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GEOLOGY OF THE HOTAILUH BATHOLITH AND
SURROUNDING VOLCANIC AND SEDIMENTARY ROCKS,
NORTH-CENTRAL BRITISH COLUMBIA

by

ROBERT GORDON ANDERSON

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

Carleton University
Ottawa

May 6, 1983

THREE SISTERS RANGE, NORTHERN BRITISH COLUMBIA.

*"A poem is never finished, it is only
abandoned"*

~Auden

(cited in Pitcher and Berger, 1972)

*"The scoffers said it couldn't be done,
The odds were so great who wouldn't.
But we tackled the job that couldn't
be done,
And what do you know? It couldn't!"*

~Anonymous

(cited in Tabor and Crowder, 1969, p.25)

The undersigned hereby recommend to the Faculty of
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ABSTRACT

The Hotailuh Batholith occurs in the northeastern part of Stikinia in the northern Canadian Cordillera. It is a composite, predominantly calc-alkaline, I-type batholith of Late Triassic and Early to Middle Jurassic age and is surrounded by volcanics and satellitic plutons of similar compositions and age. The Triassic plutonic suite consists of four plutons (in order of known or inferred intrusion): the Stikine Pluton (diorite; K-Ar date, 222 Ma); the Cake Hill Pluton (monzodiorite and quartz monzodiorite; K-Ar dates, 143-151 Ma and 218-227 Ma); the Gnat Lakes Ultramafite (hornblende and hornblende pyroxenite; K-Ar dates 227-230 Ma); and the Beggerlay Creek Pluton (gabbro and diorite; K-Ar date, 218 Ma). The Triassic plutonic suite is overlain nonconformably by the Mesozoic volcanic suite or intruded by comagmatic porphyritic intrusions. The Jurassic plutonic suite intrudes, includes and metamorphoses members of the Triassic plutonic suite.

Five units are distinguished in the deformed Paleozoic and massive Mesozoic sedimentary and volcanic rocks which fringe the batholith and satellitic plutons. The poorly dated volcanoclastics, porphyritic flows and sediments of the Upper Triassic Stuhini Group and Triassic-Jurassic volcanic unit are the most extensive. Sedimentary structures and contrasting stratigraphy along the northern and western batholith margins suggest that the eastern half of the batholith was the site of a Late Triassic volcanic edifice which shed plutonic, then volcanic detritus to the north. Rhyolite fragments in Stuhini Group volcanoclastics suggest contemporaneous felsic and mafic volcanism; two mafic to felsic "cycles" are recognized in the Triassic-Jurassic volcanics. Intrusive relations and whole rock and pyroxene chemistry suggest that the Gnat Lakes Ultramafite and Beggerlay Creek Pluton

may have been comagmatic and coeval with the Stukini Group volcanism; probable feeders for the volcanics are lithologically similar porphyritic hypabyssal dikes. Thrusting of the Upper Triassic rocks over the Lower Jurassic sediments along the northern and eastern Batholith margins predated intrusion of the Jurassic plutonic suite.

The Jurassic plutonic suite is composed of plutons within the batholith (Three Sisters and McBride River Plutons) and satellitic plutons to the north (Snowdrift Creek Pluton) and west (Pallen Creek and Tanzilla Plutons). The plutons are either lithologically homogeneous granodiorite or quartz monzodiorite (McBride River Pluton and parts of the Snowdrift Creek Pluton) or consist of compositionally expanded, sequentially intruded diorite-quartz monzodiorite-quartz monzonite-quartz syenite suites (Three Sisters, Pallen Creek and Tanzilla Plutons and parts of the Snowdrift Creek Pluton).

Intrusive relations involving the Triassic plutonic suite, Upper Triassic Stukini Group and Lower Jurassic sediments provide maximum stratigraphic age constraints in the interpretation of K-Ar (142-208 Ma), U-Pb (170 ± 1 or 184 ± 5 Ma) and Rb-Sr (155 ± 2 Ma; $^{87}\text{Sr}/^{86}\text{Sr}_1 = 0.70359 \pm 0.00003$) isotopic ages for the Jurassic plutonic suite. Most of the suite was probably emplaced after 180-188 Ma.

The complex magmatic history of the Hotailuh Batholith reflects its position at the intersection of the east-trending Stikine Arch and northwest-trending belt of Early to Middle Jurassic plutons. The distribution, geological relations, deformation and isotopic age of the plutonic and volcanic suites in and near the Hotailuh Batholith provide important constraints for plate tectonic models involving Stikinia and the northern Canadian Cordillera.

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I INTRODUCTION

I.1 General Statement

Batholiths are bodies of medium- and coarse-grained crystalline rock which underly areas greater than 104 km^2 (40 mi^2) and form an important constituent of the Earth's continental crust. They are of intellectual, geological and practical interest. Batholiths are formed by igneous activity which has no known analog at the Earth's surface; only the products of these complex processes remain from which the geological history may be unravelled. Nevertheless, the plutonic rocks which make up the batholiths are thought to be representative of melted portions of deeper parts of the Earth which are commonly inaccessible.

Many batholiths are spatially associated with volcanics of about the same composition and age. Although the igneous processes which form volcanic rocks are more easily studied at the Earth's surface, the extent, composition and isotopic age of volcanism around a batholith are commonly masked by later events. The coeval plutonic rocks may provide the best estimates of the composition and absolute age of these altered volcanic rocks.

Important mineral deposits (e.g. oxides and sulphides of copper, molybdenum, tin, tungsten, lead and zinc) occur with plutonic or volcanic rocks. Commonly their occurrence is restricted to a particular unit. An understanding of the lithology, composition, structure, geological relationships and age of the various plutonic and volcanic units in and around a batholith is a prerequisite in the search for these types of mineral deposits.

This thesis is concerned with the Mesozoic (i.e. about 65-250 million years ago) granitic and volcanic rocks in and around the Hotailuh (pronounced hō-tī-lū) Batholith in north-central British Columbia. Their distribution, lithology, structure, geological relations, age, petrography and chemical composition are established in this work. The relationships of the granitic to the volcanic rocks and of both suites to other tectono-stratigraphic assemblages in the northern Cordillera are discussed with reference to the batholith's unique position at the intersection of the Permo-Triassic Stikine Arch and a northwest-trending belt of Jurassic plutons.

1.2 Location, Physiography and Access

The Hotailuh Batholith is in north-central British Columbia, 1050 km northwest of Vancouver and about 56 km south of the community of Dease Lake (approximate center of the batholith is $58^{\circ}07'N$ and $129^{\circ}30'W$; Figure 5). The batholith and satellitic plutons outcrop in the Spatsizi (NTS map-area 104H), Cry Lake (NTS map-area 104I) and Dease Lake (NTS map-area 104J) map-areas.

The batholith underlies the Hotailuh Range of the Stikine Plateau and the Three Sisters Range of the Stikine Ranges (Holland, 1976) and southwest of the Cassiar Mountains. Various named and unnamed creeks and rivers drain the area and include: Gnat Creek and the Tanzilla River in the northwest; McBride River and Moose Creek in the east and south; and Beggerlay, Tees and Latham Creeks in the south and west (Figure 1). The Stikine River bounds the area to the south. Tsenaglodi Lake, Upper and Lower Gnat Lakes, Glacial Lake, Thenatłodi Mountain (elevation 6100 feet or 1859 m), Cake Hill (elevation 6447 feet or 1965 m), Horn Mountain

(elevation 7406 or 2257 m), Glacial Mountain (elevation 7565 feet or 2306 m), Mount Sister Mary and survey peaks 6848 feet (2087 m), 7174 feet (2187 m) and 6222 feet (1896 m) are other useful landmarks.

The batholith underlies an area of 1190 km² of which 114 km² is in the Dease Lake map-area and was not studied. The valleys are high with relief on the order of 300-650 m and the rocks are generally well-exposed.

Access to the area is by foot, truck and helicopter. The Cassiar-Stewart Highway (Highway 37), the abandoned British Columbia Railway rail-bed from the Klappan River crossing to Gnat Lakes, and small, disused mining claims roads permit easy access to the western third of the map-area. A helicopter provides the easiest access to the eastern two-thirds of the batholith and is available at bases at Eddontenajon Lake and Dease Lake. A small, commercial carrier, Trans-Provincial Airlines maintains a regular schedule at the well maintained gravel airstrip at Dease Lake and Canadian Pacific Airlines provides regular scheduled flights into the Watson Lake, Yukon airport.

I.3 Previous Work

The Hotailuh Range was named by G.M. Dawson in 1886 during his reconnaissance up the Stikine and Tanzilla Rivers:

"The mountains which extend to the southeast of the river (the Tanzilla River) here become higher than before, and take the form of a well marked range, which is known to the [Tahltan] Indians as Ho-tai'-luh."

--Dawson (1887, p.69B)

Hanson and McNaughton (1936) were the first to publish a map including the Hotailuh Batholith and were responsible for naming it. The first comprehensive reconnaissance mapping of the area occurred in 1956 during

Operation Stikine and resulted in 1:250,000 scale geological maps for the Cry Lake (Gabrielse, 1962) and Dease Lake (Gabrielse et al., 1962). A diamond drill hole was drilled in the western part of the batholith during a geothermal research program conducted by the Earth Physics Branch and the drill core was logged by Dr. J.C. Souther of the Geological Survey of Canada (Souther, 1971b). Potassium-argon age determinations on samples collected from the batholith during these studies and reported in Leech et al. (1963) and Wanless et al. (1972) indicated two groups of dates¹, 143-170 Ma and 218-222 Ma. The Hotailuh Batholith was extensively prospected during the 1960's and early 1970's in the belief that it might be associated with porphyry copper mineralization found in other Triassic-Jurassic batholiths in the Intermontane Belt. Kerswill (1975) completed a geochemical reconnaissance for Cu, Zn, Pb, Co, Mn and Fe in soil, silt, water and rock chip specimens from selected parts of the batholith and surrounding volcanics.

All of these studies emphasized a simple distribution of uniform lithologies in the batholith: a core of quartz monzonite surrounded by a rim of granodiorite. The batholith was believed to intrude Upper Triassic (Carnian) volcanics and the older K-Ar ages were considered to represent the age of intrusion whereas the younger ages were enigmatic.

Coincident with the thesis research, the Cry Lake and Dease Lake map-areas were remapped during Operation Dease. This resulted in updated preliminary geological maps (Gabrielse, 1979 and 1980a, respectively) and

1. All dates in this thesis have been revised using the new K-Ar decay constants of Steiger and Jäger (1977). The K-Ar age reported in Leech et al. (1963) is discredited since no estimate of atmospheric ⁴⁰Ar contamination was made at the time of the analysis.

preliminary reports on the regional geology (Gabrielse, 1978, 1980b), structure (Gabrielse and Mansy, 1978, 1980; Mansy, 1980), Mesozoic and Paleozoic stratigraphy (Monger and Thorstad, 1978; Thorstad, 1979, 1980; Monger, 1980), Jurassic biostratigraphy (Tipper, 1978) and ultramafic rocks (Leaming, 1978, 1980). Two baccalaureate theses were completed during this period on aspects of the Lower Jurassic sediments and volcanic rocks near and some distance from the Hotailuh Batholith (Henderson, 1979; Henderson and Perry 1981; Erdman, 1979). Aeromagnetic maps for the Cry Lake, Dease Lake and Spatsizi map-areas were also published in that period (Geological Survey of Canada, 1978 a, b, and c).

1.4 Methods of Study

Field and laboratory methods were utilized. The present study is based on nine months of field mapping, during the summers of 1977, 1978, and 1979, with the major effort directed towards the batholith, the satellite plutons and the volcanics which fringe the batholith. Mapping was done on 1:31,860 or approximately one-half mile to the inch scale aerial photographs and then transferred onto 1:50,000 scale topographic and drainage base maps. The final, 1:125,000 scale geological map shown in Figure 1 uses an enlarged 1:250,000 scale Army Survey Establishment topographic base produced between 1949-1952 with interim corrections in 1974 and 1978.

Granitic rocks were stained in the field with cobaltinitrate and hand specimen estimates of quartz, alkali feldspar, plagioclase and mafic content were used to classify them according to Streckeisen (1973). In the course of the field mapping it became apparent that units recognized on the basis of textural and mineralogical criteria had diverse modal

compositions and that use of a single rock name to designate the unit (such as proposed by Bateman et al. (1963) for units in the Sierra Nevada Batholith) would not adequately express the compositional variety in each unit. Consequently a hierarchal taxonomy of plutonic suite, pluton, phase and subphase was used. A plutonic suite consists of a number of plutons which have similar lithologies, structures, geological relations, age, petrography and chemical compositions. Plutons within each suite are mappable bodies which have consistent mineralogical, textural, petrographic and chemical characteristics and external intrusive relations. Phases, which compose plutons, are also mappable entities but are demonstrably consanguineous as shown by their interphase intrusive relations. Sub-phases are distinctive mineralogical and/or textural variants of the pre-dominant lithology of the phase.

Plutonic suite in this sense is approximately equivalent to the "super-unit" of Cobbing and Pitcher (1972) and Pitcher (1978), the magma "sequence" of Bateman and Dodge (1970) and the "suites" of Chappell and White (1974). Plutons and phases correspond to the "units" of Cobbing and Pitcher (1972) and Pitcher (1978) differing only in degree of subdivision.

Volcanic sections were measured using a Brunton pocket transit (section 577) or a Jacob staff (all other sections).

Stations were numbered consecutively over the three years' field mapping: stations 1-378 in 1977; stations 400-588 in 1978; and stations 600-721 in 1979. Stations with the prefix J or C (e.g. J-40 or C-2a) refer to field data collected by assistants Blair Jacobson or Paul Chung.

Approximately 284 thin sections and polished thin sections were studied by the usual petrographic methods and plagioclase compositions

were determined by standard flat stage techniques. An automated mechanical stage and tabulator was used to count 500-1000 points on representative thin sections.

One hundred and fourteen rock specimens were analyzed by XRF, emission spectrography and other methods (see Appendix 13) for eleven major elements, eleven trace elements, total water, carbon dioxide, sulphur, chlorine and fluorine in the chemistry laboratories of the Geological Survey of Canada. Mineral separates from eighteen specimens were isotopically dated by the K-Ar method and one specimen by the U-Pb method in the geochronology laboratories of the Geological Survey of Canada. At Carleton University, rubidium and strontium chemical analyses on twenty-nine samples were carried out and Rb-Sr isotopic analyses were done on five of those specimens. Microprobe analyses of minerals in fifteen specimens were done at the Geophysical Laboratory, Carnegie Institution of Washington and at Carleton University (see Appendix 12). Computer programs STEREO and LEMNORM9 plotted and contoured linear and planar structural data, and calculated CIPW normative minerals from chemical analyses, respectively. Revised versions of the programs EMPADR VII (Rucklidge and Gasparrini 1969) and SUPERRECAL (Rucklidge, 1971) were used in the reductions of electron microprobe data collected at Carleton University.

Preliminary reports on the thesis research in Anderson (1978, 1979, and 1980) and Anderson and Blenkinsop (1981) summarize field and isotopic results.

I.5 REGIONAL GEOLOGY OF THE NORTHERN CANADIAN CORDILLERA

I.5.1 Introduction

The Canadian Cordillera embraces most of British Columbia, Yukon Territory and the southwestern part of the District of Mackenzie. It comprises the Pacific Orogen in the west and the Columbian Orogen in the east (Figure 4). A granitic and medium- to high-grade metamorphic core characterizes each orogen (the Coast Plutonic Complex, the Pacific Orogen; the Omineca Crystalline Belt, the Columbian Orogen). Belts flanking these core zones (Insular Belt and Intermontane Fold and Thrust Belt in the Pacific Orogen; Hinterland Belt and Rocky Mountain Fold and Thrust Belt in the Columbian Orogen) have demonstrable tectonic transport (fold vergences, thrust faults) away from each core zone (Wheeler and Gabrielse, 1972). Both orogens attained their structural style during the Middle to Late Jurassic and the Middle to Late Cretaceous and Early Tertiary.

The Intermontane Belt includes the Hinterland Belt and Intermontane Fold and Thrust Belt. Because the Hotailuh Batholith is located in the northern Intermontane Belt, the geology of this region (i.e. between 54°N and 60°N) will be reviewed first. Geology of the other constituent belts of the Cordillera is also important in appreciating the complex regional setting of the Hotailuh Batholith.

Figures 3 to 6 give the location of physiographic subdivisions in the northern Canadian Cordillera, constituent tectonic elements, the "suspect" (Coney *et al.*, 1980) and paleogeographically autochthonous terranes and the 1:250,000 scale map-areas referred to throughout the thesis.

Figure 3. Tectonic elements of the northern Canadian Cordillera between 55° and 60° N (after Wheeler and Gabrielse, 1972, Fig. 7) and the location of the Hotailuh Batholith.

Figure 4. Distribution of allochthonous (or suspect) terranes in the Canadian Cordillera (after Price et al., 1981, Figs. 1 and 2) and location of the Hotailuh Batholith. Dashed lines show location of the major physiographic and geological belts which are given in more detail in inset diagram to upper right. Abbreviations are: C.O. = Columbian Orogen; P.O. = Pacific Orogen.

RMFTB = Rocky Mountain Fold
and Thrust Belt

OCB = Omineca Crystalline Belt

HB = Hinterland Belt

IB = Intermontane Belt

CPC = Coast Crystalline Complex

InB = Insular Belt

HOTAILUH
BATHOLITH

"SUSPECT" TERRANES

- EASTERN ASSEMBLAGE (of Monger, 1977)
- QUESNELLIA (Quesnel Trough and OCB, in part)
- CACHE CREEK
- STIKINIA
- GRAVINA-NUTZOTIN
- ALEXANDER
- WRANGELLIA
- BRIDGE RIVER

Figure 5. Map areas discussed in text and location of thesis area.

Figure 6. Tentative correlation of some Paleozoic and Mesozoic units and intervals of deformation around the Hotailuh Batholith (Triassic and Jurassic plutonic suites). Position of structural boundaries between belts is not intended to indicate timing of movement along structures. Barbs on fault symbols indicate hanging wall. Abbreviation "Pz" signifies undifferentiated older, distal miogeosynclinal and younger, in part volcanogenic Paleozoic rocks which underlie the Omineca Crystalline Belt. Diagram is modified from Monger (1980, Fig. 1.1B)

CPC = Coast Plutonic Complex

JPS = Jurassic plutonic suite

TPS = Triassic plutonic suite

IF = Inklil facies

TF = Takwanoni facies

KSF = King Salmon Fault

NF = Nahlin Fault

1.5.2 Intermontane Belt

The northern Intermontane Belt comprises several tectonic elements (Wheeler and Gabrielse, 1972): Atlin Terrane and Stuart Lake belt, (Pinchi Belt), Whitehorse Trough and Quesnel Trough (part of the Hinterland Belt); and the Takla-Hazleton arc, the Stikine and Skeena Arches and Nechako Trough and the Bowser and Sustut successor basins (part of the Intermontane Fold and Thrust Belt) (Figure 3). Almost all of these rocks make up the paleogeographically allochthonous terrane of "Stikinia" (Monger and Irving, 1979, Price et al., 1981).

The Hinterland Belt is defined as that part of the Intermontane Belt with southwesterly directed structures (Wheeler and Gabrielse, 1972; Monger et al., 1978b). Its contacts with the Intermontane Fold and Thrust Belt to the east and Coast Plutonic Complex to the west are discussed below.

Atlin Terrane and Stuart Lake Belt (Pinchi Belt)

The Atlin Terrane (Souther, 1971a, Monger 1975b) and Stuart Lake belt (Paterson, 1977) have marked similarities (Monger et al., 1978b). Both contain ophiolite-like assemblages of chert, argillite, carbonate, more or less altered volcanics and alpine ultramafites of the Cache Creek Group (the Cache Creek assemblage of Monger, 1977b). In the Atlin Terrane these rocks are Mississippian to Late Triassic in age (Monger, 1975, 1977b, personal communication, November, 1980); those in the Stuart Lake belt are of Mississippian to late Permian age (Paterson, 1977). Two (Atlin Terrane) or three (Stuart Lake belt) generations of minor structures are recognized. Earliest minor structures in both areas are generally athwart the present northwest regional grain of the Cordillera. Northerly-trending early folds and cleavage-bedding intersections in the Atlin Terrane (Monger, 1969)

contrast to easterly-trending fold axes and axial plane foliation of the earliest structures in the Stuart Lake belt (Paterson, 1977). Blueschist metamorphism attended the first phase of deformation in both terranes (Monger, 1969, Paterson, 1977) and is dated (by K-Ar method) concordantly between 215 Ma and 222 Ma in the Stuart Lake belt (Paterson and Harakal, 1974) and discordantly at 168 Ma and 132 Ma in the Atlin Terrane (Monger, 1975a). Biostratigraphy constrains the age of the earliest deformation in both terranes at post-Late Permian to pre-Late Triassic; likewise the second phase deformation is best dated as latest Middle to Late Jurassic or earliest Cretaceous (Monger, 1969, 1975b; Paterson, 1977; Monger *et al.*, 1978b). In the Atlin Terrane, the later structures have horizontal, northwest-trending fold axes and are south southwestward verging (Monger, 1969, 1975b).

Rocks of the Cache Creek Group in the Atlin Terrane and Stuart Lake belt are separated from deformed and metamorphosed Mesozoic rocks on their western flank by southwest-directed major thrust faults of Middle-latest Jurassic to earliest Cretaceous age (the Nahlin Fault adjacent the Atlin Terrane and the Vital Fault in the Stuart Lake belt). The younger age constraint for these faults derives in part from radiometric ages of schists and a cross-cutting ultramafic pluton (Monger *et al.*, 1978b). Farther west, undeformed middle and upper Mesozoic strata are faulted against the metamorphosed, deformed lower Mesozoic rocks along the King Salmon (thrust) Fault in the north and the Takla (transcurrent) Fault to the south.

The correlative early Mesozoic assemblages which form the footwall to upthrust Cache Creek rocks in both terranes consist of chlorite, sericite and quartz-eye schist, variably foliated acidic to basic volcanic and volcaniclastic rocks, phyllite, greywacke, conglomerate and minor carbonate.

In the Stuart Lake belt they are known as the Sitlika assemblage (Paterson, 1977) and farther north as the King Salmon assemblage (so-named as it forms the hanging wall of the King Salmon Fault southwest of the Atlin Terrane; Monger and Thorstad, 1978; Thorstad, 1979).

North and east of the Hotailuh Batholith, a tripartite stratigraphy is established in the King Salmon assemblage (Monger and Thorstad, 1978; Thorstad, 1979). The lower unit, the "Kutcho Formation" consists of: intermediate dacitic and rhyolitic breccia, tuff and flows (metamorphosed to feldspar quartz-eye sericite schist and sericite schist); minor porphyritic basalt lenses (metamorphosed Upper Triassic volcanics); and capping argillite and conglomerate. The upper conglomerate is in part gradational with the overlying carbonate, the middle unit of the King Salmon assemblage correlative with the Sinwa Formation of probable Late Triassic age (Souther, 1971a; Monger and Thorstad, 1978). Greywacke, conglomerate and phyllite form the upper of the King Salmon assemblage correlative with the Lower Jurassic Inklin Formation. Where the middle carbonate is absent, the uppermost conglomerate of the "Kutcho Formation" is also gradational with the Inklin Formation conglomerate (Thorstad, 1979).

The stratigraphic age of the "Kutcho Formation" is believed to be Late Triassic and therefore a facies equivalent of the Stuhini Group. The radiometric age obtained for the "Kutcho Formation" of 215 ± 14 Ma is probably a minimum age (Thorstad, 1980; Armstrong, 1981). The Sitlika assemblage has been shown to be the deformed equivalent of the Permian Asitka Group (acid to basic volcanics, carbonate, chert and tuff; Monger, 1977a), Upper Triassic Takla Group and Lower Jurassic Hazelton Group (Monger et al., 1978b).

Rocks of the King Salmon and Sitlika assemblages are pervasively deformed. Westerly plunging, southwesterly overturned isoclinal folds characterize the structural style in the assemblages. The schistosity trend in the King Salmon assemblage mimics the King Salmon Fault and decreases in intensity away from it suggesting contemporaneous development of both structures, i.e. during the latest Early Jurassic to earliest Cretaceous (Monger et al., 1987b; Monger and Thorstad, 1978,; Tipper, 1978). Deformation of the Sitlika assemblage is contemporaneous and both are congruent and coeval with the major, second generation deformation in the Cache Creek rocks adjacent to each terrane (Monger et al., 1978b; Thorstad, 1979). Lower greenschist metamorphism occurred during deformation of the King Salmon assemblage (Thorstad, 1979).

Whitehorse and Quesnel Troughs

Sediments of the Whitehorse and Quesnel Troughs form the western margin of the Hinterland Belt. The Whitehorse Trough or Laberge Basin is the earliest recognized successor basin in the Cordillera (Eisbacher, 1974b; Wheeler, 1961). In northern British Columbia, coarse conglomeratic subsea channel, piedmont fan and deltaic deposits of the precursor, proximal facies (Takwaoni Formation) and graded sandstone and shale submarine slope and fan deposits of the younger, distal facies (Inklin Formation) compose the Lower to Middle Jurassic Laberge Group in the Whitehorse Trough (Souther, 1971a; Eisbacher, 1974b; Bultman, 1977, 1979). The Inklin Formation may be underlain by the Cache Creek Group but the Takwahoni Formation possibly rests on Stikinia (Souther, 1971a; p.50; Bultman, 1977; 1979, p.229; Monger, 1980) and demonstrably disconformably or unconformably overlies Upper Triassic rocks (Souther, 1971a; Monger, 1980). West of the Hotailuh Batholith, in

(c) Cake Hill Pluton

The contact between the Stikine Pluton and isolated outcrops of the Cake Hill Pluton along the eastern margin of the former pluton are not exposed. Two observations support the assumed intrusive nature of the Cake Hill Pluton with respect to the Stikine Pluton. An isolated outcrop of intensely foliated amphibolitic diorite in the southwestern corner of the Cake Hill Pluton is intruded by titanite- and hornblende-bearing monzonite apophyses which may be part of the Cake Hill Pluton (station 617). The foliation in the amphibolite dips steeply to the north northwest. As mentioned above, the change in foliation orientation from easterly to north-easterly and northerly is spatially associated with isolated massive outcrops of monzodiorite of the generally northwesterly-foliated Cake Hill Pluton. Deflection of Stikine Pluton foliation may have occurred during intrusion of the Cake Hill Pluton although similar effects of emplacement of the Three Sisters Pluton on the orientation of Stikine Pluton foliation cannot be ruled out. The potassium-argon age of the Stikine Pluton is marginally older than the Cake Hill Pluton but both ages are essentially concordant within limits of analytical error.

(d) Three Sisters Pluton

A syenitic apophysis, presumably related to the intrusion of the Three Sisters Pluton's potassic marginal phase, intrudes foliated diorite of the Stikine Pluton at one locality near its eastern margin (station 673).

II.2.5 Age

A replicated, potassium-argon hornblende age of 222 ± 11 Ma from diorite of the Stikine Pluton is reported by Wanless et al. (1972, G.S.C. 70-34;

Volcanism

Triassic volcanics of the Takla-Hazleton arc in the northern Cordillera include the Upper Triassic Takla Group (Monger and Church, 1977; Monger, 1977a; Tipper and Richards, 1976) and the correlative Upper Triassic Stuhini Group (Souther, 1971a; Monger, 1980). A complete section would include: a lower sequence predominantly of pyroclastics with lesser breccias and submarine to subaerial andesitic to basaltic augite porphyry flows; a middle, partly coeval, succession of argillite and tuff; and an upper to in part coeval sequence of coarse, reddish breccia, volcanic conglomerate, tuff and lesser greywacke, siltstone and discontinuous lenses of reefoid limestone. The Takla Group (Monger and Church, 1977; Monger, 1977a) and the Stuhini Group (Souther, 1971a; Monger, 1980) are known to be late Carnian to late Norian in the northern Intermontane Belt; in the central southern Quesnel Trough, augite porphyry volcanics persist until the early Sinemurian (Campbell and Tipper, 1970). The predominantly alkaline chemistry of the Takla Group volcanics contrasts the predominantly calc-alkaline chemistry of the Stuhini Group (Souther, 1977).

The Hazelton Group, a thick and widespread assemblage of marine and nonmarine, Lower and Middle Jurassic rhyolite to basalt flows and tuffs, sedimentary rocks and minor limestone, is subdivided into two major volcanic units and one sedimentary unit (Tipper and Richards, 1976; Souther, 1977). Reddish, purple, maroon, grey and green rhyolite to basalt lavas and subordinate pyroclastics of the Telkwa Formation are the most common Hazelton Group lithology. They are Sinemurian to earliest Pliensbachian age and represent the earliest, most voluminous and most widespread unit of the Hazelton Group. Interbedded lower shale and greywacke underlying

the rhyolitic to andesitic flows, tuff and breccia of the Carruthers and Ankwel volcanics compose the early Pliensbachian to middle and ?late Callovian Nilkitkwa Formation. Middle Toarcian to lower Callovian greywacke, argillite, siltstone, sandstone, sharpstone conglomerate, glauconitic sandstone, ashfall tuff and tuffaceous sediments of the Smithers Formation are widespread across the Hazelton Trough. Distribution of and facies changes within these three units of the Hazelton Group indicate an early, western, in part subaerial proximal facies and a later, eastern distal back arc facies across the Hazelton Trough (Tipper and Richards, 1976). Hazelton Group volcanism commenced with the eruption of the Telkwa volcanics in a western arc and ended with the extrusion of the Ankwel volcanics in the eastern back arc basin. There exists a complementary shift in predominantly calc-alkaline volcanic chemistry to the east in both Telkwa and Nilkitkwa volcanics (Tipper and Richards, 1976; Souther, 1977) which is interpreted by Monger and Price (1979) to indicate a eastward dipping Jurassic subduction zone beneath the Hazelton Group volcanics.

The Toodoggone volcanics, an informally named group of flows (andesite, latite, basalt and quartz-eye dacite), agglomerate, tuffs, breccia and epiclastic sandstone, outcrop in the Toodoggone River map-area and other parts of northwestern British Columbia (Gabrielse and Dodds, 1974; Carter, 1972; Gabrielse et al., 1980). Paleontological dating indicates part of the volcanic stratigraphy, possibly the upper part, is middle Bajocian and is correlative with the Nilkitkwa Formation (Red Tuff Member; Tipper and Richards, 1976; Gabrielse et al., 1980). Radiometric dates of 185 Ma (Rb-Sr), and 179, 182 and 189 Ma (K-Ar) indicate the Toodoggone volcanics may be as old as Toarcian (Gabrielse et al., 1980). Initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios

are low (0.7036-0.7043).

Plutonism

Granitic and ultrabasic plutonism figure prominently in the magmatic evolution of the Takla-Hazleton arc (Gabrielse and Reesor, 1974). Alkaline and calc-alkaline granitic plutons spatially and temporally associated with the Upper Triassic volcanics include (from south to north): Copper Mountain (calc-alkaline; average age 198 ± 2 Ma; Preto, 1972, p.43); Allison Batholith (calc-alkaline; average age 206 ± 2 Ma; Preto *et al.*, 1979, p.1667); Guichon Creek Batholith (calc-alkaline; average emplacement and mineralization ages between 202 Ma and 205 Ma; White *et al.*, 1967; Northcote, 1969; Jones *et al.*, 1973; Olade, 1976; Preto *et al.*, 1979); Thuya Batholith (calc-alkaline; average age 197 Ma; Preto *et al.*, 1979); Campbell and Tipper, 1971); Takomkane Batholith (189 Ma; Campbell and Tipper, 1971); Hogem Batholith (alkaline and calc-alkaline; ages of three intrusive episodes at 180 Ma to 216 Ma; 165 Ma to 186 Ma; and 114 Ma to 125 Ma; Garnett, 1978; Woodsworth, 1976); and the Hotailuh Batholith whose spatial, temporal, and petrological relations with the surrounding Upper Triassic and Jurassic volcanics form the subject of this thesis. The alkaline and most of the calc-alkaline batholiths are considered comagmatic with the proximal Takla-Nicola volcanics and are commonly associated with, and their emplacement attributed to bounding normal, rift or transcurrent faults (Preto, 1972, 1977, 1979; Northcote, 1974, 1976; McMillan, 1974; Paterson, 1977; Fox, 1975). Initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio for the Guichon Creek batholith isochron is 0.7034 (Preto *et al.*, 1979). The granitic plutons are predominantly granodiorite but include all fields of the IUGS granitic classification (Streckeisen, 1973).

Dunite, peridotite, olivine clinopyroxenite, clinopyroxenite, hornblende

clinopyroxenite, and hornblendite are common lithologies in Polaris and other Alaskan-type ultrabasic plutons in the Intermontane Belt (Irvine, 1968, 1974, 1975, 1976,; Clark, 1980). These plutons, commonly emplaced in or near Takla augite porphyry volcanics, are believed to be the early, high temperature differentiates of a primitive alkaline variant of Takla magma. These bodies mark volcanic centers. A K-Ar hornblende date from pegmatitic segregations in the Wrede Creek dunite is 225 ± 8 Ma (Wong and Godwin, 1980). A north-trending belt of highly differentiated alkalic, mainly pyroxenitic and syenitic bodies in the Telegraph Creek area are believed to be comagmatic with the associated Stuhini Group volcanics (Souther, 1973; Barr, 1966; Morgan, 1976). Concordant hornblende and biotite potassium-argon dates from one such stock, the Ten Mile Creek syenite-pyroxenite pluton are 204 Ma (Morgan, 1976; Souther, personal communication, in Morgan, 1976). Other dates from the Galore Creek bodies range from 177 Ma to 201 Ma (White et al., 1968).

Topley intrusions, calc-alkaline stocks and batholiths of Early Jurassic age (175-207 Ma), intrude and are thought to be contemporaneous with the Telkwa Formation (Tipper and Richards, 1976, p.18). They underlie the Skeepa Arch along a east-northeast-trending belt. Coeval and probably comagmatic with the Toodoggone volcanics are the pink-weathering granodiorite intrusions recognized in the Toodoggone area (Gabrielse and Dodds, 1974; Gabrielse et al., 1976; Gabrielse et al., 1980). Upper Jurassic, Lower Cretaceous and mid-Cretaceous plutonism is not important in the Intermontane Belt except in the Yukon (e.g. Morrison et al., 1979) but Upper Cretaceous and Lower Tertiary plutonism is (Gabrielse and Reesor, 1974). The latter plutons comprise hornblende or hornblende-biotite granite or quartz monzonite with waxy,

pale-green, buff weathering perthitic alkali feldspar, abundant watery or smoky quartz, common miarolitic cavities and a distinctive aggregate texture. These bodies are associated with extensional faults and are coeval and at least in part comagmatic with directly overlying acidic volcanic rocks (Gabrielse and Reesor, 1974).

Stikine and Skeena Arches and Nechako Trough

Plutons coeval with the Takla-Hazleton arc form the northern (Stikine Arch), eastern (Hogem Batholith) and southern (Skeena Arch) margins of the Bowser Basin.

The Stikine Arch was a positive element from the Late-Middle Triassic onwards and shed debris eastward into the Whitehorse Trough (Souther, 1971a; Eisbacher, 1974b; Souther et al., 1979; Bultman, 1979). The arch preserves evidence of the granitic intrusion (including part of the Hotailuh Batholith), the deformation (which produced tight, north-trending folds) and the synkinematic metamorphism of pre-Upper Triassic rocks which marked the culmination of the Permian to mid-Triassic Tahltanian orogeny (Souther, 1971a; Read and Okulitch, 1977). The northwestern flank of the Stikine Arch was also the locus for extrusion and deposition of the Upper Triassic Stuhini Group. The Stikine Arch also forms the northern margin of the Bowser Basin (Figure 3).

The Skeena Arch has been an active element since the Early Jurassic (Tipper, 1979). It is a distinctive northeasterly-trending structure separating thinner crust to the north from thicker crust to the south (Richards, 1977). It also separates the later-formed Bowser Basin from the earlier deformed, intruded and mineralized late Middle Jurassic sediments and andesitic volcanics in the Nechako Basin (Tipper et al., 1979; Hutchison et al., 1979). Its rise marked the end of widespread Jurassic volcanism and

the beginning of the Middle to Late Jurassic successor basin sedimentation (Tipper and Richards, 1976; Richards, 1977). The Skeena Arch influenced this sedimentation as well as providing a locus for and a boundary between later Mesozoic and Tertiary volcanism and sedimentation (Tipper, 1979; Richards, 1977).

Bowser and Sustut Basins

The Middle and Late Jurassic Bowser Basin and Late Cretaceous to Eocene Sustut Basin were the depocenters for molasse facies of the Columbian and Pacific orogens (Eisbacher and Gabrielse, 1975; Eisbacher et al., 1974; Eisbacher, 1974a, 1974b, 1974c, 1974d). The Bowser Basin was the site of marine and nonmarine shale, siltstone, sandstone and conglomerate deposition. Deposition occurred in coastal plain, delta, prodelta and continental slope environments in the northeast part of the basin (Eisbacher, 1974a). Essentially correlative, early marine and nonmarine clastic, intermediate black shale and younger, fluvial, deltaic and marine clastic deposition occurred in the southern part of the basin. Both areas reflect a river-dominated coastal environment (Richards and Jeletzky, 1975; Jeletzky, 1976; Eisbacher, 1974b). Paleocurrents indicate northern, north-eastern, south-eastern and southwestern source areas. Fusulinid-bearing conglomerates and deformed chert clasts dominate in the northeastern part of the basin and could only have been derived from an unroofed Cache Creek terrane to the north or east. In the southeastern part of the basin, volcanic and granitoid clasts predominate. Shallow decollement, northeast-verging, recumbent folds and small thrust faults typify the passive deformation driven by the Cretaceous to Tertiary uplift of the Coast Plutonic Complex (Eisbacher, 1974b).

The nonmarine conglomerates, sandstones, mudstones, chert pebble conglomerates and ashfall tuffs in the Sustut Basin unconformably overlie Bowser Basin (Eisbacher, 1974b, 1974d). The Sustut Group is divided into two formations. Late Cretaceous to Paleocene age sediments of the lower sequence reflect the uplift and unroofing of the Omineca Crystalline Complex (Columbia Orogen) to the east in the Early and Middle Cretaceous. The Paleocene to Eocene upper sequence contains detritus shed eastward from the Coast Plutonic Complex uplifted in Late Cretaceous to Paleogene as well as coarse detritus from the Stikine Arch and Omineca Crystalline Belt. Deformation along the western margin of the Bowser Basin affected paleo-current directions (Eisbacher, 1974d).

Stikinia

Paleomagnetic studies in the Upper Triassic Takla Group have established a large part of the Intermontane Belt as paleogeographically allochthonous. Monger and Irving (1979) and Price et al., 1981 have defined the Stikine Block (or Stikinia) as including all mid-Cretaceous or older rocks lying west of either the early Tertiary Teslin lineament-Thibert Fault-Kutcho Fault and the Tintina Trench. This terrane was apparently located 13-14° south of its present position, relative to the North American craton, when the Takla volcanics were extruded (Irving and Monger, 1980; Irving et al., 1980). Demonstrable Cache Creek detritus in the Bowser Basin links Stikinia and the Cache Creek Group to the east at least by the late Middle Jurassic. However, if the Cache Creek Group is interpreted as the subduction complex for the Upper Triassic volcanism, the two terranes were adjacent much earlier (Late Triassic). Intrusion of the Coast Plutonic Complex into the Insular Belt (Wrangellia) and the Intermontane Belt (Stikinia) links the latter two belts

by the Cretaceous. "Docking" of Stikinia with autochthonous North America probably occurred between the Mid- to Late Jurassic to Mid- to Late Cretaceous (Monger and Irving, 1979; Irving et al., 1980; Price et al., 1981) although this has yet to be proven on sedimentological grounds.

I.5.3 Omineca Crystalline Belt

Omineca Crystalline Belt is the metamorphic-plutonic core of the Columbian Orogen and occurs east of the Intermontane Belt. Sediments of the Ingenika Group, whose stratigraphy has been recently redefined by Mansy and Gabrielse (1978), represent the Windermere Supergroup sedimentation in the Cassiar and Omineca Mountains and are exposed in the metamorphic culminations of the northern Omineca Crystalline Belt. Although sedimentation of the Ingenika Group occurred along the continental margin (Gabrielse, 1972), it is not known if the North American craton actually underlies the Ingenika Group; a physical linkage with the craton can only be established as early as the early Paleozoic (Monger et al., 1972). Except for the absence of the Helikian Belt-Purcell Group in the Omineca Crystalline Belt, sedimentation was similar to that in the Rocky Mountain Fold and Thrust Belt until the mid-Devonian. Mississippian and Permian sandstone, shale, carbonate and, particularly, locally abundant pyroclastics and acid to intermediate lavas distinguish the Omineca Crystalline Belt from coeval rocks in the Rocky Mountain Fold and Thrust Belt (Monger et al., 1972) and underlie (or are infolded with) the mainly Permian basalt, minor chert and gabbro, diabase and alpine ultramafites. Together these two Mississippian-Permian successions form Monger's (1977b) eastern assemblage. Northeast of the Hotailuh Batholith, in the northeast corner of the Cry Lake map-area, the

upper volcanic-ultramafic part of the eastern assemblage is demonstrably allochthonous with respect to the underlying clastic-carbonate succession, having been thrust northeastwards along a sole thrust during the Late Jurassic or Early Cretaceous (Gabrielse and Mansy, 1980).

Minor, deep water, late Triassic to mid-Jurassic sedimentation changed to nonmarine deposition of conglomerate, breccias, conglomeratic sandstones, sandstones, siltstones and mudstones from southerly flowing drainage into the Sifton Basin as sedimentation in the northern Omineca Crystalline Belt ended in the Late Cretaceous to Paleocene (Eisbacher, 1974d). Sedimentation in the Sifton Basin, which lies along the axis of structural divergence in the Omineca Crystalline Belt, was initiated by normal faulting associated with the uplift of the Omineca Crystalline Belt.

The eastern and western margins of the Omineca Crystalline Belt are defined respectively as the eastern limit of metamorphism in the belt and the eastern limit of the Whitehorse and Quesnel Troughs (Wheeler and Gabrielse, 1972). In the northern part of the Omineca Crystalline Belt, its eastern limit corresponds to the Rocky Mountain Trench Fault System and its western limit to the Teslin-Thibert-Kutcho-Finlay-Swannell Fault Systems, all of them Late Cretaceous to Eocene age (Gabrielse and Dodds, 1977; Monger, 1977b, 1980; Monger and Price, 1979).

An axis of structural divergence separating southwest-verging structures to the west and younger northeast-verging structures to the east is recognized the length of the Omineca Crystalline Belt. In northern British Columbia, it corresponds in part to the Rocky Mountain Trench but near 58°N trends northwest along the Pelly lineament and Kechika Fault (Wheeler and Gabrielse, 1972; Gabrielse, Dodds and Mansy, 1972).

Polyphase, polymetamorphic deformation is recognized in the northern Omineca Crystalline Belt (Mansy and Dodds, 1976; Gabrielse and Mansy, 1978; Parrish, 1979). Earliest structures in the Swannell Ranges and in the Cry Lake map-area north of the Hotailuh Batholith are southwest-verging (Mansy and Dodds, 1976, Gabrielse and Mansy, 1978); Parrish (1976, 1979) observed northeasterly-verging folds possibly on the underlimb of an overturned fold in his earlier phases in the Wolverine Complex. A later phase of deformation involves northeastward tectonic transport truncating southwesterly-verging structures as in northeast Cry Lake map-area (Gabrielse, 1978; Gabrielse and Mansy, 1978, 1980). Where more than two phases of deformation are recognized, the third phase produces an updoming of the earlier structures along vertical axial planes (Mansy, ms, 1979; Parrish, 1979) and is locally associated with the intrusion of mid-Cretaceous plutons (Mansy and Dodds, 1976). Metamorphism accompanied the second and third phases of deformation in the Swannell Range (Mansy and Dodds, 1976; Mansy, ms, 1979), both phases of deformation in the northeast Cry Lake map-area (Mansy, 1980) but only the second phase of deformation in the northern Wolverine Complex (Parrish, 1979). The earliest phases of deformation are believed to be Middle to Late Jurassic in age; the late regional updoming occurred in the middle Cretaceous (Parrish, 1979; Mansy, ms, 1979). A late brittle deformation, mid-Cretaceous to Tertiary age, may be related to major late Cretaceous to Eocene, dextral transcurrent faulting (Gabrielse and Dodds, 1977; Mansy, ms, 1979; Parrish, 1979).

Granitic plutonism is important in the Omineca Crystalline Belt. In the north, mid- and Early Cretaceous and less commonly Early Jurassic and Late Cretaceous-Early Tertiary plutons predominate; Jurassic and older

plutons are more common in the south (Gabrielse and Reesor, 1974). Quartz monzonite, containing common potassium feldspar megacrysts, is a characteristic and widespread lithology in the plutons of the Omineca Crystalline Belt (Gabrielse and Reesor, 1974). Locally quartz diorite is abundant in many of the early Jurassic bodies (Gabrielse, Dodds and Mansy, 1976), granodiorite forms many of the Early Cretaceous plutons and granite is common in most of the late Cretaceous plutons and granite is common in most of the Late Cretaceous-Early Tertiary bodies. Commonly the batholiths are spatially associated with major faults which have possibly served as guides for intrusion. Initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios for Tertiary granodiorite, quartz monzonite and granite of the northern (Parrish, 1979) or southern (Fairburn *et al.*, 1964) Omineca Crystalline Belt show comparatively higher values (0.7052-0.7064) to those of granitic bodies in the Intermontane Belt.

1.5.4 Rocky Mountain Fold and Thrust Belt

Rocky Mountain Fold and Thrust Belt is a folded and faulted terrane underlain by Middle Proterozoic to Early Tertiary sediments and volcanics (Price and Mountjoy, 1970; Wheeler and Gabrielse, 1972; Monger *et al.*, 1972; Monger and Price, 1979). These strata include: Helikian to mid-Devonian miogeosynclinal terrace wedge which is westwardly-thickening to the shelf break; mid-Devonian to Mississippian westward thickening shale- or carbonate-dominated successions; a Lower Mississippian? to lowermost Permian sequence of chert, minor carbonate and fine to coarse clastics derived in part from acid volcanic and metamorphic terranes to the west; fine-grained clastics, carbonate, chert and craton-derived sandstone of Mississippian to mid-Triassic age; Upper Triassic and Lower to Middle Jurassic siltstone, shale

and sandstone which reflect a subdued cratonic source and eastward regression of the Jurassic seas; and an increasingly nonmarine uppermost Jurassic to Paleocene clastic wedge whose terrigenous sediments interfinger with and finally replace the marine sediments as sedimentation advanced northeastward through time. The nature of the later nonmarine sedimentation reflects uplift of the western sources in the Omineca Crystalline Belt (Eisbacher and Gabrielse, 1975). Deformation, in the form of concentric folds and eastern tectonic transport along south-westerly rooted listric thrusts, occurred in the Late Cretaceous to Paleogene (Price and Mountjoy, 1970; Monger and Price, 1979). In the northern Rocky Mountains, folding predominates in the surface exposures but "blind" thrust faulting at depth is important (Thompson, 1979). Deformation in the north slightly predated that in the south based on K-Ar ages from chloritoid schists (around 120 Ma) and intrusion of Mid-Cretaceous plutons into folded sequences in the Mackenzie Mountains (H. Gabrielse, written communication, November, 1980).

1.5.5. Coast Plutonic Complex

The core of the Pacific Orogen is the Coast Plutonic Complex, a long narrow plutonic and metamorphic complex west of the Intermontane Belt (Roddick and Hutchison, 1974). In the northern Cordillera, the Coast Plutonic Complex is cored by a high grade metamorphic core, the Central Gneiss Complex. Migmatite, acidic gneiss, paragneiss and gneiss compose the Central Gneiss Complex and make up 15 per cent of the Coast Plutonic Complex. Granitic rocks predominate in the Coast Plutonic Complex and include (in decreasing order of abundance): quartz diorite, granodiorite and diorite and minor quartz monzonite, granite and syenite. Constituent plutons are autochthonous,

migmatitic or allochthonous (Hutchison, 1970); allochthonous plutons have moved out from their anatectic source in the Central Gneiss Complex. Across the northern Coast Plutonic Complex there is a general decrease in age to the east (e.g. 85-143 Ma in the west to 44-51 Ma in the east in the Prince Rupert area; Hutchison, 1970); granitic rocks become increasingly siliceous and potassic to the east; and plutons are more homogeneous to the east (Roddick and Hutchison, 1974). Its eastern margin is in part intrusive into (Roddick and Hutchison, 1974) and in part faulted against the Intermontane Belt (Woodsworth, 1978, 1979). The Coast Plutonic Complex is clearly intrusive along its western margin into Upper Triassic and Jurassic volcanics of the Insular Belt (Nelson, 1979). Metamorphism in the Central Gneiss Complex reaches granulite grade (Hollister, 1975). The Central Gneiss Complex protolith may be as old as Precambrian or early Paleozoic in the Prince Rupert area (Armstrong and Runkle, 1979) or as young as Permian along the eastern margin of the Coast Plutonic Complex (Woodsworth, 1978, 1979). Although there is some evidence for scattered Jurassic or older intrusions, K-Ar dates in the complex are predominantly Mid-Cretaceous to Paleogene (Roddick and Hutchison, 1974; Monger and Price, 1979) but may in part reflect uplift of the terrane rather than intrusion. Detritus from the unroofing of the Coast Plutonic Complex was apparently shed preferentially into Tertiary basins west of the complex as only minor granitic debris from the west appears late in the history of the Sustut Basin (Shouldice, 1971; Eisbacher, 1974d; Hollister, 1979). The Coast Plutonic Complex, in addition to providing a Cretaceous linkage between Wrangellia and Stikinia, was the locus of Early Cretaceous intermediate to acidic volcanism (Woodsworth and Tipper, 1980). In the Late Cretaceous, the Lower Cretaceous volcanics were metamorphosed

and intruded during initiation of uplift in the complex and the locus of volcanism shifted to the eastern margin of the Coast Plutonic Complex.

I.5.6 Insular Belt (Wrangellia)

In the northern Canadian Cordillera, the Queen Charlotte Islands best exemplify the geology of the Insular Belt (Sutherland Brown, 1966, 1968). There, the Insular Belt is bounded on the west by the thin continental shelf and slope and the transform Queen Charlotte Fault (Hutchison et al., 1979) and is separated from the Coast Plutonic Complex on the east by the Queen Charlotte Basin (Shoups, 1971). The Queen Charlotte Islands have a distinctive late Paleozoic to middle Mesozoic stratigraphy traceable north into the Alaskan Panhandle and south to Vancouver Island. Pre-Lower Permian andesitic to basaltic tuffs, flows, breccias and tuffs with associated greywacke, chert, argillite and limestone are the oldest rocks seen in the Queen Charlottes and are overlain by Lower Permian limestone and argillite, thick Middle to Upper Triassic tholeiitic massive and pillowed flows, and Upper Triassic-Lower Jurassic inner platform carbonate and argillite. The area underlain by this distinctive stratigraphy has been named Wrangellia by Jones et al. (1977) and paleomagnetic studies on the Triassic tholeiites in Wrangellia by Irving and Yule (1972), Hillhouse (1977), and Swartz et al. (1980) and Yule and Irving (1980) are interpreted to indicate eruption of these basalts within 10-20° of the paleoequator. Movement of paleogeographically allochthonous Wrangellia to its present position in the north was completed by the Middle Cretaceous (Jones et al., 1977, p.2575).

Overlying the distinctive Wrangellian stratigraphy on the Queen Charlotte Islands are Middle Jurassic porphyritic andesites, tuffs and breccias extruded

from centers now underlain by coeval Jurassic plutons along northwest-trending faults. Lower Cretaceous turbiditic greywacke and siltstone were deposited in northwest-trending grabben. Nearshore, shallow marine Upper Cretaceous sandstone and siltstone provide the first evidence of a granitic provenance. Paleocene and Eocene volcanism produced thick, subaerial alkalic basalt, breccia, and rhyolitic ash flows and was accompanied by plutonism. Upper Tertiary marine and nonmarine sandstone, conglomerate and shale, which mantle the Queen Charlotte Islands, underlie the continental slope and Queen Charlotte Basin. Pre-Early Cretaceous deformation produced tilting and open, easterly- to northwesterly-trending folds. Gentle, Cretaceous, folding parallels, and is caused in part by movement along northwest-trending faults. Active since the Early Cretaceous, these faults generally parallel the Queen Charlotte Fault and are spatially related to plutons, sedimentary basins and late folds.

Although part of the northern Insular Belt, it is beyond the scope of this review to include a summary of the collage of allochthonous and autochthonous tectonic elements which make up southeastern Alaska.

II. GEOLOGY OF THE TRIASSIC PLUTONIC SUITE

II.1 INTRODUCTION AND SUMMARY

The Triassic plutonic suite underlies most of the western half of the Hotailuh Batholith although screens and pendants of the Cake Hill Pluton in the Jurassic plutonic suite suggest that the Triassic plutonic suite once extended to the present eastern and northeastern margins of the batholith (Figure 1). It has a low topographic profile compared to the Jurassic plutonic suite. Except for the Beggerlay Creek Pluton which is characterized by the highest absolute total aeromagnetic field in the batholith, the Triassic plutonic suite is distinguished by its lower absolute total aeromagnetic field compared to the Jurassic plutonic suite (Figure 2):

Four plutons make up the Triassic plutonic suite (in known or inferred order of intrusion): Stikine Pluton (intensely foliated biotite-hornblende diorite); Cake Hill Pluton (massive to moderately foliated or lineated hornblende quartz monzodiorite, granodiorite, monzodiorite and quartz monzonite); Gnat Lakes Ultramafite (hornblende clinopyroxenite and hornblendite); and Beggerlay Creek Pluton (highly altered hornblende gabbro and diorite). The Cake Hill Pluton is the most extensive; the other plutons outcrop around its margins. Steep, east- to northeast-trending mineral foliation in the Stikine Pluton differs from the predominant steep northwest-trending mineral foliation in the Cake Hill Pluton. The other two plutons are massive or rarely compositionally layered.

Non-granitoid country rocks into which the Triassic plutonic suite was emplaced are nowhere seen in contact with it although small outcrops of Permian carbonate and marble occur to the southwest and west of the batholith.

The Triassic plutonic suite was the source area for, is demonstrably nonconformably overlain by, or is intruded by porphyritic dikes comagmatic with sediments, volcaniclastics and porphyritic flows of the Upper Triassic Stuhini Group and the sediments of the Toarcian unit. The Beggerlay Creek Pluton is the only pluton which clearly intrudes and metamorphoses the Upper Triassic Stuhini Group and part of the Triassic-Jurassic volcanic unit. Diagnostic interplutonic intrusive relations comprise inclusions of older plutons in younger plutons, intrusion of apophyses of younger plutons in older plutons and deformation of older plutons along intrusive contacts of younger plutons.

The Triassic K-Ar isotopic ages for the suite (218-230 Ma) are consistent with the stratigraphic constraint on the youngest age of emplacement of the Triassic plutonic suite but are only crudely consistent with the relative order of intrusion.

Coarse grain size, common, early formed clinopyroxene, hornblende (rarely cored by clinopyroxene), plagioclase (rarely cored by irregular, more calcic plagioclase), and magnetite, and distinctive titanite and apatite accessory minerals characterize the petrography of the Triassic plutonic suite. The Beggerlay Creek Pluton is distinguished by late, coarse, poikiloblastic biotite and a pervasive alteration of all primary phases (including olivine).

Subalkaline compositions are most common in the plutonic suite although all plutons have some alkali-rich samples and the Beggerlay Creek Pluton characteristically has alkaline affinities on the alkali-silica plot of Irvine and Baragar (1971). The mafic plutons are predominantly tholeiitic and the felsic plutons are predominantly calc-alkaline.

The Triassic plutonic suite is distinguished by: its coarser grain size; the structural grain in some plutons; more common intrapluton homogeneity (lack of extensive phases); presence of ultramafite compositions; rarity of inclusions; hornblende as sole mafic and common, coarse anhedral to euhedral titanite in the felsic plutons; more common alkaline compositions (especially on alkali-silica plots); geological relations with the Mesozoic volcanic suite; and isotopic age from the Jurassic plutonic suite.

The nature and habit of essential and accessory mineralogy of the Triassic plutonic suite are similar to the Jurassic plutonic suite and resemble I-type plutons in southeastern Australia described by White and Chappell (1977), Chappell (1978), Griffin et al. (1978) and Hine et al. (1978).

II.2 STIKINE PLUTON

II.2.1 Distribution, Physiography, Magnetic Expression

The Stikine Pluton makes up 5 per cent of the area of the Hotailuh Batholith and forms the eastern half of the southwestern apophysis of the Hotailuh Batholith which extends east into the Dease Lake map-area (Figures 1, 7). It underlies an essentially flat, swampy terrain and forms small, isolated, rounded, white-weathering granitic outcrops which form the floor of the swamps between low ridges capped by Tertiary volcanics. It is characterized by an aeromagnetic high (up to 58680 gammas; Geological Survey of Canada, 1978a) and an aeromagnetic depression (as low as 58260 gammas; Geological Survey of Canada, 1978a). The aeromagnetic high may reflect the contribution of a thick, columnar jointed olivine basalt flow which underlies a knob in the western extremity of the Stikine Pluton (Figure 2). The Stikine Pluton is named for the Stikine River which is 3 km south of the pluton.

II.2.2 Lithology

The Stikine Pluton is easily distinguished from all other plutons in the batholith. Medium-grained, equigranular, hypidiomorphic-granular diorite predominates; monzodiorite for a very minor part of the slightly heterogeneous to compositionally uniform pluton. Mafics and plagioclase together account for almost all of the rock (Figure 8). Euhedral hornblende is the predominant mafic although minor biotite is observed. Titanite is an uncommon to rare accessory; garnet is seen at two outcrops (near stations 423 and 425) where the rock is most amphibolitic in appearance. Dark grey, mafic, fine-grained diorite inclusions account for a

Figure 7. Location of the Stikine Pluton (bold outline) in the Hottailuh Batholith and of stations and samples discussed in text.

Figure 8. Modal compositions of hand samples and thin sections from the Stikine Pluton (see Appendix 1.5). Classification after Streckeisen (1973). Abbreviations are: KF = alkali feldspar; PF = plagioclase feldspar; and Qz = quartz.

small but significant part of the outcrops (see Appendix 1.1). They vary from rounded to elongate and their long axes are commonly oriented within the plane of foliation. Schlieren are observed at one locality (station 441; see Appendix 1.1).

II.2.3 Structure

Pervasive foliation characterizes the Stikine Pluton and its intensity distinguishes the Stikine Pluton from other foliated bodies in the Hotailuh Batholith. Stained handspecimens and thin sections reveal that plagioclase parallels the elongation of the hornblende. Apparent concentration of poles to foliation in the southeast and northwest quadrants of the contoured stereonet of Figure 9 results from disproportionate control in different parts of the pluton (see Appendix 1.2). In the eastern half of the pluton where outcrops are more plentiful (e.g. near station 619, and stations 623 to 626), especially in areas close to Highway 37, foliations predominantly strike northeast and dip steeply southeast or northwest. In the interior and western half of the pluton, characterized by scarce outcrops, foliations trend within 20 degrees of east, are also steeply dipping but to the north or south, and parallel the present east-west outcrop distribution of the pluton. Isolated, massive outcrops of Cake Hill Pluton occur along the eastern margin of the Stikine Pluton and are spatially associated with the change in foliation orientation from easterly-striking to northeasterly-striking. At one locality in the eastern half of the pluton, foliation is folded about southwest dipping axial planes and northwest-trending fold axes.

Figure 9. Lower hemisphere, equal area stereonet plots of lineation and poles to mineral foliation in the Stikine Pluton. Only "moderate" and "good" measurements used (see Appendix 1.2). Numbers refer to numbers of colinear poles. Contoured stereonet for mineral foliations only.

II.2.4 Intrusive Relations

As implied above, external and interpluton intrusive relations are not well exposed in the Stikine Pluton. Details of the nature of assumed and known intrusive relations involving other units and the Stikine Pluton are given in Appendix 1.3 and summarized in Figure 10.

(a) Upper Triassic Volcanics and Sediments

Contacts between the Upper Triassic augite porphyry volcanics and argillite and along its southern, northern and eastern margins are nowhere exposed and outcrops of the volcanic and sedimentary rocks are massive. At several localities along the southern margin of the Stikine Pluton, anastomosing hornblende monzonite and syenite apophyses intrude and include augite porphyry. However, these apophyses are lithologically similar to other intrusions clearly spatially-associated with the Three Sisters Pluton's potassic marginal phase farther north. Because of the absence of identifiable Stikine Pluton apophyses in the Upper Triassic volcanics and sediments and the apparent lack of contact metamorphism in these country rocks near their assumed contact with the Stikine Pluton, the Upper Triassic volcanics and sediments are assumed to post-date the Stikine Pluton. The volcanics may rest nonconformably on the pluton or be faulted against it.

(b) Tertiary Volcanics

Outcrops of Tertiary volcanics are scattered about the southwestern and southeastern parts of the Stikine Pluton. Again, the actual contacts between the two units are masked by swampy intervals. The volcanics are flat-lying and very fresh; they are assumed to also have a nonconformable contact with the Stikine Pluton.

Figure 10. Intrusive relations involving the Stikine Pluton and: (a) units external to the Hotailuh Batholith; (b) other plutons in the batholith (see Appendix 1.3). Abbreviation "Grt" refers to intrusive relationship and arrow leads from intrusion to country rock. Dashed arrow and question mark refer to uncertain intrusive relationship or unknown country rock.

(A) EXTERNAL

TERTIARY VOLCANICS

(NONCONFORMITY_P)

UPPER
TRIASSIC
VOLCANICS
AND
SEDIMENTS

(NONCONFORMITY_P)

STIKINE PLUTON
(K-Ar: 222 ± 11 Ma)

INT

P

(B) INTERPLUTON

THREE
SISTERS
PLUTON
(K-Ar: 142-189 Ma)

CAKE
HILL
PLUTON
(K-Ar: 143-151 Ma, 218-227 Ma)

INT

INT?

STIKINE PLUTON
(K-Ar: 222 ± 11 Ma)

YOUNGER

(c) Cake Hill Pluton

The contact between the Stikine Pluton and isolated outcrops of the Cake Hill Pluton along the eastern margin of the former pluton are not exposed. Two observations support the assumed intrusive nature of the Cake Hill Pluton with respect to the Stikine Pluton. An isolated outcrop of intensely foliated amphibolitic diorite in the southwestern corner of the Cake Hill Pluton is intruded by titanite- and hornblende-bearing monzonite apophyses which may be part of the Cake Hill Pluton (station 617). The foliation in the amphibolite dips steeply to the north northwest. As mentioned above, the change in foliation orientation from easterly to northeasterly and northerly is spatially associated with isolated massive outcrops of monzodiorite of the generally northwesterly-foliated Cake Hill Pluton. Deflection of Stikine Pluton foliation may have occurred during intrusion of the Cake Hill Pluton although similar effects of emplacement of the Three Sisters Pluton on the orientation of Stikine Pluton foliation cannot be ruled out. The potassium-argon age of the Stikine Pluton is marginally older than the Cake Hill Pluton but both ages are essentially concordant within limits of analytical error.

(d) Three Sisters Pluton

A syenitic apophysis, presumably related to the intrusion of the Three Sisters Pluton's potassic marginal phase, intrudes foliated diorite of the Stikine Pluton at one locality near its eastern margin (station 673).

II.2.5 Age

A replicated, potassium-argon hornblende age of 222 ± 11 Ma from diorite of the Stikine Pluton is reported by Wanless et al. (1972, G.S.C. 70-34;

see Table II.2.1 and Figure 11. The isotopic age is considered a minimum for the Stikine Pluton in the absence of other geological constraints.

II.2.6 Petrography

Quartz diorite and minor monzodiorite of the Stikine Pluton is distinguished by the nature, abundance (Figure 8 and Appendix 1.4), habit and fabric of its constituent minerals. In approximate order of crystallization they are: apatite, zircon (rare), plagioclase, hornblende, titanite, biotite (rare), quartz and alkali feldspar. Biotite, chlorite and epidote are uncommon alteration products of hornblende. Widespread, common calcite, sericite and saussurite alteration of cores and inner zones of plagioclase is characteristic.

Accessory apatite, zircon and opaque minerals are finer-grained and generally better-formed than the essential minerals. They commonly occur together; euhedral and squarish to anhedral opaque minerals commonly enclose equigranular apatite and zircon. Opaque minerals in sample 35-1 commonly occur as fractured aggregates whose fragments are separated and surrounded by a thin titanite rim.

Clinopyroxene was only observed in sample 35-1 and occurs as irregular, separate but optically continuous blebs in hornblende cores. Textural relationships between clinopyroxene and plagioclase were not observed.

Plagioclase (andesine to labradorite; An_{35-54}) is subhedral to euhedral and commonly the albite twins are slightly bent. Alignment of the long dimensions of elongate plagioclase and hornblende defines a distinctive mineral fabric in the rock. Oscillatory and predominant

TABLE II.2.1 POTASSIUM-ARGON RADIOMETRIC AGE DATA FOR THE STIKINE PLUTON¹

SPECIMEN NUMBER	PLUTON	LOCATION (LATITUDE- LONGITUDE)	LITHOLOGY	MINERAL	$\%K$	$^{40}Ar/^{40}K$	$\%^{40}Ar$	AGE (Ma)
GSC 70-34 ²	Stikine	58°04'30" N 129°57'30" W	diorite	hornblende	0.69	0.0137	79	222 ± 11
				hornblende	0.69	0.0132	79	222 ± 11

1. All potassium-argon ages are consistent with the decay constants of Steiger and Jäger (1977). All lithologies are classified according to Streckeisen (1973).

2. From Wanless et al. (1972, p. 17-21)

Figure 11. Mineral K-Ar isotopic ages for the Stikine Pluton and the Triassic portion of Armstrong's (1978a, 1981) time scale. Analytical errors in ages are 2σ (see Table 11.2.1). Solid and dashed lines give estimate of and error in worldwide Carnian-Norian boundary at 220 ± 8 Ma by Odin (1981).

discontinuous normal zoning of plagioclase changes its composition An_{5-10} (rarely as much as An_{14} ; e.g., cores = An_{54-40} , rims = An_{40-36}). In sample 35-1, plagioclase is homogeneous and comparatively more deformed. Inclusions of apatite, opaque minerals and fine-grained, subhedral hornblende occur in plagioclase cores and rims. Myrmekite is developed in plagioclase rims in a few places where it is in contact with interstitial alkali feldspar.

Hornblende occurs as commonly twinned, subhedral or euhedral, separate or elongate clots of grains whose longest dimension is aligned parallel to that of plagioclase. In sample 35-1, these clots commonly consist of finer-grained, anhedral grains. Strong absorption and distinctive pleochroic scheme (α' = light brownish yellow; β = dark olive green; γ' = dark bluish green) characterizes hornblende from the Stikine Pluton. It crystallized among or totally enclosed better-formed apatite, zircon, opaque minerals and plagioclase. Biotite and titanite also occur within hornblende; their anhedral or subhedral shape and common association with clearly secondary chlorite suggest that they are additional alteration products.

In addition to the habit described above, titanite occurs as medium-grained, separate, and euhedral grains which enclose plagioclase and apatite. In sample 35-1, titanite completely encloses fragments of fractured opaque minerals.

Biotite only occurs in a few places and its occurrence as clots or mats of small, anhedral or subhedral, clear or yellowish brown grains around and within opaque minerals, hornblende and titanite suggests

c) APM ternary for the Stikine Pluton

d) Silica - FeO*/MgO diagram for the Stikine Pluton

II.2.7 Chemical Composition

Major, minor and trace element compositions and CIPW norms for two samples from the Stikine Pluton are given in Table II.2.2 and plotted in Figure 12.

Stikine Pluton compositions are quartz-, hypersthene- and diopside-normative and plot in the subalkaline field of the normative ne'-ol'-qz' ternary (Figure 12(b); after Irvine and Baragar, 1971). One sample is alkali-enriched according to the alkali-silica plot (Figure 12(a) of Irvine and Baragar (1971). The subalkaline compositions have calc-alkaline affinities in AFM (Figure 12(c) and weight per cent Al_2O_3 -normative plagioclase (Figure 12(f); after Irvine and Baragar, 1971) plots but plot in the tholeiitic field of the SiO_2 -FeO*/MgO plot of Miyashiro (1974) and between typical Cascades and tholeiitic trends in a MgO-total iron plot (Figure 12(e); after Lowder and Carmichael, 1970; Stauffer *et al.*, 1975). The alumina-normative plagioclase plot also emphasizes the high alumina content (>17 weight per cent) of these rocks. In the weight per cent Na_2O - K_2O -CaO ternary (Figure 12(g)), Stikine Pluton compositions are enriched in CaO in proportion to the other oxides.

The calc-alkaline affinities of the Stikine Pluton are similar to other plutons of comparable age, tectonic setting and lithology farther south in the Intermontane Belt (Preto, 1972, 1978; Garnett, 1978). The average of Stikine Pluton compositions (Table II.2.2) is comparable with the average diorite as compiled by Le Maitre (1976) but is distinct from the hornblende-biotite and average diorite compositions compiled by Nockolds (1954).

TABLE II.2.2 CHEMICAL COMPOSITION OF THE STIKINE PLUTON

(a) Location and lithology of specimens

SPECIMEN	UNIT	LOCATION (Latitude and Longitude)	LITHOLOGY
35-1	Stikine Pluton	58°07'06"N 129°57'08"W	hornblende diorite
619-1	"	58°05'00"N 129°56'00"W	"

1. All lithologies classified after Streckeisen (1973)

TABLE II.2.2. CHEMICAL COMPOSITION OF THE STIKINE PLUTON

(b) Major Elements (in weight per cent)

OXIDE	SPECIMENS		AVERAGE (10)
	35-1	619-1	
SiO ₂	52.1	56.0	54.1 (2.8)
Al ₂ O ₃	17.9	18.1	18.0 (0.1)
TiO ₂	0.91	0.83	0.87 (0.06)
Fe ₂ O ₃	3.9	4.0	4.0 (0.1)
FeO	5.3	3.8	4.6 (1.1)
MnO	0.19	0.17	0.18 (0.01)
MgO	3.66	2.80	3.23 (0.61)
CaO	7.49	8.05	7.77 (0.40)
Na ₂ O	3.6	3.5	3.6 (0.4)
K ₂ O	2.69	1.47	2.08 (0.86)
P ₂ O ₅	0.47	0.29	0.38 (0.13)
H ₂ O _T	1.3	0.9	
CO ₂	B.D.	B.D.	
S	B.D.	B.D.	
Cl	0.04	0.06	
F	0.06	0.04	
Total	99.61	100.01	(98.81)

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE II.2.2 CHEMICAL COMPOSITION OF THE STIKINE PLUTON

(c) Trace Elements (in ppm)

	35-1	619-1	Average (10)
Rb	10	50	30 (28)
Sr	490	330	410 (113)
Ba	601	690	646 (63)
U	1.1	N.A.	1.1
Zr	47	28	38 (13)
Cr	64	11	38 (37)
Co	38	10	24 (20)
Ni	38	B.D.	38
V	290	180	235 (78)
Cu	76	76	76 (0)
Zn	50	100	75 (35)

B.D.: below detection limits of analytical method; N.A.: specimen not analyzed for given element or oxide.

TABLE II.2.2 CHEMICAL COMPOSITION OF THE STIKINE PLUTON
(d) CIPW Normative Minerals (in weight per cent)

NORMATIVE MINERALS	SPECIMENS	
	35-1	619-1
qz	0.26	10.10
or	15.90	8.69
ab	30.46	29.61
an	24.74	29.34
di	7.60	6.99
hy	10.77	6.23
mt	5.65	5.80
il	1.72	1.58
ap	1.11	0.68
H ₂ O	1.30	0.90
Cl	0.04	0.06
F	0.06	0.04
Total	99.61	100.01

Figure 12. Chemical variation diagrams for samples from the Stikine Pluton.

- a) Weight per cent alkali-silica diagram. Alkaline-subalkaline division after Irvine and Baragar (1971).
- b) Weight per cent, normative ne' - ol' - qz' ternary diagram ($ne' = ne + 3/5 ab$; $qz' = qz + 2/5 ab + 1/4 opx$; $ol' = ol + 3/4 opx$). Alkaline-subalkaline division after Irvine and Baragar (1971).
- c) Weight per cent $A (Na_2O + K_2O) - F (FeO + 0.8998 Fe_2O_3) - M (MgO)$ ternary diagram. Calc-alkaline - tholeiitic division after Irvine and Baragar (1971).
- d) Weight per cent $SiO_2 - FeO^*/MgO$ diagram ($FeO^* = FeO + 0.9 Fe_2O_3$). Calc-alkaline - tholeiitic division after Miyashiro (1974).
- e) Weight per cent $MgO - \text{total iron}$ diagram. Cascades, abyssal, tholeiite (AT), pigeonitic series and Thingmuli trends after Stauffer *et al.* (1974).
- f) Weight per cent alumina-normative plagioclase (weight per cent anorthite composition) diagram. Calc-alkaline - tholeiitic division after Irvine and Baragar (1971).
- g) Weight per cent $Na_2O - K_2O - CaO$ ternary diagram.

a) Alkali-silica diagram for the Stikine Pluton

b) $\text{Ne}'\text{-ol}'\text{-qz}'$ ternary for the Stikine Pluton

d) Silica - FeO*/MgO diagram for the Stikine Pluton

c) AFM ternary for the Stikine Pluton

e) MgO - total iron diagram for the Stikine Pluton

f) Alumina - normative plagioclase diagram for the Stikine Pluton

g) Na_2O - K_2O - CaO ternary for the Stikine Pluton

Other geochemical comparisons between the Stikine Pluton and other plutonic and volcanic units are made in Chapter VI. Harker variation diagrams for the Stikine pluton are given in Appendix I.5.

II.3. CAKE HILL PLUTON

II.3.1 Distribution, Physiography and Magnetic Expression

The Cake Hill Pluton underlies slightly more than one-third of the Hotailuh Batholith. It forms the bulk of the western half of the batholith, outcrops as numerous pendants and a small block in the southeastern corner and occurs as scattered small screens and inclusions throughout the eastern half of the batholith (Figure 13). Intrusion of the Three Sisters Pluton across the western part of the Cake Hill Pluton breaks the pluton into northern and southern parts. In its northern and southeastern outcrop areas the Cake Hill Pluton underlies some of the most subdued topography (flat-topped rolling ridges) in the batholith; the southern part is more rugged. Its name derives from the surveyed Cake Hill peak (elevation 1965 m (6447 feet)) which is near the centre of the pluton. It is characterized by comparatively lower aeromagnetic fields and scattered small, negative (to 58,340 gammas) and positive (to 58,710 gammas) aeromagnetic anomalies (Figure 2; Geological Survey of Canada, 1978a).

II.3.2 Lithology

Two phases are distinguished in the Cake Hill Pluton: a felsic phase, by far the most common; and a mafic phase. The mafic phase, a massive, equigranular, medium- to coarse-grained hypidiomorphic hornblende gabbro, occurs as small (e.g. 15 m x 15 m) outcrop areas at one locality and possibly as scattered inclusions. Details are found in Appendix 2.1. The mafic phase is not mappable at the scale of Figure 1. As the mafic phase is volumetrically insignificant in comparison to the felsic phase, in the following descriptions, the terms Cake Hill Pluton and felsic phase will be used

Figure 13. Location of the Cake Hill Pluton (bold outline) in the Hotailuh Batholith and of stations and samples discussed in text.

synonymously.

The felsic phase is characteristically white to mottled pink and white weathering, medium- to coarse-grained, equigranular and hypidiomorphic. Modal estimates of stained hand specimens indicate the felsic phase is overwhelmingly quartz monzodiorite to monzodiorite in composition (Figure 14); monzonite and quartz monzonite compositions are rare. Most compositions more alkali feldspar-rich than monzodiorite and quartz monzodiorite (e.g. syenite, quartz syenite) occur near or at the contact with one or more phases of the Three Sisters Plutons and are evidence for possible potash metasomatism of the Cake Hill Pluton associated with the intrusion of the Three Sisters Pluton. The felsic phase is characterized by the common presence of euhedral, tabular hornblende as the sole mafic mineral. Ubiquitous fine- to medium-grained euhedral to subhedral titanite and uncommon magnetite are important accessories visible in hand specimen. There is an uncommon association of the rare occurrence of biotite (in unmetamorphosed rocks) in monzonite to quartz monzonite bulk compositions.

Virtual absence of inclusions is another characteristic of the unmetamorphosed felsic phase. The northern half of the Cake Hill Pluton contains the most widespread inclusions; hornblendite (or hornblende gabbro), fine-grained hornblende diorite and greenstone (in order of decreasing abundance) are observed inclusion lithologies. Although more widespread to the north, they nonetheless compose less than one per cent of the outcrop. This contrasts to the frequency of inclusions in remobilized parts of the Cake Hill Pluton. The inclusions in the unmetamorphosed felsic phase are of moderate to large size, rounded to elongate and where elongate, are commonly elongate parallel to any foliation developed in the host rock.

"UNDISTURBED" SAMPLES

○ THIN SECTION (grab sample)

◇ THIN SECTION (K-Ar sample)

◆ THIN SECTION (K-Ar sample,
CHP fragment in Stuhini
Group volcanics)• HAND SAMPLE
(276 samples)**METAMORPHOSED SAMPLES**

■ THIN SECTION (grab sample)

◆ THIN SECTION (K-Ar sample)

△ THIN SECTION (CHP screen)

• HAND SAMPLE

Figure 14. Modal compositions of hand samples and thin sections from metamorphosed and "undisturbed" parts of the Cake Hill Pluton (see Appendix 2.5). Classification after Streckeisen (1973). Abbreviations are: KF = alkali feldspar; PF = plagioclase feldspar; and Qz = quartz.

II.3.3 Structure

A pervasive mineral foliation or lineation also distinguishes the felsic phase of the Cake Hill Pluton. Planar orientation of hornblende outlines the foliation (Plate I A); analogous fabrics in the plagioclase or alkali feldspars are rarely seen in stained handspecimens. Hornblende crystals are also lineated. Foliation and lineation are not observed together.

The three main areas where the Cake Hill Pluton is exposed, north of the Three Sisters Pluton apophysis (domain 1), south of the apophysis (domain 2) and in the southeastern corner of the Hotailuh Batholith (domain 3), have similar yet characteristic fabrics (Figures 1 and 15; Appendix 2.2). Domain 1 is characterized by a predominant steeply southwest- or northeast-dipping foliation compared with domain 2 (Figure 15). Massive fabrics are most common along the northern margin and in the east central part of domain 1. Domain 2 has a greater spread of foliation attitudes than domain 1 and shallow dipping foliation is more common in domain 2 than domain 1. Detailed mapping around the centre of domain 2 shows a crude, concentric arrangement of foliation in predominantly quartz-poor quartz monzodiorite (quartz less than 10 per cent) and monzodiorites around a core of massive quartz-rich (quartz greater than 10 per cent) quartz monzodiorite. The meagre data from domain 3 indicate a predominantly steep northwest- or southeast-dipping foliation (Figure 15). With the exception of domain 3 whose foliation may have been reoriented during the intrusion of the surrounding plutons, the foliation of domains 1 and 2 of the Cake Hill Pluton is markedly different than the predominant foliation of the Stikine Pluton.

Orientation of lineated hornblende is not characteristic of any domain in the Cake Hill Pluton. In domain 1 where almost all of the lineations are observed, moderate to steep northwest, southwest and southeast plunging

PLATE I: LITHOLOGICAL CHARACTERISTICS OF AND INTRUSIVE RELATIONS OF THE

CAKE HILL PLUTON

- Plate I A: Moderately developed foliation in the Cake Hill Pluton is defined by hornblende grains and elongate, fine-grained diorite inclusion. Black bar on pencil is about 5 cm long (station 564; slide 12-78-18).
- Plate I B: Cake Hill Pluton felsic phase stockwork and apophyses in irregular mass of hornblende gabbro of the mafic phase. Note fine-grained rim on one of the mafic phase fragments. Hammer is about 35 cm long (station 548; slide 10-78-1).
- Plate I C: Nonconformable contact between the white Cake Hill Pluton (C.H.P.) and dark grey, granitoid fragment-bearing basal flow of Upper Triassic Stuhini Group (Tst) along northern margin of the Hotailuh Batholith. Hammer is about 35 cm long (station 286; slide 6-77-17).
- Plate I D: Rounded fragments of Cake Hill Pluton in granitoid fragment-bearing basal flow of Upper Triassic Stuhini Group along northern margin of Hotailuh Batholith. Knife body at bottom of picture is 9 cm long (station 276; slide CBS-12-78-32).
- Plate I E: White-weathering, small to large, and angular to rounded Cake Hill Pluton fragments in basal volcanoclastic of Upper Triassic Stuhini Group along northern margin of Hotailuh Batholith. Hammer is about 35 cm long (station 701; slide 6-79-19).
- Plate I F: Large, angular fragments of the Cake Hill Pluton in basal volcanic flow of Upper Triassic Stuhini Group along northern margin of Hotailuh Batholith. Jacob's staff is 1.5 m long (near station 707; slide 8-79-22).
- Plate I G: Fluidally layered gabbro inclusion (see black arrow) in remobilized Cake Hill Pluton at contact with mafic phase of the Three Sisters Pluton. Brunton compass for scale (station 535; slide 8-78-28).
- Plate I H: Angular inclusion of massive hornblende gabbro (Three Sisters Pluton, mafic phase) in Cake Hill Pluton. Locality is 1 m above contact between remobilized Cake Hill Pluton and Three Sisters Pluton, mafic phase. Hammer is about 35 cm long (station 535; slide 7-78-30).
- Plate I I: Apophysis of inclusion-bearing mafic or central phase of the Three Sisters Pluton (outlined by dashed black line) and light grey, remobilized Cake Hill Pluton which has broken and dilated the apophysis (station 535; slide 8-78-30).
-

Figure 15a- Location of structural domains in the Cake Hill Pluton

58°15' —
129°00'

58°00' —
129°00'

Figure 15b. Lower hemisphere, equal area stereonet plots of poles to mineral foliation and of orientations of mineral lineation in three domains of the Cake Hill Pluton. Only "moderate" or "good" measurements used (see Appendix 2.2). Numbers refer to numbers of collinear poles.

CAKE HILL PLUTON (DOMAIN 2)

DATA DENSITY PER 1% AREA

0-1.47 %	1.47-2.94 %	2.94-4.41 %	5.88-7.35 %	7.35-8.82 %
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2. POLES TO MINERAL FOLIATION
(136 measurements)

CAKE HILL PLUTON (DOMAIN 3)

• POLES TO MINERAL FOLIATION
(7 measurements)

CAKE HILL PLUTON (DOMAIN 1)

• MINERAL LINEATION
(18 measurements)

(in order of decreasing frequency) lineations predominate (Figure 15).

Only one lineation was observed in either domain 2 or 3.

Near the northwestern contact of the Cake Hill Pluton and the overlying Upper Triassic volcanics, a narrow zone of strongly foliated rock is developed. Over a 250 m interval along one B.C.R. railcut, augite porphyry is highly schistose and large wavelength (2-5 m) kink bands fold the schistosity. Graphite schist is interbedded with the augite schist and to the west bedding in undeformed sediments is parallel to the schistosity. The schist-plutonic contact is not exposed. However, rocks of the Cake Hill Pluton near the outcrops of augite schist are intensely foliated. Foliation in the plutonic rocks approximately parallels schistosity in strike and dip. The zone of highly foliated diorite continues about 3.5 km farther southeast but 800 m to the north and northeast, foliation is not detected. Within the pluton this zone of closely spaced foliation is about 1 km wide and grades into the more typical, moderately foliated quartz monzodiorite of the Cake Hill Pluton's felsic phase to the east.

Near the southwestern corner of domain 2, pervasive fractures are developed in rocks which, away from this zone, resemble typical Cake Hill Pluton lithologies. In this zone however, the rock is talcose with common specular hematite and chlorite along fractures. Although these fractures generally dip steeply to the northeast, the fractured zone is approximately on trend with the zone of sheared augite porphyry and highly foliated Cake Hill Pluton diorite to the north in domain 1 and both may mark the locus of a post-Late Triassic, pre-late Early Jurassic fault. Except for common, north-trending, vertical jointing in the potassic marginal phase of the Three Sisters Pluton between these two Cake Hill Pluton localities, little

deformation is evident in the potassic marginal phase along the locus of this suspected fault.

Jointing in the Cake Hill Pluton is not distinctive. Vertical joints are better developed than horizontal joints.

II.3.4 Intrusive Relations

Intrapluton, external and interpluton intrusive relations indicate that the Cake Hill Pluton is one of the oldest plutons in the Hotailuh Batholith. Metamorphism and/or remobilization of the felsic phase of the Cake Hill Pluton occur locally near its contacts with the Three Sisters Pluton. Intrusive relationships between the Cake Hill Pluton and sediments and volcanics, plutonic rocks and hypabyssal intrusions are summarized in Figure 16 and given in detail in Appendix 2.3.

(a) Mafic Phase

Except for the presence of rare hornblendite and hornblende gabbro inclusions (mafic phase?) in the felsic phase of the Cake Hill Pluton, observations of contact relationships between the mafic and felsic phases are restricted to the only large outcrop area, about 5 km southwest of Cake Hill. There, apophyses of the felsic phase dismember the irregular mass of mafic phase hornblendite and hornblende gabbro. Locally, thin (2-3 cm) chilled selvages are observed on the mafic fragments (Plate I B).

(b) Upper Triassic Volcanics and Sediments

Upper Triassic (Carnian to Norian?), upper Lower Jurassic (Toarcian) and Tertiary (Miocene to Pleistocene) volcanics and sediments rest nonconformably on the felsic phase of the Cake Hill Pluton. The stratigraphy of these overlying units is described in Chapter III.

Figure 16. Intrusive relations involving the Cake Hill Pluton and: (a) external, intra-plutonic and other plutonic units (see Appendix 2.3); (b) hypabyssal intrusions (see Appendix 2.4). Abbreviation "IN" refers to intrusive relationship and arrow leads from intrusion to country rock. Closed arrowhead indicates most common intrusive relationship between plutons; open arrowhead less common intrusive relations. Question marks show uncertain relationships between units or unknown country rocks.

(a) EXTERNAL, INTRAPLUTON AND INTERPLUTON INTRUSIVE RELATIONS

TERTIARY
VOLCANICS

(NONCONFORMITY)

TOARCIA
SEDIMENTS

(NONCONFORMITY)

UPPER
TRIASSIC
VOLCANICS
AND
SEDIMENTS

(NONCONFORMITY)

CAKE HILL PLUTON

(K-Ar: 143 ± 6 Ma, 151 ± 8 Ma, 218 ± 11 Ma, 220 ± 11 Ma, 227 ± 14 Ma)

CAKE HILL PLUTON
mafic phase

INT

THREE
SISTERS
PLUTON

(K-Ar: $142-189$ Ma)

INT

GNAT LAKES ULTRAMAFITE
(K-Ar: $227-230$ Ma)

INT

BEGGERLAY CREEK PLUTON
(K-Ar: 218 Ma)

INT

STIKINE PLUTON
(K-Ar: 221 Ma)

INTP

INT

YOUNGER

(B) HYPABYSSAL INTRUSIONS

PLATE II: ADDITIONAL INTRUSIVE RELATIONS INVOLVING THE CAKE HILL PLUTON

- Plate II A: Natural and inked-in contact between Cake Hill Pluton (C.H.P.; top) and central phase of the Three Sisters Pluton (T.S.P.; bottom). Portion of pocket knife is 5 cm long (station 470; slides 3-78; 19 and 20).
- Plate II C: Irregular, equivocal intrusive relations between the coarser-grained, light grey, remobilized Cake Hill Pluton (C.H.P.) and the finer-grained, dark grey, central phase of the Three Sisters Pluton (T.S.P.). Vertical field of view is about 2 m (station 477; slide 4-78-8).
- Plate II D: Pyroxene porphyry dike (dark grey) in Cake Hill Pluton (white). White arrows show margins of dike. Black arrow shows knapsack for scale (between stations 191 and 196; slide 4-77-14).
- Plate II E: Fine-grained selvage of hornblende-pyroxene porphyry dike (grey) against Cake Hill Pluton (white). Left hand end of pencil rests on angular Cake Hill Pluton fragments in the dike. Black bar on pencil is approximately 5 cm long (station 698; slide 6-79-7).
- Plate II F: Round to irregular black hornblendite and hornblende gabbro inclusions in hornblende-pyroxene porphyry dike seen in Plate II E. Mafic inclusions are lithologically similar to hornblendite in the Gnat Lakes Ultramafite. Black bar on pencil is about 5 cm long (talus boulder at station 698; slide 6-79-8).
- Plate II G: White, rounded and angular blocks of the Cake Hill Pluton in grey andesite at westernmost of two possible volcanic centers along northeastern margin of Cake Hill Pluton. Figure at left hand side of photograph gives scale (station 690; slide 5-79-37).

Contacts between the felsic phase and Upper Triassic volcanics and sediments are best observed in several localities along the northern margin of the Hotailuh Batholith (Figure 17). In many of these locations known (thrust fault in sections 705, 707, and 714) or suspected (stations 276 and 701) faults separate the two units. At one locality (between station 702 and 703), an augite porphyry plug was emplaced along the contact. At two localities (stations 286 and 293), the nonconformable contact is clearly exposed (Plate I C and Figure 17). There the granitic rock has a smooth but irregular to highly irregular and jagged surface reminiscent of present day ridge surfaces in the batholith. The basal unit in the overlying rocks consists of a greenish grey volcanic conglomerate with rounded to subangular pebble to boulder size fragments of massive, foliated or lineated monzodiorite and quartz monzodiorite lithologically, petrographically and chemically similar to typical felsic phase rocks of the Cake Hill Pluton. The basal conglomeratic unit is common to all localities except one (station 705) where the Upper Triassic rocks contact or are close to the felsic phase of the Cake Hill Pluton (Plate I D, E, F).

Contact relationships between the small exposure of silicic volcanics and sediments outcropping west of Highway 37 and the felsic phase were not observed but the two units may be coeval.

(c) Upper-Lower Jurassic Sediments

The contact between the felsic phase of the Cake Hill Pluton and the upper Lower Jurassic sediments is best exposed along the northwestern margin of the batholith south of peak 2087 m (6848 feet). There, the basal, moderately clean quartz arenite of the Toarcian sequence dips steeply to the north off the Cake Hill Pluton. The contact between the two may be bracketed

Figure 17a. Detail of the northern margin of the Cake Hill Pluton. Location of Plate I C and Figure 17b are also shown.

Figure 17b. Camera lucida sketch of nonconformable contact between Cake Hill Pluton (abbreviation CHP; "x" pattern) and Upper Triassic Stuhini Group (abbreviation UTst; "v" pattern) at station 292. Cake Hill Pluton fragments in basal Stuhini Group member also shown.

to within 0.3-0.5 m and although not seen is considered nonconformable. Along the eastern margin of the batholith, calc-silicates and interlayered siltstone and shale appear to nonconformably overlie syenite of the metamorphosed Cake Hill Pluton but the actual contact is not exposed. Stratigraphy of the Toarcian sediments is described in Chapter III.

(d) Tertiary Volcanics

Tertiary volcanics overlie the felsic phase in the north-central part of domain 2 and in the southeastern outlier of the Cake Hill Pluton. The nonconformable contact is best exposed in the former locality. The nature of the Tertiary volcanics is discussed in a later section. From a distance, the volcanics clearly occupy a paleovalley in the Cake Hill Pluton and the outcrop distribution of the volcanics conforms to this ancient northerly plunging landform. Rounded Cake Hill Pluton erratics which litter the volcanics above their contact with the pluton suggest that this erosional feature and the eruption of the volcanics predates the last major advance of ice.

(e) Beggerlay Creek Pluton

Intrusive relationships between the Cake Hill and Beggerlay Creek Plutons are best exposed at the contact 18 km south of Cake Hill, near the southern margin of Cry Lake map-area (Plate III G,H). Within 1 km of the easterly-trending contact, moderately foliated hornblende monzodiorite of the felsic phase apparently grades to well-foliated hornblende diorite. Foliation in the Cake Hill Pluton swings around in approximate concordance with the contact and dips steeply to the north or northeast. At the contact, pyroxenite and fluidally foliated and massive hornblende diorite of the Beggerlay Creek Pluton intrude, include and rotate blocks of the hornblende

diorite of the Cake Hill Pluton felsic phase. About 3 km northeast of this location, gabbro dikes (probably related to the Beggerlay Creek Pluton) intrude the felsic phase of the Cake Hill Pluton. A similar gradational change in the Cake Hill Pluton from massive textures or northwest-trending foliation in the quartz monzodiorite to gabbro with intensely-developed, easterly-trending foliation is observed near the contact at this locality.

(f) Gnat Lakes Ultramafite

Outcrops at one location on the B.C.R. grade due west of the Lower Gnat Lake illustrate the intrusive relations between the felsic phase of the Cake Hill Pluton and the Gnat Lakes Ultramafite. Irregular, dun weathering apophyses of hornblende pyroxenite engulf sphene-bearing, well-foliated hornblende diorite and include rounded xenoliths of it.

(g) McBride River Pluton

No contacts between the McBride River and the Cake Hill Plutons were observed. On the basis of its K-Ar radiometric age (186 ± 13 Ma) and its intrusive contacts with Upper Triassic volcanics, the McBride River Pluton is assumed to be younger than the Cake Hill Pluton.

(h) Three Sisters Pluton

Intrusive relations between all phases of the Three Sisters Pluton and the felsic phase of the Cake Hill Pluton are exposed along the eastern contact of the Cake Hill Pluton, on or near the northwest-trending apophysis which divides the Cake Hill Pluton and in the southeastern outliers of the Cake Hill Pluton. Commonly, the intrusive relations are clear: dikes or apophyses of recognizable lithologies of the Three Sisters Pluton intrude and include recognizable Cake Hill Pluton (details given in Appendix 2.3). However, intrusive relationships are obscured or confused by apparent metamorphism and remobilization of the Cake Hill Pluton in these areas.

Intrusive relationships of the Three Sisters Pluton and metamorphism and remobilization of the felsic phase of the Cake Hill Pluton are well-exposed about 0.5 km north of peak 2187 m (7174 feet). Typical titanite-bearing, medium- to coarse-grained hornblende monzodiorite and hornblende quartz monzonite of the felsic phase is intruded and included by irregular dikes and apophyses of acicular hornblende diorite (mafic phase of the Three Sisters Pluton), inclusion-bearing monzodiorite (central phase) and syenite and quartz syenite (potassic marginal phase of the Three Sisters Pluton). Minor biotite occurs with the predominant hornblende in the Cake Hill Pluton. Locally, typical monzodiorite of the Cake Hill Pluton's felsic phase grades into syenite compositions. Farther south, at a higher elevation in the cirque, heterogeneous outcrops expose irregular masses and apophyses of titanite- and magnetite-bearing hornblende biotite granodiorite (lithologically similar to Cake Hill Pluton) which appear to intrude and include the surrounding (biotite)-acicular hornblende diorite of the Three Sisters Pluton's mafic phase. Rounded, fine-grained diorite (Three Sisters Pluton's fine-grained phase?) and fine- to medium-grained acicular hornblende diorite inclusions compose 5-30 per cent of Cake Hill apophyses and agmatites and, when elongate, locally outline a foliation in the massive apophyses.

Occupying the valley floor and part of the pass north of peak 2187 m (7174 feet) are outcrops of titanite-bearing biotite-hornblende to hornblende-biotite quartz monzodiorite which are lithologically similar to typical rocks of the Cake Hill Pluton's felsic phase. However they contain biotite as a significant mafic constituent (apparently pseudomorphing hornblende) and a significant concentration (2-10 per cent) of medium-sized (1 cm - 1 m long) round to elongate, fine-grained monzodiorite inclusions (lithologically

similar to the fine-grained phase and to inclusions seen in the central phase of the Three Sisters Pluton). Locally, an apophysis of biotite-hornblende monzodiorite typical of the Three Sisters Pluton's central phase intrudes this biotite- and inclusion-bearing Cake Hill Pluton.

At this locality the metamorphosed and remobilized felsic phase of the Cake Hill Pluton retains the following characteristics of similar rocks in undisturbed areas: coarser grain size, euhedral, tabular hornblende grains and uncommon but widespread titanite (and less commonly magnetite). These distinguish it, even where remobilized, from the Three Sisters Pluton's central phase. However, common, fine-grained monzodioritic inclusions and uncommon to common fresh, euhedral biotite in the remobilized rock contrasts the typical characteristics of the undisturbed Cake Hill Pluton.

The effect of the mafic phase's intrusion on the Cake Hill Pluton is further illustrated at one of their mutual contacts 4.5 km east northeast of Cake Hill. Typical, medium- to coarse-grained foliated hornblende quartz monzodiorite of the Cake Hill Pluton's felsic phase is separated from medium- to coarse-grained, equigranular hornblende gabbro typical of the Three Sisters Pluton's mafic phase by a 1 m interval of finer-grained fluidally layered gneiss. Moderately northwest-dipping gneissosity contrasts the steep northerly dips of foliation in the quartz monzodiorite. Foliation in the Cake Hill Pluton adjacent the mafic phase of the Three Sisters Pluton is also atwart the regional northwest grain farther west. Small to large angular inclusions of the fluidal gneiss and equigranular gabbro in the felsic phase within 3 m of the contact (Plate I G,H) and partly dilated, finer-grained, inclusion-bearing monzodiorite screens (Plate I I) at one locality near the contact confirm the intrusive nature of the Cake Hill

Pluton. A hornblende potassium-argon age of 183 ± 14 Ma from part of the mafic phase near this locality, concordant with other ages determined for the mafic phase, further suggests that the older Cake Hill Pluton was remobilized during intrusion of the Three Sisters Pluton's mafic phase.

Compositional and structural changes are observed in the felsic phase of the Cake Hill Pluton near the northwest-trending apophysis 10 km southwest of Cake Hill. Over a 2 km interval, massive quartz monzodiorite grades into a well-foliated hornblende diorite. Poorly developed feldspar augen and the intensity of the steep, northerly dipping foliation suggest slight cataclasis of the host Cake Hill Pluton during intrusion of the Three Sisters Pluton apophysis.

About 8 km northwest of the last locality (and approximately 6 km southwest of Cake Hill) foliations in the quartz monzodiorite crudely parallel the orientation of the Three Sisters Pluton's apophysis and contrast the general northwest trends in undisturbed Cake Hill Pluton to the northwest. Nearby, intense, concordant, steep, north northwest dipping foliation is developed in both the Cake Hill Pluton felsic phase and in a cross-cutting augite porphyry dike and give both lithologies a gneissic appearance. Foliation in the felsic phase of the Cake Hill Pluton continues to be crudely concordant with the contact but decreases in intensity northwards from it. Two kilometres north of the contact, "typical" northwest-trending foliation resumes. The composition of the intensely foliated felsic phase is syenitic.

Apparent potash metasomatism of the felsic phase of the Cake Hill Pluton occurs along a 2 km wide aureole parallel with the northeast known and inferred contact of the Three Sisters Pluton's apophysis. This metasomatism

is recognized as far southeast as the locality described in the last paragraph and continues northwest to outcrops west of Highway 37, 5 km east of Mount Thanatlodi. This aureole corresponds approximately to the distribution of the potassic marginal phase in the Three Sisters Pluton's major apophysis. The mottled white and pink weathering metamorphosed felsic phase is syenitic to quartz syenitic, coarse-grained, and pink and crumbly. Mafics comprise equal amounts of hornblende and biotite (locally biotite predominates) and display glomeroporphyritic and pseudomorphic (polygonized grains of biotite after hornblende) textures. Locally, bluish grey plagioclase megacrysts, typical of some parts of the potassic marginal phase, are observed in the coarse-grained syenite. Near their contact, potassic marginal phase and metamorphosed Cake Hill Pluton lithologies are indistinguishable although generally the metamorphosed rocks are coarser-grained, contain an abundance of anhedral to subhedral biotite compared to hornblende, and rarely contain alkali or plagioclase feldspar megacrysts.

The textural similarities between metamorphosed and undisturbed felsic phase of the Cake Hill Pluton range from moderate to vague. The presence of uncommon to rare, thin, irregular to dike-like bodies of fine-grained diorite, equant hornblende porphyry diorite, inclusion-bearing monzodiorite, and leucocratic hornblende diorite in assumed or known intrusive contact with the metamorphosed felsic phase, (e.g. see Plate II A,B,C), their lithological similarities to constituent phases of the Three Sisters Pluton, the spatial association of this coarse-grained syenitic lithology with both the undisturbed Cake Hill Pluton and the potassic marginal phase, and the incidence of syenitic compositions in readily recognizable Cake Hill Pluton close to other Three Sisters Pluton contacts strongly suggest that potash metasomatism of the

Cake Hill Pluton's felsic phase occurred during intrusion of the potassic marginal phase. Irregular bodies of this coarse-grained syenite within the western apophysis of the Three Sisters Pluton and in the potassic marginal phase east of Mount Thenatlodi may represent screens or small pendants of the metamorphosed Cake Hill Pluton's felsic phase.

Outliers of the Cake Hill Pluton in the southeastern corner of the Hotailuh Batholith provide further evidence of metamorphism and remobilization of the earlier plutonic rock. In these outliers, the contact between the felsic phase of the Cake Hill Pluton and the central phase of the Three Sisters Pluton is recognized by the medium to coarse-grained, homogeneous, more leucocratic, hornblende-biotite quartz syenite composition of the former and fine- to medium-grained, inclusion-bearing, more mafic biotite hornblende monzodiorite to quartz monzodiorite of the latter. Pink alkali feldspar megacrysts are locally common in the coarse-grained syenite. The contact is sharp (Plate II A,B); at one locality, fine-grained dioritic to monzodioritic inclusions are shared between the two lithologies at their contact. Uncommon inclusions of similar composition are found in the remobilized Cake Hill Pluton. The intrusive relations between these two plutonic rocks are rarely unequivocal (e.g. Plate II C) but the coarser-grained syenite caps the ridges and its contact with the underlying monzodiorite is irregular but in general moderately shallow. Acicular hornblende dikes with chilled margins up to 30 cm wide and fine-grained diorite dikes intrude these outliers of remobilized Cake Hill Pluton. As seen elsewhere at the contact between the Cake Hill and Three Sisters Plutons, the textural and mineralogical similarities between the intruded and undisturbed Cake Hill Pluton lithologies are moderate but not total; however dike lithologies similar to early phases

of the Three Sisters Pluton and at this locality, the outcrop pattern of the coarser-grained syenitic lithology strongly suggest metamorphism and remobilization of the felsic phase of the Cake Hill Pluton associated with intrusion of the Three Sisters Pluton.

Leucocratic, medium- to coarse-grained, hornblende or biotite-hornblende quartz syenite, quartz monzonite and quartz monzodiorite of the metamorphosed Cake Hill Pluton apparently nonconformably underlies metamorphosed Toarcian sediments along the eastern margin of the batholith, west of the McBride River Pluton. Irregular, metamorphosed augite and bladed plagioclase porphyry intrusions (station 170, 171) and apophyses of the central and potassic marginal phase of the Three Sisters Pluton (e.g. station 168) apparently cut the metamorphosed pluton. However, the metamorphosed pluton also appears to have back-veined and broken up one of the augite porphyry intrusions (station 171). These relationships and the lithological similarity of the rocks in this area to undisturbed Cake Hill Pluton are suggestive of metamorphism and remobilization of the pluton at its contacts with the Three Sisters Pluton. Its assumed nonconformable relationship with the Toarcian sediments along the eastern margin of the batholith also indicates that the Cake Hill Pluton may have originally extended to the present contact between the Three Sisters Pluton and the Upper Triassic volcanics.

(1) Hypabyssal Intrusions

Dikes, plugs and irregular apophyses, some peculiar to the Cake Hill Pluton, others seen in other Triassic or younger plutons are common in the Cake Hill Pluton. Some have been briefly described in the section concerning intrusive relations. Lithology and distribution of the more "volcanic" hypabyssal intrusions, many not apparently associated with any pluton, are

briefly described. A summary of dike lithologies is given in Figure 16 (and Appendix 2.4).

Augite plagioclase porphyry dikes are particularly characteristic of the Cake Hill Pluton and are found in all three domains. They occur as generally tabular to moderately irregular thin dikes (Plate II D,E) in various orientations. An east northeast trend is most common followed by a north northeast trend, however orientations in every quadrant have been recorded (Figure 18). Augite ($\pm$ plagioclase) porphyry are the most common lithologies; hornblende phenocrysts are rare. Commonly selvages are seen (Plate II E) and rarely dikes are differentiated into trachytoid plagioclase porphyry margins and a massive plagioclase-augite porphyry core. One hornblende-augite porphyry dike contains xenoliths of the felsic phase of the Cake Hill Pluton (Plate II E) and coarse-grained hornblendite and hornblende gabbro (Plate II F).

Greenish grey fine-grained andesite dikes are another common dike lithology common to the felsic phase of the Cake Hill Pluton and younger intrusions. They are commonly steeply dipping and northeasterly-trending; east southeast orientations are less common (Figure 18).

Basalt, felsite and aplite, pegmatites and fine- to medium-grained porphyries (hornblende and plagioclase) form rare dikes in the Cake Hill Pluton. Aplite and pegmatite dikes are most common near, but not restricted to, the vicinity of contacts with the Three Sisters Pluton. Orientations of these dikes are given in Figure 18.

A locus for hypabyssal intrusion appears to be the northeastern exposed margin of the Cake Hill Pluton. At least two intrusions, one a flow layered rhyolite, the other a $\pm$ hornblende $\pm$ plagioclase syenite, form common dikes

Figure 18. Lower hemisphere, equal area stereonets of poles to orientations of: pyroxene porphyry dikes (23 measurements); andesite dikes (51 measurements); and miscellaneous porphyry and siliceous dikes (27 measurements) in the Cake Hill Pluton. Some dikes are differentiated by the structural domain of the Cake Hill Pluton in which they occur. Numbers refer to numbers of colinear poles.

POLES TO ORIENTATIONS OF ANDESITE DYKES IN

- Domain 1
- Domain 2
- △ Domain 3

POLES TO ORIENTATIONS OF PYROXENE PORPHYRY DYKES IN

- Domain 1
- Domain 2
- △ Domain 3

POLES TO ORIENTATIONS OF:

2, PORPHYRY DYKES (Domain 1)

○ PORPHYRY DYKES (Domain 2)

△ SYENITIC PORPHYRY DYKES

□ APLITE, FELSITE, RHYOLITE AND PEBBLE DYKES

or irregular plugs respectively, areally restricted to the outcrop areas of the Cake Hill Pluton northeast of the Tanzilla River (Figure 17). An interesting granite-chert pebble dike also intrudes the Cake Hill Pluton in this area. Finally, in three localities in this area (Figure 17), deeply eroded volcanic centers are preserved. In the more western of the two, a transition from massive Cake Hill Pluton basement to completely disaggregated angular blocks of the Cake Hill Pluton in a mafic volcanic groundmass (Plate II G) is well exposed over a 1 km interval. Alteration of the felsic phase near the contact results in loss of visible mafics or potassium feldspar. At another, more easterly center, a whitish locally flow layered rhyolitic? intrusion engulfs both blocks from the Cake Hill Pluton basement and the grey-green basal granitic cobble-bearing andesitic flow which unconformably overlies the Cake Hill Pluton. However the Cake Hill Pluton felsic phase lithologies predominate. The clasts are rounded, reach sizes of 1.5 m x 4 m in two dimensional section, and compose up to 80 per cent of outcrop in some places. The contact of the rhyolite intrusions with the Cake Hill Pluton is difficult to distinguish due to alteration of the latter and similar weathering colour and texture in the former near the bracketed contact. Flow layering in the rhyolite groundmass is best developed in the center of the intrusion and swirls around the fragments. This intrusion is probably related to the intrusion of the flow layered rhyolitic dikes seen in the Cake Hill Pluton and surrounding volcanics in the area.

A third center, located near the southeast corner of the batholith, comprises banded, highly epidotized tuffs which appear intrusive into the Cake Hill Pluton near their contact and contain angular, granitoid blocks of various sizes.

II.3.5 Age

Four potassium-argon dates exist for the Cake Hill Pluton (Table 1 and Figure 19). One was determined from hornblende replicates from the felsic phase near Cake Hill and yielded dates of 218 ± 11 Ma and 220 ± 11 Ma (G.S.C. specimen 70-33; Wanless *et al.*, 1972). Hornblende, separated from cobbles collected from the basal volcanic flow nonconformably overlying the Cake Hill Pluton along the northern margin of the Hotailuh Batholith, yielded a date of 227 ± 14 Ma. Although these dates are internally consistent in that the younger date is expected from rocks once at a lower structural level than rocks eroded early and included in Triassic volcanics, problems in their interpretation still exist and are discussed in Chapter V.

The youngest, Jurassic, dates of 151 ± 8 Ma (hornblende) and 143 ± 6 Ma (biotite) (Wanless *et al.*, 1972, specimens G.S.C. 70-27 and 70-28) were determined from core collected at a depth of 424 m from a diamond drill hole (total depth of 427 m) located on the Cassiar-Stewart Highway and described by Souther (1971b). The lithology is very similar to that seen on surface and is apparently the host rock for several intrusions, veins and alteration, some of which resemble the mafic, central and potassic marginal phases of the Three Sisters Pluton. On surface and in drill core the dated host rock appears to be metamorphosed Cake Hill Pluton and the dates were clearly reset by the intrusion of the Three Sisters Pluton.

The oldest dates determined are consistent with estimates of the boundary between the Carnian and Norian, the assumed age of the Upper Triassic volcanics which nonconformably overlie the Cake Hill Pluton (Figure 19).

TABLE II.3.1 POTASSIUM-ARGON RADIOMETRIC AGE DATA FOR THE CAKE HILL PLUTON¹

SPECIMEN NUMBER	PLUTON	LOCATION (LATITUDE- LONGITUDE)	LITHOLOGY	MINERAL	%K	⁴⁰ Ar/ ³⁹ K	% ⁴⁰ Ar	AGE (Ma)
GSC 70-33	CAKE HILL PLUTON	58°10'N 129°39'W	monzonite/ quartz	hornblende	0.54	0.0135	47	220 ± 11
AN-77-276	CAKE HILL PLUTON (fragment)	58°13'10"N 129°31'00"W	monzonite	hornblende	0.54	0.0136	68	218 ± 11
GSC 70-27 ² GSC 70-28 ²	metamor- phosed? CAKE HILL PLUTON	59°09'36"N 129°51'54"W	quartz mon- zonite	hornblende	0.380	0.01403	77.9	227 ± 14
			grano- diorite	hornblende biotite	0.665 7.57	0.0091 0.0086	78 92	151 ± 8 143 ± 6

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1. All potassium-argon ages are consistent with the decay constants of Steiger and Jäger (1977). All lithologies are classified according to Streckeisen (1973).

2. from Wanless et al. (1972, p.17-21)

Figure 19. Mineral K-Ar isotopic ages for the Cake Hill Pluton and the Triassic portion of Armstrong's (1978a, 1981) time scale. Analytical errors in ages are 2σ (see Table II.3.1). Solid and dashed lines give estimate of and error in worldwide Carnian-Norian boundary at 220 ± 8 Ma by Odin (1981).

II.3.6 Petrography

Nature, abundance (Appendix II.5) and texture of essential and accessory mineralogy characterize the undisturbed and metamorphosed Cake Hill Pluton. Generally, its larger grain size and lack of biotite distinguishes it from Jurassic plutons.

Quartz monzodiorite predominates but monzodiorite, granodiorite and monzonite are also represented in undisturbed parts of the pluton or in fragments incorporated into basal units of the Stuhini Group (Figure 14). Accessory and essential minerals are (in approximate order of crystallization): zircon, apatite, opaque minerals, clinopyroxene, plagioclase, hornblende, allanite (rare), biotite (rare), titanite, quartz and alkali feldspar. Sample GAD-132-1 was used in K-Ar isotopic age determinations (sample GSC 70-33; Wanless *et al.*, 1972) and is typical of the undisturbed parts. Fragments of Cake Hill Pluton in basal Stuhini Group volcanics, represented by sample 276, are more felsic (more abundant quartz and lower colour index) than undisturbed parts of the pluton but contain typical hornblende and plagioclase and lack biotite. The intensely foliated part of the pluton in the northwest (sample 360-2) is distinguished by its more abundant clinopyroxene and higher colour index. Alignment of minerals is not observed in thin sections of samples collected from foliated or lineated outcrops. Epidote, chlorite and sericite are medium- to fine-grained alteration products of the ferromagnesian silicates and plagioclase.

Quartz monzonite, monzonite, syenite, granodiorite and diorite constitute screens and pendants of metamorphosed Cake Hill Pluton in the Jurassic plutonic suite. Nature and apparent order of crystallization of essential and accessory minerals are similar to the undisturbed parts

(Appendix II.5). Biotite and alkali feldspar are more abundant, hornblende and titanite less abundant and the colour index less in the metamorphosed unit. Samples 154-1 and 344 from eastern pendants or screens in the Three Sisters Pluton, central phase, are apparently least affected by the Jurassic plutonism.

Accessory minerals apatite and zircon are euhedral and commonly equigranular with square or anhedral and irregular opaque minerals (magnetite) which enclose them. In a few places zircon occurs as inclusions in apatite, or rims opaque minerals. Apatite, as inclusions in hornblende and biotite, is more abundant in the metamorphosed parts of the pluton than in undisturbed parts.

Clinopyroxene is widespread in the northwestern and southwestern parts of the undisturbed parts and sparse in the metamorphosed parts of the Cake Hill Pluton. It is most common as irregular, optically continuous blebs in cores of hornblende. In some samples with less hornblende, clinopyroxene in its original euhedral, rectangular form is observed. Subhedral or euhedral opaques and apatite are enclosed in clinopyroxene. Twinning is rare and, in sample 154-1, clinopyroxene occurs in clots in some places.

Plagioclase is subhedral, twinned and contains subhedral or euhedral opaques, apatite, clinopyroxene and hornblende inclusions in its core or rim. The low refringence of plagioclase (less than quartz and Canada balsam) and the difficulty encountered in finding well-oriented Carlsbad-albite twins for composition determination were unexpected in rocks with such a high plagioclase/alkali feldspar ratio and colour index. These features characterize plagioclase from undisturbed and metamorphosed Cake Hill Pluton. In some samples e.g., (196-2; GAD-132-1), no composition

determinations were possible. Albite-oligoclase (An_{1-14}) is typical but, in a few samples, plagioclase is oligoclase-andesine (An_{22-40}). Continuous and discontinuous reverse and normal zoning change compositions by An_{2-16} (e.g., cores = An_{2-4} , rims = An_{4-12} and core = An_{46} , rim = An_{30}). Myrmekite or irregular grain boundaries characterize plagioclase-alkali feldspar contacts.

Hornblende occurs as twinned or untwinned grains in two habits. It occurs as thin rims on euhedral, rectangular clinopyroxene in a few places. Hornblende without clinopyroxene or with clinopyroxene as irregular cores, commonly occurs as coarse poikilitic grains with euhedral or subhedral apatite, zircon, opaque minerals, plagioclase and titanite and rare anhedral quartz and alkali feldspar inclusions. Clots of hornblende, biotite, apatite, titanite and opaque minerals are common in samples of the metamorphosed pluton. Pleochroism, although patchy in some grains, distinguishes hornblende in undisturbed and metamorphosed parts. Undisturbed samples (and samples 154-1 and 344) exhibit moderate absorption (α' = light brownish yellow, β = olive green, γ' = forest or bluish green) whereas intense absorption (α' = yellowish brown; β = dark brownish green; γ' = bluish or olive green) characterizes hornblende in metamorphosed samples (447-5, 606-1, 612-4 and GA 1390).

Biotite is rare in undisturbed parts but its presence is distinctive of metamorphosed rocks. In the undisturbed rocks, it has a ragged rectangular habit, encloses opaque minerals and is intergrown with alkali feldspar. In sample 154-1, biotite appears to be an alteration product of hornblende. In other samples of metamorphosed Cake Hill Pluton, subhedral biotite contains abundant euhedral apatite and lesser, subhedral opaque minerals, zircon, plagioclase and euhedral titanite inclusions and is surrounded by fine-

grained quartz and opaque minerals. Rare biotite occurs as optically continuous blebs in plagioclase cores. Biotite pleochroism in undisturbed and metamorphosed areas are similar (α' = light yellowish brown; $\beta = \gamma'$ = dark brown or rusty brown).

Titanite is a widespread, coarse- to medium-grained accessory mineral in the Cake Hill Pluton. It is euhedral and lacks inclusions, subhedral and encloses zircon, apatite, opaque minerals, clinopyroxene, plagioclase and hornblende, or anhedral and rims opaque minerals. In some places, it is intergrown with alkali feldspar or is associated with chlorite as breakdown products of biotite and hornblende.

Quartz mainly occurs as anhedral grains which crystallized among euhedral or subhedral apatite, zircon, opaque minerals, clinopyroxene, plagioclase, hornblende and titanite. It has straight or irregular grain boundaries with or encloses alkali feldspar. It exhibits undulatory extinction and some samples (208-1, 217-1, 287-3) have uncommon quartz subgrains.

Abundance and texture of clear or moderately turbid alkali feldspar is different in the pluton's undisturbed and metamorphosed parts. Alkali feldspar in unmetamorphosed samples occurs as anhedral, untwinned aggregates of grains which enclose all other minerals except allanite, biotite and quartz. Isolated, square patches of subparallel myrmekite occur within alkali feldspar in undisturbed sample 240-1. Alkali feldspar in metamorphosed samples is characterized by a heterogeneous perthite. Common, square, optically continuous, albite twinned, plagioclase inclusions are distinctive and, in some places, can be traced into the homogeneous, relict grain. String and bleb microperthite also occurs. Carlsbad twinning and biotite inclusions (in addition to the same inclusion mineralogy as in alkali feldspar from undisturbed rocks) also distinguishes alkali feldspar in metamorphosed rocks.

II.3.7 Chemical Composition

Major, minor and trace element compositions and CIPW normative mineral contents for fourteen samples from the Cake Hill Pluton are given in Table II.3.2 and plotted in Figure 20.

The Cake Hill Pluton is predominantly subalkaline; only two samples plot in the alkaline field of the alkali-silica plot (Figure 20(a)) and all samples plot in the subalkaline field of the normative $ne'-ol'-qz'$ ternary (Figure 20(b) of Irvine and Baragar (1971)). Samples from the pluton are characterized by common normative quartz, hypersthene, and less common diopside (a few, more siliceous samples have small amounts of normative corundum). In the AFM ternary (Figure 20(c); after Irvine and Baragar, 1971), SiO_2-FeO^*/MgO (Figure 20(d); after Miyashiro, 1974), MgO -total iron (Figure 20(e); after Lowder and Carmichael, 1970; Stauffer *et al.*, 1975) and Al_2O_3 -normative plagioclase (Figure 20(f); after Irvine and Baragar, 1971) plots, the samples are predominantly calc-alkaline. The alumina-normative plagioclase plot also emphasizes the high Al_2O_3 content (>17 weight per cent) of most of the samples. In the MgO -total iron plot, most Cake Hill Pluton samples plot close to or on the typical Cascades trend. In the weight per cent Na_2O-K_2O-CaO plot (Figure 20(g)), the Cake Hill Pluton is depleted in CaO and K_2O relative to Na_2O .

Homogeneity in the Cake Hill Pluton's chemical composition parallels its characteristically monotonous lithology. Samples from domains 1 and 2 are chemically indistinguishable. In most plots, samples tightly cluster. Sample 360-2, an intensely-foliated monzodiorite collected close to the fault along the northwestern margin of the Cake Hill Pluton, is distinguished by: its normative olivine; low SiO_2 content and

TABLE IL.3.2 CHEMICAL COMPOSITION OF THE CAKE HILL PLUTON

(a) Location and lithology of specimens

SPECIMEN	UNIT	LOCATION (Latitude and Longitude)	LITHOLOGY ¹
110-1	Cake Hill Pluton	58°10'50"N 129°35'15"W	massive hornblende quartz monzo- diorite
118-1	" "	58°08'20"N 129°36'03"W	massive biotite-hornblende quartz monzodiorite
196-2	" "	58°03'57"N 129°37'38"W	massive hornblende quartz monzo- diorite
205-1	" "	58°03'13"N 129°33'45"W	foliated hornblende quartz monzo- diorite
208-1	" "	58°02'46"N 129°34'52"W	faintly foliated biotite-hornblende quartz monzodiorite
217-1	" "	58°00'39"N 129°35'30"W	massive hornblende quartz monzo- diorite
240-1	" "	58°03'02"N 129°45'45"W	foliated hornblende monzodiorite
287-3	" "	58°12'26"N 129°30'00"W	lineated hornblende quartz monzo- diorite
327-2	" "	58°13'12"N 129°45'30"W	lineated hornblende quartz monzo- diorite

1. All lithologies classified after Streckelsen (1973)

TABLE II.3.2 CHEMICAL COMPOSITION OF THE CAKE HILL PLUTON

(a) Location and lithology of specimens

SPECIMEN	UNIT	LOCATION (Latitude and Longitude)	LITHOLOGY ¹
360-2	Cake Hill Pluton	58°11'07"N 129°49'30"W	intensely foliated hornblende diorite
366-1	" "	58°05'47"N 129°51'30"W	hornblende syenite
154-1	Cake Hill Pluton screen in T.S.P., central phase	58°11'41"N 129°27'45"W	hornblende-biotite monzodiorite
344-1	metamorphosed Cake Hill Pluton	58°05'21"N 129°18'20"W	hornblende granite
276	Cake Hill Pluton	58°13'10"N 129°31'00"W	hornblende quartz monzodiorite (K-Ar SPECIMEN)

 1. All lithologies classified after Streckeisen (1973).

TABLE II.3.2 CHEMICAL COMPOSITION OF THE CAKE HILL PLUTON
(b) Major Elements (in weight per cent)

OXIDE	SPECIMENS							
	110-1	118-1	196-2	205-1	208-1	217-1	240-1	287-3
SiO ₂	64.1	62.1	61.2	59.0	61.7	61.6	57.9	64.2
Al ₂ O ₃	18.0	17.5	18.2	17.6	17.7	17.4	18.3	16.8
TiO ₂	0.29	0.55	0.55	0.59	0.56	0.27	0.58	0.23
Fe ₂ O ₃	1.5	2.4	2.3	2.3	2.5	2.2	2.6	1.5
FeO	1.5	1.9	2.1	2.5	1.9	1.6	2.4	1.4
MnO	0.07	0.07	0.08	0.10	0.08	0.09	0.11	0.04
MgO	1.35	1.82	1.75	2.45	1.76	1.69	2.02	1.22
CaO	3.08	3.94	4.17	4.95	4.50	3.77	4.63	2.96
Na ₂ O	5.9	5.1	5.5	4.6	5.3	4.8	4.6	5.3
K ₂ O	2.63	2.90	2.71	2.71	2.41	3.13	3.62	3.02
P ₂ O ₅	0.17	0.23	0.24	0.25	0.24	0.19	0.26	0.14
H ₂ O _T	0.7	0.8	0.7	0.7	0.7	0.9	0.9	0.9
CO ₂	B.D.	0.1	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.
S	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.
Cl	0.04	0.06	0.08	0.07	0.05	0.07	0.04	0.04
F	0.09	0.07	0.06	0.09	0.06	0.04	0.10	0.07
Total	99.42	99.54	99.64	97.91	99.46	97.75	98.08	97.82

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE II.3.2 CHEMICAL COMPOSITION OF THE CAKE HILL PLUTON (cont'd)
(b) Major Elements (in weight per cent)

OXIDE	SPECIMENS					AVERAGE (1σ) ¹
	327-2	360-2	366-1	276	154-1	344-1
SiO ₂	65.5	56.1	61.4	65.8	60.6	69.3
Al ₂ O ₃	16.7	19.6	17.3	16.0	16.6	15.8
TiO ₂	0.23	0.62	0.65	0.25	0.64	0.15
Fe ₂ O ₃	2.0	3.0	2.4	1.4	2.9	1.2
FeO	1.2	2.7	2.0	1.6	3.0	0.6
MnO	0.06	0.11	0.07	0.05	0.13	0.04
MgO	1.37	1.96	1.91	1.42	2.40	0.37
CaO	2.90	5.82	3.55	3.38	4.57	1.73
Na ₂ O	5.4	5.3	4.6	4.7	3.6	5.2
K ₂ O	3.03	3.18	3.76	2.92	3.88	3.01
P ₂ O ₅	0.15	0.34	0.21	0.19	0.23	0.08
H ₂ O _T	0.7	0.8	1.1	0.6	1.0	0.2
CO ₂	B.D.	B.D.	0.2	0.2	B.D.	B.D.
S	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.
Cl	0.01	0.01	0.03	N.A.	0.06	N.A.
F	0.26	0.07	0.09	N.A.	0.06	N.A.
Total	99.51	99.61	99.27	98.51	99.67	97.68
						(97.93)

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

1. Average does not include specimen 344-1

TABLE II.3.2 CHEMICAL COMPOSITION OF THE CAKE HILL PLUTON
(c) Trace Elements (in ppm)

		SPECIMENS														
		110-1	118-1	196-2	205-1	208-1	217-1	240-1	287-3	327-2	360-2	366-1	276	154-1	344-1	Average ¹ (10)
Rb	50	2.7	2.6	3.1	2.1	2.1	2.9	2.5	3.0	2.1	1.1	3.4	N.A.	2.3	N.A.	2.5 (0.6)
Sr	1300	1100	1100	980	980	1000	980	1200	950	920	1400	700	680	590	780	990 (240)
Ba	1900	1300	1700	1700	1400	1400	1500	2700	1700	1600	1800	1500	1200	1500	1600	1700 (370)
U	2.7	2.6	3.1	2.1	2.1	2.1	2.9	2.5	3.0	2.1	1.1	3.4	N.A.	2.3	N.A.	2.5 (0.6)
Zr	68	99	140	86	100	100	130	120	110	130	32	140	140	110	150	110 (30)
Cr	10	B.D.	7.2	19	B.D.	B.D.	7.5	10	6.6	9.7	B.D.	6.5	7.9	B.D.	7.0	9.4 (3.9)
Co	19	B.D.	13	17	12	12	12	19	B.D.	12	13	B.D.	B.D.	21	B.D.	15 (4)
Ni	16	B.D.	B.D.	17	B.D.	B.D.	B.D.	10	B.D.	16	B.D.	B.D.	B.D.	B.D.	B.D.	15 (3)
V	100	91	110	130	110	110	90	140	66	84	130	96	78	125	49	104 (23)
Cu	11	17	21	42	23	23	19	56	9.2	11	8.3	110	12	62	B.D.	31 (30)
Zn	20	30	30	40	40	40	30	30	B.D.	20	40	30	20	50	10	32 (9)

B.D.: below detection limits of analytical method; N.A.: specimen not analyzed for given element or oxide

1. Average does not include specimen 344-1

TABLE II.3.2 CHEMICAL COMPOSITION OF THE CAKE HILL PLUTON

(d) CIPW Normative Minerals (in weight percent)

NORMATIVE MINERALS	SPECIMENS													
	110-1	118-1	196-2	205-1	208-1	217-1	240-1	287-3	327-2	360-2	366-1	276	154-1	344-1
qz	11.05	11.01	7.89	8.21	10.49	11.42	4.98	13.71	14.75		10.60	18.41	11.79	23.50
or	15.54	17.14	16.02	16.02	14.24	18.50	21.39	17.85	17.91	18.79	22.22	17.26	22.93	17.79
ab	49.92	43.15	46.53	38.92	44.84	40.61	38.92	44.84	45.69	44.84	38.92	39.77	30.46	44.00
an	14.17	16.30	16.98	19.37	17.39	16.69	18.60	13.14	12.38	20.30	14.98	13.94	17.68	8.06
c	0.26										0.18			1.03
dl		0.88	1.71	2.84	2.66	0.61	2.14	0.51	0.80	5.09		0.26	2.81	
hy	4.53	4.85	4.74	6.65	3.78	4.76	5.51	3.82	3.32	1.54	5.50	4.87	6.93	0.92
ol										1.84				
mt	2.17	3.47	3.33	3.33	3.62	3.19	3.77	2.17	2.90	4.35	3.48	2.03	4.20	1.63
hm														0.08
il	0.55	1.04	1.04	1.12	1.06	-0.51	1.10	0.44	0.44	1.18	1.23	0.47	1.21	0.28
ap	0.40	0.54	0.56	0.59	0.57	0.45	0.61	0.33	0.35	0.80	0.49	0.45	0.54	0.19
cc		0.23									0.45	0.45		
H ₂ O	0.7	0.8	0.7	0.7	0.7	0.9	0.9	0.9	0.7	0.8	1.1	0.6	1.0	0.2
Cl	0.04	0.06	0.08	0.07	0.05	0.07	0.04	0.04	0.01	0.01	0.03		0.06	
F	0.09	0.07	0.06	0.09	0.06	0.04	0.10	0.07	0.26	0.07	0.09		0.06	
Total	99.42	99.54	99.64	97.91	99.46	97.75	98.08	97.82	99.51	99.61	99.27	98.51	97.67	97.68

Figure 20 . Chemical variation diagrams for samples from the
Cake Hill Pluton.

- a) Weight per cent alkali-silica diagram. Alkaline-subalkaline division after Irvine and Baragar (1971).
- b) Weight per cent, normative $ne'-ol'-qz'$ ternary diagram ($ne' = ne + 3/5 ab$; $qz' = qz + 2/5 ab + 1/4 opx$; $ol' = ol + 3/4 opx$). Alkaline-subalkaline division after Irvine and Baragar (1971).
- c) Weight per cent $A (Na_2O + K_2O) - F (FeO + 0.8998 Fe_2O_3) - M (MgO)$ ternary diagram. Calc-alkaline - tholeiitic division after Irvine and Baragar (1971).
- d) Weight per cent $SiO_2 - FeO^*/MgO$ diagram ($FeO^* = FeO + 0.9 Fe_2O_3$). Calc-alkaline - tholeiitic division after Miyashiro (1974).
- e) Weight per cent $MgO - \text{total iron}$ diagram. Cascades, abyssal tholeiite (AT), pigeonitic series and Thingmuli trends after Stauffer *et al.* (1975).
- f) Weight per cent alumina-normative plagioclase diagram. Calc-alkaline - tholeiitic division after Irvine and Baragar (1971).
- g) Weight per cent $Na_2O - K_2O - CaO$ ternary diagram.

Symbols are: $\bigcirc$ grab samples from unmetamorphosed Cake Hill Pluton; $\diamond$ K-Ar sample from cobbles of Cake Hill Pluton in basal flow of the Upper Triassic Stuhini Group; $\square$ sample from metamorphosed Cake Hill Pluton; $\triangle$ sample from Cake Hill Pluton screen in central phase of the Three Sisters Pluton. Filled symbol is nepheline-normative sample.

a) Alkali-silica diagram for the Cake Hill Pluton

b) Ne'-ol'-qz' ternary for the Cake Hill Pluton

c) AFM ternary for the Cake Hill Pluton

d) Silica - FeO^*/MgO diagram for the Cake Hill Pluton

e) MgO - total iron diagram for the
Cake Hill Pluton

f) Alumina - normative plagioclase diagram for
the Cake Hill Pluton

g) $\text{Na}_2\text{O} - \text{K}_2\text{O} - \text{CaO}$ ternary for the Cake Hill Pluton

resultant alkaline affinity on the alkali-SiO₂ plot (Figure 20(a)); and tholeiitic affinities on the SiO₂-FeO*/MgO (Figure 20(d)) and MgO-total iron (Figure 20(e)) plots. Metamorphosed Cake Hill Pluton, exemplified by sample 344-1, is distinguished by high SiO₂ content, alkali-enrichment (relative to iron and magnesium on the AFM plot), relative CaO depletion (relative to Na₂O and K₂O), high FeO*/MgO ratio and high normative corundum content. A sample representing a possible screen of Cake Hill Pluton in the central phase of the Three Sisters Pluton is slightly more mafic than most other samples of the pluton. The age-date sample, 276-1, collected from fragments in the basal Stuhini Group, is slightly more felsic (higher SiO₂, alkali (especially Na₂O and K₂O) enrichment relative to iron, magnesium and calcium, and lower normative diopside content) than many "typical" Cake Hill Pluton samples. This might be anticipated as this sample should represent a higher portion of the magma chamber than samples collected from present outcrops.

The calc-alkaline affinity of the Cake Hill Pluton is similar to other plutons of comparable age, tectonic setting and lithology farther south in the Intermontane Belt (Preto 1972, 1978; Garnett, 1978). The average Cake Hill Pluton composition (see Table II.3.2) is comparable to the average granodiorite of the Le Maitre (1976) but is distinct from the average granodiorite of Nockolds (1954).

Further geochemical comparisons between the Cake Hill Pluton and other plutonic and volcanic units are made in Chapter VI. Harker variation diagrams are given in Appendix 2.6.

II.4 GNAT LAKES ULTRAMAFITE

II.4.1 Distribution, Physiography and Magnetic Expression

The Gnat Lakes Ultramafite underlies 0.2 per cent of the total area of the Hotailuh Batholith and is the smallest intrusive body in the batholith (Figure 1). It is named for the Upper and Lower Gnat Lakes which occur about 3 and 8 km respectively north of the pluton. Most of the pluton outcrops west of Highway 37 and about 8 km east of Mount Thenatlodi but pyroxenite outcrops across the drift-covered valley from the main outcroppings suggest the body has an oval shape, elongate in an east northeast direction. As well, small outcrops of the Gnat Lakes Ultramafite occur farther south as a pendant within the Three Sisters Pluton's potassic marginal phase (at station 610), in the southwest corner of the Cake Hill Pluton (at station 617) presumably as a small intrusion and to the north of the main body where the Gnat Lakes Ultramafite clearly intrudes the Cake Hill Pluton. In its main outcrop area it underlies rounded, cliff-forming exposures but supports vegetation and lacks any distinctive weathering colour which separates it from surrounding dark greenish grey-weathering augite porphyry volcanics. The unit is magnetite-bearing; however, the aeromagnetic signature of the Gnat Lakes Ultramafite is masked by the overwhelming aeromagnetic high of the major, northwest-trending apophysis of the Three Sisters Pluton, although the aeromagnetic ridge is deflected northwards in the vicinity of the Gnat Lakes Ultramafite (Geological Survey of Canada, 1978a; Figure 1 and 2).

II.4.2 Lithology

Ultramafic rocks of the Gnat Lakes Ultramafite are dark greenish-grey

Figure 21. Location of the Gnat Lakes Ultramafite (bold outline) and the Hotailuh Batholith and of stations and samples discussed in text.

to black weathering, massive, equigranular, medium- to (predominantly) coarse-grained and hypidiomorphic. Hornblende pyroxenite and hornblendite are common rock types; pyroxenite commonly forms the core and hornblendite and rare (biotite-) hornblende gabbro the margins of the intrusion; however this zonation is only crudely developed and contacts between these lithologies are exposed in only one locality but intrusive relations are equivocal. No inclusions are seen but the body is characterized by heterogeneity in grain size especially in the hornblendite. Green hornblende and pale green to black pyroxene and black magnetite are euhedral and compose most of the rock; minor subhedral to anhedral epidotized plagioclase occurs interstitially with the mafic grains.

II.4.3 Structure

The Gnat Lakes Ultramafite exhibits no mineral fabric but at two isolated localities in the western half of the pluton, layering is developed over the area of a small outcrop (Appendix 3.1 for details). At one locality, alternating medium-grained, equigranular pyroxenite and coarse-grained, acicular hornblende gabbro layers trend north northeast and dip vertically (Plate III A). Interlayered, steeply southwest dipping hornblendite and augite porphyry occur at the western extremity of the main body (Plate III B). Neither layering attitude bears any apparent relation to the inferred contact of the Gnat Lakes Ultramafite and surrounding rocks.

II.4.4 Intrusive Relations

Although the contact of the Gnat Lakes Ultramafite with surrounding

rocks is poorly exposed, there are enough outcrops around its margins to indicate geological relationships with some of the other plutons of the Hotailuh Batholith and to infer its relationship with surrounding volcanic and sedimentary units (Figure 22 and Appendix 3.2).

(a) Upper Triassic Volcanics and Sediments

The actual contact between the Gnat Lakes Ultramafite and the Upper Triassic volcanics and sediments is not exposed (although see the Hypabyssal Dikes section below). The structurally lowest unit of the Upper Triassic section, exposed immediately west of the Gnat Lakes Ultramafite, consists of thin-bedded argillite, is well-cleaved and is apparently tightly folded about a north-plunging fold axis. Intrusion of augite-bladed plagioclase porphyry dikes into the Gnat Lakes Ultramafite indicates that the ultramafite predates the volcanism at least slightly. Since these dikes also truncate the sediments, the latter's deformation may be due to final emplacement of the Gnat Lakes Ultramafite or to the much later emplacement of the Three Sisters Pluton to the west. The geological relationships between the Gnat Lakes Ultramafite and the silicic volcanics and sediments to the south are not known.

(b) Three Sisters Pluton

At one locality, an apophysis of fine- to medium-grained, faintly layered hornblende gabbro of the mafic phase intrudes gabbroic hornblende pyroxenite which itself contains whitish rock fragments and pyroxene crystals (Plate III C). Hornblende monzonite of the central phase and aplitic to medium-grained and equigranular to pegmatitic syenite of the potassic marginal phase of the Three Sisters Pluton include fragments of the Gnat Lakes Ultramafite near their intrusive contacts (Plates III D, E, and F).

Figure 22. Intrusive relations involving the Gnat Lakes Ultramafite and: (a) other plutonic units (see Appendix 3.2); (b) hypabyssal intrusions (see Appendix 3.3). Abbreviation "INT" refers to intrusive relationship and arrow leads from intrusion to country rock. Question mark indicates uncertain relationship between hypabyssal dikes.

(A) INTERPLUTON

(B) HYPABYSSAL INTRUSIONS

Apophyses of the potassic marginal phase in the Gnat Lakes Ultramafite are the most common and locally form stockworks and agmatites. Ultramafic inclusions are recognized in the potassic marginal phase at one locality (station 421) 2 km from the nearest margin of the Gnat Lakes Ultramafite. Apparent local contact metamorphic effects are limited to the development of scattered alkali feldspar megacrysts in the ultramafic rock within 3-5 cm of the contact (e.g. station 610).

(c) Hypabyssal Dikes

Augite-bladed plagioclase porphyry dikes and andesite dikes intrude the Gnat Lakes Ultramafite. The augite-plagioclase porphyry is the more important of the two types and at one locality is characterized by its trachytoid bladed plagioclase phenocrysts oriented parallel with the dike's chilled, east trending and vertically dipping contact. The dike is traceable upwards through (and is highly discordant with) the thin-bedded argillite into the thick augite porphyry flow that caps the ridges west of the Gnat Lakes Ultramafite. Also, as detailed in the previous section on the Cake Hill Pluton, a hornblende-augite porphyry dike intruding that pluton (at station 698) contains hornblendite and hornblende gabbro xenoliths lithologically similar to the Gnat Lakes Ultramafite (Plate II F). Inclusion-bearing hornblende-clinopyroxene dikes in the Turnagain ultramafic complex exhibit similar intrusive relations with respect to the ultramafic and older country rocks and have similar ultramafic inclusion lithologies (Clark, 1980, p.748, 757). Thin, irregular andesite dikes also locally intrude the Gnat Lakes Ultramafite (Appendix 3.3).

II.4.5 Age

Two concordant potassium-argon hornblende dates have been determined for the Gnat Lakes Ultramafite: one from hornblendite, the other from hornblende pyroxenite (Table II.4.1). Dates of 230 ± 10 Ma and 227 ± 10 Ma from the Gnat Lakes Ultramafite compare closely with a date of 225 ± 8 Ma for hornblende segregations in the Wrede Creek zoned (Alaskan-type) ultramafic complex (Wong and Godwin, 1980) but differ from the concordant hornblende-biotite date of 204 Ma reported by Morgan (1976) for the Ten Mile Creek syenite-pyroxenite body in the Telegraph Creek map-area. The Turnagain ultramafic complex is also thought to be Late Triassic in age (Clark, 1980). Intrusive relationships between the Gnat Lakes Ultramafite and the Upper Triassic volcanics and sediments suggest that the intrusion is no younger than the suspected Carnian-Norian age for the volcanics and sediments. Its K-Ar dates and Armstrong's (1978; 1981) estimate for the Carnian-Norian boundary concur well (Figure 23).

II.4.6 Petrography

The Gnat Lakes Ultramafite is characterized by the nature, texture and abundance of its essential and accessory minerals (Appendix 3.4). In approximate order of crystallization, they are: opaque minerals (magnetite), clinopyroxene, apatite, hornblende, titanite, plagioclase and alteration products of hornblende and plagioclase (epidote, calcite and chlorite).

Opaque minerals (magnetite) form euhedral to subhedral, square to oval grains which are commonly enclosed in hornblende, titanite and clinopyroxene; in some places, clinopyroxene and magnetite which occur together show cumulate textures.

TABLE II.4.1 POTASSIUM-ARGON RADIOMETRIC AGE DATA FOR THE GNAT LAKES ULTRAMAFITE¹

SPECIMEN NUMBER	PLUTON	LOCATION (LATITUDE- LONGITUDE)	LITHOLOGY	MINERAL	%K	% ⁴⁰ Ar	AGE (Ma)
AN-79-607-1	GNAT LAKES ULTRAMAFITE	58°11'00"N 129°51'30"W	hornblende	hornblende	1.00	89.9	230 ± 10
AN-79-609-2	GNAT LAKES ULTRAMAFITE	58°11'00"N 129°51'00"W	hornblende pyroxenite	hornblende	0.67	70.5	227 ± 14

1. All potassium-argon ages are consistent with the decay constants of Steiger and Jäger (1977). All lithologies are classified according to Streckeisen (1973).

Figure 23. Mineral K-Ar isotopic ages for the Gnat Lakes Ultramafite and the Triassic portion of Armstrong's (1978a, 1981) time scale. Analytical errors in ages are 2σ (see Table II.4.1). Solid and dashed lines give estimate of and error in worldwide Carnian-Norian boundary at 220 - 8 Ma by Odin (1981).

Clinopyroxene is subhedral to round and also preserves cumulate textures where not extensively altered to amphibole.

Hornblende, apatite, titanite and rarely, opaque minerals, partly or totally enclose clinopyroxene.

The medium grain size and euhedral habit of most apatite in hornblende clinopyroxenite and hornblendite is distinctive of the Gnat Lakes Ultramafite. Apatite associated with clinopyroxene is commonly anhedral or interstitial.

Hornblende in clinopyroxenite forms light yellow to olive or brownish green to grass green, anhedral, poikilitic plates enclosing clinopyroxene, opaques and apatite. In hornblendite, it forms euhedral, distinctive optically zoned grains which preserve anhedral, highly irregular clinopyroxene cores. In clinopyroxenite, hornblende also forms anastomosing networks through clinopyroxene. Amphibole in this habit has a pleochroic scheme similar to that of the outermost rims of solitary amphibole grains. The abundance of the secondary amphibole is reflected in the subordinate modal volume of clinopyroxene in some hornblende clinopyroxenites (e.g., sample 609-2; see Appendix 6.4).

Titanite occurs as anhedral to euhedral grains; where anhedral, they are commonly interstitial to better formed clinopyroxene, apatite, opaque minerals and hornblende.

Plagioclase is rare but widespread in the hornblendite and crystallized as anhedral plates in spaces between better formed clinopyroxene, apatite, hornblende and titanite. It is pervasively altered to fine-grained sericite, calcite and epidote. One plagioclase grain yielded a minimum composition (Michel-Levy method) of An_{56} .

II.4.7 Chemical Composition

Major, minor and trace elements and CIPW norms for four samples from the Gnat Lakes Ultramafite are given in Table II.4.2 and plotted in Figure 24.

All samples contain large normative diopside contents and are olivine normative; three of the four samples are nepheline-normative. Sample 607-1 is distinguished by a small normative hypersthene content. The Gnat Lakes Ultramafite has mixed alkaline and subalkaline affinities. Hornblende pyroxenite samples (608-1, 609-1) are characterized by their alkali-enriched contents in the alkali-silica plot (Figure 24(a)) of Irvine and Baragar (1971) and plot in the alkaline field of their normative $ne'-ol'-qz'$ ternary (Figure 24(b)). Hornblendite samples (15-1, 607-1) plot in the subalkaline field of the alkali-silica plot, and one sample (607-1) plots in the subalkaline field of the normative $ne'-ol'-qz'$ ternary. All samples are characterized by low total alkali and silica contents. In the AFM ternary (Figure 24(c), Irvine and Baragar, 1971), SiO_2-FeO^*/MgO (Figure 24(d); Miyashiro, 1974), and alumina-normative plagioclase (Figure 24(f); Irvine and Baragar, 1971) plots, the Gnat Lakes Ultramafite is distinguished by its tholeiitic affinities. The alumina-normative plagioclase plot also emphasizes the lower Al_2O_3 content (between 6-7 weight per cent) compared to other plutons. In the MgO -total iron plot (Figure 24(e); after Lowder and Carmichael, 1970; Stauffer *et al.*, 1975), the samples have higher MgO and some have much higher total iron contents than "typical" tholeiitic or calc-alkaline suites. The Gnat Lakes Ultramafite samples are characterized in the weight per cent Na_2O-K_2O-CaO plot (Figure 24(g)) by their field near the CaO apex. The compositions of the age-date samples

TABLE II.4.2. CHEMICAL COMPOSITION OF THE GNAT LAKES ULTRAMAFITE

(a) Location and lithology of specimens

SPECIMEN	UNIT	LOCATION (Latitude and Longitude)	LITHOLOGY ¹
15-1	Gnat Lakes Ultramafite	58°11'31"N 129°51'27"W	hornblende
608-1	"	58°11'00"N 129°52'00"W	hornblende pyroxenite
607-2	"	58°11'00"N 129°51'30"W	hornblende (K-Ar SPECIMEN)
609-1	"	58°11'00"N 129°51'00"W	hornblende pyroxenite (K-Ar SPECIMEN)

1. All lithologies classified after Streckeisen (1973)

TABLE II.4.2 CHEMICAL COMPOSITION OF THE GNAT LAKES ULTRAMAFITE

(b) Major Elements (in weight per cent)

OXIDE	SPECIMENS			AVERAGE (1σ)
	15-1	608-1	607-1	609-1
SiO ₂	45.0	39.8	41.6	39.6
Al ₂ O ₃	5.8	11.1	6.7	6.5
TiO ₂	1.24	1.97	1.58	2.06
Fe ₂ O ₃	6.4	6.0	9.6	13.3
FeO	8.6	10.0	9.9	9.9
MnO	0.26	0.23	0.20	0.20
MgO	11.70	8.70	11.07	10.54
CaO	17.8	13.57	15.48	15.74
Na ₂ O	0.68	1.6	0.81	0.74
K ₂ O	0.48	0.72	0.55	0.42
P ₂ O ₅	0.33	1.53	0.35	0.10
H ₂ O _T	1.8	2.2	1.3	0.7
CO ₂	B.D.	0.5	0.7	0.1
S	B.D.	0.80	0.21	B.D.
Cl	0.05	0.10	0.11	0.06
F	0.04	0.14	0.05	0.04
Less O=S		0.20	0.05	
Total	100.18	98.76	100.16	100.00
				(97.56)

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE II.4.2 CHEMICAL COMPOSITION OF THE GNAT LAKES ULTRAMAFITE

(c) Trace Elements (in ppm)

	15-1	608-1	607-1	609-1	AVERAGE (1σ)
Rb	0	100	70	30	67 (35)
Sr	270	400	240	140	260 (110)
Ba	200	200	650	150	350 (260)
U	0.4	N.A.	N.A.	N.A.	
Zr	21	53	58	39	43 (17)
Y	B.D.	41	44	50	45 (5)
Cr	110	27	120	160	100 (60)
Co	64	53	57	76	63 (10)
Ni	63	33	91	150	84 (50)
V	450	530	560	750	570 (130)
Cu	13	250	210	17	120 (125)
Zn	50	130	80	140	100 (42)

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE II.4.2 CHEMICAL COMPOSITION OF THE GNAT LAKES ULTRAMAFITE
(d) CIPW Normative Minerals (in weight per cent)

NORMATIVE MINERALS	SPECIMENS			
	15-1	608-1	607-1	609-1
or	2.83	4.25	3.25	2.48
ab	4.25	12.23	6.85	3.16
an	11.36	20.98	13.02	13.17
ne	0.81	0.70		1.68
di	59.83	26.72	45.54	50.31
hy			2.44	
ol	6.80	12.79	7.87	4.74
mt	9.28	8.69	13.92	19.28
il	2.35	3.74	3.00	3.91
ap	0.78	3.60	0.83	0.24
py		1.49	0.39	
cc		1.13	1.59	0.23
H ₂ O	1.8	2.2	1.3	0.7
Cl	0.05	0.10	0.11	0.06
F	0.04	0.14	0.05	0.04
Total	100.18	98.76	100.16	100.00

Figure 24. Chemical variation diagrams for samples from the Gnat Lakes Ultramafite.

- a) Weight per cent alkali-silica diagram. Alkaline-subalkaline division after Irvine and Baragar (1971).
- b) Weight per cent, normative $ne'-ol'-qz'$ ternary diagram ($ne' = ne + 3/5 ab$; $qz' = qz + 2/5 ab + 1/4 opx$; $ol' = ol + 3/4 opx$). Alkaline-subalkaline division after Irvine and Baragar (1971).
- c) Weight per cent $A (Na_2O + K_2O) - F (FeO + 0.8998 Fe_2O_3) - M (MgO)$ ternary diagram. Calc-alkaline - tholeiitic division after Irvine and Baragar (1971).
- d) Weight per cent $SiO_2 - FeO^*/MgO$ diagram ($FeO^* = FeO + 0.9 Fe_2O_3$). Calc-alkaline - tholeiitic division after Miyashiro (1974).
- e) Weight per cent $MgO - \text{total iron}$ diagram. Cascades, abyssal tholeiite (AT), pigeonitic series and Thingmuli trends after Stauffer et al. (1975).
- f) Weight per cent alumina-normative plagioclase diagram. Calc-alkaline - tholeiitic division after Irvine and Baragar (1971).
- g) Weight per cent $Na_2O - K_2O - CaO$ ternary diagram.

Symbols are: $\circ$ grab samples; $\diamond$ K-Ar samples. Filled symbols are nepheline-normative samples.

a) Alkali-silica diagram for the Gnat Lakes Ultramafite

b) Ne'-ol'-qz' ternary for the Gnat Lakes Ultramafite

d) Silica - FeO^*/MgO diagram for the Gnat Lakes Ultramafite

c) AFM ternary for the Gnat Lakes Ultramafite.

e) MgO - total iron diagram for the
Gnat Lakes Ultramafite

f) Alumina - normative plagioclase diagram
for the Gnat Lakes Ultramafite

g) $\text{Na}_2\text{O} - \text{K}_2\text{O} - \text{CaO}$ ternary for the Gnat Lakes Ultramafite

are similar to that of the other two specimens.

The average composition of the Gnat Lakes Ultramafite (see Table II.4.2) is comparable to the average pyroxenite composition given by Le Maitre (1976) although the former is depleted in SiO_2 and MgO and enriched in FeO and Fe_2O_3 . The average alkali pyroxenite of Nockolds (1954) is similar to the average Gnat Lakes Ultramafite composition.

The mixed alkaline-subalkaline affinities of the Gnat Lakes Ultramafite, especially as defined on the alkali-silica plot, is comparable to other plutons in the Triassic plutonic suite. Other geochemical comparisons between this pluton and other plutonic and volcanic units are made in Chapter VI. Harker variation diagrams for the Gnat Lakes Ultramafite are given in Appendix 3.5.

PLATE III: LITHOLOGICAL CHARACTERISTICS OF AND INTRUSIVE RELATIONS INVOLVING THE GNAT LAKES ULTRAMAFITE AND THE

BEGGERLAY GREEK PLUTON

Plate III A: Moderately developed layering in acicular hornblende gabbro and finer-grained hornblende pyroxenite. Hammer is about 35 cm long (station 438; slide GBS-10-78-36).

Plate III B: Crude, vertical layering in hornblende or hornblende gabbro and pyroxene porphyry of Gnat Lakes Ultramafite. White syenitic apophysis of potassic marginal phase of Three Sisters Pluton is seen at bottom of photograph. Black bar on pencil is about 5 cm long (station 579; slide 1-79-30).

Plate III C: Contact between intruded and altered hornblende pyroxenite of Gnat Lakes Ultramafite (at right hand side of photograph) and layered acicular hornblende gabbro of Three Sisters Pluton, mafic phase (at left hand side of photograph). Altered, white pyroxenes and whitish rock fragments are visible in the pyroxenite near the intrusive contact. Black bar on pencil is about 5 cm long (station 571; slide 12-78-22).

Plate III D: Contact between intruded Gnat Lakes Ultramafite (dark grey) and hornblende monzonite of Three Sisters Pluton, central phase. Dark grey inclusions of the Gnat Lakes Ultramafite occur in monzonite near contact. Black bar on pencil is about 5 cm long (station 629; slide 1-79-27).

Plate III E: Angular, dark grey hornblende pyroxenite (Gnat Lakes Ultramafite) inclusions in syenitic stockwork (Three Sisters Pluton, potassic marginal phase). Pocket knife is 9 cm long (station 433; slide GBS-10-78-1).

Plate III F: Syenitic apophysis of Three Sisters Pluton, potassic marginal phase in dark grey hornblende pyroxenite of Gnat Lakes Ultramafite. Hammer is about 35 cm long (station 607; slide 1-79-7).

Plate III G: View south to contact between intruded Cake Hill Pluton (C.H.P.) in foreground and Beggerlay Creek Pluton (B.C.P.) in background. Symbols indicate zone of intensely foliated hornblende diorite of Cake Hill Pluton near contact. Intrusive contact of Beggerlay-Creek Pluton and the pyroxene porphyry flows of the Upper Triassic Stuhini Group (U.S.G.) also visible (from station 210; slide 5-88-10).

Plate III H: View west to same location as Plate IV G. Inferred contact between younger Beggerlay Creek Pluton (B.C.P.) and Cake Hill Pluton (C.H.P.) as well as zone of intensely foliated Cake Hill Pluton (symbols) are shown (from station 299; slide 7-77-20).

B.C.P. C.H.P.

II.5 BEGGERLAY CREEK PLUTON

II.5.1 Distribution, Physiography and Magnetic Expression

The Beggerlay Creek Pluton is the southernmost intrusion of the Hotailuh Batholith, forming more than one-sixteenth (7 per cent) of its area; it occurs along the southern margin of the Cake Hill Pluton (Figure 1). The Beggerlay Creek Pluton outcrops in the southwestern part of the Cry Lake (104 I) and the northwestern corner of the Spatsizi (104 H) map-areas. Small, isolated to continuous, craggy and crumbly weathering outcrops interrupt the rounded, grassy hills and ridges characteristic of the Beggerlay Creek Pluton's subdued topography (Plate III G,H). An aeromagnetic high which extends the length and breadth of the Beggerlay Creek Pluton (up to 60050 gammas) allows the extrapolation of its contacts across covered intervals (Figure 2; Geological Survey of Canada 1978 a,c). The name of the Beggerlay Creek Pluton derives from the creek which drains and bisects it.

II.5.2 Lithology

Mafic (biotite-) hornblende gabbro and more leucocratic (biotite-) hornblende diorite predominate in the slightly heterogeneous Beggerlay Creek Pluton (Figure 26). Except for rare volcanic inclusions at one locality (Appendix 4.1), heterogeneity in the pluton derives from the distribution of lithologies and mafic minerals within the pluton. More leucocratic rocks (hornblende diorite and biotite-hornblende monzodiorite) are most common near the pluton's southern contact with the Triassic-Jurassic volcanics and its southwest contact with the upper Triassic augite porphyry. Pyroxenite, mafic, fluidally foliated hornblende diorite and massive, leucocratic horn-

Figure 25. Location of the Beggerlay Creek Pluton (bold outline) in the Hottailuh Barholith and of stations and samples discussed in text.

Figure 26. Modal compositions of thin sections from the Beggerlay Creek Pluton (see Appendix 4.5). Classification after Streckeisen (1973). Abbreviations are: KF = alkali feldspar; PF = plagioclase feldspar; and Qz = quartz.

blende diorite of the Beggerlay Creek Pluton are common at the contact with the felsic phase of the Cake Hill Pluton to the north. Except along its northern margins, rocks of the Beggerlay Creek Pluton are massive, medium- to coarse-grained, equigranular and hypidiomorphic. Hornblende and biotite form the visible mafics; biotite, although less common, forms distinctive poikiloblastic plates around the subhedral hornblende and plagioclase. Rare, thin alkali feldspar rims are visible around hornblende in some stained handspecimens.

II.5.3 Structure

Fluidal foliation developed in hornblende diorite near the contact with the Cake Hill Pluton dips steeply to the southeast (Appendix 4.2). At the contact with the Cake Hill Pluton, the Beggerlay Creek Pluton includes rotated blocks of foliated Cake Hill Pluton but the small outcrop area does not expose other contacts of the fluidal foliated hornblende diorite with typical Beggerlay Creek Pluton lithologies. At another locality south of Moose Creek and 12 km northeast of the confluence of the Klappan and Stikine Rivers (station 297), a moderately developed steep southwest dipping foliation occurs in biotite-hornblende gabbro over an interval of less than one-half a kilometer. Elsewhere, rocks of the Beggerlay Creek Pluton are massive.

II.5.4 Intrusive Relations

Poor to moderate exposure of intrapluton, external and interpluton relationships involving the Beggerlay Creek Pluton hinders establishment of geological constraints on the age of the pluton. Contacts with the Upper

Triassic volcanics and Triassic-Jurassic volcanics may be bracketed but are not seen. The Beggerlay Creek Pluton's intrusive contacts with the Cake Hill Pluton are described in the previous section on the latter pluton (also see Appendix 2.4 and Plate III G,H). The known and speculative intrusive relations are shown in Figure 28.

(a) Intrapluton Intrusive Relations

As implied above, the nature of the contact between the leucocratic marginal phases of the Beggerlay Creek Pluton and the predominant gabbroic to dioritic lithology is not everywhere well exposed. Near its contact with the Cake Hill Pluton, the intrusive contacts of younger, massive leucocratic hornblende diorite with pyroxenite and fluidal foliated hornblende diorite are common and well exposed (Figure 27). Towards the interior of the pluton, more mafic hornblende gabbro passes gradationally into more felsic hornblende diorite.

(b) Upper Triassic Volcanics

The contact between the augite porphyry volcanics and the Beggerlay Creek Pluton is best exposed 3 km north of the confluence of the Klappan and Stikine Rivers. However, even there it may only be closely bracketed and forms a linear, possibly faulted(?), contact for a distance of about 2 km. The volcanics adjacent the contact appear metamorphosed (the volcanic groundmass is amphibolitic) but no gabbroic or dioritic dikes intrude the volcanics nor are the volcanics deformed. However, at another locality on the north bank of the Stikine River, 6 km downstream from (west of) its confluence with the Klappan River (station 402), an irregular hornblende gabbro apophysis appears to intrude augite porphyry volcanics. As described below, augite porphyry dikes clearly intrude the Beggerlay Creek Pluton. On

Figure 27. Notebook sketch (not to scale) of detailed intrusive relations among phases restricted to part of the northern margin of Beggerlay Creek Pluton (near station 463).

Figure 28. Intrusive relations involving the Beggerlay Creek Pluton and: (a) external and other plutonic units (see Appendix 4.3); (b) hypabyssal intrusions (see Appendix 4.4). Abbreviation "INT" refers to intrusive relationships (see Appendix 4.4) to country rock. Dashed arrow and question mark indicate uncertain intrusive relationship. "META." refers to metamorphism of Stuhini Group pyroxene porphyry near contact with Beggerlay Creek Pluton.

(A) EXTERNAL AND INTERPLUTON

YOUNGER

(B) HYPABYSSAL INTRUSIONS

the basis of the spatial association of the metamorphosed volcanics with the Beggerlay Creek Pluton, the intrusive relations outlined above and the poorly preserved augite porphyry dikes within it, extrusion of the Upper Triassic volcanics is considered to predate or be contemporaneous with the intrusion of the Beggerlay Creek Pluton.

(c) Triassic-Jurassic Volcanics

The contact between the Triassic-Jurassic volcanics and the Beggerlay Creek Pluton along the southern margin of the pluton may be closely bracketed but is not seen. In an inlier of Triassic-Jurassic porphyritic volcanics, in the southeast corner of the Beggerlay Creek Pluton and along other contacts near that locality, the volcanics appear to be amphibolitized or recrystallized. At one locality in the northwestern half of the pluton (station 234), the pluton contains uncommon fine-grained volcanic inclusions. Locally (station 267) a rare hornblende diorite dike with poikiloblastic biotite intrudes the volcanic inlier. If recrystallization of these volcanics accompanied intrusion of the Beggerlay Creek Pluton and if this rare dike is comagmatic with the intrusion, then the geological relations are clear and as tentatively assigned in Figure 28.

Uncertainty in age and correlation of the Triassic-Jurassic volcanics is emphasized in Chapter III. The meagre intrusive relations data outlined above and the K-Ar date for the Beggerlay Creek Pluton described below suggest that the volcanics are Triassic age. Considering the quality of exposure, geological relations involving these units are at best tentative.

(d) Hypabyssal Intrusions

Basalt and andesite, feldspar porphyry and augite porphyry and aplite and pegmatite dikes and intrusions invade the Beggerlay Creek Pluton (see

Appendix 4.4). The pink, irregular aplite and pegmatite dikes are characteristic of the Beggerlay Creek Pluton and the distinctive coarse-grain size and lack of mafic minerals are dissimilar to that of recognizable lithologies of the Three Sisters Pluton, potassic marginal phase.

II.5.5 Age

A potassium-argon hornblende date of 218 ± 29 Ma was determined from hornblende gabbro from the Beggerlay Creek Pluton (see Table II.5.1). This date is consistent with its known intrusive relations with the isotopically older Cake Hill Pluton although the dates of the two plutons are essentially concordant within the limits of analytical uncertainty. The isotopic age of the Beggerlay Creek Pluton is also consistent with its probable intrusive contacts with augite porphyry of presumed Carnian-Norian age (Figure 29). As mentioned above, the inferred intrusive relations of the pluton and the surrounding volcanic units and the pluton's radiometric age have interesting implications for the age and correlation of these two lithologically dissimilar volcanic units.

TABLE II.5.1 POTASSIUM-ARGON RADIOMETRIC AGE DATA FOR THE BEGGERLAY CREEK PLUTON¹

SPECIMEN NUMBER	PLUTON	LOCATION (LATITUDE- LONGITUDE)	LITHOLOGY	MINERAL	%K	% ⁴⁰ Ar	AGE (Ma)
AN-79-717-1	BEGGERLAY CREEK PLUTON	57°58'04"N 129°28'00"W	gabbro	hornblende	0.29	39.1	218 ± 29

1. All potassium-argon ages are consistent with the decay constants of Steiger and Jäger (1977). All lithologies are classified according to Streckeisen (1973).

Figure 29. Mineral K-Ar isotopic age for the Beggerlay Creek Pluton and the Triassic portion of Armstrong's (1978a, 1981) time scale. Analytical errors in age are 2σ (see Table II.5.1). Solid and dashed lines give estimate of and error in worldwide Carnian-Norian boundary at 220 ± 8 Ma by Odin (1981).

II.5.6 Petrography

Nature, abundance (Appendix 4.5; Figure 26) and texture of primary (earliest to latest: "olivine"?, apatite, opaque minerals, plagioclase, clinopyroxene) and secondary (hornblende, biotite and rutile, titanite, spinel (rare), alkali feldspar, quartz (rare)) and later alteration (chlorite, epidote and sericite and sausserite) mineralogy of gabbro and diorite in the Beggerlay Creek Pluton distinguishes it among plutons in the batholith. In many places, a distinction between some secondary and late alteration mineral parageneses is possible (e.g., chlorite and epidote alteration products of hornblende, and biotite and titanite). Among other minerals this separation is not possible (e.g., alkali feldspar and sericite and sausserite alteration products of plagioclase; or tremolite, magnetite and serpentine alteration products of "olivine"? and other secondary and late alteration mineralogy). White mica and epidote veinlets anastomose through some samples. The extent and pervasiveness of secondary and later alteration mineralogy, probably accounts for the alkaline geochemistry of the pluton and with the large colour index and paucity of alkali feldspar and quartz are characteristic of the Beggerlay Creek Pluton.

Round, elongate aggregates of fine-grained, anhedral to subhedral tremolite, round opaque minerals and rare, anhedral serpentine occur in a few samples and are believed to be alteration products of "olivine"? although no relict grains were observed. The occurrence of the opaque minerals in irregular traces through the aggregates and around their rims suggest the irregular fracture typical of olivine and a possible original cumulate texture with adjacent clinopyroxene.

Apatite is a common, euhedral, elongate accessory mineral which

is slightly finer-grained than the subhedral (squarish) or anhedral opaque minerals which commonly enclose it. The opaque minerals locally have cusped grain boundaries with clinopyroxene, suggestive of original cumulate textures, and are commonly fractured.

Plagioclase is medium- to coarse-grained and subhedral. Contacts among adjacent feldspar grains suggest mutual interference during growth. Locally, albite twins are bent and in one sample (231-1), plagioclase grains are aligned parallel to elongate clots of hornblende. Euhedral and subhedral apatite and opaque minerals are inclusions in plagioclase rims and cores. Andesine or labradorite compositions (An_{32-62}) are most common and the least altered samples contain the most calcic plagioclase (e.g., sample 717-1). Sample 231-1, one of the most altered samples, is characterized by plagioclase with low refringence (less than Canada balsam) and albite composition. Plagioclase in sample 304-1 has low refringence as well but is too altered to allow any composition determinations. Discontinuous and continuous normal zoning changes the composition An_{4-13} (e.g., core = An_{45-55} , rim = An_{32-46}). Irregular calcic cores are rare or absent.

Clinopyroxene forms euhedral or subhedral grains interstitial with respect to plagioclase where unaltered, or irregular, optically continuous blebs in hornblende cores. Euhedral apatite and subhedral opaque minerals are enclosed in clinopyroxene. Clots of fine-grained anhedral or subhedral clinopyroxene, euhedral apatite and interstitial opaque minerals are observed in a few places.

Hornblende is a common secondary mineral enclosing clinopyroxene. Degree of uranization varies from thin, optically continuous hornblende

rims to clinopyroxene cores or patchy pleochroism in a subhedral hornblende grain. Hornblende also occurs in clots of subhedral and anhedral grains which radiate outward or are randomly arranged. In one sample (231-1), the elongate clots are aligned. Apatite and opaque minerals are common inclusions. Hornblende clots are interstitial with respect to plagioclase except where alkali feldspar around the clots obscures textural relationships. Absorption is weak to moderate and pleochroism (α' = light greenish or brownish yellow; β = grass green or dark olive green; γ' = bluish green) is distinctive.

Biotite is the second main mineral to form around clinopyroxene and is anhedral, distinctively pleochroic and inclusion-rich. Biotite formed around hornblende rims on clinopyroxene and also encloses or formed interstitially amongst apatite, opaque minerals, "olivine"?, clinopyroxene and plagioclase. In a few places, fine-grained biotite is an alteration product of hornblende in mafic clots. Fine-grained, acicular rutile inclusions, arranged in triangular patterns, are distinctive. Epidote alteration products of biotite locally contain similarly arranged rutile. Green and brown biotites are characteristic of the pluton (α' = light yellowish brown; $\beta = \gamma'$ = olive green or dark brown).

Titanite and golden brown spinel are uncommon and rare alteration products. Titanite rims opaque minerals and infills fractures within them. Spinel occurs as irregular isotropic grains within plagioclase.

Anhedral alkali feldspar and quartz are rare in the pluton but the feldspar has a distinctive habit. Thin rims of fine-grained, clear, homogeneous or microperthitic, anhedral alkali feldspar grains enclose clots of hornblende, clinopyroxene and hornblende, plagioclase and

apatite. Slightly turbid, homogeneous alkali feldspar also occurs
..interstitially with respect to plagioclase and locally exhibits
Carlsbad twins. Quartz is anhedral and interstitial with respect to
plagioclase.

II.5.7 Chemical Composition

Major, minor and trace elements and CIPW norms for eight samples from the Beggerlay Creek Pluton are given in Table II.5.2 and plotted in Figure 30.

The Beggerlay Creek Pluton is characteristically olivine-normative which accords the possible olivine pseudomorphs observed in thin section. Half the samples are nepheline-normative, the others are hypersthene-normative. On the normative $ne'-ol'-qz'$ ternary plot (Figure 30(b); after Irvine and Baragar (1971)), the samples show a mixed alkaline-subalkaline character. Nepheline-normative samples are alkaline; hypersthene-normative samples are subalkaline. However, the pluton is characterized by high total alkali contents typical of alkaline rocks on an alkali-silica plot (Figure 30 (a); after Irvine and Baragar, 1971). Mixed calc-alkaline and tholeiitic affinities are also typical of the samples. In an AFM ternary (Figure 30(c); after Irvine and Baragar, 1971) and alumina-normative plagioclase (Figure 30 (f); after Irvine and Baragar, 1971) plots, all samples except 247-3 are calc-alkaline. The alumina-normative plagioclase plot also emphasizes the high Al_2O_3 content (>18 weight per cent) of the samples. In the SiO_2-FeO^*/MgO (Figure 30 (d)) and FeO^*-FeO^*/MgO (not shown; after Miyashiro, 1974) plots, all samples (except 248-6 in the FeO^*-FeO^*/MgO plot) are tholeiitic. The samples mimic the iron enrichment trend of "typical" tholeiitic suites in the MgO -total iron plot (Figure 30 (e); after Lowder and Carmichael, 1970); Stauffer *et al.*, 1975). Enrichment in CaO and depletion in Na_2O in the weight per cent Na_2O-K_2O-CaO ternary plot (Figure 30 (f)) characterizes the Beggerlay Creek Pluton compositions.

TABLE II.5.2 CHEMICAL COMPOSITION OF THE BEGGERLAY CREEK PLUTON

(a) Location and lithology of specimens

SPECIMEN	UNIT	LOCATION (Latitude and Longitude)	LITHOLOGY
231-1	Beggerlay Creek Pluton	58°00'16"N 129°37'30"W	intensely foliated gabbro near contact with Cake Hill Pluton
234-2	"	57°59'01"N 129°37'15"W	hornblende gabbro or diorite
247-1	"	58°58'17"N 129°28'15"W	hornblende gabbro with poikiloblastic biotite
248-6	"	57°58'02"N 129°39'15"W	hornblende gabbro
271-3	"	57°58'28"N 129°28'15"W	pyroxenite
304-1	"	57°58'47"N 129°31'30"W	hornblende gabbro
305-3	"	57°58'49"N 129°32'53"W	hornblende gabbro
322-7	"	57°57'58"N 129°33'00"W	hornblende gabbro

TABLE II.5.2 CHEMICAL COMPOSITION OF THE BEGGERLAY CREEK PLUTON

(b) Major Elements (in weight per cent)

OXIDE	231-1	234-2	247-1	248-6	271-3	304-1	305-3	322-7	AVERAGE (1σ)
SiO ₂	52.6	47.9	46.1	51.5	45.9	52.1	50.3	52.2	49.8 (2.8)
Al ₂ O ₃	17.8	18.7	14.2	17.8	19.6	18.6	19.5	18.8	18.1 (1.7)
TiO ₂	0.88	0.73	0.76	0.56	1.15	0.64	0.83	0.64	0.77 (0.19)
Fe ₂ O ₃	2.9	3.7	4.6	3.3	4.4	2.8	3.1	4.0	3.6 (0.7)
FeO	5.4	4.9	5.6	4.7	6.0	4.2	5.2	3.5	4.9 (0.8)
MnO	0.19	0.21	0.20	0.19	0.18	0.16	0.21	0.16	0.19 (0.02)
MgO	3.18	3.82	8.81	5.13	4.26	2.71	3.19	3.12	4.28 (1.99)
CaO	4.80	9.14	11.4	8.50	9.56	5.80	7.02	6.10	7.70 (2.23)
Na ₂ O	4.8	2.6	1.9	3.5	2.8	3.2	3.7	2.3	3.1 (0.9)
K ₂ O	2.70	3.38	1.67	2.39	2.57	6.00	3.93	6.08	3.59 (1.65)
P ₂ O ₅	0.24	0.71	0.65	0.81	1.00	0.58	0.68	0.61	0.66 (0.22)
H ₂ O _T	2.6	2.5	2.6	1.5	2.0	2.2	2.1	1.9	
CO ₂	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	
S	B.D.	B.D.	B.D.	B.D.	0.03	B.D.	B.D.	B.D.	
Cl	0.09	0.12	0.04	0.03	0.04	0.07	0.04	0.04	
F	0.04	0.05	0.07	0.04	0.07	0.05	0.04	0.05	
Less O=S					0.01				
Total	98.22	98.46	98.60	99.95	98.55	99.11	99.84	99.50	(96.78)

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE II.5.2 CHEMICAL COMPOSITION OF THE BEGGERLAY CREEK PLUTON

c) Trace Elements (in ppm)

	231-1	234-2	247-1	248-6	271-3	304-1	305-3	322-7	Average (1σ)
b	40	40	20	20	70	90	70	90	60 (30)
r	440	1700	1000	910	1400	710	160	780	890 (490)
a	660	820	630	1100	1300	930	840	1500	970 (310)
	0.5	1.5	0.7	0.8	0.3	2.2	1.3	2.5	1.2 (0.8)
r	37	48	B.D.	21	B.D.	53	40	97	49 (26)
r	B.D.	5.5	270	25	B.D.	5.7	B.D.	8.7	63.0 (116.0)
d	64	24	46	27	34	18	26	26	33 (15)
i	B.D.	21	120	23	14	B.D.	B.D.	10	38 (46)
	130	300	280	220	270	140	230	200	220 (63)
	94	230	150	420	150	200	150	230	200 (99)
	60	70	90	50	80	80	80	50	70 (15)

D.: below detection limits of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE II-5.2 CHEMICAL COMPOSITION OF THE BEGGERLAY CREEK PLUTON
(d) CIPW Normative Minerals (in weight per cent)

NORMATIVE MINERALS	SPECIMENS						
	231-1	234-2	247-1	248-6	271-3	304-1	305-3
or	15.96	19.98	9.87	14.12	15.19	35.46	23.23
ab	40.61	20.83	16.07	29.61	20.29	21.25	25.73
an	19.05	29.37	25.29	25.80	33.32	18.67	24.99
ne		0.63			1.84	3.15	3.02
di	2.62	9.19	21.53	8.92	6.14	5.16	4.41
hy	4.67		3.99	7.98			
ol	6.14	7.38	9.51	4.20	9.71	6.47	8.62
mt	4.20	5.36	6.66	4.78	6.38	4.06	4.49
il	1.67	1.38	1.44	1.06	2.18	1.21	1.57
ap	0.57	1.67	1.53	1.91	2.36	1.36	1.60
py					0.06		
H ₂ O	2.6	2.5	2.6	1.5	2.0	2.2	2.1
Cl	0.09	0.12	0.04	0.03	0.04	0.07	0.04
F	0.04	0.05	0.07	0.04	0.07	0.05	0.04
Total	98.22	98.46	98.60	99.95	98.55	99.11	99.84
							99.50

Figure 30... Chemical variation diagrams for samples from the Beggerlay Creek Pluton.

- a) Weight per cent alkali-silica diagram. Alkaline-subalkaline division after Irvine and Baragar (1971).
- b) Weight per cent, normative ne' - ol' - qz' ternary diagram ($ne' = ne + 3/5 ab$; $qz' = qz + 2/5 ab + 1/4 opx$; $ol' = ol + 3/4 opx$). Alkaline-subalkaline division after Irvine and Baragar (1971).
- c) Weight per cent A ($Na_2O + K_2O$) - F ($FeO + 0.8998 Fe_2O_3$) - M (MgO) ternary diagram. Calc-alkaline - tholeiitic division after Irvine and Baragar (1971).
- d) Weight per cent SiO_2 - FeO^*/MgO diagram ($FeO^* = FeO + 0.9 Fe_2O_3$). Calc-alkaline - tholeiitic division after Miyashiro (1974).
- e) Weight per cent MgO - total iron diagram. Cascades, abyssal tholeiite (AT), pigeonitic series and Thingmuli trends after Stauffer et al. (1975).
- f) Weight per cent alumina-normative plagioclase diagram. Calc-alkaline - tholeiitic division after Irvine and Baragar (1971).
- g) Weight per cent Na_2O - K_2O - CaO ternary diagram.

Filled symbols are nepheline-normative samples.

a) Alkali-silica diagram for the Beggerlay Creek Pluton

d) Silica - FeO^*/MgO diagram for the Beggerlay Creek Pluton.

q). AFM ternary for the Beggerlay Creek Pluton

e) MgO - total iron diagram for the
Beggerlay Creek Pluton

f) Alumina - normative plagioclase diagram
for the Beggerlay Creek Pluton

g) Na₂O - K₂O - CaO ternary for the Beggerlay Creek Pluton

The Beggerlay Pluton is distinguished by its mixed alkaline-subalkaline and calc-alkaline-tholeiitic affinities. The basic suite of the oldest intrusions of the Hogem Batholith are also characterized by its alkaline character in the alkali-silica plot (Garnett, 1978). The average composition for the Beggerlay Creek Pluton (see Table II.5.2) is higher in Al_2O_3 , Na_2O and K_2O and lower in TiO_2 , FeO , MgO and CaO than the comparable average gabbro but is somewhat comparable (except for SiO_2) with the average diorite of Le Maitre (1976). The average hornblende-augite diorite, hornblende diorite, hornblende gabbro and alkali gabbro of Nockolds (1954) are dissimilar to the average Beggerlay Creek Pluton composition.

Other geochemical comparisons between the Beggerlay Creek Pluton and other plutonic and volcanic units are made in Chapter VI. Harker variation diagrams for the Beggerlay Creek Pluton are given in Appendix 4.6.

III. PALEOZOIC, MESOZOIC AND CENOZOIC STRATIGRAPHY AROUND THE HOTAILUH BATHOLITH AND SATELLITIC PLUTONS

III.1 Introduction and Summary

Five mappable sedimentary and(or) volcanic units of Paleozoic and Mesozoic age fringe the Hotailuh Batholith and its satellitic plutons: Paleozoic (Permian?) recrystallized limestones (unit Pl); Triassic or older? silicic tuff and quartzose sediments (map unit T?s); Upper Triassic volcanic flows, conglomerate and breccia and coarse to fine sediment (map unit uTst); Triassic-Jurassic flows and minor volcanic conglomerate, breccia and sediment (map unit T Jv); and an upper Lower Jurassic shallow water sedimentary succession (map unit lJs). The role of these various units in the intrusive history of the batholith and satellitic plutons is given in Figure 32 and Figure 87. Permian recrystallized limestones occur southwest of the Cake Hill Pluton and west of the Pallen Creek Pluton. The Triassic (and older?) strata form isolated outcrops on the western and eastern margins of the batholith and although relationships are not well exposed, they appear to postdate emplacement of the Cake Hill Pluton and predate augite porphyry hypabyssal intrusion. Upper Triassic rocks are extensive, well-exposed but poorly dated. In the west, deposition of the lower distal sedimentary member preceded the subaqueous extrusion of augite porphyry. Along the northern margin of the batholith, submarine turbiditic sediments, debris flow volcanic conglomerates

Figure 31. Location map of localities in and samples from Mesozoic volcanics around the Hotaifuh Batholith.

3

Figure 32. Intrusive relations involving Mesozoic volcanic, sedimentary and hypabyssal units and plutonic units. Abbreviations are: EQUIV. means possible comagmatic relationship between syenitic porphyry intrusions and Triassic-Jurassic volcanics; INT refers to intrusive relationship; and META. indicates metamorphism of volcanic or sedimentary unit associated with particular plutonic intrusions. Arrows lead from intrusion to country rock. Faulted and nonconformable relationships between units are also shown.

and breccias and pillow lavas predominate. The occurrence of these coarse volcanoclastics exclusively along the northern margin adjacent the medial line of the batholith probably records the position of the nearby volcanic edifice in the batholith during late Triassic time. These volcanics and sediments are correlative to the Stuhini Group of Souther (1971a). Stratigraphy of the undated Triassic-Jurassic unit northeast of the batholith contrasts with Upper Triassic strata in the predominance of massive, grey to maroon plagioclase porphyry flows which appear to represent two geochemical cycles, and minor occurrence of maroon volcanoclastics derived from these flows. This stratigraphy and maroon weathering colour characterize the poorer-exposed regional stratigraphy along the eastern and southern margins. The well-dated upper Lower Jurassic (Toarcian) arkosic sandstone, sandy limestone and shale rest nonconformably on the Cake Hill Pluton and preserve a record of shallow, temperate, high energy, normal marine environment of deposition (Henderson 1979; Henderson and Perry, 1981). Normal, block and thrust faults have disrupted the strata around the Hotteluh Batholith. An important fault along the northwestern margin is associated with well developed schistosity in the augite porphyry flows and predates intrusion of the Three Sisters Pluton. A major thrust fault places the Upper Triassic strata over the Toarcian along the batholith's northern and eastern margin and is cut and probably updomed by the Three Sisters Pluton.

Fresh, massive to vesicular, olivine basalts of Miocene to Pleistocene age overlie various plutons in scattered localities.

III.2 Permian? and Triassic (or older?) Stratigraphy

(a) Distribution, Physiography and Magnetic Expression

Scattered, Permian recrystallized limestone is exposed at one locality near the southwest margin of the Cake Hill Pluton and cap ridges northwest of the Pallen Creek and northeast of the Tanzilla Pluton. Triassic or older(?) siliceous tuff and quartzose tuffaceous sediment occur in restricted outcrop areas along the western and eastern margins of the Hotailuh Batholith. Their exposures are not otherwise topographically distinct nor have these units any characteristic magnetic expression (Figures 1, 54 and 59).

(b) Stratigraphy

Light to dark grey weathering, resistant marbles around the western satellitic Jurassic plutons exhibit compositional layering, cleavage, and thin folded or boudinaged fine-grained tan weathering chert layers (Appendix 5.1). White quartz veins invade the marble. Degree of recrystallization varies among outcrops and the limestone exposed along the southwestern margin of the Hotailuh Batholith preserves crinoid stems (J. Monger, personal communication, 1977).

Rusty weathering, locally well-bedded rhyolites and siliceous welded tuffs which contain visible, altered shards occur at both localities along the western and eastern batholith margins (Plate IV A). The western outcrops are distinguished

by interbedded quartzose arenites with local small scale (1 cm) crossbeds which indicate right way up stratigraphy. At one locality (station 420) an augite porphyry dike clearly intrudes these strata. Although augite porphyry flows structurally overlie the silicic tuffs, the contact is not exposed. Selective epidote alteration of certain strata in the siliceous volcanics along the southeastern margin produces a pronounced layering in the unit although actual beds are difficult to distinguish in these fine-grained, flinty rocks. A granitoid (Cake Hill Pluton) - bearing volcanic conglomerate-breccia apparently forms the base of the unit along a steep, poorly exposed contact with the Cake Hill Pluton and the siliceous volcanics are also intruded and included as xenoliths and thin screens by augite porphyry apophyses. The rounded Cake Hill Pluton fragments in the basal conglomerate-breccia reach a size of 25 cm by 15 cm and locally exhibit planar or linear fabrics.

(c) Structure

Orientation of the compositional layering and cleavage in the recrystallized Permian? limestone varies from moderate to steeply northwest or southeast dipping (see Appendix 5.1; stations 637 and 638). Regular white cherty layers parallel the layering and cleavage attitudes. Locally, the layers are deformed into rootless isoclinal folds whose axial planes also conform to the general layering and cleavage. Boudinage also occurs.

PLATE IV: LITHOLOGIC, STRATIGRAPHIC AND STRUCTURAL CHARACTERISTICS OF THE MESOZOIC SEDIMENTARY AND VOLCANIC

UNITS AROUND THE HOTAILUH BATHOLITH

Plate IV A: Well-layered silicic tuffs of the Triassic and older(?) unit. Hammer is about 35 cm long (near station 419; slide 2-78-11).

Plate IV B: View west to section 577, Upper Triassic Stuhini Group. Pyroxene porphyry feeder dike intrudes lower sedimentary member to supply overlying pyroxene porphyry flow. Dotted line shows approximate traverse line for measurement of section (slide 13-78-27).

Plate IV C: View south to scoured and warped greywacke and shale underlying massive, light grey pyroxene porphyry flow of Upper Triassic Stuhini Group. Part of the deformation may be due to intrusion of nearby Three Sisters Pluton (near section 577; slide 13-78-38).

Plate IV D: View north to location of section 714 (dotted line is traverse line used for measurement of section). Approximate location of thrust fault (barbs on hanging wall) separating underlying Toarcian sandstone, limey sandstone, micrite and shale (ljs) from volcanics, greywacke, siltstone and pyroxene porphyry of Upper Triassic Stuhini Group (UR st). Symbol gives location of fossil collections (slide 9-29-27).

Plate IV E: View west to section 704 (dotted line is traverse line used for measurement of section). Symbol in center of picture is block fault. Distinctive massive and resistant volcanoclastic unit which contains angular rhyolite and rounded bladed plagioclase porphyry fragments forms the top one-third of section view (slide 5-79-38).

Plate IV F: View northeast to section 705 (dotted line is traverse line used in measurement of section). Thrust fault (in white; barbs are in hanging wall) separates arkosic sandstone and shale of Toarcian sediments (ljs) from volcanics and flows (resistant units) and shale and siltstone (recessive units) of Upper Triassic Stuhini Group (UR st). Also shown is contact, in part faulted, between Stuhini Group and Cake Hill Pluton (C.H.P.). Location of fossil locality shown by symbol (slide 6-79-30; this view is the right hand side of Plate IV G).

PLATE IV (cont'd)

Plate IV G: View north to part of the northern margin of the Cake Hill Pluton. Contact between Cake Hill Pluton (C.H.P.) and volcanoclastics and sediments of Upper Triassic Stuhini Group (uⁿ st) is poorly exposed and may be locally faulted. Thrust fault (barbs on hanging wall) and block faults (white symbols) isolate arkosic sandstone, micrite and shale of Toarcian unit (ljs) which is overthrust by the Stuhini Group. Part of section 705 seen on left hand horizon (see Plate IV F) and location of Plate IV^H shown (slide 8-76-36).

Plate IV H: View north to section 707 (dotted line is traverse line used to measure section). Thrust fault (barbs on hanging wall) separates Upper Triassic Stuhini Group (uⁿ st) and Toarcian sedimentary unit (ljs; see also Plate V D). Small, altered monzodiorite plug (see black arrow) seals thrust fault and may be related to emplacement of Jurassic plutonic suite. Block fault (white symbols) between Stuhini Group and Toarcian sedimentary unit, and approximate, poorly exposed contact between these two units and Cake Hill Pluton (C.H.P.) are also seen. Symbol F marks fossil locality (slide 5-77-21).

The Triassic (or older?) strata along the western margin are generally moderately northeast to east dipping (Appendix 5.1); the apparent layering in the outcrops along the southeastern margin, as emphasized by the epidote alteration, also dips moderately to the northeast.

(d) Age

Conodonts recovered from the limestone southwest of the Cake Hill Pluton and from other, more recrystallized varieties farther west indicate Permian ages (P.B. Read, personal communication, 1981). The age of the Triassic or older? unit is poorly known. Geological relations indicate that it predates eruption of augite porphyry flows and at least in one of the exposures, post-dates intrusion of the Cake Hill Pluton. The lithology of the western exposure bears some similarities to the deformed felsic volcanics in the "Kutcho Formation" but is not a direct analog (L. Thorstad, personal communication, 1978).

III.3 Upper Triassic Stratigraphy

(a) Distribution, Physiography and Magnetic Expression

Upper Triassic rocks are extensive around the southern, eastern, northern and western margins of the Hotailuh Batholith, surround the Pallen Creek and parts of the Tanzilla Plutons and make up the Stuhini Group which underlies much of the Stikine Arch (Souther, 1971a; Gabrielse, 1979, 1980a; see Figures 1 and 31). Along the northern margin of the Hotailuh

Figure 33. Measured stratigraphic sections of the Upper Triassic Stuhini Group volcanics and Toarcian sediments along the northern and western margins of the Hotailuh Batholith (see Tables III.1-III.4 and III.6 and legend below). Fossil localities (F) are detailed in Tables III.7 and III.10 and K-Ar isotopic age for Cake Hill Pluton fragments is discussed in Chapter II.3. Sections 705 and 714 are composite sections. Toarcian sediments underlie a known or inferred thrust fault.

SECTION 705

SECTION 707

177

SECTION 704

BASE NOT EXPOSED

SECTION 714

Base not exposed

Base not exposed

TFP

SECTION 577

BASE NOT EXPOSED

Batholith, the volcanics form impressive, dark grey peaks and their stratigraphy is best exposed there. Rounded ridges typify western and southwestern exposures. Aeromagnetic lows characterize the Upper Triassic rocks about the northern, western and southwestern margins (Figure 2). The negative anomalies are most dramatic at the eastern end of their exposure along the northern margin (to a low of less than 58,030 or 58,100 gammas) and steadily increase westwards (to a low of less than 58,320 gammas) towards the contact with the Three Sisters Pluton. The negative aeromagnetic anomaly along the southwestern margin also features a low total aeromagnetic field of less than 58,140 gammas, similar to the easternmost northern margin anomalies. Farther west in the Dease Lake map-area, aeromagnetic anomalies of similar magnitude distinguish scattered outcrop areas of the Upper Triassic rocks but locally are apparently overprinted by the aeromagnetic highs corresponding to nearby Jurassic plutons.

(b) Stratigraphy

Monger and Thorstad (1978) defined the lower unit of Mesozoic stratigraphy developed around the Hotailuh Batholith by the occurrence of green, grey and locally red volcanoclastics locally interbedded with argillite and siltstone. Fragments of augite porphyry and bladed plagioclase porphyry in a matrix containing augite crystals are characteristic of the volcanoclastics. Total thickness of the unit is estimated at less than 1000 m. Farther west, near the confluence of the

Tuya and Stikine Rivers, similar units, overly schistose but fossiliferous Permian carbonate. Elsewhere, they are juxtaposed tectonically (J. Monger, personal communication, June, 1979; P.B. Read, personal communication; January, 1981). Detailed studies along the southern, eastern, western and northern margins of the Hottailuh Batholith reinforce the regional stratigraphy described by Monger and Thorstad but reveal marked contrasts in stratigraphy along western and northern margins of the batholith and provide information on the nature and environment of deposition of the volcanic rocks and possible constraints on the location of the major volcanic edifice constructed in the late Triassic.

Study of the Upper Triassic stratigraphy along the southern margin, in the central Cake Hill Pluton and in the southeastern inlier is limited by cover, inaccessible cliff outcrops and the effects of the younger intrusions. Locally vesicular, augite porphyry tuffs predominate in the southwest and minor volcanic conglomerate containing rounded, fine-grained green volcanic fragments also occurs. In the central Cake Hill Pluton, along the major Three Sisters Pluton apophysis (stations 549 and 550), fine-grained, greenish grey amphibolite and rare augite-plagioclase porphyry is intruded and metamorphosed by the Three Sisters Pluton. The southeastern inlier of Upper Triassic rocks (station 501) is predominated by extensive, massive, grey weathering augite porphyry whose augite phenocryst content decreases from the structural base to top. At this

locality, the augite porphyry may be part of hypabyssal intrusions (see previous section on the eastern exposures of the Triassic or older? silicic volcanics) and (or) as distinct, thick flows. Bladed plagioclase porphyry occurs locally near the top of this member. Only at upper structural (stratigraphic?) levels where a sequence of polymict volcanic breccia and minor interlayered siliceous tuff, hornblende porphyry andesite and andesitic lapilli breccia are exposed, is a crude stratigraphy established. The basal polymict breccia contains predominantly volcanic fragments (augite porphyry, fine-grained light grey tuff, felsite and fine-grained grey volcanics) up to 1 m long.

In contrast, a stratigraphy is established in the considerably better exposed Upper Triassic rocks along the northern and western margins of the Hotailuh Batholith (Plate IV). The stratigraphy developed west and northwest of the batholith contrasts with correlative stratigraphy along the batholith's northern margin.

The rocks to the west and northwest as exemplified in sections 577 and 714 (Plate IV B, D; Tables III.1 and III.6) comprise two members: a lower, predominantly greywacke-siltstone unit and an overlying augite porphyry unit. This bipartite stratigraphy is also well exposed along the eastern side of the major north-trending ridge which separates section 577 and section 714 (e.g. stations 435, 600, 601 and 630) and along the eastern margin of the Pallen Creek Pluton. In both sections, massive, greyish green, medium-grained feldspathic

Table III.1. Stratigraphy and sedimentology of section 577, Upper Triassic Stuhini Group (in pocket). Abbreviations are: A = angular; MS = moderately sorted; PS = poorly sorted; R = rounded; T.S.P. = Three Sisters Pluton. Conventional orientation refers to dip direction conventionally oriented 90 degrees clockwise from azimuth. Lithological symbols are the same as those used in Figure 33.

Table III.2. Stratigraphy and sedimentology of section 704, Upper Triassic Stuhini Group (in pocket). Abbreviations are: A = angular; MS = moderately sorted; PS = poorly sorted; R = rounded; SA = subangular; SR = subrounded; WS = well sorted. Conventional orientation refers to dip direction conventionally oriented 90 degrees clockwise from azimuth. Lithological symbols are the same as those used in Figure 33. Location of chemically analysed samples (see Table III.12) also shown (sample numbers enclosed by boxes).

Table III.3. Stratigraphy and sedimentology of section 705, Upper Triassic Stuhini Group (in pocket). Abbreviations are: A = angular; MS = moderately sorted; PS = poorly sorted; R = rounded; SA = subangular; WS = well sorted. Conventional orientation refers to dip direction conventionally oriented 90 degrees clockwise from azimuth. Lithological symbols are the same as those used in Figure 33. Fossil locality (Ⓕ) described in Table III.7. Location of chemically analyzed samples, (see Table III.12) also shown (sample numbers enclosed by boxes).

Table III.4. Stratigraphy and sedimentology of section 707, Upper Triassic Stuhini Group (in pocket). Abbreviations are: A = angular; PS = poorly sorted; R = rounded. Conventional orientation refers to dip direction conventionally oriented 90 degrees clockwise from azimuth. Lithological symbols are the same as those used in Figure 33. Fossil locality (F) described in Table III.10. Location of chemically analyzed samples (see Table III.12) also shown (sample numbers enclosed by boxes).

Table III.5. Stratigraphy of section 711, Upper Triassic Stuhini Group (in pocket). Location of chemically analyzed sample (see Table III.12) also shown (sample number enclosed by a box).

Table III.6. Stratigraphy and sedimentology of section 714, Upper Triassic Stuhini Group (in pocket). Abbreviations are: A = angular; MS = moderately sorted; PS = poorly sorted; R = rounded; SA = subangular; SR = subrounded; WS = well sorted. Conventional orientation refers to dip direction conventionally oriented clockwise from azimuth. Lithological symbols are the same as those used in Figure 33. Fossil locality (F) above inferred thrust fault described in Table III.7; fossils collected below inferred thrust fault described in Table III.10. Location of chemically analyzed samples (see Table III.12) also shown (sample numbers enclosed by boxes).

greywacke beds and black to maroon, pyritiferous, laminated siltstone beds alternate; section 714 contrasts section 577 by its significant content of volcanic conglomerate and breccia units and more abundant dewatering structures (convolute lamination, load casts and ball and pillow structures) in the basal member, but this may be a function of the quality of exposure. Particularly distinctive of section 714 are the massive greywacke units whose bedding is defined by very thin, white, locally discontinuous, wispy siltstone laminae (e.g. units K and P). In both sections, siltstone is more important up section; greywacke at the base. Locally (station 630), greywacke contains shale rip-up clasts. The uppermost sediments of the lower member were not lithified at the time the upper greyish green augite porphyry member was erupted and were highly contorted; a feeder dike for some of these flows clearly intrudes the basal sedimentary member in section 577 (Plate IV B). Augite- or bladed plagioclase-augite porphyry dikes commonly intrude the lower sedimentary member elsewhere (e.g. stations 436, 541 and 630). The flows are sparsely vesicular except along the eastern margin of Pallen Creek Pluton where abundant plagioclase amygdules occur randomly and also outline the rims of amoeboid pillows in the augite porphyry. Submarine deposition of the lower siltstone member is suggested by the sparse ammonoid fauna collected in section 714. Near section 577, the augite porphyry flow(s) has also scoured the uppermost sediments (Plate IV C). Round,

augite porphyry fragments within the augite porphyry matrix occur over scattered intervals in unit R of section 714 (and are probably more widespread but are hidden by lichen cover). Augite porphyry breccias are uncommonly preserved elsewhere (e.g. stations 349 and 436). Locally, sandstone (station 573 and 575), polymict conglomerates and breccias (with Stikine Pluton? fragments; station 573), and bladed plagioclase porphyry (station 574) form a minor part of the exposed upper volcanic unit. Similarity of this twofold stratigraphy in the detailed sections as well as regionally allows the correlation between sections 577 and 714 at the contact between the predominantly volcanic and predominantly sedimentary members. In section 577, the uppermost unit, a volcanic breccia containing rhyolite fragments, is important in comparing these two sections to those farther east.

Along the northern margin of the batholith, sediments are subordinate to abundant volcanic conglomerate and breccia, and flows are uncommon. Representative sections are detailed in Tables III.2 - III.5 and Plate IV E, F, G and H. The coarse clastics are commonly matrix supported; locally fragment supported breccias occur (e.g. units E and H in section 705). The matrix is commonly fine-grained, pyritiferous, volcanic (sedimentary or igneous), and augite porphyry or bladed plagioclase porphyry form the groundmass for some thick conglomerates (e.g. section 705, unit D and N and section 707, unit E, C and D). Fragments are generally poorly sorted,

angular to round and may reach 0.5 m in length. Fragment lithologies are predominantly volcanic; the exceptions are recognizable Cake Hill Pluton fragments which occur extensively at the base of the Upper Triassic sections adjacent the Cake Hill Pluton (e.g. sections 714 and 707 and stations 276, 285, 286, 293, 690, 699, 701 and 702). Distinctive volcanic fragment lithologies include: white rhyolite (with rare to common quartz or feldspar phenocrysts); coarse-grained (augite-) bladed plagioclase porphyry; amygdaloidal lava; maroon fine-grained volcanic (see Triassic-Jurassic stratigraphy, section III.4); soft black shale or black fine-grained volcanic; and medium-grained porphyry (containing hornblende or plagioclase phenocrysts). The rhyolite (section 704, unit B and G and section 705, units B and I) and less commonly purplish volcanic (section 707, unit C) fragments form oligomict volcanic conglomerates and breccias. Generally, fragment abundance and lithology are useful only in local correlations within a composite section. The rhyolite fragments are important for they provide the only evidence of felsic volcanism which apparently accompanied the predominantly mafic Stuhini Group volcanism (Souther, 1971a). A distinctive, regional unit is a bimodal breccia-conglomerate (section 704, units K and L; section 705, units J, M and O; and the basal sub-unit of unit D in section 707). Small, angular, commonly squarish, white rhyolite fragments (containing uncommon flow layering or quartz and feldspar phenocrysts) predominate over the much

larger, round, light to dark grey, bladed plagioclase porphyry (and uncommon amygdaloidal lava) fragments and occur in a dark green fine-grained volcanic matrix. Soft, small, shale rip-up or angular basalt fragments also occur in this unit. Sections 704, 705 and 707 are correlated on the basis of this unit whose thickness (and the detailed stratigraphy of underlying units) varies considerably along the northern margin.

Several features of the coarse clastic deposits are important indicators of source area and depositional environment. The granitoid (Cake Hill Pluton) fragments in the basal units of the Upper Triassic section decrease in size (from 2-150 cm at base and 2-5 cm at top) and abundance (5-40 per cent at base, rare up section) with stratigraphic height. Two varieties are common: round, mafic-bearing pebbles and cobbles which are probably the result of erosion; and altered, nearly mafic-free subrounded to angular cobbles and boulders which may be accidental conduit xenoliths, clearly the case near station 690 (see Cake Hill Pluton section). At station 701, rare, leucocratic alkali feldspar granite fragments occur with Cake Hill Pluton fragments in the basal volcanic conglomerate and provide the only suggestion of a differentiated phase of that pluton. Angular volcanic fragments are common in the coarse clastics. Unit E, section 705, gradationally changes up section from a clast-supported to matrix-supported breccia. In unit H of the same section, the opposite transition

occurs. The interbedded greywacke members in unit F of section 705 exhibit normal graded bedding, each basal layer beginning with coarse, bladed plagioclase-rich greywacke. The distinctive bimodal breccia-conglomerate of unit J, section 705, is characterized by two cycles of reverse graded deposition of small rhyolite fragments at the base and larger rhyolite fragments plus the large, rounded bladed plagioclase porphyry fragments at the top of each cycle. Generally, however, the coarse volcanoclastic deposits are massive; parallel laminations are rare to absent in these units. Reverse grading and massive beds in coarse volcanoclastics have been interpreted by Tassé et al. (1978) and Lajoie (1979) to indicate accumulations from laminar suspensions such as debris flows.

The volcanoclastics commonly stand out as resistant ribs (plate IV F) separated by thin, recessive units of rusty weathering, thin-bedded siltstone and minor greywacke. Locally, the sediments are convolutedly bedded within 1-2 m of the contact with the overlying conglomerate or breccia unit. Scouring of underlying sediments by the latter deposits also occurs. At section 705 and station 276, sparse ammonoid fauna indicate marine deposition of the sediments.

Volcanic flows form a minor to significant part of sections adjacent the northern margin and appear to be more important farther north (e.g. section 711, Table III.5). In sections 704, 705 and 707, fine-grained andesite, augite

porphyry and bladed plagioclase porphyry are the flow lithologies. Some of the lithologies also form the groundmass for the conglomerates and breccias. At the top of section 707 (and near station 280), bladed plagioclase porphyry form unusual pillowed flows (Plate V A, B). The isolated, cylindrical pillows rarely have chilled rims; trachytoid plagioclase phenocrysts around the rim are separated from randomly oriented coarser phenocrysts in the pillow's core by a 20-50 cm interval of phenocryst-poor, fine-grained volcanic groundmass; and the interstices between pillows are filled, in order, by essentially identical trachytoid bladed plagioclase porphyry (with a black, fine-grained groundmass) and at the very centre of the interstice, a fine-grained maroon-grey basalt. Down dip as well as immediately overlying the porphyry flows, the pillows are broken up to form a pillow lava breccia in a turbiditic, normally graded, greenish grey greywacke (Plate V C). If section 711 (Table III.5) is representative of part of the stratigraphically higher units than in sections 704, 705 and 707, these rocks are composed of commonly vesicular, medium-grained, plagioclase porphyry, augite porphyry and minor bladed plagioclase porphyry.

Less detailed stratigraphic comparisons along the northern margin of the Hotailuh Batholith confirm the essential characteristics of the stratigraphy illustrated in the stratigraphic columns: the structurally (and probably stratigraphically) lowest unit of granitoid (Cake Hill Pluton) - bearing sedimentary

and volcanic conglomerates (stations 276, 285, 286, 293, 699, 701 and 702); the importance of rhyolite fragments in the overlying volcanoclastics and bladed plagioclase porphyry flows (station 691); the relative unimportance of sediments in the stratigraphy (stations 276 and 280); and the predominance of (stratigraphically higher) flows north of the batholith margin (e.g. station 295-296).

The tentative correlation between the northern margin stratigraphy (e.g. sections 704, 705 and 711) and the western stratigraphy (sections 577 and 714) is made at the base of the distinctive bimodal breccia-conglomerate of the former and the thick augite porphyry flow(s) of the latter (Figure 33). It is based on the presence of ammonoid faunas in the sediments which, although poorly preserved, may be the same genus (Dr. H. Tipper, personal communication, 1979). If this correlation is correct, a clear distinction exists between the high energy, proximal, turbiditic and debris flow deposition of the volcanoclastic strata along the northern margin in contrast to the distal, in part turbiditic, deposition in the northwest and west. Stratigraphy along the northern margin records erosion of the late Triassic volcanic edifice, located to the south probably at the present location of the Three Sisters Pluton. Although paleocurrent data are sparse, lithological, petrographic and chemical matching of granitoid cobbles in the basal upper Triassic sequence with the Cake Hill Pluton to the south and the present bedding orientation of the strata strongly suggest

that the source area was to the south. Cake Hill Pluton became a successively less important source area with time as it was covered up by volcanic flows and deposits from the growing edifice. Overall characteristics of the Upper Triassic stratigraphy along the northern margin are similar to features characterizing the central facies (within 0.5 to 2 km of central vents) and proximal facies (5-15 km of central vents) of Williams and McBirney (1979). The location of this edifice, is possibly constrained by the abundant proximal deposits accumulated by debris flows near the intersection of the medial line of the batholith (now defined by the Cake Hill Pluton-Three Sisters Pluton contact) and its present northern margin. In contrast, the western stratigraphy lacks these deposits and derived little detritus from the exposed Cake Hill Pluton. Further, if these deposits define the general position of the volcanic centre in the south, it implies a high degree of control of later magmatism (late Triassic volcanism and early to middle Jurassic plutonism) by the earlier emplaced Cake Hill Pluton, in concert with the views of Hamilton and Myers (1969) on emplacement of batholiths.

Intrusions in the Upper Triassic rocks are also important regionally and in the stratigraphic sections. As described in the western stratigraphy, trachytoid bladed plagioclase-augite porphyry dikes cut the basal sedimentary unit to feed overlying flows. In sections along the northern margin, augite porphyry, syenitic (hornblende-) plagioclase porphyry and uncommon

greenish grey andesite dikes intrude the sediments and volcanics. The augite porphyry intrusions reinforce evidence from the stratigraphic columns that augite porphyry does not occupy a unique stratigraphic position. One augite porphyry dike (40 cm wide), intruding the pillowed bladed plagioclase porphyry flows at the top of section 707 (and at station 280) exhibits symmetrical chilled selvages (10 cm wide). The syenitic porphyries locally produce a fracture cleavage in the groundmasses of the distinctive bimodal breccia-conglomerate of section 705. A grey-green andesite dike emplaced along the cleavage is unaffected by it, possibly suggesting it post-dates the porphyry's intrusion. Regionally, these hypabyssal intrusions along with flow-layered rhyolite, aplite, pegmatite and felsite are most important along the northern and less so along the eastern margins of the Hotailuh Batholith (see Appendix 5.2). Granitoid apophyses (acicular hornblende diorite, monzodiorite and fine-grained syenite) in the Upper Triassic rocks along the northern and eastern margins are probably related to the Three Sisters Pluton.

(c) Structure

The orientation of bedding and later developed foliation, jointing and faulting in the Upper Triassic volcanics and sediments result from their stratigraphic position post-dating the Triassic and predating the Jurassic intrusive events. The Upper Triassic strata on the western, northern and eastern margins commonly dip radially off the Hotailuh Batholith (Monger

and Thorstad, 1978; see Appendix 5.1). Along the western margin, bedding varies between moderate to steep northeast to northwest dips; strata along the eastern margin of the Pallen Creek Pluton dip moderately southeast and those along the northeastern and northwestern sides of the Tanzilla Pluton have moderate northwest dips. Beds along the northwest corner of the batholith dip northwest. With one exception, units along the northern margin dip west northwest, northwest, or rarely northeast. Layering in the volcanics along the southern margin is poorly exposed but appears to dip to the northeast; the southeastern inlier of Upper Triassic volcanics and volcanoclastics dips northwest.

Jointing is best developed in the volcanics along the ridge 1.5 km east of Thenatlodi Mountain where it is well developed, closely spaced and maintains subparallel northeast trends and moderate southeast dips (stations 41-43 and 574; Appendix 5.1). They probably reflect adjustment of the country rocks to intrusion of the flat-roofed Three Sisters Pluton in this area.

Cleavage is also locally well developed in augite porphyry along the Cassiar-Stewart Highway and less developed in the siltstone member at stations 434-436 (see Appendix 5.1). A consistent south southeast trending, commonly steep southwest dipping schistosity is developed in the volcanics near the northwest corner of the batholith. The fabric is pervasive and the original augite porphyry volcanic has been changed to

augite porphyry schist. Schistosity appears to be limited to the porphyry and at station 1 or 428, nearby, well bedded, coplanar sediments are not affected by the fabric. The deformation is probably related to an inferred fault or number of faults along the western margin of the Cake Hill Pluton which are cut by the Three Sisters Pluton apophysis. "Cleavage" developed in the siltstone member of the western Upper Triassic stratigraphy contrasts that in the augite porphyry in that no mineral growth occurs along it, and it has a predominant north northeast trend and subvertical to steep dip. Its orientation parallels that of jointing in the volcanics farther west and probably has the same origin. Finally, fracture cleavage is locally developed in the distinctive bimodal breccia-conglomerate of the northern margin, adjacent syenitic porphyry dikes.

Important and small scale faulting and folding of the Upper Triassic rocks are observed along the northern and western margins. An important, north-dipping thrust fault places Upper Triassic over the Toarcian (upper Lower Jurassic) unit in sections 714, 705 and 707 (Plate IV F, G and H; Plate V D) and is interpreted as the contact between these two units along part of the batholith's eastern margin (Gabrielse, 1979). On sedimentological grounds, the structurally overlying Upper Triassic unit was argued to consist of proximal deposits and the north dipping thrust is believed to be the locus of only small scale displacement. Extent of the thrust was not mapped but mapping of the northern plutonic-volcanic contact reveals

that it only follows that contact locally. (For example, at a few places, the Upper Triassic volcanic clearly rest non-conformably on the Cake Hill Pluton; at station 702, the contact between the pluton and granitoid-bearing conglomerates is cut by an augite porphyry intrusion.) The thrust postdates deposition of the Toarcian volcanics and pre-dates intrusion of a granitoid (monzodioritic) hornblende-plagioclase porphyry which is chilled against the Toarcian sediments, cuts the thrust and may be related to last phases of Three Sisters Pluton emplacement (Plate IV G, H). The thrust fault has probably been steepened by up-doming of the area during the emplacement and uplift of the Three Sisters Pluton. Small scale, normal faults, flexures and faults of unknown but undoubtedly small displacement in the Upper Triassic rocks adjacent the Three Sisters Pluton in the west and along the batholith's northern margins probably resulted from uplift of the batholith and intrusion of the Three Sisters Pluton.

(d) Metamorphism

Metamorphic aureoles rarely extend more than 20-100 m laterally or up section from the intrusive contact. Metamorphic effects include amphibolitization of the basic volcanics, silicification of the groundmass, urolization of pyroxene phenocrysts and minor, visible alkali metasomatism (adjacent the Three Sisters Pluton, potassic marginal phase). This low grade metamorphism is consistent with the brittle response (jointing, faulting, and warping) of the volcanics and sediments

to intrusion of the Three Sisters Pluton and indicates a shallow level of emplacement for that pluton.

(e) Age

Poorly preserved ammonoid fauna were collected from the Upper Triassic sediments along the northern margin of the Hotailuh Batholith (two localities shown in section 705 and 714; another locality is close to section 707, see Table III.7). No firm identifications could be made on the collections but the collections from sections 705 and 714 appear to contain the same genus and all collections are probably Triassic in age (H.W. Tipper, personal communication, 1977, 1979).

Similar Stuhini Group rocks are paleontologically well-dated farther west in the Stikine Arch (Tulsequah map area; Souther, 1971a; Monger, 1980) at late Carnian or Norian (Late Triassic). Farther south in the Telegraph map area, equivalent strata of Souther's (1972, p. 9) map unit 8 are suspected to be late Norian and in the McConnell Creek map area, correlative Takla Group rocks are also dated at late Carnian or early Norian (Monger, 1977). Along the Thibert Fault in the northeast corner of Dease Lake map-area, augite porphyry flows of the Shonektaw Formation possibly underlie or are facies equivalents of the volcanoclastic Nazcha Formation which are of late Triassic (Norian) age (Monger, personal communication, March, 1981).

TABLE III.7 FOSSIL COLLECTIONS IN THE UPPER TRIASSIC STUHNI GROUP

SPECIMEN	LOCATION (Latitude and Longitude)	UNIT	IDENTIFICATION
276 F	58°13'00"N 129°31'00"W (3.2 km southwest of Glacial Lake)	rusty, weathering, fissile black slate several tens of meters above Cake Hill Pluton - vol- canic contact	poorly preserved ammonoid fauna possibly of Triassic age? (H.W. Tipper, personal communication, July, 1977)
705 F	58°13'51"N 129°31'05"W (2 km south of Horn Mountain - see Plate IV F)	unit I of section 705	rare, poorly preserved ammonites and ammonite frag- ments of possible Triassic age (H.W. Tipper, personal communication July, 1979; may be the same genus as ammonites collected by J.L. Mansy from section 714; see Plate IV D)

TABLE III.8 POTASSIUM-ARGON RADIOMETRIC AGE DATA FOR A HORNBLENDE-AUGITE PORPHYRY DIKE

SPECIMEN NUMBER	GEOLOGICAL RELATIONSHIP	LOCATION (LATITUDE- LONGITUDE)	LITHOLOGY	MINERAL	ZK	$\%^{40}\text{Ar}$	AGE (Ma)
AN-79-698-3	intrusive into Coke Hill	58°13'14"N 129°34'00"W	hornblende- augite	hornblende	0.340	50.7	280 ± 19
	Pluton; comag- matic? with Upper Triassic augite porphyry (Stuhini Group)		porphyry	hornblende	0.620	73.8	170 ± 11

K-Ar isotopic determinations were made on two hornblende separates from a hornblende-augite porphyry dike intrusive into the Cake Hill Pluton (see Plate II F, G) and assumed comagmatic with the Upper Triassic augite porphyry. The euhedral hornblende phenocrysts appear to be primary and are oriented parallel to the margins of the dike. However each mineral separate is characterized by a different hornblende pleochroic scheme (R. Stevens, personal communication, March 1981). The two age determinations are discordant, 280 ± 19 Ma and 170 ± 11 Ma (Table III.8) and neither is consistent with geological constraints on its age. The older age suggests an excess Ar component whereas the younger date may indicate resetting due to intrusion of the Three Sisters Pluton. Neither date is considered an estimate of the age of the Upper Triassic volcanism.

III.4 Triassic-Jurassic Stratigraphy

(a) Distribution, Physiography and Magnetic Expression

Monger and Thorstad (1978) and Gabrielse (1979) have distinguished a Triassic-Jurassic volcanic unit that overlies the Upper Triassic unit along the northern and eastern margins of the Hotailuh Batholith (Figure 1). This stratigraphy is especially well exposed along the northeast margin of the Hotailuh Batholith and the section measured there (section 715; Table III.8) is representative of the extensive strata exposed in this area (Plate V F, G). Rugged, cliff-forming

relief provides the excellent exposure of the Triassic-Jurassic volcanics along the northeast margin of the batholith; farther northwest, north and east, these volcanics underlie rounded ridges of low to moderate relief. The volcanics are associated with several aeromagnetic highs (which steadily decrease in magnitude from 58,850 to 58,310 gammas (near section 715) west to east along the northern outcrop area and steadily increase from 58,964 gammas to 59,300 gammas north to south along their eastern outcrop areas; Figure 2) in contrast to the aeromagnetic signature of the Upper Triassic volcanics.

(b) Stratigraphy

Monger and Thorstad (1978, p. 22) describe the upper Mesozoic unit around the Hotailuh Batholith as a succession of mainly green and red flows and volcanoclastics, which are composed of fine-grained plagioclase porphyry of intermediate composition. Minor red and green, well-bedded crystal lithic tuffs, quartz porphyritic acidic flows and ignimbrites with the major lithologies form a sequence approximately 700 m thick. Results of detailed studies along the southern, eastern, northern and northeastern margins of the Hotailuh Batholith are in accord with Monger's and Thorstad's general observations and provide additional information on the petrology of the porphyry flows.

South of the Beggerlay Creek Pluton, grey to dark grey, fine- to medium-grained plagioclase porphyry, grey to maroon volcanoclastics and tuffaceous mudstones and minor grey, fine-

grained andesite and rare inclusion-bearing basalt compose the Triassic-Jurassic unit. Near the contact with the pluton and in a thick screen within the pluton, amphibolitization and hornfelsing of the volcanic groundmass point to an intrusive relationship for the Beggerlay Creek Pluton.

East of the McBride River Pluton, a moderately exposed section consists of (base to top): augite-plagioclase porphyry (less than 10 m thick); grey, fine-grained, moderately laminated siltstone; volcanic conglomerate (predominantly rounded, small chert and minor granitic fragments in a very fine-grained groundmass); ignimbrites; and a thick sequence of monotonous grey plagioclase porphyry and andesite flows, minor andesite breccia (with rare granitic fragments up to 3 cm long) and tuff and rare olivine basalt. Structurally above this sequence (and interpreted as faulted against it by Gabrielse (1979)) is a sequence of (base to top): flow layered rhyolite and rhyolitic lapilli tuff; andesitic plagioclase porphyry; maroon tuffaceous mudstone; mud-cracked, maroon and green mudstones and significant though minor greyish green andesite; and an upper heterogeneous unit of equal parts greyish green andesitic plagioclase porphyry and maroon, laminated tuffaceous mudstones with minor volcanic breccia and conglomerate and rare but significant micrite.

To the north, faulted against the flows of section 711, is a poorly exposed section of (base to top): thick brownish grey to black, locally trachytoid, medium-grained plagioclase

porphyry; bluish grey, massive andesite with conspicuous epidote patches (amygdules?); thin (3 m) interlayered welded tuff and thin grit beds; maroon volcanic breccia (containing 3-5 cm long angular feldspar porphyry fragments); minor, well bedded greywacke; and, at the top, fine-grained massive andesite breccia.

The Triassic-Jurassic unit is best exposed along the northeastern margin of the Hotailuh Batholith (section 715; Plate V E and F and Table III.9). The base of the section is composed of massive to vesicular, grey to maroon, andesite flows and maroon to brick red siltstone and fine-grained sandstone. Grey to maroon feldspar porphyry flows make up the middle (and bulk) of the section. Individual flow units, possibly tens of meters thick, are recognized with difficulty on the basis of differential resistance to weathering, concentration, size and alteration of feldspar phenocrysts and rarely, by groundmass texture. This thick sequence of porphyry flows is separated by a thin, greenish-grey, chloritized augite(?) porphyry flow (unit K). The top part of the section is composed of equal parts of plagioclase porphyry as in flows down section and maroon volcanic conglomerates and breccias. Fragments in the volcanoclastics are rounded to angular, poorly sorted, range in size from 1-45 cm long and consist of minor variations of the plagioclase porphyry lithology which composes the underlying and overlying flows. Fragments are set in a fine-grained, maroon, tuffaceous matrix. Lack

Table III.9. Stratigraphy and sedimentology of section 715, Triassic-Jurassic volcanics (in pocket). Abbreviations are: A = angular; PS = poorly sorted; R = rounded; SA = subangular. Conventional orientation refers to dip direction conventionally oriented 90 degrees clockwise from azimuth. Lithological symbols are the same as those used in Figure 35. Location of chemically analyzed samples (see Table III.12) also shown (sample numbers enclosed by boxes).

of sedimentary structures, identifiable granitic detritus, diking, and other correlative sections precludes any rigorous assessment of depositional environment. The distinctive maroon to brick red weathering colour is due to oxidation of fine- to medium-grained magnetite grains and its intensity may vary considerably within an outcrop and between outcrops. This oxidation possibly indicates a partly to wholly subaerial depositional environment.

Hypabyssal intrusions are rare in the Triassic-Jurassic unit and were not observed in section 715 (see Appendix 5.2). They consist of acidic hornblende-plagioclase porphyry in rocks along the southern margin and basalt, siliceous felsite and a granitoid hornblende-plagioclase porphyry or monzodiorite along the eastern margin, the last intrusion possibly related to the McBride River Pluton although not an exact lithologic analog.

J (c) Structure

Although Triassic-Jurassic strata in the northern, northeastern (section 715) and eastern areas dip (or are inferred to dip) moderately northeast off the batholith, strata south of the Beggerlay Creek Pluton dip steeply northwest into the pluton. The Triassic-Jurassic volcanics are faulted against the Upper Triassic volcanics near section 711.

(d) Age

This unit is designated Triassic-Jurassic because its age is poorly known. No fossils have been found in the rocks.

Intrusive relations between the well exposed strata along the northeastern margin and the Three Sisters Pluton appear to be covered. If the stratigraphy developed along the southern margin is correlative with that along the eastern and northern margins, then the unit probably predates intrusion of the Beggerlay Creek Pluton (K-Ar, 218 ± 29 Ma) and so is Triassic or older. In this study, the only contact observed between the Upper Triassic unit and the Triassic-Jurassic strata along the northern margin is faulted; along the eastern margin augite porphyry is the structurally lowest unit in the moderately exposed section described above. Monger and Thorstad (1978) reported a gradational contact between the two units, separating predominantly green weathering (Upper Triassic) strata from predominantly maroon weathering (Triassic-Jurassic) strata. They correlated the Triassic-Jurassic unit with the Lower Jurassic (Sinemurian) Telkwa Formation of the Hazelton Group in the McConnell Creek map-area. (Monger, 1977). However, in the well exposed Triassic stratigraphy in the Tulsequah map-area to the west, Monger (1980) describes dominantly maroon weathering, feldspar porphyry fragment-bearing breccia and conglomerate which is the uppermost unit in the well-dated Upper Triassic (Norian) stratigraphy. Therefore on lithological grounds, the correlation of the Triassic-Jurassic stratigraphy around the Hotailuh Batholith remains uncertain.

III.5 Lower Jurassic Stratigraphy

(a) Distribution, Physiography and Magnetic Expression

Thin, isolated, shallow water marine Lower Jurassic sedimentary units outcrop along the northern and eastern margins of the Hotailuh Batholith, structurally below the Upper Triassic rocks (see Section III.3 and Figure 33). Along the northern margin, the Lower Jurassic unit outcrops along bottoms of creek gullies and their rusty buff weathering colour is striking from a distance (e.g. Plate IV G, H) and was mistaken for granitic rock in the early reconnaissance mapping (Gabrielse, 1962). Along the eastern margin, these rocks are well exposed on ridges of moderate relief. These rocks have no characteristic magnetic expression on the regional aeromagnetic map (Geological Survey of Canada, 1978a) partly owing to their small aerial distribution and proximity to granitic rocks.

(b) Stratigraphy

Henderson (1979) and Henderson and Perry (1981) described the stratigraphy of the moderately to poorly exposed Upper Jurassic section at the base of section 714 (his Cake Hill section; see Table III.6) and another section along the eastern margin (his Three Sisters Section). He described the Cake Hill section as comprising (base to top): graded lithic wacke (section 714, unit A); interbedded clastic carbonate and massive bioclastic fine lithic wacke (top of unit A and B of section 714); rhyolitic crystal tuff (unit C, section 714); and volcanic breccia (possibly the top of

unit D or base of unit E?, section 714). His Three Sisters section consists of a lower skarn unit and an upper red weathering rhyolitic tuff and silicified argillite and minor limestone and breccia. Henderson correlated the sedimentary part of the Cake Hill section with the lower unit of the Three Sisters section and correlated the upper volcanic parts of the two sections. On the basis of the regional sections described previously, it is believed that the rhyolitic crystal tuff in Henderson's Cake Hill section is probably a porphyry dike (although it forms an isolated exposure; see Table III.6) and, depending on the fragment lithologies of the breccia, it may be part of the Triassic or Lower Jurassic unit. The thin, but significant siltstone component of the Lower Jurassic sequence at section 714 was not reported by Henderson (1979).

Elsewhere along the northern margin, a similar Lower Jurassic stratigraphy is developed (see Tables 3 and 4). The rocks are separated by thin covered intervals (6-30 m) from the structurally underlying Cake Hill Pluton and are inferred to be nonconformable on the pluton. Although the Lower Jurassic sediments are metamorphosed along the eastern margin due to the intrusion of the nearby Three Sisters Pluton, they appear to rest nonconformably on the Cake Hill Pluton (which is itself metamorphosed). Clean quartz arenite, calcareous quartz arenite and sandy carbonate and siltstone and shale are the important lithologies. In section 707,

the most complete section of the Lower Jurassic rocks, the sandstones and carbonates are most common at the base of the section and siltstone and shale much more important up section. This occurs in section 714 as well but not in section 707. Correlation of section 705 with sections 707 and 714 is based on lithological similarity.

From his detailed petrographic and paleontologic work, Henderson (1979) concluded that the lower sedimentary units in his sections were deposited in a high energy environment. The lower, graded and crossbedded sandstones represent above wave base deposition and successively slightly less energetic conditions of deposition are interpreted for sediments up section. An overall high energy, shallow (less than 15-20m), temperate normal marine environment is required to explain the faunal association and sedimentology of these sediments. The Three Sisters section was deposited in offshore or deeper conditions and represents a more stable energy regime than the Cake Hill section. This is consistent with an eastward deepening Pliensbachian basin east of the batholith and Henderson (1979) concluded that the lack of Pliensbachian sediments west of the eastern margin of the Hotailuh Batholith and his interpreted depositional environments for the Toarcian sediments imply a late Pliensbachian to early Toarcian transgression which overlapped sediments onto the Cake Hill Pluton.

(c) Structure

Given their nonconformable relationship with the Cake

Hill Pluton and their inferred shallow to slightly deeper water depositional environment; the bedding attitudes of the Lower Jurassic sediments may record the amount of tilting along the batholith's as a result of the intrusion of the Three Sisters Pluton. Along the northern margin 45-70 degree dips to the north northeast are observed in section 705, 707 and 714 and stations 325 or 449 (Appendix 5.1). Lower Jurassic beds dip 50-60 degrees to the northeast of the eastern margin. The bedding trends of the Lower Jurassic parallel the general trend of the known or inferred thrust separating these rocks from the overlying Upper Triassic strata. The thrust also may have been domed up and steepened during the intrusion of the Three Sisters Pluton. Adjacent to the thrust, the siltstones and shales have a steep fracture cleavage (see Tables III.3 and III.4).

(d) Age

The association of the cyclostome bryozoan (Heteropora, n. sp. A), endolithic blue-green alga, ammonite (Harpoceras), foraminifer (Reinholdella) and pelecypod (Weyla) fauna in the Cake Hill section (section 714, this study; see Table III.10) indicate an early Tuarcian (late Early Jurassic) age (Henderson, 1979; Henderson and Perry, 1981). The following identification of ammonites collected from the base of section 707 (Tables III.4 and III.10) was made by Dr. H. Frebold of the Geological Survey of Canada (written communication, 1980):

TABLE III.10 FOSSIL COLLECTIONS IN THE UPPER LOWER JURASSIC SEDIMENTS

SPECIMEN	LOCATION (Latitude and Longitude)	UNIT	IDENTIFICATION
325 F	58°14'30"N 129°46'00"W (0.5 km south of peak 6848 feet, unit A of section 714; see Plate IV D)	buff, weathering sandy micrite	cyclostome bryozoa (<u>Heteropora</u> n.sp. A), endolithic blue-green alga, ammonite (<u>Harpoceras</u>), foraminifer (<u>Reinholdella</u>) and pelecypod (<u>Weyla</u>) of Early Toarcian age (H.W. Tipper, personal communication, 1977; Henderson, 1979; Henderson and Perry, 1981)
707 F	58°13'19"N 129°31'03"W (3.2 km south southeast of Horn Mountain, basal unit of section 707; see Plate IV H)	buff, weathering sandy limestone	<u>Pseudogrammoceras</u> spp. indet (probably several species present) indicating a Late Toarcian age (H. Frebold, written communication, April, 1980)

"Pseudogrammoceras spp. indet."

Numerous poorly preserved fragments. Some of them have fine, others coarser ribs; Some show venter and keel and furrows, Probably several species are present."

and indicate a Late Toarcian (Thouarsense Zone) age. Ammonites collected from Lower Jurassic rocks along the eastern margin also indicate a Toarcian age (H.W. Tipper, personal communication, 1977).

III.6 Tertiary Volcanics

In the Hotailuh Batholith, the three major outcrop areas of Tertiary volcanics occur in the Stikine Pluton, the Cake Hill Pluton and the Three Sisters Pluton, leucocratic phase. In each occurrence, the lithology and geologic setting differ although the freshness of the volcanics easily distinguishes them from all other Mesozoic units.

Columnar jointed, grey to greyish brown weathering, massive to diktytaxitic to scoriaceous olivine basalt form small isolated ridges and resistant knobs in the western and eastern parts of the Stikine Pluton. In one locality, a few olivine nodules are seen (See Appendix 1.3).

In the Cake Hill Pluton, a sequence of massive, grey to dark grey weathering andesite and olivine basalt, more than 50 m thick, outcrops in a north plunging paleovalley in the pluton. At least 3 flows are distinguished.

Soft, highly vesicular, greyish brown weathering plagioclase-hornblende porphyry forms the sides of a creek valley in the southeast corner of the Three Sisters Pluton,

near the contact between the leucocratic and central phases and the Cake Hill Pluton.

The volcanics must nonconformably overlie the granitic rocks and in the Cake Hill Pluton, rounded erratics of the pluton overlie the volcanics. In the Cry Lake map-area the Tertiary volcanics are believed to be Miocene-Pleistocene age (Gabrielse, 1978a).

III.7 Hypabyssal Equivalents to the Upper Triassic and Triassic-Jurassic Volcanics

In the previous sections and chapters a close temporal and spatial link between the plutonic rocks of the batholith and the fringing volcanic rocks was shown. Despite this very close association, the magmas which produced the volcanic flows of the two sequences are unlikely to have their plutonic analogs in major phases of the batholith. For the augite and augite-bladed plagioclase porphyry volcanics of the Upper Triassic section, their volcanic roots are preserved in the augite- and augite-bladed plagioclase porphyry dikes uncommon in the Cake Hill, Gnat Lakes and Beggerlay Creek Plutons. These dikes clearly are younger than 227-230 Ma (Gnat Lake Ultramafite and Cake Hill Pluton) and some may be younger than 218 Ma (Beggerlay Creek Pluton). This is consistent with the widespread occurrence of augite porphyry flows (less so for the bladed plagioclase porphyry) in the stratigraphy along the northern margin of the Hotailuh Batholith. Geochemistry of the porphyry dikes and volcanics is similarly

permissive of their petrogenetic link.

Assessment of hypabyssal analogs of the Triassic-Jurassic feldspar porphyry flows is confounded by the lack of good geological control on the age of the volcanics. Nevertheless, the most likely candidate is the syenitic (hornblende-) plagioclase porphyry dikes, plugs and larger intrusions commonly in the Cake Hill Pluton, rarely in the Three Sisters Pluton and commonly in Upper Triassic volcanics. They are most common south and southwest of Horn Mountain along the northern margin of the batholith whether in the Cake Hill Pluton or in the volcanics. They obviously post-date the Upper Triassic volcanics and volcanoclastics (one syenite porphyry even intrudes an augite porphyry dike in section 705). One of the large syenitic porphyries is intruded by thin apophyses of acicular hornblende diorite (see station 514, Appendix 2.4(d)) and rarely occurs in the central and uncommonly in the potassic marginal phases of the Three Sisters Pluton. Because their age is similarly poorly constrained, the genetic link between these syenitic porphyry intrusions and the porphyritic Triassic-Jurassic volcanics rests most strongly on their spatial association and moderate to strong lithological similarity.

III.8 Petrography

Nature, abundance and habit of phenocryst and groundmass mineralogy distinguish the Stuhini Group from the Triassic-Jurassic volcanics and have a bearing on their respective geochemical identities. Samples from the undisturbed and metamorphosed parts of the Toarcian sediments are also described.

Stuhini Group flows and volcaniclastics are characterized by a high colour index, anorthite-rich plagioclase and widespread and pervasive alteration of the clinopyroxene, plagioclase, opaque minerals (magnetite; uncommon) and hornblende (rare) phenocrysts to calcite, chlorite, epidote and sericite (Appendix 5/4(a)).

Clinopyroxene phenocrysts are subhedral or subhedral, have a pale green pigmentation, and occur as single grains and in glomeroporphyritic masses. Twinning is common and concentric and sector optical zoning is pronounced, vague or absent. Euhedral opaque minerals (magnetite), apatite and plagioclase occur as inclusions in clinopyroxene; in sample 604-1, the inclusions are aligned parallel to crystal faces and optical zones.

Unusual, square inclusions in clinopyroxene, altered to an opaque mineral rim and sericite core, occur in a few places. Clinopyroxene locally is subophitic with plagioclase phenocrysts. Calcite and opaque minerals, chlorite and epidote are common alteration products of clinopyroxene.

Plagioclase phenocrysts are subhedral or euhedral or locally skeletal and are pilotaxitic or decussate. Opaque minerals occur as scattered inclusions and rare, concentric zones of melt? inclusions occur near plagioclase rims. Unaltered phenocrysts show discontinuous normal and oscillatory zoning. Plagioclase is generally andesine (An_{50-65}) but reaches labradorite compositions (An_{70-76}) where least altered. In hyaloclastite, plagioclase is highly turbid and albitic (An_{36} or less; commonly less refringent than Canada balsam).

Brown, fine-grained, or aphanitic groundmass of the porphyritic flows consists of fine-grained opaques, pilotaxitic or decussate plagioclase microlites and common chlorite. Most clinopyroxene porphyry along the northern and, especially the western margins of the batholith is characterized by a hyaloclastite matrix of irregular masses of green, fine-grained isotropic material of indeterminate composition or chlorite and calcite. This material is arranged in curved or circular patterns and zones which are commonly outlined by concentric trains of opaque minerals (+ titanite) and probably is the alteration product of devitrified glass which spalled off during subaqueous extrusion of clinopyroxene basalt. Irregular masses of anhedral, slightly turbid, polysynthetically twinned albite? is uncommon but widespread in the hyaloclastite along the western margin and probably accounts for its alkaline geochemical affinities (cf. section III.9, sample 604-1). Calcite (+ prehnite) veinlets occur in some places and calcite and quartz from scattered amygdulæ.

White, angular rhyolite fragments distinctive of parts section 705 (e.g., unit J) and 707 (unit D) contain rare subhedral pilotaxitic phenocrysts of plagioclase and ferromagnesian silicate? (altered to opaque minerals) set in a brown, fine-grained groundmass. Pilotaxitic plagioclase microlites are oriented parallel to faint, contorted flow-layering and vague eutaxitic textures in the matrix.

Metamorphism of clinopyroxene porphyry, near contacts with the Beggerlay Creek Pluton in the south (sample 233-2) and Three Sisters Pluton in the west (samples 19-2 and 41-3), northeast (sample 71-2) and southeast (sample 501-1) is marked by mineralogical changes in the volcanics. Clinopyroxene phenocrysts are extensively altered to light to dark green hornblende. Fine-grained, anhedral hornblende is also abundant in the

groundmass. Green and brown biotite occurs in clots around clinopyroxene and opaque minerals or in the groundmass. The mineralogy is suggestive of hornblende hornfels facies metamorphism (Turner, 1981).

Deformation of clinopyroxene porphyry is intense along the northwestern margin of the batholith where a fault separates pyroxene schist (samples 358-1 and 444-1) and intensely foliated Cake Hill Pluton. Asymmetrical amphibole overgrowths on clinopyroxene, parallel schistosity formed by chlorite, green biotite and acicular amphibole in the groundmass, are characteristic. Epidote is an additional alteration product of clinopyroxene. Fractures in opaque minerals are crudely perpendicular to schistosity. Lenses of turbid, twinned albite in pyroxene schist is similar to undeformed hyaloclastite elsewhere along the western margin; plagioclase is rare, fine-grained and anhedral. Pressure shadows are developed around pyrite in the interbedded graphitic schist at station 1 or 444.

Nature and abundance of phenocryst and groundmass mineralogy in ten samples from section 715 characterizes the Triassic-Jurassic volcanics (Appendix 5.4(b)). Changes in phenocryst and groundmass mineralogy (but not abundance) and plagioclase phenocryst composition parallels the lithological and geochemical cyclicity in the flows of section 715. Opaque and "ferromagnesian" minerals, clinopyroxene, apatite and plagioclase or alkali feldspar, quartz phenocryst and groundmass minerals constitute the flows.

Opaque minerals occur as separate, homogeneous, euhedral or anhedral phenocrysts and as alteration products (with chlorite, calcite quartz and epidote) of "ferromagnesian" phenocrysts. Euhedral, former ferromagnesian (hornblende? or clinopyroxene?) phenocrysts are represented

by opaque rims, intermediate zones of chlorite (locally) and inner zones of quartz, calcite, epidote or sericite.

Euhedral to subhedral, clinopyroxene phenocrysts are observed in sample 715L-2. They are fresh or pervasively chloritized, glomeroporphyritic, sector-zoned and enclose euhedral opaque minerals.

Rare apatite phenocrysts are euhedral or subhedral and are associated with or enclosed in opaque minerals. Apatite-bearing sample 715H-3 is the most phosphorous-rich of all the samples in the section (Figure 35).

Plagioclase phenocrysts are euhedral or subhedral (and locally skeletal). Clinopyroxene (in sample 715L-2) and square opaque mineral inclusions rarely occur in cores and rims. Plagioclase phenocryst composition (An_{30-75}) varies erratically with stratigraphic height except in the interval between samples 715D-1 and 715H-3, where it decreases in anorthite content. Normal zoning may change compositions by An_{10} . Plagioclase in the clinopyroxene-bearing, most mafic sample (715L-2), is most calcic and contains rare, irregular calcic cores. In two samples, no plagioclase composition determinations were possible but plagioclase is more refringent than Canada balsam. Sericite is a common and widespread alteration product of plagioclase cores and rims throughout the section.

In more silicic samples (715I-1 and J-2), turbid, subhedral, microperthite is the feldspar phenocryst. Carlsbad twinning of the host and polysynthetic twinning of patchy albite exsolution lamellae are common. Opaque mineral inclusions in alkali feldspar are rare.

Dark grey or maroon groundmass for the porphyritic flows consists of: decussate or pilotaxitic subhedral plagioclase (or alkali feldspar in sample 715H-3 and I-1(?)); anhedral quartz; common or abundant, fine-grained, anhedral or subhedral opaque minerals; acicular apatite (sample

715H-3); and euhedral clinopyroxene (sample 715L-2). Apatite inclusions in plagioclase are common in sample 715H-3. Alkali feldspar encloses groundmass plagioclase and opaque minerals. Locally, groundmass feldspar types cannot be separated (715I-1) or the fine-grained groundmass mineralogy determined (715J-2 and K-1). Generally, groundmass plagioclase is more refringent than Canada balsam; in sample 715L-2, groundmass plagioclase compositions (An_{61-66}) are similar to that of the phenocrysts.

Sericite, epidote, chlorite, and calcite are fine- to medium-grained alteration products of feldspar and ferromagnesian silicates. The latter three minerals with quartz and opaque minerals form common homogeneous or zoned amygdules (e.g., chlorite or calcite rims and calcite or epidote inner zones) in all samples except 715H-3, I-1 and J-2.

Nature and abundance of mineralogy in two samples from lower Jurassic sandstone and from metasediments collected near the northern and eastern margins of the batholith were studied (Appendix 5.4(c)). Angular or sub-rounded grains of quartz, alkali feldspar, plagioclase, opaque minerals and zircon (rare) set in a fine-grained silica cement and white mica matrix compose the unmetamorphosed arkosic quartz arenites. Quartz is comparatively unstrained (rare subgrains) and encloses plagioclase and sericite alteration products of hornblende. Microperthitic alkali feldspar is equigranular with quartz and encloses plagioclase and myrmekite. Plagioclase is subordinate and smaller than quartz or alkali feldspar and is less refringent than quartz or the cement. Bent albite twins and discontinuous normal zoning are common. Compositional determinations are few but plagioclase is probably albitic (e.g., $<An_8$). Opaque minerals are rare, irregular and occur at contacts between quartz grains or between quartz and cement. Zircon is rare and is subhedral to euhedral.

Assemblages of garnet-alkali feldspar (microcline and microperthite)-

plagioclase-tremolite-white mica (talc?) and garnet-diopside-calcite-white mica- phlogopite? suggest probable hornblende-hornfels facies contact metamorphism (Turner, 1981) of sandy limestone along the batholith's eastern margin. Garnet is subhedral or euhedral and isotropic or anisotropic. Anisotropic varieties exhibit sector and concentric optical zones. Diopside occurs as aggregates of fine-grained anhedral grains between garnet subhedra. Irregular, optically continuous grains of white mica are common within alkali feldspar.

III.9 Chemical Composition of the Upper Triassic Stuhini Group and Triassic-Jurassic Volcanics

Major, minor and trace element compositions and CIPW norms for some augite-bladed plagioclase porphyry dikes, Upper Triassic Stuhini Group volcanics, Triassic-Jurassic volcanics and miscellaneous dikes are given in Tables III.11 to III.14 and Figure 34. Description of the geochemistry of these rocks is detailed below by unit. All compositions used in normative calculations and shown in the figures are calculated volatile-free.

The augite porphyry dikes are believed to be coeval and comagmatic with the porphyritic Stuhini Group volcanics on the basis of intrusive relations and lithological similarities. Five samples collected from the dikes are predominantly hypersthene-, diopside- and olivine-normative; sample 630-1 contains normative nepheline and sample 121-3 is distinguished by its normative quartz content. Dike compositions straddle the alkaline-subalkaline boundary of Irvine and Baragar's (1971) alkali-silica plot (Figure 34 (a)) but only the nepheline-normative sample is alkaline according to the ne'-ol'qz' ternary plot of Irvine and Baragar (1971; see Figure 34 (b)). Subalkaline samples have mixed calc-alkaline and tholeiitic affinities depending on the classification used. In the AFM ternary (Figure 34 (c)); after Irvine and Baragar, 1971), and the alumina-normative plagioclase plot (Figure 34 (f); after Irvine and Baragar, 1971), the samples are predominantly calc-

TABLE III.11 CHEMICAL COMPOSITION OF THE AUGITE-PLAGIOCLASE PORPHYRY DIKES

(a) Location and lithology of specimens

SPECIMEN	UNIT	LOCATION (Latitude and Longitude)	LITHOLOGY
121-3	augite-plagioclase porphyry dikes	58°06'47"N 129°34'45"W	augite porphyry (intrudes Cake Hill Pluton)
340-2	"	58°06'10"N 129°34'00"W	augite porphyry (intrudes Cake Hill Pluton)
630-1	"	58°11'30"N 129°52'00"W	trachytoid bladed plagioclase-augite porphyry (intrudes Gnat Lakes Ultramafite)
7050-5	"	58°13'55"N 129°31'45"W	augite porphyry (intrudes unit 0 in section 705)
698-2	"	58°13'14"N 129°34'00"W	hornblende-augite porphyry (K-Ar SPECIMEN - intrudes Cake Hill Pluton)

TABLE III.11 CHEMICAL COMPOSITION OF THE PORPHYRY DIKES
(b) Major Elements (in weight per cent)

OXIDE	SPECIMENS					AVERAGE (1σ)
	121-3	340-2	630-1	7050-5	698-2	
SiO ₂	60.2	50.3	51.3	49.8	44.9	51.3 (5.6)
Al ₂ O ₃	16.1	16.3	17.5	16.4	15.0	16.3 (0.9)
TiO ₂	0.85	0.92	0.83	0.95	1.11	0.93 (0.11)
Fe ₂ O ₃	3.0	2.8	1.1	4.0	6.0	3.4 (1.8)
FeO	5.3	6.6	3.7	5.9	6.5	5.6 (1.2)
MnO	0.14	0.13	0.08	0.19	0.23	0.15 (0.06)
MgO	5.46	4.83	4.21	6.57	5.95	5.40 (0.92)
CaO	6.89	7.17	10.26	6.95	9.05	8.06 (1.52)
Na ₂ O	3.1	3.2	5.0	2.4	2.6	3.3 (1.0)
K ₂ O	3.35	3.53	0.38	3.51	1.63	2.48 (1.42)
P ₂ O ₅	0.56	0.48	0.59	0.31	0.23	0.43 (0.16)
H ₂ O _T	2.0	1.4	1.8	3.2	3.5	
CO ₂	B.D.	B.D.	2.0	0.4	3.2	
S	B.D.	B.D.	0.20	B.D.	B.D.	
Cl	0.05	0.04	N.A.	N.A.	N.A.	
F	0.07	0.09	N.A.	N.A.	N.A.	
Less O=S			0.05			
Total	107.07	97.79	98.90	100.58	99.90	(97.35)

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE III.11. CHEMICAL COMPOSITION OF THE PORPHYRY DIKES,

(c) Trace Elements (in ppm)

	SPECIMENS					AVERAGE (1σ)
	121-3	340-2	630-1	7050-5	698-2	
Rb	B.D.	80*	20	50	60	50 (30)
Sr	790	730	1400	840	660	880 (300)
Ba	1200	950	410	1200	790	910 (330)
U	4.6	3.9	N.A.	N.A.	N.A.	4.3 (0.5)
Zr	160	140	150	54	56	110 (50)
Cr	130	15	81	47	23	59 (47)
Co	37	36	14	25	41	31 (11)
Ni	79	29	40	16	34	40 (24)
V	300	300	230	230	390	290 (66)
Cu	270	220	260	82	140	190 (80)
Zn	B.D.	B.D.	60	120	140	110 (40)

B.D.: below detection limit of analytical methods; N.A.: specimen not analyzed for given element or oxide

TABLE III.11 CHEMICAL COMPOSITION OF THE AUGITE-DIAGENOCASE PORPHYRY DIKES
(d) CIPW Normative Minerals (in weight percent¹)

NORMATIVE MINERALS	SPECIMENS				
	121-3	340-2	630-1	7050-5	698-2
qz	7.16				
or	18.85	21.69	2.36	21.40	10.34
ab	24.96	28.09	41.74	20.90	23.61
an	19.19	20.45	25.44	24.36	26.21
ne			1.45		
di	8.02	10.83	19.32	7.33	16.33
hy	14.89	0.01		11.20	4.39
ol		11.72	4.45	6.23	6.93
mt	4.14	4.21	1.68	5.92	9.34
il	1.54	1.82	1.65	1.86	2.26
ap	1.25	1.18	1.46	0.75	0.59
py			0.39		
Total	100.00	100.00	99.94	100.00	100.00

¹ Calculated volatile-free

TABLE III.12 CHEMICAL COMPOSITION OF SOME UPPER TRIASSIC STUHINI GROUP VOLCANICS

(a) Location and lithology of specimens

SPECIMEN	UNIT	LOCATION (Latitude and Longitude)	LITHOLOGY
604-1	Stuhini Group	58°03'00"N 129°54'30"W	slightly unalitized augite porphyry
7041-2	"	58°14'11"N 129°35'30"W	fine-grained, light grey andesite
704K-4	"	same as specimen 7041-2	fragment of bladed plagioclase porphyry in bimodal breccia conglom- erate
705C-1	"	58°13'39"N 129°33'00"W	augite porphyry
705I-8	"	same as specimen 705C-1	altered augite porphyry (pyroxenes highly altered)
705L-2	"	58°13'47"N 129°32'24"W	bladed plagioclase porphyry (flow)
707B-3	"	58°13'19"N 129°31'03"W	fine-grained augite porphyry matrix of volcanic breccia
707D-6	"	same as specimen 707B3	coarse-grained bladed plagioclase porphyry (flow)
711A-3	"	58°16'01"N 129°29'30"W	augite?-plagioclase porphyry
714H-2	"	58°14'52"N 129°45'00"W	augite porphyry (flow or sill)
632-1	"	58°12'30"N 129°56'00"W	schistose augite porphyry

TABLE III.12 CHEMICAL COMPOSITION OF SOME UPPER TRIASSIC STUHINI GROUP VOLCANICS (cont'd)

(a) Location and lithology of specimens

SPECIMEN	UNIT	LOCATION (Latitude and Longitude)	LITHOLOGY
714R-3	Stuhini Group	same as specimen 714H-2	augite porphyry (flow)

TABLE III.12 CHEMICAL COMPOSITION OF SOME OF THE UPPER TRIASSIC STUHINI GROUP VOLCANICS

(b) Major Elements (in weight per cent)

OXIDE	SPECIMENS						
	604-1	632-1	704I-2	704K-4	705C-1	705I-8	705L-2
SiO ₂	47.5	46.8	50.8	53.5	48.4	48.0	50.9
Al ₂ O ₃	11.0	10.5	16.0	17.1	16.6	15.1	16.8
TiO ₂	0.70	0.45	0.71	0.95	0.98	0.88	1.12
Fe ₂ O ₃	2.7	4.0	0.0	0.2	2.3	0.9	2.0
FeO	7.6	6.7	7.2	7.3	7.9	8.0	6.9
MnO	0.20	0.16	0.15	0.14	0.19	0.18	0.13
MgO	10.99	12.99	3.71	0.89	5.86	5.15	2.85
CaO	11.93	9.86	7.36	4.54	9.13	9.81	7.14
Na ₂ O	1.5	1.3	2.3	7.7	2.0	1.9	2.4
K ₂ O	2.16	3.20	2.82	0.48	1.22	1.96	3.46
P ₂ O ₅	0.48	0.41	0.26	0.56	0.22	0.31	0.49
H ₂ O _T	2.3	2.2	3.8	2.3	3.8	3.4	3.1
CO ₂	B.D.	0.8	4.6	2.8	1.8	3.7	2.8
S	B.D.	B.D.	0.03	0.02	B.D.	0.09	B.D.
Cl	N.A.	0.02	N.A.	N.A.	N.A.	N.A.	N.A.
F	N.A.	0.03	N.A.	N.A.	N.A.	N.A.	N.A.
Less O=S			0.01	0.01		0.02	
Total	99.06	99.42	99.73	98.47	100.40	99.36	100.09

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE III.12 CHEMICAL COMPOSITION OF SOME OF THE UPPER TRIASSIC STUHINI GROUP VOLCANICS (cont'd)

(b) Major Elements (in weight per cent)

OXIDE	SPECIMENS					AVERAGE (1σ)
	707B-3	707D-6	711A-3	714H-2	714R-3	
SiO ₂	50.1	51.6	51.2	49.4	49.4	49.8 (1.9)
Al ₂ O ₃	16.1	18.3	17.5	14.5	15.0	15.4 (2.4)
TiO ₂	0.87	1.09	0.90	0.86	0.80	0.86 (0.18)
Fe ₂ O ₃	2.9	1.1	4.8	1.8	1.0	2.2 (1.4)
FeO	4.7	6.8	5.1	8.3	8.3	7.1 (1.2)
MnO	0.15	0.17	0.16	0.22	0.20	0.17 (0.03)
MgO	2.85	2.50	5.76	7.50	6.85	5.66 (3.56)
CaO	8.11	6.26	5.65	9.03	9.89	8.23 (2.11)
Na ₂ O	3.3	2.0	4.0	2.5	2.5	2.8 (1.7)
K ₂ O	2.34	5.34	1.73	2.39	2.63	2.48 (1.22)
P ₂ O ₅	0.30	0.72	0.41	0.29	0.30	0.40 (0.15)
H ₂ O _T	3.7	2.5	3.0	3.4	2.9	
CO ₂	5.1	1.7	0.2	0.3	0.1	
S	B.D.	0.02	0.07	B.D.	B.D.	
Cl	N.A.	N.A.	N.A.	N.A.	N.A.	
F	N.A.	N.A.	N.A.	N.A.	N.A.	
Less O=S		0.01	0.02			
Total	100.52	100.09	100.46	100.49	99.87	(95.10)

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE III.12 CHEMICAL COMPOSITION OF SOME OF THE UPPER TRIASSIC STUHINI GROUP VOLCANICS

(c) Trace Elements (in ppm)

	SPECIMENS						
	604-1	632-1	7041-2	704K-4	705C-1	7051-8	705L-2
Rb	50	70	60	50	80	40	50
Sr	670	600	740	180	460	830	550
Ba	480	470	1300	110	600	1100	1600
U	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Zr	47	21	58	200	60	58	200
Cr	420	690	27	B.D.	39	28	11
Co	41	40	14	B.D.	27	19	17
Ni	92	190	70	B.D.	21	16	15
V	230	180	170	97	280	210	200
Cu	120	130	96	200	68	92	150
Zn	90	80	80	80	130	100	90

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide.

TABLE III.12 CHEMICAL COMPOSITION OF SOME OF THE UPPER TRIASSIC STUHINI GROUP VOLCANICS (cont'd)

(c) Trace Elements (in ppm)

	SPECIMENS					AVERAGE (1σ)
	707B-3	707D-6	711A-3	714H-2	714R-3	
Rb	70	120	70	70	40	60 (20)
Sr	390	760	830	900	1000	660 (240)
Ba	650	1400	800	900	960	860 (430)
U	N.A.	N.A.	N.A.	N.A.	N.A.	
Zr	51	220	63	67	60	92 (70)
Cr	B.D.	9	20	160	160	160 (230)
Co	10	B.D.	16	23	25	23 (10)
Ni	B.D.	B.D.	16	35	35	54 (57)
V	160	130	250	250	280	203 (58)
Cu	44	230	120	150	160	130 (53)
Zn	90	110	120	100	90	97 (16)

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE III.12 CHEMICAL COMPOSITION OF SOME OF THE UPPER TRIASSIC STUHINI GROUP VOLCANICS
(d) CIPW Normative Minerals (in weight percent¹)

NORMATIVE MINERALS	SPECIMENS						
	604-1	632-1	704I-2	704K-4	705C-1	705I-8	705L-2
qz			2.82		1.73	0.15	2.98
or	13.18	19.62	18.26	3.01	7.63	12.53	21.69
ab	12.78	9.02	21.32	61.00	17.85	17.43	21.57
an	17.48	13.88	27.37	11.43	34.50	29.13	26.40
ne	0.18.	1.30		4.76			
di	32.53	27.16	9.01	7.62	9.66	17.68	6.52.
hy			19.02		22.61	18.87	14.28
ol	17.27	21.11		8.48			
mt	4.04	6.01		0.30	3.52	1.42	3.07
il	1.36	0.89	1.48	1.94	1.96	1.80	2.26
ap	1.18	1.01	0.66	1.41	0.54	0.80	1.23
py			0.05	0.04		0.17	
Total	100.00	100.00	99.99	99.99	100.00	99.98	100.00

1. Calculated volatile-free

TABLE III.12 (cont'd)
(d) CIPW Normative Minerals (in weight percent¹) (cont'd)

NORMATIVE MINERALS	SPECIMENS				
	705B-3	707D-6	711A-3	714H-2	714R-3
qz	2.54	0.06	0.07		
or	15.07	32.91	10.52	14.60	16.02
ab	30.46	17.68	34.78	21.83	19.61
an	24.20	26.23	25.39	22.00	22.66
ne					1.20
di	14.32	1.06	0.55	18.24	21.32
hy	6.25	16.44	18.64	3.94	
ol				14.31	15.40
mt	4.58	1.66	7.15	2.69	1.49
il	1.81	2.16	1.76	1.69	1.57
ap	0.78	1.76	0.99	0.70	0.73
py		0.03	0.13		
Total	<u>100.00</u>	<u>99.99</u>	<u>99.98</u>	<u>100.00</u>	<u>100.00</u>

1. Calculated volatile-free

TABLE III.13 CHEMICAL COMPOSITION OF THE TRIASSIC-JURASSIC VOLCANICS

(a) Location and lithology of specimens

SPECIMEN	UNIT	LOCATION (Latitude and Longitude)	LITHOLOGY
715B-2	Triassic-Jurassic volcanics	58°10'08"N 129°15'45"W	grey, fine-grained andesite
715D-2	"	same as specimen 715B-2	purplish-grey, fine-grained andesite
715F-2	"	"	plagioclase porphyry
715H-4	"	"	magnetite-bearing, plagioclase porphyry
715I-2	"	"	purplish-grey plagioclase porphyry
715J-3	"	"	pink plagioclase porphyry
715K-2	"	"	green, augite? (chlorite) porphyry
715L-2	"	"	plagioclase porphyry
715P-2	"	"	plagioclase porphyry
715Q-3	"	"	plagioclase porphyry

TABLE III.13 CHEMICAL COMPOSITION OF THE TRIASSIC-JURASSIC VOLCANICS

(b) Major Elements (in weight per cent)

OXIDE	SPECIMENS										AVERAGE (1σ)
	715B-2	715D-2	715F-2	715H-4	715I-2	715J-3	715K-2	715L-3	715P-2	715Q-3	
SiO ₂	63.0	50.6	52.7	56.5	66.4	67.3	60.3	51.7	49.9	51.8	57.0 (6.7)
Al ₂ O ₃	17.1	17.7	17.8	18.5	15.8	15.8	15.9	19.0	19.3	18.9	17.6 (1.4)
TiO ₂	0.70	0.90	0.83	0.80	0.44	0.36	0.71	0.80	0.77	0.78	0.71 (0.17)
Fe ₂ O ₃	3.8	7.8	7.6	5.5	3.1	3.8	2.8	5.3	8.1	8.1	5.6 (2.2)
FeO	0.7	1.4	0.6	1.3	1.2	0.6	4.1	4.4	0.8	1.0	1.6 (1.4)
MnO	0.07	0.16	0.13	0.13	0.07	0.07	0.17	0.24	0.19	0.22	0.15 (0.06)
MgO	1.17	3.74	1.84	1.38	0.40	0.36	3.71	3.99	3.49	2.26	2.23 (1.41)
CaO	2.17	7.15	5.03	4.79	1.39	1.16	3.86	7.92	5.71	6.30	4.55 (2.37)
Na ₂ O	5.2	3.8	6.5	5.9	3.6	4.9	4.5	3.1	4.7	6.9	4.9 (1.2)
K ₂ O	2.98	1.90	2.55	3.14	5.80	5.09	0.63	1.52	2.80	0.56	2.70 (1.72)
P ₂ O ₅	0.27	0.38	0.47	0.56	0.07	0.08	0.15	0.19	0.24	0.17	0.26 (0.16)
H ₂ O _F	1.9	2.4	1.4	1.4	1.0	0.5	2.9	1.9	2.4	1.9	
CO ₂	0.9	2.6	2.3	0.1	0.8	0.7	0.8	0.5	2.2	1.7	
S	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	0.03	B.D.	B.D.	B.D.	
Cl	N.A.	N.A.	N.A.	N.A.	N.A.N	N.A.	N.A.	N.A.	N.A.	N.A.	
F	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	
Less O=S							0.01				
Total	99.96	100.53	99.75	100.00	100.07	100.72	100.55	100.56	100.60	100.59	(97.30)

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE III.13 CHEMICAL COMPOSITION OF THE TRIASSIC-JURASSIC VOLCANICS

(c) Trace Elements (in ppm)

	SPECIMENS										AVERAGE (1σ)
	715E-2	715D-2	715F-2	715H-4	715I-2	715J-3	715K-2	715L-3	715P-2	715Q-3	
Rb	70	40	40	50	170	160	150	50	40	40	80 (60)
Sr	470	930	720	690	160	68	570	730	670	610	560 (270)
Ba	880	910	1100	940	370	140	210	620	1400	150	670 (440)
U	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	
Zr	300	150	130	200	650	600	130	30	38	32	230 (230)
Cr	B.D.	11	B.D.	B.D.	B.D.	B.D.	15	8.8	B.D.	B.D.	12 (3)
Co	B.D.	13	B.D.	B.D.	B.D.	B.D.	13	22	13	13	15 (4)
Ni	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	11	B.D.	B.D.	B.D.	11
V	47	240	180	90	B.D.	B.D.	150	250	540	100	200 (160)
Cu	8.6	11	8.3	7.4	16	10	530	24	13	14	64 (164)
Zn	100	100	80	70	70	30	90	130	110	70	90 (30)

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE III.13 CHEMICAL COMPOSITION OF THE TRIASSIC-JURASSIC VOLCANICS

(d) CIPW Normative Minerals (in weight per cent¹)

NORMATIVE MINERALS	SPECIMENS										
	715B-2	715D-2	715F-2	715H-4	715I-2	715J-3	715K-2	715L-2	715P-2	715Q-3	
qz	16.19	3.11		0.59	20.26	16.63	16.85	5.26			
or	18.15	11.76	15.66	18.85	34.87	30.20	3.84	9.19	17.25	3.43	
ab	45.27	33.67	46.83	50.68	30.97	41.63	39.34	26.73	36.96	51.25	
an	9.23	26.82	12.35	14.94	6.54	5.28	18.82	34.07	24.23	19.56	
ne			5.66						2.43	4.82	
c	2.09				1.28	0.32	1.17				
di		5.97	8.09	4.24				3.77	2.84	8.96	
hy	2.99	6.99		1.52	1.02	0.90	13.98	11.18			
ol			0.72						5.43	1.15	
mt	0.46	2.57		2.33	2.86	1.12	4.19	7.82	0.98	1.75	
hm	3.59	6.39	7.91	3.97	1.18	3.05			7.76	7.14	
il	1.37	1.78	1.60	1.54	0.85	0.68	1.39	1.54	1.53	1.52	
pf			0.02								
ap	0.66	0.94	1.16	1.34	0.17	0.19	0.35	0.44	0.59	0.42	
py							0.06				
Total	100.00	100.00	100.00	100.00	100.00	100.00	99.99	100.00	100.00	100.00	

1. Calculated volatile-free

TABLE III.14 CHEMICAL COMPOSITION OF MISCELLANEOUS DIKES

(a) Location and lithology of specimens

SPECIMEN	UNIT	LOCATION (Latitude and Longitude)	LITHOLOGY
60-2	miscellaneous dikes	58°08'02"N 129°22'53"W	fine-grained light grey andesite? (intrudes Three Sisters Pluton, central phase)
664-2	"	58°05'32"N 129°27'15"W	greenish-grey andesite (intrudes Three Sisters Pluton, central phase)
683-3	"	58°05'41"N 129°23'45"W	same as specimen 665-2

TABLE III.14 CHEMICAL COMPOSITION OF MISCELLANEOUS DIKES
(b) Major Elements (in weight per cent)

OXIDE	SPECIMENS	
	60-2	683-3
SiO ₂	59.1	53.3
Al ₂ O ₃	15.6	17.5
TiO ₂	1.07	0.84
Fe ₂ O ₃	2.5	3.0
FeO	5.0	4.3
MnO	0.15	0.21
MgO	1.78	3.64
CaO	3.53	6.59
Na ₂ O	3.8	3.7
K ₂ O	4.56	2.13
P ₂ O ₅	0.71	0.32
H ₂ O _T	0.8	3.2
CO ₂	B.D.	1.0
S	B.D.	B.D.
Cl	0.08	N.A.
F	0.09	N.A.
Total	99.77	99.67
		99.98

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE III.14 CHEMICAL COMPOSITION OF MISCELLANEOUS DIKES
(c) Trace Elements (in ppm)

	SPECIMENS		
	60-2	664-2	683-3
Rb	150	40	60
Sr	340	1100	390
Ba	1300	1400	340
U	3.8	N.A. ✓	N.A.
Zr	210	95	44
Cr	B.D.	10	60
Co	18	14	29
Ni	B.D.	12	21
V	86	190	290
Cu	39	77	120
Zn	120	100	140

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE III.14 CHEMICAL COMPOSITION OF MISCELLANEOUS DIKES
(d) CIPW Normative Minerals (in weight percent¹)

NORMATIVE MINERALS	SPECIMENS		
	60-2	664-2	683-3
qz	9.14	4.46	
or	27.54	13.18	4.02
ab	32.91	32.83	35.19
an	12.30	26.01	25.90
di	0.70	4.84	10.40
hy	9.92	11.66	0.14
ol			13.89
mt	3.71	4.55	8.15
il	2.06	1.67	1.65
ap	1.72	0.80	0.66
Total	100.00	100.00	100.00

1. Calculated volatile-free

Figure 34. Chemical variation diagrams for samples from the Mesozoic volcanics and dikes.

- a) Weight per cent alkali-silica diagram. Alkaline-subalkaline division after Irvine and Baragar (1971).
- b) Weight per cent, normative ne'-ol'-qz' ternary diagram (ne' = ne + 3/5 ab; qz' = qz + 2/5 ab + 1/4 opx; ol' = ol + 3/4 opx). Alkaline-subalkaline division after Irvine and Baragar (1971).
- c) Weight per cent A ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) - F ($\text{FeO} + 0.8998 \text{Fe}_2\text{O}_3 - \text{M}(\text{MgO})$) ternary diagram. Calc-alkaline - tholeiitic division after Irvine and Baragar (1971).
- d) Weight per cent SiO_2 - FeO^*/MgO diagram ($\text{FeO}^* = \text{FeO} + 0.9 \text{Fe}_2\text{O}_3$). Calc-alkaline - tholeiitic division after Miyashiro (1974).
- e) Weight per cent MgO - total iron diagram. Cascades, abyssal tholeiite (AT), pigeonitic series and Thingmuli trends after Stauffer et al. (1975).
- f) Weight per cent alumina-normative plagioclase diagram. Calc-alkaline - tholeiitic division after Irvine and Baragar (1971).
- g) Weight per cent $\text{Na}_2\text{O} - \text{K}_2\text{O} - \text{CaO}$ ternary diagram.

Symbols for the individual units are as follows:

Pyroxene porphyry dikes: ○ grab samples; ◇ K-Ar sample.
Filled symbol is nepheline-normative sample.

Stuhini Group volcanics: □ grab sample from isolated outcrop;
○ grab samples from measured sections; ○ schistose pyroxene porphyry schist. Filled symbols are nepheline-normative samples.

Triassic-Jurassic volcanics: △ grab samples from "first cycle";
○ grab samples from "second cycle". Numbers increase with increasing stratigraphic height. Filled symbols are nepheline-normative samples.

Miscellaneous dikes: □ light grey andesite; ○ greenish grey andesite.

All compositions calculated volatile-free.

a) Alkali-silica diagram

b) $Ne'-ol'-qz'$ ternary diagram

b) Ne'-ol'-qz' ternary (continued)

c) AFM ternary

TRIASSIC-JURASSIC VOLCANICS

"First Cycle"

"Second Cycle"

c) AFM ternary (continued)

c) AFM ternary (continued)

d) Silica-FeO*/MgO diagram

d) Silica-FeO*/MgO diagram (continued)

e) MgO - total iron diagram

e) MgO - total iron diagram (continued)

STUHINGI GROUP VOLCANICS

PYROXENE PORPHYRY DYKES

f) Alumina-normative plagioclase composition diagram

TRIASSIC-JURASSIC VOLCANICS MISCELLANEOUS DYKES

f) Alumina-normative plagioclase composition diagram (continued)

K₂O

CaO

STUHINI GROUP VOLCANICSCaO Na₂Og) Na₂O - K₂O - CaO ternaryK₂OPYROXENE PORPHYRY DYKES121-28
340-2

●

◊

g) $Na_2O - K_2O - CaO$ ternary (continued)

PYROXENE PORPHYRY DYKES

h) Normative colour index - normative plagioclase composition diagram

STUHINI GROUP VOLCANICS

h) Normative colour index - normative plagioclase composition diagram (continued)

TRIASSIC-JURASSIC VOLCANICS

Normative Plagioclase Composition (An weight %)

h) Normative colour index-
normative plagioclase
composition diagram
(continued)

MISCELLANEOUS DYKES

Normative Plagioclase Composition (An weight %)

h) Normative colour index - normative plagioclase composition diagram (continued)

4

alkaline. The alumina-normative plagioclase plot also emphasizes the range in Al_2O_3 content of the dikes (commonly 15-17 weight per cent). In the $\text{FeO}^*-\text{FeO}^*/\text{MgO}$ plot (not shown; after Miyashiro, 1974), $\text{SiO}_2-\text{FeO}^*/\text{MgO}$ (Figure 34 (d); after Miyashiro, 1974) and MgO -total iron (Figure 34 (e); after Lowder and Carmichael, 1970; Stauffer *et al.*, 1975) plots, mixed calc-alkaline and tholeiitic characteristics are observed for the suite and are fairly consistent for each sample among the latter three plots. This mixed subalkaline-alkaline and tholeiitic-calc-alkaline classification for this unit is similar to that seen in members of the Triassic plutonic suite (including the Gnat Lakes Ultramafite and Beggerlay Creek Pluton). On the weight per cent $\text{Na}_2\text{O}-\text{CaO}-\text{K}_2\text{O}$ ternary plot (Figure 34 (g)), the porphyry dikes are characterized by relative CaO -enrichment and variable $\text{Na}_2\text{O}(\text{Na}_2\text{O}+\text{K}_2\text{O})$ ratios. Subalkaline samples belong to the K-rich series of Irvine and Baragar (1971) and are basalts according to their classification (Figure 34 (h)). The single alkaline sample belongs to their sodic series and is a hawaiite (Figure 34 (h)). The average composition for the porphyry dikes given in Table III.11 has similarities to both the average basalt and hawaiite compiled by Le Maitre (1976) differing mainly in its lower TiO_2 content. It also has some similarities with the average "central" basalt of Nockolds (1954).

The Upper Triassic Stuhini Group is represented by twelve samples of aphanitic and porphyritic flows and minor volcaniclastics collected from scattered outcrops and measured sections.

Their major, minor and trace element compositions and (volatile-free) CIPW norms are given in Table III.12 and Figure 34.

The samples are predominantly diopside-, quartz- and hypersthene-normative; however four samples contain normative nepheline and five samples are olivine-normative. The Stuhini Group flows and volcanoclastics straddle the alkaline-subalkaline boundary of Irvine and Baragar (1971) in the alkali-silica plot (Figure 34 (a)); three of the five samples classified as alkaline in this plot contain normative nepheline. All nepheline-normative samples are classified as alkaline on the $ne'-ol'-qz'$ ternary plot (Figure 34(b)) of Irvine and Baragar (1971). In AFM ternary (Figure 34(c); after Irvine and Baragar, 1971), SiO_2-FeO^*/MgO (Figure 34(d); after Miyashiro, 1974), FeO^*-FeO^*/MgO (not shown; after Miyashiro, 1974), MgO -total iron (Figure 34(e); after Lowder and Carmichael, 1970; Stauffer et al., 1975) and alumina-normative plagioclase (Figure 34(f); after Irvine and Baragar, 1971) plots, the subalkaline Stuhini Group flows have calc-alkaline and tholeiitic affinities which are not always consistent among classification schemes for a given sample. Equivocal classification of these rocks is common to the porphyry dikes and mafic plutons or phases of the Triassic and Jurassic plutonic suites. The flows are relatively CaO -rich compared to Na_2O and K_2O in the weight per cent Na_2O-K_2O-CaO plot (Figure 34(g)) and have variable $Na_2O/(Na_2O + K_2O)$ ratios. According to the classification of Irvine and Baragar (1971), the subalkaline flows and volcanoclastics belong to the "average" and K-rich series and are

predominantly basalt (Figure 34 (h)). One of the four alkaline samples belongs to the sodic series and is a mugearite; the other three samples belong to the potassic series and are ankaramite or alkali basalt (Figure 34 (h)). The average composition of the Stuhini Group rocks (see Table III.12) compares closely with the average basalt of Le Maitre (1976) except for slightly higher K_2O and slightly lower TiO_2 , Fe_2O_3 , MgO and CaO contents. The average basalt compositions compiled by Nockolds (1954) are dissimilar to the average composition of the Stuhini Group flows and volcanoclastics.

Unlike the Triassic-Jurassic volcanics, no consistent geochemical trend with stratigraphic height was detected. In two sections (704 and 714), the nepheline-normative, alkaline sample was the stratigraphically higher of the two samples collected in each section. The nepheline-normative, alkaline samples occur most commonly along the western margin of the batholith.

The Triassic-Jurassic volcanics are distinguished by two partially defined mafic to felsic geochemical cycles consistent with the stratigraphy of the flows. Major, minor and trace element compositions and (volatile-free) CIPW norms are compiled in Table III.13 and plotted in Figures 34 and 35.

Normative quartz or olivine, nepheline or hypersthene, and diopside or corundum contents vary with stratigraphic height. Quartz, hypersthene and corundum are increasingly abundant with stratigraphic height in each "cycle" whereas normative olivine,

Figure 35. Variation of chemical composition with stratigraphic height in the Triassic-Jurassic volcanics, Section 715. Symbols given below are identical to those used in Table III.9. Major and minor oxide compositions are corrected for volatile content (see Table III.13). Figure located in pocket.

LEGEND

massive amygdaloidal andesite

completely chloritized pyroxene(?) porphyry

maroon to grey, medium-grained feldspar (plagioclase or alkali feldspar) porphyry

lithic crystal tuff and tuffaceous greywacke

massive fine-grained andesite

volcanic breccia: heterolithic grey to maroon plagioclase porphyry fragments in a maroon fine-grained groundmass

volcanic conglomerate: heterolithic, grey to maroon, locally vesicular or amygdaloidal plagioclase porphyry fragments in a maroon fine-grained groundmass.

alternating siltstone or shale and sandstone

----- gradational contact

715H-4

3

left hand label: sample number; right hand number is that used in chemical variation diagrams

massive

medium bedded

laminated

nepheline and diopside are more abundant at the base of each "cycle" (see Table III.13). Normative hematite is distinctive of the Triassic-Jurassic volcanics and accords their rusty maroon weathering colour. One nepheline-normative flow contains a very small amount of normative-perovskite (pf symbol in Table III.13). These changes in normative mineralogy correspond to sympathetic increases in SiO_2 , K_2O , Rb and Zr and decreases in Al_2O_3 , TiO_2 , Fe_2O_3 , MnO, MgO, CaO, Sr, Ba, V and Zn in each "cycle" (see Figure 35). Behavior of FeO, Na_2O and Cu is erratic in each "cycle". The first "cycle" may include the top part of an earlier, incompletely exposed cycle. The geochemical trends in the second "cycle" are not as well developed as in the first "cycle". The stratigraphic and geochemical "break" between "cycles" apparently occurs within or slightly above the mafic flow(s) of unit K. There is no evidence for a major eruptive hiatus and the apparent femic to salic character of the "cycles" may represent a similar cyclic evolution and tapping of magma chamber(s) supplying the flows. If true, it would be characteristic of this period of volcanism.

Changes in the normative mineralogy with stratigraphic height in each "cycle" corresponds to a similar change from alkaline to subalkaline chemical affinity of the flows (see Figure 34 (a) and (b); classification after Irvine and Baragar (1971)). According to their classification in the AFM (Figure 34 (c)) and alumina-normative plagioclase (Figure 34 (f)) plots, the subalkaline samples are calc-alkaline. On the AFM

diagram in particular, subalkaline and alkaline samples define typical calc-alkaline, alkali-enrichment trends for each "cycle". The alumina-normative plagioclase plot also emphasizes the wide range in Al_2O_3 content (16-18 weight per cent, calculated volatile-free). In the SiO_2 - FeO^*/MgO plot (Figure 34 (d); after Miyashiro, 1974), the increasing SiO_2 and FeO^*/MgO ratio with stratigraphic height is apparent; it is uncertain if the resultant tholeiitic classification has any significance. In the MgO -total iron plot (Figure 34 (e); after Lowder and Carmichael, 1970; Stauffer et al., 1975), the first "cycle" compositions partly mimic the iron-enrichment trend of the classic Japanese pigeonitic (tholeiitic) series compiled by these authors. This tholeiitic affinity is less well-developed in the second "cycle". The first "cycle" flows crudely define a relative K_2O -enrichment, CaO -depletion trend with stratigraphic height in a weight per cent Na_2O - K_2O - CaO plot (Figure 34 (g)); again the trends for the second "cycle" in this plot are more erratic. The Triassic-Jurassic volcanics in section 715 are distinguished by two mafic to felsic lithological and geochemical "cycles" of volcanism which correspond to changes from alkaline affinities to or towards subalkaline chemistry with time in each cycle. As with the Stuhini Group volcanics and some plutons in the plutonic suites, mixed calc-alkaline and tholeiitic affinities characterize these volcanics as well.

Subalkaline flows in the Triassic-Jurassic volcanics belong to the "average" or K-rich series of Irvine and Baragar (1971) and include basalt, andesite, dacite and rhyolite (Figure 34 (h)).

Alkaline flows represent the sodic and potassic series of their classification and include trachybasalt, mugearite, and tristanite (Figure 34 (h)).

The average composition of the Triassic-Jurassic volcanics, given in Table III.13, compares closely with the average andesite of Le Maitre (1976; especially within the broad standard deviation of the mean) except for lower FeO and higher Fe_2O_3 and Na_2O . The average composition most closely matches the average latite or larvikite of Nockolds (1954) but large discrepancies in TiO_2 , Fe_2O_3 , FeO, MgO, Na_2O , K_2O and P_2O_5 exist.

Three samples were collected from dikes which intrude the Three Sisters Pluton: two samples of greenish-grey dikes, which typically occur in that pluton; and one sample of a grey, aphanitic dike which was suspected to be representative of the fine-grained phase but is petrographically and geochemically distinct from it. Major, minor and trace element compositions and (volatile-free) CIPW norms for the dikes are given in Table III.14.

The dikes have dissimilar compositions but all are hypersthene- and diopside-normative. Two dikes are quartz-normative; the other is olivine-normative. The compositions lie in the alkaline and subalkaline fields of an alkali-silica plot (Figure 34 (a)) close to the boundary established by Irvine and Baragar (1971). On the ne'-ol'-qz' ternary plot (Figure 34 (b)), all dikes are subalkaline although one dike composition lies on the boundary between the two fields (after Irvine and Baragar, 1971). The AFM ternary (Figure 34(c); after Irvine and Baragar, 1971); SiO_2 -FeO*/MgO (Figure 34(d); after Miyashiro, 1974);

MgO-total iron (Figure 34 (e); after Lowder and Carmichael, 1970; Stauffer et al., 1975) and alumina-normative plagioclase Figure 34 (f); after Irvine and Baragar, 1971) plots show the dike compositions to be predominantly calc-alkaline with minor tholeiitic affinities. The variable Al_2O_3 content (16-19 weight per cent, calculated volatile-free) of the dikes is also emphasized in the alumina-normative plagioclase plot. In the weight per cent $\text{Na}_2\text{O}-\text{K}_2\text{O}-\text{CaO}$ ternary plot (Figure 34 (g)), the dike compositions are characterized by constant Na_2O_3 content relative to the variable K_2O and CaO_2 contents. According to the classification of Irvine and Baragar (1971), the dikes compositions belong to the "average" series and are basalt or andesite (Figure 34 (h)). Owing to the diverse compositions represented, no average composition for the dikes was calculated.

Geochemical comparisons between the Mesozoic volcanic units and the plutonic suites are made in Chapter VI. Data is presented in that chapter which further suggest a possible cogenetic link among the Gnat Lakes Ultramafite (and possibly the Beggerlay Creek Pluton), the porphyry dikes and the porphyritic volcanics of the Stuhini Group. Harker variation diagrams for the augite-plagioclase dikes, Stuhini Group flows and volcanics, Triassic-Jurassic volcanics and miscellaneous dikes are given in Appendix 5.3.

PLATE V: DISTRIBUTION, LITHOLOGIES AND STRUCTURAL CHARACTERISTICS OF THE UPPER
TRIASSIC STUHINI GROUP, TRIASSIC-JURASSIC VOLCANIC UNIT AND MEMBERS OF
THE JURASSIC PLUTONIC SUITE

Plate V A: Pillowed, bladed plagioclase porphyry flows near the top of section 707. Jacob's staff is 1.5 m long (slide 8-79-37).

Plate V B: Interstitial fillings of bladed (locally trachytoid) plagioclase porphyry and later, fine-grained massive basalt between bladed plagioclase porphyry pillows. Hammer is about 35 cm long (top of section 707; slide 8-79-36).

Plate V C: Pillow lava fragments in normally graded turbiditic greywacke unit stratigraphically above pillow lavas in Plate V B and immediately to the north, laterally equivalent to the pillow lavas (top of section 707; slide 8-79-40).

Plate V D: Thrust fault contact between overthrust, dark, fracture-cleaved shales of Toarcian unit (bottom; 1Js) and structurally overlying volcanic conglomerate of Upper Triassic Stuhini Group (top; uT st). Jacob's staff (see black arrow in uT st unit) is 1.5 m long (section 707; slide 8-79-23).

Plate V E: Aerial view of section 715 (see Plate V F) and extent of Upper Triassic Stuhini Group (uT st), Triassic-Jurassic volcanic unit (partly in shadow; T Jv) and Three Sisters Pluton along north-eastern margin of the Hotailuh Batholith (slide 5-77-36).

Plate V F: Location of part of section 715 (dotted line is traverse line used in measurement of section) in Triassic-Jurassic volcanic unit. Differential weathering of individual(?) plagioclase porphyry flows is visible (slide 10-79-4).

Plate V G: View west across McBride River to western and approximate northern contacts of the McBride River Pluton (M.R.P.), Upper Triassic Stuhini Group (uT st) and Three Sisters Pluton (T.S.P.; slide 7-77-29).

Plate V H: Seriate, acicular hornblende diorite of the Three Sisters Pluton, mafic phase. Hammer handle is about 30 cm long (station 98; slide 4-79-16). This lithology is closely similar to the hornblende tonalite porphyry of Tabor and Crowder (1974, Figure 13).

Plate V I: Equant hornblende porphyry diorite of the Three Sisters Pluton, mafic phase. Seriate texture of this variety of the mafic phase imparts a distinctive "spotted" or "salt-and-pepper" weathering appearance to the rock. Black bar on pencil is about 5 cm long (station 336; slide 8-78-10).

IV. GEOLOGY OF THE JURASSIC PLUTONIC SUITE

IV.1 INTRODUCTION AND SUMMARY

The Jurassic plutonic suite outcrops mainly in the eastern half of the Hotailuh Batholith and is inferred from its aeromagnetic expression and detailed mapping to connect with outcrops in the northwestern part of the batholith via a thin, northwest-trending apophysis (Figure 1).

Satellititic plutons occur to the north and west of the batholith (Figures 49, 54, 59). Part of the eastern Jurassic plutonic suite underlies the most rugged terrain in the batholith; however the McBride River Pluton in the east and the satellitic plutons and western exposures of the Three Sisters Pluton underlie valleys and are barely unroofed. Three Sisters, Pallen Creek and Tanzilla Plutons are distinguished by positive absolute total aeromagnetic field anomalies compared to the Triassic plutonic and volcanic units; the McBride River and parts of the Snowdrift Creek Plutons have low absolute total aeromagnetic fields (Figure 2).

Batholithic Jurassic plutons comprise the Three Sisters and McBride River Plutons. Snowdrift Creek, Pallen Creek and Tanzilla Plutons are the satellitic plutons studied in the Jurassic plutonic suite. Together, they represent two main lithological suites: a homogeneous, sparsely inclusion-bearing, hornblende-biotite granodiorite (McBride River and part of the Snowdrift Creek Plutons); and a heterogeneous, compositionally expanded diorite-quartz monzodiorite or granodiorite to quartz monzonite-quartz syenite suite containing hornblende, biotite, and common mafic inclusions (Three Sisters, Pallen Creek, Tanzilla and part of the Snowdrift Creek Pluton). Scattered, faintly to moderately foliated outcrops occur in most plutons but there is no consistent structural grain and foliation in

a few places is outlined by oblate mafic inclusions in a massive host.

The Triassic plutonic suite formed part of the country rock for the emplacement of the Jurassic plutonic suite and in part, was remobilized and metamorphosed as a result.

The Jurassic plutonic suite intruded, included and(or) metamorphosed units in the Mesozoic volcanics and sediments. Upper Triassic Stuhini Group rocks are intruded by all plutons in the suite; the Triassic or older(?) silicic tuff occurs as inclusions in the potassic marginal phase of the Three Sisters Pluton. Toarcian sediments were metamorphosed during intrusion of the Three Sisters Pluton. Pliensbachian sediments and structures related to early movements on the King Salmon Fault are intruded by the Snowdrift Creek Pluton. The relationship between the Triassic-Jurassic volcanics and the Jurassic plutonic suite is poorly known.

Intrusive relations involving the Three Sisters and McBride River Plutons were not established. Intrapluton intrusive relations in the Three Sisters Pluton indicate a general mafic to felsic, radially east-to southeastward emplacement of four of the five phases which make up the eastern exposures of the Three Sisters Pluton. This might suggest that the McBride River Pluton, farther east yet, represents the last magma to be intruded. Similar mafic to felsic intrapluton intrusive relations characterize other composite plutons in the Jurassic plutonic suite.

K-Ar isotopic ages are generally consistent with the stratigraphic constraint on the oldest age of intrusion (metamorphism of the Toarcian sediments; post-188 Ma according to the timescale of Armstrong (1978, 1981)) but range from 142-208 Ma. Intrusion of most of the Jurassic plutonic suite is considered to have occurred between 180-188 Ma (see also Chapter V) but there is no stratigraphic constraint on the youngest age of the suite and

an intrusive event around 150 Ma (Snowdrift Creek Pluton?) cannot be ruled out.

Subhedral to euhedral clinopyroxene, plagioclase, hornblende, biotite and magnetite and the accessory minerals allanite, zircon, titanite and apatite are distinctive of part or all of the Jurassic plutonic suite. Alkali feldspar and quartz are interstitial to the other minerals. The fine-grained, mafic, central and rarely, potassic marginal phases of the Three Sisters Pluton can be related petrographically by common clinopyroxene cores in hornblende and irregular, fractured, more calcic plagioclase cores. Petrography of the fine-grained phase is closely similar with that of mafic inclusions in the Three Sisters Pluton, and combined with inter-phase intrusive relations and geochemical data presented in this chapter and in Chapter VI suggest that at least some of the mafic inclusions could have been derived from the fine-grained phase which was initially emplaced and later disrupted by sequential intrusion of the mafic and central phases of the Three Sisters Pluton.

Subalkaline chemical affinities predominate for the Jurassic plutonic suite. There is a consistent change in composition from tholeiitic affinities in the mafic phases to calc-alkaline affinities in the more felsic phases although those classifications are plot dependent. The homogeneous, siliceous granodioritic compositions are distinguished by small normative corundum contents.

The Jurassic plutonic suite is distinguished by: finer grain size; overall massive fabric; composite nature of most plutons; lack of ultramafic compositions; relative abundance of mafic inclusions; common biotite as an early-formed mineral as well as clinopyroxene cores in hornblende and irregular calcic plagioclase cores; predominance of subalkaline compositions;

intrusive relationship with the Mesozoic volcanics and sediments; and isotopic age from the Triassic plutonic suite.

Many of the field aspects (e.g., expanded compositional suite) and mineralogical characteristics (e.g., apatite habit, clinopyroxene cores in hornblende, calcic cores in plagioclase, biotite habit and pleochroism) of the Jurassic plutonic suite are identical to I-type plutons in southeastern Australia described by White and Chappell (1977), Chappell (1978), Griffin et al. (1978) and Hine et al. (1978).

IV.2 THREE SISTERS PLUTON

IV.2.1 Distribution, Physiography and Magnetic Expression

Outcrops of the composite Three Sisters Pluton underlie the eastern and western parts of the Hotailuh Batholith and compose almost one-third of it (Figure 1, 36). The main masses of the pluton in the east and west are connected by a narrow (1.5-3 km wide) easterly-trending apophysis which bisects the Cake Hill Pluton. The distribution of various phases in the eastern part of the pluton, with the exception of the fine-grained phase, mirrors their overall intrusive chronology, i.e. the older mafic phase, closest to the Cake Hill Pluton is followed outwards by the successively younger central, potassic marginal and leucocratic phases. The potassic marginal phase predominates in the western part of the pluton with minor outcrops of the central, mafic and leucocratic phases; the central phase and subordinate potassic marginal, leucocratic, mafic and fine-grained phases make up the eastern intrusion. The area of each constituent phase relative to the total area of the pluton given in Table IV.2.1 is a minimum, because almost all phases occur as irregular agmatitic masses or apophyses within and at the contacts with adjacent phases and the area of these bodies is difficult to calculate. Nevertheless the contribution of these outcrops to the area, compared to the main mappable masses of each phase, is probably less than one or two per cent of the total area of the Three Sisters Pluton.

Figure 36. Location of the Three Sisters Pluton (bold outline) in the Hotailuh Batholith and of some stations and samples discussed in text (see Figure 1 also).

TABLE IV.2.1 PER CENT AREAS OF PHASES IN THE THREE SISTERS PLUTON

COMPARED WITH OTHER BATHOLITHS

BATHOLITH OR PLUTON

mafic rocks

intermediate rocks

felsic rocks

Hotaluh Batholith,
Three Sisters Pluton
(total pluton area = 327.0 km²)

3%	52%	45%
(fine-grained phase (12.5 km ²) + mafic phase (5.4 km ²))	(central phase (171.2 km ²))	(potassic marginal phase (135.1 km ²) + leucocratic phase (12.9 km ²))

Coastal Batholith;
central Peruvian portion
(Pitcher 1978, p. 167)

16%¹58%²26%³

Southern California Batholith
(Larsen, 1948, Table 26,
Column 2)

7%¹91%²2%³

Compilation of I-type
or Andinotype batholiths
(Pitcher, 1979a, p. 651)

15%¹50%²35%³

1. diorite, gabbro

2. granodiorite, tonalite

3. monzogranite, syenogranite, granite

In its eastern part, the Three Sisters Pluton underlies the most rugged topography in the batholith; subdued topography characterizes much of the western part where it commonly outcrops along the valley floors. In the eastern part of the pluton, the central and fine-grained phases underlie the most rugged topography, the mafic and potassic marginal phases variably rugged and rounded ridges, and the leucocratic phase the most subdued relief. The pluton takes its name from the Three Sisters Range (the "Three Sisters" probably refer to peak 7174 feet and the two peaks immediately south of it, also more the 6500 feet high (see frontispiece)).

Aeromagnetic highs (up to 59340 gammas from a minimum of about 58060 gammas) characterize the Three Sisters Pluton and provide a useful aid for mapping in areas of poor exposure (Geological Survey of Canada, 1978a, b; Figure 2). For example, the thin apophysis which bisects the Cake Hill Pluton and forms the western part of the Three Sisters Pluton is part of a northwest-trending aeromagnetic high that continues past Thenatlodi Mountain to Hluey Lakes in the Dease Lake map-area where other Jurassic plutons crop out (Gabrielse, 1978b). This aeromagnetic high is interpreted to represent the near surface, northwest-trending extension of the Three Sisters Pluton in the covered areas since it has characteristic low topographic expression. Although the aeromagnetic highs are more common in the central phase, the aeromagnetic data generally cannot resolve the distribution of the phases of the Three Sisters Pluton.

IV.2.2 Lithology

The Three Sisters Pluton is the most lithologically heterogeneous of all the plutons recognized in the Hotailuh Batholith. Nevertheless, various lithological, mineralogical and textural features as well as the variable abundance of inclusions distinguish the constituent phases.

The fine-grained phase is the most homogeneous. Dark grey to white weathering, equigranular, fine- to medium-grained, massive, hypidiomorphic and devoid of inclusions, it is easily distinguished from all other phases in the Three Sisters Pluton but is lithologically similar to the common inclusions in the central phase (Plate VI D). Locally in the connecting apophysis between the eastern and western parts of the Three Sisters Pluton (e.g. stations 551 and 555), acicular hornblendes and small inclusions are common in the interiors of fine-grained dioritic dikes and apophyses. Characteristic fine grain size renders modal estimates of stained specimens difficult (Figure 37) but commonly the fine-grained phase is dioritic; less commonly monzodioritic. Hornblende is commonly the only recognizable mafic but biotite also occurs in scattered outcrops. Medium-grained plagioclase phenocrysts are rare.

The mafic phase is mineralogically simple but texturally very heterogeneous. Acicular hornblende diorite (Plate V H), equant hornblende porphyry diorite (Plate V I) and equigranular hornblende gabbro are distinguished (Figure 37). They form roughly equal areas of the main outcrops of the mafic

Figure 37. Modal compositions of hand samples and thin sections from phases in the Three Sisters Pluton (see Appendix 6.5). Classification after Streckeisen (1973). Abbreviations are: KF = alkali feldspar; PF = plagioclase; and Qz = quartz.

Figure 37 (continued)

phase and of outlying apophyses or agmatites. Where best exposed, the lithologies are clearly gradational and no intrusive relations amongst them are detected. Alternations of the characteristic lithologies crudely define a northwest-trending layering. The mafic phase is light grey weathering, medium-grained to coarse-grained, seriate (especially the acicular hornblende diorite) to porphyritic (the equant hornblende porphyry diorite) and hypidiomorphic. Diorite or gabbro predominate; monzodiorite is less common (Figure 37). Hornblende is the predominant mafic and is characteristically euhedral or subhedral; biotite is rarely developed except locally near the contacts with the potassic marginal phase or near station 523. Subhedral plagioclase is the predominant felsic mineral; anhedral alkali feldspar and quartz are rare. A mineral foliation is rarely developed (Appendix 6.2). Small, randomly oriented, inclusions are less common in the mafic phase than in the central phase and are generally fine-grained diorite. They commonly compose 2-7 per cent and as much as 30-40 per cent of the outcrop. At some locations, acicular hornblende diorite inclusions which exhibit fine-grained (chilled?) rims (Plate VI C) and interesting graded, cumulate layered hornblende diorite inclusions also occur in acicular hornblende diorite (Plate VI A, B). In the western part of the Three Sisters Pluton (station 572), hornblende gabbro contains rare metavolcanic (augite porphyry?) inclusions.

The central phase is mineralogically more complex but

equally texturally heterogeneous as the mafic phase. Its name derives from its central position in the Three Sisters Pluton. Monzodiorite, quartz monzodiorite, monzonite and quartz monzonite are most common although more alkali-feldspar-rich compositions occur, commonly close to potassic marginal phase apophyses (Figure 37). The rock is light grey to white weathering, commonly massive, equigranular to seriate, fine- to medium-grained to medium-grained and hypidiomorphic. Mineralogical and textural characteristics include: anhedral to subhedral hornblende; fresh, euhedral biotite; poikilitic alkali feldspar; and accessory anhedral to subhedral titanite and magnetite. Absolute mafic abundance and hornblende-biotite ratios vary moderately to considerably throughout the phase. A distinctive granitic biotite porphyry occurs in several places (stations 154, 497, 576, 654, 655, 668, 669, 672, 674, 676, 677, 678, 680 and 686) but its significance in the central and southeastern parts of the central phase is poorly understood. Contrasting textures in the "typical" and biotite porphyry central phase emphasize their gradational to rarely intrusive (biotite porphyry intrudes equigranular monzodiorite) contacts. The presence of small, generally rounded, randomly oriented, fine-grained diorite to monzodiorite inclusions is also characteristic of the central phase (Appendix 6.1, Plate VI D). Locally, outcrops are agmatitic (Appendix 6.1 and 6.3) and may grade into stockworks where the typical central phase monzodiorite apophyses invade

the fine-grained diorite. Augite porphyry and coarse-grained hornblende inclusions are present but rare. The finer grain size of the rock, its common massive texture, greater mafic content and presence of anhedral to subhedral hornblende, fresh euhedral biotite and the ubiquitous small fine-grained diorite inclusions in the monzodiorite of the Three Sisters Pluton's central distinguish it from the Cake Hill Pluton monzodiorite.

The potassic marginal phase occurs in a number of large mappable masses in the western, southern and eastern parts of the Three Sisters Pluton and, like other phases, also as small irregular masses and thin apophyses in earlier emplaced units. Its alkali feldspar-rich composition and distribution about the margins of the Three Sisters Pluton lead to its name. Less heterogeneous than the mafic and central phases, the potassic marginal phase is sufficiently variable in quartz and alkali feldspar content to encompass monzonite, quartz monzonite, syenite, quartz syenite and granite (Figure 37). Aplites are commonly alkali-feldspar quartz syenites and alkali-feldspar granites. The potassic marginal phase is pink weathering, massive, commonly inclusion-free, equigranular, medium-grained, and hypidiomorphic. The alkali feldspar is generally pink- to brick red-weathering and subhedral to euhedral. Subhedral, white plagioclase contrast to the alkali feldspar. Quartz is generally rounded, clear to grey, and anhedral. Mafics are uncommon and generally subhedral; fresh

biotite predominates but subhedral hornblende also occurs.

Two uncommon but distinctive lithologies are also included in the potassic marginal phase. One is a white-weathering, massive, fine- to medium-grained hornblende syenite which outcrops in northeastern (stations 103, 619 and 620), central (stations 674 and 675) and southeastern (station 168) parts of the Three Sisters Pluton. The equigranular, hypiomorphic texture and especially the rareness of biotite and idiomorphic texture of the hornblende distinguishes this lithology. The other is a very distinctive, white to pink weathering, porphyritic to seriate, coarse-grained, anti-rapakivi syenite porphyry. Rounded to generally oval megacrysts of bluish grey plagioclase with uncommon, thin to rare alkali feldspar rims, are found in a fine- to medium-grained, biotite-hornblende alkali feldspar syenite matrix. It also occurs in the western (station 20 or 436) as well as northeastern (stations 68, 69 and 453), central (station 674) and southeast (stations 181 and 484) parts of the Three Sisters Pluton's potassic marginal phase. Bluish grey plagioclase megacrysts are uncommon but distinctive of the central phase along some of its contacts with the eastern potassic marginal phase (e.g. stations 175 and 176) where the rock has textural and mineralogical affinities to both the Three Sisters Pluton (central and potassic marginal phases) and the metamorphosed Cake Hill Pluton (see previous section on metamorphism and remobilization of the Cake Hill Pluton).

Rare, small, rounded inclusions of fine-grained melanocratic diorite and leucocratic monzonite occur in the potassic marginal phase (see Appendix 6.1). The exceptions are larger and more common: augite porphyry volcanic and Cake Hill Pluton inclusions near intrusive contacts.

Fine grain, more euhedral grain shapes and more common quartz content of the potassic marginal phase contrast the coarse-grained, allotriomorphic to hypidiomorphic syenite and alkali-feldspar syenite of the alkali-metasomatized Cake Hill Pluton. At well-exposed gradational contacts between the central and potassic marginal phases the lithology cannot be unambiguously assigned to either phase although such assignments are easily made away from the contact on the basis of alkali feldspar, mafic content, texture and presence of inclusions.

The leucocratic phase is also more homogeneous than the mafic, central and potassic marginal phases. It is white weathering, massive, equigranular, medium-grained and hypidiomorphic. Leucocratic quartz diorite and diorite, rarely tonalite, compose the leucocratic phase (Figure 37). It characteristically contains subhedral plagioclase, uncommon to common, rounded, anhedral quartz but little alkali feldspar. It is distinctively leucocratic with rare euhedral black hornblende and slightly more common, subhedral, lime-green epidote. Small, rounded, fine-grained diorite inclusions are more felsic than in the mafic and central phases and vary in abundance from rare to absent.

IV.2.3 Structure

Although the Three Sisters Pluton is characterized by a general lack of fabric, the mafic minerals and(or) inclusions in the mafic and central phases locally exhibit a linear or planar fabric (Appendix 6.2). Only at two localities, near station 676 in the central phase and between stations 95 and 96 in the mafic phase are both fabrics developed in adjacent outcrops; however even there they do not occur together. At some places in the central phase, large, elongate inclusions which define a subvertical foliation or lineation are contained in a massive, equigranular medium-grained monzodiorite (Plate VI D; Appendix 6.2). At another locality (station 683), a massive monzodiorite apophysis in the mafic phase contains elongate inclusions oriented parallel with the margins of the apophysis (Figure 38). Mineral foliation and oblate inclusions in the central and mafic phases define a crudely circular structure; the fabric in the centre of the body is commonly steeper than towards the margins (Figure 1, 39). Mineral lineations are commonly gently plunging whereas prolate inclusions are subvertical to vertical. Rarely hornblende and, less commonly, biotite in central phase stockworks are lineated or rarely foliated parallel with the irregular borders of these apophyses near the margins of the main mass of the mafic phase and near margins of mafic phase blocks in isolated central phase stockworks and agmatites. Within one metre of the contact between the main body of the mafic phase and the

Figure 38. Notebook sketch (not to scale) of detailed intrusive relations between mafic and central phases of Three Sisters Pluton (near station 683). Elongate, fine-grained, mafic inclusions in the central phase are oriented approximately parallel to intrusive contacts. Dot-dash pattern for acicular hornblende diorite (mafic phase) symbolizes local, finer grain size towards contact with central phase.

THREE SISTERS PLUTON—Mafic and Central Phases

POLES TO MINERAL AND INCLUSION

FOLIATION (27 Measurements)

MINERAL AND INCLUSION LINEATION

(5 Measurements)

Figure 39. Lower hemisphere, equal area stereonet plots of mineral and inclusion lineation and poles to mineral and inclusion foliation in mafic and central phases of the Three Sisters Pluton. Only "moderate" and "good" measurements used (see Appendix 6.2).

remobilized Cake Hill Pluton, a fluidal gneissosity is developed in the mafic phase. The gneissosity consists of alternations of slightly less and slightly more mafic, medium-grained layers (up to 5-10 mm thick). The gneiss grades into slightly coarser-grained, massive, equigranular hornblende gabbro. Adjacent the contact, two recumbent, low amplitude (35 cm), rootless, isoclinal, symmetrical to asymmetrical, locally east to east-southeast verging minor folds are developed in the gneiss. Although no cleavage is developed, the trace of the axial plane parallels the gently west northwesterly dipping gneissosity which itself is in marked discordance with the near vertical east-trending foliation in the remobilized Cake Hill Pluton. As described in the section on the Cake Hill Pluton, both equigranular gabbro and gneissic inclusions occur in the Cake Hill Pluton within 2-3 metres of this contact and bear marked lithological similarities to the mafic phase at this locality (station 535).

Also characteristic of the central phase and mafic phase agmatites in the central phase is the development of vertical and horizontal joints (Plate VI E). These give the appearance of steps up steep cliff faces, especially when accentuated by green moss growth on the horizontal joints, and produce flat ramps on the ridge tops.

IV.2.4 Intrusive Relations

Intrapluton, external and interpluton intrusive relations

showing that the Three Sisters Pluton is one of the youngest and most heterogeneous plutons in the Hotailuh Batholith are summarized in Figure 40 and Appendix 6.3. Interpluton intrusive relations with the Stikine Pluton, Cake Hill Pluton, Gnat Lakes Ultramafite and Beggerlay Creek Pluton are detailed in earlier sections. Intrapluton intrusive relations of the Three Sisters Pluton provide strong evidence for consanguinity of the constituent phases and provide some insight into emplacement mechanism.

(a) Intrapluton Intrusive Relations

As described above, the distribution of the main bodies of the mafic, central, potassic marginal and leucocratic phases of the eastern part of the Three Sisters Pluton with respect to the eastern margin of the undisturbed Cake Hill Pluton mirrors the most common intrapluton intrusive chronology shown in Figure 40. Intrusive relations are deduced from apophysis of one phase clearly intruding, chilled against and (or) including parts of another phase and are given in detail in Appendix 6.3. Local reversals of intrusive relationships provide evidence for diachronous emplacement of the phases and at the same time evidence for the contemporaneity of their magmas on a batholithic scale.

The fine-grained phase, as represented by the large outcrop areas in the southeastern part of the Hotailuh Batholith, and in various small agmatitic zones in the mafic and central phases (see Appendix 6.3), is the oldest phase recognized in

Figure 40. Intrusive relations involving the Three Sisters Pluton and: (a) external, other plutonic and intraplutonic units (see Appendix 6.3); (b) hypabyssal intrusions (see Appendix 6.4). Abbreviation "INT" refers to intrusive relationship and arrow leads from intrusion to country rock. Filled-in arrowhead indicates most common intrusive relationship; open arrowhead, the less common relationship. Dashed arrow and question mark show uncertainty in intrusive relationship. "META." refers to metamorphism of Toarcian sediments associated with intrusion of the Three Sisters Pluton.

(A) EXTERNAL, INTERPLUTON AND INTRAPLUTON INTRUSIVE RELATIONS

(EXTERNAL)

(INTERPLUTON)

(INTRAPLUTON)

(B) HYABYSSAL INTRUSIONS

PLATE VI: LITHOLOGICAL, STRUCTURAL AND INTRUSIVE CHARACTERISTICS OF THE THREE SISTERS PLUTON

Plate VI A: Rare, layered hornblende gabbro inclusions in mafic phase of Three Sisters Pluton. Black bar on pencil is about 5 cm long (between stations 535 and 536; slide 8-78-5).

Plate VI B: Detail of mineralogical and grain size gradations in layered hornblende gabbro inclusions in mafic phase of Three Sisters Pluton. Black bar on pencil is about 5 cm long (between stations 535 and 536; slide 8-78-6).

Plate VI C: Fine-grained rim (see white arrow) of medium-grained acicular hornblende diorite inclusions in similar, slightly coarser-grained lithology of Three Sisters Pluton, mafic phase. Portion of inclusion seen here is about 15 cm long (between stations 535 and 536; slide 8-78-7).

Plate VI D: Elongate, oblate, fine-grained mafic inclusions define foliation in massive quartz monzodiorite of Three Sisters Pluton, central phase. Hammer at center left hand edge of photograph is about 35 cm long (between station 652 and 653; slide 2-79-31).

Plate VI E: View south to peak 7174 feet and prominent vertical and horizontal jointing characteristic of central and mafic phases of the Three Sisters Pluton. Figure in bottom left of photograph gives scale (station 506; slide 5-78-14).

Plate VI F: Apophysis of acicular hornblende diorite (numbered 2) of mafic phase in fine-grained phase (numbered 1) of Three Sisters Pluton (station 555; slide 11-78-29).

Plate VI G: Sequential intrusion of the Cake Hill Pluton (C.H.P.) by fine-grained phase (numbered 1), central phase (numbered 2) and finally, potassic marginal phase (numbered 3) of Three Sisters Pluton. White box gives location of detailed photograph in Plate VI H. Hammer is about 35 cm long (station 551; slide 11-78-19).

Plate VI H: Detail of bleached contact in Cake Hill Pluton (C.H.P.) against intruded fine-grained phase (numbered 1) which itself was disrupted during intrusion of the central phase (numbered 2) of the Three Sisters Pluton. See Plate VI G for location of photograph. Black bar or pencil is about 5 cm long (slide 11-78-20).

A

C

B

D

E

F

G

H

PLATE VII: INTRUSIVE RELATIONS INVOLVING PHASES OF THE THREE SISTERS PLUTON

- Plate VII A: Equivocal intrusive relations between the fine-grained phase (numbered 1) and the central phase (numbered 2) of the Three Sisters Pluton and the intruded and remobilized Cake Hill Pluton (C.H.P.). Pencil gives scale (station 477; slide 3-78-31).
- Plate VII B: Central phase stockworks in mafic phase of Three Sisters Pluton. White bar at top of photograph is approximately 30 cm long (near station 528; slide 7-78-20).
- Plate VII C: Potassic marginal phase apophysis (numbered 2 and contacts inked in) in mafic phase of Three Sisters Pluton. White arrow points to hammer, about 35 cm long (station 528; slide 7-78-20). K-Ar sample 528-3 collected at this locality.
- Plate VII D: Decrease in grain size (between two black arrows) at rim of acicular hornblende diorite fragment in central phase stockwork or agmatite, Three Sisters Pluton. Black bar on pencil is about 5 cm long (station 720; slide 10-79-14).
- Plate VII E: Decrease in grain size of acicular hornblende diorite (numbered 1) within a few centimeters of contact with central phase apophysis (numbered 2), Three Sisters Pluton. Black bar on pencil is about 5 cm long (station 683; slide 5-79-21).
- Plate VII F: Contact between central (numbered 1) and potassic marginal (numbered 2) phases, Three Sisters Pluton. Locally at contact, potassic marginal phase becomes finer grained (e.g. near pencil). Black bar on pencil is 5 cm long (talus boulder near contact in outcrop at station 678; slide 5-79-5).
- Plate VII G: Decrease in grain size (between black arrows) in potassic marginal phase (numbered 2) at contact with central phase (numbered 1), Three Sisters Pluton. Elsewhere along same contact, small inclusions of the central phase occur in the potassic marginal phase. Hammer handle is about 3 cm wide (station 678; slide 5-79-4).
- Plate VII H: Central phase (light grey; numbered 1) intruded and included in potassic marginal phase apophysis (white; numbered 2). Hammer is about 35 cm long (station 572; slide 13-78-9).

the Three Sisters Pluton. It caps two adjacent ridges, and its relationships with the central phase is clearly exposed along its eastern contact and with the mafic phase along its central and northwestern contacts. To the east, the fine-grained phase is clearly gradational with the central phase (stations 486 and 487). Along one of its central contacts (station 488), acicular hornblende diorite stockworks clearly intrude the fine-grained phase. To the west (station 491), over a 15 m interval, the fine-grained phase grades into the equant hornblende porphyry diorite of the mafic phase which in turn grades into acicular hornblende diorite away from the contact. Other contacts between the fine-grained phase and central phase are poorly exposed in felsenmeer or talus. The fine-grained phase also occurs as dismembered angular blocks occupying up to 50 per cent of mafic phase and central phase agmatites and stockworks which cap the tops of ridges. In the apophysis linking the eastern and western parts of the Three Sisters Pluton, the fine-grained phase clearly was the earliest phase intruded into the Cake Hill Pluton and is itself intruded by acicular hornblende diorite (mafic phase; Plate VI F) or monzodiorite (central phase; Plate VI G, H). In a few places, lithologically similar inclusions in the central and mafic phases exhibit fine-grained hornblende needles in the cores of the inclusions. Minor fine-grained diorite apophyses occur within monzodiorite of the central phase but always below the latter phase's contact with the remobilized Cake

Hill Pluton; as Plate VII A illustrates, the contact relations between the two phases are equivocal. Any external intrusive relations involving the fine-grained phase are apparently not preserved.

The mafic phase also crops out as a large body, in agmatites and as rare apophyses and dikes. Its intrusive relations with the fine-grained phase described above indicate its general contemporaneity with that phase; yet locally the mafic phase was still mobile enough to intrude the fine-grained phase. Around the margins of the main body of the mafic phase, stockworks, agmatites and apophyses of the central and potassic phases (Plate VII B, C) and the felsic phase of the Cake Hill Pluton show that the emplacement of the mafic phase predated the emplacement of the other phases and the remobilization of the Cake Hill Pluton. Agmatites of the mafic phase cap ridges along the "backbone" of the central phase, a major, south-trending system of ridges from peak 7174 feet. Peculiar to some central phase stockwork contacts in acicular hornblende diorite of the mafic phase (e.g. at stations 77, 470, 539?, 659, 661, 683 and 684) is a marked grain size reduction and only rare mineralogical change (increased biotite content) produced in the acicular hornblende diorite within 1-5 cm of the contact (Plate VII D, E). This effect is not seen at contacts between the central phase and other lithologies of the mafic phase. It is interpreted as minor chilling of the dioritic magma by intrusion of

slightly cooler monzodioritic magma and is considered evidence for the contemporaneous nature of the two phases. Minor irregular hornblende porphyry (with acicular hornblende diorite groundmass) and equigranular hornblende gabbro apophyses, probably related to the mafic phase, intrude the monzodiorite (see Appendix 6.3). Adjacent to the potassic marginal phase apophyses at stations 528 and 576, the mafic phase becomes more leucocratic and biotite-bearing. At station 522, acicular hornblende veinlets clearly intrude the potassic marginal phase.

Emplacement of the central phase clearly predates emplacement of much of the potassic marginal phase. Intrusive relations between the two phases comprise: stockworks (Plate VII H) dikes and irregular apophyses of typical aplitic to fine- to medium-grained potassic marginal phase lithologies locally chilled against the monzodiorite phase; sharp contacts between equigranular central phase and irregular bodies of potassic marginal phase, minor chilled margins and generally equivocal intrusive relations; and clearly gradational contacts between the two typical equigranular, medium-grained lithologies (see Appendix 6.3). Apophyses with 2-5 cm wide chilled margins (Plate VII F, G) or monzodiorite inclusions, aplitic dikes (Plate VII G, H) and syenitic veinlets which invade the central phase across generally sharp contacts with the potassic marginal phase clearly attest to the later emplacement of the potassic marginal phase at these localities. Rarely,

alkali feldspar megacrysts are developed in the central phase at its sharp contact with the intrusive potassic marginal phase. At station 666, a potassic marginal phase-central phase contact is gradational over a 1-5 cm interval but a thin biotite-rich schlieren is developed in the monzodiorite and is oriented parallel with the horizontal to subhorizontal "contact". Other, non-intrusive contact relations point to a contemporaneity of the two magmas. Sharp contacts along which no grain size reduction occurs in either of the equigranular, medium-grained or fine- to medium-grained phases are observed at scattered localities and are usually associated with irregular masses of syenite rather than discrete apophyses. Locally (e.g. station 528) inclusions appear to be shared across these contacts. On the outcrop scale steeply dipping and horizontal or gently dipping contacts are encountered; from a distance, along the southwest face of the ridge where stations 675-677 were made, distinctive pinkish versus dark grey talus of the potassic marginal and central phases respectively, define a steeply dipping contact. Uncommonly, aplite dikes follow the prominent horizontal and vertical joint sets characteristic of the central phase. Gradational contacts where the intermediate rock is transitional between the typical central phase and potassic marginal phase lithologies also suggest the coexistence of two magmas which formed these phases. At station 484, the unusual anti-rapakivi syenite porphyry is intruded by a fine-grained monzodioritic equivalent of the central phase. Dikes and irregular apophyses

of the leucocratic phase intrude the central phase in several places (Appendix 6.3).

The potassic marginal phase was one of the latest phases to be emplaced in the Three Sisters Pluton. As described above, it generally intrudes, is less commonly gradational with and rarely is intruded by earlier emplaced phases. Lithologically distinct sub-phases such as the anti-rapakivi syenite porphyry and the hornblende syenite described above, may occur with the more typical hornblende-biotite quartz syenite of the potassic marginal phase. Contacts between the two minor lithologies and the more typical lithology were not observed. Between stations 109 and 674 a clear gradational change between the megacryst-bearing syenite porphyry and the hornblende syenite was observed. However, the anti-rapakivi syenite porphyry may represent relict screens of completely metasomatized Cake Hill Pluton. The hornblende syenite exhibits similar intrapluton (forms intrusive stockworks in the central phase) and external (clearly intrudes bladed plagioclase porphyry) intrusive relations as the typical quartz syenite of the potassic marginal phase. Although the location of all three sub-phases are denoted on Figure 1, they are interpreted as essentially contemporaneous. Aside from apophyses of the leucocratic phase and hypabyssal dikes, no other plutonic phase intrudes the potassic marginal phase.

The leucocratic phase is clearly the youngest phase in the Three Sisters Pluton. It intrudes the central and potassic

marginal phases and is only intruded by glassy, pink to light grey syenitic plagioclase porphyry and two other distinctive Three Sisters Pluton hypabyssal dikes. There are no reliable geological relations that indicate that the leucocratic phase was necessarily contemporaneous with other phases.

(b) Triassic? Silicic Volcanics and Sediments

Near the inferred contact between the Stikine Pluton and potassic marginal phase of the Three Sisters Pluton, a sequence of Triassic? or older silicic volcanics and sediments is clearly intruded by thin, irregular apophyses of leucocratic hornblende-biotite granite of the potassic marginal phase. At one locality (station 421), long, angular xenoliths of the tuffaceous sediments are included in the potassic marginal phase.

(c) Upper Triassic Volcanics and Sediments

Deposition of the Upper Triassic volcanics and sediments clearly predated the emplacement of the Three Sisters Pluton (see Appendix 6.3). Of the constituent phases, the potassic marginal phase is the most common at the intrusive contacts. Rarely, the mafic phase (stations 550 and 572), central phase (stations 28, 550 and 572), and leucocratic phase (stations 90, 92, and 550) intrude, include and metamorphose the Triassic volcanics. All contacts with the Upper Triassic strata, with the exception of possible pendants or screens at stations 182, 520 and 550, occur around the margins of the Three Sisters Pluton. There, the potassic marginal phase develops small

scale agmatite (Plate VIII A, B), invades the volcanics as a number of anastomosing aplitic dikes and locally exhibits mineralogical changes near the contacts. Granitic, leucocratic aplites most commonly occur at the contacts with the volcanic rocks whether the contacts consist of intruding thin, anastomosing apophyses (station 70) or regular horizontal to vertical contacts (stations 4, 42, 43, 44, 167, 349-354 and 574). Where the contact areas are well exposed, a gradation within 5-10 cm of the volcanic-plutonic contact from typical medium-grained syenite to finer-grained, leucocratic aplite is commonly observed (Plate VIII C) although at two localities (stations 250 and 574), the aplite is more mafic within 5-8 cm of the contact. The central phase on the other hand, in a well exposed contact at station 577, becomes gradationally more leucocratic while remaining equigranular within 10-15 cm of the contact. Particularly in the western part of the Three Sisters Pluton, aplite is common along the contact even where medium-grained central phase monzodiorite persists to within meters of the contact. Agmatites and stockworks incorporating volcanic xenoliths are commonly restricted (with an exception at stations 520 and 550) to the margins, are local and of limited extent (on the order of 100-1500 square meters) and involve medium-grained potassic marginal phase lithologies (e.g. stations 19 or 436, 182, 520, 549, 550, 620 and 675). The major volcanic-plutonic contacts are steep along the northeastern margin of the Three Sisters Pluton but are nearly horizontal

in the western part of the pluton. Metamorphism of the basic volcanics which make up the Upper Triassic unit is difficult to recognize in the field but amphibolitized groundmasses of the augite porphyries extend laterally or vertically less than 50-100' m from contacts and, like the agmatites, are not developed everywhere. Alteration of the volcanics including bleaching of the groundmass (from green to white), pinkish potassic alteration along fractures and extensive uranization of the pyroxene phenocrysts near the contact is more widespread along the western margins of the Three Sisters Pluton.

(d) Upper Lower Jurassic Sediments

Although, as described in section II.3.4(c) (Cake Hill Pluton), the metamorphosed Toarcian sediments along the eastern margin probably overlie the metamorphosed Cake Hill Pluton and in the areas investigated, no recognizable Three Sisters Pluton phases were observed, the spatial association of the two plutons and the metamorphosed nature of the Cake Hill Pluton in that area leave little doubt that intrusion of the Three Sisters Pluton was responsible for the metamorphism of the Toarcian sediments along the eastern margin and so post-dated their deposition.

(e) Tertiary Volcanics

Fresh, vesicular, plagioclase porphyry volcanics of probable Tertiary age occur along the inferred northern margin of the leucocratic phase, in the southeastern Hotailuh Batholith. Although the two units are not observed in contact, the volcanics

must nonconformably overlie the leucocratic phase.

(f) Hypabyssal Intrusions

Andesite; aplite, pegmatite and felsite; porphyry; basalt, diabase and diorite; rhyolite; and lamprophyre dikes, in descending order of importance intrude the Three Sisters Pluton (see Appendix 6.4). Rarely is the relative order of intrusion established among them and no dikes intrude the main body of fine-grained phase. One variety of andesite, a greyish green or greenish grey weathering, epidotized andesite very commonly intrudes the pluton. As the augite-bladed plagioclase porphyry dikes characterize the Triassic suite of plutons, so these andesites appear to be the distinctive hypabyssal intrusions for the Three Sisters Pluton, although they also occur in the Cake Hill Pluton. They range from 0.3-4 m in thickness. All phases but the fine-grained phase are intruded by the greenish-grey andesites. They trend within 20 degrees of south with southeasterly trends most common, and commonly dip steeply west (Figure 41). No difference in dike orientations is observed among phases intruded by large numbers of grey green andesite dikes nor in the overall attitudes of these dikes between the Cake Hill Pluton and Three Sisters Pluton. Other andesite dikes in the Three Sisters Pluton are differently oriented as well as being lithologically distinct. However the locus of their attitudes at approximately 90 degrees opposed to the predominant east southeast trend of the green-grey andesite dikes probably reflects the two main

Figure 41. Lower hemisphere, equal area stereonet plots of poles to andesite, porphyry and felsic dike orientations. Numbers refer to colinear poles. Andesite dike orientations are distinguished according to the host phase.

ANDESITE DYKES

2, • POLES TO DYKE ORIENTATIONS IN CENTRAL PHASE
 Δ " " " " " POTASSIC MARGINAL PHASE

PORPHYRY DYKES

APLITE, PEGMATITE, FELSITE & RHYOLITE DYKES

A circular Wulffian projection showing the pole orientations of 30 porphyry dykes. The circle has a vertical line through its center, with 'N' at the top and a tick mark at the bottom. Data points are represented by small dots. A dense cluster of approximately 15 dots is located in the upper right quadrant. A few other dots are scattered in the lower right and along the bottom edge. Two dots in the upper right quadrant are labeled '2'.

2. POLES TO DYKE ORIENTATIONS IN ALL PHASES
(30 measurements)

A circular Wulffian projection showing the pole orientations of 20 dykes from the aplite, pegmatite, felsite, and rhyolite phases. The circle has a vertical line through its center, with 'N' at the top and a tick mark at the bottom. Data points are represented by small dots. The dots are more widely distributed than in the first figure, with a small cluster in the upper right and several dots scattered throughout the circle, particularly in the lower half.

POLES TO DYKE ORIENTATIONS IN
ALL PHASES (20 measurements)

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directions of subvertical jointing particularly characteristic of the central phase which hosts by far the greatest numbers of these dikes.

Aplite, pegmatite and felsite dikes are also most common in the central phase, uncommon in the potassic marginal phase and rare in the mafic phase. They are generally irregular; tabular ones have similar orientations as the greenish grey andesite dikes. Some aplites bear marked lithological resemblance, though finer grained, to the typical potassic marginal phase lithologies. At one location (station 680; see Appendix 6.3), a pegmatite exhibits small scale symmetrical zonation from a 2 cm thick plagioclase-rich core to 3 cm thick alkali feldspar-rich margins.

Combinations of hornblende, biotite and plagioclase form phenocrysts in porphyritic dikes which intrude the central, potassic marginal and leucocratic phases. Syenitic porphyries (at stations 108, 109, 140, 142A, 159, 162 and 249) are most common in the central part of the eastern Three Sisters Pluton and are distinguished by a light greyish brown, potassium-rich (as determined by staining) groundmass. Acicular hornblende diorite veins intrude a similar syenitic porphyry intrusion along the northern margin of the Cake Hill Pluton as described earlier in the Cake Hill Pluton section. In the leucocratic phase by station 6 or 447, an order of intrusion is established in the hypabyssal intrusions (youngest to oldest): grey, fine-grained andesite intrudes a glassy, pink (white along

selvages) plagioclase porphyry which intrudes a hornblende-plagioclase porphyry which intrudes the leucocratic phase.

The attitudes of the porphyry dikes in the Three Sisters Pluton have no preferred orientation.

Basalt, diabase and fine-grained diorite dikes are uncommon in the central and potassic marginal phases and also exhibit no preferred orientation. Flow-layered rhyolite dikes are observed at three locations in the central and north-eastern parts of the eastern Three Sisters Pluton. One poorly exposed hornblende porphyry lamprophyre featuring euhedral hornblende rosettes in a dark brown, fine-grained groundmass was observed in the southwestern region of the eastern Three Sisters Pluton.

IV.2.5 AGE

Potassium-argon age-dates determined from the 5 phases of the Three Sisters Pluton are given in Table IV.2.2 and Figure 42. The dates apparently indicate a 66 million year period of intrusion for the Three Sisters Pluton (the youngest age of 142 Ma for the leucocratic phase to the oldest age of 208 Ma determined from one specimen from the potassic marginal phase). Although the 208 Ma date from the potassic marginal phase compares closely with a 204 Ma date reported from syenite from the Ten Mile Creek pyroxenite-syenite body by Morgan (1976), the age of this specimen from the potassic marginal phase is considered to reflect excess Ar for the following reasons:

TABLE IV.2.2 POTASSIUM-ARGON RADIOMETRIC AGE DATA FOR THE THREE SISTERS PLUTON¹

SPECIMEN NUMBER	PLUTON	LOCATION (LATITUDE- LONGITUDE)	LITHOLOGY	MINERAL	ZK	$^{40}\text{Ar}/^{39}\text{K}$	$\%^{40}\text{Ar}$	AGE (Ma)
AN-79-719-1	THREE SIS- TERS PLUTON (fine-grained phase)	58°03'40"N 129°19'30"W	monzodiorite	whole rock	2.38	0.00909	94.2	150 ± 4
AN-78-523-1	THREE SIS- TERS PLUTON (mafic phase)	58°10'24"N 129°30'15"W	acicular hornblende diorite	hornblende biotite	0.75 5.92	0.01159 0.01093	86.6 93.6	189 ± 14 179 ± 6
AN-78-542-1	THREE SIS- TERS PLUTON (mafic phase)	58°10'20"N 129°35'18"W	acicular hornblende diorite	hornblende	0.74	0.01117	61.2	183 ± 14
AN-79-661-3	THREE SIS- TERS PLUTON (mafic phase)	58°04'44"N 129°26'15"W	equant hornblende porphyry diorite	hornblende hornblende	0.52 0.52	0.01033 0.01050	19.1 54.3	170 ± 16 172 ± 13

1. All potassium-argon ages are consistent with the decay constants of Steiger and Jäger (1977). All lithologies are classified according to Streckeisen (1973).

TABLE IV.2.2 POTASSIUM-ARGON RADIOMETRIC AGE DATA FOR THE THREE SISTERS PLUTON¹ (cont'd)

SPECIMEN NUMBER	PLUTON	LOCATION (LATITUDE- LONGITUDE)	LITHOLOGY	MINERAL	$^{40}\text{Ar}/^{39}\text{K}$	$\%^{40}\text{Ar}$	AGE (Ma)
GSC 70-30 ²	THREE SIS- TERS PLUTON (central phase)	58°08'36"N ³ 129°22'00"W	quartz monzonite	hornblende	0.0096	63	159 ± 8
GSC 70-31 ² GSC 70-32 ²	THREE SIS- TERS PLUTON (central phase)	58°07'30"N 129°30'00"W	quartz monzonite or granodio- rite	hornblende biotite	0.0101 0.0102	77 93	167 ± 9 167 ± 7
AN-77-345-1	THREE SIS- TERS PLUTON (central phase)	58°09'30"N 129°29'40"W	quartz monzodiorite	hornblende	0.01033	74.2	170 ± 11
GSC 70-29 ²	THREE SIS- TERS PLUTON (potassic marginal phase)	58°08'30"N 129°52'00"W	granite	hornblende	0.0104	67	170 ± 8
				hornblende	0.0096	32	161 ± 11

1. All potassium-argon ages are consistent with the decay constants of Steiger and Jäger (1977). All lithologies are classified according to Streckeisen (1973).

2. from Wanless et al. (1972, p.17-21)

3. correct location given here; incorrect location given in Wanless et al. (1972, p.19)

TABLE IV.2.2 POTASSIUM-ARGON RADIOMETRIC AGE DATA FOR THE THREE SISTERS PLUTON¹ (cont'd)

SPECIMEN NUMBER	PLUTON	LOCATION (LATITUDE- LONGITUDE)	LITHOLOGY	MINERAL	ZK	⁴⁰ Ar/ ⁴⁰ K	⁴⁰ Ar	AGE (Ma)
AN-77-356-1	THREE SIS- TERS PLUTON (potassic marginal phase)	58°11'30"N 129°55'00"W	quartz syenite	hornblende	0.95	0.01029	86.5	169 ± 11
				biotite	7.28	0.01076	92.5	176 ± 5
AN-78-505-5	THREE SIS- TERS PLUTON (potassic marginal phase)	58°10'48"N 129°30'08"W	quartz syenite	hornblende	0.371	0.01283	52.8	208 ± 15
AN-78-528-3	THREE SIS- TERS PLUTON (potassic marginal phase)	58°10'43"N 129°33'00"W	quartz syenite	biotite	7.20	0.01098	95.4	180 ± 5
AN-79-718-1	THREE SIS- TERS PLUTON (leucocra- tic phase)	58°02'23"N 129°18'45"W	quartz diorite	hornblende	0.065	0.00857	9.3	142 ± 53 ²
				hornblende	0.156	0.01130	42.0	185 ± 28 ²

1. All potassium-argon ages are consistent with the decay constants of Steiger and Jäger (1977). All lithologies are classified according to Streckeisen (1973).

2. Hornblende pleochroism in each mineral separate is different.

Figure 42. Mineral and whole-rock K-Ar isotopic ages for phases of the Three Sisters Pluton and the Jurassic portion of Armstrong's (1978a, 1981) time scale. Analytical errors in ages are 2σ (see Table IV.2.2). Toarcian time interval between dashed horizontal lines is age of youngest unit metamorphosed during intrusion of the Three Sisters Pluton. Heavy dashed vertical lines separate determinations for each phase.

it is collected from the potassic marginal phase within 50-100 m of its intrusive contact with the Cake Hill Pluton; other nearby outcrops of the potassic marginal phase contain Cake Hill Pluton xenoliths (see Appendix 6.1, potassic marginal phase, station 522); the Cake Hill Pluton is suspected to be remobilized in the vicinity of peak 7174 feet where the sample was collected (see chapter and section II.3.4), and there are no lithological, chemical or petrographic differences between the age-date sample and other samples of the potassic marginal phase which yield younger ages.

It is apparent from Table IV.2.2 and Figure 42 that K-Ar ages determined for individual phases only grossly reflect the relative emplacement chronology of the major phases as deduced from the fieldwork i.e. mafic phase (170-189 Ma), central phase (158-170 Ma), and potassic marginal phase (160-180 Ma) and within the 95 per cent confidence limits their ages overlap considerably. The areal distribution of the ages (Figure 42) exhibit a clustering of >180 Ma ages in the vicinity of peak 7174 feet and a gradual apparent younging of K-Ar ages east to the margin of the Three Sisters Pluton. The phenomena is observed in individual phases (e.g. central and mafic phases) in the eastern part of the Three Sisters Pluton as well as for the pluton as a whole. If K-Ar ages record the time elapsed since the individual mineral systems passed through their isotopic blocking temperatures, the distribution of intrapluton K-Ar dates may indicate sequential uplift of the eastern portion

of the Three Sisters Pluton from west to east. Alternatively, an event around 150 Ma may have selectively reset some of the ages. Concordance of individual hornblende-biotite mineral pair dates suggests that uplift during this 35-50 million year period was fairly rapid. As noted above, the leucocratic phase may not be comagmatic with other phases of the Three Sisters Pluton; its isotopic K-Ar age differs greatly between hornblende replicates (see Table IV.2.2). In the western part of the Three Sisters Pluton, dominated by the potassic marginal phase, two concordant mineral pairs indicate moderately rapid uplift from 161-176 Ma. In one determination the hornblende date (169 ± 11 Ma) is anomalously younger than the biotite date (176 ± 5 Ma). The emplacement of the Three Sisters Pluton probably occurred no later than 180 Ma and no earlier than 188 Ma, a conclusion supported by the Toarcian age of the metamorphosed sediments along the eastern margin of the Three Sisters Pluton, the revised time-scale (Armstrong 1978a, 1981) and the oldest dates determined from the Three Sisters Pluton (Figure 42). In a later section whole rock Rb-Sr and zircon U-Pb isotopic data collected from the Three Sisters Pluton and further interpretation of the behavior of the various isotopic systems are presented.

IV.2.6 Petrography

Nature, abundance and habit of essential and accessory minerals characterize the Three Sisters Pluton (Appendix 6.5). Intraplutonic phases are distinguished on the basis of systematic changes in: quartz-plagioclase feldspar-alkali feldspar proportions (Figure 37), grain size (increases with intrusive sequence), colour index (decreases with intrusive sequence), plagioclase composition (decreases with intrusive sequence) and alkali feldspar habit. Nonetheless, consistent petrographic features (e.g., clinopyroxene cores in hornblende, biotite accompanying hornblende, biotite and hornblende pleochroism and irregular calcic cores in plagioclase) support a comagmatic link amongst most of these phases. The leucocratic phase is texturally and compositionally distinct (Figure 37, and Appendix 6.5).

The resemblance between mafic inclusions and the fine-grained phase is striking. Inclusions are generally fine-grained analogs of the host rock but contain less quartz and more anorthite-rich plagioclase (cf. Appendix 6.5(a) and (c)). Rarely, biotite is the sole mafic silicate in mafic inclusions. Generally, there are no reaction rims between inclusions and host rock although hornblende may be more common close to the margin of an inclusion than in its core. In one inclusion (sample 652-4), recrystallization resulted in 120° grain boundaries among plagioclase. In the mafic phase, the equant hornblende porphyry variety has less plagioclase, more hornblende, less biotite, and a larger colour index than the acicular hornblende variety. The acicular hornblende variety has remarkable lithological and petrographic similarities compared with the hornblende tonalite porphyry in the Glacier Peak area (Tabor and Crowder, 1969; cf. their Figure 13 with Plate V H, this study). There is little petrographic difference among

samples from the eastern and western parts of the potassic marginal phase (Figure 37).

Essential and accessory minerals in the Three Sisters Pluton are (in approximate order of crystallization): zircon, apatite, opaque minerals (magnetite; rare pyrite and chalcopyrite in mafic phase), clinopyroxene, plagioclase, hornblende, biotite, titanite, quartz, alkali feldspar (apparently crystallized before quartz in the potassic marginal, leucocratic and parts of the central phases) and allanite (distinctive of the potassic marginal phase). Epidote and chlorite (+ titanite) are uncommon but widespread alteration products of clinopyroxene, hornblende and biotite; calcite of clinopyroxene, plagioclase and hornblende; and sericite and saussurite of plagioclase (commonly occurring in the core and inner zones). Common epidote is distinctive of parts of the leucocratic phase. Calcite-chlorite veinlets occur in a few places.

Subhedral or euhedral zircon and apatite accessory minerals occur in all other minerals. Zircon is not observed in the fine-grained phase, is sparse in the mafic and central phases but is a widespread though rare inclusion in hornblende and biotite in the potassic marginal phase. Coarse, euhedral zircon is typical of some samples of the leucocratic phase. Metamict zircon is rarely observed and radiation damage haloes about zircon in hornblende and biotite are common. Locally, in the potassic marginal phase, zircon partly encloses allanite, apatite and opaque minerals. Euhedral, stubby prisms of apatite are widespread but acicular grains are especially common in fine-grained and mafic phases. Squarish or rounded opaque minerals are predominantly magnetite and enclose apatite, zircon, clinopyroxene (rare) and plagioclase. In the mafic phase, opaque minerals are locally glomero-

porphyritic. Opaque minerals are rare or absent in the leucocratic phase.

Clinopyroxene is a rare but widespread and distinctive subhedral or anhedral mineral in all phases. In parts of the leucocratic phase it is the main mafic silicate. Its textural relationships with other minerals is best preserved in the fine-grained and mafic phases and mafic inclusions where it crystallized interstitially among plagioclase. Where subhedral or euhedral, clinopyroxene encloses acicular apatite, zircon, opaque minerals and plagioclase. Clinopyroxene is most common as irregular grains or isolated, optically continuous blebs in hornblende cores. The leucocratic phase is characterized by irregular patches of glomeroporphyritic clinopyroxene. Twinning is rare and in a few places, hornblende rims crudely mimic the twin law in clinopyroxene.

Nature and habit of plagioclase is distinctive of the Three Sisters Pluton. Plagioclase is generally subhedral or euhedral and increases in grain size with interphase intrusive sequence. Variable grain size in the mafic inclusions and fine-grained and mafic phases results in a seriate texture. Generally, anorthite content decreases with intrusive sequence although there is considerable overlap among the fine-grained phase (An_{40-68}), mafic phase (An_{38-64}), central phase (An_{32-55}) and potassic marginal phase (An_{35-59}). Oscillatory and discontinuous and continuous normal zoning account for changes in composition of An_{6-17} for most samples. The potassic marginal and leucocratic phases are characterized by andesine or oligoclase cores and albite rims. The most striking feature of plagioclase in the Three Sisters Pluton is the inclusion of irregular, locally skeletal, highly fractured and altered andesine or labradorite cores in host oligoclase or andesine of all phases but the leucocratic phase. Anorthite content in the cores reaches An_{84-95} in the fine-grained and mafic phases but only An_{54-58} in central and

potassic marginal phases where the cores are less common. Subhedral, locally skeletal; fine-grained zircon, apatite, opaque minerals and clinopyroxene are additional inclusions which occur in cores and rims of the host plagioclase. In a few places, opaque mineral and clinopyroxene inclusions are arranged concentrically about a host plagioclase core; elsewhere, they are scattered throughout the grains. Irregular or isolated but optically continuous hornblende, biotite and titanite blebs in host plagioclase cores are uncommon. Plagioclase has irregular grain boundaries with interstitial alkali feldspar but little myrmekite is developed except locally in the potassic marginal phase.

Hornblende occurs as twinned, euhedral or subhedral, separate grains or as anhedral, glomeroporphyritic, poikilitic plates among subhedral plagioclase (some with calcic cores). Zircon, apatite, opaque minerals, and biotite and titanite patches are additional inclusions in hornblende. Hornblende is most euhedral in the acicular hornblende gabbro or quartz diorite variety of the mafic phase. As described above, clinopyroxene cores in hornblende are typical. Hornblende which contains clinopyroxene varies in habit from thin rims around subhedral or euhedral pyroxene to more or less homogeneous, subhedral or anhedral grains. Hornblende without clinopyroxene cores may have patchy pleochroism or abundant round quartz blebs in the cores. Brown, fine-grained elongate exsolution? lamellae are observed in a few places in mafic phase amphiboles. Pleochroic scheme (α' = light greenish or brownish yellow; β = olive; γ' = bluish or grass green) is distinctive of the fine-grained, mafic, central and potassic marginal phases. Locally in the potassic marginal phase, hornblende rims have a distinctive greenish blue pleochroism along γ' , suggesting late alkali amphibole growth. Hornblende in the leucocratic phase is characterized by its weak absorption and pleochroic scheme

(α' = clear or pale yellow; β = pale grass green; γ' = pale yellowish green).

Biotite forms subhedral, rectangular grains, anhedral grains and patches of glomeroporphyritic anhedral interstitial to plagioclase and anhedral patches as an alteration product of hornblende. Zircon (rare except in the potassic marginal phase), apatite, opaque minerals, clinopyroxene, plagioclase, hornblende and titanite (rare) are enclosed by biotite. In a few places, especially in the potassic marginal phase, biotite is rimmed by fine-grained opaque minerals. Generally, biotite is euhedral where enclosed by anhedral alkali feldspar; where alkali feldspar is subhedral, biotite rarely encloses it. Biotite pleochroism is similar for all phases (α' = light yellow; $\beta = \gamma'$ = dark walnut or orange brown).

Titanite is euhedral or subhedral and separate, interstitial with respect to plagioclase, hornblende and opaque minerals or occurs with chlorite as an alteration product of ferromagnesian silicates. It rims opaque minerals and encloses apatite, clinopyroxene, plagioclase, alkali feldspar (in potassic marginal phase), hornblende and biotite. Locally, in the central and potassic marginal phase, it is intergrown with or occurs as anhedral grains within subhedral alkali feldspar and hornblende.

Quartz is anhedral and comparatively undeformed (undulatory extinction but rare subgrains). It crystallized as coarse poikilitic plates among all other minerals except alkali feldspar and allanite. In the mafic inclusions, fine-grained phase, mafic phase and most parts of the central phase, quartz has straight grain boundaries with alkali feldspar. Where alkali feldspar is subhedral or euhedral, (potassic marginal, leucocratic and parts of the central phases), quartz appears to be intergrown with or interstitial to it.

Alkali feldspar is homogeneous or microperthitic and becomes increasingly turbid with intrusive sequence (very turbid alkali feldspar is typical of the potassic marginal phase). Euhedralism also increases with intrusive

sequence. In mafic inclusions and fine-grained, mafic and parts of the central phases, alkali feldspar occurs as extensive poikilitic grains which are interstitial to or enclose all other minerals (except allanite in some parts of the potassic marginal phase). In the potassic marginal, leucocratic and parts of the central phases, alkali feldspar is subhedral or euhedral, Carlsbad-twinning and contains fewer inclusions; anhedral varieties are also observed. In a few places (more common in felsic phases), irregular or graphic quartz-alkali feldspar intergrowths are observed.

Allanite is distinctive of the potassic marginal phase and is anhedral or rounded and concentrically zoned. It is interstitial with respect to alkali feldspar and anastomoses along microfractures in quartz.

IV.2.7 Chemical Composition

Major, minor and trace element compositions and CIPW norms for the fine-grained, mafic, central, potassic marginal and leucocratic phases of the Three Sisters Pluton are given in Table IV.2.3 and are plotted in Figure 43.

All samples from the Three Sisters Pluton are hypersthene-normative; changes in abundance of some normative minerals occur with intrusive sequence. Most basic samples in the fine-grained and mafic phases are olivine-normative; the more siliceous samples in the potassic marginal phase have small amounts of normative corundum. The mafic phase commonly has normative pyrite. One sample in the leucocratic phase is distinguished by normative wollastonite and hematite.

The Three Sisters Pluton has clear subalkaline affinities. In the alkali-silica plot (Figure 43(a)) the samples commonly plot in the subalkaline field or in the alkaline field near the dividing line of Irvine and Baragar (1971). This distinguishes the Three Sisters Pluton from members of the Triassic plutonic suite. In the normative $ne'-ol'-qz'$ plot (Figure 43(b)), all samples plot in the subalkaline field of Irvine and Baragar (1971) in accord with their hypersthene-normative character.

In the AFM ternary (Figure 43(d); after Irvine and Baragar, 1971), SiO_2-Fe^*/MgO (Figure 43(d); after Miyashiro, 1974), Fe^*-FeO^*/MgO (not shown; after Miyashiro, 1974), MgO -total iron (Figure 43(e); after Lowder and Carmichael, 1970; Stauffer *et al.*, 1975) and alumina-normative plagioclase (Figure 43(f);

TABLE IV.2.3 CHEMICAL COMPOSITION OF THE THREE SISTERS PLUTON, FINE-GRAINED PHASE

(a) Location and lithology of specimens

SPECIMEN	UNIT	LOCATION (Latitude and Longitude)	LITHOLOGY ¹
262-1	Three Sisters Pluton, fine-grained phase	58°03'45"N 129°21'12"W	fine-grained monzodiorite.
652-6	Three Sisters Pluton, fine-grained phase?	58°05'41"N 129°30'47"W	fine-grained diorite inclusion in Three Sisters Pluton, central phase
660-3	Three Sisters Pluton, fine-grained phase	58°04'28"N 129°26'30"W	fine-grained diorite inclusion in Three Sisters Pluton, central phase stockwork
719-2	Three Sisters Pluton, fine-grained phase	58°03'40"N 129°19'30"W	fine-grained monzodiorite (K-Ar SPECIMEN)

 1. All specimens classified after Streckeisen (1973)

TABLE IV.2.3 CHEMICAL COMPOSITION OF THE THREE SISTERS PLUTON, FINE-GRAINED PHASE
(b) Major Elements (in weight per cent)

OXIDE	262-1	652-6	660-3	719-2	AVERAGE (1σ)
SiO ₂	60.1	49.6	54.1	61.4	56.3 (5.5)
Al ₂ O ₃	17.1	18.6	18.2	17.0	17.7 (0.8)
TiO ₂	0.67	1.03	0.93	0.67	0.83 (0.18)
Fe ₂ O ₃	2.3	4.8	4.8	2.9	3.7 (1.3)
FeO	3.6	6.0	3.4	3.0	4.0 (1.4)
MnO	0.13	0.23	0.17	0.13	0.17 (0.05)
MgO	2.42	4.78	3.33	2.07	3.15 (1.21)
CaO	5.27	8.95	7.19	5.02	6.61 (1.84)
Na ₂ O	3.8	3.5	3.6	3.7	3.7 (0.1)
K ₂ O	2.68	1.82	2.24	2.93	2.42 (0.49)
P ₂ O ₅	0.21	0.29	0.33	0.22	0.26 (0.06)
H ₂ O _T	1.4	0.9	1.3	0.6	
CO ₂	B.D.	B.D.	0.4	B.D.	
S	B.D.	0.01	B.D.	B.D.	
Cl	0.07	0.07	0.04	0.08	
F	0.04	0.05	0.05	0.04	
Loss O=S		0.00			
Total	99.79	100.63	100.08	99.76	(98.84)

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE IV.2.3 CHEMICAL COMPOSITION OF THE THREE SISTERS PLUTON, FINE-GRAINED PHASE
(c) Trace Elements (in ppm)

	SPECIMENS				Average (1σ)
	262-1	652-6	660-3	719-2	
Rb	60	50	50	60	60 (10)
Sr	690	690	600	430	600 (120)
Ba	1000	1100	860	1100	1000 (110)
U	2.3	N.A.	N.A.	N.A.	2.3
Zr	91	160	76	97	110 (37)
Cr	B.D.	9.0	B.D.	B.D.	9.0
Co	16	25	10	B.D.	17 (8)
Ni	B.D.	15	B.D.	B.D.	15
V	110	280	200	120	180 (80)
Cu	38	150	31	33	63 (58)
Zn	50	130	80	80	85 (33)

B.D.: below detection limits of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE IV.2.3 CHEMICAL COMPOSITION OF THE THREE SISTERS PLUTON,
FINE-GRAINED PHASE

(d) CIPW Normative Minerals (in weight per cent)

NORMATIVE MINERALS	SPECIMENS			
	262-1	652-6	660-3	719-2
qz	12.34		6.64	14.92
or	15.84	10.76	13.24	17.32
ab	32.15	29.61	30.46	31.30
an	21.69	29.67	26.89	21.13
di	2.51	10.38	3.23	1.89
hy	8.65	1.54	7.83	6.49
ol		8.03		
hrc	3.33	6.96	6.95	4.20
il	1.27	1.96	1.76	1.27
ap	0.50	0.68	0.78	0.52
py		0.02		
cc			0.91	
H ₂ O	1.4	0.9	1.30	0.6
Cl	0.07	0.07	0.04	0.08
F	0.04	0.05	0.05	0.04
Total	99.79	100.63	100.08	99.76

TABLE IV.2.3 CHEMICAL COMPOSITION OF THE THREE SISTERS PLUTON, MAFIC PHASE

(a) Location and lithology of specimens

SPECIMEN	UNIT	LOCATION (Latitude and Longitude)	LITHOLOGY
99-3	Three Sisters Pluton, mafic phase	58°05'04"N 129°26'53"W	acicular hornblende diorite
657-4	same as specimen 99-3	58°04'44"N 129°25'52"W	equant hornblende porphyry diorite
661-5	" " "	58°04'44"N 129°26'15"W	acicular hornblende diorite
683-7	" " "	58°05'41"N 129°23'45"W	acicular hornblende diorite
720-1	" " "	58°10'24"N 129°35'00"W	equant hornblende porphyry diorite
523-1A	" " "	58°10'24"N 129°30'15"W	biotite-acicular hornblende diorite (K-Ar SPECIMEN)
523-1B	" " "	same as specimen 523-1A	same as specimen 523-1A (replicate analysis K-Ar SPECIMEN)
542-1A	" " "	58°10'20"N 129°35'18"W	acicular hornblende diorite (K-Ar SPECIMEN)
542-1B	" " "	same as specimen 542-1A	same as specimen 542-1A (replicate analysis, K-Ar SPECIMEN)

1. All lithologies classified after Streckeisen (1973)

TABLE IV.2.3 CHEMICAL COMPOSITION OF THE THREE SISTERS PLUTON, MAFIC PHASE (cont'd)

(a) Location and lithology of specimens

SPECIMEN	UNIT	LOCATION (Latitude and Longitude)	LITHOLOGY
661-2	same as specimen 99-3	58°04'44"N 129°26'15"W	equant hornblende porphyry diorite

TABLE IV.2.3 CHEMICAL COMPOSITION OF THE THREE SISTERS PLUTON, MAFIC PHASE

(b) Major Elements (in weight per cent)

OXIDE	SPECIMENS										AVERAGE (10)
	99-3	657-4	661-5	683-7	720-1	523-1A	523-1B	542-1A	542-1B	661-2	
SiO ₂	54.0	53.0	51.3	53.9	45.4	50.2	50.4	48.6	49.2	47.0	50.3 (2.9)
Al ₂ O ₃	17.6	17.9	18.0	18.1	16.5	17.7	18.6	18.4	18.8	19.1	18.1 (0.7)
TiO ₂	0.89	0.81	1.29	0.81	0.95	1.01	0.99	1.03	1.00	1.04	0.98 (0.14)
Fe ₂ O ₃	4.3	4.7	4.7	5.3	6.3	4.7	5.2	5.1	5.2	5.9	5.1 (0.6)
FeO	4.3	4.9	5.0	3.6	6.7	5.2	4.8	5.7	5.7	6.5	5.2 (0.9)
MnO	0.13	0.16	0.17	0.17	0.26	0.21	0.24	0.17	0.21	0.14	0.19 (0.04)
MgO	3.39	4.12	4.06	3.65	7.38	3.95	3.96	4.54	4.33	5.21	4.46 (1.14)
CaO	7.43	7.95	8.08	6.91	10.40	8.94	8.73	9.72	9.52	9.81	8.75 (1.14)
Na ₂ O	3.6	3.3	3.1	3.8	2.3	4.0	4.1	3.2	3.4	2.5	3.3 (0.6)
K ₂ O	1.61	1.62	1.99	2.25	0.98	1.28	1.27	1.18	1.09	1.07	1.43 (0.42)
P ₂ O ₅	0.29	0.19	0.27	0.30	0.17	0.33	0.32	0.29	0.30	0.22	0.27 (0.06)
H ₂ O _T	1.4	1.1	2.0	1.6	2.3	1.1	1.1	2.0	1.6	1.8	
CO ₂	B.D.	B.D.	0.1	B.D.	0.1	0.1	B.D.	0.1	B.D.	B.D.	
S	0.02	0.02	0.06	0.01	B.D.	0.14	0.03	0.17	0.08	0.09	
Cl	0.04	0.04	0.05	0.09	0.09	N.A.	0.11	N.A.	0.09	0.06	
F	0.06	0.06	0.06	0.04	0.04	N.A.	0.03	N.A.	0.02	0.03	
Less O=S	0.01	0.01	0.02	0.00		0.03	0.01	0.04	0.02	0.02	
Total	99.05	99.86	100.21	100.53	99.87	98.83	99.87	100.16	100.52	100.45	(98.08)

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE IV.2.3 CHEMICAL COMPOSITION OF THE THREE SISTERS PLUTON, MAFIC PHASE

(c) Trace Elements (in ppm)

	99-3	657-4	661-5	683-7	720-1	523-1A	523-1B	542-1A	542-1B	661-2	Average (1σ)
Rb	40	50	50	40	50	30	40	20	40	70	40 (10)
Sr	560	540	740	820	780	880	810	910	840	760	760 (120)
Ba	470	580	610	850	440	650	670	460	520	440	570 (130)
U	2.4	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	2.4
Zr	83	27	28	29	37	84	57	45	20	20	43 (24)
Cr	B.D.	B.D.	8	B.D.	8	B.D.	5.8	B.D.	5.4	B.D.	6.8 (1.4)
Co	19	17	19	14	42	35	25	31	25	17	24 (9)
Ni	B.D.	B.D.	12	B.D.	15	20	10	13	11	B.D.	14 (4)
V	220	220	250	170	410	230	230	240	250	220	240 (60)
Cu	59	51	78	47	140	110	100	110	110	51	86 (33)
Zn	50	70	90	70	120	110	110	90	90	70	87 (22)

B.D.: below detection limits of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE IV.2.3 CHEMICAL COMPOSITION OF THE THREE SISTERS PLUTON, MAFIC PHASE
(d) CIPW Normative Minerals (in weight per cent)

NORMATIVE MINERALS	SPECIMENS									
	99-3	657-4	661-5	683-7	720-1	523-1A	523-1B	542-1A	542-1B	661-2
qz	7.04	5.06	3.59	4.67						
or	9.51	9.57	11.76	13.30	5.79	7.57	7.50	6.97	6.44	6.32
ab	30.46	27.92	26.23	32.15	19.46	33.84	34.60	27.07	28.76	21.15
an	27.11	29.25	29.33	25.69	31.81	26.56	28.60	32.36	32.82	37.74
di	6.30	7.20	6.70	5.23	14.46	12.08	10.11	10.73	10.04	7.65
hy	8.49	10.83	10.26	7.82	6.44	6.55	5.51	9.89	9.85	13.91
ol					7.92	1.13	1.99	0.55	0.60	0.58
mt	6.23	6.81	6.81	7.68	9.13	6.81	7.54	7.39	7.54	8.55
il	1.69	1.54	2.45	1.54	1.80	1.92	1.88	1.96	1.90	1.97
ap	0.68	0.45	0.63	0.70	0.40	0.78	0.75	0.68	0.71	0.52
py	0.04	0.04	0.11	0.02		0.26	0.06	0.33	0.15	0.17
cc			0.23		0.23	0.23		0.23		
H ₂ O	1.4	1.1	2.0	1.6	2.3	1.1	1.1	2.0	1.6	1.8
Cl	0.04	0.04	0.05	0.09	0.09		0.11		0.09	0.06
F	0.06	0.06	0.06	0.04	0.04		0.03		0.02	0.03
Total	99.05	99.86	100.21	100.53	99.87	98.83	99.87	100.16	100.52	100.45

TABLE IV.2.3 CHEMICAL COMPOSITION OF THE THREE SISTERS PLUTON, CENTRAL PHASE

(a) Location and lithology of specimens

SPECIMEN	UNIT	LOCATION (Latitude and Longitude)	LITHOLOGY ¹
62-3	Three Sisters Pluton, central phase	58°07'42"N 129°22'53"W	hornblende-biotite quartz monzodiorite
96-2	same as specimen 62-3	58°06'07"N 129°27'08"W	biotite-hornblende monzodiorite
124-1	" "	58°07'58"N 129°32'14"W	hornblende-biotite monzodiorite
135-1	" "	58°07'47"N 129°29'45"W	hornblende-biotite monzodiorite
137-4	" "	58°07'40"N 129°27'45"W	hornblende-biotite quartz monzodiorite
331-1	" "	58°05'39"N 129°31'08"W	biotite-hornblende monzodiorite
345-1	" "	58°09'30"N 129°29'40"W	biotite hornblende quartz monzodiorite (K-Ar SPECIMEN)

1. All lithologies classified after Streckeisen (1973)

TABLE IV.2.3 CHEMICAL COMPOSITION OF THE THREE SISTERS PLUTON, CENTRAL PHASE
(b) Major Elements (in weight per cent)

OXIDE	62-3	96-2	124-1	135-1	137-4	331-1	345-1	AVERAGE (1σ)
SiO ₂	61.2	59.9	53.3	56.9	62.2	53.8	58.5	58.0 (3.5)
Al ₂ O ₃	17.3	17.5	18.6	17.5	16.8	18.8	16.6	17.6 (0.8)
TiO ₂	0.54	0.59	0.64	0.65	0.58	0.75	0.66	0.63 (0.07)
Fe ₂ O ₃	2.2	2.5	3.4	3.2	2.2	2.0	3.7	2.7 (0.7)
FeO	2.9	3.3	3.7	3.9	2.9	5.2	3.2	3.6 (0.8)
MnO	0.10	0.10	0.14	0.11	0.10	0.16	0.12	0.12 (0.02)
MgO	1.96	2.07	3.02	3.07	1.89	3.00	2.87	2.55 (0.55)
CaO	4.57	5.12	6.44	6.40	4.03	6.29	5.64	5.50 (0.96)
Na ₂ O	3.4	3.9	4.1	3.6	3.4	4.0	3.2	3.7 (0.3)
K ₂ O	3.60	2.68	2.34	2.32	4.02	2.48	3.00	2.92 (0.66)
P ₂ O ₅	0.17	0.20	0.22	0.23	0.16	0.39	0.19	0.22 (0.08)
H ₂ O _T	1.1	1.4	1.7	1.3	1.2	1.6	1.2	
CO ₂	B.D.	B.D.	0.2	B.D.	B.D.	B.D.	0.1	
S	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	
Cl	0.08	0.04	0.04	0.07	0.06	0.03	N.A.	
F	0.06	0.06	0.05	0.05	0.06	0.04	N.A.	
Total	99.18	99.36	97.89	99.30	99.60	98.54	98.98	(97.54)

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE IV.2.3 CHEMICAL COMPOSITION OF THE THREE SISTERS PLUTON, CENTRAL PHASE

(c) Trace Elements (in ppm)

SPECIMENS								
	62-3	96-2	124-1	135-1	137-4	331-1	345-1	Average (1σ)
Rb	110	60	50	60	110	10	40	60 (40)
Sr	540	570	670	570	440	850	480	590 (140)
Ba	940	990	1400	1300	1100	1400	800	1100 (200)
U	1.7	2.6	1.7	3.0	2.9	1.4	N.A.	2.2 (0.7)
Zr	140	180	150	110	150	85	104	130 (30)
Cr	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	7.8	7.8
Co	16	12	27	21	23	23	20	20 (5)
Ni	B.D.	B.D.	11	13	B.D.	B.D.	25	16 (8)
V	130	120	200	140	120	140	190	150 (30)
Cu	48	24	70	24	32	2	81	40 (28)
Zn	40	40	60	60	30	70	50	50 (10)

B.D.: below detection limits of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE IV.2.3 CHEMICAL COMPOSITION OF THE THREE SISTERS PLUTON, CENTRAL PHASE
(d) CIPW Normative Minerals (in weight per cent)

NORMATIVE MINERALS	SPECIMENS					
	62-3	96-2	124-1	135-1	137-4	331-1 345-1
qz	14.18	12.38	2.73	8.97	14.84	1.59 12.83
or	21.28	15.84	13.83	13.71	23.76	14.66 17.73
ab	28.77	33.00	34.69	30.46	28.77	33.84 27.07
an	21.32	22.34	25.44	24.74	18.71	26.02 22.07
di	0.20	1.43	3.07	4.45	0.19	2.17 3.22
hy	7.58	7.66	9.23	9.14	7.35	13.35 7.57
mt	3.19	3.62	4.93	4.64	3.18	2.90 5.36
il	1.02	1.12	1.21	1.23	1.10	1.42 1.25
ap	0.40	0.47	0.52	0.54	0.38	0.92 0.45
cc			0.45			0.23
fo	1.1	1.4	1.7	1.3	1.2	1.2
cl	0.08	0.04	0.04	0.07	0.06	0.03
f	0.06	0.06	0.05	0.05	0.06	0.04
Total	99.18	99.36	97.89	99.30	99.60	98.54 98.98

TABLE IV.2.3 CHEMICAL COMPOSITION OF THE THREE SISTERS PLUTON, POTASSIC MARGINAL PHASE

(a) Location and lithology of specimens

SPECIMEN	UNIT	LOCATION (Latitude and Longitude)	LITHOLOGY ¹
5-2	Three Sisters Pluton, western part of potassic marginal phase	58°09'17"N 129°51'23"W	biotite-hornblende monzonite
8-1	same as specimen 5-2	58°08'37"N 129°51'23"W	biotite quartz syenite
20-1	" " "	58°10'36"N 129°53'23"W	biotite-hornblende quartz monzonite
43-1	" " "	58°10'39"N 129°55'00"W	hornblende-biotite monzodiorite
349-1	" " "	58°12'50"N 129°57'26"W	
58-1	Three Sisters Pluton, eastern part of potassic marginal phase	58°08'09"N 129°20'00"W	hornblende quartz syenite
79-1	same as specimen 58-1 (specimen from apophysis in central phase)	58°06'47"N 129°24'12"W	hornblende-biotite granite
84-2	same as specimen 58-1	58°04'24"N 129°20'12"W	biotite-hornblende quartz syenite
152-1	" " "	58°11'27"N 129°28'00"W	hornblende-biotite quartz syenite

 1. All lithologies classified after Streckeisen (1973)

TABLE IV.2.3 CHEMICAL COMPOSITION OF THE THREE SISTERS PLUTON, POTASSIC MARGINAL PHASE (cont'd)

(a) Location and lithology of specimens

SPECIMEN	UNIT	LOCATION (Latitude and Longitude)	LITHOLOGY ¹
162-4	same as specimen 58-1	58°10'51"N 129°23'38"W	hornblende-biotite quartz syenite
249-1	" " "	58°04'54"N 129°16'30"W	hornblende quartz syenite
257-2	" " "	58°03'16"N 129°27'17"W	biotite-hornblende quartz syenite
356-1	same as specimen 5-2	58°11'30"N 129°55'00"W	biotite-hornblende quartz syenite (K-Ar SPECIMEN)
505-5A	same as specimen 58-1	58°10'48"N 129°30'08"W	hornblende-biotite quartz syenite (K-Ar SPECIMEN)
505-5B	" " "	same as specimen 505-5A	same as specimen 505-5A (replicate analysis; K-Ar SPECIMEN)
528-3A	" " "	58°10'43"N 129°33'00"W	hornblende biotite quartz syenite (K-Ar SPECIMEN)
528-3B	" " "	same as specimen 528-3A	same as specimen 528-3A (replicate analysis; K-Ar SPECIMEN)

1. All lithologies classified after Streckeisen (1973)

TABLE IV.2.3 CHEMICAL COMPOSITION OF THE THREE SISTERS PLUTON, POTASSIC MARGINAL PHASE

(b) Major Elements (in weight per cent)

OXIDE	SPECIMENS									
	5-2	8-1	20-1	43-1	349-1	356-1	58-1	79-1	84-2	152-1
SiO ₂	60.8	73.3	60.1	56.4	67.2	65.4	66.6	66.8	67.1	69.8
Al ₂ O ₃	18.1	15.0	16.7	18.0	16.5	16.4	16.2	15.5	16.1	15.0
TiO ₂	0.28	0.15	0.72	0.76	0.28	0.25	0.17	0.22	0.19	0.14
Fe ₂ O ₃	1.7	0.8	1.9	3.1	1.5	1.7	1.2	1.4	1.6	1.2
FeO	2.7	0.6	4.8	3.1	1.9	2.4	2.5	1.6	1.4	0.8
MnO	0.05	0.05	0.13	0.12	0.07	0.08	0.08	0.05	0.07	0.02
MgO	0.41	0.25	0.42	2.71	0.53	0.45	0.20	0.55	1.04	0.35
CaO	2.40	1.11	4.37	4.45	2.00	2.00	0.96	2.68	2.34	1.80
Na ₂ O	5.2	3.8	4.0	4.2	3.4	4.0	4.3	3.7	4.0	4.0
K ₂ O	4.94	4.57	3.97	3.76	5.44	5.59	5.76	3.79	4.12	3.87
P ₂ O ₅	0.11	0.04	0.34	0.30	0.15	0.11	0.05	0.09	0.11	0.07
H ₂ O _T	0.7	0.7	1.0	0.9	0.9	0.3	0.9	1.1	0.7	0.5
CO ₂	B.D.	B.D.	B.D.	B.D.	0.1	B.D.	B.D.	B.D.	B.D.	B.D.
S	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.
Cl	0.04	0.04	0.10	0.10	0.13	N.A.	0.07	0.03	0.05	0.07
F	0.12	0.08	0.12	0.13	0.13	N.A.	0.05	0.06	0.05	0.05
Total	97.55	100.49	100.67	98.03	100.23	98.68	99.04	97.57	98.87	97.67

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE IV.2.3 CHEMICAL COMPOSITION OF THE THREE SISTERS PLUTON, POTASSIC MARGINAL PHASE (cont'd)
 (b) Major Elements (in weight per cent)

OXIDE	SPECIMENS							
	162-4	249-1	257-2	505-5A	505-5B	528-3A	528-3B	AVERAGE (1σ)
SiO ₂	67.8	65.5	63.8	68.8	68.9	66.2	65.4	65.9 (4.0)
Al ₂ O ₃	15.0	16.7	16.2	14.6	15.2	16.2	16.3	16.1 (1.0)
TiO ₂	0.24	0.21	0.38	0.18	0.29	0.29	0.46	0.31 (0.18)
Fe ₂ O ₃	1.3	1.5	1.7	1.4	1.0	2.0	1.2	1.5 (0.5)
FeO	1.8	1.7	2.7	1.0	1.3	1.5	2.5	2.0 (1.0)
MnO	0.07	0.05	0.10	0.04	0.04	0.05	0.06	0.07 (0.03)
MgO	1.17	0.33	1.34	0.51	0.77	0.71	1.0	0.87 (0.72)
CaO	2.29	1.53	2.70	2.05	2.09	3.39	3.45	2.45 (0.99)
Na ₂ O	3.2	4.2	3.6	4.1	4.3	3.8	3.8	4.0 (0.4)
K ₂ O	4.56	5.55	5.19	4.21	4.25	4.21	4.12	4.58 (0.69)
P ₂ O ₅	0.08	0.08	0.21	0.11	0.11	0.21	0.22	0.14 (0.09)
H ₂ O _T	0.8	0.7	0.7	0.7	0.5	0.9	0.5	
CO ₂	0.1	B.D.	B.D.	0.1	B.D.	0.1	B.D.	
S	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	
Cl	0.05	0.08	0.07	0.09	N.A.	0.07	N.A.	
F	0.05	0.05	0.09	0.02	N.A.	0.03	N.A.	
Total	98.51	98.18	98.78	97.91	98.75	99.66	99.01	(97.92)

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE IV.2.3 CHEMICAL COMPOSITION OF THE THREE SISTERS PLUTON, POTASSIC MARGINAL PHASE

(c) Trace Elements (in ppm)

SPECIMENS									
	5-2	8-1	20-1	43-1	349-1	58-1	79-1	84-2	152-1
Rb	110	190	150	120	190	170	110	60	160
Sr	220	170	440	520	260	730	390	300	500
Ba	480	680	770	1200	890	450	110	930	930
U	9.6	6.5	12.9	3.8	9.6	6.4	3.4	3.6	6.4
Zr	400	100	320	150	290	610	92	99	65
Cr	B.D.	B.D.	6.6	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.
Co	B.D.	B.D.	19	14	B.D.	B.D.	B.D.	B.D.	B.D.
Ni	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.
V	22	25	120	140	48	24	54	45	37
Cu	22	B.D.	22	47	25	23	27	11	11
Zn	B.D.	B.D.	40	50	20	30	B.D.	B.D.	B.D.

B.D.: below detection limits of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE IV.2.3 CHEMICAL COMPOSITION OF THE THREE SISTERS PLUTON, POTASSIC MARGINAL PHASE (cont'd)

(c) Trace Elements (in ppm)

	SPECIMENS								AVERAGE (1σ)
	162-4	249-1	257-2	356-1	505-5A	505-5B	528-3A	528-3B	
Rb	100	150	170	170	110	100	120	110	140 (40)
Sr	300	230	370	200	440	430	580	460	390 (150)
Ba	750	660	1100	640	1600	1400	990	1000	860 (360)
U	6.0	6.0	9.9	N.A.	N.A.	N.A.	N.A.	N.A.	7.0 (2.9)
Zr	180	350	290	620	370	94	120	150	250 (180)
Cr	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	6.6
Co	B.D.	B.D.	11	B.D.	B.D.	B.D.	B.D.	B.D.	15 (4)
Ni	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	
V	87	30	75	45	42	41	64	65	57 (33)
Cu	26	21	21	22	50	56	10	14	26 (14)
Zn	10	10	20	40	20	40	40	70	30 (20)

B.D.: below detection limits of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE IV. 3 CHEMICAL COMPOSITION OF THE THREE SISTERS PLUTON, POTASSIC MARGINAL PHASE
(d) CIPW Normative Minerals (in weight per cent)

NORMATIVE MINERALS	SPECIMENS								
	5-2	8-1	20-1	43-1	349-1	356-1	58-1	79-1	84-2
qz	4.45	30.94	7.53	4.10	21.35	14.84	15.75	23.77	21.32
or	29.20	27.01	23.46	22.22	32.15	33.04	34.04	22.40	24.35
ab	44.00	32.15	33.84	35.54	28.77	33.84	36.38	31.31	33.84
an	11.19	5.25	15.89	19.16	8.31	9.20	4.44	12.71	10.89
c	0.10	1.88			1.97	0.40	1.27	0.65	1.07
di			2.95	0.76					
hy	4.20	0.91	10.86	8.48	3.24	3.86	3.97	2.88	3.66
mt	2.46	1.16	2.35	4.49	2.17	2.46	1.73	2.03	2.32
il	0.53	0.28	1.37	1.44	0.53	0.48	0.32	0.42	0.36
ap	0.26	0.09	0.80	0.71	0.35	0.26	0.12	0.21	0.26
cc					0.23				
H ₂ O	0.7	0.7	1.0	0.9	0.9	0.3	0.9	1.1	0.7
Cl	0.04	0.04	0.10	0.10	0.13		0.07	0.03	0.05
F	0.12	0.08	0.12	0.13	0.13		0.05	0.06	0.05
Total	97.55	100.49	100.67	98.03	100.23	98.68	99.04	97.57	98.87

TABLE IV.2.3 CHEMICAL COMPOSITION OF THE THREE SISTERS PLUTON, POTASSIC MARGINAL PHASE (cont'd)
(d) CIPW Normative Minerals (in weight per cent)

NORMATIVE MINERALS	SPECIMENS							
	152-1	162-4	249-1	257-2	505-5A	505-5B	528-3A	528-3B
qz	27.41	24.68	15.54	14.39	24.06	21.78	20.22	18.01
or	22.87	26.95	32.80	30.68	24.88	25.12	24.88	24.35
ab	33.84	27.07	35.54	30.46	34.69	36.38	32.15	32.15
an	8.47	10.21	7.07	12.02	8.82	9.63	14.72	15.25
c	1.13	1.06	1.19	0.25	0.07			
di						0.02	0.08	0.35
hy	1.16	4.88	2.45	6.45	1.72	3.06	2.44	5.27
mt	1.74	1.88	2.17	2.46	2.03	1.45	2.90	1.74
il	0.27	0.46	0.40	0.72	0.34	0.55	0.55	0.87
ap	0.16	0.19	0.19	0.49	0.26	0.26	0.49	0.52
cc		0.23			0.23		0.23	
H ₂ O	0.5	0.8	0.7	0.7	0.7	0.5	0.9	0.5
Cl	0.07	0.05	0.08	0.07	0.09		0.07	
F	0.05	0.05	0.05	0.09	0.02		0.03	
Total	97.67	98.51	98.18	98.78	97.91	98.75	99.66	99.01

TABLE IV.2.3 CHEMICAL COMPOSITION OF THE THREE SISTERS PLUTON, LEUCOCRATIC PHASE

(a) Location and lithology of specimens

SPECIMEN	UNIT	LOCATION (Latitude and Longitude)	LITHOLOGY ¹
605-1	Three Sisters Pluton, leucocratic phase	58°09'00"N 129°52'00"W	leucocratic hornblende quartz diorite
686-3	same as specimen 605-1	58°08'07"N 129°26'17"W	leucocratic lime-green hornblende diorite
718-3	" " "	58°02'23"N 129°18'45"W	leucocratic epidote-bearing horn- blende quartz diorite

1. All lithologies classified after Streckeisen (1973)

TABLE IV.2.3 CHEMICAL COMPOSITION OF THE THREE SISTERS PLUTON, LEUCOCRATIC PHASE
(b) Major Elements (in weight per cent)

OXIDE	605-1	686-3	718-3	AVERAGE (1σ)
SiO ₂	64.3	62.1	72.2	66.2 (5.3)
Al ₂ O ₃	19.2	17.9	15.6	17.6 (1.8)
TiO ₂	0.75	0.58	0.25	0.53 (0.25)
Fe ₂ O ₃	1.1	0.96	0.43	0.83 (0.35)
FeO	0.9	2.7	0.8	1.5 (1.1)
MnO	0.04	0.03	0.01	0.03 (0.02)
MgO	0.98	1.85	0.70	1.18 (0.60)
CaO	5.30	7.53	4.26	5.70 (1.67)
Na ₂ O	7.9	6.1	5.5	6.5 (1.2)
K ₂ O	0.40	0.21	0.14	0.25 (0.13)
P ₂ O ₅	0.21	0.24	0.11	0.19 (0.07)
H ₂ O _T	0.4	0.7	0.3	
CO ₂	B.D.	B.D.	B.D.	
	B.D.	B.D.	B.D.	
Cl	0.03	0.02	0.07	
F	0.06	0.08	0.02	
Total	101.57	101.00	100.39	(100.51)

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE IV.2.3 CHEMICAL COMPOSITION OF THE THREE SISTERS PLUTON, LEUCOCRATIC PHASE
(c) Trace Elements (in ppm)

	SPECIMENS			AVERAGE (1σ)
	605-1	686-3	718-3	
Rb	20	10	10	10 (10)
Sr	770	770	600	710 (100)
Ba	110	260	220	200 (80)
U	N.A.	N.A.	N.A.	6
Zr	1200	B.D.	110	660 (770)
Cr	B.D.	B.D.	B.D.	B.D.
Co	B.D.	B.D.	B.D.	B.D.
V	60	100	38	66 (31)
Ni	B.D.	B.D.	B.D.	B.D.
Cu	7.4	B.D.	B.D.	7.4
Zn	20	20	10	17 (6)

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE IV.2.3 CHEMICAL COMPOSITION OF THE THREE SISTERS PLUTON,
LEUCOCRATIC PHASE

(d) CIPW Normative Minerals (in weight per cent)

NORMATIVE MINERALS	SPECIMENS		
	605-1	686-3	718-3
qz	6.57	9.34	30.12
or	2.36	1.24	0.83
ab	66.84	51.61	46.54
an	15.76	20.85	17.47
di	5.26	12.22	2.37
wo	1.00		
hy		1.88	1.32
mt	0.86	1.39	0.62
hm	0.51		
il	1.42	1.10	0.47
ap	0.50	0.57	0.26
H ₂ O	0.4	0.7	0.3
Cl	0.03	0.02	0.07
F	0.06	0.08	0.02
Total	101.57	101.00	100.39

Figure 43. Chemical variation diagrams for samples from the constituent phases of the Three Sisters Pluton.

- Weight per cent alkali-silica diagram. Alkaline-subalkaline division after Irvine and Baragar (1971).
- Weight per cent, normative ne' - ol' - qz' ternary diagram ($ne' = ne + 3/5 ab$; $qz' = qz + 2/5 ab + 1/4 opx$; $ol' = ol + 3/4 opx$). Alkaline-subalkaline division after Irvine and Baragar (1971).
- Weight per cent A ($Na_2O + K_2O$) - F ($FeO + 0.8998 Fe_2O_3 - M(MgO)$) ternary diagram. Calc-alkaline - tholeiitic division after Irvine and Baragar (1971).
- Weight per cent SiO_2 - FeO^*/MgO diagram ($FeO^* = FeO + 0.9 Fe_2O_3$). Calc-alkaline - tholeiitic division after Miyashiro (1974).
- Weight per cent MgO - total iron diagram. Cascades, abyssal tholeiite (AT), pigeonitic series and Thingmuli trends after Stauffer et al. (1975).
- Weight per cent alumina-normative plagioclase diagram. Calc-alkaline - tholeiitic division after Irvine and Baragar (1971).
- Weight per cent Na_2O - K_2O - CaO ternary diagram.

Symbols for the individual units are as follows:

Fine-grained phase: $\bigcirc$ grab sample from fine-grained phase; $\diamond$ K-Ar sample from fine-grained phase; $\triangle$ fine-grained dioritic inclusion in central phase host; $\square$ fine-grained dioritic inclusion in central phase stockwork.

Mafic phase: $\bigcirc$ grab sample; $\diamond$ K-Ar sample (2 samples have replicate analyses).

Central phase: $\bigcirc$ grab sample; $\diamond$ K-Ar sample.

Potassic marginal phase: $\bigcirc$ grab sample from western exposures of potassic marginal phase; $\square$ K-Ar sample from western exposures of potassic marginal phase; $\triangle$ grab samples from eastern exposures of potassic marginal phase; $\diamond$ K-Ar samples from eastern exposures of potassic marginal phase.

Leucocratic phase: $\bigcirc$ grab sample; $\diamond$ K-Ar sample.

Q

a) Alkali-silica diagram

a) Alkali-silica diagram (continued)

a) Alkali-silica diagram (continued)

b) Ne'-ol'-qz' ternary

b) Ne'-ol'-qz' ternary (continued)

b) Ne' - ol' - qz' ternary (continued)

5

a) AFM ternary

c) AFM ternary (continued)

Leucocratic Phase

c) AFM ternary (continued)

d) Silica - FeO*/MgO diagram

d) Silica - FeO^*/MgO diagram (continued)

d) Silica - FeO*/MgO diagram (continued)

e) MgO - total iron diagram (continued)

e) MgO - total iron diagram (continued)

f) Alumina - normative plagioclase diagram

f) Alumina - normative plagioclase diagram (continued)

f) Alumina - normative plagioclase diagram (continued)

g) $\text{Na}_2\text{O} - \text{K}_2\text{O} - \text{CaO}$ ternary

g) Na_2O - K_2O - CaO ternary (continued)

g) $\text{Na}_2\text{O} - \text{K}_2\text{O} - \text{CaO}$ ternary (continued)

after Irvine and Baragar, 1971) plots, the Three Sisters Pluton has mixed tholeiitic and calc-alkaline affinities which vary, in part, with intrusive sequence. The alumina-normative plagioclase plot also emphasizes the overall high Al_2O_3 content of the fine-grained and mafic phases (>17 weight per cent) which steadily decreases in younger phases. In an AFM ternary plot, there is a smooth, typically calc-alkaline, trend from alkali-depleted, iron- and magnesium-enriched compositions in the mafic phase through intermediate compositions in the central phase to alkali-enriched, iron- and magnesium-depleted compositions in the potassic marginal and, in part, leucocratic phases. Two samples of the mafic phase have tholeiitic affinities based on the AFM boundary suggested by Irvine and Baragar (1971).

In SiO_2 - FeO^*/MgO , FeO^*-FeO^*/MgO (not shown) and MgO -total iron plots, similar trends emerge. The mafic phase is clearly tholeiitic, is characterized by a fairly consistent FeO^*/MgO ratio and mimics the iron-enrichment trends characteristic of the classic tholeiitic series on the MgO -total iron plot. In these plots, the central phase has mixed tholeiitic and calc-alkaline affinities and the leucocratic phase samples are calc-alkaline. An exception is the potassic marginal phase in the SiO_2 - FeO^*/MgO and FeO^*-FeO^*/MgO (not shown) plots. The distribution of its compositions reflects the wide range of predominantly high FeO^*/MgO ratios and the significance of apparently mixed tholeiitic and calc-alkaline geochemistry is not known. The Al_2O_3 -normative plagioclase plot classifies

all but one sample of the Three Sisters Pluton as calc-alkaline.

In the weight per cent. Na_2O - K_2O - CaO ternary plot, there is also a smooth variation from the comparatively CaO -enriched rocks of the mafic phase through the intermediate compositions of the central phase finally to the comparatively K_2O -enriched, CaO -poor compositions of the potassic marginal phase. The leucocratic phase is characterized by extreme K_2O -depletion relative to Na_2O and CaO .

Although the classifications are plot-dependent, samples from the Three Sisters Pluton are considered representative of a subalkaline, tholeiitic to calc-alkaline suite from mafic through potassic marginal phases. The smooth variations seen among the three phases in many of the plots (e.g. alkali-silica, AFM, MgO -total iron) and the Harker variation diagrams (see Appendix 6.6), are considered typical of differentiation via fractional crystallization in calc-alkaline suites and are in accord with the contemporaneity of the phases as revealed in the outcrop intrusive relations. The fine-grained phase is one exception in that field relations indicate it was the earliest phase emplaced but in most plots it clearly compositionally overlaps the mafic phase and central phase compositions (see also Chapter VI, Figure 72). This is consistent with an interpretation that the fine-grained phase is a fine-grained equivalent of the mafic and(or) central phases and that it was intruded and quickly crystallized before most of the central or mafic phase magmas were intruded. Further intrusion

disrupted the fine-grained phase and dispersed it as some of the rounded, fine-grained mafic inclusions characteristic of the mafic and central phases.

The distinctive lithology, petrography, chemical composition and intrusive relations of the leucocratic phase suggest that it may be coeval but may not be comagmatic with the other phases of the Three Sisters Pluton.

Average compositions for the phases in the Three Sisters Pluton are given in Table IV.2.3. Generally, all age-date specimens are geochemically typical of the particular phase. The average composition of the fine-grained phase compares closely with Le Maitre's (1976) average diorite but is different from most diorite compositions compiled by Nockolds (1954). The mafic phase has some similarities with Le Maitre's gabbro but compares most closely with the average diorite composition of that compilation; average mafic phase composition compares moderately with the average diorite compositions of Nockolds except for Fe_2O_3 and FeO contents. The mafic phase is also compositionally similar to the early emplaced gabbroids in the super-units of the Peruvian batholith (Pitcher, 1977). Average diorite, granodiorite and tonalite compositions compiled by Le Maitre (1976) all have some similarities to the average central phase composition. Nockolds' (1954) average hornblende-biotite monzonite is fairly similar to the average central phase composition except for TiO_2 , K_2O and Fe_2O_3 (higher) and Al_2O_3 (lower). The average potassic marginal phase is

most closely comparable to Le Maitre's average granite and granodiorite and most similar to Nockolds' (1954) average hornblende-biotite adamellite and hornblende-biotite granodiorite. There is little geochemical difference between the composition of samples collected from the eastern part and samples collected from the northwestern outcrops of the potassic marginal phase. Finally, the leucocratic phase has, on average, lower Fe_2O_3 , FeO , MgO and much lower K_2O and higher CaO and much higher Na_2O than Le Maitre's (1976) granodiorite but does not compare with any of the typical calc-alkaline plutonic rock compositions compiled by Nockolds (1954).

Further geochemical comparisons between the Three Sisters Pluton and other plutonic and volcanic units is given in Chapter VI including further evidence for a cogenetic link amongst the fine-grained, mafic and central phases.

PLATE VIII: INTRUSIVE RELATIONS AND STRUCTURAL CHARACTERISTICS OF THE THREE
SISTERS, SNOWDRIFT CREEK, PALLAN CREEK AND TANZILLA PLUTONS

Plate VIII A: Three Sisters Pluton, potassic marginal phase stockworks (white) in pyroxene porphyry volcanics (grey) of the Upper Triassic Stuhini Group. Pocket knife is 9 cm long (station 19 or 436; slide 1-77-21).

Plate VIII B: Distinctive hornblende syenite (white) subphase of the potassic marginal phase, Three Sisters Pluton, forms stockwork in bladed plagioclase porphyry of Upper Triassic Stuhini Group (uT st). Pocket knife in lower center of photograph is 9 cm long (station 520; slide 6-78-12).

Plate VIII C: Inked-in contact between bleached pyroxene(?) porphyry volcanics of Upper Triassic Stuhini Group (uT st) and potassic marginal phase, Three Sisters Pluton. Potassic marginal phase at contact (subphase a) is leucocratic and fine-grained compared to rock a few centimeters from contact (subphase b); gradational contact is marked by inked-in dashed line. Black bar on pencil is about 5 cm long (station 42; slide 13-78-20).

Plate VIII D: Aligned hornblende and biotite express moderately developed mineral foliation in southeastern part of Snowdrift Creek Pluton. Hammer-handle is about 3 cm wide (station 708; slide 9-79-7).

Plate VIII E: Mafic schlieren in southeastern part of the Snowdrift Creek Pluton. Hammer is about 35 cm long (station 708; slide 9-79-1).

Plate VIII F: Panoramic view southwest to Pallan Creek Pluton and Tanzilla Pluton (on the horizon). Dotted lines are approximate western contacts of Pallan Creek Pluton with pyroxene porphyry of Upper Triassic Stuhini Group (uT st) which is structurally overlain by deformed, compositionally layered Permian marble (Pc). Locally pillowed and amygdaloidal pyroxene and plagioclase porphyry volcanics of the Stuhini Group are in left foreground. Triangles denote locations of K-Ar age-date samples GSC 70-25 and 70-26 (right hand triangle) and AN-79-635-1 (left hand triangle) (from station 639; slide 1-79; 35 and 36).

Plate VIII G: Fine-grained, white syenitic aplite apophysis (numbered 2) in light grey hornblende-biotite quartz monzonite (numbered 1) in Pallan Creek Pluton. Black bar on pencil is about 5 cm long (station 644; slide 2-79-9).

Plate VIII H: Gabbro inclusions (numbered 1) in quartz monzonite agmatite (numbered 2) in Pallan Creek Pluton. Hammer handle is about 33 cm long (station 644; slide 2-79-8).

Plate VIII I: White, aplite apophyses (numbered 2) in grey, hornblende-biotite quartz monzodiorite (numbered 1) of Tanzilla Pluton. Hammer is about 35 cm long (station 639; slide 2-79-3).

A

B

C

D

E

F

G

H

I

IV.3 McBRIDE RIVER PLUTON

IV.3.1 Distribution, Physiography and Magnetic Expression

The McBride River Pluton forms the easternmost apophysis of the Hotailuh Batholith and contributes to nearly 10 per cent of the total area of the batholith (Figure 1, 44). Characteristic low, subdued topography provides exposures along the eastern and western sides of the valley incised by the McBride River which bisects the pluton and gives it its name (Plate V G). Outcrops of the McBride River Pluton above tree-line were examined; outcrops of the pluton exist below tree-line but are difficult of access. The McBride River Pluton is neither characterized by aeromagnetic highs nor lows but rather by fairly steadily eastwardly increasing values from 58400 gammas along its western margin to a small local high of more than 59020 gammas just east of its eastern margin (Figure 2).

IV.3.2 Lithology

The McBride River Pluton is one of the most homogeneous plutons in the Hotailuh Batholith. White weathering, massive, equigranular, medium-grained hypidiomorphic granodiorite or quartz monzodiorite characterizes the pluton (Figure 45). Biotite commonly predominates over hornblende and is the more euhedral of the two. Abundant rounded, clear to grey quartz is distinctive. Plagioclase is better formed and more abundant than uncommon alkali feldspar. Titanite is a rare accessory. Mafic, rounded or elongate, fine-grained diorite inclusions are widespread but rare and randomly oriented (Appendix 5.1). The abundant quartz, more euhedral biotite and hornblende, scarcity of inclusions and homogeneity distinguish the McBride River Pluton from the central phase of the Three Sisters Pluton.

Figure 44. Location of the McBride River Pluton (bold outline) in the Hotailuh Batholith and of stations and samples discussed in text.

Figure 45. Modal compositions of hand samples and thin sections from the McBride River Pluton (see Appendix 7.4). Classification after Streckeisen (1973). Abbreviations are: KF = alkali feldspar; PF = plagioclase feldspar; and Qz = quartz.

IV.3.3 Intrusive Relations

The position of the McBride River Pluton in the Hotailuh Batholith and the dearth of well exposed contacts prevents establishment of reliable geological constraints on the age of intrusion. The known intrusive relations are summarized in Figure 46.

(a) Upper Triassic Volcanics and Sediments

The McBride River Pluton clearly intrudes the Upper Triassic augite porphyry and fine-grained equigranular andesite (see Appendix 5.2). Characteristic of the intrusive contact is the widespread development of quartz veining in the volcanics and pluton. Although the main contact is poorly exposed, the attitude of the quartz veins in the volcanics near the contact, as well as the attitude of the thin to thick apophyses in the volcanics west of the main contact, suggest a steep, probably westerly dipping intrusive contact. Amphibolitization of the volcanics is restricted to the vicinity of the intrusive contacts of the McBride River Pluton.

(b) Triassic-Jurassic Volcanics

Along the eastern margin of the McBride River Pluton, the contact with the Triassic-Jurassic volcanics is nowhere exposed. Apparent hornfelsed or silicified groundmass textures in a limestone breccia near the inferred contact near station 308 and distinctive, medium-grained leucocratic, granitoid hornblende-plagioclase porphyry apophyses which intrude plagioclase-augite porphyry volcanics or laminated siltstone in two places near the contact (stations 308 and 312) imply an intrusive relationship. This tenuous relationship is uninformative because the age of these volcanics and sediments is poorly known.

Figure 46. Intrusive relations involving the McBride River Pluton and: (a) units external to the Hotailuh Batholith (see Appendix 7.2); (b) hypabyssal intrusions (see Appendix 7.3). Abbreviation "INT" refers to intrusive relationship and arrow leads from intrusion to country rock. Dashed arrow and question mark indicate uncertain intrusive relationship.

(A) EXTERNAL

(B) HYPABYSSAL INTRUSIONS

(c) Hypabyssal Intrusions

Brown to dun weathering, crudely columnar jointed, fine-grained diabase apparently intrudes the McBride River Pluton along part of the latter's eastern border. The contact is nowhere exposed but near the contact the diabase contains small, rounded, rusty and epidotized granitoid inclusions which probably represent highly altered xenoliths of the McBride River Pluton. A minor plagioclase-hornblende porphyry also locally intrudes the McBride River Pluton.

IV.3.4 Age

A potassium-argon hornblende date of 186 ± 11 Ma has been determined for a representative specimen of the McBride River Pluton (Table IV.3 and Figure 47). This date, intrusive relations with the Upper Triassic volcanics and gross similarity to the Three Sisters Pluton suggest that the McBride River Pluton belongs to the suite of Jurassic plutons which form part of the Hotailuh Batholith (cf. Figures 42 and 47).

IV.3.5 Petrography

Nature, abundance (Figure 45 and Appendix 7.4) and habit of essential and accessory minerals in the McBride River Pluton distinguish it from the Three Sisters Pluton and are similar to satellitic plutons of the Jurassic plutonic suite. Apatite, zircon, opaque minerals, plagioclase, hornblende, biotite, titanite, quartz, allanite and alkali feldspar apparently crystallized in about that order to form granodiorite of the McBride River Pluton. The rocks are fresh and the uncommon, late-formed alteration products of

TABLE IV.3.1 POTASSIUM-ARGON RADIOMETRIC AGE DATA FOR THE MCBRIDE RIVER PLUTON¹

SPECIMEN NUMBER	PLUTON	LOCATION (LATITUDE- LONGITUDE)	LITHOLOGY \ MINERAL	ZK	Z ⁴⁰ Ar	AGE (Ma)
AN-78-467	MCBRIDE RIVER PLUTON	58° 03' 12" N 129° 08' 00" W	granodiorite hornblende	0.338	66.8	186 ± 13

1. All potassium-argon ages are consistent with the decay constants of Steiger and Jäger (1977). All lithologies are classified according to Streckeisen (1973).

Figure 47. Mineral K-Ar isotopic age for the McBride River Pluton and the Jurassic portion of Armstrong's (1978a, 1981) time scale. Analytical errors in age are 2σ (see Table IV.3.1). Dashed horizontal lines outline time interval of most of the oldest K-Ar isotopic ages determined for the Three Sisters Pluton.

hornblende, biotite and cores of plagioclase are chlorite and sericite.

Apatite and zircon are small to medium-sized, subhedral to euhedral grains commonly associated with or enclosed in opaque minerals. Pale brown opaque dustings are common in cores of some apatite grains. Opaques occur as euhedral, separate and squarish grains or as subhedral or anhedral and more inclusion-rich aggregates. The better-formed variety commonly occurs with hornblende and biotite; clots of subhedral or anhedral hornblende, biotite, apatite and (or) opaque minerals are rare but distinctive.

Plagioclase (predominantly oligoclase to andesine; An_{32-51}) is subhedral to euhedral and encloses well-formed apatite, zircon, and opaque minerals. Hornblende (predominantly as smaller, euhedral grains) is also a rare inclusion and commonly occurs in the outer part of a plagioclase grain. Discontinuous, normal and oscillatory zoning are responsible for compositional changes up to An_8 (e.g., core = An_{40-45} , rim = An_{33-37}); irregular, calcic cores are only very rarely observed. Myrmekite is developed at a few contacts between plagioclase and alkali feldspar.

Euhedral to subhedral hornblende is commonly twinned and encloses and (or) crystallized among better-formed apatite, zircon, opaque minerals, and plagioclase. Brown pigmentation of hornblende in sections perpendicular to z and its distinctive pleochroic scheme (α' = very pale brownish or greenish yellow; β = brownish olive green; γ' = light grass green) is similar to amphiboles in satellitic members of the Jurassic plutonic suite. Grains with patchy pleochroism are uncommon. Uncommon mafic clots consist of some or all of subhedral and euhedral hornblende, apatite, opaque minerals and biotite.

Biotite is characterized by its subhedral, rectangular sections which enclose apatite, zircon, opaque minerals and plagioclase and by its patchy

secondary habit where it encloses or occurs within hornblende.

Locally it is also intergrown with quartz and alkali feldspar.

Biotite pleochroism is also typical for these marginal or satellite Jurassic plutons: α' = light brownish yellow; $\beta = \gamma'$ = rusty or dark brown.

Titanite is predominantly anhedral and interstitial with respect to opaques, plagioclase and hornblende. It is also associated with irregular, optically continuous veinlets which occur along cleavage in adjacent biotite or anastomose through and enclose parts of late-formed alkali feldspar grains. Rare allanite was another late-forming accessory mineral which encloses hornblende and occurs as veins along quartz-plagioclase grain boundaries.

Quartz is comparatively little strained, anhedral and crystallized against or around better-formed zircon, opaque minerals, plagioclase, hornblende and biotite. A subhedral habit or straight grain boundaries with alkali feldspar is common but not ubiquitous.

Slightly turbid or clear alkali feldspar apparently crystallized late in the sequence among or around all other minerals except titanite; rare quartz inclusions are subhedral. Alkali feldspar is uncommonly microperthitic and exhibits rare Carlsbad twins.

IV.3.6 Chemical Composition

Major, minor and trace elements and CIPW norms for six samples (seven analyses) from the McBride River Pluton are given in Table IV.3.2 and are plotted in Figure 48.

Minor normative corundum and hypersthene characterize the McBride River Pluton and the abundant normative quartz accords the abundance of visible quartz which distinguishes the rock.

In the familiar alkali-silica plot (Figure 48 (a); after Irvine and Baragar, 1971) and normative $ne'-ol'-qz'$ ternary (Figure 48 (b); after Irvine and Baragar, 1971), the McBride River Pluton is clearly subalkaline. The calc-alkaline affinity of the samples is illustrated in the AFM (Figure 48 (c); after Irvine and Baragar, 1971), SiO_2-FeO^*/MgO (Figure 48 (d); after Miyashiro, 1974), MgO -total iron (Figure 48 (e); after Lowder and Carmichael, 1970; Stauffer *et al.*, 1975) and Al_2O_3 -normative plagioclase (Figure 48 (f); after Irvine and Baragar, 1971) plots. The alumina-normative plagioclase plot also emphasizes the lower Al_2O_3 content of the McBride Pluton (>17 weight per cent) compared with more mafic phases or plutons in the Jurassic or Triassic plutonic suites. In the weight per cent $Na_2O-K_2O-CaO_2$ ternary plot, the McBride River Pluton is distinguished by nearly equal proportions of each oxide. The characteristic compositional homogeneity of the pluton is exemplified in most variation diagrams by the tight clustering of sample compositions and in low standard deviation (1σ) from the average composition (Table IV.3.2).

The average composition of the McBride River Pluton (see Table IV.3.2) compares closely with the average granodiorites of Le Maitre (1976) and

TABLE IV.3.2 CHEMICAL COMPOSITION OF THE MCBRIDE RIVER PLUTON

(a) Location and lithology of specimens

SPECIMEN	UNIT	LOCATION (Latitude and Longitude)	LITHOLOGY ¹
164-2	McBride River Pluton	58°05'55"N 129°13'00"W	biotite-hornblende quartz monzo- diorite
253-1	"	58°05'16"N 129°12'45"W	biotite-hornblende quartz monzo- diorite
307-1	"	58°04'52"N 129°04'30"W	biotite-hornblende quartz monzo- diorite
309-3	"	58°04'00"N 129°05'30"W	biotite-hornblende quartz monzo- diorite
310-1	"	58°03'33"N 129°05'00"W	biotite-hornblende quartz monzo- diorite
467A	"	58°03'12"N 129°08'00"W	biotite-hornblende quartz monzo- diorite (K-Ar SPECIMEN)
467B	"	same as specimen 467A	same as specimen 467A

1. All lithologies classified after Streckeisen (1973)

TABLE IV.3.2. CHEMICAL COMPOSITION OF THE McBRIDE RIVER PLUTON

(b) Major Elements (in weight per cent)

OXIDE	SPECIMENS							AVERAGE (1σ)
	164-2	253-1	307-1	309-3	310-1	467A	467B	
SiO ₂	64.8	67.1	66.0	68.5	67.2	67.5	67.3	66.9 (1.2)
Al ₂ O ₃	17.1	15.2	16.6	15.2	16.2	15.5	15.5	15.9 (0.7)
TiO ₂	0.29	0.28	0.27	0.25	0.23	0.29	0.41	0.29 (0.06)
Fe ₂ O ₃	1.8	1.6	1.4	1.7	1.5	1.7	1.4	1.6 (0.2)
FeO	2.1	1.5	2.0	1.5	1.6	1.7	2.0	1.8 (0.3)
MnO	0.08	0.07	0.07	0.06	0.06	0.07	0.07	0.07 (0.1)
MgO	1.87	1.45	1.65	1.58	1.42	1.51	1.36	1.55 (0.17)
CaO	3.86	3.17	3.35	3.28	3.19	3.47	3.37	3.38 (0.23)
Na ₂ O	4.3	3.6	3.9	3.6	3.9	4.1	3.8	3.9 (0.3)
K ₂ O	2.16	3.10	2.75	2.66	2.85	3.30	3.20	2.86 (0.39)
P ₂ O ₅	0.17	0.07	0.11	0.11	0.09	0.13	0.14	0.12 (0.03)
H ₂ O _T	1.4	0.7	0.7	0.4	0.8	1.2	0.8	
CO ₂	B.D.	B.D.	0.1	B.D.	B.D.	0.1	B.D.	
S	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	
Cl	0.03	0.04	0.03	0.03	N.A.	N.A.	N.A.	
F	0.04	0.03	0.03	0.02	N.A.	N.A.	N.A.	
Total	100.00	97.91	98.96	99.09	98.84	100.57	99.35	(98.37)

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE IV.3.2 CHEMICAL COMPOSITION OF THE MCBRIDE RIVER PLUTON

(c) Trace Elements (in ppm)

	SPECIMENS							AVERAGE (1σ)
	164-2	253-1	307-1	310-1	309-3	467A	467B	
Rb	20	90	50	40	30	90	80	60 (30)
Sr	470	510	460	430	390	480	430	450 (40)
Ba	610	1000	620	780	930	980	930	840 (170)
U	2.2	2.3	2.3	1.9	N.A.	N.A.	N.A.	2.2 (0.2)
Zr	100	110	28	B.D.	33	98	120	82 (40)
Cr	B.D.	B.D.	B.D.	B.D.	8.1	B.D.	B.D.	8.1
Co	11	17	B.D.	B.D.	B.D.	B.D.	B.D.	14 (4)
Ni	B.D.	B.D.	B.D.	B.D.	13	B.D.	B.D.	13
V	84	90	75	63	84	73	66	76 (10)
Cu	29	23	36	20	20	15	14	22 (8)
Zn	20	20	10	20	30	60	90	36 (29)

B.D.: below detection limits of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE IV.3.2 CHEMICAL COMPOSITION OF THE McBRIDE RIVER PLUTON
(d) CIPW Normative Minerals (in weight per cent)

NORMATIVE MINERALS	SPECIMENS						
	164-2	253-1	307-1	310-1	309-3	467A	467B
qz	20.01	25.04	22.73	24.25	27.83	21.69	23.20
or	12.77	18.32	16.25	16.84	15.72	19.50	18.91
ab	36.38	30.46	33.00	33.00	30.46	34.69	32.15
an	18.04	15.27	15.27	15.24	15.55	14.15	15.79
c	1.08	0.33	1.61	1.12	0.70		
dl						1.27	0.01
hy	6.69	4.71	6.31	4.97	4.99	4.52	5.35
mt	2.61	2.32	2.03	2.17	2.46	2.46	2.03
fl	0.55	0.53	0.51	0.44	0.47	0.55	0.78
ap	0.40	0.16	0.26	0.21	0.26	0.31	0.33
cc			0.23			0.23	
H ₂ O	1.4	0.7	0.7	0.8	0.4	1.2	0.8
Cl	0.03	0.04	0.03	0.03			
F	0.04	0.03	0.03	0.02			
Total	100.00	97.91	98.86	99.09	98.84	100.57	99.35

Figure 48. Chemical variation diagrams for samples from the McBride River Pluton.

- a) Weight per cent alkali-silica diagram. Alkaline-subalkaline division after Irvine and Baragar (1971).
- b) Weight per cent normative ne' - ol' - qz' ternary diagram ($ne' = ne + 3/5 ab$; $qz' = qz + 2/5 ab + 1/4 opx$; $ol' = ol + 3/4 opx$). Alkaline-subalkaline division after Irvine and Baragar (1971).
- c) Weight per cent A ($Na_2O + K_2O$) - F ($FeO + 0.8998 Fe_2O_3$) - M (MgO) ternary diagram. Calc-alkaline - tholeiitic division after Irvine and Baragar (1971).
- d) Weight per cent SiO_2 - FeO^*/MgO diagram ($FeO^* = FeO + 0.9 Fe_2O_3$). Calc-alkaline - tholeiitic division after Miyashiro (1974).
- e) Weight per cent MgO - total iron diagram. Cascades, abyssal tholeiite (AT), pigeonitic series and Thingmuli trends after Stauffer *et al.* (1975).
- f) Weight per cent alumina-normative plagioclase diagram. Calc-alkaline - tholeiitic division after Irvine and Baragar (1971).
- g) Weight per cent Na_2O - K_2O - CaO ternary diagram.

Symbols are: ○ grab samples; ◇ replicate K-Ar samples.

a) Alkali-silica diagram for the McBride River Pluton

b) Ne'-ol'-qz' ternary for the McBride River Pluton

c) AFM ternary for the McBride River Pluton

d) Silica - FeO*/MgO diagram for the McBride River Pluton

f) Alumina - normative plagioclase diagram for the McBride River Pluton

g) Na_2O - K_2O - CaO ternary for the McBride River Pluton

Nockolds (1954) except for slightly lower TiO_2 , FeO and P_2O_5 contents.

The age-date sample is compositionally similar to other samples from the pluton.

Further geochemical comparisons between the McBride River Pluton and other plutonic and volcanic units are discussed in Chapter VI.

Harker variation diagrams for the pluton are given in Appendix 7.5.

IV.4 SNOWDRIFT CREEK PLUTON

IV.4.1 Distribution, Physiography and Aeromagnetic Expression

The Snowdrift Creek Pluton comprises several large outcrop areas separated by large areas of Recent cover in and around Snowdrift Creek. If they are all part of one body, they indicate an area of 67 km². Two outcrop areas were investigated in this study: one at the most northwesterly of these large outcrops and the other at the most southeasterly of these exposures (Figure 49). A small apophysis in the Upper Triassic volcanics near stations 690 and 699 was also mapped and is probably one of the most southerly stocks of a north northeasterly-trending belt of small intrusions southwest of the Snowdrift Creek Pluton. The pluton underlies rounded ridges and low lying creek outcrops. A large aeromagnetic depression (to a low of 58360 gammas) occupies the central part which is devoid of outcrop; the outcrops around the margins are characterized by local aeromagnetic highs (up to 58670 gammas), are on the flanks of aeromagnetic highs (up to 58670 gammas) or are on the flanks of aeromagnetic "ridges" (e.g. with values between 58590 and 58650 gammas; see Figure 2).

IV.4.2 Lithology

The two main outcrop areas examined in this study are generally similar. Both are quartz monzodiorite to granodiorite in composition in contrast to the small stock at stations 690 and 699 which is diorite (Figure 50). All rocks are white weathering, equigranular to moderately seriate, medium-grained and hypidiomorphic. In the northwestern outcrops, biotite predominates over uncommon hornblende, and quartz is common; the rock bears marked similarities to that of the McBride River Pluton. In

(modified from Gabrielse, 1979)

- drift
- Snowdrift Creek Pluton
- Takwahoni Formation
- Triassic-Jurassic volcanics
- Stuhini Group

Figure 49. Geological and station map for the Snowdrift Creek Pluton (SCP). Abbreviations are: KSF = King Salmon Fault; JPS = Jurassic Plutonic Suite; PCP = Pallen Creek Pluton; TP = Tanzilla Pluton. Other symbols as in Figure 1. Inset map shows location of satellitic plutons relative to the Hotailuh Batholith.

Figure 50. Modal compositions of hand samples and thin sections from Snowdrift Creek Pluton (see Appendix 8.4). Classification after Streckeisen (1973). Abbreviations are: KF = alkali feldspar; PF = plagioclase feldspar; and Qz = quartz.

the southeastern part, hornblende is equal to or predominates over biotite and quartz is less common. The stock at stations 690 and 699 is also hornblende-rich. In all cases the mafics are euhedral to subhedral. As implied above, quartz is an important constituent. Plagioclase is subhedral but alkali feldspar appears interstitial and anhedral. Titanite locally is a important accessory (especially in the southeastern outcrop area). Fine-grained mafic diorite inclusions and mafic schlieren are rare but widespread in the southeastern outcrops and at station 690 (Appendix 7.1); in the northwestern part, no xenoliths were observed. Local lithological similarities between parts of the Snowdrift Creek Pluton and the McBride Pluton were noted above; the common fabric in the Snowdrift Creek Pluton distinguishes it from the McBride River Pluton.

IV.4.3 Structure

A widespread, moderate to well developed mineral foliation characterizes the northwestern and southeastern exposures of the Snowdrift Creek Pluton (Plate VIII D); the small stock at stations 690 and 699 is massive. Hornblende and biotite, rarely alkali feldspar, outline the fabric. In the northwest, the foliation trends northeast and dips fairly steeply northwest; in the southeast, planar fabrics also strike northeasterly but dip southeast (Appendix 7.2). Schlieren, more common in the southeastern outcrop, parallel foliation (Plate VIII E). The fabric along the southeastern margin is also concordant with the attitude of the intruded volcanics and sediments. From the two outcrop areas investigated, the mineral foliation and schlieren appear to define steeply northwesterly and southeasterly dipping margins for the body at the present level of erosion.

IV.4.4 Intrusive Relations

Intrapluton, external and interpluton intrusive relations suggest more than one pulse of plutonic emplacement and provide a broad constraint on the maximum age of the Snowdrift Creek Pluton (Appendix 7.3 and Figure 51).

(a) Intrapluton Intrusive Relations

Along the northwestern margin of the Snowdrift Creek Pluton, an irregular apophysis, at least 4 m wide, of fine- to medium-grained biotite monzodiorite appears to intrude the coarser-grained hornblende-biotite quartz monzodiorite or granodiorite. Along the southeastern margin of the body, thin pegmatite or medium-grained quartz syenite veins locally intrude the monzodiorite. The small stock south of Horn Mountain decreases in grain size to a fine- to medium-grained diorite near its inferred contact with the Cake Hill Pluton. Elsewhere in the small stock, an irregular, leucocratic diorite dike intrudes the monzodiorite.

(b) External Intrusive Relations

Along the southeastern margins of the pluton, Upper Triassic? augite porphyry is intruded, included as discrete xenoliths and small screens and metamorphosed along the intrusive contacts. The Snowdrift Creek Pluton increases in mafic content towards its intrusive contacts with these country rocks. Within a short distance of the contact, arkosic? sediments, apparently interbedded with mafic porphyritic volcanic flows, have a granular, almost gneissic, appearance but retain vestiges of bedding. From a distance, the contrasting white weathering talus of the granitic rocks and dark grey weathering talus of the metavolcanic rocks define a subvertical contact between the southeastern part of the pluton and its Upper Triassic? country rocks (Figure 51). About 1 km farther east, at station 710, a large,

Figure 51. Intrusive relations involving the Snowdrift Creek Pluton and: (a) units external to the pluton; (b) intraplutonic units (see Appendix 8.3 for both). Abbreviation "INT" refers to intrusive relationship and arrow leads from intrusion to country rock. Dashed arrow and question mark indicates uncertainty in intrusive relationship.

glassy, plagioclase porphyry apophysis (similar to that seen in the Three Sisters Pluton's leucocratic and potassic marginal phases) intrudes augite-plagioclase porphyry volcanics.

Along the northwestern margin of the pluton, in another creek exposure (station 330), rusty, tough, very fine-grained hornfelsed argillites occur. Well developed bedding is commonly folded about irregular axes and locally, a 3 m wide, fine-grained biotite monzodiorite apophysis anastomoses through the sediments. Elsewhere, similar folded, though less metamorphosed sediments preserve Pleinsbachian ammonites (H. Gabrielse, personal communication, August 1977).

IV.4.5 Age

A K-Ar biotite date of 147 ± 5 Ma was determined for a specimen from the northwestern outcrop area of the Snowdrift Creek Pluton (Table IV.4.1). The date is consistent with the geologically inferred post-Pleinsbachian intrusion of the pluton (Figure 52) and is the minimum age of intrusion. Because the pluton intrudes folded Pleinsbachian sediments, its intrusion may also post-date earliest movements on the King Salmon Fault (H. Gabrielse, personal communication, February, 1981).

TABLE IV.4.1 POTASSIUM-ARGON RADIOMETRIC AGE DATA FOR THE SNOWDRIFT CREEK PLUTON¹

SPECIMEN NUMBER	PLUTON	LOCATION (LATITUDE- LONGITUDE)	LITHOLOGY	MINERAL	ZK	$Z^{40}Ar$	AGE (Ma)
AN-77-329	SNOWDRIFT CREEK PLUTON	58°20'30"N 129°36'00"W	granodiorite	biotite	7.57	90.1	147 ± 5

1. All potassium-argon ages are consistent with the decay constants of Steiger and Jäger (1977). All lithologies are classified according to Streckeisen (1973).

Figure 52. Mineral K-Ar isotopic age for the Snowdrift Creek Pluton and the Jurassic portion of Armstrong's (1978a; 1981) time scale. Analytical errors in age are 2σ (see Table IV.4.1). Pliensbachian age of folded sediments intruded by the Snowdrift Pluton is shown by cross-hatched pattern.

IV.4.6 Petrography

Snowdrift Creek Pluton granodiorite and tonalite is characterized by the nature, abundance (Figure 50 and Appendix 8.4) and texture of its essential and accessory minerals (in inferred order of crystallization): apatite, zircon, opaque minerals, plagioclase, hornblende, titanite, biotite, quartz and alkali feldspar. Anhedral epidote, chlorite, white mica and calcite are uncommon late forming alteration products of ferromagnesian minerals and plagioclase.

Accessory minerals apatite, zircon and opaque minerals are generally finer-grained and better-formed than the essential minerals. Euhedral apatite and zircon occur separately and in places are medium-grained, but are most commonly associated with and enclosed in subhedral squarish opaque minerals which are distinguished by their abundance of inclusions. Locally, opaque minerals are not well formed and are interstitial with respect to hornblende and plagioclase. Allanite is a very rare, subhedral accessory.

Plagioclase (oligoclase to andesine: An_{27-44}) is subhedral to euhedral. Irregular calcic cores are absent and oscillatory and discontinuous normal zoning are common. Compositional changes of up to An_6 between core and rim are observed (e.g., core composition of An_{33} and rim composition of An_{27}). Euhedral zircon, subhedral opaque minerals and rarely subhedral hornblende are enclosed in plagioclase. Myrmekite is developed along plagioclase rims at some contacts with interstitial alkali feldspar.

Hornblende occurs as subhedral to euhedral, commonly twinned grains and has distinctive pleochroism (α' = clear to pale greenish or brownish yellow; β = olive green; γ' = bluish or grass green). In the south-

eastern part of the pluton, hornblende has a characteristic brown pigmentation. Subhedral to euhedral apatite, opaque minerals and rarely, plagioclase are inclusions in hornblende.

Titanite forms uncommon subhedral to anhedral grains which are subhedral where enclosed by biotite and anhedral where it crystallized between and around better-formed opaque minerals, plagioclase and hornblende. Rare titanite is optically zoned.

Light yellow to sienna or dark brown biotite has a subhedral, rectangular habit or occurs as poorer-formed grains between euhedral plagioclase, subhedral hornblende and anhedral quartz. Biotite also occurs as secondary ragged, optically continuous patches in hornblende. Apatite (associated with rare pleochroic haloes), opaque minerals, plagioclase, hornblende and titanite occur as inclusions in biotite. Distinctive oval or elliptical white mica(?) alteration zones along cleavage in biotite are common.

Rare glomeroporphyritic clots of hornblende, biotite and opaque minerals distinguish rocks from the southeastern part of the pluton.

Quartz is commonly anhedral except in a few places where it is in contact with or enclosed by alkali feldspar and has subhedral grain boundaries. Subgrains are common to uncommon. Quartz crystallized among or enclosed better-formed apatite, opaque minerals, plagioclase and hornblende.

Alkali feldspar is anhedral and homogeneous or rarely microperthitic. It is more abundant in the southeastern part of the pluton (sample 708-1) compared with western outcrops (sample 329; Appendix 8.4). Opaque minerals, zircon, plagioclase, hornblende, biotite and quartz are euhedral to subhedral inclusions in alkali feldspar anhedral.

IV.4.7 Chemical Composition

Two samples from the Snowdrift Creek Pluton were analyzed for major, minor and trace elements (see Table IV.4.2 for analyses and CIPW norms and Figure 53). The samples were collected from the northwestern (329) and southeastern (708-2) parts of the pluton and differ chemically. Both contain normative hypersthene and quartz. Sample 329 is more siliceous and is distinguished by normative corundum compared with the normative diopside and hematite of sample 708-2. Alkali-silica (Figure 53(a)) and the normative $ne'-ol'-qz'$ ternary (Figure 53(b)) plots illustrate the subalkaline nature of the two samples (classification after Irvine and Baragar, 1971). The AFM ternary (Figure 53(c); after Irvine and Baragar, 1971), SiO_2-FeO^*/MgO (Figure 53(d); after Miyashiro, 1974), MgO -total iron (Figure 53(e); after Lowder and Carmichael, 1970; Stauffer *et al.*, 1975) and Al_2O_3 -normative plagioclase (Figure 53(f); after Irvine and Baragar, 1971) plots show the calc-alkaline nature of the compositions. The alumina-normative plagioclase plot also emphasizes the lower Al_2O_3 content (about 16 weight per cent) of these samples compared to mafic and some felsic plutons or phases in the Triassic and Jurassic plutonic suites. The Snowdrift Creek Pluton is depleted in K_2O relative to Na_2O and CaO as seen in the weight per cent Na_2O-K_2O-CaO ternary plot (Figure 53(g)).

The average composition of the Snowdrift Creek Pluton (see Table Table IV.4.2) compares crudely with the average granodiorite of Le Maître (1976) and the biotite granodiorite, hornblende-biotite granodiorite and average granodiorite of Nockolds (1954); the main discrepancies occur in Al_2O_3 , Fe_2O_3 , FeO , MgO , CaO , Na_2O and K_2O contents. Sample 329 compares most closely with McBride River Pluton compositions and

TABLE IV.4.2 CHEMICAL COMPOSITION OF THE SNOWDRIFT CREEK PLUTON

(a) Location and lithology of specimens

SPECIMEN	UNIT	LOCATION (Latitude and Longitude)	LITHOLOGY ¹
329	Snowdrift Creek Pluton	58°20'30"N 129°36'00"W	hornblende-biotite quartz monzo- diorite (K-Ar SPECIMEN)
708-2	" "	58°16'33"N 129°23'45"W	biotite-hornblende quartz monzo- diorite

¹ All lithologies classified after Streckeisen (1973)

TABLE IV.4.2 CHEMICAL COMPOSITION OF THE SNOWDRIFT CREEK PLUTON
(b) Major Elements (in weight per cent)

OXIDE	SPECIMENS		AVERAGE (1σ)
	708-2	329	
SiO ₂	64.7	67.2	66.0 (1.8)
Al ₂ O ₃	16.3	15.6	16.0 (0.5)
TiO ₂	0.58	0.28	0.43 (0.21)
Fe ₂ O ₃	3.0	2.4	2.7 (0.4)
FeO	1.2	1.3	1.3 (0.1)
MnO	0.08	0.07	0.08 (0.01)
MgO	2.42	1.97	2.20 (0.32)
CaO	4.61	3.94	4.28 (0.47)
Na ₂ O	4.4	4.2	4.3 (0.1)
K ₂ O	1.80	1.65	1.73 (0.11)
P ₂ O ₅	0.16	0.15	0.16 (0.01)
H ₂ O _T	0.4	0.6	
CO ₂	B.D.	0.1	
S	B.D.	B.D.	
Cl	0.03	N.A.	
F	0.03	N.A.	
Total	99.71	99.46	(99.18)

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE IV.4.2 CHEMICAL COMPOSITION OF THE SNOWDRIFT CREEK PLUTON
(c) Trace Elements (in ppm)

	SPECIMENS		AVERAGE (σ)
	708-2	329	
Rb	80	20	50 (40)
Sr	540	390	470 (110)
Ba	700	590	650 (80)
U	N.A.	N.A.	
Zr	B.D.	84	84
Cr	15	10	13 (4)
Co	B.D.	B.D.	
V	78	69	74 (6)
Ni	B.D.	B.D.	
Cu	15	11	13 (3)
Zn	60	40	50 (14)

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE IV.4.2 CHEMICAL COMPOSITION OF THE SNOWDRIFT CREEK PLUTON
(d) CIPW Normative Minerals (in weight per cent)

NORMATIVE MINERALS	708-2	329
qz	19.70	25.74
or	10.64	9.75
ab	37.23	35.54
an	19.41	17.93
c		0.33
df	1.87	
hy	5.16	4.98
mt	2.45	3.48
hm	1.31	
tl	1.10	0.53
ap	0.38	0.35
cc		0.23
H ₂ O	0.4	0.6
Cl	0.03	
F	0.03	
Total	<u>99.71</u>	<u>99.46</u>

Figure 53. Chemical variation diagrams for samples from the Snowdrift Creek Pluton.

- a) Weight per cent alkali-silica diagram. Alkaline-subalkaline division after Irvine and Baragar (1971).
- b) Weight per cent, normative $ne'-ol'-qz'$ ternary diagram ($ne' = ne + 3/5 ab$; $qz' = qz + 2/5 ab + 1/4 opx$; $ol' = ol + 3/4 opx$). Alkaline-subalkaline division after Irvine and Baragar (1971).
- c) Weight per cent A ($Na_2O + K_2O$) - F ($FeO + 0.8998 Fe_2O_3$) - M (MgO) ternary diagram. Calc-alkaline - tholeiitic division after Irvine and Baragar (1971).
- d) Weight per cent SiO_2 - FeO^*/MgO diagram ($FeO^* = FeO + 0.9 Fe_2O_3$). Calc-alkaline - tholeiitic division after Miyashiro (1974).
- e) Weight per cent MgO - total iron diagram. Cascades, abyssal tholeiite (AT), pigeonitic series and Thingmuli trends after Stauffer et al. (1975).
- f) Weight per cent alumina-normative plagioclase diagram. Calc-alkaline - tholeiitic division after Irvine and Baragar (1971).
- g) Weight per cent Na_2O - K_2O - CaO ternary diagram.

Symbols are: ○ grab samples; ◇ K-Ar sample.

a) Alkali-silica diagram for the Snowdrift Creek Pluton

b) Ne' - ol' - qz' ternary for the Snowdrift Creek Pluton

c) AFM ternary for the Snowdrift Crek Pluton

d) Silica - FeO*/MgO diagram for the Snowdrift Crk Pluton

e) MgO - total iron diagram for the Snowdrift Creek Pluton

f) Alumina - normative plagioclase diagram for the Snowdrift Creek Pluton

g) $\text{Na}_2\text{O} - \text{K}_2\text{O} - \text{CaO}$ ternary for the Snowdrift Creek Pluton

sample 708-2 is similar to intermediate compositions in the composite plutons of the Jurassic plutonic suite.

Further geochemical comparisons between the Snowdrift Creek Pluton and other volcanic and plutonic units are made in Chapter VI. Harker variation diagrams for the pluton are given in Appendix 8.5.

IV.5 PALLAN CREEK PLUTON

IV.5.1 Distribution, Physiography and Magnetic Expression

The Pallen Creek Pluton underlies an area of 44.8 km² west-northwest of the Hotailuh Batholith and comprises a granodiorite margin (15.7 km²) and quartz monzonite core (29.2 km²) (Gabrielse, 1980a; Figure 54). In two traverses across the body during this study (Figure 54), the granodiorite marginal phase was not observed. The pluton is characterized by subdued relief; it occupies the valley floor incised by Pallen Creek, and outcrops are scattered except along the sides of the valley (Plate VIII-F). Regionally, the Pallen Creek Pluton is also distinguished by an aeromagnetic high (from 58500 to 59300 gammas) although in detail a number of small, local highs (between 58880 and 59000 gammas) and one aeromagnetic low (to 58790 gammas) occur within its margins (Figure 2).

IV.5.2 Lithology

Quartz monzodiorite and quartz monzonite with alkali feldspar megacrysts are the most common lithologies in the parts of the Pallen Creek Pluton studied (Figure 55). A pinkish cream weathering, massive, equigranular, medium-grained, hypidiomorphic quartz monzodioritic groundmass contains the more euhedral, medium- to coarse-grained to coarse-grained, seriate alkali feldspar megacrysts. Hornblende predominates over biotite but both are subhedral. Plagioclase is less well formed than the alkali feldspar megacrysts and quartz is anhedral. Titanite is an uncommon accessory. Rare, small (4 cm long) fine-grained diorite inclusions are present.

At the northeast end of the pluton (station 644), three other distinctive but areally insignificant, lithologies were observed. An equigranular,

Figure 54. Geological and station location map for the Pallen Creek Pluton (PCP) modified from Gabrielse (1980a). Inset map shows location of satellitic plutons and Hotailuh Batholith. Abbreviations are: KSF = King Salmon Fault; JPS = Jurassic Plutonic Suite; SCP = Snowdrift Creek Pluton; TP = Tanzilla Pluton; and TPS = Triassic Plutonic Suite. Other symbols as in Figure 1.

○ THIN SECTION (grab sample,
felsic phase)

● THIN SECTION (grab sample,
mafic phase)

◇ THIN SECTION (K-Ar
sample, felsic phase)

• HAND SAMPLE (9
samples),

Figure 55. Modal compositions of hand samples and thin sections from the felsic and mafic phases of Pallen Creek Pluton (see Appendix 9.3). Classification after Streckeisen (1973). Abbreviations are: KF = alkali feldspar; PF = plagioclase feldspar; and Qz = quartz.

medium-grained, hypidiomorphic-granular biotite-hornblende monzodiorite occurs with an irregular body of melanocratic, equigranular, medium-grained gabbro and hypidiomorphic-granular, fine- to medium-grained leucocratic hornblende-biotite quartz syenite. Only the gabbro exhibits any fabric. Except for unambiguous inclusions of earlier formed phases or volcanic country rock in later intrusions, these three lithologies are devoid of other inclusions.

IV.5.3 Structure

The minor, irregular gabbro body exhibits well developed vertical foliation which trends east southeast (Appendix 9.1) and is highly discordant with the plutonic-volcanic contact.

IV.5.4 Intrusive Relations

Intrapluton and external intrusive relations are best exposed along the eastern and northeastern margins of the pluton (Figure 56; Appendix 9.2).

(a) Intrapluton Intrusive Relations

Along the northeastern margin, apophyses of the equigranular biotite-hornblende monzodiorite intrudes and includes the biotite-hornblende gabbro (Plate VIII H). Thin, irregular aplitic quartz syenite apophyses intrude the monzodiorite and the gabbro (Plate VIII G). The quartz syenite intrudes the more extensive alkali feldspar megacryst-bearing quartz monzodiorite but the relationship of the latter with the gabbro and equigranular monzodiorite phases was not observed.

(b) External Intrusive Relations

The Pallen Creek Pluton intrudes, includes and metamorphoses the Upper

Figure 56. Intrusive relations involving the Pallen Creek Pluton and: (a) a unit external to the pluton; (b) intraplutonic units (see Appendix 9.2 for both). Abbreviation "INT" refers to intrusive relationship and arrow leads from intrusion to country rock. Question mark refers to uncertain relationship between units.

(A) EXTERNAL

PALLEN CREEK PLUTON
(K-Ar: 145 ± 7 Ma, 165 ± 8 Ma,
 197 ± 18 Ma)

INT

UPPER TRIASSIC
VOLCANICS AND
SEDIMENTS

(B) INTRAPLUTON

YOUNGER

Triassic thin-bedded argillite and massive augite porphyry volcanics. Near station 633, a small, oval, equigranular aplitic monzonite cuts augite porphyry breccia.

At station 637, augite porphyry appears to structurally underlie the recrystallized Permian? limestone and may separate it from the intrusion; elsewhere, a broad covered area separates the recrystallized limestone and the Pallen Creek Pluton (Plate VIII F).

IV.5.5 Age

Three K-Ar isotopic dates have been determined for the Pallen Creek Pluton. Discordant hornblende-biotite dates of 165 ± 8 Ma and 145 ± 7 Ma from one specimen of quartz monzodiorite (probably the alkali feldspar megacryst-bearing variety) from the northwest corner of the Pallen Creek Pluton are reported by Wanless et al. (1972, p.17; see also Plate VIII F, Figure 57 and Table IV.5.2). A hornblende date of 197 ± 18 Ma was determined for a typical alkali feldspar megacryst-bearing quartz monzodiorite in the south central part of the pluton. Clearly, all three dates, apparently from the same unit, span the same interval (within the 2σ analytical uncertainty) as the K-Ar dates from the Three Sisters Pluton which is in accord with the similar range in lithologies and analogous intrapluton and external intrusive relations.

TABLE IV.5.1 POTASSIUM-ARGON RADIOMETRIC AGE DATA FOR THE PALLEN CREEK PLUTON¹

SPECIMEN NUMBER	PLUTON	LOCATION (LATITUDE- LONGITUDE)	LITHOLOGY	MINERAL	ZK	$^{40}\text{Ar}/^{39}\text{K}$	% ^{40}Ar	AGE (Ma)
GSC 70-25 ²	PALLEN CREEK	58°15'30"N 130°15'30"W	quartz monzonite	hornblende	0.47	0.0099	60	165 ± 8
GSC 70-26 ²	PLUTON			biotite	5.80	0.0086	93	145 ± 7
AN-79-635	PALLEN CREEK PLUTON	58°14'00"N 130°15'00"W	quartz monzo- diorite	hornblende	0.43		75.3	197 ± 18

1. All potassium-argon ages are consistent with the decay constants of Steiger and Jäger (1977). All lithologies are classified according to Streckeisen (1973).

2. from Wanless et al. (1972, p.17)

Figure 57. Mineral K-Ar isotopic ages for the Pallen Creek Pluton and the Jurassic portion of Armstrong's (1978a, 1981) time scale. Analytical errors in ages are 2σ (see Table IV.5.1). Dashed horizontal lines give time interval for most of the oldest K-Ar isotopic ages determined for the Three Sisters Pluton.

IV.5.6 Petrography

Diorite of the mafic phase and granodiorite and granite of the felsic phase of the Pallen Creek Pluton are distinguished by the nature, abundance (Figure 55 and Appendix 9.3) and habit of their essential and accessory minerals. Petrography of the samples used for K-Ar isotopic age determinations in this work (sample 635-1) and in previous studies (Wanless et al., 1972; sample GA-67-97) are petrographically identical with other samples of the felsic phase.

Apatite, plagioclase, clinopyroxene, hornblende, biotite, opaque minerals and quartz (in approximate order of crystallization) make up diorite of the mafic phase (Appendix 9.3, sample 644-3). Extensive alteration of plagioclase to fine-grained sericite and sausserite and of hornblende and biotite to epidote and chlorite is distinctive of the mafic phase and is similar in intensity to the pervasive alteration of the Beggerlay Creek Pluton although the primary mineralogy and textures of the latter unit are dissimilar.

Fine- to medium-grained, subhedral or euhedral apatite grains are enclosed in plagioclase, hornblende and opaque minerals. Concentric, optical zonation in apatite is indicated by areas of greater or lesser abundance of brown, very fine-grained opaques.

Plagioclase is inequigranular and forms medium-grained, subhedral grains of equal size to other essential minerals as well as smaller, subhedral to anhedral grains which together with quartz form a groundmass. The coarser variety is ubiquitously altered to white mica (sericite) and sausserite; alteration of groundmass feldspar is common but not as widespread. Remnant grains indicate plagioclase is apparently homogeneous

and andesine (An_{41-47}) in composition. Euhedral apatite inclusions occur in plagioclase.

Clinopyroxene has a subophitic habit with plagioclase. Common, separate, finer-grained, subhedral biotite and separate but optically continuous amphibole patches within clinopyroxene result in a sieve-like texture. Nonetheless, these minerals are probably late-formed alteration products rather than primary inclusions. Clinopyroxene also forms irregular cores in subhedral and euhedral hornblende.

Hornblende occurs as clusters of euhedral and round, subhedral or anhedral grains which are commonly twinned. Anhedral varieties crystallized interstitially with respect to or enclose apatite, plagioclase and clinopyroxene. Hornblende pleochroism ($\alpha' =$ brownish yellow; $\beta = \gamma' =$ dark forest or olive green) and strong absorption are characteristic. Subhedral but apparently late crystallizing, fine-grained biotite commonly occurs in hornblende and produces a similar textural result as for clinopyroxene.

Common and widespread occurrence of light yellow to rusty brown biotite as fine-grained, rectangular sections within clinopyroxene and hornblende is distinctive of the Pallen Creek Pluton mafic phase and gives the rock an apparent hornfels appearance.

Opaque minerals form irregular, inclusion-rich, subhedral to anhedral grains which enclose apatite, plagioclase and biotite.

Quartz is a rare, anhedral, round mineral confined to the finer-grained groundmass.

Felsic phase granodiorite and granite are composed of apatite, zircon,

opaque minerals, plagioclase, hornblende, biotite, titanite, quartz and alkali feldspar (in approximate order of crystallization). Common chlorite and lesser amounts of epidote and sericite are alteration products of the ferromagnesian minerals and plagioclase.

Early-formed, fine-grained, subhedral to euhedral apatite and zircon are commonly associated with and enclosed within inclusion-rich, subhedral and squarish opaque minerals. The opaques commonly occur in clusters. A rare, coarse, and anhedral variety of opaque mineral crystallized late in the sequence and surrounds euhedral to subhedral hornblende, biotite and titanite.

Plagioclase (andesine to labradorite; An_{35-54}) is subhedral to euhedral, commonly zoned and contains few irregular calcic cores. Inner zones are preferentially altered to sericite and in a few places the cores are outlined by subhedral, concentrically oriented apatite and secondary biotite and epidote. Fine-grained, subhedral opaque minerals are also rare inclusions. Discontinuous normal and oscillatory zoning changes its composition up to An_{20} (e.g., core = An_{46-54} , rim = An_{26-37}).

Hornblende is subhedral to euhedral, commonly twinned and encloses subhedral to euhedral opaque minerals, apatite, plagioclase and rare, subhedral quartz; secondary(?) titanite and ragged, patchy biotite are apparently the alteration products of hornblende cores. Its pleochroism (α = pale brownish yellow; β = olive green; γ = grass green) is typical of amphiboles in other marginal or satellitic plutons of the Jurassic plutonic suite. Locally, hornblende has patchy pleochroism. Sections perpendicular to z show a distinctive brown pigmentation. Very rare

and irregular clinopyroxene forms cores in subhedral hornblende.

Light brownish yellow to medium or dark brown biotite occurs as subhedral, rectangular sections and is commonly altered to chlorite. Better-formed opaque minerals, plagioclase and titanite occur as inclusions in subhedral biotite or occur along the margins of anhedral, interstitial biotite. In a few places, it encloses rare zircon which is surrounded by a pleochroic halo.

Although titanite in these rocks is conspicuous in its euhedral to subhedral, diamond-shaped habit, very commonly these grains are associated with irregular, optically continuous, titanite veinlets that penetrate and enclose parts of apatite, opaque minerals, plagioclase, quartz and alkali feldspar. Isolated grains also occur within hornblende and biotite.

Quartz occurs as comparatively unstrained, anhedral grains which are interstitial with respect to or enclose better-formed apatite, zircon, opaque minerals, plagioclase, hornblende, biotite and titanite. An exception to this habit is locally where quartz is in contact with or included in alkali feldspar and has straight crystal margins and (or) a subhedral form.

Moderately to highly turbid, greyish brown anhedral of alkali feldspar form coarse, poikilitic plates around all other minerals. Fine-grained beads and rare strings of albitic plagioclase in the orthoclase host indicate the common microperthitic nature of these megacrysts which typify the felsic phase.

IV.5.7 Chemical Composition

Four samples collected from the Pallen Creek Pluton and analyzed for major, minor and trace elements (analyses and CIPW norms given in Table IV.5.2) are compositionally similar with the Three Sisters Pluton (see Figure 58).

Three of the four samples contain normative quartz, diopside (or very minor corundum) and hypersthene. Sample 644-3, representative of the mafic phase, is distinguished by its normative olivine and nepheline. These distinctions extend to the alkali-silica (Figure 58 (a); after Irvine and Baragar, 1971) and normative $ne'-ol'-qz'$ ternary (Figure 58(b); after Irvine and Baragar, 1971) plots where the mafic phase sample is slightly alkaline compared with the subalkaline felsic samples. The AFM and alumina-normative plagioclase plots (Figures 58(c) and 58(f); after Irvine and Baragar, 1971) show calc-alkaline affinities for the Pallen Creek Pluton compositions whereas the $SiO-FeO^*/MgO$ (Figure 58(d)) and FeO^*-FeO^*/MgO (not shown; both after Miyashiro, 1974) plots and the MgO -total iron variation diagram clearly discriminate between the calc-alkaline composition of the felsic samples and the tholeiitic affinities of the mafic phase. The alumina-normative plagioclase plot also emphasizes the high alumina content of the mafic phase (>17 weight per cent Al_2O_3) compared with the felsic samples (<17 weight per cent Al_2O_3). The significance of a tholeiitic designation for the mafic phase in view of its slightly alkaline character is uncertain. Except for the mafic phase which is CaO -enriched, the other samples contain nearly equal weight per cent proportions of Na_2O , K_2O and CaO (Figure 58(g)). Clearly, the range in compositions for the Pallen Creek Pluton is similar to the Three Sisters Pluton.

TABLE IV.5.2 CHEMICAL COMPOSITION OF THE PALLEN CREEK PLUTON

(a) Location and lithology of specimens

SPECIMEN	UNIT	LOCATION (Latitude and Longitude)	LITHOLOGY ¹
634-1	Pallen Creek Pluton	58°14'00"N 130°13'30"W	alkali feldspar megacryst-bearing quartz monzonite
643-2	"	58°17'43"N 130°26'00"W	biotite hornblende quartz monzonite with alkali feldspar megacrysts
644-3	"	58°15'30"N 130°12'00"W	hornblende gabbro
635-1	"	58°14'00"N 130°15'00"W	alkali feldspar megacryst-bearing quartz monzodiorite (K-Ar SPECIMEN)

 1. All lithologies classified after Streckeisen (1973).

TABLE IV.5.2 CHEMICAL COMPOSITION OF PALLIN CREEK PLUTON
(b) Major Elements (in weight per cent)

OXIDE	SPECIMENS			AVERAGE (1σ) ¹
	634-1	643-2	644-3	
SiO ₂	65.5	66.0	46.9	67.1 (0.8)
Al ₂ O ₃	16.9	15.9	17.5	16.2 (0.5)
TiO ₂	0.40	0.41	1.07	0.39 (0.01)
Fe ₂ O ₃	1.9	1.9	1.8	0.8 (0.6)
FeO	1.9	1.7	9.3	2.5 (0.4)
MnO	0.07	0.08	0.22	0.07 (0.01)
MgO	1.29	1.27	5.34	1.12 (0.09)
CaO	3.64	3.25	9.92	3.54 (0.20)
Na ₂ O	3.9	4.0	2.6	3.8 (0.1)
K ₂ O	3.91	3.91	1.81	3.57 (0.20)
P ₂ O ₅	0.14	0.16	0.45	0.15 (0.01)
H ₂ O _T	0.6	0.9	2.9	0.7
CO ₂	B.D.	B.D.	B.D.	B.D.
S	B.D.	B.D.	0.07	B.D.
Cl	0.05	0.05	0.05	0.04
F	0.05	0.04	0.06	0.05
Loss O=S			0.02	
Total	100.25	100.03	99.97	99.57 (99.03)

B.D. below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

1. Average does not include specimen 644-3

TABLE IV.5.2 CHEMICAL COMPOSITION OF THE PALLIN CREEK PLUTON

(c) Trace Elements (in ppm)

	SPECIMENS				AVERAGE ¹ (1σ)
	634-1	643-2	644-3	635-1	
Rb	90	120	90	120	110 (20)
Sr	450	420	620	410	430 (20)
Ba	1300	1200	390	1300	1300 (60)
U	N.A.	N.A.	N.A.	N.A.	
Zr	110	120	27	64	98 (27)
Cr	B.D.	B.D.	24	B.D.	24
Co	B.D.	B.D.	39	B.D.	39
V	59	59	320	56	58 (2)
Ni	B.D.	B.D.	B.D.	B.D.	
Cu	22	10	59	39	24 (15)
Zn	50	50	90	60	54 (6)

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

1. Average does not include specimen 644-3

TABLE IV.5.2 CHEMICAL COMPOSITION OF PALLIN CREEK PLUTON
(d) CIPW Normative Minerals (in weight per cent)

NORMATIVE MINERALS	SPECIMENS			
	634-1	643-2	644-3	635-1
qz	17.91	19.15		20.94
or	23.11	23.11	10.69	21.10
ab	33.00	33.84	20.57	32.15
an	17.06	13.89	30.74	16.58
ne			0.77	
c				0.01
di	0.06	0.95	1.28	
hy	4.57	3.73		6.21
ol			15.48	
mt	2.75	2.75	2.61	1.16
il	0.76	0.78	2.03	0.74
ap	0.33	0.38	1.06	0.15
py			0.13	
H ₂ O	0.60	0.9	2.9	0.7
Cl	0.05	0.04	0.05	0.05
F	0.05	0.05	0.06	0.04
Total	100.25	99.57	99.97	100.03

Figure 58. Chemical variation diagrams for samples from the Pallen Creek Pluton.

- a) Weight per cent alkali-silica diagram. Alkaline-subalkaline division after Irvine and Baragar (1971).
- b) Weight per cent, normative ne' - ol' - qz' ternary diagram ($ne' = ne + 3/5 ab$; $qz' = qz + 2/5 ab + 1/4 opx$; $ol' = ol + 3/4 opx$). Alkaline-subalkaline division after Irvine and Baragar (1971).
- c) Weight per cent A ($Na_2O + K_2O$) - F ($FeO + 0.8998 Fe_2O_3$) - M (MgO) ternary diagram. Calc-alkaline - tholeiitic division after Irvine and Baragar (1971).
- d) Weight per cent SiO_2 - FeO^*/MgO diagram ($FeO^* = FeO + 0.9 Fe_2O_3$). Calc-alkaline - tholeiitic division after Miyashiro (1974).
- e) Weight per cent MgO - total iron diagram. Cascades, abyssal tholeiite (AT), pigeonitic series and Thingmuli trends after Stauffer *et al.* (1975).
- f) Weight per cent alumina-normative plagioclase diagram. Calc-alkaline - tholeiitic division after Irvine and Baragar (1971).
- g) Weight per cent Na_2O - K_2O - CaO ternary diagram.

Symbols are: $\circ$ grab samples; $\diamond$ K-Ar sample. Filled symbol is nepheline-normative sample.

a) Alkali-silica diagram for the Pallen Creek Pluton

b) Ne'-ol'-qz' ternary for the Pallen Creek Pluton

c) AFM ternary for the Pallen Creek Pluton

d) Silica - FeO*/MgO diagram for the Pallen Creek Pluton

e) MgO - total iron diagram for the Pallen Creek Pluton

f) Alumina - normative plagioclase diagram for the Pallen Creek Pluton

g) Na_2O - K_2O - CaO ternary for the Pallen Creek Pluton

The average composition of the Pallen Creek Pluton (Table IV.5.2; not including sample 644-3) has higher Al_2O_3 , Fe_2O_3 and K_2O and lower TiO_2 , FeO , MgO and CaO than Le Maitre's (1976) average granodiorite and compares moderately with the average granodiorite of Nockolds (1954). The age-date sample is geochemically similar to other felsic rocks from the Pallen Creek Pluton. The composition of the mafic phase specimen is not comparable with the average gabbro of Le Maitre (1976) but its composition does fall within the standard deviation of the mean. It is closely similar to the average olivine gabbro of Nockolds (1954) except for discrepancies in FeO , MgO , CaO and K_2O .

Further geochemical comparisons between the Pallen Creek Pluton and other volcanic and plutonic units are made in Chapter VI. Harker variation diagrams for the pluton are given in Appendix 9.4.

IV.6 TANZILLA PLUTON

IV.6.1 Distribution, Physiography and Aeromagnetic Expression

The Tanzilla Pluton is the westernmost of the isolated Jurassic plutons east of the Tanzilla River and occupies an area of 13.9 km² (Gabrielse, 1980a; P.B. Read, written communication, January 1981; Figure 59; Plate VIII F). Its name derives from its proximity to the Tanzilla River. The pluton has an almost circular (3-4 km diameter) outline and forms a small, resistant, rounded mountain clearly visible on an airphotograph (e.g. British Columbia airphotograph BC5311-162). An aeromagnetic high (from a low of 58250 gammas to a high of 59000 gammas) characterizes the Tanzilla Pluton (Figure 2). Two traverses across the best exposed parts of the Tanzilla Pluton constituted the studies undertaken by the author (Figure 59).

IV.6.2 Lithology

White-weathering, massive, equigranular, medium-grained, hypidiomorphic monzodiorite, quartz monzodiorite and rare diorite are the predominant lithologies in the Tanzilla Pluton (Figure 60). Pink weathering massive, similar textured syenite or alkali feldspar syenite occurs along the north-eastern margin of the body. Subhedral biotite and hornblende both occur in the typical monzodiorite; biotite predominates. Subhedral plagioclase, subhedral to anhedral alkali feldspar and anhedral quartz are the constituent felsic minerals. These feldspars differ from those in the Three Sisters Pluton, central phase, by the distinctive greyish colour of the former in contrast to the white colour of the latter. Titanite is a rare accessory, seen only locally. Rounded, fine-grained diorite inclusions are also rare but more widespread (Appendix 9.1).

Figure 59. Geological and station map for the Tanzilla Pluton (TP) modified from Gabrielse (1980a). Inset map shows location of satellite plutons and the Hotsail Batholith. Abbreviations are KSF = King Salmon Fault; JPS = Jurassic Plutonic Suite; PCP = Pallen Creek Pluton; SCP = Snowdrift Creek Pluton; TPS = Triassic Plutonic Suite. Other Symbols as in Figure 1.

- Lower Jurassic Tanzilla Pluton
- Upper Triassic Stuhini Group
- Permian recrystallized cherty limestone

Figure 60. Modal compositions of hand samples and thin sections from the Tanzilla Pluton (see Appendix 10.3). Classification after Streckéisen (1973). Abbreviations are: KF = alkali feldspar; PF = plagioclase feldspar; and Qz = quartz.

IV.6.3 Structure

The Tanzilla Pluton is massive but is regionally characterized by two subparallel sets of north northeast- and southeast-trending lineaments which are expressed in outcrop by two well developed vertical joint sets. On airphotographs the southeast-trending lineaments are more closely spaced, more regularly oriented and apparently better developed than the more irregular north northeast-trending set. In outcrop a horizontal joint set is also seen.

IV.6.4 Intrusive Relations

Intrapluton and the nature of the external intrusive relations are best exposed along the northeastern margin of the Tanzilla Pluton. Elsewhere along the northern and western margins, the plutonic-volcanic contact is closely bracketed over several tens to a few hundred metres but covered; the contact is poorly known along the southern and most of the eastern margins. Appendix 9.2 details the intrapluton and external intrusive relations outlined in Figure 61.

(a) Intrapluton Intrusive Relations

At station 639, pink, irregular thin syenite to alkali feldspar syenite apophyses form a stockwork in the monzodiorite of the main phase of the pluton (Plate VIII I). Apparently no mafic phase occurs in the Tanzilla Pluton; nevertheless these intrapluton intrusive relations are analagous with, though on a smaller scale than, those in the Three Sisters Pluton in the Hotailuh Batholith.

(b) External Intrusive Relations

Hornfelsed augite porphyry volcanics fringe the inferred plutonic-

Figure 61. Intrusive relationship involving the Tanzilla Pluton and Stuhini Group volcanics. Abbreviation "INT" refers to intrusive relationship and arrow leads from intrusion to country rock (see Appendix 10.2).

volcanic contact at stations 638 and 639 and imply an intrusive relationship for the Tanzilla Pluton. Within a half kilometre of the northwestern contact (stations 647 and 649), the sediments of the lower member of the Upper Triassic unit contain common to uncommon quartz veins which may have been related to the intrusion of the pluton. The trend of bedding is parallel with the northwestern contact and the sediments dip steeply away from the pluton.

IV.6.5 Age

Potassium-argon isotopic dates of 171 ± 14 Ma and 188 ± 4 Ma were determined for hornblende and biotite, respectively, from a specimen of the Tanzilla Pluton (Table IV.6.1 and Figure 62). Although barely concordant, the younger hornblende age is anomalous. Irregularities in the K-Ar isotopic system appear to be characteristic of these barely unroofed plutons west of the Hotailuh Batholith and of the northwestern apophysis of the Three Sisters Pluton. The dates compare closely with those determined for the Three Sisters and McBride River Plutons and other similarities in aeromagnetic expression, lithology, jointing, external and intrapluton relations and chemistry suggest that the Tanzilla Pluton is part of the Jurassic plutonic suite.

TABLE IV.6.1 POTASSIUM-ARGON RADIOMETRIC AGE DATA FOR THE TANZILLA PLUTON

SPECIMEN NUMBER	PLUTON	LOCATION (LATITUDE- LONGITUDE)	LITHOLOGY	MINERAL	%K	% ⁴⁰ Ar	AGE (Ma)
AN-79-716	TANZILLA PLUTON	58°14'00"N 130°25'30"W	quartz monzodiorite	hornblende biotite	0.50 6.61	65.1 93.0	171 ± 14 188 ± 4

1. All potassium-argon ages are consistent with the decay constants of Steiger and Jäger (1977). All lithologies are classified according to Streckeisen (1973).

6

6

Figure 62. Mineral K-Ar isotopic ages for the Tanzilla Pluton and the Jurassic portion of Armstrong's (1978a, 1981) time scale. Analytical errors in ages are 2σ (see Table IV.6.1). Dashed horizontal lines give time interval for most of the oldest K-Ar isotopic ages determined for the Three Sisters Pluton.

IV.6.6. Petrography

Abundance, nature and texture of essential and accessory minerals distinguish quartz monzodiorite and granodiorite of the Tanzilla Pluton (see Figure 60 and Appendix 10.3 for modal compositions). These minerals include (in approximate order of crystallizations, based on textural relations): apatite, zircon, opaque minerals, plagioclase, hornblende, biotite, titanite, quartz and alkali feldspar. Sericite, and calcite, epidote and chlorite are uncommon, late alteration products of plagioclase and the ferromagnesian minerals, respectively.

Accessory minerals apatite, zircon and squarish opaques commonly occur together as finer grained, euhedral or subhedral grains and are enclosed in plagioclase, hornblende, biotite, quartz, alkali feldspar. Opaque minerals commonly partly or totally enclose apatite and zircon. A rare, different variety of coarse-grained, interstitial, poikilitic opaque mineral also encloses hornblende and biotite.

Plagioclase (andesine to labradorite: An_{42-64}) occurs as euhedral to subhedral grains with rare, highly irregular, more calcic altered cores. Oscillatory and discontinuous normal, zoning are common. Textural relationships with euhedral hornblende are commonly equivocal; in a few places, hornblende clearly encloses plagioclase.

Hornblende forms euhedral, twinned grains with distinctive pleochroism (α = clear or pale greenish yellow; β = brownish or olive green; γ = grass green). It is locally optically zoned or contains irregular overgrowths of amphibole of different pleochroic scheme (pale bluish green to bluish green). Hornblende contains subhedral to euhedral apatite, opaque minerals and zircon; in a few places it occurs together with biotite and opaque minerals in glomeroporphyritic clots.

Light brownish yellow to dark brown biotite occurs as subhedral to euhedral rectangular sections and as anhedral, secondary intergrowths in hornblende. Plagioclase, opaque minerals and apatite occur as inclusions in the better formed varieties.

Titanite forms rare, anhedral to subhedral grains which commonly enclose hornblende and are interstitial with respect to plagioclase.

Quartz is anhedral except locally, where it is in contact with or enclosed in alkali feldspar and is subhedral to euhedral. It is little strained and contains few subgrains. Quartz encloses or is interstitial with respect to apatite, opaque minerals, plagioclase, hornblende, biotite and titanite.

Microperthitic or homogeneous alkali feldspar forms anhedral poikilitic plates which enclose apatite, opaques, plagioclase, hornblende, biotite and quartz.

IV.6.7 Chemical Composition

Two samples from the quartz monzodiorite of the Tanzilla Pluton were analyzed for major, minor and trace elements (see Table IV.6.2 for analyses and CIPW norms and Figure 63).

The compositions are similar and are distinguished by normative quartz, diopside and hypersthene. In the alkali-silica (Figure 63(a)) and normative $ne'-ol'-qz'$ ternary (Figure 63(b)) plots, the two samples are clearly subalkaline based on the classification of Irvine and Baragar (1971). The samples have clear calc-alkaline affinities according to the AFM (Figure 63(c); after Irvine and Baragar, 1971), SiO_2-FeO^*/MgO (Figure 63(d); after Miyashiro, 1974), MgO -total iron (Figure 63(e); after Lowder and Carmichael, 1970; Stauffer *et al.*, 1975) and Al_2O_3 -normative plagioclase (Figure 63(f); after Irvine and Baragar, 1971). The alumina-normative plagioclase plot also emphasizes the lower Al_2O_3 content (between 16 and 17 weight per cent) compared with mafic and some felsic plutons in the plutonic suites. The Tanzilla Pluton compositions are slightly enriched in CaO relative to nearly equal proportions of Na_2O and K_2O on the weight per cent Na_2O-K_2O-CaO plot (Figure 63(g)).

The average composition of the Tanzilla Pluton (Table IV.6.2) lies between the average monzonite and the average tonalite of Le Maitre (1976) but has few analogs in the average granitic compositions compiled by Nockolds (1954). Chemical composition of the Tanzilla Pluton is similar to the central phase of the Three Sisters Pluton.

Further geochemical comparisons between the Tanzilla Pluton and other plutonic and volcanic units are made in Chapter VI. Harker variation diagrams for the pluton are given in Appendix 10.4.

TABLE IV.6:2 CHEMICAL COMPOSITION OF THE TANZILIA PLUTON

(a) Location and lithology of specimens

SPECIMEN	UNIT	LOCATION (Latitude and Longitude)	LITHOLOGY ¹
639-2	Tanzilia Pluton	58°14'00"N 130°25'30"W	hornblende-biotite monzodiorite
640-2	"	58°14'00"N 130°26'00"W	hornblende-biotite monzodiorite

1. All lithologies classified after Streckeisen (1973)

TABLE IV.6.2 CHEMICAL COMPOSITION OF THE TANZILLA PLUTON
(b) Major Elements (in weight per cent)

OXIDE	SPECIMENS	
	639-2	640-2
		AVERAGE (10)
SiO ₂	61.9	64.3
Al ₂ O ₃	16.4	16.3
TiO ₂	0.64	0.56
Fe ₂ O ₃	2.1	1.3
FeO	3.2	3.2
MnO	0.09	0.09
MgO	2.34	2.08
CaO	5.17	4.49
Na ₂ O	3.6	3.7
K ₂ O	2.60	2.92
P ₂ O ₅	0.20	0.20
H ₂ O _T	1.1	0.9
CO ₂	B.D.	0.2
S	B.D.	B.D.
Cl	0.26	0.04
F	0.06	0.05
Total	99.66	100.33
		(98.79)

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE IV.6.2 CHEMICAL COMPOSITION OF THE TANZILIA PLUTON
(c) Trace Elements (in ppm)

	SPECIMENS		AVERAGE (1 σ)
	639-2	640-2	
Rb	70	80	80 (10)
Sr	380	420	400 (30)
Ba	1400	1200	1300 (140)
U	N.A.	N.A.	
Zr	120	75	98 (32)
Cr	8.7	5.7	7.2 (2.1)
Co	B.D.	10	10
V	120	98	110 (16)
Ni	B.D.	B.D.	
Cu	23	10	17 (9)
Zn	90	60	75 (21)

B.D.: below detection limit of analytical method; N.A.: specimen not analyzed for given element or oxide

TABLE IV.6.2 CHEMICAL COMPOSITION OF THE TANZILIA PLUTON
(d) CIPW Normative Minerals (in weight per cent)

NORMATIVE MINERALS	SPECIMENS	
	639-2	640-2
qz	16.26	18.25
br	15.37	17.26
ab	30.46	31.31
an	20.92	19.25
di	2.78	0.37
hy	7.73	9.04
mt	3.04	1.88
il	1.21	1.06
ap	0.47	0.47
cc		0.45
H ₂ O	1.1	0.9
Cl	0.26	0.04
F	0.06	0.05
Total	99.66	100.33

Figure 63. Chemical variation diagrams for samples from the Tanzilla Pluton.

- a) Weight per cent alkali-silica diagram. Alkaline-subalkaline division after Irvine and Baragar (1971).
- b) Weight per cent, normative $ne'-ol'-qz'$ ternary diagram ($ne' = ne + 3/5 ab$; $qz' = qz + 2/5 ab + 1/4 opx$; $ol' = ol + 3/4 opx$). Alkaline-subalkaline division after Irvine and Baragar (1971).
- c) Weight per cent A ($Na_2O + K_2O$) - F ($FeO + 0.8998 Fe_2O_3$) - M (MgO) ternary diagram. Calc-alkaline - tholeiitic division after Irvine and Baragar (1971).
- d) Weight per cent SiO_2 - FeO^*/MgO diagram ($FeO^* = FeO + 0.9 Fe_2O_3$). Calc-alkaline - tholeiitic division after Miyashiro (1974).
- e) Weight per cent MgO - total iron diagram. Cascades, abyssal tholeiite (AT), pigeonitic series and Thingmuli trends after Stauffer et al. (1975).
- f) Weight per cent alumina-normative plagioclase diagram. Calc-alkaline - tholeiitic division after Irvine and Baragar (1971).
- g) Weight per cent $Na_2O - K_2O - CaO$ ternary diagram.

a) Alkali-silica diagram for the Tanzilla Pluton

b) Ne' - ol' - qz' ternary for the Tanzilla Pluton

c) AFM ternary for the Tanzilla Pluton

d) Silica vs FeO*/MgO diagram for the Tanzilla Pluton

e) MgO - total iron diagram for the Tanzilla Pluton

f) Alumina - normative plagioclase diagram for the Tanzilla Pluton

g) $\text{Na}_2\text{O} - \text{K}_2\text{O} - \text{CaO}$ ternary for the Tanzilla Pluton

V. GEOCHRONOMETRY

V.1 INTRODUCTION AND SUMMARY

The geochronometry of constituent and satellitic plutons of the Hoptailuh Batholith in context of the regional setting of the batholith and the recently revised Mesozoic time-scale for northern British Columbia (Armstrong 1978a, 1981) is reviewed. Details of individual K-Ar dates and interpretations for each pluton are presented in previous chapters.

With six exceptions, the thirty-five K-Ar dates previously published or determined in this study form two groups: Late Triassic (dates from 218-230 Ma) and Jurassic (dates from 150-189 Ma) (Figure 64). These groups are consistent with the Triassic and Jurassic plutonic suites established on the basis of geological relations. Dates for the Triassic suite demonstrate internal (intrapluton) concordancy and fit geological constraints on their minimum age.

The Jurassic suite is characterized by discordant ~~intrapluton~~ and intraphase K-Ar dates, a characteristic found elsewhere in the Canadian (e.g. Peto and Armstrong, 1976; Garnett, 1978) and northwestern American Cordillera (e.g. Armstrong et al., 1977). ^{40}Ar - ^{40}K and $^{40}\text{Ar}/^{36}\text{Ar}$ - $^{40}\text{K}/^{36}\text{Ar}$ plots for members of the Jurassic suite reveal a minimum of excess argon or argon loss. The necessary assumptions for the use of these plots as "isochrons" (Shafiqullah and Damon, 1974) and the control of these "isochrons" by one or two biotite determinations hinder further interpretation. Some of the oldest K-Ar ages (180-190 Ma) compare closely with one possible interpretation for zircon U-Pb data for the Three Sisters Pluton. A crude geographical distribution of ages in the eastern part of the Three Sisters Pluton younging

Figure 64. Compilation of mineral K-Ar isotopic ages for: (a) Triassic plutonic suite; (b) batholithic Jurassic plutonic suite; and (c) satellitic Jurassic plutonic suite. Triassic and Jurassic portions of the time scale after Armstrong (1978, 1981). Carnian-Norian boundary from Odin (1981) also shown. Oldest stratigraphic age (Toarcian) for batholithic Jurassic plutonic suite shown in shaded interval. Age of folded sediments intruded by Snowdrift Creek Pluton is also shown.

(a) Triassic plutonic suite. Abbreviations are: BCP = Beggerlay Creek Pluton; CHP = Cake Hill Pluton; GLU = Gnat Lakes Ultramafite; SP? = Stikine Pluton (? indicates uncertainty in material dated from Stikine Pluton).

(b) batholithic Jurassic plutonic suite. Abbreviations are: MRP = McBride River Pluton; TSP = Three Sisters Pluton (cp = central phase; fgp = fine-grained phase; lp = leucocratic phase; mp = mafic phase; pmp = potassic marginal phase).

(c) satellitic Jurassic plutonic suite. Abbreviations are: PCP = Pallen Creek Pluton; SCP = Snowdrift Creek Pluton; TP = Tanzilla Pluton.

Figure 42 (continued). Distribution of K-Ar isotopic ages in Three Sisters Pluton (TSP) and McBride River Pluton (MRP). Triangular symbols indicate isotopic ages reported in Wanless et al. (1972); other symbols denote isotopic ages determined for this study. Abbreviations are: Bi = biotite; Hb = hornblende; WR = whole rock; fgp = fine grained phase; cp = central phase; lp = leucocratic phase; mp = mafic phase; and pmp = potassic marginal phase. Ruled areas are Triassic plutonic suite.

towards the eastern margin may indicate differential uplift and cooling of the pluton.

Slightly discordant, zircon U-Pb data for the potassic marginal phase of the Three Sisters Pluton suggest two alternative interpretations:

170 ± 1 Ma (average of U-Pb ages) and 184 ± 5 Ma (average of Pb-Pb ages and concordia intercept). The younger age agrees best with the average K-Ar age for the Three Sisters Pluton and geological constraints on its oldest age. A five point, analytically excellent, Rb-Sr isochron for the Three Sisters Pluton yields an age of 155 ± 2 Ma and an initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.70359 ± 0.00003 . The whole rock Rb-Sr isochron age is discordant with the oldest K-Ar dates and the zircon ages but is similar to the youngest K-Ar dates determined for the Jurassic plutonic suite and may reflect a resetting event around 150-155 Ma (coincident with extrusion of the Late Jurassic volcanics around Mount Blair?). The low initial ratio indicates equilibration of the magmas with a source having low Rb/Sr and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, such as the upper mantle, and reflects the position of the Hotailuh Batholith outboard of the inferred limit of continental crust in the Canadian Cordillera (Armstrong, 1979).

The batholithic and satellitic Jurassic plutonic suites with similar, earlier described intrusive, petrographic, chemical and aeromagnetic properties are also of approximately the same age.

V.2 K-Ar GEOCHRONOMETRY

Potassium-argon dating has proved useful in distinguishing a Late Triassic plutonic suite and a Jurassic plutonic suite in the Hotailuh Batholith and satellitic bodies (Figure 1). These age distinctions are corroborated by the detailed external geological relations.

V.2.1 Triassic Plutonic Suite

The oldest dates, 227 ± 14 Ma and 230 ± 10 Ma, for the Cake Hill Pluton and Gnat Lakes Ultramafite are in accord with nonconformable relations of overlying volcanics and sediments of suspected Carnian-Norian age and/or younger, equivalent, hypabyssal intrusions. The Carnian-Norian boundary, set at 225 Ma by Armstrong (1978a, 1981) is now thought to be closer to 220 ± 8 Ma (G.S. Odin, 1981, R.L. Armstrong, written communication, January, 1981). The revised date suggests the Cake Hill Pluton cooled, was uplifted and unroofed, and shed detritus into the developing Late Triassic basin to the north in a span of 10 million years or so. The 227 ± 14 Ma age for the Cake Hill Pluton may be a minimum since the Cake Hill Pluton is intruded by the Gnat Lakes Ultramafite (dated at 227 ± 14 Ma and 230 ± 10 Ma) for which there is no evidence of it being unroofed at the same time as the Cake Hill Pluton and whose massive texture contrasts with the predominantly northwest structural grain of the Cake Hill Pluton. The poorly exposed external and interpluton geological relations of the Stikine Pluton (222 ± 11 Ma) as well as the large associated (20) errors on the K-Ar dates do not permit unequivocal interpretation of its age; however unmetamorphosed Upper Triassic volcanics near its southern contact indicate it is a minimum age of emplacement. Poorly known structural style and timing of the deformation (other than pre-Late Triassic and post-Permian) in Paleozoic rocks to the west, hinders assignment of maximum age constraints for the foliated Stikine and Cake Hill Plutons.

A date of 218 ± 29 Ma for the Beggerlay Creek Pluton, which intruded and metamorphosed augite porphyry is consistent with the suspected age of these country rocks. West of the Hotailuh Batholith, the Kakitsa Stock

(hornblende K-Ar, 222 ± 8 Ma; biotite K-Ar 218 ± 6 Ma) also intrudes Upper Triassic volcanic and sedimentary rocks (McMillan et al., 1974; Panteleyev, 1975). Geological relations and K-Ar age-dating of the Triassic plutonic suite suggest an interval of 9-12 million years for the eruption of at least part of the Upper Triassic Stuhini Group around the Hotailuh Batholith.

The minimum ages for members of the Triassic plutonic suite and the estimate for the duration of the Stuhini Group volcanism must be regarded as tentative due to the large (2 σ) uncertainties associated with the K-Ar dates and the uncertainty in the absolute age of the Carnian-Norian boundary.

V.2.2 Upper Triassic and Triassic-Jurassic volcanics

Neither of the two hornblende K-Ar dates (280 ± 19 Ma and 170 ± 11 Ma) for a hornblende-augite porphyry dike in the Cake Hill Pluton is consistent with its intrusive relations and assumed consanguinity with Upper Triassic Stuhini Group volcanics. If the Triassic-Jurassic volcanics are intruded by the Beggerlay Creek Pluton and if the pluton's age is Triassic, then these volcanics are also Triassic age.

V.2.3 Jurassic Plutonic Suite

K-Ar dates for the Jurassic suite, with six exceptions, span the interval between 150-189 million years (Figures 64 and 65). The exceptions are: a biotite date of 143 ± 6 Ma (G.S.C. 70-28; Wanless et al., 1972) from the metamorphosed Cake Hill Pluton collected from the bottom of a 427 m deep drill hole (Southey, 1971b) and concordant with a hornblende K-Ar date of 151 ± 8 Ma date (G.S.C. 70-28) determined from the same specimen; a hornblende date of 208 ± 15 Ma collected from the potassic marginal phase of the Three Sisters Pluton near peak 2187 m (7174 feet); a date of 142 ± 53 Ma on a hornblende with a very low potassium content collected from the leucocratic

Figure 65. Histogram of Jurassic K-Ar isotopic ages determined from the Jurassic plutonic suite and metamorphosed Cake Hill Pluton (CHP). Other abbreviations are: MRP = McBride River Pluton; PCP = Pallén Creek Pluton; SCP = Snowdrift Creek Pluton; TP = Tanzilla Pluton; TSP = Three Sisters Pluton; cp = central phase; fgp = fine-grained phase; lp = leucocratic phase; mp = mafic phase; pmp = potassic marginal phase.

phase of the Three Sisters Pluton which is concordant with a date of 185 ± 28 Ma from a determination of slightly different hornblende from the same specimen (Table IV.2.2); a biotite date of 147 ± 5 Ma from the Snowdrift Creek Pluton; and a biotite age of 145 ± 7 Ma and a hornblende age of 197 ± 18 Ma from two different specimens from the Pallen Creek Pluton. The first four exceptions are discussed in previous sections for the given plutons; the latter two are discussed below.

The Jurassic plutonic suite in and around the Hotailuh Batholith is characterized by a range of K-Ar dates for any given pluton or phase, many of which are discordant on an intrapluton and intraphase scale. This characteristic is similar to other well-dated Jurassic plutons of composite Mesozoic batholiths in the northern and southern Canadian Cordillera (e.g. in the Jennings River map-area (H. Gabrielse, personal communication, March, 1981; the Hogen Batholith (Garnett, 1978; G. Woodsworth and R.L. Armstrong, personal communication, December, 1978; and the "Okanagan" Batholith; Peto and Armstrong, 1976) and in Washington, Idaho and Oregon (Armstrong *et al.*, 1977)). This anomalous behavior of the K-Ar isotopic system is well illustrated in the western apophyses and satellitic bodies. The potassic marginal phase of the Three Sisters Pluton is dated concordantly at 169 ± 11 Ma and 176 ± 5 Ma but the apparently older age is from the biotite of the hornblende-biotite pair. In the Tanzilla Pluton, the oldest of the two concordant ages, 171 ± 14 Ma and 188 ± 4 Ma, is determined from biotite. The Pallen Creek Pluton has three dates from two specimens, 145 ± 7 , 165 ± 8 and 197 ± 18 Ma, no two concordant. As indicated in Chapter IV (Figure there is a crude zonation of ages irrespective of the phase dated, younging from northwest (≥ 180 Ma) to east and southeast (150-160 Ma) in the eastern

part of the Three Sisters Pluton.

V.2.4. Possible Explanations for Anomalous K-Ar Dates for the Jurassic Plutonic Suite

There are at least four possible explanations for the distribution and nature of the K-Ar ages for the Jurassic plutonic suite. First, the dates are cooling ages and are estimates of the period of multipulse emplacement of magma in the area during the Jurassic. Second, the dates reflect early disturbances in the isotopic system, namely excess Ar or Ar loss, and the individual ages have no geological meaning. Third, the dates are cooling ages and record differential uplift in the batholith and satellitic plutons. Fourth, a disturbance around 150 Ma partly to totally reset the K-Ar dates.

V.2.4(a) Multiple intrusive pulses

It is unlikely that the K-Ar dates reflect emplacement of multiple pulses of magma on a batholithic scale over a period of 40 million years. For the Three Sisters Pluton, the recurring mafic to salic intrusive sequence amongst the identical (or very similar) three or four lithologies in various localities was emphasized in Chapter IV. Although minor subphases are recognized in the mafic, central and potassic marginal phases, with the exception of the mafic phase, only the freshest rocks representative of the most widespread lithologies of each phase were dated. Also, the distribution of the major phases in the eastern part of the Three Sisters Pluton defines a relatively simple pattern with no evidence for repeated, sequential, intrusion of major basic to acid subphases from northwest to southeast. Likewise, there is no lithological or chemical difference between the dated northern and central parts of the Pallen Creek Pluton. If these subphases exist and are responsible for the discrepancy in K-Ar dates, they are so similar as to defy their recognition in the field.

V.2.4(b) Excess Ar and K-Ar "isochron" plots

Plots of ^{40}Ar versus ^{40}K and $^{40}\text{Ar}/^{36}\text{Ar}$ versus $^{40}\text{K}/^{36}\text{Ar}$ are believed by some workers (e.g. Hayatsu, 1972; Hayatsu and Carmichael, 1972, 1977; and Shafiqullah and Damon, 1974) to indicate the presence of an initial argon excess or argon loss subject to some stringent requirements. The method derives from the conventional equation for the calculation of a potassium-argon date:

$$^{40}\text{Ar}_{\text{rad}} = (\lambda_e / \lambda) ^{40}\text{K} (e^{\lambda t} - 1) \quad (\text{V.1})$$

where $^{40}\text{Ar}_{\text{rad}}$ is the amount of ^{40}Ar produced by radiogenic decay of ^{40}K after correction for atmospheric contamination (i.e. $^{40}\text{Ar}_{\text{rad}} = ^{40}\text{Ar}_{\text{measured}} - ^{40}\text{Ar}_{\text{atmospheric}}$); λ is the sum of λ_e and λ_β , the partial decay constants for electron capture and beta decay, respectively, of ^{40}K ; and t is the time required to generate the radiogenic argon from the measured amount of potassium. Harper (1970) derived the ^{40}Ar - ^{40}K plot as a means to detect uniform amounts of excess argon or diffusional loss by adding an additional term to equation V.1 (nomenclature after Shafiqullah and Damon, 1974):

$$^{40}\text{Ar}_{\text{rad}} = (\lambda_e / \lambda) (e^{\lambda t} - 1) ^{40}\text{K} + \text{Ar}_1 \quad (\text{V.2})$$

where the initial Ar, Ar_1 , at the time of homogenization of argon isotopes is:

$$^{40}\text{Ar}_1 = ^{40}\text{Ar}_{\text{excess}} - ^{40}\text{Ar}_{\text{diff}} \quad (\text{V.3})$$

($^{40}\text{Ar}_{\text{diff}}$ is the amount of ^{40}Ar lost by diffusion and $^{40}\text{Ar}_{\text{excess}}$ is all the ^{40}Ar component in excess of the atmospheric component). In this plot, the $^{40}\text{Ar}_{\text{rad}}$ is corrected for atmospheric contamination in the conventional way.

Equation V.2 is in the form of an equation of a line and three possibilities

exist. If $^{40}\text{Ar}_1 = 0$, the individual ages calculated from equations (V.1) or (V.2) date a geological event. If $^{40}\text{Ar}_1$ is positive, the sample has excess argon and the slope of the line gives the age of closure of the K-Ar system providing all samples have the same $^{40}\text{Ar}_1$. If $^{40}\text{Ar}_1$ is negative, argon loss is indicated and the date of closure is determined from the slope, provided $^{40}\text{Ar}_1$ remained constant from sample to sample.

The $^{40}\text{Ar}/^{36}\text{Ar} - ^{40}\text{K}/^{36}\text{Ar}$ plot (Hayatsu and Carmichael, 1970; Hayatsu, 1972; Mellor and Mussett, 1975) is derived from equation (V.2) by substitution of equation (V.3) and :

$$^{40}\text{Ar}_{\text{rad}} = ^{40}\text{Ar}_{\text{meas}} - ^{40}\text{Ar}_{\text{atmos}}$$

the difference between measured and atmospheric ^{40}Ar , and dividing by $^{36}\text{Ar}_{\text{meas}}$ (measured ^{36}Ar content) to give:

$$\begin{aligned} ^{40}\text{Ar}_{\text{meas}}/^{36}\text{Ar}_{\text{meas}} &= (\lambda/\lambda)(e^{\lambda t} - 1)^{40}\text{K}/^{36}\text{Ar}_{\text{meas}} + ^{40}\text{Ar}_{\text{atmos}}/^{36}\text{Ar}_{\text{meas}} \\ &+ ^{40}\text{Ar}_{\text{excess}}/^{36}\text{Ar}_{\text{meas}} - ^{40}\text{Ar}_{\text{diff}}/^{36}\text{Ar}_{\text{meas}} \end{aligned} \quad (\text{V.4})$$

In the event that there is significant excess argon or diffusional loss, an age determined from the slope of the line is again only strictly correct if the difference between $^{40}\text{Ar}_{\text{excess}}/^{36}\text{Ar}_{\text{meas}}$ and $^{40}\text{Ar}_{\text{diff}}/^{36}\text{Ar}_{\text{meas}}$ is zero or if the term

$$^{40}\text{Ar}_{\text{atmos}}/^{36}\text{Ar}_{\text{meas}} + ^{40}\text{Ar}_{\text{excess}}/^{36}\text{Ar}_{\text{meas}} - ^{40}\text{Ar}_{\text{diff}}/^{36}\text{Ar}_{\text{meas}}$$

is constant for all specimens. In the former case the intercept is 295.5, the accepted value for the atmospheric $^{40}\text{Ar}/^{36}\text{Ar}$ ratio (Steiger and Jäger, 1977). Shafiqullah and Damon (1974) have pointed out that the latter assumption is not strictly true as $^{40}\text{Ar}_{\text{excess}}/^{36}\text{Ar}_{\text{meas}}$ and $^{40}\text{Ar}_{\text{diff}}/^{36}\text{Ar}_{\text{meas}}$ are likely also to be variables.

Other requirements must be met for the correct use of these isochrons.

It is assumed that complete homogenization of Ar isotopes occurs at the time of closure and that the system remains closed. Minerals with sufficient spread of potassium (the effects of variable initial argon isotopic ratios is accentuated in potassium-poor minerals) or with different initial argon contents must be used. However, the most important requirement for the isochron plots is a minimum of atmospheric contamination during the analyses. Careful bake-out procedures such as those employed by Hayatsu and Carmichael (1977) ensure reproducible ^{36}Ar contents and satisfy the latter major requirement. Shafiqullah and Damon (1974) have pointed out the inadequacies of the isochron method in the event of argon gain or loss without isotopic homogenization and Armstrong (1978b) has expressed doubts that the tightly bound excess argon added naturally to minerals during secularly increasing alteration processes could be removed without removal of the radiogenic component as well. Hayatsu (1972) considers the $^{40}\text{Ar}/^{36}\text{Ar} - ^{40}\text{K}/^{36}\text{Ar}$ isochron most suited for cogenetic samples younger than 100 Ma where effects of initial argon are not overshadowed by the diffusional argon losses more important in older rocks.

The $^{40}\text{Ar}_{\text{rad}} - ^{40}\text{K}$ and $^{40}\text{Ar}/^{36}\text{Ar} - ^{40}\text{K}/^{36}\text{Ar}$ isochron plots shown in Figure 66 were used for Jurassic plutons or phases which had more than two dated samples: the mafic, central and potassic marginal phases of the Three Sisters Pluton and the Pallen Creek Pluton. Replicate analyses of hornblendes from the mafic phase (specimen 661-3) and the potassic marginal phase (specimen 70-29) are similar and apparently indicate that the effect of atmospheric contamination in producing the straight line in the $^{40}\text{Ar} - ^{40}\text{K}$ plot is negligible (Hayatsu and Carmichael, 1977). However as Table V.1

TABLE V.1 COMPILATION OF $^{40}\text{Ar}_{\text{rad}}$, ^{40}Ar AND ^{40}K CONCENTRATIONS AND $^{40}\text{Ar}/^{36}\text{Ar}$ AND $^{40}\text{K}/^{36}\text{Ar}$ RATIOS FOR SPECIMENS FROM THE TRIASSIC AND JURASSIC PLUTONIC SUITE (cont'd)

SPECIMEN NUMBER	PLUTON OR PHASE	MINERAL	$^{40}\text{Ar}_{\text{rad}}$ ($10^{-5}\text{cm}^3\text{STP-g}^{-1}$)	^{40}Ar ($10^{-10}\text{mol-g}^{-1}$)	^{40}K (10^{-8}mol-g^{-1})	$^{40}\text{Ar}/^{36}\text{Ar}$	$^{40}\text{K}/^{36}\text{Ar}$ ($\times 10^5$)
An-78-523-1	T.S.P., Mafic Phase	Hb Bt	0.5818 4.332	2.5959 19.328	2.2388 17.6716	2200 4607	1.643 3.943
An-78-542-1	T.S.P., Mafic Phase	Hb	0.5532	2.4680	2.2089	760.9	0.4165
An-79-661-3	T.S.P., Mafic Phase	Hb Hb	0.3595 0.3653	1.6038 1.6297	1.5522 1.5522	365.4 646.7	0.0676 0.3345
GSC 70-30	T.S.P., Central Phase	Hb	0.245	1.0930	1.1341	793	0.530
GSC 70-31	T.S.P., Central Phase	Hb	0.339	1.5134	1.4920	1298	1.010
GSC 70-32		Bt	5.128	22.879	22.533	4281	4.00
An-77-345-1	T.S.P., Central Phase	Hb	0.2881	1.2855	1.2448	1146	0.8239
GSC 70-29	T.S.P., Potassic Marginal Phase	Hb Hb	0.424 0.451	1.8921 2.0127	1.9399 1.9399	433.6 888	0.140 0.580
An-77-356-1	T.S.P., Potassic Marginal Phase	Hb Bt	0.6542 5.240	2.9186 23.379	2.8357 21.731	2185 3952	1.836 3.399
An-78-505-5	T.S.P., Potassic Marginal Phase	Hb	0.3185	1.4211	1.1075	626.1	0.2576

TABLE V.1 COMPILATION OF $^{40}\text{Ar}_{\text{rad}}$, ^{40}Ar AND ^{40}K CONCENTRATIONS AND $^{40}\text{Ar}/^{36}\text{Ar}$ AND $^{40}\text{K}/^{36}\text{Ar}$ RATIOS FOR SPECIMENS FROM THE TRIASSIC AND JURASSIC PLUTONIC SUITE

SPECIMEN NUMBER	PLUTON OR PHASE MINERAL	$^{40}\text{Ar}_{\text{rad}}$ ($10^{-5}\text{cm}^3\text{STP-g}^{-1}$)	^{40}Ar ($10^{-10}\text{mol-g}^{-1}$)	^{40}K (10^{-8}mol-g^{-1})	$^{40}\text{Ar}/^{36}\text{Ar}$	$^{40}\text{K}/^{36}\text{Ar}$ ($\times 10^5$)
GSC 70-34	Stikine Pluton	Hb 0.634	2.8285	2.0593	884	0.440
		Hb 0.634	2.7075	2.0593	1410	0.830
GSC 70-33	Cake Hill Pluton	Hb 0.487	2.1714	1.6116	928	0.480
		Hb 0.492	2.1940	1.6116	562	0.200
AN-77-276	Cake Hill Pluton (Fragment)	Hb 0.3567	1.5915	1.1343	1338	0.7427
GSC 70-27	Metamorphosed?	Hb 0.406	1.8121	1.9847	1299	1.120
GSC 70-28	Cake Hill Pluton	Bi 4.370	19.495	22.592	3892	4.25
AN-79-607-1	Gnat Lakes Ultramafite	Hb 0.9553	4.2621	2.9851	2932	1.846
AN-79-609-2	Gnat Lakes Ultramafite	Hb 0.6308	2.8141	2.0000	1000	0.5008
AN-79-717	Beggerlay Creek Pluton	Hb 0.2615	1.1666	0.86567	485.7	0.1411
AN-79-698-3	Augite-Hornblende Porphyry Dike	Hb 0.3997	1.7834	1.0149	599.3	0.1729
		Hb 0.4297	1.9169	1.8507	1126	0.8022
AN-79-719-1	T.S.P., fine- grained phase Rock	Whole Rock 1.447	6.4569	7.1044	5052	5.233

TABLE V.1 COMPILATION OF $^{40}\text{Ar}/^{36}\text{Ar}$, ^{40}Ar AND ^{40}K CONCENTRATIONS AND $^{40}\text{Ar}/^{36}\text{Ar}$ AND $^{40}\text{K}/^{36}\text{Ar}$ RATIOS FOR SPECIMENS FROM THE TRIASSIC AND JURASSIC PLUTONIC SUITE (cont'd)

SPECIMEN NUMBER	PLUTON OR PHASE	MINERAL	$^{40}\text{Ar}_{\text{rad}}$ ($10^{-5}\text{cm}^3\text{STP-g}^{-1}$)	^{40}Ar ($10^{-10}\text{mol-g}^{-1}$)	^{40}K (10^{-8}mol-g^{-1})	$^{40}\text{Ar}/^{36}\text{Ar}$	$^{40}\text{K}/^{36}\text{Ar}$ ($\times 10^3$)
An-78-528-3	T.S.P., Potassic Marginal Phase	B1	5.292	23.609	21.492	6404	5.561
An-79-718-1	T.S.P., Leucocratic Phase	Hb	0.0373	0.16633	1.9403	325.7	0.0352
		Hb	0.1179	0.52618	0.46567	509.3	0.1891
An-78-467	McBride River, Pluton	Hb	0.2573	1.1481	1.0089	891.4	0.5237
GSC 70-25	Pallen Creek Pluton	Hb	0.316	1.4103	1.4027	746	0.460
GSC 70-26		B1	3.400	15.1700	17.3100	4096	4.42
An-79-635	Pallen Creek Pluton	Hb	0.3482	1.5537	1.2836	1196	0.7438
An-77-329	Snowdrift Creek	B1	4.513	20.135	22,597	2989	3.023
An-79-716	Tanzilla Pluton	Hb	0.3477	1.5512	1.4925	847.6	0.5311
		B1	5.106	22.779	19.7312	4206	3.388

Figure 66. $^{40}\text{Ar} - ^{40}\text{K}$ and $^{40}\text{Ar}/^{36}\text{Ar} - ^{40}\text{K}/^{36}\text{Ar}$ plots for the Pallen Creek Pluton and Three Sisters Pluton, mafic, central and potassic marginal phases. Intercept, age and correlation coefficient (r) are given for each "isochron" plot. Numbers refer to sample numbers (see Table V.1); abbreviations are: Bi = biotite (filled symbols); Hb = hornblende (open symbols); and symbols denote mineral pairs or replicate determinations.

THREE SISTERS PLUTON-Mafic Phase

THREE SISTERS PLUTON - Potassic Marginal Phase

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indicates for both replicates, the potassium content was not redetermined for the subsequent Ar replicate analyses. If atmospheric contamination introduced by analytical processes was not a factor in producing the straight line plots, then the intercepts and slopes are meaningful. For phases of the Three Sisters Pluton, where intercepts are very near zero in the $^{40}\text{Ar} - ^{40}\text{K}$ plot and approach 295.5 in the $^{40}\text{Ar}/^{36}\text{Ar}$ vs $^{40}\text{K}/^{36}\text{Ar}$ plot, no argon excess or loss is indicated and the individual K-Ar ages are meaningful (Figure 66). Interpretation of the plots for the Pallen Creek Pluton (Figure 66) whose intercepts indicate excess argon, is hindered by the fact that the lines are essentially a two-point "isochron" and the ages of 142 Ma and 136 Ma determined from their slopes reflects control of the line by the biotite analysis (whose conventional K-Ar age is 145 Ma). Consequently the potassium-argon dates determined for the Jurassic plutonic suite are assumed to record geological events.

V.2.4(c) K-Ar ages and differential uplift and cooling in the Jurassic plutonic suite

K-Ar and Rb-Sr dates determined from mineral separates may not date the crystallization of the magma but rather the time elapsed since the minerals cooled below a closure temperature and retention of daughter products in the minerals occurred. This phenomenon was first recognized in geochronological studies in the Alps (for example, Jäger, 1965; and Armstrong *et al.*, 1966). Dodson (1973, 1975) related closure temperatures to cooling rates and diffusion parameters and found an inverse relationship between closure temperature and cooling rate. For example, closure temperatures of 280°C and 300°C were calculated for Rb-Sr dates of 20 Ma and 10 Ma respectively on Alpine biotites from diffusion parameters and grain size assumptions (Dodson, 1973). In the Canadian Cordillera, recent work in the

Coast Plutonic Complex (Harrison et al., 1979; Parrish, 1981) and Wolverine Complex in the Omineca Crystalline Belt (Parrish, 1979) illustrates the importance of the concept of closure temperature in uplift studies. K-Ar closure temperatures for hornblende and biotite determined or estimated in these studies are 400-550°C and $220 \pm 40^\circ\text{C}$ respectively (Harrison et al., 1979; Parrish, 1979). These temperatures conform to the qualitative order of retentivity of Ar by these minerals (hornblende > biotite; Hart, 1964; Evernden and Kistler, 1970) but are determined for areas of deduced moderate ($<0.1 - 0.3 \text{ km/Ma}$; Parrish, 1979; Harrison et al., 1979) to high ($>0.5 \text{ km/Ma}$; Parrish, 1981) uplift (Schaer et al., 1975).

Rocks emplaced or thermally disturbed in the Cenozoic are particularly well-suited for uplift and cooling history studies because discordances in K-Ar and Rb-Sr mineral dates are not masked by large analytical error limits. Moreover, the studies indicate that uplift or cooling rates were rapid enough to justify the use of the inferred closure temperatures. An explicit assumption in the formulation of closure temperatures for volume diffusion in geochronological systems is a linear relationship between the maximum temperature achieved (e.g. emplacement temperature) and closure temperature (Dodson, 1973, 1975). Dodson (1973, p.209) concludes that this assumption may not be valid for elements of Mesozoic orogens which may have been maintained for long periods of time at temperatures where diffusion still occurred, an observation borne out by the discrepancy in Jura-Cretaceous Rb-Sr and K-Ar mica dates in the Wolverine Complex (Parrish, 1979, pp.1430-1432).

Large analytical (2σ) error limits on K-Ar isotopic dates from most phases in the Three Sisters Pluton render them indistinguishable. Nevertheless

interphase and intraphase K-Ar isotopic discordancy exists in the pluton and the Pallen Creek Pluton. This characteristic, plus the older biotite dates in hornblende-biotite pairs of western apophyses and satellitic plutons suggests a complex uplift and cooling history for the Jurassic plutonic suite, spanning approximately 40 million years (150-190 Ma), followed its emplacement sometime between 180-188 million years ago. An "average" age for the Three Sisters Pluton based on all K-Ar ages determined for it is 170 ± 9 Ma (16).

The locus of K-Ar dates greater than 180 Ma in the eastern part of the Three Sisters Pluton is due south of Upper Triassic stratigraphy dominated by volcanoclastic rocks (Figure 42). Inferred facies changes in the Upper Triassic stratigraphy indicate near source, southerly derivation of the volcanoclastics from a volcanic edifice whose position may have been influenced by the Cake Hill Pluton (Chapter III). The simple distribution of phases in the eastern part of the Three Sisters Pluton and their observed intrusive relations suggest control of intrusion by the Cake Hill Pluton. Provided there was little geographic or secular change in the closure temperature for hornblende and biotite across the eastern part of the Three Sisters Pluton, greater uplift occurred in the vicinity of Peak 2187 m (7174 feet) than along the eastern margin where vestiges of roof rock (i.e. pendants of metamorphosed and remobilized Cake Hill Pluton and the fine-grained phase of the Three Sisters Pluton) have escaped erosion. The anomalous K-Ar isotopic behavior of the western apophysis of the Three Sisters Pluton and the Pallen Creek and Tanzilla Plutons may be due to the fact that the roof zones are presently being sampled and circulating hydrothermal solutions may have affected the isotopic systems. Comparisons of the K-Ar dates with

U-Pb and Rb-Sr dates provide a further basis of discussion.

V.3 ZIRCON U-Pb GEOCHRONOMETRY

Zircons were obtained from a representative specimen of the potassic marginal phase of the Three Sisters Pluton (specimen 356-1). Hornblende and Biotite from this sample have been dated by K-Ar method at 169 ± 11 Ma and 176 ± 5 Ma respectively (section V.2) and Rb-Sr isotopic analyses of a replicate specimen 572-2, lie on the 155 ± 2 Ma whole rock isochron discussed in the next section. Analytical procedures are detailed in Appendix 12 but descriptions of the zircons analyzed are provided below.

Four zircon fractions were separated initially on the basis of size and magnetic properties (Sullivan and Loveridge, 1980). In the case of discordant ages this permits sampling of the extremes of the disturbed system and detection of possible inherited zircon systematics (Silver and Deutch, 1963; Krogh and Davis, 1972). The two size fractions, larger than 100 mesh (-105 to $+74\mu\text{m}$) and intermediate between 140 and 200 mesh ($+149\mu\text{m}$), were each split into a less and more magnetic fraction (so-called nonmagnetic and magnetic fractions). The magnetic criteria corresponds to a clear petrographic subdivision (Figure 67; R.W. Sullivan, written communication, 1981). The nonmagnetic split of both size fractions contains clear to very pale tan, euhedral prismatic zircons (plus fragments of similar zircons broken in the crushing process) with sharp terminations and uncommon faint zoning, black speck inclusions and bubble inclusions or cracks (especially prevalent in the larger zircons). Magnetic zircons are predominantly brown to purple and transparent, euhedral, prismatic and more or less sharply terminated (or fragments of the same type) and are characterized by

Figure 67. Sketch from microphotograph of zircon fractions from sample AN-77-367 (x40 magnification): clear, prismatic euhedral grains of nonmagnetic fraction 1 ($-105 \pm 74 \mu\text{m}$) in upper diagram; and the euhedral, concentrically zoned, magnetic fraction 2 and 4 ($-149 \pm 105 \mu\text{m}$) in lower diagram.

pronounced concentric zoning, uncommonly about a visible, rounded core. More than one quarter of the magnetic zircons contain striking, small black speck inclusions. Although the rounded cores may indicate a xenocryst origin, the transparent, euhedral, sharply terminated nature of both fractions leaves little doubt that the zircons are primary crystallization products of a magma. These criteria allowed hand picking of the various fractions to obtain a pure concentrate. During the initial preparation of one zircon fraction, cross contamination occurred with a completely different fraction of smaller, round zircons; however, the foreign fraction was considered easily identified and painstaking hand picking of the contaminated sample separated them.

Uranium-lead isotopic analyses and $^{206}\text{Pb}/^{238}\text{U}$, $^{207}\text{Pb}/^{235}\text{U}$ and $^{207}\text{Pb}/^{206}\text{Pb}$ apparent ages for the zircon fractions are given in Table V.2. The various fractions exhibit several important isotopic characteristics. The U-Pb ages for any given zircon fraction are slightly discordant with respect to the concordia (Figure 69) but within the 0.7% error limits for $^{206}\text{Pb}/^{238}\text{U}$ and $^{207}\text{Pb}/^{235}\text{U}$ ratios at the 95% confidence level, they are essentially concordant. In every case, the $^{207}\text{Pb}/^{235}\text{U}$ dates are the oldest of the pair. Discordance among zircon fractions may result from U gain, Pb loss and/or loss of intermediate daughter products and is believed to result from radiation damage to the crystal lattice (Banks and Silver, 1966). Commonly, discordancy increases with decreasing grain size or increasing uranium content of the zircon fraction (e.g. Silver and Deutch, 1963; Banks and Silver, 1966; Krogh and Davis, 1972, 1973; and Mattinson, 1978). In this study this is not the case for discordancy and grain size but the discordancy-uranium content relationship approximately holds (Figure 68). Krogh and

TABLE V.2 ZIRCON U-Pb ANALYSES FOR THE THREE SISTERS PLUTON,

POTASSIC MARGINAL PHASE

Zircon fraction number	1	2	3	4
Fraction size (μm)	-105+74	-105+74	+149	+149
Magnetic of non-magnetic	nonmagnetic	magnetic	nonmagnetic	magnetic
Colour	clear	brown	clear	brown
Weight (mg)	2.10	2.15	5.47	4.05
Total Pb (ng)	40.60	95.95	76.54	111.6
Pb blank (%)	2.6	2.1	2.6	1.7
Observed $^{206}\text{Pb}/^{204}\text{Pb}$	2096	1982	285	2768
Abundances ($^{206}\text{Pb}/^{204}\text{Pb} \times 100$):				
^{204}Pb	0.0050	0.0221	0.3050	0.0085
^{207}Pb	5.0511	5.3103	9.4552	5.0953
^{208}Pb	13.117	14.437	23.425	16.018
Radiogenic Pb (ppm)	52.91	120.6	32.64	97.75
Radiogenic Pb (%)	99.69	98.64	83.14	99.48
Uranium (ppm)	1958	4469	1217	3539
Atomic ratios:				
$^{206}\text{Pb}/^{238}\text{U}$	0.026638	0.026451	0.026561	0.026600
$^{207}\text{Pb}/^{235}\text{U}$	0.18285	0.18184	0.18212	0.18230
$^{207}\text{Pb}/^{206}\text{Pb}$	0.049781	0.049856	0.049726	0.049704
Ages (Ma)				
$^{206}\text{Pb}/^{238}\text{U}$	169.5	168.3	169.0	169.3
$^{207}\text{Pb}/^{235}\text{U}$	170.5	169.6	169.9	170.0
$^{207}\text{Pb}/^{206}\text{Pb}$	184.8	188.3	182.2	181.2

Figure 68. Variation of $^{206}\text{Pb}/^{238}\text{U}$ apparent isotopic age with uranium content in zircon from sample 356-1, Three Sisters Pluton, potassic marginal phase. Size, colour and relative magnetic characteristics (M = magnetic; NM = nonmagnetic) of the fractions are also shown.

Figure 69. Concordia plot for U-Pb isotopic analyses on zircon from sample AN-77-356, Three Sisters Pluton, potassic marginal phase. The size and magnetic-nonmagnetic fractions are numbered as in Table V.2. Intercept of the concordia with a "best fit" chord through the origin and the data gives an age of 184 ± 5 Ma (2 σ error based on standard error of mean ^{207}Pb - ^{206}Pb ages; Loveridge, written communication, January, 1981). K-Ar isotopic ages for hornblende and biotite from the same sample are also given. A replicate sample, AN-78-572-2, was included in a Rb-Sr isochron plot which yielded an age of 155 ± 2 Ma.

Davis (1972) showed that clear, nonmagnetic zircons tend to have the lowest U contents as do zircons from the potassic marginal phase of the Three Sisters Pluton. In their detailed study of zircon U-Pb systematics, Silver and Deutsch (1963) concluded that lead loss by diffusion was the most reasonable interpretation of discordance. Loss of lead may be either episodic (Wetherill, 1956) or continuous (Tilton, 1960). If any lead is lost from the system, a minimum age can be calculated using the $^{207}\text{Pb}/^{206}\text{Pb}$ ratio (Faure, 1977). This date is not an independent check on the $^{206}\text{Pb}/^{238}\text{U}$ and $^{207}\text{Pb}/^{235}\text{U}$ dates and assumes that the Pb loss occurred recently and no isotopic fractionation occurred during the loss. The $^{207}\text{Pb}/^{206}\text{Pb}$ ages will be intermediate between the U-Pb isotopic dates and the true age of the rock (Banks and Silver, 1966). The $^{207}\text{Pb}/^{206}\text{Pb}$ dates (181-188 Ma) are significantly older than the separate U-Pb dates (168-171 Ma) and show a negative correlation with apparent age and with zircon grain size. In the case of very recent episodic lead loss in young (~100 Ma) zircons where various discordant fractions plot along a straight line below the discordia extending to the origin, the $^{207}\text{Pb}/^{206}\text{Pb}$ date for each fraction will approach the true age of the sample. The upper intercept of a discordia chord through the zircon fractions and the origin is 184 Ma (Figure 69) similar to an average $^{207}\text{Pb}/^{206}\text{Pb}$ age of 184 ± 5 Ma (2 σ uncertainty calculated from standard error of the mean of the 4 data; D. Loveridge, written communication, January 1981).

An alternative interpretation, that the more precise U-Pb isotopic ages, which average to 170 ± 1 Ma (2 σ uncertainty based on standard error of the mean), are the best estimate of the time of intrusion, is more consistent with

the K-Ar isotopic ages for the same sample (Figure 69) and intrusive relations.

V.4 WHOLE ROCK Rb-Sr GEOCHRONOMETRY

V.4.1 Introduction

Representative specimens from the Cake Hill Pluton and from all phases of the Three Sisters Pluton were analyzed for Rb and Sr (Table V.3) and of these, specimens from the constituent phases of the Three Sisters Pluton were chosen for whole rock isotopic analysis. The Cake Hill Pluton proved too homogeneous (minimum spread in the Rb/Sr ratio) to provide a meaningful whole rock isochron.

Detailed sampling and analytical procedures are given in Appendix. The results in Table V.3 are normalized and reported relative to the Eimer and Amend SrCO_3 standard $^{87}\text{Sr}/^{86}\text{Sr} = 0.70800$. Estimated precision for $^{87}\text{Rb}/^{86}\text{Sr}$ ratios is 0.7% (1 σ) and 0.003% (1 σ) for $^{87}\text{Sr}/^{86}\text{Sr}$ ratios. Slopes and intercepts were determined according to York (1969) and mean square of weighted deviates (MSWD), a statistical parameter relating to the "goodness of fit" of experimental points to a straight line, is quoted (Brooks *et al.*, 1972). Ages were calculated on the basis of the decay constant of $1.42 \times 10^{-11} \text{ yr}^{-1}$ for ^{87}Rb (Steiger and Jäger, 1977).

Two of the specimens have been dated by other methods. Hornblende and biotite from specimen 523 (mafic phase) is dated concordantly by the K-Ar method at $189 \pm 14 \text{ Ma}$ and $179 \pm 6 \text{ Ma}$ respectively. Specimen 572-2 (same locality as specimen 356-1; potassic marginal phase) yields concordant K-Ar hornblende and biotite dates of $169 \pm 11 \text{ Ma}$ and $176 \pm 5 \text{ Ma}$ and the zircon U-Pb concordia intercept age of $184 \pm 5 \text{ Ma}$ discussed above.

V.4.2. Data

A five point whole rock isochron, including samples from the fine-grained mafic, central and potassic marginal phases, yields a date of 155 ± 2 Ma and an intercept, $^{87}\text{Sr}/^{86}\text{Sr}_i$, of 0.70359 ± 0.0003 (Figure 70). An MSWD of 1.1 for the isochron is close to the ideal case of $\text{MSWD} = 1$, and indicates that the scatter in the points on the isochron plot can be accounted for by experimental rather than geological error. The slope of the line is controlled by the Rb-rich specimens of the potassic marginal phase and the intercept by specimens from the mafic, fine-grained and central phases (in order of increasing $^{87}\text{Rb}/^{86}\text{Sr}$ and $^{87}\text{Sr}/^{86}\text{Sr}$ contents). A line through only the potassic marginal phase data (2 points) leads to an age of roughly 162 Ma and initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.7034; regression of the other three data points gives a comparable age and initial ratio of 162 ± 9 Ma and 0.70356 ± 0.00005 .

From the discussions in the previous sections of this chapter, it is clear that these whole rock Rb-Sr isochron dates are 10-15 per cent younger than the oldest K-Ar and zircon ages of 180-190 Ma, determined from some of the same specimens dated by the Rb-Sr method.

V.4.3 Discussion of Rb-Sr Data

V.4.3(a) Assumptions in Rb-Sr Dating

Assumptions inherent in whole rock Rb-Sr age-dating are as follows (Faure, 1977; Faure and Powell, 1972): (1) during crystal fractionation, which produces the required spread in Rb/Sr ratio, it is assumed that if the Sr isotopic ratio in the magma remains constant, all differentiates will also have the same initial ratio; (2) the time of crystallization was

TABLE V.3 RUBIDIUM-STROMTIUM DATA FOR THE CAKE HILL AND THREE SISTERS PLUTONS

SAMPLE NUMBER	PLUTON OR PHASE	LOCATION (LATITUDE-- LONGITUDE)	LITHOLOGY ¹	-AVG. ² Rb (ppm)	AVG. ² Sr (ppm)	AVG. ² Rb/Sr	MEASURED 87Rb/86Sr	INITIAL ³ 87Sr/86Sr
CAKE HILL PLUTON								
AN-78-461	Cake Hill	58°01'25" N 129°37'15" W	hornblende quartz monzodiorite	84	843	0.100	87Rb/86Sr	87Sr/86Sr
AN-78-543-2	"	58°07'17" N 129°37'30" W	hornblende quartz monzodiorite	69	991	0.069		
AN-78-560-1	"	58°08'31" N 129°40'45" W	hornblende quartz monzodiorite	80	890	0.090		
AN-78-560-2	"	58°08'37" N 129°40'15" W	hornblende quartz monzonite	74	987	0.075		
AN-78-563-2	"	58°10'32" N 129°43'30" W	hornblende quartz monzodiorite	73	925	0.079		

1. Lithologies are classified according to Streckeisen (1973)

2. Average of 2 or 4 determinations (analyses for specimens 560-2, 563-2 and 565-2 have a difference of 2% between replicates; all other specimen replicates agree to within 1% or better)

3. Calculated initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio assumes an age of 185 Ma and the isotopic data for Rb and Sr as measured or calculated

TABLE V.3 RUBIDIUM-STRONTIUM DATA FOR THE CAKE HILL AND THREE SISTERS PLUTONS (cont'd)

SAMPLE NUMBER	PLUTON OR PHASE	LOCATION (LATITUDE-- LONGITUDE)	LITHOLOGY ¹	AVG. ² Rb (ppm)	AVG. ² Sr (ppm)	AVG. ² Rb/Sr	MEASURED $^{87}\text{Rb}/^{86}\text{Sr}$	INITIAL ³ $^{87}\text{Sr}/^{86}\text{Sr}$
CAKE HILL PLUTON (cont'd)								
AN-78-565-2	Cake Hill	58°10'56" N 129°41'30" W	hornblende quartz monzodiorite	97	839	0.116		
AN-78-568-2	"	58°12'58" N 129°44'15" W	hornblende quartz monzodiorite	67	1011	0.067		
AN-78-569-3	"	58°12'34" N 129°45'00" W	biotite- hornblende quartz monzodiorite	97	808	0.120		
AN-78-581	"	58°10'32" N 129°44'15" W	hornblende quartz monzodiorite	57	998	0.057		
AN-78-582-2	"	58°12'58" N 129°46'30" W	hornblende quartz monzodiorite	90	887	0.101		

1. Lithologies are classified according to Streckeisen (1973)

2. Average of 2 or 4 determinations (analyses for specimens 560-2, 563-2 and 565-2 have a difference of 2% between replicates; all other specimen replicates agree to within 1% or better)

3. Calculated initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio assumes an age of 185 Ma and the isotopic data for Rb and Sr as measured or calculated

TABLE V.3 RUBIDIUM-STROMTIUM DATA FOR THE CAKE HILL AND THREE SISTERS PLUTONS, (cont'd)

SAMPLE NUMBER	PLUTON OR PHASE	LOCATION (LATITUDE-- LONGITUDE)	LITHOLOGY ¹	CAKE HILL PLUTON (cont'd)		AVG. ² Rb (ppm)	AVG. ² Sr (ppm)	AVG. ² Rb/Sr	⁸⁷ Rb/ ⁸⁶ Sr	MEASURED ⁸⁷ Sr/ ⁸⁶ Sr	INITIAL ³ ⁸⁷ Sr/ ⁸⁶ Sr
An-78-459	metamorphosed Cake Hill	58°10'55" N 129°18'15" W	hornblende quartz monzonite	64	955			0.067			
THREE SISTERS PLUTON											
AN-78-477-2	fine-grained	58°04'12" N 129°19'48" W	fine-grained monzodiorite	70	594			0.118	0.338	0.70433	0.70346
AN-78-523		58°10'24" N 129°35'15" W		23	812			0.028	0.078	0.70375	0.70355
AN-78-477-1	central	58°04'12" N 129°19'48" W	biotite- hornblende monzonite	92	456			0.202	0.581	0.70491	0.70342

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1. Lithologies are classified according to Streckeisen (1973)

2. Average of 2 or 4 determinations (analyses for specimens 560-2, 563-2 and 565-2 have a difference of 2% between replicates; all other specimen replicates agree to within 1% or better)

3. Calculated initial ⁸⁷Sr/⁸⁶Sr ratio assumes an age of 185 Ma and the isotopic data for Rb and Sr as measured or calculated

TABLE V.3 RUBIDIUM-STRONTIUM DATA FOR THE CAKE HILL AND THREE SISTERS PLUTONS (cont'd)

SAMPLE NUMBER	PLUTON OR PHASE	LOCATION (LATITUDE-- LONGITUDE)	LITHOLOGY ¹	AVG. ²		AVG. ² Rb/Sr	MEASURED ⁸⁷ Rb/ ⁸⁶ Sr	INITIAL ³ ⁸⁷ Sr/ ⁸⁶ Sr
				Rb (ppm)	Sr (ppm)			
THREE SISTERS PLUTON (cont'd)								
AN-78-404	potassic marginal	58°08'17" N 129°50'30" W	biotite quartz monzonite	160	207	0.773	2.22	0.70280
AN-78-572-2	potassic marginal	58°11'30" N 129°55'00" W	hornblende- biotite quartz syenite	234	332	0.705	2.02	0.70285
AN-78-405	potassic marginal	58°08'40" N 129°50'30" W	biotite quartz monzonite	155	201	0.770		
AN-78-505-5	potassic marginal	58°10'48" N 129°30'08" W	hornblende- biotite quartz syenite	103	407	0.247		
AN-78-538-3	potassic marginal	58°10'33" N 129°33'41" W	hornblende biotite quartz monzonite	117	559	0.209		

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1. Lithologies are classified according to Streckeisen (1973)

2. Average of 2 or 4 determinations (analyses for specimens 560-2, 563-2 and 565-2 have a difference of 2% between replicates; all other specimen replicates agree to within 1% or better)

3. Calculated initial ⁸⁷Sr/⁸⁶Sr ratio assumes an age of 185 Ma and the isotopic data for Rb and Sr as measured or calculated

TABLE V.3 RUBIDIUM-STRONTIUM DATA FOR THE CAKE HILL AND THREE SISTERS PLUTONS (cont'd)

SAMPLE NUMBER	PLUTON OR PHASE	LOCATION (LATITUDE- LONGITUDE)	THREE SISTERS PLUTON (cont'd)			MEASURED $^{87}\text{Rb}/^{86}\text{Sr}$	INITIAL ³ $^{87}\text{Sr}/^{86}\text{Sr}$
			LITHOLOGY ¹	AVG. ² ^{87}Rb (ppm)	AVG. ² ^{87}Sr (ppm)		
AN-78-549-4	potassic marginal	58°06'38" N 129°40'00" W	hornblende biotite quartz syenite	153	367	0.417	
AN-78-488	fine-grained	58°03'36" N 129°19'30" W	fine-grained monzodiorite	62	579	0.108	
AN-79-661-3	mafic	58°04'44" N 129°26'15" W	equant horn- blende porphyry diorite	25	833	0.030	
AN-78-452	central	58°08'37" N 129°21'15" W	hornblende- biotite monzonite	72	632	0.114	
AN-78-526-2	central	58°11'13" N 129°28'45" W	hornblende- biotite monzodiorite	73	647	0.113	

1. Lithologies are classified according to Streckeisen (1973)

2. Average of 2 or 4 determinations (analyses for specimens 560-2, 563-2 and 565-2 have a difference of 2% between replicates; all other specimen replicates agree to within 1% or better)

3. Calculated initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio assumes an age of 185 Ma and the isotopic data for Rb and Sr as measured or calculated

TABLE V.3 RUBIDIUM-STRONTIUM DATA FOR THE CAKE HILL AND THREE SISTERS PLUTONS (cont'd)

SAMPLE NUMBER	PLUTON OR PHASE	LOCATION (LATITUDE-- LONGITUDE)	LITHOLOGY ¹	AVG. ² Rb (ppm)	AVG. ² Sr (ppm)	AVG. ² Rb/Sr	MEASURED ⁸⁷ Rb/ ⁸⁶ Sr	INITIAL ³ ⁸⁷ Sr/ ⁸⁶ Sr
THREE SISTERS PLUTON (cont'd)								
AN-78-528-4	central	58°10'43" N 129°33'00" W	biotite- hornblende monzodiorite	69	813	0.085		
AN-78-551-4	central	58°06'04" N 129°38'15" W	hornblende- biotite diorite	35	698	0.050		
AN-79-688-2	central	58°09'00" N 129°26'45" W	biotite- hornblende quartz monzodiorite	70	619	0.113		
AN-78-574-5	potassic marginal	58°10'32" N 129°55'30" W	biotite- hornblende quartz syenite	158	222	0.712		
AN-78-718-2	leucocratic	58°02'23" N 129°18'45" W	leucocratic quartz diorite	1.1	627	0.001		

1. Lithologies are classified according to Streckeisen (1973)

2. Average of 2 or 4 determinations (analyses for specimens 560-2, 563-2 and 565-2 have a difference of 2% between replicates; all other specimen replicates agree to within 1% or better)

3. Calculated initial ⁸⁷Sr/⁸⁶Sr ratio assumes an age of 185 Ma and the isotopic data for Rb and Sr as measured or calculated

Figure 70. Rb-Sr isochron diagram for the Three Sisters Pluton with whole rock isotopic data for the fine-grained, mafic, central and potassic marginal phases. K-Ar and U-Pb mineral isotopic ages from the same or replicate samples are included for the mafic and potassic marginal phases. Error in age and initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio (2σ) refer to last significant figure. Abbreviations are: cp = central phase; fgp = fine-grained phase; mp = mafic phase; pmp = potassic marginal phase.

fairly short, with the consequence that; (3) rocks produced by this process of fractionation have nearly the same age. It is implicit in these assumptions that the analyzed samples can be shown to be contemporaneous and comagmatic. McCarthy and Cawthorn (1980) have demonstrated that protracted fractional crystallization can result in significantly different whole rock initial $^{87}\text{Rb}/^{86}\text{Sr}$ ratios in late stage, fractionated phases (e.g. for comagmatic granites, pegmatites and aplites ranging in Rb/Sr ratios from 3 to >500) compared to earlier formed comagmatic phases. No aplitic or pegmatitic members were dated in this study and the low Rb/Sr ratios of the Three Sisters Pluton suggest that this was not a significant factor. Interpretations of available data for other isotopic systems indicate that the ages of the constituent phases of the Three Sisters Pluton are indistinguishable and so they may all be assumed to conform to assumptions (2) and (3). The intrusive relations and mineral and whole rock geochemical data indicate contemporaneous intrusion of the constituent phases and permit a probable comagmatic origin for them.

V.4.3(b) Open system behavior in Rb-Sr systems

It is generally conceded (e.g. Brooks et al., 1972; Faure, 1977, p.80) that a satisfactory fit of the experimental data to an isochron line justifies these assumptions to at least a first approximation, and the age, as determined from the slope of the line, is regarded as the time of crystallization from the magma.

There is a growing body of geochronological research (e.g. Compston et al., 1966; Brooks, 1968; Lanphere, 1968; Cormier, 1969; Hart and Davis, 1969; Fairburn and Hurley, 1970; Van Schmus, 1971; Bickford and Mose, 1972, 1975; Goldich, 1972; Krogh and Davis, 1972, 1973; Van Schmus et al., 1975;

Van Schmus and Bickford, 1976; Roddick and Compston, 1977; Bell and Blenkinsop, 1978; Page, 1978; Priem et al., 1978; Field and Rheim 1979a, b, 1980; and Dallmeyer et al., 1981) that indicates good quality Rb-Sr isochrons may be obtained which have little or no geological meaning when interpreted with stratigraphic age constraints on the possible age or when compared with other isotopic systems. The magnitude of and limits to open system Rb-Sr isotopic behavior must be considered when interpreting anomalous isochron ages.

Many of these studies concern Precambrian, fine-grained gneissic or volcanic rocks whose Rb-Sr whole rock isochron ages are 10-15 per cent younger than discordia intercept zircon ages. There appears to be some lithological and chemical control on Rb-Sr whole rock discordancy (Field and Rheim, 1979a, b; Bell and Blenkinsop, 1978; Page, 1978; Priem et al., 1978; Van Schmus and Bickford, 1976; Bickford and Mose, 1975; Van Schmus, 1971; Fairburn and Hurley, 1970; and Van Schmus et al., 1975). Fine-grained sedimentary and volcanic rocks are more susceptible than granitic and metamorphic rocks to resetting of the Rb-Sr whole rock systematics. Isochron arrays with higher, more limited range of Rb/Sr ratios (and corresponding lower Sr contents), higher SiO₂ and K₂O contents and lower $Fe^{3+}/Fe^{2+} + Fe^{3+}$ ratios tend to produce younger ages than arrays with more dispersed, though generally lower, Rb/Sr ratios and more basic, more oxidized bulk chemistry. Nevertheless, granitic rocks can yield anomalously low Rb/Sr whole rock ages (Bickford and Mose, 1975; Page, 1978; Dallmeyer et al., 1981). Disturbance of the Rb-Sr system can occur at metamorphic grades as low as sub- to low greenschist grade (e.g. Field and Rheim, 1979a, b, 1980; Page, 1978; Priem et al., 1978; R.L. Armstrong, personal communication, 1981). In

volcanic rocks, the interaction of water in a shallow crustal environment (essential to the redistribution of Sr isotopes), possibly enhanced by somewhat elevated temperatures and associated processes of unmixing and/or breakdown of alkali feldspars or devitrification of glass, is thought to have reset their Rb-Sr systematics (Van Schmus and Bickford, 1976; Page, 1978; Preim et al., 1978). Loss of Sr (and reduction in $^{87}\text{Sr}/^{86}\text{Sr}$) or gain of Rb would have the individual or combined effect of lowering isochron ages and Brooks (1968) showed that in alteration of feldspars in granite, mobility of radiogenic Sr, ^{86}Sr and ^{87}Rb has occurred. Bickford and Mose (1975) and Page (1978) concluded that correlation between model Rb-Sr age and Sr content and inverse correlation of model Rb-Sr age and $^{87}\text{Rb}/^{86}\text{Sr}$ isotopic composition for discordant samples resulted from loss of total Sr or loss of radiogenic Sr or redistribution of either or both, and had the effect of lowering the whole rock ages. Field and Rheim (1979a, b) found no petrographic evidence for Rb distribution (e.g. late growth of Rb-rich phases) in the small whole rock subvolumes they analyzed and concluded that during corrosion of Rb-rich biotite, highly radiogenic Sr was removed, was redistributed on a scale larger than the outcrop scale they sampled and led to a lower whole rock isochron age. Hart (1981) determined a polybaric, compensation effect convergence temperature of 460C for elemental diffusion of Na, K, Rb, Ar, Sr and oxygen in equilibrated perthitic feldspars (albite, orthoclase, microcline, andularia, sanidine and anorthite). For typical batholithic cooling rates of 10^1 - 10^3 C/Ma (e.g. see Harrison et al., 1979), he concluded that the closure temperature for these species in the feldspar would be 400-600C. This might be an estimate for the minimum temperature for redistribution of Sr by diffusion from the feldspars. One

estimate of the temperature of the type of low grade alteration seen in isotopically reequilibrated granitic rocks is 50-100°C from stable isotope geochemistry (Wenner and Taylor, 1976). Petrography of the Three Sisters Pluton samples analyzed in this study, indicates turbid brick-red alkali feldspars and minor chloritization of mafic minerals in the age-controlling potassic marginal phase specimens despite the best efforts to collect fresh, representative samples from this phase. It is conceivable that radiogenic Sr distribution in such a low temperature environment would have effectively reequilibrated the Rb-Sr isotopic system and so the date defined by the Rb-Sr isochron represents an age of final cooling of the Three Sisters Pluton.

The Rb-Sr isochron date closely compares with the youngest K-Ar dates determined for the Jurassic plutonic suite. An alternative explanation to an inferred (and unlikely) 40 million year cooling of the Three Sisters Pluton is a major thermal event around 150-155 million years ago which selectively reset these isotopic systems.

V.4.3(c) Extent of reequilibration

If disturbance of the Rb-Sr isotopic system in the Three Sisters Pluton has resulted in rotation of the isochron to a lower slope, consideration of the extent of reequilibration must be made. Krogh and David (1973), Montgomery and Hurley (1978), Field and Råheim (1980) and Kalsbeek and Pidgeon (1980) have shown that even at high grades of metamorphism (including granulite grade) Rb-Sr isotopic equilibrium is only achieved over distances of a few (e.g. 1-7 cm, Krogh and Davis, 1973) to several (e.g. 6-10 cm or more, Montgomery and Hurley, 1978) centimeters. Roddick and Compston (1977) concluded that the range and style of preserved Rb-Sr isotopic systematics

during a thermal event is the most important factor in interpretation of whole rock isochron ages, even for unmetamorphosed granitic batholiths. Important parameters are the volume (V_e) in which strontium isotopic equilibration is effective during the thermal event and the minimum subvolumes (V_s) into which the body can be divided such that each subvolume V_s has the same mean $^{87}\text{Rb}/^{86}\text{Sr}$ (and thus $^{87}\text{Sr}/^{86}\text{Sr}$) for the entire body. If $V_e > V_s$ the thermal event will effectively reset whole rock Rb-Sr systematics and a metamorphic age will result (and homogenization of the entire body will appear to have occurred). If $V_s > V_e$, the original pre-event isochron will be approximately preserved. If V_e is on the scale of individual minerals, any scale of whole rock sampling for any Rb/Sr distribution pattern will determine the original age. In the case of well-fitted isochrons, the impression of regional homogenization of isotopes and the observation of differing Rb/Sr ratios between samples are not mutually exclusive; this indicates that the volume of strontium isotopic equilibrium is greater than the individual sample volume but less than the volumes representing the mean Rb/Sr for the particular pluton or batholith. This is thought to be the case for the Three Sisters Pluton where low temperature hydrothermal redistribution of strontium isotopes occurred over volumes greater than the average 2 l volume of collected samples. This alteration is most important in the age-controlling high Rb/Sr (potassic marginal phase) samples and these are geologically the ones which are intruded last and closest to the roof and margins of the pluton.

A composite batholith between Princeton and Okanagan Lake exhibits a nearly identical discrepancy between K-Ar mineral and Rb-Sr whole rock dates (Petö and Armstrong, 1976). Discordant potassium-argon ages range from

144-189 Ma and a poorly defined composite whole rock Rb-Sr isochron yielding a date of 156 ± 6 Ma (MSWD = 6.53) is discordant with the oldest K-Ar dates. A more refined isochron date of 166 ± 53 Ma (MSWD = 1.65) for the mafic members of the batholith is concordant within its broad error envelope with the oldest K-Ar dates. Widespread, post-emplacement metamorphism is invoked for this suite to explain the reset K-Ar and the whole rock Rb-Sr systems. Visible signs of this alteration include ubiquitous late chlorite, epidote, saussurite and sericite in quartz diorite and granodiorite phases.

V.4.3(d) Interpretation of Rb-Sr initial ratio with respect to the Canadian Cordillera

If small scale reequilibration has occurred, what is the significance of the low isotopic ratio? "Model" initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios for an age of 185 Ma are listed for each analyzed specimen in Table V.3. A difference in age of 5 million years will affect the model initial ratio less than 3 parts in 7000. As expected, the initial ratios are less than the isochron value of 0.7036 and approach it with decreasing Rb/Sr ratio (i.e. specimens not as susceptible to alkali feldspar alteration have the lowest Rb/Sr and highest initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios). This range of "model" initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of 0.7038-0.7035 and the isochron value of 0.7036 are within the range determined by Hamilton (1981) for the Late Cenozoic lavas of the Table Mountain Range (0.7025-0.7044).

Mantle evolution in Rb-Sr indicates a major mantle contribution to parental magmas with initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios less than 0.704 little contribution from the sialic crust (Faure and Powell, 1972; Faure, 1977). Pankhurst (1979) and Jones and Kesler (1980) argue that other potential sources for magmas with low $^{87}\text{Sr}/^{86}\text{Sr}$ initial ratios include: young igneous crust within

the continental crust, underplating it or in the subducted lithosphere; immature sediments derived from this young crust; the mantle wedge above the subduction zone; or even old crustal rocks with very low Rb/Sr ratios. Around the Mesozoic Californian batholiths, Permian or younger country rocks qualify isotopically as possible source rocks for the batholithic magmas but they contain insufficient (<400 ppm) strontium compared to the granitic rocks (Kistler and Peterman, 1973). Available analyses for the Upper Paleozoic Cache Creek Group of the Atlin Terrane (Monger, 1975), analogs to rocks possibly subducted and melted to form the Jurassic plutonic suite, do not include determinations for strontium or strontium isotopic ratios. Analyses of the coeval Mesozoic volcanics around the Hotailuh Batholith also are characterized by moderately high (>400 ppm) Sr contents. Generally, eugeo-synclinal sediments are too enriched with radiogenic Sr ($^{87}\text{Sr}/^{86}\text{Sr} > 0.705$) to qualify as source rocks for granitic rocks with low initial Sr isotopic ratios (<0.704; Peterman et al., 1967).

The nature of the crust through which magmas are intruded exerts a profound influence on their initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios. A critical isotopic contour known as the "0.706 line" was first recognized in the Peninsular Ranges of California by Early and Silver (1973), in the Californian Mesozoic batholiths by Kistler and Peterman (1973), and was extended north through Washington, Oregon and Idaho by Armstrong et al. (1977). Its location in the Canadian Cordillera summarized by Armstrong (1979; Figure 71) is based on the data from numerous workers (e.g. Ryan, 1973; Le Couteur and Templeman-Kluit, 1976; Petö and Armstrong, 1976; Pigage, 1977; Armstrong et al., 1979; Duncan et al., 1979; Harrison et al., 1979; Morrison et al., 1979; Parrish, 1979; Preto et al., 1979; Berman and Armstrong, 1980; Hamilton, 1981).

Figure 71. Location of Hotailuh Batholith, initial $^{87}\text{Sr}/^{86}\text{Sr} = 0.706$ line for the Canadian Cordillera (Armstrong, 1979; Price et al., 1981, Fig. 2) and the distribution of the Cache Creek Group. Initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.7036 from Rb-Sr isochron for Three Sisters Pluton is also given.

The $^{87}\text{Sr}/^{86}\text{Sr}$ 0.706 line separates igneous rocks with initial Sr isotopic ratios greater or less than 0.706 regardless of age. This line corresponds to the ensimatic (eugeosynclinal)-ensialic (miogeosynclinal) boundary established on geological and geochemical grounds (e.g. Kistler and Peterman, 1973; Rogers *et al.*, 1974; Armstrong *et al.*, 1977; Armstrong, 1979; Monger and Price, 1979) and illustrates the sensitivity of the initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio to the type of crust with which the magma equilibrates on its ascent (Armstrong *et al.*, 1977). In the northwestern United States and Canadian Cordillera, the 0.704-0.706 Sr isotopic transition zone marks the boundary between the Precambrian crust to the east and Phanerozoic eugeosyncline to the west (Armstrong *et al.*, 1977; Armstrong, 1979). However, the Intermontane Belt is surrounded on the east, north (north of the Whitehorse Trough) and west (Coast Plutonic Complex) by the 0.704-0.706 transitional zone (Figure 71). For the Three Sisters Pluton, the absence of interaction between its parental magma and sialic crust, as indicated by a low initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio (<0.704) is consistent with a lack of inherited zircon component in the U-Pb isotope systematics. A similar correlation between Rb-Sr and U-Pb isotopic systematics is observed in the Caledonide granitoids (Halliday *et al.*, 1979; Pankhurst, 1979).

V.5 CONCLUSIONS

The Triassic plutonic suite was intruded prior to and contemporaneous with the Late Triassic, Stuhini Group volcanism. A K-Ar age range of 218-230 Ma is a reasonable, geologically consistent estimate of the minimum age of emplacement for the Stikine and Cake Hill Plutons and for the actual age of emplacement for the Gnat Lakes Ultramafite. The Beggerlay Creek Pluton,

which intrudes the Stuhini Group, is dated at 218 ± 29 Ma, a date comparable to another Triassic pluton which also intrudes the Stuhini Group, and is a minimum estimate of emplacement age for this member of the Triassic plutonic suite.

Interpretation of K-Ar, U-Pb and Rb-Sr isotopic systematics in the Three Sisters Pluton emphasized their internal discordancy in isotopic age. This apparent discordancy can be reduced if: a) the average U-Pb age of 170 ± 1 Ma is accepted as the best estimate for the time of intrusion; b) an average K-Ar age of 170 ± 9 Ma is the best estimate of the cooling age for the pluton; and c) the possibility that interphase variations in initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, suggested by the preliminary data, may explain the anomalously young Rb/Sr isotopic age. Emplacement of the Three Sisters Pluton later than 180-188 Ma (absolute age of Toarcian stage according to Armstrong (1978a, 1981) is more consistent with the depositional pattern in the Early Jurassic around the batholith and intrusive relations involving the Three Sisters Pluton and Early to Late Toarcian sediments.

Further isotopic studies are necessary to refine the age of emplacement of the Three Sisters Pluton. More potassium-argon data, especially from the eastern part of the Three Sisters Pluton, would test the apparent geographical zonation of mineral separate and concordant mineral pair dates determined in this study. Additional U-Pb data from the eastern outcrops of zircon-bearing potassium marginal phase would shed more light on the age of crystallization of this phase. Detailed Rb-Sr studies of samples from the mafic, central and potassic marginal phases would help resolve the importance of isotopic subvolumes and shed some light on the postulated hydrothermal disturbance of the Rb-Sr system. An indication of the extent of $^{87}\text{Sr}/^{86}\text{Sr}$ initial

ratio evolution in the generation of these magmas would also result from such a study. In particular, a locality 6 km due east of Cake Hill Pluton (at the locality of K-Ar specimen 528-3: $58^{\circ}10'42''\text{N}$, $129^{\circ}33'00''\text{W}$) would be especially amenable to a detailed Rb-Sr study as the mafic phase is clearly intruded by the potassic marginal phase (Plate VIIc) which, south of the contact is clearly gradational with the central phase. Whole rock isotopic lead and Sm/Nd isotope studies would refine the contribution of other sources of low initial $^{87}\text{Sr}/^{86}\text{Sr}$ magmas which cannot be distinguished from the present Rb-Sr data, namely young oceanic crust in subducted lithosphere and the mantle wedge above the subduction zone (e.g. Doe and Delevaux, 1973; Kay *et al.*, 1978; Hawkesworth *et al.*, 1979). Stable oxygen and hydrogen isotope studies could refine the extent to which magmas interacted with meteoric water and the contribution of this interaction to the resetting of radiogenic isotopic systems (e.g. Wenner and Taylor, 1976; Taylor, 1977; Hart and Allegre, 1980).

Present studies indicate that the spread of isotopic ages in the Three Sisters Pluton occurred as a result of sequential uplift and slow cooling over a 35-40 million year period or a major thermal event around 150 Ma, which selectively reset the isotopic systems. The pluton was generated from a parental magma with probable mantle affinities and a minimum of sialic crustal contamination. Batholithic and satellitic members of the Jurassic Plutonic Suite having similar aeromagnetic, lithological, intrusive petrographic and chemical characteristics are also of about the same isotopic age.

VI GEOCHEMISTRY

VI. 1 Introduction and Summary

The purpose of this chapter is to compile and compare the chemical composition of the Triassic plutonic suite, Jurassic plutonic suite, augite-bladed plagioclase porphyry dikes in the Triassic plutonic suite, Upper Triassic Stuhini Group volcanics and the Triassic-Jurassic volcanics.

Average chemical compositions of the various plutons and volcanic units broadly overlap but a few plutons and the two major volcanic units are distinctive. These comparisons are facilitated in a composition-relative time plot. Without the relative intrusive or extrusive sequence established from the field relations, such comparisons could not be made. The augite-bladed plagioclase porphyry dikes and the Beggerlay Creek Pluton compare most closely with compositions of the Stuhini Group volcanics.

The familiar AFM ternary, alkali-silica plot, normative $ne'-ol'-qz'$ ternary, Miyashiro's (1974) plot, Irvine and Baragar's (1971) Al_2O_3 -normative plagioclase plot and the Na_2O-K_2O-CaO ternary show that each plutonic and volcanic suite is characterized by alkaline and subalkaline compositions. The subalkaline rocks are more common and calc-alkaline and tholeiitic compositions are represented. Tholeiitic compositions are mainly confined to the mafic plutons or phases in each plutonic suite and in the Jurassic plutonic suite, the intrusive relations between the tholeiitic and calc-alkaline rocks suggest at least a close temporal if not genetic link. The alkaline, tholeiitic and calc-alkaline compositions of the volcanics exhibit no apparent preference for stratigraphic position.

Plutons of the Triassic and Jurassic plutonic suites have chemical

characteristics typical of I-type granitoids as defined by Chappell and White, (1974); White and Chappell, (1977); Griffin et al., (1978); Hine et al., (1978) and Chappell, (1978). These include high Na_2O contents relative to K_2O , higher TiO_2 contents relative to Zr, higher Fe_2O_3 contents relative to FeO and lower molar $\text{Al}_2\text{O}_3/(\text{Na}_2\text{O} + \text{K}_2\text{O} + \text{CaO})$ ratios than S-type granitoids. This chemical classification agrees with the I-type lithological and petrographic characteristics. Specimens which have molar $\text{Al}_2\text{O}_3/(\text{Na}_2\text{O} + \text{K}_2\text{O} + \text{CaO})$ ratios greater than 1.05 also have slightly more than 1 per cent normative corundum and are the most siliceous of the specimen suite. Smooth intrapluton variation in normative diopside or corundum with SiO_2 suggests hornblende fractionation may account for some of these characteristics (Cawthorn and Brown, 1976).

Microprobe data for pyroxenes, indicate a similarity in pyroxene compositions among the augite porphyry volcanics, the augite-bladed plagioclase porphyry dikes and the Gnat Lakes Ultramafite; these data suggest a genetic link which is consistent with some of their geological relations. Relict pyroxenes in the fine-grained phase, mafic phase, central phase and inclusions in the central phase are similar in composition and also suggest a possible cogenetic link among these coeval phases.

VI.2 Chemical Composition of the Triassic and Jurassic Plutonic Suites, Augite-Bladed Plagioclase Porphyry Dikes and Mesozoic Volcanic Suites

In previous chapters, the chemistry of the plutonic and volcanic rocks in and around the Hotailuh Batholith was presented, and particular chemical characteristics within each pluton, phase or volcanic unit were discussed. The average composition of major, minor and trace elements for

each pluton, phase, hypabyssal dike or volcanic unit were presented. The average composition of major, minor and trace elements for the members of the Triassic plutonic suite, Mesozoic volcanic suite and Jurassic plutonic suite is given in Figure 72, in order of intrusion or extrusion as constrained by intrusive and other geological relations.

A number of characteristics are shown on Figure 72. Plutons which are most lithologically homogeneous (e.g. the Cake Hill, McBride River and Tanzilla Plutons) have the smallest standard deviations from their average value when compared to other units having similar numbers of specimens. In the Triassic plutonic suite, there is no apparent geochemical cycle that can be related to the order of intrusion. Each pluton apparently intruded as a geochemically distinct magma.

The Triassic-Jurassic porphyritic lavas are more felsic than the Upper Triassic Stuhini Group porphyritic lavas. There is a moderate to good correspondence between the average compositions of the augite-bladed plagioclase porphyry dikes and the Stuhini Group augite-bladed plagioclase porphyry flows. Of particular interest is the compositional overlap between the porphyritic volcanics and the Beggerlay Creek Pluton. This is consistent with the intrusive relationships which suggest that the Beggerlay Creek Pluton was contemporaneous with the volcanism. Petrographic features of the Beggerlay Creek Pluton also suggest that it may be subvolcanic and highly altered.

Variation in average chemical composition within the mafic, central and potassic marginal phases of the Three Sisters Pluton and the mafic and felsic units of the Pallen Creek Pluton indicate an increasingly felsic character in the magmas with time. The leucocratic phase appears geochemically distinct in its alkali and alkaline earth elements with respect to

Figure 72. Average major, minor and trace element contents and ratios for major units in the Triassic plutonic suite, Mesozoic volcanics and dikes and Jurassic plutonic suite in approximate order of intrusion or extrusion. Vertical bars indicate $\pm 1\sigma$ error in the average. Refer to sections for individual plutons or units for raw data and numbers of samples used in averages (especially for trace elements). Abbreviations are:

(a) Triassic plutonic suite: BCP = Beggerlay Creek Pluton; CHP = Cake Hill Pluton; GLU = Gnat Lakes Ultramafite; SP = Stikine Pluton; (b) Mesozoic volcanics and dikes: PPD = pyroxene porphyry dikes; SGV = Stuhini Group volcanics; TJV = Triassic-Jurassic volcanics; (c) Jurassic plutonic suite: MRP = McBride River Pluton; PCP = Pallen Creek Pluton (fp = felsic phase; mp = mafic phase); SCP = Snowdrift Creek Pluton; TP = Tazilla Pluton; TSP = Three Sisters Pluton (cp = central phase; fgp = fine-grained phase; lp = leucocratic phase; mp = mafic phase, pmp = potassic marginal phase). Compositions for the Mesozoic volcanics and dikes are calculated volatile-free. Average Rb/Sr ratios for Cake Hill Pluton and Three Sisters Pluton include data from Table V.3.

the average compositional trends of the mafic, central and potassic marginal phases; in other elements, its average composition is consistent with the trends of these phases. The fine-grained phase of the Three Sisters Pluton overlaps the compositions of the mafic and central phases. The McBride River, Snowdrift Creek and Tanzilla Plutons are chemically if not lithologically similar to the central and potassic marginal phases.

Perhaps the most important point illustrated by Figure 72 is the similarity in average chemical composition among the three major plutonic and volcanic suites. Even at one standard deviation, with the exception of the chemically distinctive Gnat Lakes Ultramafite, separation of plutonic or volcanic specimens whose field relations were unknown would be difficult or impossible.

VI.3 Classification

VI.3.1 Classification of magma types

The major, minor and trace element chemical composition of the various plutons, phases and volcanic suites and their classification were presented in previous chapters. A compilation of these data, in the form of AFM, $\text{Na}_2\text{O}-\text{K}_2\text{O}-\text{CaO}$ and normative $\text{ne}'-\text{ol}'-\text{qz}'$ ternary plots and alkali-silica, $\text{SiO}_2-\text{FeO}/\text{MgO}$ (Miyashiro, 1974) and Al_2O_3 -normative plagioclase (Irvine and Baragar, 1971) binary plots, is given for the Triassic plutonic suite, Jurassic plutonic suite, augite-bladed plagioclase porphyry dikes, the Upper Triassic Stuhini Group and the Triassic-Jurassic volcanics in Figure 73.

In each plutonic and volcanic suite, alkaline and subalkaline compositions are represented. This is characteristic of other large, composite,

Figure 73. Chemical variation diagrams for: the Triassic Plutonic Suite (abbreviations: BCP = Beggerlay Creek Pluton; CHP = Cake Hill Pluton; GLU = Gnat Lakes Ultramafite; SP = Stikine Pluton); the Mesozoic volcanics and dikes (abbreviations: PPD = pyroxene porphyry dikes; SGV = Stuhini Group volcanics; TJV = Triassic-Jurassic volcanics); batholithic Jurassic plutonic suite (abbreviations: MRP = McBride River Pluton; TSP = Three Sisters Pluton; fgp = fine-grained phase; cp = central phase; lp = leucocratic phase; mp = mafic phase; pmp = potassic marginal phase); and the saffellitic Jurassic plutonic suite (abbreviations: PCP = Rallen Creek Pluton; SCP = Snowdrift Creek Pluton; TP = Tanzilla Pluton). The geochemical variations for each pluton or phase are described in earlier chapters. The diagrams are as follows:

- a) Weight per cent alkali-silica diagram. Alkaline-subalkaline division after Irvine and Baragar (1971).
- b) Weight per cent, normative $ne'-ol'-qz'$ ternary diagram ($ne' = ne + 3/5 ab$; $qz' = qz + 2/5 ab + 1/4 opx$; $ol' = ol + 3/4 opx$). Alkaline-subalkaline division after Irvine and Baragar (1971).
- c) Weight per cent $A (Na_2O + K_2O) - F (FeO + 0.8998 Fe_2O_3) - M (MgO)$ ternary diagram. Calc-alkaline - tholeiitic division after Irvine and Baragar (1971).
- d) Weight per cent $SiO_2 - FeO^*/MgO$ diagram ($FeO^* = FeO + 0.9 Fe_2O_3$). Calc-alkaline - tholeiitic division after Miyashiro (1974).
- e) Weight per cent $MgO - \text{total iron}$ diagram. Cascades (C), abyssal tholeiite (AT), pigeonitic series (PS) and Thingmuli (T) trends after Stauffer et al. (1975).
- f) Weight per cent alumina-normative plagioclase (weight per cent anorthite composition) diagram. Calc-alkaline - tholeiitic division after Irvine and Baragar (1971).
- g) Weight per cent $Na_2O - K_2O - CaO$ ternary diagram.

All variation diagrams involving volcanic rocks or dikes use volatile-free compositions.

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TRIASSIC PLUTONIC SUITE

MESOZOIC VOLCANICS AND DYKES

a) Alkali-silica diagram

BATHOLITHIC JURASSIC PLUTONIC SUITE SATELLITIC JURASSIC PLUTONIC SUITE

b) $Ne'-ol'-qz'$ ternary

b) Ne'-ol'-qz' ternary (continued)

c) AFM ternary

c) AFM ternary (continued)

TRIASSIC PLUTONIC SUITE

d) Silica - FeO^*/MgO diagram

d) Silica - FeO*/MgO diagram (continued)

BATHOLITHIC JURASSIC PLUTONIC SUITE

SATELLITIC JURASSIC PLUTONIC SUITE

e) MgO - total iron diagram

TRIASSIC PLUTONIC SUITE **MESOZOIC VOLCANICS AND DYKES**

e) MgO - total iron diagram (continued)

BATHOLITHIC JURASSIC PLUTONIC SUITE

SATELLITIC JURASSIC PLUTONIC SUITE

7

f) Alumina - normative plagioclase composition diagram

TRIASSIC PLUTONIC SUITE **MESOZOIC VOLCANICS AND DYKES**

f) Alumina - normative plagioclase composition diagram (continued)

BATHOLITHIC JURASSIC PLUTONIC SUITE SATELLITIC JURASSIC PLUTONIC SUITE

g) $Na_2O - K_2O - CaO$ ternary

K₂OK₂O CaO Na₂ONa₂O

CaO

BATHOLITHIC JURASSIC PLUTONIC SUITESATELLITIC JURASSIC PLUTONIC SUITE

Triassic-Jurassic batholiths and coeval volcanic suites in the Canadian Cordillera (e.g. Garnett, 1979; Preto, 1972; Tipper and Richards, 1976; Monger, 1977a). Within the subalkaline compositions, calc-alkaline and tholeiitic rocks are common. In the Triassic plutonic suite, the mafic plutons (Stikine Pluton, Gnat Lakes Ultramafite and Beggerlay Creek Pluton) are most commonly alkaline. With the exception of the Gnat Lakes Ultramafite, subalkaline rocks in the latter plutons are calc-alkaline according to the AFM and Al_2O_3 -normative plagioclase plots but are tholeiitic according to the SiO_2 - FeO^*/MgO and $\text{FeO}^*-\text{FeO}^*/\text{MgO}$ (not shown in Figure 73) plots of Miyashiro (1974) and compositions in the Beggerlay Creek Pluton plot parallel to iron-enrichment trends of classic tholeiitic suites on a MgO -total iron plot (Lowder and Carmichael, 1970; Stauffer *et al.*, 1975). Subalkaline compositions in the Gnat Lakes Ultramafite are tholeiitic according to all the plots. The Cake Hill Pluton is clearly subalkaline and predominantly calc-alkaline.

A similar pattern emerges for the volatile-free compositions of the hypabyssal rocks and two volcanic units. Alkaline and subalkaline compositions are equally common. In the Upper Triassic Stuhini Group volcanics, alkaline compositions are especially common in specimens along the western margin of the batholith (specimens 604-1 and 632-1) but there is no other variation of alkaline and subalkaline or calc-alkaline and tholeiitic compositions with stratigraphic or geographical position. In the Triassic-Jurassic volcanics, alkaline, calc-alkaline and tholeiitic compositions are found in each "cycle" but no coherent pattern is detected. On the variation diagrams, the broad fields of the porphyritic hypabyssal dikes and the porphyritic Stuhini Group volcanics overlap.

Alkaline and subalkaline compositions are also represented in the Jurassic plutonic suite. Again, there is a classification problem. The fine-grained, mafic, central and potassic marginal phases of the Three Sisters Pluton and the mafic phase of the Pallen Creek Pluton (one specimen) have some alkaline and subalkaline specimens and the alkaline character depends on which plot is used (Three Sisters Pluton, fine-grained, mafic central and potassic marginal phases are predominantly subalkaline). The leucocratic phase of the Three Sisters Pluton, McBride River Pluton, Snowdrift Creek Pluton, Pallen Creek Pluton (felsic specimens) and Tanzilla Pluton are clearly subalkaline.

Among the subalkaline specimens, calc-alkaline and tholeiitic compositions are common. In particular, specimens from the mafic phase of the Three Sisters Pluton are rarely to predominantly tholeiitic depending on the plot used for classification. The central and potassic marginal phases are predominantly calc-alkaline to mixed tholeiitic and calc-alkaline. The Three Sisters Pluton's fine-grained phase (the mappable body, not the inclusions) and leucocratic phase, as well as the McBride River Pluton, Snowdrift Creek Pluton, Pallen Creek Pluton (felsic specimens) and Tanzilla Pluton are exclusively calc-alkaline.

Figure 73 also illustrates two other points. In the Three Sisters Pluton, compositions of both the mappable and inclusion parts of the fine-grained phase clearly overlap the compositional "fields" of the mafic and central phases; this is consistent with the interpretation of the fine-grained phase as a chilled equivalent of the mafic and central phase magmas. The overlap of compositional fields for the Triassic plutonic suite, the Mesozoic volcanic suite and the Jurassic plutonic suite illustrates the

difficulty in using these diagrams to meaningfully separate specimens whose geological relationships are not known. The Triassic plutonic suite provides a clear example of the dangers in this approach. A differentiation sequence from the "parental" Gnat Lakes Ultramafite through Stikine Pluton and Beggerlay Creek Pluton to the Cake Hill Pluton might be invoked if all specimens from the Triassic plutonic suite were plotted without reference to their intrusive relations. When considered, the intrusive relationships among these plutons demand that intrusion of the plutons was a series of discrete, episodic, chemically distinct events. Similarly, the characteristic intrapluton intrusive relations (or lack of them) as well as distinctive compositional fields of the Three Sisters Pluton and the McBride River Pluton argue for two separate (although coeval) intrusions of distinctive magma.

Discussion of the chemical classification of the plutonic and volcanic suites points out the difficulty in applying these various plots and arriving at consistent results. Alkaline-subalkaline dividing lines in the alkali-silica and normative $ne'-ol'-qz'$ plots of Irvine and Baragar (1971) generally agree. The AFM, and Al_2O_3 -normative plagioclase plots of Irvine and Baragar (1971) and the SiO_2-FeO^*/MgO and FeO^*-FeO^*/MgO plots of Miyashiro, (1974) commonly disagree in the predominance of calc-alkaline or tholeiitic compositions. These distinctions are important because the role of early emplaced, commonly tholeiitic, gabbroic phases in the evolution of composite granitic plutons and batholiths has long been recognized (e.g. Larsen, 1948; Bateman et al., 1963; Erikson, 1969, 1977; Cann, 1970; Cobbing and Pitcher, 1972; Hietanen, 1973; Gastil, 1975; Mullan and Bussell, 1977; Pitcher, 1978; Brown and Hennessy, 1978; Strong 1979). Recent studies of voluminous ash flows

have also suggested the importance of basaltic magmas in the physico-chemical evolution of the high level magma chambers which supply these flows (Hildreth, 1979; Smith, 1979; Sparks et al., 1977). Tholeiitic, calc-alkaline and alkaline compositions are commonly associated in island arc magmatism (e.g. Miyashiro, 1974; Green, 1980). The question of whether the early tholeiitic magmas are the primitive magmas from which more felsic magmas differentiated or whether passage of mantle-derived, tholeiitic magmas through the lower crust induced partial melting which produced the associated felsic magmas remains controversial (cf. Erikson, 1977; Green, 1980; Strong, 1979; Brown and Hennessey, 1978).

VI.3.2 I and S granitoid classification

In earlier chapters, mineralogy, mineral pleochroism, textures and petrographic features were shown to compare closely with I-type granitoids of the Tasman Orogenic Zone of eastern Australia. Chappell and White (1974), Griffin et al. (1978), Hine et al. (1978) and Chappell (1978) have also separated I- and S-type plutons on geochemical parameters: Na_2O and K_2O content (Figure 74), TiO_2 (weight per cent) and Zr (ppm) content (Figure 75), Fe_2O_3 and FeO content (Figure 76) and molar $\text{Al}_2\text{O}_3/(\text{Na}_2\text{O} + \text{K}_2\text{O} + \text{CaO})$ ratio (Figure 77). Specimens from all plutons and phases in the Triassic and Jurassic plutonic suites have predominantly I-type geochemical characteristics: higher Na_2O relative to K_2O ; higher TiO_2 relative to Zr; and higher Fe_2O_3 relative to FeO than the classic S-type granitoids. Generally the plutons in the Hotailuh Batholith have higher Na_2O , TiO_2 and Fe_2O_3 contents than the fields for the I-type plutons from the Kosciusko Batholith (Hine et al., 1978). The high Zr content of the potassic marginal

Figure 74 . Weight per cent $\text{Na}_2\text{O} - \text{K}_2\text{O}$ diagram for the Triassic plutonic suite, Mesozoic volcanics and dikes and Jurassic plutonic suite. Fields for I-type and S-type granitoids of the Kosciusko Batholith, southeastern Australia from Hine *et al.* (1978). Abbreviations for the Triassic plutonic suite are: BCP = Beggérlay Creek Pluton; CHP = Cake Hill Pluton; GLU = Gnat Lakes Ultramafite; and SP = Stirling Pluton. Abbreviations for the Mesozoic volcanics and dikes are: MD = miscellaneous dikes; PPD = pyroxene porphyry dikes; SGV = Stuhini Group Volcanics; and TJV = Triassic-Jurassic volcanics. Abbreviations for the Jurassic plutonic suite are: MRP = McBride River Pluton; PCP = Pallen Creek Pluton; SCP = Snow-drift Creek Pluton; TP = Tanzilla Pluton; and TSP = Three Sisters Pluton (cp = central phase; fgp = fine-grained phase; lp = leucocratic phase; mp = mafic phase; pmp = potassic marginal phase).

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Figure 75 . Weight per cent TiO_2 versus parts per million Zr plot for the Triassic plutonic suite, the Mesozoic volcanics and dikes and Jurassic plutonic suite. Fields for I-type and S-type granitoids of the Kosciusko Batholith after Hine et al. (1978). Abbreviations for the Triassic plutonic suite: BCP = Beggerlay Creek Pluton; CHP = Cake Hill Pluton; GLU = Gnat Lakes Ultramafite; and SP = Stikine Pluton. Abbreviations for Mesozoic volcanics and dikes are: MD = miscellaneous dikes; PPD = pyroxene porphyry dikes; SGV = Stuhini Group volcanics; and TJV = Triassic-Jurassic volcanics. Abbreviations for the Jurassic plutonic suite are: MRP = McBride River Pluton; PCP = Pallen Creek Pluton; SCP = Snowdrift Creek Pluton; TP = Tanzilla Pluton; TSP = Three Sisters Pluton (cp = central phase; fgp = fine-grained phase; lp = leucocratic phase; mp = mafic phase; and pmp = potassic marginal phase).

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Figure 76. Weight per cent Fe_2O_3 - FeO diagram for the Triassic plutonic suite, Mesozoic volcanics and dikes and Jurassic plutonic suite. Division of I-type and S-type granitoids of the Kosciusko Batholith after Hine et al. (1978). Abbreviations for the Triassic plutonic suite are: BCP = Beggerlay Creek Pluton; CHP = Cake Hill Pluton; GLU = Gnat Lakes Ultramafite; and SP = Stikine Pluton. Abbreviations for the Mesozoic volcanics and dikes are: MD = miscellaneous dikes; PPD = pyroxene porphyry dikes; SGV = Stuhini Group volcanics; and TJV = Triassic-Jurassic volcanics. Abbreviations for the Jurassic plutonic suite are: MRP = McBride River Pluton; PCP = Pallen Creek Pluton; SCP = Snowdrift Creek Pluton; TP = Tanzilla Pluton; and TSP = Three Sisters Pluton (cp = central phase; fgp = fine-grained phase; lp = leucocratic phase; mp = mafic phase; and pmp = potassic marginal phase).

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BATHOLITHIC JURASSIC PLUTONIC SUITE **SATELLITIC JURASSIC PLUTONIC SUITE**

Figure 77. Molar $\text{Al}_2\text{O}_3/(\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O})$ ratios for the Triassic plutonic suite, Mesozoic volcanics and dikes, and Jurassic plutonic suite. Division between hornblende-bearing I-type granitoids $\text{Al}_2\text{O}_3/(\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O}) < 1.025$; (dot-dash line) and muscovite-bearing, S-type granitoids $\text{Al}_2\text{O}_3/(\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O}) > 1.5$; (dashed line) for the Moonbi district of southeastern Australia (Chappell, 1978). Abbreviations for the Triassic plutonic suite are: BCP = Beggerlay Creek Pluton; CHP = Cake Hill Pluton; GLU = Gnat Lakes Ultramafite; and SP = Stikine Pluton. Abbreviations for the Mesozoic volcanics and dikes are: MD = miscellaneous dikes; PPD = pyroxene porphyry dikes; SGV = Stuhini Group volcanics; and TJV = Triassic-Jurassic volcanics. Abbreviations for the Jurassic plutonic suite are: MRP = McBride River Pluton; PCP = Pallen Creek Pluton; TP = Tanzilla Pluton; and TSP = Three Sisters Pluton (cp = central phase; fgp = fine-grained phase; lp = leucocratic phase; mp = mafic phase; and pmp = potassic marginal phase).

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Number of samples

TP

PCP, felsic phase

PCP, mafic phase

SCP

MRP

TSP, lp

TSP, pmp

TSP, cp

TSP, mp

TSP, fgp

Al₂O₃/(CaO+Na₂O+K₂O) (molar ratio)

phase and the compositional overlap among the fine-grained, mafic and central phases of the Three Sisters Pluton are also shown on these plots.

Molar $\text{Al}_2\text{O}_3/(\text{Na}_2\text{O} + \text{K}_2\text{O} + \text{CaO})$ ratios for the plutonic suites in the Hotailuh Batholith are predominantly less than 1.1, corresponding to I-type granitoids as originally defined by White and Chappell (1974; Figure 77). In the Moonbi district, Chappell (1978) distinguished hornblende-bearing, I-type granitoids with molar $\text{Al}_2\text{O}_3/(\text{Na}_2\text{O} + \text{K}_2\text{O} + \text{CaO})$ ratios less than 1.025, from muscovite-bearing, S-type granitoids with molar $\text{Al}_2\text{O}_3/(\text{Na}_2\text{O} + \text{K}_2\text{O} + \text{CaO})$ ratios greater than 1.05 (which define the shaded zone in Figure 77). In a compilation of Canadian Cordilleran plutons, Griffiths (1981) suggested a similar ratio of 1.05 to separate I- and S-type granitoids. Most plutonic specimens in the Hotailuh Batholith have a ratio less than 1.025. The specimens which have ratios greater than either 1.025-1.05 or 1.1 are predominantly from the Jurassic plutonic suite (the metamorphosed Cake Hill Pluton specimen, 344-1, has a ratio of 1.06) and include specimens from the potassic marginal phase of the Three Sisters Pluton (specimens 8-1, 349-1, 58-1, 84-2, 152-1 and 249-1) and the McBride River Pluton (specimens 307-1 and 310-1).

Specimens from the Mesozoic volcanic suite are also plotted on the diagrams in Figures 74 to 78. In the $\text{Na}_2\text{O}-\text{K}_2\text{O}$, TiO_2-Zr and $\text{Fe}_2\text{O}-\text{FeO}$ plots, the volcanic compositions are indistinguishable from those of the plutonic rocks. The volcanics commonly have lower molar $\text{Al}_2\text{O}_3/(\text{Na}_2\text{O} + \text{K}_2\text{O} + \text{CaO})$ ratios than the plutonic suites with the exception of the Triassic-Jurassic volcanics. Three specimens of this unit have ratios greater than 1.05 (specimens 714B-2, 715I-2 and 715K-2) and these correspond to the base of each "cycle" and the top of "cycle" one.

Figure 78 . Weight per cent normative dropside or corundum versus silica plot for the Triassic plutonic suite, Mesozoic volcanics and dikes and the Jurassic plutonic suite. Abbreviations for the Triassic plutonic suite are: BCP = Beggerlay Creek Pluton; CHP = Cake Hill Pluton; GLU = Gnat Lakes Ultramafite; and SP = Stikine Pluton. Abbreviations for Mesozoic volcanics and dikes are: PPD = pyroxene porphyry dikes; SGV = Stuhini Group volcanics; and TJV = Triassic-Jurassic volcanics. Abbreviations for the Jurassic plutonic suite are: MRP = McBride River Pluton; PCP = Pallen Creek Pluton; SCP = Snowdrift Creek Pluton; TP = Tanzilla Pluton; and TSP = Three Sisters Pluton (cp = central phase; fgp = fine-grained phase; lp = leucocratic phase; mp = mafic phase; and pmp = potassic marginal phase).

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None of the plutonic specimens with anomalously high molar $\text{Al}_2\text{O}_3/(\text{Na}_2\text{O} + \text{K}_2\text{O} + \text{CaO})$ ratios are lithologically or petrographically different from other specimens in their pluton or phase: all are hornblende- and biotite-bearing and small mafic inclusions are uncommon in outcrops where the McBride River Pluton specimens were collected (Appendix 7.1). All specimens with S-type molar $\text{Al}_2\text{O}_3/(\text{Na}_2\text{O} + \text{K}_2\text{O} + \text{CaO})$ ratios also are characterized by slightly greater than 1 percent normative corundum, another S-type characteristic (White and Chappell, 1974) and are among the most siliceous of the particular phase, pluton or unit (Figure 78). Cathorn *et al.* (1976) and Cawthorn and Brown, (1976) suggest amphibole fractionation as a possible mechanism for generating these siliceous, corundum-normative magmas. The Pluton and McBride River Pluton cross from the diopside-normative field to corundum-normative field at approximately 65 percent SiO_2 similar to suites compiled by Cawthorn and Brown (1976).

VI.4 Mineral Compositions

VI.4.1 Introduction

A reconnaissance study of predominantly ferromagnesian mineral compositions using the electron microprobe was undertaken. The samples represent: the Upper Triassic Stuhini Group pyroxene porphyry volcanics (samples 233-2, 325-1, 444-1 and 604-1); pyroxene porphyry dykes (samples 411-3 and 698-3) believed to be comagmatic with the porphyritic volcanics; Gnat Lakes Ultramafite (samples 433-2, 445-3 and 607-2) argued elsewhere in the thesis on lithologic, geochronological and tectonic grounds to be a deeper-seated expression of the porphyritic volcanism; and the fine-grained phase (samples 488-1 and 490-1), mafic phase (samples 523 and 536-2) and central phase (samples 114-3 and 529-3) believed to be coeval and probably comagmatic from intrusive relations, petrography, geochemistry and geochronology. Mineral compositional data for clinopyroxenes, amphiboles, and

TABLE VI.I. AVERAGE COMPOSITION (AND UNCERTAINTY (1σ)) FOR PYROXENE MICROPROBE ANALYSES

UNIT:	Gnat	Lakes	Ultramafite	Augite	Porphyry	Dykes	Augite	Porphyry	Flows
SPECIMEN:	AN-78-433-21	AN-78-445-32	AN-78-411-3	AN-79-698-3	AN-77-233-2				
NO. OF ANALYSES:	13	20	17	9	18				
Oxide	AVG. (1σ)	AVG. (1σ)	AVG. (1σ)	AVG. (1σ)	AVG. (1σ)				
SiO ₂	50.75 (0.81)	50.69 (0.93)	51.03 (0.97)	50.52 (0.43)	51.68 (1.50)				
Al ₂ O ₃	3.61 (0.82)	3.74 (0.85)	3.51 (1.06)	4.65 (0.37)	3.05 (1.26)				
TiO ₂	0.66 (0.14)	0.69 (0.16)	0.63 (0.20)	0.54 (0.05)	0.33 (0.16)				
Cr ₂ O ₃	0.01 (0.02)	0.01 (0.01)	0.02 (0.01)	0.00 (0.01)	0.22 (0.23)				
FeO _T	7.89 (0.82)	7.07 (0.69)	9.92 (1.41)	7.58 (0.27)	5.66 (1.93)				
MgO	13.90 (0.93)	14.43 (0.78)	13.29 (0.63)	14.62 (0.29)	15.63 (1.38)				
MnO	0.20 (0.03)	0.16 (0.03)	0.50 (0.12)	0.20 (0.01)	0.17 (0.06)				
NiO	0.05 (0.02)	0.05 (0.02)	0.05 (0.02)	0.05 (0.02)	0.02 (0.02)				
CaO	23.06 (0.25)	23.47 (0.40)	21.00 (1.48)	22.65 (0.16)	22.20 (0.57)				
Na ₂ O	0.37 (0.10)	0.31 (0.11)	0.66 (0.14)	0.32 (0.04)	0.31 (0.13)				
K ₂ O	0.00 (0.00)	0.00 (0.00)	0.11 (0.14)	0.00 (0.00)	0.01 (0.04)				
(TOTAL)	(100.50)	(100.62)	(100.71)	(101.13)	(99.28)				
Mg/(Mg + Fe)	0.76 (0.03)	0.78 (0.02)	0.71 (0.04)	0.78 (0.01)	0.83 (0.06)				

1. location: 58°11'15"N, 129°51'00"W

2. location: 58°11'15"N, 129°51'30"W

TABLE VI.I. AVERAGE COMPOSITION (AND UNCERTAINTY (1σ)) FOR PYROXENE MICROPROBE ANALYSES (cont'd)

UNIT:	Augite	Porphyry	Flows	(cont'd)	Three Sisters fine-grained phase	Pluton
SPECIMEN:	AN-77-325-1	AN-78-444-1	AN-79-604-1	AN-78-488-1	AN-78-490-1	
NO. OF ANALYSES:	22	19	12	20	10	
Oxide	AVG. (1σ)	AVG. (1σ)	AVG. (1σ)	AVG. (1σ)	AVG. (1σ)	
SiO ₂	50.09 (1.12)	50.36 (0.79)	50.40 (0.81)	51.87 (1.10)	52.42 (0.59)	
Al ₂ O ₃	4.67 (0.97)	4.22 (0.45)	4.57 (0.84)	2.47 (1.20)	1.91 (0.41)	
TiO ₂	0.57 (0.16)	0.35 (0.05)	0.63 (0.15)	0.49 (0.22)	0.37 (0.06)	
Cr ₂ O ₃	0.10 (0.13)	0.14 (0.04)	0.05 (0.03)	0.02 (0.02)	-	
FeO _T	7.33 (1.24)	6.62 (0.18)	7.71 (0.49)	9.07 (1.07)	10.51 (0.96)	
MgO	14.50 (0.90)	15.25 (0.37)	14.49 (0.54)	14.93 (0.87)	13.85 (0.75)	
MnO	0.20 (0.04)	0.15 (0.02)	0.19 (0.03)	0.28 (0.08)	0.56 (0.04)	
NiO	0.02 (0.02)	0.03 (0.02)	0.02 (0.02)	0.00 (0.01)	-	
CaO	21.60 (0.52)	21.93 (0.48)	22.50 (0.22)	20.31 (1.08)	21.21 (0.45)	
Na ₂ O	0.39 (0.09)	0.33 (0.04)	0.37 (0.04)	0.32 (0.17)	0.42 (0.03)	
K ₂ O	0.00 (0.01)	0.00 (0.01)	0.00 (0.00)	0.02 (0.04)	-	
(TOTAL)	(99.47)	(99.38)	(100.93)	(99.78)	(101.25)	
Mg/(Mg + Fe)	0.78 (0.04)	0.81 (0.01)	0.77 (0.02)	0.75 (0.03)	0.70 (0.30)	

TABLE VI.I. AVERAGE COMPOSITION (AND UNCERTAINTY (1 σ)) FOR PYROXENE MICROPROBE ANALYSES (cont'd)

UNIT:	Three Sisters Pluton			phase	central	phase	AN-78-523	AN-78-536-2	AN-77-114-3 (host)	AN-77-114-3 (inclusion)	AN-78-529-1
	mafic	mafic	central								
SPECIMEN:	9	11	3	7	21						
NO. OF ANALYSES:	9	11	3	7	21						
Oxide	AVG. (1 σ)	AVG. (1 σ)	AVG. (1 σ)	AVG. (1 σ)	AVG. (1 σ)						
SiO ₂	52.96 (0.29)	53.24 (0.41)	52.77 (0.34)	51.51 (0.75)	53.02 (0.79)						
Al ₂ O ₃	0.74 (0.07)	0.68 (0.38)	0.29 (0.11)	0.91 (0.16)	0.80 (0.67)						
TiO ₂	0.11 (0.02)	0.10 (0.07)	0.02 (0.02)	0.15 (0.01)	0.14 (0.16)						
Cr ₂ O ₃	-	0.00 (0.00)	-	-	0.00 (0.01)						
FeO _T	8.16 (0.41)	7.25 (0.37)	7.97 (0.58)	8.32 (0.32)	9.37 (0.79)						
MgO	14.63 (0.25)	14.41 (0.18)	14.42 (0.31)	14.92 (0.40)	13.39 (0.32)						
MnO	0.95 (0.06)	0.28 (0.03)	1.05 (0.04)	1.04 (0.09)	0.54 (0.08)						
NiO	-	0.01 (0.01)	-	-	0.02 (0.01)						
CaO	22.83 (0.34)	23.59 (0.31)	24.20 (0.34)	22.68 (0.54)	22.09 (1.16)						
Na ₂ O	0.41 (0.02)	0.27 (0.07)	0.34 (0.06)	0.43 (0.03)	0.29 (0.13)						
K ₂ O	-	0.00 (0.00)	-	-	0.02 (0.06)						
(TOTAL)	(100.79)	(99.83)	(101.06)	(99.96)	(99.68)						
Mg/(Mg + Fe)	0.76 (0.00)	0.78 (0.01)	0.77 (0.02)	0.76 (0.00)	0.72 (0.02)						

TABLE VI.2. AVERAGE COMPOSITION (AND UNCERTAINTY (1σ)) FOR AMPHIBOLE MICROPROBE ANALYSES

UNIT:	Gnat	Lakes	Ultramafite	Hornblende- Augite Porphyry Dyke
SPECIMEN:	AN-78-433-2	AN-78-445-3	AN-79-607-2	AN-79-698-3
NO. OF ANALYSES:	9	10	45	11
Oxide	AVG. (1σ)	AVG. (1σ)	AVG. (1σ)	AVG. (1σ)
SiO ₂	41.03 (0.40)	41.00 (0.73)	42.76 (2.30)	41.83 (0.34)
Al ₂ O ₃	13.05 (0.64)	13.47 (0.33)	11.52 (2.36)	13.67 (0.21)
TiO ₂	2.49 (0.14)	2.27 (0.11)	1.90 (0.55)	2.04 (0.09)
Cr ₂ O ₃	0.01 (0.01)	0.00 (0.01)	0.00 (0.01)	0.01 (0.01)
FeO _T	13.98 (1.62)	11.30 (0.42)	13.28 (2.59)	11.56 (0.26)
MgO	12.10 (1.00)	14.22 (0.20)	12.96 (1.60)	14.28 (0.22)
MnO	0.19 (0.03)	0.12 (0.02)	0.11 (0.05)	0.18 (0.02)
NiO	0.04 (0.01)	0.04 (0.02)	0.02 (0.02)	0.04 (0.02)
CaO	11.92 (0.14)	12.08 (0.55)	11.89 (0.28)	12.00 (0.11)
Na ₂ O	2.16 (0.09)	2.16 (0.09)	1.93 (0.37)	2.50 (0.10)
K ₂ O	1.15 (0.06)	1.51 (0.14)	1.16 (0.26)	0.72 (0.03)
(TOTAL)	(98.12)	(98.17)	(97.53)	(98.83)
Mg/(Mg + Fe)	0.61 (0.05)	0.69 (0.01)	0.64 (0.07)	0.69 (0.01)

TABLE VI.2. AVERAGE COMPOSITION (AND UNCERTAINTY (1 σ)) FOR AMPHIBOLE MICROPROBE ANALYSES. (cont'd)

UNIT:	Three fine- grained phase	Sisters mafic phase	central	Pluton phase
SPECIMEN:	AN-78-488-1	AN-78-536-2	AN-77-114-3	AN-78-529-1
NO. OF ANALYSES:	7	10	10	7
Oxide	AVG. (1 σ)	AVG. (1 σ)	AVG. (1 σ)	AVG. (1 σ)
SiO ₂	47.89 (2.85)	45.04 (3.39)	48.14 (1.02)	47.83 (0.63)
Al ₂ O ₃	5.72 (1.84)	9.58 (3.07)	6.50 (0.62)	6.52 (0.18)
TiO ₂	1.07 (0.51)	1.61 (0.61)	0.83 (0.30)	1.21 (0.10)
Cr ₂ O ₃	0.02 (0.02)	0	-	0.01 (0.01)
FeO _T	15.29 (0.69)	13.01 (0.66)	15.60 (0.69)	15.51 (0.19)
MgO	13.63 (1.14)	13.51 (0.99)	13.71 (0.66)	12.83 (0.19)
MnO	0.40 (0.32)	0.19 (0.04)	0.59 (0.04)	0.38 (0.03)
NiO	0.02 (0.02)	0.01 (0.02)	-	0.02 (0.01)
CaO	10.60 (0.80)	12.01 (0.20)	12.51 (0.19)	11.35 (0.21)
Na ₂ O	1.08 (0.44)	1.39 (0.48)	0.90 (0.14)	1.21 (0.16)
K ₂ O	0.66 (0.27)	0.62 (0.17)	0.58 (0.14)	0.64 (0.05)
(TOTAL)	(96.38)	(96.97)	(99.36)	(97.51)
Mg/(Mg + Fe)	0.61 (0.02)	0.65 (0.03)	0.61 (0.02)	0.60 (0.01)

TABLE VI.3. AVERAGE COMPOSITION (AND UNCERTAINTY (1 σ)) FOR BIOTITE MICROPROBE ANALYSES (cont'd)

UNIT:	Three fine- grained phase AN-78-488-1	Sisters	Pluton central phase AN-78-529-1
SPECIMEN:			
NO. OF ANALYSES:	2	11	
Oxide	AVG. (1 σ)	AVG. (1 σ)	
SiO ₂	38.83 (0.64)	37.84 (0.62)	
Al ₂ O ₃	14.18 (0.09)	13.52 (0.41)	
TiO ₂	1.96 (0.37)	4.28 (0.24)	
Cr ₂ O ₃	0.01 (0.01)	0.00 (0.00)	
FeO _T	20.14 (0.42)	18.86 (0.60)	
MgO	11.44 (0.37)	12.25 (0.16)	
MnO	0.29 (0.02)	0.22 (0.03)	
NiO	0.03 (0.02)	0.02 (0.02)	
CaO	0.06 (0.06)	0.11 (0.06)	
Na ₂ O	0.00 (0.00)	0.08 (0.08)	
K ₂ O	8.99 (0.21)	8.56 (0.52)	
(TOTAL)	(95.93)	95.74	
Mg/(Mg + Fe)	0.50 (0.01)	0.54 (0.01)	

biotites for some or all of these units is given in Appendix 11 and summarized as average compositions and standard deviations (1 σ) in Tables VI.1 to VI.3.

Clinopyroxene compositions are emphasized since petrographically they appear to be the earliest ferromagnesian mineral formed (i.e. in the volcanics and dykes they occur as phenocrysts or in the plutonic rocks are rimmed by or form cores in hornblende whose own crystallization may have predated crystallization of biotite). They might be expected to show any possible cogenetic relationships among consanguineous volcanic, hypabyssal and plutonic rocks (e.g. Irvine, 1973) or comagmatic intraplutonic phases. Also, the problem of Fe³⁺ contents of the various ferromagnesian phases (which is indistinguishable from Fe²⁺ in electron microprobe analyses) is less serious in pyroxenes (although see Deer *et al.*, 1978, p.15 and Cameron and Papike, 1981, p.3-4) than in amphiboles (e.g. Dodge *et al.*, 1968; Czamanske and Wones, 1973, p.351-352; and Leake, 1978, p.1052) and biotites (e.g. Dodge *et al.*, 1969). The effect of including Fe₂O₃ in the pyroxene analysis is to increase the weight per cent oxide total (which for the analyses reported here ranges from 98.05-102.11) and decrease the sum of octahedrally coordinated cations (which for these analyses ranges from 1.977-2.168; see Appendix 11).

VI.4.2 Clinopyroxene compositions

Average compositions for clinopyroxenes from the various Triassic and Jurassic units are given in Table VI.1 (see also Appendix 11) and plotted in Figure 79. The greatest differences in average clinopyroxene compositions between the Triassic units and the Jurassic phases occur in SiO₂, Al₂O₃, TiO₂, Cr₂O₃, MnO and CaO contents although some compositional overlaps occur within one standard deviation of the means. There is an

Figure 79. Average weight per cent oxide clinopyroxene composition for some members of the Triassic plutonic suite, Mesozoic dikes and volcanics and Jurassic plutonic suite in known or inferred order of intrusion or extrusion (see Table VI.1). Numbers at top of each set of diagrams refer to sample numbers and vertical bars are one standard deviation. Abbreviations are: GLJ = Gnat Lakes Ultramafite; PPD = pyroxene porphyry dikes; SGV = Stuhini Group volcanics; TSP = Three Sisters Pluton; cp = central phase; fgp = fine-grained phase; and mp = mafic phase. In sample 114-3 from the Three Sisters Pluton, central phase, inclusion pyroxenes and pyroxene cores in hornblende of the host rock are distinguished.

(INCLUSION)

114-3
114-3
114-3523
536-2488-1
490-1604-1
444-1325-2
233-2698-3
411-3445-2
433-2TiO₂ (weight %)

TSP, cp

TSP, mp

TSP, fgp

SGV

PPD

GLU

 $I = \pm 1\sigma$ Cr₂O₃ (wt.%)

TSP, cp

TSP, mp

TSP, fgp

SGV

PPD

GLU

FeO_T (weight %)

TSP, cp

TSP, mp

TSP, fgp

SGV

PPD

GLU

529-1
(INCLUSION)
114-3
(HOST)
114-3

523
536-3

490-1
488-1

604-1
444-1
528-2
233-2

698-3
411-3

445-3
445-2

MgO (weight %)

$\sigma = \pm 1$

MnO (weight %)

NiO (weight %)

overall increase in SiO_2 , MnO and CaO and decrease in Al_2O_3 , TiO_2 and Cr_2O_3 contents with time between the Triassic and Jurassic units within the batholith. FeO_T , MgO , NiO , Na_2O and K_2O contents and the atomic ratio $\text{Mg}/(\text{Mg} + \text{Fe}_{\text{total}})$ are similar in clinopyroxenes from the Triassic and Jurassic units.

There is a good compositional overlap amongst the Triassic clinopyroxene-bearing plutonic, hypabyssal and volcanic units which is permissive of the cogenetic link suggested by their intrusive relations, petrography, whole rock chemistry and stratigraphic and isotopic age. There are no consistent, detectable compositional trends between cores and rims of the clinopyroxene phenocrysts in the Stuhini Group volcanics. Monger *et al.* (1978a) reported similar findings on clinopyroxenes from the Takla Group volcanics. Clinopyroxene phenocrysts in volcanics from the Takla (Monger *et al.*, 1978a) and Stuhini Groups have remarkably similar Al_2O_3 , TiO_2 , Na_2O_3 and Cr_2O_3 compositions and $\text{Mg}/(\text{Mg} + \text{Fe}_{\text{total}})$ ratios. Sample 444-1, an augite schist collected near its contact south of Upper Gnat Lakes with intensely foliated Cake Hill Pluton, is distinguished by the compositional homogeneity of its clinopyroxenes (low ls values) which may reflect reequilibration during deformation.

Clinopyroxenes from phases of the Three Sisters Pluton also show an overall increase in SiO_2 , MnO and CaO and decrease in Al_2O_3 , TiO_2 and Cr_2O_3 with intrusive sequence although these interphase trends are more ambiguous than those between the Triassic and Jurassic units. Analyses of clinopyroxenes in sample 114-3 from the clinopyroxene cores in hornblende of the host and from those in a coexisting mafic inclusion clearly show that the latter pyroxenes are distinguished by lower SiO_2 , and CaO , and higher Al_2O_3 , TiO_2 , MgO and Na_2O . Apparently clinopyroxenes in the inclusion still retain vestiges of their original composition despite

incorporation in and possible equilibration with the quartz monzodiorite central phase. There is no consistent trend in average $Mg/(Mg + Fe_{total})$ atomic ratios with intrusive sequence in contrast to other well-studied plutonic complexes (e.g. Best and Mercy, 1967; Haslam, 1968; Czamanske and Wones, 1973).

There are also some differences in the classification of clinopyroxenes in Triassic and Jurassic units (Figure 80). According to the classification adopted by Deer *et al.* (1978), salite, augite and diopside compositions are represented. Pyroxenes in the Stuhini Group volcanics are distinguished by their diopside compositions although salite is the most common and rare augite compositions occur. In the Takla Group, augite compositions are more common but diopside and salite are also represented (Monger *et al.*, 1978a). Salite compositions are also abundant in the pyroxene porphyry dykes and Gnat Lakes Ultramafite although augite compositions are more common in the dyke clinopyroxenes. Augite compositions are more common in clinopyroxenes of the Jurassic units compared with the Triassic pyroxenes although salite compositions are more common in the mafic and central phases compared with the fine-grained phase of the Three Sisters Pluton. Although there are some distinctions, generally the clinopyroxene Ca-Mg-Fe proportions within and between the Triassic and Jurassic units are similar.

Clinopyroxenes from the Stuhini group volcanics are predominantly alkaline with rare non-alkaline compositions (Figure 81) according to the classification of LeBas (1962) based on atomic proportions of $(Ca + Na + K)$, $(Fe^{2+} + Fe^{3+} + Mn)$ and Mg. Clinopyroxenes from the dykes and Gnat Lakes Ultramafite define very similar fields on this plot. Because this classification was developed for volcanic rocks, it may have limited applicability

Figure 80. Clinopyroxene microprobe analyses for various units within and around the Hotailuh Batholith in terms of relative Ca, Mg and total iron (as FeO) atomic proportions. Classification of calcic pyroxenes in $\text{CaMgSi}_2\text{O}_6$ - $\text{CaFeSi}_2\text{O}_6$ - $\text{Mg}_2\text{Si}_2\text{O}_6$ - $\text{Fe}_2\text{Si}_2\text{O}_6$ system (after Deer *et al.*, 1978) is also given. Parenthesized figures are numbers of analyses for particular sample (sample number is underlined; see Appendix 11 and Table VI.1). For sample 114-3 (Three Sisters Pluton, central phase), clinopyroxene compositions for pyroxenes in an inclusion (dots; 7 analyses) and as pyroxene cores in hornblende of the host quartz monzodiorite (crosses; 3 analyses) are distinguished.

PYROXENE PORPHYRY DIKES

STUHINI GROUP VOLCANICS

THREE SISTERS PLUTON PYROXENES

Figure 81. Clinopyroxene microprobe compositions for units within and around the Hotailuh Batholith in terms of: Ca + Na + K; total iron (as FeO) + Mn; and Mg atomic per cent (see inset ternary diagram) and the subalkaline (subalk.), alkaline (alk.) and peralkaline (peralk.) divisions of Le Bas (1962). Core (dots) and rim (crosses) compositions are distinguished on the plots for the Gnat Lake Ultramafite and pyroxene porphyry dykes only; for sample 114-3 from the central phase of the Three Sisters Pluton, clinopyroxenes from an inclusion (crosses) and from pyroxene cores in hornblendes from the host quartz monzodiorite (dots) are distinguished. Sample numbers are underlined.

GNAT LAKES ULTRAMAFITE

PYROXENE PORPHYRY DYKES

PYROXENE PORPHYRITIC STUHINI GROUP VOLCANICS

Atomic per cent Total Fe + Mn

THREE SISTERS PLUTON

to plutonic rocks; for example there is nothing in the bulk rock geochemistry of the Gnat Lakes Ultramafite to confirm the peralkaline classification of some of its clinopyroxenes according to LeBas (Figure 81). The classification provides a fair distinction between the alkaline clinopyroxenes of the Takla Group and the non-alkaline clinopyroxenes of the Hazelton Group which is consistent with their whole rock chemistry (Monger *et al.*, 1978). Again, it is not known whether the apparent trend from non-alkaline (fine-grained phase) to alkaline (fine-grained mafic and central phases) to peralkaline (central phase) clinopyroxenes characteristic of the Three Sisters Pluton (Figure 81) is significant in view of its predominantly subalkaline (tholeiitic to calc-alkaline) whole rock chemistry.

The SiO_2 - Al_2O_3 classification plot of LeBas (1962; after Kushiro, 1960) is more consistent with the whole rock geochemistry of the Triassic and Jurassic units (Figure 82). As discussed above (see Figure 79), there is good compositional overlap in SiO_2 and Al_2O_3 contents of clinopyroxenes from the Triassic plutonic, hypabyssal and volcanic units. These pyroxenes are commonly alkaline or non-alkaline, consistent with whole rock geochemistry. The Jurassic clinopyroxenes are predominantly non-alkaline and are characterized by higher SiO_2 and lower Al_2O_3 contents with order of intrusion.

The TiO_2 - MnO - Na_2O (weight per cent) triangular diagram (Figure 83) and discriminant function plot (Figure 84) developed by Nisbet and Pearce (1977) for distinguishing volcanic pyroxenes from different tectonic settings reaffirm some essential characteristics of the Triassic and Jurassic units. For the Stuhini Group volcanics, the triangular plot (Figure 83) is not useful in discriminating among the various tectonic settings for the MnO , TiO_2 and Na_2O compositions of the pyroxenes. It does emphasize the overall compositional similarity of pyroxenes in the volcanics, porphyritic dykes and

Figure 82. Weight per cent variation of SiO_2 and Al_2O_3 in clinopyroxenes from various units within and around the Hotailuh Batholith and the subalkaline, alkaline and peralkaline division of Le Bas (1962). Except for sample 114-3, filled symbols are core compositions, open symbols are rim compositions, and half-filled symbols are analyses whose position was not recorded; an inverted triangle for sample 536-2 of the mafic phase of the Three Sisters Pluton represents an analysis from an intermediate position in a clinopyroxene grain. For sample 114-3 (Three Sisters Pluton, central phase), compositions of clinopyroxenes in an inclusion (squares) and as cores in hornblendes in the host quartz monzodiorite are distinguished but their positions in the analyzed grains are unknown.

GNAT LAKES ULTRAMAFITE

PYROXENE PORPHYRY DYKES

PYROXENE PORPHYRITIC STUHNI GROUP VOLCANICS

THREE SISTERS PLUTON

Figure 83. Weight per cent $\text{MnO-TiO}_2\text{-Na}_2\text{O}$ ternary of Nisbet and Pearce (1977) and clinopyroxene compositions from the Gnat Lakes ²Ultramafite, pyroxene porphyry dikes, Stuhini Group volcanics, and fine-grained, mafic and central phases of the Three Sisters Pluton (sample numbers are underlined). Except for sample 114-3, filled symbols are core compositions, open symbols are rim compositions, half filled symbols represent analyses whose positions were not recorded, and for sample 536-2, the inverted symbol is a composition from an intermediate location. Compositions of inclusion pyroxenes (squares) and pyroxene cores in amphiboles of the host quartz monzodiorite (circles) are distinguished. Abbreviations for tectonic settings are: ALL = all tectonic settings distinguished by Nisbet and Pearce (1977); OFB = ocean floor basalt; VAB = volcanic arc basalt; WPA = within plate alkali basalt; and WPT = within plate tholeiite.

TiO₂

TiO₂

PYROXENE PORPHYRITIC STUHINI GROUP
VOLCANICS

THREE SISTERS PLUTON

TiO₂

MnO

Fine-grained Phase

Mafic

Phase

Na₂O

Figure 84. Discriminant function plot of Nisbet and Pearce (1977) for average microprobe analyses of clinopyroxenes from various units within and around the Hotailuh Batholith (see Table VI.1). Abbreviations of tectonic settings are: OFB = ocean floor basalt; VAB = volcanic arc basalt; WPA = within plate alkali basalt; and WPT = within plate tholeiite. $F_1 = -0.0120 \text{ SiO}_2 + 0.0026 \text{ Al}_2\text{O}_3 - 0.0807 \text{ TiO}_2 - 0.0012 \text{ FeO}_{\text{total}} + 0.0087 \text{ MgO} - 0.0626 \text{ MnO} - 0.0128 \text{ CaO} - 0.0419 \text{ Na}_2\text{O}$; and $F_2 = -0.0469 \text{ SiO}_2 - 0.0212 \text{ Al}_2\text{O}_3 + 0.0818 \text{ TiO}_2 - 0.0041 \text{ FeO}_{\text{total}} - 0.0029 \text{ MgO} - 0.1435 \text{ MnO} + 0.0085 \text{ CaO} + 0.0160 \text{ Na}_2\text{O}$ (all oxides in weight per cent).

GNAT LAKES ULTRAMAFITE

PYROXENE PORPHYRY DYKES

STUHINI GROUP VOLCANICS

THREE SISTERS PLUTON PYROXENES

Gnat Lakes Ultramafite although for the latter two units the significance of the tectonic classification is not known. The $\text{MnO-TiO}_2\text{-Na}_2\text{O}_3$ ternary also emphasizes the Na_2O -poor nature (relative to MnO and Na_2O) of the Three Sisters Pluton pyroxenes and crudely shows the decrease in relative TiO_2 content with intrusive sequence.

The F_1 versus F_2 discriminant plot of Nisbet and Pearce (1977; Figure 84) more effectively separates pyroxene compositions from the various tectonic settings. According to this plot, average clinopyroxene compositions for the Stuhini Group porphyritic volcanics are typical of volcanic arc basalts. This is consistent with the tectonic setting inferred from other evidence (Souther, 1977; Monger and Price, 1979; Price et al., 1981). This plot also emphasizes the close compositional similarity among average pyroxene compositions for the Gnat Lakes Ultramafite and porphyritic dykes. It contrasts the average pyroxene compositions of the Triassic and Jurassic units but this largely reflects the contribution of the contrasting SiO_2 , Al_2O_3 , TiO_2 and MnO contents of the two suites to the discriminant functions (Nisbet and Pearce, 1977; see Figure 84).

VI.4.3 Amphibole and biotite compositions

Average compositions for the amphiboles and biotites studies are given in Table VI.2 and VI.3, respectively, and individual compositions are listed in Appendix 11.

Amphiboles from the Gnat Lakes Ultramafite and the hornblende-pyroxene porphyry dyke are predominantly of ferroan pargasite composition according to the amphibole classification of Leake (1978) and assuming all $\text{FeO}_{\text{total}}$ is Fe^{2+} . Amphiboles from these two units have remarkably similar average compositions which further supports the notion that the Gnat Lakes Ultramafite

is the plutonic equivalent of the Stuhini Group porphyritic volcanics and feeder dykes as implied by the similar pyroxene compositions and the presence of uncommon hornblendite inclusions in the dyke sampled as 698-3 (see Plate II F).

An effort was made in sample 607-2 to investigate the optical zoning characteristic of the hornblendite of the Gnat Lakes Ultramafite (see Appendix 11). Traverses from core to rim of several grains commonly show erratic compositional changes (especially in Al_2O_3 , TiO_2 , MgO and Na_2O) but some generalizations can be made. SiO_2 , $\text{FeO}_{\text{total}}$ and MnO contents commonly increase towards the rim (where locally sharp increases are seen) whereas CaO and K_2O contents as well as the $\text{Mg}/(\text{Mg} + \text{Fe})$ atomic ratio consistently decrease from core to rim or are smaller at the rim than in the core of the grain. Small decreases in $\text{Mg}/(\text{Mg} + \text{Fe})$ atomic ratios for rim compositions compared to core compositions are observed in amphiboles from other samples of the Gnat Lakes Ultramafite. These observations contrast with an apparent lack of consistent compositional change in the optically zoned clinopyroxenes of the Stuhini Group volcanics.

Amphiboles in the fine-grained, mafic and central phases of the Three Sisters Pluton on average contain more SiO_2 , $\text{FeO}_{\text{total}}$ and MnO , less Al_2O_3 , TiO_2 , Na_2O and K_2O and have lower $\text{Mg}/(\text{Mg} + \text{Fe})$ atomic ratios than amphiboles in the Triassic units. Magnesio-hornblende is the most common composition represented but actinolitic, ferroan-pargasitic and tschermakitic hornblende compositions are also observed (classification according to Leake (1978) and assumes all $\text{FeO}_{\text{total}}$ is Fe^{2+}). Amphibole compositions from the Three Sisters Pluton compare closely with those from the Ben Nevis Complex in Scotland (Haslam, 1968) which is also characterized by clinopyroxene cores in alumina-poor amphiboles. Haslam (1968) considered this relationship indicative of

low pressure crystallization of primary clinopyroxene and later, lower temperature replacement of the pyroxene by alumina-poor amphibole. Amphiboles from the Three Sisters Pluton are comparable with amphiboles from other well-studied calc-alkaline complexes (with exceptions in parentheses): Guadalupe igneous complex (it has higher Fe, Ti and K and lower Mg and Na contents; Best and Mercy, 1967); the Finnmarka complex granodiorites (they have higher Na contents and Mg/(Mg + Fe) atomic ratios, much higher Mn and lower Al and Fe contents; Czamanske and Wones, 1973) and the Sierra Nevada Batholith (it has higher Fe and Mn, lower Mg and more variable Mg/(Mg + Fe) atomic ratios and K contents; Dodge *et al.*, 1968).

Average biotite analyses from two samples from the Three Sisters Pluton are given in Table VI.3 and individual analyses in Appendix 11. They differ in Al₂O₃, TiO₂ and MgO contents but closely compare with biotites in the Ben Nevis complex (Haslam, 1968) and less closely with the biotites in the Guadalupe (Best and Mercy, 1967) and Finnmarka (Czamanske and Wones, 1973) complexes and the Sierra Nevada Batholith (Dodge *et al.*, 1969).

VI.4.4 Summary

A reconnaissance electron microprobe study of clinopyroxene, amphibole and biotite compositions in the Gnat Lakes Ultramafite, pyroxene porphyry dykes, porphyritic Stuhini Group volcanics and the fine-grained, mafic and central phases of the Three Sisters Pluton emphasizes similarities within the Triassic and Jurassic units and contrasts the mineral compositions of the two groups. Closely similar clinopyroxene and amphibole compositions of the Gnat Lakes Ultramafite, porphyry dykes and volcanics are permissive of a comagmatic link between the plutonic, hypabyssal and extrusive

expressions of coeval magmatism in the Late Triassic. The clinopyroxene compositions of the porphyritic volcanics span the alkaline and non-alkaline fields of LeBas (1962) and are typical of volcanic arc basalts as defined by Nisbet and Pearce (1977). Clinopyroxene compositions in the fine-grained, mafic and central phases show some trends typical of fractional crystallization of a parental melt; mafic inclusions in the central phase retain vestiges of more mafic clinopyroxene compositions. Although fewer in number, amphibole compositions for these phases do not show any consistent chemical trends with intrusive sequence; however, they are distinguished by their alumina-poor compositions. These preliminary results are consistent with a comagmatic link between phases and suggest that the fine-grained phase was an early-crystallized precursor or equivalent to the later-emplaced mafic and central phases. Mafic inclusions in the mafic and central phases may testify to the more widespread original distribution of the fine-grained phase which was disrupted and incorporated into the later-emplaced phases of the Three Sisters Pluton as mafic inclusions. The petrography and electron microprobe compositions of the mafic inclusions, irregular, corroded, calcic plagioclase cores and clinopyroxene cores in amphiboles which characterize the Three Sisters Pluton need not necessarily be explained by the restite model of Bateman et al. (1963), Bateman and Dodge (1970), Chappell and White (1974), Bateman and Nokleberg (1978) and Bateman and Chappell (1979).

This preliminary reconnaissance of ferromagnesian mineral compositions of Triassic and Jurassic units in and around the Hotailuh Batholith will provide a framework for future, more comprehensive studies.

VI.5 Conclusions

In the Hotailuh Batholith, the Triassic plutonic suite was emplaced as a series of four chemically distinct magmas in contrast to the Jurassic plutonic suite which was emplaced as both separate, chemically distinct magmas (e.g. the McBride River Pluton and possibly the Snowdrift Creek Pluton) and as multiphase groups of coeval magmas whose compositions vary in a systematic manner that is suggestive of some sort of comagmatic relationship (e.g. the Three Sisters Pluton and Pallen Creek Pluton). In the Three Sisters Pluton, the leucocratic phase may not be related to the mafic, central and potassic marginal phase. The fine-grained phase overlaps the mafic and central phase compositions, consistent with its interpretation as a chilled equivalent of these magmas. Alkaline and subalkaline (calc-alkaline and tholeiitic) compositions are represented but their identification is dependent on the variation diagram used. The earliest phase of the multiphase Jurassic plutons is commonly alkaline or tholeiitic. The geochemistry of the plutonic suites is predominantly I-type; S-type molar $Al_2O_3/(Na_2O + K_2O + CaO)$ ratios and presence of small amounts of normative corundum are characteristic of the most silicic compositions and suggest hornblende fractionation in the magma genesis (Cawthorn and Brown, 1976).

Porphyritic volcanics of the Mesozoic volcanic suite become generally more felsic with time and exhibit alkaline, calc-alkaline and tholeiitic characteristics. The compositional similarity among the Stuhini Group volcanics, the porphyritic dikes, the Beggerlay Creek Pluton and Gnat Lakes Ultramafite is supportive of the coeval, comagmatic relationship suggested by geological relations, petrography and pyroxene chemistry.

Although intrusive relationships do not permit comagmatic links between other plutons in the Triassic or Jurassic plutonic suites and the Mesozoic volcanics, the broad geochemical similarities among the three suites imply that the Hotailuh Batholith has been the locus for similar magma generating processes for its 50-80 million year history.

A corollary to this conclusion concerns the striking compositional overlap of the three suites in a variety of binary and ternary variation diagrams. Use of such diagrams to differentiate cogenetic plutonic or volcanic suites, unconstrained by the geological history of the specimens, will lead to uninformative results.

CHAPTER VII EVOLUTION OF THE HOTAILUH BATHOLITH AND THE TECTONICS OF NORTHERN BRITISH COLUMBIA

VII Introduction

The concept of tectonostratigraphic "assemblages", as applied to the Canadian Cordillera (e.g. by Monger, 1975a; Monger and Price, 1979; Price et al., 1981) has proven successful in delimiting areas contiguous with the North American continent and in isolating allochthonous or "suspect" terranes (Coney et al., 1980). An analogous concept of plutonic "suites" has been used in this thesis to group distinctive plutons in the Hotailuh Batholith and environs which have a common geological history. This classification also emphasizes the unique position of the Hotailuh Batholith at the intersection of the east-trending Stikine Arch, the locus of the Permo-Triassic Tahltanian orogeny of Souther (1971a), and the broad north-west-trending belt of Early and Middle Jurassic plutons which fringes the eastern margin of the Bowser and Sustut basins (Figure 85). Considering the current "mobilitist" view of the evolution of the Canadian Cordillera (e.g. Monger, 1977; Monger and Price, 1979; Templeman-Kluit, 1979; Irving et al., 1980; Price et al., 1981), spatial and temporal proximity of the various tectonostratigraphic assemblages are critical cornerstones in any model of Cordilleran evolution. The geological history of the various plutonic and volcanic suites in and around the Hotailuh Batholith is reviewed in this chapter with respect to the tectonic history of adjacent terranes (Figures 3 and 4).

VII.2 Evolution of the Triassic Plutonic Suite: Felsic Plutons

Apparently, the characteristic east-west elongation of the Hotailuh Batholith was established early in its plutonic history during emplacement

Figure 85. Distribution of Triassic and Jurassic plutons, Triassic Alaskan ultramafic complexes, major tectonic elements and structures around the Hotanlun Batholith (modified from Souther *et al.* (1979) and Gabrielse and Reesor (1978)). Abbreviations are: KSF = King Salmon Fault; MF = Nöhlén Fault; and OCB = Omineca Crystalline Belt. Barbs on thrust faults indicate hanging wall.

of the felsic plutons of the Triassic plutonic suite. The Stikine Pluton has an east-trending outcrop area and the foliation in its western part parallels its outcrop distribution. Although dismembered by the Jurassic batholithic plutons, xenoliths and large screens of the Cake Hill Pluton extend to the eastern margin of the batholith where locally they are nonconformably overlain by Toarcian sediments. Highly discordant to its original east-trending outcrop distribution is the predominantly northwest-trending mineral foliation in the Cake Hill Pluton. These pervasive structures are not seen in the Gnat Lakes Ultramafite, the Beggerlay Creek Pluton or younger volcanics and sediments.

The Stikine and Cake Hill Plutons appear to be older than suggested by their range of K-Ar dates, between 218-227 Ma. Poorly preserved intrusive relations, described in Chapter II, suggest that emplacement of the Stikine Pluton predates emplacement of the Cake Hill Pluton which itself is older than 227-230 Ma (the K-Ar dates from fragments in the basal member of the Upper Triassic Stuhini Group and from specimens of the Gnat Lakes Ultramafite which is intrusive into the Cake Hill Pluton). The country rock, into which these two plutons intruded, apparently was covered by younger strata or intruded and uplifted by younger intrusions and eroded. In the western part of the Stikine Arch (the Tulsequah map-area; Souther, 1971a), Upper Triassic plutons clearly truncate north-trending units and structures in the Permian carbonates, chert and argillite. The inferred emplacement of the Stikine and Cake Hill Plutons, using Armstrong's (1978a; 1981) time scale occurred probably no later than 230 Ma and possibly no earlier than 248 Ma. The easterly elongation of batholith at that time (and foliation in the Stikine Pluton) parallels the Stikine Arch and suggests that if these calc-alkaline magmas are subduction-related, this magmatism may have originated

in a subduction zone parallel or sub-parallel with the Stikine Arch in the Early to Mid-Triassic.

VII.3 Tectonics of the Surrounding Area During Emplacement of the Stikine and Cake Hill Plutons

Crucial, in any tectonic interpretation involving the Triassic plutonism in the Stikine Arch is the geological history of the surrounding areas; which terranes were juxtaposed at the time of intrusion? Certainly the rocks of the Stikine assemblage of Monger (1977b) were autochthonous with respect to the Triassic plutonic suite of the Stikine Arch at the end of the Tahltanian orogeny as they are intruded by plutons of the Triassic plutonic suite.

The importance of the Cache Creek Group in the nearby Atlin Terrane is less clear-cut. The Stikine Arch underlies part of northern Stikinia which on geological and paleontological grounds is considered a "suspect" terrane (details are included in Chapter I; Coney et al., 1980). Preliminary paleomagnetic data (Monger and Irving, 1979, 1980; Irving et al., 1980) indicate that in the Late Triassic, rocks within Stikinia were approximately 13-14° south of their present latitude. A conservative view is that Stikinia was adjacent to North America, near the present California-Oregon border (Irving et al., 1980). In northern British Columbia, Monger (1980; in Price et al., 1981) considers that the Paleozoic rocks of the eastern, Cache Creek-Bridge River and Stikine assemblages were linked in the Late Triassic. Two main lines of evidence suggest this: the juxtaposition of two similar Upper Triassic volcanic stratigraphies (Stuhini Group on the southwest; Shonektaw Formation to the northeast) and the Cache Creek Group; and similar, southwest to northeast, proximal to distal, facies transitions

in both the Upper Triassic Stuhini Group and the Lower to Middle Jurassic Laberge Group (in the Whitehorse Trough). The latter geological relationships presumably reflect the transition away from the high-standing Stikine Arch towards an ocean basin floored by the Cache Creek Group. However, assignment of the uppermost stratigraphy in the Tulsequah map-area (described by Monger (1980) and used in correlation of the Shonektaw Formation) remains controversial (Gabrielse, February, 1981, personal communication); the relationship between the Nazcha and Shonektaw Formations and the Cache Creek Group are unknown (Monger, 1980, p.8); and in the Tulsequah (Souther, 1971a), Dease Lake (Gabrielse, 1980) and Cry Lake (Gabrielse, 1979) map-areas the proximal (Takwahoni Formation) and assumed distal (Inklin Formation) parts of the Laberge Group are everywhere separated by the Early Jurassic to Late Cretaceous King Salmon Fault. Consequently, the juxtaposition of these terranes in northern British Columbia during the late Triassic-Early Jurassic is "possible but not proven" (Monger, in Price et al., 1981, p.300). In the southern and central Cordillera, various Paleozoic terranes are thought to be linked to Stikinia in the latest Triassic by overlapping Upper Triassic rocks. A Cretaceous layered intrusion intrusive into the Cache Creek Group yields similar paleopole positions as the Upper Triassic Takla Group in Stikinia. The Cache Creek Group is interpreted in the southern Cordillera as the subduction complex for the Upper Triassic alkaline to calc-alkaline volcanics (Monger et al., 1972; Monger, 1977; Paterson, 1977; Travers, 1978; Monger in Price et al., 1981) from erosional-depositional links between the two units, overlapping stratigraphic age and K-Ar dates (215-222 Ma) from blueschists in the Cache Creek of the Stuart Lake area (Paterson and Harakal, 1974; Paterson, 1977). In the northern

Cordillera, distinctive radiolarian chert and verbeekiniid fusulinid-bearing carbonate fragments first appear in the Middle to Upper Jurassic Bowser Lake Group and a Middle Jurassic volcano-sedimentary succession indicating an possible erosional-depositional link between the Bowser Basin in Stikinia and an uplifted Cache Creek Group source area no earlier than the Middle to Late Jurassic (Souther and Armstrong, 1966, p.178; Eisbacher, 1974, p.280; Monger et al., 1978, p.826). Discordant blueschist ages of 168 Ma and 132 Ma (Monger, 1975a) determined in the Cache Creek of the Atlin Terrane also contrast with those dates determined farther south.

In the absence of similar geological and geochronological constraints for the Cache Creek of the Atlin Terrane, the role of this terrane in the production of the felsic plutons of the Triassic plutonic suite of the Hotailuh Batholith is ambiguous. If subduction of the Cache Creek of the Atlin Terrane occurred, it was probably important in the production of the mafic plutons of Triassic plutonic suite and members of the Triassic-Jurassic volcanic suite and probably post-dated the production of the Stikine and Cake Hill Plutons. Further, in view of the paleomagnetic evidence for a distant place of origin for Stikinia and, in the absence of geological links in the Mid- to Late Triassic between presently juxtaposed terranes, plate tectonic models for the generation of the felsic plutons of the Triassic plutonic suite remain elusive.

Berger and Pitcher (1970) and Pitcher and Berger (1972) believe that mineral foliation in granitic rocks reflects the ductility contrast between pluton and country rock envelope. The pervasive northwest-trending foliation in the Cake Hill Pluton may indicate that a northeast-southwest directed compressional regime, during the emplacement of that pluton, replaced earlier,

north-south directed compression in the Stikine Arch (as indicated in the elongation of the Hotailuh Batholith and foliation in the western part of the Stikine Pluton). In the absence of the country rock envelope for the Cake Hill Pluton, the igneous foliation may give the only indication of the tectonic regime preceding emplacement of the Gnat Lakes Ultramafite and Beggerlay Creek Pluton and eruption and sedimentation of the Stuhini Group. The northeast-southwest compression may be due to the initial collision of Stikinia with North America in Middle to early Late Triassic time (and may be the ultimate cause of the Tahltanian orogeny?). Timing of the first phase of deformation in the Atlin Terrane around Dease Lake is similar to that proposed for the intrusion and deformation of the Cake Hill Pluton, but in the Atlin Terrane, north-trending fold axes were produced (Monger, 1969).

However it was generated, the emplacement of the voluminous Cake Hill Pluton played an important part in the subsequent tectonism, volcanism and intrusion associated with the Hotailuh Batholith.

VII.4 Emplacement of Mafic Plutons of the Triassic Plutonic Suite and Eruption of the Mesozoic Volcanic Suite

The Cake Hill Pluton apparently served as a guide for the intrusion of the Gnat Lakes Ultramafite and the Beggerlay Creek Pluton and for the extrusion of some of the flows which form the Stuhini Group and the Triassic-Jurassic volcanic unit of the Mesozoic volcanic suite. Both of the basic plutons of the Triassic plutonic suite intrude along the present margins of the Cake Hill Pluton. Two possible volcanic centers for the Stuhini Group, as deduced from irregular outcrop areas of brecciated Cake Hill Pluton in an andesitic groundmass, also fringe the pluton, along its

northern margin.

The Gnat Lakes Ultramafite clearly predates eruption of some of the augite-bladed plagioclase porphyry flows of the Stuhini Group because the ultramafic rocks are intruded by porphyritic dikes lithologically similar to the porphyritic flows. Nevertheless, similar pyroxene compositions for the hornblende pyroxenite of the ultramafite, the hypabyssal porphyritic dikes and the porphyritic flows, in addition to the rarely observed hornblende xenoliths in these porphyritic hypabyssal dikes provide a strong comagmatic link between the pluton and coeval volcanic flows. The Gnat Lakes Ultramafite had at least partly solidified before intrusion of the volcanic feeder dikes although both may have been generated from the same magma.

In the McConnell Creek map-area, there is also a common association of Upper Triassic, Alaskan-type ultramafic plutons and thick sequences of Upper Triassic mafic volcanic (e.g. Irvine, 1968, 1974, 1975, 1976; Monger, 1977a) and Irvine (1974) considers that there is a possible comagmatic link between the two.

The Beggerlay Creek Pluton is the most demonstrably coeval intrusion in the batholith with respect to the Stuhini Group volcanism. Augite porphyry dikes are rarely observed intruding the Beggerlay Creek Pluton; yet augite porphyry along its southwest margins is apparently metamorphosed and intruded by it. Also, the compositions of the two units compare closely. Together these features suggest a comagmatic link between the pluton and the mafic volcanics.

The Hotailuh Batholith was the locus for at least part of the Mesozoic volcanism. The augite-bladed plagioclase porphyry dikes, lithologically and geochemically identical to flows in the Stuhini Group, occur

throughout the plutons of the Triassic plutonic suite and are characteristic of that suite. As well, they occur in the upper parts of the Stuhini Group stratigraphy along the western, northwestern and northern margins of the Hottailuh Batholith. Although other attitudes are observed, a predominance of east southeast trends for these dikes distinguishes them from other dikes in the batholith such as the south southwesterly-oriented, greyish-green, andesite dikes found in both the Jurassic and Triassic plutonic suites (Figure 86). The east southeast to easterly trend of the porphyritic dikes emphasized in detail what Souther and Armstrong (1966) and Souther (1971a, 1977) observed regionally: that the Stikine Arch appears to be an important structure for localization of the calc-alkaline Stuhini Group volcanism. As argued above and elsewhere in this thesis, the plutons of the Triassic plutonic suite in the Hottailuh Batholith were not necessarily the magma chambers from which the volcanics were erupted. Rather, the batholith was a focussing conduit for magmatism along that part of the Stikine Arch. However, the same arguments against the Cache Creek Group of the Atlin Terrane necessarily being involved in the generation of the felsic plutons of the Triassic plutonic suite may also be applied for the formation of the mafic plutons of the Triassic plutonic suite and Stuhini Group. In the structural and geochronological analysis of the Stuart Lake terrane, Paterson (1977, p.1337-1338) has proposed a northeast-oriented spreading centre for that area. He considers the possibility that in the Late Triassic the spreading centre was displaced north and south along the dextral Pinchi transform fault. The spreading centre to the west of the fault could conceivably feed a north- to northwest-dipping subduction zone beneath the Stikine Arch although little evidence for the subduction complex remains.

PYROXENE PORPHYRY DYKES

DATA DENSITY FOR
POLES TO DYKE
ORIENTATIONS
(PER 1% AREA)

(35 measurements)

Figure 86a. Lower hemisphere, contoured equal area stereonet plot of poles to pyroxene porphyry dyke orientations in and around the Hotailuh Batholith

"GREENISH GREY" ANDESITE DYKES

Figure 86b. Lower hemisphere, contoured equal area stereonet plot of poles to "greenish grey" andesite dike orientations in and around the Hotailuh Batholith.

The geological relations between the Triassic or older siliceous sediments and tuffs and the other volcanic and plutonic units are poorly preserved but indicate that eruption and deposition of this minor unit postdated the emplacement of the Cake Hill Pluton but predated eruption of at least some of the augite porphyry flows of the Stuhini Group. It is not clear whether or not these rocks are part of the felsic volcanism associated with the predominantly basic volcanism of the Stuhini Group.

The record of the Late Triassic Stuhini Group volcanism may only be read in the stratigraphy along the northern margin of the Hotailuh Batholith. As interpreted in Chapter III, it indicates deposition of volcanoclastic debris flows in a marine trough to the north of the batholith. The Upper Triassic Stuhini Group in a few places demonstrably nonconformably overlies the Cake Hill Pluton, another example of the pre-Upper Triassic unconformities described from other parts of the Canadian Cordillera by Read and Okulitch (1977). Cake Hill Pluton fragments in the basal parts of some of the sections clearly point to a southern source area. Sedimentary structures and the contrast between a shale- and sandstone-dominated stratigraphy to the northwest and an oligomictic volcanoclastic-dominated stratigraphy to the east suggest that a volcanic edifice, possibly established at the present location of the eastern part of the Three Sisters Pluton, shed detritus northwest and north to give the distal and proximal stratigraphy recorded in these respective sections. The record of felsic volcanism which occurred with the basaltic and andesitic volcanism is only preserved in some of these volcanoclastic units.

The Triassic-Jurassic volcanic rocks believed to gradationally overlie the Stuhini Group (Monger and Thorstad, 1978), are distinguished from the

latter, by their maroon-red weathering colour and may mark the subaerial emergence of a thickening volcanic pile along the northern margin of the Hotailuh Batholith. The age and correlation of these volcanics remain unknown but speculations are detailed in Chapter III. Possible subvolcanic intrusions which may have been feeders for these volcanics are also confined to the present margins of the Cake Hill Pluton.

VII.5 Evolution of the Whitehorse Trough and the Early Jurassic Sedimentological Record around the Hotailuh Batholith

Emergence of the Stikine Arch during the Late Triassic was partly a result of the plutonism and volcanism which occurred during the Tahltanian orogeny (Souther, 1971a). The record of that emergence is preserved in the Lower to Middle Jurassic Laberge Group sediments of the Whitehorse Trough, the earliest recognized successor basin in the Cordillera (e.g. Wheeler, 1961; Eisbacher, 1974b; Bultman, 1977, 1979). Regionally, the emplacement, uplift and unroofing of the Triassic plutonic suite and establishment of a volcanic highland through eruption of the Triassic-Jurassic volcanic suite along the Stikine Arch provided a source area for the granitic and porphyritic andesitic fragments in the southwesterly-derived channel conglomerates along the southwestern margin of the trough (Eisbacher, 1974b). Around the Hotailuh Batholith, however, only a slight southwestward coarsening of the Takwahoni Formation gives any indication of the importance of the batholith as a source area in the Early Jurassic (Tipper, 1978). Henderson (1979, p.33) concluded that a transgression, beginning in the late Pliensbachian to earliest Toarcian (middle to late Early Jurassic) overlapped sediments of the Jurassic basin, which had formerly been restricted to the eastern margin of the batholith, onto the Cake Hill

Pluton. During initiation of the Whitehorse Trough in the Early Jurassic, the Hotailuh Batholith may have been topographically low, synvolcanic erosion having levelled most of the volcanic highland established in the Late Triassic and re-exposed parts of the Cake Hill Pluton.

VII.6 Jurassic Tectonics in the Northern Cordillera, Evolution of the Jurassic Plutonic Suite, and Initiation of the Bowser Basin

The northern Canadian Cordilleran was tectonically active during the latest part of the Early Jurassic to Early Cretaceous. Among events which occurred during this time are: the second period of deformation producing south southwest-directed folds with northwest fold axes in the Cache Creek Group of the southeastern part of the Atlin Terrane (Monger, 1969, 1975b); northeastward transport of the Sylvester allochthon during the Late Jurassic or Early Cretaceous (Gabrielse and Mansy, 1980; Gabrielse, personal communication, May 1981); production of the southwesterly-directed Nahlin and King Salmon thrusts in Middle to Late Jurassic to earliest Cretaceous age (Monger *et al.*, 1978; Tipper, 1978); post-Early Jurassic to post-earliest Cretaceous deformation of the Whitehorse Trough (Bultman, 1977, 1979); and initiation of the Middle Jurassic to Early Cretaceous Bowser Basin (Eisbacher, 1974b). In and around the Hotailuh Batholith, the Upper Triassic Stuhini Group was thrust over the Toarcian (Early Jurassic) sediments and emplacement of the Jurassic plutonic suite occurred during the Early to Late Jurassic. Farther north, in the Yukon Territory, Templeman-Kluit (1979) has suggested that a major ocean closure, imbrication of cataclasized trench melange, sheared ophiolite and cataclastic granitic rocks, and northeastern transport of these three assemblages onto the Omineca Crystalline Belt occurred during the Mid-Jurassic to Early Cretaceous

and records a major arc-continent collision at that time.

Thrusting of the Upper Triassic Stuhini Group over the Toarcian sediments is fairly well-dated by the fossiliferous overthrust sediments (Early to Late Toarcian; Henderson, 1979; Henderson and Perry, 1981; Erebald, written communication April 24, 1980) and by the small monzodiorite plug which intrudes the thrust (e.g. Plate IV H). This plug is probably part of the Jurassic plutonic suite as it is lithologically similar to monzodioritic phases of the batholithic and satellitic plutons of that suite. Therefore, around the Hotailuh Batholith, the age of the thrusting is constrained to about 188-150 Ma (according to Armstrong's (1978a; 1981) time scale). On paleontological and sedimentological grounds, Tipper (1978) has determined that southwesterly directed thrusting of the Lower Jurassic strata northeast of the Hotailuh Batholith occurred in Early Toarcian to Middle Bajocian time. According to the timescale cited above, this corresponds approximately to 188-174 Ma, a good temporal overlap with thrusting around the northern and eastern margins of the Hotailuh Batholith. Tipper (1978) considers that these thrusts may be related to the King Salmon Fault and so date its earliest movements at latest Early to Middle Jurassic. Intrusion of the Snowdrift Creek Pluton (K-Ar age, 148 Ma) post-dates these earliest movements. In the Dease Lake map-area, the northern margins of the Snow Peak Pluton are also affected by movement along the King Salmon Fault (Gabrielse, personal communication, December, 1980). The Snow Peak pluton has yielded a K-Ar date of 73 Ma on one K-Ar determination which indicates that latest movements along the King Salmon Fault may have occurred in the Late Cretaceous (Gabrielse, personal communication, December, 1980).

In Chapters IV and V, a number of characteristics were emphasized concerning the emplacement of the Jurassic plutonic suite. Within the batholithic and satellitic plutons, two main types of magmas can be recognized: a compositionally expanded gabbro-monzodiorite-granite suite (Three Sisters Pluton, part of the Snowdrift Creek Pluton, Pallen Creek Pluton and Tanzilla Pluton) and a homogenous, compositionally-restricted, corundum-normative, granodiorite to quartz monzodiorite suite (the McBride River Pluton and part of the Snowdrift Creek Pluton). Although the Jurassic plutonic suite is demonstrably epizonal, parts of it are characterized by low topographic relief, i.e. are exposed in creek or river valleys (e.g. Pallen Creek Pluton; the western part of the Three Sisters Pluton; and the McBride River Pluton). The emplacement age for the best dated intrusion, the Three Sisters Pluton, can be estimated at 180-188 Ma, but the range of isotopic dates for the Jurassic plutonic suite indicate a protracted cooling interval of about 40-45 million years (between 150-190 Ma) perhaps due to a major event around 150-155 Ma.

The northern Bowser Basin was initiated in the latest Middle Jurassic (Eisbacher, 1974b) and established on transitional crust (Monger and Price, 1979). It is surrounded by Jurassic plutons emplaced before or during the basin's existence (including the northwest-trending Jurassic plutonic belt of which the Hotailuh Batholith is a part). Paleocurrent directions indicate transport radially into the basin along its northwest, northeast, east and southeast margins (Eisbacher, 1974b; Jeletzky, 1976; Monger and Price, 1979). Despite these characteristics, detritus in the conglomerate distributary channels is predominantly chert (Eisbacher, 1974b; Eisbacher et al., 1974, Figure 14, p.162); granitoid fragments are common only in the

southeastern part of the basin and are probably derived from the Topley intrusions (Richards and Jeletzky, 1975). The common interpretation is that the chert could only have come from high-standing Cache Creek Group terranes at that time (e.g. Monger et al., 1978b, p.826). Souther and Armstrong (1966, p.178-179) advocated a northern shoreline for the Bowser Basin extending to the present southern margin of the Atlin Terrane. The sedimentological record and the implications of the range in isotopic dates for the Jurassic plutonic suite suggest it was not rapidly uplifted and unroofed despite its epizonal intrusive characteristics.

A subduction model for the generation of the magmas in the Jurassic is as difficult to constrain for the Jurassic plutonic suite as for the Triassic plutonic suite. Templeman-Kluit (1979) has suggested that the Teslin suture zone marks the position of a southwesterly-dipping subduction zone in the Late Triassic-Early Jurassic (220-165 Ma) which ultimately brought Stikinia into contact with the Omineca Crystalline Belt and produced the arc which was ultimately thrust over the Omineca Crystalline Belt. The Teslin suture zone could be extrapolated south to include the Atlin Terrane and the Jurassic part of the arc would be represented by the northwest-trending Jurassic plutonic suite. The difficulty in applying the subduction part of this model is that the Jurassic plutonic suite extends northwest into the Atlin Terrane in the form of the Tachilta Lakes plutons for which a preliminary K-Ar date of 170 Ma was determined (Gabrielse, personal communication, December, 1980). Moreover, the second period of deformation in the Atlin Terrane occurred at about the same time (Middle Jurassic to Early Cretaceous) and was probably responsible for resetting the blueschist ages (169 Ma, 132 Ma) reported by Monger (1975a, Figure 2, p.7). At this time

then, the Cache Creek Group in the Atlin Terrane is an unlikely candidate for a subducting slab. The alternate choice of northeast-directed subduction to generate the Jurassic plutonic suite is an "open-ended" hypothesis since no evidence for any subduction complex is preserved southwest of the Hotailuh Batholith and, even if once present, would probably have been destroyed by erosion during the Late Cretaceous-Tertiary uplift and unroofing of the Coast Plutonic Complex.

VII.7 A Possible Model for Jurassic-Early Cretaceous Tectonics in Northern British Columbia

A collision involving Stikinia and North America during the Jurassic and Early Cretaceous may be applied to northern British Columbia to explain many of the salient features of its Jurassic to Early Cretaceous tectonics.

Generation of the Jurassic magmas would occur near the margin of Stikinia by some collision-induced, perturbation in the mantle. In the Hotailuh Batholith, the Cake Hill Pluton would again act as the guide to the rising magmas. Contemporaneous tectonism beginning in the latest Early Jurassic, as collision began between Stikinia and North America had at least two important consequences. One, intrusion of the three main phases of the Three Sisters Pluton occurred in the order deduced from intrusive relations (i.e. in approximate order of increasing viscosity) induced by southwesterly directed compression. Secondly, southwesterly-verging folds and southwesterly-directed thrust faults in the Atlin Terrane, Whitehorse Trough, the King Salmon assemblage and around the northern and eastern margins of the Hotailuh Batholith occurred in response to the collision.

Crystal fractionation in the parental Three Sisters Pluton magma, which may have produced the constituent phases, occurred originally in a static tectonic environment (as evidenced by cumulate layered, hornblende diorite inclusions in the mafic phase of the Three Sisters Pluton). On intrusion, the Three Sisters Pluton magmas may have initially reused a conduit along the northeastern and eastern margins of the Cake Hill Pluton, opened by the magmas which gave rise to the Stuhini Group volcanics. There is a longitudinal correspondence between the volcanoclastic-dominated Upper Triassic stratigraphy along the northern margin of the batholith and the area of oldest K-Ar dates in the Three Sisters Pluton. However, the volume of Three Sisters Pluton magma was such that the Cake Hill Pluton roof foundered in the eastern part of the batholith and the main massif of the Cake Hill Pluton was split by the major, northwest-trending apophysis of the Three Sisters Pluton. The McBride River Pluton magma, probably generated at about the same time but by a different process was intruded outboard of the intruding Three Sisters Pluton magmas.

Collision-induced, south southwestward tectonic thickening of the crust, in particular, thrusting of the Stuhini Group over parts of the northern margin of the batholith, might have had two effects on the evolution of this part of the Cordillera. In the Hotailuh Batholith, it may have retarded the uplift and unroofing of the Three Sisters Pluton especially around the margins of this pluton where there is obvious or inferred evidence for this thrusting and for younger K-Ar dates. This would explain the extraordinarily long cooling history as indicated from the isotopic dates. The Jurassic plutons in this way would be eliminated as a source terrane for the Bowser Basin. Instead, the Cache Creek Group in the tectonically uplifted Atlin

Terrane would form the predominant source area for the Bowser assemblage. Secondly, the Bowser Basin may have formed due to isotatic compensation to the tectonic shortening and thickening of the crust north and east and so would be a foreland-type of successor basin.

The magnitude of thrusting and degree of shortening involved in the folding during the Middle Jurassic to Early Cretaceous tectonism is poorly known. Around the Hotailuh Batholith, the size and abundance of Cake Hill fragments in the basal members of the underthrust Upper Triassic panel suggest a proximal source area and indicate that the displaced panel did not travel very far. Locally the Nahlin Fault is unimportant with respect to the southwestern margins of the Atlin Terrane as depositional contacts occur between it and the Upper Triassic Kutcho strata (Gabrielse, 1980; Monger, 1980, p.7). The paleomagnetic results still do not clearly indicate the location of Stikinia when the Mid-Jurassic to Early Cretaceous deformation occurred although Price *et al.*, (1981) consider that accretion of Stikinia to North America occurred at that time.

Continued collision may have produced the late Early to Middle Cretaceous northeasterly directed-structures in the Omineca Crystalline Belt (e.g. Mansy and Dodds, 1976; Gabrielse and Mansy, 1978, 1980) and depression of the sialic basement to produce the Middle to Upper Cretaceous granitic plutons typical of the Omineca Crystalline Belt (Gabrielse, 1981).

SUMMARY AND CONCLUSIONS

This study establishes some of the complex relationships amongst the plutonic, hypabyssal and volcanic expressions of Triassic and Jurassic magmatism in and around the Hotailuh Batholith (Figure 87). These relationships are most easily understood in terms of the emplacement of a Triassic plutonic suite and a Jurassic plutonic suite separated by deposition and eruption of Triassic and Jurassic sediments and volcanics.

A plutonic suite and its constituent plutons are recognized on the basis of their absolute total aeromagnetic field, physiography, lithology, mineral (and inclusion) fabric, petrography, geological relationships with other units, isotopic age and geochemistry. Similarly, units which make up the Paleozoic, Mesozoic and Cenozoic stratigraphy are characterized by their aeromagnetic signature, lithology, stratigraphy, geological relationships, age, petrography and geochemistry.

Emplacement of the Triassic plutonic suite began with the intrusion of two different magmas: first, the hornblende diorite of the Stikine Pluton and later, the hornblende quartz monzodiorite of the Cake Hill Pluton. The final emplacement of each pluton occurred in differently oriented, compressional stress regimes and resulted in distinctive orientation of mineral foliation and(or) lineation. Their emplacement is inferred or known to predate eruption and deposition of the Stuhini Group. Permian carbonate, exposed in small, isolated outcrops southwest and west of the batholith, is the only country rock known to be older than the Triassic plutonic suite. Both the early plutons in this suite have calc-alkaline affinities.

Figure 87. Compilation of intrusive and geological relationships amongst members of the Triassic plutonic suite, Mesozoic and Cenozoic volcanic and sediments and Jurassic plutonic suite in and around the Hotalluh Batholith. Arrows lead from intrusive unit to country rock: solid arrow indicates most common intrusive relation; open arrow less common relationship. Dashed lines indicate probable but uncertain geological relationships. Question marks indicate unknown relationships. Abbreviations are: INT = intrusive, META = metamorphoses.

The Cake Hill Pluton subsequently acted as a guide and country rock for the intrusion of the Gnat Lakes Ultramafite along its northwestern margin and the Beggerlay Creek Pluton along its southern margin. Intrusive relationships and isotopic ages suggest intrusion of these mafic magmas (represented by the hornblende pyroxenite and hornblendite of the Gnat Lakes Ultramafite and altered hornblende gabbro and diorite of the Beggerlay Creek Pluton) just predated or was contemporaneous with eruption of lavas of the Late Triassic Stuhini Group.

The mafic plutons of the Triassic plutonic suite are alkaline or subalkaline and tholeiitic geochemical affinities predominate in the subalkaline samples. Salites, calcic augites and diopsides in the Gnat Lakes Ultramafite also have compositions typical of groundmass clinopyroxenes in alkaline and subalkaline volcanic arc basalts according to LeBas (1962) and Nisbet and Pearce (1977).

On the basis of similar average whole rock compositions, closely similar clinopyroxene and amphibole compositions and evidence for coeval intrusion or extrusion, the Beggerlay Creek Pluton and particularly the Gnat Lakes Ultramafite, clinopyroxene porphyry dikes and Stuhini Group clinopyroxene porphyry flows are considered probable plutonic, hypabyssal and effusive expressions of the same Carnian-Norian age magmatism.

Potassium-argon isotopic ages for the Triassic plutonic suite are consistent with the minimum Carnian-Norian stratigraphic age (and Armstrong's (1978, 1981) time-scale) for intrusion of most of the Triassic plutonic suite but only crudely conform to the relative order of intrusion (oldest to youngest): Stikine Pluton (222 ± 11 Ma); Cake Hill Pluton (218 ± 11 Ma, 220 ± 11 Ma, 227 ± 14 Ma); Gnat Lakes Ultramafite (227 ± 14 Ma, 230 ± 10 Ma); and Beggerlay Creek Pluton (218 ± 29 Ma). In the case of the older felsic

plutons, the isotopic ages are minimum estimates for the time of intrusion.

The Triassic plutonic suite consists of four distinctive magma compositions which are distinguished from the Jurassic plutonic suite by their composition, grain size, homogeneity, inclusion and mafic content, structural grain, intrusive relations with the Mesozoic volcanics and sediments, petrography and isotopic age. The lack of contact relationships with older country rock; poor stratigraphic control on the oldest age of intrusion or deformation of the felsic plutons; and a poor understanding of the temporal and spatial relationships of Stikinia to the Atlin Terrane in pre-Late Triassic time provide few constraints on a model involving subduction of a Cache Creek Group analog to produce the earliest felsic magmas represented in the Triassic plutonic suite. Nonetheless, history of the uplift and unroofing of some of the Triassic plutonic suite is recorded in the sediments of the Early to Mid-Jurassic Whitehorse Trough (Bultman, 1977, 1979) and, locally, in the eruption and deposition of the Upper Triassic Stuhini Group.

Mesozoic volcanics and sediments along the western, southern, eastern, and, in particular, northern margins of the Hotailuh Batholith record: the construction and erosion of a major volcanic edifice at the approximate location of the batholith; unroofing of part of the Triassic plutonic suite; part of the regional Early Jurassic marine incursion; and the effects of Early to Late Jurassic regional tectonics. An early(?) period of felsic pyroclastic volcanism was apparently followed by extensive eruption and deposition of volcanic conglomerates, porphyritic flows and turbiditic sediments of the Upper Triassic Stuhini Group into a marine basin north of the batholith and in a probable submarine environment west of the batholith.

These volcanics are poorly dated around the batholith but in adjacent map areas are known to be Carnian-Norian in age (Souther 1971a; Monger, 1980). In the east, the coarse volcanic conglomerates are abundant and contain common lava fragments, in part, lithologically similar to intercalated flows. Basal units are characterized by uncommon but widespread fragments of foliated, lineated or massive Cake Hill Pluton which decrease in abundance and size up section. Occurrence of these debris flow deposits exclusively east of the medial line of the batholith (which roughly corresponds to the present Cake Hill Pluton-Three Sisters Pluton contact) suggests that the volcanic source area was nearby and to the south, possibly at the present position of the eastern part of the Three Sisters Pluton. The alkaline to subalkaline (calc-alkaline to tholeiitic) whole rock chemistry of the porphyritic basalts is also reflected in alkaline to subalkaline affinities of the salite, diopside and calcic augite phenocryst compositions typical of volcanic arc basalts (LeBas, 1962; Nisbet and Pearce, 1977). East- to northeast-trending, geochemically similar, pyroxene-bladed plagioclase porphyry dikes, which intrude the Triassic plutonic suite but are not seen in the Jurassic plutonic suite, are probable feeders for the porphyritic flows of the Stuhini Group.

Undated felsic plagioclase porphyry flows, minor volcaniclastics and rare tuffaceous mudstones make up the Triassic-Jurassic volcanics along the northeastern margin of the Hotailuh Batholith. They are distinguished by their maroon weathering colour, lithology, stratigraphy and geochemistry from the Stuhini Group. The relationship of this unit to either plutonic suite was not established but it is believed to gradationally overly the Stuhini Group (Monger and Thorstad, 1978). Two mafic to felsic "cycles" are recognized geochemically and lithologically in the volcanic flows.

Calc-alkaline compositions predominate but alkaline compositions do occur in the flows which range from basalt to rhyolite in the calc-alkaline rocks and mugearite, trachybasalt and tristanite in the alkaline rocks (nomenclature after Irvine and Baragar, 1971).

Well-dated, Toarcian limestone, limey arkosic sandstone and shale were deposited nonconformably on the Cake Hill Pluton and preserve a record of a shallow, high energy, temperate, normal marine environment (Henderson, 1979; Henderson and Perry, 1981).

The Mesozoic volcanics have been disrupted by block and thrust faults. One fault, separating schistose clinopyroxene porphyry and intensely foliated Cake Hill Pluton along the northwestern margin of the pluton predates intrusion of the Three Sisters Pluton. An important thrust fault which places Upper Triassic Stuhini Group onto the Toarcian sediments along the batholith's northern and eastern margins is sealed by a small intrusion probably related to the emplacement of the Jurassic plutonic suite. Minor block faults also disrupt the Mesozoic stratigraphy.

Timing of the major structures is coincident with a series of Middle to Late Jurassic to earliest Cretaceous thrusts (Monger *et al.*, 1978b; Tipper, 1978) which probably record the initial stages of final suturing of Stikinia to the North American continental margin.

South of the Hotailuh Batholith, good stratigraphic evidence and isotopic ages suggest a temporal spatial association of the Cache Creek Group in a subduction-related genesis of Upper Triassic Nicola and Takla Groups and coeval plutons (e.g. Monger *in* Price *et al.*, 1981; Paterson, 1977). A similar relationship for the Atlin Terrane in the generation of the mafic plutons of the Triassic plutonic suite and the Mesozoic volcanics is suggested by Monger (*in* Price *et al.*, 1981) but is not yet

stratigraphically proven. Coincidence of collisional tectonics and the generation of the Jurassic plutonic suite have important implications for the final emplacement history of the suite.

The Jurassic plutonic suite is represented by batholithic and satellite plutons. Their composition, grain size, heterogeneity, inclusion and mafic content, lack of mineral fabric, intrusive relations with the Mesozoic volcanics and sediments, petrography and isotopic age distinguishes them from the Triassic plutonic suite and suggest coeval and comagmatic links between plutons within the suite. Two major magma types are represented in the plutons: a heterogeneous, inclusion-bearing composite series of sequentially intruded, hornblende- and biotite-bearing dioritic, quartz monzodioritic or granodioritic and granitic phases (Three Sisters, Pallen Creek, Tanzilla and part of the Snowdrift Creek Plutons); and a homogeneous, inclusion-bearing, compositionally restricted, hornblende- and biotite-bearing granodiorite (McBride River and part of the Snowdrift Creek Plutons). The plutons are commonly massive.

The Jurassic plutonic suite intruded, included and metamorphosed members of the Triassic plutonic suite and units in the Mesozoic volcanic and sediments. In some areas it appears to be barely unroofed and is associated with narrow contact metamorphic aureoles. The youngest intruded volcano-sedimentary units constrain the oldest stratigraphic age for intrusion of the Three Sisters Pluton to Toarcian; for the Snowdrift Creek Pluton to Pliensbachian; and for all other plutons to Carnian-Norian. Intrapluton intrusive relations for the composite plutons indicate consistent mafic to felsic intrusion of the phases. Presence of biotite with hornblende, common mafic inclusions, and in one pluton, clinopyroxene cores in hornblende, irregular calcic plagioclase cores and petrographic similarities between

mafic inclusions and an early emplaced, fine-grained phase characterize the Jurassic plutonic suite.

A smooth trend of tholeiitic to calc-alkaline compositions with mafic to felsic intrapluton intrusive sequence is characteristic of the predominantly subalkaline composite plutons in the Jurassic plutonic suite. The homogeneous plutons are siliceous and corundum-normative. In the Three Sisters Pluton, the calcic augite, salite and diopside cores in alumina-poor amphibole are geochemically distinct from Triassic clinopyroxenes and express chemical trends with intrusive sequence. This may suggest that these clinopyroxenes (and the calcic plagioclase cores) are inherited from an earlier period of crystal fractionation rather than a restite component of the source rocks even though these granitoids have unequivocal petrographic and geochemical I-type characteristics.

Concordance of K-Ar and zircon U-Pb isotopic ages with stratigraphic constraints (and Armstrong's (1978, 1981) time-scale) suggest that most of the Jurassic plutonic suite was emplaced between 170-188 Ma. The range of Jurassic K-Ar isotopic ages (142-197 Ma), their geographic distribution, and a Rb-Sr isochron for the Three Sisters Pluton (155 ± 2 Ma with initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.70359 ± 0.00003) may imply a protracted 40 million year cooling period or, more likely, a low temperature hydrothermal "event" around 150-155 Ma which selectively disturbed K-Ar and Rb-Sr isotopic systems of samples closest to the roof or margins of the plutons.

Collision of Stikinia with the North American continent had important consequences in the magmatic evolution of the Three Sisters Pluton. It may have caused the cessation of crystal fractionation in a tectonically static environment (as shown in the rare, disrupted, cumulate-layered mafic inclusions in the mafic phase) and provided the compressional environment

for replacement of differentiated phases higher in the crust (in the order of decreasing viscosity demonstrated in outcrop intrusive relations). Spatial association of young K-Ar dates with the Mid- to Late Jurassic thrust faults may suggest that continued suturing of Stikinia to the North American margin perturbed the isotopic systems, but similar effects of late granitic intrusion (e.g. the Snowdrift Creek Pluton?) cannot be ruled out.

The Jurassic plutonic suite as defined in and around the Hotailuh Batholith on the basis of various lithological, structural, petrographic, geochemical and isotopic age similarities may be extended southeast to include plutons along the northeastern margin of the Bowser Basin (Gabrielse et al., 1980) and northwest to include the Tachilta Lakes plutons in the Atlin Terrane. The latter correlation provides a linkage between Stikinia and the Atlin Terrane in the Early to Mid-Jurassic and would preclude the Cache Creek Group as subducting slab in a subduction-related model for the genesis of the magmas. However, the location of a possible southwest- or northeast-dipping subduction zone is otherwise unconstrained. The Early to Late Jurassic plutonism around the Mid- to Late Jurassic Bowser Basin is distinguished by the absence of a sedimentological record of its uplift and unroofing in this clastic wedge compared to the record of the unroofing of the Triassic plutonic suite in the Whitehorse Trough north of the Stikine Arch. The collision-induced, south-southwestward tectonic thickening of the crust, in particular, the documented thrusting of the Stuhini Group over parts of the northern margin of the Hotailuh Batholith, may have retarded the uplift, final cooling and unroofing of the Jurassic plutonic suite, eliminating it as a potential source area for the Bowser Basin.

Apparently, the latest recognizable igneous event in and around the Hotailuh Batholith was the eruption of fresh, Miocene to Pleistocene, vesicular to diktytaxitic, olivine basalt and plagioclase porphyry andesite which lie nonconformably on the Triassic and Jurassic plutonic suites.

The complex Triassic and Jurassic magmatic history localized in and around the Hotailuh Batholith is readily interpretable in terms of the intrusion of a Triassic plutonic suite, eruption and deposition of Late Triassic and Early to Mid(?) - Jurassic volcanics and sediments, and intrusion of an Early to Late(?) Jurassic plutonic suite. The spatial overlap of this magmatism reflects the Hotailuh Batholith's unique position at the intersection of the east-trending Permo-Triassic Stikine Arch and a northwest-trending belt of Early to Middle Jurassic plutons along the northeastern edge of Stikinia. The intrusive and geological relations between the plutonic and volcano-sedimentary units provide some constraints on possible tectonism involved in collision of Stikinia with the North American continent during the Jurassic.

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GEOLOGICAL MAP OF THE

10F

130°00'
58°15'

CANIC ROCKS

40F

LEGEND AND

QUATERNARY

PLEISTOCENE AND RECENT

Glacial and glacio-fluvial deposits, stream

TERTIARY

MIOCENE TO PLEISTOCENE

Massive and diktytaxitic olivine basalt, andesite

JURASSIC

LOWER AND MIDDLE JURASSIC

McBRIDE RIVER PLUTON: hornblende-biotite

THREE SISTERS PLUTON:

leucocratic phase: leucocratic (clinopyroxene)

potassic marginal phase: biotite-, hornblende-
granite, quartz syenite, syenite

central phase: biotite-hornblende quartz monzodiorite

mafic phase: biotite-hornblende quartz monzodiorite

fine-grained phase: fine-grained clinopyroxene
quartz monzodiorite

LOWER JURASSIC

TOARCIC

creamy brown shale, sandy limestone, calc

000'

58°15'

OF

LEGEND AND SYMBOLS

deposits, stream deposits, soil

fine basalt, andesite, plagioclase-hornblende porphyry

hornblende-biotite granodiorite

quartz dioritic (clinopyroxene-) hornblende granodiorite, quartz monzodiorite

biotite-, hornblende-biotite and hornblende quartz monzonite, arenite

hornblende quartz monzodiorite, monzodiorite, quartz monzonite

hornblende quartz diorite, diorite, gabbro

hornblende-clinopyroxene-biotite-hornblende quartz diorite, diorite and

limestone, calcareous arkosic arenite, arkosic quartz arenite

mixed
ImJsm, ImJ
metamorph
uKst

58°00' +
130°00'

GEOLOGY FROM THIS STUDY AND MODIFIED FROM
GABRIELSE (1979; unit mJgd west of Horn
Mountain not shown)

5

6 of

58°00'
129°00'

25 30

Legend area containing various symbols and labels:

- IR
- TRI
- PER
- U
- 30

fine-grained phase: fine-grained clinopyroxene-biotite-hornblende
quartz monzodiorite

LOWER JURASSIC

TOARCIAN

IJsl

creamy brown shale, sandy limestone, calcareous arkosic arenite,

TRIASSIC

TRIASSIC AND JURASSIC

TJu

grey and maroon plagioclase porphyry, andesite, volcanic conglomerate,

UPPER TRIASSIC

STUHINI GROUP: dark grey and greenish grey siltstone, shale, greywacke,
pillowed clinopyroxene- and bladed plagioclase porphyritic and aphanitic

UPPER TRIASSIC P

TPv

rhyolite, welded tuff, quartz arenite

UPPER TRIASSIC

BEGGERLAY CREEK PLUTON: biotite-hornblende diorite, gabbro

GNAT LAKES ULTRAMAFITE: hornblende clinopyroxenite, hornblende

uTch

CAKE HILL PLUTON: (biotite-) hornblende quartz monzodiorite,
monzonite (and metamorphosed equivalents); rare hornblende diorite

STIKINE PLUTON: (biotite-) hornblende quartz diorite, monzodiorite

PERMIAN

PI

limestone with crinoid stems

Geological boundary (defined, approximate, gradational, assumed)

Bedding, inclined

Foliation, schistosity (inclined, vertical)

Lineation

Thrust fault (teeth on upthrust side; defined, approximate)

Fault (defined, approximate)

Drift boundary

ed clinopyroxene-biotite-hornblende quartz diorite, diorite and

estone, calcareous arkosic arenite, arkosic quartz arenite

hyry, andesite, volcanic conglomerate, tuffaceous mudstone

greenish grey siltstone, shale, greywacke, volcanoclastics, massive and
led plagioclase porphyritic and aphanitic basalt and hyaloclastite

renite

biotite-hornblende diorite, gabbro, monzodiorite, pyroxenite

: hornblende clinopyroxenite, hornblendite

-) hornblende quartz monzodiorite, granodiorite, monzodiorite,
d equivalents); rare hornblende diorite

hornblende quartz diorite, monzodiorite

pproximate, gradational, assumed)

d, vertical)

st side; defined, approximate)

100510

STATION AND SAMPLE

A

130°00'
58°15'

MAP LOCATION MAP FOR THE AND SURROUNDING VOLCAN

30F

THE HOTAILUH BATHOLITH

ANICS

40F

0'

58°15'

• station location

619• location of station discussed in C

o location of chemically analyzed s

on location

on of station discussed in Chapter IV.2

on of chemically analyzed sample

58°00' +
130°00'

5

0

60F

Km

0

5

10

15

20

70F

25

30

8 OF

619. location of station discuss

○ location of chemically and

□ location of sample used in

◇ location of sample used in

Ⓔ fossil locality

58°00'

129°00'

90F

on of station discussed in Chapter IV.2

on of chemically analyzed sample

on of sample used in Rb-Sr isotopic dating

on of sample used in K-Ar isotopic dating

locality

AEROMAGNETIC MAP FOR SURROUNDING VOLCANICS

20F

MAP FOR THE HOTAILUH BATHO L CANICS AND SATELLITIC PLU

30F

HOTAILUH BATHOLITH, SATELLITIC PLUTONS

+58°00'
130°30'

LEGEND

60,000–60,250 gammas
59,750–60,000 gammas
59,500–59,750 gammas
59,250–59,500 gammas
59,000–59,250 gammas
58,750–59,000 gammas
58,500–58,750 gammas
58,250–58,500 gammas
58,000–58,250 gammas
57,750–58,000 gammas

(MODIFIED FROM GEOLOGICAL SURVEY OF CANADA)

gammas

gammas

gammas

gammas

gammas

gammas

gammas

gammas

gammas

gammas

..... Generalized outline of plutons and volcanic units (from this study and Gabrielse (1979, 1980a))

MODIFIED FROM GEOLOGICAL SURVEY OF CANADA (1978a, b, c))

20

m

Generalized outline of plutons and major
volcanic units (from this study (cf. Figure 1)
and Gabrielse (1979, 1980a))

6 of 6

△ "First Cycle"

○ "Second Cycle"

cle"

o "Second Cycle"

20F2

△ "First Cycle"

○ "Second Cycle"

First Cycle"

o "Second Cycle"

Section 577

CLASTIC	OR	UNIT	SEDIMENTQLOGY			
PS	SHAPE	SIZE	UNIT OR FRAGMENT LITHOLOGY	VOLCANICLASTIC MATRIX	SEDIMENTARY STRUCTURES	COMMENTS
	A to R	average 1-2 cm to 5-10 cm	glassy, whitish rhyolite	light grey aphanitic, fine-grained volcanic		minimum estimated thickness
			maroon siltstone and black argillite mudstone			feeder dike to massive pyroxene-plagioclase porphyry flow(s) clearly intrudes basal siltstone and sandstone
			grit, greywacke and arkose		small scale scours	minor greyish brown arkose
						mudstone is signifi- cant towards top of unit A; grit, grey- wacke predominate in lower part of unit

Section 704

100 m

VOLCANICLASTIC

OR

UNIT

SEDIMENTOLOGY

SORTING	SHAPE	SIZE	UNIT OR FRAGMENT LITHOLOGY	VOLCANICLASTIC MATRIX	SEDIMENTARY STRUCTURES	COMMENTS
PS	rhyolite fragments A; plagioclase porphyry fragments R	bimodal: plagioclase porphyry fragments 5-7 cm; rhyolite fragments 1-2 cm, decreasing in size upwards	smaller, angular rhyolite fragments; larger, rounded bladed plagioclase porphyry fragments	dark grey pyritiferous fine-grained volcanic		lapilli volcanic breccia grades up to volcaniclastic grit; abundance of porphyry fragments decreases from 5% to 0 to top of unit; base of unit similar to unit K
rhyolite fragments WS; plagioclase porphyry fragments PS	rhyolite fragments A; plagioclase porphyry fragments R	bimodal: plagioclase porphyry fragments ≤ 60 cm (average 20-25 cm) rhyolite fragments 1-2 cm	angular, small rhyolite fragments and less common, larger rounded bladed plagioclase porphyry fragments	matrix supported; matrix is light grey, pyritiferous fine-grained volcanic		bladed plagioclase porphyry fragments more important in top part of unit where they compose up to 15-25% of rock
MS to PS		medium- to coarse-grained fine-grained				poorly bedded
PS (upper unit); WS (lower unit)	R (upper unit); A (lower unit)		rhyolite (upper unit) fine-grained volcanic (lower part)	pyritiferous volcanic (upper unit); coarse grey-wacke (lower unit)		upper unit similar to unit C
						distinctive hornblende-plagioclase crystal tuff
PS	A and R fragments	fragment size increases towards top of unit	white rhyolite (common), dark grey plagioclase porphyry (less common) and minor hornblende-plagioclase porphyry			fragments decrease in abundance but increase in size and roundness to top of unit; syenitic plagioclase porphyry dyke
PS	A to SR	≤ 4 cm; average 0.5 cm	white rhyolite and darker dacite	bluish-grey fine-grained, pyritiferous volcanic		fragment abundance 30%
MS	A		black shale fragments	matrix supported breccias; fine-grained sediment		fragments locally densely packed and compose 60-80% of breccias
WS	A	≤ 1.5 cm (average 0.5 cm)	white siliceous rhyolite	matrix supported; fine-grained grey volcanic matrix		fragment abundance 20-30%

Section 705

REVERSE FAULT

UNIT
THICKNESS
(m)

HEIGHT
ABOVE
BASE
(m)

— 27.0 — 4640

— 2645 — 4370

WEATHERING
COLOUR

CONVEN
BEDD
ATTIT

greenish
gray

subhor
tal bu
ular c
with u
0

black
lichen
cover
but
white
weathering

greenish
gray

70/10
100/13
105/5
(local

dark
greenish
gray

black
to
dark
gray

rusty
brown

white

300/44
(lowest
unit)

rusty
brown

	WEATHERING COLOUR	CONVENTIONAL BEDDING ATTITUDE	BED THICKNESS (cm)	VOLCANICLASTIC		OR	UNIT SIZE	UNIT OR FRAGMENT LITHOLOGY	VOLCANICLASTIC MATRIX
				SORTING	SHAPE				
	greenish grey	subhorizontal but irregular contact with unit 0		PS	R		average: 5-10 cm; up to 20 cm	black plagioclase porphyry	fine- to medium-grained pyroxene-plagioclase porphyry
	black lichen cover but white weathering			lapilli breccia matrix MS; round, larger fragments PS-MS	lapilli breccia matrix fragments A; larger fragments R		lapilli breccia matrix fragments 0.5-1 cm; larger round, fragments 10 cm	larger, round fragments; bladed plagioclase porphyry (locally with brown, 0.5 cm thick weathering rinds) and less common amygdaloidal lava fragments; lapilli breccia matrix fragments; white, hard, rhyolite (locally with plagioclase phenocrysts or rounded quartz "eyes") and soft, black shale or fine-grained volcanic fragments towards top of unit rhyolite and shale fragments decrease in abundance	fine-grained light grey volcanic
	greenish grey	70/10 100/13 105/5 (local)	greywacke 50; shale 1-2						
	dark greenish grey			breccia matrix fragments PS to MS	larger fragments R; breccia fragments A		larger fragments 10-15 cm; breccia matrix fragments 0.5-1 cm	uncommon, larger, bladed plagioclase porphyry and rare amygdaloidal lava fragments; in breccia matrix white, hard, locally flow layered, rhyolite and black shale or fine-grained volcanic fragments	
	black to dark grey rusty brown			PS			amygdaloidal lava fragments 10-15 cm; dark plagioclase porphyry 5 cm; bladed plagioclase porphyry 10 cm (average, 30 cm)	two clastic units (lower volcanic breccia and upper volcanic conglomerate) separated by a shale unit fragments (most to least common): dark plagioclase porphyry, bladed plagioclase porphyry, and amygdaloidal lava fragments in lower breccia; dark plagioclase porphyry, amygdaloidal lava and light grey plagioclase porphyry fragments in upper conglomerate	fragment supported at base of breccia unit matrix of vesicular amygdaloidal plagioclase porphyry
HEIGHT ABOVE BASE (m) 7.0-4640	white	300/44 (lowest unit)		base to top of each sub-unit: sandstone is MS; breccia is PS; breccia-conglomerate is PS	A (breccia) to A and R (breccia-conglomerate)		basal breccia 1 cm; breccia-conglomerate bimodal, 1 cm for rhyolite fragments and up to 40 cm (10 cm average) for bladed plagioclase porphyry fragments	consists of two similar subunits, each with a basal fine- to medium-grained lithic arkosic arenite grading up to monolithic (rhyolite and/or dark, fine-grained volcanic fragment) basal breccia which in turn grades upwards to coarser bimodal breccia-conglomerate (rhyolite and less common black shale or fine-grained volcanic fragments in the breccia; bladed plagioclase porphyry and rare, flow layered rhyolite fragments in the conglomerate)	each sub-unit is matrix supported
4.5-4370									
	rusty brown		alternating turbiditic greywacke (1-5 cm)	PS	A (breccia) to R (volcanic conglomerate)		fragment size increases upwards in	breccias and conglomerates are monolithic and contain whitish, fine-grained	breccia and conglomerate units are

SHAPE	SIZE	UNIT OR FRAGMENT LITHOLOGY	VOLCANICLASTIC MATRIX	SEDIMENTARY STRUCTURES	COMMENTS
R	average: 5-10 cm; up to 20 cm	black plagioclase porphyry	fine- to medium-grained pyroxene-plagioclase porphyry		contact with unit O marked by disappearance of rhyolite fragments
lapilli breccia matrix fragments A; larger fragments R	lapilli breccia matrix fragments 0.5-1 cm; larger round, fragments 10 cm	larger, round, fragments: bladed plagioclase porphyry (locally with brown, 0.5 cm thick weathering rinds) and less common amygdaloidal lava fragments; lapilli breccia matrix fragments: white, hard, rhyolite (locally with plagioclase phenocrysts or rounded quartz "eyes") and soft, black shale or fine-grained volcanic fragments towards top of unit rhyolite and shale fragments decrease in abundance	fine-grained, light gray volcanic		rhyolite fragments compose 30-40%, shale or volcanic fragments 15-20% and larger, round fragments 5-15% of the rock unit intruded by pyroxene porphyry, fine-grained andesite and syenitic (hornblende) plagioclase porphyry dikes; pyroxene porphyry dike intruded by syenitic porphyry; fine-grained andesite dike unaffected by fracture cleavage (may postdate fracture cleavage?)
larger fragments R; breccia fragments A	larger fragments 10-15 cm; breccia matrix fragments 0.5-1 cm	uncommon, larger, bladed plagioclase porphyry and rare amygdaloidal lava fragments; in breccia matrix white, hard, locally flow layered, rhyolite and black shale or fine-grained volcanic fragments			bladed plagioclase porphyry fragments start to appear within top 63 m of unit M fracture cleavage oriented at 130/65 (conventional orientation) locally, bladed plagioclase phenocrysts are trachytoid
	amygdaloidal lava fragments 10-15 cm; dark plagioclase porphyry 5 cm; bladed plagioclase porphyry 10 cm (average, 30 cm)	two clastic units (lower volcanic breccia and upper volcanic conglomerate) separated by a shale unit fragments (most to least common): dark plagioclase porphyry, bladed plagioclase porphyry, and amygdaloidal lava fragments in lower breccia; dark plagioclase porphyry, amygdaloidal lava and light grey plagioclase porphyry fragments in upper conglomerate	fragment supported at base of breccia unit; matrix of vesicular or amygdaloidal plagioclase porphyry		fragments form 25% of breccia or conglomerate unit correlative to unit H
A (breccia) to A and R (breccia-conglomerate)	basal breccia: 1 cm; breccia-conglomerate: bimodal, 1 cm for rhyolite fragments and up to 40 cm (10 cm average) for bladed plagioclase porphyry fragments	consists of two similar subunits, each with a basal fine- to medium-grained lithic arkosic arenite grading up to monolithic (rhyolite and/or dark, fine-grained volcanic fragment) basal breccia which in turn grades upwards to coarser bimodal breccia-conglomerate (rhyolite and less common black shale or fine-grained volcanic fragments in the breccia); bladed plagioclase porphyry and rare, flow layered rhyolite fragments in the conglomerate	each subunit is matrix supported	each subunit exhibits crude inverse grading	in each subunit: basal breccia consists of 60-80% fragments (ratio of rhyolite to dark volcanic fragments is 1:1); the breccia-conglomerate consists of 30-40% angular fragments and 10-15% larger, rounder fragments
A (breccia) to R (volcanic conglomerate)	fragment size increases upwards in three breccias	breccias and conglomerates are monolithic and contain wither whitish, fine-grained volcanics (breccias)	breccia and conglomerate units are matrix	rounded, vesicular fragment (bomb?) associated with sag in shales at one locality	pyroxene porphyry forms top unit; syenitic plagioclase porphyry dike intrudes upper part of unit I

					plagioclase porphyry fragments	turn grades upwards to coarser bimodal breccia-conglomerate (rhyolite and less common black shale or fine-grained volcanic fragments in the breccia; bladed plagioclase porphyry and rare, flow layered rhyolite fragments in the conglomerate)		
rusty brown		alternating turbiditic greywacke (1-5 cm) and shale (0.5-1 cm)	PS	A (breccia) to R (volcanic conglomerate)	fragment size increases upwards in three breccia units (lapilli-sized in lowest breccia to medium-sized fragments in upper breccia)	breccias and conglomerates are monolithic and contain wither whitish, fine-grained volcanics (breccias) or plagioclase porphyry (conglomerates)	breccia and conglomerate units are matrix supported	rounded, fragment associated sag in shale one local
light grey			PS	A to SA	framework fragments 1 cm; other fragments 10 cm average, 30 cm maximum	(most to least common): dark green-grey plagioclase porphyry; dark grey fine-grained volcanic; white rhyolite	fragment supported at top; matrix supported at base	
rusty brown	287/42 295/44	alternating black shale (0.5-1 cm) and brown greywacke (5 cm)		R to SA	5-10 cm to < 1 cm	predominantly amygdaloidal lava	matrix supported	in one breccia fragments bricated
greyish white		2-5 (greywacke); 1-3 (siltstone)	PS (volcaniclastics and greywacke)	SA to R	3-4 cm (average) in basal volcaniclastic unit; 10 cm average and 3 m maximum size for upper volcaniclastic unit	(most to least common): bladed plagioclase porphyry and amygdaloidal lava	matrix supported; bluish grey, fine-grained pyritiferous volcanic	local normaling in turbiditic units with coarse plagioclase spar-rich scouring common
rusty brown (volcaniclastics) to bluish grey (sandstone)	236/42 (upper units) 193/30 (lower units)	1-5 (lower units)	WS (lower sandstone unit)	A to R (upper volcaniclastic unit)	fine-grained lower sandstone unit	dark, fine-grained volcanic and less common, rounded, amygdaloidal lava fragments	matrix supported; greywacke matrix lower volcaniclastic unit changes from fragment to matrix supported towards top	highly con bedding in at base of
rusty brown			PS	A	2-7 cm; 4 cm average	predominantly dark grey, fine-grained volcanic and distinctive rounded amygdaloidal lava fragments	fragment supported; matrix is fine-grained pyritiferous volcanic	
grey			PS to MS	R to SA	3-5 cm average size at base to 10-12 cm average size at top	(most to least common): pyroxene-plagioclase porphyry; greyish-green, fine-grained volcanic; bladed plagioclase porphyry; dark grey volcanic	fine- to medium-grained pyroxene porphyry; matrix supported	
greenish grey								
grey								
dark greenish grey								
light greenish grey			PS	A	7 cm (maximum) 1-2 cm (average)	white rhyolite	matrix supported	
greyish brown (arkose) rusty brown (shale)	290/55		WS (arkose)		fine- to medium-grained (arkose)			

	plagioclase porphyry fragments	turn grades upwards to coarser bimodal breccia-conglomerate (rhyolite and less common black shale or fine-grained volcanic fragments in the breccia; bladed plagioclase porphyry and rare, flow layered rhyolite fragments in the conglomerate)			
(breccia) R (volcanic conglomerate)	fragment size increases upwards in three breccia units (lapilli-sized in lowest breccia to medium-sized fragments in upper breccia)	breccias and conglomerates are monolithic and contain wither whitish, fine-grained volcanics (breccias) or plagioclase porphyry (conglomerates)	breccia and conglomerate units are matrix supported	rounded, vesicular fragment (bomb?) associated with sag in shales at one locality	pyroxene porphyry forms top unit; syenitic plagioclase porphyry dike intrudes upper part of unit I
to SA	framework fragments 1 cm; other fragments 10 cm average, 30 cm maximum	(most to least common): dark green-grey plagioclase porphyry; dark grey fine-grained volcanic; white rhyolite	fragment supported at top; matrix supported at base		common vertical fractures in fragments
to SA	5-10 cm to < 1 cm	predominantly amygdaloidal lava	matrix supported	in one breccia unit, fragments are imbricated	turbidite sequence with minor volcanic conglomerate; intruded by hornblende porphyry dike; conglomerate similar to that in unit F
to R	3-4 cm (average) in basal volcaniclastic unit; 10 cm average and 3 m maximum size for upper volcaniclastic unit	(most to least common): bladed plagioclase porphyry and amygdaloidal lava	matrix supported; bluish grey, fine-grained pyritiferous volcanic	local normal grading in turbiditic layers (each turbiditic unit starts with coarse, bladed plagioclase feldspar-rich greywacke; scouring of siltstone common	interfayered volcanic conglomerate-breccia and turbiditic greywacke-siltstone units
to R upper volcaniclastic unit)	fine-grained lower sandstone unit	dark, fine-grained volcanic and less common, rounded, amygdaloidal lava fragments	matrix supported; greywacke matrix lower volcaniclastic unit changes from fragment to matrix supported towards top	highly convoluted bedding in unit E at base of unit F	marked NW thinning of breccia and thickening of siltstone at top of unit E lower sandstone unit is pyritiferous and increases in grain size upwards; lower volcaniclastic unit similar to unit E in NW section
A	2-7 cm; 4 cm average	predominantly dark grey, fine-grained volcanic and distinctive rounded amygdaloidal lava fragments	fragment supported; matrix is fine-grained pyritiferous volcanic		
to SA	3-5 cm average size at base to 10-12 cm average size at top	(most to least common): pyroxene-plagioclase porphyry; greyish-green, fine-grained volcanic; bladed plagioclase porphyry; dark grey volcanic	fine- to medium-grained pyroxene porphyry; matrix supported		fragments less common at base of unit (3-5% at base and 20-40% at top)
					rare pyroxene(?) phenocrysts rare pyroxene phenocrysts pyroxene phenocrysts uncommon; epidote veining uncommon
A	7 cm (maximum) 1-2 cm (average) fine- to medium-grained (arkose)	white rhyolite	matrix supported		Toarcian(?) unit; poorly bedded arkose and well cleaved, poorly bedded pyritiferous shale

Section 707

PORTING	SHAPE	UNIT SIZE	SEDIMENTOLOGY		VOLCANICLASTIC MATRIX	SEDIMENTARY STRUCTURES	COMMENTS
			UNIT OR FRAGMENT LITHOLOGY				
PS	R to A	2-7 cm (at base) to 15-20 cm (upper subunit; maximum 30 cm)	bladed plagioclase porphyry (locally with 0.5-1 cm weathering rind); light greyish purple volcanic fragments in pyroxene capilli tuff		feldspar-rich, poorly sorted grey-wacke in uppermost unit		
	R for fragments midway up section	fragments midway up section average 7 cm and range 3-30 cm	bladed plagioclase porphyry		bladed plagioclase porphyry matrix only slightly less coarse than fragments		bladed plagioclase flows are locally pillowed in upper part of unit D and form part of a pillow lava breccia down dip and in overlying unit E
	in basal subunit, rhyolite fragments A; bladed feldspar porphyry fragments R	in basal subunit, rhyolite fragments 1-2 cm; bladed plagioclase porphyry fragments 5-7 cm					rhyolite fragments at base of unit D have quartz phenocrysts
							bladed plagioclase porphyry fragments compose 15% of volcaniclastics
PS	R	purple volcanic fragments 2-5 cm fragment size decreases markedly at top of unit to 1-3 cm	predominant fragment lithology is purplish fine-grained volcanic and plagioclase porphyry; others are: pyroxene porphyry, vesicular lava and black plagioclase porphyry near top of unit, fragments of light grey, fine-grained volcanic are common		pyroxene-plagioclase porphyry is common matrix; in middle of unit, purplish volcanic locally is matrix; matrix becomes finer grained at top of unit		abundance of: purple volcanic fragments (5-10%); amygdaloidal lava fragments (10-20%)
		granitoids: 10-20 cm at base; 507 cm midway in unit; and 2-3 cm at top of unit (and may reach sizes of more than 30 m x 50 m x 10 m)	granitoid fragments (decrease in size and abundance up section; are foliated, lineated or massive; and are similar to Cake Hill Pluton); plagioclase porphyry fragments; and fine-grained volcanic fragments		pyroxene porphyry (increases in pyroxene content up section)		abundant granitoid fragments (5-10%) decrease in size and abundance up section; plagioclase porphyry fragments (10-20%); purple volcanic fragments (5%)
		average size of all fragments is 7-15 cm					
MS (arkose)			at base, black, medium-grained quartzose greywacke fines up to medium-grained white, quartzose arkosic arenite (which contains hornblende grains in some basal beds); interlayered black, pyritiferous, locally quartz-bearing, massive shale predominates in the top two-thirds of the section and sustains a fracture cleavage near the thrust fault; rare, buff sandy carbonate also occurs at the base of the section				Toarcian unit and structurally overlying Upper Triassic Stuhini Group intruded by inclusion-bearing hornblende monzodiorite which exhibits chilled margins against the Toarcian unit

Section 711

VOLCANICLASTIC SORTING	OR SHAPE	UNIT SIZE	SEDIMENTOLOGY UNIT OR FRAGMENT LITHOLOGY	VOLCANICLASTIC MATRIX	SEDIMENTARY STRUCTURES	COMMENTS
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massive, bladed plagioclase-pyroxene porphyry

fine- to medium-grained massive (pyroxene-) plagioclase porphyry is distinguished by closely spaced, moderately southeast dipping jointing

crumbly, highly amygdaloidal and fractured pyroxene-plagioclase porphyry

massive (pyroxene-) plagioclase porphyry; vesicles and pyroxene phenocrysts rare; rare 1-3 cm wide quartz veins

massive, amygdaloidal plagioclase porphyry (rare pyroxene)

vesicles or amygdules have scattered occurrence; pyrite is uncommon

pyritiferous, amygdaloidal, fine- to medium-grained plagioclase porphyry (pyroxene phenocrysts rare)

calcite fills vesicles, pyrite disseminated and in veins

Section 714

WEATHERING COLOUR	CONVENTIONAL % BEDDING ATTITUDE	BED THICKNESS (cm)	VOLCANICLASTIC		OR	UNIT	SEDIMENTOLOGY		VOLCANICLASTIC MATRIX
			SORTING	SHAPE		SIZE	UNIT OR FRAGMENT LITHOLOGY		
rusty dun brown				SA to R		2-5 cm (up to 20 cm)	massive pyroxene porphyry unit which grades in and out of massive flows and pyroxene fragment volcanic conglomerates; near top of unit, minor black plagioclase porphyry also occurs		matrix supported; pyroxene porphyry matrix
olive grey and light grey	239/45 246/36	1-5					medium laminated to thin bedded siltstone		
rusty brown	242/31 250/29 244/23		PS (grey-wacke)				interbedded, fractured, pyritiferous black shale and bedded, medium-grained feldspathic greywacke with distinctive white, delicate siltstone (tuff?) laminae which mark the tops of sandstone beds		
greenish grey to rusty brown		shale: 1-3 sandstone: 5-10					interbedded fissile shale and dark grey greywacke		
light grey							porcellanite, hornfelsed, thinly laminated siltstone		
greenish grey to brown to rusty brown		3-5 (grey-wacke and shale)					greywacke interbedded with fissile, pyritiferous, very fine-grained greywacke or siltstone		
black and rusty brown	250/35 241/34 237/34	sandstone 2-3 cm to 20-45 cm to 140-150 cm; siltstone laminae 2-5 mm; beds 2-3 cm					interlayered massive bluish grey greywacke and laminated black siltstone		
brownish grey			MS				massive, well indurated, medium-grained, bluish grey greywacke with rare, discontinuous, white wispy siltstone (tuff?) laminae		
light grey				A		5-1 cm	black siltstone similar to unit I; breccia contains white rhyolite and plagioclase porphyry fragments		plagioclase porphyry
grey to black	235/47						massive, bluish grey greywacke overlain by tough black siltstone interlaminated with very thin, delicately layered white siltstone laminae		
bluish grey to rusty brown							grain size decreases towards top of unit and pyroxene porphyry becomes bluish grey fine-grained volcanic		
brownish grey (siltstone), greenish grey (grey-wacke)	244/34 250/32 247/25 (siltstone) 247/34 245/33 (grey-wacke)	0.25-0.5 (siltstone)	PS to MS (greywacke)				possible sill?		
white			PS	A to R		1-3 cm (breccia fragments); 10 cm average size for rounded fragments	interbedded grey, medium-grained, thin-bedded greywacke and thinly laminated, white weathering siltstone		
grey			PS	R		lapilli-sized fragments generally <5 cm except in	basal, poorly bedded, greywacke		matrix supported; matrix is grey plagioclase porphyry
							white rhyolitic hornblende? plagioclase porphyry		black, aphanitic matrix (same as western Hill Pluton?)

VOLCANICLASTIC	OR	UNIT	SEDIMENTOLOGY	VOLCANICLASTIC MATRIX	SEDIMENTARY STRUCTURES	COMMENTS
PORTING	SHAPE	SIZE	UNIT OR FRAGMENT LITHOLOGY			
	SA to R	2-5 cm (up to 20 cm)	massive pyroxene porphyry unit which grades in and out of massive flows and pyroxene fragment volcanic conglomerates; near top of unit, minor black plagioclase porphyry also occurs medium laminated to thin bedded siltstone	matrix supported; pyroxene porphyry matrix	convolute laminations within 5 cm of contact with overlying unit R	fragments compose between 5-15% of rock locally
(grey-ke)			interbedded, fractured, pyritiferous black shale and bedded, medium-grained feldspathic greywacke with distinctive white, delicate siltstone (tuff?) laminae which mark the tops of sandstone beds			
			interbedded fissile shale and dark grey greywacke.			
			porcellanite, hornfelsed, thinly laminated siltstone		convolute lamination	massive, equigranular monzodiorite sill intrudes and metamorphoses unit
			greywacke interbedded with fissile, pyritiferous, very fine-grained greywacke or siltstone		rare, recessive weathering concretions in greywacke	
			interlayered massive bluish grey greywacke and laminated black siltstone		load casts, ball and pillow and flame structures	
			massive, well indurated, medium-grained, bluish grey greywacke with rare, discontinuous, white wispy siltstone (tuff?) laminae			
		51 cm	black siltstone similar to unit I; breccia contains white rhyolite and plagioclase porphyry fragments	plagioclase porphyry		
			massive, bluish grey greywacke overlain by tough black siltstone interlaminated with very thin, delicately layered white siltstone laminae			
			grain size decreases towards top of unit and pyroxene porphyry becomes bluish grey fine-grained volcanic			
			possible sill?			
			interbedded grey, medium-grained, thin bedded greywacke and thinly laminated, white weathering siltstone		convoluted siltstone beds beneath unit H	
			basal, poorly bedded, greywacke		greywacke is distinguished by recessive weathering concretions (0.5-1 cm in diameter)	
	A to R	1-3 cm (breccia fragments); 10 cm average size for rounded fragments	white rhyolitic hornblende? plagioclase porphyry	matrix supported; matrix is grey plagioclase porphyry		fragments compose 40% of breccia; fragment size decreases to top of unit
	R	lapilli-sized fragments generally 4.5 cm except in	similar to western unit B but this unit has uncommon granitoid fragments (Coke Hill Pluton?)	black, aphanitic matrix (same as western unit E)		western and eastern E units correlated on similar matrix and fragment lithologies

40F

Color	Sample	Thickness	Unit	Bedding	Grain Size	Notes	Matrix
grey	250/35	3-5 (grey-wacke and shale)	MS			porcellanite, hornfelsed, thinly laminated siltstone	
greenish grey to brown to rusty brown	241/34					greywacke interbedded with fissile, pyritic, very fine-grained greywacke or siltstone	
black and rusty brown	237/34	sandstone 2-3 cm to 20-25 cm to 60-150 cm; siltstone laminae 2-5 mm; beds 2-3 cm				interlayered massive bluish grey greywacke and laminated black siltstone	
brownish grey						massive, well indurated, medium-grained, bluish grey greywacke with rare, discontinuous, white wispy siltstone (tuff?) laminae	
light grey						black siltstone similar to unit I; breccia contains white rhyolite and plagioclase porphyry fragments	plagioclase porphyry
grey to black	235/47					massive, bluish grey greywacke overlain by tough black siltstone interlaminated with very thin, delicately layered white siltstone laminae	
bluish grey to rusty brown						grain size decreases towards top of unit and pyroxene porphyry becomes bluish grey fine-grained volcanic	
brownish grey (siltstone)	244/34	0.25-0.5 (siltstone)	PS to MS (greywacke)			possible sill?	
greenish grey (greywacke)	250/32					interbedded grey, medium-grained, thin bedded greywacke and thinly laminated, white weathering siltstone	
white	247/25					basal, poorly bedded, greywacke	
	247/34					white rhyolitic hornblende?-plagioclase porphyry	matrix supported; matrix is grey plagioclase porphyry
	245/33						
grey						similar to western unit E but this unit has uncommon granitoid fragments (Cape Hill Pluton?)	black, aphanitic matrix (same as western unit E)
light grey	264/43					vesicular lava fragments, fine-grained plagioclase porphyry, fine-grained light grey volcanic fragments	matrix supported; fine-grained black volcanic
	267/47					dark, fine-grained volcanic fragments	pale bluish white, fine-grained volcanic matrix
rusty brown	260/45					massive feldspathic greywacke and interbedded black shale and coarsely laminated siltstone	
rusty brown						massive, medium-grained hornblende-plagioclase porphyry dike(?)	
rusty cream	269/58					massive sandy micrite and limey quartzose arkosic arenite	
						sandy carbonate (in talus)	
						quartzose arkosic arenite	

porcellanite, horn-
fused, thinly lami-
nated siltstone

convolute lamination

massive, equigranular
monzodiorite sill
intrudes and metamor-
phoses unit

greywacke interbedded
with fissile, pyriti-
ferous, very fine-
grained greywacke or
siltstone
interlayered massive
bluish grey grey-
wacke and laminated
black siltstone

rare, recessive
weathering concretions
in greywacke

load casts, ball and
pillow and flame
structures

massive, well indur-
ated, medium-grained,
bluish grey grey-
wacke with rare, dis-
continuous, white
wispy siltstone (tuff?)
laminae

A 51 cm

black siltstone
similar to unit
I; breccia contains
white rhyolite
and plagioclase
porphyry fragments
massive, bluish grey
greywacke overlain
by tough black silt-
stone interlaminated
with very thin, deli-
cately layered white
siltstone laminae
grain size decreases
towards top of unit
and pyroxene porphyry
becomes bluish grey
fine-grained volcanic

plagioclase
porphyry

possible sill?

interbedded grey,
medium-grained, thin
bedded greywacke and
thinly laminated,
white weathering silt-
stone

convoluted siltstone
beds beneath unit H

greywacke is distin-
guished by recessive
weathering con-
cretions (0.5-1 cm
in diameter)

A to R

1-3 cm
(breccia
fragments);
10 cm
average
size for
rounded
fragments

basal, poorly bedded,
greywacke
white rhyolitic
hornblende?-
plagioclase porphyry

matrix
supported:
matrix is
grey plagioclase
porphyry

fragments compose 40%
of breccia; fragment
size decreases to
top of unit

R

lapilli-
sized
fragments
generally
4-5 cm
except in
basal unit
(≈ 10 cm)

similar to western
unit E but this unit
has uncommon grani-
toid fragments (Cape
Hill Pluton?)

black,
aphanitic
matrix
(same as
western
unit E)

western and eastern
E units correlated
on similar matrix
and fragment litho-
logies

SA to R

10-15 cm
in basal
conglomer-
ate; 3-5
cm in
upper
conglomer-
ate

vesicular lava
fragments, fine-
grained plagioclase
porphyry, fine-grained
light grey volcanic
fragments

matrix
supported;
fine-grained
black vol-
canic

volcanic conglomerates.
(fragment abundance
12-25%) interbedded
with thin bedded
sandstone

A

1-3 cm

dark, fine-grained
volcanic fragments

pale bluish
white, fine-
grained
volcanic
matrix

massive feldspathic
greywacke and inter-
bedded black shale
and coarsely laminated
siltstone

massive, medium-
grained hornblende-
plagioclase porphyry
dike(?)

massive sandy
micrite and limey
quartzose arkosic
arenite

sandy carbonate (in-
talus)

quartzose arkosic
arenite

units A and B are
part of the Toarcian
sedimentary unit

trough cross beds in
talus blocks

Section 715

VOLCANICLASTIC	OR	UNIT	SEDIMENTOLOGY			
SORTING	GRAIN	SIZE	UNIT OR FRAGMENT LITHOLOGY	VOLCANICLASTIC MATRIX	SEDIMENTARY STRUCTURES	COMMENTS
PS	SA to R	up to 30 cm	massive, fine- to medium-grained plagioclase porphyry basal, homogeneous plagioclase porphyry (with 2-3% round plagioclase porphyry fragments) grading up to volcanic conglomerate composed of light and dark grey and maroon varieties of non-vesicular plagioclase porphyry fragments	matrix supported		
PS	SA to R	1-45 cm	predominantly light to dark grey plagioclase porphyry; fragments are vesicular or amygdaloidal	matrix supported, maroon, fine- to medium-grained plagioclase porphyry		
PS	A	range 1-15 cm; average 4 cm	fine- to medium-grained plagioclase porphyry with 5-7% quartz- and epidote-filled amygdules	matrix supported; amygdaloidal, fine-grained tuff		
	A (thin breccia subunit)	1-1.5 cm (thin breccia subunit)	predominantly grey, fine-grained plagioclase porphyry and minor, fine-grained maroon siltstone fragments	fine-grained maroon volcanic matrix for breccia		
			massive, locally moderately to highly vesicular, fine- to medium-grained plagioclase porphyry			
			plagioclase phenocrysts form 40% of rock at base, 15-20% at top of unit			
			minor lapilli breccia contains fine- to medium-grained plagioclase porphyry fragments			
			vesicles are more common at base of unit (10-15%) and virtually absent at top			
			chloritized pyroxene? plagioclase porphyry at base grading upwards to fine-grained plagioclase porphyry?			
			pink plagioclase porphyry with 15-20% fine-grained to medium-grained plagioclase phenocrysts in a dark fine-grained volcanic groundmass			unit J distinguished from other plagioclase porphyry units by its pink plagioclase phenocrysts
			massive, fine-grained plagioclase			plagioclase phenocrysts are less common, finer grained and more altered compared with those in unit H
			medium-grained plagioclase porphyry; individual flow units may be distinguished by decrease or increase in plagioclase phenocryst content, physiographic expression or less distinctively by groundmass colour			epidote and minor red calcite, quartz and chlorite fill vesicles
			magnetite also forms uncommon phenocrysts			
			local vesicular intervals are also distinctive			
			laminated mudstone			

100 m

3 units of apparent 30-40 m thickness may be distinguished only by physiographic expression

0.5-1

306/28

30F

plagioclase
porphyry

A range 1-15
cm; average
4 cm

fine- to medium-
grained plagioclase
porphyry with 5-7%
quartz- and epidote-
filled amygdules
predominantly grey,
fine-grained plagio-
clase porphyry and
minor, fine-grained
maroon siltstone
fragments

matrix
supported;
amygdaloidal,
fine-grained
tuff

A (thin
breccia
subunit)

1-1.5 cm
(thin brec-
cia subunit)

massive, locally
moderately to highly
vesicular, fine- to
medium-grained
plagioclase
porphyry

fine-
grained
maroon
volcanic
matrix for
breccia

plagioclase pheno-
crysts form 40% of
rock at base, 15-20%
at top of unit

minor lapilli breccia
contains fine- to
medium-grained plagio-
clase porphyry
fragments

vesicles are more
common at base of
unit (10-15%) and
virtually absent
at top

chloritized pyroxene?
plagioclase porphyry
at base grading up-
wards to fine-grained
plagioclase porphyry?

pink plagioclase
porphyry with 15-
20% fine-grained
to medium-grained
plagioclase pheno-
crysts in a dark
fine-grained
volcanic ground-
mass

unit J distinguished
from other plagioclase
porphyry units by its
pink plagioclase
phenocrysts

massive, fine-grained
plagioclase

plagioclase phenocrysts
are less common, finer
grained and more altered
compared with those in
unit H

medium-grained
plagioclase porphyry;
individual flow units
may be distinguished
by decrease or in-
crease in plagioclase
phenocryst content,
physiographic ex-
pression or less
distinctively by
groundmass colour

epidote and minor
red calcite, quartz
and chlorite fill
vesicles

magnetite also forms
uncommon phenocrysts

local vesicular in-
tervals are also
distinctive

laminated mudstone

medium-grained plagio-
clase porphyry

groundmass colour
varies from maroon
to grey even at hand
specimen scale

faintly bedded, fine-
grained siltstone to
fine-grained sand-
stone overlain by
fine- to medium-
grained lithic crystal
tuff or tuffaceous
greywacke

scours in siltstone

medium-grained plagio-
clase porphyry and
maroon grey, fine-
grained andesite

amygdaloidal lava

massive, tough, fine-
grained andesite

massive, amygdaloidal
lava

similar to unit A

calcite-, quartz- and
chlorite-filled amyg-
dules

APPENDIX 6.6

○ FINE-GRAINED PHASE □ MAFIC PHASE △ CENTRAL PHASE ◇ POTASSIC MARGINAL PHASE ○ LEUCOCRATIC PHASE ◇ K-Ar SAMPLE □ REPLICATE ANALYSES

APPENDIX 6.6 (continued)

○ FINE-GRAINED PHASE □ MAFIC PHASE △ CENTRAL PHASE ◇ POTASSIC MARGINAL PHASE ○ LEUCOCRATIC PHASE ◇ K-Ar SAMPLES □ REPLICATE ANALYSES

APPENDIX 1. DETAILS OF THE GEOLOGY OF THE STIKINE PLUTON

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1.5 Harker Variation Diagrams for the Stikine Pluton	A-9

-
1. Dip direction conventionally oriented 90 degrees clockwise from azimuth.
 2. Rock classification after Streckeisen (1973).

APPENDIX 1.1 - LITHOLOGICAL CHARACTERISTICS OF THE STIKINE PLUTON

a) Inclusions in the Stikine Pluton

Location (at or near station:)	Abundance (%)	Dimensions	Comments
441	1	5 cm long	rare triangular, mafic inclusion and rare schlieren (up to 8 cm wide)
619	1-3	up to 15 cm long (average size 2-3 cm)	angular to rounded or elongate mafic diorite inclusions generally oriented parallel to foliation
623	1	5 cm long	small elongate inclusions oriented parallel to foliation
624	1-3	3-7 cm long	rounded mafic diorite inclusions oriented roughly parallel to foliation

APPENDIX 1.2 - STRUCTURAL DATA FOR THE STIKINE PLUTON

a) Mineral foliation

Location (at or near station:)	Conventional Orientation Quality of Foliation		
	Poor	Moderate	Good
33			290/58 287/85 265/73
34			90/80 290/73
35	163/23	92/23	287/50
369			233/72 246/55 256/66
373	340/69		251/50
423		112/85	93/70
425		56/75	93/82
440	303/24 (in place?)		
441	237/68	78/72	308/65 (schlieren)
617			264/80
619		212/72 209/67 61/80	243/44 263/65 227/45 246/63 250/48 236/78 232/60 263/40 225/61 256/65 251/66 72/83 74/90 95/37
623		210/57 153/48	205/69 203/72 200/63 191/61

APPENDIX 1.2 (cont'd)

a) Mineral foliation (cont'd)

Location (at or near station:)	Conventional Orientation Quality of Foliation		
	Poor	Moderate	Good
624			182/45 188/46 214/62 191/38 217/48 219/45
625			275/74 290/74 185/73
626			11/71 3/73 21/76 221/83

APPENDIX 1.2 (cont'd)

b) Mineral lineation

Location (at or near station:)	Conventional Orientation Quality of Lineation		
	Poor	Moderate	Good
33			103/37
441			205/30
619	238/32		
623		202/60	43/25
624		196/26 215/7	

APPENDIX 1.3 - INTRUSIVE RELATIONS INVOLVING THE STIKINE PLUTON

a) External intrusive relations

Location (at or near station:)	Comments
--------------------------------------	----------

INTRUSIVE RELATIONS INVOLVING THE STIKINE PLUTON AND THE TRIASSIC VOLCANICS

423, 442 and 620	contact between Stikine Pluton and Upper Triassic augite porphyry volcanics is bracketed but not exposed; no identifiable Stikine Pluton apophyses in or contact metamorphism of the volcanics is observed near the contact
------------------	---

Location (at or near station)	Comments
-------------------------------------	----------

INTRUSIVE RELATIONS INVOLVING THE STIKINE PLUTON AND THE TERTIARY VOLCANICS

31	assumed nonconformable contact between Stikine Pluton and columnar jointed cap of very fresh, olivine nodule-bearing olivine basalt
----	---

368, 370, 371, 372, 373, and 424	black, massive olivine basalts and highly vesicular or diktytaxitic olivine basalts horizontally lie on presumed nonconformable surface of Stikine Pluton
-------------------------------------	---

b) Interpluton intrusive relations

Location (at or near station)	Comments
-------------------------------------	----------

INTRUSIVE RELATIONS INVOLVING THE STIKINE PLUTON AND THE CAKE HILL PLUTON (FELSIC PHASE)

617	1 m wide, slightly irregular, sphene- and hornblende-bearing aplitic, siliceous, leucocratic monzonite (Cake Hill Pluton, felsic phase?) intrudes well foliated amphibolite (Stikine Pluton?)
-----	---

APPENDIX 1.3 (cont'd)

b) Interpluton intrusive relations (cont'd)

Location
(at or near
station:)

Comments

INTRUSIVE RELATIONS INVOLVING THE STIKINE PLUTON AND THE THREE SISTERS PLUTON
(POTASSIC MARGINAL PHASE)

373

more than 1 m wide syenite dike (Three Sisters Pluton, potassic marginal phase?) intrudes foliated hornblende diorite or gabbro (Stikine Pluton)

APPENDIX 1.4. MODAL COMPOSITION OF THE STIKINE PLUTON

SAMPLE NUMBER
GA-67-98c³
(GSC 70-34)

35-1² 369-1³ 619-1³ 624-1³

67.4

plagioclase

7.2

quartz

6.5

alkali feldspar

0.7

clinopyroxene

15.5

hornblende

0.4

biotite

2.6

opaque minerals

0.4

titanite

Tr

apatite

Tr

zircon

Tr

chlorite

Tr

epidote

Tr

sericite and saussurite

Tr

calcite

An₄₀₋₄₆An₃₅₋₅₀An₄₂₋₅₄An₃₉₋₄₉An₃₈₋₄₆

PLAGIOCLASE COMPOSITION

18.9

Colour Index

1000

Point Counts

1. Tr = trace

2. monzodiorite

APPENDIX 1.5

Sample numbers are given in alumina-silica variation diagram (see Table II.2.2).

APPENDIX 1.5

APPENDIX 1.5 (continued)

APPENDIX 2. DETAILS OF THE GEOLOGY OF THE CAKE HILL PLUTON

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1. Dip direction conventionally oriented 90 degrees clockwise from azimuth.

APPENDIX 2.1 - LITHOLOGICAL CHARACTERISTICS OF THE CAKE HILL PLUTON

a) Inclusions in the undisturbed and remobilized Cake Hill Pluton

Location (at or near station:)	Abundance (%)	Dimensions	Comments
UNDISTURBED AREAS			
<u>Domain 1</u>			
416	<<1	30 cm long	greenstone inclusion
417	<<1	10 cm long	wedge-shaped greenstone inclusion
543	<<1		small, medium-grained hornblendite inclusion
544	<<1	2-30 cm long	medium-grained hornblendite and fine-grained metavolcanic inclusions
546	<<1	24 cm x 30 cm	rounded, foliated inclusion of similar composition, though slightly finer-grained as including C.H.P. monzodiorite
	≤2	60 cm long	elongate, epidotized, augite-plagioclase porphyry inclusion
	1	5 cm long	elongate amphibolite inclusion oriented parallel to foliation
561	<<1	2 cm long	one small, rounded, medium-grained hornblendite inclusion
563	<<1	30 cm x 15 cm	one large, rounded, medium-grained hornblendite inclusion
	<<1	2 cm	rare, rounded hornblendite inclusion
564	1	2-35 cm long	fine- to medium-grained hornblende diorite (SEE PLATE 1 A)

APPENDIX 2.1 (cont'd)

a) Inclusions (cont'd)

Location (at or near station:)	Abundance (%)	Dimensions	Comments
UNDISTURBED AREAS			
<u>Domain 1</u> (cont'd)			
564 (cont'd)	<<1	5-20 cm long	two inclusion types: medium-grained leucocratic hornblende diorite; and fine-grained diorite
568	<<1	2-4 cm long	rounded, fine- to medium- grained hornblendite inclusion
	<<1	15 cm x 25 cm	one subangular to subrounded hornblende pyroxenite inclusion
		30 cm x 15 cm	elongate, fine- to medium- grained leucocratic horn- blende diorite to monzodiorite
580	<<1	8 cm	rounded inclusion of fine- to medium-grained hornblendite
		5 cm	elongate, fine-grained diorite oriented parallel to foliation
582	<<1	5 cm long	elongate inclusion of fine- grained diorite
584	<<1		rare, fine-grained diorite and more common hornblende gabbro inclusions
586	<<1	10 cm x	elongate, fine- to medium grained gabbro inclusion oriented parallel to foliation
		7 cm x	
		4 cm	

APPENDIX 2.1 (cont'd)

a) Inclusions (cont'd)

Location (at or near station:)	Abundance (%)	Dimensions	Comments
UNDISTURBED AREAS			
<u>Domain 2</u>			
221	<<1	3 cm long	two inclusions: one is fine-grained diorite; the other is fine-grained diorite with schlieren
225		3 cm long	talus boulder exposure: inclusion of fine-grained diorite
226	<1	1-3 cm	fine-grained diorite inclusions in talus boulder exposures
<u>Domain 3</u>			
499	<<1	3 cm long	fine-grained diorite inclusion
	<<1		hornblendite inclusion
502	<<1	15 cm long	ovoid inclusion of fine- to medium-grained diorite

Location (at or near station:)	Abundance (%)	Dimensions	Comments
--------------------------------------	------------------	------------	----------

AREAS OF REMOBILIZED CAKE HILL PLUTON (INCLUDES PENDANTS AND SCREENS IN THE THREE SISTERS PLUTON)

Domain 1

511	5	≤10 cm long	fine-grained diorite in euhedral hornblende-biotite monzodiorite
522	2	max. size of 10 cm	rounded, fine-grained diorite, acicular hornblende diorite and rare metamorphosed augite porphyry inclusions

APPENDIX 2.1 (cont'd)

a) Inclusions (cont'd)

Location (at or near station:)	Abundance (%)	Dimensions	Comments
--------------------------------------	------------------	------------	----------

**AREAS OF REMOBILIZED CAKE HILL PLUTON (INCLUDES PENDANTS AND SCREENS IN THE
THREE SISTERS PLUTON)**

Domain 1 (cont'd)

525	2	2-3 cm long	rounded, fine-grained horn- blende diorite inclusions in euhedral hornblende biotite monzodiorite
-----	---	-------------	--

see also station 535 in Remobilized and Metamorphosed Cake Hill Pluton
section in Appendix 2.3

Domain 3

75	5	≤25 cm long	fine-grained diorite inclusions
83	1	2 cm long (average)	rounded, fine-grained diorite inclusions
95	1	≤3 cm long	fine-grained diorite
152	<1	2 cm long	oval-shaped, fine-grained diorite inclusions

9

APPENDIX 2.2 - STRUCTURAL DATA FOR THE CAKE HILL PLUTON

a) Mineral foliation

Location (at or near station:)	Conventional Orientation Quality of Foliation		
	Poor	Moderate	Good
<u>Domain 1</u>			
5	120/80	127/57	100/62 338/64 290/73
26		126/87	
29	190/78		24/90 34/88 59/90 67/85 53/90 235/80
30			205/87 203/78 207/89
119	76/45		
129			315/44 322/44
339			277/33
340			238/47 238/66 287/52
341			292/60
358			165/86 338/83 183/81 320/85 138/70 350/87 163/74 353/84
359		000/64 119/72	319/79 334/84 326/62 341/62

APPENDIX 2.2 (cont'd)

b) Mineral foliation (cont'd)

Location (at or near station:)	Conventional Orientation Quality of Foliation		
	Poor	Moderate	Good
<u>Domain 1</u> (cont'd)			
359			343/84 169/85 134/76 168/81 173/74 152/76
360			154/82 128/77 174/82 161/78
361			146/84 199/86 323/74 178/73 349/67
411			318/77 8/76
412		212/74	15/79 35/84
413		215/66 (outcrop in place?)	
414			160/84
415	175/90		150/78 175/89 179/83
416		140/78	190/81 168/88
418		175/85	
457		91/48	
505		37/34	
513	187/36 208/53		

APPENDIX 2.2 (cont'd)

a) Mineral foliation (cont'd)

Location (at or near station:)	Conventional Orientation. Quality of Foliation		
	Poor	Moderate	Good
<u>Domain 1</u> (cont'd)			
517			37/72
521			45/53
534		119/33	
535			270/88 290/83
543	290/57	343/84 348/61	303/42
544	208/65	295/53 323/67 348/53 285/83	325/73 323/53 20/65
545	35/68 283/41 20/38		
546			337/46 357/61 97/23
548	233/38	291/30	282/25 300/39 262/26 295/30 323/25
552		298/83	
554	110/83 130/87		
556		273/88 257/62 270/76	256/67 269/69 260/75 236/72
557			296/60

APPENDIX 2.2 (cont'd)

a). Mineral foliation (cont'd)

Location (at or near station:)	Conventional Orientation Quality of Foliation		
	Poor	Moderate	Good
<u>Domain 1</u> (cont'd)			
558	285/68 270/84		3/66 6/77 13/67 353/74 291/74 294/61
559		276/77	277/86 313/83 328/66 334/68 190/50 000/58
560	110/48	299/43 131/81 120/64 260/75	39/50 315/87 355/84 359/78 305/34 302/55 337/78 335/80 145/90 158/74 136/60 135/69 146/50 146/67 274/82
561		290/75 302/83 323/68	347/70 330/79 331/81 321/78
562		140/84	125/72 127/72 344/72 325/74 325/73 309/74 110/74 108/72

APPENDIX 2.2 (cont'd)

a) Mineral foliation (cont'd)

Location (at or near station:)	Conventional Orientation Quality of Foliation		
	Poor	Moderate	Good
<u>Domain 1</u> (cont'd)			
562			120/68
563		100/88 271/86 304/84 280/76 323/88	145/81 270/86 285/81 324/80
564		327/70 (SEE PLATE I A)	325/45 350/75 353/55 68/30 80/37
565		323/83 336/50	334/47
566	325/37	38/31	
567	308/81	304/71 285/83	98/66
568		294/86 112/80 118/54 151/79	118/77 138/86 107/77 135/64 140/58 140/74 136/84 152/71 153/72 138/77 140/78 125/69 125/74 139/87 150/71 152/75 140/86 138/82 147/78 148/86

APPENDIX 2.2 (cont'd)

a) Mineral foliation

Location (at or near station:)	Conventional Orientation Quality of Foliation		
	Poor	Moderate	Good
<u>Domain 1</u> (cont'd)			
			166/68
			132/79
			142/84
569		163/79	155/62
570		128/72	143/74
		187/70	139/73
			148/83
			151/85
			178/75
			190/68
			152/84
			155/82
			159/70
			145/90
580			318/78
			317/85
			145/77
			127/85
			347/84
			342/82
582		140/75	136/85
			318/84
			328/83
			134/88
			350/87
			168/72
			138/78
			132/88
			4/73
			141/87
			140/90
			152/86
583			148/74
			135/80
			146/83
			107/80
			124/81

APPENDIX 2.2 (cont'd)

a) Mineral foliation

Location (at or near station:)	Conventional Orientation Quality of Foliation		
	Poor	Moderate	Good
<u>Domain 1</u> (cont'd)			
584			125/84
585		336/81	164/78 140/78 157/75 146/73 87/70 95/77 110/65 123/45
586		303/58 305/60 280/65 275/72 148/63	108/87 108/87 133/76 323/85 313/72 332/82 132/65
588	128/35	183/63 203/55	114/85 120/42 116/75
<u>Domain 2</u>			
191	68/72 220/53	25/35	
193	223/63		
196A		245/23 200/5 160/13	47/37 43/52 23/35 48/28 26/45 120/21 141/53 128/67
197		146/30 145/33 118/47	180/23 158/60 148/50

APPENDIX 2.2 (cont'd)

a) Mineral foliation

Location (at or near station:)	Conventional Orientation Quality of Foliation		
	Poor	Moderate	Good
<u>Domain 2</u> (cont'd)			
197			155/62
198			123/74 120/60 154/54 133/88 313/64 336/78
199			324/78 131/88 133/88
200			141/84 131/88 133/86
201			138/55 148/80 131/84 120/70 110/80
202		107/82	120/68 118/80 139/84
204			116/45
205		109/80 148/56	133/35 120/30 105/52 122/30 123/60
206	160/68 162/30 125/68 133/48		157/66 118/68 119/76 90/53 125/74 123/77

APPENDIX 2.2 (cont'd)

a) Mineral foliation (cont'd)

Location (at or near station:)	Conventional Orientation Quality of Foliation		
	Poor	Moderate	Good
<u>Domain 2</u> (cont'd)			
208	80/65 110/55 108/65		90/44
209	93/50		80/61 78/70 110/43 86/41
210	73/43	92/27	
211			98/64
212	99/84 272/80		
220		91/65	89/69
224		104/60	
230			105/85 115/85 315/85 320/85 312/75 330/76 315/79
235			125/80
240			140/83
241		138/82	151/76
617		324/79 112/87 307/87	137/84 317/87 316/76
618			307/87
J-30			128/76 127/74 125/55 129/55

APPENDIX 2.2 (cont'd)

a) Mineral foliation (cont'd)

Location (at or near station:)	Conventional Orientation Quality of Foliation		
	Poor	Moderate	Good
<u>Domain 2</u> (cont'd)			
J-30			120/70
J-31			135/80
J-32			115/55 110/60 111/59 125/62
J-35			142/66
J-40			320/62 318/45 320/52 325/52
<u>Domain 3</u>			
75		35/63	20/66
499	260/73	83/82 240/70	62/90
502			233/80
503		68/70	

APPENDIX 2.2 (cont'd)

b) Mineral lineation

Location (at or near station:)	Conventional Orientation Quality of Lineation		
	Poor	Moderate	Good
<u>Domain 1</u>			
287		80/15 315/35	248/58 255/33 210/63 320/45 4/78 315/35
326			277/35 284/36
414			130/52 138/64
417		355/45	
531	73/20		
546			195/21 148/10
548		72/58	
566			330/18
584			282/53
<u>Domain 2</u>			
192		173/0	
<u>Domain 3</u>			
499		23/80	

APPENDIX 2:3 - INTRUSIVE RELATIONS INVOLVING THE CAKE HILL PLUTON

a) Intrapluton intrusive relations

Location (at or near station:)	Comments
--------------------------------------	----------

INTRUSIVE RELATIONS INVOLVING THE MAFIC PHASE WITH THE FELSIC PHASE

548

hornblende monzodiorite of felsic phase forms a stockwork and alters dense hornblende gabbro and hornblendite of the mafic phase

thin (1-2 cm), fine-grained reaction (chilled?) rims are visible on included mafic phase fragments
(SEE PLATE I B)

b) External intrusive relations

Location (at or near station:)	Granitic Abundance (%)	Fragments Dimensions	Comments
--------------------------------------	------------------------------	-------------------------	----------

INTRUSIVE RELATIONS INVOLVING THE FELSIC PHASE AND THE TRIASSIC VOLCANICS

Domain 1.

276 or 460	≤5 at base decreasing up section	30 cm at base; 2-3 cm up section	granitic cobble-bearing green andesite flow; rounded granitoid fragments (SEE PLATE I D)
285, 286	<15; decreasing up section	range from 2-45 cm long; average size is 10-15 cm	granitic cobble-bearing green basaltic to andesitic flow which is underlain by brown weathering basaltic ? material; these volcanics demonstrably nonconformably overlie the Cake Hill Pluton (SEE PLATE I C)
293	≤40	2 cm-1.5 m long	basalt flow with rounded to subrounded granitic fragments; underlain by rusty weathering basalt locally well exposed contact is jagged and irregular

APPENDIX 2.3 (cont'd)

b) External intrusive relations (cont'd)

Location (at or near station:)	Granitic Abundance (%)	Fragments Dimensions	Comments
--------------------------------------	------------------------------	-------------------------	----------

INTRUSIVE RELATIONS INVOLVING THE FELSIC PHASE AND THE TRIASSIC VOLCANICS (cont'd)

Domain 1 (cont'd)

294			greenish basalt flow with rounded granitic fragments
690	≤5	1 cm-2 m long	angular, pebble- to boulder-size granitic fragments in matrix-supported volcanic conglomerate
692			highly altered siliceous granitic rock broken up by stockwork of black andesitic lava
699			<p>from this location towards the northwest:</p> <ol style="list-style-type: none"> 1) the original hornblende quartz monzodiorite becomes increasingly brecciated and altered by intrusive andesitic volcanic material 2) breccia fragments are increasingly rotated and dilated until breccia is matrix supported 3) breccia becomes increasingly polymictic and fragments more rounded <p>near this zone anastomosing andesite dikes remain common and form stockworks in the granitic rock (SEE PLATE II G)</p>

APPENDIX 2.3 (cont'd)

b) External intrusive relations (cont'd)

Location (at or near station:)	Granitic Abundance (%)	Fragments Dimensions	Comments
--------------------------------------	------------------------------	-------------------------	----------

INTRUSIVE RELATIONS INVOLVING THE FELSIC PHASE AND THE TRIASSIC VOLCANICS (cont'd)

Domain 1 (cont'd)

702	10-25	2 cm long to frag- ments 100 cm x 40 cm x 30 cm average size is 10 cm long	monolithic granitic fragment- bearing volcanic conglomerate developed near contact with Cake Hill Pluton clasts rounded to subrounded contact obscured by augite porphyry intrusion
-----	-------	---	---

(see also sections 705, 707 and 714)

Domain 3

500, 500A	≤15	≤25 cm long and 15 cm wide	granitic pebble (xenolith?) bearing volcanic breccia at base of partly tuffaceous, siliceous volcanic pile pebbles are rounded, and rarely foliated
--------------	-----	-------------------------------------	--

INTRUSIVE RELATIONS INVOLVING THE FELSIC PHASE AND TOARCIAN SEDIMENTS

325, 449, or section 714			basal, moderately to very clean quartz arenite of Toarcian sequence is conven- tionally oriented 270/63 and nonconformably overlies the Cake Hill Pluton
section 705			basal shale, siltstone and quartz arenite nonconformably overlie the Cake Hill Pluton with a conventional orientation of 290/55 but the actual contact is not exposed

APPENDIX 2.3 (cont'd)

b) External intrusive relations (cont'd)

Location (at or near station:)	Granitic Abundance (%)	Fragments Dimensions	Comments
--------------------------------------	------------------------------	-------------------------	----------

INTRUSIVE RELATIONS INVOLVING THE FELSIC PHASE AND THE TOARCIAN SEDIMENTS (cont'd)

Domain 1 (cont'd)

section 707			basal shale and minor quartz arenite and micrite noncon- formably overlie the Cake Hill Pluton with an orienta- tion of 288/65 but the actual contact is not exposed
----------------	--	--	---

INTRUSIVE RELATIONS INVOLVING THE FELSIC PHASE AND TERTIARY VOLCANICS

195			approximately 50 m thick section of basalt and andesite flows nonconformably overlie the Cake Hill Pluton in a U- shaped, north-plunging paleovalley
-----	--	--	---

			rounded Cake Hill Pluton cobbles and boulders overlie the volcanics above their contact with the Cake Hill Pluton
--	--	--	---

c) Interpluton intrusive relations

Location (at or near station:)	Inclusions Abundance (%)	Dimensions	Comments
--------------------------------------	--------------------------------	------------	----------

INTRUSIVE RELATIONS INVOLVING THE FELSIC PHASE AND THE STIKINE PLUTON

617			1 m wide slightly irregular sphene- and hornblende- bearing aplitic, siliceous leucocratic monzonite (C.H.P.?) intrudes well foliated amphi- bolite (of Stikine Pluton?)
-----	--	--	---

APPENDIX 2.3 (cont'd)

c) Interpluton intrusive relations (cont'd)

INTRUSIVE RELATIONS INVOLVING FELSIC PHASE AND GNAT LAKES ULTRAMAFITE

Location
(at or near
station:)

Comments

30, 401
or 427

dun weathering hornblende pyroxenite engulfs
rounded Cake Hill Pluton fragments

INTRUSIVE RELATIONS INVOLVING THE FELSIC PHASE AND THE BEGGERLAY CREEK PLUTON

Domain 2

230, 231,
462 and
463

over approximately 1-2 km interval, Cake Hill
Pluton felsic phase becomes more mafic
(dioritic), more intensely foliated (foliation
parallels east-trending contact) and displays
evidence of cataclasis (feldspar augen) towards
contact with more massive gabbro and pyroxenite
of Beggerlay Creek Pluton
(SEE PLATE III G, H)

blocks of foliated augen gneiss are included
and rotated in massive and fluidal foliated
hornblende diorite, and pyroxenite apophyses
of the Beggerlay Creek Pluton

499 (Domain 3)

pyroxene-hornblende gabbro dike intrudes quartz
monzodiorite of the felsic phase

J-41

20 cm wide gabbro dike (Beggerlay Creek Pluton)
with sharp, regular contacts (attitude 30/90)
intrudes quartz monzodiorite (Cake Hill Pluton,
felsic phase)

also, the granodiorite (Cake Hill Pluton)
increases in mafic content and becomes more
intensely foliated near this station

J-43, 44
45, and
47

intensely foliated gabbro (altered Cake Hill
Pluton, felsic phase?) developed near contact
between Cake Hill Pluton and Beggerlay Creek
Pluton with conventional foliation attitudes
289/80, 90/20 and 80/80 assumed parallel to
contact

quartz monzonite (Cake Hill Pluton, felsic phase)
is well foliated with conventional foliation
attitude 93/60 assumed parallel to contact

APPENDIX 2.3 (cont'd)

c) Interpluton intrusive relations (cont'd)

Location
(at or near
station:)

Comments

INTRUSIVE RELATIONS INVOLVING THE FELSIC PHASE AND THE THREE SISTERS PLUTON
(FINE-GRAINED PHASE)

Domain 1

125	1 m fine-grained hornblende diorite dike, oriented 92/76, intrudes the felsic phase
505	fine-grained diorite dikes (Three Sisters Pluton, fine-grained phase) intrude quartz monzodiorite of the Cake Hill Pluton
516	fine-grained diorite dikes (Three Sisters Pluton, fine-grained phase) intrude quartz monzonite of Cake Hill Pluton
550 and 551	fine- to medium-grained hornblende diorite (Three Sisters Pluton, fine-grained phase?) dikes oriented 58/52 and 82/83 intrude quartz syenite of the metamorphosed and remobilized Cake Hill Pluton
551	fine-grained diorite intrudes and includes quartz monzodiorite of the Cake Hill Pluton
554	rare dikes of fine-grained diorite occur as isolated outcrops in and locally clearly intrude coarse-grained hornblende-biotite syenite of the metamorphosed and remobilized Cake Hill Pluton
556	small exposure of fine-grained to medium-grained hornblende diorite within gneissic Cake Hill Pluton is probably an intrusive apophysis

INTRUSIVE RELATIONS INVOLVING THE FELSIC PHASE AND THE THREE SISTERS PLUTON
(MAFIC PHASE)

Domains 1 and 3

75

foliated, coarse- to medium-grained monzonite (Cake Hill Pluton, felsic phase) is intruded by common, irregular dikes of medium-grained, massive acicular hornblende diorite (Three

APPENDIX 2.3 (cont'd)

c) Interpluton intrusive relations (cont'd)

Location
(at or near
station:)

Comments

INTRUSIVE RELATIONS INVOLVING THE FELSIC PHASE AND THE THREE SISTER PLUTON
(MAFIC PHASE) (cont'd)

Domains 1 and 3 (cont'd)

75 (cont'd)	Sisters Pluton, mafic phase)
76, 77	monzodiorite (Three Sisters Pluton, central phase) and acicular hornblende diorite to monzodiorite (Three Sisters Pluton, mafic phase) are finer-grained near their presumed intrusive contact with monzonite to syenite (Cake Hill Pluton, felsic phase)
95	coarse-grained hornblende-biotite monzonite to quartz monzonite screen (remobilized and metamorphosed Cake Hill Pluton) occurs within hornblende diorite and monzodiorite (respectively Three Sisters Pluton, mafic and central phases)
112	screen of lineated hornblende monzodiorite (Cake Hill Pluton, felsic phase) is included between intrusions of hornblende gabbro (Three Sisters Pluton, mafic phase) and hornblende-biotite monzodiorite (Three Sisters Pluton, central phase)
118	8-10 m zone of hornblende gabbro (Three Sisters Pluton, mafic phase?) apparently grades into a dioritic plagioclase porphyry near intrusive contact with Cake Hill Pluton
178 and
474	highly irregular, chilled acicular hornblende apophyses (Three Sisters Pluton, mafic phase) intrude biotite-hornblende monzonite (metamorphosed Cake Hill Pluton)
	width of selvage (i.e. change from fine-grained to medium-grained acicular hornblende) varies from 5-30 cm

APPENDIX 2.3 (cont'd)

c) Interpluton intrusive relations (cont'd)

Location
(at or near
station:)

Comments

INTRUSIVE RELATIONS INVOLVING THE FELSIC PHASE AND THE THREE SISTER PLUTON
(MAFIC PHASE) (cont'd)

Domains 1 and 3 (cont'd)

550 and
551	fine- to medium-grained hornblende diorite dikes (Three Sisters Pluton, mafic phase?) oriented 58/52 and 82/83 intrude quartz syenite of the metamorphosed and remobilized Cake Hill Pluton
551	fine- to medium-grained acicular hornblende diorite apophysis (Three Sisters Pluton, mafic phase) is chilled to fine-grained diorite within 0.5-1 cm of its intrusive contact with quartz monzodiorite of the Cake Hill Pluton
554	irregular apophyses of fine-grained to medium-grained, inclusion-bearing, euhedral hornblende and acicular hornblende diorite (Three Sisters Pluton, mafic phase) intrude coarse-grained hornblende-biotite syenite of the metamorphosed and remobilized Cake Hill Pluton
555	acicular hornblende diorite intrudes hornblende-biotite quartz monzodiorite of the Cake Hill Pluton

INTRUSIVE RELATIONS INVOLVING THE FELSIC PHASE AND THE THREE SISTERS PLUTON
(CENTRAL PHASE)

Domain 1

111	15 m wide apophysis of acicular to subhedral hornblende monzonite (Three Sisters Pluton, central phase) is chilled along its intrusive contacts with hornblende quartz monzodiorite (Cake Hill Pluton, felsic phase) and carries inclusions of the Cake Hill Pluton along with fine-grained diorite inclusions
152	contact between Cake Hill Pluton and Three Sisters Pluton, central phase is well bracketed but poorly exposed due to talus cover

APPENDIX 2.3 (cont'd)

c) Interpluton intrusive relations (cont'd)

Location
(at or near
station:)

Comments

INTRUSIVE RELATIONS INVOLVING THE FELSIC PHASE AND THE THREE SISTERS PLUTON
(CENTRAL PHASE) (cont'd)

Domain 1 (cont'd)

177

although contact between monzodiorite (Three Sisters Pluton, central phase) and biotite-hornblende monzonite (metamorphosed Cake Hill Pluton) is faulted, the abundance of irridescient plagioclase phenocrysts in the monzodiorite increases towards the contact

178

contact between Cake Hill Pluton and Three Sisters Pluton is obscured by cover

183

contact between monzodiorite (Three Sisters Pluton, central phase) and monzonite (metamorphosed Cake Hill Pluton) is not well exposed

470,
473

monzodiorite (Three Sisters Pluton, central phase) intrudes and is chilled against monzodiorite screens of the Cake Hill Pluton (SEE PLATE II A,B)

505

irregular dikes and apophyses of inclusion-bearing monzodiorite (Three Sisters Pluton, central phase) intrude Cake Hill Pluton quartz monzodiorite

522

euhedral hornblende monzodiorite dikes (Three Sisters Pluton, central phase) intrude quartz monzodiorite of the Cake Hill Pluton

525

inclusion-bearing hornblende-biotite monzodiorite apophyses (Three Sisters Pluton, central phase) in two localities are irregular and unchilled at their intrusive contact with quartz monzodiorite of the Cake Hill Pluton

534

irregular, 4 m wide, inclusion-bearing monzodiorite (Three Sisters Pluton, central phase) intrudes and includes foliated quartz monzodiorite of the Cake Hill Pluton

APPENDIX 2.3 (cont'd).

c) Interpluton intrusive relations (cont'd)

Location
(at or near
station:)

Comments

INTRUSIVE RELATIONS INVOLVING THE FELSIC PHASE AND THE THREE SISTERS PLUTON
(CENTRAL PHASE) (cont'd)

Domain 1 (cont'd)

551

1 m wide subhorizontal monzodiorite (Three Sisters Pluton, central phase) apophyses intrude but are not chilled against the quartz monzodiorite of the Cake Hill Pluton

rounded to angular, 5-15 cm long Cake Hill Pluton inclusions in inclusion-bearing monzodiorite of the Three Sisters Pluton, central phase

587

irregular, fine- to medium-grained mafic biotite-hornblende monzodiorite (Three Sisters Pluton, central phase) intrudes monzodiorite of the Cake Hill Pluton

FELSIC PHASE AND THREE SISTERS PLUTON (POTASSIC MARGINAL PHASE)

Domain 1

5

gradational to intrusive contact between foliated, inclusion-bearing monzonite (remobilized Cake Hill Pluton) and hornblende syenite (Three Sisters Pluton, potassic marginal phase)

hornfelsed augite porphyry dike intrudes the foliated monzonite

505

8-10 m wide hornblende-biotite granitic apophysis (Three Sisters Pluton, potassic marginal phase) intrudes syenite of the metamorphosed and remobilized Cake Hill Pluton along a sharp contact (neither body is chilled along the contact)

3 cm wide apophyses also intrude and bleach the Cake Hill Pluton within 1-3 cm of its contact

519

contact between Cake Hill Pluton and Three Sisters Pluton, potassic marginal phase is well-

APPENDIX 2.3 (cont'd)

c) Interpluton Intrusive relations (cont'd)

Location
(at or near
station:)

Comments

FELSIC PHASE AND THREE SISTERS PLUTON (POTASSIC MARGINAL PHASE) (cont'd)

Domain 1 (cont'd)

- 519 (cont'd) bracketed but poorly exposed in felsenmeer and intrusive relations are not known
- 522 biotite-hornblende quartz monzonite of the Cake Hill Pluton is intruded and included by common, massive biotite-hornblende syenite dikes (Three Sisters Pluton, potassic marginal phase)
- 523 some distance from station 523, pink syenite dike (Three Sisters Pluton, potassic marginal phase?) is chilled against its intrusive contact with hornblende-biotite quartz monzodiorite of the Cake Hill Pluton
- 550 aplite dikes (Three Sisters Pluton, potassic marginal phase?) intrude the quartz syenite of the metamorphosed and remobilized Cake Hill Pluton
- 551 1 m fine-grained monzonite dike (Three Sisters Pluton, potassic marginal phase?) intrudes the quartz monzodiorite of the Cake Hill Pluton
- 554 biotite-hornblende syenite apophyses (Three Sisters Pluton, potassic marginal phase) apparently intrude coarse-grained hornblende-biotite syenite of the metamorphosed and remobilized Cake Hill Pluton
- 555 fine- to medium-grained monzonite apophysis (Three Sisters Pluton, potassic marginal phase) intrudes quartz monzodiorite of the Cake Hill Pluton

Domain 2

236

12 m wide anastomosing syenitic hornblende-plagioclase porphyry dike (Three Sisters Pluton, potassic marginal phase?) intrudes quartz monzodiorite of the Cake Hill Pluton

APPENDIX 2.3 (cont'd)

c) Interpluton intrusive relations (cont'd)

Location
(at or near
station:)

Comments

FELSIC PHASE AND THREE SISTERS PLUTON (POTASSIC MARGINAL PHASE) (cont'd)

Domain 3

504

2 m irregular hornblende-bluish plagioclase megacryst syenitic dike intrudes quartz monzodiorite of the Cake Hill Pluton

INTRUSIVE RELATIONS INVOLVING THE FELSIC PHASE AND THE THREE SISTERS PLUTON (LEUCOCRATIC PHASE)

255

apophysis of leucocratic hornblende quartz diorite (Three Sisters Pluton, leucocratic phase) intrudes quartz monzodiorite (Cake Hill Pluton) but the contacts are poorly exposed

612

1.5-2 m wide, slightly irregular leucocratic hornblende diorite dike intrudes crumbly biotite-rich syenite of metamorphosed and remobilized Cake Hill Pluton

METAMORPHISM AND REMOBILIZATION OF THE CAKE HILL PLUTON DUE TO THE INTRUSION OF THE THREE SISTERS PLUTON

75

elongate inclusions in hornblende monzonite (Cake Hill Pluton, felsic phase) parallels conventional attitude of mineral foliation at 35/63 and 20/66

83

contact between biotite-hornblende monzonite (metamorphosed Cake Hill Pluton) and monzodiorite (Three Sisters Pluton, central phase) is bracketed but intrusive relations are not known

167,
168

leucocratic, coarse-grained hornblende quartz syenite to syenite (metamorphosed and remobilized Cake Hill Pluton) is intruded by recognizable apophyses of syenite (Three Sisters Pluton, potassic marginal phase) and monzodiorite (Three Sisters Pluton, central phase)

the monzodiorite apophysis contains rare hornblende inclusions lithologically similar to the Gnat Lakes Ultramafite

APPENDIX 2.3 (cont'd)

c) Interpluton intrusive relations (cont'd)

Location
(at or near
station:)

Comments

METAMORPHISM AND REMOBILIZATION OF THE CAKE HILL PLUTON DUE TO THE INTRUSION
OF THE THREE SISTERS PLUTON (cont'd)

169	pink, highly fractured aplite separates syenite (Three Sisters Pluton, potassic marginal phase) from coarser-grained quartz syenite (metamorphosed Cake Hill Pluton)
171	equant hornblende porphyry gabbro (Three Sisters Pluton, mafic phase) and aplite (Three Sisters Pluton, potassic marginal phase) apophyses intrude original augite porphyry apophyses in the Cake Hill Pluton

as well, thin apophyses of Cake Hill Pluton back-vein and are chilled against augite porphyry screen (former dike?) in the metamorphosed Cake Hill Pluton |
259	although contact is covered, it is well-bracketed between medium-grained syenite and monzodiorite (Three Sisters Pluton, potassic marginal phase and central phase, respectively) and coarse-grained syenite (metamorphosed Cake Hill Pluton)
408	thin, plagioclase-biotite porphyry intrudes coarse-grained syenite with bluish grey plagioclase (metamorphosed Cake Hill Pluton)
409	in coarse-grained syenite (metamorphosed Cake Hill Pluton), plagioclase megacrysts occur and hornblende is partly to completely pseudomorphed by biotite
410	coarse-grained syenite (metamorphosed Cake Hill Pluton) has hornblende pseudomorphed by fine-grained biotite
421	coarse-grained quartz syenite (metamorphosed Cake Hill Pluton) with plagioclase megacrysts and bimodal grain size in euhedral hornblende
422	local exposures (screens?) of coarse-grained monzonite to syenite (metamorphosed Cake Hill

APPENDIX 2.3 (cont'd)

c) Interpluton intrusive relations (cont'd)

Location
(at or near
station:)

Comments

METAMORPHISM AND REMOBILIZATION OF THE CAKE HILL PLUTON DUE TO THE INTRUSION
OF THE THREE SISTERS PLUTON (cont'd)

422 (cont'd)

Pluton) alternate with exposures of Three Sisters Pluton potassic marginal phase

5 or
429

gradation observed between coarse-grained hornblende syenite which is faintly foliated (metamorphosed Cake Hill Pluton?) and massive hornblende-biotite syenite of the Three Sisters Pluton, potassic marginal phase

473

screen of Cake Hill Pluton quartz monzonite intruded by finer-grained monzodiorite (Three Sisters Pluton, central phase) which is locally chilled against the Cake Hill Pluton screen

178 and
474

coarse-grained quartz syenite (metamorphosed and remobilized Cake Hill Pluton) has common biotite and plagioclase megacrysts and is intruded by acicular hornblende diorite apophyses and dikes (Three Sisters Pluton, mafic phase) which are chilled along their margins.

475

sharp contact between coarser-grained biotite hornblende syenite (metamorphosed and remobilized Cake Hill Pluton) and finer-grained, inclusion-bearing monzodiorite (Three Sisters Pluton, central phase).

neither body is chilled and rarely the fine-grained diorite inclusions of the monzodiorite are shared across the contact

contact is generally moderately shallow but in detail is highly irregular

locally, fine-grained grey, rarely porphyritic diorite (Three Sisters Pluton, fine-grained phase?) and acicular hornblende diorite dikes (Three Sisters Pluton, mafic phase) intrude the syenite of the Cake Hill Pluton

APPENDIX 2.3 (cont'd)

c) Interpluton intrusive relations (cont'd)

Location
(at or near
station:)

Comments

METAMORPHISM AND REMOBILIZATION OF THE CAKE HILL PLUTON DUE TO THE INTRUSION
OF THE THREE SISTERS PLUTON (cont'd)

- 476 no chilling effects between the mottled pink and white weathering, coarse-grained, homogeneous, leucocratic hornblende-biotite syenite (metamorphosed and remobilized Cake Hill Pluton) and white weathering, fine- to medium-grained, inclusion-bearing, more mafic hornblende-biotite monzodiorite (Three Sisters Pluton, central phase)
- 477 highly irregular (amoeboid) contact between syenite (Cake Hill Pluton) and monzodiorite (Three Sisters Pluton, central phase) is equivocal with respect to intrusive relations (SEE PLATE II C)
- fine-grained monzodiorite (Three Sisters Pluton, fine-grained phase?) occurs approximately 1 m below the Cake Hill-Three Sisters Plutons' contact
- 481 wide apophysis of fine- to medium-grained monzodiorite (Three Sisters Pluton, fine-grained phase) intrudes metamorphosed Cake Hill Pluton
- 484 fine-grained monzodiorite (Three Sisters Pluton, fine-grained phase) intrudes mottled weathering syenite (remobilized and metamorphosed Cake Hill Pluton)
- 505 large screens or blocks of hornblende-biotite quartz monzonite to granite (metamorphosed and remobilized Cake Hill Pluton) occur rarely within inclusion-bearing monzodiorite (Three Sisters Pluton, central phase)
- the metamorphosed and remobilized Cake Hill Pluton screens have common (locally 30-40%), large (1-2 m long), "granitized" augite? porphyry inclusions uncommonly back-veined by the Cake Hill Pluton

APPENDIX 2.3 (cont'd)

c) Interpluton intrusive relations (cont'd)

Location
(at or near
station:)

Comments

METAMORPHISM AND REMOBILIZATION OF THE CAKE HILL PLUTON (cont'd)

505 (cont'd)

the metamorphosed and remobilized Cake Hill Pluton screens are intruded at one locality by 0.5-1 m wide, fine- to medium-grained hornblende diorite (Three Sisters Pluton, fine-grained phase) dike

Cake Hill Pluton is locally syenitic and has biotite pseudomorphs after hornblende

511

biotite occurs as a significant though minor mafic in quartz monzodiorite of the remobilized Cake Hill Pluton; inclusions compose up to 5 per cent of Cake Hill Pluton outcrops

522

locally, the biotite-hornblende monzonite screens appear to grade into syenite of the Three Sisters Pluton, potassic marginal phase

biotite developed as a minor mafic constituent in quartz monzodiorite of the Cake Hill Pluton close to Three Sisters Pluton apophyses

523

sphene-bearing, hornblende-biotite monzodiorite (remobilized and metamorphosed Cake Hill Pluton) intrudes acicular hornblende diorite (Three Sisters Pluton, mafic phase) and includes fine-grained diorite and fine-grained acicular hornblende diorite (Three Sisters Pluton, fine-grained and mafic phases respectively) as rounded to elongate (up to 30 cm long; composing 5-30 per cent of the outcrop) inclusions, in agmatites or as 0.25-1 m screens

elongate inclusions are commonly aligned in a plane within massive Cake Hill Pluton lithologies

some distance from station 523 quartz monzodiorite of the Cake Hill Pluton has common euhedra and tabular (hornblende pseudomorphs) grains of biotite and is intruded by pink syenite. At this locality the Cake Hill Pluton

APPENDIX 2.3 (cont'd)

c) Interpluton intrusive relations (cont'd)

Location
(at or near
station:)

Comments

METAMORPHISM AND REMOBILIZATION OF THE CAKE HILL PLUTON (cont'd)

523 (cont'd)

contains up to 1 per cent inclusions

525

biotite-hornblende quartz monzodiorite (biotite fresh, pseudomorphs hornblende) (metamorphosed and remobilized Cake Hill Pluton) has uncommon sphene and magnetite accessories and 2 per cent small (2-3 cm), fine-grained hornblende diorite inclusions (Three Sisters Pluton, fine-grained phase?)

the Cake Hill Pluton is intruded by medium-grained, inclusion-bearing irregular monzodiorite apophyses (Three Sisters Pluton, central phase) which are not chilled against the Cake Hill Pluton

in talus block exposure, metamorphosed hornblende (augite pseudomorph) porphyry intrudes the Cake Hill Pluton

535

moderately foliated quartz monzodiorite (remobilized Cake Hill Pluton) contains inclusions of fluidal layered gneiss and hornblende gabbro (Three Sisters Pluton, mafic phase) up to 3 m above the contact between the Cake Hill Pluton and the Three Sisters Pluton's mafic phase and intrudes and includes two pieces of inclusion-rich, fine-grained diorite or monzodiorite apophysis or screen (Three Sisters Pluton, phase uncertain)

(SEE PLATES I G, H and I)

except for the intruded screens, inclusions of the Three Sisters Pluton in the remobilized Cake Hill Pluton range in size from 8-35 cm, in shape from rounded to angular and make up 15-20 per cent of the outcrop

540

sphene- and magnetite-bearing Cake Hill Pluton monzodiorite forms stockwork in Three Sisters Pluton mafic phase hornblende gabbro

APPENDIX 2.3 (cont'd)

c) Interpluton intrusive relations (cont'd)

Location
(at or near
station:)

Comments

METAMORPHISM AND REMOBILIZATION OF THE CAKE HILL PLUTON (cont'd)

550

apophyses of massive, medium- to coarse-grained syenite with uncommon sphene (metamorphosed and remobilized Cake Hill Pluton) intrude augite porphyry, and are themselves intruded by aplite dikes (Three Sisters Pluton, potassic marginal phase?)

551

locally, remobilized Cake Hill Pluton forms stockworks and intrudes the fine-grained diorite of the Three Sisters Pluton, fine-grained phase

552

coarse-grained hornblende-biotite syenite (metamorphosed Cake Hill Pluton) has coarse glomeroporphyritic mafics

580

isolated exposure of pink, coarse-grained hornblende-biotite granite (metamorphosed Cake Hill Pluton?)

606

coarse-grained hornblende-biotite monzodiorite (metamorphosed Cake Hill Pluton), in poor quality outcrop, is intruded by an apophysis of inclusion-bearing to agmatitic, fine- to medium-grained monzodiorite (Three Sisters Pluton, central phase)

polygonized biotite grains pseudomorph hornblende

612

crumbly, coarse-grained hornblende-biotite syenite (metamorphosed Cake Hill Pluton) is intruded by 3 cm wide, irregular, inclusion-bearing biotite-hornblende monzonite (Three Sisters Pluton, central phase)

biotite in the metamorphosed Cake Hill Pluton occurs as polygonized coarse grains pseudomorphing hornblende

also near station 612, coarse, crumbly, biotite-rich syenite (metamorphosed Cake Hill Pluton) is intruded by a 1.5-2.0 m wide slightly

APPENDIX 2.3 (cont'd)

c) Interpluton intrusive relations (cont'd)

Location
(at or near
station:)

Comments

METAMORPHISM AND REMOBILIZATION OF THE CAKE HILL PLUTON (cont'd)

612 (cont'd)

irregular, white weathering, leucocratic horn-
blende diorite dike (Three Sisters Pluton,
leucocratic phase)

614

fine- to medium-grained, irregular hornblende
syenite dike (Three Sisters Pluton, potassic
marginal phase) intrudes coarse-grained biotite
syenite (metamorphosed Cake Hill Pluton)

APPENDIX 2.4 - HYPABYSSAL INTRUSIONS IN THE CAKE HILL PLUTON

a) Augite-plagioclase porphyry dikes

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Domain 1</u>				
5	augite porphyry	anastamosing	0.03- 0.10	has chilled margins along intrusive con- tact with met- amorphosed, foliated mon- zonite (Cake Hill Pluton) and is also hornfelsed
118	bladed plagioclase porphyry	poorly exposed		
119	augite- plagioclase porphyry	30/65 (average attitude of irregular dike)	10-15	bladed, trachy- toid plagio- clase porphyry developed at dike margins; augite porphyry in core of dike
121	augite- plagioclase porphyry	poorly exposed con- tacts but probably irregular		bladed, trachy- toid plagio- clase porphyry developed at dike margins; augite porphyry in core of dike
125	augite- plagioclase porphyry	exposed in felsenmeer		
126	augite- plagioclase porphyry	70/85	5	bladed, trachy- toid plagio- clase porphyry developed within 1 m of contact
	bladed plagioclase porphyry	35/73	18-20	

APPENDIX 2.4 (cont'd)

a) Augite-plagioclase porphyry dikes

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Domain 1</u> (cont'd)				
130	bladed plagioclase porphyry	113/77	15	
287	augite porphyry	irregular	≤2	
288	augite?- plagioclase porphyry	irregular		
290	augite- plagioclase porphyry	245/73 350/70		
340	augite- plagioclase porphyry	irregular	24	bladed, trachy- toid plagio- clase porphyry developed within 0.2-1 m of con- tact; massive augite porphyry core
411	augite porphyry	contacts poorly exposed		
412	augite porphyry	contacts poorly exposed	several metres	
513	bladed plagioclase porphyry	106/78	2.5	plagioclase is trachytoid
514	metamorphosed? augite porphyry	150/43		apparently intruded by 3 m wide pink syenitic horn- blende porphyry

APPENDIX 2.4 (cont'd)

a) Augite-plagioclase porphyry dikes (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Domain 1</u> (cont'd)				
518	augite- plagioclase porphyry	185/53	6	irregular
532	augite?- plagioclase porphyry	134/68	0.05	
554	augite?- plagioclase- hornblende porphyry	325/70 Q	not recorded	
556	cataclasized augite porphyry	trends 110°	1.5	not well expo- sed; deformed with the Cake Hill Pluton it intrudes, as a result of the intrusion of the Three Sis- ters Pluton apophysis
558	augite porphyry	260/85	1.75	
	bladed plagioclase porphyry	74/65	2	trachytoid plagioclase
698	hornblende- augite porphyry	117/72	3	dike has 8-25 cm chill zone, horn- blende grains are flow-foliated parallel to the contact and Cake Hill Pluton and hornblendite and hornblende gabbro (Gnat Lakes Ultra- mafitite?) xenoliths are contained in

APPENDIX 2.4 (cont'd)

a) Augite-plagioclase porphyry dikes (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Domain 1</u> (cont'd)				
698 (cont'd)				the dike (SEE PLATE II E,F)
702	augite porphyry	150/75 (attitude of one contact of plug)		plug-like body intruded along nonconformity between Cake Hill Pluton and Triassic volcanics
<u>Domain 2</u>				
191	plagioclase- augite porphyry		1-2	anastomosing (SEE PLATE II D)
192	augite porphyry	irregular contact	1.5	anastomosing (2 dikes exposed)
193	augite- plagioclase porphyry	257/58	2.3	
205	augite- plagioclase porphyry	175/85		slightly anastomosing
228	augite? porphyry	20/90 210/64	0.3 1	slightly anastomosing; 2 dikes exposed
J-36	augite- plagioclase porphyry	200/84	1	dike appears hornfelsed (locality near contact with Beggerlay Creek Pluton)

APPENDIX 2.4. (cont'd)

a) Augite-plagioclase porphyry dikes (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Domain 3</u>				
170	bladed plagioclase porphyry	168/90	1	
171 or 483	augite porphyry		100	irregular intrusion whose margins have been modified by the later Three Sisters Pluton apophyses (especially the northern end of this easterly-trending body which has a diffuse, "granitized" contact with granitic rock which is increasingly mafic towards the augite porphyry intrusion
499	augite- plagioclase porphyry	180/83		
503	augite porphyry	253/38	1	

b) Andesite, basalt, dioritic and diabasic dikes

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Domain 1</u>				
29	andesite	poorly exposed	0.3	grey, aphanitic

APPENDIX 2.4 (cont'd)

b) Andesite, basalt, dioritic and diabasic dikes (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Domain 1</u> (cont'd)				
119	andesite or basalt	272/75		
120	basalt	195/57 one exposed in felsens- meer	10	two dikes exposed
125	andesite	190/65 estimated from poor exposure		
	green-grey andesite	195/86	2	
126	andesite	190/70	≥ 0.5	fine-grained
	green-grey andesite	205/80	4-5	epidotized
129	greenish andesite	103/85	≥ 0.5	
	andesite	115/83	2	
130	andesite	90/62 100/64	1.5 0.3	two dikes exposed
131	andesite	90/43	2	
132	green-grey andesite	100/82	6	epidotized
275	andesite	167/84		
286	basalt	143/68 195/56	0.6 1	two dikes exposed
289	grey-green andesite	196/63	1.5	
290	andesite to basalt	183/60 187/55	2.5 0.4	

APPENDIX 2.4¹ (cont'd)

b) Andesite, basalt, dioritic and diabasic dikes (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Domain 1</u> (cont'd)				
2291	andesite	260/68	1	rare
3358	andesite	60/77	0.2	
3359	basalt	irregular		rare dike
360	basalt	irregular		uncommon dikes
514	grey-green andesite	170/55	2	
516	basalt	irregular		dikelets and dikes
	greenish brown andesite	207/67	0.5	
	hornblende dioritic dike	contacts not well exposed		fine-grained; may be a Three Sisters Pluton phase?
517	grey-green andesite	188/79	3	
525	green-grey andesite	120/63	0.25	two dikes exposed
536	grey andesite	poorly exposed	≤2	
546	grey-brown diabase	62/90	2	becomes a plagio- clase porphyry near contact
566	hornblende diorite	23/75	5	fine- to medium- grained dike has 1 m wide chilled margins
587	grey-green andesite	40/65	not recorded	

APPENDIX 2.4 (cont'd)

b) Andesite, basalt, dioritic and diabasic dikes (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Domain 1</u> (cont'd)				
689	green-grey andesite	170/88	7-10	dike becomes nearly diabasic towards core
692	grey-green andesite	141/80	8	
695	green-grey andesite	115/75	1	rare hornblende phenocrysts
696	grey-green andesite	140/65	2	two dikes exposed
697	grey-green andesite	178/88	1.5	several dikes exposed near one locality
		348/78	0.8	
		158/82	1	
		150/55	0.3	
701	bluish-grey andesite	158/80	7	
	grey-green andesite	10/75	0.4	
	green-grey andesite	195/75	4	
702	greenish- grey andesite	195/75	4	dikes highly sheared
<u>Domain 2</u>				
192	greenish andesite	207/70	2	
196A	green andesite	334/84	1	
197	green-grey andesite	poorly exposed or anastomosing	≤1	numerous dikes

APPENDIX 2.4 (cont'd)

b) Andesite, basalt, dioritic and diabasic dikes (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Domain 2</u> (cont'd)				
198	green-grey andesite	not recorded		
	grey andesite	117/82	2	
199	green-grey andesite	236/76	0.4-4	anastomosing to regular dikes
201	andesite	263/80 328/75	0.6 2	irregular to regular contacts
209	andesite		5	anastomosing
	olivine? basalt	183/57	3	slightly irregu- lar; contains irregular grani- tic fragments near contact
<u>Domain 3</u>				
170	grey andesite	230/68	1.75	
	green andesite	62/43	0.2-0.5	
172	rusty andesite	262/73	2	
495	andesite			irregular and fine-grained
499	dioritic			fine- to medium grained
	andesite	223/71	1.75	possibly finer- grained equiva- lent of dioritic dike
503	dioritic dike	195/70	2	

APPENDIX 2.4 (cont'd)

c) Porphyry dikes

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)-	Comments
<u>Domain 1</u>				
110	plagioclase- hornblende porphyry	irregular		associated with an aplite dike
286	plagioclase porphyry			fine-grained
475	hornblende porphyry diorite	irregular	1.5-2	
499	hornblende porphyry			
518	hornblende porphyry	anastamosing		
568	plagioclase porphyry	40/50	3	
585	plagioclase porphyry	6/70	2	
692	plagioclase porphyry	irregular	not recorded	common
	hornblende porphyry	17/87	0.8-1	flow layered
699	hornblende porphyry andesite	285/72	not recorded	dioritic? (related to the Snowdrift Creek Pluton?)
700	hornblende?- plagioclase porphyry	8/72	5.5	brown weather- ing, highly sheared

APPENDIX 2.4 (cont'd)

c) Porphyry dikes (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Domain 2</u>				
220	pink horn- blende- plagioclase porphyry	305/65	1.3	
228	pink plagioclase porphyry	exposed in felsenmeer	0.3	anastamosing?
237	plagioclase or hornblende- plagioclase porphyry	358/50 18/85	1-3	irregular, sharp and rarely chilled contacts of these dikes with the Cake Hill Pluton
<u>Domain 3</u>				
495	plagioclase- hornblende porphyry			irregular; intrudes andesite dike at this location; and has acicular hornblende phenocrysts
504	hornblende- plagioclase porphyry	irregular	2	

d) Syenitic porphyry dikes

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Domain 1</u>				
288	plagioclase and horn- blende plag- ioclase por- phyry syenite	irregular	2-3	

APPENDIX 2.4 (cont'd)

d) Syenitic porphyry dikes (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Domain 1</u> (cont'd)				
289	pink weathering syenitic dikes	irregular	4	numerous dikes
514	hornblende porphyry syenite	175/52	3	locally intruded by acicular horn- blende apophysis several hornblende- plagioclase syeni- tic dikes seen near this station one dike intrudes augite porphyry which is metamor- phosed
515	hornblende- plagioclase porphyry syenites			dike swarm; por- phyry syenite bodies compose up to 90 per cent of the outcrop
516	biotite- hornblende porphyry syenite	irregular	2.3	
	biotite- hornblende- plagioclase porphyry syenite	irregular plug		syenite intruded by a grey-green andesite dike
518	porphyritic syenites	340/75 203/73 220/80	20	porphyritic syenite dikes common and irregular
692	plagioclase porphyry syenite	irregular		

APPENDIX 2.4 (cont'd)

d) Syenitic porphyry dikes (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Domain 1</u> (cont'd)				
694	hornblende- plagioclase porphyry syenite	irregular	2	
695	hornblende- plagioclase porphyry syenite	154/67 (one contact)	15	irregular body
697	hornblende- plagioclase porphyry	22/66	4	hornblende grains are weakly flow foliated approxi- mately parallel to contact
698	hornblende- plagioclase porphyry syenite	exposed in felsenmeer		
699	hornblende- plagioclase porphyry	33/74	2	irregular
700	hornblende- plagioclase porphyry syenite	irregular or poorly exposed		two intrusions exposed at this locality
701	syenitic body	irregular	thin	
<u>Domain 2</u>				
236	hornblende- plagioclase porphyry syenite	267/73	12	anastamosing

APPENDIX 2.4 (cont'd)

d) Syenitic porphyry dikes (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Domain 3</u>				
93, 499	plagioclase- megacryst- bearing syenite dike			coeval with the Three Sisters Pluton, potassic marginal phase?

e) Aplite, pegmatite and felsite dikes

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Domain 1</u>				
30	pegmatite	irregular		stringers and fracture fillings
110	aplite	irregular		associated with plagioclase- hornblende porphyry dike
120	pink aplite	not recorded		rare
274	highly altered rusty dikes	not recorded		
275	plagioclase porphyry	240/25	≤1.5	flow layered
286	felsite			rusty
287	pink felsite			
288	pink aplite			
289	syenites and aplites	irregular		
291	felsite	not recorded		rare dike
359	aplite	irregular		rare dike

APPENDIX 2.4 (cont'd)

e) Aplite, pegmatite and felsite dikes (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Domain 1</u> (cont'd)				
361	white and pink aplite	anastamosing		uncommon dikes
401	aplite and pegmatite	anastamosing		veins
409	aplite and felsite	irregular	irregu- lar	common dikes
411	aplite	not recorded	<1	common
412	whitish felsite	not recorded		common
475	pink and white aplite	irregular	≤1	common
513	grey to pink felsite	10/90	2	
516	pink and white felsite	irregular		dikes and dikelets common
517	aplite	irregular	15	
518	aprites and white felsite	irregular		uncommon
692	leucodiorite	irregular		common
698	pink aplite	irregular? (exposed in felsenmeer)		
<u>Domain 2</u>				
192	grey felsite	3/84	2	
202	pink aplite	290/75	3	
	pink aplite	anastamosing		
205	pink aplite	poorly exposed in felsenmeer		

APPENDIX 2.4 (cont'd)

e) Aplite, pegmatite and felsite dikes (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Domain 2</u> (cont'd)				
206	pink aplite			common and anastomosing
209	bluish felsite not recorded		0.4-2	
<u>Domain 3</u>				
170	aplite			common pink aplite dikes and veins ≤ 5 cm wide anastomose through metamor- phosed Cake Hill Pluton

f) Rhyolite dikes and diatremes

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Domain 1</u>				
290	rhyolite	157/80 234/75	1 0.3	flow layered dikes
	chert- granite pebble dike	60/90	0.3	fragments rounded to subrounded; ≤ 5 cm long
292	rhyolite	160/67		flow layered
296	rhyolite diatreme	117/85 105/80 attitude of part of southern contact		white weathering, locally (in centre) flow layered rhyo- lite contains ≤ 80 per cent Cake Hill Pluton granitic clasts, ≤ 4 m long also contains the basal granitic- fragment-bearing flow as inclusions

APPENDIX 2.4 (cont'd)

f) Rhyolite dikes and diatremes (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Domain 1</u> (cont'd)				
401	rhyolite?		1	flow layered
512	rhyolite	not recorded	not recorded	
692	andesite stockwork			highly altered, siliceous grani- tic rock (Cake Hill Pluton) is broken up by stockwork of black andesitic lava
699	andesite stockwork			massive, leuco- cratic hornblende quartz monzodio- rite (Cake Hill Pluton) becomes increasingly brecciated and breccia fragments more rotated as the volcanic centre is appro- ached towards the northwest; percen- tage of andesitic material composing veins and the stock- work also increases towards the north- west (SEE PLATE II G)
701	plagioclase porphyry rhyolite	145/35		flow layering developed in 15- 25 cm zone along the contact

APPENDIX 2.5 MODAL COMPOSITION OF CAKE HILL PLUTON ("UNDISTURBED" PLUTON)

SAMPLE NUMBER	118-1 ³	196-2 ³	208-1 ³	217-1 ³	240-1 ⁴	287-3 ³	327-2 ³	360-2 ⁵	569-3 ³	GAD-132-1 ³ (GSC 70-33)	276 ⁶
plagioclase	54.8	60.8	62.2	51.7	45.3	59.8	62.4	52.5	52.3	61.2	47.1
alkali feldspar	14.6	18.0	8.9	15.6	41.4	16.0	16.5	28.5	26.1	18.4	21.5
quartz	10.9	11.9	15.5	16.3	1.8	13.4	12.7	1.6	9.5	10.9	27.7
hornblende	16.4	6.1	11.8	12.7	7.2	8.7	5.0	7.6	9.0	7.9	2.7
clinopyroxene	1.1	0.3	0.3		1.2		0.3	5.5	0.2	Tr	
opaque minerals	2.1	0.9	1.1	1.1	1.5	1.3	1.8	1.2	1.6	1.3	0.5
biotite									0.8		
apatite	0.2	0.5	Tr	0.1	0.6	0.3	0.4	0.4	0.2	0.2	0.1
titanite	1.0	0.6	Tr	1.9	0.3	0.3	0.6	0.6	0.3	0.1	0.4
zircon	Tr ¹	0.1	Tr	Tr		Tr	0.2		Tr	Tr	Tr
allanite									Tr		
epidote	Tr	Tr	Tr	0.3	Tr	0.2	Tr	0.8		Tr	
chlorite	Tr	Tr	Tr	0.3	0.6	Tr	0.1	1.3	Tr		
sericite	Tr	Tr			0.1						
PLAGIOCLASE COMPOSITION	An ₅₋₁₃	nd ²	An ₈₋₁₄ , An ₂₂	An ₈₋₁₂	An ₄₋₁₂	An ₁₀₋₁₃	An ₆₋₁₄	An ₂₈₋₃₁	An ₂₅	nd	An ₇
Colour Index	18.7	9.3	13.2	16.4	11.4	10.8	8.4	17.4	12.1	9.5	3.7
Point Counts	1000	1000	627	692	1000	1000	1000	1000	633	1000	1000
1. Tr = trace	2. nd = no determinations	3. quartz monzodiorite	4. monzonite	5. monzodiorite	6. granodiorite						

A-64

APPENDIX 2.5 (continued) MODAL COMPOSITION OF CAKE HILL PLUTON ("METAMORPHOSED" PLUTON)

SAMPLE NUMBER	154-1 ²	344 ³	447-5 ⁴	606-1 ⁶	612-4 ²	GA 1390 ⁵ (GSC 70-27, 70-28)
plagioclase	44.8	47.4	13.4	28.1	35.2	65.0
alkali feldspar	29.2	19.4	76.3	48.0	46.1	3.1
quartz	7.6	29.6	1.7	1.0	4.4	2.1
hornblende	13.4	2.7	5.1	4.2	4.7	15.8
clinopyroxene	0.3			1.8		1.0
opaque minerals	1.6	0.5	0.6	1.6	2.0	2.5
biotite	0.5		2.7	12.2	7.2	
apatite	0.6	0.1	0.1	1.6	0.3	1.6
titanite	0.2	0.3		Tr	0.1	0.3
zircon	Tr ¹	Tr	Tr	Tr	Tr	Tr
allanite				Tr		0.2
epidote	0.2			0.1		
chlorite	1.2		0.1	0.1		
sericite	0.4			1.3		
PLAGIOCLASE COMPOSITION	An ₁₋₁₃	An ₁₀	An ₁₋₂	An ₃₂₋₃₆	An ₃₆₋₄₀	An ₂₋₁₃
Color Index	18.0	3.6	8.6	21.6	14.3	21.4
Point Counts	1006	1000	809	690	1000	1018
1. Tr = trace	2. quartz monzonite	3. granodiorite	4. syenite	5. diorite		

APPENDIX 2.6

Symbols represent samples from:

- undisturbed Cake Hill Pluton
- ◇ K-Ar sample from Cake Hill Pluton fragments
in lowermost unit of Upper Triassic Stuhini
Group
- metamorphosed Cake Hill Pluton
- △ Cake Hill Pluton screen in Three Sisters Pluton,
central phase

Sample numbers are given in alumina-silica variation diagram (see Table II.3.2).

APPENDIX 2.6

APPENDIX 2.6 (continued)

APPENDIX 2.6 (continued)

APPENDIX 2.6 (continued)

APPENDIX 2.6 (continued)

APPENDIX 3. DETAILS OF THE GEOLOGY OF THE GNAT LAKES ULTRAMAFITE

	Page
3.1 Structural Data for the Gnat Lakes Ultramafite ¹	A-73
3.2 Intrusive Relations Involving the Gnat Lakes Ultramafite ²	A-74
(a) External intrusive relations	A-74
(b) Interpluton intrusive relations	A-74
3.3 Hypabyssal Intrusions in the Gnat Lakes Ultramafite ¹	A-76
(a) Augite-plagioclase porphyry dikes	A-76
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3.4 Modal Compositions for the Gnat Lakes Ultramafite ³	A-77
3.5 Harker Variation Diagrams for the Gnat Lakes Ultramafite	A-78

-
1. Dip direction conventionally oriented 90 degrees clockwise from azimuth.
 2. Intrusive relations between this pluton and older plutons are given in appendices for the older plutons.
 3. Rock classification, in part, after Streckeisen (1973). Some hornblende pyroxenites apparently contain more hornblende than pyroxene due to the common, thin uraninite veins in the pyroxene.

APPENDIX 3.1 - STRUCTURAL DATA FOR THE GNAT LAKES ULTRAMAFITE

Location (at or near station)	Conventional Orientation of Layering	Comments
438	23/90	alternating layers of hornblendite (or horn- blende gabbro; layers 4-15 cm thick) and rusty pyroxenite (layers 10 cm thick) exposed in 0.5 m x 2 m outcrop (SEE PLATE III A)
579 or 608	135/75	hornblende grains are coarse-grained and acicular 5-8 cm thick alterna- ting layers of horn- blendite and augite porphyry (SEE PLATE III B)

APPENDIX 3.2 - INTRUSIVE RELATIONS INVOLVING THE GNAT LAKES ULTRAMAFITE

a) External intrusive relations

Location
(at or near
station:)

Comments

434, 435 and 630

although the contact is not seen, thin bedded, cherty argillite structurally overlying outcrops of Gnat Lakes Ultramafite is conventionally oriented 190/66, 192/83, 23/80, and 274/33 which defines a tight, moderately north plunging fold

b) Interpluton intrusive relations

Location
(at or near
station)

Comments

INTRUSIVE RELATIONS INVOLVING THE GNAT LAKES ULTRAMAFITE AND THE THREE SISTERS PLUTON (MAFIC PHASE AND CENTRAL PHASE)

571

pyritiferous, acicular hornblende diorite (Three Sisters Pluton, mafic phase) clearly intrudes and alters coarse-grained pyroxenite or gabbro (Gnat Lakes Ultramafite) (SEE PLATE III C)

629

epidotized hornblende monzonite apophyses (Three Sisters Pluton, central phase) intrudes hornblende pyroxenite (Gnat Lakes Ultramafite) and along its intrusive contact included 1-5 cm long, angular pyroxenite fragments (SEE PLATE III D)

APPENDIX 3.2 (cont'd)

b) Interpluton intrusive relations (cont'd)

Location
(at or near
station:)

Comments

INTRUSIVE RELATIONS INVOLVING THE GNAT LAKES ULTRAMAFITE AND THE THREE SISTERS PLUTON (POTASSIC MARGINAL PHASE)

14	common, 1-2 cm wide aplite veins (Three Sisters Pluton, potassic marginal phase) which intrude and form stockworks in the hornblendite (Gnat Lakes Ultramafite)
15 or 433	white aplite and local pegmatites (Three Sisters Pluton, potassic marginal phase) intrude and form stockworks (fragments up to 10 cm long) in hornblendite and hornblende pyroxenite (Gnat Lakes Ultramafite) (SEE PLATE III E)
421	small (up to 2 cm long) rounded, uncommon ultramafic inclusions occur in hornblende quartz syenite (Three Sisters Pluton, potassic marginal phase) near its intrusive contact with the Gnat Lakes Ultramafite
445 or 609, 607	leucocratic hornblende monzonite (Three Sisters Pluton, potassic marginal phase) apophyses locally intrude hornblende pyroxenite (Gnat Lakes Ultramafite) (SEE PLATE III F)
571	anastomosing felsic veins and veinlets (Three Sisters Pluton, potassic marginal phase?) intrude hornblendite close to augite-trachytoid bladed plagioclase porphyry dike
610	irregular stringers and 15-20 cm wide irregular, fine-grained to medium-grained dikes of biotite-hornblende alkali feldspar syenite and alkali feldspar porphyry syenite (Three Sisters Pluton, potassic marginal phase) intrude and include fragments of medium-grained hornblende pyroxenite (Gnat Lakes Ultramafite)
617	irregular pegmatitic to aplitic syenite apophyses (Three Sisters Pluton, potassic marginal phase) intrude hornblende pyroxenite (Gnat Lakes Ultramafite)

APPENDIX 3.3 - HYPABYSSAL INTRUSIONS IN THE GNAT LAKES ULTRAMAFITE

a) Augite-plagioclase porphyry dikes

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
571 or 630	trachytoid bladed plagioclase-augite porphyry	94/85 85/78	2.5 m	dike intrudes hornblende and is chilled within 15 cm of its contact orientation of trachytoid bladed plagioclase parallels attitude of contact

b) Andesite dikes

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
433	andesite			thin, irregular, inclusion- and epidote-bearing fine-grained andesite dike intrudes hornblende pyroxenite

APPENDIX 3.4. MODAL COMPOSITION OF GNAT LAKES ULTRAMAFITE

SAMPLE NUMBER	15-1 ⁵	433-2 ^{2,5}	445-3 ^{3,5}	607-2 ⁶	608-1 ⁶	609-2 ^{4,5}
clinopyroxene	49.7	65.6	53.6	2.9		27.0
hornblende	37.8	26.5	31.4	88.7	78.2	56.0
plagioclase		1.5		4.4	8.2	
magnetite	8.1	5.9	14.1	3.5	2.6	11.4
apatite	0.6	0.4	0.8	Tr ¹	1.8	0.1
titanite	0.7	0.1	0.1	0.5	2.0	0.8
epidote	2.3					
chlorite	0.8					4.1
biotite						0.2

PLAGIOCLASE COMPOSITION

>An₅₆

POINT COUNTS 1000 1000 1000 1000 1000

1. Tr = trace

2. Location:

3. Location:

4. Replicate chemical analysis sample labelled 609-1

5. Hornblende clinopyroxenite

6. Hornblende

APPENDIX 3.5

Symbols represent samples from:

- Gnat Lakes Ultramafite, grab samples
- ◇ Gnat Lakes Ultramafite, K-Ar samples

Sample numbers are given in alumina-silica variation diagram (see Table II.4.2).

APPENDIX 3.5

APPENDIX 3.5 (continued)

APPENDIX 3.5 (continued)

APPENDIX 3.5 (continued)

APPENDIX 4. DETAILS OF THE GEOLOGY OF THE BEGGERLAY CREEK PLUTON

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1. Dip direction conventionally oriented 90 degrees clockwise from azimuth.

2. Intrusive relations between this pluton and older plutons are given in appendices for the older plutons.

3. Rock classification, in part, after Streckeisen (1973).

APPENDIX 4.1 - LITHOLOGICAL CHARACTERISTICS OF THE BEGGERLAY CREEK PLUTON

a) Inclusions in the Beggerlay Creek Pluton

Location (at or near station:)	Abundance (%)	Dimensions	Comments
234	≤ 1	≤ 5 cm long	angular to rectangular, light grey, fine-grained volcanic inclusions

APPENDIX 4.2 - STRUCTURAL DATA FOR THE BEGGERLAY CREEK PLUTON

a) Mineral foliation

Location
(at or near
station:)Conventional Orientation
Quality of Foliation

Poor

Moderate

Good

297

337/88
174/65
138/75
146/65

463

23/85

APPENDIX 4.3 - INTRUSIVE RELATIONS INVOLVING THE BEGGERLAY CREEK PLUTON

a) Intrapluton intrusive relations

Location
(at or near
station:)

Comments

463

leucocratic and massive hornblende diorite with uncommon but characteristic poikiloblastic biotite intrudes pyroxenite and fluidal foliated hornblende diorite near the contact between the Beggerlay Creek Pluton and the Cake Hill Pluton

b) External intrusive relations

Location
(at or near
station:)

Comments

INTRUSIVE RELATIONS INVOLVING THE BEGGERLAY CREEK PLUTON AND THE TRIASSIC VOLCANICS

233

groundmass of augite porphyry volcanics amphibolitized (metamorphosed?) close to and at some distance from the contact with hornblende diorite (Beggerlay Creek Pluton) but actual contact is covered

402

thin, irregular, moderately exposed hornblende gabbro sill appears to intrude the augite porphyry volcanics

(see also station 322 in Appendix 4.3 (Triassic-Jurassic volcanics) and Appendix 4.4)

INTRUSIVE RELATIONS INVOLVING THE BEGGERLAY CREEK PLUTON AND THE TRIASSIC-JURASSIC VOLCANICS

247

contact not well exposed but extrapolated at beginning of gabbro felsenmeer

248

contact is bracketed within 2 m but nature of contact cannot be unequivocally established although volcanics appear to be metamorphosed

267

volcanic inlier appears metamorphosed (amphibolitized) near contact with hornblende gabbro (Beggerlay Creek Pluton)

hornblende diorite dike with poikiloblastic

APPENDIX 4.3 (cont'd)

b) External intrusive relations (cont'd)

Location
(at or near
station:)

Comments

INTRUSIVE RELATIONS INVOLVING THE BEGGERLAY CREEK PLUTON AND THE TRIASSIC-
JURASSIC VOLCANICS (cont'd)

267 (cont'd)

biotite (Beggerlay Creek Pluton?) anastomoses
through volcanics in inlier

269

feldspar porphyry volcanics appear partly
recrystallized? within 35 m of contact with
Beggerlay Creek Pluton

322

contact between fine-grained andesite and
plagioclase porphyry volcanics and hornblende
gabbro (Beggerlay Creek Pluton) is well bracketed but not exposed

hornblende gabbro locally grades into more
feldspathic diorite towards contact with
volcanics

isolated screen? or dike? of unmetamorphosed
augite porphyry occurs in gabbro (Beggerlay
Creek Pluton) but contacts are not exposed

APPENDIX 4.4 - HYPABYSSAL INTRUSIONS IN THE BEGGERLAY CREEK PLUTON.

a) Diorite, basalt and andesite dikes

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
248	basalt	182/56	2.5	slightly irregular contacts
270	basalt	190/43	1	
271	hornblende andesite	poorly exposed		fine-grained
298	hornblende diorite	334/81	0.3	contacts not well exposed; dike fine-grained

b) Porphyry dikes

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
268	leucocratic plagioclase porphyry			lithologically similar to dike which intrudes Triassic-Jurassic volcanic inlier
270	plagioclase porphyry	poorly exposed contacts contacts		
298	hornblende- plagioclase porphyry	irregular		
302	hornblende- plagioclase porphyry			pinkish groundmass
303	grey plagioclase porphyry	irregular	4	
305	cream plagioclase- hornblende porphyry	irregular to regular	0.1	

APPENDIX 4.4 (cont'd)

b) Porphyry dikes

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
454	augite porphyry	irregular	1	augite porphyry dike is intruded by black, fine- grained diabase
271, 304 322, and 718	augite porphyry			isolated outcrops of augite porphyry within the Begger- lay Creek Pluton, may be intrusions or screens (con- tacts are not exposed) at station 304, augite porphyry appears metamorphosed

c) Pegmatite, aplite and felsite dikes

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
230	pegmatite	anastamosing	≤ 5 cm	intrudes intensely foliated horn- blende gabbro
231	pegmatite			stringers intrude gneiss
232	pegmatite			intrudes massive hornblende gabbro
248	aplite			
266	pegmatite			veins and irregu- lar dikes are common in massive hornblende gabbro

APPENDIX 4.4 (cont'd)

c) Pegmatite, aplite and felsite dikes (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
298	aplitic hornblende- plagioclase porphyry			possibly a Three Sisters Pluton, potassic marginal phase equivalent
299	aplite	64/83	0.15	contacts generally irregular
301	aplite			exposed in felsenmeer
303	fine-grained felsite			
455	grey felsite and pink aplite			both lithologies intrude the Beggerlay Creek Pluton either as dikes (felsite) or veins (aplite)

APPENDIX 4.5 MODAL COMPOSITION OF THE BEGGERLAY CREEK PLUTON

SAMPLE NUMBER	231-1	234-2	247-1	248-6	271-3	304-1	717-1
plagioclase	50.1	35.6	36.8	65.3	55.9	46.1	44.6
alkali feldspar	3.9	2.1	0.2	0.6	0.3	3.3	
quartz	0.1						
clinopyroxene		6.7	18.7	6.1	4.9		16.3
hornblende	29.8	18.9	19.1	11.5	13.8	37.8	14.1
biotite	4.5	5.2	10.3	8.1	16.9	1.1	11.1
"olivine" (?) ¹		Tr	3.6				7.9
opaque minerals	0.6	0.9	2.4	2.1	2.7	Tr	3.1
apatite	0.2	1.7	1.1	1.5	0.5	0.5	1.5
titanite		0.2	Tr	Tr	0.1		
rutile	Tr ²	Tr	Tr	Tr	Tr		
spinel						0.8	
chlorite	Tr	0.4	2.6	2.5	0.3		1.4
epidote	1.2	0.4	0.2	0.8	1.5	0.3	Tr
sericite and sausserite	9.6	17.9	5.0	1.5	3.1	10.1	Tr
PLAGIOCLASE COMPOSITION	An ₂₋₆	An ₃₃₋₄₆	An ₃₂₋₅₇	An ₄₀₋₅₀	An ₃₈₋₅₀	nd ³	An ₅₂₋₆₂
Colour Index	36.3	44.4	58.0	32.6	40.7	40.5	55.4
Point Counts	1000	1002	1031	1000	1000	612	1000

1. aggregates of tremolite + opaque minerals + serpentine

2. Tr = trace

3. nd = no determinations

APPENDIX 4.6

Sample numbers are given in alumina-silica variation diagram (see Table II.5.2).

APPENDIX 4.6

APPENDIX 4.6 (continued)

SiO₂ (weight %)

MgO (weight %)

SiO₂ (weight %)

MnO (weight %)

A-94

APPENDIX 4.6 (continued)

APPENDIX 4.6 (continued)

APPENDIX 5. DETAILS OF THE GEOLOGY OF THE PALEOZOIC AND MESOZOIC VOLCANICS
AND SEDIMENTS

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1. Dip direction conventionally oriented 90 degrees clockwise from azimuth.

APPENDIX 5.1 - BEDDING ATTITUDES OF PALEOZOIC AND MESOZOIC ROCKS

AROUND THE HOTAILUH BATHOLITH

a) Paleozoic (Permian?) recrystallized limestones

Location (at or near station:)	Conventional Orientation Quality of Bedding	
	Good	

637	203/48	
	15/58	
	32/72	
	198/78	
638	182/75	
	25/49	

b) Triassic or older volcanics and sediments

Location (at or near station)	Conventional Orientation Quality of Bedding	
	Moderate	Good

419	350/40	315/45
	300/45	346/46
	358/37	338/53
		333/44
		347/47
		300/58
420	346/88	5/55
421		322/80
500		320/34
		325/39
500A		333/60

APPENDIX 5.1 (cont'd)

c) Upper Triassic Volcanics and Sediments (bedding)

Location
(at or near
station:)Conventional Orientation
Quality of Bedding

Moderate

Good

Western Margin

2

25/50

20/55

22

326/78

320/85

319/82

38

325/67

434

23/80

435

274/33

436

315/74

571

94/85

85/78

268/79

285/62

575

145/59

147/35

600

160/85

159/88

0/69

630

190/65

190/66

213/70

220/65

192/83

214/78

239/83

644

18/52

30/51

17/56

19/45

647

227/42

207/39

220/74

213/57

APPENDIX 5.1 (cont'd)

c) Upper Triassic Volcanics and Sediments (bedding) (cont'd)

Location (at or near station:)	Conventional Orientation Quality of Bedding	
	Moderate	Good
648		237/62 233/69
649		219/54 237/54
<u>Northern Margin</u>		
276		300/28 279/55 337/53
278		280/44
279		285/54
280		278/44
295		307/57
325		238/46 232/31
377		298/37 290/38
428		153/73
448		232/45 223/33 246/35
691		263/52 258/48 250/45 273/47 275/45
702		150/75
708		67/70 71/55

APPENDIX 5.1 (cont'd)

c) Upper Triassic Volcanics and sediments (bedding) (cont'd)

Location
(at or near
station:)

Conventional Orientation
Quality of Bedding

Good

Eastern Margin

501

255/48
205/35
243/33
245/30

Southern Margin

233

333/64

603

253/10

APPENDIX 5.1 (cont'd)

d) Upper Triassic volcanics and sediments (foliation and fracture cleavage).

Location
(at or near
station:)Conventional Orientation
Quality of Foliation

Good

Western Margin

1, 428

152/62
158/68

434

22/90

435

23/90

436

23/68

444

156/74
162/64
164/83

579

15/90
355/80

600

148/84

631

147/90

Northern Margin

705

299/84
300/85
297/85

711

99/80

APPENDIX 5.1 (cont'd)

e) Upper Triassic volcanics and sediments (jointing possibly related to intrusion of Three Sisters Pluton)

Location (at or near station:)	Conventional Orientation Quality of Bedding
--------------------------------------	--

Western Margin

20	177/74
41	48/45 48/43 50/45 48/63
43	153/63 58/28
574	65/54 40/43 47/55

f) Triassic-Jurassic volcanics and sediments

Moderate Good

Northern Margin

712	286/46
713	300/61

Eastern Margin

316	73/40 3/32 352/28	352/28 355/29
317	122/35	0/22

Southern Margin

242	213/75 233/78 253/64	
244		214/75

(APPENDIX 5.1 (cont'd)

g) Toarcian Sediments

Location
(at or near
station:)

Conventional Orientation
Quality of Bedding

Good

Northern Margin

325 or
449

273/63
275/67

Eastern Margin

343

322/53
320/57
331/50

APPENDIX 5.2 - HYPABYSSAL INTRUSIONS IN VOLCANIC AND SEDIMENTARY ROCKS AROUND THE HOTAILUH BATHOLITH

a) Dikes in Triassic or older volcanics and sediments

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
420	augite porphyry	270/85	2	chilled within 5-10 cm of con- tact with tuffs
500	granitoid felsite			probably related to the Three Sisters Pluton, leucocratic phase
500A	augite porphyry			small intrusion which contains small inclusions (12 cm long and rounded) and a 0.5 m wide screen of the siliceous tuffs but contacts not well exposed

b) Dikes in Upper Triassic volcanics and sediments

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Western Margin</u>				
28	granitic apophyses			possible intru- sions of Three Sisters Pluton?
44	pink weathering aplite			irregular apophy- ses of Three Sisters Pluton, potassic marginal phase?
<u>Northern Margin</u>				
282	augite porphyry		0.40	irregular; sym- metrical 10 cm wide chilled margins
	syenitic hornblende-			irregular dikes

APPENDIX 5.2 (cont'd)

b) Dikes in Upper Triassic volcanics and sediments (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Northern Margin</u> (cont'd)				
285	syenitic hornblende- plagioclase porphyry felsite	irregular	thin	poorly exposed contacts flaggy weathering
295	flow layered rhyolite	irregular (flow layering varies 245/73 to 67/90	3	
296	felsite and sye- nitic plag- ioclase porphyry rhyolite diatreme			irregular and rare irregular appo- hyses intrude fine-grained andesite flows
690	leucocratic diorite	31/68	2	granitoid medium- grained dike exhibits chilled margins within 20 cm of contact
702	augite porphyry	150/75		plugs intrude between more or less altered Cake Hill Pluton and granitoid- fragment-bearing conglomerate
709	plagioclase porphyry	90/80		intrudes augite- plagioclase por- phyry volcanics intruded by the

APPENDIX 5.2 (cont'd)

b) Dikes in Upper Triassic volcanics and sediments (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Northern Margin</u> (cont'd)				
section 704	syenitic plagioclase porphyry		8-12	
section 705	hornblende porphyry	15/80		intrudes unit G
	syenitic plagioclase porphyry	300/65	1	intrudes unit I
	syenitic plagioclase porphyry	299/84 } 302/85 } 297/85 -	south side of dike north side of dike	dike intrudes unit O; attitudes from fracture cleavage developed in host rocks
	greyish green andesite		0.60	
	augite porphyry	70/64(north contact) 120/55(south contact)	1 dike	intrudes unit O
		120/64	0.60	
		125/72	3	
		332/29 } 125/90 }	2 contacts one dike	4
	augite porphyry dike	80/80 150/58 172/65	10-20	
	syenitic hornblende- plagioclase porphyry	300/67 323/73 (one dike)	25	intrudes unit O
	biotite- hornblende monzodiorite	190/75	2	intrudes augite porphyry dike

APPENDIX 5.2 (cont'd)

b) Dikes in Upper Triassic volcanics and sediments (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
section 707	augite porphyry	175/75	12	intrudes unit B
714	acicular hornblende monzodiorite		3	fine-grained sill intrudes and metamorpho- ses unit H
<u>Central Portion</u>				
550	simple pegmatite			uncommon irre- gular apophyses
<u>Eastern Margin</u>				
70	aplite and fine-grained syenite			Three Sisters Pluton, potassic marginal phase intrusive apophyses
165	felsic hornblende plagioclase por- phyry and dacite apophyses	195/65		
166	leucocratic fine- to medium- grained monzo- diorite	358/78	15-20	apophysis of McBride River Pluton intrudes and metamorphoses (producing 5 m aureole) augite porphyry
	fine-grained acicular horn- blende diorite	25/56	2.5	
	dacite	212/87	2.5	
167	aplite			separates volcan- ics from possible remobilized Cake Hill Pluton

APPENDIX 5.2 - HYPABYSSAL INTRUSIONS IN VOLCANIC AND SEDIMENTARY ROCKS AROUND
THE HOTAILUH BATHOLITH (cont'd)

b) Dikes in Upper Triassic volcanics and sediments (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Eastern Margin</u> (cont'd)				
250	basalt	157/83	10	regular basalt dike separates amphibolitized augite porphyry from possible remobilized Cake Hill Pluton at their contact
251	aplite			uncommon to common aplite dikes intrude metavol- canic screen

APPENDIX 5.2 (cont'd)

c) Dikes in the Triassic-Jurassic volcanics and sediments

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Eastern Margin</u>				
312	siliceous felsite			apparently intrudes and silicifies silt- stone of basal part of Triassic- Jurassic section
	basalt	205/63	1.25	
313	hornblende quartz monzodiorite	irregular		possibly related to the McBride River Pluton?
468	granitoid hornblende- plagioclase porphyry			similar to that seen at station 313 - related to the McBride River Pluton?
<u>Southern Margin</u>				
320, 321, 322	acidic hornblende plagioclase porphyry			uncommon, irregu- lar dikes

APPENDIX 5.3

Symbols represent samples from:

- ☐ light grey andesite dike
- ☐ greenish-grey andesite dikes
- ☐ Triassic-Jurassic volcanics
- ☐ Stuhini Group volcanics
- ☐ pyroxene-porphyry dikes, grab sample
- ☐ pyroxene porphyry dike, K-Ar sample

Sample numbers are given in alumina-silica variation diagram (see Tables III.11 to III.14).

APPENDIX 5.3 (continued; volatile-free)

10

APPENDIX 5.3 (continued; volatile-free)

APPENDIX 5.3 (continued; volatile-free)

APPENDIX 5.3 (continued; volatile-free)

APPENDIX 5.3 (continued; volatile-free)

APPENDIX 5.3 (continued; volatile-free)

APPENDIX 5.3 (continued; volatile-free)

APPENDIX 5.3 (continued; volatile-free)

APPENDIX 5.4(a) MINERALOGICAL COMPOSITION OF UPPER TRIASSIC VOLCANICS AND DIKE

SAMPLE NUMBER 698-1 281-1 325-1² 377-1 448-3² 604-1 704K-2 705J-2 707D-1
(dike)

Phenocrysts

"ferromagnesian
minerals"

0.6

clinopyroxene 11.2 x³ x x x
plagioclase 0.4 x x x 27.0 x x
hornblende 10.5 x
opaque minerals 3.4 x 0.5

PLAGIOCLASE PHENOCRYST
COMPOSITION (n.d.)
no determinations)

An₅₆₋₆₁ An₃₉₋₅₂ An₅₁₋₆₅Groundmass

plagioclase 46.3
alkali feldspar
(albite)

H⁵ H⁴ H⁴ H⁴ H

clinopyroxene

hornblende

opaque minerals

titanite

biotite

apatite

quartz

epidote

chlorite

sericite

calcite

Point Counts 1000

1. altered to calcite and chlorite

2. sample from same unit as section 714, unit R (325-1 top, 448-3 base)

3. x = present

4. fine-grained or aphanitic material composed of feldspar microlites and opaque minerals

5. H = hyaloclastite groundmass

APPENDIX 5.4(a) MINERALOGICAL COMPOSITION OF METAMORPHOSED UPPER TRIASSIC VOLCANICS

SAMPLE NUMBER 19-1 41-3 71-2 233-2 358-1 444-1 501-1

"Phenocrysts"

clinopyroxene	x		x	38.9	x	x	
uralite (hornblende)			x				x
plagioclase	x	x		4.7			x
opaque minerals		x		Tr ²	x		x

PLAGIOCLASE PHENOCRYST COMPOSITION	n.d. ³	An ₄₉₋₅₅	An ₅₀₋₇₂	n.d.	An ₃₀₋₃₆
------------------------------------	-------------------	---------------------	---------------------	------	---------------------

"Groundmass"

plagioclase	x	x	x	10.9	x	x	
alkali feldspar	x	x	x				x
clinopyroxene				8.9			
hornblende	x	x	x	3.5	x	x	x
biotite	x		x	33.2	x	x	x
opaque minerals	x	x	x				x
apatite	x	x	x	0.6			
titanite		x					
epidote					x		x
chlorite						x	
sericite							
calcite							

Point Counts

1. x = present
2. Tr = trace
3. n.d. = no determinations

709

APPENDIX 5.4(b) MODAL COMPOSITIONS FOR THE TRIASSIC-JURASSIC VOLCANICS

SAMPLE NUMBER	715B-1	715D-1	715F-1	715H-3	715I-1	715J-2	715K-f	715L-2	715P-1	715Q-2
Phenocrysts										
plagioclase	2.2	31.8	25.6	41.4			6.4	48.0	30.8	25.8
alkali feldspar					7.0	11.8	Tr ⁵			0.2
quartz					2.4		0.2			
opaque minerals	0.2	5.4	0.6	2.2	0.8	0.8	2.8	1.2	4.6	0.8
and "ferromagnesian minerals" ¹										
clinopyroxene								4:8		
apatite				0.4						
PLAGIOCLASE PHENOCRYST COMPOSITION	An ₃₀₋₄₁	An ₅₆₋₆₂	An ₂₈₋₃₆	An ₂₉₋₃₅		n.d. ⁴	n.d.	An ₆₄₋₇₅	n.d.	An ₃₈

A-122

Groundmass (Continued on next page)

APPENDIX 5.4(b) (continued)

SAMPLE NUMBER	715B-1	715D-1	715F-1	715H-3	715I-1	715J-2	715K-1	715L-2	715P-1	715Q-2
Groundmass ²						71.2	69.0			
feldspar ³					67.0					
plagioclase	76.4	38.0	28.2				11.8	31.0	21.6	51.6
alkali feldspar		Tr		45.6				Tr		
quartz	7.8		8.6	1.4	5.2		0.2			Tr
opaque minerals	4.0	10.0	22.4	4.0	4.0	13.2	0.8	6.2	28.2	12.6
clinopyroxene								3.6		
apatite				Tr	Tr					
epidote	Tr ⁵			2.0			3.2	0.4	0.2	4.0 ^{A-123}
sericite and calcite	5.4	Tr	0.8				1.6	1.2	2.0	0.8
chlorite		Tr		1.8			2.0	1.0	2.8	3.4
calcite		14.8	12.0	1.2	6.6	3.0	2.0	2.6	9.8	0.8
POINT COUNTS (for Phenocrysts and Groundmass)	500	500	500	500	500	500	500	500	500	500

1. aggregates of opaque minerals + chlorite + calcite + quartz alteration products of pyroxene? or amphibole?
2. modal volume estimate of undifferentiated groundmass composed of fine-grained feldspar and opaque minerals.
3. modal volume estimate of undifferentiated albitic plagioclase and alkali feldspar.

4. no determinations.

5. Tr = trace

APPENDIX 5.4(c) MODAL COMPOSITIONS FOR TOARCAN SEDIMENTS AND METASEDIMENTS

459-4 459-5

SAMPLE NUMBER

414-1 449-1

quartz

50.0 63.0

alkali feldspar

30.0 17.5

plagioclase

10.0 11.3

opaque minerals

Tr 3 0.7

zircon

Tr

cement

10.0 7.5

garnet

X X

diopside

X

tremolite

X

white mica (talc?)

X X

calcite

X

phlogopite?

X

PLAGIOCLASE COMPOSITION

 $\angle \text{An}_8$

Point Counts

400 400

1. X = present
2. microcline and microperthite
3. Tr = trace

APPENDIX 6. DETAILS OF THE GEOLOGY OF THE THREE SISTERS PLUTON

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-
1. Dip direction conventionally oriented 90 degrees clockwise from azimuth.
 2. Intrusive relations between this pluton and older plutons given in appendices for older plutons.
 3. Rock classification after Streckeisen (1973).

APPENDIX 6.1 - LITHOLOGICAL CHARACTERISTICS OF THE THREE SISTERS' PLUTON

a). Inclusions in the Three Sisters Pluton

i) Mafic Phase

Location (at or near station:)	Abundance (%)	Dimensions	Comments
138	1-2	≤5 cm	fine-grained equant hornblende diorite inclusions
523	7		rounded, fine-grained hornblende diorite inclusions
527			rare inclusions
535			gabbro becomes inclusion-bearing within 1 m of its contact with the re-mobilized Cake Hill Pluton
536	30-40	≤0.5 m (average 15-20 cm long)	generally angular fine- to medium-grained acicular hornblende diorite and fine-grained hornblende diorite inclusions which commonly have a 0.5 cm finer-grained (chilled) rim (SEE PLATE VI C) one inclusion, 0.5 m long shows three, thin (2-6 cm thick), graded cumulate hornblende diorite layers (SEE PLATE VI A,B)
538			very rare small inclusions
554	1-2	1-2 cm long	rounded, fine-to medium-grained diorite
572	2	≤12 cm long (average 5-6 cm long)	rounded, fine-grained diorite

APPENDIX 6.1 (cont'd)

a) Inclusions (cont'd)

ii) Central Phase

Location (at or near station:)	Abundance (%)	Dimensions	Comments
62	1-2	≤5 cm long	fine-grained diorite inclusions
63	1-2		rounded, fine-grained diorite inclusions
	≤5	≤20 cm long	fine-grained diorite inclusions are rounded to elongate to oval
			rare biotite clots
64	1		fine-grained diorite
66	<1		
73	≤5	≤2 cm long	rounded chloritized fine-grained diorite inclusions
75, 76?			large inclusion or screen of medium- to coarse-grained hornblende monzonite to syenite of the Cake Hill Pluton felsic phase in monzodiorite of Three Sisters Pluton central phase
76		≤20 cm long	elongate inclusions are parallel to mineral foliation at 347/73
			locally elongate inclusion and schlieren parallel foliation at 327/73
	10		elongate inclusions crudely parallel faint foliation at 115/43
77	1-5		rounded, fine-grained diorite
78	1-2		fine-grained diorite composition

APPENDIX 6.1 (continued)

a) Inclusions (cont'd)

ii) Central Phase (cont'd)

Location (at or near station:)	Abundance (%)	Dimensions	Comments
80	2	≤10 cm long	rounded inclusions
81	≤10	≤5 cm long	rounded inclusions
82	≤5		rounded inclusions
83	≤1	2 cm long	rounded diorite inclusions
84	1		
87	≤50	5 cm long (average size)	abundant angular fine- grained dioritic in- clusions in monzodiorite agmatite
101	1-5	≤5 cm long	rounded, fine-grained diorite
108	20-50	≤15 cm long	rounded to elongate inclusions of fine-grained hornblende diorite increase in size and abundance towards station location
113	5	3-5	elongate inclusions parallel foliation developed in mafics and felsic minerals
	10	≤30	
114	5-10		rounded fine- to medium- grained hornblende diorite
115	≤5	10-15 cm long	rounded to elongate fine- grained biotite hornblende diorite
116	7		fine-grained diorite
124	≤5	3 cm (average)	rounded, fine-grained diorite inclusions
134	30	3 cm long	rounded, fine-grained biotite diorite inclusions
	10	≤35 cm long	

APPENDIX 6.1 (cont'd)

a) Inclusions (cont'd)

ii) Central Phase (cont'd)

Location (at or near station:)	Abundance (%)	Dimensions	Comments
	5	≤ 20 cm long	elongate to rounded inclusions
135	< 5	≤ 20 cm long	rounded to elongate fine-grained diorite inclusions
138	1-3	2 cm long (average)	rounded, fine-grained diorite
	1	2 cm long (average)	rounded, fine-grained diorite
140	2-5	≤ 5 cm long	rounded, fine-grained diorite inclusions
143	1-5		small, rounded fine-grained diorite inclusions
145	1-3	≤ 20 cm long	rounded to oval inclusions
146	≤ 3	≤ 2 cm long	rounded, fine-grained diorite inclusions
150	1-3		rounded to subrounded greenstone inclusions
153	≤ 2	≤ 3 cm long	rounded to oval, fine-grained diorite inclusions
154	≤ 2	≤ 5 cm long	rounded
155	≤ 5	≤ 30 cm long	rounded to subangular
156	≤ 50	≤ 30 cm long	subangular
	≤ 5	≤ 10 cm long	rounded
161	≤ 1	≤ 3 cm long	rounded
168			rare angular hornblende inclusion
178	≤ 5		rounded inclusions
179	≤ 5	≤ 3 cm long	rounded, fine-grained diorite inclusions

APPENDIX 6.1 (cont'd)

a) Inclusions (cont'd)

ii) Central Phase (cont'd)

Location (at or near station:)	Abundance (%)	Dimensions	Comments
264	1	≤3 cm long	rounded, fine-grained diorite inclusions
333	≤3	≤5 cm long	rounded, fine-grained diorite inclusions
	60	≤30 cm long	fine-grained diorite inclusions are rounded to sub-angular in monzodiorite (central phase) agmatite
334	2-5	≤5 cm long	elongate to rounded fine-grained diorite inclusions
335	≤20 (average ≤5)	≤15 cm long	elongate to rounded diorite inclusions
336	5-7	≤20 cm long	rounded to elongate diorite inclusions
450	1-3	≤25 cm long	elongate, oblong or rounded
451	≤5		rounded, fine-grained diorite inclusions
469	1-2	≤4 cm long	randomly oriented, rounded to elongate fine-grained diorite inclusions
470		≤10 cm long (average size 5 cm long)	
471	1	≤5 cm long	rounded, fine-grained diorite inclusions
472	<<1	≤1 cm long	rounded, fine-grained diorite inclusions are more easily seen on weathered surface than in finer-grained monzodiorite

APPENDIX 6.1 (cont'd)

a) Inclusions (cont'd)

ii) Central Phase (cont'd)

Location (at or near station:)	Abundance (%)	Dimensions	Comments
473	1		
474	<1	1 cm long	rounded dioritic inclusions
480	<1		rounded, fine-grained diorite inclusions
486			rare inclusions
	<<1		rounded inclusions
492		1-5 cm long	uncommon, rounded fine-grained diorite inclusions
493	<<1		fine-grained monzodiorite inclusions
497	<<1		one large (30 cm) rounded plagioclase porphyry diorite inclusion
505	≤3%	≤5 cm long	rounded to elongate inclusions in monzodiorite apophysis in Cake Hill Pluton
		≤1 m long	angular to rounded fine-grained diorite inclusion and rare pink granite inclusion
	≤30-40	1-30 cm long	inclusion-bearing monzodiorite in very heterogeneous zone (Cake Hill Pluton, and Three Sisters Pluton potassic marginal and central phase occur together)
			further east observe elongate inclusion and schlieren in massive monzodiorite ground-mass
506	1-2		small rounded, fine-grained diorite inclusions

APPENDIX 6.1 (cont'd)

a) Inclusions (cont'd)

ii) Central Phase (cont'd)

Location (at or near station:)	Abundance (%)	Dimensions	Comments
	2-3	≤30 cm long (average 2-4 cm long)	fine-grained diorite inclusions
508	≤5 (average 2)	≤5 cm long	rounded, fine-grained diorite inclusions
509	1-2	≤10 cm long	
510	1-2	≤5 cm long	rounded, fine-grained diorite inclusions
524	2	≤2 cm long	
525	10-20	≤1 m long	fine-grained diorite inclusions are elongate, oval blocky or rounded and are randomly oriented or define a foliation
	≤5	1-2 cm long	fine-grained diorite inclusions
526	1-2	1-10 cm long	
528	<1		rounded, fine-grained diorite inclusions
529	1-3	≤15 cm long (average 2-5 cm long)	rounded, fine-grained diorite inclusion
530			rounded, fine-grained diorite inclusions
534	1	≤10 cm long	fine-grained diorite in- clusions and one inclusion of acicular hornblende diorite (mafic phase) and one 12-15 cm long inclusion of Cake Hill Pluton in monzodiorite (central phase) apophysis in Cake Hill Pluton

APPENDIX 6.1 (cont'd)

a) Inclusions (cont'd)

ii) Central Phase (cont'd)

Location (at or near station:)	Abundance (%)	Dimensions	Comments
535	15-20	≤15 cm long (average 2-5 cm long)	rounded to elongate fine- grained diorite inclusions
538	<<1	1 cm long	fine-grained diorite inclusions
539	≤1	1-2 cm long	fine-grained diorite inclusions
550	30-40	2-10 cm long	rounded to oblong fine- grained diorite inclusions occur locally in monzodiorite agmatite especially along the contact between the Cake Hill Pluton and the monzodiorite (Three Sisters Pluton, central phase) rare, meta-augite por- phyry inclusions also occur in agmatite
552	≤2	≤2 cm long	inclusions finer-grained monzodiorite than host
555	2-3	2-3 cm long	elongate fine-grained diorite inclusions parallel foliation in monzodiorite
572	1	2-5 cm long	rounded fine-grained diorite inclusions
		2 m x 1.5 m x 1.0 m	inclusion of acicular horn- blende diorite (mafic phase) in monzodiorite
	≤15		fine-grained diorite inclusions

APPENDIX 6.1 (cont'd)

a) Inclusions (cont'd)

ii) Central Phase (cont'd)

Location (at or near station:)	Abundance (%)	Dimensions	Comments
573	1-2		
	2-4		fine-grained diorite inclusions
	1-2	1-3 cm long	rounded, fine-grained diorite to amphibolite inclusions
577	1-2		rounded, fine-grained diorite inclusions
612		1-3 cm long	common angular, fine- grained diorite or monzodiorite inclusions in central phase apophysis intruding the met- amorphosed Cake Hill Pluton
652	1-3	2-10 cm long	elongate to rounded fine- grained diorite inclusions contain rare plagioclase megacrysts
	10-15	30-40 cm long	elongate to rounded fine- grained diorite inclusions which locally parallel mineral foliation (SEE PLATE VI D)
658	1	1-2 cm long	rounded, fine-grained diorite inclusions
659	1	1-3	rounded to elongate, fine- grained diorite inclusions
660	1-2		small rounded, fine-grained diorite inclusions
662			abundant fine-grained hornblende diorite in- clusions occur in mon- zodiorite apophyses
663		0.5 m	angular fine-grained hornblende monzodiorite to diorite inclusions in agmatite

APPENDIX 6.1 (cont'd)

a) Inclusions (cont'd)

ii) Central Phase (cont'd)

Location (at or near station:)	Abundance (%)	Dimensions	Comments
664	2-4	2-5 cm long	rounded inclusions locally elongate inclusions parallel mineral foliation
665	7-10	≤10 cm long	subrounded to subangular fine-grained diorite inclusions
	1-2		
666	<1	4-6 cm long	rounded, fine-grained diorite inclusions
667	1-2	1-3 cm long	rounded, fine-grained monzodiorite to diorite inclusions
	>25	10 cm long (average size)	varies from common rounded inclusions to agmatite finally farther east to typical in- clusion content (2-5%, average size 7 cm)
668	1-2	3-5 cm long	rounded inclusions
669	1-2	1-2 cm long	rounded fine-grey diorite inclusions
670	<1		
671	2	25 cm long (average size 5 cm long)	rounded, fine-grained diorite inclusions
672	1-2		rounded inclusions
673	≤1-2	2-4 cm long	rounded, fine-grained diorite inclusions
676	≤25	≤30 cm long (average 15 cm long)	fine-grained diorite inclusions elongate and define a vertical lineation and locally a faint to moderate foliation

APPENDIX 6.1 (cont'd)

a) Inclusions (cont'd)

ii) Central Phase (cont'd)

Location (at or near station:)	Abundance (%)	Dimensions	Comments
677	1	2-10 cm long	round, fine-grained diorite inclusions
678	1	≤10 cm long (average 2-4 cm long)	fine-grained monzodiorite inclusions
	≤10	≤20 cm long	rounded, to subangular to elongate fine-grained diorite inclusions randomly oriented or locally lineated subvertically
679	<1		
680	1-2		typical fine-grained diorite inclusions
681	1	2-5 cm long	rounded, fine-grained biotite monzodiorite inclusions
	≤5	≤15 cm long	rounded inclusions
682	1-2	5-10 cm long	
683	≤1	2-5 cm long	rounded, fine-grained mon- zodiorite inclusions
686	1		small rounded inclusions
	1	≤30 cm long (average 5-10 cm long)	rounded, fine-grained diorite or monzodiorite inclusions
687	2-3	≤10 cm long (average 2-4 cm long)	rounded inclusions
688	2	≤10 cm long (average 2-5 cm long)	rounded, fine-grained diorite inclusions

APPENDIX 6.1 (cont'd)

a) Inclusions (cont'd)

iii) Potassic Marginal Phase

Location (at or near station:)	Abundance (%)	Dimensions	Comments
138	1-2	≤5 cm long	diorite inclusions
407	1-2		rounded, fine-grained diorite inclusions
439	≤2	2-5 cm long	irregular black diorite inclusions
505	<1	1-2 cm long	fine-grained diorite inclusions in potassic marginal phase apophysis in Cake Hill Pluton
522	≤7	10-20 cm long	blocky, common metamorphosed "augite" (hornblende) porphyry inclusions and less common Cake Hill Pluton inclusions
551		1-4 cm long	rounded, fine-grained diorite inclusions are contained in latest quartz syenitic apophysis to intrude the Cake Hill Pluton
573		10-20 cm long	locally agmatitic with fine-grained diorite inclusions

APPENDIX 6.1 (cont'd)

a) Inclusions (cont'd)

iv) Leucocratic Phase

Location (at or near station:)	Abundance (%)	Dimensions	Comments
494			rare but widespread light grey fine-grained horn- blende monzonite inclusions (apparently mineralogically similar though finer-grained, to host rock)
550			rare fine grained dioritic inclusions

APPENDIX 6.2 - STRUCTURAL DATA FOR THE THREE SISTERS PLUTON

a) Mineral foliation

i) Mafic phase mineral foliation

Location (at or near station:)	Conventional Orientation Quality of Foliation		
	Poor	Moderate	Good
77		323/80	
95		295/43	290/48 286/24
663			48/20 345/6 3/27

ii) Central phase mineral foliation

75	120/76	43/90	
76	176/60 295/43		254/84 347/73 327/73
77			315/74
102	105/80 103/68		
113	38/45	58/54	316/40
116		115/35	
332	314/64		
421			288/52
555			294/22
652			307/72
659	92/77 275/58		
664		293/32	240/33 273/36

APPENDIX 6.2 (cont'd)

a) Mineral foliation (cont'd)

iii) Central phase inclusion foliation

Location
(at or near
station:)Conventional Orientation
Quality of Foliation,
Moderate

Poor

Good

525

23/20

577

22/68

(schlieren in
monzodiorite)

653

359/64

312/62

(SEE PLATE VI D)

654

352/63

676

170/43

20/50

APPENDIX 6.2 - STRUCTURAL DATA FOR THE THREE SISTERS PLUTON

(b) Mineral lineation

(i) Mafic phase mineral lineation			
Location (at or near station:)	Conventional Orientation Quality of Lineation		
	Poor	Moderate	Good
76		243/27	
96		104/43	

Location (at or near station:)	(ii) Central Phase inclusion lineation		
	Conventional Orientation		
	Quality of Lineation		
	Poor	Moderate	Good
134		100/35	80/75
676			vertical
678			subvertical

APPENDIX 6.3 - INTRUSIVE RELATIONS INVOLVING THE THREE SISTERS PLUTON

a) Intrapluton intrusive relations

INTRUSIVE RELATIONS INVOLVING THE FINE-GRAINED PHASE AND MAFIC PHASE

Location (at or near station:)	Comments
99	contact between fine-grained monzodiorite (fine-grained phase) and acicular hornblende diorite (mafic phase) is poorly known but may be gradational
100	where actual sharp contacts between hornblende diorite (mafic phase) and fine-grained diorite or monzodiorite (fine-grained phase) are seen, intrusive relations are equivocal
488	fine-grained diorite occurs as inclusions in acicular hornblende diorite stockwork
491	over 15 m interval the fine-grained monzodiorite is gradational with equant hornblende porphyry diorite (mafic phase) which itself grades into acicular hornblende diorite (mafic phase)
555	fine-grained diorite (fine-grained phase) is locally intruded by apophyses of fine- to medium-grained acicular hornblende diorite (mafic phase) in two localities (SEE PLATE VI F)
656	fine-grained monzodiorite (fine-grained phase) forms angular blocks 20-30 cm long which compose at least 25 per cent of acicular hornblende diorite (mafic phase) stockworks and agmatites
657	fine-grained diorite (fine-grained phase) caught up in monzodiorite (central phase) stockworks and agmatites blocks are up to 3 m long, angular and account for 5-50 per cent of outcrop

INTRUSIVE RELATIONS INVOLVING THE FINE-GRAINED PHASE AND CENTRAL PHASE

62	locally near this station, monzodiorite (central phase) forms stockworks in fine-grained diorite (fine-grained phase) separating subrounded to angular blocks (up to 20 cm long) of the latter phase
----	--

APPENDIX 6.3 (cont'd)

a) Intrapluton intrusive relations (cont'd)

FINE-GRAINED PHASE AND CENTRAL PHASE

Location
(at or near
station:)

Comments

86,
87

at one contact (station 87) between fine-grained monzodiorite to diorite (fine-grained phase) and medium-grained monzodiorite (central phase), a monzodiorite agmatite with up to 50 per cent angular fine-grained dioritic to monzodioritic inclusions is developed

at other contacts the two phases are separated by a white aplite dike (station 86) or the fine-grained phase apparently becomes coarser-grained and grades into the central phase

112

fine-grained diorite (fine-grained phase?) is included in monzodiorite stockwork (central phase)

137

fine-grained diorite (fine-grained phase?) included in monzodiorite agmatite (central phase)

477

contacts between fine-grained monzodiorite (fine-grained phase) and monzodiorite (central phase) are well-exposed, irregular and equivocal with respect to intrusive relations (SEE PLATE VII A)

486,
487

contact between fine-grained slightly porphyritic diorite (fine-grained phase) and monzodiorite (central phase) is clearly gradational

551

fine-grained diorite apophysis (fine-grained phase) in Cake Hill Pluton is broken up by irregular monzodiorite apophysis (central phase) (SEE PLATE VI G,H)

555

near outcrops where fine-grained phase is intruded by mafic phase, it is also caught up in monzodiorite (central phase) agmatites

656

fine-grained monzodiorite (fine-grained phase) forms angular blocks 30-50 cm long which compose at least 25 per cent of quartz monzodiorite (central phase) stockworks and agmatites

APPENDIX 6.3 - (cont'd)

a) Intrapluton intrusive relations (cont'd)

FINE-GRAINED PHASE AND CENTRAL PHASE

Location (at or near station:)	Comments
--------------------------------------	----------

659	angular fine-grained hornblende diorite (fine-grained phase) blocks (up to 3 m long) are caught up in monzodiorite (central phase) stockworks
-----	---

INTRUSIVE RELATIONS INVOLVING THE FINE-GRAINED PHASE AND POTASSIC MARGINAL PHASE

99	contact between the quartz syenite and syenite (potassic marginal phase) and fine-grained monzodiorite (fine-grained phase) is abrupt and well bracketed but intrusive relations are poorly known
----	---

INTRUSIVE RELATIONS INVOLVING THE FINE-GRAINED PHASE AND LEUCOCRATIC PHASE

489	2 m wide, epidote-bearing felsite (leucocratic phase?) intrudes the fine-grained phase monzodiorite at conventional orientation of 23/73
-----	--

INTRUSIVE RELATIONS INVOLVING THE MAFIC PHASE AND CENTRAL PHASE

76	lineated acicular hornblende diorite (mafic phase) occurs with monzodiorite (Three Sisters Pluton, central phase) but contact relationships are poorly known
----	--

77	fine-grained biotite-acicular hornblende diorite (mafic phase) contacts inclusion-bearing biotite hornblende quartz monzodiorite (central phase) but intrusive relations are not known
----	--

near this locality the medium-grained acicular hornblende diorite (mafic phase) becomes increasingly finer-grained near contact with inclusion-bearing monzodiorite (central phase)

79	small intervals of acicular hornblende diorite (mafic phase) alternate with wider intervals of quartz monzodiorite (central phase) but intrusive relationships are unknown
----	--

95	contact between acicular hornblende diorite (mafic phase) and monzodiorite (central phase) is bracketed but only poorly exposed in felsenmeer
----	---

APPENDIX 6.3 (cont'd)

a) Intrapluton intrusive relations (cont'd)

INTRUSIVE RELATIONS INVOLVING THE MAFIC PHASE AND CENTRAL PHASE (cont'd)

Location (at or near station:)	Comments
96,97	contact between acicular hornblende diorite (mafic phase) and monzodiorite (central phase) is bracketed but poorly exposed or known
100	contact between acicular hornblende diorite (mafic phase) and monzodiorite (central phase) is approximately bracketed but intrusive relations are not known
112	in two exposures near station 112, contacts between hornblende gabbro (mafic phase) and monzodiorite (central phase) occur. At one contact, the hornblende gabbro is clearly included in a monzodiorite stockwork; at the other contact the intrusive relations are not exposed
137	acicular hornblende diorite (mafic phase) included in monzodiorite stockworks and agmatite (central phase)
335	contact between acicular hornblende diorite (mafic phase) and monzodiorite (central phase) well bracketed but intrusive relations poorly exposed
470	at contact between small screen of acicular hornblende diorite (mafic phase) and monzodiorite (central phase), the hornblende diorite decreases in grain size towards the contact
475	15-20 cm long, rounded acicular hornblende diorite (mafic phase) inclusions occur in monzodiorite (central phase) near its contact with the remobilized Cake Hill Pluton
491	contact between mafic and central phases is poorly exposed
527	irregular hornblende monzodiorite (central phase) dikelets intrude and form stockwork in hornblende gabbro (mafic phase).
528	monzodiorite stockwork (central phase) developed in equigranular to acicular hornblende gabbro to diorite (mafic phase) (SEE PLATE VII B)

APPENDIX 6.3 (cont'd)

a) Intrapluton intrusive relations (cont'd)

INTRUSIVE RELATIONS INVOLVING THE MAFIC PHASE AND CENTRAL PHASE (cont'd)

Location (at or near station:)	Comments
528 (cont'd)	<p>mafic phase fragments are 10-15 cm long and angular to elongate</p> <p>mafics in monzodiorite and foliated parallel to irregular stockwork margins</p>
536	thin (5-10 cm wide) but irregular leucocratic hornblende monzodiorite apophysis in mafic phase
538	<p>broad zone of monzodiorite (central phase) stockworks are developed in hornblende gabbro (mafic phase)</p> <p>irregular foliation developed in monzodiorite parallels and reflects irregular orientation of apophyses</p> <p>farther southeast, a 10 m wide inclusion-bearing monzodiorite (central phase) intrudes gabbro of the mafic phase</p>
539	anastomosing monzodiorite stockworks occur in fine-grained equivalent of acicular hornblende diorite
540	monzodiorite (central phase) adjacent contact with fine-grained diorite (mafic phase) contains inclusions of similar lithology to the fine-grained diorite
551	<p>the fine-grained phase apophysis is chilled along its contact with the Cake Hill Pluton but increases in grain size towards center to an acicular hornblende diorite</p> <p>the finer-grained variety locally contains small inclusions</p>
555	monzodiorite (central phase) apophyses intrude acicular hornblende diorite (mafic phase)
572	contact between equant hornblende porphyry diorite (mafic phase) and hornblende-biotite monzodiorite is poorly exposed

APPENDIX 6.3 (cont'd)

a) Intrapluton intrusive relations (cont'd)

INTRUSIVE RELATIONS INVOLVING THE MAFIC PHASE AND CENTRAL PHASE (cont'd)

Location
(at or near
station:)

Comments

- 573 medium-grained hornblende-biotite monzodiorite (central phase) contains acicular hornblende diorite (mafic phase) inclusions
- 653 intrusive relations between monzodiorite (central phase) and equant hornblende porphyry diorite and acicular hornblende diorite (mafic phase), which occur together in very heterogeneous zone, are unknown
- 656 apophyses and stockworks of monzodiorite (central phase) intrude hornblende gabbro and monzodiorite (mafic phase)
- gabbro has seriate texture but grain size unrelated to location of monzodiorite apophyses
- 657 acicular hornblende diorite and equant hornblende porphyry diorite (mafic phase) form blocks in monzodiorite stockworks and apophyses
- blocks are up to 3 m long, angular and account for 5-50 per cent of outcrop
- 659 acicular hornblende diorite (mafic phase) gradationally becomes a fine- to medium-grained diorite towards its sharp contact with the monzodiorite (central phase)
- the acicular hornblende diorite also develops coarse- to medium-grained biotite towards the contact
- at another nearby locality, a fine- to medium-grained equant hornblende porphyry diorite (mafic phase) appears to grade to a more mafic monzodiorite typical of the central phase
- farther north, intervals of seriate, fine- to medium-grained acicular hornblende diorite and equant hornblende porphyry diorite (mafic phase) alternate with intervals of and are intruded by stockworks of monzodiorite (central phase)

APPENDIX 6.3 (cont'd)

a) Intrapluton intrusive relations (cont'd)

INTRUSIVE RELATIONS INVOLVING THE MAFIC PHASE AND CENTRAL PHASE (cont'd)

Location (at or near station:)	Comments
659 (cont'd)	fine-grained monzodiorite and diorite with common acicular hornblendes also make up blocks in these stockworks
661	acicular diorite blocks (mafic phase) are intruded by monzodiorite (central phase) stockworks a crude foliation around the mafic phase inclusions is developed in the central phase and the mafic phase inclusions are noticeably chilled within a few centimeters of the monzodiorite
662	near monzodiorite (central phase) apophysis biotite is developed in equigranular hornblende diorite as a subordinate mafic
663	rare monzodiorite (central phase) apophyses in acicular hornblende diorite (mafic phase)
683, 684	one screen of acicular hornblende diorite (mafic phase) is oriented 130/70 in monzodiorite (central phase) and other screens of acicular hornblende diorite are intruded by apophyses of monzodiorite (central phase) the irregular contacts are marked by an increase in biotite content and fine-grained diorite inclusion content in the monzodiorite and a reduction in grain size (but little mineralogical change) in the acicular hornblende diorite near the contact (SEE PLATE VII E)
	generally the contact dips south moderately farther west both lithologies distinctive of the mafic phase, acicular hornblende diorite and equant hornblende porphyry diorite, occur together and with monzodiorite of the central phase. The two mafic phase lithologies are clearly gradational and occur as irregular masses in one another; only the acicular hornblende diorite exhibits any grain reduction at the contact with

APPENDIX 6.3 ((cont'd)

a) Intrapluton intrusive relations (cont'd)

INTRUSIVE RELATIONS INVOLVING THE MAFIC PHASE AND CENTRAL PHASE (cont'd)

Location
(at or near
station:)

Comments

683, 684 (cont'd),

the monzodiorite apophyses (generally within 2-5 cm of the contact)

the monzodiorite is uncommonly foliated parallel to the apophysis contacts and locally exhibits an up to 1 cm wide, mafic selvage along each margin; at one locality elongate, fine-grained diorite inclusions in the monzodiorite are oriented parallel to the apophysis contacts

720

fragments of acicular hornblende diorite (Three Sisters Pluton, mafic phase) exhibit finer-grained (chilled?) contacts with monzodiorite of intruding stockwork (Three Sisters Pluton, central phase)
(SEE PLATE VII D)

INTRUSIVE RELATIONS INVOLVING THE MAFIC PHASE AND THE POTASSIC MARGINAL PHASE

98

contacts between syenite and quartz syenite (potassic marginal phase) and equant hornblende porphyry diorite (mafic phase) is bracketed but intrusive relations are not known

103

contacts between syenite (potassic marginal phase) and equigranular hornblende gabbro (mafic phase?) is poorly exposed in felsenmeer

however near the main gabbro body common fine- to medium-grained diorite apophyses and dikes intrude the syenite

104

aplite apophysis (potassic marginal phase) contains mafic biotite-hornblende diorite inclusions (mafic phase?)

138

contact between syenite (potassic marginal phase) and acicular hornblende diorite (mafic phase) is well bracketed but intrusive relations unknown

528

1-2 m wide syenite apophysis (potassic marginal phase) intrudes equigranular hornblende gabbro (mafic phase) along an average contact of 143/33
(SEE PLATE VII C)

APPENDIX 6.3 (cont'd)

a) Intrapluton intrusive relations (cont'd)

INTRUSIVE RELATIONS INVOLVING THE MAFIC PHASE AND THE POTASSIC MARGINAL PHASE (cont'd)

Location
(at or near
station:)

Comments

528 (cont'd)

near the contacts with the apophysis the gabbro becomes more leucocratic and biotite-bearing

572

intrusive relations between granite (potassic marginal phase) and equant hornblende diorite (mafic phase) are masked by lichen cover commonly but at one location a syenite apophysis intrudes the diorite at 33/88

576

near volcanic pendant, a small exposure of hornblende gabbro (mafic phase) presumably intrusive into the volcanics is itself intruded by thin veinlets of syenite or granite (potassic marginal phase) and has biotite megacrysts

660

medium-grained syenite (potassic marginal phase) veins intrude the equant hornblende porphyry diorite (mafic phase)

662

uncommon aplitic hornblende-biotite granite (potassic marginal phase) intrudes hornblende diorite (mafic phase)

farther north hornblende diorite (mafic phase) is apparently intruded by apophyses of syenite and quartz syenite (potassic marginal phase)

663

fine- to medium-grained hornblende diorite (mafic phase) uncommonly intruded by monzodiorite stockworks; however nearby quartz syenite apophysis (potassic marginal phase) is inclusion free and apparently did not participate in stockwork event

INTRUSIVE RELATIONS INVOLVING THE CENTRAL PHASE AND THE FINE-GRAINED PHASE

332

1 m wide dike of fine-grained biotite diorite (fine-grained phase) intrudes biotite monzodiorite (central phase) with average attitude of 263/68

477

near contact with remobilized Cake Hill Pluton fine-grained biotite-hornblende diorite with uncommon plagioclase phenocrysts (fine-grained phase) forms apophyses in the monzodiorite of central phase; however the apophyses are irregular

APPENDIX 6.3 (cont'd)

a) Intrapluton intrusive relations (cont'd)

INTRUSIVE RELATIONS INVOLVING THE CENTRAL PHASE AND THE FINE-GRAINED PHASE (cont'd)

Location
(at or near
station:)

Comments

477 (cont'd)

and the intrusive relations equivocal in some places

the fine-grained phase never appears to contact the remobilized Cake Hill Pluton and generally outcrops 0.1-1 m below the Three Sisters-Cake Hill Pluton's contact

486,487

contact between fine-grained, slightly porphyritic (e.g. similar to fine-grained phase at station 477) is clearly gradational to medium-grained monzodiorite of central phase

489

monzodiorite (central phase) intruded by fine-grained monzodiorite? (fine-grained phase?)

INTRUSIVE RELATIONS INVOLVING THE CENTRAL PHASE AND THE MAFIC PHASE

155

irregular, fine- to medium-grained hornblende porphyry diorite (mafic phase) dike intrudes monzodiorite of central phase; attitude of 2 m wide dike varies between 33/76 and 0/82 and its groundmass consists of fine-grained acicular hornblende diorite

334

7-10 m wide irregular hornblende gabbro (mafic phase) intrudes monzodiorite (central phase)

INTRUSIVE RELATIONS INVOLVING THE CENTRAL PHASE AND THE POTASSIC MARGINAL PHASE

10

hornblende-biotite quartz monzonite (Three Sisters Pluton, central phase) is apparently intruded by fine-grained quartz syenite (potassic marginal phase)

20

medium-grained, mafic hornblende-biotite monzodiorite (central phase) and syenite (potassic marginal phase) occur together near the contact with augite porphyry, but contacts between the two granitic lithologies are not exposed or are not determinative

43

biotite monzodiorite (central phase) is intruded by anastomosing aplite dikes (potassic marginal

APPENDIX 6.3 (cont'd)

a) Intrapluton intrusive relations (cont'd)

CENTRAL PHASE AND THE POTASSIC MARGINAL PHASE (cont'd)

Location (at or near station:)	Comments
43 (cont'd)	phase) near contact with augite porphyry
60	mafic, biotite-hornblende monzodiorite (central phase) occurs within syenite (potassic marginal phase) but their mutual contacts are not exposed although the monzodiorite is intruded by thin, irregular aplite and pegmatite veins
62	contact relationships between monzodiorite and quartz monzonite (central and potassic marginal phases respectively) are not exposed
68	contact is closely bracketed but not well exposed between monzodiorite of central phase and monzonite to quartz syenite of potassic marginal phase
77	near station location, apophysis of medium- to coarse-grained biotite quartz syenite (potassic marginal phase) intrudes monzodiorite (central phase)
78	monzodiorite (central phase) intruded by small quartz syenite (potassic marginal phase) apophysis
97	small apophysis of syenite to quartz syenite (potassic marginal phase) intrudes monzodiorite (central phase)
101	intrusive relations between quartz syenite (potassic marginal phase) and monzodiorite (central phase) is obscured by small shear zone developed at contact
102	sharp contact between monzodiorite (central phase) and thin, slightly finer-grained syenite apophysis (potassic marginal phase) which locally clearly intrudes the central phase
114	intrusive relations between hornblende-biotite monzodiorite (central phase) and small hornblende-biotite syenite apophysis? (potassic marginal phase) are not known although contact is well bracketed
138, 139	location of contact between central and potassic marginal phases is moderately well bracketed but

APPENDIX 6.3 (cont'd)

a) Intrapluton intrusive relations (cont'd)

CENTRAL PHASE AND THE POTASSIC MARGINAL PHASE (cont'd)

Location (at or near station:)	Comments
138, 139 (cont'd)	not investigated
143	quartz syenite (potassic marginal phase) intrudes monzodiorite (central phase) along partly steep (160/63) and partly anastomosing contact country rock contains coarse (≤ 1 cm) alkali feldspar megacrysts
146, 147, 150	rare aplitic quartz syenite veins (potassic marginal phase) intrude monzodiorite (central phase) at station 150, aplitic quartz syenite appears to have intruded along joints in the monzodiorite
158	contact between central phase and potassic marginal phase is covered but bracketed within 1-2 m; lithologies of both phases near the contact are of equal, medium grain size
159	small monzonite pendant (central phase) separated from underlying syenite (potassic marginal phase) by irregular hornblende-biotite aplite which clearly intrudes the central phase and though finer-grained is lithologically identical to other potassic marginal phase lithologies and grades into coarser rocks away from contact the contact is irregular but on average is gently dipping (347/23)
160	monzodiorite to diorite screens (central phase) intruded by common fine- to medium-grained hornblende syenite apophyses and dikes (potassic marginal phase)
162	contact between monzodiorite (central phase) and syenite (potassic marginal phase) is sharp, steep (205/75) and ambiguous with respect to intrusive relations (both lithologies of the same, medium, grain size)
259	contact between potassic marginal and central phases poorly exposed in talus but both units are

APPENDIX 6.3 (cont'd)

a) Intrapluton intrusive relations (cont'd)

CENTRAL PHASE AND THE POTASSIC MARGINAL PHASE (cont'd)

Location
(at or near
station:)

Comments

259 (cont'd)

medium-grained

505

contact between central and potassic marginal phases is well exposed but both lithologies are of equal grain size and intrusive relations are equivocal

528

syenite (potassic marginal phase) which forms apophysis in the mafic phase is clearly gradational away from the contact to monzodiorite typical of the central phase,

farther south, sharp contacts are observed between the monzodiorite and the more irregular anastomosing syenite apophysis; however neither phase appears to be chilled against the other, both phases contain similar inclusion lithologies and an inclusion is shared between the two phases along their contact

539

although contacts between monzodiorite (central phase) and syenite (potassic marginal phase) are sharp and well exposed; no chilling of one phase against the other is apparent and the intrusive relations are equivocal

near this location, thin syenitic veinlets (potassic marginal phase) clearly intrude monzodiorite (central phase)

551

monzodiorite apophysis in Cake Hill Pluton and in the Three Sisters Pluton, fine-grained phase is itself intruded by fine- to medium-grained, leucocratic quartz syenite or granite (potassic marginal phase)

555

fine- to medium-grained granite (potassic marginal phase) intrudes foliated monzodiorite (central phase)

572

fine- to medium-grained locally aplitic granite (potassic marginal phase) becomes finer-grained towards contact with equally fine- to medium-grained monzodiorite (central phase) and thin irregular granite apophyses intrude and include

APPENDIX 6.3 (cont'd)

a) Intrapluton intrusive relations (cont'd)

CENTRAL PHASE AND THE POTASSIC MARGINAL PHASE (cont'd)

Location
(at or near
station:)

Comments

572 (cont'd)

the monzodiorite
(SEE PLATE VII H)

not everywhere are the intrusive relations along the irregular contact so clear-cut; commonly both lithologies are of equal grain size at the contact and no apophyses are visible

573

inclusion-bearing monzodiorite (central phase) is intruded by granite (potassic marginal phase) apophyses (5-15 cm wide) at several localities

577

monzodiorite (central phase) intruded by apophyses of fine- to medium-grained granite which also contains inclusions (up to 2 m x 1.5 m to 10 cm x 8 cm in size) of the monzodiorite

652

granite apophyses (potassic marginal phase) and irregular granite masses occur within monzodiorite (central phase)

some apophyses are up to 15-20 m wide, have 2-3 cm chilled margins and contain rare, large (10-20 cm long) elongate monzodiorite inclusions and one is conventionally oriented 240/80 and 25/75

contacts between irregular masses of granite (potassic marginal phase) and monzodiorite (central phase) are gradational, i.e. both phases are of equal grain size and can be recognized on either side of the "contact" but the actual contact is not sharp

at one locality a fine-grained diorite inclusion is shared across the contact,

at one locality, a small granite body in the monzodiorite is chilled within 4-6 cm of the contact along one border yet is equigranular with the monzodiorite along the other border although fine- to medium-grained veinlets intrude the monzodiorite close to the contact

654

contacts between small granite body (potassic marginal phase) and monzodiorite (central phase)

APPENDIX 6.3 (cont'd)

a) Intrapluton intrusive relations (cont'd)

CENTRAL PHASE AND THE POTASSIC MARGINAL PHASE (cont'd)

Location (at or near station:)	Comments
654 (cont'd)	range from sharp (with 5 cm wide selvages developed in the granite) to gradational
656	hornblende-biotite quartz syenite (potassic marginal phase) also occurs in monzodiorite (central phase) and fine-grained diorite agmatite interval but intrusive relations are poorly known
663	intrusive relations between stockwork-forming monzodiorite (central phase) and homogeneous quartz syenite (potassic marginal phase) apophysis are not exposed farther north, quartz syenite (potassic marginal phase) appears to decrease in grain size to an aplite adjacent poorly exposed contact with monzodiorite (central phase) adjacent this contact the monzodiorite is agmatitic
666	contact between monzodiorite (central phase) and small apophysis of quartz syenites (potassic marginal phase) is gradational but 5 cm above essentially horizontal contact, a thin mafic schlieren is developed in the central phase a simple pegmatite vein intrudes both phases and 10 m from this exposure, monzodiorite extends structurally far below extension of contact and is intruded by an aplite dike
669	two syenite apophyses (potassic marginal phase) apparently intrude monzodiorite (central phase)
671	apparently gradational contacts occur between monzodiorite (central phase) and syenite (potassic marginal phase) apophysis
672	small syenite apophyses (potassic marginal phase) which generally have gradational contacts but at one location, an irregular grey aplite marks one of the contacts

APPENDIX 6.3 (cont'd)

a) Intrapluton intrusive relations (cont'd)

CENTRAL PHASE AND THE POTASSIC MARGINAL PHASE (cont'd)

Location (at or near station:)	Comments
672 (cont'd)	farther west, thin (10 m) apophysis of quartz syenite (potassic marginal phase) intrudes monzodiorite (central phase)
673	contact between central and potassic marginal phases are covered
674	along contacts between syenite apophyses (potassic marginal phase) and monzonite (central phase) the syenite becomes finer-grained within 1 cm of contact but just as commonly, the contact is gradational and both phases are equigranular farther north, the contact between monzodiorite and bluish plagioclase megacryst syenite are poorly exposed in felsenneer.
675	mafic, altered monzodiorite or diorite (central phase) is intruded by stockworks of distinctive hornblende syenite (potassic marginal phase) closer to station location, less altered monzodiorite is also intruded by an irregular, mottled weathering syenite (potassic marginal phase) apophysis
676	over 0.5 km interval, interspersed inclusion-bearing monzodiorite (central phase) and syenite (potassic marginal phase) bodies occur. Although the exposed contacts between the two phases are gradational, syenite veinlets clearly intrude the monzodiorite
678	toward contact with quartz syenite (potassic marginal phase) monzodiorite (central phase) is intruded by dikes of syenite, one conventionally oriented at 153/70 3-5 m to 1-2 cm from the contact, the syenite decreases in grain size to an aplite, syenitic apophyses occur in the monzodiorite and a small (1 cm long) monzodiorite inclusion in the syenite near the contact indicate clear intrusive relationships (SEE PLATE VII F,G)

APPENDIX 6.3 (cont'd)

a) Intrapluton intrusive relations (cont'd)

CENTRAL PHASE AND THE POTASSIC MARGINAL PHASE (cont'd)

Location (at or near station:)	Comments
678 (cont'd)	the average contact between the two phases is fairly flat and alkali-feldspar in the monzodiorite near the contact is pink
680	irregular, almost pegmatitic quartz syenite apophyses (potassic marginal phase) intrude fine- to medium-grained monzodiorite (central phase) at one locality a 7 cm wide syenite vein is "layered" symmetrically with a 2 cm thick plagioclase rich core and 3 cm wide alkali-feldspar margins
686	irregular quartz syenite apophyses (potassic marginal phase) intrude monzodiorite (central phase)
688	small interval of quartz syenite (potassic marginal phase) within monzodiorite (central phase) but intrusive relations are unknown

INTRUSIVE RELATIONS INVOLVING THE CENTRAL PHASE AND THE LEUCOCRATIC PHASE

89	contact between leucocratic hornblende diorite (leucocratic phase) and monzodiorite (central phase) is not exposed but may be bracketed
141	2 m wide leucocratic hornblende diorite dike (leucocratic phase) intrudes hornblende-biotite monzodiorite (central phase) and has the attitude 5/86
144	irregular apophysis of leucocratic quartz diorite (leucocratic phase) intrudes quartz monzodiorite (central phase)
486	extensive but irregular, sucrose-textured leucocratic felsite apophyses (leucocratic phase) occurs in monzodiorite (central phase)
491	felsite (leucocratic phase?) dikes intrude monzodiorite (central phase)
494	contact between central and leucocratic phases

APPENDIX 6.3 (cont'd)

a) Intrapluton intrusive relations (cont'd)

CENTRAL PHASE AND THE LEUCOCRATIC PHASE (cont'd)

Location (at or near station:)	Comments
494 (cont'd)	is poorly exposed in felsenmeer
686	30-50 m wide, tabular, horizontal apophysis of leucocratic diorite (leucocratic phase) intrudes the monzodiorite (central phase); the apophysis is oriented 258/22 to 266/36 farther southwest, 4 m wide leucocratic diorite (leucocratic phase) intrudes the monzodiorite (central phase) at 23/90

INTRUSIVE RELATIONS INVOLVING THE POTASSIC MARGINAL PHASE AND THE FINE-GRAINED PHASE

484	unusual anti-rapakivi textured feldspar porphyry (potassic marginal phase or metamorphosed Cake Hill Pluton?) is intruded by apophyses of fine-grained diorite (fine-grained phase or central phase)
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INTRUSIVE RELATIONS INVOLVING THE POTASSIC MARGINAL PHASE AND THE MAFIC PHASE

522	veinlets of acicular hornblende diorite (mafic phase) intrude syenite (potassic marginal phase)
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INTRUSIVE RELATIONS INVOLVING THE POTASSIC MARGINAL PHASE AND THE CENTRAL PHASE

60	mafic, hornblende-biotite monzodiorite (Three Sisters Pluton, central phase) occurs within syenite (Three Sisters Pluton, potassic marginal phase) but their mutual contacts are not exposed although the monzodiorite is intruded by thin, irregular aplite and pegmatite veins
----	--

INTRUSIVE RELATIONS INVOLVING THE POTASSIC MARGINAL PHASE AND THE LEUCOCRATIC PHASE

6, 447	anastomosing leucocratic diorite apophyses (leucocratic phase) intrude hornblende-biotite syenite, (potassic marginal phase)
159	0.5-1 m wide leucocratic hornblende quartz diorite dikes (leucocratic phase) intrude syenite of potassic marginal phase and are themselves intruded

APPENDIX 6.3 (cont'd)

a) Intrapluton intrusive relations (cont'd)

INTRUSIVE RELATIONS INVOLVING THE POTASSIC MARGINAL PHASE AND THE LEUCOCRATIC PHASE

Location (at or near station:)	Comments
159 (cont'd)	by hornblende porphyry dikes
610	30-50 cm wide irregular hornblende leucodiorite (leucocratic phase) apophysis intrudes granite (potassic marginal phase)

b) Intraphase intrusive relations

INTRUSIVE RELATIONS INVOLVING SUBPHASES IN THE POTASSIC MARGINAL PHASE

Location (at or near station:)	Comments
20	contact between equigranular medium-grained syenite and porphyritic anti-rapakivi syenite is bracketed but not exposed

c) External intrusive relations

INTRUSIVE RELATIONS INVOLVING THE THREE SISTERS PLUTON (ALL PHASES)
AND TRIASSIC? OR OLDER VOLCANICS AND SEDIMENTS

Location (at or near station:)	Comments
419, 437	biotite granite (Three Sisters Pluton, potassic marginal phase) intrudes thin bedded tuffs and quartz-rich sandstones of Triassic? age
421	heterogeneous granite intrudes and includes (as angular, long xenoliths) the grey thin bedded Triassic? tuff

APPENDIX 6.3 (cont'd)

c) External intrusive relations (cont'd)

INTRUSIVE RELATIONS INVOLVING THE THREE SISTERS PLUTON (ALL PHASES)

AND UPPER TRIASSIC STUHINI GROUP VOLCANICS

Location (at or near station:)	Comments
4	syenitic plagioclase porphyry (Three Sisters Pluton, potassic marginal phase) is chilled adjacent to its sharp contact with fine-grained augite? porphyry
19, 436	mafic hornblende-biotite monzodiorite (Three Sisters Pluton, central phase) and fine-grained, locally aplite granite and quartz syenite (Three Sisters Pluton, potassic marginal phase) occur near the contact with augite porphyry volcanics and in the case of the potassic marginal phase, clearly form stockworks and agmatites in the hornfelsed augite porphyry (SEE PLATE VIII A)
28	uncommon hornblende-biotite monzodiorite (Three Sisters Pluton, central phase) apophyses intrude augite porphyry volcanics
37, 38	fine-grained maroon, poorly to thin bedded hornfelsed argillite occurs but no Three Sisters Pluton contacts are exposed
42, 43, 44,	medium-grained biotite monzonite to monzodiorite (Three Sisters Pluton, central phase) is replaced by aplite (Three Sisters Pluton, potassic marginal phase) close to the contact with locally bleached-looking silicified augite porphyry volcanics
45	aplitic granite and biotite-rich monzodiorite (Three Sisters Pluton, potassic marginal and central phases respectively) occur along contact with altered augite porphyry but their mutual relationship is not exposed.
70	abundant dikes of pink and light grey aplite and coarser grained biotite monzonite intrude and metamorphose augite porphyry volcanics

APPENDIX 6.3 (cont'd)

c) External intrusive relations (cont'd)

Location (at or near station:)	Comments
349-354	contact between Upper Triassic volcanics (augite porphyry, andesite, volcanic breccia) is fairly shallow to plot; the syenite to granite of the potassic marginal phase locally becomes finer-grained towards contact and the volcanics locally appear metamorphosed (amphibolitic groundmass or hornfelsed appearance to tough rock)
520	hornblende syenite (Three Sisters Pluton, potassic marginal phase) forms stockwork and agmatites in bladed plagioclase porphyry volcanics near contact with pendant (SEE PLATE VIII B)
549, 550	syenite (potassic marginal phase) forms stockworks and agmatites in fine-grained amphibolite, andesite and augite porphyry at station 550 monzodiorite (central phase) and fine- to medium-grained acicular hornblende diorite (mafic phase) to leucocratic diorite (leucocratic phase) also form stockworks in the metavolcanic; predominantly angular meta-augite porphyry inclusions have maximum sizes of 1-2 m; smaller ones occur in a monzodiorite agmatite
572	equant hornblende diorite (mafic phase) and hornblende biotite monzodiorite (central phase) intrude and include metamorphosed augite porphyry
574	at contact with volcanics, plutonic rock is medium-grained to aplitic granite (potassic marginal phase); few intrusive relations (other than chilling of the granite) are deduced but where volcanics are medium-grained thin apophyses intrude the volcanics at the contact

APPENDIX 6.3 (cont'd)

c) External intrusive relations (cont'd)

Location
(at or near
station:)

Comments

349-354

contact between Upper Triassic volcanics (augite porphyry, andesite, volcanic breccia) is fairly shallow to plot; the syenite to granite of the potassic marginal phase locally becomes finer-grained towards contact and the volcanics locally appear metamorphosed (amphibolitic groundmass or hornfelsed appearance to tough rock

520

hornblende syenite (Three Sisters Pluton, potassic marginal phase) forms stockwork and agmatites in bladed plagioclase porphyry volcanics near contact with pendant (SEE PLATE VIII B)

549, 550

syenite (potassic marginal phase) forms stockworks and agmatites in fine-grained amphibolite, andesite and augite porphyry

at station 550 monzodiorite (central phase) and fine- to medium-grained acicular hornblende diorite (mafic phase) to leucocratic diorite (leucocratic phase) also form stockworks in the metavolcanic; predominantly angular meta-augite porphyry inclusions have maximum sizes of 1-2 m; smaller ones occur in a monzodiorite agmatite

572

equant hornblende diorite (mafic phase) and hornblende biotite monzodiorite (central phase) intrude and include metamorphosed augite porphyry

574

at contact with volcanics, plutonic rock is medium-grained to aplitic granite (potassic marginal phase); few intrusive relations (other than chilling of the granite) are deduced but where volcanics are medium-grained thin apophyses intrude the volcanics at the contact

APPENDIX 6.3 (cont'd)

c) External intrusive relations (cont'd)

Location
(at or near
station:)

Comments

potassic alteration along fractures in the volcanics occurs near the volcanic-plutonic contact

locally the granite or aplite becomes more mafic and medium- to coarse-grained 5-8 cm adjacent the contact with the volcanics

within 0.25 - 0.5 km of contact a well developed 5 - 15 cm spaced jointing is developed in the volcanics at 65/54, 40/43 or 47/53 depending on locality but restricted to contact area

575

volcanics commonly altered adjacent their contact with the granite (potassic marginal phase) to resemble "granitic"-looking rock

576

plutonic-volcanic contact is irregular and may reverse dip in detail but generally dips gently east

pendant is clearly intruded by granite apophyses and stockworks

577

although no apophyses intrude basal members of Triassic section, the monzodiorite (central phase) becomes more leucocratic within 10-15 cm of contact and contains rare small (2-4 cm long) metavolcanic inclusions

620

irregular hornblende monzonite apophyses intrude augite porphyry volcanics

675

distinctive hornblende syenite forms stockworks in small altered plagioclase porphyry volcanic ? screen

APPENDIX 6.3 (cont'd)

c) External intrusive relations (cont'd)

INTRUSIVE RELATIONS INVOLVING THE THREE SISTERS PLUTON AND THE TOARCIAN

SEDIMENTS
Location
(at or near
station:)

Comments

343, 459

thin bedded sediments and carbonate
are flinty and clearly metamorphosed due
to proximity of remobilized Cake Hill Pluton
and proximity to Three Sisters Pluton

APPENDIX 6.4 HYPABYSSAL DIKES IN THE THREE SISTERS PLUTON

a) Andesite dikes

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Mafic Phase</u>				
98	grey-green andesite	253/57	1.5	
<u>Central Phase</u>				
76	grey-green andesite	176/83 353/83	2 0.3	
113	brownish-grey andesite	232/80	4	dike highly cleaved
134	green-grey andesite	182/55 005/90	1.5 2	
136	green-grey andesite	165/61	1	
139	andesite	140/60 188/76 10/90	dikes 0.3-1 m wide	
140	amygdaloidal andesite	2/83	1.5	
141	green andesite	23/90	4	°
142A	andesite	168/80 160/78 150/70	1.5 1	one andesite dike intrudes syenitic plagioclase porphyry
143	andesite	182/87 175/66	2 0.3	
144	andesite	155/62 175/85	1 10	andesite dikes common and are par- allel to these attitudes
145	green andesite	182/45	1	
146	green andesite	160/87 183/74	0.4 2	
147	green andesite	185/82 152/76	3 0.8	

APPENDIX 6.4 (cont'd)

a) Andesite dikes (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Central Phase</u> (cont'd)				
149	andesite	186/57	0.6	
150	andesite	97/75	2.5	
155	dark green andesite	163/74		
156	grey andesite	51/83	1	
	green andesite	57/67	1	
	green andesite	40/60 (irregular)	1	
157	green andesite	215/70	1	attitude highly variable highly cleaved
	brown andesite	183/83	0.8	
176	grey andesite	245/80	1	
183	green-grey andesite	201/70	2	
505	dun brown andesite	195/78	1.5	
509	greenish-brown andesite	164/64	0.5	
530	grey-green andesite	trends 160°	0.75	poorly exposed felsenmeer
539	grey-green andesite			poorly exposed
	brownish-grey andesite	173/66	2.5	
654	brown weathering andesite	340/80 (average)	2	
657	green-grey andesite	165/72 160/78	0.6 0.6	
663	grey-green andesite	210/85 10/90 30/90 213/84 40/83 208/62	1.5 2 0.2 2	

APPENDIX 6.4 (cont'd)

a) Andesite dikes (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Central Phase (cont'd)</u>				
665	green-grey andesite	199/85	0.70	
		178/80	2.0	
		15/90	0.40	
		180/83	0.45	
		185/66	4.0	
		160/63	0.6	
		195/85	1.0	
		170/66	1.5	
		200/74	0.80	
666	green-grey andesite	213/84	0.8	dike is sheared
671	epidotized andesite	200/78	0.60	
672	green andesite	195/85		
677	greenish-grey andesite			poorly exposed dike
679	greyish-green andesite	160/70	0.6	
		177/70	0.7	
C-1a	green andesite	352/88	1.3	
683	green-grey andesite	165/70	1.5	
684	green-grey andesite	182/62	1	
686	green-grey andesite	150/78	0.60	
		341/68	0.75	
		11/54	0.70	
		142/78	0.80	
		18/84	0.50	
687	greenish-grey andesite	158/83	0.90	poorly exposed in felsemeer
		163/70	1.8	
		190/72		
		183/86	0.40	
		168/90		
<u>Potassic Marginal Phase</u>				
6,447	grey, fine-grained andesite	175/73	1.1	intrudes potassic marginal phase.

APPENDIX 6.4 (cont'd)

a) Andesite dikes (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Potassic Marginal Phase</u> (cont'd)				
6,447 (cont'd)				syenite; locally dike contains hornblende pheno- crysts
11	grey andesite	14/84	0.67	
143	andesite	160/85	1	
160	andesite	215/63	1.5	rare hornblende phenocrysts
162	andesite	203/65	2	
182	andesite	190/80 (approximate)		poorly exposed
572	grey andesite	215/28	0.8	2 cm wide chilled margins
662	grey-green andesite	186/68		
663	greenish-grey andesite	181/65	0.65	
<u>Leucocratic Phase</u>				
686	greenish-grey andesite	155/72	0.90	

APPENDIX 6.4 (cont'd)

b) Porphyry dikes

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Central Phase</u>				
64	syenitic hornblende- plagioclase porphyry	contacts not well exposed		fine-grained grey groundmass
81	grey-green plagioclase porphyry	184/64 exposed in felsenmeer	1 1	
	grey aplite plagioclase porphyry		≤10 m	
108	syenitic plagio- clase porphyry			dikes compose up to 50 per cent of outcrop
139	quartz porphyry	345/76	1.5	
140	hornblende (augite?) porphyry	183/83	3	
	plagioclase porphyry	355/85	2	fresh appearance
	syenitic plagio- clase porphyry	5/86	2	
142	grey-green plagio- clase porphyry	176/80	0.15	
142A	syenitic plagio- clase porphyry	164/75		intruded by grey- green andesite dikes
143	plagioclase- hornblende porphyry	5/80 (average)	2.5	irregular contact
149	acid plagioclase porphyry	188/75	8	

APPENDIX 6.4 (cont'd)

b) Porphyry dikes (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Central Phase</u> (cont'd)				
155		33/76 to 0/82	2	dike irregular
333	grey plagioclase porphyry			irregular contacts
451	hornblende plagioclase porphyry	187/80	2	chilled margins on dike and its thickness pinches and swells along strike
482	hornblende porphyry		2	irregular contacts
491	plagioclase- hornblende porphyry			
573	trachytoid- hornblende porphyry	345/80	0.8	forms 0.5 cm, white reaction rim in biotite- plagioclase por- phyry monzodiorite host
683	hornblende porphyry	203/66	2	possibly related to lamprophyre dike at station 334?
684	hornblende porphyry andesite	210/71	1.5	similar to dike at stations 683 and 334?
686	plagioclase porphyry	358/82	1	
	hornblende- plagioclase porphyry andesite	175/83	0.70	

APPENDIX 6.4 (cont'd)

b) Porphyry dikes (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Potassic Marginal Phase</u>				
6, 447	pink plagioclase porphyry	irregular		
11	plagioclase porphyry	270/75	2	groundmass fine- to medium-grained
59	plagioclase porphyry	203/68	1.5	medium- to coarse- grained plagioclase phenocrysts in black fine-grained ground- mass
	hornblende- plagioclase and acicular hornblende porphyries	208/74	15	acicular hornblendes form flow foliation parallel to dike margins
60	biotite-plagioclase porphyry			granular, fine- to medium-grained groundmass and locally poikilitic plagioclase
61	biotite porphyry			groundmass melano- cratic and fine- to medium-grained
109	syenitic plagioclase porphyry	295/80		dike swarm; con- tacts are poorly exposed due to lichen cover there- fore attitudes, thicknesses and abundances are poorly known
	syenitic hornblende plagioclase porphyry			
159	syenitic hornblende plagioclase porphyry	203/80 214/73	8	sharp but irregular contacts
	hornblende porphyry	216/60 211/66 208/73	0.8-1 0.6 0.15	acicular hornblende phenocrysts; dikes common

APPENDIX 6.4 (cont'd)

b) Porphyry dikes (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Potassic Marginal Phase</u> (cont'd)				
162	syenitic plagioclase porphyry	203/84	4	
163	hornblende porphyry	195/70	0.2	amygdaloidal
182	hornblende plagioclase porphyry	189/66	1	
249	syenitic plagioclase porphyry			anastomosing dikes of various thicknesses; melanocratic
257	plagioclase porphyry	212/70	0.4	
353	plagioclase porphyry		25-30	
439	quartz-plagioclase dacitic porphyry	8/90	1.25	
672	biotite-plagioclase porphyry			irregular dikes similar to station 6,447

Leucocratic Phase

6,447

hornblende
class porphyry

hornblende-plagioclase porphyry with thin selvages intrudes lit-par-lit with leucocratic hornblende quartz diorite dikes and is truncated by the glassy grey to pink plagioclase porphyry which is included in a grey fine-grained andesite

APPENDIX 6.4 (cont'd)

b) Porphyry dikes (cont'd)

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Leucocratic Phase</u> (cont'd)				
6,447	pink plagioclase porphyry			dike groundmass becomes grey towards intrusive contact with leu- cocratic diorite (Three Sisters Pluton, leucocratic phase)

APPENDIX 6.4 (cont'd)

c) Aplite, pegmatite and felsite dikes

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Mafic Phase</u>				
663	aplite			
<u>Central Phase</u>				
63	aplitic biotite granite	anastamosing		contacts appear partly gradational with monzodiorite (Three Sisters Pluton, central phase) and the lithology is simi- lar to that of potas- sic marginal phase
	aplite	anastamosing	8-10	aplite dike both horizontal and vertical
66	aplite			pink aplite locally intrudes monzodiorite of Three Sisters Pluton, potassic marginal phase
	biotite aplite		5-7	
86, 87	grey to white aplite			large irregular body poorly exposed in felsenmeer
88	grey aplite			dikes appear to intrude monzodiorite but are poorly exposed
97	aplite			rare dikes
144	siliceous felsite	170/75	1	
	aplite	355/78	0.1	
	cleaved felsic dike	173/78	3	contains monzodiorite fragments up to 10 cm long

APPENDIX 6.4 (cont'd)

c) Aplite, pegmatite and felsite dikes

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Central Phase</u> (cont'd)				
144 (cont'd)	aplite	5/75		broad aplitic zone in monzodiorite (lithologically similar though finer-grained to potassic marginal phase)
145	aplite	anastamosing		
154	aplite			
156	pegmatite		0.5	anastamosing body whose thickness decreases up dip
	aplite	315/85	0.5	
180	felsite	345/85	4	poor exposure
333	aplite			irregular contacts
334	aplite			irregular; lithologically similar to potassic marginal phase although finer-grained
336	aplite		8	orientation not recorded
451	aplite			nearly flat, 0-5 m thick sheet intrudes monzodiorite along horizontal joints (lithologically similar to the potassic marginal phase)
	aplite	245/80	1.5	
469	aplite		<0.1	irregular aplite veinlets

APPENDIX 6.4 (cont'd)

c) Aplite, pegmatite and felsite dikes

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Central Phase</u> (cont'd)				
473	leucocratic diorite	irregular		intrudes mafic mon- zodiorite and may be part of the leuco- cratic phase
491	aplite			
507	aplite			
529	aplite	340/58	1.25	fine- to medium- grained granite aplite
538	pegmatite		0.1-0.15	separates monzodio- rite apophysis from hornblende gabbro
654	pink and white aprites			uncommon and irregular
657	syenitic aplite			uncommon; intrude inclusions and monzo- diorite of agmatites
663	felsite	25° trend		limonite boxwork alteration
666	aplite	irregular		
671	white syenitic? aprites	anastomosing		
674	aplite			common dikes
677	aplite and plagio- clase hornblende porphyry aplite			poorly exposed dikes
678	aplite	4/45 (average attitude)	0.4	generally irregular
679	aplite			essentially vertical locally forms a stock- work in the monzo- diorite

APPENDIX 6.4 (cont'd)

c) Aplite, pegmatite and felsite dikes

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Central Phase (cont'd)</u>				
680	aplite	17/73	1-2	
C-1a	aplite	240/30	1	
684	aplite	83/90		orientation of southern contact given; aplite is generally irregular
686	aplitic quartz syenite	170/60 (average)	3	irregular
<u>Potassic Marginal Phase</u>				
5	aplite	357/43	1.5	also several irregu- lar aplite dikes at same locality which locally compose 40% of outcrop
58	aplite	178/39	20	light tan aplite
		163/70	7	slightly irregular contact
				locally fine layering is developed in the aplite within 2 m. of its contacts
59	aplite	174/64	7.5	tan aplite
		170/77	2	pink aplite
61	aplite			common dikes at this locality
159	quartz veins			associated with zone of highly fractured and altered syenite
168	aplite		0.15-0.2	anastomosing dikes intrude leucocratic hornblende quartz syenite

APPENDIX 6.4 (cont'd)

c) Aplite, pegmatite and felsite dikes

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Potassic Marginal Phase</u> (cont'd)				
350, 353	pegmatites			small, local pegmatites with rare tourmaline or hornblende
	felsite		25-30	locally felsite has plagioclase phenocrysts
505	pegmatite		0.10-0.20	anastomosing simple pegmatite
674	grey, glassy felsite			similar to ground-mass lithology of biotite-plagioclase porphyry of stations 6 and 672

APPENDIX 6.4 (cont'd)

d) Basalt, diabase and lamprophyre dikes

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Central Phase</u>				
140	olivine basalt	143/80	0.3-1	
157	basalt	178/80	1	
183	fine-grained diorite			intrudes and includes fragments from central phase
334	lamprophyre		1-2	dike poorly exposed; hornblende pheno- crysts in rosettes
<u>Potassic Phase</u>				
5, 429	basalt	3/62	0.04-0.15	pinch and swell along length some dikes porphyritic
10, 431	basalt?			
162	basalt	218/73	0.3	
182	basalt	203/75	0.2	
481	diabase			irregular intrusive contacts with potas- sic marginal phase

APPENDIX 6.4 (cont'd)

e) Rhyolite dikes

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
<u>Central Phase</u>				
108	flow layered rhyolite	198/76	10	thin, flow layered dense rhyolite dike
453	flow layered rhyolite	163/65	1	associated with aplite dike
<u>Potassic Marginal Phase</u>				
160	layered rhyolite	275/53		poorly exposed but contact appears to be sharp and layering parallel to contact

APPENDIX 6.5(a) MODAL COMPOSITIONS OF THE THREE SISTERS PLUTON, FINE-GRAINED PHASE

SAMPLE NUMBER	262-1 ⁵	490-1 ³	719-1 ³	114-3 ^{2,4}	345-1 ^{2,4}	525-2 ^{2,3}	652-6 ^{2,4}
plagioclase	54.0	63.9	63.7	61.8	65.9	59.8	56.6
quartz	10.7	4.7	8.4	0.6	0.9	4.3	1.8
alkali feldspar	8.2	3.8	4.3	0.1	3.2	0.1	0.7
hornblende	14.1	20.3	19.3	0.7	23.4	1.8	10.2
clinopyroxene	0.2	1.5	0.5	13.0	0.9	14.2	8.8
biotite	1.7	3.8	2.0	20.5	3.8	15.7	16.1
opaque minerals	1.8	1.9	1.8	3.1	1.5	3.7	5.2
titanite	Tr			0.1	0.3	0.3	Tr
apatite	0.2	0.1	Tr	0.1	0.1	0.1	0.4
zircon					Tr		
epidote	1.3		Tr			Tr	0.1
chlorite	0.5		Tr			Tr	
calcite						Tr	
sericite and sausserite	7.3						0.1
PLAGIOCLASE COMPOSITION							
corroded core	An ₈₈	An ₆₅	An ₆₂₋₇₈				An ₇₄
host	An ₃₂₋₄₂	An ₅₀₋₆₇	An ₅₅₋₅₈	An ₄₅₋₆₈	An ₄₃₋₅₄	An ₄₇₋₆₁	An ₄₀₋₄₇
Colour Index	19.2	27.6	23.6	37.5	30.0	35.8	40.8
Point Counts	1000	1060	1000	1000	1003	1001	1000

1. Tr = trace

2. mafic inclusion in central phase

3. quartz diorite

4. diorite

APPENDIX 6.5(b) MODAL COMPOSITIONS OF THE THREE SISTERS PLUTON, MAFIC PHASE

SAMPLE NUMBER	98-3,6	523 ^{2,5}	536-2 ^{3,4}	542-1 ^{2,5}	657-3 ^{2,6}	661-3 ^{3,4}	661-4 ^{2,6}
plagioclase	44.8	63.2	43.1	58.3	53.5	45.3	51.9
quartz	3.5	1.7	2.4	2.3	9.0	2.5	6.2
alkali feldspar	3.9	0.3	1.6	2.6	5.2	1.2	4.0
hornblende	38.1	13.9	46.4	32.0	27.7	45.0	25.8
clinopyroxene	0.7	7.8	2.5	0.1		0.3	
biotite		9.3	0.4	0.1	1.3	1.4	2.6
opaque minerals	5.5	3.7	2.9	3.7	2.0	3.6	2.9
titanite	1.0	0.1	0.6	0.1	0.1	0.5	1.7
apatite	0.5	Tr ¹	0.1	0.4	0.3	0.2	0.4
zircon				Tr	Tr	Tr	Tr
epidote	1.2	Tr		Tr	0.1	Tr	0.3
chlorite	0.3	Tr	Tr	Tr	0.7	Tr	1.2
sericite and sausserite	0.1	Tr		Tr	0.1	Tr	2.9
calcite	0.4			Tr		Tr	0.1

PLAGIOCLASE COMPOSITION

corroded core	An ₆₇₋₈₀	An ₈₉	An ₈₄₋₉₅	An ₈₈	An ₆₁₋₆₅	An ₆₂
host	An ₄₀₋₅₈	An ₄₈₋₅₇	An ₄₄₋₅₅	An ₅₈	An ₄₁₋₅₇	An ₃₈₋₄₈
Colour Index	47.3	34.8	52.9	36.8	51.0	35.0
Point Counts	1030	1000	1006	1005	1010	1020
1. Tr = trace	2. acicular hornblende variety	3. equant hornblende porphyry variety	4. diorite			
	5. gabbro	6. quartz diorite				

APPENDIX 6.5(c) MODAL COMPOSITIONS OF THE THREE SISTERS PLUTON, CENTRAL PHASE

SAMPLE NUMBER	62-2 ³	96-2 ³	114-3 ^{2,4}	124-1 ³	135-1 ³	345-1 ^{3,4}	529-1 ³	GAD-67 132-2 ³	GAD-67 132-3 ³
plagioclase	47.6	60.2	61.3	58.8	51.7	45.5	51.1	42.6	49.4
alkali-feldspar	26.0	12.2	5.7	10.0	17.2	20.8	14.6	21.3	21.3
quartz	11.6	12.1	6.4	6.4	9.9	15.2	14.8	11.2	8.4
hornblende	8.7	7.6	15.8	10.2	12.2	14.0	4.9	10.8	16.4
biotite	3.6	5.5	5.8	5.5	6.6	2.4	8.3	10.9	0.6
clinopyroxene	0.2	0.3	2.4	0.3	Tr	0.2	3.9	1.8	
opaque minerals	1.3	0.5	2.0	1.9	1.4	1.1	1.8	1.3	3.3
titanite	0.1	1.2	0.6	0.1	0.5	0.4		Tr	0.4
apatite	0.3	0.1	Tr	0.2	0.2	0.1	0.6	Tr	0.1
zircon	Tr ¹	Tr	Tr	Tr	Tr	Tr	Tr	0.1	0.1
epidote		0.1	Tr	0.1	0.2	0.3		Tr	
chlorite	0.3	0.2	Tr	1.8	0.1	Tr		Tr	Tr
sericite and sausserite	0.3	Tr	Tr	0.9	Tr		Tr		
calcite				3.8					

PLAGIOCLASE COMPOSITION

core An₅₈

host

An₅₄An₂₅₋₄₉An₃₂₋₄₈An₄₄₋₄₈An₃₂₋₄₈An₃₂₋₄₅An₄₀₋₄₈An₄₃₋₅₅An₄₀₋₅₀An₃₇₋₄₄

Colour Index

Point Counts

1. Tr = trace

2. see Appendix 6.5(a) for data on inclusion

3. quartz monzodiorite

4. quartz diorite

20.9

24.9

1031

1004

1003

1500

1006

1006

1006

1006

1006

1001

APPENDIX 6.5(d) MODAL COMPOSITIONS OF THE THREE SISTERS PLUTON, POTASSIC MARGINAL PHASE

SAMPLE NUMBER	20-1 ^{2,5}	43-1 ^{2,6}	102-2 ^{3,6}	162-4 ^{3,4}	257-2 ^{3,5}	349-1 ^{2,5}	356-1 ^{2,5}	505-5 ^{3,4}	528-3 ^{3,4}
alkali feldspar	26.0	29.8	26.0	46.4	39.3	42.2	47.5	37.7	42.3
plagioclase	39.9	47.0	49.7	24.6	33.2	28.9	28.6	33.8	28.8
quartz	4.8	2.9	11.0	21.8	16.0	15.0	11.6	25.0	20.2
hornblende	22.1	9.7	6.1	2.9	4.0	7.8	7.9	1.8	
biotite	5.3	7.8	5.4	2.8	6.0	4.1	3.2	1.2	7.2
clinopyroxene	0.4		Tr	0.4	Tr	0.4	0.1		
opaque minerals	0.9	1.9	1.2	0.5	1.1	1.3	0.3	0.5	0.9
apatite	0.3	0.3	0.4	0.1	0.2	0.1	Tr	Tr	0.3
titanite		0.2	0.2		0.2	0.1		Tr	0.3
zircon	0.1	0.1	Tr	Tr	Tr	Tr	0.1	Tr	Tr
allanite			Tr	Tr	Tr	Tr	0.7	Tr	
epidote			Tr						
chlorite	Tr	Tr	Tr	0.4	Tr	Tr		Tr	Tr
sericite and saussurite	0.1	0.3	Tr	0.1		0.1		Tr	Tr
PLAGIOCLASE COMPOSITION									
core of grain ⁷	An ₃₂₋₅₆	An ₃₅₋₄₈	An ₄₄₋₅₅	An ₃₆₋₄₈	An ₃₈₋₄₁	An ₄₆₋₅₃	An ₃₅₋₅₅	An ₄₀₋₅₆	An ₃₂₋₅₈
Colour Index	29.3	20.3	13.3	7.2	11.5	13.9	12.3	3.5	8.7
Point Counts	1000	1000	1000	1000	1000	1000	1001	1000	1000

1. Tr = trace 2. western part 3. eastern part 4. granite 5. quartz monzonite 6. monzonite

7. rims generally less refringent than quartz but not correctly oriented for determinations; zoning in cores cores changes composition as much as An₁₃ (e.g., core = An₄₁; rim = An₂₈)

APPENDIX 6.5(e) MODAL COMPOSITIONS OF THE THREE SISTERS PLUTON, LEUCOCRATIC PHASE

SAMPLE NUMBER	605-1 ^{2,4}	686-2 ^{3,5}	718-1 ^{3,6}
plagioclase	9.0	58.5	46.2
Quartz	3.3	11.9	25.3
alkali feldspar	83.0	18.7	23.0
hornblende	0.8		2.8
clinopyroxene	1.8	9.9	
titanite	0.6	0.5	0.3
apatite	0.4	0.4	0.2
zircon	0.5	Tr	
epidote	0.6	0.1	2.2
chlorite	Tr ¹		Tr ¹

PLAGIOCLASE COMPOSITION

core	An ₃₈₋₆₀	
rim	An ₁₄₋₂₀	An ₂₋₅
Colour Index	4.7	5.5
Point Counts	1000	1000

1. Tr = trace 2. western apophysis 3. eastern part 4. alkali feldspar syenite.
 5. quartz monzodiorite 6. granodiorite

APPENDIX 6.6 (in pocket)

Sample numbers are given in alumina-silica diagram; abbreviations given at bottom of each set of diagrams (see Table IV.2.3)

APPENDIX 7. DETAILS OF THE GEOLOGY OF THE McBRIDE RIVER PLUTON

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7.2 Intrusive Relations Involving the McBride River Pluton	A-190
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7.4 Modal Compositions for the McBride River Pluton ²	A-193
7.5 Harker Variation Diagrams for the McBride Pluton	A-194

1. Dip direction conventionally oriented 90 degrees clockwise from azimuth.

2. Rock classification after Streckeisen (1973).

APPENDIX 7.1 - LITHOLOGICAL CHARACTERISTICS OF THE McBRIDE RIVER PLUTON

a) Inclusions in the McBride River Pluton

Location (at or near station:)	Abundance (%)	Dimensions	Comments
164		3 cm long	rare rounded fine- grained dioritic in- clusions
	1		oval to round to an- gular fine-grained diorite inclusions
252	≤10	≤3 cm long	rounded to subgranular fine-grained mafic diorite or metavolcanic(?) inclusions
309	≤3	≤10 cm long	rounded fine-grained diorite inclusions locally with hornblende phenocrysts
464	≤1		though rare, inclusions are widespread and may be metavolcanic in origin
467	1	2 cm long	fine-grained diorite or amphibolite inclusions

APPENDIX 7.2 - INTRUSIVE RELATIONS INVOLVING THE McBRIDE RIVER PLUTON

a) External intrusive relations

INTRUSIVE RELATIONS INVOLVING THE McBRIDE RIVER PLUTON AND THE UPPER

TRIASSIC VOLCANICS AND SEDIMENTS

Location
(at or near
station:)

Comments

165

towards intrusive contact with metamorphosed augite porphyry volcanics quartz content in the McBride River Pluton decreases; however contact between the two units is not exposed but bracketed within 2 m and its orientation estimated at 160/65

thick quartz vein developed at this contact and is oriented 176/60

farther west 30 cm wide apophysis of granodiorite (McBride River Pluton) anastomoses through the augite porphyry

farther west a wide (<8 m wide) apophysis of quartz monzodiorite (McBride River Pluton) intrudes amphibolitized volcanics and within 1 m of the contact quartz veining is well developed in the quartz monzodiorite.

166

15-20 cm wide leucocratic fine- to medium-grained biotite quartz monzodiorite (McBride River Pluton) intrudes the augite porphyry at 358/78; metamorphic aureole in volcanics extends <5 m

252

in felsenmeer outcrops pass volcanic-McBride River Pluton contacts; both western apophysis and main western contact of main body of McBride River Pluton are observed and are parallel to position of similar units at stations 165 and 166

APPENDIX 7.2 (cont'd)

a) external (cont'd)

INTRUSIVE RELATIONS INVOLVING THE McBRIDE RIVER PLUTON AND THE TRIASSIC-JURASSIC VOLCANICS

Location
(at or near
station:)

Comments

308, 311, 312,
466, 468

although contact between McBride River Pluton and feldspar porphyry of the Triassic-Jurassic volcanics is well bracketed it is not observed and the geological relations are poorly known

near station 308, the groundmass of a limestone-chert breccia near the inferred contact is hornfelsed or silicified

near the contact, at stations 312 and 468 distinctive, leucocratic medium-grained, granitoid hornblende plagioclase porphyry apophyses intrude plagioclase-augite porphyry volcanics and laminated siltstone and may be related to the McBride River Pluton

APPENDIX 7.3 - HYPABYSSAL INTRUSIONS IN THE McBRIDE RIVER PLUTON

a) Diabase and porphyry dikes

Location (at or near station:)	Lithology	Conventional Orientation	Width (m)	Comments
306-310, 464	brown to dun diabase			major intrusion; locally up to 3 per cent poorly preserved, rounded epidotized, rusty granitoid? inclusions (up to 2 cm long) in diabase near its contact with the McBride River Pluton suggests the diabase intrudes the McBride River Pluton
468	plagioclase- hornblende porphyry			irregularly intrudes granodiorite of the McBride River Pluton

APPENDIX 7.4. MODAL COMPOSITION OF THE MCBRIDE RIVER PLUTON

SAMPLE NUMBER	164-2 ²	166-3 ²	253-1 ²	309 ²	467 ²
plagioclase	64.0	45.1	49.2	44.5	53.5
quartz	18.4	23.7	19.4	27.8	21.1
alkali feldspar	10.0	22.2	23.0	15.7	15.8
hornblende	3.4	2.8	4.0	5.7	3.9
biotite	2.9	5.8	3.6	5.1	4.5
opaque minerals	0.5	Tr	0.4	1.0	0.5
titanite	0.2	0.1	0.3	0.1	0.6
apatite	0.1	Tr	0.2	0.1	0.1
zircon	Tr ¹	Tr	Tr	Tr	Tr
allanite		0.1			
chlorite	0.5	0.2	Tr	Tr	Tr
sericite	Tr	Tr	Tr	Tr	Tr
PLAGIOCLASE COMPOSITION					
	An ₃₃₋₃₄	An ₃₂₋₄₅	An ₃₅₋₄₅	An ₃₇₋₅₁	An ₃₃₋₄₆
Colour Index	7.6	9.0	8.5	12.0	9.6
Point Counts	1000	1000	1000	1000	1000

1. Tr = trace

2. granodiorite

APPENDIX 7.5

Symbols represent samples from:

○ grab samples

◇ replicate analyses of K-Ar sample

Sample numbers are given in alumina-silica variation diagram (see Table IV.3.2).

APPENDIX 7.5

APPENDIX 7.5 (continued)

APPENDIX 8. DETAILS OF THE GEOLOGY OF THE SNOWDRIFT CREEK PLUTON

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(a) Mineral foliation	A-199
8.3 Intrusive Relations Involving the Snowdrift Creek Pluton	A-200
(a) Intrapluton intrusive relations	A-200
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8.4 Modal Compositions for the Snowdrift Creek Pluton ²	A-202
8.5 Harker Variation Diagrams for the Snowdrift Creek Pluton	A-203

1. Dip direction conventionally oriented 90 degrees clockwise from azimuth.

2. Rock classification after Streckeisen (1973).

APPENDIX 8.1 - LITHOLOGICAL CHARACTERISTICS OF THE SNOWDRIFT CREEK PLUTON

a) Inclusions in the Snowdrift Creek Pluton

Location (at or near station:)	Abundance (%)	Dimensions	Comments
690			rare, small rounded fine-grained diorite inclusions
708	1	≤3 cm long (average 2-5 cm)	rounded, fine-to medium- grained hornblende-biotite diorite; rare augite por- phyry inclusions seen
	≤1		elongate, fine-grained hornblende biotite diorite

APPENDIX 8.2 - STRUCTURAL DATA FOR THE SNOWDRIFT CREEK PLUTON

a) Mineral Foliation

Location (at or near station:)	Conventional Orientation Quality of Foliation		
	Poor	Moderate	Good
329		236/28	238/45
708	224/84	59/62 52/69 45/90 50/90 56/78 (SEE PLATE VIII D)	222/57 (schlieren-SEE PLATE VIII I)

APPENDIX 8.3 - INTRUSIVE RELATIONS INVOLVING THE SNOWDRIFT CREEK PLUTON

a) Intrapluton intrusive relations

Location (at or near station:)	Comments
329	foliated hornblende-biotite granodiorite is intruded by irregular (4 m wide) monzodiorite apophysis
690,699	the medium-grained hornblende diorite decreases in grain size to a fine- to medium-grained diorite towards the contact with the Cake Hill Pluton the medium-grained hornblende diorite is intruded by an irregular leucocratic diorite dike
708	thin pegmatite to medium-grained biotite quartz syenite veins intrude quartz monzodiorite

b) External intrusive relations

INTRUSIVE RELATIONS INVOLVING THE SNOWDRIFT CREEK PLUTON AND UPPER TRIASSIC
VOLCANICS AND SEDIMENTS

Location (at or near station:)	Comments
690,699	the small stock decreases in grain size to fine- to medium-grained diorite near the poorly exposed contact with the Cake Hill Pluton and andesite breccia
708	some distance from station 708, monzodiorite from the Snowdrift Creek Stock becomes more mafic (mafic more biotite-rich) towards contact with augite porphyry screen; in talus, rounded to elongate augite porphyry-inclusions in the monzodiorite confirm its intrusive character

APPENDIX 8.3 (cont'd)

b) External intrusive relations (cont'd)

Location
(at or near
station:)

Comments

708 (cont'd)

further east observe highly metamorphosed arkoses? with compositional layering and amphibolite all oriented approximately parallel with the mineral foliation: conventional orientation of layering is 67/70 and 71/55

710

large, irregular apophysis of glassy, plagioclase porphyry intrudes augite?-plagioclase porphyry volcanics

intrusion is lithologically similar to similar apophyses at station 6 or 447 (Three Sisters Pluton, leucocratic phase) and 672 (Three Sisters Pluton, potassic marginal phase)

INTRUSIVE RELATIONS INVOLVING THE SNOWDRIFT CREEK PLUTON AND LOWER

JURASSIC SEDIMENTS

Location
(at or near
station:)

Comments

330

in creek cut, Pleinsbachian sediments, assumed close to the contact are rusty weathering, pyritic, hornfelsed, highly folded and at one locality intruded by a 3 m wide anastomosing fine- to medium-grained monzodiorite apophysis

APPENDIX 8.4. MODAL COMPOSITION OF SNOWDRIFT CREEK PLUTON

SAMPLE NUMBER 3292 708-13

Plagioclase 52.6 55.1

Quartz 34.4 21.6

Alkali feldspar 1.9 6.8

Biotite 7.9 7.5

Hornblende 2.6 7.2

Opaque minerals 0.5 0.9

Apatite 0.1 0.5

Titanite Tr¹ 0.3

Zircon Tr Tr

Epidote Tr Tr

Chlorite Tr Tr

Calcite Tr Tr

White mica Tr Tr

PLAGIOCLASE COMPOSITION An₃₇₋₄₄ An₂₇₋₄₀

Colour Index 11.1 16.5

Point Counts 1000 1000

1. Tr = trace 2. granodiorite 3. tonalite

APPENDIX 8.5

Symbols represent samples from:

- southeastern Snowdrift Creek Pluton,
grab sample
- ◇ western Snowdrift Creek Pluton, K-Ar
sample

Sample numbers are given in alumina-silica
variation diagram (see Table IV.4.2)

APPENDIX 8.5

APPENDIX 8.5 (continued)

APPENDIX 9. DETAILS OF THE GEOLOGY OF THE PALLEN CREEK PLUTON

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9.3 Modal Compositions for the Pallen Creek Pluton ²	A-210
9.4 Harker Variation Diagrams for the Pallen Creek Pluton	A-211

-
1. Dip direction conventionally oriented 90 degrees clockwise from azimuth.
 2. Rock classification after Streckeisen (1973).

APPENDIX 9.1 - STRUCTURAL DATA FOR THE PALLAN CREEK PLUTON

a) Mineral Foliation

Location
(at or near
station:)

Conventional Orientation
Quality of Foliation

Poor

Moderate

Good

644

125/90

APPENDIX 9.2 - INTRUSIVE RELATIONS INVOLVING THE PALLAN CREEK PLUTON

a) Intrapluton intrusive relations

Location
(at or near
station:)

Comments

643

the hornblende-biotite monzodiorite is intruded by quartzose and syenitic veins near plutonic-volcanic contact

644

monzonite, monzodiorite and gabbro occur in isolated patches near the plutonic-volcanic contact; the monzonite and gabbro are both intruded by an irregular fine-to medium-grained hornblende-biotite syenite dike (SEE PLATE VIII G) and the gabbro is intruded by the monzodiorite which contains gabbroic and augite porphyry volcanic inclusions (SEE PLATE VIII H)

b) External intrusive relations

INTRUSIVE RELATIONS INVOLVING THE PALLAN CREEK PLUTON AND THE PALEOZOIC

(PERMIAN?) LIMESTONE

Location
(at or near
station:)

Comments

637, 646

although contact between Pallan Creek Stock and deformed and recrystallized limestone is bracketted within a few hundred metres, no contact is observed

at station 637, in talus, mafic and plagioclase content increases (monzonite becomes a monzodiorite) as contact is approached, but a screen of structurally underlying augite porphyry separates the limestone from the pluton (SEE PLATE VIII F)

APPENDIX 9.2 (cont'd)

b) External intrusive relations (cont'd)

INTRUSIVE RELATIONS INVOLVING THE PALLAN CREEK PLUTON AND THE UPPER

TRIASSIC VOLCANICS AND SEDIMENTS

Location
(at or near
station:)

Comments

633

small, fine- to medium-grained quartz monzonite intrusions (Pallen Creek Stock) clearly cuts the augite porphyry breccia

643

contact between intrusive hornblende-biotite monzonite (Pallen Creek Stock) and tough hornfelsed augite porphyry is bracketted within 10 m but is not seen

further north, contact is observed and is irregular and the augite porphyry is cut by quartzose and syenite veinlets

the quartz monzonite does not appear to decrease in grain size towards the plutonic-volcanic contact

644

augite porphyry and underlying flinty hornfelsed siltstones and argillites are intruded by the monzodiorite (which contains augite porphyry inclusions), apparently by the gabbro and by quartzose and syenitic veinlets near its irregular contact

monzodiorite also forms thin apophyses along bedding planes in the thin bedded siltstone and argillite

11 11 OF/DE

APPENDIX 9.3. MODAL COMPOSITION OF Pallen Creek Pluton

SAMPLE NUMBER	644-3 ²	634-1 ³	635-1 ⁴	643-2 ⁴	GA-67-97 ⁴
plagioclase	35.7	41.6	49.9	45.3	47.3
quartz	1.4	18.8	24.1	22.5	23.2
alkali feldspar		26.9	18.8	24.3	21.2
clinopyroxene	5.0	Tr			
hornblende	34.5	5.8	1.9	3.2	3.3
biotite	12.0	4.3	3.5	2.8	3.3
opaque minerals	1.4	1.2	1.2	1.3	1.3
titanite		0.1	0.3	0.3	0.3
apatite	0.6	0.3	0.3	Tr	0.1
zircon		Tr	Tr	Tr	Tr
allanite			Tr		Tr
chlorite	1.1	1.0	Tr	0.3	Tr
epidote	0.7	Tr	Tr	Tr	Tr
sericite and saussurite	7.6	Tr	Tr	Tr	Tr
PLAGIOCLASE COMPOSITION	An ₄₁₋₄₇	An ₄₀₋₅₂	An ₄₀₋₅₂	An ₃₈₋₅₄	An ₃₅₋₄₆
Colour Index	* 62.9	12.7	7.2	7.9	8.3
Point Counts	1007	1001	1000	1000	1000
1. Tr = trace	2. diorite	3. granite	4. granodiorite		

APPENDIX 9.4

Symbols represent samples from:

- megacrystic felsic phase, grab samples
- ◇ megacrystic felsic phase, K-Ar sample
- mafic phase, grab sample

Sample numbers are given in alumina-silica variation diagram (see Table IV.5.2).

APPENDIX 9.4

APPENDIX 9.4 (continued)

APPENDIX 9.4 (continued)

APPENDIX 9.4 (continued)

APPENDIX 10. DETAILS OF THE GEOLOGY OF THE TANZILLA PLUTON

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10.4 Harker ² Variation Diagrams for the Tanzilla Pluton	A-220

1. Rock classification after Streckeisen (1973).

APPENDIX 10.1 - LITHOLOGICAL CHARACTERISTICS OF THE TANZILLA PLUTON

a) Inclusions in the Tanzilla Pluton

Location (at or near station:)	Abundance (%)	Dimensions	Comments
639			rare but widespread rounded, fine-grained diorite inclusions
640	<1		rounded fine-grained diorite inclusions
641			only one 7 cm long rounded fine-grained diorite inclusion seen in whole outcrop
651			rare, fine-grained diorite inclusions

APPENDIX 10.2 - INTRUSIVE RELATIONS INVOLVING THE TANZILLA PLUTON

a) Intrapluton intrusive relations

Location
(at or near
station:)

Comments

639

at one locality, pink syenite stockwork developed in hornblende-biotite monzodiorite (SEE PLATE VIII I).

b) External intrusive relations

INTRUSIVE RELATIONS INVOLVING THE TANZILLA PLUTON AND UPPER TRIASSIC
VOLCANICS AND SEDIMENTS

Location
(at or near
station:)

Comments

638, 639

at contact with intrusive hornblende-biotite monzodiorite augite porphyry volcanics are hornfelsed

647, 649

common quartz veining in argillite within 0.5 km of plutonic-sedimentary contact

APPENDIX 10.3 MODAL COMPOSITION OF TANZILIA PLUTON

SAMPLE NUMBER	639-22	640-22	716 (K-Ar)2
plagioclase	43.2	47.8	54.0
quartz	21.8	21.5	20.3
alkali feldspar	18.6	14.2	8.9
biotite	6.3	5.5	8.2
hornblende	8.9	9.3	6.7
opaque minerals	0.9	1.3	1.4
apatite	0.2	0.2	Tr
titanite	0.1	0.1	0.4
zircon	Tr ¹	0.1	0.1
sericite	Tr	Tr	Tr
chlorite	Tr	Tr	Tr
epidote	Tr	Tr	Tr
calcite	Tr	Tr	Tr
PLAGIOCLASE COMPOSITION	An ₄₂₋₆₁	An ₄₇₋₅₆	An ₅₂₋₅₈
COLOUR INDEX	16.4	16.5	16.8
POINT COUNTS	1000	1000	1000

1. Tr = trace amounts

2. granodiorite

APPENDIX 10.4

Sample numbers are given in alumina-silica variation diagram (see Table IV.6.2).

APPENDIX 10.4

APPENDIX 11. ELECTRON MICROPROBE ANALYSES AND ATOMIC PROPORTIONS FOR
PYROXENES, AMPHIBOLES AND BIOTITES

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(a) Microprobe Pyroxene Analyses (by unit)	A-223
(b) Microprobe Amphibole Analyses (by unit)	A-244
(c) Microprobe Biotite Analyses (by unit)	A-255

APPENDIX 11: a) MICROPROBE PYROXENE ANALYSES
1. Augite porphyry flows

SPECIMEN AN-77-233-2

GRAIN LOCATION	1 core	2 intermed	2 rim	3 core	3 rim	4 rim	4 rim	5 core	5 intermed	5 rim	5 rim	6 core
Oxide (Wt. %)												
SiO ₂	50.88	50.26	49.84	51.18	52.27	51.45	51.18	50.86	52.28	50.77	50.52	50.19
Al ₂ O ₃	4.13	3.64	5.00	3.17	2.36	2.91	3.79	3.91	2.72	4.56	3.70	3.95
TiO ₂	0.48	0.38	0.63	0.36	0.23	0.28	0.40	0.45	0.27	0.45	0.46	0.45
Cr ₂ O ₃	0.07	0.04	0.09	0.11	0.29	0.37	0.10	0.04	0.20	0.06	0.05	0.02
FeO _T	7.23	6.75	7.85	5.13	4.80	5.07	7.25	6.92	6.62	7.00	7.10	7.07
MgO	14.66	15.11	13.89	15.39	16.09	15.65	14.17	14.56	15.32	14.86	14.82	14.71
MnO	0.18	0.20	0.21	0.13	0.16	0.11	0.27	0.23	0.23	0.20	0.23	0.18
NiO	0.04	0.06	0.03	0.03	0.01	0.00	0.01	0.00	0.03	0.02	0.04	0.04
CaO	22.30	22.29	22.01	22.66	22.73	23.21	21.81	21.88	22.12	21.63	21.24	21.55
Na ₂ O	0.34	0.40	0.40	0.38	0.20	0.22	0.55	0.41	0.34	0.50	0.33	0.41
K ₂ O	0.01	0.00	0.01	0.01	0.00	0.00	0.04	0.00	0.00	0.17	0.00	0.00
TOTAL	100.32	99.13	99.96	98.55	99.14	99.27	99.55	99.26	100.13	100.31	98.49	98.53

Structural Formulae based on 6 Oxygens

Si	1.881	1.881	1.857	1.910	1.935	1.908	1.905	1.895	1.928	1.875	1.898	1.886	1.974
Al ^{IV}	0.119	0.119	0.143	0.090	0.065	0.092	0.095	0.105	0.072	0.125	0.102	0.114	0.026
Al ^{VI}	0.061	0.041	0.076	0.049	0.037	0.034	0.071	0.066	0.046	0.073	0.061	0.060	0.023
Ti	0.013	0.010	0.017	0.010	0.006	0.007	0.011	0.012	0.007	0.012	0.012	0.012	0.002
Cr	0.001	0.000	0.002	0.003	0.007	0.011	0.002	0.000	0.005	0.001	0.001	0.000	0.012
Mg	0.808	0.842	0.771	0.855	0.887	0.865	0.786	0.808	0.842	0.817	0.829	0.824	0.982
Fe	0.222	0.210	0.244	0.160	0.147	0.157	0.225	0.215	0.203	0.219	0.223	0.222	0.089
Mn	0.005	0.005	0.006	0.003	0.004	0.003	0.007	0.006	0.006	0.005	0.006	0.005	0.002
Ni	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000
Ca	0.883	0.893	0.878	0.906	0.901	0.922	0.870	0.874	0.873	0.855	0.854	0.867	0.872
Na	0.023	0.028	0.028	0.026	0.013	0.015	0.039	0.029	0.023	0.036	0.023	0.029	0.007
K	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
oct. cations	2.017	2.030	2.022	2.012	2.002	2.014	2.012	2.010	2.005	2.025	2.010	2.020	1.989

APPENDIX 11: a) MICROPROBE PYROXENE ANALYSES (cont'd)
1. Augite porphyry flows (cont'd)

SPECIMEN AN-77-233-2 (cont'd)

GRAIN	6	6	6	7	7
LOCATION	core	rim	rim	core	rim

Oxide

(Wt. %)

SiO ₂	54.33	54.39	54.20	51.51	50.61
Al ₂ O ₃	0.96	1.09	1.05	3.19	3.66
TiO ₂	0.08	0.09	0.08	0.36	0.41
Cr ₂ O ₃	0.47	0.72	0.75	0.08	0.07
FeO _T	2.58	2.14	2.27	6.32	6.71
MgO	18.99	17.86	18.00	15.27	14.89
MnO	0.07	0.07	0.06	0.16	0.19
NiO	0.00	0.01	0.02	0.00	0.01
CaO	22.81	22.73	22.82	22.44	21.22
Na ₂ O	0.16	0.20	0.16	0.20	0.28
K ₂ O	0.00	0.00	0.01	0.00	0.00
TOTAL	99.55	99.30	99.42	99.53	98.05

Structural Formulae based on 6 Oxygens

Si	1.978	1.979	1.975	1.910	1.905
Al IV	0.022	0.021	0.025	0.090	0.095
Al VI	0.019	0.025	0.019	0.049	0.066
Ti	0.002	0.002	0.002	0.010	0.011
Cr	0.013	0.020	0.021	0.002	0.001
Mg	0.981	0.969	0.977	0.843	0.835
Fe	0.078	0.065	0.068	0.196	0.211
Mn	0.002	0.002	0.001	0.004	0.005
Ni	0.000	0.000	0.000	0.000	0.000
Ca	0.889	0.885	0.890	0.891	0.855
Na	0.010	0.014	0.010	0.014	0.020
K	0.000	0.000	0.000	0.000	0.000
oct. cations	1.994	1.982	1.988	2.009	2.004

APPENDIX 11: a) MICROPROBE PYROXENE ANALYSES (cont'd)

1. Augite porphyry flows (cont'd)

SPECIMEN: AN-77-325-1

GRAIN	1	1	1	2	2	3	3	3	3	4	4	4	4
LOCATION	core	core	rim	core	rim	core	core	rim	rim	core	intermed	intermed	rim
Oxide													
(Wt. %)													
SiO ₂	50.19	50.84	50.63	50.07	50.74	49.48	48.03	48.75	49.96	53.08	50.06	49.14	50.14
Al ₂ O ₃	5.07	3.66	3.86	4.32	3.73	4.71	6.17	5.85	5.17	2.36	4.92	5.52	4.81
TiO ₂	0.57	0.48	0.58	0.49	0.50	0.75	0.90	0.79	0.73	0.21	0.48	0.61	0.57
Cr ₂ O ₃	0.07	0.09	0.02	0.19	0.05	0.04	0.03	0.02	0.04	0.48	0.16	0.02	0.07
FeO _T	8.55	6.95	7.44	7.37	7.19	8.39	7.86	8.68	8.21	3.43	6.77	8.14	7.61
MgO	14.29	14.78	14.54	14.94	14.76	14.12	13.36	13.62	13.93	17.28	14.69	13.99	14.37
MnO	0.25	0.20	0.20	0.25	0.18	0.21	0.17	0.23	0.23	0.13	0.16	0.18	0.21
NiO	0.00	0.03	0.00	0.05	0.02	0.00	0.03	0.03	0.01	0.02	0.04	0.04	0.03
CaO	20.45	22.21	22.10	21.27	21.96	20.96	21.86	20.90	21.73	22.38	22.32	21.41	21.26
Na ₂ O	0.63	0.30	0.39	0.45	0.33	0.46	0.35	0.45	0.41	0.23	0.31	0.43	0.40
K ₂ O	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00
TOTAL	100.07	99.55	99.76	99.40	99.47	99.18	98.76	99.33	100.42	99.60	99.91	99.49	99.47

Structural Formulae based on 6 Oxygens

Si	1.865	1.895	1.885	1.869	1.891	1.857	1.815	1.832	1.853	1.939	1.858	1.840	1.869
Al ^{IV}	0.135	0.105	0.115	0.131	0.109	0.143	0.185	0.168	0.147	0.061	0.142	0.163	0.131
Al ^{VI}	0.086	0.054	0.054	0.058	0.054	0.067	0.088	0.090	0.078	0.040	0.072	0.083	0.080
Ti	0.015	0.013	0.015	0.013	0.013	0.021	0.025	0.022	0.020	0.005	0.013	0.016	0.015
Cr	0.001	0.002	0.000	0.005	0.001	0.000	0.000	0.000	0.001	0.013	0.004	0.000	0.001
Mg	0.791	0.820	0.806	0.831	0.819	0.790	0.751	0.763	0.770	0.940	0.812	0.780	0.797
Fe	0.265	0.216	0.230	0.230	0.223	0.263	0.248	0.272	0.254	0.104	0.210	0.255	0.237
Mn	0.007	0.005	0.005	0.007	0.005	0.006	0.004	0.006	0.006	0.003	0.004	0.005	0.006
Ni	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ca	0.813	0.885	0.881	0.850	0.877	0.843	0.885	0.841	0.863	0.876	0.887	0.858	0.849
Na	0.044	0.021	0.027	0.032	0.023	0.033	0.024	0.032	0.029	0.015	0.021	0.031	0.028
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
oct. cations	2.022	2.016	2.018	2.027	2.015	2.013	2.025	2.026	2.021	1.996	2.023	2.028	2.013

APPENDIX 11: a) MICROPROBE PYROXENE ANALYSES (cont'd)

1. Augite porphyry flows (cont'd)

SPECIMEN: AN-77-325-1 (cont'd)

GRAIN	4	5	5	5	5	6	6	6	6
LOCATION	rim	core	core	rim	rim	core	intermed	rim	rim
Oxide									
(Wt. %)									
SiO ₂	49.32	51.52	49.33	40.13	49.38	51.49	49.15	49.26	51.39
Al ₂ O ₃	5.34	3.18	5.39	4.26	5.14	4.24	5.64	5.66	3.66
TiO ₂	0.59	0.29	0.57	0.59	0.68	0.30	0.64	0.67	0.52
Cr ₂ O ₃	0.02	0.35	0.10	0.00	0.03	0.35	0.07	0.04	0.02
FeO _T	7.71	5.20	7.32	7.55	8.21	5.38	7.68	8.32	7.23
MgO	13.94	15.94	14.26	14.53	13.85	15.73	13.72	13.57	14.73
MnO	0.27	0.20	0.17	0.18	0.21	0.11	0.18	0.23	0.21
NiO	0.01	0.03	0.01	0.00	0.00	0.04	0.03	0.02	0.03
CaO	20.88	21.91	22.00	21.71	21.59	21.70	21.65	20.99	21.84
Na ₂ O	0.47	0.28	0.34	0.41	0.38	0.36	0.29	0.49	0.34
K ₂ O	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.01
TOTAL	98.55	98.90	99.49	99.38	99.47	99.70	99.05	99.25	99.98

Structural Formulae based on 6 Oxygens

Si	1.857	1.913	1.844	1.873	1.850	1.893	1.844	1.847	1.903
Al ^{IV}	0.143	0.087	0.156	0.127	0.150	0.107	0.156	0.153	0.097
Al ^{VI}	0.093	0.051	0.081	0.061	0.076	0.076	0.093	0.097	0.062
Ti	0.016	0.007	0.015	0.016	0.019	0.007	0.018	0.019	0.014
Cr	0.000	0.010	0.002	0.000	0.000	0.009	0.002	0.000	0.000
Mg	0.782	0.881	0.794	0.809	0.772	0.862	0.767	0.758	0.813
Fe	0.242	0.161	0.228	0.235	0.257	0.165	0.241	0.260	0.224
Mn	0.007	0.005	0.004	0.005	0.005	0.003	0.005	0.006	0.005
Ni	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
Ca	0.842	0.871	0.880	0.868	0.866	0.854	0.870	0.842	0.866
Na	0.034	0.020	0.024	0.028	0.027	0.024	0.021	0.035	0.023
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
oct. cations	2.016	2.006	2.028	2.022	2.022	2.001	2.017	2.017	2.007

APPENDIX 11: a) MICROPROBE PYROXENE ANALYSES (cont'd)

1. Augite porphyry flows (cont'd)

SPECIMEN: AN-78-444-1

GRAIN	1	1	1	2	2	2	2	2	3	3	3	3	4
LOCATION	core	core	rim	core	core	core	rim	rim	core	core	rim	rim	core
Oxide													
(Wt. %)													
SiO ₂	49.36	49.70	49.47	49.51	49.64	50.66	49.48	49.54	51.18	50.34	50.77	50.82	49.87
Al ₂ O ₃	4.62	4.72	5.01	4.76	4.46	4.24	4.72	4.68	3.60	4.02	3.87	4.09	4.22
TiO ₂	0.39	0.40	0.45	0.43	0.39	0.35	0.39	0.36	0.30	0.36	0.33	0.37	0.32
Cr ₂ O ₃	0.13	0.07	0.13	0.18	0.13	0.16	0.11	0.14	0.09	0.19	0.13	0.13	0.21
FeO _T	6.47	6.71	6.84	6.41	6.55	6.59	6.78	6.64	6.45	6.69	6.32	6.66	6.59
MgO	14.88	14.87	14.63	14.78	15.04	15.12	15.00	14.88	15.82	15.42	15.70	15.56	15.23
MnO	0.16	0.16	0.17	0.16	0.16	0.16	0.18	0.15	0.14	0.18	0.13	0.13	0.14
NiO	0.02	0.05	0.02	0.01	0.03	0.01	0.02	0.01	0.00	0.03	0.03	0.00	0.07
CaO	22.30	21.89	21.86	21.72	22.22	22.20	21.95	21.47	21.89	22.14	22.14	22.43	21.57
Na ₂ O	0.36	0.31	0.37	0.31	0.34	0.34	0.31	0.38	0.35	0.34	0.30	0.34	0.31
K ₂ O	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.02	0.00	0.00
TOTAL	98.69	98.88	98.95	98.27	98.96	99.83	98.95	98.35	99.82	99.71	99.74	100.53	98.53

Structural Formulae based on 6 Oxygens

Si	1.855	1.861	1.854	1.864	1.859	1.879	1.854	1.864	1.893	1.870	1.881	1.872	1.872
Al ^{IV}	0.145	0.139	0.146	0.136	0.141	0.121	0.146	0.136	0.107	0.130	0.119	0.128	0.128
Al ^{VI}	0.059	0.069	0.075	0.075	0.056	0.064	0.062	0.072	0.049	0.045	0.049	0.049	0.058
Ti	0.010	0.011	0.012	0.011	0.011	0.008	0.010	0.010	0.007	0.010	0.008	0.009	0.009
Cr	0.003	0.001	0.003	0.004	0.003	0.004	0.003	0.003	0.002	0.005	0.003	0.003	0.005
Mg	0.833	0.830	0.817	0.829	0.840	0.836	0.836	0.833	0.872	0.854	0.867	0.854	0.852
Fe	0.203	0.209	0.213	0.201	0.204	0.204	0.212	0.212	0.198	0.207	0.195	0.204	0.206
Mn	0.004	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.005	0.004	0.003	0.003
Ni	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
Ca	0.898	0.878	0.877	0.876	0.892	0.882	0.880	0.866	0.867	0.881	0.878	0.885	0.867
Na	0.025	0.022	0.026	0.022	0.024	0.024	0.022	0.026	0.025	0.024	0.021	0.023	0.022
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Σ oct. cations	2.035	2.025	2.027	2.022	2.034	2.026	2.030	2.026	2.024	2.031	2.024	2.030	2.023

APPENDIX 11: a) MICROPROBE PYROXENE ANALYSES (cont'd)

1. Augite porphyry flows (cont'd)

SPECIMEN: AN-78-444-1 (cont'd)

GRAIN	4	5	5	6	6	7
LOCATION	rim	core	rim	core	rim	core
Oxide						
(Wt. %)						
SiO ₂	50.75	50.73	50.23	51.25	51.88	51.62
Al ₂ O ₃	4.20	4.23	3.95	3.68	3.47	3.65
TiO ₂	0.33	0.31	0.33	0.30	0.28	0.30
Cr ₂ O ₃	0.13	0.10	0.13	0.13	0.21	0.19
FeO _T	7.01	6.70	6.64	6.55	6.34	6.79
MgO	15.42	15.27	15.14	15.82	15.82	15.34
MnO	0.13	0.13	0.15	0.09	0.14	0.18
NiO	0.04	0.05	0.02	0.05	0.08	0.07
CaO	22.14	20.69	21.83	21.39	22.29	21.57
Na ₂ O	0.29	0.37	0.33	0.34	0.23	0.36
K ₂ O	0.00	0.00	0.01	0.00	0.00	0.02
TOTAL	100.44	98.58	98.76	99.60	100.74	100.09

Structural Formulae based on 6 Oxygens

Si	1.872	1.894	1.882	1.896	1.900	1.903
Al	0.128	0.106	0.118	0.104	0.100	0.097
Al	0.054	0.080	0.055	0.055	0.049	0.061
Ti	0.008	0.007	0.009	0.007	0.007	0.007
Cr	0.003	0.002	0.003	0.003	0.005	0.005
Mg	0.848	0.849	0.845	0.872	0.863	0.842
Fe	0.215	0.209	0.208	0.202	0.193	0.208
Mn	0.003	0.003	0.004	0.002	0.004	0.005
Ni	0.001	0.001	0.000	0.001	0.002	0.001
Ca	0.875	0.827	0.876	0.848	0.875	0.851
Na	0.021	0.026	0.023	0.023	0.016	0.024
K	0.000	0.000	0.000	0.000	0.000	0.000
oct. cations	2.028	2.004	2.023	2.013	2.014	2.004

APPENDIX II: a) MICROPROBE PYROXENE ANALYSES (cont'd)

2. Augite porphyry dykes

SPECIMEN: AN-78-411-3

GRAIN	1	1	1	1	2	2	2	2	2	2	3	3	3	4	4
LOCATION	core	core	rim	rim	core	core	core	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	core	core
Oxide															
(Wt. %)															
SiO ₂	51.85	51.72	50.55	51.25	50.10	50.99	52.48	49.94	51.00	50.77	50.36	52.53	50.44		
Al ₂ O ₃	3.55	3.32	4.14	3.40	4.11	3.80	0.77	4.72	3.46	3.86	4.19	1.84	4.02		
TiO ₂	0.66	0.62	0.78	0.67	0.72	0.70	0.08	0.82	0.58	0.70	0.69	0.30	0.65		
Cr ₂ O ₃	0.02	0.04	0.04	0.03	0.00	0.02	0.02	0.03	0.00	0.00	0.00	0.01	0.02		
FeO _T	7.91	8.01	9.21	8.34	10.53	10.21	9.53	10.40	11.63	11.12	12.32	9.45	9.74		
MgO	14.48	14.16	13.89	14.29	12.68	13.08	13.25	12.71	12.85	12.81	12.53	13.33	13.18		
MnO	0.32	0.31	0.38	0.28	0.56	0.55	0.65	0.52	0.53	0.55	0.56	0.65	0.51		
NiO	0.05	0.04	0.04	0.07	0.04	0.07	0.08	0.05	0.03	0.06	0.01	0.09	0.05		
CaO	21.79	21.78	19.43	21.82	21.22	20.58	23.48	20.50	19.68	20.51	18.84	22.94	21.09		
Na ₂ O	0.47	0.57	0.80	0.46	0.73	0.76	0.37	0.78	0.73	0.72	0.81	0.49	0.71		
K ₂ O	0.00	0.00	0.13	0.00	0.09	0.13	0.01	0.07	0.31	0.02	0.32	0.07	0.01		
TOTAL	101.00	100.57	99.39	100.61	100.78	100.89	100.72	100.54	100.80	101.12	100.63	101.70	100.42		

Structural Formulae based on 6 Oxygens

Si ^{IV}	1.904	1.911	1.893	1.898	1.875	1.897	1.964	1.867	1.909	1.892	1.890	1.941	1.885		
Al ^{IV}	0.096	0.089	0.107	0.102	0.125	0.103	0.033	0.133	0.091	0.108	0.110	0.059	0.115		
VI															
Al	0.057	0.055	0.075	0.045	0.055	0.063	0.000	0.074	0.061	0.061	0.075	0.021	0.061		
Ti	0.017	0.016	0.021	0.018	0.020	0.020	0.002	0.023	0.015	0.019	0.019	0.007	0.017		
Cr	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
Mg	0.792	0.779	0.774	0.790	0.707	0.725	0.739	0.708	0.716	0.710	0.701	0.734	0.733		
Fe	0.242	0.247	0.288	0.257	0.330	0.317	0.297	0.325	0.363	0.345	0.386	0.292	0.304		
Mn	0.009	0.009	0.012	0.008	0.018	0.017	0.020	0.016	0.016	0.016	0.018	0.019	0.015		
Ni	0.001	0.000	0.001	0.001	0.001	0.001	0.002	0.001	0.000	0.001	0.000	0.002	0.001		
Ca	0.857	0.862	0.779	0.865	0.850	0.820	0.794	0.820	0.789	0.818	0.757	0.908	0.844		
Na	0.032	0.040	0.057	0.032	0.053	0.054	0.026	0.056	0.052	0.051	0.058	0.035	0.050		
K	0.000	0.000	0.005	0.000	0.004	0.005	0.000	0.002	0.014	0.000	0.014	0.003	0.000		
Σ oct. cations	2.007	2.009	2.013	2.016	2.038	2.022	2.027	2.025	2.026	2.021	2.028	2.021	2.025		

APPENDIX 11: a) MICROPROBE PYROXENE ANALYSES (cont'd)

2. Augite porphyry dykes (cont'd)

SPECIMEN: AN-78-411-3 (cont'd)

GRAIN	4	5	5	5
LOCATION	rim	core	n.r.	n.r.
Oxide				
(Wt. %)				
SiO ₂	52.16	51.74	50.43	48.98
Al ₂ O ₃	2.13	3.20	4.30	4.83
TiO ₂	0.35	0.69	0.80	0.83
Cr ₂ O ₃	0.02	0.02	0.03	0.04
FeO _T	10.40	8.28	9.14	12.48
MgO	12.91	13.81	13.52	12.50
MnO	0.64	0.38	0.48	0.56
NiO	0.01	0.04	0.02	0.06
CaO	21.46	22.73	21.38	17.82
Na ₂ O	0.71	0.55	0.72	0.79
K ₂ O	0.39	0.01	0.00	0.33
TOTAL	101.18	101.45	100.82	99.22

Structural Formulae based on 6 Oxygens

Si	1.942	1.904	1.875	1.865
Al ^{IV}	0.058	0.096	0.125	0.135
Al ^{VI}	0.035	0.042	0.063	0.080
Ti	0.010	0.018	0.021	0.023
Cr	0.000	0.000	0.000	0.000
Mg	0.715	0.757	0.749	0.709
Fe	0.323	0.255	0.284	0.396
Mn	0.020	0.012	0.014	0.018
Ni	0.000	0.000	0.000	0.001
Ca	0.855	0.896	0.851	0.726
Na	0.051	0.039	0.051	0.058
K	0.017	0.000	0.000	0.016
oct. cations	2.026	2.019	2.033	2.027

APPENDIX 11: a) MICROPROBE PYROXENE ANALYSES (cont'd)

2. Augite porphyry dykes (cont'd)

SPECIMEN: AN-79-698-3

GRAIN	1	1	1	1	1	2	2	2	2	2
LOCATION	core	core	core	rim	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.
Oxide										
(Wt. %)										
SiO ₂	51.09	50.11	50.39	49.88	51.19	50.36	50.58	50.78	50.31	
Al ₂ O ₃	4.37	5.26	4.81	4.89	4.25	4.64	5.04	4.38	4.25	
TiO ₂	0.52	0.62	0.56	0.62	0.49	0.53	0.56	0.50	0.49	
Cr ₂ O ₃	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.02	0.00	
FeO _T	7.55	8.13	7.48	7.63	7.49	7.61	7.75	7.41	7.13	
MgO	14.72	14.09	14.55	14.67	14.95	14.55	14.28	14.95	14.82	
MnO	0.21	0.20	0.19	0.19	0.20	0.18	0.29	0.21	0.19	
NiO	0.04	0.05	0.05	0.03	0.06	0.05	0.05	0.08	0.07	
CaO	22.77	22.51	22.77	22.80	22.75	22.77	22.35	22.47	22.64	
Na ₂ O	0.37	0.35	0.30	0.29	0.32	0.37	0.26	0.30	0.34	
K ₂ O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
TOTAL	101.64	101.32	101.10	101.02	101.70	101.06	101.07	101.10	100.24	
Structural Formulae based on 6 Oxygens										
Si ^{IV}	1.868	1.845	1.853	1.842	1.872	1.855	1.861	1.867	1.867	
Al ^{IV}	0.132	0.155	0.147	0.158	0.128	0.145	0.139	0.133	0.133	
Al ^{VI}	0.056	0.073	0.061	0.054	0.054	0.056	0.079	0.055	0.052	
Ti	0.014	0.016	0.015	0.016	0.013	0.014	0.015	0.013	0.013	
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Mg	0.801	0.733	0.797	0.807	0.814	0.799	0.782	0.819	0.819	
Fe	0.230	0.249	0.229	0.235	0.229	0.234	0.237	0.228	0.221	
Mn	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	
Ni	0.001	0.001	0.001	0.000	0.001	0.001	0.001	0.002	0.002	
Ca	0.892	0.888	0.896	0.901	0.891	0.898	0.881	0.885	0.899	
Na	0.025	0.023	0.021	0.021	0.022	0.026	0.018	0.021	0.024	
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Σ oct. cations	2.024	2.028	2.025	2.039	2.029	2.033	2.018	2.028	2.015	

APPENDIX 11: a) MICROPROBE PYROXENE ANALYSES (cont'd)

3. Gnat Lakes Ultramafite

SPECIMEN: AN-78-433-2

GRAIN	1	1	1	2	2	2	3	3	4	4	5	5	5
LOCATION	core	rim	rim	core	rim	rim	core	rim	core	rim	core	core	rim
Oxide													
(Wt. %)													
SiO ₂	51.29	49.92	49.60	51.88	50.04	50.79	49.77	50.30	51.16	50.40	52.12	51.38	51.10
Al ₂ O ₃	2.46	4.44	4.78	3.01	4.21	4.30	4.42	3.55	3.69	3.89	2.40	2.51	3.29
TiO ₂	0.46	0.72	0.90	0.55	0.77	0.76	0.84	0.60	0.68	0.71	0.49	0.48	0.57
Cr ₂ O ₃	0.04	0.00	0.01	0.00	0.00	0.00	0.01	0.03	0.04	0.00	0.02	0.00	0.02
FeO	9.09	8.30	8.08	6.81	7.48	7.46	7.55	9.21	7.05	7.72	7.39	7.23	9.15
MgO	13.16	12.43	13.08	14.88	13.88	14.23	14.18	12.99	14.50	13.81	15.32	15.23	12.98
MnO	0.19	0.20	0.23	0.17	0.18	0.18	0.16	0.23	0.20	0.20	0.18	0.21	0.28
NiO	0.05	0.06	0.04	0.07	0.00	0.06	0.05	0.07	0.01	0.03	0.05	0.05	0.05
CaO	22.98	23.61	23.46	22.99	23.09	22.76	23.16	22.87	23.21	23.08	22.77	22.88	22.91
Na ₂ O	0.54	0.45	0.45	0.23	0.35	0.31	0.36	0.47	0.30	0.38	0.24	0.24	0.48
K ₂ O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.26	100.13	100.63	100.59	100.00	100.85	100.50	100.32	100.84	100.22	100.98	100.21	100.83

Structural Formulae based on 6 Oxygens

Si	1.918	1.869	1.847	1.912	1.864	1.872	1.849	1.885	1.885	1.876	1.917	1.906	1.902
Al ^{IV}	0.082	0.131	0.153	0.088	0.136	0.128	0.151	0.115	0.115	0.124	0.083	0.094	0.098
Al ^{VI}	0.026	0.064	0.056	0.041	0.049	0.058	0.042	0.041	0.045	0.046	0.021	0.015	0.045
Ti	0.012	0.020	0.025	0.015	0.021	0.021	0.022	0.016	0.018	0.020	0.013	0.013	0.015
Cr	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mg	0.733	0.693	0.726	0.816	0.770	0.782	0.785	0.725	0.796	0.766	0.840	0.841	0.720
Fe	0.284	0.259	0.251	0.209	0.233	0.229	0.234	0.288	0.217	0.240	0.227	0.224	0.284
Mn	0.005	0.005	0.006	0.004	0.005	0.005	0.004	0.006	0.005	0.005	0.005	0.006	0.008
Ni	0.001	0.001	0.001	0.001	0.000	0.000	0.001	0.001	0.001	0.000	0.001	0.001	0.001
Ca	0.920	0.947	0.936	0.907	0.922	0.898	0.921	0.918	0.916	0.920	0.897	0.909	0.913
Na	0.038	0.032	0.031	0.016	0.024	0.021	0.025	0.034	0.021	0.027	0.016	0.016	0.035
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Σ oct. cations	2.020	2.021	2.032	2.009	2.024	2.015	2.034	2.029	2.018	2.024	2.020	2.025	2.021

APPENDIX 11: a) MICROPROBE PYROXENE ANALYSES (cont'd)
3. Gnat Lakes Ultramafite (cont'd)

SPECIMEN: AN-78-445-3

GRAIN LOCATION	1		2		3		4		5		6	
	rim	core	rim	core	rim	core	rim	core	rim	core	rim	core
Oxide												
(Wt. %)												
SiO ₂	49.72	49.89	50.23	50.06	52.20	51.25	51.04	49.63	50.46	50.94	49.39	51.71
Al ₂ O ₃	4.16	4.09	4.25	4.57	2.47	3.34	3.29	4.65	4.03	3.72	4.92	2.52
TiO ₂	0.82	0.79	0.81	0.80	0.51	0.59	0.57	0.84	0.71	0.59	0.88	0.55
Cr ₂ O ₃	0.02	0.00	0.00	0.00	0.00	0.02	0.01	0.02	0.00	0.00	0.00	0.01
FeO _T	7.12	7.16	6.93	7.15	6.38	6.50	6.76	8.58	7.14	8.33	7.49	6.38
MgO	14.21	14.52	14.45	14.25	15.52	15.05	15.21	13.15	14.00	13.62	13.93	15.46
MnO	0.16	0.14	0.13	0.13	0.11	0.13	0.16	0.21	0.19	0.23	0.17	0.14
NiO	0.03	0.01	0.05	0.05	0.05	0.07	0.05	0.04	0.06	0.06	0.03	0.05
CaO	23.66	23.27	23.16	23.43	23.10	23.48	23.42	22.90	23.67	23.27	23.27	23.38
Na ₂ O	0.29	0.24	0.30	0.32	0.18	0.23	0.37	0.47	0.38	0.46	0.27	0.26
K ₂ O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.19	100.11	100.31	100.76	100.52	100.66	100.86	100.49	100.64	101.22	100.35	100.46
												100.85

Structural Formulae based on 6 Oxygens

Si IV	1.855	1.858	1.863	1.851	1.918	1.888	1.882	1.852	1.869	1.883	1.838	1.907	1.916
Al	0.145	0.142	0.137	0.149	0.082	0.112	0.118	0.148	0.131	0.117	0.162	0.093	0.084
VI													
Al	0.037	0.037	0.048	0.049	0.024	0.033	0.025	0.056	0.044	0.044	0.053	0.016	0.038
Ti	0.021	0.021	0.021	0.021	0.014	0.016	0.015	0.023	0.020	0.016	0.024	0.015	0.012
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mg	0.790	0.805	0.799	0.786	0.850	0.826	0.835	0.731	0.772	0.749	0.772	0.850	0.735
Fe	0.221	0.228	0.214	0.220	0.195	0.200	0.208	0.267	0.220	0.257	0.232	0.196	0.260
Mn	0.004	0.004	0.003	0.003	0.003	0.003	0.004	0.005	0.005	0.006	0.004	0.004	0.006
Ni	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.001	0.001
Ca	0.946	0.928	0.919	0.928	0.909	0.926	0.925	0.916	0.939	0.920	0.927	0.923	0.927
Na	0.021	0.021	0.021	0.022	0.012	0.016	0.026	0.033	0.027	0.032	0.019	0.018	0.044
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Oct. cations	2.040	2.034	2.034	2.030	2.008	2.021	2.039	2.032	2.028	2.025	2.031	2.023	2.023

Σ oct. cations

APPENDIX 11: a) MICROPROBE PYROXENE ANALYSES (cont'd)

3. Gnat Lakes Ultramafite (cont'd)

SPECIMEN: AN-78-445-3 (cont'd)

GRAIN	6	7	7	8	8	8	8
LOCATION	rim	core	rim	core	core	rim	rim
Oxide							
(Wt. %)							
SiO ₂	51.24	51.54	51.24	52.34	49.41	50.33	49.66
Al ₂ O ₃	3.98	2.48	2.92	2.78	5.00	4.22	4.68
TiO ₂	0.53	0.53	0.56	0.52	0.99	0.77	0.90
Cr ₂ O ₃	0.05	0.01	0.01	0.00	0.00	0.00	0.00
FeO _T	6.98	6.38	6.41	6.29	6.65	6.87	7.40
MgO	13.89	15.63	14.89	15.58	13.45	14.47	14.07
MnO	0.16	0.14	0.18	0.13	0.13	0.13	0.16
NiO	0.05	0.02	0.04	0.07	0.05	0.03	0.07
CaO	24.16	22.99	23.65	23.49	24.68	23.59	23.55
Na ₂ O	0.32	0.22	0.29	0.23	0.12	0.30	0.36
K ₂ O	0.00	0.00	0.00	0.00	0.00	0.00	0.01
TOTAL	101.36	99.94	100.19	101.43	100.48	100.71	100.86

Structural Formulae based on 6' Oxygens

Si	1.882	1.910	1.899	1.907	1.834	1.859	1.839
Al	0.118	0.090	0.101	0.093	0.166	0.141	0.161
VI							
Al	0.054	0.017	0.026	0.026	0.053	0.042	0.042
Ti	0.014	0.014	0.015	0.014	0.027	0.021	0.025
Cr	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Mg	0.760	0.863	0.822	0.846	0.744	0.796	0.777
Fe	0.213	0.197	0.198	0.191	0.206	0.211	0.228
Mn	0.004	0.004	0.005	0.003	0.003	0.003	0.004
Ni	0.001	0.000	0.000	0.002	0.001	0.000	0.001
Ca	0.951	0.912	0.938	0.917	0.981	0.933	0.934
Na	0.022	0.015	0.021	0.016	0.007	0.021	0.025
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000
oct. cations	2.020	2.022	2.025	2.015	2.022	2.027	2.036

APPENDIX 11: a) MICROPROBE PYROXENE ANALYSES (cont'd)

4. Three Sisters Pluton, fine-grained phase

SPECIMEN: AN-78-488-1

GRAIN	1	2	3	4	4	5	6	7	7	8	8	9	9
LOCATION	core	n.r.	n.r.	core	rim	n.r.	core	core	rim	core	rim	core	rim
Oxide													
(Wt. %)													
SiO ₂	52.57	52.27	52.54	48.93	51.92	53.18	52.46	51.66	52.53	51.92	51.51	51.45	52.32
Al ₂ O ₃	2.58	1.59	1.89	5.20	2.70	2.25	0.80	2.32	1.78	2.29	2.43	3.83	1.94
TiO ₂	0.47	0.41	0.40	0.78	0.51	0.43	0.23	0.45	0.39	0.42	0.50	0.36	0.34
Cr ₂ O ₃	0.02	0.04	0.01	0.04	0.00	0.02	0.00	0.01	0.01	0.00	0.00	0.04	0.02
FeO _T	7.14	11.41	8.47	8.98	9.00	8.63	10.78	8.47	10.09	8.57	9.62	10.64	9.81
MgO	16.05	14.77	15.55	14.43	15.37	16.09	13.72	13.99	14.92	15.89	13.91	14.65	13.45
MnO	0.15	0.44	0.32	0.18	0.27	0.20	0.44	0.33	0.36	0.31	0.25	0.24	0.38
NiO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00
CaO	21.53	19.25	20.24	20.65	19.68	19.69	20.74	22.03	19.43	19.96	19.81	17.46	21.30
Na ₂ O	0.22	0.27	0.34	0.27	0.27	0.20	0.22	0.28	0.32	0.24	0.35	0.45	0.29
K ₂ O	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.13	0.09	0.00
TOTAL	100.73	100.45	99.77	99.46	99.72	100.69	99.40	99.54	99.83	99.60	98.52	99.22	99.85

Structural Formulae based on 6 Oxygens

Si	1.925	1.949	1.950	1.836	1.929	1.949	1.980	1.934	1.958	1.930	1.946	1.922	1.958
Al ^{IV}	0.075	0.051	0.050	0.164	0.071	0.051	0.020	0.066	0.042	0.070	0.054	0.078	0.042
Al ^{VI}	0.035	0.019	0.033	0.065	0.047	0.046	0.015	0.036	0.036	0.030	0.053	0.099	0.042
Ti	0.013	0.011	0.011	0.021	0.014	0.012	0.006	0.012	0.011	0.011	0.013	0.010	0.008
Cr	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000
Mg	0.876	0.821	0.859	0.806	0.851	0.879	0.771	0.780	0.828	0.880	0.783	0.816	0.750
Fe	0.218	0.355	0.262	0.281	0.279	0.265	0.340	0.265	0.314	0.266	0.304	0.332	0.306
Mn	0.004	0.013	0.010	0.005	0.007	0.005	0.013	0.010	0.011	0.010	0.007	0.006	0.011
Ni	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ca	0.845	0.768	0.805	0.831	0.783	0.772	0.838	0.883	0.775	0.795	0.802	0.698	0.854
Na	0.015	0.019	0.024	0.019	0.018	0.013	0.015	0.020	0.021	0.016	0.025	0.032	0.020
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.003	0.000
oct. cations	2.006	2.007	2.004	2.028	1.999	1.992	1.998	2.006	1.996	2.008	1.992	1.987	1.991

APPENDIX 11: (a) MICROPROBE PIXONENE ANALYSES (cont'd)

4. Three Sisters Pluton, fine-grained phase (cont'd)

SPECIMEN: AN-78-488-1 (cont'd)

GRAIN	10	11	12	12	13	13	14
LOCATION	core	core	core	rim	core	rim	n.r.
Oxide							
(Wt. %)							
SiO ₂	52.63	52.38	51.72	51.68	51.78	49.03	52.88
Al ₂ O ₃	1.76	1.95	2.83	3.09	2.44	5.29	0.48
TiO ₂	1.02	0.39	0.56	0.51	0.50	0.99	0.07
Cr ₂ O ₃	0.02	0.04	0.04	0.00	0.03	0.05	0.00
FeO _T	8.21	8.81	8.73	8.11	8.58	9.61	7.75
MgO	15.48	15.31	15.33	15.29	15.64	13.29	15.45
MnO	0.25	0.26	0.23	0.21	0.27	0.21	0.30
NiO	0.00	0.00	0.00	0.02	0.00	0.03	0.01
CaO	20.56	20.20	20.46	21.51	20.15	19.55	22.03
Na ₂ O	0.87	0.24	0.26	0.21	0.27	0.70	0.14
K ₂ O	0.14	0.00	0.00	0.00	0.00	0.03	0.00
TOTAL	100.94	99.58	100.16	100.63	99.66	98.78	99.11

Structural Formulae based on 6 Oxygens

Si	1.937	1.948	1.918	1.905	1.928	1.854	1.979
Al ^{IV}	0.063	0.052	0.082	0.095	0.072	0.146	0.021
Al ^{VI}	0.012	0.033	0.041	0.039	0.035	0.089	0.000
Ti	0.028	0.011	0.015	0.014	0.013	0.027	0.001
Cr	0.000	0.001	0.000	0.000	0.000	0.001	0.000
Mg	0.849	0.848	0.847	0.839	0.868	0.748	0.861
Fe	0.252	0.274	0.270	0.250	0.267	0.304	0.243
Mn	0.007	0.007	0.006	0.006	0.007	0.006	0.009
Ni	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ca	0.810	0.804	0.813	0.849	0.803	0.791	0.883
Na	0.062	0.016	0.018	0.014	0.019	0.051	0.010
K	0.006	0.000	0.000	0.000	0.000	0.000	0.000
oct. cations	2.026	1.994	2.010	2.011	2.012	2.017	2.007

APPENDIX 11: a) MICROPROBE PYROXENE ANALYSES (cont'd)

4. Three Sisters Pluton, fine-grained phase (cont'd)

SPECIMEN: AN-78-490-1 (P. Jones, Carleton University, analyst)

GRAIN	1		2		3		4		5		6		7	
	core	rim	n.r.	core	rim	core	rim	core	rim	core	core	core	core	core
LOCATION														
Oxide														
(Wt. %)														
SiO ₂	51.17	52.00	52.35	53.02	52.80	53.14	52.73	52.74	52.27	52.00				
Al ₂ O ₃	2.70	2.18	1.54	2.22	1.37	1.78	1.88	1.90	1.42	2.11				
TiO ₂	0.48	0.35	0.30	0.40	0.27	0.34	0.39	0.41	0.32	0.42				
Cr ₂ O ₃	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.				
FeO _T	10.36	9.75	9.97	9.41	11.48	9.65	11.96	9.82	11.88	10.78				
MgO	13.74	13.98	13.60	14.54	12.19	14.71	13.33	14.66	13.73	14.02				
MnO	0.52	0.51	0.59	0.58	0.56	0.58	0.54	0.52	0.63	0.56				
NiO	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.				
CaO	21.18	20.85	21.92	21.66	21.67	21.24	20.66	20.94	21.36	20.61				
Na ₂ O	0.42	0.41	0.37	0.44	0.43	0.41	0.41	0.36	0.46	0.44				
K ₂ O	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.				
TOTAL	100.57	100.03	100.64	102.27	100.77	101.85	101.90	101.35	102.07	100.94				

Structural Formulae based on 6 Oxygens

Si	1.913	1.943	1.953	1.937	1.976	1.949	1.950	1.944	1.938	1.935				
Al ^{IV}	0.087	0.057	0.047	0.063	0.024	0.051	0.050	0.056	0.062	0.065				
Al ^{VI}	0.032	0.039	0.021	0.033	0.036	0.026	0.032	0.027	0.000	0.028				
Ti	0.013	0.010	0.008	0.011	0.008	0.009	0.011	0.011	0.009	0.012				
Cr														
Mg	0.765	0.779	0.756	0.792	0.680	0.804	0.735	0.806	0.759	0.778				
Fe	0.324	0.305	0.311	0.287	0.359	0.296	0.370	0.303	0.368	0.336				
Mn	0.016	0.016	0.019	0.018	0.018	0.018	0.018	0.016	0.020	0.018				
Ni														
Ca	0.848	0.835	0.876	0.848	0.869	0.835	0.819	0.827	0.849	0.822				
Na	0.030	0.030	0.027	0.031	0.031	0.029	0.029	0.025	0.033	0.032				
K														
Σ oct. cations	2.028	2.014	2.018	2.020	2.001	2.017	2.014	2.015	2.038	2.026				

APPENDIX 11: a) MICROPROBE PYROXENE ANALYSES (cont'd)

5. Three Sisters Pluton, mafic phase

SPECIMEN: AN-78-523 (P. Jones, Carleton University, analyst)

GRAIN	1	1°	2	3	4	4	5	6	6
LOCATION	core	rim	core	rim	core	rim	core	core	rim
Oxide									
(Wt. %)									
SiO ₂	53.08	52.46	53.20	52.77	52.79	53.06	53.41	53.09	52.75
Al ₂ O ₃	0.76	0.79	0.86	0.68	0.69	0.74	0.80	0.69	0.62
TiO ₂	0.12	0.11	0.10	0.07	0.12	0.11	0.13	0.10	0.10
Cr ₂ O ₃	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
FeO _T	8.29	8.14	8.14	8.28	8.49	8.21	8.51	8.24	8.14
MgO	14.86	14.34	14.47	14.75	14.97	14.84	14.53	14.69	14.22
MnO	1.03	0.99	0.83	0.96	0.99	0.94	0.96	0.91	0.98
NiO	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
CaO	22.41	23.16	22.92	22.59	22.54	22.43	23.32	23.12	22.96
Na ₂ O	0.43	0.39	0.42	0.39	0.42	0.40	0.45	0.39	0.42
K ₂ O	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
TOTAL	100.98	100.38	100.94	100.49	101.01	100.73	102.11	101.23	100.19

Structural Formulae based on 6 Oxygens

Si ^{IV}	1.965	1.959	1.969	1.964	1.958	1.968	1.961	1.963	1.971
Al ^{VI}	0.033	0.035	0.031	0.030	0.030	0.032	0.034	0.030	0.027
Al ^{VI}	0.000	0.000	0.007	0.000	0.000	0.000	0.000	0.000	0.000
Ti	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003
Cr	0.820	0.798	0.798	0.818	0.827	0.820	0.795	0.810	0.792
Mg	0.257	0.254	0.252	0.258	0.263	0.255	0.261	0.255	0.254
Fe	0.032	0.031	0.026	0.030	0.031	0.029	0.030	0.029	0.031
Mn									
Ni									
Ca	0.889	0.926	0.909	0.901	0.896	0.891	0.917	0.916	0.919
Na	0.031	0.028	0.031	0.028	0.030	0.029	0.032	0.028	0.030
K									
Σ oct. cations	2.032	2.040	2.026	2.037	2.050	2.027	2.038	2.041	2.029

APPENDIX 11: a) MICROPROBE PYROXENE ANALYSES (cont'd)

5. Three Sisters Pluton, mafic phase (cont'd)

SPECIMEN: AN-78-536-2

GRAIN	1	1	2	2	2	3	3	4	5	6	7
LOCATION	core	rim	core	intermed	rim	core	rim	core	core	rim	rim
Oxide											
(Wt. %)											
SiO ₂	53.13	52.93	53.48	53.70	52.50	53.75	53.34	53.08	52.76	53.32	53.70
Al ₂ O ₃	1.00	0.57	0.94	0.32	0.57	0.63	0.55	0.47	1.61	0.51	0.30
TiO ₂	0.16	0.13	0.13	0.04	0.07	0.07	0.07	0.07	0.27	0.03	0.02
Cr ₂ O ₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
FeO _T	7.65	7.22	6.95	6.80	7.43	7.05	7.13	7.50	7.28	7.97	8.79
MgO	14.28	14.56	14.44	14.46	14.26	14.53	14.54	14.46	14.70	14.04	14.29
MnO	0.29	0.29	0.26	0.29	0.30	0.25	0.27	0.28	0.23	0.31	0.32
NiO	0.02	0.01	0.00	0.00	0.02	0.01	0.00	0.00	0.01	0.03	0.04
CaO	23.73	23.55	23.80	24.36	23.42	23.76	23.73	23.52	22.95	23.49	24.16
Na ₂ O	0.35	0.35	0.32	0.13	0.26	0.26	0.29	0.21	0.36	0.28	0.20
K ₂ O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	100.61	99.61	100.32	100.10	98.83	100.31	99.92	98.60	100.17	99.98	99.82

Structural Formulae based on 6 Oxygens

	Si	Al ^{IV}	Al ^{VI}	Ti	Cr	Ng	Fe	Mn	Ni	Ca	Na	K	oct. cations
	1.968	1.977	1.977	1.992	1.992	1.977	1.987	1.983	1.983	1.955	1.987	1.997	1.998
	0.032	0.023	0.023	0.008	0.023	0.023	0.013	0.017	0.017	0.045	0.013	0.003	0.003
	0.011	0.001	0.017	0.005	0.002	0.014	0.007	0.003	0.003	0.024	0.008	0.010	0.008
	0.004	0.003	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.007	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.788	0.810	0.795	0.799	0.800	0.800	0.805	0.805	0.811	0.811	0.780	0.791	0.780
	0.237	0.225	0.214	0.210	0.233	0.218	0.221	0.233	0.225	0.248	0.248	0.210	0.210
	0.008	0.008	0.007	0.008	0.009	0.007	0.007	0.008	0.006	0.010	0.010	0.010	0.010
	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
	0.941	0.942	0.942	0.967	0.945	0.940	0.945	0.940	0.910	0.910	0.937	0.962	0.962
	0.024	0.025	0.022	0.008	0.019	0.018	0.021	0.015	0.025	0.025	0.020	0.014	0.014
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	2.013	2.014	2.000	1.998	2.010	1.998	2.007	2.005	2.008	2.008	2.003	1.998	1.998

APPENDIX II: a) MICROPROBE PYROXENE ANALYSES (cont'd)

6. Three Sisters Pluton, central phase

SPECIMEN: AN-77-114-3 (P. Jones, Carleton University, analyst)

GRAIN	1 ^a	1 ^a	2 ^a	3 ^a	4 ^a	5 ^a	6 ^b	7 ^b	8 ^b	
LOCATION	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	
Oxide										a. pyroxene in an inclusion in host
(wt. %)										b. pyroxene cores of hornblende in host

SiO ₂	49.91	51.60	52.17	51.92	51.97	51.53	52.57	53.16	52.59	
Al ₂ O ₃	1.12	1.00	0.96	0.64	0.82	1.02	0.41	0.22	0.23	
TiO ₂	0.16	0.15	0.14	0.14	0.15	0.17	0.04	0.03	0.00	
Cr ₂ O ₃	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	
FeO _T	8.69	8.43	8.59	7.76	8.36	8.43	8.58	7.42	7.92	
MgO	15.51	15.11	15.24	14.73	14.60	14.93	14.08	14.67	14.52	
MnO	1.06	0.99	1.08	0.99	0.99	1.21	1.05	1.08	1.01	
NiO	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	
CaO	23.55	22.17	22.08	23.04	23.01	22.39	23.82	24.48	24.30	
Na ₂ O	0.44	0.40	0.39	0.43	0.42	0.49	0.39	0.35	0.27	
K ₂ O	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	
TOTAL	100.74	99.85	100.65	99.65	100.32	100.17	100.94	101.41	100.87	

Structural Formulae based on 6 Oxygens

Si _{IV}	1.884	1.938	1.943	1.952	1.946	1.934	1.961	1.965	1.960	
Al	0.050	0.044	0.042	0.028	0.036	0.045	0.018	0.009	0.010	
Al ^{VI}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Ti	0.004	0.004	0.004	0.004	0.004	0.005	0.001	0.001	0.000	
Cr	-	-	-	-	-	-	-	-	-	
Mg	0.872	0.846	0.846	0.826	0.815	0.835	0.783	0.808	0.807	
Fe	0.274	0.265	0.267	0.244	0.262	0.264	0.268	0.229	0.247	
Mn	0.034	0.031	0.034	0.032	0.031	0.038	0.033	0.033	0.032	
Ni	-	-	-	-	-	-	-	-	-	
Ca	0.952	0.892	0.881	0.928	0.923	0.900	0.952	0.970	0.970	
Na	0.032	0.031	0.028	0.031	0.030	0.036	0.028	0.025	0.020	
K	-	-	-	-	-	-	-	-	-	
Oct. cations	2.168	2.069	2.060	2.065	2.065	2.078	2.065	2.066	2.076	

APPENDIX 11: a) MICROPROBE PYROXENE ANALYSES (cont'd)
6. Three Sisters Pluton, central phase (cont'd)

SPECIMEN: AN-78-529-1

GRAIN	1	1	2	3	4	4	5	5	6	6	7	7
LOCATION	core	rim	core	core	core	rim	core	rim	core	rim	core	rim
Oxide												
(Wt. %)												
SiO ₂	52.75	52.76	50.89	52.97	52.17	51.11	52.81	53.66	52.84	53.20	53.24	53.24
Al ₂ O ₃	0.51	0.43	2.91	0.86	0.63	2.36	0.45	0.30	1.39	0.73	0.79	0.88
TiO ₂	0.11	0.12	0.48	0.50	0.11	0.18	0.10	0.02	0.50	0.11	0.09	0.16
Cr ₂ O ₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
FeO _T	8.15	8.75	11.24	9.67	10.34	8.61	8.46	8.20	9.76	9.34	9.72	9.83
MgO	13.83	13.01	12.99	13.50	13.57	13.01	13.30	13.68	13.31	13.94	13.65	13.79
MnO	0.50	0.43	0.43	0.53	0.61	0.53	0.47	0.48	0.41	0.48	0.50	0.56
NiO	0.00	0.04	0.00	0.03	0.01	0.03	0.03	0.00	0.04	0.01	0.03	0.01
CaO	22.91	23.15	19.08	22.05	21.27	21.70	22.59	23.70	21.21	21.26	21.40	21.36
Na ₂ O	0.31	0.40	0.68	0.38	0.45	0.43	0.32	0.19	0.22	0.33	0.25	0.24
K ₂ O	0.00	0.00	0.22	0.00	0.00	0.09	0.00	0.01	0.12	0.00	0.00	0.00
TOTAL	99.07	99.09	98.92	100.49	99.16	98.05	98.53	100.24	99.80	99.40	99.67	99.74

Structural Formulae based on 6 Oxygens

Si	1.989	1.992	1.933	1.975	1.978	1.949	2.000	1.999	1.979	1.995	1.995	1.991	1.994
Al ^{IV}	0.011	0.008	0.067	0.025	0.022	0.051	0.000	0.001	0.021	0.005	0.005	0.009	0.006
Al ^{VI}	0.011	0.011	0.062	0.012	0.005	0.054	0.020	0.012	0.039	0.027	0.029	0.026	0.032
Ti	0.002	0.003	0.013	0.013	0.002	0.004	0.002	0.000	0.013	0.002	0.002	0.004	0.004
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mg	0.776	0.732	0.736	0.749	0.767	0.738	0.750	0.758	0.743	0.779	0.762	0.765	0.758
Fe	0.256	0.275	0.356	0.301	0.327	0.274	0.268	0.254	0.305	0.292	0.304	0.308	0.308
Mn	0.015	0.013	0.013	0.016	0.019	0.017	0.014	0.014	0.012	0.014	0.015	0.017	0.016
Ni	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ca	0.924	0.936	0.776	0.880	0.863	0.886	0.917	0.945	0.851	0.854	0.858	0.852	0.851
Na	0.022	0.028	0.049	0.027	0.032	0.031	0.023	0.013	0.015	0.023	0.018	0.021	0.016
K	0.000	0.000	0.010	0.000	0.000	0.004	0.000	0.000	0.005	0.000	0.000	0.000	0.000
oct. cations	2.006	1.999	2.015	1.998	2.015	2.008	1.994	1.996	1.983	1.991	1.988	1.993	1.985

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APPENDIX 11: a) MICROPROBE PYROXENE ANALYSES (cont'd)

6. Three Sisters Pluton, central phase (cont'd)

SPECIMEN: AN-78-529-1 (cont'd)

GRAIN	8	9	9	10	10	11	11	11	12
LOCATION	rim	core	rim	core	rim	n.r.	n.r.	n.r.	core
Oxide									
(Wt. %)									
SiO ₂	53.51	53.20	53.14	53.66	53.70	53.84	53.54	53.62	
Al ₂ O ₃	0.70	0.40	0.55	0.49	0.28	0.31	0.59	0.26	
TiO ₂	0.07	0.02	0.05	0.06	0.00	0.04	0.06	0.00	
Cr ₂ O ₃	0.01	0.00	0.01	0.02	0.00	0.00	0.00	0.00	
FeO _T	10.44	8.78	9.65	9.68	8.96	9.62	9.21	8.50	
MgO	13.21	13.25	12.88	13.52	12.89	13.37	13.60	13.30	
MnO	0.76	0.64	0.61	0.59	0.59	0.55	0.49	0.58	
NiO	0.01	0.01	0.01	0.03	0.03	0.03	0.03	0.04	
CaO	20.93	23.31	22.40	21.96	24.08	22.57	22.20	23.47	
Na ₂ O	0.28	0.16	0.23	0.24	0.09	0.23	0.17	0.15	
K ₂ O	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	
TOTAL	99.92	99.77	99.53	100.25	100.64	100.76	99.89	99.92	
Structural Formulae based on 6 Oxygens									
Si	2.003	1.996	2.000	2.001	2.000	2.000	2.000	2.004	
Al ^{IV}	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	
Al ^{VI}	0.031	0.014	0.024	0.021	0.012	0.021	0.025	0.011	
Ti	0.001	0.000	0.001	0.001	0.000	0.000	0.001	0.000	
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Mg	0.737	0.740	0.722	0.750	0.716	0.740	0.757	0.740	
Fe	0.326	0.275	0.303	0.302	0.278	0.298	0.287	0.265	
Mn	0.023	0.020	0.019	0.017	0.017	0.017	0.015	0.017	
Ni	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Ca	0.839	0.937	0.902	0.876	0.960	0.898	0.888	0.940	
Na	0.020	0.011	0.015	0.016	0.005	0.015	0.012	0.010	
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
oct. cations	1.977	1.997	1.986	1.983	1.988	1.989	1.985	1.983	

APPENDIX 11: b) MICROPROBE AMPHIBOLE ANALYSES (cont'd)

2. Gnat Lakes Ultramafite

SPECIMEN: AN-78-433-2

GRAIN	1	1	2	2	2	3	3	4	4
LOCATION	rim	rim	core	rim	rim	core	rim	core	rim
Oxide (Wt. %)									
SiO ₂	40.57	40.58	41.37	41.31	41.63	40.99	41.30	40.59	40.91
Al ₂ O ₃	13.88	13.71	13.35	13.24	12.80	12.04	12.11	13.36	12.93
TiO ₂	2.43	2.40	2.45	2.32	2.11	2.67	2.70	2.54	2.55
Cr ₂ O ₃	0.01	0.00	0.00	0.01	0.00	0.02	0.04	0.00	0.02
FeO _T	13.92	13.40	11.83	12.17	12.36	15.07	15.33	15.73	16.00
MgO	11.95	12.12	13.68	13.12	13.16	11.49	11.32	11.08	10.95
MnO	0.15	0.21	0.14	0.18	0.18	0.20	0.20	0.20	0.21
NiO	0.03	0.03	0.04	0.03	0.04	0.05	0.07	0.04	0.04
CaO	11.84	11.96	12.12	11.90	12.12	11.84	11.73	11.73	12.01
Na ₂ O	2.13	2.12	2.35	2.11	2.22	2.16	2.11	2.16	2.05
K ₂ O	1.20	1.16	1.04	1.12	1.09	1.20	1.21	4.15	1.15
TOTAL	98.11	97.69	98.37	97.51	97.91	97.73	98.12	98.62	98.82
Structural Formulae based on 23 Oxygens									
Si	6.041	6.057	6.084	6.133	6.160	6.168	6.183	6.064	6.107
Al IV	1.959	1.943	1.916	1.867	1.840	1.832	1.817	1.936	1.893
TOTAL	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
VI									
Al	0.475	0.464	0.396	0.445	0.395	0.299	0.318	0.414	0.380
Ti	0.268	0.265	0.265	0.257	0.253	0.299	0.303	0.280	0.284
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000
Mg	2.645	2.691	2.998	2.898	2.902	2.572	2.526	2.469	2.434
Fe	1.729	1.668	1.453	1.507	1.530	1.894	1.917	1.963	1.997
Mn	0.015	0.019	0.015	0.019	0.019	0.019	0.019	0.019	0.027
Ni	0.000	0.000	0.004	0.000	0.004	0.004	0.004	0.000	0.004
TOTAL	5.132	5.107	5.131	5.126	5.103	5.087	5.091	5.145	5.126
Ca	1.886	1.909	1.905	1.890	1.917	1.909	1.878	1.882	1.917
Na	0.610	0.613	0.667	0.606	0.633	0.625	0.610	0.621	0.590
K	0.222	0.219	0.192	0.207	0.203	0.230	0.230	0.219	0.219
TOTAL	2.718	2.741	2.764	2.703	2.753	2.764	2.718	2.722	2.726

APPENDIX 11: b) MICROPROBE AMPHIBOLE ANALYSES (cont'd)

2. Gnat Lakes Ultramafite (cont'd)

SPECIMEN: AN-78-445-3

GRAIN	1	1	2	2	3	4	4	4	4
LOCATION	core	rim	core	core	rim	core	core	rim	rim
Oxide (wt. %)									
SiO ₂	41.16	41.44	38.97	40.94	41.26	41.38	41.32	41.06	41.14
Al ₂ O ₃	13.10	13.41	13.89	13.10	13.54	12.91	13.63	13.81	13.74
TiO ₂	2.13	2.27	2.07	2.27	2.26	2.26	2.25	2.48	2.37
Cr ₂ O ₃	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.01	0.00
FeO _T	10.97	10.81	12.22	11.59	11.53	11.28	11.13	11.50	10.97
MgO	14.32	14.21	14.35	13.99	14.07	13.91	14.36	14.06	14.46
MnO	0.14	0.11	0.16	0.12	0.13	0.14	0.14	0.10	0.10
NiO	0.03	0.00	0.05	0.03	0.03	0.07	0.05	0.04	0.03
CaO	12.03	12.26	10.55	12.17	12.21	12.23	12.36	12.24	12.36
Na ₂ O	2.00	2.05	2.22	2.29	2.29	2.15	2.14	2.17	2.09
K ₂ O	1.54	1.66	1.22	1.44	1.40	1.43	1.64	1.55	1.57
TOTAL	97.42	98.22	95.70	97.96	98.73	97.76	99.02	99.02	98.83
Structural Formulae based on 23 Oxygens									
Si	6.099	6.087	5.911	6.064	6.052	6.126	6.034	6.003	6.022
Al IV	1.901	1.913	2.089	1.936	1.948	1.874	1.956	1.997	1.978
TOTAL	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
VI									
Al	0.388	0.406	0.395	0.349	0.394	0.376	0.376	0.380	0.387
Ti	0.234	0.249	0.230	0.249	0.245	0.245	0.242	0.268	0.257
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mg	3.163	3.109	3.247	3.086	3.074	3.067	3.124	3.063	3.151
Fe	1.357	1.326	1.549	1.434	1.411	1.392	1.357	1.403	1.338
Mn	0.015	0.012	0.015	0.012	0.012	0.012	0.015	0.008	0.008
Ni	0.000	0.000	0.004	0.000	0.000	0.008	0.004	0.004	0.000
TOTAL	5.157	5.102	5.440	5.130	5.136	5.100	5.118	5.126	5.141
Ca	1.909	1.924	1.714	1.928	1.917	1.936	1.932	1.917	1.936
Na	0.567	0.583	0.648	0.656	0.648	0.613	0.602	0.613	0.587
K	0.291	0.310	0.023	0.268	0.257	0.268	0.303	0.288	0.291
TOTAL	2.767	2.817	2.385	2.852	2.822	2.817	2.837	2.818	2.814

APPENDIX 11: b) MICROPROBE AMPHIBOLE ANALYSES (cont'd)

2. Gnat Lakes Ultramafite (cont'd)

SPECIMEN: AN-79-607-2 (cont'd)

STAIN	7	7	7	8	8	8
LOCATION	core	int	rim	core	int	rim
Oxide (Wt. %)						
SiO ₂	41.39	41.02	47.05	49.89	41.14	46.05
Al ₂ O ₃	11.81	13.18	6.79	5.37	12.11	7.76
TiO ₂	2.39	2.40	0.44	1.18	2.41	1.08
Cr ₂ O ₃	0.00	0.00	0.00	0.00	0.00	0.00
FeO _T	15.46	14.50	16.93	8.94	14.93	15.52
MgO	11.01	11.33	11.95	17.23	11.42	12.27
MnO	0.14	0.14	0.16	0.09	0.16	0.16
NiO	0.03	0.00	0.01	0.03	0.05	0.02
CaO	11.57	11.86	11.76	12.87	11.49	11.59
Na ₂ O	2.06	2.21	1.11	1.25	2.24	1.36
K ₂ O	1.18	1.16	0.54	0.43	1.14	0.76
TOTAL	97.04	97.80	96.74	97.28	97.09	96.57
Structural Formulae based on 23 Oxygens						
Si	6.268	6.133	7.073	7.191	6.214	6.195
Al IV	1.732	1.867	0.927	0.809	1.786	1.805
TOTAL	8.000	8.000	8.000	8.000	8.000	8.000
VI						
Al	0.373	0.452	0.273	0.100	0.368	0.437
Ti	0.268	0.268	0.046	0.127	0.268	0.119
Cr	0.000	0.000	0.000	0.000	0.000	0.000
Mg	2.484	2.522	2.676	3.699	2.568	2.745
Fe	1.955	1.813	2.128	1.073	1.882	1.947
Mn	0.015	0.015	0.015	0.008	0.015	0.015
Ni	0.000	0.000	0.000	0.000	0.004	0.000
TOTAL	5.095	5.070	4.835	5.007	5.105	5.263
Ca	1.875	1.901	1.894	1.990	1.855	1.863
Na	0.602	0.640	0.322	0.345	0.656	0.391
K	0.226	0.219	0.100	0.077	0.219	0.142
TOTAL	2.703	2.760	2.316	2.412	2.730	2.396

2. Gnat Lakes Ultramafite (cont'd)

SPECIMEN: AN-79-607-2

Structural Formulae based on 23 Oxygens

Si	6.202	6.647	6.153	6.141	6.164	6.183	6.145	6.103	6.693	6.153	6.068	6.210	6.133
Al ^{IV}	1.798	1.353	1.847	1.859	1.836	1.817	1.855	1.897	1.307	1.847	1.932	1.790	1.867
TOTAL	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
VI													
Al ₃	0.475	0.246	0.380	0.410	0.407	0.403	0.448	0.426	0.272	0.388	0.383	0.433	0.422
Ti	0.242	0.169	0.226	0.226	0.219	0.211	0.249	0.268	0.172	0.245	0.242	0.230	0.268
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mg	2.818	2.668	3.232	3.270	3.266	3.247	2.913	2.576	2.599	3.117	3.166	2.887	2.545
Fe	1.560	2.050	1.257	1.227	1.200	1.269	1.468	1.809	2.055	1.349	1.342	1.553	1.878
Mn	0.015	0.027	0.000	0.004	0.000	0.008	0.012	0.008	0.019	0.008	0.004	0.012	0.012
Ni	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.000
TOTAL	5.110	5.160	5.095	5.137	5.092	5.138	5.090	5.087	5.125	5.107	5.137	5.115	5.125
Ca	1.871	1.852	1.917	1.905	1.909	1.909	1.863	1.882	1.855	1.909	1.905	1.898	1.878
Na	0.579	0.468	0.633	0.598	0.641	0.564	0.636	0.698	0.464	0.625	0.652	0.564	0.583
K	0.245	0.199	0.265	0.265	0.265	0.242	0.242	0.222	0.192	0.261	0.265	0.261	0.234
TOTAL	2.695	2.519	2.815	2.768	2.815	2.715	2.741	2.802	2.511	2.795	2.822	2.723	2.695

APPENDIX 11: b) MICROPROBE AMPHIBOLE ANALYSES (cont'd)

2. Gnat Lakes Ultramafite (cont'd)

SPECIMEN: AN-79-607-2 (cont'd)

GRAIN	3	3	3	4	4	4	4	4	4	4	4	4	4	4
LOCATION	int	int	rim	core	rep.	int	rep	int	rep.	int	rep	int	rep	int
Oxide (Wt. %)														
SiO ₂	41.15	40.91	41.18	42.18	42.01	41.86	41.73	41.77	42.41	41.62	41.62	41.62	40.86	41.22
Al ₂ O ₃	13.01	13.26	12.04	12.76	13.09	12.80	12.80	12.98	12.17	13.14	13.14	12.79	13.57	13.34
TiO ₂	2.05	2.40	2.39	2.02	2.09	2.03	2.04	2.04	2.02	2.09	2.09	2.00	2.29	2.26
Cr ₂ O ₃	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.00
FeO _T	13.44	14.00	16.38	11.71	11.09	9.82	9.89	10.28	10.36	10.36	10.36	11.51	11.13	10.90
MgO	12.45	11.88	10.75	13.48	13.88	15.38	15.02	14.75	14.84	14.66	14.66	14.27	13.82	14.05
MnO	0.13	0.11	0.13	0.05	0.07	0.04	0.06	0.07	0.07	0.09	0.09	0.04	0.07	0.07
NiO	0.03	0.01	0.04	0.01	0.02	0.00	0.00	0.03	0.00	0.04	0.04	0.03	0.03	0.04
CaO	12.08	11.93	11.66	12.12	12.19	12.22	12.02	12.20	11.55	12.13	12.13	12.10	12.08	11.98
Na ₂ O	2.04	2.19	2.16	1.95	2.05	2.24	2.09	2.20	2.16	2.12	2.12	2.01	2.19	2.11
K ₂ O	1.33	1.17	1.16	1.34	1.41	1.39	1.36	1.34	1.32	1.34	1.34	1.40	1.26	1.30
TOTAL	97.71	97.86	97.89	97.63	97.90	97.78	97.01	97.66	96.90	97.61	97.61	97.77	97.30	97.27
Structural Formulae based on 23 Oxygens														
Si	6.145	6.107	6.206	6.229	6.176	6.141	6.164	6.145	6.268	6.126	6.126	6.149	6.061	6.103
Al IV	1.855	1.893	1.794	1.771	1.824	1.859	1.836	1.855	1.732	1.874	1.874	1.851	1.939	1.897
TOTAL	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
VI														
Al	0.434	0.434	0.341	0.449	0.445	0.353	0.391	0.391	0.384	0.406	0.406	0.372	0.434	0.430
Ti	0.226	0.265	0.268	0.222	0.230	0.219	0.226	0.222	0.222	0.230	0.230	0.222	0.249	0.245
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mg	2.768	2.641	2.415	2.963	3.036	3.362	3.308	3.232	3.266	3.216	3.216	3.140	3.051	3.097
Fe	1.679	1.748	2.062	1.441	1.357	1.200	1.223	1.261	1.277	1.272	1.272	1.422	1.380	1.346
Mn	0.012	0.012	0.012	0.004	0.004	0.004	0.004	0.004	0.008	0.008	0.008	0.004	0.008	0.004
Ni	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.004	0.000	0.000	0.004
TOTAL	5.119	5.100	5.102	5.079	5.072	5.138	5.152	5.110	5.157	5.136	5.136	5.160	5.122	5.126
Ca	1.932	1.905	1.878	1.917	1.921	1.921	1.898	1.920	1.825	1.909	1.909	1.913	1.917	1.898
Na	0.587	0.629	0.629	0.556	0.583	0.636	0.594	0.625	0.617	0.606	0.606	0.571	0.625	0.602
K	0.249	0.219	0.222	0.249	0.261	0.257	0.253	0.249	0.245	0.249	0.249	0.261	0.234	0.242
TOTAL	2.768	2.753	2.729	2.722	2.765	2.814	2.745	2.794	2.687	2.764	2.764	2.745	2.766	2.742

APPENDIX 11: b) MICROPROBE AMPHIBOLE ANALYSES (cont'd)

2. Gnat Lakes Ultramafite (cont'd)

SPECIMEN: AN-79-607-2 (cont'd)

GRAIN	4	4	4	4	4	5	5	5	5	5	6	6	6
LOCATION	int	rep	int	rep	rim	rep	core	int	int	rim	core	int	rim
Oxide (Wt. %)													
SiO ₂	41.30	40.82	41.95	40.55	47.01	46.52	41.80	41.75	46.73	44.21	47.19	44.40	46.31
Al ₂ O ₃	13.18	13.08	12.06	12.25	7.03	7.70	12.76	12.96	7.59	10.15	7.27	9.07	7.41
TiO ₂	2.44	2.47	2.37	2.31	0.96	1.08	2.05	2.03	1.02	1.53	0.47	1.37	0.86
Cr ₂ O ₃	0.00	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00
FeO _T	13.64	14.43	15.80	15.88	15.93	16.71	14.64	10.54	16.43	16.76	14.97	17.02	16.04
MgO	12.26	11.53	11.01	11.04	12.71	11.90	10.77	14.71	12.25	10.62	12.85	11.32	12.11
MnO	0.11	0.14	0.14	0.15	0.16	0.13	0.07	0.06	0.18	0.15	0.14	0.18	0.14
NiO	0.04	0.05	0.04	0.00	0.00	0.03	0.03	0.00	0.01	0.05	0.03	0.03	0.04
CaO	11.93	11.77	11.69	11.75	11.81	11.49	12.09	12.05	11.82	11.15	12.01	11.59	11.78
Na ₂ O	2.23	2.24	2.15	2.05	1.33	1.45	2.07	2.15	1.33	1.39	1.15	1.59	1.16
K ₂ O	1.10	1.20	1.16	1.21	0.71	0.82	1.34	1.29	0.77	1.03	0.58	1.05	0.71
TOTAL	98.23	97.75	98.37	97.20	97.65	97.83	97.62	97.54	98.17	97.04	96.66	97.62	96.56
Structural Formulae based on 23 Oxygens													
Si	6.126	6.110	6.275	6.153	6.992	6.927	6.164	6.149	6.931	6.655	7.046	6.677	6.969
Al IV	1.874	1.890	1.725	1.847	1.008	1.073	1.836	1.851	1.069	1.345	0.954	1.333	1.031
TOTAL	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
VI													
Al	0.430	0.418	0.399	0.338	0.223	0.276	0.380	0.395	0.257	0.453	0.323	0.273	0.280
Ti	0.268	0.276	0.261	0.222	0.104	0.119	0.226	0.219	0.111	0.173	0.054	0.153	0.092
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mg	2.706	2.568	2.453	2.496	2.814	2.637	3.220	3.228	2.706	2.381	2.856	2.534	2.714
Fe	1.687	1.806	1.974	2.013	1.978	2.078	1.330	1.296	2.036	2.108	1.867	2.139	2.016
Mn	0.012	0.012	0.012	0.015	0.015	0.012	0.008	0.004	0.019	0.015	0.012	0.019	0.012
Ni	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000
TOTAL	5.103	5.084	5.099	5.084	5.134	5.122	5.164	5.142	5.129	5.134	5.112	5.118	5.114
Ca	1.894	1.882	1.867	1.909	1.878	1.832	1.909	1.901	1.875	1.798	1.917	1.867	1.898
Na	0.640	0.648	0.617	0.602	0.380	0.418	0.587	0.613	0.383	0.399	0.326	0.460	0.334
K	0.203	0.230	0.219	0.230	0.130	0.153	0.249	0.242	0.142	0.192	0.107	0.199	0.130
TOTAL	2.737	2.760	2.703	2.741	2.388	2.403	2.745	2.756	2.400	2.389	2.350	2.526	2.362

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APPENDIX II b) MICROPROBE AMPHIBOLE ANALYSES (cont'd)

3. Three Sisters Pluton, fine-grained phase

SPECIMEN: AN-78-488-1

GRAIN	1	2	3	4	5	6	6
LOCATION	n.r.	n.r.	n.r.	n.r.	n.r.	core	rep
Oxide (Wt. %)							
SiO ₂	53.89	48.05	47.18	46.93	48.12	45.43	45.63
Al ₂ O ₃	1.70	6.38	6.92	7.16	6.07	5.80	5.98
TiO ₂	0.10	1.11	1.64	1.45	0.76	1.20	1.21
Cr ₂ O ₃	0.02	0.04	0.00	0.00	0.03	0.02	0.03
FeO ^T	15.06	14.88	14.35	15.66	16.17	14.85	16.08
MgO	15.90	13.62	13.86	12.73	13.35	13.64	12.32
MnO	1.12	0.23	0.23	0.30	0.30	0.28	0.31
NiO	0.00	0.02	0.00	0.04	0.00	0.03	0.03
CaO	8.82	10.86	10.88	10.87	10.65	10.86	11.23
Na ₂ O	0.12	1.27	1.41	1.31	1.17	1.09	0.98
K ₂ O	0.12	0.70	0.98	0.86	0.57	0.72	0.68
TOTAL	96.85	97.16	97.45	97.31	97.19	94.12	94.48
Structural Formulae based on 23 Oxygens							
Si	7.851	7.114	6.977	6.981	7.157	7.000	7.030
Al ^{IV}	0.149	0.886	1.023	1.019	0.843	1.000	0.970
TOTAL	8.000	8.000	8.000	8.000	8.000	8.000	8.000
VI							
Al	0.142	0.225	0.181	0.234	0.215	0.047	0.114
Ti	0.008	0.113	0.176	0.161	0.081	0.134	0.138
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mg	3.450	3.001	3.055	2.818	2.956	3.132	2.825
Fe	1.836	1.840	1.767	1.947	2.005	1.913	2.070
Mn	0.138	0.023	0.023	0.035	0.035	0.035	0.035
Ni	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TOTAL	5.574	5.202	5.202	5.195	5.292	5.261	5.182
Ca	1.372	1.721	1.721	1.733	1.691	1.790	1.852
Na	0.035	0.364	0.399	0.376	0.334	0.383	0.288
K	0.019	0.130	0.180	0.161	0.104	0.138	0.130
TOTAL	1.426	2.215	2.300	2.270	2.129	2.311	2.270

APPENDIX 11: b) MICROPROBE AMPHIBOLE ANALYSES (cont'd)

4. Three Sisters Pluton, mafic phase

SPECIMEN: AN-78-536-2

GRAIN	1	1	2	3	3	3	4	4	5	5
LOCATION	core	rim	core	core	int	rim	core	rim	core	rim
Oxide (Wt. %)										
SiO ₂	50.06	48.38	50.06	41.89	42.26	42.40	45.07	41.78	42.66	45.87
Al ₂ O ₃	5.23	6.41	5.23	12.43	12.82	12.14	9.34	12.30	11.36	8.54
TiO ₂	0.66	0.86	0.71	1.99	1.93	2.14	1.85	2.06	2.06	1.87
Cr ₂ O ₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO _T	12.55	13.38	12.55	12.61	12.62	13.34	14.91	14.01	13.29	13.83
MgO	14.66	14.10	15.41	13.05	13.00	13.10	13.94	12.11	12.73	13.04
MnO	0.26	0.23	0.25	0.17	0.18	0.17	0.18	0.18	0.15	0.17
NiO	0.00	0.01	0.00	0.00	0.03	0.01	0.00	0.04	0.03	0.00
CaO	12.25	11.93	12.27	12.13	12.05	11.99	12.10	11.86	11.61	11.93
Na ₂ O	0.70	0.90	0.71	1.82	1.95	1.77	1.39	1.86	1.57	1.22
K ₂ O	0.40	0.50	0.39	0.57	0.59	0.62	0.79	0.72	0.81	0.85
TOTAL	96.77	96.70	97.58	96.66	97.43	97.68	96.57	96.92	96.28	97.32
Structural Formulae based on 23 Oxygens										
Si	7.329	7.142	7.280	6.248	6.252	6.279	6.678	6.264	6.409	6.789
Al ^{IV}	0.671	0.858	0.720	1.752	1.748	1.721	1.322	1.736	1.591	1.211
TOTAL	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
VI										
Al	0.226	0.254	0.173	0.433	0.487	0.395	0.307	0.438	0.418	0.276
Ti	0.073	0.092	0.077	0.219	0.211	0.234	0.203	0.230	0.230	0.203
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mg	3.193	3.101	3.335	2.902	2.867	2.890	3.078	2.706	2.848	2.875
Fe	1.533	1.652	1.522	1.572	1.556	1.652	1.472	1.756	1.668	1.710
Mn	0.031	0.023	0.027	0.015	0.019	0.015	0.019	0.019	0.015	0.015
Ni	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000
TOTAL	5.056	5.122	5.134	5.141	5.140	5.186	5.079	5.153	5.179	5.079
Ca	1.921	1.886	1.909	1.940	1.905	1.898	1.917	1.901	1.863	1.889
Na	0.192	0.253	0.196	0.525	0.556	0.502	0.395	0.541	0.456	0.345
K	0.073	0.088	0.069	0.104	0.107	0.115	0.146	0.134	0.153	0.161
TOTAL	2.186	2.227	2.174	2.569	2.568	2.515	2.458	2.576	2.472	2.395

APPENDIX 11: b) MICROPROBE AMPHIBOLE ANALYSES (cont'd)

5. Three Sisters Pluton, central phase

SPECIMEN: AN-77-114-3 (P. Jones, Carleton University, analyst)

GRAIN	1 ^a	1 ^a	2 ^a	2 ^a	3 ^a	3 ^a	4 ^b	5 ^b	6 ^a	a. hornblende in host	b. hornblende in inclusion
LOCATION	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.	n.r.		
Oxide (Wt. %)											
SiO ₂	47.80	47.70	48.47	48.58	49.32	47.98	45.78	47.69	49.18	48.89	
Al ₂ O ₃	7.07	6.88	6.49	6.60	5.94	5.95	7.49	7.02	5.94	5.61	
TiO ₂	1.15	1.09	0.99	0.93	0.50	0.50	1.09	1.05	0.50	0.46	
Cr ₂ O ₃	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	
FeO _T	14.74	14.69	15.66	15.80	15.05	15.14	16.46	16.74	16.02	15.66	
MgO	13.93	14.12	13.79	13.71	14.39	14.32	12.41	12.68	13.78	13.95	
MnO	0.57	0.53	0.55	0.58	0.58	0.61	0.56	0.60	0.64	0.64	
NiO	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	
CaO	12.48	12.53	12.54	12.66	12.57	12.55	11.99	12.65	12.57	12.52	
Na ₂ O	1.08	1.11	0.89	0.89	0.77	0.93	0.91	1.00	0.70	0.71	
K ₂ O	0.71	0.68	0.55	0.58	0.44	0.59	0.72	0.77	0.39	0.37	
TOTAL	99.53	99.33	99.93	100.33	99.56	98.57	97.41	100.20	99.72	98.81	
Structural Formulae based on 23 Oxygens											
Si	6.946	6.947	7.026	7.020	7.138	7.054	6.865	6.951	7.136	7.155	
Al IV	1.054	1.053	0.974	0.980	0.862	0.946	1.135	1.049	0.864	0.845	
TOTAL	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	
VI											
Al	0.158	0.128	0.135	0.145	0.151	0.084	0.189	0.156	0.152	0.122	
Ti	0.126	0.119	0.108	0.101	0.054	0.055	0.123	0.115	0.055	0.051	
Cr	-	-	-	-	-	-	-	-	-	-	
Mg	3.017	3.066	2.979	2.953	3.105	3.137	2.774	2.756	2.981	3.044	
Fe	1.792	1.789	1.898	1.909	1.822	1.976	2.064	2.041	1.944	1.917	
Mn	0.070	0.066	0.067	0.071	0.071	0.076	0.072	0.074	0.079	0.079	
Ni	-	-	-	-	-	-	-	-	-	-	
TOTAL	5.163	5.168	5.187	5.179	5.203	5.328	5.222	5.142	5.211	5.213	
Ca	1.943	1.955	1.948	1.960	1.949	1.976	1.927	1.975	1.955	1.963	
Na	0.303	0.312	0.251	0.249	0.217	0.266	0.265	0.282	0.198	0.201	
K	0.131	0.127	0.102	0.106	0.081	0.110	0.138	0.144	0.072	0.068	
TOTAL	2.377	2.394	2.301	2.315	2.247	2.352	2.330	2.401	2.225	2.232	

5. Three Sisters Pluton, central phase (cont'd)

GRAIN	1	2	3	4
LOCATION	core	rim	core	rim
Oxide				
(Wt. %)				
SiO ₂	47.07	46.94	48.61	48.32
Al ₂ O ₃	6.75	6.78	6.34	6.38
TiO ₂	1.34	1.29	1.12	1.12
Cr ₂ O ₃	0.01	0.02	0.01	0.00
FeO _T	15.41	15.39	15.32	15.87
MgO	12.54	12.83	13.10	12.64
MnO	0.38	0.39	0.38	0.39
NiO	0.03	0.01	0.02	0.01
CaO	11.00	11.34	11.43	11.50
Na ₂ O	1.43	1.32	1.04	1.08
K ₂ O	0.72	0.70	0.61	0.59
TOTAL	96.68	97.38	97.98	97.98
Structural Formulae based on				
Si	7.046	7.004	7.149	7.130
Al IV	0.954	0.924	0.851	0.870
TOTAL	8.000	8.000	8.000	8.000
VI				
Al	0.238	0.196	0.245	0.238
Ti	0.150	0.138	0.119	0.119
Cr	0.000	0.000	0.000	0.000
Mg	2.795	2.852	2.871	2.779
Fe	1.928	1.917	1.882	1.955
Mn	0.042	0.046	0.042	0.046
Ni	0.000	0.000	0.000	0.000
TOTAL	5.153	5.172	5.159	5.137
Ca	1.760	1.809	1.802	1.836
Na	0.410	0.376	0.291	0.295
K	0.134	0.130	0.111	0.107
TOTAL	2.304	2.315	2.204	2.239

APPENDIX 11: c) MICROPROBE BIOTITE ANALYSES
 1. Three Sisters Pluton, fine-grained phase

SPECIMEN: AN-78-488-1

GRAIN	1	2
LOCATION	core	core
Oxide		
(Wt. %)		
SiO ₂	39.28	38.37
Al ₂ O ₃	14.11	14.24
TiO ₂	1.70	2.22
Cr ₂ O ₃	0.00	0.02
FeO _T	19.84	20.44
MgO	11.70	11.18
MnO	0.30	0.27
NiO	0.01	0.04
CaO	0.10	0.02
Na ₂ O	0.00	0.00
K ₂ O	8.84	9.13
TOTAL	95.88	95.93

Structural Formulae based on 22 Oxygens

Si	5.914	5.815
Al IV	2.086	2.185
Al TOTAL	8.000	8.000
VI		
Al	0.415	0.360
Ti	0.191	0.249
Cr	0.000	0.000
Mg	2.625	2.523
Fe	2.497	2.592
Mn	0.033	0.029
Ni	0.000	0.000
TOTAL	5.761	5.753
Ca	0.011	0.000
Na	0.000	0.000
K	1.698	1.760
TOTAL	1.709	1.760

APPENDIX 11: c) MICROPROBE BIOTITE ANALYSES (cont'd)

2. Three Sisters Pluton, central phase

SPECIMEN: AN-78-529-1

GRAIN	1	2	2	2	3	3	4	4	5	6	6
LOCATION	core	core	rim	rep	core	rim	core	rim	rim	core	rim
Oxide (Wt. %)											
SiO ₂	36.60	38.14	37.45	37.80	37.21	38.12	37.60	39.00	38.14	38.17	38.00
Al ₂ O ₃	13.84	13.02	12.87	13.34	13.64	13.54	13.63	13.34	14.41	13.39	13.67
TiO ₂	4.32	4.51	4.55	4.55	4.16	4.49	4.39	4.18	3.84	4.08	4.02
Cr ₂ O ₃	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
FeO _T	20.05	18.70	18.33	18.30	19.37	17.89	18.86	18.63	19.41	18.89	18.99
MgO	12.14	12.41	12.28	12.42	11.97	12.18	12.02	12.36	12.37	12.31	12.34
MnO	0.21	0.16	0.22	0.17	0.23	0.23	0.22	0.25	0.25	0.27	0.22
NiO	0.00	0.00	0.00	0.04	0.01	0.03	0.02	0.02	0.05	0.03	0.05
CaO	0.16	0.09	0.08	0.05	0.15	0.04	0.08	0.07	0.12	0.26	0.16
Na ₂ O	0.17	0.14	0.18	0.20	0.00	0.07	0.02	0.06	0.01	0.01	0.01
K ₂ O	8.21	8.88	8.92	9.10	7.75	8.88	8.47	8.62	7.91	8.09	8.35
TOTAL	95.71	96.05	94.88	95.97	94.49	95.48	95.32	96.53	96.51	95.50	95.81
Structural Formulae based on 22 Oxygens											
Si	5.559	5.731	5.713	5.691	5.680	5.738	5.691	5.804	5.680	5.749	5.716
Al IV	2.441	2.269	2.287	2.309	2.320	2.262	2.309	2.196	2.320	2.251	2.284
TOTAL	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
VI											
Al	0.030	0.034	0.027	0.060	0.129	0.136	0.122	0.140	0.210	0.121	0.140
Ti	0.488	0.506	0.521	0.513	0.473	0.506	0.495	0.466	0.429	0.458	0.451
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mg	2.746	2.779	2.787	2.787	2.724	2.732	2.710	2.739	2.743	2.765	2.761
Fe	2.545	2.305	2.336	2.299	2.471	2.248	2.383	2.314	2.416	2.380	2.387
Mn	0.026	0.015	0.026	0.015	0.026	0.026	0.026	0.029	0.029	0.029	0.026
Ni	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.004	0.000	0.004
TOTAL	5.835	5.639	5.697	5.674	5.823	5.648	5.736	5.688	5.831	5.753	5.769
Ca	0.022	0.011	0.007	0.004	0.022	0.004	0.007	0.007	0.015	0.040	0.022
Na	0.048	0.040	0.048	0.059	0.000	0.015	0.004	0.011	0.000	0.000	0.000
K	1.591	1.698	1.731	1.745	1.503	1.701	1.635	1.632	1.500	1.551	1.599
TOTAL	1.661	1.749	1.786	1.808	1.525	1.720	1.646	1.650	1.515	1.591	1.621

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APPENDIX 12. SOME ANALYTICAL METHODS AND UNCERTAINTIES

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APPENDIX 12: SOME ANALYTICAL METHODS AND UNCERTAINTIES

Petrography and Modal Composition

Modal compositions based on handspecimen point count estimates of stained samples, when compared to compositions based on 500-1000 thin section point counts, generally underestimate the abundance of quartz (up to 50 per cent of the amount determined from thin section) but provide fair estimates of plagioclase:alkali feldspar ratios. Rock names used in lithological descriptions of plutonic units are based on the handspecimen estimates; refinements to the names are presented in the petrographic descriptions. All plutonic rock names follow the recommendations of Streckeisen (1973).

Reliability of modal compositions based on thin section point counts may be judged using the chart of van der Plas and Tobi (1965), the per cent volume abundance of the mineral and the total point counts (see appropriate appendices). For most of the petrographic work, volume per cent modal compositions are reliable within $\pm 1-4$ volume per cent at the 95 per cent (2 σ) confidence level. Spacing of points was chosen to correspond to the average grain size of the particular sample and generally was 0.5 mm.

K-Ar, U-Pb and Rb-Sr Isotopic Age Determinations

K-Ar isotopic age determinations

Experimental procedures used in and the reliability of potassium determinations performed by the Geological Survey of Canada for mineral separate and whole rock samples are given in Wanless et al. (1965, p.1-4) and Wanless et al. (1968, p.1-6) for amphibole and whole rock samples. Argon extraction and isotopic analysis techniques are described in Wanless et al. (1979). Calculation of the reported errors (at the 95 per cent confidence levels) in individual age determinations are given in Wanless et al. (1965, p.1-4).

U-Pb isotopic age determinations

Experimental procedures used by the Geological Survey of Canada for U-Pb isotopic analyses of zircon separates and calculation of uncertainties in the age determinations are given in Loveridge (1980) and Sullivan and Loveridge (1980). Common lead corrections are based on model lead compositions (Stacey and Kramers, 1975) for the upper concordia intercept age of the sample. For sample AN-77-356-1, these common lead corrections are $^{208}\text{Pb}/^{204}\text{Pb} = 38.29(4)$, $^{207}\text{Pb}/^{204}\text{Pb} = 15.61(4)$ and $^{206}\text{Pb}/^{204}\text{Pb} = 18.41(8)$ for a sample U-Pb isotopic age of 185 Ma. The uncertainty in the zircon U-Pb isotopic age is the product of the standard error of the mean of the four $^{207}\text{Pb}/^{206}\text{Pb}$ ages at the 95 per cent confidence level and the standard deviation.

Rb-Sr isotopic age determinations

Laboratory procedures used at Carleton University for determination of total Rb and Sr concentrations, Rb/Sr ratios and isotopic analyses of Sr and their reliability are given in Bell and Blenkinsop (1977) and Bell and Dodson (1981). Slopes and intercepts for $^{87}\text{Sr}/^{86}\text{Sr}$ versus $^{87}\text{Rb}/^{86}\text{Sr}$ isochron plots were determined according to the method of York (1966, 1967, 1969) using the $1.42 \times 10^{-11} \text{ yr}^{-1}$ decay constant for ^{87}Rb (Steiger and Jäger, 1977). Mean square of weighted deviates (MSWD), a statistical estimate of the "goodness of fit" of experimental data to a straight line is calculated according to the method of Brooks et al. (1972).

Whole Rock Major, Minor and Trace Element Chemical Analysis

The following methods are used in the Geological Survey of Canada analytical laboratories for routine analysis of rock samples: X-ray fluorescence (for SiO_2 , Al_2O_3 , total iron as Fe_2O_3 , MgO , CaO , Na_2O and K_2O concentrations greater than 1.0%; TiO_2 and MnO concentrations greater than 0.5%; and P_2O_5 ,

Rb, S, Ba and Zn concentrations); and optical emission spectroscopy (for Ag, As, B, Ba, Be, Ce, Co, Cr, Cu, La, Mo, Ni, Pb, Sb, Sn, Sr, U, V, Yb, Zn and Zr). However many of these trace elements in the samples from the Hotailuh Batholith were below detection limits of the analytical method: Ag (5.0 ppm); As (2000 ppm); B (50ppm); Be (3.0 ppm); Ce (200 ppm); Co (10 ppm); Cr (5.0 ppm); Cu (7.0 ppm); La (100 ppm); Mo (50 ppm); Ni (10 ppm); Pb (700 ppm); V (20 ppm); Sb (500 ppm); Sn (200 ppm); Y (40 ppm); Yb (4.0 ppm); and Zn (200 ppm) (W.H. Champ, written communication, March, 1979; see also Champ *et al.*, 1976).

FeO determinations are done by cold acid decomposition and $K_2Cr_2O_7$ back titration. Total water is determined by sample fusion in Penfield tube and Karl Fisher titration. Acid evolution and titration methods are used for Co determinations. Fluorine and chlorine are determined by carbonate fusion and selective ion electrode techniques. Absolute (given in weight per cent) and relative (given in per cent) errors in determinations of these oxides are: SiO_2 (± 0.30 wt. per cent); Al_2O_3 (± 0.30 wt. per cent); TiO_2 (for concentrations < 0.5 wt. per cent, relative error of $\pm 15\%$; for concentrations > 0.5 wt. per cent, absolute error of ± 0.01 wt. per cent); total iron as Fe_2O_3 (± 0.06 wt. per cent); MnO (for concentrations < 0.5 wt. per cent, a relative error of $\pm 15\%$; for concentrations > 0.5 wt. per cent, an absolute error of ± 0.01 wt. per cent); CaO (± 0.05 wt. per cent); Na_2O (± 0.10 wt. per cent); K_2O (± 0.03 wt. per cent); P_2O_5 (± 0.01 wt. per cent); Rb (± 0.002 wt. per cent); Ba (± 0.002 wt. per cent); S (± 0.02 wt. per cent); Zn (± 0.002 wt. per cent); H_2O (± 0.05 wt. per cent); CO_2 (± 0.02); and all other trace elements ($\pm 15\%$) (R.M. Rousseau, written communication, April 30, 1980; W.H. Champ, written communication, March, 1979). Replicate chemical analyses were done for samples of the McBride River Pluton and the mafic and potassic marginal phases of the Three Sisters Pluton (see appropriate tables in text). Uranium

analyses, performed at the AECL laboratories have an uncertainty of ± 0.05 ppm (D. Boyle, personal communication, April, 1981).

Electron Microprobe Mineral Analyses

Most of the mineral analyses reported here were done on the MAC microprobe (energy dispersive system) at the Carnegie Institute of Washington, Geophysical Laboratories, utilizing the Krisel Control Model 2003 automation system. An accelerating voltage of 15 kv, beam current of about 50 nA and focussed and slightly defocussed beams were used. Standards included natural and synthetic materials: WEF-13 (for Si, Ca, and Fe); Ni Oliv (for Ni); DJ-35 (for Na); P-140 (for Mg); Ortho (for Al, K); Di2Ti (for Ti); 52NL11 (for Cr); and TRIP (for Mn). Analyses included SiO_2 , Al_2O_3 , Cr_2O_3 , TiO_2 , $\text{FeO}_{\text{total}}$, MgO, MnO, NiO, CaO, Na_2O and K_2O .

At Carleton University, a Cambridge MK2 (wavelength dispersive system) electron microprobe was used under an accelerating voltage of 15 kv and a sample current of about 50 nA. Standards CAMARGO, KAERSUTITE, OR 1596, DIOPSIDE, and KAK HB were used in the pyroxene and amphibole analyses.

Precision of analyses was not checked consistently; generally one core and one rim analysis were performed on each grain. In two grains where one or several sets of replicate analyses were taken (sample 607-2, grain 4, Gnat Lakes Ultramafite, amphibole; and sample 529-1, grain 2, Three Sisters Pluton, central phase, biotite - see Appendix 11), major elements varied 1-5 per cent between replicate analyses and minor elements varied 20-40 per cent. Generally, precision of analyses from the MAC microprobe is 1 to 2 per cent for major elements (T.N. Irvine, personal communication, March, 1980).

END

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