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**VOLCANIC AND TECTONIC EVOLUTION
OF THE HAZELTON GROUP
IN SPATSIZI RIVER (104H) MAP-AREA,
NORTH-CENTRAL BRITISH COLUMBIA**

by

Derek John Thorkelson

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

**Department of Earth Sciences
Carleton University
Ottawa, Ontario, Canada
1992**

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ABSTRACT

Three Lower Jurassic volcanic successions are recognized in northern Spatsizi River (104H) map-area. The oldest succession, named the Griffith Creek volcanics, comprises subaerially deposited mafic lava flows and intermediate to felsic tuff and sills. U-Pb (zircon) dates from the Griffith Creek (203.1 ± 0.4 Ma; 205.8 ± 0.9 Ma) correlate with an Hettangian to Lower Sinemurian biostratigraphic age. The middle unit, the Cold Fish Volcanics, is a silica-bimodal succession of mafic lava flows, and rhyolitic tuff and sills. It was deposited as a composite volcano and rhyolitic caldera complex in a subsiding, coastal environment. Four U-Pb (zircon) dates from the succession (193.5 ± 2.0 Ma; 193.9 ± 1.1 Ma; $194.0 \pm 2.8/-2.3$ Ma; and 194.8 ± 1.0 Ma) and from the synvolcanic Spatsizi River Stock (190.0 ± 7.1 Ma) are consistent with its Early Pliensbachian biostratigraphic age. The youngest unit, the Mount Brock volcanics, is a mainly subaerial succession of mafic lava flows and subordinate felsic tuff that subsided as it was deposited in Early and Middle Toarcian time. All three units are moderately to highly potassic, with volcanic arc trace element signatures. Precambrian isotopic inheritance in some of the fractions of analyzed zircons indicates that the successions are partly underlain by rocks of Precambrian age or provenance.

These successions belong to the Hazelton Group, a voluminous volcanic

and sedimentary assemblage that was deposited on the Stikine Terrane (Stikinia) in Early and early Middle Jurassic time. Regional patterns of volcanic and sedimentary facies indicate that the group was deposited as a pair of volcanic arcs separated by the Hazelton Trough, a subsiding marine back-arc basin produced by protracted extension of Stikinian lithosphere. The volcanic arcs, located along the eastern and western margins of Stikinia, developed in response to westward subduction of oceanic lithosphere of the Cache Creek Terrane, and eastward subduction of another oceanic plate (directions in terms of present geographical orientation).

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For Sherry

*whose help, love and understanding
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Chapter One

Introduction

Thesis objectives, and location of the study area

The Canadian Cordillera hosts an abundance of volcanic successions ranging in age from Precambrian to Holocene. Many have been investigated in comprehensive petrologic and stratigraphic studies, while others have received only cursory inspection. In the Spatsizi River (104H) map area of northern British Columbia (Figures 1 and 2), where this report is focused, large areas are underlain by Lower Jurassic volcanic successions of the Hazelton Group. Prior to work by the author, these successions had been mapped at 1:125 000 scale (locally 1:50 000 scale), and little had been written on their stratigraphic, petrologic, or geochemical characteristics, or isotopic ages.

The main purpose of this thesis is to describe in greater detail the Lower Jurassic volcanic successions (Hazelton Group) in the northern Spatsizi River map area. Work was concentrated in the area of Figure 3 (in pocket; see location in Figure 2), hereafter referred to as the *study area*, a northwest-trending belt about 95 km long and 15-25 km wide. The study area was geologically mapped at scales between 1:25 000 and 1:100 000, and compiled at 1:100 000. It has been divided by the author into several geographical districts, for ease of reference (Figure 2). The Nation district was examined in

greatest detail and is represented by an inset 1:25 000 scale geological map of the main map (Figure 3).

The geographical districts, from northwest to southeast, are: the Brock district, named after Mount Brock; the "Knife Edge" district, named after the narrow, unnamed ridge in the western part of that area; the Cartmel district, named after Mount Cartmel; the Ice Box district, named after Ice Box Canyon; the Nation district, named after Nation Peak, the "Plateau" district, named after the relatively flat area in the centre of that area; the Joan district, named after Joan Lake; the Will district, named after Mount Will, and the Griffith district, named after Griffith Creek.

Field mapping in all of the districts by the author is the basis for most of the geological detail on the maps in Figure 3, particularly the stratigraphic and structural detail of the volcanic successions. C. A. Evenchick made significant contributions to the mapping of the central and southeastern parts of the study area, especially in recognition of structures, and placement of geological contacts along the margins of the volcanic successions and among other units. The 1:125 000 scale reconnaissance map of Gabrielse and Tipper (1984) was used as a basis for the field studies of the author and of Evenchick, but did not include any stratigraphic details of the volcanic successions. The 1:50 000 scale map of Read and Psutka (1990) divided the volcanic successions in the northwestern part of the study area (Brock, Cartmel and "Knife Edge" districts)

Figure 1. Distribution of the Hazelton Group in map-areas of north-central British Columbia (modified slightly from Wheeler and McFeely, 1987).

Figure 2. Location of the study area (stippled area and enclosed districts) within the northern three-quarters of the Spatsizi River map-area of north-central British Columbia. Names of the informal geographical districts of the study area are indicated.

into several units, some of which were recognized in the compilation of the 1:100 000 scale map of Figure 3. In addition, Read and Psutka (ibid.) provided geological details of areas not visited by the author. The map of Thomson (1985) provided some geological details in the Joan district.

Terminology and nomenclature

The stratigraphic nomenclature used in this thesis generally follows the usage recommended in the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983). Formally defined lithostratigraphic units are capitalized (e.g., Hazelton Group), whereas informal units are not. An important difference between the language recommended by the Commission, and the terminology used in this thesis, is the use of the term *volcanics* (in lieu of *formation*) for units composed of predominantly volcanic material. Where *volcanics* is capitalized (e.g., Cold Fish Volcanics), the volcanic formation is regarded as a formal geological unit.

The names and numerical ages of geological time periods, and correlations between biostratigraphic ages and numerical ("absolute") ages adhere to the geological time scale of Harland et al. (1990). The only inconsistency in usage is that the Rhaetian stage (uppermost stage of the Triassic, according to Harland et al., ibid) is not recognized, and the Norian stage (which is beneath the Rhaetian in Harland et al., ibid) is considered to

extend from the end of the Carnian stage of the Upper Triassic to the base of the Jurassic. This expanded range of the Norian stage is consistent with ages assigned to macrofossil collections in northern British Columbia (H. W. Tipper, personal communication, 1990).

Terminology applied to igneous rocks follows that used in well-known articles and textbooks. Plutonic rocks are named according to recommendations of the International Union of Geological Sciences (IUGS) Subcommittee on the Systematics of Igneous Rocks (Streckeisen, 1976). Compositional names of volcanic rocks are based on those of Peccerillo and Taylor (1976), Basaltic Volcanism Study Project (1981), and Ewart (1982). Terms referring to volcanic rock textures and types of volcanic deposits are those used in textbooks on volcanology. For example, the terms *lapilli tuff*, *airfall tuff* and *ignimbrite* are used extensively in this thesis in the sense of Williams and McBirney (1979).

Regional geological context of the study area

The study area is located in the east-central part of the Stikine Terrane (Stikinia), the largest of several suspect terranes (Coney et al., 1980; Monger et al., 1982; Monger, 1984) in the Canadian Cordillera (Figures 4 and 5). Exposures of Stikinia consist mainly of stratified and intrusive rocks of zeolite to greenschist metamorphic grades (Wheeler and McFeely, 1987; Read, 1988).

Figure 4. Simplified terrane map of the Canadian Cordillera, showing Stikinia (ST), the Cache Creek Terrane (CC), insular terranes (INS), Quesnellia (Q), continental, pericratonic and marginal basin terranes (C,P,M), and ancestral North America (NA), based mainly on Wheeler et al. (1988). Rectangle outlines area of Figure 5.

Figure 5. Distribution of the Hazelton Group in north-central British Columbia in context of some principal geological features. The distance that Stikinia extends into the Coast Plutonic and Metamorphic Complex is uncertain.

Prior to about the Middle Jurassic, Stikinia consisted of, or was part of, an oceanic microplate that had evolved separately, for at least part of its history, from other terranes such as the Cache Creek Terrane and Quesnellia (Figure 4). By the Middle Jurassic, Stikinia had become amalgamated with these terranes, and the composite landmass was impinging against, or colliding with, the western margin of ancestral North America. The tectonic collage was subsequently modified by transcurrent, contractional and extensional tectonism, together with widespread magmatism and accretion of more outboard terranes (Monger et al., 1982; Ewing, 1980; Armstrong, 1988; Parrish et al., 1988; Thorkelson and Smith, 1989). By the Middle Eocene, the evolving landmass had been transported northward by hundreds or thousands of kilometres. The translation was northward according to paleontologic and structural evidence (Smith and Tipper, 1986; Gabrielse, 1985), but may have been southward until about the middle Cretaceous, then northward, according to paleomagnetic and regional interpretations (Ave Lallernant and Oldow, 1988; Marquis and Globerman, 1988; Irving and Wynne, 1990; Irving and Thorkelson, 1990). After the Middle Eocene, the Intermontane Belt collage underwent little deformation, although some areas became loci of middle to late Cenozoic mafic volcanism (Bevier et al., 1979).

Previous work in the study area

Several studies of volcanic rocks in the study area have provided a solid foundation for this thesis. Erdman (1978) studied the petrologic, geochemical and Rb-Sr isotopic characteristics of an 800 m-thick succession in the Ice Box district. She produced a five point Rb-Sr scatterchron with an age of 189 ± 26 Ma (2 sigma), and an initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.7043 ± 0.0002 (2 sigma) (Gabrielse et al., 1980). Using data from four chemical analyses plotted on major element discriminant diagrams, Erdman (1978) classified the succession as an "iron enriched-magnesium depleted calc-alkaline suite, weakly transitional to the island arc tholeiite series." Monger and Thorstad (1978) briefly described the lithostratigraphic relations of a succession of Triassic rocks in the "Knife Edge" district. Gabrielse and Tipper (1984) compiled a 1:125 000 scale map of the northern Spatsizi River area from records of several years of regional mapping. They divided Triassic and Jurassic volcanic and related sedimentary rocks in the study area into six units; however, all of the Jurassic volcanic rocks were mapped as a single unit and called the "Toodoggone volcanics" on the basis of a loose correlation with similar strata in the Toodoggone River (93 E) map area. Smith et al. (1984) and Thomson et al. (1986) described ammonite biostratigraphy of the Lower to Middle Jurassic Spatsizi Group, a sedimentary succession herein regarded as part of the Hazelton Group (unit IJs on Figure 3; see also chapters 2 and 3). Based on

field relations between the sedimentary succession and volcanic strata, they subdivided the "Toodoggone volcanics" into three units of Early Pliensbachian, Toarcian and Bajocian ages. Read and Psutka (1990) produced a 1:50 000 scale map which included the Brock and "Knife Edge" areas, following several years of geological mapping by Geotex Consultants. They divided Triassic and Lower Jurassic volcanic rocks into several depositional units that defined a relatively detailed stratigraphy. Evenchick (1991, and previous papers) described field relations throughout much of the study area, and developed a regional fold and thrust belt model.

Geological overview of the Spatsizi River area

The depositional and structural history of the Spatsizi River area was summarized by Thomson et al. (1986) and Evenchick (1991). The area is entirely underlain by rocks belonging to either the Stikine Terrane, or those deposited onto or emplaced within that terrane after its accretion. The oldest rocks exposed are Devonian(?) to Middle Triassic in age (Read and Psutka, 1990), which correlate, at least in part, with the Stikine assemblage (Table 1; D. A. Brown et al., 1991). Generally, they consist of sedimentary and igneous (arc?) rocks that were deformed, cleaved and metamorphosed during the Middle Triassic Tahltanian orogeny (Souther, 1971). Above this basement is a succession of Middle(?) to Upper Triassic volcanic and sedimentary rocks of

the Stuhini Group (and probably the "Tsaybahe" group of Read and Psutka, 1990). The volcanic rocks are predominantly greenish-grey basaltic lava flows, commonly hosting large (3-10 mm) augite phenocrysts. The sedimentary rocks vary from thick epiclastic sequences of mudstone to conglomerate, and thin beds of limestone that locally have yielded Norian bivalves and conodonts. The majority of the Triassic strata were deposited in a submarine environment, probably as part of a primitive island arc (Souther, 1977). Overlying the Triassic rocks are complex successions of Lower to Middle Jurassic volcanic and sedimentary rocks of the Hazelton Group (Tables 1 and 2). In contrast with the Upper Triassic volcanic strata, most of the Hazelton volcanic rocks were deposited subaerially, and display a wide range of chemical composition (basalt to rhyolite) and deposit types (lava and pyroclastic rocks). Together, the Stuhini and Hazelton successions, and associated plutonic rocks such as those of the Hotailu Batholith (Anderson, 1983), represent about 60 m.y. of intermittent arc and back-arc(?) magmatism and related basinal sedimentation (Table 1).

Overlying the Hazelton Group, conformably to slightly discordantly, is the Middle Jurassic to middle Cretaceous Bowser Lake Group, a marine sequence of shale and chert-rich conglomerate that is succeeded by shallow marine to fluvial sandstone (Table 1). The strata coarsen upward and indicate rapid infilling of a marine basin by turbidites and prograding fan deltas (Eisbacher,

TABLE 1

Table of Formations in the Study Area

Erathem	System	Series	Stage	Ma	Group	Formation
Cenozoic						
Mesozoic	Cretaceous	Upper	Maastrichtian	65.0	Sustut Group	Brothers Peak Formation
			Campanian			
			Santonian			
			Coniacian			
			Turonian			Tango Creek Formation
			Cenomanian	97		
	Jurassic	Lower	Albian		Bowser Lake Group	
			Aptian			
			Barremian			
			Hauterivian			
			Valanginian			
			Berriasian	145.6		
		Upper	Tithonian			
			Kimmeridgian	157.1		
			Oxfordian			
			Callovian			
	Triassic	Middle	Bathonian		Hazelton Group	Quock Formation
			Bajocian			undivided Hazelton Group sedimentary rocks
			Aalenian	178		Mount Brock volcanics
		Lower	Toarcian			Cold Fish Volcanics
			Pliensbachian			Griffith Creek volcanics
			Sinemurian			conglomerate
Paleozoic	Permian Pennsylvanian Mississippian Devonian	Upper	Hettangian	208	Stuhini Group	volcanic & sed. rocks
			Norian			(?)
			Carnian	235.0		"Tsaybahe group"
		Middle		241.1		
				245		
		Lower				
				408.5		Meta-sedimentary & igneous rocks (partly Stikine Assemblage ?)

Numerical time scale is from Harland et al. (1990).

TABLE 2

Table of Upper Triassic to Middle Jurassic formations by district

Districts										
Series	Stage	Ma	Brock, "Knife Edge," Cartmel		Ice Box, Nation		Joan, "Plateau," Will		Griffith	
			Age Det		Age Det		Age Det		Age Det	
Middle Jurassic	Bathonian	166.1	Bowser Lake Group		Bowser Lake Group		Bowser Lake Group		Bowser Lake Group	
	Bajocian	Upper								
	Lower	173.5			Quook Formation		Quook Formation		Quook Formation	F
	Aalenian	178			volcanics? seds	F	undivided	F		
Lower Jurassic	Toarcian	Upper	Mount	F			Hazelton Group	F		
		Middle	Brock volcanics	F			sedimentary rocks	F		
	Lower	187	Hazelton sed rocks	F			(lower Spatsizi Group of Thomson et al., 1986)	F		
	Plensbachian	Upper			Hazelton sed rocks	F	Cold Fish Volcs	F, I		
	Lower	194.5			Cold Fish Volcs	F, I				
	Sinemurian	Upper							Griffith Creek volcanics	I
	Lower	203.5	conglomerate		Griffith Creek volcanics				congl	
	Hettangian	208							Stuhini Group	F
Upper Triassic	Norian	235.0	Stuhini Group	F, I					volcanics and seds	
	Carrian		volcanics and seds							

Notes:

- (1) "Age Det" columns indicate methods and stratigraphic levels of age determinations, where F = macrofauna (molluscs), f = microfauna (conodonts), and I = isotopic dates (U-Pb, zircon).
- (2) Age of the lowest Bowser Lake Group is assumed to be Bathonian in all districts.
- (3) Carnian age of Stuhini Group is assumed.

1981; Moffat et al., 1988; Cookenboo and Bustin, 1989; MacLeod and Hills, 1990; Green, 1991; Ricketts and Evenchick, 1991). The basin is usually referred to as the Bowser Basin, although its architecture was mainly inherited from the Hazelton Trough, an intra-volcanic depression which had persisted from the Early Jurassic (Tipper and Richards, 1976; Ricketts and Evenchick, 1991; Marsden and Thorkelson, in press; see chapters 2 and 3). The main source of the clastic detritus was the Cache Creek Terrane, an oceanic and volcanic arc terrane which emerged during its obduction onto Stikinia in the late Early or early Middle Jurassic (Souther and Armstrong, 1966; Thorstad and Gabrielse, 1986). Although it is commonly called an overlap assemblage, the Bowser Lake Group is restricted to Stikinia and is more properly described as a sedimentological or provenance linkage between Stikinia and the Cache Creek Terrane.

In Early Cretaceous time (Barremian to Albian; Sweet and Evenchick, 1990), deposition of the Sustut Group began along the northern and eastern margins of the Bowser Basin, in an elongate trough known as the Sustut Basin (Eisbacher, 1974). The lower part of the Sustut Group, the Tango Creek Formation, is composed of mainly nonmarine siltstone, shale, sandstone and conglomerate. Source regions for the detritus included the Bowser Lake Group to the west, and micaceous metamorphic rocks to the east. In the upper part of the Sustut Group (Brothers Peak Formation; late Campanian to

Maastrichtian), alluvial sedimentation was accompanied by deposition of fine-grained airfall tuff that was presumably related to distant silicic volcanic centres located a considerable distance, perhaps one hundred kilometres or more, to the west. Paleomagnetic aberrances from Early and Late Cretaceous volcanic rocks of Stikinia (Marquis and Globberman, 1988) and Quesnellia (Irving and Thorkelson, 1990), corroborate an analysis of strike-slip faults (Gabrielse, 1985) which indicates that the terrane on which the Sustut Basin developed underwent considerable northward translation (several hundred kilometres to about 2500 km) after its inception in the Early Cretaceous.

Folding and thrust faulting that occurred throughout much of the central Intermontane Belt in Late Jurassic to early Late Cretaceous time formed the Skeena Fold Belt (Evenchick, 1991). In the Spatsizi River area, where northeasterly verging deformation resulted in about 44% shortening, the Hazelton Group has been deformed into structures varying from open, upright folds to tight, overturned folds and intraformational thrust panels (Evenchick, 1991). Block faulting occurred prior to, after, and perhaps during development of the fold belt. Some block faulting was probably synchronous with volcanism of the Hazelton Group (Chapter 3). Most block faulting may have ended by the middle Tertiary.

In the late Cenozoic, probably in Miocene to Pleistocene time, mafic lavas known as the Maitland Creek volcanics (Evenchick and Green, 1990)

were erupted mainly in the western part of the Spatsizi River area. These lavas are broadly coeval with the Mount Edziza volcanic complex, a voluminous peralkaline succession situated to the west in the neighbouring Telegraph Creek area (Souther, 1972). Small volcanic necks and dykes in the Griffith and Will districts are probably broadly correlative with the Maitland Creek rocks. At least one of these, a Pleistocene dyke of alkaline basalt in the Griffith Creek area, hosts abundant peridotite nodules indicating rapid magma ascent from mantle depths. In the Quaternary, the Spatsizi River area was glaciated by continental ice sheets. Following ablation of the last main continental glacier, valley glaciers were, and continue to be, active in the more mountainous regions.

Chapter Two

Tectonic and magmatic setting of the Hazelton Group

Stikinia: suspect terrane, and basement to the Hazelton Group

The Canadian Cordillera is a complex orogen composed of deformed miogeoclinal rocks of ancestral North America and numerous terranes (Coney et al., 1980; Monger, 1984). It has a complex magmatic, sedimentological and tectonic history dating back to the Precambrian. Its present form as five geomorphic belts is largely the result of Mesozoic terrane accretions (Monger, 1982) modified by Late Mesozoic and Early Cenozoic coastwise translation and transcurrent faulting (Gabrielse, 1985; Ave Lallemant and Oldow, 1988; Irving and Thorkelson, 1990), Early Cenozoic extensional deformation (Parrish et al., 1988), and Late Cenozoic subduction, underplating, and uplift (Clowes et al., 1987).

The terranes are defined on the basis of unique geological histories, manifested by particular stratigraphic, plutonic, metamorphic and geophysical characteristics. That some of the terranes spent parts of their histories at more southerly and perhaps more easterly locations, with reference to ancestral North America, is implied by the presence of exotic fauna (Tozer, 1982; Monger, 1977; Smith and Tipper, 1986) and paleomagnetic aberrances (Irving

and Wynne, 1990). Furthermore, some of the terranes, notably the Cache Creek, Stikine, Quesnel, Wrangellia and Alexander terranes, comprise volcanic successions of island arc affinity, implying the former presence of intervening subduction zones and oceanic lithosphere. Many of the volcanic successions have not been studied in detail, and their potential for constraining the timing and nature of geologic processes within and among the terranes has not been fully exploited.

Stikinia is the largest terrane in the Canadian Cordillera, extending from south-central British Columbia to the southwestern Yukon (2000 x 300 km). Its oldest exposed rocks form a Devonian to Permian complex of moderately metamorphosed volcanic and sedimentary strata known as the Stikine assemblage (Monger, 1977; D. A. Brown et al., 1991). Following a period of deformation, termed the Tahltanian orogeny (Souther, 1971), the overlying Stuhini Group was deposited in Middle to Late Triassic time. The Stuhini Group comprises diverse volcanic and sedimentary strata, and is characterized by porphyritic mafic lava and breccia hosting prismatic augite or bladed plagioclase phenocrysts (Souther, 1977; Monger and Church, 1977). The Hazelton Group, which overlies the Stuhini Group conformably to unconformably, was the last succession deposited prior to the amalgamation of Stikinia with the Cache Creek and other more inboard terranes.

The amalgamation of Stikinia to the Cache Creek Terrane was previously

thought to have begun in Late Triassic time, on the basis of field relations in the southern Yukon (Monger, 1984). There, greywacke of apparent Stikinian affinity is intercalated with chert of the northern Cache Creek Terrane. However, the source of the greywacke is now thought to have been Quesnellia (Gabrielse, 1991; Monger, pers. comm., 1991). Furthermore, the ages of radiolaria in the chert are as young as Pliensbachian or Toarcian, indicating that oceanic conditions in the northern Cache Creek Terrane persisted, at least locally, into the Early Jurassic (Cordey et al., 1991).

The onset of the amalgamation between Stikinia and the northern Cache Creek Terrane occurred later, in the late Early or early Middle Jurassic, when parts of Stikinia near the King Salmon Fault received detritus shed from the obducting Cache Creek Terrane, and were deformed by southerly directed folding and faulting (Tipper, 1978; Thorstad and Gabrielse, 1986; Gabrielse, 1991). Large areas of the Cache Creek Terrane had emerged by the Bathonian (Middle Jurassic), when large amounts of chert were eroded from Cache Creek and deposited on Stikinia in the Bowser Basin (Souther and Armstrong, 1966; Eisbacher, 1981). Obduction of the Cache Creek was broadly coincident with waning of Hazelton Group volcanism, a relationship discussed in more detail later. Linkage between the southern part of the Cache Creek Terrane and Stikinia was probably also accomplished in the Early to Middle Jurassic (Cordey et al., 1987).

In central and southern British Columbia, contacts between the Stikinia Terrane and more westerly terranes generally lie within the Coast Belt where they are difficult to recognize because of metamorphism, plutonism, and complex deformation. Among others, Monger et al. (1982), Crawford et al. (1987) and Thorkelson and Smith (1989) suggested that Stikinia may not have collided with terranes of the Insular Belt until the middle Cretaceous, a view which contrasts with that of van der Heyden (1991; and previous works) who suggested accretion in the Middle Jurassic or earlier.

In northwestern British Columbia and the southern Yukon, rocks of Stikinia are juxtaposed with those of the Nisling Terrane (northwestern part of terrane region "C,P,M" in Figure 4)(Currie, 1991). Initial Pb, Nd and Sr isotopic ratios of rocks from the Nisling terrane indicate a large component of evolved Precambrian material was involved in their petrogenesis, whereas those of Stikinia are much more juvenile, and consistent with an origin in an island arc (Gabrielse et al., 1980; Samson et al., 1989; Gehrels et al., 1990). However, Gehrels et al. (1990) suggested that the Nisling Terrane and Stikinia may not be separate terranes, but rather the lower and upper parts, respectively, of the same terrane. Their suggestion is supported, to a limited extent, by U-Pb analyses of zircons from Early Jurassic igneous rocks of Stikinia that reveal a degree of Precambrian inheritance (Bevier and Anderson, 1991; this thesis), indicating that rocks of Precambrian age or provenance have existed in the

subsurface of Stikinia since at least the Early Jurassic.

Nomenclature, age and geological characteristics of the Hazelton Group

Lower and lower Middle Jurassic volcanic and sedimentary rocks are exposed throughout much of Stikinia (Figure 5). South of approximately latitude $58^{\circ}30'$ (Figure 1), the rocks are diverse, ranging from lava and tuff to limestone and shale. In the Smithers, Hazelton and McConnell Creek areas of north-central British Columbia, Tipper and Richards (1976) followed Leach (1910) and applied the term Hazelton Group to a succession of volcanic and sedimentary rocks of lower Sinemurian to Callovian age. Subsequently, the term Hazelton Group has been applied to volcano-sedimentary strata from other regions of central and southern Stikinia (Diakow and Koyanagi, 1988; Britton and Alldrick, 1988; Brown et al., 1990). Recently, Marsden and Thorkelson (in press) suggested that the Hazelton Group should include all Lower to Middle Jurassic volcanic and related sedimentary rocks on Stikinia, south of about $58^{\circ}30'$ latitude, and that definition will be followed in this report. Strata north of about $58^{\circ}30'$ belong to the Laberge Group (Wheeler, 1961; Templeman-Kluit, 1978) and are predominantly sedimentary in character, with only rare volcanic members. The Laberge sedimentary rocks are generally not related to Jurassic volcanism but rather to erosion of Triassic igneous rocks (Templeman-Kluit, 1978, 1980; Hart and Radloff, 1990). The volcanic members (Hart and Radloff,

1990) are most reasonably regarded as part of the Laberge Group, and not as distant outliers of the Hazelton Group.

The Hazelton Group comprises a wide variety of rock types, making characterization based on a simple lithologic description difficult. As such, one of the features common to the group as a whole is diversity. In many successions, the Hazelton Group includes felsic to mafic lava, breccia, tuff, limestone, and epiclastic rocks ranging from conglomerate to shale. Many of the volcanic rocks show subaerial indicators such as maroon color and welded pyroclasts. Other characteristics general to the group are low metamorphic grade, typically of zeolite to prehnite-pumpellyite facies (Tipper and Richards, 1976; Mihalynuk, 1987; Read, 1988; Marsden, 1990; this thesis), and the absence of cleavage or foliation. However, the Triassic Stuhini and "western Takla" groups also show mixed volcanic and sedimentary character, and are commonly not discernably more deformed or metamorphosed than the Hazelton. Younger strata, generally sedimentary in character, may also resemble clastic sequences of the Hazelton.

Although lithologic features are essential discriminants, a principal criterion that has been used to determine whether a given succession belongs to the Hazelton Group is Early to Middle Jurassic age. Discriminating on the basis of age rather than lithologic character is not the most appealing method of defining stratigraphic nomenclature, especially for the field geologist.

Nevertheless, age provides a common element among diverse successions whose lack of lateral continuity may preclude correlation based on stratigraphic or petrologic similarity.

Several formations are recognized within the Hazelton Group, each typically comprising a laterally and vertically restricted, and lithologically distinctive sequence. Some of the formations have been subdivided into members or facies. Ages are based on isotopic dating and fossil determinations, but rarely have both methods been applied to a single succession (as they have been in this thesis). Where dating is precise, ages are known to a part of a stage (for example, lower Sinemurian), or within a few million years. However, the ages of most of the volcanic piles are not as well constrained, and the uncertainties in age are likely to be considerably larger than the durations of volcanism in many of the formations. Thus, in many cases, determining the age of volcanism in one geographical area relative to that in another is beyond the current resolution of modern geochronology. Nevertheless, rock ages from most areas are known well enough to provide comparable records of volcanism and sedimentation.

The areal distribution of the Hazelton Group (Figures 1 and 5) resembles scattered pieces of a jigsaw puzzle, and the lack of continuous exposure is the greatest impediment to a complete understanding of depositional history. The Bowser and Sustut basins of Middle Jurassic to Late Cretaceous age

(Eisbacher, 1974, 1981; Evenchick, 1991) cover a vast area in central Stikinia. The Hazelton Group is exposed around the periphery of these basins, and correlative strata probably lie beneath them. However, the nature and subsurface distribution of rocks that are correlative with the Hazelton Group are unknown, and suggestions concerning their origin and lithology (Tipper and Richards, 1976; Marsden and Thorkelson, in press) are speculative.

Structural deformation is another complicating factor in understanding the geology of the Hazelton Group. As discussed by Evenchick (1991), the Bowser Basin and most of the older rocks peripheral to the basin were shortened by 40-50% during the Late Jurassic to Late Cretaceous or Tertiary by the formation of generally northwest-trending folds and thrust faults. The region of deformation, which she named the Skeena Fold Belt, includes most of central Stikinia, and therefore most of the Hazelton Group was involved in the contraction. Prior to this event, the Hazelton is inferred to have been extended by an uncertain amount along syndepositional normal faults (Tipper and Richards, 1976; MacIntyre et al., 1987). However, the amount of extension is likely to have been modest relative to the amount of contraction that occurred during development of the Skeena Fold Belt (Marsden and Thorkelson, in press). Block faulting also occurred after the Skeena contractional event, but the amounts of extension or contraction accommodated by these structures are also likely to have been small.

Transcurrent displacements may have occurred in conjunction with, or separate from, any of the aforementioned extensional or contractional events. For example, strike-slip faulting may have been related to extensional deformation during deposition of the Hazelton Group or Bowser Basin sediments (Greig et al., 1991; Marsden and Thorkelson, in press). The Bowser Basin does not appear to have been significantly disrupted by transcurrent displacements, and if large-scale strike-slip faulting occurred after infilling of the basin, it must have been concentrated in peripheral areas. Such faulting within the Hazelton successions has not been reported.

Synthesis of Hazelton Group evolution

In spite of the complex history of deformation and an incomplete geochronological data set, the general histories and environments of deposition of most Hazelton Group successions are understood. The first comprehensive, regional description of Hazelton strata was made by Tipper and Richards (1976), based on geology in the Smithers, Hazelton and McConnell Creek areas. Using biostratigraphic, petrologic, lithogeochemical, and regional field studies, they documented the evolution of the Hazelton Group in terms of three formations, from lower Sinemurian to Callovian time (according to H.W. Tipper, pers. comm. 1991, the top of the Hazelton is more appropriately placed at the top of the lower Bajocian). Their synthesis became widely used as a

benchmark for geologists working on Jurassic strata throughout Stikinia.

Tipper and Richards (1976) determined that the central part of the Smithers to McConnell Creek region was a locus of marine sedimentation and volcanism throughout Hazelton time. The areas flanking this marine basin, particularly during the Sinemurian and early Pliensbachian, were sites of relatively shallow sedimentation and subaerial volcanism. Within the basin, called the Hazelton Trough (Figure 1), stratigraphic thicknesses were found to be at least 4200 m, considerably thicker than along the basin margins. Citing these features, Tipper and Richards (1976) suggested that the trough was a region of syndepositional subsidence caused by normal faulting. They speculated that the axis of the trough trended northwest.

Since the work of Tipper and Richards (*ibid*), our knowledge of the Hazelton Group has grown immensely. Using data from many areas, Marsden and Thorkelson (*in press*) provided a recent synthesis and tectonic model. Their compilation supported the northwest orientation of the Hazelton Trough, and depicted the flanking regions as shallow marine and emergent areas which were the loci of episodic subaerial to submarine volcanism. The axis of the trough was shown to extend from the Hazelton area to the western Spatsizi River and eastern Telegraph Creek areas.

Evidence that the Hazelton Trough actually continued as an elongate syndepositional depression for 300 km in the region now blanketed by the

Bowser Basin is based mainly on an analysis of depositional facies of the Hazelton Group. In the central part of the study area, in the Spatsizi River area, over 700 m of lower Pliensbachian to lower Bajocian fine-grained marine sedimentary rocks overlie at least 2 km of subaerially deposited lower Pliensbachian volcanic rocks (Cold Fish Volcanics, Chapter 3; Thomson et al., 1986). Eustatic sea level rise during the Early and Middle Jurassic is on the order of 100 m (Hallam, 1981; Vail and Todd, 1981), and subsidence must therefore account for about 85% of the sediment thickness (plus all of the thickness of the overlying ocean water). In the northwestern part of the study area, marine sedimentary rocks of Toarcian age occur as thin horizons in a mainly subaerial volcanic succession (Mount Brock volcanics, Chapter 3; Read and Psutka, 1990). They occur as high as 2 km above the base of the volcanic pile. Subsidence may have been caused by extension in the trough, perhaps in combination with sediment loading, and cooling following cessation of Pliensbachian magmatism. A thicker sequence was deposited in the eastern Telegraph Creek area, where over 2300 m of entirely marine sedimentary and volcanic rocks were deposited from (?)late Hettangian to early Bajocian time (units 13 and 14 of Souther, 1972; H.W. Tipper, pers. comm. 1991). An apparently overlying succession of at least 2400 m of Bajocian(?) pillow lava and sedimentary rocks (unit 15 of Souther, 1972; Evenchick, 1991) may not have been related to subsidence in the Hazelton Trough, but rather to a

younger, north-trending narrow depression that extends southward into the Iskut River area (Anderson and Thorkelson, 1990).

Marsden and Thorkelson (in press) have shown that volcanism on either side of the postulated trough axis formed a chain of terrestrial volcanic fields, volcanic islands and seamounts. On the western side, from the Whitesail Lake to Telegraph Creek areas, subaerial volcanism occurred in various areas during intervals in the Sinemurian, Pliensbachian, Toarcian, Aalenian and possibly the Bajocian. On the eastern side, from the Cry Lake to McConnell Creek regions, subaerial volcanism occurred in the Sinemurian, Pliensbachian, Toarcian and Bajocian. Submarine volcanism was common within and to the west of the trough, but was scarce along the eastern flank. Subaerial volcanism within the trough was, according to existing field interpretations, restricted to the top of a seamount in middle Toarcian time (Tipper and Richards, 1976).

Overall, volcanic activity was concentrated early in the history of the Hazelton Group, particularly in the Sinemurian and Pliensbachian. By the Bajocian, volcanism had become relatively scarce, and marine sediments were accumulating over successions that had been deposited in subaerial environments. This major transgression (Tipper and Richards, 1976; Thomson et al., 1986) was probably caused by a general thermal subsidence of Stikinia, in conjunction with waning magmatism (cf. Karig and Moore, 1975). Eustatic sea level rise, continuing lithospheric extension, (Anderson and Thorkelson,

1990), and incipient obduction of the Cache Creek Terrane (Thorstad and Gabrielse, 1986; Ricketts and Evenchick, 1991) may have contributed to the widespread submersion.

In Bathonian time, (Bajocian according to Gabrielse, 1991), the Hazelton Trough began receiving voluminous chert-rich turbidites from the north, a change which marks the transition from the Hazelton Group to the Bowser Lake Group (Souther and Armstrong, 1966; Tipper and Richards, 1986; Thomson et al., 1976). The beginning of Bowser Lake Group deposition also marks the end to what is regarded as the Hazelton Trough, and the beginning of what is called the Bowser Basin. Deposition in the Hazelton Trough was dominated by volcanoclastic detritus of local provenance, whereas Bowser Basin sediments were derived mainly from the obducting Cache Creek Terrane (Souther and Armstrong, 1966). The transition in sediment type and provenance thereby reflects a radical change in the tectonic setting of Stikinia, from an independent oceanic terrane to part of an amalgamating landmass. Sedimentation in the Bowser Basin, which was dominated by rapidly prograding turbidites, fan deltas and fluvial systems, continued until the middle Cretaceous (Moffat et al., 1988; MacLeod and Hills, 1990; Ricketts and Evenchick, 1991).

The sediment-dominated character of the Bowser Lake Group indicates that the Bowser Basin inherited its basic form from the Hazelton Trough, and not through a separate phase of extensional tectonism. For 60 m.y. prior to the

inception of Bowser Lake Group sedimentation, Stikinia had been host to episodic, voluminous arc magmatism (Stuhini and Hazelton groups and related intrusions). Consequently, in the early Middle Jurassic, Stikinia is likely to have been a region of high heat flow (cf. Watanabe et al., 1977), and Stikinian crust is likely to have directly overlain metasomatized asthenosphere (cf. Gill, 1981). Extension of Stikinia during this period would almost certainly have been coupled with alkalic to tholeiitic mafic magmatism, in the manner of Late Cenozoic back-arcs and rifted arcs of the western Pacific (Weaver et al., 1979; Lordkipanidze et al., 1979; Taylor and Karner, 1983; Tamaki, 1985; Gill and Whelan, 1989). However, the Stikinian stratigraphic record indicates diminishing Hazelton volcanism toward the end of Early Jurassic time, and no magmatism whatsoever in the proximity of the basin during deposition of the lower Bowser Lake Group. The only igneous rocks of Jurassic age within the Bowser Basin are the Upper Jurassic Netazul volcanics, a set of minor successions along the eastern and southern margins of the basin (Tipper and Richards, 1976). It is therefore most probable that the amount of extension within the Hazelton Trough lessened during the evolution of the Hazelton Group, becoming virtually nil by the time of earliest Bowser Lake Group sedimentation. The Bowser Lake Group thus infilled an existing marine basin that was centered by the Hazelton Trough and flanked by eroded and subsided remnants of Hazelton volcanoes.

The Hazelton Group is exposed across a width of approximately 300 km.

However, if the effects of contractional and extensional deformation are accounted for, the width of the Hazelton belt restores to about 450 km in the Early Jurassic (Evenchick, 1991; Marsden and Thorkelson, in press). Marsden and Thorkelson (ibid.) compared the ages, depositional environments, and geochemical characteristics of volcanic rocks from the eastern, central and western belts of the Hazelton Group, and concluded that: (1) the geochemical characteristics are of volcanic arc affinity, and do not show pronounced variation in degree of alkalinity from east to west; and (2) volcanism of similar ages occurred across a width which greatly exceeds that of modern arcs. These findings imply that the Hazelton Group was not deposited above a single subduction system.

To accommodate the great width and apparent geochemical uniformity of the Hazelton Group, Marsden and Thorkelson (ibid.) invoked a model in which subduction of oceanic lithosphere occurred beneath Stikinia from both the eastern and western sides (in present geographical coordinates). They argued that the distance from trench to volcanic front on each side was about 175 km, based on postulated subduction angles averaging 30° to a depth of 150 km. Hence, the Hazelton Group was interpreted to have formed as a pair of coeval island arcs, separated by a marine trough, on an 800 km-wide microplate. Accordingly, the Stikinia Terrane now preserved in the Canadian Cordillera represents only the central part of that microplate. The eastern forearc region

Figure 6. Possible tectonic environment of Stikinia in Early Jurassic time. Subducting oceanic plates dip symmetrically beneath Stikinia from opposite sides, generating "eastern" and "western" volcanic arcs. The Hazelton Trough is a region of back-arc extension and subsidence common to both arcs. On the basis of reasonable subduction rates of 7 cm/a, the leading edges of the plates would reach depths of about 200 km after about 5 million years of subduction, and would intersect deep in the asthenosphere after 10 million years of subduction. After Marsden and Thorkelson (in press).

has probably been overridden by the Cache Creek Terrane, and dismembered by transcurrent faulting (cf. Gabrielse, 1985). Rocks of the western arc-trench gap may also have been underthrust and attenuated by faulting, although relations have been blurred by subsequent magmatism, metamorphism and uplift in the region of the Coast Plutonic and Metamorphic Complex (Figure 5).

The Stikinia microplate may have begun to collide with the Cache Creek Terrane in the Toarcian. The timing of this event is implied by the paucity of post-Pliensbachian volcanism in the eastern belt, probably caused by reduced activity in the eastern subduction system, and is supported by the sedimentological and structural evidence mentioned earlier. Subduction at the eastern trench may have continued at a slower rate, or episodically, until the Bajocian, as implied by the small number of Toarcian to Bajocian volcanic piles in the eastern belt.

The magnitude of volcanic activity in the central and western belts decreased sharply after the Toarcian, suggesting that subduction at the western trench began to slow in conjunction with collision to the east. The complete absence of Hazelton volcanic rocks younger than Bajocian indicates that both subduction systems had ceased to operate by that time. Whether cessation of subduction along the western margin of Stikinia was caused by collision with more outboard terranes, or by changes in plate motions related to accretion with the Cache Creek Terrane, is uncertain.

Chapter Three

Geology of the study area

Basement to the Hazelton Group

Rocks which form the basement to the Hazelton Group include Carboniferous to Permian metasedimentary and meta-igneous rocks (CPm), the Early to Late Triassic Railway pluton (Tm), and possibly other intrusive rocks (TTg), Upper Triassic Stuhini Group (TS) volcanic and sedimentary rocks, and Upper Triassic to Lower Jurassic conglomeratic strata (TJc). Only the Stuhini Group and unit TJc were investigated by the author (Tables 1 and 2).

Unit CPm (Stikine assemblage?)

Unit CPm (Figure 3) is mainly restricted to the Brock district, where it was described by Read and Psutka (1990). It consists of cleaved and deformed greenstone, limestone, other sedimentary rocks, and mafic to felsic plutonic rocks. Polyphase, noncoaxial folds distinguish this unit from younger rocks. The greater degree of deformation in unit CPm is presumably a result of tectonism during the Middle Triassic, in what is referred to as the Tahltanian orogeny (Souther, 1971). Rocks of this unit are probably correlative with the Stikine assemblage of Monger (1977) and D. A. Brown et al. (1991). In the southwestern Brock district, volcanic rocks of unit CPm unconformably underlie

volcanic rocks of unit Jv. In the western Griffith district, an outcrop of coarse marble was considered most likely to be Paleozoic by Gabrielse and Tipper (1984), and is correspondingly included in unit CPm of this study. The only other occurrences of unit CPm in the study area are variably recrystallized limestone and chert clasts in conglomeratic rocks of unit TJc. Some of the limestone clasts have yielded Permian conodonts (M. Orchard, personal communication, 1989; Read and Psutka, 1990).

Units Tm and TTg (Railway Pluton and other intrusive rocks)

The Railway pluton (Tm), of the western Brock district was briefly described by Read and Psutka (1990) as an unfoliated, weakly metamorphosed monzodiorite that yielded a U-Pb (zircon) isotopic age of 227 ± 9 Ma (Table 6). The pluton is nonconformably overlain by granitic pebble to cobble conglomerate (TSsc) and limestone of Norian age (Read and Psutka, *ibid*). In the west-central Brock District, a small ($<0.5 \text{ km}^2$), undated inlier nonconformably underlies Upper Pliensbachian to Lower Toarcian sedimentary rocks of unit Js, which conformably underlie the Mount Brock volcanics (Smith et al., 1984; Thomson et al., 1986; Read and Psutka, 1990). Read and Psutka (*ibid*) also correlated the Railway pluton with similar rocks that crosscut Permian and (?) older rocks a few kilometres west of the Brock district. Other intrusive rocks which may be older than the Hazelton Group, but may be as young as

Tertiary, are included in unit TTg.

Stuhini Group (TS)

Stuhini Group volcanic (TSv) and sedimentary (TSs) rocks were recognized in the Brock, "Knife Edge," Cartmel, and Griffith districts. The volcanic rocks consist of greenish grey, aphyric to porphyritic mafic lava flows and related breccia and olistostrome. The most conspicuous phenocryst phase is augite (2-15 mm), but plagioclase and serpentinized olivine are also common, and biotite is less common. The sedimentary rocks vary from shale, to sandstone and conglomerate, and limestone.

In the "Knife Edge" district (Table 2), lava flows are typically 5-10 m thick, and are intercalated with beds of feldspathic and augitic wacke, and siltstone. Rare beds of limestone yielded Upper Norian conodonts (Read and Psutka, 1990). Locally, the lava flows grade into, or are interbedded with, coarse volcanic breccia and olistostrome. In these deposits, the volcanic clasts tend to be more porphyritic (coarsely augite-phyric) than the massive flows. The siltstone is typically laminated, and varies from thinly bedded turbidites to thick, massive, convoluted beds which form the matrix of olistostrome. Locally abundant felsic sills of unknown age (probably Late Triassic or Early Jurassic) have intruded the succession. In the western "Knife Edge" district, limestone clasts which were collected by the author from olistostrome, within a section

dominated by lava and siltstone, yielded Early Permian (Artinskian) conodonts (M. J. Orchard, personal communication, 1989).

Near the centre of the "Knife Edge" district, thinly bedded (5-10 cm) siltstone turbidites hosting the Upper Norian bivalve *Monotis* sp. (H. W. Tipper, personal communication, 1988) coarsen and thicken upsection, over a 20 m interval, to sandstone beds 0.5-1.5 m thick. The sandstone, which hosts fossilized fragments of wood, is abruptly overlain by sedimentary melange and conglomerate (unit TJc) that contains clasts of volcanic rock, limestone, and chert. Read and Psutka (1990) included these and other conglomeratic rocks in the Stuhini Group. However, in this area and elsewhere the conglomerates form thick, distinctive successions which may, in part, be of Early Jurassic age, i.e., younger than the accepted age of the Stuhini Group.

Rocks similar to those in the "Knife Edge" area are exposed in the Griffith district (Table 2). There, greenish-grey lava flows (5-10 m thick), with rare, maroon flow-top breccia, are also interbedded with laminated siltstone and marble- and limestone-bearing olistostrome. Upper Triassic fossils were collected by the Geological Survey of Canada from strata about 1 km east of the Griffith Fault and identified by E. T. Tozer (H. W. Tipper, personal communication, 1990). A bed of micritic limestone, which can be traced on both sides of the Griffith Fault, was sampled for conodonts but yielded no specimens (M. J. Orchard, personal communication, 1988).

Sills and dykes of hornblende-orthoclase-plagioclase dacite were emplaced within the Stuhini succession in the Griffith district. The orthoclase grains (0.1-2 cm) are trachytically (flow) aligned oikocrysts that enclose smaller grains of hornblende, plagioclase and orthoclase. These intrusions bear a striking resemblance to the Texas Creek ("Premier porphyry") intrusions of the Iskut River region, 200 km to the southwest, which have been linked to gold mineralization (Brown, 1987).

Conglomeratic deposits (TJc) overlie and may be interbedded with the Stuhini strata; however, unresolved geological structures in the Griffith and "Knife Edge" areas preclude a more certain description of the stratigraphic relations. In the southeastern Griffith district, nearly vertically dipping lava flows and clastic rocks of the Stuhini Group are unconformably overlain by gently dipping Middle to Late Jurassic shale and conglomerate of the Bowser Lake Group (JBL).

Stuhini Group rocks in the Cartmel and Brock districts (Read and Psutka, 1990) were not inspected by the author.

A cursory petrographic inspection was made on some Stuhini Group lavas. Large-augite basalt from the study area typically contains phenocrysts of augite and serpentinized olivine, and minor amounts of plagioclase and magnetite. Biotite, commonly pseudomorphed by opaque oxides (magnetite?), is present in some of the augite-phyric samples. The augite grains (2-8 mm)

are optically zoned and poikilitic, enclosing microcrystalline inclusions, and chadacrysts of serpentinized olivine and saussuritized plagioclase. The microcrystalline inclusions probably represent trapped blebs of melt which have undergone magmatic crystallization and/or devitrification. Plagioclase is typically lathlike, and variably altered (most strongly in cores) to sericite, calcite, and epidote-group minerals. Biotite is usually altered to opaque oxides, but in some samples is completely fresh. Less porphyritic samples contain a similar phenocryst assemblage. Samples from about 4 km northwest of Todagin Mountain (Figure 2), to the west of the study area, also contain large augite oikocrysts and altered biotite phenocrysts, and are correlated with the Stuhini Group.

Mihalynuk (1987) reported the presence of mafic lava and breccia hosting phenocrysts of augite, plagioclase and biotite, in the eastern Terrace area, south of the Bowser Basin. Although he regarded these volcanic rocks as part of the Telkwa Formation of the Hazelton Group, they are perhaps lithologically more similar to the Stuhini Group, and, as noted in Mihalynuk and Ghent (1986), may be of Triassic age. The presence of both biotite and augite as phenocrysts in mafic, arc-related volcanic rocks is unusual (Gill, 1981; Ewart, 1982), and may serve as a valuable tool in regional correlations of Early Mesozoic rocks of Stikinia.

Read and Psutka (1990) informally defined a succession of augite-phyric

mafic lavas and related breccias in the Tsaybahe Mountain region (Figure 2) as the upper "Tsaybahe Group." Underlying phyllitic rocks were defined as the lower "Tsaybahe Group," an assemblage that Read and Psutka (ibid) correlated with fossiliferous, Middle Triassic rocks in the northwestern Spatsizi River area. Read and Psutka (ibid) assigned a Middle Triassic age to the upper "Tsaybahe Group," and distinguished it from the Stuhini Group by its greater content of volcanic rocks, and ubiquity of augite phenocrysts in the volcanic rocks. The use of augite as a discriminant seems inappropriate, however, because the Stuhini Group is well-known for its abundant augite phenocrysts (e.g., Souther, 1977; Monger and Church, 1977). The possibility that the Stuhini and "Tsaybahe" groups are correlative is strengthened by their petrographic similarity.

Volcanic and sedimentary rocks of the Stuhini Group in the study area were deposited in a predominantly submarine environment, as indicated by the presence of marine fossils, turbidites, and olistostrome. The lavas are mainly greenish grey, and host olivine which has been altered to serpentine; only rarely do they show features of post-eruptive oxidation associated with subaerial deposition, such as reddish flow margins, and iddingsitized olivine. In the sedimentary rocks, no intertidal or fluvial sedimentary structures have been observed. However, the presence of sandstone turbidites that host fragments of fossilized wood imply that nearby regions were emergent.

Unit TJc (Triassic-Jurassic conglomerate)

Conglomeratic and olistostromal deposits that are not clearly related to Stuhini or Hazelton group strata were mapped as unit TJc. This unit crops out in the Brock, "Knife Edge," Ice Box and Griffith districts (Table 2). In the central "Knife Edge" district, the conglomeratic unit abruptly overlies Upper Norian Stuhini turbidites (Thorkelson, 1988). The succession begins with a coarse sedimentary melange containing cobbles and boulders of marble and limestone, and chert granules. The occurrence of Upper Norian conodonts (M. J. Orchard, personal communication, 1989) in a large (5 m) limestone clast indicates that at least some of the carbonate blocks were derived by erosion of the Stuhini Group. Other limestone clasts may be Early Permian, such as those found in olistostrome of the Stuhini Group, and elsewhere in unit TJc. Overlying the melange to the north is a succession of conglomerate and sandstone, and minor shale and mafic lava. Whether the mafic lava, which is augite and plagioclase phyrlic, is correlative with lava in the Stuhini Group, or is part of the Hazelton Group is uncertain. The conglomerate, which varies from clast- to matrix-supported, is largely composed of subangular to subrounded fragments of hornblende-plagioclase andesite, forms massive, poorly stratified sections. The matrix of the conglomerate is hornblende and plagioclase wacke, which is very similar in appearance to, and difficult to distinguish from, the volcanic clasts. In other parts of the "Knife Edge" district, the conglomerate hosts blocks

of marble which have yielded Artinskian (Early Permian) conodonts (Read and Psutka, 1990; M. J. Orchard, personal communication, 1989). A thick succession of Stuhini lava, siltstone and sandstone on the western end of the "Knife Edge" district may overlie the conglomerate, although field relations are uncertain.

In the Griffith district, some deposits of unit TjC also overlie the Stuhini Group (Thorkelson, 1988). Micritic limestone, shale and sandstone at the top of the Stuhini Group are abruptly to gradationally overlain to the northeast by coarse, cross-bedded sandstone and conglomerate. The conglomerate is dominated by clasts of volcanic rocks, particularly hornblende-plagioclase andesite, but is locally rich in marble, limestone and chert (and in other areas, granitic rocks). Clasts of crinoidal limestone yielded Early Permian, probably Sakmarian conodonts; reddish-grey marble yielded Permian conodonts; and grey micritic limestone with pelecypod fragments yielded Carnian conodonts (M. J. Orchard, pers. comm., 1988). The chert fragments are red, green, light blue, white and black, and typically angular to subangular. Several chert clasts examined by F. Cordey (personal communication, 1989) were barren of radiolaria. Many of the volcanic clasts weather recessively. The conglomerate has been intruded by mafic dykes and sills, which locally have thickened the succession by as much as 30%. Some of the intrusions contain phenocrysts of augite, biotite and plagioclase, an assemblage which matches that of some

Stuhini Group lava flows. If these sills and dykes are comagmatic with the Stuhini Group, then the conglomerate in this area is probably Norian in age. Abruptly overlying the conglomerate, perhaps disconformably, are welded ignimbrite and mafic lavas of the Griffith Creek volcanics (JG).

Elsewhere in the Griffith district, field relations of unit TJc are poorly understood, and some of the conglomeratic deposits may be interbedded with strata of the Stuhini Group. Contributing to the uncertainty is a lack of understanding of the main geological structures. The crudely symmetrical map pattern, in which the Stuhini Group is flanked on both sides by the conglomerate, is suggestive of anticlinal geometry. Further work is necessary to determine if an anticline, faults, or interbedding of the Stuhini and conglomeratic rocks is responsible for the symmetry.

In the Ice Box district, a succession of unit TJc is faulted against the Sustut Group (KS) and the Cold Fish Volcanics (JC)(cross section A-B on Figure 3). The succession forms a 2 km-thick homoclinal panel of maroon to grey conglomerate and debris flows. The most abundant clast type in the conglomeratic rocks is hornblende-plagioclase andesite. In the maroon debris flows, which may be synvolcanic laharic deposits, the clasts are angular and supported by a matrix of hornblende-plagioclase wacke. The succession is either directly overlain by the Sustut Group, as shown in the cross section, or separated from it by a rather thin (<500 m) intervening unit. This stratigraphic

relationship contrasts with those to the southwest, across the Cullivan Fault, where the Sustut Group rests on a thick succession of the Cold Fish Volcanics (JC).

Conglomeratic rocks of unit TJc were also recognized during reconnaissance fieldwork 3-4 km northwest of Todagin Mountain area (Figure 2). One well-exposed succession comprises coarse sediment gravity flows containing abundant clasts of hornblende-plagioclase andesite. The debris flows vary from 1-4 m thick, are generally supported by a dark brown sandy matrix, and host subrounded to subangular, resistant clasts up to 20 cm in diameter (Plate 2(a)). In another locality, clasts of hornblende-plagioclase andesite up to 30 cm across weather recessively, and are difficult to distinguish from matrix.

Previously, the conglomeratic successions in the study area were not recognized as a distinct geological unit. Instead, they were included in either the Stuhini or Hazelton groups by Read and Psutka (1990) and Gabrielse and Tipper (1984). For example, unit TSsc, in the western Brock district, was assigned to the Stuhini Group by Read and Psutka (1990), apparently on the basis of Norian limestone within this conglomeratic unit; their assignment has been followed in this thesis. Further studies may indeed demonstrate that some of the various conglomeratic deposits that constitute unit TJc are more appropriately regarded as parts of the Stuhini or Hazelton groups. However,

much of unit TJc is lithologically distinctive, mappable over a broad area, and not obviously correlative with either group.

Especially distinctive are the massive conglomerate beds and sediment gravity flows hosting clasts of predominantly hornblende-plagioclase andesite. Some of the deposits are maroon, and may be lahars derived from nearby andesitic edifices. Other aspects of unit TJc, such as the incorporation of Permian detritus, and the apparent age equivalence of some of the conglomeratic deposits to rocks of Stuhini Group require other explanations. Deposition of the Permian clasts seems to require uplift and exhumation of older crust, perhaps related to regional faulting (cf. Tipper and Richards, 1976; Marsden and Thorkelson, in press). Possibly, some of the conglomeratic strata may be genetically related to extensive conglomerate successions of the Takwahoni Formation in the Cry Lake, Telegraph Creek and adjacent areas of northern British Columbia. More work is needed to clarify the ages, stratigraphic positions and origins of the various deposits of unit TJc.

Lower Jurassic volcanic successions in the study area

Introduction

Three Lower Jurassic volcanic successions are recognized in the study area (Tables 1, 2 and 3; Thorkelson et al., 1991). The oldest is the Griffith Creek volcanics, an informally defined (this thesis) succession of mafic lava,

Table 3 GENERALIZED STRATIGRAPHY in study area

and intermediate to felsic pyroclastic rocks and sills. It is exposed over too small an area, and is not understood well enough to be considered a formal unit. The middle unit is the Cold Fish Volcanics, a succession of mafic to intermediate lava, and felsic pyroclastic rocks and sills. It was informally named and briefly described by Thomson et al. (1986). It is regarded as a formal volcanic formation in this thesis ("Volcanics" is capitalized), and will be properly defined in a later publication; its type locality will be defined as the Nation district or part thereof. The youngest unit is the Mount Brock volcanics, an informally defined sequence of mafic lava and pyroclastic rocks. Read and Psutka (1990) informally called this unit the Brock volcanics, but because of conflict with existing Canadian nomenclature (T. Bolton, personal communication, 1990), the term *Mount Brock* will be used here. The Mount Brock volcanics are exposed over a large enough area to be considered a formal stratigraphic unit. However, the succession was not studied in enough detail to permit a thorough stratigraphic description; further work is necessary to provide a solid basis for identification of a type section or locality, and formalization of lithostratigraphy.

On the basis of age, lithology, and regional context, all three successions have been included in the Hazelton Group (Thomson et al., 1986; Thorkelson, 1988; Marsden and Thorkelson, in press). Each succession was examined by the author, with the greatest attention being given to the Cold Fish Volcanics.

The ages of the Hazelton Group successions are known from fossil collections and U-Pb (zircon) isotopic age determinations. The fossils were collected primarily by: Geological Survey of Canada (GSC) officers H. W. Tipper, H. Gabrielse and C. A. Evenchick (and their assistants); P. L. Smith and R. C. Thomson of The University of British Columbia; Geotex Consultants; and the author. Macrofossils, mainly ammonites, belemnites and pelecypods, were identified by Tipper, Smith and Thomson. Conodonts (microfossils) from older rocks were identified by M. Orchard of the GSC. Relevant fossil ages are mentioned in discussions of each of the Hazelton volcanic units. For more detail, the reader is referred to Thomson et al. (1986) and Read and Psutka (1990). The isotopic dates, provided by the GSC from rocks collected by the author, are described in detail in Chapter 5.

Isotopic ages from the Griffith Creek volcanics are 203.1 ± 0.4 and 205.8 ± 0.9 Ma, corresponding to an Hettangian or (Early ?) Sinemurian age on the time scale of Harland et al. (1990). The Cold Fish Volcanics are intercalated with and are overlain by strata hosting macrofauna of Early Pliensbachian age. Four U-Pb isotopic ages (194.8 ± 1.0 ; $194.0 \pm 2.8/-2.3$; 193.9 ± 1.1 ; and 193.5 ± 2.0 Ma) from the volcanic succession, and one from the synvolcanic Spatsizi River Stock (190.0 ± 7.1 Ma) are consistent with the age of the macrofossils. The Mount Brock volcanics are underlain by strata hosting Early Jurassic ammonites, and are interbedded with sedimentary rocks

of Early and Middle Toarcian ages.

The distribution of these successions (JG, JC, and JM) is shown in Figure 3. In some parts of the study area, available geological data were insufficient to assign rocks to a particular Hazelton Group succession, and therefore the nonspecific unit designators Jv, TJu and TJ have been used. Unit Jv refers to rocks which may belong to any of the Hazelton Group volcanic units; unit TJu is used where rocks may include those of the Cold Fish Volcanics, the Griffith Creek volcanics, the Triassic Stuhini Group (TS), and Triassic to Jurassic conglomerate (TJc). The possible rocks included in unit TJ are the same as in TJu, except that the Cold Fish succession is excluded. The possibility that future work on rocks of these nonspecific units may identify Hazelton Group rocks which are distinct from the three main successions cannot be ruled out.

Chemical analyses of major and trace elements, cation normative mineralogy, common petrologic indices, and phenocryst contents of rocks collected from the Hazelton Group and other units, together with analytical methods are listed in Appendix 1.

Griffith Creek volcanics (JG)

The Griffith Creek volcanics are the oldest part of the Hazelton Group in the study area. They are mainly exposed in the Griffith district, where rocks

assigned to the formation underlie approximately 10 km². Only one small (<0.5 km²) outlier of the Griffith Creek has been recognized outside of the Griffith district, in the northeastern Ice Box district. The succession consists of mafic to intermediate lava flows, and intermediate to felsic ignimbrite, airfall tuff and sills. The Griffith Creek is distinguished from the Stuhini Group mainly by its abundance of subaerially deposited, intermediate to felsic pyroclastic rocks.

The base of the formation is exposed in the Griffith District, on either side of the Griffith Fault. In both places, the volcanic succession overlies conglomeratic rocks of unit TJC. On the northwest side, the succession begins with densely welded ignimbrite containing chloritized fiamme. It is overlain by several mafic lava flows with locally reddened flow margins. Augite is the most conspicuous phenocryst of the lavas, although plagioclase, and serpentinized or iddingsitized olivine were observed in some of the rocks. The lavas are apparently overlain by another welded ignimbrite, but the likelihood of structural disruption or repetition of the sequence makes this interpretation uncertain. Southeast of the Griffith Fault, the basal unit of the succession is a lava flow of basaltic andesite containing hornblende and plagioclase phenocrysts. Overlying strata were not investigated.

Dacitic to (?) rhyolitic rocks of the Griffith Creek volcanics (JGf) form a fault-bounded succession on the northwestern side of the Griffith Fault, north of the mainly mafic basal sequence (JGm). The succession consists of welded

and nonwelded ignimbrite, airfall tuff, and sills. The ignimbritic deposits contain abundant mineral grains, of which feldspar, quartz, hornblende and biotite are the most abundant. Most of the sills are phenocryst-poor. However, a 3 km-long slightly discordant sill (JGfs) which was emplaced into Stuhini Group strata and unit TJc to the south of the ignimbritic succession, is composed of highly porphyritic dacite with abundant phenocrysts of hornblende, biotite, quartz and feldspar. The sill thus bears a striking resemblance to the ignimbritic rocks, and is correlated with them. Also correlative is a small outcrop of weakly welded ignimbrite hosting abundant biotite, in the northeastern Ice Box area.

Petrographic analysis of the Griffith Creek volcanics reveals a number of significant features. The basal flow of mafic lava from the southeast side of the Griffith Fault comprises about 20% plagioclase, 15% hornblende altered to opaque oxides, and 65% groundmass (Plate 1(b)). The groundmass is a felty network of plagioclase, magnetite, and oxide-psuedomorphed hornblende. In contrast, mafic lava flows to the northwest of the fault do not contain hornblende, and instead contain augite and altered olivine, together with partly altered plagioclase grains in a granular to felted groundmass. In one of the lavas northwest of the fault, the phenocryst assemblage consists of small (<2 mm), euhedral grains of augite, olivine (altered to iddingsite and (?) hematite) and plagioclase that occupy about 15% of the rock volume. In another, the phenocrysts are larger, and consist of 12% augite (up to 4 mm), 5%

Plate 1. Photomicrographs of the Griffith Creek volcanics. Scale bars are 1 mm long. PL = plane polarized light; XP = crossed polarized light.

(a) Basaltic andesite (chemical sample 87-228-3): anhedral, embayed grain of augite (At) in groundmass of plagioclase, serpentinized olivine, and magnetite. XP.

(b) Basaltic andesite (chemical sample 87-219-2): oxide-pseudomorphed hornblende (Hb), and saussuritized plagioclase (Pl) phenocrysts in fine grained groundmass of altered plagioclase and hornblende. PL.

(c) Dacitic sill (chemical sample 87-234-2): euhedral, partially chloritized hornblende (Hb) and saussuritized plagioclase (Pl) phenocrysts. PL.

(d) Andesitic weakly welded tuff (chemical sample 87-142-2): unaltered biotite (Bi) and quartz (Q), and weakly altered orthoclase grains in matrix of slightly flattened shards. PL.

serpentinized olivine, 2% saussuritized plagioclase, and 1% magnetite. In that sample, the silicate minerals are anhedral to deeply embayed (Plate 1(a)), indicating that they were in disequilibrium with the melt. The grains may have grown in one magma which subsequently mixed with another, resulting in a hybrid liquid which corroded the entrained phenocrysts. Alternatively, the grains could be xenocrysts derived from country rock. Supporting this possibility is the resemblance of the pyroxene grains to those in some Stuhini Group lavas; the augite is poikilitic, and encloses serpentinized olivine chadacrysts. In addition, the lava contains small fragments (several mm) of serpentinized olivine-augite peridotite of identical mineralogy. Possibly, magma which was parental to this lava had partly assimilated xenoliths of igneous wallrock of Stuhini lineage.

The felsic rocks contrast petrographically with mafic lavas in both mineral content and texture. Most different are the dacitic ignimbritic rocks, some of which have a eutaxitic texture (flattened glass shards and pumice fragments). Many are very rich in mineral grains (up to 60% by volume), which are typically about 2 mm long. One sample of nonwelded ignimbrite from the Griffith district contains about 28% potassic feldspar (slightly sericitized), 15% plagioclase (moderately saussuritized), 14% quartz, 2% opaque oxides (magnetite?), and 1% biotite. Trace amounts of spherulitic to granular cassiterite, muscovite, and tridymite or cristobalite, have crystallized in vugs. These accessory phases

were probably deposited from high temperature vapour during cooling of the ignimbrite, in the manner of "automineralization" described by Duffield et al. (1990). Cassiterite also appears to have partially replaced pseudomorphs of magnetite-after-hornblende. Other ignimbrites have similar mineral contents, but host up to 10% biotite which gives them a speckled appearance. The isolated outcrop of maroon ignimbrite in the Ice Box area, for example, contains about 25% orthoclase perthite, 13% plagioclase, 15% embayed quartz, 5% biotite and 2% (?) magnetite (Plate 1(c)). It strongly resembles some of the rocks in the Griffith district. The large sill which was emplaced into older rocks (JGfs) is also dacitic, and resembles the ignimbrites. It contains 50% phenocrysts, up to 4 mm long, of plagioclase (15%), hornblende (13%), potassic feldspar (10%), quartz (5%), biotite (5%), and magnetite (2%), set in a granular, very fine grained groundmass (Plate 1(d)).

Two U-Pb (zircon) dates indicate that the Griffith Creek volcanics are close in age to that of the Triassic-Jurassic boundary (Chapter 5). The older date, 205.8 ± 0.9 Ma, was obtained from the basal lava flow of hornblende-plagioclase basaltic andesite on the southeastern side of the Griffith Fault. The younger date, 203.1 ± 0.4 Ma, was obtained from the large dacitic sill (JGfs) on the northwestern side of the fault. On the time scale of Harland et al. (1990), shown on Tables 1, 2 and 3, these dates are Hettangian to early Sinemurian, i.e., slightly younger than the Triassic/Jurassic boundary (208 Ma). On another

time scale (Cowie and Basset, 1989), a 205 Ma age was assigned to the Triassic/Jurassic boundary, an age selection which has been recently supported by U-Pb (zircon) chronometry of the Palisades and Gettysburg sills of the northeastern United States (Dunning and Hodych, 1990). In this thesis, the age of the Griffith Creek succession is considered to be Hettangian to Lower Sinemurian (Tables 2 and 3).

The Griffith Creek volcanics were deposited subaerially, as indicated by the abundant welded ignimbrite, and reddened margins of the mafic lava flows. No indicators of aqueous deposition have been observed. Although the present exposure of this formation is very limited, the original distribution may have been much greater. Possibly, the Griffith Creek formed a sequence that originally underlay much of the study area. It is likely that further field studies in the nonspecific units Jv, TJ, and TJu will reveal additional outcrops of the Griffith Creek succession.

Cold Fish Volcanics (JC)

Introduction

The Cold Fish Volcanics (JC) are the best exposed and most widely distributed rocks in the study area, underlying an area of about 450 km². They were examined in greatest detail in the Nation district, where they were mapped at 1:25 000 scale (inset map of Figure 3). The base of the Cold Fish

succession has not been observed by the author or previous workers, although it could possibly be exposed above beds of sedimentary rock (mapped as TJu) in the southern Will area, noted by C. A. Evenchick (personal communication, 1990) during reconnaissance mapping. The top of the succession is exposed in several places, in the Joan, "Plateau," Will, Nation and Ice Box districts, where it is conformably overlain by Hazelton Group sedimentary rocks. The average stratigraphic thickness of the succession is thought to exceed 2 km (Figure 7; in pocket). After accounting for about 50% shortening, which was incurred during contractional deformation of the Jura-Cretaceous Skeena Fold Belt (Evenchick, 1991), the area of deposition represented by the exposures in the study area is estimated at about 900 km², with a volume of about 1 800 km³.

Seventeen detailed stratigraphic sections (a to q), mainly from the Nation district and adjacent areas are displayed at 1:2 500 scale in Figure 7 (section locations are shown in Figure 3). The sections were not measured, but were constructed from the geological maps, field notes, and photographs. The uncertainty in thickness of individual depositional units varies, but is estimated to be about 20%. The sections are arranged by district, and have been correlated with one another, where possible, on the basis of lithostratigraphy. The top of the Cold Fish is used as the primary datum to which the sections are stratigraphically related.

Three cross sections of the study area have been drawn to show the

stratigraphic and structural relationships within the Cold Fish Volcanics, and between the Cold Fish and other units. Sections A-B and C-D are drawn at 1:100 000 scale, and their traces are located on Figure 3. Section C-D is modified after the "Joan Lake section" of Evenchick (1991). Section E-F-G is drawn at 1:25 000 scale, and its trace is also shown in Figure 3 (inset map of Nation District).

Generalized stratigraphy

The Cold Fish Volcanics are well exposed and widely distributed in the study area, underlying much of the Will, "Plateau," Joan, Nation, Ice Box, and Cartmel districts. They are a composite succession, mainly comprising lava flows, sills and tuffaceous rocks, with minor epiclastic rocks and limestone. Compositionally, they range from basalt ($<53\% \text{ SiO}_2$) to high-silica rhyolite ($>75\% \text{ SiO}_2$). Dacitic compositions are rare, however, and the succession is strongly bimodal with reference to silica (Table A-1; Figure 8). Thus, Cold Fish rocks can be divided into *rhyolite* (including high-silica rhyolite), and a *mafic* suite of basalt, basaltic andesite, andesite, and minor dacite. The mafic rocks were emplaced as lava flows and related breccias, and dykes, whereas the rhyolitic rocks are more varied in their emplacement types, which include lava flows, breccia, airfall tuff, ignimbrite, sills and dykes.

The regional distribution of rhyolitic and mafic rocks is not uniform. In

Figure 8. Histogram of silica concentrations of the Cold Fish Volcanics, showing pronounced bimodality, and a paucity of data in the 60-70% range of SiO_2 .

Cold Fish Volcanics

the Will district, rhyolitic sills and related tuffaceous rocks predominate, and mafic rocks are scarce. The voluminous rhyolitic rocks in this area are probably genetically related to the Spatsizi River Stock, an alkali-feldspar granite (International Union of Geological Sciences classification; Streckeisen, 1976) which is interpreted as a synvolcanic intrusion. The relative abundance of mafic rocks generally increases toward the northwest, and in the Ice Box district mafic lava is more abundant than rhyolite. Although this regional trend may be partly a function of changes in exposed stratigraphic level, it probably reflects a fundamental depositional bias, with mainly mafic volcanism in the northwest giving way to mostly felsic volcanism in the Will district.

Most of the Cold Fish Volcanics were deposited in a subaerial environment. Subaerial indicators in the terrestrial parts of the Cold Fish include densely welded ignimbrite, maroon to brick-red mafic lavas and tuffaceous rocks, and an absence of interbedded marine sedimentary rocks. About 5% of the succession was deposited under submarine conditions (mainly in the Ice Box district), and comprises greenish-grey lava flows, pillow lava and pillow breccia, aquagene tuff, sandstone, shale and limestone. Macrofossils (including diagnostic ammonites) collected from limestone and limey siltstone in the Ice Box and Nation areas by H. W. Tipper, C. A. Evenchick, and other employees of the Geological Survey of Canada, were identified by H. W. Tipper and determined to be of Early Pliensbachian age (H. W. Tipper, personal

communication, 1986-1991).

Upper ignimbrite sequence

The Cold Fish Volcanics were studied in greatest detail in the Nation, Joan, eastern "Plateau," and western Will districts. Stratigraphic sections from these districts have been correlated in a 1:2 500 scale diagram (Figure 7). Three of the sections, one from each of the Nation, "Plateau" and Joan districts, extend slightly above the Cold Fish succession and into overlying Hazelton Group sedimentary rocks (Js). The Cold Fish / sedimentary rock contact thus serves as a common datum for most of the other sections.

Forming the top of the Cold Fish succession in each of the Nation, "Plateau," Joan and Will districts are deposits of rhyolitic tuff and tuff-breccia. Although they range in degree of welding, from densely welded in the Joan and south-central Nation areas, to nonwelded and rich in vugs in the northeastern "Plateau" area, they are probably all ignimbrite, i.e., deposits of pyroclastic flows. Typically, they contain collapsed pumiceous fragments (fiamme), grains of feldspar, and accessory lithic clasts. In the eastern Joan district, the rhyolite is crosscut by veins of fluorite. A 193.9 ± 1.1 Ma U-Pb (zircon) isotopic age was obtained from ignimbritic rocks of the Joan district.

In several places, this rhyolitic cap to the Cold Fish succession comprises two or three depositional units which can be distinguished from one

another on the basis of color, abundance of juvenile and accessory clasts, and crystal contents. Because the degree of welding also tends to differ among the depositional units, the ignimbrites were probably deposited from individual pyroclastic eruptions, forming separate cooling units (cf. Christiansen, 1979).

The thickness of this sequence varies from about 50-250 m, with individual depositional units ranging in thickness from about 25-100 m. Correlation among individual units in the Will and "Plateau" districts indicates that some of the units were deposited over an area of at least 64 km². Further work is likely to result in correlation of these units with those in the Nation and/or Joar: districts, increasing their recognized area of deposition to perhaps 300 km². Using these areas of distribution, and assuming an average thickness of 50 m, the estimated volume of an individual pyroclastic deposit ranges from 3-15 km³. If the pre-diagenetic porosity of the ignimbrite were about 30% (cf. Smith, 1979; Cas and Wright, 1967), then the equivalent magma volume would range from 2-10 km³. Altogether, the upper ignimbrite sequence appears to represent a magma volume of 4-20 km³.

A laterally extensive rhyolitic sill was emplaced below the ignimbrite "cap" sequence in the "Plateau" and Will districts (see sections (k) and (m)). The sill varies in thickness from about 5 to 50 m, and intruded the volcanic strata at roughly the same stratigraphic level, approximately 50 m from the top of the Cold Fish succession. It is identified as a sill and not a lava flow on the basis of

(1) smooth, nearly planar contacts (both top and bottom), (2) the absence of associated breccias (Manley and Fink, 1987), (3) the presence of thin (metre-scale) but otherwise identical sills within underlying bedded tuffs, (4) its great lateral continuity, and (5) a very low thickness to area ratio. It crops out over an area of about 65 km², which equates to a predeformational area of about 130 km². At an assumed average thickness of 15 m, the sill represents about 2 km³ of rhyolitic magma. Because intrusive and extrusive igneous rocks are absent in the sedimentary succession that overlies the ignimbrites, Cold Fish magmatism is inferred to have ceased (at least in this area) prior to sedimentation. Sedimentary deposition was apparently conformable, and not preceded or accompanied by significant erosion of Cold Fish strata. These relationships infer that the sill was emplaced at depths no greater than the thickness of the ignimbrites which overlie it, i.e., at a depth of 50 m or less.

To the northwest, in the Ice Box and Cartmel districts, the depositional top of the Cold Fish succession is not as clearly defined. There, sedimentary rocks that overlie subaerially deposited volcanic rocks are comparatively thin, are not demonstrably conformable, and may have been deposited after a period of erosion, and possibly also minor tilting. Furthermore, details of structural geometry have not been resolved, precluding the construction of thick stratigraphic columns, and obscuring unit correlations. Despite the lack of control, the western Ice Box district appears to be broadly anticlinal, with a

somewhat greater relative abundance of rhyolitic rocks on the flanks of the district, toward the apparent top of the succession (cross section A-B). These felsic rocks, which include massive lava, block lava, tuffaceous rocks and possibly sills, may be generally correlative with the ignimbritic cap to the southeast.

In the northeastern part of the Ice Box district, where a sequence of mafic, marine lavas is interbedded with sandstone, dark siltstone, and limestone, the top of the Cold Fish Volcanics is arbitrarily defined at the top of the highest unit of lava, whilst siltstone from the succession beneath this flow yielded ammonites of Early Pliensbachian age (H. W. Tipper and C. A. Evenchick, personal communication, 1990). Siltstone from an uncertain location either beneath or above the lava flow yielded Aalenian ammonites (H. W. Tipper, personal communication, 1990). The sedimentary rocks above the highest lava flow are therefore Aalenian or younger, and are assigned to unit Js. They include a deposit of clast-supported breccia composed mainly of rhyolitic pebbles and (?) dark siltstone. Whether this unit was produced by volcanic activity, or was derived by erosion of older rhyolitic rocks, is uncertain. If the former is true, then this deposit could represent a minor episode of felsic volcanism in Aalenian or Bajocian time, in the vicinity of the study area (Hazelton Group volcanic activity was clearly over by the end of Bajocian time, prior to the deposition of the Bowser Lake Group). If further field studies

demonstrate the presence of Aalenian strata beneath the highest mafic lava flow, then mafic volcanism of Aalenian or Bajocian age would be indicated. The confirmation of volcanic activity of either composition during this time interval would be significant in that no proximal or medial facies of Jurassic volcanic strata younger than Toarcian age have been identified in the Spatsizi River area.

Lower composite succession

Beneath the ignimbritic cap, the Cold Fish succession consists mainly of interbedded mafic lava, rhyolitic pyroclastic rocks, and rhyolitic sills. Rhyolitic rocks, particularly sills, dominate the succession in the Will district, whereas mafic lava flows constitute an equal or greater proportion of the pile in the Joan, "Plateau," Nation, Ice Box and Cartmel districts. Thicknesses of individual stratigraphic sections (b, m, and p) exceed 1000 m, and the aggregate thickness of correlated sections b-f (some of which are linked with considerable uncertainty) approaches 2400 m.

Section (a) represents the combined mafic and rhyolitic nature of the rocks in the Joan district. Beneath the upper ignimbrites is a thin unit of mafic lava, followed by densely welded ignimbrite with prominent fiamme. Beneath this ignimbrite is a succession of several mafic lava flows, 10-20 m-thick, that are intercalated with well-bedded, green and maroon tuff. The mafic flows are purple and maroon, and vary from massive and nonamygdaloidal, to

scoriaceous and rubbly. The lowest exposed flow hosts abundant 3-5 mm-long phenocrysts of plagioclase, in contrast to the overlying lavas which are less porphyritic. All of the strata in the Joan district were deposited subaerially, and not, as suggested by Thomson et al. (1986), in a largely submarine environment. The conformably overlying, highly fossiliferous Joan Formation (Thomson et al., 1986) is the earliest record of marine conditions in rocks of this district.

Section (b) illustrates the top 1200 m of Cold Fish strata that lie beneath conformable Hazelton Group sedimentary rocks in the southern Nation district. Beneath the cap of ignimbrite (approximately 200 m thick), the succession can be divided into a chiefly felsic but highly variable sequence, down to a stratigraphic depth of about 625 m. Below this level, the succession is dominated by mafic lava flows intercalated with minor horizons of airfall tuff. A correlative succession on the ridge 1 km to the west is shown in Plate 2(b). In the upper, composite sequence, mafic lava flows are interbedded with nonwelded tuff, which has been intruded by rhyolitic sills. The mafic flows in the lower sequence are maroon, and host phenocrysts of olivine (pseudomorphed to (?)iddingsite) and plagioclase. In some of the flows, plagioclase, 3-6 mm in length, is tabular to bladed, and occupies about 20% of rock volume. A correlative succession 3 km to the west of section (b) is also mainly subaerial, but includes rare (subaqueous) pillow lava (Plate 2(c)).

Plate 2. Photographs of Triassic-Jurassic conglomerate, and the Cold Fish Volcanics.

(a) Purplish-brown debris flow deposits of Triassic-Jurassic conglomerate, 3 km northwest of Todagin Mountain (Figure 2).

(b) Composite, subaerial succession of the Cold Fish Volcanics forming ridge one kilometre west of (and correlative with) section (b), Nation district. Dark ridge in foreground is composed of mainly mafic lava flows. Cliffy exposure in middle ground consists of a sequence of welded ignimbrite, airfall tuff, and mafic lava flows that has been intruded by white-weathering and buff-weathering rhyolitic sills. View is to the south.

(c) Mafic pillow lava of the Cold Fish Volcanics on ridge located three kilometres west of section (b), south of Nation Peak. This subaqueous flow is underlain and overlain by maroon lavas of subaerial origin.

The mafic lavas toward the base of section (b) are considered to be broadly chronostratigraphic with similar maroon flows at the top of section (c). Below these lavas, which are crosscut by numerous mafic dykes, is a unit of greenish, bedded tuff, probably of airfall origin. Below the tuff is a massive, crudely columnar jointed, pinkish rhyolitic sill, nearly 200 m thick (called the "pink rhyolite" in the field). The central parts of the sill host up to 10% of 2-4 mm-long phenocrysts of perthitic alkali feldspar, and contain miarolitic cavities filled by granular quartz. The margins of the sill are strongly flowbanded and spherulitic, and contain no phenocrysts. Tuffaceous strata, similar to those above the sill, also form the lower contact.

The "pink rhyolite" also crops out to the north, forming the upper part of section (d). There, the sill hosts a huge xenolith of greenish bedded tuff which is over one fifty metres long and five metres thick. Although the xenolith has been silicified, it strongly resembles the tuffaceous strata that host the intrusion, and was clearly derived from them. Most likely, this sliver of tuffaceous strata was engulfed by magma as the sill advanced for about a hundred metres along two horizons of the tuffaceous unit, about ten metres apart. The presence of this xenolith is one of the best indications that the rhyolite was emplaced as an intrusion, not a lava flow. The absence of block lavas or breccias associated with the rhyolite is further evidence, but perhaps the most convincing information comes from its intrusive, upper contact. At one locality, the top ten

metres of the sill interdigitates with overlying tuffaceous rocks on metre to centimetre scales, and has incorporated xenoliths of tuff ranging in diameter from 1 cm-2 m.

This sill is very distinctive and laterally quite extensive, cropping out over a 7 km² area in the Nation district, and a 1 km² area in the southeastern part of the Ice Box district. If this sill were emplaced at a postulated average thickness of 100 m throughout the area in which it crops out, including the region between its exposures in the Nation and Ice Box districts, then its volume at emplacement would have been about 1.4 km³. In the Ice Box district, the sill is underlain by mafic flows, and is crosscut by a large mafic dyke of Cold Fish affinity (Plate 3(a)) which indicates that mafic Cold Fish magmatism occurred before and after sill emplacement.

In section (d), below the tuff at the base of the pink sill, is a 15 m-thick deposit of poorly stratified conglomerate and breccia, interpreted as a lahar. Clasts within the deposit are mainly pebbles and cobbles of mafic lava, including aphyric and bladed (4-6 cm) plagioclase-phyric varieties. Deposits of this type are uncommon in the Cold Fish Volcanics, constituting less than 1% of the total succession volume. Beneath the lahar is a 250 m-thick sequence of brown, green and red, well-bedded tuff and tuff-breccia of probable airfall origin, intercalated with maroon, mafic lavas with red flow margins.

The mafic lava at the base of section (d) has been speculatively

Plate 3. Photographs of the Cold Fish Volcanics.

(a) Subaerially deposited mafic lava (bottom resistant unit) and bedded tuff (red and green recessive unit) that has been intruded by the "pink rhyolite" sill (top unit) and subsequently crosscut by a mafic dyke, on ridge about 4.5 km northwest of Nation Peak, in the Ice Box district. Section thickness is about 200 m. The dyke, outlined by dashed lines on the right side of the photograph, crosscuts all of the strata. A normal fault with about 15 m displacement is indicated on the left. Part of the Sustut basin is visible in the background.

(b) Subaerial mafic lava flows intercalated with bedded airfall tuff, section (l), "Plateau" district. Thickness of section is about 400 m.

(c) Well-bedded maroon airfall tuff toward the base of section (n) in the Will district. Grains vary in size from ash and dust in the dark maroon layers, to lapilli in the whiter layers.

correlated with similar lavas at the top of section (e). The lavas of section (e) are underlain by bedded airfall tuff, a rhyolitic sill, more maroon mafic lava, and a thick (125 m) succession of welded and nonwelded tuff. The nonwelded tuffaceous rocks are moderately well bedded, and are probably airfall deposits. The welded tuff is a massive and highly indurated ignimbrite with abundant fiamme. It is probably correlative with a similar, 85 m-thick horizon of welded ignimbrite located about 1 km to the northeast, near the top of section (f). That ignimbrite unit is underlain by a 150 m-thick sequence of welded and nonwelded tuffs, representing multiple depositional and cooling units, which was intruded by rhyolitic sills. The highest sill, over 125 m thick, is reddish brown and strongly flowbanded. The tuffaceous and intrusive rocks of this section may be correlative with those of section (g), although definitive links between these stratigraphic columns were not recognized. Section (g) is entirely rhyolitic, with ignimbritic and airfall deposits intruded by rhyolitic sills. Rhyolitic and mafic dykes crosscut the layered rocks. A U-Pb (zircon) age of 194.8 ± 1.0 Ma, obtained on a reddish-brown sill near the base of section (g), agrees well with a U-Pb (zircon) age of $194.0 \pm 2.8/-2.3$ Ma from a crosscutting pyritic rhyolite dyke.

Correlations among sections (h), (i) and (j), in the central and northern Nation district, are made with certainty. Unfortunately, these strata cannot be linked as precisely to any of the other Nation district sections, and the proposed

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correlation between the top of a mainly mafic lava sequence in section (b) with those in sections (h-j) is uncertain. The higher stratigraphic position of sections (i) and (j), with respect to section (g), is consistent with the observed structural relationship (Evenchick, 1986) in which rocks of section (g) have been thrust over those of sections (i) and (j).

Sections (h), (i) and (j) share a prominent fossiliferous limestone and sandy limestone marker horizon that, in section (i), has yielded Early Pliensbachian ammonites (Evenchick, 1986). In section (h), the limestone hosts fragments of carbonized wood, and is overlain by welded ignimbrite, nonwelded tuff, and maroon mafic lava. It is underlain by maroon mafic lava, weakly welded ignimbrite, a rhyolitic sill, and more subaerially deposited lava. The limestone horizon thereby represents a period of transient marine conditions in an otherwise subaerially deposited succession. In section (i), the limestone is overlain by greenish lava which may have been deposited subaqueously, but is underlain by a thick (900 m) subaerial succession characterized by welded and partly welded red and green tuff, and maroon lava flows with reddened flow margins. The flows vary in thickness from about 15 to 30 m. The only units within this sequence that may have been deposited in a submarine environment are the units of sandstone and mafic lava that lie directly below the limestone, and a brown, tuffaceous siltstone horizon at about 150 m below the limestone. In section (j), the limestone marker is overlain by greenish pillow breccia and

aquagene tuff, a thin (2 m) bed of rhyolite-pebble conglomerate, and a second horizon of limestone. Beneath the marker limestone, a succession of shale, bedded tuff hosting accretionary lapilli, weakly welded tuff and more shale indicate variably marine to nonmarine conditions of deposition.

Sections (k), (l) and (m), in the "Plateau" district, are reliably correlated with one another, and also with sections (a) and (b). Below the rhyolitic sill that marks the base of the ignimbritic cap (discussed above), the aggregate succession consists mainly of mafic lava flows and intercalated bedded airfall deposits (Plate 3(b)). Many of the flows, which are 20-35 m thick, are maroon with red flow bottoms, and are separated from one another by reddish-brown tuffaceous (and possibly soil) horizons that vary in thickness from less than 1 m to over 25 m. Rhyolitic sills are common toward the base of the succession.

The top of section (n), in the Will district, probably correlates with the top of the highest sill in the lower part of section (m). Section (n) comprises mainly rhyolitic sills which have intruded a sequence of mafic lava and tuff. The sills are so thick (up to 225 m) and numerous that the total thickness of the eruptive rocks in this 500 m section is only about 90 m. The 225 m-thick sill, which is pink and strongly flowbanded throughout, crops out along strike to the east for nearly 4 km. A horizon of maroon bedded tuff near the bottom of section (n) (Plate 3(c)) correlates with one near the top of section (o), which is also dominated by thick sills. The sill that lies beneath the tuff horizon is 150 m

thick, and has highly convoluted flowbands near its upper contact (Plate 4(a)). At one locality, it interfingers with and bulges into (on decimetre to metre scales) the overlying bedded tuff. A 193.5 ± 2.0 Ma U-Pb (zircon) age was obtained from another sill, of uncertain stratigraphic position, about 2 km southeast of section (o).

The other two sections in the Will district (p and q) are located several kilometres from each other and from the other Cold Fish sections, and have not been correlated with other units. Section (p), about 1450 m thick, is dominated by four flowbanded rhyolitic units (interpreted as sills) that range in thickness from 150-450 m. Existing field information obtained at the reconnaissance level, suggests that each of these units was emplaced as an individual intrusion. However, more detailed work is necessary to determine whether these rhyolites are individual units, or compound units comprising two or more sills (or flows?) of similar lithology. The apparent uniformity of these rhyolites infers that, if they are composite, they comprise a few thick sills (or flows?) rather than many thin ones. About two-thirds of the way down the section, a mafic lava flow is crosscut by a thick, orange-weathering rhyolitic dyke, which is itself cut by a green, mafic dyke.

Section (q), like the other sections from the Will district, is composed of primarily rhyolitic rocks (Plate 4(b)). Lying below a massive rhyolitic sill, and a few metres of bedded tuff, is about 30 m of highly oxidized (maroon and red)

Plate 4. Photographs of the Cold Fish Volcanics, the Stuhini Group, and the Bowser Lake Group.

(a) Convoluted flowbands in the rhyolitic sill that forms the middle of section (o) in the Cold Fish Volcanics, Will district. Black bars at top of scale card are 1 cm long.

(b) Thick rhyolitic units of the Cold Fish Volcanics in section (q), Will district. Section thickness is about 600 m. The lower part of the section (unit 1 on plate) was not examined, but appears to consist of thick, rhyolitic strata. Unit 2 is a rhyolitic sill; unit 3 is welded ignimbrite; unit 4 is a composite section of tuff, sills and mafic, maroon lava; and unit 5 is a rhyolitic sill.

(c) Angular unconformity between steeply dipping lava flows of the Stuhini Group, and gently dipping shaley strata of the Bowser Lake Group, in the Griffith district. Exposure is about 150 m high.

mafic lava. Below the lava is about 75 m of welded tuff and sills, followed by a thick (125 m) bed of welded ignimbrite, and a reddish brown, flowbanded rhyolitic sill. Rocks beneath the sill were not examined, but appear to be thick-bedded and resistant, and are probably mainly sills and welded tuff.

The sill is about 65 m thick at the trace of the section, and thins gradually to the west. If an interpretation of aerial photographs is correct, the sill pinches out about 600 m from the section line. The angle of taper, i.e., the angle between the top and bottom contacts, is therefore about 6° . If the sill had a flat base, and a sloping roof (6° dip), and were radially symmetrical, its geometry would approximate that of a low-profile cone. If the maximum height of the sill (i.e., the height at the centre of the cone) were that observed at the section line (65 m), then the volume of the sill would be about $.025 \text{ km}^3$. Although the assumption of a conical shape may be useful for estimating volumes of other sills, the angle of taper for many appears to be much less than 6° . For example, the sill near the top of section (e), in the Nation district, crops out for 3 km to the northwest with nearly constant thickness, and is essentially tabular over its 3 km^2 area of exposure.

The Spatsizi River Stock is an epizonal, leucocratic alkali-feldspar granite located in the eastern Will district. Three lines of evidence point to its probable origin as a synvolcanic intrusion, coeval with the Cold Fish Volcanics. Firstly, it is mineralogically and chemically similar to the rhyolites that dominate the

succession into which it was emplaced. Secondly, it is crosscut by mafic dykes (e.g., chemical sample 86-111-3 in Appendix 1) that lithologically and chemically resemble mafic Cold Fish lavas. Thirdly, the 2-sigma range in the interpreted U-Pb (zircon) age of the stock (190.0 ± 7.1 Ma) overlaps with those from the Cold Fish (Chapter 5). The country rocks within a kilometre or two of the stock appear to have undergone weak propylitic alteration, possibly by metasomatizing fluids related to circulation of magmatic and heated meteoric fluids during emplacement and crystallization of the stock. Two gossanous zones near the stock are probably also genetically related to the emplacement and crystallization of the stock.

The Cold Fish succession in the Ice Box district differs slightly from the mainly mafic sequences in other districts. The most important difference is the greater abundance of marine sedimentary and volcanic rocks (although most of the succession is still subaerial in origin). These marine horizons are concentrated in the northeastern part of the district, but also crop out in the more southerly parts as thin, discontinuous lenses. Fossils collected by members of the Geological Survey of Canada, and the author, belong to three different ammonite zones of the Early Pliensbachian (H. W. Tipper, personal communication, 1990) which serves to demonstrate the longevity of volcanism in this area. Another difference is that beds of lahar, although still very low in abundance, are more common here than in other areas. A third difference is

the prominence of rhyolitic block lavas (and associated massive lava flows), so rare in the other districts. Fourthly, in the northwestern part of the Ice Box district, Cretaceous siltstone of the Sustut Group unconformably overlies the Cold Fish in a half-graben south of a normal fault (cross section A-B on Figure 3; Gabrielse and Tipper, 1984). This lacuna contrasts with more conformable relationships to the southeast.

Upper Triassic fossils were collected by the Geological Survey of Canada from a locality in the southwestern part of the Ice Box district, south of a prominent fault (Figure 3; H. W. Tipper, personal communication, 1987). The age of these fossils led Gabrielse and Tipper (1984) to assign the rocks in this area to the Triassic Stuhini Group. The fossil locality was subsequently re-examined by the author. It was found that the fossils were hosted by numerous limestone cobbles and boulders that were scattered over a small part (roughly 20 m in diameter) of a hillside covered by blocky volcanic talus. These limestone clasts are probably remnants of a glacial erratic, and not part of the Cold Fish succession. Evidence in support of this interpretation includes: (1) the strong similarity between the volcanic rocks of this area and those north of the prominent fault; (2) the absence of Triassic limestone in outcrop; and (3) the stratigraphic superposition of Hazelton Group sedimentary rocks and Bowser Lake Group strata on the southern flank of this area.

Synthesis of physical volcanology

The Cold Fish Volcanics accumulated as a compositionally bimodal volcanic succession in a mainly subaerial environment. The succession can be divided into two geographically distinct volcanic facies. In the southeastern part of the study area (Will district), strata are almost entirely rhyolitic in composition, comprising thick sills, ignimbrite sheets, beds of airfall tuff, and only minor volumes of mafic lava. The fine-grained Spatsizi River Stock, also of rhyolitic chemical composition, is spatially and genetically linked to rocks of this felsic facies. In contrast, strata in the other districts constitute a compositionally mixed facies in which abundant (locally dominant) basaltic and andesitic lava flows are intercalated with rhyolitic rocks.

Although the northwestward increase in the proportion of mafic rocks is apparent at a regional scale, the succession is dominated locally by pronounced vertical trends. For example, at the top of the succession in the central and southern parts of the study area, mixed mafic and rhyolitic rocks are succeeded by deposits of rhyolitic ignimbrite. This ignimbritic cap represents the last of several major, explosive pulses that were interspersed with less voluminous pyroclastic events, extrusion of mafic lava flows, emplacement of rhyolitic sills, and occasional deposition of epiclastic rocks and limestone.

Intrusive and depositional relationships indicate that the emplacement of the rhyolitic sills was broadly contemporaneous with volcanism. Some of the

sills are crosscut by mafic and/or rhyolitic Cold Fish dykes, but overlie other mafic and rhyolitic eruptive rocks, indicating that mafic and felsic volcanism occurred before and after sill emplacement. Other sills, particularly those at high stratigraphic levels, may be completely younger than the volcanic pile into which they were injected. Their emplacement is likely to have occurred shortly after cessation of eruptive activity, however, because conformably overlying Hazelton Group sedimentary rocks are not crosscut by Cold Fish intrusions. As discussed earlier, the Spatsizi River Stock is also synvolcanic.

Mafic lava was deposited mainly as pahoehoe flows, 10-35 m thick. Many of the flows have reddened, fine-grained (chilled) flow bottoms 0.5-1 m thick that typically contain granules of volcanic rock, presumably derived from the underlying tuffaceous strata, the top of an underlying flow, or possibly soil. Although soil horizons were not positively identified, their local development seems likely, especially in light of the fossilized wood found in silty Cold Fish limestone. Above the flow bottoms, the lavas are generally maroon or grey, and commonly grade upward from non-amygdaloidal to amygdaloidal textures. The top metre or two of many flows is highly amygdaloidal, and maroon flow-top breccias hosting pebble to cobble sized clasts of scoria are present locally. Where exposure is exceptional, ropey surface features are visible. The textural features of these lavas, and their mainly mafic, moderately alkaline compositions (Chapter 4), indicate that they had low viscosities, and probably behaved like

modern Hawaiian basalts during flowage.

Mafic dykes that crosscut the succession, and are interpreted as feeders to the mafic flows, have a wide variety of orientations. Where they are most abundant, in the Nation district near sections (c) and (d), they occur as a north-northwesterly trending swarm. This swarm marks the location of a major fissure system related to east-northeast crustal dilation.

The morphology and environment of deposition of the Cold Fish Volcanics can be inferred from the nature and relative abundance of the various lithotypes which form the succession. The most significant general aspect is the purely volcanic (or intrusive) origin of most of the strata; only a very small proportion of the succession volume, probably about 1%, is made up of epiclastic and bioclastic rocks. Lahar is scarce, and the paucity of this deposit type contrasts with its high abundance in steep-flanked stratovolcanic sequences that typify volcanic arcs. The near-absence of lahar implies that the volcanic edifices were gently sloping, and may have been low in elevation.

Two lines of evidence corroborate the suggestion of a low-profile, topographically low volcanic field. Firstly, deposit types such as felsic lavas and coarse volcanic breccias, that tend to pile up near eruptive vents and contribute to the generation of steep cones, are generally not abundant. Although rocks of rhyolitic composition are plentiful, they were mainly emplaced as ash-rich airfall tuff, pyroclastic flows, and sills with low angles of taper. Secondly, the

Cold Fish succession underwent hundreds of metres of subsidence during its deposition, a process which kept the succession from accumulating to high elevations. Synvolcanic subsidence is indicated by thin beds of limestone and other marine rocks within mainly subaerial sequences. In the Nation district, for example, thin marine sedimentary members of the Cold Fish lie above an 800 m thick, almost entirely subaerial succession (section (i)).

The trend of subsidence during deposition continued well after cessation of Cold Fish volcanism, as indicated by the hundreds of metres of conformably overlying marine epiclastic rocks (Thomson et al., 1986), which far exceed the thicknesses that would result simply from postulated increases in global sea level (Chapter 2). Long-lived subsidence in Early Jurassic time also conforms to the regionally recognized, protracted history of syndepositional subsidence in the Hazelton Trough (Tipper and Richards, 1976; Marsden and Thorkelson, in press; Chapter 2, this thesis). The axis of this northwest-trending trough is suspected to lie about 50 km to the southwest of the study area.

Subsidence of the Cold Fish succession is likely to have been controlled by normal faults related to regional tension or transtension (cf. Greig et al., 1991). The location, timing and style of downfaulting, however, was almost certainly related to magmatic processes. A magmatic influence is supported by the preponderance of rhyolitic ignimbrite sheets and thick sills in the southeastern part of the study area. Some of the ignimbrites are over 100 m

thick, and may have been deposited over areas of 20 to 100 km² (or more), and represent the rapid evisceration of 2 km³ to perhaps 10 km³ of magma from an epizonal chamber. Ignimbrites of this magnitude are almost always associated with cauldron subsidence (Smith, 1979).

Caldera formation in the Will district is also implied by the paucity of mafic lavas in this area. Mafic lava tends to be scarce within felsic caldera sequences because the relatively high density of mafic magma prevents it from rising through the upper, felsic, less dense parts of subcaldera magma chambers (Smith, 1979; Hildreth, 1979; Christiansen, 1979). The Will district is also coincident with a roughly circular and concentric, moderately positive aeromagnetic anomaly (Anonymous, 1978). The Spatsizi River Stock appears to represent high-level emplacement of subcaldera magma, possibly during a period of resurgence.

The bounding faults of the suspected Will caldera have not been directly observed. This is not surprising, considering the lack of good exposure in broad valleys, and structural complications imposed by subsequent folding, thrust faulting, and block faulting. Even in Tertiary and Quaternary calderas that have not been structurally deformed, bounding faults are often difficult to delineate (e.g., Francis, 1983; Aldiss and Ghazali, 1984). Not uncommonly, the faults may be blanketed by syn- and postcaldera volcanic deposits (e.g., Best et al., 1989). In addition, recognition may be more difficult in calderas that have

undergone several periods of collapse and resurgence, accompanied by changes in the location of the cauldron margins. Multiple resurgence is likely to have occurred in the inferred Will caldera, where the presence of several thick ignimbritic cooling units, and evidence of a protracted history of sill emplacement indicate the occurrence of several cycles of magmatism.

The Spatsizi River Fault (Figure 3) is probably one of main bounding faults of the inferred Will caldera. Although it has not been observed directly (it lies beneath thick alluvium in the Spatsizi River valley), its presence is inferred by striking contrasts in stratigraphic level and degree of structural deformation in rocks on opposite sides of the Spatsizi River. On the western side, "intracaldera" strata of the Cold Fish Volcanics, at least 1.5 km thick (perhaps as much as 3 km thick), have been deformed into generally open folds. To the east, Cold Fish rocks are absent, and older rocks of the Griffith Creek volcanics, the Stuhini Group, and presumably unit CPM, have been folded tightly into subvertical orientations. In this area, Cold Fish strata probably formed a relatively thin succession that was subsequently eroded prior to Bathonian time when the Bowser Lake Group was deposited on both sides of the fault.

These geological contrasts infer that motion along the Spatsizi River Fault resulted in 1.5 km or more of west-side-down vertical displacement.

Furthermore, if the interpretation of a large, epizonal magma chamber beneath

the evolving Will caldera is correct, then the fault seems to mark the eastern margin of the chamber. No felsic plutonic rocks that could represent the eastern continuation of the magma chamber are present in the Griffith district. Thus, the Spatsizi River Fault appears to coincide with the eastern margin of high-level Cold Fish plutonism, and is most suitably explained as a syncaldera structure.

The Spatsizi River Fault may have continued well beyond the study area, serving not only as the eastern boundary of the inferred Will caldera, but also as a regional extensional fault. Regional faults bound parts of the Toba caldera in Sumatra (Aldiss and Ghazali, 1984), and the Askja caldera in Iceland (D. C. Brown et al., 1991). Possibly, the Spatsizi River Fault was also one of the principal structures controlling the widespread subsidence of the Cold Fish volcanic field. Such a fault could represent one of several broadly synchronous extensional faults which accommodated regional subsidence of central Stikinia, and facilitated development of the Hazelton Trough. A similar model of caldera development and block faulting was invoked to explain stratigraphic relations in a Lower Jurassic succession in the southwestern United States (Riggs and Busby-Spera, 1990).

Figure 9 illustrates the stratigraphic evolution of a generalized succession of the Cold Fish Volcanics in a locality west of the inferred Will caldera, such as the Nation district. The diagram was drawn on the basis of a mainly eastern

Figure 9. Generalized, hypothetical stratigraphic section through the Cold Fish Volcanics. Numbers in "Unit #" column indicate relative age of rock units (unit 1 is oldest). Numbers in "Sill #" column indicate order of sill emplacement.

rhyolitic magma source, and a western mafic magma source, consistent with the recognized compositional polarity in the study area (the actual distribution of mafic and felsic centres was probably more complex). The order in which the various stratigraphic units were emplaced is given to the left of the column, and the order of sill emplacement is indicated on the right. A lithosphere-scale cross section (Figure 10) provides a broader view of the proposed volcanic and plutonic features. The lowest strata shown in the stratigraphic column of Figure 9 represents an intermediate stratigraphic level in the Cold Fish succession, about 500 m from the stratigraphic top. The base of the Cold Fish has not been observed in the study area, and the early history of the volcanic pile is therefore not depicted.

The following discussion of the generalized succession (Figure 9) is an attempt to depict the most reasonable environment of deposition and sequence of geological events involved in the genesis of the Cold Fish Volcanics. However, it should be noted that many of the specific elements in this reconstruction are poorly constrained. Deposition of the lowest strata, at the bottom of Figure 9, begins above an unknown sequence of previously deposited Cold Fish strata. Mafic (and subordinate intermediate) lava flows are extruded from fissures or a summit crater to the west. The lavas (units 1, 3 and 5) erupt by fire-fountaining and quiescent outpouring, in the manner of Hawaiian eruptions, and accumulate as pahoehoe flows on the flank of a gently sloping

Figure 10. Suggested magmatic and volcanic setting of part of the Cold Fish Volcanics. Basaltic magma (solid black) is generated by partial fusion of the upper mantle (in the vicinity of point A) as a result of subduction-induced metasomatism, and decompression melting of rising peridotite diapirs. Primary magma collects at or near the base of the crust (Moho), transfers heat to the lower crust, evolves to less magnesian compositions, and rises through conduits to shallower depths. Anatexis of crustal rock, which may be partly Precambrian in age, produces rhyolitic melts (point B), which rise toward the surface. Mafic and rhyolitic magmas pool and evolve in the upper crust, near the Spatsizi River Fault (SRF), in a large zoned chamber (C) beneath the Will caldera. To the west (in the present geographical orientation), mafic magma feeds a gently sloping composite volcano. Cauldron subsidence occurs synchronously with Plinian eruptions that lead to deposition of rhyolitic ignimbrite sheets and airfall tuff, and subsequent emplacement of relatively anhydrous sills. Timing of eruption and related cauldron subsidence are partly controlled by magmatic fluxes and volatile accumulation, and partly by seismicity and episodic displacements along the Spatsizi River Fault.

volcanic edifice (cf. Basaltic Volcanism Study Project, 1981). Eruptions are punctuated by periods of inactivity, during which intermittent violent eruptions eject mixtures of gas and rhyolitic tephra in Plinian columns or Vulcanian clouds (cf. Fisher and Schminke, 1984). Dust, ash, lithic lapilli, and minor accretionary lapilli shower onto the mafic flows to form well-bedded airfall tuff, and thin ignimbrites (units 2, 4 and 7). These explosive eruptions may occur from vents along the Spatsizi River Fault and other fractures that rim or transect the inferred Will caldera, and perhaps partly from a minor felsic magma source within or near the mainly mafic volcano to the west. Viscous rhyolitic lava, and coarse volcanic breccia are not deposited in appreciable amounts, and the volcanic sequence accumulates with a low profile. Consequently, laharic deposits (unit 6) are seldom generated.

The minor felsic explosions are discharge only a fraction of the evolving mass of volatile-rich silicic magma that has been accumulating at the top of the subcaldera chamber (cf. Smith, 1979; Hildreth, 1979). Introduction of additional, relatively mafic magma into the base of the chamber causes it to swell, slightly doming the roof (cf. Smith, 1979; Sigurdsson and Sparks, 1981; Francis, 1983). Initiated by a large explosion, perhaps triggered by seismicity and motion along the Spatsizi River Fault, a major Plinian eruption occurs above the the caldera. The roof of the caldera founders as perhaps 4 km³ of vesiculating magma are ejected from vents along the cauldron rim. Collapse of the eruptive column(s)

produces voluminous pyroclastic flows (cf, Sparks and Wilson, 1976; Sparks et al., 1978). The flows spread out over the volcanic field, covering a broad area, perhaps 20 to 100 km² or more, and accumulate as a poorly stratified ignimbrite (unit 8) in thicknesses up to 200 m. Fine-grained tephra (unit 9) settles from the eruption cloud onto the surface of the cooling and degassing deposit. Where the ignimbrite is hottest and thickest, sintering of glass shards and collapse of pumice fragments (welding) produces eutaxitic flow texture. In many places, welding occurs throughout much of the ignimbrite column, and the unit gradually deflates by tens of metres as trapped gas escapes and porosity is reduced. The eruption eviscerates the top, volatile-rich zones of the magma chamber, leaving magma that is relatively poor in dissolved gases, with little potential for violent eruption (cf. Smith, 1979).

After the major Plinian episode, mafic lava (unit 11), and relatively small volumes of rhyolitic tephra (unit 13), continue to erupt. As well, rhyolitic sills (units 10, 12 and 17) derived from the volatile-poor magma below the caldera occasionally intrude the succession, thickening it by tens to hundreds of metres (about 100 m in Figure 9). Because of regional extension and normal faulting, the volcanic field has been gradually subsiding throughout the history of Cold Fish deposition. Until now, aggradation of the land surface through the accumulation of volcanic deposits and the intrusion of sills had prevented this part of the volcanic field from dropping below sea level. Now, however, an

increase in the rate of subsidence relative to that of aggradation causes the land surface to sink into the ocean, permitting deposition of silty limestone (unit 14). Felsic and mafic eruptions follow, and sufficient lava and tuff accumulate (units 15, 16, 18 and 19) to build the sequence out of the sea, and to restore subaerial conditions.

Toward the end of Cold Fish volcanism, mafic magma stops rising beneath the volcanic field. Replenishment ceases in the caldera chamber, and in chambers below the mafic edifices; mafic volcanism ends. Differentiation in the subcaldera chamber proceeds to where a large volume of volatile-rich magma is concentrated at the top. A final series of voluminous Plinian eruptions above the caldera accompany partial evacuation of the chamber, and lead to the deposition of thick ignimbritic deposits units 20 and 21). The succession is then intruded by a series of rhyolitic sills, (units 22, 23, 24 and 25), one of which is emplaced at a depth of only 50 m below the surface. Lastly, fluorine-bearing aqueous fluids released during crystallization of subvolcanic magma rise through fractures, and fluorite is deposited in veins.

Descriptions of the volcanic processes in the foregoing scenario were based on detailed and generalized accounts of recent volcanic eruptions, and interpretations of Upper Cenozoic volcanic successions. Although an exact modern analogue has not been identified, the envisaged tectonic and magmatic setting, and depositional history of the Cold Fish Volcanics is broadly similar to

those of some successions in the Great Basin and Rio Grande Rift of the southwestern United States (Christiansen and Lipman, 1972). The greatest difference, of course, is that the successions in the U.S. were deposited in a continental setting, whereas the Cold Fish evolved on an oceanic microplate.

One major similarity between the Cold Fish Volcanics and Upper Cenozoic volcanic successions in the southwestern United States is mafic-felsic bimodality. As with the Cold Fish, mafic lavas in many of the U.S. fields were erupted along with rhyolite, including high-silica varieties (Lipman, 1975; Steven et al., 1984; Ratte et al., 1984). Also, deposition of the successions in the U.S. was broadly contemporaneous with regional extension (Best and Christiansen, 1991; Armstrong and Ward, 1991). Locally, synchronous block faulting controlled patterns and facies of deposition (Gans et al., 1989; Ingersol et al., 1990), with the associated development of numerous calderas, and eruption of voluminous pyroclastic flows (e.g., Christiansen, 1979; Best et al., 1989).

Figure 11 is a schematic diagram of a speculative tectonic and magmatic setting of part of eastern Stikinia in Pliensbachian time. In the Toodoggone River area, high-K calc-alkaline magmas of predominantly intermediate composition erupt in a frontal arc setting to form the Toodoggone formation (Diakow et al., 1985, 1991; Marsden 1990). Deposition is concentrated in a subsiding, northwest-trending terrestrial depression (Diakow et al., 1991). At about the same time, mafic and rhyolitic rocks of the bimodal Cold Fish

Figure 11 . Suggested tectonic environment of volcanic successions in east-central Stikinia during Pliensbachian time. Stratovolcanoes and ignimbrite fields of the Toodoggone Formation accumulate in an subsiding, terrestrial volcano-tectonic depression (Diakow et al., 1991). Concurrently, or within one or two million years, bimodal Cold Fish volcanic rocks are deposited in a subaerial to shallow marine back-arc region that is extending and subsiding. The Spatsizi River Fault (SRF) could be one of the principal normal faults along which extension occurs. The degree of lithospheric thinning increases toward the west, in the Hazelton Trough. The subducting oceanic slab is considered to be part of the Cache Creek Terrane which has not yet amalgamated with Stikinia. To the west of the Hazelton Trough, beyond the illustrated region, volcanic successions are accumulating as part of another volcanic chain which may be related to eastward subduction of a second oceanic slab (Figure 6; Chapter 2).

Volcanics are emplaced in an extensional back-arc setting. Farther behind the arc, marine sedimentary rocks accumulate in the subsiding Hazelton Trough. Extension is accommodated by large, north-northwest striking normal faults that feed into a subhorizontal shear zone.

Cold Fish volcanism originates by melting of the asthenosphere caused by release of volatiles from the subducting slab, and decompression related to asthenospheric upwelling beneath the extending Stikinian lithosphere (cf. Presnall et al., 1979; Gill, 1981; McKenzie and Bickle, 1988). The mafic magma pools and differentiates within Stikinia, and magma chambers become established at various depths (Figures 10 and 11). Immediately behind the Spatsizi River Fault, shown here as a principal block fault leading into a major detachment zone, a large, epizonal magma chamber develops. The chamber becomes vertically zoned (i.e., in horizontal layers), with mafic liquids at the base overlain by volatile-poor rhyolitic liquids, and capped by volatile-rich rhyolitic melts (cf. Smith, 1979; Hildreth, 1979). The rhyolitic magmas were probably produced partly by differentiation from mafic magma, and partly by crustal anatexis or assimilation. Differentiation from a mafic parent is suggested by similarity in incompatible element profiles between the mafic and rhyolitic rocks (Chapter 4), and a Rb-Sr scatterchron from the Ice Box area, in which $^{87}\text{Sr}/^{86}\text{Sr}$ initial ratios of mafic samples are not significantly different from those of rhyolites (Erdman, 1978). Involvement of mature, perhaps continental crust

is indicated by the emplacement of highly siliceous fluorite- and tin-bearing rhyolites, and inheritance of Precambrian U and Pb isotopic ratios in zircon (Chapter 5). More comprehensive isotopic investigations are necessary to determine the age, and degree of influence of the crustal component.

Petrography

mafic to intermediate lava

The primary (magmatic) phenocryst mineral assemblages of mafic (and subordinate intermediate) Cold Fish lava flows are dominated by plagioclase, olivine and augite (Appendix 1). Phenocrysts of (?)magnetite and apatite are generally scarce, with apatite appearing in only the most evolved mafic flows. Groundmass mineral assemblages, dominated by plagioclase, are similar to those of the phenocrysts. However, the relative abundances of magnetite and augite are greater in the groundmass, and the relative abundance of olivine is lesser in groundmass than in phenocryst populations. Devitrified glass is either absent, or constitutes only a few percent of rock modes.

Plagioclase is ubiquitous in the mafic lavas. It is also the most abundant phenocryst mineral, typically representing 3-20% of rock volume. The grains range from 0.5-8 mm in length, and vary in freshness from virtually unaltered to highly saussuritized. The larger grains are typically bladed or tabular, whereas the smaller grains are generally lathlike or of stubby prismatic habit.

Compositions of An_{65} to An_{86} (mole%) were determined for phenocrysts in some samples, by either optical microscopy or electron microprobe. Large grains are commonly zoned, either normally, or in oscillations with a generally normal trend. Although plagioclase phenocrysts are euhedral in most samples, in some rocks they are subhedral to anhedral, and appear to have been corroded. Plagioclase grains tend to be isolated (surrounded mainly by groundmass), but in some lavas they form glomerocrysts with augite and/or olivine, and rarely magnetite. In some samples, pilotaxitic to hyalopilitic (flow-alignment) textures are defined by alignment of phenocrysts and/or microlites of plagioclase.

Augite phenocrysts are almost always lower in abundance than those of plagioclase, and are absent in some of the lavas. They are typically unaltered, or weakly altered along crystal faces, fractures and cleavage planes to chlorite and/or iron oxides. They range in size from 0.5-3 mm, and in composition from En_{70} to En_{86} (mole%; determinations by electron microprobe). Their habit is generally stubby-prismatic, and they occur as individual to glomerocrystic grains. Less commonly, they are present as interstitial crystals among phenocrysts of plagioclase + /- olivine (Plate 5(c)), giving rise, in some cases, to sub-ophitic texture. Individual and glomerocrystic grains of augite are commonly subhedral to anhedral (Plate 5(b)). Many are embayed, and occur in contact with smaller grains of (?) magnetite. Apparently, early-formed grains of

Plate 5. Photomicrographs of the Cold Fish Volcanics. Scale bars are 1 mm long. PL = plane polarized light; XP = crossed polarized light.

(a) Basalt (chemical sample 86-78-4): euhedral olivine (Ol) phenocrysts (pseudomorphed by (?)magnetite) and tiny plagioclase (Pl) phenocrysts set in pilotaxitic groundmass of plagioclase, magnetite(?), augite, and oxide-pseudomorphed olivine. PL.

(b) Basalt (chemical sample 86-5-2): anhedral (corroded) augite (At) and altered olivine (Ol) phenocrysts in groundmass dominated by plagioclase and augite. XP.

(c) Basalt (chemical sample 87-156-2): generally euhedral plagioclase (Pl) grains (early formed) with saussuritized cores, and interstitial (late formed) augite (At). PL.

(d) Flowbanded rhyolitic sill: phenocryst of orthoclase microperthite (Or), partially replaced by granular cassiterite (C). PL.

(e) Partly welded airfall tuff: collapsed and chloritized pumice fragment (F) within matrix dominated by undeformed, partially devitrified shards (see arrows). PL.

(f) Accretionary lapilli tuff: unbroken lapilli (top) overlies ash and fragments of lapilli. PL.

augite were partially resorbed, and occasionally partially replaced by magnetite, in response to changing pressure, temperature, or composition of the magma.

Olivine phenocrysts are typically euhedral, and have been pseudomorphed by one or more mineral species, including iddingsite, serpentine, and magnetite (Plate 5(a)). Olivine is generally less abundant than plagioclase, and commonly about equal in abundance with augite. Olivine tends to be less abundant than augite, or absent, in the more evolved (intermediate) lavas.

Rock textures vary from amygdaloidal to nonamygdaloidal, highly porphyritic to nearly aphyric, and flow-aligned (pilotaxitic to devitrified-hyalopilitic) to randomly oriented. Vesicles of amygdaloidal varieties host secondary minerals of low (generally zeolite) metamorphic grade, such as heulandite, chlorite, celadonite, pumpellyite, epidote, calcite and quartz. Flow alignment is most often developed by plagioclase microlites (0.1-0.5 mm long), although larger plagioclase grains also tend to be aligned if they are bladed or tabular with high aspect ratios.

A generalized paragenetic sequence of mineral crystallization is inferred from the textures in lava flows of mafic to intermediate compositions. Cold Fish mafic magma seems to have undergone (1) early precipitation of augite + plagioclase, followed by (2) resorption of augite, precipitation of olivine, and either resorption, or more typically growth of plagioclase, followed by (3)

crystallization of plagioclase, augite, magnetite and apatite. This order reflects mineral textures within individual flows, and the overall trend of crystallization from more primitive to more evolved magma compositions.

Early augite growth is indicated by the presence of corroded augite in many of the samples, where it occurs alongside euhedral olivine and euhedral to anhedral plagioclase. Moreover, augite occurs with plagioclase and/or olivine in some of the most primitive samples. Particularly relevant is the presence of euhedral augite and plagioclase, but no olivine, in the second most primitive lava (sample 86-44-5: $Mg\# = 64.5$; Appendix 1). These relationships can be explained by polybaric crystallization (cf. Frey et al., 1990), initiated by precipitation of augite and plagioclase from primary or near-primary magma deep in Stikinian lithosphere, at high pressure (under high pressure pyroxene tends to crystallize before olivine; Presnall et al., 1978; Basaltic Volcanism Study Project, 1981; Meen, 1987, 1990). After a small degree of fractionation, the residual but still primitive magma rises through the lithosphere, with its entrained phenocrysts of augite and plagioclase, and pools in higher-level magma chambers. Under these conditions of reduced pressure, olivine replaces augite as the stable ferromagnesian liquidus phase, and entrained augite undergoes resorption. In some cases, plagioclase is also corroded. The higher-level magma subsequently differentiates through fractionation of olivine and plagioclase, and augite grows as the third phase in the crystallization sequence.

As the magma evolves to more siliceous compositions, augite replaces olivine as the principal Fe-Mg silicate mineral; magnetite and apatite also form. Trace element characteristics corroborate the inference of augite, plagioclase, olivine, magnetite and apatite fractionation, except that plagioclase fractionation appears to have been mainly restricted to evolved andesitic magmas (Chapter 4).

The actual magmatic history of mafic Cold Fish rocks was certainly more complex than the foregoing, simple depiction. Processes such as recurrent magma chamber replenishment, and assimilation of country rocks, are likely to have played major roles in the evolution of magma compositions and phase relations. Evidence for assimilation comes from rare, corroded quartz xenocrysts. Magma chamber recharge is inferred from chemical variability and the absence of consistently more evolved compositions with increasing stratigraphic level (Chapter 4).

Rhyolitic rocks

Cold Fish rhyolites are texturally varied, but mineralogically rather uniform. The crystallinity of sills (and (?)flows) and pyroclastic rocks are similar, generally ranging from 5-20%. Phenocryst mineralogy is dominated by grains of micropertthitic orthoclase, 0.5-4 mm long, and to a lesser degree, albitic plagioclase (0.5-3 mm). Trace amounts of magnetite, biotite, pyrite, zircon and

anatase are present in some samples. Cassiterite is a locally prominent trace phase, occurring mainly as granular crystals (<0.1 mm) within orthoclase microperthite (Plate 5(d)), and more rarely as a separate phase in matrix, groundmass, vesicles or miarolitic cavities. Phenocrysts of quartz (or its polymorphs) were not observed in any of the samples, although flowbands in some of the sills are highly siliceous, and resemble extremely flattened amygdules or planar quartz gashes where they are filled by drusy quartz. Groundmass in nonfragmental rocks is composed primarily of spherulitic and snowflake-texture intergrowths of potassium feldspar and quartz. These textures developed in rapidly cooling liquid, or in volcanic glass. Originally a major constituent of the rhyolitic rocks, glass has been almost entirely devitrified. It survives, rarely, in some sills and tuffaceous rocks. In some rocks, vesicles or miarolitic cavities are filled by granular quartz.

The most common textures in the nonfragmental rocks are flowbands and spherulites. They commonly occur together, with trains of spherulites conforming to the earlier-formed flow texture. In pyroclastic rocks, features vary from sintered shards and collapsed pumice fragments in welded ignimbrite, to uncompacted, angular textures in vuggy, poorly indurated breccia, to accretionary lapilli (Figure 5(f)).

One of the most intriguing textures that has been observed occurs in a thinly bedded (5-50 cm) tuffaceous sequence of the Nation district (900-1050 m

interval of section (i); Figure 7). Changes within and among the beds include, (1) sorting of grain sizes, from mixtures of dust and ash, to lapilli and ash, (2) changes in colour from green to red, (3) changes in the abundance of feldspar crystals, and (4) changes in the degree of flattening of pumiceous lapilli. These variations, and the general appearance of stratification, indicate that the tuffs were not deposited from pyroclastic flows. Rather, they probably accumulated as airfall deposits. The collapse of pumice fragments to form fiamme, however, indicates that the tuffs were very hot when they were deposited, and that the tephra had not undergone extensive cooling during their descent from a high-altitude eruption cloud. Instead, they were probably formed from showers of incandescent ejecta which followed arcuate, ballistic trajectories from a nearby eruptive vent. Welded airfall tuffs, although not common, have been recognized in several Quaternary volcanoes (for review, see Cas and Wright, 1987).

The most striking aspect of these tuffs is the contrasting appearance of thick-walled glass shards and highly flattened pumice clasts in the same hand sample (Plate 5(e)). The fiamme are chloritized, whereas the thick-walled shards are only slightly devitrified. These differences could perhaps be explained by relating the degree of deformation and alteration to thinness of the glass walls, but seem to be more consistent with contrasting chemical compositions. If, for example, the pumice clasts were less siliceous and richer in FeO, MgO, and other oxides than the thick-walled shards, they would tend to

be less viscous (and would deform more readily), and have a greater tendency to alter to chlorite. These partly welded tuffs may, therefore, record the simultaneous eruption of two compositionally distinct magma types (cf. Blake, 1981), resulting in the deposition of rheologically bimodal glass. That possibility has implications for chemical zonation in Cold Fish magma chambers, and mechanisms of eruption, and could be further investigated through the determination of clast compositions by electron microprobe analysis.

Spatsizi River Stock

Located within the eastern Will district, the Spatsizi River Stock is a mildly peraluminous, alkali feldspar granite that appears to represent an upward bulge of the inferred Will subcaldera pluton. It is mineralogically similar to the rhyolites into which it was emplaced, with phenocrysts of orthoclase perthite (40% by volume) surrounded by interstitial granophyre (45%), and filled miarolitic cavities. The cavities are filled mainly by granular quartz, and partly by fluorite, chlorite, magnetite and cassiterite.

Undivided Hazelton Group sedimentary rocks (Js)

The Cold Fish and Mount Brock volcanic successions are broadly coeval with sedimentary rocks, mainly sandstone, siltstone, shale, tuffaceous siltstone, and conglomerate (Smith et al., 1984; Gabrielse and Tipper, 1984; Thomson et

al., 1986). Where the sedimentary rocks dominate a given succession, they have been mapped on Figure 3 as "Undivided sedimentary rocks of the Hazelton Group." Where they are subordinate to volcanic strata, they are regarded as sedimentary members of the volcanic pile.

On the basis of detailed biostratigraphy and lithostratigraphy in the Joan district, Thomson et al. (1986) divided a thick (<700 m) sedimentary succession that overlies the Cold Fish Volcanics (Tables 1 and 2) into five formations. The lowest of these is the Lower Pliensbachian Joan Formation (Figure 7), and the highest is the Lower Bajocian Quock Formation (Tables 2 and 3). This sequence, and other mainly sedimentary successions in and near the study area (e.g., Smith et al., 1984), were considered by Thomson et al. (1986) to compose the Spatsizi Group, a heretofore unrecognized stratigraphic unit. Except for the Quock, none of the formations was easily recognized beyond the Joan district; the sedimentary strata have been mapped as a single unit in this study.

The assignment of the sedimentary rocks in the Spatsizi River area to the Spatsizi Group provides a useful local division among the varied volcanic and sedimentary strata. In a regional context, however, the recognition of a sedimentary group that is separate from the Hazelton Group creates conflict in nomenclature, and difficulty in relating the Jurassic volcano-sedimentary succession in the study area to those elsewhere on Stikinia.

Problems with the usage of "Spatsizi Group" have occurred because of conflict with previously established nomenclature and depictions of the Hazelton Group. The most comprehensive and widely accepted definition of the Hazelton Group was made by Tipper and Richards (1976) on the basis of studies in three 1:250 000 scale map areas along the southeastern margin of the Bowser Basin (Figures 1 and 5). There, the Hazelton Group is regarded as a volcanic and sedimentary succession of Early and Middle Jurassic age that formed prior to deposition of the Bowser Lake Group. Subsequently, many authors adopted this broad definition, and applied it to coeval volcanic and sedimentary strata from other regions, including the study area (see review in Marsden and Thorkelson, in press). This trend has resulted in progressive inclusion within the Hazelton Group of lithologically and chemically diverse volcanic successions, and highly variable sedimentary sequences. Exclusion of the sedimentary strata in the Spatsizi River area from the Hazelton Group thereby obfuscates regional correlations, and is an impediment to paleogeographic depictions.

Arguments that the "Spatsizi Group" is lithologically dissimilar to sedimentary sequences of the Hazelton Group, and should therefore be excluded from the Hazelton Group, are considered invalid. Any differences in sedimentary character, such as colour, induration, bedding or grain size, are no more striking than the contrasts in volcanic character among the disparate and

varied volcanic successions of the Hazelton Group. Furthermore, the Quock Formation of the "Spatsizi Group" (Tables 2 and 3) is correlative with similar successions of banded, tuffaceous siltstone ("pyjama beds") that have been assigned to the Hazelton Group in other areas. Moreover, interbedding between the volcanic and sedimentary rocks in the Spatsizi River area, and the locally tuffaceous nature of the sedimentary rocks there, are typical of other Hazelton Group successions. Therefore, abandonment of the term "Spatsizi Group" is recommended in favour of Hazelton Group.

Mount Brock volcanics (JM)

The Mount Brock succession (originally named the "Brock volcanics" by Read and Psutka, 1990) is the youngest of the three Hazelton Group volcanic piles in the study area. Located in the northwestern part of the study area, it strongly resembles the Cold Fish Volcanics, comprising over 4000 m (Read and Psutka, 1990) of mafic to intermediate lava flows, and subordinate felsic pyroclastic rocks. The succession was deposited in a dominantly subaerial environment, as inferred from the reddened margins of lava flows, and dense welding in pyroclastic flow deposits. Thin members of marine sedimentary and volcanic rocks are interbedded with the subaerial rocks. They include pillow lava, siltstone, sandstone and limestone. In the small region mapped as JMmp in the southwestern part of the Brock district, for example, fossiliferous siltstone

fills interpillow interstices of a mafic pillow lava sequence. In other areas, particularly in the eastern Brock district, laterally extensive interbeds of fossiliferous limestone were mapped by Read and Psutka (1990). Fossils collected from some of the marine sedimentary layers were determined to be Early and Middle Toarcian in age (Read and Psutka, 1990). Isotopic dating of the succession, which could help to define the geological time scale, was not carried out.

Exposed beneath the western margin of the Mount Brock volcanics are 350-600 m of fossiliferous sedimentary strata and intercalated marine volcanic rocks (section 1 of Smith et al., 1984; section "Z" of Thomson et al., 1986; Read and Psutka, 1990). This marine succession nonconformably overlies granitoid rocks (Smith et al., 1984) that have been correlated by Read and Psutka (1990) with the Triassic Railway pluton. Biostratigraphic analysis by Smith et al. (1984) indicates that the lower part of the section is broadly Early Jurassic in age, and that the middle and upper parts are of Late Pliensbachian (P. L. Smith, personal communication, 1990), and Early Toarcian ages, respectively. Whether or not some of the strata in the lower part of the succession are Early Pliensbachian in age, and coeval with the Cold Fish Volcanics, is unknown.

The lowest Mount Brock volcanics were conformably deposited on, or gradationally deposited within, a Lower Toarcian shallow marine sedimentary succession. Aggradation (and possibly uplift) produced subaerial conditions

within metres or tens of metres of the base, which were occasionally replaced by shallow marine conditions of short-lived oceanic transgressions during deposition of the lower 500 m of section. Subsequently, through the remainder of the Early Toarcian and into Middle Toarcian time, subaerial conditions prevailed during accumulation of a thick subaerial succession, and were only rarely interrupted by marine transgressions. Some marine sediments were deposited above at least 2000 m of mainly subaerial volcanic rocks. The top of the Mount Brock volcanics is not exposed.

Composed predominantly of lava flows of mainly andesitic and dacitic composition (Appendix 1), and devoid of lahar, the succession probably formed on the flanks of a moderately sloping volcano. The marine interbeds indicate that the succession was subsiding as it was accumulating, so that perhaps only a few hundred metres of the volcano were emergent at any given time. Syndepositional subsidence, as noted for the Cold Fish Volcanics, was probably related to regional extensional faulting.

Phenocryst assemblages in the Mount Brock lavas are dominated by plagioclase, with subordinate olivine and augite. Olivine has been altered to iddingsite, magnetite and serpentine. Plagioclase is variably altered to sericite and epidote, and augite is relatively unaltered. In one unusual lava hornblende phenocrysts, altered to opaque oxides, occupy 5% of rock volume. In another, biotite, altered to chlorite and magnetite, is present in trace amounts. Magnetite

is common as a groundmass mineral, along with plagioclase, augite and olivine, but is rare as a phenocryst. Apatite is common as a chadacryst in plagioclase, and is a minor constituent of groundmass. Granular cassiterite grains were observed in one sample. Textures vary from felted to pilotaxitic, hyalopilitic (devitrified), and diktytaxitic.

Rocks younger than or coeval with the Hazelton Group

Cartmel Stock (JTg)

The Cartmel Stock is a little-studied, multiple-phase intrusion in the southeastern Cartmel district. It appears to crosscut rhyolitic and possibly mafic volcanic rocks that have been correlated with the Cold Fish Volcanics. Three of the intrusive phases comprise medium-grained biotite hornblende quartz monzonite, pink fine-grained hornblende granite, and grey fine-grained hornblende +/- pyroxene quartz diorite. Whether any of these phases are coeval with the Cold Fish or Mount Brock successions, or are of intermediate or entirely younger ages, is unknown.

McEwan Creek Pluton (JTI)

The southern margin of the Mount Brock volcanics, and strata to the west were intruded by quartz monzonite to leucogranite of the McEwan Creek Pluton (Gabrielse and Tipper, 1984; Read and Psutka, 1990). Where it has

intruded the Mount Brock, it is generally concordant with the volcanic strata, and resembles a sill. To the east, it crosscuts older plutonic and stratified rocks. Although it is probably of Middle Toarcian to Bajocian age, its actual age is unknown, and it could be as young as Tertiary.

Bowser Lake Group (JBL)

The Bowser Lake Group is a "Molasse" succession of shale, conglomerate, siltstone and sandstone that was conformably to unconformably deposited on older rocks in Middle Jurassic (Bathonian) to Late Jurassic or Early Cretaceous time (Eisbacher, 1981; Gabrielse and Tipper, 1984; Thomson et al., 1986; Moffatt et al., 1988; Cookenboo and Bustin, 1989; MacLeod and Hills, 1990; Green, 1991). It represents rapid infilling of the Bowser Basin, a marine depocentre whose architecture was mainly inherited from the Hazelton Trough (Tipper and Richards, 1976; Ricketts and Evenchick, 1991; Marsden and Thorkelson, in press). The basinal deposits are rich in chert clasts derived from the Cache Creek Terrane (Souther and Armstrong, 1966), which had begun to obduct onto Stikinia in the late Early Jurassic (Tipper, 1978; Thorstad and Gabrielse, 1986), becoming emergent in Bajocian (Gabrielse, 1991) or Bathonian time.

In the study area, the Bowser Lake succession rests with conformity, disconformity, or very slight angular discordance on the Cold Fish Volcanics or

overlying Hazelton sedimentary strata (Gabrielse and Tipper, 1984; Thomson et al., 1986). In the central Ice Box area, exposures of chert pebble conglomerate that have been correlated with the Bowser Lake Group (Gabrielse and Tipper, 1984) seem to form the core of a pronounced syncline (see speculative projection on cross section A-B of Figure 3). The axial trace of this inferred fold trends toward a prominent, tight syncline in the northeastern Ice Box district. Underlying the conglomerate beds in the central Ice Box district is a thin-bedded succession of siltstone, from which Aalenian ammonites were collected (H. W. Tipper, personal communication, 1986). Evenchick (personal communication, 1990) noted that the siltstone interdigitates with the lower parts of the conglomerate, and suggested that the conglomerate was, at least in part, of Aalenian age. However, the stratigraphic position of the Aalenian ammonites relative to the lowest conglomerate beds is unclear, and the possibility remains that the siltstone succession becomes younger over a short stratigraphic interval (<5 m), and that the siltstone beds which are interbedded with the conglomerate are younger than Aalenian, and perhaps Bathonian in age.

A pronounced angular unconformity (about 70°) separates the Bowser Lake Group from the Stuhini Group, and Triassic-Jurassic conglomerates (TJc), in the Griffith district (Plate 4(c)). In contrast, the Griffith Creek volcanics in that area are generally concordant with the Stuhini Group and unit TJc. These relationships imply that an event of deformation, probably involving folding,

occurred between the time of Griffith Creek volcanism and deposition of Bowser Lake strata. The time of deformation is further constrained by the absence of significant discordance between the Cold Fish Volcanics and the Bowser Lake Group (Thomson et al., 1986). Thus, the Griffith Creek volcanics and older rocks were apparently folded prior to deposition of the Cold Fish succession.

Sustut Group (KS)

The Sustut Group is a succession of conglomerate, sandstone, siltstone, and distal-facies airfall tuff (Eisbacher, 1974), of Early and Late Cretaceous age (Barremian to Maastrichtian; Sweet and Evenchick, 1990). It was deposited in an elongate, terrestrial basin along the northeastern margin of the Bowser Basin. In the study area, the Sustut Group was deposited on the Bowser Lake Group, the Cold Fish Volcanics (in the Ice Box district), and volcanic rocks (TJu) of uncertain identity (in the Griffith district). These variations in the basement to the Sustut, and the local absence of intervening Bowser Lake strata, infer that the study area had undergone considerable erosion prior to Sustut deposition (Evenchick, 1987).

Late Cenozoic intrusions (MPv)

Two small, mafic intrusions of probable Miocene to Pleistocene age were observed in the study area. One of them is a 10 m wide "microgabbro" dyke

that crosscuts the Spatsizi River Stock. The sample of the dyke taken for chemical analysis (sample 86-112-2 in Appendix 1) contains about 23 weight% MgO but only 6% CaO, which infers that it does not approximate a "liquid composition," and has almost certainly been enriched in magnesia through accumulation of olivine or orthopyroxene. Whether this sample is representative of the dyke as a whole is unknown. The microgabbro dyke has no known or suspected correlatives.

The other intrusion is a nephelinite (nepheline-normative basalt: chemical sample 87-224-2) that crosscuts Stuhini Group rocks in the Griffith district. It was dated by the K-Ar (whole rock) method at 1.30 ± 0.03 Ma (M. L. Bevier, personal communication, 1991), indicating a Pleistocene age. It hosts abundant nodules of Cr-spinel ilherzolite to harzburgite (chemical sample 87-224-3) that were probably derived from underlying lithospheric mantle. The nephelinite has a low Mg# (57.4), and a modest Cr concentration (174 ppm), indicating that it was formed from a rather evolved magma, and not a primary, mantle-equilibrated liquid (cf. Basaltic Volcanism Study Project, 1981). Apparently, it underwent considerable fractional crystallization of olivine or other mafic silicate phases below the Moho, before rising rapidly to the surface. The peridotite xenoliths were probably incorporated into the melt just prior to penetration of the lower crust, at the beginning of its rapid ascent.

A third intrusion is indicated on the map about 0.3 km southwest of the

nodule-bearing nephelinite, where it apparently crosscuts the Bowser Lake Group. Its existence was inferred by interpretation of a dark, circular feature on aerial photographs, and supported by its proximity to the nodule-bearing intrusion; whether it is actually present is unknown. The nephelinite dykes are probably coeval and perhaps consanguineous with Late Tertiary lavas and volcanic necks in the western Spatsizi River map area (Gabrielse and Tipper, 1984).

Structure

A comprehensive study of structural geology in the Spatsizi River area was carried out by Evenchick (1991 and references therein). Based partly on earlier mapping and interpretations (Gabrielse and Tipper, 1984; Read and Psutka, 1990), she determined that the region was intensely deformed by northeasterly-directed contractional faulting and folding during intervals in the Late Jurassic to Late Cretaceous. The degree of shortening was estimated at about 44%. Traces of the main fold axes and thrust faults trend northwest, and are indicated on Figure 3. The deformation in the Spatsizi River area was linked to faulting and folding throughout much of northern Stikinia, and considered to be part of a regional orogen that she named the Skeena Fold Belt. Superposed on the fold belt in the Spatsizi River area are numerous block faults, many of which strike northeast or northwest. For example, the Griffith Fault is a major

northeast-striking block fault in the Griffith district along which hundreds of metres of southeast-side-down displacement occurred (Evenchick, 1986).

Not all faults in the study area, however, are well understood. Motion along the Nation Fault (in the Nation district), for example, was almost certainly south-side-down, the opposite to what Gabrielse and Tipper (1984) and Evenchick (1991) indicated. Its sense of displacement is inferred by the stratigraphic sequences exposed on opposite sides of the fault. South of the fault, as illustrated in section (b), the sequence progresses upward from a thick section of mainly mafic lava flows, to a more composite pile of tuffaceous rocks, lava flows and thin sills, that is capped by ignimbrite and overlain by sedimentary rocks (Figures 3 and 7). North of the fault, Cold Fish strata are highly variable, and cut by numerous faults. However, none of the northern strata extend upward to the top of the volcanic succession. Furthermore, the sequences directly north of the fault, represented by sections (c), (d) and (e), bear little resemblance to the succession south of the fault, and are inferred to be almost entirely, if not wholly, deeper level strata. If the southern strata had been displaced upward, as indicated by the previous authors, then the northern succession would be expected to be of higher, not lower stratigraphic level. The dip of the fault is too steep to determine whether the fault is normal or reverse.

The Gladys Fault is a long normal fault that extends northeasterly from

the Joan district (Gabrielse and Tipper, 1984; Thomson et al., 1986) through and probably beyond the "Plateau" district. It crosscuts the Mount Will thrust fault (Gabrielse and Tipper, 1984; Evenchick, 1991), and intersects a steep reverse (?) fault in the "Plateau" district. Southwest of that intersection, the Gladys Fault is consistently northwest-side-down. Northeast of the intersection, displacement along the Gladys Fault involves a considerable component of rotation, such that the fault block on the southeast side of the Gladys Fault is tilted toward the northeast by 30° - 40° , whereas strata northwest of the Gladys Fault are nearly flat-lying. Accordingly, the Gladys Fault is indicated to have northwest-side-down displacement immediately north of the intersection, changing to southeast-side-down displacement farther to the northeast.

Many other faults in the study area are poorly exposed, or assumed on the basis of abrupt changes in stratigraphic level, and their differentiation as reverse, normal or strike-slip faults is not possible. For example, the South Fork, McEwan Creek and Cullivan faults (Read and Psutka, 1990), in and near the "Knife Edge" district, are largely inferred on the basis of abrupt stratigraphic changes. Whether their displacements occurred in a regime of predominantly compression, extension or transcurrent, is uncertain.

Chapter Four

Geochemistry of the Hazelton Group in the Study Area

Introduction

Prior to work by the author, the only geochemical information on the Hazelton Group was provided by a cursory study of four samples from the Cold Fish Volcanics by Erdman (1978). On the basis of major element characteristics, she concluded that the Cold Fish had calc-alkaline to tholeiitic volcanic arc affinity. Work by the author (Thorkelson, 1988; this thesis) was undertaken to: (1) further characterize the Cold Fish in terms of (a) tectonic affinity, (b) stratigraphic variation, and (c) petrogenesis; and (2) assist in the determination of the tectonic affinity of the Mount Brock and Griffith Creek volcanics.

Eighty-four samples of the Hazelton Group, collected by the author from the study area, were analyzed for major and trace elements. Sixty-three of these are from the Cold Fish Volcanics, ten are from the Griffith Creek volcanics, and seven are from the Mount Brock volcanics. The analyses, together with cation normative mineralogy, common petrologic indices, and phenocryst contents (for selected samples), are listed in Table A-1 (Appendix 1). Analytical techniques, and the reliability of the data in terms of precision and accuracy, and the influence of contamination by grinding, are also addressed in Appendix 1. All the rock samples selected for analysis were non-amygdaloidal,

devoid of major fractures and secondary petrofabrics, and metamorphosed to only zeolite or prehnite-pumpellyite grades (Chapter 3; Read, 1988).

Comparative geochemistry, and tectonic affinity

Geochemical character is very similar among the three volcanic formations. With the exception of rhyolites of the Cold Fish Volcanics, which are weakly peraluminous, almost all of the Hazelton Group rocks are metaluminous, i.e., their molar $\text{Al}_2\text{O}_3/(\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O})$ ratios are less than 1, and their molar $\text{Al}_2\text{O}_3/(\text{Na}_2\text{O} + \text{K}_2\text{O})$ ratios are greater than 1. All of the Hazelton rocks have magnesium numbers (Mg#) less than 67, indicating that they are not primary, mantle-equilibrated melts ($\text{Mg\#} = 100[\text{Mg}/(\text{Mg} + \text{Fe}^{2+})_{\text{molar}}]$ based on $(\text{Fe}_2\text{O}_3/\text{FeO}) = 0.3)_{\text{weight}}$ (Gill, 1981)). A few of the Cold Fish and Griffith Creek samples are rather primitive, with Mg# values in the low to mid 60's, and Cr concentrations over 300 ppm. Most, however, have more evolved Mg#'s, typically from 35-55 (less in the rhyolites). Mount Brock and Griffith Creek compositions tend to be quartz normative to weakly olivine normative, whereas the Cold Fish rocks are typically olivine normative to weakly (< 10%) nepheline normative (except for the rhyolites which are quartz normative). Mount Brock and Cold Fish rocks with $\text{SiO}_2 < 54\%$ have $\text{Al}_2\text{O}_3 > 16.5\%$, and are categorized as high-alumina basalt (Kuno, 1960; Crawford et al., 1987; Brophy, 1989), whereas mafic Griffith Creek rocks have lower alumina concentrations of about 13-14%.

Potash-silica trends are displayed in Figures 12 and 13. Although they are somewhat scattered, the data from each of the formations forms a trend which extends from generally medium and high K alkalinity at mafic compositions, to high K and shoshonitic alkalinity at intermediate and felsic compositions (diagram modified slightly from Peccerillo and Taylor, 1976; Basaltic Volcanism Study Project, 1981; Ewart, 1982). Although post-magmatic alteration may be responsible for much of the scatter, the overall trend towards high K and shoshonitic character is considered to be magmatic. Features which support the primary nature of this trend are: (1) the generally "fresh" appearance and low metamorphic grade of the rocks; (2) consistent interelement variations among the large-ion lithophile elements (LILE: Ba, Rb, Th, K, and Sr), and between the LILE and high field-strength elements (HFSE) such as Sm and Y (Figures 15 and 16, discussed later); and (3) the complete absence of medium K and low K compositions at silica contents above 57%. Furthermore, if the degree of alkalinity were mainly a result of potassic alteration, rocks in some areas might be expected to be more severely effected than those in others. To the contrary, geographically related trends in alkalinity are not apparent.

The range in silica content differs among the data from the three formations. The Cold Fish rocks range in composition from basalt to high-silica rhyolite, whereas the rocks from the other formations have compositions that

Figure 12. Potash-silica classification of the Cold Fish Volcanics (diagram modified slightly from Peccerillo and Taylor, 1976; Basaltic Volcanism Study Project, 1981; and Ewart, 1982). Principal compositional names (basalt to high-silica rhyolite) are based on SiO_2 concentration. Degree of potassic alkalinity is indicated by fields that taper to the left, labelled "Low K" to "Shosh.", where the latter denotes shoshonitic affinity. The Cold Fish data generally follow a high-K to shoshonitic trend of potash enrichment.

Cold Fish Volcanics

Weight% SiO₂

f = lava flow d = dyke s = sill t = welded tuff SRS = Spatsizi River Stock

Figure 13 . Potash-silica classification of the Griffith Creek and Mount Brock volcanics. Data from both formations follow a general trend of high-K alkalinity.

The graph plots Weight% K₂O (0 to 8) against volcanic rock types. The rock types are categorized into Basalt, Basaltic Andes., Andesite, Dacite, Rhyolite, and High-silica Rhyolite. The graph is divided into four fields: Shosh., High K, Med. K, and Low K. Data points are plotted as 'G' (granite) and 'M' (monzonite) for various samples, showing their K₂O content relative to the rock types.

G = Griffith Creek

extend from basalt to only dacite. This difference may be a result of biased sampling of the Griffith Creek and Mount Brock volcanics, both of which include strata of apparent rhyolitic composition that were not collected for geochemistry. However, in both of those formations, rocks of suspected rhyolitic composition are low in abundance, and clearly subordinate to mafic and intermediate rocks. The Cold Fish Volcanics thereby differ from the Griffith Creek and the Mount Brock in their high abundance of very siliceous rocks. The Cold Fish also differs from the other successions by its low abundance of dacitic and siliceous andesitic compositions (only six of the sixty-three samples have silica contents between 60% and 70% SiO_2 ; Figure 8). For simplicity, this bimodal formation is divided into a *rhyolitic* suite, and a *mafic* suite of mafic to (subordinate) intermediate rocks (Chapter 3).

Tholeiitic to weakly calc-alkaline patterns are evident on Figure 14, where silica contents are plotted against FeO^*/MgO ratios (FeO^* = total iron as FeO). Cold Fish mafic and intermediate rocks plot almost entirely in the tholeiitic field, and similarly the rhyolites are dominated by tholeiitic compositions, with many specimens showing extreme Fe/Mg enrichment (diagram from Miyashiro, 1974). The Mount Brock volcanics follow a trend similar to that of the non-rhyolitic Cold Fish, whereas the data from the Griffith Creek volcanics straddle the tholeiitic/calc-alkaline boundary.

Figures 15, 16 and 17 are logarithmic profiles of trace element data that

Figure 14. Tholeiitic/calc-alkaline discrimination diagram (Miyashiro, 1974) for the Cold Fish, Griffith Creek and Mount Brock volcanics. Cold Fish and Mount Brock data follow a tholeiitic trend of FeO^*/MgO enrichment, whereas the Griffith Creek volcanics are transitionally calc-alkaline.

Cold Fish Volcanics

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Figure 15. Logarithmic trace element profiles of the Cold Fish Volcanics, normalized to "normal" mid-ocean ridge basalt (N-MORB).

Figure 16. Logarithmic trace element profiles of the Griffith Creek and Mount Brock volcanics normalized to N-MORB. Primitive Cold Fish basalt is shown for comparison.

Mount Brock volcanics

Griffith Creek volcanics

Figure 17. Comparison of primitive Cold Fish basalt with volcanic arc and ensialic marine back-arc compositions on $\log_{10}$ trace element N-MORB normalized diagrams.

Volcanic Arc Ensialic Marine Back Arc

have been normalized to normal mid-ocean ridge basalt (N-MORB). The normalizing values, compiled from Langmuir et al. (1977); Basaltic Volcanism Study Project (1981); and Sun and McDonough (1989) are listed in Table 4. Following the general order of elements used by Pearce (1982), Saunders and Tarney (1984), and Thomson et al. (1984), the LILE, except for Sr, are plotted on the left, magmatophile HFSE (Nb-Yb) and Sr are plotted in the centre, and "compatible" transition metals (TM: Mn-Ni) are plotted on the right. Element compatibility with mafic silicate phases generally increases toward the right. In each of the trace element profiles, two data sets are indicated by lines and symbols (either plus-signs or diamonds), and one is indicated by lines only. The lines-only profile, in all of the graphs, is that of "primitive Cold Fish basalt," an average of the nine most Mg-rich basalts (average MgO concentration = 6.7%; trace element concentrations listed in Table 4).

The profiles of Figure 15 show how primitive Cold Fish basalt compares with other Cold Fish compositions that have been averaged from data in Appendix 1. An average with a composition of basaltic andesite composition (MgO concentration = 4.2%, $n=25$), closely follows the primitive basalt pattern, displaying general increases in LILE and HFSE, and decreases in TM. The average composition of the remaining (more evolved) samples of the mafic suite is andesitic (MgO concentration = 1.9%, $n=10$). It also shows these trends, but differs in its relative depletion of Th, Sr, P, Eu, Ti, V, and Co. Profiles of the

TABLE 4**Normalizing Values used in Trace Element Profiles**

Component		N-MORB	Primitive Cold Fish Basalt
Ba	ppm	6.3	647.1
Rb	ppm	0.56	42.1
Th	ppm	0.12	2.2
K ₂ O	weight %	0.0723	1.3
Nb	ppm	2.33	4.1
La	ppm	2.5	11.7
Ce	ppm	7.5	25.4
Sr	ppm	90	467
P ₂ O ₅	weight %	0.117	0.30
Zr	ppm	74	64.4
Sm	ppm	2.63	3.3
Eu	ppm	1.02	1.3
Gd	ppm	3.68	4.1
TiO ₂	weight %	1.27	1.1
Dy	ppm	4.55	4.1
Y	ppm	28	21.3
Yb	ppm	3.05	2.1
Mn	ppm	0.165	0.24
Zn	ppm	85	93.6
V	ppm	250	256.0
Sc	ppm	38	31.3
Co	ppm	47	34.5
Cu	ppm	86	53.6
Cr	ppm	270	159.9
Ni	ppm	135	63.0

N-MORB normalizing values from Langmuir et al. (1977), Basaltic Volcanism Study Project (1981), and Sun and McDonough (1989).

Primitive Cold Fish Basalt values are averages from the nine most MgO-rich basalts (Appendix 1).

average compositions for the rhyolitic rocks show more variation ("high-Mg," MgO concentration=0.4%, n=10; "low-Mg," MgO concentration=0.2%, n=9). Relative to the primitive basalt profile, both of the rhyolite patterns show enrichments in the LILE, Nb and Zr, and all of the lanthanides except for Eu, depletion of Ba with respect to other LILE, and marked depletions of P, Eu, Sr, Ti, and the TM.

In Figure 16, average mafic and intermediate compositions of the Griffith Creek and Mount Brock volcanics are compared to primitive Cold Fish basalt. The "mafic" Griffith Creek (n=3) composition has a MgO concentration of 7.7%, about 1% greater than that of the primitive Cold Fish basalt. The "intermediate" composition (n=4) is considerably more evolved, with a MgO content of 2.4%. The patterns are similar to that of the Cold Fish reference basalt in the LILE-HFSE range, except that Ti and the heavy rare-earth elements are considerably lower, and alkalinity is greater. The Griffith profiles thereby cross the Cold Fish profile toward the left hand side of the HFSE range. In the TM range, Cu and Cr in the mafic Griffith Creek rocks have near-MORB levels, whereas Ni is less abundant than in primitive Cold Fish basalt. Although the Mount Brock "mafic" and "intermediate" compositions are both more evolved than the Cold Fish reference basalt, their profiles are very similar to that of the Cold Fish primitive composition, and are almost identical to the profiles of the more evolved mafic Cold Fish compositions shown in Figure 15. The Mount Brock mafic

composition ($n=6$) and the intermediate composition ($n=8$) have MgO concentrations of 4.0% and 1.4%, respectively.

Figure 17 displays profiles of some Late Cenozoic volcanic arc and back-arc rocks. The two volcanic arc compositions were chosen because their profiles strongly resemble that of primitive Cold Fish basalt. The "Cascades + Aleutians" composition is an average of 92 basaltic rocks (MgO concentration=6.7%) from the Cascade and Aleutian arcs (Ewart, 1982). The "Mexican calc-alkaline" profile represents a single analysis (MgO concentration=8.8%) from Luhr et al. (1989). Both of these profiles resemble the Cold Fish reference pattern, particularly in the diagnostic LILE-HFSE range where Nb is depleted with respect to K and La, and Sr is enriched with respect to Ce and P. These specific features, as well as the general enrichment of LILE over HFSE, are typical of supra-subduction zone basalts (Pearce, 1982; Saunders and Tarney, 1984; Thompson et al., 1984).

The two profiles of "ensialic marine back arc" rocks illustrate some of the great variability in the chemical character of back-arc rocks. They were selected because their tectonic setting is similar to that which is interpreted for the Hazelton Group volcanic strata in the study area (chapters 2 and 3). One sample is from Kula Island in the Aegean Sea (MgO concentration=6.8%; Pe-Piper and Piper, 1989), and the other is from Penguin Island in the Bransfield Strait (MgO concentration=7.8%; Weaver et al., 1979). The Aegean profile is

typical of back-arcs built on continental or transitional crust, such as the Patagonian basalts in the southern Andes (Stern et al., 1990), the Ngatutura basalts behind the Taupo volcanic zone in New Zealand, and the alkaline basalts in Korea, eastern China, and southwestern Japan (Nakamura et al., 1989). Mafic rocks from these locations have profiles which follow a smooth transition from low Y and Yb contents to high LILE concentrations. They represent a plume-like or rift-like ("intraplate") chemical end-member to the compositional spectrum of back-arc basalts, the other end-member of which is MORB-like. The Penguin Island sample is similar to other back-arc rocks in Bransfield Strait, and chemically resembles alkaline basalts behind the volcanic front in the south-central Andes (Munoz and Stern, 1989). It is moderately alkaline, and depleted in some of the HFSE, notably Nb, Zr, and Ti, relative to the lanthanides and LILE. Rocks of this compositional type represent a transition from the intraplate variety toward less alkaline basalts with nearly flat profiles that are common in back-arc basins of the western Pacific region (Gill, 1976; Saunders and Tarney, 1984; Jenner et al., 1987; Price et al., 1990).

The foregoing comparison of chemical characteristics indicates that the Hazelton Group successions in the study area were deposited in either a volcanic arc or back-arc setting. A back-arc setting, inferred from regional geological relationships (Marsden and Thorkelson, in press; chapters 2 and 3), is supported by the pronounced silica bimodality, and transitionally silica-

saturated to undersaturated normative mineralogy in the Cold Fish Volcanics. Silica bimodality and undersaturated compositions are relatively rare in volcanic arcs, but common in terrestrial extensional settings (Martin and Piwinski, 1972; Strong, 1979; Bacon et al., 1984).

The high-silica content of most of the Cold Fish rhyolites, and the high K content of all the Hazelton successions in the study area, imply that the crust beneath the successions was thick and mature. Orogenic volcanic rocks built on thick, felsic crust are typically richer in alkali and alkaline earth elements than those built on thinner, more mafic crust (Ewart, 1982). Possible reasons for the greater alkalinity include: (1) greater depth of fractionation (high-pressure fractionation of pyroxene leads to more alkaline derivative magmas; Meen, 1987; 1990); (2) assimilation of silicic, alkali-rich crust (DePaolo, 1981); (3) chemical contribution to primary magma through subduction of sediment (Stern, 1991); and (4) partial fusion, or other involvement with enriched or "subcontinental" lithospheric mantle (Varne, 1985). A fifth cause of high alkalinity, but one which does not implicate thick or mature crust, is small degrees of partial fusion (cf. Meijer and Reagan, 1983).

Constraints on petrogenesis of the Cold Fish Volcanics

Petrogenesis of the mafic Cold Fish Volcanics is evaluated on the basis of the trace element profiles of Figure 18, where the andesite and basaltic

Figure 18. Cold Fish andesite and basaltic andesite compositions $\log_{10}$ -normalized to primitive Cold Fish basalt. Normalizing values are listed in Table 4.

Mafic Cold Fish Volcanics

andesite compositions of Figure 15 have been normalized to primitive Cold Fish basalt (normalizing values are listed in Table 4). The variation in trace element concentrations from primitive to more evolved profiles in Figure 18 reveals that differentiation of the mafic Cold Fish Volcanics from primitive basalt to dacite may have been principally controlled by fractional crystallization. The other two processes that have been routinely invoked to explain the chemical evolution of mafic suites, namely variable degrees of partial melting, and mixing of basaltic magma with various proportions of felsic magma, are rejected on the following grounds. For all but very high degrees of melting, partial melting results in a suite of liquids that vary greatly in the concentration of incompatible elements such as the LILE and HFSE, but vary little in the concentrations of compatible elements such as Ni and Cr (Shaw, 1970; Gill, 1981). In the mafic Cold Fish suite, the opposite trend is evident, with Ni and Cr contents varying by a far greater proportion than those of the incompatible elements. For example, Ni decreases by over 0.54 log units from primitive basalt to the basaltic andesite composition (63 ppm to 18 ppm), whereas Ba increases by only 0.19 log units (1014 ppm to 1356 ppm) over the same interval.

Mixing of magmas is expected to produce hybrid compositions that reflect the chemical composition of each of its parents (Wilcox, 1979). If chemical variability in the mafic Cold Fish suite were produced by mixing between primitive basalt and Cold Fish rhyolite, then increasingly more evolved

mafic lavas would have progressively more rhyolitic trace element profiles. Specifically, hybrids would tend to be enriched, relative to primitive basalt, in LILE, Nb, Zr, and the lanthanides, and depleted in P, Sr, Eu, Ti, and the TM. In contrast, the two profiles of more evolved mafic compositions only partly match the predicted hybrid trends, and differ significantly in several respects. Firstly, the basaltic andesite profile is depleted with respect to primitive basalt in only Mn and Sc-Ni, and is either enriched or unchanged in all other trace elements. Even V, which has a very low abundance in rhyolite, is not depleted in the basaltic andesite composition. Secondly, the more evolved composition (andesite) shows extreme depletion in most of the TM, but only slight depletion in Sr, P, Eu, Mn and Zn. Furthermore, Ba concentrations in the andesitic composition are higher than in the rhyolites. These non-uniform trends in depletion and enrichment preclude mixing as the principal cause of magma evolution.

The elimination of "mixing" and "melting" as first-order petrogenetic controls lends support to the interpretation that fractional crystallization may have been the main cause of differentiation. Rigorous, quantitative modelling that is necessary to properly test this hypothesis will not be presented here. However, the following brief discussion of trace element depletion and enrichment with reference to fractionation of modal phenocryst phases (Chapter 3; Appendix 1) provides an initial, qualitative evaluation of the efficacy of this

process. Fractional crystallization results in depletion of trace elements that are "compatible" with the fractionating phases, and enrichment of trace elements that are not (e.g., Allegre and Minster, 1978). The types and relative proportions of the phases involved should be reflected in changes in the trace element profiles of successively more evolved compositions. Element compatibility is reasonably well known from experimental and empirical studies (see reviews by Gill, 1981; and Henderson, 1982).

The evolution of primitive Cold Fish magma to less magnesian compositions is evaluated in terms of possible olivine, augite, plagioclase, magnetite and apatite fractionation. Two stages in differentiation are considered, the first from primitive basalt to the basaltic andesite composition, and the second from the basaltic andesite to the andesite composition. In the first stage, as indicated by differences between the the primitive basalt and basaltic andesite profiles (Figures 15 and 18) concentrations of the LILE, HFSE, and Zn increased, the concentration of V remained constant, and Mn, Sc, Co, Cu, Cr and Ni contents decreased. The depletions in the TM, particularly in Sc, Cr and Ni, imply fractionation of augite and olivine. The absence of Ti and V depletion indicates that Fe-Ti oxides such as magnetite did not fractionate in significant quantities. Similarly, the lack of Sr and Eu depletion is evidence that plagioclase removal was minimal. In the second stage, as indicated by the andesite profile, derivative magmas continued to be depleted in Mn, Sc, Co, Cu,

Cr, and Ni. These depletions infer the continued fractionation of augite and olivine. However, the removal of other phases, is indicated by: (1) modest depletions in Sr and P; (2) the development of an Eu anomaly (decreased Eu/Sm and Eu/Gd ratios); and (3) large depletions in Ti and V. The Sr and relative Eu depletions infer fractionation of plagioclase. P depletion is explained by apatite precipitation. Removal of magnetite was the probable cause of the Ti and V depletion, and may also have been responsible for the sharp drop in Co concentration.

This depiction of the fractionation history of the Cold Fish mafic magmas is generally consistent with magma evolution as inferred by petrography (Chapter 3), except that plagioclase, which is so abundant as a phenocryst phase in mafic rocks of all compositions, was apparently not precipitated in significant quantities until relatively evolved (andesitic) compositions had been reached. Possibly, plagioclase precipitated but did not fractionate readily because its density was close to that of the melt (Gill, 1981). Confirmation of the foregoing model of crystal fractionation requires a more thorough petrological investigation.

Although fractional crystallization may have been the main differentiation process, it was probably active in conjunction with assimilation, and mixing among mafic magmas. As noted in Chapter 3, assimilation is indicated by embayed quartz xenocrysts; mixing of mafic magmas is implied by

corroded plagioclase and augite phenocrysts. The degree of assimilation, and its importance relative to fractional crystallization (cf. DePaolo, 1981), has not been addressed.

The postulate of mafic magma mixing is supported by stratigraphically related changes in the MgO concentration of lava flows in section (i) of the Nation district (Figure 19). The data points, labelled with their chemical sample numbers, represent mafic lava flows from section (i), and flows from neighbouring ridges (within 2 km of the section trace) that have been projected into the section with confidence. The base of the volcanic succession is not exposed, and the lowest sample (86-27-8) was erupted at an intermediate stratigraphic level. MgO concentrations fluctuate with stratigraphic order, starting from less than 2% in the lowest flow, and varying thereafter from just below 3% to more than 8% (86-33-2). Although not all of the lava flows in the sequence were sampled, and the complete pattern of MgO fluctuation is likely to be more complex, the existing data indicate that MgO levels increased and decreased at least three times during deposition of about 800 m of section.

These fluctuations could have resulted from intercalation of lava flows that were erupted from a few nearby vents, each fed from a separate body of magma. Another possibility is that the fluctuations resulted from progressive evisceration of temporally distinct magma chambers, each of which followed a single cycle of differentiation toward more evolved compositions. A more

Figure 19. Variation in MgO concentration of mafic Cold Fish lavas in section (i) of the Nation district. Samples are arranged according to stratigraphic position, such that the lowest flow (sample 86-27-8) is in position 1, and the highest flow (86-11-3) is in position 15.

Section i
Nation district

plausible explanation is that the fluctuations were a result of chemical changes that occurred within a single, long-lived chamber which underwent periods of differentiation punctuated by influx of more primitive liquids rising from below. Replenishment and subsequent mixing would thereby raise MgO concentrations in the magma chamber, marking the beginning of another cycle of (?) fractional crystallization, and evolution toward intermediate compositions. As indicated on Figure 27, the data are consistent with three major events of chamber recharge. Chemical trends in MORB have been modelled in terms of sequential fractionation and recharge by Dungan and Rhodes (1978). O'Hara (1977) and O'Hara and Mathews (1981) provided a numerical model for chemical evolution in a fractionating, periodically replenished magma chamber, which may be useful in the interpretation of this set of data.

The origin and chemical evolution of the Cold Fish rhyolites have not been thoroughly evaluated. Some general comments regarding their character are: (1) the majority of the LILE and HFSE elements describe a trend that lies above and generally parallels the profiles of mafic Cold Fish rocks; (2) depletions of the TM, Sr, P, Eu, and Ti are consistent with (a) fractionation of mafic silicate phases, Fe-Ti oxides, plagioclase and apatite from a parental magma, or (b) crustal anatexis, and separation of rhyolite from restite composed of those mineral phases; and (3) on the basis of profile similarity, fractionation from a mafic Cold Fish parental magma appears to be reasonable.

Detailed petrology and isotope geochemistry (cf. Hildreth, 1979; Bacon et al., 1984) are necessary to constrain the source rocks and petrogenetic history.

Chapter Five

U-Pb geochronology

Introduction

Prior to this study, the ages of the three Hazelton Group volcanic formations in the study area were constrained mainly by ammonite biostratigraphy. Specifically, the age of the Mount Brock volcanics was known to be Early and Middle Toarcian on the basis of fauna collected beneath and within the volcanic succession (Smith et al., 1984 ; Read and Psutka, 1990). The Cold Fish Volcanics were assigned an Early Pliensbachian age on the basis of fossils within and above the succession (Thomson et al., 1986; Evenchick, 1991). The age of the Griffith Creek volcanics had not been directly determined, although it was considered to be younger than the Norian (Late Triassic) age of underlying Stuhini Group rocks, and older than the Bajocian (Middle Jurassic) age of the Quock Formation onto which the Griffith Creek succession was thrust (Thomson et al., 1986; Evenchick, 1986). The only isotopic date on the Hazelton rocks was an imprecise 189 ± 26 Ma (2 sigma) "age" of an Rb-Sr scatterchron from the Cold Fish Volcanics (Erdman, 1978; Gabrielse et al., 1980).

Dating of the Cold Fish and Griffith Creek successions by the U-Pb method on zircon was undertaken jointly by the author and J. K. Mortensen of the Geological Survey of Canada. The author collected the samples, selected

("picked") the zircons to be analyzed, and abraded the grains prior to their dissolution. The chemical and isotopic data were interpreted mainly by Mortensen (although the presentation of those interpretations in this thesis was written solely by the author).

The purpose of the project was to provide precise isotopic dates in order to (1) constrain the numerical ("absolute") ages of the successions; (2) compare the isotopic age of the Cold Fish Volcanics with the range in numerical age assigned to the Early Pliensbachian interval on the geological time scale of Harland et al. (1990); and (3) provide an improved basis for correlation between Hazelton rocks in the study area, and those elsewhere on Stikinia. In addition, dating of the Spatsizi River Stock was undertaken to determine whether the stock was coeval with the Cold Fish Volcanics, as indicated by field relationships, petrography and geochemistry.

Analytical techniques

Zircon concentrates were prepared from 4-6 kg samples of crushed rock using conventional Wilfley table and heavy liquid techniques. All of the zircon fractions were abraded prior to isotopic analysis to minimize effects of surface-correlated Pb loss (Krogh, 1982). Criteria for selection of grains for analysis, and procedures used for dissolution, chemical extraction and purification of U and Pb, and mass spectrometry are described in detail in Parrish et al. (1987).

Procedural blanks were 5 to 25 pg for Pb, and < 1pg for U. U-Pb analytical data are given in Table 5, and the data are displayed on U-Pb concordia plots in Figures 20-26. Errors attached to individual analyses were calculated using the numerical error propagation method of Roddick (1987). The decay constants recommended by Steiger and Jäger (1975) and compositions for initial common Pb taken from the model of Stacey and Kramers (1975) were used for age calculations. Concordia intercept ages and weighted $^{207}\text{Pb}/^{206}\text{Pb}$ average ages were calculated using a modified York-II model (York, 1969; Parrish et al., 1987), and the algorithm of Ludwig (1980). All errors are given at the 2-sigma (95% confidence) level. The foregoing description of techniques was written by J. K. Mortensen, and included in this thesis with his permission (1991).

Age determinations

Age of the Cold Fish Volcanics

Four samples of the Cold Fish Volcanics were analyzed using the U-Pb method on zircon. The isotopic data are presented on concordia diagrams in Figures 20-24, and the interpreted (2-sigma) ages are displayed in Figure 27. Sample 87-157-2 was collected from a reddish-brown rhyolite sill in the Nation district. The sill forms part of a rhyolitic sequence (section (g)) that was thrust onto a more mafic succession (sections (i) and (j); Figures 3 and 7) . The

Table 5. U-Pb analytical data

Fraction, Size ¹	Weight (mg)	U (ppm)	Pb ² (ppm)	²⁰⁶ Pb/ ²⁰⁴ Pb	²⁰⁸ Pb/ (%)	²⁰⁶ Pb/ ²³⁸ U	²⁰⁷ Pb/ ²³⁵ U	²⁰⁷ Pb/ ²⁰⁶ Pb	²⁰⁷ Pb age ³ ²⁰⁶ Pb
GAT-87-157-2 (Cold Fish Volcanics)									
A N2,+74	0.103	856	26.2	9209	10.7	0.03027(.10)	0.2087(.11)	0.05000(.03)	194.9 (1.5)
B N2,-74	0.105	671	20.5	6359	10.4	0.03034(.11)	0.2102(.12)	0.05026(.04)	206.9 (1.8)
C N2,+74-105	0.120	870	26.7	5948	11.1	0.03024(.11)	0.2085(.12)	0.05001(.04)	195.5 (1.7)
D N2,+74-105	0.110	920	28.4	2665	11.5	0.03018(.10)	0.2080(.13)	0.04998(.06)	194.2 (2.7)
E N2,+74-105	0.029	1101	34.0	2422	11.5	0.03027(.09)	0.2085(.12)	0.04996(.06)	193.3 (2.9)
F N2,+74	0.003	1047	33.1	383	11.0	0.03113(.16)	0.2156(.86)	0.05025(.76)	206.5(35.4)
G N2,+74	0.005	318	9.4	109	4.6	0.03143(.42)	0.2136(2.43)	0.04930(2.1)	162.0(100.5)
GAT-86-56-3 (Cold Fish Volcanics)									
A N1,+105,<M	0.076	517	15.6	2807	10.8	0.02981(.09)	0.2054(.11)	0.04997(.05)	193.4 (2.1)
B N1,+105,>M	0.259	558	16.9	6663	10.8	0.02988(.11)	0.2058(.12)	0.04997(.04)	193.6 (1.7)
C N2,+74,u	0.167	592	17.8	3426	11.5	0.02943(.11)	0.2029(.13)	0.05000(.05)	195.1 (2.3)
D N2,+74	0.045	540	16.3	1683	10.5	0.02986(.09)	0.2054(.15)	0.04990(.10)	190.3 (4.7)
GAT-87-159-2 (Cold Fish Volcanics)									
A N1,+74-105	0.124	1195	34.4	6212	10.3	0.02857(.13)	0.1971(.14)	0.05004(.04)	196.7 (1.9)
B N2,+74-105	0.251	1149	33.7	2474	10.8	0.02900(.14)	0.2000(.17)	0.05003(.07)	196.3 (3.0)
C N3,+105	0.376	1561	41.6	12340	10.7	0.02637(.50)	0.1822(.50)	0.05012(.03)	200.3 (1.4)
D N3,+105	0.219	1120	31.7	1347	10.7	0.02797(.13)	0.1934(.19)	0.05011(.11)	202.4 (5.3)
E N3,+74-105	0.289	1528	40.4	9898	10.3	0.02623(.19)	0.1813(.20)	0.05014(.03)	201.7 (1.5)
GAT-87-181-2 (Cold Fish Volcanics)									
A N2,-105,u	0.057	248	7.9	1178	16.1	0.02966(.10)	0.2045(.21)	0.05001(.16)	195.4 (7.5)
B N3,+105	0.019	1917	67.1	3745	16.0	0.03243(.09)	0.2398(.10)	0.05363(.04)	355.7 (1.8)
C N2,-105	0.069	649	21.1	3143	16.3	0.03017(.09)	0.2079(.11)	0.04997(.04)	193.5 (2.0)
D N1,-105,u	0.312	278	8.9	2543	16.3	0.02977(.10)	0.2058(.12)	0.05013(.06)	201.1 (2.7)
E N2,-74	0.039	302	9.7	788	15.2	0.03006(.15)	0.2084(.33)	0.05027(.29)	207.6(13.7)
GAT-87-219-4 (Griffith Cr. volcanics)									
A N1,+105,<M	0.575	225	7.1	5217	8.6	0.03190(.11)	0.2210(.12)	0.05024(.04)	206.1 (1.9)
B N1,+105,<M	0.180	206	6.5	2331	8.7	0.03182(.10)	0.2206(.14)	0.05027(.08)	207.5 (3.6)
C N1,+105	0.569	235	7.4	8720	8.7	0.03175(.11)	0.2199(.12)	0.05023(.04)	205.7 (1.6)
D N1,+74-105,<M	0.845	233	7.3	6310	9.0	0.03166(.17)	0.2192(.18)	0.05022(.04)	205.4 (1.9)
E N1,+74-105	0.456	230	7.2	7710	9.0	0.03167(.09)	0.2193(.11)	0.05022(.04)	205.3 (2.0)
GAT-87-234-3 (Griffith Cr. volcanics)									
A N1,+105,<M,s	0.720	224	7.1	3365	8.5	0.03201(.10)	0.2216(.12)	0.05022(.05)	205.0 (2.4)
B N1,+105,<M,p	0.338	253	8.2	3750	9.3	0.03241(.08)	0.2247(.10)	0.05028(.05)	207.7 (2.3)
C N1,+74-105	0.558	315	9.9	9021	9.6	0.03147(.08)	0.2181(.10)	0.05025(.03)	206.4 (1.6)
D N1,+105,<M,e	0.116	209	6.6	1348	8.5	0.03200(.09)	0.2213(.16)	0.05016(.11)	202.4 (4.9)
GAT-86-111-6 (Spallizi R. Stock)									
A N2,+74	0.040	303	10.1	832	17.8	0.03035(.10)	0.2099(.20)	0.05015(.15)	202.1 (7.0)
B N2,+74-105	0.175	269	8.9	3665	17.8	0.03016(.10)	0.2080(.11)	0.05003(.05)	196.4 (2.5)
C N2,+105	0.146	2539	84.0	3846	17.6	0.03017(.09)	0.2081(.11)	0.05001(.05)	195.5 (2.2)
D N2,+74-105	0.134	383	13.0	1859	19.5	0.03013(.09)	0.2077(.13)	0.04999(.07)	194.4 (3.3)

¹sizes (-74+62) refer to length aspect of zircons in microns (i.e. through 74 micron sieve but not the 62 micron sieve); N1,2=non-magnetic cut with Frantz at 1 or 2 degrees side slope; u=unabraded; s=stubby prisms; e=equant; p=elongate prisms

²radiogenic Pb

³measured ratio, corrected for spike and fractionation

⁴corrected for blank Pb and U and common Pb (errors quoted are 1σ in percent)

⁵corrected for blank and common Pb (errors are 2σ in Ma)

Decay constants used are those of Steiger and Jäger (1977); initial common Pb compositions from Stacey and Kramers (1975).

zircons of fractions A to E are generally clear and colorless, stubby to slightly elongate euhedral prisms, with a few inclusions ("tubes and rods"), and without visible cores. The error envelopes of fractions A, C, D and E overlap one another, and plot on or near concordia (Figure 20). The weighted average $^{207}\text{Pb}/^{206}\text{Pb}$ age of these data is 194.8 ± 1.0 Ma, which is the interpreted age of crystallization of the sill. Fraction B plots to the right, toward older model ages on concordia, and has a $^{207}\text{Pb}/^{206}\text{Pb}$ age of 206.9 ± 1.8 Ma, indicating that it contains an older, inherited component of Pb. Analyses F and G were made on single grains that were separated from the other fractions because they had "frosted," slightly anhedral surfaces, and were suspected of being xenocrysts. Although these analyses are considerably less precise than those of the multigrain fractions, they yield somewhat older U/Pb ages, confirming that they are inherited from a slightly older source.

Sample 87-159-2 was collected from pyritic/limonitic rhyolite dyke that crosscuts the strata of section g. Although it does not actually intrude the sill of sample 87-157-2, it belongs to a set of yellowish-white dykes that crosscut the entire section, and is therefore almost certainly younger than the sill. The zircon grains in this sample are similar to those from the sill, differing mainly in their color and clarity. Many of the grains were slightly cloudy and/or yellowish-brown, characteristics which may be related to alteration of pyrite to limonite. In Figure 21, the data describe a linear array that fit a line with an upper intercept

Figure 20 . U-Pb concordia plot and interpreted age of sample 87-157-2 from the Cold Fish Volcanics.

Figure 21. U-Pb concordia plot and interpreted age of sample 87-159-2 from the Cold Fish Volcanics.

Figure 22 . U-Pb concordia plot and interpreted age of sample 86-56-3 from the Cold Fish Volcanics.

GAT-86-56-3 (Cold Fish Volcanics)

Figure 23. U-Pb concordia plot and interpreted age of sample 87-181-2 from the Cold Fish Volcanics.

Figure 24. U-Pb concordia plot of sample 86-111-6 from the Spatsizi River Stock. See text for discussion of interpreted age of 190.0 ± 7.1 Ma.

3

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GAT86-111-6 (Spasizi R. Stock)

Figure 25. U-Pb concordia plot and interpreted age of sample 87-219-4 from the Griffith Creek volcanics.

Figure 26. U-Pb concordia plot and interpreted age of sample 87-234-3 from the Griffith Creek volcanics.

at $194.0 \pm 2.8/-2.3$ Ma which is considered to be the age of the dyke. The array appears to be a result of recent Pb loss, possibly related to acidic conditions caused by breakdown of pyrite during surface weathering.

Sample 86-56-3 was collected from densely welded rhyolitic ignimbrite near the top of the volcanic succession in the Joan district. Like the zircons from the sill in the Nation district, those from this sample are clear, colourless (to very pale yellow), euhedral stubby prisms with some inclusions and almost no visible zoning. A regression line fit through the data of the three most precise analyses (fractions A, B and C) has an upper intercept of 193.9 ± 1.1 Ma, which is the interpreted rock age (Figure 22). The analysis of fraction D is slightly less precise, and overlaps both the discordia line and concordia. Its $^{207}\text{Pb}/^{206}\text{Pb}$ age, at 190.3 ± 4.7 Ma, has an upper limit of 195 Ma which overlaps the interpreted age.

Sample 87-181-2 was collected from a porphyritic rhyolite sill in the Will district. Its zircons are clear and euhedral, without visible cores, and generally similar to those from the ignimbrite in the Joan district. In Figure 23, four of the data ellipses (A, C, D and E) plot slightly below or marginally overlap the concordia curve. Of these, fractions A and C are centred closest to concordia, and have $^{207}\text{Pb}/^{206}\text{Pb}$ ages of 195.4 ± 7.5 Ma and 193.5 ± 2.0 Ma, respectively. The latter is regarded as the best estimate of rock age. Fractions D and E have higher $^{207}\text{Pb}/^{206}\text{Pb}$ ages of 201.1 ± 2.7 and 207.6

+/- 13.7 Ma, implying a component of isotopic inheritance. Point B plots much farther away from concordia, reflecting significant inheritance from zircon of Precambrian, possibly Middle Proterozoic age.

Age of the Spatsizi River Stock

Sample 86-111-6 was collected from fine-grained alkali feldspar granite of the Spatsizi River Stock. The stock is chemically indistinguishable from rhyolites of the Cold Fish Volcanics, and is crosscut by mafic dykes that have been correlated with the mafic component of the Cold Fish. The zircons are clear, colourless, stubby euhedral prisms with abundant clear inclusions, and minor dark (mineral?) inclusions. Zoning is common, but cores are not visible. The data describe a tightly clustered array extending from very near concordia at about 192 Ma toward older model ages. A best-fit line through the array of Figure 24 has a lower intercept of $190 \pm 0.6/-7.8$ Ma, and a very imprecise upper intercept of about 880 Ma. Despite its imprecision, the upper intercept age corroborates the interpretation of Precambrian inheritance noted for sample 87-181-2 from a rhyolite sill. The three data points nearest to concordia, B, C and D, give a rather precise, weighted average $^{207}\text{Pb}/^{206}\text{Pb}$ age of 195.6 ± 1.5 Ma, which contrasts with the younger age of the lower discordia intercept, and is consistent with the pattern of recent Pb loss evident in other samples (e.g., 87-159-2). Its range in uncertainty (194.1-197.1 Ma) overlaps the

interpreted ages of all of the Cold Fish samples, and is therefore attractive as the age of the stock. However, both inheritance and Pb loss seem to have effected the isotopic ratios, and a more prudent interpretation should consider the total range in uncertainty of the two interpretive methods, i.e., 182.9 to 197.1 Ma. Thus, the age of crystallization is interpreted as 190.0 ± 7.1 Ma, which overlaps with the interpreted ages of the Cold Fish Volcanics to which the stock is genetically linked.

Age of the Griffith Creek volcanics

Sample 87-219-4 was collected from a hornblende and plagioclase phyric lava flow of basaltic andesite composition in the Griffith district. The flow lies above a succession of coarse conglomerate of unit Tjc, and is interpreted to be the lowest flow of the Griffith Creek formation at that location. About 5 km to the northwest, the basal unit of densely welded ignimbrite is overlain by augite phyric mafic lavas; the relative stratigraphic position of the hornblende-bearing basaltic andesite is unknown.

The zircons of this sample differ from those of the Cold Fish Volcanics and the Spatsizi River Stock by their slightly pink colour, and higher relative abundance of multifaceted, rather equant grains. The grains are clear and euhedral, with slightly visible zoning, and commonly contain small, colourless inclusions. In Figure 25, the data form a linear array that fits a line with an

upper intercept age of 205.8 ± 0.9 Ma, which is interpreted as the age of the lava flow.

Sample 87-234-3 was obtained from a sill of the Griffith Creek volcanics that was emplaced into rocks of the Stuhini Group and unit TJC. The sill is of dacitic composition, with abundant phenocrysts of plagioclase, hornblende, perthite, biotite and quartz. Data from two of the four zircon fractions (A and D) overlap the concordia curve at about 203 Ma (Figure 26). The error ellipse of fraction D is more closely centred on the curve, and its age, which is interpreted as the age of crystallization, is 203.1 ± 0.4 Ma. Fraction B, which marginally overlaps concordia at a model age of about 205.5 Ma, and has a $^{207}\text{Pb}/^{206}\text{Pb}$ model age of 207.7 ± 2.3 Ma is considered to have a component of isotopic inheritance. Zircon fractions A and C have $^{207}\text{Pb}/^{206}\text{Pb}$ model ages of 205.0 ± 2.4 Ma and 206.4 ± 1.6 Ma, respectively, which are close to that of fraction B, but not significantly different (at the 95% confidence level) from that of fraction D (202.4 ± 4.9 Ma).

Isotopic inheritance

Zircon fractions in four of the samples (87-157-2; 87-181-2; 86-111-6; 87-234-3) are considered to have inherited some of their isotopic character in the form of older zircon cores (even though cores were not visually identified). Most of the fractions that contain inherited Pb have $^{207}\text{Pb}/^{206}\text{Pb}$ model ages

within a few million years of the interpreted ages of sample crystallization. This closeness in age infers that either the relative contribution from inherited cores was small, or that the average age of the cores was not much greater than that of the samples (not more than a few million, or a few tens of million years). For example, a small difference between rock sample and contaminant ages is indicated by the marginally concordant position of fraction B on the concordia plot of sample 87-234-3 of the Griffith Creek volcanics (Figure 26). If the average age of the older Pb component were much older (e.g., of Precambrian age) than the sample age, then the ellipse of fraction B would have been located well below the concordia curve. In contrast, all of the other fractions that have significant inheritance plot away from concordia, and may have contained zircon cores that were considerably older than the samples. All but one of these fractions, however, have $^{207}\text{Pb}/^{206}\text{Pb}$ model ages within a few million years of the interpreted sample ages, and it is uncertain whether they are discordant because of inheritance from a slightly older component, in combination with Pb loss, or because the contaminant was much older.

Precambrian inheritance is clearly indicated by the old $^{207}\text{Pb}/^{206}\text{Pb}$ model age (355.7 $\pm$ 1.8 Ma) and high degree of discordance of fraction B from sample 87-181-2 of the Cold Fish Volcanics (Figure 23). Fraction B contained a significant amount of "old Pb" which was probably Proterozoic in age. This finding demonstrates for the first time that eastern Stikinia was at least partly

underlain by rock of Precambrian age or provenance in Early Jurassic time. It corroborates the recent discovery of Precambrian xenocrystic zircon in the Late Triassic or Early Jurassic (211 $\pm$ 7/-5 Ma) Zippa Mountain syenite complex in the Iskut area of western Stikinia (Bevier and Anderson, 1991; M. L. Bevier, personal communication, 1991).

Conclusions

The interpreted ages of all the analyzed samples are summarized in Figure 27, and Table 6. The isotopic ages of the four samples from the Cold Fish Volcanics cluster around 194 Ma, with a total range in 2-sigma uncertainty extending from 191.2 to 196.3 Ma. This determination is consistent with its Early Pliensbachian biostratigraphic age, and is remarkably close to $^{40}\text{Ar}/^{39}\text{Ar}$ dates obtained by Clark and Williams-Jones (1991) from some of the Toodoggone Formation strata in the Toodoggone River area (192.9 $\pm$ 2.7 Ma; 193.8 $\pm$ 2.6 Ma; and 194.2 $\pm$ 3.6 Ma [errors 2-sigma]). The 2-sigma age of the Spatsizi River Stock overlaps the Cold Fish dates, and is consistent with field and petrologic evidence which indicate that the Spatsizi River Stock was emplaced as a subvolcanic intrusion during deposition of the Cold Fish Volcanics. The Griffith Creek volcanics are older than the Cold Fish succession by about 10 million years (Table 6), which is equivalent to an Hettangian to lower Sinemurian age on the Harland et al. (1990) time scale (Figure 27). The

Figure 27. Summary diagram of interpreted U-Pb ages (with 2-sigma error bars) obtained in this study, in the context of the Harland et al. (1990) geological time scale.

TABLE 6

Interpreted ages, and locations of U-Pb (zircon) samples

Number on map	Unit	Sample #	Rock Type	District	UTM E	UTM N	Age (Ma)	2-sigma uncertainty
A3	Cold Fish Volcanics	87-157-2	Rhyolite sill	Nation	510400	6389600	194.8	+/-1.0
A2		87-159-2	Rhyolite dyke	Nation	509400	6389600	194.0	+2.8/-2.3
A4		86-56-3	Rhy. ignimbrite	Joan	504900	6371700	193.9	+/-1.1
A5		87-181-2	Rhyolite sill	Will	515000	6376300	193.5	+/-2.0
A6	Spatsizi R. Stock	86-111-6	Alkali-feldspar granite	Will	520600	6378100	190.0	+/-7.1
A8	Griffith Creek volcanics	87-219-4	Basaltic andesite lava	Griffith	532300	6370100	205.8	+/-0.9
A7		87-234-3	Dacite sill	Griffith	528100	6372900	203.1	+/-0.4
A1	Railway Pluton	(see note)	Monzodiorite	Brock	461300	6416900	227	+/-9

Note: Railway Pluton data (A1) are from Read and Psutka (1990)

crust underlying the study area contributed a component of Precambrian radiogenic Pb to some of the zircon fractions. Whether the source of this contaminant was crystalline basement of Precambrian age, or a siliciclastic sedimentary or metasedimentary succession derived from erosion of a Precambrian terrane, is unknown. However, none of the pre-Jurassic rocks exposed on Stikinia (Devonian to Triassic; D. A. Brown et al., 1991) have been recognized as sedimentary derivatives of Precambrian rock, and all have juvenile isotopic signatures (Samson et al., 1989). Therefore, if the source of the contaminant were sedimentary rock of Precambrian provenance, its depositional age would probably be Early Paleozoic or Precambrian.

Chapter Six

Conclusions

Ages of the Hazelton Group successions

Volcanic rocks of the Hazelton Group in northern Spatsizi River (104H) map-area comprise three temporally distinct successions: the Griffith Creek volcanics (oldest), the Cold Fish Volcanics, and the Mount Brock volcanics (youngest). The Griffith Creek volcanics, an informally defined succession of very limited exposure, have yielded two U-Pb (zircon) isotopic dates which correlate with Hettangian to Lower Sinemurian biostratigraphic ages (203.1 ± 0.4 Ma; 205.8 ± 0.9 Ma). The Cold Fish Volcanics form a voluminous succession (at least $1\,800\text{ km}^3$) that is regarded as a formal stratigraphic unit. It has yielded four U-Pb (zircon) isotopic dates (193.5 ± 2.0 Ma; 193.9 ± 1.1 Ma; $194.0 \pm 2.8/-2.3$ Ma; and 194.8 ± 1.0 Ma) that confirm its previously established Early Pliensbachian biostratigraphic age. It was intruded by the Spatsizi River Stock, a synvolcanic alkali-feldspar granitic body that yielded a U-Pb (zircon) age of 190 ± 7.1 Ma. The Mount Brock succession is an informal stratigraphic unit which has been dated by Early and Middle Toarcian ammonites.

Stratigraphic relations among the successions

The Griffith Creek succession comprises mafic lava flows and

intermediate to felsic sills and tuff that were conformably to disconformably deposited in a subaerial environment on older conglomeratic strata of Late Triassic and/or Early Jurassic age. It is separated from the Cold Fish Volcanics by a lacuna in which the Griffith Creek and older strata were deformed by folding. The Cold Fish Volcanics were deposited in a mainly subaerial environment as a bimodal succession (>2000 m) of rhyolitic rocks (mainly airfall tuff, welded tuff and sills), and mafic lava flows. The base of the Cold Fish is not exposed, but the top of the volcanic succession is conformably overlain by a thick (>700 m) basinal sedimentary succession, of Early Pliensbachian to Early Bajocian age, which is herein regarded as part of the Hazelton Group. The Mount Brock volcanics were deposited as a thick succession (>4000 m) of mafic to intermediate lava flows, and intermediate to felsic pyroclastic rocks, in a mainly subaerial environment above conformable Lower Toarcian strata of the Hazelton sedimentary succession. Overlying the latter are shale and conglomerate of the Middle Jurassic Bowser Lake Group.

Volcanic evolution of the Cold Fish Volcanics

The Cold Fish Volcanics comprise a silica-bimodal succession that formed as a set of coalescing gently sloping composite volcanoes (or one very large volcano), and a resurgent caldera. The volcanoes accumulated as a succession of *mafic* (mafic and subordinate intermediate) lava flows that were

interbedded with rhyolitic airfall tuff, ignimbrite, and minor beds of lahar, sandstone and limestone. Within the caldera, thick rhyolitic ignimbrites were deposited together with airfall tuff, and minor mafic lava and sandstone. Mafic lava was erupted by fire-fountaining and quiescent outpouring in the manner of Hawaiian volcanoes, whereas the rhyolitic tuffs were deposited from pyroclastic flows and falls related to explosive Plinian to Vulcanian eruptions. Following major explosive events, rhyolitic sills intruded the intracaldera succession and (to a lesser degree) the stratovolcanic sequences, thickening them by tens to hundreds of metres. Subsidence was concurrent with deposition, prohibiting the volcanic field from building to high elevations.

Inferred primary melts that were parental to the mafic magmas were generated by partial fusion of asthenospheric mantle. They differentiated to basalt and basaltic andesite mainly by fractional crystallization of olivine and augite, and to andesite and (rare) dacite by olivine, augite, plagioclase, apatite and magnetite. Other processes such as mixing among mafic magmas, and crustal assimilation are likely to have contributed to differentiation. Rhyolitic magma was produced by crustal anatexis, or by extreme differentiation of the mafic magmas involving crustal assimilation, or (most likely) by a combination of both processes. Beneath the caldera, a large zoned magma chamber developed that underwent periods of volatile accumulation near its roof, leading to episodes of partial evisceration during eruptions of rhyolitic tephra.

Geochemical affinities

All three of the volcanic successions follow a trend from medium and high-K alkalinity in mafic compositions, to high-K and Shoshonitic alkalinity in intermediate and felsic compositions. The Griffith Creek volcanics follow a transitionally tholeiitic to calc-alkaline trend of iron enrichment, whereas the Cold Fish and Mount Brock successions describe an unambiguous tholeiitic trend. The Griffith Creek also differs from the younger successions in its (1) "normal" alumina concentrations (The Cold Fish and Mount Brock have $\text{Al}_2\text{O}_3 > 16.5$ weight% and are categorized as "high alumina" rocks), and (2) lower concentrations of high-field strength elements with reference to those of large-ion lithophile elements. However, patterns of trace element concentrations among all the volcanic formations are remarkably similar to one another, especially in their high alkalinity and low Nb contents. These patterns strongly resemble those of modern, mature volcanic arcs, and some back-arcs, and confirm that the genesis of the Hazelton volcanic successions was related to subduction.

Basement to volcanic successions

Rocks that form the "basement" to the Hazelton Group, that crop out in the study area, consist of Upper Triassic (Stuhini Group) volcanic and sedimentary rocks, and Upper Paleozoic (and (?) Devonian) meta-igneous and

metasedimentary rocks. Although rocks representing middle and lower crustal levels are not exposed, the highly siliceous, fluorine- and tin-rich compositions of the Cold Fish rhyolites suggest that the volcanic successions were built on "mature," largely felsic crust. Precambrian inheritance in the isotopic composition of Pb in some zircons from the Cold Fish Volcanics indicate the presence of Precambrian crystalline rocks, or pre-Upper Paleozoic metasedimentary rocks of Precambrian provenance, in the sub-Hazelton crust.

Regional tectonic framework

The volcanic rocks in the study area belong to the Hazelton Group, a voluminous and widespread assemblage of volcanic arc rocks and related basinal sedimentary rocks that were deposited on the Stikine Terrane (Stikinia) in Early and Middle Jurassic time. The volcanic rocks erupted to form two volcanic chains, one on the eastern side of Stikinia (related to west-dipping subduction), and one on the western side (caused by east-dipping subduction of a second oceanic plate; all directions given in present geographical terms). These chains were separated by the Hazelton Trough, an elongate marine basin that subsided by thousands of metres during the period of volcanism. The subsidence, which was caused primarily by extensional deformation of Stikinia, also affected the volcanic successions in the study area. The Cold Fish Volcanics, and perhaps all of the volcanic successions in the study area, were

deposited in the back-arc region of the eastern volcanic arc in the Toodoggone River area.

Jurassic volcanic activity on Stikinia declined during the latter parts of the Early Jurassic, becoming extinct in the early Middle Jurassic (Bajocian). The reduction in magmatism was accompanied by cooling and thermal subsidence of Stikinia, which led to a regional marine transgression. These trends were coincident with progressive obduction of the Cache Creek Terrane, which started in the late Early Jurassic (Toarcian), and continued until the Middle Jurassic (at least until the Bathonian). The amalgamation of Stikinia with the Cache Creek Terrane was the final consequence of subduction of the Cache Creek oceanic plate beneath eastern Stikinia, and closure of the Cache Creek ocean. Chert-rich conglomeratic deposits derived from erosion of the emergent Cache Creek Terrane were deposited in the region of the Hazelton Trough; the distribution of these and correlative deposits generally defines the extent of what is regarded as the Bowser Basin.

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Appendix 1

Chemical Analyses

Chemical analyses of major and trace elements were obtained for 118 samples (Table A-1, parts (a) and (b)). Of these, 100 were collected by the author in 1986 and 1987 from the Spatsizi River (104H) map area, mainly from the study area. Of the remaining 18, 12 were provided by M.G. Mihalynuk from his Master's thesis area in the eastern Terrace (103I) map-area, and 6 were donated by L.J. Diakow from his Ph.D. thesis area in the Toodoggone River (94E) map area. The sample contributions by Mihalynuk and Diakow, geologists with the British Columbia Geological Survey Branch, are gratefully acknowledged.

Samples were prepared for analysis at the Geological Survey of Canada (GSC) by (1) crushing of fist-size specimens to chips in a metal jaw crusher, and (2) pulverization of rock chips to fine powder in a ceramic grinder ("paint shaker"). Exceptions are the samples donated by Mihalynuk and Diakow which were already in powder form.

Analysis of all elements was carried out at the geochemical laboratories of the GSC in Ottawa, Canada, except for that of Nb, Sc, Th and U. Nb was determined by inductively coupled plasma emission spectrometry (ICP) at X-Ray Assay Laboratories of Don Mills, Canada, and Sc, Th and U were measured by

instrumental neutron activation analysis (INAA) by Bondar Clegg of Ottawa, Canada. The techniques used by the GSC were: wavelength-dispersive X-ray fluorescence spectrometry (XRF) of glass disks to determine all the major oxides plus Ba, Rb, Sr, and Zr; and ICP for Co, Cr, Cu, Ni, V, Zn, La, Ce, Nd, Sm, Eu, Gd, Dy, Y and Yb. Analyses at the GSC were performed in three different batches or analytical "runs." Runs 1, 2 and 3 were made in 1987, 1988 and 1990, respectively.

Three factors concerning the validity of the analyses are (1) contamination by grinding, (2) analytical precision and consistency among analytical runs, and (3) accuracy. The first two points are explored graphically in Figures A-1(a) to A-1(t), based on data in Table A-2; estimates of analytical precision are listed in Table A-3. Accuracy with reference to standard samples is presented in Table A-4.

The possibility of sample contamination by grinding apparatus was discussed by Hickson and Juras (1986). They indicated that grinding in ceramic was likely to contaminate rock samples with a variety of elements. To address this concern, fractions of 14 specimens in the form of rock chips were ground in agate at X-Ray Assay Laboratories (Hickson and Juras identified agate as the grinding material least likely to contaminate). The fractions ground in agate were then submitted for analysis along with fractions of the same samples ground in ceramic. The analyses of both fractions are given in

Table A-2, where agate-ground and ceramic-ground values from the same analytical run (Run 3) are given in the bottom two rows of each chemical component. This information is displayed graphically for major oxides and selected trace elements in Figures A-1(a) to A-1(t).

In Figures A-1(a) to A-1(t), data from three analytical runs are used to evaluate contamination and precision. The abscissa is used for analyses of ceramic-ground samples in Run 3 ("Ceramic, 3"). The ordinate is used for analyses of agate-ground samples from Run 3, as well as for values obtained from the two previous runs of ceramic-ground samples. Open squares are used for data points which represent analyses of ceramic-ground fractions plotted against those of agate-ground fractions of the same run (Run 3). The middle line of the three lines shown on each graph is one of unity, with a slope of 1 and an ordinate intercept of 0. Thus, if the reported concentration of a given component in a ceramic-ground fraction is identical to that reported for its agate-ground counterpart, the data point will lie precisely on the line of unity. Similarly, if the degree of contamination by grinding in ceramic is insignificant, the data points will tend to scatter evenly about the line of unity (the amount of scatter being dependent on the analytical precision). Conversely, if the fractions ground in ceramic were systematically enriched in a given component during the grinding process, the data points will tend to scatter to the right of the line of unity.

Overall, scatter caused by contamination appears to be slight, and indistinguishable from that due to analytical uncertainty. Possible exceptions are suggested by Figures A-1(q), A-1(s) and A-1(t) (La, Gd, Dy), where distribution of the squares is very slightly displaced toward higher "Ceramic, 3" values. However, even in these cases, most of the data points are scattered closely about the line of unity and systematic contamination is not indicated. Importantly, not even Al_2O_3 , a principal constituent in the ceramic material, shows systematically higher contents for the ceramic-ground fraction (Figure A-1(c)). Three samples ground in agate show *higher* levels of Al_2O_3 , perhaps caused by "cross-contamination" among samples during grinding or handling. Contamination of *agate-ground* samples also seems to be indicated by a few scattered points in some of the other major-element diagrams.

Analytical precision, and consistency among the three analytical runs, are also evaluated in Figures A-1(a) to (t). On each graph, the pair of lines which bound the line of unity represent an envelope of analytical precision at about the 2 standard error (95% confidence) level. The envelope, for most components, encloses most or all of the data points (crosses and plus-signs represent data from Run 3 plotted against those of Runs 1 and 2, respectively). The envelopes are described by the values of absolute and relative uncertainty listed in Table A-3, parameters which have been visually established by trial and error computer iterations. In most cases, the levels of either or both of the

parameters have been increased from the values suggested by the GSC, and in no case have they been decreased. Because the envelopes enclose data from three different runs, they are a measure of not only "machine drift" and other errors inherent in a single set of analyses, but also of changes in calibration and analytical technique from year to year.

The concentrations of four elements, Zr, Co, V and Cr, were found to be systematically higher in Run 2 than in Runs 1 and 3 (V: Figure A-1(o); Zr: Figure A-1(s)). The difference was particularly striking for Zr, whose concentrations from Run 2 were almost double those from the other runs. In order to compensate for this systematic variability, the concentrations of Zr, Co, V and Cr, for analyses of Run 2, were reduced by 45%, 13%, 13% and 10% respectively. Using the reduced values, the data points scattered nearly evenly about the lines of unity, within the envelopes of uncertainty (Figures A-1(p) and A-1(t)).

Samples of five internationally recognized geochemical standards were run along with the other samples, and the results are given in Table A-4. The first row of each component gives the concentration measured in the analysis. The second row lists the "expected" value ("certified" or preliminary standard value) as given in Abbey (1983). The third row is the difference (measured-expected), and the fourth is the 2 standard error uncertainty in the measured value. In most cases, the difference was less than the precision. The elements

which seem to have been analyzed least accurately are the transition metals Co, Cr, Cu, Ni, V, Zn and Sc whose measured values are generally lower than expected by 5-15%.

TABLE A-1

Chemical Analyses, Normative Mineralogy and Phenocryst Contents

Part (a) of this table lists major elements abundances, normative mineralogy, and phenocryst contents. Part (b) lists trace element concentrations.

Both parts of the table are headed by information about the rock samples and their sources. The samples are listed by formation with older rock units appearing toward the back of the table. All samples were collected in the Spatsizi River (104H) map area by the author in 1986 and 1987, except those from the two formations listed last (**Toodog** and **Stu/Haz**; see below). Within each formation samples are ordered by decreasing MgO contents.

Formation names have been abbreviated as follows:

MPv = Miocene to Pliocene volcanic necks and dykes;

McEwan = McEwan Creek Pluton;

M Brock = Mount Brock volcanics of the Hazelton Group;

Spats R = Spatsizi River Stock;

Cold F = Cold Fish Volcanics of the Hazelton Group;

Grif Ck = Griffith Creek volcanics of the Hazelton Group;

Hazel? = Probably Hazelton Group, possibly correlative with the Griffith Creek, Cold Fish or Mount Brock volcanics;

Stu? = Probably Stuhini Group;

Stuhini = Stuhini or "Tsaybahe" group;

Toodog = Toodoggone Formation of the Hazelton Group. Collected from the Toodoggone River (94E) map area and kindly donated by L.J. Diakow;

Stu/Haz = Telkwa formation of the Hazelton Group and/or Stuhini Group.

Collected from the eastern Terrace (103I) map area and kindly donated by M.G. Mihalynuk.

Unit Type refers to the type of geological unit sampled. **Nod** = peridotite nodule in basalt; **Gran** = granitic intrusion; **MD** = mafic or intermediate dyke; **MF** = mafic or intermediate lava flow; **RD** = rhyolitic dyke; **RS** = rhyolitic sill; **RwT** = rhyolitic welded tuff; **DwT** = dacitic welded tuff.

TABLE A-1, continued

Simple **Rock Names** have been given to the samples, based mainly on silica content or normative mineralogy, according to the Basaltic Volcanism Study Project (1981, p. 193), and Steckensen (1976). **Harzb** = Cr-spinel harzburgite; **Q syen** = quartz syenite; **Afs G** = alkali feldspar granite; **neph** = nephelinite; **bas** = basalt; **B and** = basaltic andesite; **dac** = dacite; **rhy** = rhyolite.

If the sample were collected from within the study area, the informal **District** name within the study area is indicated.

Concentrations of major elements, in weight percent, have been recalculated from the reported values to 100%, on a volatile-free basis. Concentrations, in weight percent, of CO_2 and H_2O are those reported in the original analyses. **Sum** refers to the total of major oxides, plus CO_2 and H_2O in the original analyses. Cation normative mineralogy (**ap** to **ne**) and petrologic indices were calculated by computer program Norm*Stoner (Thorkelson, 1990) according to the procedure given in Morse (1980). **An%** is the molecular percentage of anorthite in normative plagioclase. **Fo, En, Di%** is the molecular percentage of MgO in $\text{MgO} + \text{FeO}$ of normative olivine, hypersthene and diopside.

Commonly used petrological indices are also listed. **Mg#** is the magnesium number, calculated as $100(\text{Mg}^{2+} / [\text{Mg}^{2+} + \text{Fe}^{2+}])_{\text{atomic}}$ based on $0.3 = (\text{Fe}_2\text{O}_3 / \text{FeO})_{\text{weight}}$ (Gill, 1981). **Class** lists the alumina-alkali category, based on the **A/CNK** and **A/NK** ratios, where **A** = Al_2O_3 , **C** = CaO , **N** = Na_2O , and **K** = K_2O , all in molecular proportions; **P Al** and **M Al** indicate the categories *peraluminous* and *metaluminous*, respectively (Shand, 1927). **K or Na** indicates *potassic* or *sodic* alkalinity; sodic alkalinity was distinguished from potassic alkalinity if, in weight%, $\text{Na}_2\text{O} > (\text{K}_2\text{O} + 2)$ (Le Bas, 1986).

Phenocryst contents, in volume%, were estimated visually during thin section petrography. **TOTAL%Phenos** refers to the total percentage of phenocrysts (and ?xenocrysts). **Kfs** is potassic feldspar. Trace amounts are indicated by **tr**. *Only those samples that have a value entered in the Total%Phenos row have been petrographically analyzed.*

In part (b), concentrations of trace elements are given in parts per million, by weight.

Concentrations of Zr, Co, V and Cr were reduced from the values originally reported in Run 2 by 45, 13, 13 and 10 percent respectively (see text for explanation).

TABLE A-1, continued, part (a)

SAMPLE:		87-224-3	86-112-2	87-224-2	87-69-7	87-56-4	87-40-3	87-39-3
Analytical Run		2	1	2	2	2	2	2
FORMATION		MPv	MPv	MPv	McEwan	M Brock	M Brock	M Brock
Unit Type		Nod	MD	MD	Gran	MF	MD	MF
Rock Name		harzb	bas	neph	Q syen	bas	B and	B and
District		Griffith	Will	Griffith	Brock	Brock	Brock	Brock
UTM E		532500	520400	532500	466900	466300	491900	471600
UTM N		6368800	6378400	6368800	6410400	6413300	6410400	6410000
Major Oxides in weight% by XRF re- calculated to 100% on volatile- free basis	SiO ₂	45.2	45.8	44.7	67.5	51.1	53.6	54.6
	TiO ₂	0.05	0.56	2.30	0.68	1.49	1.12	1.08
	Al ₂ O ₃	1.6	11.5	14.3	15.9	17.5	18.4	18.3
	FeO*	8.7	10.7	13.3	3.8	10.1	9.6	9.5
	MnO	0.14	0.19	0.24	0.05	0.20	0.30	0.16
	MgO	43.5	22.8	9.0	1.3	5.4	5.3	3.4
	CaO	0.7	6.9	9.0	2.1	9.3	3.6	8.1
	Na ₂ O	0.0	1.2	4.4	8.3	3.2	5.0	3.3
	K ₂ O	0.0	0.3	1.9	0.1	1.2	2.8	1.3
	P ₂ O ₅	0.01	0.09	0.83	0.22	0.50	0.32	0.26
original values reported	H ₂ O	0.1	4.1	0.6	0.6	2.4	3.8	1.9
	CO ₂	0.0	0.1	0.1	0.5	0.1	1.0	1.3
	SUM	100.3	100.9	101.7	99.9	99.9	101.2	99.8
Mg#		90.9	81.0	57.4	40.9	51.6	52.2	41.9
Cation Norms in %	ap	0.0	0.2	1.7	0.5	1.0	0.6	0.6
	il	0.1	0.7	3.2	0.9	2.1	1.5	1.5
	or	0.0	1.7	11.1	0.5	6.9	16.2	7.6
	ab	0.0	9.9	11.2	73.1	29.0	44.6	29.4
	an	3.0	24.3	13.4	5.4	29.9	15.4	32.0
	c	0.4	0.0	0.0	0.0	0.0	1.4	0.0
	mt	1.9	2.5	3.3	0.9	2.5	2.3	2.4
	di	0.0	6.2	20.3	2.5	10.6	0.0	5.3
	hy	29.3	15.8	0.0	5.5	15.9	1.5	15.8
	ol	65.2	38.6	19.1	0.0	2.0	16.3	0.0
	q	0.0	0.0	0.0	10.7	0.0	0.0	5.5
	ne	0.0	0.0	16.9	0.0	0.0	0.0	0.0
An%		100.0	71.0	25.4	6.9	50.7	25.6	52.1
Fo, En, Di%		92.8	85.4	68.8	53.6	62.6	61.6	51.8
Class		P Al	M Al	M Al	M Al	M Al	P Al	M Al
A/CNK		1.3	0.8	0.6	0.9	0.7	1.0	0.9
A/NK			5.2	1.5	1.1	2.7	1.6	2.7
K or Na			K	Na	Na	Na	Na	K
TOTAL%Phenos						8		20
%Plagioclase						4		14
%Augite						1		3
%Olivine						3		3
%Opaques								
%Hornblende								
%Biotite								
%Perthite/Kfs								
%Quartz								

TABLE A-1, continued, part (a)

SAMPLE:		87-42-3	87-34-2	87-30-2	87-47-2	87-50-2	87-57-1	87-38-4
Analytical Run		2	2	2	2	2	2	2
FORMATION		M Brock	M Brock	M Brock	M Brock	M Brock	M Brock	M Brock
Unit Type		MF	MF	MF	MF	MF	MF	MF
Rock Name		and	B and	and	and	and	and	dac
District		Brock	Brock	Brock	Brock	Brock	Brock	Brock
UTM E		472400	474500	479700	472300	473100	466300	471300
UTM N		6410400	6410400	6407200	6411600	6412900	6412800	6409700
Major Oxides in weight% by XRF re- calculated to 100% on volatile- free basis	SiO ₂	60.3	56.3	57.6	60.3	60.0	62.8	63.7
	TiO ₂	0.90	1.03	1.02	0.91	1.10	0.95	0.85
	Al ₂ O ₃	16.7	18.0	16.8	16.9	16.7	17.3	16.4
	FeO*	6.6	8.3	8.5	6.7	7.2	5.6	4.6
	MnO	0.17	0.16	0.14	0.24	0.13	0.17	0.14
	MgO	3.4	3.1	3.0	2.8	2.0	1.7	1.5
	CaO	4.9	6.8	6.4	6.1	5.0	2.1	3.1
	Na ₂ O	4.0	3.9	3.8	3.3	4.3	5.8	5.2
	K ₂ O	2.7	2.0	2.4	2.5	3.0	3.1	4.2
	P ₂ O ₅	0.22	0.29	0.34	0.31	0.45	0.38	0.29
original values reported	H ₂ O	2.1	1.7	1.4	1.9	1.9	1.7	1.5
	CO ₂	0.9	0.2	0.2	1.3	0.3	1.0	1.9
	SUM	100.6	100.2	100.4	100.6	100.2	99.9	99.4
Mg#		50.8	42.7	41.6	45.1	35.8	38.2	38.8
Cation Norms in %	ap	0.5	0.6	0.7	0.7	1.0	0.8	0.6
	il	1.2	1.4	1.4	1.3	1.5	1.3	1.2
	or	16.0	12.1	14.1	14.8	17.9	18.3	24.6
	ab	36.1	35.2	34.2	30.0	38.9	51.6	46.7
	an	19.5	25.6	21.9	24.0	17.2	7.9	8.6
	c	0.0	0.0	0.0	0.0	0.0	1.6	0.0
	mt	1.6	2.1	2.1	1.7	1.8	1.4	1.1
	di	2.6	4.9	6.4	3.5	3.7	0.0	3.8
	hy	14.1	13.8	13.0	12.2	10.0	9.5	6.0
	oi	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fo, En, Di% Class	q	8.4	4.3	6.1	11.9	7.9	7.6	7.4
	ne	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	An%	35.1	42.1	39.0	44.5	30.6	13.3	15.6
	M Al	61.2	53.1	51.9	55.3	46.9	49.7	50.9
	M Al	0.9	0.9	0.8	0.9	0.9	1.0	0.9
A/CNK A/NK K or Na	1.8	2.1	1.9	2.1	1.6	1.3	1.2	1.2
	K	K	K	K	K	Na	K	K
	K	K	K	K	K	Na	K	K
TOTAL%Phenos		15	20		5			
%Plagioclase		11	16		3			
%Augite		2	3		1			
%Olivine		2			1			
%Opaques			1					
%Hornblende								
%Biotite								
%Perthite/Kfs								
%Quartz								

TABLE A-1, continued, part (a)

SAMPLE:		87-48-3	87-55-2	87-41-3	87-45-2	86-111-5	86-33-2	86-44-5
Analytical Run		2	2	2	2	1	1	1
FORMATION		M Brock	M Brock	M Brock	M Brock	Spats R	Cold F	Cold F
Unit Type		MF	DF	MF	MF	Gran	MF	MD
Rock Name		dac	dac	dac	dac	Afs G	bas	bas
District		Brock	Brock	Brock	Brock	Will	Nation	Nation
UTM E		472500	466900	472500	472000	520500	506800	509500
UTM N		6411800	6413200	6410500	6410800	6378100	6392700	6390000
Major Oxides in weight% by XRF re- calculated to 100% on volatile- free basis	SiO ₂	65.5	67.2	66.1	66.8	73.8	49.5	49.8
	TiO ₂	0.57	0.78	0.67	0.68	0.24	1.16	0.98
	Al ₂ O ₃	15.4	15.7	16.0	15.4	13.8	17.0	16.3
	FeO*	4.7	3.9	4.4	4.4	1.6	9.7	8.3
	MnO	0.14	0.11	0.19	0.03	0.15	0.22	0.31
	MgO	1.3	0.9	0.4	0.2	0.2	8.2	7.6
	CaO	3.4	1.4	3.4	0.4	0.6	10.3	12.5
	Na ₂ O	5.0	5.3	3.7	2.3	4.0	2.6	1.6
	K ₂ O	3.8	4.3	4.9	9.7	5.5	1.1	2.4
original values reported	P ₂ O ₅	0.19	0.20	0.25	0.24	0.02	0.30	0.27
	H ₂ O	1.2	0.9	1.4	0.4	0.6	3.4	3.9
	CO ₂	1.8	0.6	2.3	0.0	0.2	0.1	4.5
SUM		100.0	100.1	100.6	100.5	100.1	98.7	100.4
Mg#		35.8	32.2	15.2	8.1	15.6	62.8	64.5
Cation Norms in %	ap	0.4	0.4	0.5	0.5	0.0	0.6	0.6
	il	0.8	1.1	0.9	0.9	0.3	1.6	1.3
	or	22.3	25.3	29.0	57.6	32.8	6.7	14.1
	ab	44.7	47.3	33.9	21.0	36.4	22.8	14.8
	an	8.4	5.8	12.6	0.2	2.9	31.5	29.9
	c	0.0	0.2	0.0	1.2	0.1	0.0	0.0
	mt	1.2	1.0	1.1	1.1	0.4	2.4	2.1
	di	5.8	0.0	2.2	0.0	0.0	13.9	24.2
	hy	5.0	5.8	4.0	4.3	2.0	9.0	2.1
	ol	0.0	0.0	0.0	0.0	0.0	11.6	11.0
	q	11.5	13.1	15.7	13.1	24.9	0.0	0.0
	ne	0.0	0.0	0.0	0.0	0.0	0.0	0.0
An% Fo, En, Di% Class A/CNK A/NK K or Na		15.8	10.9	27.1	0.8	7.3	58.0	66.9
		45.4	44.3	21.4	12.5	20.5	71.7	72.6
		M Al	M Al	M Al	P Al	P Al	M Al	M Al
		0.8	1.0	0.9	1.0	1.0	0.7	0.6
		1.3	1.2	1.4	1.1	1.1	3.1	3.1
TOTAL%Phenos					20		15	20
%Plagioclase					15		6	12
%Augite							2	8
%Olivine							7	
%Opaques								
%Hornblende					5			
%Biotite								
%Perthite/Kfs								
%Quartz								

TABLE A-1, continued, part (a)

SAMPLE:		86-78-4	86-23-5	86-72-3	86-5-2	87-139-2	87-156-2	86-67-2
Analytical Run		1	1	1	1	2	2	1
FORMATION		Cold F	Cold F	Cold F	Cold F	Cold F	Cold F	Cold F
Unit Type		MF	MF	MF	MF	MF	MF	MF
Rock Name		bas	bas	bas	bas	bas	bas	bas
District		Nation	Nation	Nation	Nation	Ice Box	Ice Box	Nation
UTM E		510000	509400	504600	509200	501600	499600	504900
UTM N		6387200	6391200	6390300	6391600	6393200	6394100	6389600
Major Oxides in weight% by XRF re- calculated to 100% on volatile- free basis	SiO ₂	49.4	47.4	52.3	49.8	51.4	49.2	51.7
	TiO ₂	1.14	0.85	1.01	1.13	1.07	1.21	1.13
	Al ₂ O ₃	17.6	19.0	17.7	19.0	16.7	17.7	16.7
	FeO*	10.3	10.7	6.9	10.1	9.6	11.5	9.8
	MnO	0.30	0.21	0.23	0.27	0.21	0.21	0.21
	MgO	7.4	6.7	6.7	6.2	6.1	5.7	5.7
	CaO	9.1	10.7	10.8	8.4	10.6	10.9	10.2
	Na ₂ O	2.8	2.7	2.7	4.2	2.7	2.4	3.0
	K ₂ O	1.5	1.3	1.4	0.5	1.3	0.9	1.4
original values reported	P ₂ O ₅	0.45	0.26	0.29	0.31	0.27	0.27	0.29
	H ₂ O	2.7	3.5	1.9	2.9	1.7	2.2	1.8
	CO ₂	0.2	1.7	0.2	0.2	0.0	0.1	0.0
	SUM	100.7	99.9	100.4	100.1	99.6	99.3	100.7
Mg#		58.8	55.7	65.8	55.1	56.0	50.0	53.9
Cation Norms in %	ap	0.9	0.5	0.6	0.6	0.6	0.6	0.6
	il	1.6	1.3	1.4	1.6	1.5	1.7	1.6
	or	8.9	7.9	8.3	3.0	7.6	5.4	8.0
	ab	25.0	20.0	23.8	37.1	24.2	21.8	26.7
	an	30.9	35.9	31.8	31.2	29.9	35.0	28.3
	c	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	mt	2.5	2.6	1.7	2.5	2.4	2.9	2.4
	di	8.9	12.5	15.5	6.5	17.0	14.4	16.6
	hy	8.1	0.0	16.5	0.5	15.4	14.3	13.6
	ol	13.2	18.9	0.2	17.1	1.4	4.0	2.3
	q	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ne	0.0	2.4	0.0	0.0	0.0	0.0	0.0
Fo, En, Di% Class A/CNK A/NK K or Na	An%	55.3	60.0	57.2	45.7	55.3	61.7	51.4
	Fo, En, Di%	67.6	64.4	74.7	64.3	65.4	59.6	63.6
	Class	M Al	M Al	M Al	M Al	M Al	M Al	M Al
	A/CNK	0.8	0.7	0.7	0.8	0.7	0.7	0.7
	A/NK	2.8	3.2	3.0	2.6	2.9	3.6	2.6
	K or Na	K	K	K	Na	K	K	K
TOTAL%Phenos		10	70	15	5	10	90	4
%Plagioclase		3	60	7	1	7	50	1
%Augite			3	4	1	1	18	2
%Olivine		7	7	4	3	2	18	1
%Opaques							4	
%Hornblende								
%Biotite								
%Perthite/Kfs								
%Quartz								

TABLE A-1, continued, part (a)

SAMPLE:		86-18-4	86-35-2	86-2-2	86-38-5	86-57-3	86-109-3	87-97-3
Analytical Run		1	1	1	1	1	1	2
FORMATION		Cold F	Cold F	Cold F	Cold F	Cold F	Cold F	Cold F
Unit Type		MF	MF	MF	MD	MF	MF	MF
Rock Name		bas	bas	bas	bas	bas	bas	B and
District		Nation	Nation	Nation	Nation	Joan	Plateau	Ice Box
UTM E		508200	506000	509300	505000	506700	510500	490400
UTM N		6391100	6391100	6391200	6390600	6371300	6382400	6395500
Major Oxides	SiO ₂	50.6	50.4	52.7	52.3	50.8	51.0	54.9
in weight%	TiO ₂	1.00	0.99	1.10	1.08	1.36	1.38	0.88
by XRF	Al ₂ O ₃	19.1	20.9	19.0	20.7	17.6	18.2	16.9
re-	FeO*	9.3	7.6	9.1	7.1	10.9	9.0	8.3
calculated	MnO	0.20	0.26	0.17	0.41	0.21	0.28	0.15
to 100% on	MgO	5.4	5.3	5.3	5.0	5.0	4.9	4.9
volatile-	CaO	8.3	8.7	7.4	8.0	7.2	9.4	9.1
free basis	Na ₂ O	4.2	4.5	4.0	4.0	4.8	3.3	3.1
	K ₂ O	1.5	1.0	1.1	1.1	1.6	2.0	1.5
	P ₂ O ₅	0.27	0.27	0.29	0.30	0.39	0.36	0.25
original values	H ₂ O	4.4	3.2	2.5	3.7	2.7	1.7	1.3
reported	CO ₂	0.1	2.5	0.1	2.5	0.2	0.1	0.2
	SUM	100.4	99.8	100.0	100.2	100.1	99.6	100.1
Mg#		53.6	58.3	53.7	58.7	47.9	52.2	54.2
Cation Norms in %	ap	0.6	0.6	0.6	0.6	0.8	0.8	0.5
	il	1.4	1.4	1.5	1.5	1.9	1.9	1.2
	or	8.9	5.8	6.3	6.5	9.6	12.0	8.7
	ab	33.0	33.8	35.5	35.4	36.0	29.7	27.7
	an	28.4	33.3	30.5	34.8	21.5	28.8	28.1
	c	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	mt	2.3	1.9	2.2	1.7	2.7	2.2	2.1
	di	8.3	5.8	3.1	2.0	9.2	12.3	12.5
	hy	0.0	0.0	17.4	12.1	0.0	2.4	15.2
	ol	14.5	13.9	2.8	5.5	14.3	9.8	0.0
Fo, En, Di% Class	q	0.0	0.0	0.0	0.0	0.0	0.0	4.1
	ne	2.7	3.6	0.0	0.0	4.1	0.0	0.0
	An%	43.1	45.6	46.2	49.6	33.5	49.2	50.4
	M Al	63.0	67.6	63.7	67.9	58.3	62.9	63.6
	A/CNK	0.8	0.9	0.9	0.9	0.8	0.7	0.7
K or Na	A/NK	2.2	2.5	2.5	2.7	1.8	2.4	2.5
	Na	Na	Na	Na	Na	Na	K	K
TOTAL%Phenos		50	15	15	20	5	15	10
%Plagioclase		40	12	10	18	2	11	6
%Augite		4		2	2	1	2	2
%Olivine		6	3	3		2	2	2
%Opaques							tr	
%Hornblende								
%Biotite								
%Perthite/Kfs								
%Quartz								

TABLE A-1, continued, part (a)

SAMPLE:		86-14-4	86-19-4	86-8-5	86-40-8	86-105-2	87-97-5	87-203-3
Analytical Run		1	1	1	1	1	2	2
FORMATION		Cold F	Cold F	Cold F	Cold F	Cold F	Cold F	Cold F
Unit Type		MF	MF	MF	MF	MF	MF	MF
Rock Name		bas	bas	bas	B and	B and	B and	B and
District		Nation	Nation	Nation	Nation	Plateau	Ice Box	Cartmel
UTM E		508300	508000	509400	506700	508800	490400	482700
UTM N		6392100	6391100	6391500	6391600	6382300	6395300	6499300
Major Oxides in weight% by XRF re- calculated to 100% on volatile- free basis	SiO ₂	49.1	51.3	51.8	53.2	55.6	53.2	54.8
	TiO ₂	1.16	0.93	1.09	1.18	0.76	1.23	1.14
	Al ₂ O ₃	17.9	19.4	18.9	17.2	15.9	17.1	17.3
	FeO*	11.7	8.5	7.6	8.6	7.1	9.7	8.8
	MnO	0.19	0.14	0.15	0.16	0.17	0.16	0.22
	MgO	4.7	4.6	4.4	4.4	4.4	4.2	4.2
	CaO	8.6	8.8	11.6	10.1	7.7	9.1	6.5
	Na ₂ O	3.4	4.2	3.0	3.2	6.2	3.2	4.2
	K ₂ O	2.9	1.9	1.0	1.5	2.0	1.8	2.5
	P ₂ O ₅	0.29	0.24	0.29	0.30	0.23	0.31	0.44
original values reported	H ₂ O	3.0	3.3	2.5	1.7	1.1	1.3	3.0
	CO ₂	2.0	0.3	1.5	0.7	0.0	0.1	1.1
	SUM	99.5	99.5	100.4	99.7	100.1	100.2	100.8
Mg#		44.6	51.5	53.7	50.8	54.9	46.3	48.7
Cation Norms in %	ap	0.6	0.5	0.6	0.6	0.5	0.6	0.9
	il	1.6	1.3	1.5	1.7	1.0	1.7	1.6
	or	17.3	11.3	6.2	8.9	11.6	10.8	14.9
	ab	20.5	30.9	27.3	29.0	40.3	28.7	37.5
	an	24.9	28.0	34.8	28.2	9.1	27.3	20.8
	c	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	mt	2.9	2.1	1.9	2.1	1.7	2.4	2.2
	di	12.6	10.8	16.7	16.2	21.3	13.1	6.8
	hy	0.0	0.0	10.7	11.9	0.0	13.9	13.7
	ol	13.3	11.2	0.0	0.0	5.8	0.0	1.8
	q	0.0	0.0	0.3	1.3	0.0	1.5	0.0
	ne	6.2	3.9	0.0	0.0	8.7	0.0	0.0
An%		44.6	42.8	56.0	49.3	14.2	48.7	35.7
Fo, En, Di%		54.1	61.3	64.4	61.5	64.1	56.9	59.0
Class		M Al	M Al	M Al	M Al	M Al	M Al	M Al
A/CNK		0.7	0.8	0.7	0.7	0.6	0.7	0.8
A/NK		2.0	2.1	3.1	2.5	1.3	2.4	1.8
K or Na		K	Na	K	K	Na	K	K
TOTAL%Phenos		5	20	30	5	5	15	3
%Plagioclase		1	17	22		3	11	2
%Augite		1		3	5	2	2	1
%Olivine		3	3	5			2	
%Opaques							tr	
%Hornblende								
%Biotite								
%Perthite/Kfs								
%Quartz								

TABLE A-1, continued, part (a)

SAMPLE:		86-7-2	87-111-4	86-M12-3	86-18-2	86-40-2	86-40-4	87-188-3
Analytical Run		1	2	1	1	1	1	2
FORMATION		Cold F	Cold F	Cold F	Cold F	Cold F	Cold F	Cold F
Unit Type		MF	MF	MD	MF	MF	MF	MD
Rock Name		bas	and	bas	B and	bas	B and	B and
District		Nation	Ice Box	Nation	Nation	Nation	Nation	Will
UTM E		509300	494900	507000	508100	506600	506600	520700
UTM N		6391600	6394200	6389800	6391200	6391800	6391700	6382800
Major Oxides in weight% by XRF re- calculated to 100% on volatile- free basis	SiO ₂	50.4	59.8	52.8	54.2	52.9	54.8	55.8
	TiO ₂	1.20	1.06	1.75	1.75	1.33	1.42	1.40
	Al ₂ O ₃	20.1	16.9	17.3	16.7	17.3	17.8	16.4
	FeO*	9.6	6.4	10.3	10.5	10.5	8.8	10.0
	MnO	0.34	0.20	0.45	0.26	0.16	0.16	0.21
	MgO	4.2	3.9	3.9	3.6	3.5	3.3	3.3
	CaO	9.5	4.9	7.6	4.8	8.4	7.9	5.2
	Na ₂ O	3.3	3.8	3.6	5.9	3.6	3.4	3.0
	K ₂ O	1.1	2.7	1.9	1.8	1.9	2.0	3.8
	P ₂ O ₅	0.30	0.26	0.53	0.52	0.34	0.37	0.84
original values reported	H ₂ O	2.4	2.4	2.7	2.4	2.0	2.4	3.3
	CO ₂	0.1	1.5	2.2	0.4	0.8	2.5	2.9
	SUM	100.7	99.2	100.1	100.6	100.1	99.7	100.5
Mg#		46.5	55.1	42.9	40.6	40.1	42.9	39.8
Cation Norms in %	ap	0.6	0.6	1.1	1.1	0.7	0.8	1.8
	il	1.7	1.5	2.5	2.4	1.9	2.0	2.0
	or	6.5	15.7	11.3	10.3	11.2	11.9	22.7
	ab	29.7	34.2	32.8	52.2	33.0	30.9	27.3
	an	36.9	21.2	25.4	13.7	25.4	27.6	20.4
	c	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	mt	2.4	1.6	2.6	2.6	2.6	2.2	2.5
	di	6.8	1.0	7.1	5.4	11.5	7.4	0.2
	hy	10.6	15.9	16.4	0.0	13.6	13.2	18.1
	ol	4.9	0.0	0.0	12.0	0.0	0.0	0.0
	q	0.0	8.5	1.0	0.0	0.1	4.1	5.0
	ne	0.0	0.0	0.0	0.2	0.0	0.0	0.0
An%		55.4	38.3	43.7	20.6	43.5	47.2	42.7
Fo, En, Di%		56.2	66.0	53.9	52.4	50.7	54.8	50.6
Class		M Al	M Al	M Al	M Al	M Al	M Al	M Al
A/CNK		0.8	0.9	0.8	0.8	0.7	0.8	0.9
A/NK		3.0	1.9	2.2	1.4	2.2	2.3	1.8
K or Na		Na	K	K	Na	K	K	K
TOTAL%Phenos		40	15	3	3	5	5	2
%Plagioclase		34	11	3	2	4	3	2
%Augite		1			1	1	1	
%Olivine		5	4				1	
%Opaques								tr
%Hornblende								
%Biotite								
%Perthite/Kfs								
%Quartz								

TABLE A-1, continued, part (a)

SAMPLE:		86-130-2	86-23-3	86-31-4	86-67-5	86-M5-2	86-11-3	86-40-6
Analytical Run		1	1	1	1	1	1	1
FORMATION		Cold F	Cold F	Cold F	Cold F	Cold F	Cold F	Cold F
Unit Type		MF	MF	MF	MF	MF	MF	MF
Rock Name		and	B and	bas	B and	B and	and	and
District		Nation	Nation	Nation	Nation	Joan	Nation	Nation
UTM E		504900	509400	507200	504800	505200	508200	506500
UTM N		6388700	6390900	6393600	6389700	6371300	6391300	6391600
Major Oxides in weight% by XRF re- calculated to 100% on volatile- free basis	SiO ₂	59.2	56.9	51.5	54.8	55.7	57.5	58.8
	TiO ₂	1.08	1.02	1.10	1.52	1.06	0.97	1.30
	Al ₂ O ₃	15.9	17.6	20.3	17.6	18.2	17.9	15.9
	FeO*	7.8	7.9	8.4	8.6	7.9	7.3	9.1
	MnO	0.16	0.21	0.10	0.17	0.34	0.17	0.15
	MgO	3.2	3.0	3.0	3.0	2.9	2.8	2.7
	CaO	5.3	4.9	9.7	7.7	4.3	4.0	4.6
	Na ₂ O	3.2	6.8	3.7	3.9	6.3	6.5	3.7
	K ₂ O	3.9	1.3	2.0	2.3	2.9	2.5	3.5
	P ₂ O ₅	0.30	0.29	0.32	0.47	0.36	0.29	0.38
original values reported	H ₂ O	2.0	1.9	1.4	1.6	2.3	2.0	1.9
	CO ₂	0.0	0.4	0.6	0.1	2.4	0.6	1.0
	SUM	100.3	99.9	100.1	100.6	100.5	100.8	100.4
Mg#		44.8	42.8	41.5	40.6	42.7	43.5	36.9
Cation Norms in %	ap	0.6	0.6	0.7	1.0	0.7	0.7	0.8
	il	1.5	1.4	1.5	2.1	1.4	1.4	1.8
	or	23.4	7.7	11.7	13.7	16.7	16.7	20.7
	ab	28.8	58.1	32.5	35.0	47.0	47.0	33.9
	an	17.7	13.2	32.9	23.8	12.4	12.4	16.5
	c	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	mt	1.9	1.9	2.1	2.1	1.9	1.9	2.3
	di	5.4	7.1	10.3	9.2	5.1	5.1	3.1
	hy	13.1	0.0	0.0	10.9	0.0	0.0	13.9
	ol	0.0	8.7	7.8	0.0	9.5	9.5	0.0
	q	7.6	0.0	0.0	2.1	0.0	0.0	7.1
	ne	0.0	1.3	0.5	0.0	5.3	5.3	0.0
An%		38.0	17.9	49.7	40.5	18.1	18.1	32.7
Fo, En, Di%		55.6	53.0	52.4	52.9	52.4	52.4	47.9
Class		M Al	M Al	M Al	M Al	M Al	M Al	M Al
A/CNK		0.8	0.8	0.8	0.8	0.8	0.8	0.9
A/NK		1.7	1.4	2.5	2.0	1.3	1.3	1.6
K or Na		K	Na	K	K	Na	Na	K
TOTAL%Phenos		5	20	53	15		30	15
%Plagioclase		2	14	50	13		22	10
%Augite		3	4	1	1		5	2
%Olivine			2	2	1		1	3
%Opaques		tr					2	
%Hornblende								
%Biotite								
%Perthite/Kfs								
%Quartz								

TABLE A-1, continued, part (a)

SAMPLE:		87-194-2	87-177-7	86-111-3	86-27-8	86-95-4	87-116-2	86-74-4
Analytical Run		2	2	1	1	1	2	1
FORMATION		Cold F	Cold F	Cold F	Cold F	Cold F	Cold F	Cold F
Unit Type		MF	MF	MD	MF	RD	MF	MF
Rock Name		and	and	dac	and	rhy	dac	dac
District		Will	Will	Will	Nation	Nation	Ice Box	Nation
UTM E		517400	512900	520900	508000	510800	495200	504900
UTM N		6383100	6379600	6378100	6390000	6387500	6396100	6392300
Major Oxides in weight% by XRF re- calculated to 100% on volatile- free basis	SiO ₂	59.2	57.1	63.4	61.0	75.9	64.7	65.2
	TiO ₂	1.10	1.65	0.84	0.82	0.24	0.87	0.68
	Al ₂ O ₃	16.8	16.7	16.3	17.0	12.6	16.6	17.4
	FeO*	7.4	8.1	4.9	6.7	2.2	4.8	4.4
	MnO	0.18	0.20	0.14	0.14	0.03	0.11	0.07
	MgO	2.7	2.6	1.7	1.7	1.0	1.0	0.8
	CaO	4.0	5.6	1.7	3.1	0.2	3.2	0.9
	Na ₂ O	4.1	4.1	5.6	5.2	1.4	4.7	5.6
	K ₂ O	4.1	3.3	5.2	4.1	6.3	3.7	4.9
	P ₂ O ₅	0.46	0.73	0.28	0.30	0.06	0.31	0.16
original values reported	H ₂ O	1.8	1.3	1.6	1.5	1.3	1.2	1.3
	CO ₂	1.0	0.1	1.0	0.4	0.1	0.3	0.4
	SUM	100.5	100.3	99.8	100.7	100.5	99.8	100.9
Mg#		41.8	39.0	41.0	33.2	47.8	28.8	26.5
Cation Norms in %	ap	1.0	1.5	0.6	0.6	0.1	0.6	0.3
	il	1.5	2.3	1.2	1.1	0.3	1.2	0.9
	or	24.2	19.6	30.0	23.8	38.4	21.8	28.4
	ab	37.2	36.9	49.2	46.5	13.1	42.4	49.6
	an	15.1	17.4	4.4	10.9	0.5	13.2	3.4
	c	0.0	0.0	0.0	0.0	3.6	0.0	1.8
	mt	1.8	2.0	1.2	1.6	0.6	1.2	1.1
	di	1.4	4.4	1.5	2.1	0.0	0.6	0.0
	hy	13.1	11.6	8.1	9.7	4.9	6.4	5.9
	ol	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	q	4.7	4.2	3.9	3.7	38.5	12.5	8.6
	ne	0.0	0.0	0.0	0.0	0.0	0.0	0.0
An% Fo, En, Di% Class A/CNK A/NK K or Na	An%	28.8	32.1	8.2	18.9	3.5	23.8	6.5
	Fo, En, Di%	52.9	52.2	52.7	42.9	57.8	40.1	36.6
	Class	M Al	M Al	M Al	M Al	P Al	M Al	P Al
	A/CNK	0.9	0.8	0.9	0.9	1.3	0.9	1.1
	A/NK	1.5	1.6	1.1	1.3	1.4	1.4	1.2
	K or Na	K	K	K	K	K	K	K
TOTAL%Phenos		18	3	10	22	10	2	15
%Plagioclase		15	2	10	16	5	2	14
%Augite		3	1		5			1
%Olivine			tr		1			
%Opaques								
%Hornblende								
%Biotite								
%Perthite/Kfs						5		
%Quartz								

TABLE A-1, continued, part (a)

SAMPLE:		87-181-2	86-M4-2	86-36-2	87-158-2	87-161-2	86-34-6	87-159-2
Analytical Run		2	1	1	2	2	1	2
FORMATION		Cold F	Cold F	Cold F	Cold F	Cold F	Cold F	Cold F
Unit Type		RS	FWT	RS	RS	RS	RS	RD
Rock Name		rhy	rhy	rhy	rhy	rhy	rhy	rhy
District		Will	Joan	Nation	Nation	Nation	Nation	Nation
UTM E		515000	505300	505700	510200	509500	506600	509300
UTM N		6376200	6371200	6390400	6389600	6390100	6391500	6389600
Major Oxides in weight% by XRF re- calculated to 100% on volatile- free basis	SiO ₂	69.4	71.4	76.7	73.5	75.3	79.5	83.0
	TiO ₂	0.36	0.42	0.21	0.18	0.18	0.11	0.09
	Al ₂ O ₃	15.7	13.9	11.3	14.2	13.3	10.3	8.8
	FeO*	2.3	3.8	2.9	2.2	1.7	1.0	0.8
	MnO	0.11	0.13	0.03	0.05	0.13	0.01	0.00
	MgO	0.6	0.6	0.3	0.3	0.3	0.3	0.3
	CaO	1.3	1.0	0.2	0.4	1.3	0.2	0.0
	Na ₂ O	3.8	4.6	2.3	3.3	2.9	0.3	0.1
	K ₂ O	6.4	4.2	5.9	5.9	4.9	8.2	6.8
	P ₂ O ₅	0.07	0.08	0.00	0.02	0.02	0.01	0.02
original values reported	H ₂ O	0.9	1.1	0.6	0.9	1.2	0.7	0.5
	CO ₂	0.7	0.5	0.2	0.3	1.1	0.0	0.0
	SUM	99.6	100.1	99.4	99.6	99.7	100.7	99.0
Mg#		35.8	23.9	18.6	23.4	28.3	39.2	41.7
Cation Norms in %	ap	0.2	0.2	0.0	0.0	0.0	0.0	0.0
	il	0.5	0.6	0.3	0.3	0.2	0.2	0.2
	or	37.9	24.6	35.9	35.0	29.2	50.1	50.1
	ab	34.0	41.4	21.5	29.6	26.3	2.8	2.8
	an	5.7	4.3	1.1	2.0	6.6	0.9	0.9
	c	0.4	0.3	0.7	1.9	1.0	0.7	0.7
	mt	0.6	0.9	0.7	0.5	0.4	0.3	0.3
	di	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	hy	3.9	5.3	3.9	3.1	2.7	1.9	1.9
	ol	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	q	16.8	22.5	35.8	27.6	33.6	43.2	43.2
	ne	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fo, En, Di% Class A/CNK A/NK K or Na	An%	14.4	9.4	4.8	6.4	20.0	24.6	24.6
	Fo	45.8	31.2	24.6	30.2	34.5	49.3	49.3
	Class	P Al	P Al	P Al	P Al	P Al	P Al	P Al
	A/CNK	1.0	1.0	1.1	1.1	1.1	1.1	1.1
	A/NK	1.2	1.2	1.1	1.2	1.3	1.1	1.1
	K or Na	K	K	K	K	K	K	K
TOTAL%Phenos			25	10			0	
%Plagioclase			4					
%Augite								
%Olivine								
%Opzques								
%Hornblende								
%Biotite				tr				
%Perthite/Kfs			15	10				
%Quartz								

TABLE A-1, continued, part (a)

SAMPLE:		87-157-2	86-93-2	86-56-2	87-91-2	87-160-3	87-115-2	86-80-4
Analytical Run		2	1	1	2	2	2	1
FORMATION		Cold F	Cold F	Cold F	Cold F	Cold F	Cold F	Cold F
Unit Type		RS	RS	RwT	RF	RD	RF	RS
Rock Name		rhy	rhy	rhy	rhy	rhy	rhy	rhy
District		Nation	Nation	Joan	Ice Box	Nation	Ice Box	Nation
UTM E		510400	511700	504900	491200	509300	494700	509200
UTM N		6389500	6387700	6371800	6399300	6389900	6396200	6386900
Major Oxides	SiO ₂	75.4	74.2	74.0	76.2	78.3	74.0	75.6
	TiO ₂	0.10	0.17	0.17	0.10	0.28	0.25	0.20
	Al ₂ O ₃	13.0	14.1	12.6	13.3	10.4	14.2	11.1
	FeO*	2.1	2.0	2.7	1.0	2.3	1.7	2.8
by XRF	MnO	0.10	0.05	0.03	0.02	0.01	0.02	0.06
re-	MgO	0.3	0.3	0.2	0.2	0.2	0.2	0.2
calculated	CaO	1.0	0.2	0.1	0.2	0.2	0.9	1.5
to 100% on	Na ₂ O	3.3	2.8	0.6	1.9	2.4	3.8	1.5
volatile-	K ₂ O	4.7	6.3	9.6	6.9	5.9	4.8	7.1
free basis	P ₂ O ₅	0.01	0.02	0.00	0.01	0.06	0.06	0.02
original	H ₂ O	0.8	1.1	0.9	1.1	1.0	0.8	1.1
values	CO ₂	0.8	0.1	0.0	0.0	0.1	0.1	2.0
reported	SUM	99.1	100.4	100.2	99.6	99.4	99.4	100.2
	Mg#	20.7	20.8	14.0	29.7	15.1	18.9	10.6
	ap	0.0	0.0	0.0	0.0	0.1	0.1	0.0
	il	0.1	0.2	0.2	0.1	0.4	0.4	0.3
	or	28.2	37.4	58.1	41.7	36.0	28.5	42.9
	ab	30.0	25.7	5.6	17.7	21.9	34.1	13.4
	an	5.0	0.8	0.6	1.1	0.0	4.3	2.9
	c	0.7	2.6	1.1	2.5	0.0	1.4	0.0
	mt	0.5	0.5	0.7	0.3	0.6	0.4	0.7
	di	0.0	0.0	0.0	0.0	0.4	0.0	3.8
	hy	3.1	2.7	3.4	1.6	2.5	2.1	1.4
	ol	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	q	32.3	30.0	30.3	35.0	38.1	28.8	34.4
	ne	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	An%	14.3	3.1	9.2	5.9	0.0	11.2	18.0
	Fo, En, Di%	25.3	27.1	18.6	38.2	21.5	27.1	14.2
	Class	P Al	P Al	P Al	P Al	M Al	P Al	M Al
	A/CNK	1.1	1.2	1.1	1.2	1.0	1.1	0.9
	A/NK	1.2	1.2	1.1	1.2	1.0	1.2	1.1
	K or Na	K	K	K	K	K	K	K
TOTAL%Phenos			15	15				10
%Plagioclase								
%Augite								
%Olivine								
%Opaques			tr					
%Hornblende								
%Biotite								tr
%Perthite/Kfs			15	15				10
%Quartz								

TABLE A-1, continued, part (c)

SAMPLE:		86-88-11	86-M4-5	87-171-2	86-3-4	86-54-2	87-228-3	87-231-2
Analytical Run		1	1	2	1	1	2	2
FORMATION		Cold F	Cold F	Cold F	Cold F	Cold F	Griff Ck	Griff Ck
Unit Type		RS	RwT	MF	RD	RwT	MF	MF
Rock Name		rhy	rhy	and	rhy	rhy	B and	bas
District		Nation	Joan	Will	Nation	Joan	Griffith	Griffith
UTM E		509400	505000	512700	509200	502400	529700	529000
UTM N		6388300	6371200	6377100	6391300	6372800	6373000	6373600
Major Oxides in weight% by XRF re- calculated to 100% on volatile- free basis	SiO ₂	72.8	76.7	62.4	78.4	72.4	53.3	51.2
	TiO ₂	0.29	0.37	0.69	0.11	0.35	0.73	0.81
	Al ₂ O ₃	14.5	12.0	17.0	11.0	12.6	13.1	14.3
	FeO*	2.5	2.3	4.9	1.7	4.0	8.8	9.0
	MnO	0.05	0.03	0.07	0.02	0.12	0.18	0.22
	MgO	0.1	0.1	0.1	0.1	0.1	8.6	8.0
	CaO	0.3	0.1	1.0	0.2	1.2	9.7	11.3
	Na ₂ O	6.0	3.8	2.6	1.8	3.3	2.0	2.1
	K ₂ O	3.5	4.5	11.1	6.6	5.9	3.3	2.8
	P ₂ O ₅	0.03	0.03	0.12	0.01	0.05	0.33	0.33
original values reported	H ₂ O	0.4	0.3	0.4	0.5	0.4	2.0	1.8
	CO ₂	0.0	0.1	0.4	0.1	1.0	0.5	0.1
	SUM	99.9	100.5	100.0	100.1	100.5	99.7	99.6
Mg#		9.6	10.3	4.7	12.3	3.4	66.0	63.7
Cation Norms in %	ap	0.1	0.1	0.3	0.0	0.1	0.7	0.7
	il	0.4	0.5	1.0	0.2	0.5	1.0	1.1
	or	20.6	27.1	65.5	39.7	35.4	19.4	16.4
	ab	53.1	34.7	23.7	16.7	30.5	17.7	18.6
	an	1.0	0.5	2.0	1.2	1.9	17.1	21.4
	c	0.6	0.8	0.0	0.6	0.0	0.0	0.0
	mt	0.6	0.6	1.2	0.4	1.0	2.2	2.2
	di	0.0	0.0	1.6	0.0	3.0	23.0	26.0
	hy	2.6	2.3	3.9	2.1	2.7	13.8	1.3
	ol	0.0	0.0	0.0	0.0	0.0	5.1	12.3
	q	21.0	33.5	0.8	39.2	24.9	0.0	0.0
	ne	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fo, En, Di%	An%	1.9	1.3	7.7	6.5	5.9	49.1	53.6
	Class	13.8	15.8	7.2	16.5	4.7	73.4	71.5
	P Al	P Al	P Al	M Al	P Al	M Al	M Al	M Al
	A/CNK	1.0	1.1	0.9	1.0	0.9	0.5	0.5
	A/NK	1.1	1.1	1.0	1.1	1.1	1.9	2.2
K or Na		Na	K	K	K	K	K	K
TOTAL%Phenos			15	15	0		20	
%Plagioclase				15			2	
%Augite							12	
%Olivine							5	
%Opaques							1	
%Hornblende								
%Biotite								
%Perthite/Kfs			15					
%Quartz								

TABLE A-1, continued, part (a)

SAMPLE:		87-229-2	87-219-2	87-234-2	87-142-2	87-226-7	87-9-3	87-81-2
Analytical Run		2	2	2	2	2	2	2
FORMATION		Grif Ck	Grif Ck	Grif Ck	Grif Ck	Grif Ck	Hazel?	Hazel?
Unit Type		MF	MF	DS	DwT	MF	MD	RD
Rock Name		B and	B and	dac	and	and	B and	rhy
District		Griffith	Griffith	Griffith	Ice Box	Griffith		Knife Edge
UTM E		529500	532400	528200	500600	529300	440900	483900
UTM N		6373000	6370400	6372800	6398400	6373900	6393500	6402400
Major Oxides in weight% by XRF re- calculated to 100% on volatile- free basis	SiO ₂	56.8	56.4	64.2	62.9	61.5	53.3	75.1
	TiO ₂	0.69	0.80	0.53	0.52	0.60	1.90	0.18
	Al ₂ O ₃	14.9	17.2	15.6	16.6	18.0	14.5	14.0
	FeO*	8.0	8.6	6.0	5.8	6.3	12.8	1.4
	MnO	0.17	0.18	0.15	0.11	0.13	0.24	0.03
	MgO	6.6	3.5	2.4	1.9	1.7	4.7	0.7
	CaO	5.9	6.0	3.0	4.5	4.3	8.9	1.8
	Na ₂ O	3.4	4.7	5.1	3.8	3.7	2.9	2.4
original values reported	K ₂ O	3.2	2.1	2.9	3.6	3.5	0.4	4.4
	P ₂ O ₅	0.31	0.54	0.22	0.25	0.26	0.39	0.03
	H ₂ O	2.7	2.7	1.6	2.0	1.7	3.0	1.5
Mg#	CO ₂	0.5	3.7	0.5	1.9	1.5	2.5	1.3
	SUM	99.7	99.8	100.3	99.4	99.7	101.1	99.8
Mg#		62.0	44.7	44.0	40.1	35.5	42.3	50.5
Cation Norms in %	ap	0.7	1.1	0.5	0.5	0.5	0.8	0.1
	il	1.0	1.1	0.7	0.7	0.8	2.7	0.2
	or	19.0	12.4	17.2	21.3	20.9	2.2	26.7
	ab	29.9	41.6	45.4	34.2	33.0	26.3	21.7
	an	15.9	19.8	10.9	17.6	19.6	26.0	8.7
	c	0.0	0.0	0.0	0.0	1.1	0.0	2.3
	mt	2.0	2.1	1.5	1.4	1.6	3.2	0.4
	di	9.0	5.1	2.0	2.5	0.0	13.7	0.0
	hy	21.2	15.2	11.2	9.7	10.9	18.2	3.3
	ol	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	q	1.4	1.6	10.6	12.0	11.6	7.1	36.5
	ne	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fo, En, Di%	An%	34.7	32.2	19.4	34.0	37.3	49.7	28.6
	Class	70.0	53.9	52.9	49.1	44.3	53.7	60.7
	M Al	M Al	M Al	M Al	M Al	P Al	M Al	P Al
	A/CNK	0.8	0.8	0.9	0.9	1.0	0.7	1.2
	A/NK	1.6	1.7	1.3	1.6	1.8	2.8	1.6
K or Na		K	Na	Na	K	K	Na	K
TOTAL%Phenos		15	35	50	60			
%Plagioclase		3	20	15	13			
%Augite		8						
%Olivine		4						
%Opaques				2	2			
%Hornblende			15	13				
%Biotite				5	5			
%Perthite/Kfs				10	25			
%Quartz				5	15			

TABLE A-1, continued, part (a)

SAMPLE:		87-218-16	87-86-2	P87-10-2	87-19-2	TSAYB	87-221-3	87-222-2
Analytical Run		2	2	2	2	3	2	2
FORMATION		Stu?	Stu?	Stu?	Stu?	Stuhini	Stuhini	Stuhini
Unit Type		MS	MD?	MF	MF/D	MF	MF	MF
Rock Name		bas	bas	B and	and	bas	B and	B and
District		Griffith	KnifeEdge	KnifeEdge			Griffith	Griffith
UTM E		532800	484100	485900	454400		531800	531700
UTM N		6369800	6403800	6403800	6404000		6369300	6368900
Major Oxides in weight% by XRF re- calculated to 100% on volatile- free basis	SiO ₂	50.3	51.4	54.1	57.1	50.7	56.9	56.3
	TiO ₂	0.80	0.75	0.75	0.88	0.79	0.72	0.77
	Al ₂ O ₃	15.5	16.8	17.5	16.5	13.8	14.7	14.9
	FeO*	11.1	9.2	8.2	7.6	9.1	8.4	8.6
	MnO	0.20	0.21	0.24	0.11	0.17	0.15	0.21
	MgO	7.8	5.5	4.3	4.2	8.0	6.9	6.7
	CaO	10.1	8.5	6.8	7.8	12.2	5.1	5.6
	Na ₂ O	1.9	3.4	5.0	3.5	2.9	2.3	2.1
	K ₂ O	1.8	3.9	2.7	1.9	1.9	4.5	4.4
	P ₂ O ₅	0.41	0.37	0.38	0.31	0.49	0.35	0.38
original values reported	H ₂ O	4.8	2.5	3.3	2.1	2.5	2.8	2.9
	CO ₂	6.4	2.5	4.6	3.3	0.0	0.8	0.8
	SUM	100.9	99.9	100.5	99.7	100.4	99.9	100.1
Mg#		58.5	54.4	51.1	52.4	63.6	61.9	60.7
Cation Norms in %	ap	0.9	0.8	0.8	0.6	1.0	0.7	0.8
	il	1.1	1.0	1.0	1.2	1.1	1.0	1.1
	or	10.9	23.0	15.6	11.5	11.1	26.3	26.2
	ab	17.3	19.2	38.0	31.5	20.6	20.8	18.9
	an	28.3	18.7	17.0	23.5	18.9	16.6	18.2
	c	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	mt	2.7	2.3	2.0	1.9	2.2	2.1	2.1
	di	15.5	16.4	11.0	10.7	30.2	5.1	5.8
	hy	18.1	0.0	0.0	13.3	0.0	24.5	23.8
	ol	5.1	11.9	10.5	0.0	11.7	0.0	0.0
	q	0.0	0.0	0.0	5.8	0.0	3.0	3.1
	ne	0.0	6.7	4.0	0.0	3.0	0.0	0.0
An%		62.0	38.0	27.6	42.7	42.4	44.4	49.1
Fo, En, Di%		66.5	62.8	59.7	62.4	71.5	70.0	68.8
Class		M Al	M Al	M Al	M Al	M Al	M Al	M Al
A/CNK		0.7	0.7	0.7	0.7	0.5	0.8	0.8
A/NK		3.0	1.7	1.6	2.1	2.0	1.7	1.8
K or Na		K	K	Na	K	K	K	K
TOTAL%Phenos							15	
%Plagioclase							1	
%Augite							10	
%Olivine							3	
%Opaques							1	
%Hornblende								
%Biotite								
%Perthite/Kfs								
%Quartz								

TABLE A-1, continued, part (a)

SAMPLE:		87-88-2	87-74-2	LD-291-3	2-AP-TS5	LD-314-1	D-283-2a	LD-316-1
Analytical Run		2	2	3	3	3	3	3
FORMATION		Stuhini	Stuhini	Toodog	Toodog	Toodog	Toodog	Toodog
Unit Type		MF	MF					
Rock Name		bas	bas	and	bas	and	and	dac
District		KnifeEdge	KnifeEdge					
UTM E		494000	481400					
UTM N		6404900	6404300					
Major Oxides in weight% by XRF re- calculated to 100% on volatile- free basis	SiO ₂	50.0	51.4	58.5	51.9	62.2	58.4	64.4
	TiO ₂	1.02	1.03	0.78	1.05	0.61	0.74	0.51
	Al ₂ O ₃	14.9	18.0	17.2	18.4	16.6	17.4	16.4
	FeO*	11.3	9.3	7.5	9.5	5.5	6.9	4.9
	MnO	0.24	0.17	0.17	0.16	0.17	0.22	0.15
	MgO	5.8	5.5	4.2	3.8	3.1	2.7	2.1
	CaO	10.3	10.4	3.3	8.8	3.0	6.6	4.0
	Na ₂ O	2.8	2.5	4.6	3.8	4.3	3.9	3.4
	K ₂ O	3.1	1.4	3.6	2.3	4.2	2.8	4.0
	P ₂ O ₅	0.49	0.23	0.26	0.36	0.26	0.30	0.20
original values reported	H ₂ O	2.7	2.6	2.3	1.2	2.2	3.0	2.3
	CO ₂	0.1	2.0	0.2	0.0	1.0	0.1	0.1
	SUM	99.7	100.3	99.9	100.2	99.8	99.9	100.3
Mg#		50.7	54.2	53.1	44.5	53.1	43.4	46.0
Cation Norms in %	ap	1.0	0.5	0.5	0.7	0.5	0.6	0.4
	il	1.4	1.4	1.1	1.5	0.8	1.0	0.7
	or	18.6	8.1	21.3	13.7	24.8	16.3	23.5
	ab	18.0	22.9	40.4	33.0	38.1	34.7	30.6
	an	18.7	33.8	14.4	26.3	13.1	22.1	17.8
	c	0.0	0.0	0.5	0.0	0.1	0.0	0.0
	mt	2.8	2.3	1.8	2.3	1.4	1.7	1.2
	di	23.3	13.2	0.0	11.8	0.0	7.1	0.8
	hy	0.0	17.5	18.5	0.0	13.8	10.5	10.1
	ol	11.6	0.0	0.0	10.0	0.0	0.0	0.0
	q	0.0	0.4	1.5	0.0	7.3	5.9	14.8
	ne	4.5	0.0	0.0	0.5	0.0	0.0	0.0
Fo, En, Di% Class A/CNK A/NK K or Na	An%	42.3	59.6	26.2	43.7	25.6	38.9	36.7
	Fo, En, Di%	59.6	63.8	62.4	54.4	62.2	52.6	55.2
	Class	M Al	M Al	M Al	M Al	M Al	M Al	M Al
	A/CNK	0.6	0.7	1.0	0.7	1.0	0.8	1.0
	A/NK	1.8	3.2	1.5	2.1	1.4	1.9	1.7
TOTAL%Phenos %Plagioclase %Augite %Olivine %Opaques %Hornblende %Biotite %Perthite/Kfs %Quartz	K or Na	K	K	K	K	K	K	K
		30	10					
		12	5					
		12	4					
			1					
		6						

TABLE A-1, continued, part (a)

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SAMPLE:		LD-311-9	85MM68	4MM77-1	MM138-1	5MM75-1	85MM90	5MM12-2
Analytical Run		3	2	2	2	2	2	2
FORMATION		Toodog	Stu/Haz	Stu/Haz	Stu/Haz	Stu/Haz	Stu/Haz	Stu/Haz
Unit Type								
Rock Name		dac	bas	bas	bas	bas	bas	B and
District								
UTM E								
UTM N								
Major Oxides in weight% by XRF re- calculated to 100% on volatile- free basis	SiO ₂	65.1	50.1	50.4	52.9	49.9	51.2	53.4
	TiO ₂	0.50	0.80	0.81	1.03	1.27	1.22	1.58
	Al ₂ O ₃	16.3	15.8	17.4	18.5	17.2	20.4	17.6
	FeO*	4.8	9.7	9.4	8.4	13.4	9.9	10.4
	MnO	0.14	0.21	0.15	0.21	0.21	0.37	0.23
	MgO	1.8	8.5	7.2	5.7	5.0	4.4	4.0
	CaO	3.9	11.8	11.0	8.5	8.2	6.7	6.2
	Na ₂ O	3.7	2.4	3.0	2.9	3.0	4.2	4.9
	K ₂ O	3.5	0.5	0.5	1.4	1.5	1.4	1.2
	P ₂ O ₅	0.19	0.13	0.14	0.28	0.25	0.21	0.51
original values reported	H ₂ O	2.0	1.4	2.2	2.6	1.7	3.0	3.5
	CO ₂	0.5	0.1	0.3	0.9	0.0	0.0	4.0
	SUM	100.3	100.0	99.2	100.5	100.2	100.6	100.5
Mg#		43.1	63.6	60.3	57.4	42.6	47.2	43.3
Cation Norms in %	ap	0.4	0.3	0.3	0.6	0.5	0.4	1.1
	il	0.7	1.1	1.1	1.4	1.8	1.7	2.2
	or	21.0	2.9	3.2	8.4	9.0	8.2	7.1
	ab	33.4	21.1	27.1	26.2	27.2	37.1	43.9
	an	17.4	31.0	32.0	33.3	29.5	31.9	22.5
	c	0.0	0.0	0.0	0.0	0.0	0.3	0.0
	mt	1.2	2.4	2.3	2.1	3.3	2.4	2.6
	di	0.5	21.3	16.9	5.6	8.2	0.0	3.9
	hy	9.5	13.0	7.5	20.7	14.1	7.5	13.0
	ol	0.0	6.8	9.5	0.0	6.4	10.5	3.8
	q	16.0	0.0	0.0	1.8	0.0	0.0	0.0
	ne	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fo, En, Di% Class	An%	34.2	59.4	54.1	56.0	52.0	46.2	33.9
		52.3	71.3	68.6	66.9	52.1	56.7	54.6
	M Al		M Al	M Al	M Al	M Al	M Al	M Al
	A/CNK	1.0	0.6	0.7	0.9	0.8	1.0	0.9
	A/NK	1.6	3.6	3.1	2.9	2.6	2.4	1.9
K or Na		K	K	Na	K	K	Na	Na
TOTAL%Phenos								
%Plagioclase								
%Augite								
%Olivine								
%Opaques								
%Hornblende								
%Biotite								
%Perthite/Kfs								
%Quartz								

TABLE A-1, continued, part (a)

SAMPLE: 85MM54-1		5MM84-4	4MM68-1	5MM33-3	MM127-1	5MM1003	
Analytical Run		2	2	2	2	2	
FORMATION		Stu/Haz	Stu/Haz	Stu/Haz	Stu/Haz	Stu/Haz	
Unit Type							
Rock Name		bas	B and	B and	and	dac	
District							
UTM E							
UTM N							
Major Oxides in weight% by XRF re- calculated to 100% on volatile- free basis	SiO2	52.1	55.3	55.7	59.2	63.7	66.0
	TiO2	1.05	1.71	1.35	1.54	1.19	0.57
	Al2O3	22.1	15.8	17.0	15.5	15.6	15.8
	FeO*	7.9	10.8	9.5	9.3	6.1	4.7
	MnO	0.12	0.36	0.43	0.23	0.39	0.16
	MgO	3.7	3.7	3.4	3.0	1.5	1.5
	CaO	3.1	4.6	5.1	4.7	4.1	3.1
	Na2O	3.3	4.3	6.3	4.2	4.4	4.6
	K2O	6.1	2.6	0.9	1.8	2.4	3.4
	P2O5	0.47	0.75	0.38	0.64	0.60	0.18
original values reported	H2O	1.9	2.6	2.5	1.3	1.0	1.5
	CO2	0.1	0.0	0.2	0.1	0.0	2.2
	SUM	100.5	101.0	99.9	100.7	99.9	100.0
Mg#		48.4	40.8	41.8	39.0	33.5	38.1
Cation Norms in %	ap	1.0	1.6	0.8	1.4	1.3	0.4
	il	1.4	2.4	1.9	2.2	1.7	0.8
	or	35.8	15.5	5.4	10.6	14.0	20.3
	ab	27.9	39.0	55.5	37.9	39.7	41.3
	an	12.3	15.9	15.4	18.4	16.1	12.3
	c	5.9	0.0	0.0	0.0	0.0	0.0
	mt	1.9	2.7	2.3	2.3	1.5	1.2
	di	0.0	1.8	5.6	0.5	0.5	1.7
	hy	0.0	19.2	7.1	16.1	9.4	7.5
	ol	12.9	0.0	6.1	0.0	0.0	0.0
	q	0.0	1.9	0.0	10.6	15.9	14.6
	ne	0.8	0.0	0.0	0.0	0.0	0.0
An%		29.6	29.0	21.7	32.7	28.8	22.9
Fo, En, Di%		59.2	51.7	51.7	50.6	47.2	47.7
Class		P Al	M Al	M Al	M Al	M Al	M Al
A/CNK		1.2	0.9	0.8	0.9	0.9	0.9
A/NK		1.8	1.6	1.5	1.8	1.6	1.4
K or Na		K	K	Na	Na	Na	K
TOTAL%Phenos							
%Plagioclase							
%Augite							
%Olivine							
%Opaques							
%Hornblende							
%Biotite							
%Perthite/Kfs							
%Quartz							

TABLE A-1, continued, part (b)

SAMPLE:		87-224-3	86-112-2	87-224-2	87-69-7	87-56-4	87-40-3	87-39-3
Analytical Run		2	1	2	2	2	2	2
FORMATION		MPv	MPv	MPv	McEwan	M Brock	M Brock	M Brock
Unit Type		Nod	MD	MD	Gran	MF	MD	MF
Rock Name		harzb	bas	neph	Q syen	bas	B and	B and
District		Griffith	Will	Griffith	Brock	Brock	Brock	Brock
UTM E		532500	520400	532500	466900	466300	491900	471600
UTM N		6368800	6378400	6368800	6410400	6413300	6410400	6410000
	ppm							
XRF	Ba	41	195	820	79	640	1459	564
	Rb	23	14	50	29	63	50	64
	Sr	0	143	929	121	599	437	531
	Zr	20	60	168	224	87	81	72
ICP	Co	96	75	50	6	30	28	23
	Cr	1620	1000	171	12	65	30	25
	Cu	8	75	68	16	43	55	38
	Ni	2000	710	170	12	36	26	15
	V	46	130	165	54	226	200	252
	Zn	54	85	96	9	98	280	73
	La	0	4	54	20	18	16	12
	Ce	0	8	100	51	41	34	26
	Nd	1	7	49	32	29	28	20
	Sm	0.0	1.0	8.6	6.7	5.4	4.0	3.8
	Eu	0.0	0.5	2.7	1.3	1.9	1.4	1.4
	Gd	0.0	2.0	7.0	7.1	6.0	4.4	4.2
	Dy	0.0	2.3	5.9	7.4	5.6	4.3	4.3
	Y	1	13	30	43	29	23	23
	Yb	0.0	1.4	2.6	5.3	2.9	2.4	2.4
	Nb	1		56	14	6		3
INAA	Sc						23	28
	Th						4.6	1.6
	U						2.2	0.8
weight% ratios	Ba/La	137	54	15	4	36	91	47
	La/Yb		2.6	20.8	3.8	6.2	6.7	5.0
	La/Nb	0.30		0.96	1.43	3.00		4.00
	K/Rb		180	315	26	154	464	165
	Rb/Sr		0.10	0.05	0.24	0.11	0.11	0.12

Values for Zr, Co, V and Cr for samples analyzed in Run 2 have been reduced by 45%, 13%, 13% and 10% respectively from the original concentrations reported.

TABLE A-1, continued, part (b)

SAMPLE:		87-42-3	87-34-2	87-90-2	87-47-2	87-50-2	87-57-1	87-38-4
Analytical Run		2	2	2	2	2	2	2
FORMATION		M Brock	M Brock	M Brock	M Brock	M Brock	M Brock	M Brock
Unit Type		MF	MF	MF	MF	MF	MF	MF
Rock Name		and	B and	and	and	and	and	dac
District		Brock	Brock	Brock	Brock	Brock	Brock	Brock
UTM E		472400	474500	479700	472300	473100	466300	471300
UTM N		6410400	6410400	6407200	6411600	6412900	6412800	6409700
	ppm							
XRF	Ba	823	808	905	1083	936	1319	1056
	Rb	54	50	57	48	83	58	91
	Sr	351	550	471	418	480	405	256
	Zr	139	89	102	122	145	136	147
ICP	Co	17	22	21	17	13	10	10
	Cr	50	23	20	38	14	15	15
	Cu	36	90	62	57	23	23	20
	Ni	14	15	9	13	2	0	3
	V	131	226	183	148	87	57	53
	Zn	58	80	76	69	94	160	110
	La	18	16	19	22	23	27	29
	Ce	40	35	41	47	51	58	56
	Nd	26	25	28	28	36	37	33
	Sm	4.5	4.3	5.0	4.8	6.1	7.2	5.8
	Eu	1.3	1.4	1.5	1.4	2.0	1.9	1.6
	Gd	4.9	4.7	5.3	4.9	6.9	7.4	5.5
	Dy	5.2	4.5	5.3	4.8	6.7	7.2	5.5
	Y	29	25	27	27	38	39	33
	Yb	3.3	2.6	3.0	3.0	4.1	4.2	3.5
	Nb		5	6	8	8		9
INAA	Sc	18	25		17		12	10
	Th	4.6	3.5		5.7		6.3	6.3
	U	2.2	2.1		2.7		3.2	2.9
weight% ratios	Ba/La	46	51	48	49	41	49	36
	La/Yb	5.5	6.2	6.3	7.3	5.6	6.4	8.3
	La/Nb		3.20	3.17	2.75	2.88		3.22
	K/Rb	416	338	346	430	303	448	383
	Rb/Sr	0.15	0.09	0.12	0.11	0.17	0.14	0.36

Values for Zr, Co, V and Cr for samples analyzed in Run 2 have been reduced by 45%, 13%, 13% and 10% respectively from the original concentrations reported.

TABLE A-1, continued, part (b)

SAMPLE:		87-48-3	87-55-2	87-41-3	87-45-2	86-111-5	86-33-2	86-44-5
Analytical Run		2	2	2	2	1	1	1
FORMATION		M Brock	M Brock	M Brock	M Brock	Spats R	Cold F	Cold F
Unit Type		MF	DF	MF	MF	Gran	MF	MD
Rock Name		dac	dac	dac	dac	Afs G	bas	bas
District		Brock	Brock	Brock	Brock	Will	Nation	Nation
UTM E		472500	466900	472500	472000	520500	506800	509500
UTM N		6411800	6413200	6410500	6410800	6378100	6392700	6390000
	ppm							
XRF	Ba	851	1186	1122	2640	102	564	704
	Rb	93	100	118	170	136	35	40
	Sr	351	188	142	78	49	373	261
	Zr	124	160	128	129	257	78	49
ICP	Co	10	5	6	5	1	36	36
	Cr	41	14	11	11	10	340	380
	Cu	28	19	18	17	5	94	53
	Ni	13	0	0	0	5	140	130
	V	74	37	30	23	0	220	210
	Zn	93	89	43	3	120	84	78
	La	23	30	29	12	43	10	10
	Ce	47	63	58	40	79	23	22
	Nd	26	35	35	24	40	18	17
	Sm	4.0	6.5	6.1	3.6	6.6	3.8	2.6
	Eu	1.0	1.5	1.8	0.5	0.4	1.3	1.1
	Gd	4.1	6.3	6.2	3.9	7.3	4.3	3.5
	Dy	4.1	6.5	6.3	4.4	7.7	4.3	3.2
	Y	25	38	37	26	47	23	16
	Yb	3.0	4.4	4.0	3.3	5.2	2.3	1.5
	Nb	9	12		7	18	4	
INAA	Sc		7		9	4		31
	Th		10.0		5.3	14.0		
	U		4.2		2.3	5.5		
weight% ratios	Ba/La	37	40	39	220	2	57	73
	La/Yb	7.7	6.8	7.3	3.6	8.3	4.3	6.5
	La/Nb	2.56	2.50		1.71	2.39	2.48	
	K/Rb	338	358	342	471	338	270	495
	Rb/Sr	0.26	0.53	0.83	2.18	2.78	0.09	0.15

Values for Zr, Co, V and Cr for samples analyzed in Run 2 have been reduced by 45%, 13%, 13% and 10% respectively from the original concentrations reported.

TABLE A-1, continued, part (b)

SAMPLE:		86-78-4	86-23-5	86-72-3	86-5-2	87-139-2	87-156-2	86-67-2
Analytical Run		1	1	1	1	2	2	1
FORMATION		Cold F	Cold F	Cold F	Cold F	Cold F	Cold F	Cold F
Unit Type		MF	MF	MF	MF	MF	MF	MF
Rock Name		bas	bas	bas	bas	bas	bas	bas
District		Nation	Nation	Nation	Nation	Ice Box	Ice Box	Nation
UTM E		510000	509400	504600	509200	501600	499600	504900
UTM N		6387200	6391200	6390300	6391600	6393200	6394100	6389600
	ppm							
XRF	Ba	836	762	561	523	665	548	661
	Rb	47	29	51	0	75	53	49
	Sr	586	523	364	652	469	548	425
	Zr	72	54	88	47	67	56	71
ICP	Co	36	38	29	39	33	35	29
	Cr	110	150	190	100	55	85	30
	Cu	120	22	35	27	28	64	39
	Ni	78	74	27	43	20	35	20
	V	230	250	220	310	278	296	290
	Zn	97	100	86	120	86	93	98
	La	17	10	14	10	13	9	13
	Ce	34	21	30	22	28	21	28
	Nd	23	16	20	17	19	18	21
	Sm	3.3	2.5	3.0	3.1	4.1	3.8	3.8
	Eu	1.5	1.1	1.2	1.4	1.3	1.3	1.4
	Gd	4.3	3.4	4.3	4.0	4.4	4.2	4.6
	Dy	4.1	3.4	4.6	3.7	4.5	4.2	4.8
	Y	22	18	25	18	23	21	26
	Yb	2.1	1.8	2.5	1.7	2.5	2.3	2.6
	Nb	6	3	5	4	4	3	
INAA	Sc		28	28	30	39		32
	Th		1.9	4.3	1.1	2.0		1.9
	U		1.0	1.7	0.7	1.2		0.9
weight%	Ba/La	49	76	40	52	51	60	51
	La/Yb	8.1	5.6	5.6	5.9	5.2	4.0	5.0
ratios	La/Nb	2.83	3.33	2.80	2.50	3.25	3.03	
	K/Rb	267	386	231		143	141	229
	Rb/Sr	0.08	0.06	0.14		0.16	0.10	0.12

Values for Zr, Co, V and Cr for samples analyzed in Run 2 have been reduced by 45%, 13%, 13% and 10% respectively from the original concentrations reported.

TABLE A-1, continued, part (b)

SAMPLE:		86-18-4	86-35-2	86-2-2	86-38-5	86-57-3	86-109-3	87-97-3
Analytical Run FORMATION Unit Type Rock Name		1	1	1	1	1	1	2
		Cold F	Cold F	Cold F	Cold F	Cold F	Cold F	Cold F
		MF bas	MF bas	MF bas	MD bas	MF bas	MF bas	MF B and
District		Nation	Nation	Nation	Nation	Joan	Plateau	Ice Box
UTM E		508200	506000	509300	505000	506700	510500	490400
UTM N		6391100	6391100	6391200	6390600	6371300	6382400	6395500
		ppm						
XRF	Ba	2359	637	1081	423	712	901	751
	Rb	38	23	59	49	39	70	82
	Sr	1378	519	575	449	849	621	460
	Zr	79	72	93	75	71	84	76
ICP	Co	31	23	32	26	27	26	24
	Cr	99	25	89	54	38	30	41
	Cu	33	21	21	48	17	27	28
	Ni	30	10	23	18	17	6	10
	V	270	220	280	250	290	280	191
	Zn	91	89	100	380	92	110	88
	La	12	11	14	14	13	13	13
	Ce	26	23	29	28	28	28	28
	Nd	19	17	19	18	21	21	18
	Sm	2.4	2.9	3.6	3.1	3.9	3.6	3.8
	Eu	1.2	1.2	1.3	1.2	1.6	1.5	1.2
	Gd	4.0	3.6	4.3	4.1	4.8	4.9	3.9
	Dy	4.0	3.5	4.4	3.9	4.7	5.0	4.1
	Y	22	19	23	19	24	27	22
	Yb	2.3	1.9	2.4	1.7	2.3	2.6	2.3
	Nb	4						4
INAA	Sc		27	26				28
	Th		1.7	2.7				3.3
	U		0.7	1.2				1.5
weight% ratios	Ba/La	197	58	77	30	55	69	58
	La/Yb	5.2	5.8	5.8	8.2	5.7	5.0	5.7
	La/Nb	3.00						3.25
	K/Rb	351	360	152	190	349	242	148
	Rb/Sr	0.03	0.04	0.10	0.11	0.05	0.11	0.18

Values for Zr, Co, V and Cr for samples analyzed in Run 2 have been reduced by 45%, 13%, 13% and 10% respectively from the original concentrations reported.

TABLE A-1, continued, part (b)

SAMPLE:		86-14-4	86-19-4	86-8-5	86-40-8	86-105-2	87-97-5	87-203-3
Analytical Run FORMATION Unit Type Rock Name		1	1	1	1	1	2	2
		Cold F	Cold F	Cold F	Cold F	Cold F	Cold F	Cold F
		MF bas	MF bas	MF bas	MF B and	MF B and	MF B and	MF B and
District		Nation	Nation	Nation	Nation	Plateau	Ice Box	Cartmel
UTM E		508300	508000	509400	506700	508800	490400	482700
UTM N		6392100	6391100	6391500	6391600	6382300	6395300	6499300
		ppm						
XRF	Ba	1648	701	778	689	668	721	1983
	Rb	49	67	0	39	42	49	51
	Sr	674	1609	462	482	398	503	575
	Zr	41	62	81	76	98	84	112
ICP	Co	35	29	47	28	22	26	24
	Cr	49	52	210	37	110	25	41
	Cu	48	20	55	18	17	35	31
	Ni	31	36	72	17	16	11	0
	V	300	240	230	290	180	244	226
	Zn	87	84	99	140	70	93	130
	La	8	11	11	13	19	15	21
	Ce	18	23	24	29	37	33	44
	Nd	16	16	18	20	20	22	28
	Sm	3.0	2.3	3.5	3.5	3.0	4.9	4.8
	Eu	1.2	1.1	1.3	1.4	1.1	1.5	1.5
	Gd	3.6	3.5	4.2	4.6	4.0	4.8	4.7
	Dy	3.4	3.7	4.3	4.5	4.3	4.8	4.6
	Y	17	20	23	22	24	25	24
	Yb	1.6	2.1	2.3	2.1	2.5	2.6	2.3
	Nb			4	5			7
INAA	Sc	30	29	29		25		24
	Th	0.8	1.9	1.4		7.5		4.0
	U	0.4	0.9	0.8		3.9		1.2
weight%	Ba/La	201	64	71	53	35	48	94
	La/Yb	5.1	5.2	4.8	6.2	7.6	5.8	9.1
ratios	La/Nb			2.75	2.60			3.00
	K/Rb	497	239		321	398	307	411
	Rb/Sr	0.07	0.04		0.08	0.11	0.10	0.09

Values for Zr, Co, V and Cr for samples analyzed in Run 2 have been reduced by 45%, 13%, 13% and 10% respectively from the original concentrations reported.

TABLE A-1, continued, part (b)

SAMPLE:		86-7-2	87-111-4	86-M12-3	86-18-2	86-40-2	86-40-4	87-188-3
Analytical Run FORMATION Unit Type Rock Name		1	2	1	1	1	1	2
		Cold F	Cold F	Cold F	Cold F	Cold F	Cold F	Cold F
		MF bas	MF and	MD bas	MF B and	MF bas	MF B and	MD B and
District		Nation	Ice Box	Nation	Nation	Nation	Nation	Will
UTM E		509300	494900	507000	508100	506600	506600	520700
UTM N		6391600	6394200	6389800	6391200	6391800	6391700	6382800
ppm								
XRF	Ba	757	976	644	1474	1219	774	1118
	Rb	27	54	58	51	19	63	99
	Sr	643	415	384	547	612	418	243
	Zr	68	102	146	150	119	121	91
ICP	Co	35	23	29	28	27	23	17
	Cr	76	19	29	20	34	32	13
	Cu	55	42	43	45	31	34	15
	Ni	34	7	14	10	13	12	11
	V	290	191	340	370	320	340	157
	Zn	110	93	140	140	99	220	85
	La	12	17	23	21	17	18	19
	Ce	25	36	48	44	36	36	45
	Nd	19	22	30	29	23	23	48
	Sm	3.8	5.0	5.9	5.1	3.7	3.3	5.5
	Eu	1.4	1.3	1.9	1.8	1.4	1.5	2.0
	Gd	4.4	4.8	6.8	6.5	5.0	5.1	6.7
	Dy	4.3	5.1	6.5	6.4	4.8	4.8	5.6
	Y	22	29	36	35	24	24	30
	Yb	2.2	3.1	3.5	3.2	2.1	2.2	3.0
	Nb		7					
INAA	Sc	27		31	31			
	Th	1.7		4.6	4.2			
	U	1.0		2.2	2.0			
weight% ratios	Ba/La	63	57	28	70	72	43	59
	La/Yb	5.5	5.5	6.6	6.6	8.1	8.2	6.3
	La/Nb		2.43					
	K/Rb	339	409	281	287	823	263	319
	Rb/Sr	0.04	0.13	0.15	0.09	0.03	0.15	0.41

Values for Zr, Co, V and Cr for samples analyzed in Run 2 have been reduced by 45%, 13%, 13% and 10% respectively from the original concentrations reported.

TABLE A-1, continued, part (b)

SAMPLE:		86-130-2	86-23-3	86-31-4	86-67-5	86-M5-2	86-11-3	86-40-6
Analytical Run FORMATION Unit Type Rock Name		1	1	1	1	1	1	1
		Cold F	Cold F	Cold F	Cold F	Cold F	Cold F	Cold F
		MF and	MF B and	MF bas	MF B and	MF B and	MF and	MF and
District UTM E UTM N		Nation 504900 6388700	Nation 509400 6390900	Nation 507200 6393600	Nation 504800 6389700	Joan 505200 6371300	Nation 508200 6391300	Nation 506500 6391600
		ppm						
XRF	Ba	969	1354	944	1067	1348	1700	1398
	Rb	72	13	48	61	71	47	54
	Sr	586	871	779	538	360	566	510
	Zr	155	101	71	130	101	107	132
ICP	Co	19	19	21	23	21	30	16
	Cr	15	22	40	25	18	50	16
	Cu	25	61	33	23	28	41	26
	Ni	9	24	15	9	8	13	6
	V	210	190	240	270	160	200	200
	Zn	94	87	80	100	110	99	110
	La	23	15	12	18	16	16	20
	Ce	48	32	26	38	34	34	43
	Nd	28	22	20	26	23	22	27
	Sm	4.1	3.5	3.0	5.1	3.7	4.3	4.3
	Eu	1.4	1.3	1.3	1.7	1.6	1.4	1.6
	Gd	5.9	4.5	4.2	5.9	4.9	4.7	5.8
	Dy	5.9	4.5	4.1	6.1	4.4	4.7	5.4
	Y	35	25	22	34	23	25	27
	Yb	3.6	2.6	2.2	3.3	2.1	2.6	2.4
	Nb							8
INAA	Sc	20		25		19	20	22
	Th	6.5		2.6		3.6	4.5	4.7
	U	3.0		1.3		2.3	2.2	2.2
weight%	Ba/La	42	90	79	59	84	106	70
	La/Yb	6.4	5.8	5.5	5.5	7.6	6.2	8.3
ratios	La/Nb							2.50
	K/Rb	454	853	357	314	337	447	533
	Rb/Sr	0.12	0.01	0.06	0.11	0.20	0.08	0.11

Values for Zr, Co, V and Cr for samples analyzed in Run 2 have been reduced by 45%, 13%, 13% and 10% respectively from the original concentrations reported.

TABLE A-1, continued, part (b)

SAMPLE:		87-194-2	87-177-7	86-111-3	86-27-8	86-95-4	87-116-2	86-74-4
Analytical Run FORMATION Unit Type Rock Name		2	2	1	1	1	2	1
		Cold F	Cold F	Cold F	Cold F	Cold F	Cold F	Cold F
		MF and	MF and	MD dac	MF and	RD rhy	MF dac	MF dac
District		Will	Will	Will	Nation	Nation	Ice Box	Nation
UTM E		517400	512900	520900	508000	510800	495200	504900
UTM N		6383100	6379600	6378100	6390000	6387500	6396100	6392300
		ppm						
XRF	Ba	1422	1548	1284	1266	5540	1588	1287
	Rb	108	74	127	87	118	80	89
	Sr	535	626	220	447	226	438	161
	Zr	132	120	164	154	147	127	258
ICP	Co	17	17	6	11	9	9	3
	Cr	21	27	14	11	9	19	11
	Cu	32	34	13	16	17	28	6
	Ni	4	7	3	5	0	1	1
	V	148	122	38	89	15	40	20
	Zn	78	100	120	79	56	73	180
	La	26	26	24	22	28	23	41
	Ce	57	58	49	48	52	50	82
	Nd	41	46	29	28	25	31	46
	Sm	5.9	7.0	4.6	4.5	2.3	6.5	8.1
	Eu	1.8	2.4	1.5	1.5	0.3	1.7	2.3
	Gd	6.2	7.5	5.7	5.4	3.0	6.0	8.6
	Dy	6.1	6.7	5.8	5.4	3.4	5.8	9.1
	Y	33	36	32	31	20	32	53
INAA	Yb	3.7	3.7	3.4	3.1	2.7	3.4	5.8
	Nb			9			8	17
	Sc	16						10
weight%	Th	7.5						10.0
	U	3.0						5.1
ratios	Ba/La	55	60	54	58	198	69	31
	La/Yb	7.0	7.0	7.1	7.1	10.4	6.8	7.1
	La/Nb			2.67			2.88	2.41
	K/Rb	315	371	337	386	446	383	453
ratios	Rb/Sr	0.20	0.12	0.58	0.19	0.52	0.18	0.55

Values for Zr, Co, V and Cr for samples analyzed in Run 2 have been reduced by 45%, 13%, 13% and 10% respectively from the original concentrations reported.

TABLE A-1, continued, part (b)

SAMPLE:		87-181-2	86-M4-2	86-36-2	87-158-2	87-161-2	86-34-6	87-159-2
Analytical Run		2	1	1	2	2	1	2
FORMATION		Cold F	Cold F	Cold F	Cold F	Cold F	Cold F	Cold F
Unit Type		RS	RwT	RS	RS	RS	RS	RD
Rock Name		rhy	rhy	rhy	rhy	rhy	rhy	rhy
District		Will	Joan	Nation	Nation	Nation	Nation	Nation
UTM E		515000	505300	505700	510200	509500	506800	509300
UTM N		6376200	6371200	6390400	6389600	6390100	6391500	6389600
	ppm							
XRF	Ba	1157	1039	130	207	223	929	635
	Rb	228	82	145	148	136	117	164
	Sr	129	114	81	72	81	72	62
	Zr	172	246	482	173	179	102	66
ICP	Co	4	4	1	3	3	2	3
	Cr	13	14	12	10	9	9	6
	Cu	12	13	10	28	12	7	12
	Ni	0	5	5	7	6	3	0
	V	15	38	11	3	3	1	3
	Zn	52	130	43	27	25	14	0
	La	33	37	64	41	36	32	28
	Ce	68	67	120	82	76	60	34
	Nd	43	36	59	37	38	25	11
	Sm	5.5	6.3	9.6	7.3	6.6	3.4	1.5
	Eu	1.4	1.3	0.4	0.3	0.5	0.1	0.1
	Gd	5.6	7.7	12.0	6.6	6.5	3.4	1.3
	Dy	5.5	8.9	13.0	7.3	7.4	4.1	1.5
	Y	33	53	81	44	44	23	9
	Yb	3.9	5.9	10.0	5.7	5.8	3.3	1.6
	Nb	14						8
INAA	Sc	4			4	5	2	1
	Th	11.0			14.0	14.0	20.9	22.7
	U	6.7			3.2	4.1	7.7	6.8
weight% ratios	Ba/La	35	28	2	5	6	29	23
	La/Yb	8.5	6.3	6.4	7.2	6.2	9.7	17.5
	La/Nb	2.36						3.50
	K/Rb	233	420	340	327	297	581	346
	Rb/Sr	1.77	0.72	1.79	2.07	1.68	1.63	2.65

Values for Zr, Co, V and Cr for samples analyzed in Run 2 have been reduced by 45%, 13%, 13% and 10% respectively from the original concentrations reported.

TABLE A-1, continued, part (b)

SAMPLE:		87-157-2	86-93-2	86-56-2	87-91-2	87-160-3	87-115-2	86-80-4
Analytical Run FORMATION Unit Type Rock Name		2	1	1	2	2	2	1
		Cold F	Cold F	Cold F	Cold F	Cold F	Cold F	Cold F
		RS rhy	RS rhy	RwT rhy	RF rhy	RD rhy	RF rhy	RS rhy
District		Nation	Nation	Joan	Ice Box	Nation	Ice Box	Nation
UTM E		510400	511700	504900	491200	509300	494700	509200
UTM N		6389500	6387700	6371800	6398300	6389900	6396200	6386900
		ppm						
XRF	Ba	129	478	1189	581	836	1190	514
	Rb	169	150	240	228	98	142	78
	Sr	32	37	43	72	93	313	53
	Zr	175	263	412	103	134	113	360
ICP	Co	3	2	3	3	3	5	2
	Cr	13	10	15	6	11	12	21
	Cu	19	5	8	12	18	17	15
	Ni	9	3	5	1	1	0	6
	V	7	1	10	6	28	10	7
	Zn	49	52	70	19	1	18	53
	La	55	28	81	32	28	23	43
	Ce	110	58	130	63	60	44	87
	Nd	45	28	82	25	28	21	45
	Sm	9.0	4.3	16.0	4.5	3.6	3.8	8.5
	Eu	0.1	0.3	0.5	0.3	0.7	0.6	0.3
	Gd	8.0	4.9	15.0	4.1	2.8	3.2	9.7
	Dy	9.2	5.8	14.0	4.8	3.9	3.5	12.0
	Y	55	39	79	30	23	22	73
	Yb	7.0	4.6	7.8	3.9	2.9	2.7	8.5
	Nb			27				23
INAA	Sc	2			2		3	
	Th	19.0			19.0		12.0	
	U	5.2			6.0		3.9	
weight% ratios	Ba/La	2	17	15	18	32	52	12
	La/Yb	7.9	6.1	10.4	8.2	9.7	8.5	5.1
	La/Nb			3.00				1.87
	K/Rb	231	346	331	254	503	280	752
	Rb/Sr	5.28	4.05	5.58	3.14	1.05	0.45	1.47

Values for Zr, Co, V and Cr for samples analyzed in Run 2 have been reduced by 45%, 13%, 13% and 10% respectively from the original concentrations reported.

TABLE A-1, continued, part (b)

SAMPLE:		86-88-11	86-M4-5	87-171-2	86-3-4	86-54-2	87-228-3	87-231-2
Analytical Run		1	1	2	1	1	2	2
FORMATION		Cold F	Cold F	Cold F	Cold F	Cold F	Grif Ck	Grif Ck
Unit Type		RS	RwT	MF	RD	RwT	MF	MF
Rock Name		rhy	rhy	and	rhy	rhy	B and	bas
District		Nation	Joan	Will	Nation	Joan	Griffith	Griffith
UTM E		509400	505000	512700	509200	502400	529700	529000
UTM N		6388300	6371200	6377100	6391300	6372800	6373000	6373600
	ppm							
XRF	Ba	171	1273	720	406	1265	1417	866
	Pb	56	84	260	151	102	71	69
	Sr	56	105	68	122	104	444	548
	Zr	336	212	144	107	250	74	59
ICP	Co	1	4	4	2	4	35	32
	Cr	9	13	16	14	20	387	216
	Cu	7	21	21	7	12	72	130
	Ni	5	5	4	4	5	91	39
	V	11	10	29	7	18	200	226
	Zn	53	31	10	21	55	91	71
	La	47	14	35	33	29	12	11
	Ce	93	28	71	60	60	26	25
	Nd	49	13	40	25	34	19	21
	Sm	9.9	1.4	7.6	4.4	4.9	2.9	3.2
	Eu	0.9	0.4	1.2	0.1	1.2	0.9	1.1
	Gd	9.6	1.7	7.5	4.0	7.3	3.3	3.8
	Dy	11.0	2.0	7.0	4.5	8.8	3.3	3.7
	Y	63	14	36	25	52	17	19
	Yb	6.9	2.4	4.1	3.1	5.8	1.9	2.0
	Nb		9	17	13		6	
INAA	Sc	7		17	2		26	31
	Th	13.0		6.3	20.2		4.9	2.1
	U	3.5		2.8	8.0		2.4	0.9
weight% ratios	Ba/La	4	91	21	12	44	118	79
	La/Yb	6.8	5.8	8.5	10.6	5.0	6.3	5.5
	La/Nb		1.56	2.06	2.54		2.00	
	K/Rb	521	448	353	360	480	386	335
	Rb/Sr	1.00	0.80	3.82	1.24	0.98	0.16	0.13

Values for Zr, Co, V and Cr for samples analyzed in Run 2 have been reduced by 45%, 13%, 13% and 10% respectively from the original concentrations reported.

TABLE A-1, continued, part (b)

SAMPLE:		87-229-2	87-219-2	87-234-2	87-142-2	87-226-7	87-9-3	87-81-2
Analytical Run FORMATION Unit Type Rock Name		2	2	2	2	2	2	2
		Griff Ck	Griff Ck	Griff Ck	Griff Ck	Griff Ck	Hazel?	Hazel?
		MF B and	MF B and	DS dac	DwT and	MF and	MD B and	RD rhy
District		Griffith	Griffith	Griffith	Ice Box	Griffith		Knife Edge
UTM E		529500	532400	528200	500600	529300	440900	483900
UTM N		6373000	6370400	6372800	6398400	6373900	6393500	6402400
		ppm						
XRF	Ba	1733	572	1576	1216	1496	317	972
	Rb	67	46	58	71	91	34	105
	Sr	571	495	465	404	572	271	114
	Zr	91	94	103	86	103	96	123
ICP	Co	26	7	13	11	14	34	5
	Cr	180	15	18	15	15	43	6
	Cu	33	21	32	20	31	52	17
	Ni	32	9	0	3	0	31	0
	V	183	131	96	104	96	357	7
	Zn	96	86	67	82	70	110	0
	La	12	24	18	17	19	14	29
	Ce	26	48	36	34	38	31	55
	Nd	21	26	22	25	22	34	24
	Sm	2.9	4.7	3.6	3.9	3.4	4.8	3.6
	Eu	0.9	1.5	0.9	1.1	1.1	1.8	0.5
	Gd	3.3	4.3	3.3	3.7	3.4	7.1	3.4
	Dy	3.3	3.9	3.3	3.4	3.2	7.9	3.6
	Y	18	21	19	19	17	45	21
	Yb	2.0	2.2	2.2	2.2	2.0	5.0	2.8
	Nb	5	11	5	5	6		
INAA	Sc	25	19		12		37	2
	Th	2.1	5.0		5.3		1.9	17.0
	U	0.9	1.9		2.1		1.0	6.0
weight%	Ba/La	144	24	88	72	79	23	34
	La/Yb	6.0	10.9	8.2	7.7	9.5	2.8	10.4
ratios	La/Nb	2.40	2.18	3.60	3.40	3.17		
	K/Rb	401	381	420	420	322	91	352
	Rb/Sr	0.12	0.09	0.12	0.18	0.16	0.13	0.92

Values for Zr, Co, V and Cr for samples analyzed in Run 2 have been reduced by 45%, 13%, 13% and 10% respectively from the original concentrations reported.

TABLE A-1, continued, part (b)

SAMPLE: 87-218-16		87-86-2	P87-10-2	87-19-2	TSAYB	87-221-3	87-222-2
Analytical Run		2	2	2	3	2	2
FORMATION		Stu?	Stu?	Stu?	Stuhini	Stuhini	Stuhini
Unit Type		MS	MD?	MF	MF	MF	MF
Rock Name		bas	bas	B and	bas	B and	B and
District		Griffith	KnifeEdge	KnifeEdge		Griffith	Griffith
UTM E		532800	484100	485900	454400	531800	531700
UTM N		6369800	6403800	6403800	6404000	6369300	6368900
	ppm						
XRF	Ba	311	1155	854	1023	319	1824
	Rb	67	76	49	44	34	106
	Sr	297	771	437	583	718	539
	Zr	52	82	50	84	51	91
ICP	Co	34	29	23	23	31	27
	Cr	153	33	23	64	180	162
	Cu	110	120	170	97	140	81
	Ni	52	20	12	22	60	22
	V	235	218	209	200	260	200
	Zn	72	110	87	88	51	72
	La	10	9	13	12	16	13
	Ce	21	21	24	25	34	26
	Nd	13	16	18	55	17	19
	Sm	3.0	2.9	2.4	2.0	4.9	3.0
	Eu	0.9	1.0	0.8	1.1	1.4	0.8
	Gd	3.0	3.5	2.6	42.0	4.2	3.0
	Dy	3.1	3.4	2.8	2.7	3.6	3.1
	Y	16	16	15	17	20	17
	Yb	1.6	1.7	1.6	1.6	1.7	1.8
	Nb		6				1.9
INAA	Sc	30		22			25
	Th	1.9		1.7			4.7
	U	0.8		0.8			2.3
weight% ratios	Ba/La	31	124	66	85	20	140
	La/Yb	6.3	5.5	8.1	7.5	9.4	7.2
	La/Nb		1.55				
	K/Rb	228	428	455	366	463	349
	Rb/Sr	0.23	0.10	0.11	0.08	0.05	0.17

Values for Zr, Co, V and C for samples analyzed in Run 2 have been reduced by 45%, 13%, 13% and 10% respectively from the original concentrations reported.

TABLE A-1, continued, part (b)

SAMPLE:		87-88-2	87-74-2	LD-291-3	2-AP-TS5	LD-314-1	D-283-2a	LD-316-1
Analytical Run		2	2	3	3	3	3	3
FORMATION		Stuhini	Stuhini	Toodog	Toodog	Toodog	Toodog	Toodog
Unit Type		MF	MF					
Rock Name		bas	bas	and	bas	and	and	dac
District	KnifeEdge	KnifeEdge						
UTM E	484000	481400						
UTM N	6404900	6404300						
	ppm							
XRF	Ba	1105	458	1569	1549	1654	1418	1309
	Rb	58	88	100	25	102	63	94
	Sr	1555	493	637	985	560	902	544
	Zr	94	57	93	65	108	90	101
ICP	Co	34	30	23	21	19	22	17
	Cr	17	79	11	8	9	9	12
	Cu	130	32	33	37	6	14	12
	Ni	13	19	0	0	0	0	0
	V	278	235	190	250	110	150	99
	Zn	83	83	63	88	57	80	53
	La	8	8	14	20	16	15	18
	Ce	18	19	29	46	31	31	34
	Nd	20	16	18	30	17	20	20
	Sm	3.2	2.9	3.8	6.4	3.8	4.1	3.9
	Eu	1.2	1.2	1.2	1.8	1.2	1.3	1.1
	Gd	4.5	3.9	3.7	5.1	3.5	4.0	3.5
	Dy	4.6	4.1	3.4	4.1	3.3	3.6	3.2
	Y	22	21	20	22	20	22	19
	Yb	2.3	2.2	2.0	1.9	2.1	2.1	1.8
	Nb							
INAA	Sc	32	29					
	Th	1.0	0.8					
	U	0.9	0.4					
weight% ratios	Ba/La	147	56	112	77	103	95	73
	La/Yb	3.3	3.7	7.0	10.5	7.6	7.1	10.0
	La/Nb							
	K/Rb	450	129	302	773	344	363	350
	Rb/Sr	0.04	0.18	0.16	0.03	0.18	0.07	0.17

Values for Zr, Co, V and Cr for samples analyzed in Run 2 have been reduced by 45%, 13%, 13% and 10% respectively from the original concentrations reported.

TABLE A-1, continued, part (b)

SAMPLE:		LD-311-9	85MM68	4MM77-1	MM138-1	5MM75-1	85MM90	5MM12-2
Analytical Run FORMATION Unit Type Rock Name	3		2	2	2	2	2	2
	Toodog		Stu/Haz	Stu/Haz	Stu/Haz	Stu/Haz	Stu/Haz	Stu/Haz
	dac		bas	bas	bas	bas	bas	B and
District UTM E UTM N								
ppm								
XRF	Ba	1352	151	327	701	653	599	244
	Rb	74	44	36	66	66	38	67
	Sr	521	518	435	574	546	773	291
	Zr	96	42	41	54	51	64	98
ICP	Co	17	40	37	30	39	31	26
	Cr	10	324	270	60	35	22	32
	Cu	4	25	36	100	36	54	37
	Ni	0	94	77	31	20	9	10
	V	94	235	296	270	322	235	209
	Zn	81	100	59	74	100	96	130
	La	17	6	36	9	8	6	15
	Ce	33	14	9	21	18	15	17
	Nd	17	12	10	17	16	16	28
	Sm	3.9	2.1	1.8	2.7	3.2	2.8	6.1
	Eu	1.1	0.8	0.7	0.9	1.2	1.2	2.1
	Gd	3.4	2.3	2.4	2.7	3.9	3.5	6.6
	Dy	3.2	2.7	2.7	2.5	4.1	3.8	6.6
	Y	20	14	13	13	22	21	32
	Yb	2.1	1.3	1.3	1.3	2.4	2.3	2.9
	Nb		2	1				
INAA	Sc		35	36	27	33	30	
	Th		0.4	0.4	1.6	0.8	1.1	
	U		<.2	<.2	0.7	0.3	<.2	
weight% ratios	Ba/La	80	25	9	75	86	94	16
	La/Yb	8.1	4.6	27.7	7.2	3.2	2.8	5.2
	La/Nb		3.00	36.00				
	K/Rb	396	93	126	178	189	304	148
	Rb/Sr	0.14	0.08	0.08	0.11	0.12	0.05	0.23

Values for Zr, Co, V and Cr for samples analyzed in Run 2 have been reduced by 45%, 13%, 13% and 10% respectively from the original concentrations reported.

TABLE A-1, continued, part (b)

SAMPLE:		85MM54-1	5MM84-4	4MM68-1	5MM33-3	MM127-1	5MM1003
Analytical Run		2	2	2	2	2	2
FORMATION		Stu/Haz	Stu/Haz	Stu/Haz	Stu/Haz	Stu/Haz	Stu/Haz
Unit Type							
Rock Name		bas	B and	B and	and	dac	dac
District							
UTM E							
UTM N							
		ppm					
XRF	Ba	1428	961	461	797	1222	1479
	Rb	94	62	58	62	63	69
	Sr	253	436	184	551	450	125
	Zr	111	101	77	92	87	89
ICP	Co	22	27	27	21	10	11
	Cr	25	30	74	59	59	60
	Cu	20	26	160	19	15	13
	Ni	1	1	46	4	0	0
	V	157	174	261	139	42	44
	Zn	73	220	390	110	110	54
	La	23	18	11	15	17	13
	Ce	52	43	27	35	40	27
	Nd	35	34	23	28	33	22
	Sm	6.3	6.9	4.4	5.9	6.0	3.4
	Eu	1.7	2.1	1.3	1.9	2.2	1.2
	Gd	6.0	7.7	5.0	6.5	6.8	3.9
	Dy	5.5	7.6	5.1	6.7	6.7	4.7
	Y	29	40	27	34	36	29
INAA	Yb	3.0	4.2	2.9	3.1	3.8	3.3
	Nb				5		
	Sc		27		25	20	13
	Th		2.5		2.2	3.5	3.3
weight%	U		1.1		0.8	1.5	1.4
	Ba/La	62	53	42	53	72	114
	La/Yb	7.7	4.3	3.8	4.8	4.5	3.9
	La/Nb				3.00		
ratios	K/Hb	541	350	136	239	310	414
	La/Cr	0.37	0.14	0.30	0.11	0.14	0.55

Values for Zr, Co, V and Cr for samples analyzed in Run 2 have been re
45%, 13%, 13% and 10% respectively from the original concentrations r

Figure A-1

Graphs of major oxides and selected trace elements for fourteen rock samples (Table A-2), illustrating analytical precision, variability among analytical runs, and the absence of significant contamination by grinding. The abscissa is used for analyses from the third analytical run of fractions ground in ceramic (Ceramic, 3). The ordinate is used for analyses of different fractions of the same sample which had been either analyzed in a different run (Ceramic, 1; Ceramic, 2), or ground in agate (Agate, 3). See text and Table A-2 for details.

Figure A-1(a)

Figure A-1(b)

TiO₂
weight %

265

Figure A-1(c)

Al₂O₃
weight %

Figure A-1(d)

Figure A-1(e)

Figure A-1(f)

MgO
weight %

267

Figure A-1(g)

CaO
weight %

Figure A-1(h)

Na₂O
weight %

268

Figure A-1(i)

K₂O
weight %

Figure A-1(j)

P205

weight %

Figure A-1(k)

Ba

ppm

Figure A-1(l)

Sr
ppm

270

Continued...

Figure A-1(m)

Zr
ppm

271

Figure A-1(n)

Zr (-45%)
ppm

Figure A-1(o)

V
ppm

272

Figure A-1(p)

V (-13%)
ppm

4

of/de

4

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Figure A-1(q)

La
ppm

273

Figure A-1(r)

Nd
ppm

Figure A-1(s)

Figure A-1(t)

TABLE A-2

Concentrations of major and trace elements obtained from three analytical runs at the geochemical laboratories of the Geological Survey of Canada (GSC) in Ottawa, Canada. Run 1: 1987; Run 2: 1988; Run 3: 1990. Grinding of rock chips to powder was done in ceramic by the GSC, and in agate by X-Ray Assays Laboratories. Crushing of rocks to rock chips was done with a metal jaw crusher at the GSC.

The concentrations of Zr, Co, Cr and V from Run 2 were found to be systematically higher than those from Runs 1 and 3. Adjusted values for each of these elements are given in additional rows; the percentage by which these elements have been reduced is given in the Grinding Material column.

Grinding Material	Run	Samples														
		86-7-2	86-18-2	86-38-5	86-44-5	86-80-4	87-40-3	87-74-2	87-88-2	87-97-5	87-139-2	87-221-3	87-226-7	87-231-2		
SiO ₂	ceramic	50.4	54.2	52.3	49.8	75.6										
	ceramic						56.3	51.4	50.0	53.2	51.4	56.9	61.5	51.2		
	agate	50.2	53.8	52.0	40.1	75.8	56.2	51.0	50.6	53.0	51.0	56.6	61.9	51.1		
	ceramic	50.3	54.1	52.1	49.4	75.7	56.2	50.9	49.7	52.8	51.2	56.9	62.5	50.7		
TiO ₂	ceramic	1.20	1.75	1.08	0.55	0.20										
	ceramic						1.03	1.12	1.03	1.02	1.23	1.07	0.72	0.60	0.81	
	agate	1.18	1.74	1.08	0.95	0.17	1.06	1.14	0.99	0.98	1.24	1.08	0.73	0.58	0.86	
	ceramic	1.19	1.74	1.06	0.95	0.16	1.05	1.13	1.00	1.01	1.24	1.10	0.71	0.57	0.82	
Al ₂ O ₃	ceramic	20.1	16.7	20.7	16.3	11.1										
	ceramic						18.0	18.0	14.9	17.1	16.7	14.7	18.0	14.3		
	agate	20.0	16.8	20.6	16.5	11.2	18.2	18.6	18.4	17.3	17.3	15.6	17.8	16.1		
	ceramic	20.1	16.8	20.8	16.5	11.3	18.3	18.4	18.6	14.9	17.3	17.2	14.8	17.7	14.6	
FeO*	ceramic	9.6	10.5	7.1	8.3	2.8										
	ceramic						8.3	9.6	9.3	11.3	9.7	9.6	8.4	6.3	9.0	
	agate	9.6	10.1	7.3	8.1	2.7	8.1	9.4	9.0	10.7	9.4	9.3	8.0	5.9	8.9	
	ceramic	9.5	10.5	7.0	8.2	2.7	8.0	9.4	9.0	11.2	9.6	9.2	8.2	5.8	8.9	
MnO	ceramic	0.34	0.26	0.41	0.31	0.06										
	ceramic						0.16	0.30	0.17	0.24	0.16	0.21	0.15	0.13	0.22	
	agate	0.34	0.28	0.40	0.32	0.06	0.16	0.29	0.17	0.21	0.15	0.19	0.15	0.13	0.20	
	ceramic	0.33	0.25	0.39	0.30	0.06	0.16	0.30	0.17	0.24	0.16	0.20	0.14	0.11	0.22	

TABLE A-2, continued

Grinding Material	Run	Samples														
		86- 7-2	86- 18-2	86- 38-5	86- 44-5	86- 49	86- 80-4	87- 34-2	87- 40-3	87- 74-2	87- 88-2	87- 97-5	87- 139-2	87- 221-3	87- 226-7	87- 231-2
Zr	ceramic	68	150	75			360	161	148	104	170	152	122	166	187	107
	ceramic							89	81	57	94	84	67	91	103	59
	-45% agate	52	157	87	56	442		111	108	58	71	102	78	99	108	59
	ceramic	56	156	84	55	423		109	111	57	67	106	80	83	111	54
	ceramic	35	28	26	36	2		25	32	35	39	30	38	31	16	37
Co	ceramic							22	28	30	34	26	33	27	14	32
	-13% agate	27	27	26	36	2		16	25	25	28	21	27	24	12	27
	ceramic	26	24	24	32	1		20	26	25	30	21	26	24	12	27
	ceramic	76	20	54	380	21		26	33	88	19	28	61	180	17	240
Cr	ceramic							23	30	79	17	25	55	162	15	216
	-10% agate	20	14	54	340	15		10	26	72	8	17	43	120	12	150
	ceramic	21	14	53	340	14		14	27	58	9	18	41	150	13	210
	ceramic	55	45	48	53	15		90	55	32	130	35	28	81	31	130
Cu	ceramic	26	30	38	44	14		51	39	11	100	12	7	55	19	84
	agate	32	29	36	42	10		51	38	11	100	16	16	59	19	92
	ceramic	34	10	18	130	6		15	26	19	13	11	20	22	0	39
Ni	ceramic	14	0	12	120	7		3	18	12	2	1	8	15	0	21
	agate	12	0	10	110	1		5	19	7	5	1	10	17	0	25
	ceramic	290	370	250	210	7		260	230	270	320	280	320	230	110	260
V	ceramic							226	200	235	278	244	278	200	96	226
	-13% agate	260	350	260	210	10		220	200	240	290	260	290	200	100	220
	ceramic	280	350	250	200	9		210	190	240	290	250	280	200	100	220
	ceramic	110	140	380	78	53		80	280	83	83	93	86	72	70	71
Zn	ceramic							69	270	56	68	86	67	61	64	57
	agate	72	110	370	57	48		75	270	56	65	79	67	63	64	53
	ceramic	75	110	350	52	45		16	16	8.2	7.5	15	13	13	19	11
	ceramic	12	21	14	9.7	43		15	15	7.4	7.5	15	13	12	15	12
La	ceramic							18	15	9.1	6.7	15	27	12	15	11
	-10% agate	11	18	14	10	43		15	15	7.4	7.5	15	13	12	15	12
	ceramic	11	18	14	10	45		18	15	9.1	6.7	15	27	12	15	11

TABLE A-2, continued

Grinding Material	Run	Samples														
		86- 7-2	86- 18-2	86- 38-5	86- 44-5	86- 80-4	87- 34-2	87- 40-3	87- 74-2	87- 88-2	87- 97-5	87- 139-2	87- 221-3	87- 226-7	87- 231-2	
Ce	ceramic	25	44	28	22	87	35	34	19	18	33	28	26	38	25	
	ceramic	25	42	28	24	86	32	32	16	16	32	28	25	31	26	
	agate	23	39	28	23	92	39	32	20	15	32	61	25	31	23	
Nd	ceramic	19	29	18	17	45	25	28	16	20	22	19	19	22	21	
	ceramic	2					28	30	23	66	35	19	16	16	16	
	agate	3	17	21	12	7.2	10	15	6.1	13	19	46	22	13	22	
Sm	ceramic	1	3.8	5.1	3.1	2.6	8.5	4.3	4	2.9	3.2	4.9	4.1	3	3.2	
	ceramic	2	4.5	6.4	4.3	4.1	10	4.7	2.9	1.8	4.4	4.2	3.4	3.7	4	
	agate	3	4.5	6.6	4.4	4.3	10	5.5	4.7	3.6	3.4	4.9	7.2	3.6	4.2	
Eu	ceramic	1	1.4	1.8	1.2	1.1	0.3	1.4	1.4	1.2	1.2	1.5	1.3	0.8	1.1	
	ceramic	2	1.5	1.8	1.3	1.3	0.4	1.4	1.5	1.1	1	1.5	1.4	0.9	1.1	
	agate	3	1.4	1.8	1.3	1.3	0.4	1.6	1.4	1.3	1.3	1.6	2.1	0.9	1.1	
Gd	ceramic	1	4.4	6.5	4.1	3.5	9.7	4.7	4.4	3.9	4.5	4.8	4.4	3	3.4	
	ceramic	2	4.3	6.2	4	3.5	10	4.6	4.6	3.3	3.5	4.8	4.5	3.3	3.3	
	agate	3	4.3	6.5	4.4	3.5	10	4.7	4.2	3.5	4.2	5	5.8	3.2	3.2	
Dy	ceramic	1	4.3	6.4	3.9	3.2	12	4.5	4.3	4.1	4.6	4.8	4.5	3.1	3.2	
	ceramic	2	4.2	6.1	4	3.4	11	4.5	4.4	3.6	3.7	4.8	4.4	3.2	3	
	agate	3	4.1	6.1	4.3	3.4	12	4.6	4.1	3.7	4.3	5	5.1	3.3	3.1	
Y	ceramic	1	22	35	19	16	73	25	23	21	22	25	23	17	17	
	ceramic	2	24	35	23	18	75	26	25	21	21	28	26	19	18	
	agate	3	19	30	22	18	78	25	22	20	23	28	28	19	17	
Yb	ceramic	1	2.2	3.2	1.7	1.5	8.5	2.6	2.4	2.2	2.3	2.6	2.5	1.8	2	
	ceramic	2	2.3	3.4	2.4	1.8	8.4	2.6	2.4	2.1	2.1	2.8	2.5	1.8	2.1	
	agate	3	1.6	2.4	2	1.8	8.6	2.6	2.3	2.1	2.3	2.9	2.6	1.9	1.8	

TABLE A-3

		Analytical Precision		Method of Analysis
		absolute	relative%	
Weight %	SiO ₂	0.4	1	XRF
	TiO ₂	0.03	1	
	Al ₂ O ₃	0.4	1	
	FeO*	0.1	3	
	MnO	0.01	2	
	MgO	0.1	2	
	CaO	0.2	2	
	Na ₂ O	0.5	1	
	K ₂ O	0.1	2	
	P ₂ O ₅	0.02	1	
ppm	Ba	20	10	ICP
	Rb	20	2	
	Sr	20	15	
	Zr	20	10	
	Be	10	5	
	Co	5	5	
	Cr	10	5	
	Cu	10	5	
	Ni	10	5	
	V	5	5	
	Zn	5	5	ICP
	La	0.8	10	
	Ce	0.8	10	
	Nd	10	30	
	Sm	0.3	5	
	Eu	0.1	8	
	Gd	0.2	6	
	Dy	0.3	5	
	Y	1.5	8	
	Yb	0.3	10	
	Nb	1	5	INAA
	Sc	0.4	5	
	Th	0.5	5	
	U	0.5	5	

Total uncertainty = absolute + relative% (approximately two standard errors).

Absolute uncertainty given in percent for oxides, and ppm for trace elements.

All analyses performed at the Geological Survey of Canada in Ottawa, Canada, except for Nb, which was analyzed by X-Ray Assay Laboratories, Don Mills, Canada, and Sc, U and Th which were analyzed by Bondar-Clegg, Ottawa, Canada.

XRF = X-ray fluorescence; ICP = inductively coupled plasma; INAA = instrumental neutron activation analysis.

TABLE A-4

Measured and expected values of chemical components of international standards, a sample of optically clear quartz, and a basaltic andesite analyzed in 1985 by X-ray fluorescence at the Dept. of Oceanography, The University of British Columbia. Expected values for international standards are from Abbey, (1983). For each pair of measured and expected values, the difference has been calculated, and may be compared to the uncertainty of precision (approximately two standard errors) for the measured value.

Meas = measured value Exp = expected value Diff = measured value - expected value
2 SE = approximate 2 standard error uncertainty in measured value

		International Standards					Clear Quartz	UBC 84-327
		AN-G	BM	GS-N	BE-N	BHVO-1		
SiO ₂	Meas	46.2	52.4	67.1	40.1		99.2	
	Exp	46.3	49.5	66.0	38.4		100.0	
	Diff	-0.1	2.9	1.1	1.7		-0.8	
	2 SE	0.86	0.92	1.07	0.80		1.39	
TiO ₂	Meas	0.22	1.19	0.66	2.72		0.01	
	Exp	0.22	1.14	0.68	2.62		0.00	
	Diff	0.00	0.05	-0.02	0.10		0.01	
	2 SE	0.032	0.042	0.037	0.057		0.030	
Al ₂ O ₃	Meas	29.8	17.2	15.2	10.4		0.7	
	Exp	29.8	16.2	14.7	10.1		0.0	
	Diff	0.0	1.0	0.5	0.3		0.7	
	2 SE	0.80	0.57	0.55	0.50		0.41	
FeO*	Meas	2.2	9.2	3.3	12.2		0.0	
	Exp	3.0	8.7	3.4	11.6		0.0	
	Diff	-0.8	0.5	-0.1	0.6		0.0	
	2 SE	0.27	0.48	0.30	0.57		0.20	
MnO	Meas	0.04	0.15	0.05	0.21		0.00	
	Exp	0.04	0.14	0.06	0.20		0.00	
	Diff	0.00	0.01	0.00	0.01		0.00	
	2 SE	0.011	0.013	0.011	0.014		0.010	
MgO	Meas	1.8	7.8	2.3	13.7		0.1	
	Exp	1.8	7.5	2.3	13.2		0.0	
	Diff	0.0	0.3	0.0	0.5		0.1	
	2 SE	0.14	0.26	0.15	0.37		0.10	
CaO	Meas	16.0	6.7	2.5	14.8		0.0	
	Exp	15.9	6.5	2.5	13.9		0.0	
	Diff	0.1	0.2	0.0	0.9		0.0	
	2 SE	0.52	0.33	0.25	0.50		0.20	
Na ₂ O	Meas	1.6	5.1	3.8	3.3		0.0	
	Exp	1.6	4.6	3.8	3.2		0.0	
	Diff	0.0	0.5	0.0	0.1		0.0	
	2 SE	0.52	0.55	0.54	0.53		0.50	
K ₂ O	Meas	0.1	0.2	4.7	1.5		0.0	
	Exp	0.1	0.2	4.6	1.4		0.0	
	Diff	0.0	0.0	0.1	0.1		0.0	
	2 SE	0.10	0.10	0.19	0.13		0.10	
P ₂ O ₅	Meas	0.02	0.11	0.28	1.09		0.00	
	Exp	0.01	0.11	0.28	1.06		0.00	
	Diff	0.01	0.01	0.00	0.03		0.00	
	2 SE	0.020	0.021	0.023	0.031		0.020	

TABLE A-4, continued

		International Standards					Clear Quartz	UBC 84-327
		AN-G	BM	GS-N	BE-N	BHVO-1		
Ba	Meas	97	282	1341			4	363
	Exp	34	260	1400			0	387
	Diff	63	22	-59			4	-24
	2 SE	30	48	154			20	56
Rb	Meas	4	9	189			34	21
	Exp	1	13	190			0	16
	Diff	3	-4	-1			34	6
	2 SE	20	20	24			21	20
Sr	Meas	79	249	662			0	695
	Exp	76	230	570			0	666
	Diff	3	19	92			0	29
	2 SE	32	57	119			20	124
Zr	Meas	13	108	265			12	116
	Exp	15	98	240			0	118
	Diff	-2	10	25			12	-2
	2 SE	21	31	47			22	32
Co	Meas	22	36	63			1	22
	Exp	25	34	65			0	
	Diff	-3	2	-2			1	
	2 SE	6	7	8			5	6
Cr	Meas	44	110	56			1	18
	Exp	50	120	55			0	17
	Diff	-6	-10	1			1	1
	2 SE	12	16	13			10	11
Cu	Meas	14	37	20			1	64
	Exp	19	45	20			0	
	Diff	-5	-8	0			1	
	2 SE	11	12	11			10	13
Ni	Meas	30	52	26			2	18
	Exp	35	56	34			0	15
	Diff	-5	-4	-8			2	3
	2 SE	12	13	11			10	11
V	Meas	56	180	59			0	190
	Exp	70	180	62			0	231
	Diff	-14	0	-3			0	-41
	2 SE	8	14	8			5	15
Zn	Meas	0	93	30			0	61
	Exp	20	115	48			0	
	Diff	-20	-22	-18			0	
	2 SE	5	10	7			5	8
La	Meas	3	8	63			0	12
	Exp	2	9				0	
	Diff	1	-1				0	
	2 SE	1.1	1.6	7.1			0.8	2.0
Ce	Meas	6	19	120			1	28
	Exp	5	27				0	
	Diff	1	-8				1	
	2 SE	1.4	2.7	12.8			0.9	3.6
Nd	Meas	3	14	47			1	19
	Exp	2					0	
	Diff	1					1	
	2 SE	11	14	24			10	16

TABLE A-4, continued

		International Standards					Clear Quartz	UBC 84-327
		AN-G	BM	GS-N	BE-N	BHVO-1		
Sm	Meas	0.9	4.1	7.0			0.0	4.6
	Exp	0.7	3.7				0.0	
	Diff	0.2	0.4				0.0	
	2 SE	0.35	0.51	0.65			0.30	0.53
Eu	Meas	0.4	1.2	1.6			0.0	1.4
	Exp	0.4	1.1				0.0	
	Diff	0.0	0.1				0.0	
	2 SE	0.13	0.20	0.23			0.10	0.21
Gd	Meas	1.0	4.4	4.6			0.0	4.2
	Exp						0.0	
	Diff						0.0	
	2 SE	0.26	0.46	0.48			0.20	0.45
Dy	Meas	1.3	4.9	3.1			0.2	3.9
	Exp						0.0	
	Diff						0.2	
	2 SE	0.37	0.55	0.46			0.31	0.50
Y	Meas	8	28	17			0	23
	Exp	8	26				0	23
	Diff	0	2				0	0
	2 SE	1.9	2.9	2.4			1.5	2.7
Yb	Meas	0.8	2.5	1.5			0.0	2.1
	Exp	0.9	3.5				0.0	
	Diff	0.0	-1.0				0.0	
	2 SE	0.38	0.55	0.45			0.30	0.51
Nb	Meas					16		4
	Exp					19		5
	Diff					-3		-1
	2 SE					1.8		1.2
Sc	Meas	8	28					24
	Exp	10	34					
	Diff	-2	-6					
	2 SE	0.8	1.8					1.6
Th	Meas	0.2	2.6					2.1
	Exp		3.0					
	Diff		-0.4					
	2 SE	0.50	0.63					0.60
U	Meas	0.2	0.7					0.7
	Exp							
	Diff							
	2 SE	0.50	0.54					0.54

Top of the Cold Fish Volcanics

"Plateau" District

m

Quaternary cover

"Plateau" District

present erosional surface

?

130°W
58°N

Figure 3

Geological Map of the Study Area

Scale 1:100 000 - Échelle 1/100 000

LEGEND

QUATERNARY

- Unconsolidated glacial, fluvial and colluvial sediments

LATE CENOZOIC

MIOCENE to PLEISTOCENE

- Mafic volcanic dykes or necks, in places hosting spinel harzburgite or ilmenite nodules

CRETACEOUS

BARREMIAN to MAASTRICHTIAN

- SUSTUT GROUP: sandstone, siltstone and shale

MIDDLE and UPPER JURASSIC to (?) MIDDLE CRETACEOUS

- BOWSER LAKE GROUP: conglomerate, sandstone, siltstone and shale

EARLY JURASSIC to TERTIARY

- McEwan Creek pluton and other stocks: biotite hornblende leucogranite, and quartz monzonite. Intrudes the Mount Brock volcanics

LOWER to MIDDLE JURASSIC

LOWER to MIDDLE TOARCIAN

Mount Brock volcanics (JM) of the HAZELTON GROUP:

- Undivided lava and volcanoclastic rocks; minor epiclastic rocks and limestone
- Mafic to intermediate lava flows, mainly subaerial; minor felsic volcanic rocks, limestone and sandstone; JMm, pillow lava and marine sedimentary rocks
- Felsic volcanoclastic rocks including welded ignimbrite; minor mafic volcanic rocks; JMw, welded ignimbrite

LOWER PLEISTOCENE to BAJOCIAN

- Undivided sedimentary rocks of the HAZELTON GROUP, including the JOAN, WOLF DEN, MELISSON, ABOU and QUOCK FORMATIONS: shale, siltstone, tuffaceous siltstone, sandstone, conglomerate, breccia and limestone; includes mafic lava and felsic volcanoclastic rocks southwest of Bug Lake and west of Mount Brock

EARLY JURASSIC to TERTIARY

Quaternary cover

57°45'

UNITED
NATIONS
THE
EAGLENE
RANGE

Geological Map of the Nation District

Scale 1:25 000 - Echelle 1/25 000

Metres 500 0 500 1000 1500 2000 Metres

COLD

WOLF DEN, MELISSON, ABOU and QUOCK FORMATIONS: shale, siltstone, tuffaceous siltstone, sandstone, conglomerate, breccia and limestone; includes mafic lava and felsic volcanoclastic rocks southwest of Bug Lake and west of Mount Brock

EARLY JURASSIC to TERTIARY

JTg

Cartmel stock: Fine grained granite and quartz diorite; medium grained quartz monzonite. Intrudes the COLD FISH VOLCANICS

EARLY JURASSIC

Ja

Spatsizi River stock: fine grained alkali feldspar granite. Coeval with the COLD FISH VOLCANICS

LOWER JURASSIC

LOWER PLIENSACHIAN

COLD FISH VOLCANICS (JC) of the HAZELTON GROUP:

JCu

Undivided mafic to felsic lava, sills, dykes, and fragmental volcanic rocks; minor epiclastic rocks and limestone

JCs

Subaerial mafic lava flows interbedded with felsic airfall tuff and nonwelded ignimbrite; minor felsic sills, welded ignimbrite, conglomerate, sandstone, shale and subaqueous mafic lava.

Marine mafic lava; minor sandstone, shale, limestone, tuff and subaerial mafic lava

JCF

Felsic volcanic rocks including sills, dykes, welded and nonwelded ignimbrite, airfall tuff, breccia and lava; minor mafic lava and epiclastic rocks; **JCfi**, mainly ignimbrite; **JCfa**, mainly felsic sills and massive flows; **JCfb**, mainly block lava and associated massive lava

JC8

Epilastic and bioclastic rocks: lahar, breccia, conglomerate, sandstone, siltstone, shale and limestone; minor tuff and lava; **JCS**, mainly shale, siltstone and limestone; **JCa**, mainly lahar, breccia and conglomerate

JCg

Gossan

HETTANGIAN and/or SINEMURIAN to TOARCIAN

Undivided Lower Jurassic volcanics of the HAZELTON GROUP, may include rocks of the Griffith Creek volcanics (JG), the COLD FISH VOLCANICS (JC), and the Mount Brock volcanics (JM)

HETTANGIAN and/or LOWER SINEMURIAN

Griffith Creek volcanics (JG) of the HAZELTON GROUP:

JGm

Malic lava flows, mainly with phenocrysts of plagioclase and augite or hornblende; minor welded ignimbrite and felsic sills, some hosting grains of feldspar, biotite, quartz or hornblende

JGf

Felsic to intermediate sills, ignimbrite and airfall tuff, some units rich in plagioclase, biotite, hornblende or quartz; minor epiclastic rocks and mafic lava; JG1s, sill emplaced in older formations

UPPER TRIASSIC to LOWER JURASSIC

CARNIAN(?) and NORIAN(?) to HETTANGIAN and/or LOWER SINEMURIAN

TJC

Conglomerate, sandstone, shale, mafic to intermediate volcanic breccia, and olistostrome. Conglomerate clasts are predominantly hornblende and plagioclase porphyry andesite, but include augite phyric mafic lava and other volcanic rocks, Norian and Permian limestone, undated varicoloured chert, and felsic to intermediate granitoid. Older than the Griffith Creek volcanics.

CARNIAN(?) and NORIAN to LOWER PLIENSCHACHIAN

[illegible]

Undivided volcanic and sedimentary rocks; may include rocks of the STUHINI

Nation District
f

Quaternary cover

Quaternary cov

Quaternary cover

Quaternary cover

Quaternary cover

?

?

?

Quaternary cover

LEGEND

QUATERNARY

Qs Unconsolidated glacial, fluvial and colluvial sediments

LOWER TO MIDDLE JURASSIC

HAZELTON GROUP (Js , JC)

LOWER PUENSACHIAN TO BAJOCIAN

Undivided sedimentary rocks: may include rocks of the JOAN, WOLF DEN, MELISSON, ABOU and QUOCK FORMATIONS. silt: silt, sandstone, tuffaceous siltstone, conglomerate and limestone

UPPER TRIASSIC to LOWER JURASSIC

CARMAN(?) and NORIAN(?) to HETTANGIAN and/or LOWER SINEMURIAN

KJC

Conglomerate, sandstone, shale, mafic to intermediate volcanic breccia, and olistostrome. Conglomerate clasts are predominantly hornblende and plagioclase porphyry andesite, but include augite phyric mafic lava and other volcanic rocks, Norian and Permian limestone, undated varicoloured chert, and felsic to intermediate granitoid. Older than the Griffith Creek volcanics.

CARNIAN(?) and NORIAN to LOWER PLIENSACHIAN

TJu

Undivided volcanic and sedimentary rocks; may include rocks of the STUHNI GROUP (TS), unit T₁lc, the Griffith Creek volcanics (JG), and the COLD FISH VOLCANICS (JC)

CARNIAN(?) and NORIAN to HETTANGIAN and/or LOWER SINEMURIAN

TJ

Undivided volcanic and sedimentary rocks; may include rocks of the STUHNI GROUP (TS), unit T₁c, and the Griffith Creek volcanics (JG)

LATE TRIASSIC to TERTIARY

Felsic to intermediate, fine to medium grained intrusive rocks

UPPER TRIASSIC

CARNIAN(?) to NORIAN

STUHINI GROUP, TS :

Mafic lava flows, mainly aphyric to augite phyric; minor conglomerate, sandstone, mudstone, limestone and olistostrome.

Mudstone, shale, sandstone and olistostrome; minor conglomerate and mafic lava; TS_{9c}, granitoid pebble and cobble conglomerate and Norian limestone

EARLY to LATE TRIASSIC

Railway pluton and related intrusions: mainly biotite augite meta-monzodiorite

DEVONIAN(?) to CARBONIFEROUS and PERMIAN

Variably deformed and metamorphosed sedimentary and igneous rocks

REFERENCE SYMBOLS FOR MAIN AND INSET MAPS

Geological (stratigraphic and intrusive) boundary
(defined, approximate, assumed).....

Bedding, top known (inclined, horizontal, overturned)..... / + ~~✓~~

Bedding, top unknown (inclined, vertical)..... / /

Bedding, estimated from distant sighting or aerial
photographs (inclined, horizontal, vertical)..... / +

Foliation or cleavage, inclined..... 1

Normal fault (dot on downthrown side)
(defined, approximate, assumed).....

Normal or reverse fault (D, U on downthrown, upthrown sides; defined, approximate, assumed).....

Thrust fault (teeth on hanging wall)
(defined, approximate, assumed).....

Axial trace of upright antiline
(defined, approximate, assumed). . . .

Nation District

f

present erosional surface

Nation District

g

present erosional surface

?

A 2

A 3

thrust fault

LEGEND

QUATERNARY

Qs Unconsolidated glacial, fluvial and colluvial sediments

LOWER to MIDDLE JURASSIC

HAZELTON GROUP (Js, JC)

LOWER PUENSBACHIAN to BAJOCCIAN

Js Undivided sedimentary rocks; may include rocks of the JOAN, WOLF DEN, MELISSON, APOU and QUOCK FORMATIONS: sandstone, siltstone, tuffaceous siltstone, conglomerate, breccia and limestone

LOWER PUENSBACHIAN

COLD FISH VOLCANICS, JC:

JCu	Undivided mafic lava, airfall tuff, welded and nonwelded ignimbrite, felsic silt, tuff, limestone, sandstone, siltstone and shale
JCam	Mafic lava flows intercalated with airfall tuff and nonwelded ignimbrite, minor welded ignimbrite and felsic silt
JCa	Subaerial mafic lava flows, amygdaloidal to dense, aphyric to porphyritic with plagioclase, augite and serpentinized olivine phenocrysts; JCam, mafic marine lava and pillow breccia
JCh	Airfall tuff, lapilli tuff and nonwelded ignimbrite; minor welded ignimbrite, accretionary lapilli tuff, felsic silt and epiclastic rocks
JCw	Welded ignimbrite; minor nonwelded ignimbrite and airfall tuff
JCs	Felsic silt and dikes, flowbanded to massive, aphyric to slightly porphyritic with feldspar phenocrysts
JCi	Felsic volcanic rocks including silt, dikes, welded and nonwelded tuffaceous rocks; minor mafic lava and epiclastic rocks
JCl	Limestone, silty limestone, siltstone and shale

129°00'

Bedding, top unknown (inclined, vertical).....

Bedding, estimated from distant sighting or aerial photographs (inclined, horizontal, vertical).....

Foliation or cleavage, inclined.....

Normal fault (dot on downthrown side)
(defined, approximate, assumed).....

Normal or reverse fault (D, U on downthrown,
upthrown sides; defined, approximate, assumed).....

Thrust fault (teeth on hanging wall)
(defined, approximate, assumed).....

Axial trace of upright anticline
(defined, approximate, assumed).....

Axial trace of syncline (upright, overturned)
(defined, approximate, assumed).....

Location of stratigraphic section (arrows point toward
section top).....

Trace of cross section.....

U-Pb (zircon) age determination.....

Compiled by Derek J. Thorkelson and Carol A. Evenchick, 1991, from geological mapping by Thorkelson (1986, 1987) and Evenchick (1985-1990), and from earlier works: Gabrielse and Tipper (1984); Thomson (1985); Thomson et al. (1986); Read and Psutka (1990).

Figure 7
 Stratigraphic Sections of the Cold Fish Valley

- section letters given at top of sections correspond to those on map
- vertical scale = 1:2 500 (1cm = 25m)
- Uncertainty in unit thickness is about 20%

Quaternary cover

the Cold Fish Volcanics

ons correspond to those on map of study area

m)

u

KEY

Derek John Thorkelson, 1992

Th

Thorkelson, 1992

Stratigraphic correlation:

known _____

probable — ? —

unknown ? ?

Mafic dyke

(A) 3 — U-Pb (zircon) age determination
with reference number

END

24.1 2.92

FIN