350900	621950
9-2-5	12	6350650	622050
9-7-12	12	6353700	620000
9-6-7	12int	6351300	621550

Sample No.	Unit	UTM Northing	UTM Easting
8-10-18	12int	6348950	619700
8-40-11	13	6347250	624950
8-40-13	13	6347200	625100
8-44-12	13	6348400	623800
8-44-13	14	6348300	623800
8-45-13	14	6349300	624400
9-4-13	BLs	6346150	618700
9-11-3	BLs	6344000	620500
9-8-7	A	6353700	621250
9-9-14	A	6352700	623600
9-5-5	A	6349150	625850
9-9-13	B	6352700	623650
9-13-7	B	6351200	623500
8-41-8	B	6346300	625100
8-23-13	B	6352150	619900
8-45-6	B	6348850	624950

Sample No.	Unit	UTM Northing	UTM Easting
8-44-23	B	6348800	623900
8-44-11	C	6348500	623800
8-40-15	C	6346650	625400
9-5-9	C	6348500	623800

Appendix I: Petrography: Stuhini Group (unit 1)

Sample	Unit	Primary Mineralogy					Accessory					Alteration					
		Qz	Kf	Pf	Hb	Px	Bi	Others	Mt	Ap	Zi	Other	Ch	Ep	Se	Py	Others
9-11-11	1a	§ mm		35		30		mx 25 amg 10		pr			w		w		cal pump
		Comments: Pillow lava-hyaloclastite transition															
9-10-16	1a	§ mm		25		40		amg 15		pr			w				pump zeo qtz
		Comments: Amygdaloidal isolated pillow margin															
9-10-6	1a	§ mm		30		25		mx 45 amg 10		pr			m				cal pump
		Comments: Glomeroporphyritic.															
9-10-12	1a	§ mm		30		10		mx 30 amg 25		pr			m				zeo cal pump
		Comments:															
8-56-16	1a	§ mm		45		10		mx 30 amg 20		pr			m				pump zeo
		Comments: Abundant amygdules. Poor whole rock sample															
8-56-12	1a	§ mm		30		20		mx 30 amg 20					w				pump cal zeo
		Comments: Abundant amygdules. Poor whole rock sample															
8-49-1	1b	§ mm		pr		pr											
		Comments: Heterolithic volcanic conglomerate, altered Stuhini clasts, sandy mx.															

Abbreviations: amg=amygdules, ap=apatite, bi=biotite, cal=calcite, ch=chlorite, ep=epidote, hb=hornblende, kf=potassic feldspar, m=moderate, mt=magnetite, mx=matrix, pf=plagioclase, pr=present, pump=pumpellyite, px=pyroxene, py=pyrite, qz=quartz, s=strong, w=weak, wr=whole rock sample, zi=zircon.

*** Plagioclase feldspar composition determined by Michel-Levy method***

Appendix I cont.. Units 2 and 3

Sample	Unit	Primary Mineralogy						Accessory						Alteration					
		Qt	Kf	Pf	Hb	Px	Bi	Others	Mt	Ap	Zi	Other	Ch	Ep	Se	Py	Others		
8-37-13	2	\$		40	15			rf 10										cal	
		mm	.	0.5	0.7			mx 35											
		Comments: Sand-sized fragments in a red mud matrix.																	
8-12-3	2	\$		40	15			mx 45										cal	
		mm		1.0	0.7														
		Comments: Hornblende is oxidized to opaques and sericite.																	
8-34-15	2	\$		50	20			mx 30										cal	
		mm		0.5	0.3														
		Comments: Muddy volcanic sandstone with red mud matrix.																	
		\$	10		40			rf 15										cal	
		mm						mx ?											
		Comments: Very strong carbonatization																	
8-34-9	3	\$	10		40			lap 20										cal	
		mm	0.6		1.3			mx 30											
		Comments: Tuff fragments in a volcanic sandstone.																	
8-35-5b	3	\$	10		50			rf 15										cal	
		mm	0.6		0.5			mx 25											
		Comments:																	
8-35-7	3	\$	10		50			mx 40?										cal	
		mm	0.8		1.5														
		Comments: Altered, devitrified tuff?																	

Abbreviations: amg=amygdules, ap=apatite, bi=biotite, cal=calcite, ch=chlorite, ep=epidote, hb=hornblende, kf=potassic feldspar, m=moderate, mt=magnetite, mx=matrix, pf=plagioclase, pr=present, pump=pumpellyite, px=pyroxene, py=pyrite, qz=quartz, s=strong, w=weak, wt=whole rock sample, zi=zircon.

*** Plagioclase feldspar composition determined by Michel-Levy method***

Sample	Unit	Qz	Kf	Pf	Hb	Px	Bi	Others	Mt	Ap	Zi	Other	Ch	Ep	Se	Py	Others
1	1	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
2	2	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
3	3	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
4	4	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
5	5	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
6	6	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
7	7	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
8	8	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
9	9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
11	11	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
12	12	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
13	13	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
14	14	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
15	15	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
16	16	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
17	17	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
18	18	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
19	19	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
20	20	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
21	21	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
22	22	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
23	23	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
24	24	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
25	25	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
26	26	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
27	27	10	10	1													

*** Plagioclase feldspar composition determined by Michel-Levy method***

Appendix 1: cont.. unit 4a

Sample	Unit	Primary Mineralogy							Accessory					Alteration				
		Qt	Kf	Pf	Hb	Px	Bi	Others	Mt	Ap	Zi	Other	Ch	Ep	Se	Py	Others	
8-8-14	4a	{ mm	5 1.6	40 1.8	5 1.0		5 1.0	mx 55	pr	pr			v	v	v			
Comments: Plagioclase is An 32.																		
8-48-11	4a	{ mm	5 0.6	30 2.0	2 1.0			mx 65	pr				v	v	v			
Comments: Plagioclase An 28																		
89-33 KR	4a	{ mm	5 0.5	35 2.2	10 0.8		5? 0.8	mx 40	pr	pr			v		v		cal	
Comments: Weakly altered.																		
9-12-6 WR	4a	{ mm	5 1.2	35 3.0			5 1.5	mx 65	pr	pr				v	v		cal	
Comments:																		
8-59-1 WR	4a	{ mm	5 2.0	40 2.0	10 0.8		5 0.8	mx 40	pr	pr			v		v		cal	
Comments:																		
9-14-10	4a	{ mm	3	40			5	mx 50	pr	pr			v	v	v		cal	
Comments:																		
Comments:																		

Abbreviations: amg=amygdules, ap=apatite, bi=biotite, cal=calcite, ch=chlorite, ep=epidote, hb=hornblende, kf=potassic feldspar, m=moderate, mt=metre, mx=matrix, pf=plagioclase, pr=present, pump=pumpellyite, px=pyroxene, py=pyrite, qz=quartz, s=strong, v=weak, vr=whole rock sample, zi=zircon.

*** plagioclase feldspar composition determined by Michel-Levy method***

Appendix I: cont..units 4b and 5

Sample	Unit	Primary Mineralogy						Accessory						Alteration					
		Qtz	Kf	Pl	Hb	Px	Bi	Cthers	Mt	Ap	Zi	Other	Ch	Ep	Se	Py	Others		
8-33-8c	4b	§ mm		50 2.0			7 1.2	mx 40	pr	pr			v	v	m				
Comments: Welded tuff with prominent biotite.																			
88-28b	4b	§ mm	15 1.8	60 2.0			5 2.5	mx 35	pr				v		s				
Comments: Edges of fragments and matrix are altered to clay or sericite.																			
88-1 WR	5	§ mm	15 0.6	50 0.8			5 0.5	lap 5 acc 5	pr	pr			m		s		cal		
Comments: Well preserved welding textures, moderate alteration.																			
88-14 WR	5	§ mm	15 1.0	45 0.9			5 0.5	mx 30 acc 5	pr	pr			m				cal		
Comments: Well preserved matrix, biotite is pseudomorphed by opaques and ser.																			
88-24 WR	5	§ mm	10 0.6	50 1.2			5 0.5	mx 20 lap 30	pr	pr			v		s		cal		
Comments: Lappilli are altered to sericite and calcite.																			
88-08	5	§ mm	15 1.0	55 0.8			5 0.5	mx 20	pr	pr			m		m		cal		
Comments:																			
8-32-1	5	§ mm	15 1.0	55 1.0			5 0.8	mx 20	pr	pr			v		m		cal		
Comments:																			

Abbreviations: amg=amygdulites, ap=apatite, bi=biotite, cal=calcite, ch=chlorite, ep=epidote, hb=hornblende, kf=potassic feldspar, m=moderate, mt=magnetite, mx=matrix, pl=plagioclase, pr=present, pump=pumpellyite, px=pyroxene, py=pyrite, qz=quartz, s=strong, v=weak, wr=whole rock sample, zi=zircon.

*** Plagioclase feldspar composition determined by Michel-Levy method***

Appendix I: cont...unit 6

Sample	Unit	Primary Mineralogy						Accessory						Alteration					
		Qt	Kf	Pf	Hb	Px	Bl	Others	Mt	Ap	Zi	Other	Ch	Ep	Se	Py	Others		
8-9-1	6	15		40					pr			sph 1							
		mm 1.0		1.2															
	Comments: Possibly pyroclastic. Prominent sphene.																		
clast in 8-9-8	6	10		30	15			mx 45	pr	pr		sph 0.3					cal		
		mm 1.2		1.5	0.6														
	Comments: Porphyry with oxidized mafics and sphene in a quartz-feldspathic mx.																		
8-48-7	6	15		60	1		1	mx 25	pr	pr							cal		
		mm 1.3		1.0	0.5		0.5												
	Comments: Pyroclastic? Partially recrystallized matrix.																		
8-48-16	6	15		50			2	rf 20	pr	pr							cal		
		mm 0.6		0.8			0.5	mx 15											
	Comments: Oxidized rock fragments in a muddy matrix.																		
8-5-1b	6	10		40			5	rf 20	pr	pr									
		mm 0.5		1.2			0.5	mx 25											
	Comments: Matrix is a mud-supported crystal fragment sand.																		
	Comments:																		
	Comments:																		

Abbreviations: smg=amygdules, ap=apatite, bi=biotite, cal=calcite, ch=chlorite, ep=epidote, hb=hornblende, kf=potassic feldspar, m=moderate, mt=magnetite, mx=matrix, pf=plagioclase, pr=present, pump=pumpellyite, px=pyroxene, py=pyrite, qz=quartz, s=strong, v=weak, vt=whole rock sample, zi=zircon.

*** Plagioclase feldspar composition determined by Michel-Levy method***

Appendix I: cont... units 7 and 8.

Sample	Unit	Primary Mineralogy						Accessory						Alteration					
		Qtz	Kf	Pf	Hb	Px	Bi	Others	Mt	Ap	Zi	Other	Ch	Ep	Se	Py	Others		
8-9-5	7	\$	5		60			glass	pr	pr			w	w	m		cal		
	mm	0.6		1.8				mx 20											
89-36 WR	7	\$	10		60			glass	pr	pr			m	w	w		cal		
	mm							20											
8-56-2 WR	7	\$	5		60	2		3	glass	pr	pr	pr		m		w	cal		
	mm	0.8		2.3	0.5		1.5	mx 10											
8-10-10	7	\$																	
	mm																		
8	\$	10		60	5		?	glass	pr	pr	pr						zeo		
	mm	1.8		1.6	0.6		20												
	\$																		
	mm																		
	\$																		
	mm																		

Abbreviations: amg=amygdules, ap=apatite, bi=biotite, cal=calcite, ch=chlorite, ep=epidote, hb=hornblende, kf=potassic feldspar, m=moderate, mt=magnetite, mx=matrix, pf=plagioclase, pr=present, pump=pumpellyite, px=pyroxene, py=pyrite, qz=quartz, s=strong, w=weak, wr=whole rock sample, zi=zircon.

*** Plagioclase feldspar composition determined by Michel-Levy method***

Appendix I: cont.... unit 9

Sample	Unit	Primary Mineralogy										Accessory										Alteration				
		Qz	Kf	Pf	Hb	Px	Bi	Others	Mt	Ap	Zi	Other	Ch	Ep	Se	Py	Others									
8-10-16	9	3 mm	0.5	30	10	5																				
		Comments: Broken flow; cracks filled with silt/sand of same mineralogy																								
8-11-1b	9	3 mm		35	15																					
		Comments: Broken flow with sandy infilling of same mineralogy as blocks.																								
8-11-12	9	3 mm		40	20																					
		Comments: Plagioclase shows strange patchy extinction-thermal-cracking																								
8-11-12 in block	9	3 mm		40	20																					
		Comments: Chilled block, very fresh, feldspars not patchy.																								
8-22-10 above	9	3 mm	0.6	40	15																					
		Comments: volcanic sandstone?-same patchy feldspars as 8-11-12.																								
8-24-8	9	3 mm	0.4	60	5																					
		Comments: Muddy volcanic sandstone. Layers rich in sphene and magnetite.																								
8-5-13	9	3 mm		55	15																					
		Comments: Large spherulite; Evenly recrystallized matrix. An 58																								

Abbreviations: amg=amygdules, ap=apatite, bi=biotite, cal=calcite, ch=chlorite, ep=epidote, hb=hornblende, kf=potassic feldspar, m=moderate, mt=magnetite, mx=matrix, pf=plagioclase, pr=present, pump=pumpellyite, px=pyroxene, py=pyrite, qz=quartz, s=strong, w=weak, wr= whole rock sample, zi=zircon.

*** Plagioclase feldspar composition determined by Michel-Levy method***

Appendix I: Cont...unit 11a

Sample	Unit	Primary Mineralogy							Accessory							Alteration				
		Qt	Kf	Pf	Hb	Px	Bi	Others	Mt	Ap	Zi	Other	Ch	Ep	Se	Py	Others			
8-25-14 WR	11a	§ mm	15 0.7		40 1.9	15 0.7		2 1.2		pr	pr	0.2		sph	0.8			w		
Comments: Weakly devitrified. Fresh.																				
8-50-16 WR	11a	§ mm	2 1.0		40 1.8	10 1.0			mx 45 0.2	pr	pr					m		w		pump
Comments: Devitrified to quartz and kspar. Mafics altered to chlorite. An 48.																				
9-9-1 WR	11a	§ mm	5 0.9		35 2.0	15 0.8		2 1.5	glass 40	pr	pr			sph	0.5			w		cal
Comments: Primary glass in matrix and lapilli.																				
9-13-8 WR	11a	§ mm	5 1.0		40 2.0	10 0.7		3 1.5	glass 40	pr	pr			sph			w			
Comments: Weak devitrification. Some chlorite and sericite.																				
8-4-1c	11a	§ mm	15			50	5		5 glass + mx 30	pr	pr			sph	0.6		m	w		
Comments:																				
8-21-4	11a	§ mm	10 1.6		40 2.0	15 0.6		5 0.7	glass 30	pr	pr	pr		sph				w		cal
Comments: Primary glass preserved.																				
8-21-4b intr. clast	11a	§ mm	25 2.0	40 4.0	25 3.0	10 1.4				pr	pr	pr		sph	0.8			w		cal
Comments: Granodiorite and aplite clast in 11a.																				

Abbreviations: amg=amygdules, ap=apatite, bi=biotite, cal=calcite, ch=chlorite, ep=epidote, hb=hornblende, kf=potassic feldspar, m=moderate, mt=magnetite, mx=matrix, pf=plagioclase, f=present, pump=pumpellyite, px=pyroxene, py=pyrite, qz=quartz, s=strong, w=weak, wr=whole rock sample, zi=zircon.

*** Plagioclase feldspar composition determined by Michel-Levy method***

Appendix I: cont...units 11b and 11c.

Sample	Unit	Primary Mineralogy						Accessory				Alteration						
		Qz	Kf	Pf	Hb	Px	Bi	Others	Mt	Ap	Zi	Other	Ch	Ep	Se	Py	Others	
8-45-16	11a	\$	15		50	15		3				pr						cal
	mm	0.7		1.8	0.6		1.2											
	Comments: Partially devitrified with welding textures preserved.																	
9-9-9	\$																	
	mm																	
	Comments:																	
8-20-5	11b	\$	15		40	10				mx	35		pr					cal
	mm	0.8		1.4	0.7													
	Comments: Lacks any welding texture. Recrystallized matrix.																	
8-19-12	11c	\$	3		35	10		2		mx	50							cal
	mm	0.4		1.3	0.8		1.0											
	Comments: Pebbly volcanic sandstone. Plagioclase is An 50.																	
8-20-10	11c	\$	3		35			2		rt	20		pr					cal
	mm	0.3		1.3			1.0		mx	40								
	Comments: Poorly sorted, hematitic pebbly volcanic sandstone.																	
	11c	\$	10		75					mx	15		pr					
	mm	0.4		0.5														
	Comments: Grain supported volcanic sandstone with concentrations of sphene/mt.																	
	\$																	
	mm																	
	Comments:																	

Abbreviations: amg=amygdulites, ap=apatite, bi=biotite, cal=calcite, ch=chlorite, ep=epidote, hb=hornblende, kf=potassic feldspar, m=moderate, mt=magnetite, mx=matrix, pf=plagioclase, pr=present, pump=pumpellyite, px=pyroxene, py=pyrite, qz=quartz, s=strong, w=weak, wr=whole rock sample, zi=zircon.

*** Plagioclase feldspar composition determined by Michel-Levy method***

Appendix I: cont..unit 12

Sample	Unit	Primary Mineralogy							Accessory				Alteration				
		Qtz	Kf	Pf	Hb	Px	Bi	Others	Mt	Ap	Zi	Other	Ch	Ep	Se	Py	Others
8-19-9b	12	\$		30		20		mx 50	pr				v		v		hem
	mm			2.0		2.5											
	Comments: Oxidized flow.																
9-2-5	12	\$		30		20		mx 50	pr						v		hem
	mm			1.8		4.0											
	Comments: Oxidized flow.																
9-7-12	12	\$		45		20		mx 35	pr						v		cal hem
	mm			1.0		1.1											
	Comments: Finer grained than above.																
9-6-7	12	\$		30		5		mx 50	pr						v		cal
	mm			2.2		1.3											
	Comments: Pyroxene and hornblende pseudomorphs (oxidized).																
8-10-18	12 ?	\$		25		15		mx 50	pr						v		cal
	mm			2.5		0.3											
	Comments: Very oxidized porphyry. Hornblende and pyroxene pseudomorphs.																
JK sill	12	\$															
	mm																
	Comments:																

Abbreviations: amg=amygdules, ap=apatite, bi=biotite, cal=calcite, ch=chlorite, ep=epidote, hb=hornblende, kt=potassic feldspar, m=moderate, mt=magnetite, mx=matrix, pf=plagioclase, pr=present, pump=pumpellyite, px=pyroxene, py=pyrite, qz=quartz, s=strong, w=weak, wr=whole rock sample, zi=zircon.

*** plagioclase feldspar composition determined by Michel-Levy method***

Appendix I: cont...units A and B

Sample	Unit	Primary Mineralogy						Accessory						Alteration					
		Qz	Kf	Pf	Hb	Px	Bi	Others	Mt	Ap	Zi	Other	Ch	Ep	Se	Py	Others		
9-4-13 WR	Bls	‡ 20 mm 1.5	25	40	15		<5? ?		pr	pr				w					
	Comments: Equigranular granodiorite, An 35(?). Some myrmekite																		
9-9-14 WR	Bls	‡ 20 mm 1.5	30	40	15		2		pr	pr				w					
	Comments: weak sericitization of plagioclase. An 45																		
9-8-7 WR	A	‡ 20 mm 1.0	20	50	10				pr	pr				w		w			
	Comments: Equigranular. Sericitization of feldspars																		
9-9-14 WR	A	‡ 20 mm	25	45	10		?		pr	pr				w		w			
	Comments: Equigranular, weak alteration of feldspars																		
9-5-5	A?	‡ 2 mm 0.1	?	75	10				pr	pr									
	Comments: Very crowded porphyry. Amphibole is riebeckite?																		
9-9-13	B	‡ 5 mm 0.5		35	20			mx	40	pr	pr			w		w			
	Comments:																		
9-13-7	B	‡ 5 mm 1.0		35	20			mx	40	pr	pr			w		s			
	Comments:																		

Abbreviations: amg=amygdules, ap=apatite, bi=biotite, cal=calcite, ch=chlorite, ep=epidote, hb=hornblende, kf=potassic feldspar, m=moderate, mt=magnetite, mx=matrix, pf=plagioclase, pr=present, pump=pumpellyite, px=pyroxene, py=pyrite, qz=quartz, s=strong, v=weak, wr=whole rock sample, zi=zircon.

*** Plagioclase feldspar composition determined by Michel-Levy method***

Appendix I: cont..units B and C

Samp. #	Unit	Primary Mineralogy							Accessory					Alteration				
		Qtz	Kf	Pf	Hb	Px	Bi	Others	Mt	Ap	Zi	Other	Ch	Ep	Se	Py	Others	
8-41-8	B	% mm	25 0.2	25 0.2	30 3.0	20 1.5			pr	pr	pr	sph		w		w		
	Comments: A distinctly crystalline groundmass.																	
8-23-13	B	% mm	30 0.5	20 0.5	30 2.0	20 1.5			pr	pr				w		w		
	Comments: Fresh phenocrysts in a crystalline groundmass.																	
8-45-6	B	% mm	30 0.1	30 0.1	30 2.5	10 1.5			pr	pr		sph		w		w		
	Comments:																	
8-44-23	B	% mm			30 1.9	15 1.3		mx 55	pr	pr				w		w		
	Comments: Oxidized and fractured but similar to B. Shallow level intrusive?																	
8-44-11	C	% mm			45 1.5		15 2.0	mx 40	pr					w		w		
	Comments: Augite and plagioclase (An40) in a matrix of fine plagioclase.																	
8-40-15	C	% mm			15 1.7		20 2.0	amg 30 mx 25									pump zeo	
	Comments: Abundant amygdules with several varieties of zeolite.																	
9-5-9 WR	C	% mm	3 0.1		65 1.5		30 2.5		pr					w			cal	
	Comments: Glomeroporphyritic augite-matrix is fine quartz and plagioclase. An 30																	

Abbreviations: amg=amygdules, ap=apatite, bi=biotite, cal=calcite, ch=chlorite, ep=epidote, hb=hornblende, kf=potassic feldspar, m=moderate, mt=magnetite, mx=matrix, pf=plagioclase, pr=present, pump=pumpellyite, px=pyroxene, py=pyrite, qz=quartz, s=strong, w=weak, wr=whole rock sample, zi=zircon.

*** plagioclase feldspar composition determined by Michel-Lévy method***

Appendix II: Whole rock sample descriptions**Unit 1 Stuhini Group**

1 9HM 10-12:

UTM N 6344250 E622850

Pyroxene-feldspar phyric pillow basalt. Sample contains 25% fresh euhedral augite, 30 % weakly sericitized plagioclase and up to 20% vesicles filled with chlorite, pumpellyite, zeolite and calcite within a matrix of plagioclase, augite and opaques.

2 9HM 10-6

UTM N6344250 E621000

Pyroxene-feldspar flow. A glomeroporphyritic basalt with large clots of plagioclase (30%), 25% augite phenocrysts and 10% vesicles filled with chlorite and calcite within a fine crystalline matrix of plagioclase, augite and opaques.

3 8HM 56-16

UTM N6344700 E 622300

Pyroxene-feldspar phyric pillow basalt. 10% euhedral augite, 45% subhedral plagioclase and 25% vesicles filled with chlorite, pumpellyite and calcite within a fine

Appendix II: Whole rock sample descriptions**Unit 1 Stuhini Group**

1 9HM 10-12:

UTM N 6344250 E622850

Pyroxene-feldspar phyric pillow basalt. Sample contains 25% fresh euhedral augite, 30 % weakly sericitized plagioclase and up to 20% vesicles filled with chlorite, pumpellyite, zeolite and calcite within a matrix of plagioclase, augite and opaques.

2 9HM 10-6

UTM N6344250 E621000

Pyroxene-feldspar flow. A glomeroporphyritic basalt with large clots of plagioclase (30%), 25% augite phenocrysts and 10% vesicles filled with chlorite and calcite within a fine crystalline matrix of plagioclase, augite and opaques.

3 8HM 56-16

UTM N6344700 E 622300

Pyroxene-feldspar phyric pillow basalt. 10% euhedral augite, 45% subhedral plagioclase and 25% vesicles filled with chlorite, pumpellyite and calcite within a fine

crystalline matrix of plagioclase, pyroxene and opaques.

4 8HM 56-12

UTM N6344500 E622300

Pyroxene-feldspar phyric pillow basalt. 25% augite, 35% plagioclase and 20% amygdules with chlorite, pumpellyite, zeolite and calcite within a fine crystalline matrix of plagioclase, pyroxene and opaques.

Unit: Black Lake Stock

5 9HM 11-3

UTM

Equigranular granodiorite with 20% anhedral quartz, 40% subhedral plagioclase, 25% anhedral orthoclase and 15% hornblende. Minor chlorite replacing hornblende (or biotite?).

6 9HM 4-13

UTM N6346150 E 618700

Equigranular granodiorite with 20% quartz, 40% weakly altered (sericite and calcite) plagioclase, 25% orthoclase and 15% hornblende. Minor chlorite.

Unit: Intrusive A

7 9HM 9-13

UTM N 6362700 E 623650

A pink hornblende-feldspar porphyry. 35% sericitized plagioclase, 20% hornblende and 5% quartz in a microcrystalline matrix.

8 9HM 13-7

UTM N 6351200 E 623500

A pink hornblende-feldspar porphyry. 35% sericitized plagioclase, 20% hornblende and 5% quartz in a microcrystalline matrix.

9 8HM 41-8

UTM N 6346300 E 625100

A brown hornblende-feldspar porphyry. 30% plagioclase (weak sericite and chlorite), 20% hornblende, weakly chloritized in a fine crystalline matrix of quartz and potassium feldspar.

Unit: Intrusive B

10 9HM 9-14

UTM N 6352700 623650

A medium grained equigranular granodiorite with 45% plagioclase, 25% orthoclase and 20% quartz, 10% hornblende (weak chlorite alteration).

Unit 1 Intrusive C

11 9HM 5-5

UTM N 6349150 E 625850

A dark green feldspar-pyroxene porphyry with 25% plagioclase and 30% glomeroporphyritic augite in a fine crystalline matrix of plagioclase and opaques.

Unit 3 Green quartz-feldspar phytic tuffs

12 DDH 88-28

UTM N 6346750 E 621200

A dark green welded lapilli tuff. 40% sericitized plagioclase, 5% partially chloritized hornblende and 20% lapilli altered to pumpellyite. Matrix contains calcite, pumpellyite.

Unit 4a Quartz-biotite-feldspar dacite

13 DDH 88-08

UTM N 6346900 E 621150

Pink and green quartz-biotite-plagioclase porphyry. 40% weakly altered plagioclase, 5% quartz and 5% chloritized biotite in a microcrystalline matrix. weak chlorite, epidote and sericite throughout.

14 DDH 89-33

UTM N 6347600 E 621800

Quartz-biotite-feldspar porphyry with 35% white plagioclase (sericite and calcite), 10% chloritized hornblende, 5% chloritized biotite and 5% quartz in a microcrystalline matrix

15 9HM 12-6

UTM N 6347700 E 622200

Quartz-biotite-feldspar porphyry with 35% pale pink plagioclase (Weak sericite, calcite), 5% chloritized biotite and 5% quartz in microcrystalline matrix. Minor epidote throughout.

16 8HM 59-1

UTM N 6347450 E 621200

Quartz-biotite-feldspar porphyry with 40% pink plagioclase, 10% chloritized hornblende, 5% chloritized biotite and 5% quartz in a microcrystalline matrix. Minor epidote, chlorite, sericite and calcite throughout.

17 DDH 88-2

UTM N 6347200 E 621250

Quartz-biotite-feldspar porphyry with 40% pink plagioclase, 10% chloritized biotite, 5% chloritized hornblende and 5% quartz in a microcrystalline matrix. Minor

epidote, chlorite and calcite throughout.

18 FQXT

UTM N 6347400 E 621200

Quartz-biotite-feldspar porphyry with 35% pale pink feldspar, 10% chloritized biotite, 5% chloritized hornblende and 5% quartz in a microcrystalline matrix. Minor chlorite, epidote and calcite throughout.

19 9HM 14-10

UTM N 6347200 E 622750

Quartz-biotite-feldspar porphyry with 40% white feldspar, 5% chloritized biotite and 3% quartz in a grey microcrystalline matrix. Minor calcite, chlorite, epidote and sericite throughout.

Unit 5: Quartz-feldspar lapilli tuffs

20 DDH 88-1

UTM N 6347300 E 621200

Quartz and feldspar phyric lapilli tuff with 50% pink plagioclase, 5% chloritized biotite, 15% quartz and 10% chloritized pumiceous lapilli in a matrix of quartz, feldspar, chlorite and sericite.

21 DDH 88-14

UTM N 6347200 E 621050

Quartz and feldspar phyric lapilli tuff with 45% pink plagioclase, 15% quartz, 5% chloritized biotite, 15% chloritized pumiceous lapilli and 5% accidental porphyry fragments in a matrix of quartz, feldspar, chlorite and minor calcite.

22 DDH 88-24

UTM N 6347100 E 621350

Quartz-feldspar phyric lapilli tuff with 50% white plagioclase, 5% chloritized biotite (and hornblende?), 10% quartz and 15% chloritic lapilli in a matrix of quartz, potassium feldspar, sericite and chlorite,

Unit 7: Welded chloritic lapilli tuff

23 DDH 89-36

UTM N 6344700 E 621400

Welded lapilli tuff with 60% white plagioclase, 10% quartz and 25% brown volcanic glass as shards and flattened lapilli. Sericite in feldspars and minor chlorite and calcite throughout.

24 8HM 56-2

UTM N 6347550 E 621000

Welded lapilli tuff with 60% white plagioclase, 5%

quartz, 5% chloritized hornblende and biotite, 20% glass and 10% fine crystalline quartz and feldspar. Sericite in feldspars and minor quartz and calcite throughout

Unit 11: Saunders Grey dacite

25 8HM 25-14

UTM N 6351500 E 618200

Welded lapilli crystal tuff with 40% white plagioclase, 15% quartz, 15% fresh hornblende, 2% biotite (sericite and opaques) and 25% glass as shards and lapilli. Prominent accessory sphene.

26 8HM 50-16

UTM N 6349300 E 619800

Welded lapilli crystal tuff with 40% white plagioclase, 2% quartz, 10% hornblende in a devitrified matrix of quartz and potassium feldspar. minor chlorite, pumpellyite and sericite.

27 9HM 9-1

UTM N 6352150 E 622300

Welded lapilli, crystal tuff with 35% weakly sericitized feldspar, 5% quartz, 15% hornblende, 2% biotite (muscovite and opaques) and 45% glass as shards and lapilli.

28 9HM 13-8

UTM N 6351200 E 623700

Welded lapilli, crystal tuff with 40% white plagioclase (sericite), 5% quartz, 15% hornblende, 5% biotite (sericite and opaques) and 40% glass as lapilli and partially devitrified shards in matrix.

Unit 12: Theban andesites

29 9HM 2-5

UTM N 635650 E 621950

Medium grained pyroxene-feldspar phyric flow. 20% augite and 30% white plagioclase in a fine crystalline matrix dominated by plagioclase lathes. Weak sericite and hematite.

30 9HM 7-12

UTM N 6353700 E 620000

Fine grained pyroxene-feldspar porphyry. 20% augite, 45% white plagioclase in a very fine crystalline matrix. Weak calcite and hematite

Unit 12int: Theban subvolcanic intrusives

31 9HM 6-7

UTM N 6351300 E 621550

Medium grained hornblende-feldspar porphyry with 30% plagioclase, 15% hornblende, 5% pyroxene and 2% biotite in a fine crystalline matrix.

Appendix III: Analytical methods and controls

Analytical procedure

Several kilograms of each sample were crushed in a Chipmunk crusher and then split prior to pulverizing in a steel alloy ring grinder. Pellets were fused in platinum crucibles using lithium tetraborate and lithium carbonate as a flux and then analysed for major and trace elements by Ron Hartree at the University of Ottawa. USGS rhyolite, andesite and basalt standards and sample duplicates were run to check the consistency of the analyses. Loss on ignition (LOI) was determined by heating a 1 gram sample for two hours each at 120° C and 1050° C and determining weight loss. The results of these analyses and their standard deviations ($\text{std dev} = \text{square root of } (x - \text{average})^2 / \text{number of samples} - 1$) are listed in the following table. Sample DR-N(X) is the same standard as DR-N(1) but for two separate sample batches.

¹
² Replicates and standards with standard deviations

Sample No	DR-N(X)	DR-N(X)	DR-N(X)	DR-N(X)	DR-N(1)	DR-N(1)	DR-N(1)	DR-N(1)	DR-N(1)	Std dev.
SiO ₂	53.21	53.17	53.08	53.12	53.14	53.21	53.20	53.36	53.15	0.08
Al ₂ O ₃	17.71	17.75	17.73	17.60	17.64	17.70	17.63	17.70	17.72	0.05
FeO ⁺	9.66	9.76	9.70	9.66	9.67	9.68	9.64	9.70	9.66	0.03
MgO	4.33	4.32	4.36	4.40	4.44	4.32	4.37	4.40	4.47	0.05
CaO	7.03	7.01	6.99	6.99	7.02	7.03	7.01	7.02	7.02	0.01
Na ₂ O	3.01	3.18	3.03	2.98	3.11	3.15	3.08	3.26	3.17	0.09
K ₂ O	1.73	1.73	1.72	1.72	1.71	1.71	1.71	1.72	1.71	0.01
TiO ₂	1.05	1.06	1.05	1.05	1.04	1.04	1.04	1.04	1.05	0.01
P ₂ O ₅	0.25	0.25	0.25	0.23	0.24	0.23	0.22	0.25	0.23	0.01
MnO	0.23	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.00
S	0.02	0.02	0.02	0.02	0.06	0.06	0.05	0.06	0.06	0.02
BA	399	402	395	365	382	393	383	396	418	14
CR	51	51	54	50	41	48	43	48	48	4
ZR	140	133	134	133	124	128	126	128	124	5
SR	399	404	399	399	398	400	398	399	400	2
RB	67	69	69	70	68	70	67	69	69	1
Y	30	27	32	29	25	28	28	28	27	2
NB	23	5	3	4	0	2	2	4	0	7
ZN	159	164	154	153	132	135	131	139	132	12
NI	19	25	24	24	18	18	17	25	21	3
V	216	234	229	246	223	210	224	239	230	11

GA-1	GA-1	GA-1	Sid dev.	MRG-1	MRG-1	MRG-1	Sid dev.
69.03	68.95	68.85	0.07	39.33	39.37	39.50	0.07
14.45	14.46	14.51	0.03	8.52	8.42	8.53	0.05
2.77	2.78	2.77	0.00	17.93	17.82	17.90	0.05
1.07	1.10	1.03	0.03	13.62	13.53	13.84	0.13
2.41	2.41	2.41	0.00	14.69	14.72	14.81	0.05
3.40	3.08	3.59	0.21	1.30	1.01	1.24	0.12
4.01	4.02	4.02	0.00	0.17	0.18	0.17	0.00
0.34	0.35	0.35	0.00	3.74	3.78	3.78	0.02
0.14	0.09	0.12	0.02	0.00	0.01	0.00	0.00
0.09	0.00	0.09	0.04	0.17	0.17	0.17	0.00
0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00
						0.00	
826	818	824	3	0	0	0	0
29	28	25	2	480	473	482	4
149	153	152	2	94	93	95	1
304	304	303	0	268	265	265	1
167	171	170	2	5	0	4	2
22	22	21	0	13	15	14	1
4	6	6	1	24	19	19	2
91	96	97	3	189	197	194	3
10	13	13	1	207	192	196	6
22	17	23	3	568	563	552	7

89-33	89-33D	Std dev.	9-5-9	9-5-9D	Std dev.	89-36	89-36D	Std dev.
64.25	64.24	0.00	51.25	50.86	0.19	58.99	58.72	0.13
15.55	15.55	0.00	17.84	17.62	0.11	16.59	16.57	0.01
4.21	4.26	0.02	10.19	10.04	0.07	5.29	5.26	0.01
1.53	1.51	0.01	3.62	3.58	0.02	1.74	1.85	0.05
3.23	3.22	0.01	8.30	8.25	0.03	4.19	4.21	0.01
3.56	3.67	0.05	3.43	3.23	0.07	4.69	4.65	0.02
3.70	3.70	0.00	1.64	1.61	0.01	2.78	2.78	0.00
0.38	0.39	0.00	0.96	0.95	0.00	0.47	0.47	0.00
0.16	0.18	0.01	0.39	0.36	0.02	0.21	0.21	0.00
0.11	0.11	0.00	0.20	0.20	0.00	0.15	0.15	0.00
0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00
1388	1389	1	1302	1256	23	1118	1129	6
45	43	1	42	46	2	38	41	2
95	95	0	82	81	1	96	92	2
506	510	2	844	837	4	533	532	1
120	119	1	31	31	0	76	78	1
16	16	0	25	26	1	21	20	1
4	2	1	0	0	0	0	0	0
80	73	4	108	103	3	82	86	2
16	26	5	12	15	2	12	11	1
76	71	3	270	294	12	95	86	5

E 622500

E 622750

B'''

N 6348250

Looking west

N 6348000

6

4a

6

? 7

3

1350

N 6347750

Measured with
bear bones

fractured with
shear zones

N 6347750

fractured with
shear zones

M-S arc-chl-py

N 6347750

N 6347500

N 6347250

9-14-10

9-48-11 A_n

- A₁ Quartz-ksp. pervasive pinking, some primary textures
- A₂ Quartz-ksp. no primary texture
- A₃ Quartz-ksp-sericite, pale brown overprint on A₂

Stratigraphy

- A₁ Chlorite-biotite-ksp. weak pinking of matrix
- A₂ Quartz-ksp. pervasive pinking, some primary textures
- A₃ Quartz-ksp. no primary texture
- A₄ Quartz-ksp-sericite, pale brown overprint on A₃

Stratigraphy

Q, Q₁, Q₂, Q₃, Q₄ Unconsolidated sediments: till < 1 m, till > 1 m, glaciofluvial, fluvial

Jock Creek Section

- ☐ 7 Welded chloritic lapilli tuffs
- ☐ 6 Laharic deposits
- Shasta dome complex
- ☐ 5c Quartz-feldspar phryic lapilli tuffs
- ☐ 5b Dark green tuff with carbonized wood fragments and green siltstone
- ☐ 5a Unit 5c with abundant cobbles of unit 4a
- ☐ 4b Coarse volcanic breccia, blocks of tuff in siltstone and well bedded volcanic sediments
- ☐ 4a Quartz-biotite-hornblende-feldspar phryic dacite
- ☐ 3b Purple and green volcanic conglomerate and sandstone
- ☐ 3a Green quartz-feldspar phryic lapilli tuff and volcanic sediments
- ☐ 2c Volcanic conglomerate with hornblende phryic cobbles
- ☐ 2b Purple and green volcanic conglomerate with pyroxene phryic clasts

COMPILED BY NADIR MAPPING CORPORATION
FROM PHOTOGRAPHY FLOWN 1983

N 6346500

N 6346500

N 6346250

GEOLOGY OF THE SHASTA PROPERTY

NTS 94E
UTM ZONE 9V XP

MAP 2
Scale: 1:2500
Mapping: H. Marsden 1988, 1989

E 632500

SHASTA PROPERTY

ESSO RESOURCES CANADA LIMITED

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

LEGEND

- 10 strike and dip of bedding
- 50 strike and dip of veins
- outcrop
- suboutcrop
- geologic contact
- o- alteration contact
- U/D fault: upthrown/downthrown

Alteration

- (i) Argillic alteration
- (ii) Advanced argillic alteration
- (iii) Potassic alteration

silicification

Stratigraphy

Units of uncertain age

- 14 Purple lapilli tuff and volcanic sandstone
- 13 Quartz-feldspar welded chloritic lapilli tuff

Theban Member

- 12(int) Subvolcanic hornblende-feldspar porphyry
- 12 Pyroxene phytic flows and tuffs
- 12a Volcanic conglomerate with cobbles of 12 (int), volcanic siltstone

Saunders Member

Stuhini Group

- 1b Well bedded sandstone, siltstone, and volcanic conglomerate
- 1a Pillow basalt and hyaloclastite

Intrusive rocks

- C Pyroxene feldspar porphyry
- B Pink hornblende-feldspar porphyry
- A Equigranular granodiorite

LEGEND

- 10 strike and dip of bedding
- 50 strike and dip of veins
- outcrop
- suboutcrop
- geologic contact
- alteration contact
- U/D fault: upthrown/downthrown

Alteration

- (i) Argillic alteration
- (ii) Advanced argillic alteration
- (iii) Potassic alteration

silicification

Stratigraphy

Units of uncertain age

- 14 Purple lapilli tuff and volcanic sandstone
- 13 Quartz-feldspar welded chloritic lapilli tuff

Theban Member

- 12(int) Subvolcanic hornblende-feldspar porphyry
- 12 Pyroxene phytic flows and tuffs
- 12a Volcanic conglomerate with cobbles of 12 (int), volcanic siltstone

Saunders Member

Stuhini Group

- 1b Well bedded sandstone, siltstone, and volcanic conglomerate
- 1a Pillow basalt and hyaloclastite

Intrusive rocks

- C Pyroxene feldspar porphyry
- B Pink hornblende-feldspar porphyry
- A Equigranular granodiorite

12a Volcanic conglomerate with cobbles of 12 (int), volcanic siltstone

Saunders Member

B Pink hornblende-feldspar porphyry

A Equigranular granodiorite

12 Pyroxene phryic flows and tuffs

12a Volcanic conglomerate with cobbles of 12 (int), volcanic siltstone

Saunders Member

11c Purple volcanic sandstone

11b Crystal lapilli tuff

11a Quartz-hornblende-biotite-feldspar phryic ignimbrite

10 Purple ash and lapilli tuff

Jock Creek Section

9 Hornblende-feldspar phryic tuffs and breccias

8 Laminated crystal ash tuffs

7 Welded chloritic lapilli tuffs

6 Laharic deposits

Shasta dome complex

5 Quartz-feldspar phryic lapilli tuffs

4a Quartz-biotite-hornblende-feldspar phryic dacite

4b Associated epiclastic deposits

3 Green lapilli tuff and volcanic sediments

2 Heterolithic conglomerate

C Pyroxene feldspar porphyry

B Pink hornblende-feldspar porphyry

A Equigranular granodiorite

Abbreviations

Alu alunite
bor bornite
bx breccia
carb carbonate
ep epidote
qz quartz
sili silicification
sus sulphides
sw stockwork

▲ 9-5-6 Sample location: Year 89-Traversal station

COMPILED BY NADIR MAPPING CORPORATION
FROM PHOTOGRAPHY FLOWN 1986

SCALE 1:10000

B-41-4

13

B-41-4

13

37

carb

71

35

44

(i)

80

carb-sus

B

NTS 94E

1500

13

13

(i)

up

85

A

53

3

3

GEOLOGICAL SETTING OF THE

SHASTA PROPERTY

NTS 94E

MAP 1

UTM ZONE 9V XP

Scale: 1:10,000

Mapping: H. Marsden 1988, 1989

SHASTA PROPERTY

ESSO RESOURCES CANADA LIMITED

END

04-03-92

FIN