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GEOLOGY AND GEOCHRONOLOGY

of the

Guichon Creek Batholith

by

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PREFACE

The material in this report was originally presented by Mr. Northcote to the Department of Geology of the University of British Columbia in the form of a thesis in partial fulfilment of the requirements for a Ph.D. degree. The field work was sponsored by Kennco Explorations, (Western) Limited, and the laboratory work was financed by a grant from the National Research Council, Ottawa.

Although both the field and laboratory work was completed prior to Dr. Northcote's joining the staff of the Mineralogical Branch, Department of Mines and Petroleum Resources, the work is considered a sufficiently important contribution to the geology of the Guichon Creek batholith to justify its publication in bulletin form by the Department. It complements the detailed work of Dr. J. M. Carr in the Highland Valley and may be considered part of the Department's continuing study of the Guichon Creek batholith.

M. S. HEDLEY,
Chief, Mineralogical Branch.

TABLE OF CONTENTS

TABLES

FIGURES

PHOTOGRAPHS

GEOLOGY AND GEOCHRONOLOGY OF THE GUICHON CREEK BATHOLITH

Summary

The Guichon Creek batholith is exposed within an area of 400 square miles in south-central British Columbia. In shape it is an elongate, semi-concordant dome. Sedimentary and volcanic rocks of the Cache Creek Group (Permian) and Nicola Group (Upper Triassic) are intruded by the batholith. In the few places where outer intrusive contacts are exposed, the older rocks have been metamorphosed to albite-epidote and hornblende hornfels and to epidote-chlorite skarn.

Middle and Upper Jurassic sediments, Lower Cretaceous and Tertiary volcanic rocks, and sediments unconformably overlie intrusive rocks. Pleistocene glacial and interglacial deposits mantle the batholith, leaving less than 3 per cent of the surface of the batholith exposed.

The Guichon Creek batholith is a composite, upper mesozonal to epizonal, intrusive pluton consisting of several nearly concentric phases. There are a variety of contacts between phases, including sharp intrusive contacts, intrusive contacts of dyke-like bodies, and brecciated contacts. Contacts between two phases, although generally intrusive, may be gradational in some parts of the batholith. Contacts between varieties of a phase are gradational and were not observed in intrusive contact.

Twenty-six potassium-argon age determinations for the various phases of the batholith are centred around 198±8 million years. It is not possible to distinguish among phases on the basis of potassium-argon apparent ages because variations are within analytical limits of uncertainty of techniques used. No interval of time can be given for the period of emplacement of the Guichon Creek batholith, but isotopic and geologic evidence indicate it was emplaced approximately 198 million years ago, after Karnian stage of Upper Triassic but prior to Middle Jurassic. All phases began retaining argon at approximately the same time, 198±8 million years ago. The batholith has undergone no significant metamorphism since that time.

The magma is thought to have been emplaced in a series of pulses as a crystal mush and by a combination of sidewall and roof stoping, forceful intrusion, assimilation of older rock, and possibly by the action of gravity on the different densities of magma and surrounding country rock. It is believed to have crystallized during a short period of geologic time. It is suggested that erosion of overlying sedimentary and volcanic rocks, as indicated by the absence of Lower Jurassic strata, accompanied emplacement and crystallization of successive phases of the batholith. This may explain the association of mesozonal features of older phases at the batholith margin with epizonal features of younger inner phases.

Effects of assimilation are evident in outer contaminated margins of the Hybrid and Highland Valley phases. Textures of these rocks are extremely varied, and the rocks range in composition from hornblendite to quartz monzonite. Inner uncontaminated phases have orderly compositional and textural variations. The outermost uncontaminated rock, granodiorite, is thought to represent closely the composition of the original magma. Compositional differences within the inner phases are the result of differentiation within the magma chamber. The most effective process of differentiation was upward and outward movement of alkalis and silica accompanying diffusion of volatiles to regions of lower temperature and pressure. The differentiated material collected in cupolas and along walls of the magma chamber. Pressure, built up at the roof of the magma chamber, may have exceeded the confining pressure and resulted in fracturing, which allowed emplacement of magma into older crystalline phases and into surrounding country rock. The number of phases may have been largely determined by rate of diffusion of volatiles. Emplacement of differentiated magma from the margin of the chamber into cooler wallrock produced dyke-like bodies of various textures and compositions. Undifferentiated magma remaining in the magma chamber crystallized more slowly and produced rock of more uniform texture and composition.

CHAPTER I

Introduction

The Guichon Creek batholith was selected for detailed geologic and geochronologic study because it is an area of intense economic interest, because reconnaissance work had shown it to be a somewhat symmetrical complex batholith composed of rock of varied texture and composition, and because previous potassium-argon dates showed lack of agreement. A K/A date of 186 millions years, ±5 per cent, was reported for one phase by Baadsgaard, Folinsbee, and Lipson (1961) and was used by Kulp (1961) to help determine the Triassic-Jurassic time boundary. Ten K/A dates of biotite, published by the Geological Survey of Canada (1963, 1964), range from 224 to 265 million years.*

The Guichon Creek batholith underlies an area of 400 square miles within the Interior Plateau of British Columbia. The batholith is bounded by the Thompson, Nicola, and Guichon Creek Valleys (*see* Fig. 1) and is traversed by two major easterly trending upland valley systems, the Highland Valley and the Skuhun-Broom Creek Valley.

The area is readily accessible. The town of Ashcroft, at the northwest corner of the map-area, and the village of Spences Bridge, at the junction of the Nicola and Thompson Rivers, are connected by Canadian Pacific Railway and Canadian National Railway main lines and by the Trans-Canada Highway. A secondary paved highway and a Canadian Pacific Railway spur-line follow the Nicola Valley to the town of Merritt, 10 miles southeast of the area. An unpaved secondary road follows Guichon Creek Valley, along the east side of the batholith, north from Shulus to Savona. A secondary road from Ashcroft, paved for 28 miles to service the Bethlehem Copper Corporation mine, follows Highland Valley and joins the Shulus–Savona road. As a result of recent mining activity the entire area is readily accessible, few places being more than 2 miles from a road or trail.

The Thompson and Lower Nicola Valleys, between 1,000 and 3,000 feet elevation, are hot and dry in summer and support only a sagebrush or scrubby vegetation. Above 3,000 feet elevation, lower temperatures and increasing rainfall encourage grasslands and sparse pine forests, which become denser with increasing elevation. The higher ridges, ranging from 5,000 to 6,000 feet, and particularly their north slopes, support denser forest growth consisting of a mixture of pine, fir, and spruce. The upland valleys, above 4,000 feet elevation, are grasslands with aspen and willow and commonly are marshy and partly flooded because of beaver dams. Most of the area is fairly free of underbrush, but tree growth becomes extremely dense on moist north-facing slopes. Traversing is difficult in scattered,

* Since this manuscript was prepared four additional K/A age determinations from the Guichon Creek batholith have been published by the Geological Survey of Canada. These dates range from 184±8 million years to 197±10 million years and are in agreement with results obtained at the University of British Columbia (*see* R. K. Wanless, R. D. Stevens, G. R. Lachance, and C. M. Edmonds, Age Determinations and Geological Studies, K-Ar Isotopic Ages, Report 8, *Geol. Surv., Canada*, Paper 67-2, Part A, pp. 35–39).

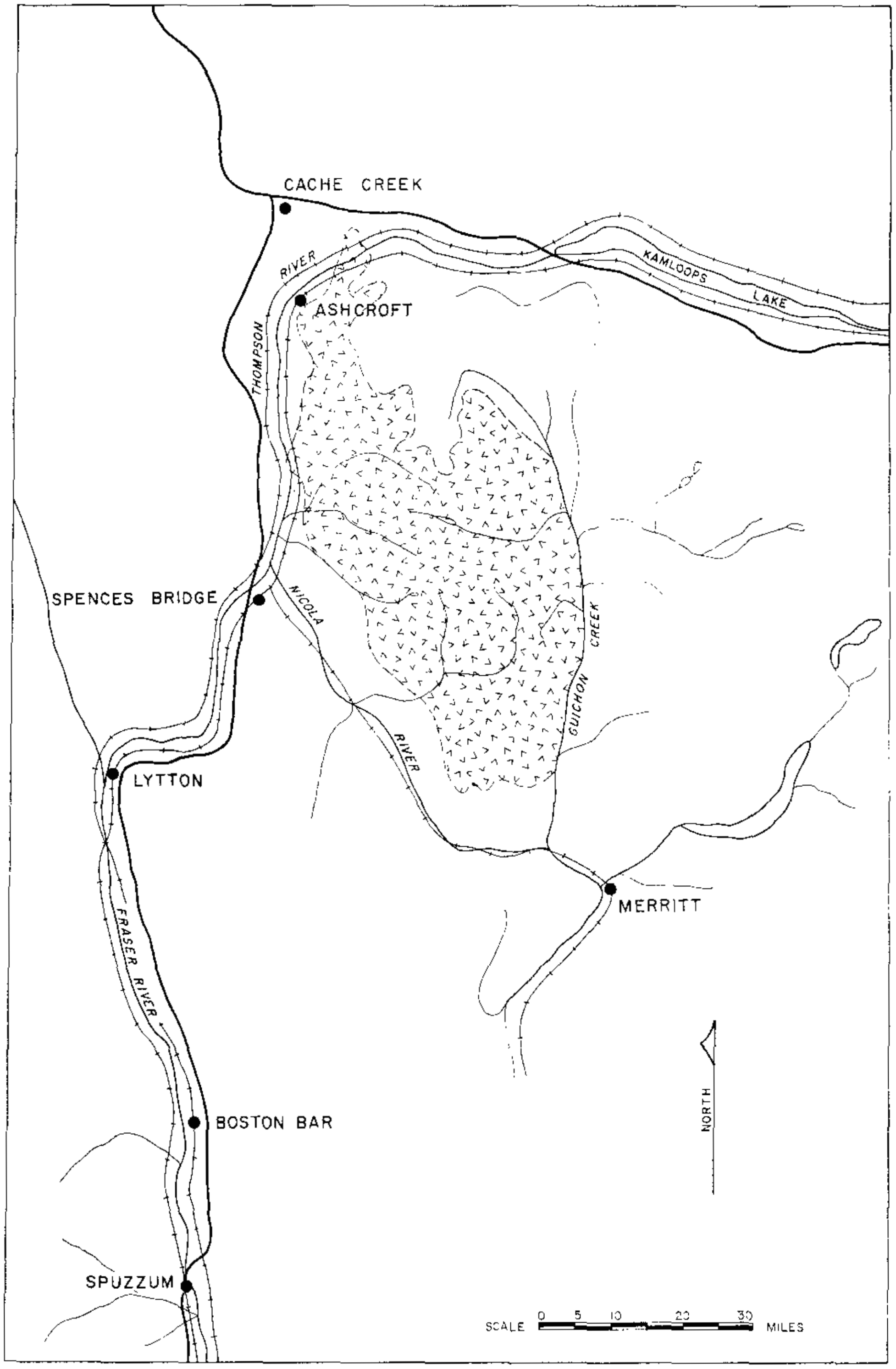

Fig. 1. Index map of Guichon Creek batholith.

large, windfall and burned-off areas, but in general the batholith is fairly easily traversed and is a very pleasant area in which to work.

Bedrock exposures are not numerous. Outcrops probably total less than 3 per cent of the area, and most of that is partly obscured by moss and lichen. Fortunately, outcrops are fairly evenly distributed, so that it is possible to map the area and project contacts from one outcrop to the next with confidence. The best exposures are found along flanks and crests of ridges, in abandoned meltwater channels, and, to a lesser extent, in stream beds.

GLACIAL FEATURES

Pleistocene glaciation was the major geomorphological process which formed the present topography of the area. Glacial and fluvioglacial features have been modified only slightly by later subaerial processes.

At its maximum thickness the Pleistocene ice-sheet, moving to the southeast, overrode the highest hills, more than 6,000 feet high, rounding their tops, deepening existing valleys, and accentuating zones of structural weakness. Areas of thick accumulation of glacial drift were moulded by the ice, forming what are now southeasterly trending drumlins, swales, and marshes.

As the thickness of the ice cap diminished, active glaciers became confined to the deeper valleys, through which now flow the Thompson and Nicola Rivers. Ablation of icefields at higher elevations resulted in deposition of thick deposits of glacial material in the previously scoured upland valleys.

Smaller glacial features were also impressed upon the landscape. In places, series of 25 or more meltwater channels were cut subparallel to contours of ridge flanks at successively lower levels as the ice receded. Many streams changed their courses as alternate channels, previously blocked by ice, became open. Kame terraces, eskers, crevasse fillings, lateral moraines, ground moraines, and erratics were deposited during wasting of icefields. These glacial features resulted in the swell and swale topography prevalent throughout the area.

During ablation of glaciers, ice stagnated in major valleys and formed series of ice-dammed lakes. Thick beds of white silt were deposited and impressions of old shorelines were left on the valley walls (Mathews, 1944). Streams from the highlands poured from hanging valleys into the deepened major valleys, cut canyons into steep valley walls, and deposited large alluvial fans in ice-dammed lakes. Possibly other lakes were formed by alluvium blocking the main river channels. Gradually the ice disappeared, lake water was released, water flow diminished, meltwater channels became dry, and upland streams were reduced to relative trickles.

The dendritic pattern of streams is modified by structure and by glacial lineaments. The rivers in the major valleys began the long process of cutting downward through glacial material, alluvial fans, and lake deposits, forming a series of terraces. Uplands, with their restricted water flow, remained relatively unmodified, their glacial features preserved.

PREVIOUS WORK

Geological mapping on a scale of 4 miles to 1 inch was done on the east half of the Guichon Creek batholith by W. E. Cockfield (1948), and on the west half by S. Duffell and K. C. McTaggart (1952). J. M. Carr, of the British Columbia Department of Mines and Petroleum Resources, has prepared a number of papers describing parts of the batholith and adjacent areas. He has mapped in detail, scale 1 inch to 1,000 feet, the area between Gnawed and Forge Mountains, in preparation, and has published maps and descriptions of the geology adjacent to the Craigmont mine and of the Thompson Valley between Ashcroft and Spences Bridge in the Annual Reports of the Minister of Mines and Petroleum Resources for 1960 and 1962 respectively. Papers describing the geology of mineral deposits of the Highland Valley area have been published by W. H. White, R. M. Thompson, and K. C. McTaggart in 1957, and J. M. Carr in 1960. A map of the batholith south of Witches Brook was prepared by R. E. Chaplin as a B.A.Sc. report, University of British Columbia, 1958, and was used as a guide during the initial stages of field work. As a result of intense mining activity of this area, numerous unpublished private company maps and reports have been prepared.

A K/A date of 186 million years ±5 per cent was published by Baadsgaard *et al.,* from the batholith in 1961. The Geological Survey of Canada has published 10 K/A dates for biotite from the Guichon Creek batholith. These dates appear in Geological Survey of Canada Papers 63-17 and 64-17, prepared by R. K. Wanless, G. B. Leech, and others*. Concurrently with K/A age determinations for this report, another geochronological study was being carried out by G. E. Dirom for dykes and major phases occurring on the Bethlehem property. The results of his work form a M.A.Sc. thesis prepared for the Department of Geophysics, University of British Columbia, 1965.

ACKNOWLEDGMENTS

Dr. W. H. White initiated building a K/A laboratory at the University of British Columbia and, as chairman of a departmental committee, supervised field work, K/A analyses, and all stages of preparation of this report. Professor G. P. Erickson designed and built the argon extraction and analytical system. J. E. Harakal supervised all and made many of the argon analyses. Dr. K. C. McTaggart gave advice on field work, petrographic and petrologic problems, and preparation of the manuscript. Very able and willing assistance was given in the field by my father, J. S. Northcote, during the 1963 and 1964 field seasons and by S. C. Gower during the early part of the 1963 season. Fruitful discussions were held in the field with J. M. Carr, and with G. E. Dirom in the K/A laboratory.

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* *See* footnote, page 11.

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CHAPTER II

Geology of the Batholith

REGIONAL SETTING

Pre-batholithic Rocks

The Guichon Creek batholith intrudes Cache Creek volcanic and sedimentary rocks of Mississippian to Permian age on its west flank in the vicinity of Spatsum. Elsewhere it intrudes Nicola volcanic and sedimentary rock of Karnian age (*see* Carr, 1963, pp. 28–45; Duffell and McTaggart, 1952, pp. 15–31; Cockfield, 1948, p. 11). The intrusive contacts are covered in most places by younger sedimentary and volcanic rocks, unconsolidated glacial drift, and recent stream sediment.

Cache Creek Group

The Cache Creek Group is in contact with the west side of the Guichon Creek batholith for approximately 5 miles in the vicinity of Spatsum (*see* Fig. 2 in pocket). The rocks of the group include greenstone, chert, tuff, argillite, limestone, siltstone, and greywacke composed largely of grains of volcanic origin (*see* Carr, 1963, pp. 29–32). The thickness of the Cache Creek Group near Spatsum is not known. A thin halo of metamorphic rock, one-sixteenth to one-half mile wide, separates Cache Creek sedimentary rock from the outer edge of the batholith.

Beds close to the batholith are shown by Carr to strike northwesterly, with moderate northeasterly dips toward the batholith, suggesting a discordant contact relationship. One mile to the west, across the Thompson River, the dips are moderate in the opposite direction, indicating a northwesterly trending antiform parallel to the river.

The Cache Creek Group is considered to range in age from Mississippian to Permian (*see* Duffell and McTaggart, 1952, p. 23).

Nicola Group

Rocks of the Nicola Group are well exposed on the northwest side of the batholith at Basque and east of Ashcroft and less well exposed on the south and east sides of the batholith.

The Nicola Group in the type area near Nicola Lake consists principally of volcanic rocks of various colours and textures. Most of them are altered and are commonly referred to as greenstone. At Basque, on the west side of the batholith, the Nicola Group is divided by Carr into six units. The lower five units, comprising two-thirds of the section, are composed of tuff, greywacke, siltstone, limestone, chert, breccia, and conglomerate; the upper unit is largely greenstone (*see* Carr, 1963, pp. 32–35).

There is little structural information available for Nicola rocks near the margin of the batholith because of extensive cover by younger rocks (*see* Fig. 2). Near Basque, however, rocks of the Nicola Group are well exposed and bedding strikes northeasterly at an angle to the batholith margin and dips northwesterly away from the batholith. On the east side of the batholith, 1 mile south of Witches Brook, foliation in pre-batholithic rock (Nicola?) strikes northerly parallel to the batholith margin and has a moderate easterly dip away from the batholith. At these two localities the contacts may be semi-concordant. In most places, however, the contact appears to be discordant. At the northwest side of the batholith, 4 miles east of Ashcroft, layering in pre-batholithic rock strikes northerly and has steep to vertical dips. Beds of Nicola Group in a roof remnant exposed on the west side of Glossy Mountain strike northerly and have vertical dips. At Craigmont mine, Nicola beds have a steep south dip and are cut at a small angle by intrusive batholithic rock (*see* Rennie, 1962, p. 50; Drummond, 1965, p. 117). Older rocks at the batholith margin are metamorphosed and cut by granitic dykes.

Metamorphism of Pre-batholithic Rocks

A thin metamorphic envelope formed in older rock at the batholith margin. Metamorphic grade varies from place to place. The metamorphic rocks on the north and west sides of the batholith are predominantly of epidote-albite hornfels facies of metamorphism. The older rock is epidotized, chloritized, weakly carbonatized, and silicified. Close to the intrusive contact, siliceous hornfels and epidote skarns occur, locally rich in disseminated pyrite and magnetite.

Two areas each at least 2 miles long on the east margin of the batholith are underlain by rock referred to as gabbro in earlier reports (*see* Cockfield, 1948, pp. 16, 17). The first area is 3 miles northwest of the junction of Guichon Creek and Witches Brook, and the second is 8 miles south of the same stream junction. These rocks are cut by dykes of hybrid rock at the east side of the batholith 3 miles north of Witches Brook. The rock is relatively fine grained, compared to intrusive rock of the batholith, is dark and shows textural and compositional variations. It consists predominantly of labradorite with poikiloblastic hornblende containing augite, very minor amounts of interstitial quartz and opaque grains associated with mafic minerals. Tremolite or actinolite is recognized in place of hornblende in some thin-sections, in others abundant sphene and traces of garnet are found. Some thin-sections show marked preferred orientation of plagioclase; others show no preferred orientation. In some sections small anhedral grains of plagioclase, hornblende, and sphene form a " paving block " texture. Mafic minerals are anhedral, have poikiloblastic texture, and are interstitial to plagioclase. Hornblende and tremolite veins are common. Structure, texture, and composition suggest that these rocks are not genetically related to the Guichon Creek batholith but are older rocks, possibly recrystallized Nicola Group volcanic rocks, which belong to the hornblende hornfels facies of contact metamorphism.

Temperature of country rock at the batholithic contact can be estimated from the degree of thermal metamorphism, which grades from albite-epidote hornfels to hornblende hornfels facies. Maximum temperature of country rock at the contact would be about 650 degrees centigrade if buried to a depth of 6 kilometres or 550 degrees centigrade if buried to a depth of just over 1 kilometre (*see* Winkler, 1965, p. 63).

Post-batholithic Rocks

Intrusive rocks of the Guichon Creek batholith are unconformably overlain by sediments of Middle and Upper Jurassic age, Spences Bridge Group volcanics of Lower Cretaceous age, Tertiary volcanics of probable Eocene age, and by unconsolidated Pleistocene glacial and Recent deposits.

Middle and Upper Jurassic

Middle and Upper Jurassic strata overlie the northwest part of the Guichon Creek batholith and extend northward, as a zone 14 miles long and 5 miles wide centred on the town of Ashcroft (*see* Carr, 1963, p. 37; Crickmay, 1930, pp. 23–74; Duffell and McTaggart, 1952, pp. 31–33). Unaltered Jurassic shales, conglomerates, and sandstones are exposed on the west flank of Glossy Mountain.

The Jurassic strata have been described in detail by Crickmay, who divided them into two series totalling 4,900 feet in thickness. The lower series, referred to as the Thompson series, 1,800 feet thick, consists of a basal conglomerate overlain by calcareous arkose and, forming the upper three-quarters of the section, black shale with minor sandstone. The upper series, referred to as the Ashcroft series, 3,100 feet thick, has conglomerate at its base overlain by black shale with intercalated sandstone beds (*see* Crickmay, 1930, p. 37). The conglomerates contain boulders of fine-grained porphyritic quartz diorite, quartz porphyry, and feldspar porphyry which are similar in texture and composition to rocks of the Guichon Creek batholith. It also contains boulders of cherty rock, greenstone, porphyritic volcanic rock, and some sandstone (*see* Carr, 1963, p. 37).

On the basis of pelecypod and ammonite fossils, these strata are considered to range from Middle to Upper Jurassic (*see* Crickmay, 1930, p. 37).

Spences Bridge Group

The Spences Bridge Group of volcanic strata unconformably overlies the southwest flank of the Guichon Creek batholith. It forms a belt 2 to 15 miles wide extending from the southwest corner of the map-area northwesterly for at least 75 miles. It is exposed along the northeast side of Nicola Valley and crosses the Thompson River between Pimainus and Inkikuh Creeks, where it unconformably overlies rocks of Cache Creek Group. Hybrid intrusive rocks, adjacent to the east margin of Spences Bridge Group, are cut by swarms of northwesterly and westerly trending porphyritic feeders of the Spences Bridge Group.

Rocks of the Spences Bridge Group are lavas and pyroclastic rocks of a variety of lithologies and colours. Minor amounts of conglomerate, sandstone, and waterlain tuff are also present. The volcanic rocks are mainly porphyritic andesite and dacite with lesser amounts of rhyolite and basalt. Agglomerates and breccias are important constituents in the sequence (*see* Duffell and McTaggart, 1952, pp. 52–54). W. A. Bell, of the Geological Survey of Canada, established the age of the Spences Bridge Group, by fossil plants, as Aptian stage of the Lower Cretaceous (*see* Duffell and McTaggart, 1952, pp. 54–55).

Kingsvale Group

The Kingsvale Group crops out at the southern edge of the map-area and unconformably overlies Nicola Group rocks in the vicinity of Craigmont mine. Outside the map-area, where it is estimated to be 3,600 feet thick, the group unconformably overlies the Spences Bridge Group (*see* Duffell and McTaggart, 1952, pp. 55–58).

The Kingsvale Group is composed of rocks of rhyolitic, andesitic, and basaltic composition consisting of lava flows, breccias, agglomerates, and tuffs. Basaltic flows and basaltic breccias predominate. Arkose and conglomerate are present in small amounts (*see* Cockfield, 1948, pp. 19–21).

Age determinations of plant fossils from outside the map-area indicate the Kingsvale Group was deposited during the Albian stage of the Lower Cretaceous (*see* Duffell and McTaggart, 1952, p. 58). A K/A age of 80 million years by the Geological Survey of Canada on biotite from Kingsvale volcanics indicates an Upper Cretaceous age for this group (*see* Lowden, J. A., 1963, p. 19).

Kamloops Group

Strata of the Kamloops Group are 3,500 feet thick in a plateau to the north of the Guichon Creek batholith (*see* Duffell and McTaggart, 1962, p. 66). Nearly flat-lying flows unconformably overlie Jurassic shales and cap many of the high mountains in the area. Volcanic plugs and dykes cut the batholith in several places, notably at the Simons zone of the Bethlehem property, on the south slope of Forge Mountain, at two places on the ridge on the south side of Highland Valley, and on the east side of Gypsum Mountain. Some plugs are fragmental, others have a chalky appearance. A few have steeply dipping to vertical, thinly laminated flow layering.

The volcanic rocks of the Kamloops Group consist mainly of basalt, with lesser andesite, and minor rhyolite. Associated pyroclastics range from tuff to agglomerate. The lavas are commonly vesicular or amygdaloidal, mainly black but include red, brown, grey, green, mauve, buff, and white varieties (*see* Duffell and McTaggart, 1952, pp. 66–68).

Two K/A dates of 49 and 51 ± 3 million years obtained from analyses of unaltered biotite from fragmental dacite at the south side of Highland Valley indicate that some of the volcanic rocks are Eocene (*see* White *et al.*, 1967, p. 686). Mathews (1963) obtained four isotopic dates which range from 45 to 53 million years, middle Eocene, from Princeton, Kamloops Lake, and Francois Lake basins of volcanic and sedimentary rocks. Hills and Baadsgaard (1967) resolved earlier palæobotanical problems in these strata and obtained 15 K/A dates ranging from 47 to 52 million years. These age determinations are from Tertiary volcanic rocks in eight localities in British Columbia and confirm a middle Eocene age for the Kamloops Group.

Petrology of the Guichon Creek Batholith

Introduction

The intrusive rocks of the Guichon Creek batholith may be divided into several distinctive units by their field relationships, texture, mineral content, and mineral composition. Some units are clearly intrusive into others and illustrate their relative age by dykes, contact brecciation, xenoliths, and, less commonly, by chilled contacts. Other units show only a gradation from one to another. A unit, however, shows intrusive contacts with another unit in one area and gradational contacts with the same unit elsewhere. In order to distinguish between units with intrusive contacts and those showing only gradational contacts, the terms " phases " and " varieties " are used respectively. Phases are separated at least locally by sharp contacts where, generally, relative ages can be determined. A variety is a subdivision of a phase which has a gradational contact with that phase.

Figure 2 shows the distribution of phases and varieties of the batholith, which are as follows:—

Table I.—Phases and Varieties of Intrusive Rocks

Relatively Old	Intermediate Age	Relatively Young
Hybrid phase. Quartz diorite, granodiorite (1).*	Gump Lake phase. Granodiorite, quartz monzonite (3).	Bethsaida phase. Quartz monzonite, granodiorite (6).
Highland Valley phase. Guichon variety — quartz diorite, granodiorite (2G). Chataway variety — granodiorite, quartz monzonite (2C).	Bethlehem phase. Granodiorite, quartz monzonite (4). Witches Brook phase. Variety A—granodiorite (5*a*). Variety B—granodiorite (5*b*). Variety C — granodiorite, quartz monzonite, granite (5*c*).	Gnawed Mountain porphyries, younger Bethlehem poryhyries, and associated intrusive breccias (7). Leucocratic dykes and irregular-shaped bodies.
LeRoy granodiorite. Granodiorite, quartz monzonite (2LR).	Bethlehem porphyries.	

* Rock classification after A. Johannsen, 1931.

The Guichon Creek batholith underlies an area of 400 square miles. It is a semi-concordant composite intrusive pluton consisting of 10 phases. The major phases show a nearly concentric arrangement and, in general, decrease in age inward.

Hybrid Phase

The Hybrid phase is peripheral to the batholith and is intrusive into Cache Creek and Nicola Group rocks. It probably has been contaminated by pre-batholith rock, with the result that there is gradation in relative proportion and composition of minerals toward the periphery. It is predominantly quartz diorite but shows variation from hornblendite through diorite to quartz monzonite. The Hybrid phase is cut by dykes and irregular bodies of Highland Valley and Witches Brook phases. The Hybrid phase is the oldest intrusive rock of the batholith.

Highland Valley Phase

The Highland Valley phase forms a concentric ring within the Hybrid phase, and consists of two varieties called Guichon and Chataway. The Guichon variety shows effects of contamination by older rock and ranges in composition from quartz diorite to granodiorite. The Chataway variety occurs mainly in the south part of the batholith, whereas the Guichon variety is abundant in the north. Guichon and Chataway varieties cut the Hybrid phase as dykes or form a matrix between brecciated fragments of Hybrid phase. The Highland Valley phase is younger than the Hybrid phase.

LeRoy Granodiorite

LeRoy granodiorite forms small, irregular dyke-like bodies in the Chataway variety. There is no large well-defined mass of LeRoy granodiorite as there is for Guichon and Chataway varieties and Bethlehem and Bethsaida phases. An overprint pattern on the geologic map (*see* Fig. 2) marks areas where dyke-like bodies of LeRoy are abundant.

Gump Lake Phase

The concentric configuration of successive phases of the Guichon batholith is interrupted by the Gump Lake phase, which covers an area of 9 square miles on the east side of the batholith. The Gump Lake phase is predominantly granodiorite and quartz monzonite. It is cut by, and is therefore older than, the Witches Brook phase.

Bethlehem Phase

The Bethlehem phase almost completely surrounds a central core of the batholith. This phase is of uniform granodiorite composition. Xenoliths of the Guichon variety occur in the Bethlehem phase, so Bethlehem is clearly the younger.

Witches Brook Phase

The concentric configuration of major intrusive phases is further interrupted by varieties of the Witches Brook phase. There is no well-defined mass of Witches Brook as there is of other major phases. Witches Brook occurs as dyke-like bodies and irregular-shaped masses within the older phases throughout the batholith but is most abundant on the east side at Witches Brook, the stream after which the phase was named. A second overprint pattern on the geologic map (*see* Fig. 2) marks areas where the Witches Brook phase is most abundant. Texturally this phase closely resembles Bethlehem but shows wide variations in grain size and composition from granodiorite to granite. The Witches Brook phase cuts Guichon and Chataway varieties and Hybrid and Gump Lake phases; therefore, the Witches Brook phase is of intermediate age.

Bethsaida Phase

The Bethsaida phase forms a central core of the Guichon Creek batholith. It is predominantly of quartz monzonite composition. The Bethsaida phase has chilled contacts against Bethlehem phase and Guichon variety, so is clearly the youngest of these phases.

Bethlehem and Gnawed Mountain Porphyries

Porphyry dykes and irregular porphyry bodies, many closely associated with pipe breccias, occur in the Bethsaida, Bethlehem, and Highland Valley phases. These porphyries are believed to be genetically related to the young phases of the batholith. A notable swarm of northerly trending porphyry dykes, at least 10 miles long and 3 to 5 miles wide, crosses Highland Valley on, and to the west of, Bethlehem Copper Corporation property (*see* Carr, 1960, pp. 71–73).

Modal Analyses

Rock specimens considered to be most representative of each phase and variety were used to establish modes, and consequently rocks of each phase or

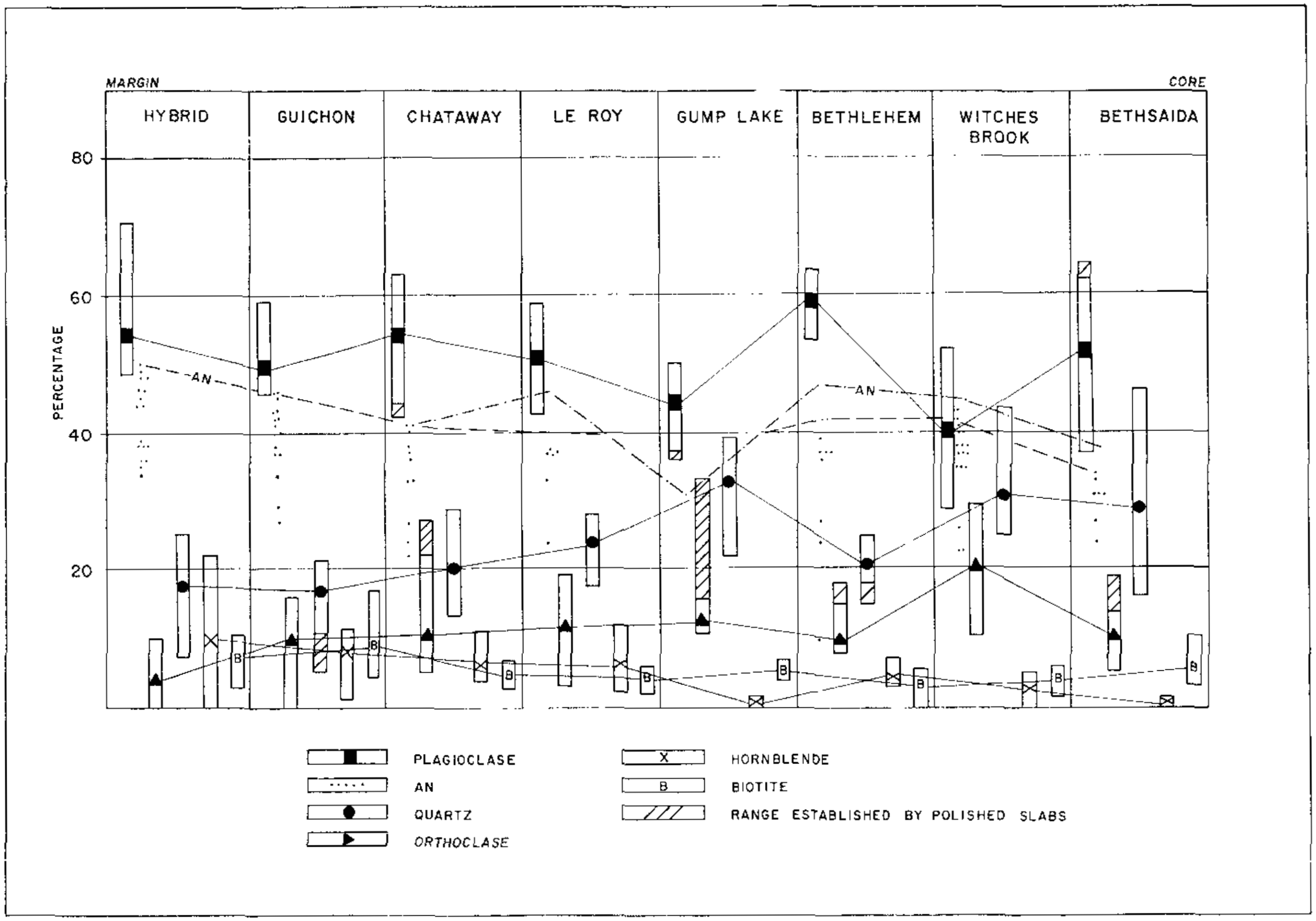

Fig. 3. Graphic representation of modes.

variety can be expected to show greater compositional variation than indicated by Table II. Modal analyses are summarized on Figure 3.

Standard thin-sections were used for modal analyses, and from 3,000 to 5,500 points per thin-section were counted with a Swift & Son point counter. Point counts were made of at least six thin-sections for each phase or variety, except Gump Lake phase, for which there were three. A chart for judging the reliability of point-counting results indicates a precision within 2 per cent for those many fine-grained specimens where grain size is smaller than point-count spacing (*see* Van Der Plas and Tobi, 1965, pp. 87–90).

Modes established by counts of single thin-sections for coarse-grained phases are not accurate because the rocks are heterogeneous. It was particularly difficult to determine the amount of orthoclase in coarse-grained phases, where it occurs as irregularly distributed interstitial masses commonly 2 or more centimetres in diameter. Polished slabs, measuring 2½ to more than 4 inches in largest diameter, were etched in hydrofluoric acid and orthoclase was stained yellow by a sodium cobaltinitrite solution. The modes of the slabs were measured in the following way: The polished slabs were photographed in daylight on 35-millimetre Kodak Kodachrome II film. The coloured slides were projected onto a grid screen with grid spacing made suitable to the grain size by moving the projector closer to or farther from the grid screen. Six thousand points were counted on each of two surfaces which were at least one-half inch apart in the rock. Using the slab method, plagioclase and quartz were particularly difficult to distinguish, but a good check was provided for orthoclase content.

Modes obtained from thin-sections for each phase are listed in Table II and are summarized on Figure 3. Figures 4 and 5 are ternary plots of each mode in terms of quartz, orthoclase, and plagioclase (oligoclase-andesine) content and allow classification of the rock (*see* Johannsen, Vol. 1, p. 143). For purposes of the ternary diagrams, modal percentages have been recalculated so that orthoclase plus plagioclase plus quartz equals 100 per cent. For that reason the per cent quartz, orthoclase, or plagioclase read off the figures will not agree with percentages listed in Table II.

Table II.—Modal Analyses in Weight per Cent

HYBRID PHASE

	K63-13	K64-156a	K64-15	K64-15	K64-10	K64-10-I	K63-224a
Plagioclase	53.75	49.86	51.40	48.55	70.29	55.23	54.04
Orthoclase	4.39	10.09	2.49	4.95	0.13	0.07	0.12
Quartz	19.45	20.20	23.27	25.12	7.27	19.32	10.35
Biotite	8.30	6.49	10.50	7.66	2.99	6.67	8.66
Hornblende	11.18	N.C.	9.55	12.10	5.66	11.76	22.02
Augite	1.43	10.83	0.82	0.08	10.67	3.42	0.04
Opaque	1.37	2.47	1.98	1.34	2.35	3.36	4.70
Sphene	0.08	N.C.	N.C.	0.09	0.52	N.C.	N.C.
Apatite	0.02	0.07	N.C.	N.C.	0.06	0.17	0.09
Zircon	0.03	N.C.	N.C.	0.12	0.03	N.C.	N.C.

Table II.—Modal Analyses in Weight per Cent—Continued

GUICHON VARIETY

	K63-223	K63-223-II	K63-223-II	K63-223-II	K64-50aV	K63-33b-I	K63-136-I	K63-196
Plagioclase	45.75	45.98	47.79	47.96	52.32	48.36	52.66	58.93
Orthoclase	12.29	14.32	16.03	15.47	11.42	8.24	2.71	N.C.
Quartz	20.68	19.80	18.00	18.55	18.75	17.55	16.32	11.70
Biotite	9.54	8.09	5.06	4.22	5.92	10.41	16.95	13.22
Hornblende	8.85	8.47	10.68	11.36	9.68	10.05	1.49	4.61
Augite	0.31	1.17	1.74	0.26	0.47	1.06	7.94	6.73
Opaque	1.86	1.59	0.24	1.51	2.38	4.08	1.94	4.02
Sphene	0.65	0.47	0.40	0.45	0.03	0.24	N.C.	0.79
Apatite	0.06	0.08	0.02	0.02	N.C.	N.C.	N.C.	N.C.
Zircon	0.03	0.03	0.03	0.20	0.03	N.C.	N.C.	N.C.

CHATAWAY VARIETY

	K64-116a	K64-48-I	K63-204-IV	K63-44	K63-185	K63-204-IV	K63-34
Plagioclase	55.69	54.18	52.89	63.49	48.32	62.20	43.62
Orthoclase	6.90	7.13	11.65	4.89	21.98	8.82	15.17
Quartz	23.33	23.65	22.12	13.15	16.06	17.47	28.69
Biotite	6.26	7.49	6.43	5.15	2.91	5.37	2.72
Hornblende	*6.02*	*5.49*	*4.98*	*11.31*	*7.95*	*4.57*	*6.96*
Augite	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.
Opaque	1.42	1.78	1.81	1.29	2.51	1.45	2.59
Sphene	0.07	0.28	0.05	0.50	0.20	0.09	0.25
Apatite	0.18	0.02	0.07	0.23	0.06	0.02	N.C.
Zircon	0.10	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.

LEROY GRANODIORITE

	K64-54	K64-47a-III	K63-202-V	K63-37	K63-220	K64-101
Plagioclase	43.69	58.64	56.19	42.91	57.23	45.80
Orthoclase	17.53	2.48	9.02	19.37	9.32	14.86
Quartz	25.61	27.10	23.90	28.01	17.75	25.59
Biotite	5.80	3.69	3.54	4.22	1.81	5.95
Hornblende	4.77	6.77	4.97	3.83	12.39	5.62
Augite	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.
Opaque	*2.46*	*1.13*	*2.15*	*1.21*	*1.39*	*1.69*
Sphene	0.11	0.16	0.20	0.24	0.09	0.49
Apatite	0.02	0.03	0.02	0.17	0.02	N.C.
Zircon	N.C.	N.C.	N.C.	0.03	N.C.	N.C.

GUMP LAKE PHASE

	K64-98-I	K64-89	K64-91
Plagioclase	36.97	48.72	49.95
Orthoclase	16.08	11.98	11.02
Quartz	38.87	32.64	29.11
Biotite	5.67	4.81	6.67
Hornblende	0.90	0.49	0.95
Augite	N.C.	N.C.	N.C.
Opaque	1.26	1.26	2.62
Sphene	N.C.	0.05	N.C.
Apatite	*0.10*	*0.05*	*0.18*
Zircon	0.16	N.C.	N.C.

Table II.—Modal Analyses in Weight per Cent—Continued

BETHLEHEM PHASE

	K63-192	K63-189a-II	K63-188a	K64-61	K64-60a	K63-115	K64-186a
Plagioclase	58.95	58.92	56.53	63.47	63.04	58.42	53.76
Orthoclase	10.82	15.51	8.12	5.98	8.67	12.70	7.82
Quartz	19.70	19.26	23.83	20.01	19.57	18.26	25.06
Biotite	0.51	1.98	5.37	5.73	1.55	1.88	5.12
Hornblende	7.05	2.66	2.67	2.48	3.76	5.85	5.83
Augite	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.
Opaque	2.94	1.24	2.80	2.05	2.84	2.00	2.33
Sphene	N.C.	0.43	0.51	0.20	0.34	0.65	N.C.
Apatite	0.02	N.C.	0.17	0.07	0.23	0.14	0.04
Zircon	N.C.	N.C.	N.C.	N.C.	N.C.	0.10	0.03

WITCHES BROOK PHASE

	K64-105-I	K63-171	K64-102	K64-111	K64-203	K63-84	K63-28a	K64-17	K64-17	K63-222
Plagioclase	39.76	52.11	43.03	46.13	50.93	40.79	39.28	28.08	30.26	31.00
Orthoclase	20.05	10.44	18.20	15.89	12.14	18.87	24.28	26.20	25.44	29.42
Quartz	27.92	25.74	26.86	26.72	27.84	29.09	25.50	43.19	41.53	36.61
Biotite	3.34	5.18	5.50	5.18	5.99	5.04	4.88	1.86	2.02	2.41
Hornblende	5.33	3.78	3.81	4.71	2.23	5.57	3.47	N.C.	N.C.	N.C.
Augite	N.C.	0.03	N.C.	N.C.	N.C.	0.30	0.68	0.04	N.C.	N.C.
Opaque	1.38	1.99	1.77	1.06	0.65	1.10	1.71	0.64	0.75	0.56
Sphene	2.13	0.31	0.77	0.30	0.18	0.23	0.11	N.C.	N.C.	N.C.
Apatite	0.03	0.03	0.02	N.C.	N.C.	N.C	N.C.	N.C.	N.C.	N.C.
Zircon	N.C.	0.05	N.C.	N.C.	0.03	N.C.	0.08	N.C.	N.C.	N.C.

BETHSAIDA PHASE

	K64-64	K63-115a	K63-238a	K63-239	K63-231	K63-187
Plagioclase	46.21	62.16	57.97	37.62	52.07	56.67
Orthoclase	5.88	13.93	14.55	5.28	10.76	12.95
Quartz	35.22	16.38	22.08	45.71	30.14	26.81
Biotite	11.82	4.49	3.62	10.17	4.82	2.71
Hornblende	0.42	0.55	0.14	0.81	0.29	0.18
Augite	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.
Opaque	0.44	2.05	1.24	0.25	1.26	0.56
Sphene	N.C.	0.20	0.23	0.10	0.33	0.05
Apatite	0.02	0.21	0.18	N.C.	0.30	0.07
Zircon	N.C.	0.05	N.C.	0.05	0.03	N.C.

Table III.—Average Modes in Weight per Cent (Summary of Table II)

	Hybrid	Guichon	Chataway	LeRoy	Gump Lake	Witches Brook	Bethlehem	Bethsaida
Plagioclase	54.72	49.91	54.34	50.72	45.06	40.16	49.02	52.11
Orthoclase	3.18	10.04	10.93	12.10	13.03	20.10	9.95	10.56
Quartz	17.85	17.65	20.64	24.67	33.55	31.02	20.81	29.39
Biotite	7.32	9.16	5.19	4.17	5.72	4.14	3.16	6.27
Hornblende	10.35	8.14	6.76	6.40	0.78	2.89	4.33	0.40
Augite	3.89	2.46	....	....	....	0.11	....	....
Opaque	2.51	2.20	1.84	1.67	1.71	1.16	2.31	0.97
Sphene	0.09	0.38	0.22	0.22	0.02	0.40	0.30	0.15
Apatite	0.06	0.02	0.08	0.04	0.08	0.01	0.10	0.13
Zircon	0.03	0.04	....	0.01	0.05	0.02	0.02	0.02

Table IV.—Modes in Weight per Cent Measured from Polished Slabs (Random Specimens)

	Guichon	Chataway	Gump Lake	Bethlehem	Bethsaida
Plagioclase	58	54	37	63	54
Orthoclase	9	19	25	10	5
Quartz	6	13	28	15	22
Plagioclase	52	60	39	61	58
Orthoclase	10	13	26	11	13
Quartz	6	14	26	17	22
Plagioclase	....	52	36	57	64
Orthoclase	....	17	33	13	14
Quartz	....	14	22	19	18
Plagioclase	....	45	40	54	52
Orthoclase	....	22	31	12	19
Quartz	....	20	22	23	22
Plagioclase	....	42	....	54	....
Orthoclase	....	27	....	18	....
Quartz	....	23	....	20	....

Description of Phases

Hybrid Phase

Distribution and Relations to Other Phases

The Hybrid phase forms the periphery of the batholith and is intrusive into Cache Creek and Nicola Group rocks. The Hybrid phase has a gradation of texture and relative abundance of its main minerals inward from the batholith margin. Inward from contacts with stratified rocks the Hybrid phase generally has fairly uniform textures and compositions, but this is not everywhere true. For example, immediately west of Spaist and Skwilkwakwil Mountains, several miles from its contact with older rocks, a hornblende-rich Hybrid rock has a strongly foliated, locally swirled structure and is cut by dykes of younger phases.

The Hybrid phase is cut by irregular dykes and masses of at least two younger phases as well as by aplitic to pegmatitic material. Dykes of Highland Valley and Witches Brook phases cut Hybrid rocks and form the cement between fragments of Hybrid rocks at several places on the south and east sides of the batholith.

Petrography

No particular specimen can be designated as typical of the Hybrid phase. Specimens, by visual estimate of mineral content, range from hornblendite through diorite to quartz diorite and granodiorite. Most of the Hybrid rocks are quartz diorite (*see* Plates I and II). They are equigranular, holocrystalline, commonly foliated, and consist of quartz, plagioclase, orthoclase, biotite, augite, and minor hypersthene. Accessory minerals include sphene, zircon, apatite, magnetite, and hematite. Sulphides which were observed in some specimens are pyrite, chalcopyrite, and rarely bornite and molybdenite.

Modes for seven specimens thought to be fairly representative of the most abundant Hybrid types are plotted on a ternary diagram (*see* Fig. 4 *a*). Six modes

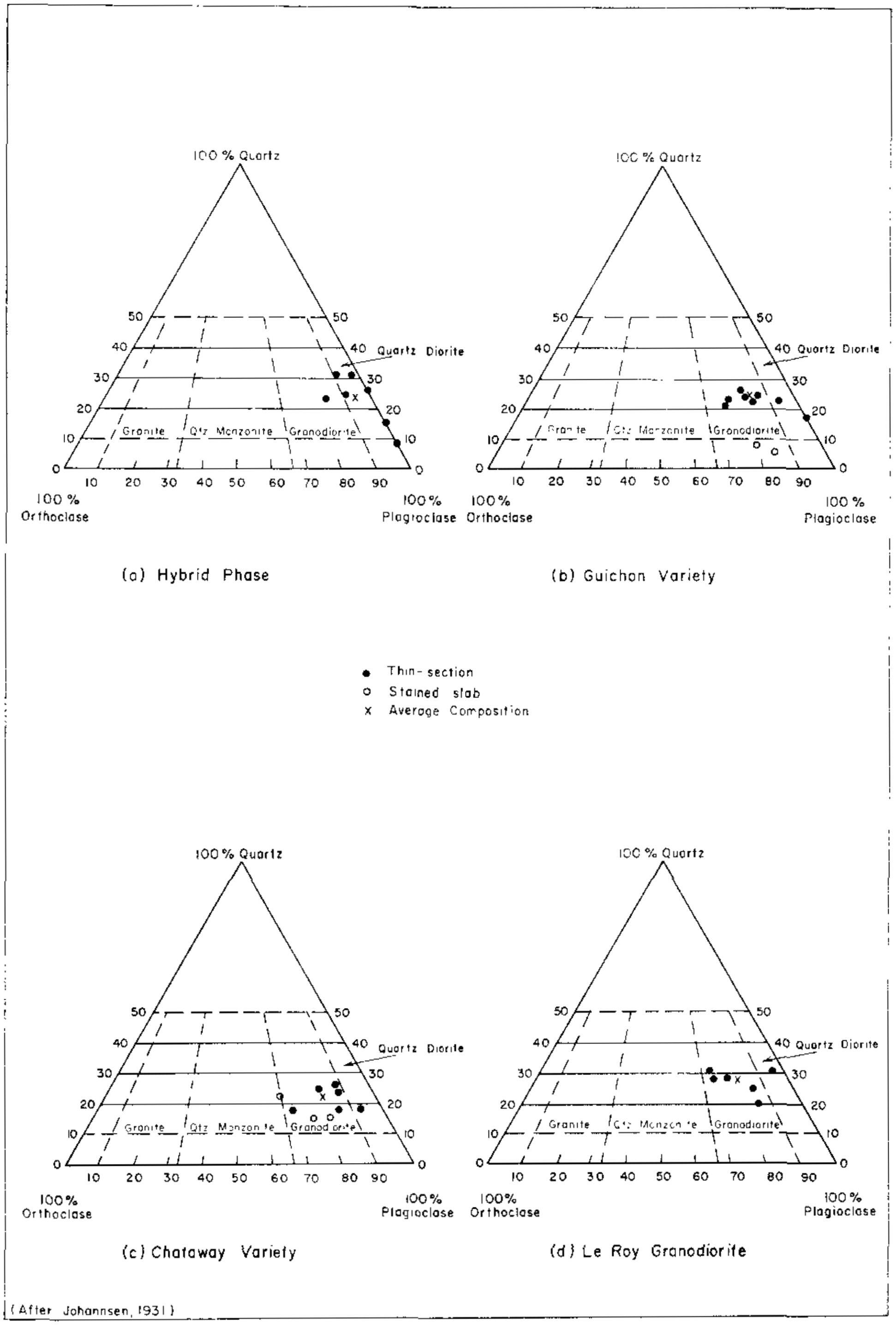

Fig. 4. Modal analyses.

fall within quartz diorite and one within granodiorite fields of the diagram. Modes listed on Table II show a range in quartz content from 7 to 25 per cent, in orthoclase content from 0.1 to 10 per cent, and in plagioclase content from 49 to 70 per cent. Total mafic content ranges from 17 to 31 per cent, with an average of 22 per cent.

Plagioclase is euhedral to subhedral and shows preferred orientation in most thin-sections. Measured composition using albite twin ($X \wedge 010$ Max$<$in zone $\perp 010$; $X \wedge 010 \perp a$) and carlsbad-albite methods of measurement indicate a range of composition from An_{27} to An_{50} with An_{36} to An_{46} being most common. Normal zoning was observed with cores An_{38} and margins An_{27}. Albitic alteration of the margins of plagioclase is very common. Granophyric intergrowths of quartz and albite commonly occur in clear albitic margins surounding more calcic cores clouded with saussurite and sericitic alteration.

Orthoclase is present in small amounts. It is interstitial, anhedral, and is clouded by a grey to slightly reddish-brown alteration.

Quartz is anhedral, everywhere occurs interstitially or as graphic intergrowths with albite, and usually shows fractures and mottled extinction resulting from stress.

The mafic minerals, hornblende, biotite, augite, and rare hypersthene, vary in relative abundance. Most mafic grains are subhedral to anhedral with ragged outlines and form aggregates. Augite commonly forms isolated rounded anhedral grains in subhedral hornblende. The amount of augite present is variable but is usually only in minor amounts. Biotite, seen in most thin-sections, has a ragged outline, is bent, and commonly is altered largely to chlorite.

The accessory minerals, apatite and zircon, occur as euhedral to subhedral crystals usually within larger grains of rock-forming minerals. Sphene is either euhedral, subhedral, or occurs as irregular aggregates of anhedral grains closely associated with mafic or opaque minerals. This association suggests that sphene (and leucoxene) is an alteration product of titaniferous magnetite or ilmenite. The opaque minerals, predominantly magnetite, occur as minute anhedral aggregates of grains closely associated with mafic minerals.

Highland Valley Phase

Distribution, Varieties, and Relations to Other Phases

The Highland Valley phase forms a concentric shell around the inner, younger phases of the batholith and is enclosed by the Hybrid marginal phase. The Highland Valley phase is compositionally and texturally more uniform than the Hybrid phase, although its outer margin shows an increase in amount of mafic minerals at contacts with the Hybrid phase and older stratified rocks. In some places the Highland Valley phase has gradational contacts with the Hybrid phase, in others it seems to have partly assimilated or mixed with the Hybrid phase, and in still others the Highland Valley phase clearly has intruded crystalline Hybrid rocks. The Guichon variety occurs chiefly in the northern part of the batholith but is also found in the south adjacent to contacts of the Hybrid phase with the Chataway variety. The Chataway variety occurs chiefly in the southern part of the batholith.

Petrography

Primary rock-forming minerals in the Highland Valley phase are plagioclase, orthoclase, quartz, hornblende, biotite, and minor augite. Accessory minerals include apatite, zircon, sphene, and opaque grains (magnetite, ilmenite, chalcopyrite, pyrite). Secondary minerals, products of deuteric and hydrothermal alteration and weathering, include epidote, sericite, chlorite, carbonate, leucoxene, zeolites, iron and manganese oxides, and clay minerals. Modes are listed on Table II and shown on Figure 4 *b* and *c*.

Guichon Variety

The Guichon variety, mainly granodiorite, is richer in mafic minerals, particularly biotite, than the Chataway variety and shows the widest textural and compositional differences. This variety was first described and named by White, Thompson, and McTaggart (*see* White *et al.*, 1957, p. 276).

The Guichon variety (*see* Plate III) is light grey to cream-grey, usually mottled by pink, and is evenly flecked by black to dark green-grey mafic minerals. The rock is medium to coarse grained, hypidiomorphic granular with plagioclase showing preferred orientation.

Modes of the Guichon variety fall mainly in the granodiorite field of the ternary diagram, Figure 4 *b*. Two fall in the quartz diorite field of the diagram. These two specimens were taken from the outer margin of the area underlain by Guichon variety and probably show effects of contamination by Hybrid phase and older stratified rocks. Table II shows ranges, for the six specimens of granodiorite composition, of 46 to 52 per cent plagioclase, 8 to 16 per cent orthoclase, 18 to 21 per cent quartz, and 12 to 22 per cent mafic minerals. The two specimens of quartz diorite composition contain 53 and 59 per cent plagioclase, 0 and 3 per cent orthoclase, 12 and 16 per cent quartz, and 25 and 26 per cent mafic minerals.

Feldspar makes up from 55 to 65 per cent of the rock, and up to 75 per cent of the total feldspar is plagioclase. Plagioclase is euhedral to subhedral and commonly shows poorly developed normal zoning and preferred orientation in most thin-sections. Measured compositions show a range of An_{33} to An_{46}. Orthoclase forms coarse interstitial masses poikilitically enclosing quartz, plagioclase, and mafic minerals. Quartz is anhedral, interstitial, and commonly shows fractures and strained extinction.

Alignment of mafic minerals gives the rock a foliated appearance. Dark minerals, particularly biotite, commonly form evenly distributed clusters of grains. The amount of biotite and augite relative to hornblende, as well as total mafic content, increases toward contacts with rocks of the Hybrid phase. Biotite is generally ragged in outline and grains are bent. Hornblende also has an irregular anhedral outline and is commonly poikilitic containing small anhedral remnant augite grains. Both biotite and hornblende generally have a slightly poikilitic texture enclosing anhedral grains of quartz, feldspar, and opaque minerals.

The opaque minerals, largely magnetite, commonly occur as anhedral grains or aggregates of grains closely associated with mafic minerals. Sphene may be euhedral or interstitial to plagioclase and generally is closely associated with opaque grains, suggesting the presence of titaniferous magnetite or ilmenite. Other accessory minerals, zircon and apatite, are euhedral to subhedral and occur in or between rock-forming grains.

Chataway Variety

The Chataway variety (*see* Plate IV) is mainly granodiorite, mottled light cream-green, light grey and pink, and is medium to coarse grained with well-separated, evenly disseminated, euhedral to subhedral mafic grains. A marked poikilitic texture of hornblende is characteristic of this variety.

Figure 4 *c* shows six of seven specimens falling within the granodiorite field of the ternary diagram. One specimen of quartz diorite composition is probably the result of contamination by nearby Hybrid phase. Table II shows plagioclase ranging from 48 to 63 per cent and averages 54 per cent. Orthoclase ranges from 5 to 22 per cent with an average of 11 per cent. Quartz content has a range between 13 and 29 per cent with an average of 21 per cent. Total mafic content ranges between 10 and 16 per cent with an average of 12 per cent. Hornblende is commonly in excess of biotite.

Plagioclase is subhedral to euhedral and shows preferred orientation. It commonly has normal zoning which ranges from An_{41} in the core to An_{22} at the margins. Orthoclase occurs as very coarse-grained interstitial masses with uneven distribution, hence the wide variation in orthoclase content from one rock specimen to another. Quartz is interstitial to plagioclase and commonly shows strained extinction.

Mafic minerals have distinct outlines and are evenly distributed throughout the matrix. Hornblende poikilitically encloses quartz, plagioclase, biotite, and opaque grains. Many hornblende grains have corroded margins caused by partial replacement by quartz and orthoclase. Biotite grains are commonly bent. Opaque minerals are intimately associated with mafic minerals.

LeRoy Granodiorite

Distribution and Relations to Other Phases

The LeRoy granodiorite occurs in rocks of the Chataway variety, and possibly in the Witches Brook phase, in irregular masses and dyke-like bodies which range in thickness from a few feet to a few hundred feet. Accurate estimate of size of most LeRoy granodiorite bodies is not possible because of small size and number of outcrops. Its occurrence is not confined to any well-defined area. On the geologic map (*see* Fig. 2) the area shown by the overprint pattern for LeRoy granodiorite is mainly underlain, it is believed, by Chataway variety.

Petrography

The LeRoy granodiorite resembles the Chataway variety in texture and composition but is finer grained. It can be confused easily with the Witches Brook phase. Primary rock-forming minerals, accessory minerals, and secondary minerals are the same as for the uncontaminated Highland Valley phase. LeRoy granodiorite is light cream-grey with some pink mottling. A characteristic of this unit is that mafic minerals are evenly distributed, have poikilitic textures, and have distinct crystal margins (*see* Plate V).

Modes of LeRoy granodiorite, like Chataway variety, also fall largely within the granodiorite field of the ternary diagram (*see* Fig. 4 *d*) with only one of six specimens being quartz diorite. Feldspar makes up 60 to 66 per cent of the rock, of which 4 to 31 per cent of the total feldspar is orthoclase. Table II shows that plagioclase content ranges from 43 to 59 per cent and averages 51 per cent. Orthoclase has a range of 2 to 19 per cent with an average of 12 per cent. The apparent variation in orthoclase content may be largely the result of sampling error. Quartz content ranges from 18 to 28 per cent and averages 25 per cent. Total mafic content ranges between 8 and 14 per cent with an average value of 11 per cent. In most specimens the amount of hornblende is approximately equal to the amount of biotite, although in some hornblende is dominant.

Plagioclase is subhedral, has a preferred orientation, and commonly shows normal zoning. Measurement of plagioclase composition using the albite twin method gives a range from An_{37} to An_{46}. Orthoclase occurs as large interstitial anhedral grains several millimetres in size. It poikilitically encloses plagioclase and is slightly perthitic. Quartz is interstitial wedge-shaped, poikilitically encloses plagioclase, and has strained extinction.

Gump Lake Phase

Distribution and Field Relations

The Gump Lake phase crops out in an area of 9 square miles east of Gump Lake. Texturally and compositionally the Gump Lake phase closely resembles the Bethsaida phase, which is one of the youngest phases of the batholith. Gump Lake rocks are coarse grained, porphyritic, and are of granodiorite or quartz monzonite composition with a low mafic mineral content. Plagioclase has oscillatory zoning similar to that of the Bethlehem phase. It is cut by the Witches Brook phase of intermediate to young age which also cuts the Highland Valley phase. The Gump Lake phase is considered, on the scanty evidence available, to be of intermediate age, possibly between Highland Valley and Bethlehem phases.

Petrography

Rocks of the Gump Lake phase (*see* Plate VI) are mottled pink and light cream-grey and are medium to coarse grained with seriate to porphyritic texture.

Figure 5 *a* shows the modes for the Gump Lake phase determined from thin-sections fall in the granodiorite field of the ternary diagram and modes determined from stained slabs fall in the quartz monzonite field of the diagram. Modes of stained slabs (*see* Table IV) show values of 36 to 40 per cent plagioclase, 25 to 33 per cent orthoclase, and 22 to 28 per cent quartz. Table II lists three thin-sections of Gump Lake phase having a range of 37 to 49 per cent plagioclase, 11 to 16 per cent orthoclase, 29 to 39 per cent quartz, and 5 to 8 per cent total mafic minerals with biotite more abundant than hornblende.

Plagioclase (An_{35}) shows poorly developed oscillatory zoning and has albitized margins of grains in which there is a poorly developed granophyric texture. Parts of some plagioclase grains are intensely sericitized. Orthoclase is anhedral, interstitial, perthitic, and poikilitically encloses small anhedral plagioclase grains.

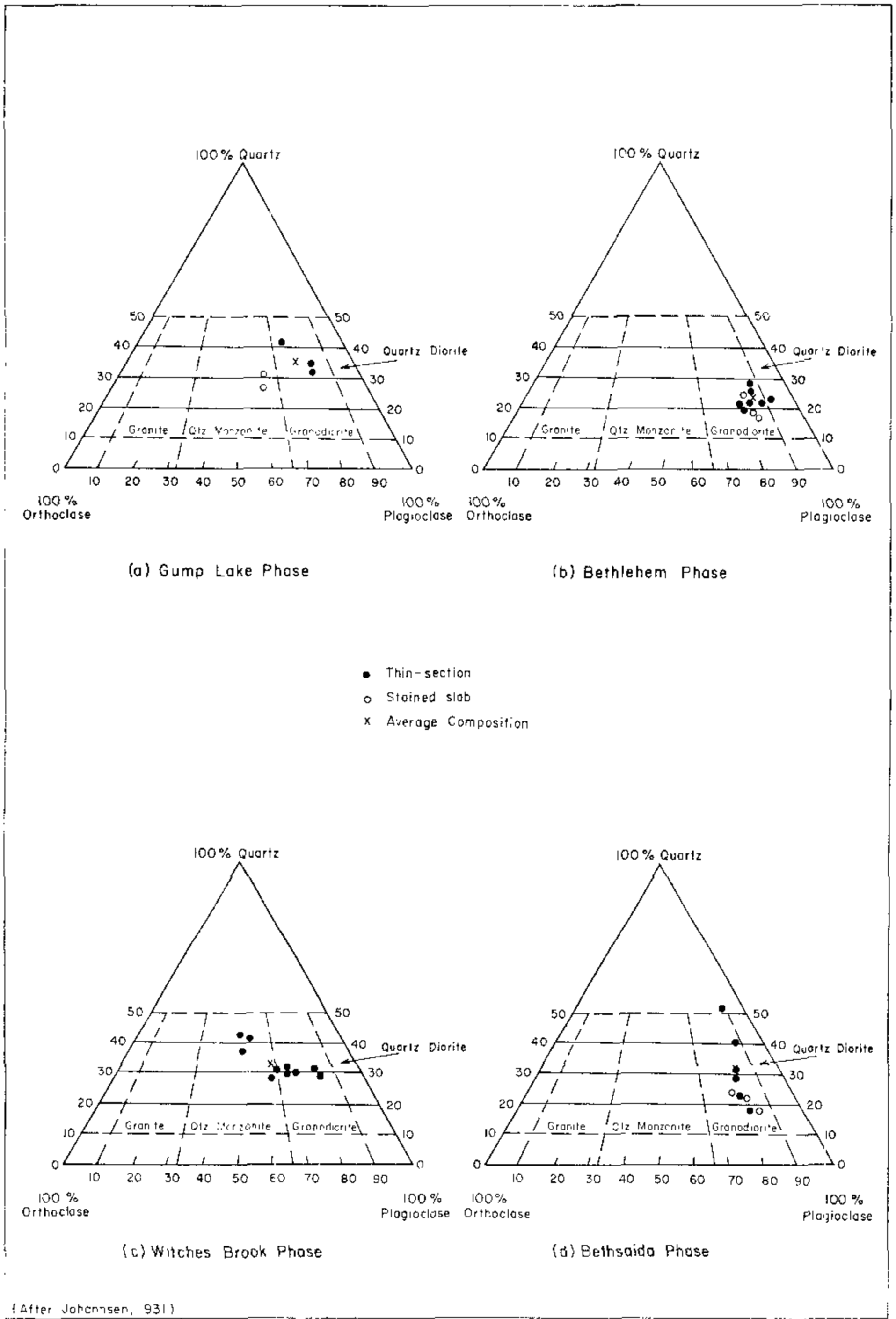

Fig. 5. Modal analyses.

Quartz forms conspicuous, anhedral, interstitial, very coarse grains or aggregates of smaller grains. A few grains show fractures and strained extinction.

The mafic minerals are anhedral and have weak poikilitic textures, enclosing plagioclase and quartz. Biotite is commonly more abundant than hornblende.

Bethlehem Phase

Distribution and Field Relations

Bethlehem phase granodiorite, which almost completely encircles the central core of the Guichon Creek batholith, was first described and named, after its type locality on the Bethlehem property, by White, Thompson, and McTaggart (*see* White *et al.*, 1959, p. 277). In common with other phases, the Bethlehem phase has minor variations. A xenolith, 7 feet in diameter, of Guichon variety in the Bethlehem phase occurs on the Bethlehem property. Although no chilled contacts were noted, it clearly shows that the Bethlehem phase is the younger.

Petrography

The mineralogy of the Bethlehem phase is similar to that of other phases, although augite is rare. The rock-forming minerals are plagioclase, orthoclase, quartz, biotite, and hornblende with accessory minerals, sphene, zircon, rutile?, apatite, and opaque grains. Alteration products include epidote, chlorite, tremolite (actinolite), tourmaline, zeolites, and prehnite?. The Bethlehem phase has a slightly porphyritic texture, which is more conspicuous near the inner contact with the Bethsaida phase.

Modes listed on Table II show that the Bethlehem phase is composed of 54 to 63 per cent plagioclase, 6 to 16 per cent orthoclase, 18 to 25 per cent quartz, and 5 to 11 per cent mafic minerals with either hornblende or biotite dominant.

Plagioclase exhibits oscillatory zoning with composition of centres of grains ranging from An_{36} to An_{47}, but most thin-sections indicate a smaller variation from An_{36} to An_{39}. Preferred orientation of plagioclase is common. Orthoclase is interstitial, poikilitic, perthitic, and forms large patches an inch or two in diameter. Quartz is anhedral, interstitial, and has strained extinction.

Biotite crystals are commonly bent. Hornblende has a conspicuous poikilitic texture and irregular distribution, which are characteristic of this phase (*see* Plate VII).

Witches Brook Phase

Distribution, Varieties, and Field Relations

The concentric arrangement of major intrusive phases is interrupted by varieties of the Witches Brook phase. There is no well-defined mass of Witches Brook phase as there is for most other phases, and its occurrences and varieties cannot adequately be shown on a map scale of 1 inch to 2 miles. Irregular masses and dyke-like bodies of Witches Brook cut the Guichon and Chataway varieties and the Hybrid and Gump Lake phases. It also occurs as a cement of breccia filling interstices between angular fragments of the older phases. Although Witches Brook phase can be seen in older phases almost everywhere in the batholith, only areas where it is most abundant are outlined on Figure 2. A body of quartz monzonite, locally called Bethlehem granite on the Bethlehem property, which intrudes Bethlehem phase, texturally resembles the Witches Brook phase and is therefore tentatively assigned to that phase. For the same reason a similar quartz monzonite, on the west margin of the batholith near Spatsum, is also assigned to the Witches Brook phase.

The Witches Brook phase shows more textural and compositional variations than any phase other than the Hybrid phase. Where the phase forms large bodies the rock is similar in texture to the Bethlehem phase. Where Witches Brook occurs as smaller bodies, it is notably finer in grain and richer in quartz and orthoclase. As there apparently is a complete gradation in texture, grain size, and composition, the Witches Brook phase cannot easily be separated into units. For ease of description, three varieties are distinguished: A, B, and C (*see* Plates VIII, IX, and X).

Petrography

Mineralogy of the Witches Brook phase is similar to that of the Bethlehem phase. Rock-forming minerals include plagioclase, orthoclase, quartz, biotite, hornblende, and minor augite. Accessory minerals include apatite, sphene, opaque grains (largely magnetite with very sparse chalcopyrite, bornite, and pyrite). Alteration products are chlorite, epidote, sericite, prehnite, and zeolites.

Modes plotted on the ternary diagram (*see* Fig. 5 *c*) and listed on Table II show a range of 28 to 52 per cent plagioclase, 10 to 29 per cent orthoclase, 26 to 43 per cent quartz, and 2 to 11 per cent mafic minerals with biotite commonly more abundant than hornblende. Mafic content is low, in the order of 2 per cent, in Spatsum quartz monzonite and Bethlehem granite, and in other areas it is 9 to 11 per cent with an average of slightly more than 9 per cent. In view of the generally fine grain size and homogeneity of the rock within small areas, the variation shown on Figure 5 *c* is considered to be a true one, probably illustrating differentiation within the phase.

Witches Brook Variety A

Witches Brook variety A (*see* Plate VIII) is a light- to medium-grey granodiorite; usually it is slightly mottled by pink, is medium to coarse grained, and weakly porphyritic in texture. The rock is 60 per cent feldspar, of which 70 to 80 per cent of the total feldspar is plagioclase (An_{38}).

Mafic content is about 10 per cent with hornblende usually slightly more abundant than biotite. Commonly small amounts of augite are present. The mafic minerals characteristically occur as aggregates of very fine to coarse grains, resulting in small dark clots with indistinct outlines. In addition, varieties A and B have randomly disseminated coarse-grained poikilitic hornblende crystals. In thin-section the plagioclase (An_{38}) shows weak oscillatory zoning and a poorly developed preferred orientation. This variety of Witches Brook phase closely resembles Bethlehem phase and, indeed, may be a variety of that phase.

Witches Brook Variety B

Variety B (*see* Plate IX) is similar to variety A but is finer grained and somewhat richer in orthoclase and quartz. Texturally the two varieties have the same characteristics.

Variety B is light to medium grey or medium to dark grey in colour, usually mottled slightly with pink. The rock is composed of from 55 to 65 per cent feldspar, of which 65 to 85 per cent is plagioclase (An_{35} to An_{38}). Some plagioclase grains show poorly developed oscillatory zoning, particularly the coarser grains, and have albitized rims showing a granophyric texture. Orthoclase is interstitial and poikilitic. Quartz is interstitial, conspicuous, anhedral, and constitutes about 25 per cent of the rock.

The rock contains 10 per cent mafic minerals with about equal proportions of biotite and hornblende and minor augite. The mafic minerals characteristically form aggregates of small grains showing indistinct outlines with some unevenly disseminated coarser-grained poikilitic hornblende.

Witches Brook Variety C

Variety C (*see* Plate X) is similar to B, has a finer-grained matrix, and is usually more distinctly porphyritic as a result of abundantly disseminated medium to coarse grains of plagioclase. The rock is pink, mottled by light grey.

Variety C is richer in orthoclase and quartz than varieties A and B. Feldspar constitutes about 50 to 65 per cent of the rock, of which 50 to 60 per cent of the total feldspar is plagioclase (An_{40}). Orthoclase is interstitial, poikilitically enclosing plagioclase, quartz, and mafic minerals. Quartz, ranging from 25 to 40 per cent, is anhedral and interstitial to plagioclase.

Mafic minerals range from 2 to 10 per cent with biotite predominating over hornblende. The dark minerals form aggregates of fine grains.

Bethsaida Phase

Distribution and Field Relations

The Bethsaida phase (*see* Plate XI) forms the central core, 13 miles long by 4½ miles wide, of the Guichon Creek batholith. A dyke thought to be related to Bethsaida phase or Gnawed Mountain porphyry, chilled against Guichon variety, appears on the north side of Highland Valley on the Bethlehem property and is locally called the Spud Lake porphyry. A variety of Bethsaida phase (*see* Plate XII) occurs as an easterly projection into Bethlehem phase. This variety, probably representing rapidly crystallized Bethsaida phase, is chilled against Bethlehem granodiorite on the south peak of Gnawed Mountain. This is the only major contact in the area of the Guichon Creek batholith that was seen showing the fine grain size indicative of chilling.

Petrography

Bethsaida granodiorite-quartz monzonite forms distinctive exposures with rough weathered surfaces. Preferential weathering of softer minerals leaves quartz standing in relief.

On Table II, plagioclase ranges in amount from 38 to 62 per cent, orthoclase from 5 to 15 per cent, quartz from 16 to 46 per cent, and mafic minerals from 3 to 12 per cent with biotite more abundant than hornblende. Much of the variation in quartz content results from the fact that it occurs unevenly disseminated as coarse, subhedral phenocrysts.

Plagioclase (An_{31} to An_{38}) is euhedral and has oscillatory zoning. Some quartz grains are subhedral or interstitial to plagioclase, but they also form large, clear phenocrysts, which are a conspicuous feature of this phase. Orthoclase is interstitial to plagioclase, quartz and mafic minerals, and is perthitic.

Very coarse-grained, euhedral, book-like biotite phenocrysts are characteristic of this phase. Where there is an increase in the amount of poikilitic hornblende, the rock type is difficult to distinguish from coarse-grained, porphyritic Bethlehem phase near the Bethlehem-Bethsaida contact.

Late Phases

Bethlehem Porphyries

Porphyry dykes of various textures and compositions, believed to be genetically related to the younger phases of the batholith, occur in a northerly trending swarm crossing Highland Valley west of Bethlehem property. The swarm is at least 10 miles long and 3 to 5 miles wide, becoming narrower at the north end. These dykes have been described by White, Thompson, and McTaggart and subsequently by Carr (*see* White *et al.*, 1957, p. 278; Carr, 1960, pp. 71–73). Similar porphyries have been noted in other places in the area of the batholith as single dykes or groups of two or three dykes, but the Highland Valley swarm is by far the most notable occurrence.

White (*see* White *et al.*, 1957, p. 228) distinguished two types of dykes on the Bethlehem property which, though of similar composition, differ markedly in texture. The two groups are dacite porphyry and quartz diorite porphyry. On the basis of subtle differences in texture and mineralogy, presence or absence of quartz phenocrysts, Carr further subdivided the porphyries (*see* Carr, 1959).

Gnawed Mountain Porphyries

The Gnawed Mountain porphyries are thought to represent the youngest phase of the batholith. These occur as small irregular bodies and dykes with fine-grained margins in Bethsaida and to a lesser extent in Bethlehem and older phases. One such body forms a small breccia pipe on the west flank of Gnawed Mountain, another forms a large northerly trending dyke on the east shoulder of Gnawed Mountain. Others are reported to occur on the Lornex property (Carr, personal communication).

Gnawed Mountain porphyries consist of 25 to 35 per cent coarse-grained euhedral to subhedral plagioclase and very coarse-grained quartz crystals set in a fine-grained quartz and feldspar-rich matrix. Where the margin of the Gnawed Mountain porphyries were chilled, the matrix of the rock is very fine grained to cryptocrystalline. These rocks are similar in appearance and are probably closely related to the Gnawed Mountain variety of Bethsaida (*see* Plate XII).

Leucocratic Rocks

Leucocratic dykes and small irregular leucocratic masses can be seen at almost any place in the area of the batholith but are most abundant near contacts of younger phases and within the Bethsaida phase. A leucocratic body of unknown extent occurs about 2 miles west of Gump Lake in the Witches Brook-LeRoy-Chataway-

Guichon complex. One outcrop area consisting entirely of leucocratic rock is at least 150 feet in longest diameter, is fine to medium grained, equigranular, and weathers pinkish white.

The leucocratic bodies and dykes are variable in grain size, ranging from aplite to pegmatite, and are composed principally of quartz, orthoclase, and plagioclase. Chalcopyrite and bornite are sparsely distributed in these bodies.

Breccias within the Batholith

Three main types of breccia occur within the batholith: fault breccia, intrusion breccia, and pipe breccia. Fault breccias form complicated branching and braided structures of sheared, slickensided, comminuted, altered rock and gouge ranging from a few feet to hundreds of feet in width. Hydrothermal alteration and mineralization are particularly prevalent in fault breccias which possibly served as channelways for hydrothermal fluids.

Intrusion breccias are common at intrusive contacts between Hybrid, Guichon, and Witches Brook phases. Angular fragments of the older phases are healed by a cement of the younger phase.

Pipes of breccia, closely associated with porphyries, intrude Highland Valley, Bethlehem, and Bethsaida phases and occur on the Bethlehem, Trojan, Krain, Salmo Prince, and Gnawed Mountain properties. They range in size from a few feet to 2,000 feet in longest dimension, are commonly elongate, but may be nearly equidimensional in plan. Drill-core data from Bethlehem and Trojan properties suggest they are pipe-like in shape tapering downward (*see* White *et al.*, 1957, p. 278). Most breccia pipes are closely associated with late porphyries and younger phases at contacts with older phases. Most fragments are angular, few are rounded; most are less than 2 inches across, but blocks several feet in diameter are common. The matrix is composed of comminuted rock material, largely broken grains of feldspar, quartz, and small rock fragments, and is commonly impregnated and partly replaced by biotite, tourmaline, quartz, chalcopyrite, bornite, and hematite.

Although breccia pipes of the area are similar in gross appearance, they differ in detail. Contacts between breccia and surrounding rock may be sharp with relatively sound material, as in the Iona Breccia on the Bethlehem property, or gradational showing increase in size of fragments toward the margins where fragments are only slightly displaced, as at Gnawed Mountain. Some pipe breccias show gradation in size of fragments; others show predominantly two distinct sizes of angular fragments in a fine-grained matrix. Breccia fragments may be touching or well separated. The dominant non-metallic minerals which replace finely comminuted interstitial matrix vary from one pipe of breccia to another. Fine-grained biotite with only minor amounts of tourmaline replaces much of the matrix of the Iona Breccia. Tourmaline is the dominant non-metallic mineral replacing the matrix of breccia at Trojan and some breccias at Gnawed Mountain. At the Salmo Prince property, the breccia matrix is largely comminuted rock fragments hydrothermally altered to epidote with some calcite. Other small pipes of breccia at Gnawed Mountain have a matrix composed largely of quartz and feldspar. Some pipes of breccia contain economic chalcopyrite and bornite, others contain hematite, and still others are unmineralized by metallic minerals.

Suggested modes of origin of pipes of breccia are surface brecciation, faulting, solution collapse, shrinkage accompanying metasomatism, collapse consequent on release of magmatic pressure, and explosion in the lower part of a volcanic structure.

Physical characteristics and composition of pipes of breccia occurring within the batholith eliminate most of the suggested modes of origin (*see* White *et al.*, 1957, p. 279). The breccias are generally of a cross-cutting nature, and are composed entirely of plutonic rock, so are not formed on the surface by sedimentary or volcanic processes. Origin by faulting is precluded on the basis of absence of related major faults in most breccias, nearly equidimensional outline of many breccia zones, local abundance of fine matrix, and absence of fragments showing slickensides. Collapse by solution, shrinkage during alteration, and withdrawal of supporting magma are not favoured as mechanisms for producing pipes of breccia because of the abundance of small fragments in local areas, abundance of extremely comminuted fine-grained matrix, general low grade of alteration, and because of the presence of small (fraction of an inch) cavities, many of which are post-breccia.

It is believed that pipes of breccia were formed in the Guichon Creek batholith by subvolcanic explosions when the pressure of volatiles exceeded the confining strength in cupolas. An increase in pressure of volatiles may have been brought about by upward and outward diffusion of volatiles in order to equalize vapour pressure of volatiles throughout the magma (*see* Kennedy, 1955, pp. 489–502). Separation of anhydrous phases by continued cooling would increase vapour pressure of volatiles (*see* Kennedy, 1955, p. 498). Carr suggested a similar origin for pipes of breccia in Highland Valley (*see* Carr, 1960, p. 73).

Deuteric and Hydrothermal Alteration

The deuteric and hydrothermal alteration throughout the batholith is similar to that found by White *et al.* (1957) on the Bethlehem property. Widespread deuteric alteration, which probably occurred during a late magmatic stage, was followed by more localized hydrothermal alteration. Deuteric alteration is primarily propylitic and saussuritic and has affected to a varying degree older rocks at the batholith margin and all intrusive phases. In many rocks that have been deuterically altered, orthoclase and, to a lesser extent, plagioclase are red. Biotite and hornblende are chloritized and epidotized. Replacement of hornblende by pale to colourless actinolite occurs locally, as noted by White *et al.* on the Bethlehem property. Such alteration is also common in the Hybrid phase at the batholith margin.

Hydrothermal minerals associated with the copper sulphide ore deposits at Bethlehem include epidote, tremolite, tourmaline, rutile, quartz, biotite, albite, prehnite, calcite, muscovite, clay minerals (montmorillonite, possibly kaolinite, illite, and alunite), zeolites (leonhardite, heulandite, stilbite, chabazite), and chlorite (*see* White *et al.*, 1957, p. 281). To this list should be added orthoclase, which occurs in other deposits of the area. The relative abundance of these alteration minerals varies from place to place in the batholith. For example, tourmaline is common, although not abundant, in the Iona Breccia at the Bethlehem property; whereas at the Trojan property, 2 miles to the northwest, and at Gnawed Mountain, 3 miles to the south, it is a major constituent of breccias. Secondary quartz is relatively scarce on the Bethlehem property but is more abundant on the Lornex property, 5 miles to the southwest. Secondary biotite constitutes a large part of the matrix of Iona Breccia but was not observed in quantity elsewhere in the batholith. Muscovite is commonly developed in vein-type deposits, particularly in those of O.K., Empire, Skeena, and Snowstorm properties (*see* White *et al.*, 1957, p. 280).

Chlorite, epidote, tourmaline, and, to a lesser extent, potassium feldspar are widespread throughout the batholith in joints or other fractures, commonly accompanied by traces of copper sulphides.

Specific Gravities of Phases

The specific gravity of most rock specimens was measured, using a specific gravity balance patterned after the design illustrated in Brush and Penfield, 1911, 16th Edition, page 235. The balance used in the present study was built by J. Parry, who used it to test the feasibility of distinguishing between various phases of the Guichon batholith by means of specific gravity (*see* Parry, 1964). Because Parry's preliminary results were encouraging, specific gravities were measured for more than 850 specimens of the various phases of the batholith. The specific gravity data were punched on computer cards and programmed for computation of means and standard deviations by A. J. Sinclair, of the University of British Columbia. Standard normal distribution curves based on standard deviation were drawn. The curves provide a means of comparing phases and varieties (*see* Fig. 6). The broader curves have a greater standard deviation and wider range of measured specific gravities. The narrower curves have a smaller standard deviation and indicate a smaller range of measured values. Because of the range of specific gravities of rock specimens of each phase, it is not possible to assign specimens to certain phases on the basis of their specific gravity. However, once the phases have been defined by other methods, standard normal curves of specific gravity measurements are useful to detect orderly changes in average specific gravity among phases. Specific gravities, except those of the Gump Lake phase, decrease progressively from the outer marginal phases, with an average of 2.80, to the inner and younger Bethsaida phase, with an average of 2.64. Specific gravities of the Bethlehem and Witches Brook phases are almost identical.

Table V.—Mean Values and Standard Deviations of Specific Gravities

Phase or Variety	Number of Specimens	Mean Specific Gravity	Standard Deviation
Hybrid	185	2.7977	0.0848
Guichon	177	2.7423	0.0427
Chataway	127	2.6957	0.0349
LeRoy	59	2.6876	0.0202
Gump Lake	13	2.6500	0.0286
Bethlehem	61	2.6746	0.0248
Witches Brook	173	2.6744	0.0325
Bethsaida	74	2.6436	0.0182

Phases and varieties listed in order of decreasing specific gravity as expressed by the curves of Figure 6 and relative age as interpreted from field work are compared as follows:—

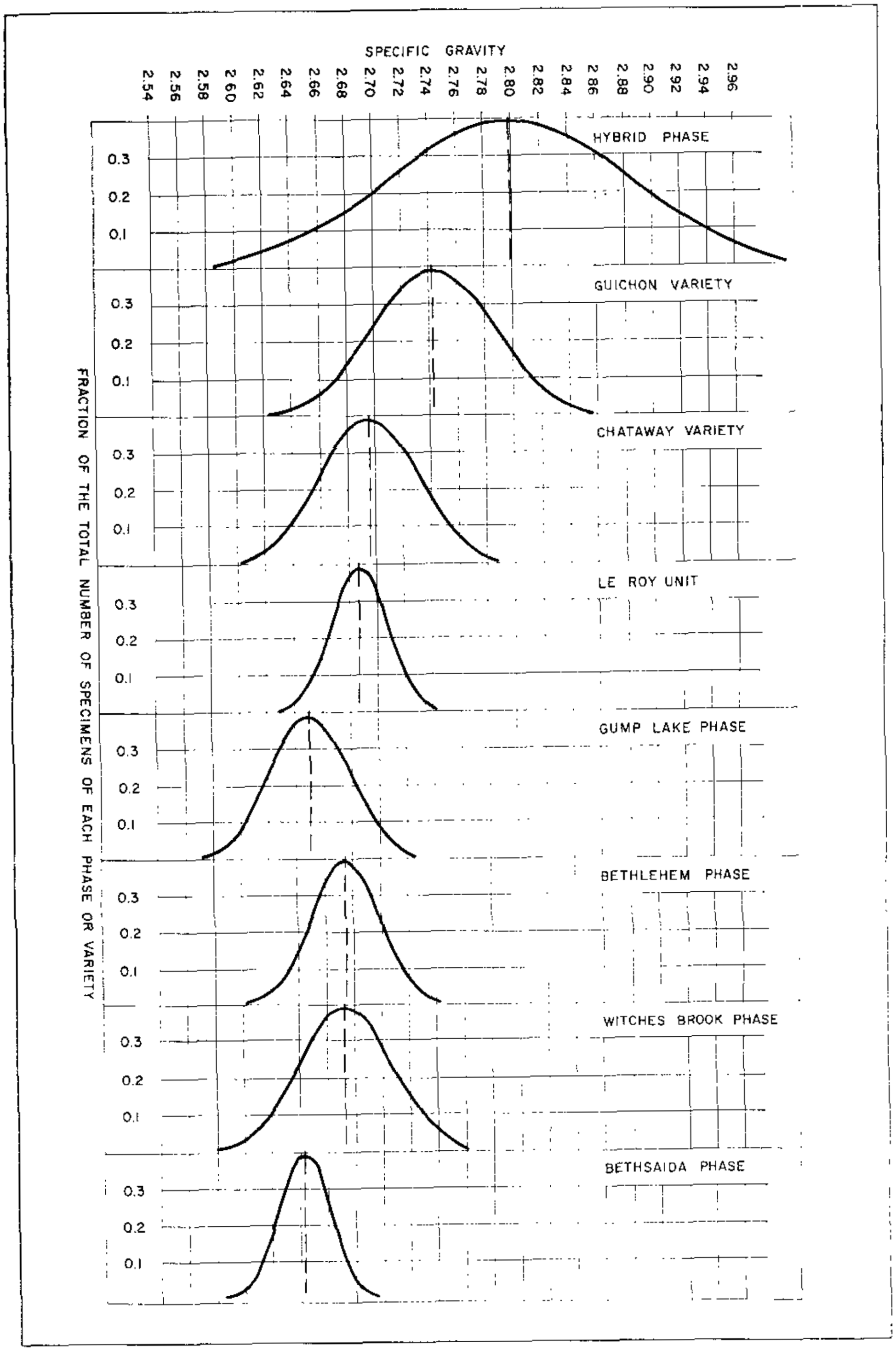

Fig. 6. Specific gravity.

Table VI.—Specific Gravity and Relative Age of Phases

Specific Gravity	Relative Age
Hybrid	Hybrid
Guichon	Guichon
Chataway	Chataway
LeRoy	LeRoy
Bethlehem[1]	Bethlehem
Witches Brook[1]	Gump Lake
Gump Lake	Witches Brook
Bethsaida	Bethsaida

[1] Same specific gravity.

With the exception of the Gump Lake phase, where relative age is problematical, correlation of specific gravity and relative age is excellent.

The decrease in specific gravity with decreasing age of phase is thought to be largely the result of a decrease in amount of mafic minerals and, to a lesser extent, a decrease in amount of magnetite in younger phases. A relatively large amount of orthoclase and quartz, although not showing a consistent increase with decreasing age, contributes to a lower specific gravity of some of the younger phases. Possibly more intergranular porosity in the younger phases is also a factor contributing to lower specific gravity.

Structure

Structural features of the Guichon Creek batholith include foliation, joints, shear and fault zones, dykes, veins, and xenoliths. Some of these structural data are shown on Figures 7 (in pocket), 8, and 9. Also shown are those linears, observed on air photographs, that may have some structural significance.

External Structural Relations

Both discordant and concordant relationships with older rock are evident at intrusive contacts between the Guichon Creek batholith and older stratified rocks.

Discordant contact relationships are found at the northwest margin of the batholith where bedding in pre-batholithic rocks is truncated by intrusive rock. A similar relationship occurs at the southeast margin of the batholith, at Craigmont mine, where Nicola Group rocks are truncated at a low angle by the batholith (*see* Rennie, 1962, p. 50). At Spatsum, on the west side of the batholith, the predominant dip of Cache Creek Group rock is northeasterly; that is, toward the batholith (*see* Carr, 1963, Fig. 1). Layering in a Nicola Group(?) roof remnant on the west side of Glossy Mountain strikes northerly and has a vertical dip.

The Guichon Creek batholith is a concordant intrusive body in the sense that it is elongate in a direction parallel to the structural grain of older stratified country rocks. Semi-concordant contact relationships are suggested by bedded Nicola Group sedimentary and volcanic rocks at the flanks of the batholith, particularly on its northwest side. Here Nicola Group strata strike northeasterly and have moderate northwesterly dips away from the batholith, suggesting displacement of older rocks during emplacement of magma. Similar but poorly exposed Nicola

Group rock can be seen dipping away from the east side of the batholith. These semi-concordant relationships may, however, be the result of later faulting along both sides of the batholith.

A large roof remnant projects from beneath Kamloops Group volcanic cover on Glossy Mountain and is in contact with the Hybrid phase. Smaller roof remnants occur on the east side of the batholith within the Hybrid phase. The degree of contamination of the Hybrid phase increases approaching such roof remnants. Original layering remains visible in these remnants, which have undergone only low-grade albite-epidote hornfels facies contact metamorphism. It is suspected that the heterogeneous assemblage of Hybrid rocks at Spaist Mountain in the west-central part of the batholith shows incomplete assimilation and homogenization of a roof remnant that formerly existed at and above the present erosion surface.

Internal Structural Relations

Xenoliths.—Xenoliths are abundant in older phases at the batholith margin and show great variation in size, degree of recrystallization, assimilation, and grade of metamorphism. Central phases of the batholith are relatively free of xenoliths. A large xenolith of quartzite can be seen in the Bethsaida phase near the middle of the batholith (White, personal communication). Some xenoliths have retained their granular texture, have angular outlines, and are in sharp contact with the plutonic rock. Others are rich in mafic minerals, have rounded outlines, and have indistinct contacts with intrusive rock. It is possible that fine-grained mafic-rich clots in the Hybrid phase may represent xenoliths that have been assimilated but incompletely mixed with magma.

Contacts.—Phase contacts are sharply intrusive, brecciated, or broadly gradational. The same contact may be sharply intrusive at one place and be gradational at another. Chilled contacts were seen only in two places. At Gnawed Mountain there appears to be a chilled contact of the Bethsaida rocks against Bethlehem phase. An off-shoot of the Bethsaida phase, locally called the Spud Lake Porphyry on the Bethlehem property, shows the effects of chilling against Guichon variety. Late dykes commonly show chilled margins against older phases. Temperature differences between successive phases appear to have been insufficient to cause chilling, except where fractures channelled magma into the relatively cool outer margin of the batholith.

Foliation.—Interpretation of foliation in older phases suggests that the batholith is a dome with steeply dipping sides (*see* Figs. 8 and 9). Foliation of intrusive phases of the batholith is seen as planar orientation of mafic minerals in outcrop and preferred orientation of plagioclase in thin-section. Foliation of mafic minerals is best developed in the Hybrid phase and the Guichon variety near the margin of the batholith and in dyke-like varieties of Witches Brook phase. Preferred orientation of plagioclase is best developed in the Hybrid phase and the Guichon variety but is common in all phases except the Bethsaida and Gump Lake.

As indicated by Figure 9, foliation of mafic minerals parallels main batholith contacts and internal phase contacts. Strong foliation is best developed parallel to margins of dyke-like bodies of the Witches Brook phase. Along the west margin of the batholith nearly all measured foliations strike northerly and dip either verti-

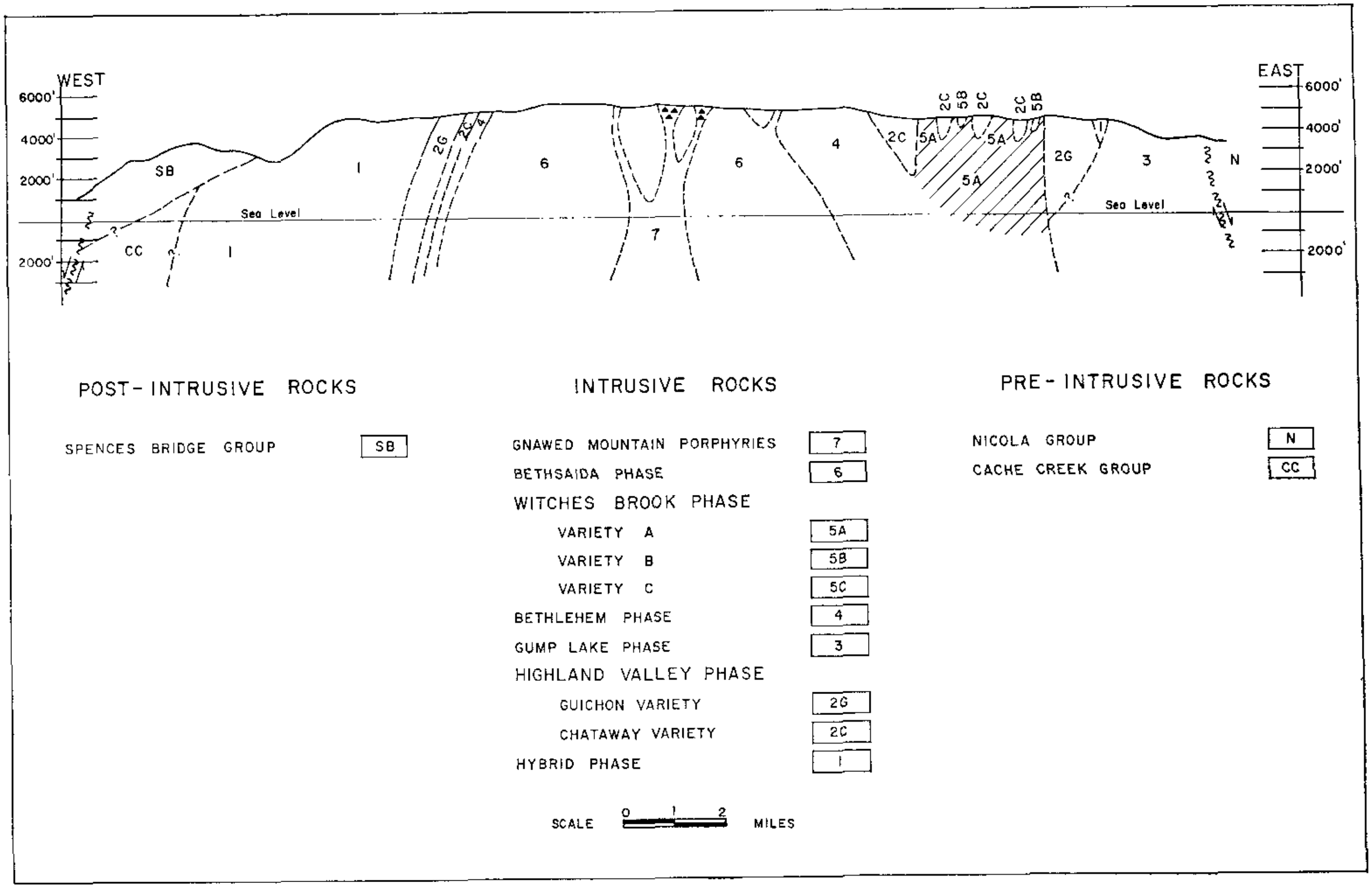

Fig. 8. Diagrammatic cross-section west to east across centre of Guichon Creek batholith.

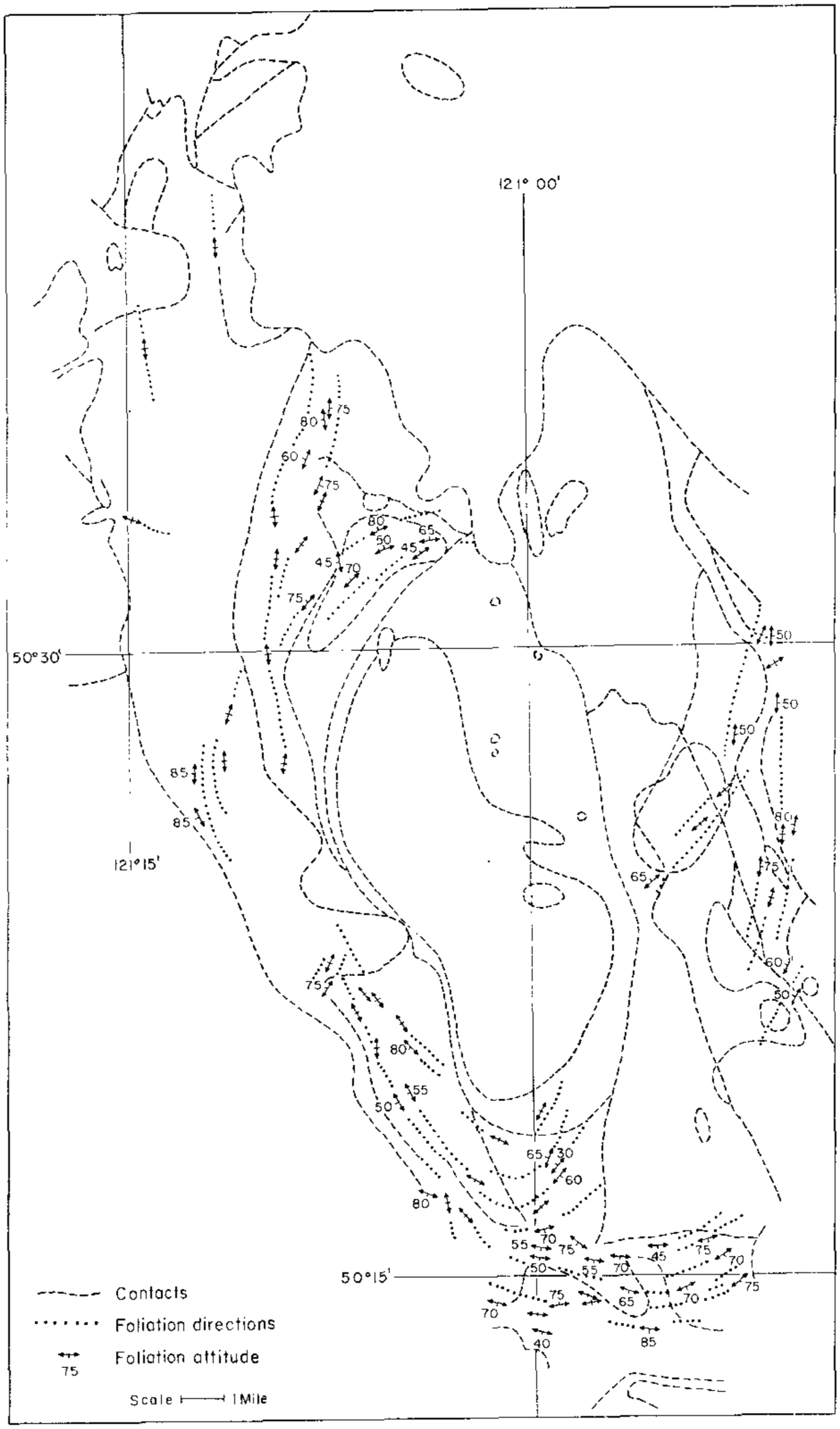

Fig. 9. Foliation directions in the Guichon Creek batholith.

cally or steeply to the west. In the Guichon and Chataway varieties in the north-central part of the batholith, foliation dips moderately to the northwest and north. Foliations on the east flank of the batholith vary in dip from vertical to moderately east. At the south end of the batholith the foliation seems to wrap around the batholith. Dips are moderate to steep southerly.

In summary, foliation tends to parallel batholith contacts and to dip outward; that is, toward the margins of the batholith.

Linears, Probable Faults.—Both glacial and structural linears are detectable on air photographs. Glacial linears are conspicuously superimposed on those of structural origin, which may be either masked or accentuated, depending on whether the trend of structural linears crosses or parallels the direction of Pleistocene ice movement. Prominent linears of probable structural origin are shown on Figure 7, and the frequency of their direction is shown on Figure 10. Glacial linears are excluded from this figure. Structural linears are depressions which contain relatively easily erodible material. They extend for many miles, have widely divergent trends, and commonly transect prominent ridges. Watercourses follow and deepen the structural linears and thereby modify the normal dendritic drainage pattern of the Guichon Creek batholith area. These features suggest that most structural linears are loci of faults or shear zones.

Most sulphide mineral occurrences in the Guichon Creek batholith are associated with faults. The best-known faults are therefore those occurring on mining properties where they are seen in surface exposures, mine workings, and in drill core. White *et al.* describes several of these. Prominent faults on the Bethlehem property strike within 20 degrees of north and dip steeply either easterly or westerly. They are described as complicated, branching or braided structures of sheared, comminuted, altered rock and gouge ranging in width from a few feet to more than 100 feet (*see* White *et al.*, 1957, p. 276). Similar faults occur on the Trojan, Krain, O.K., and Skeena properties, all within a 6-mile radius of the Bethlehem property. A notable fault occurs on the Skeena property. There the fault zone is more than 300 feet wide, strikes northeasterly, and has internal slickensides dipping moderately easterly (*see* White *et al.*, 1957, p. 276).

Linears that are more prominent than those coinciding with known faults are visible on air photographs. It is suspected that many of these prominent linears are faults containing wide gouge zones and possibly having large displacement. However, faults of this magnitude have not been recognized. No fault contacts between phases were observed which would suggest large displacement, although it is possible that such contacts occur but have been covered by glacial drift.

Northwesterly trending linears between north 15 degrees west to north 45 degrees west, approximately parallel to southeasterly movement of ice, and north 5 degrees east are most numerous (*see* Fig. 10). The northwesterly trending linears are probably accentuated by ice scouring and are therefore more noticeable on air photographs. Therefore, it is possible that the numerous linears plotted with this trend may be of less significance than the less numerous linears with trends transverse to the direction of ice movement.

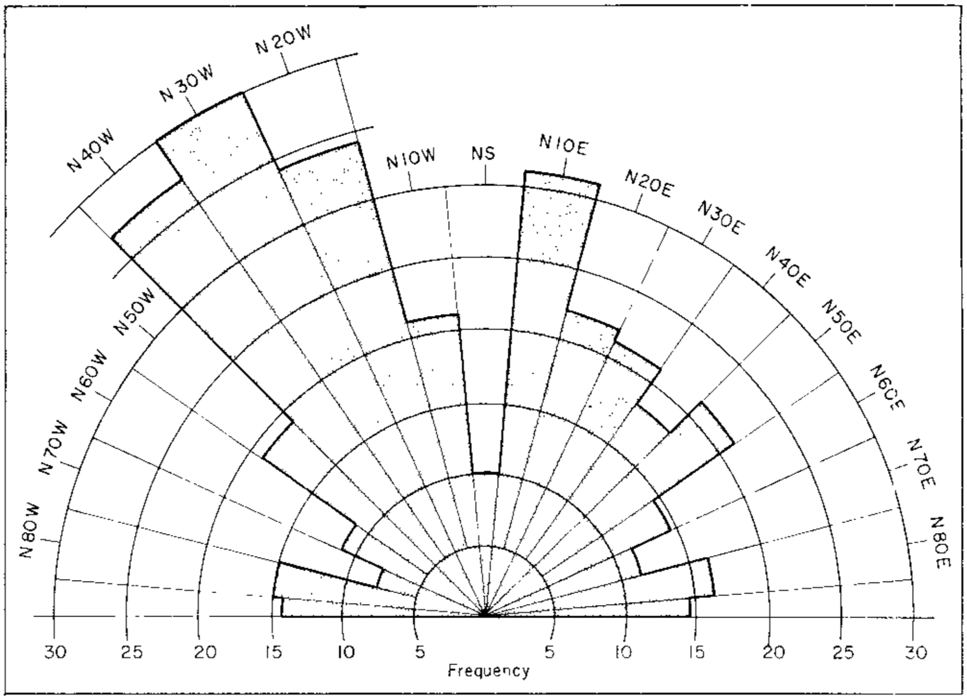

Fig. 10. Direction of structural linears on aerial photographs.

CHAPTER III

Geochronology

INTRODUCTION

This report includes early results obtained from the potassium-argon laboratory at the University of British Columbia. The laboratory was established to carry out geochronological studies of igneous rocks of British Columbia and to study theoretical problems of potassium-argon dating techniques. A major equipment grant from the National Research Council equipped the project in 1962, and it has since been supported by National Research Council operating grants. Professor W. H. White was responsible for establishing the potassium analysis laboratory. Professor G. P. Erickson designed and built the argon extraction and analytical equipment. J. R. Harakal supervised argon analyses, and some analyses reported here were made by him. The laboratory became operational late in 1964, and during the course of work on the Guichon Creek batholith about 50 age determinations were made, including interlaboratory checks.

While potassium-argon analyses for age determinations were being done for this project, a similar programme of age determinations was being carried out by G. E. Dirom as a M.A.Sc. thesis on porphyry dykes and major phases of the Guichon Creek batholith occurring on the Bethlehem property (*see* Dirom, 1965). The results of these two isotopic projects are complementary and have been published elsewhere (*see* White *et al.*, 1967).

The Appendix of this report includes an account of sampling methods, biotite separation, potassium analyses, argon analyses, operational characteristics, K/A interlaboratory comparisons, and description of biotite samples used in age determinations.

GUICHON CREEK BATHOLITH K/A RESULTS

Analytical data are listed on Table VII. The apparent age of each sample was calculated on the basis of those data and $\pm$ values show the estimated limits of error. Figure 11 diagrammatically shows 26 age determinations clustered around an average age of 198 ± 8 million years. They are shown on this figure from oldest to youngest on the basis of geological field relationships.

Dirom (1965) obtained concordant ages for hornblende and biotite for the Guichon phase on the Bethlehem property and for the Bethlehem phase using hornblende from sample K63-115, which was taken 6 miles to the southwest.

Geological evidence places the age of the Guichon Creek batholith within limits of early Upper Triassic and Middle Jurassic (*see* Duffell and McTaggart, 1952, p. 79). Major phases of the batholith can be placed in approximate order of relative age on the basis of geological evidence. Figure 11 relates phases in approximate order of age to K/A apparent ages obtained during the course of this study.

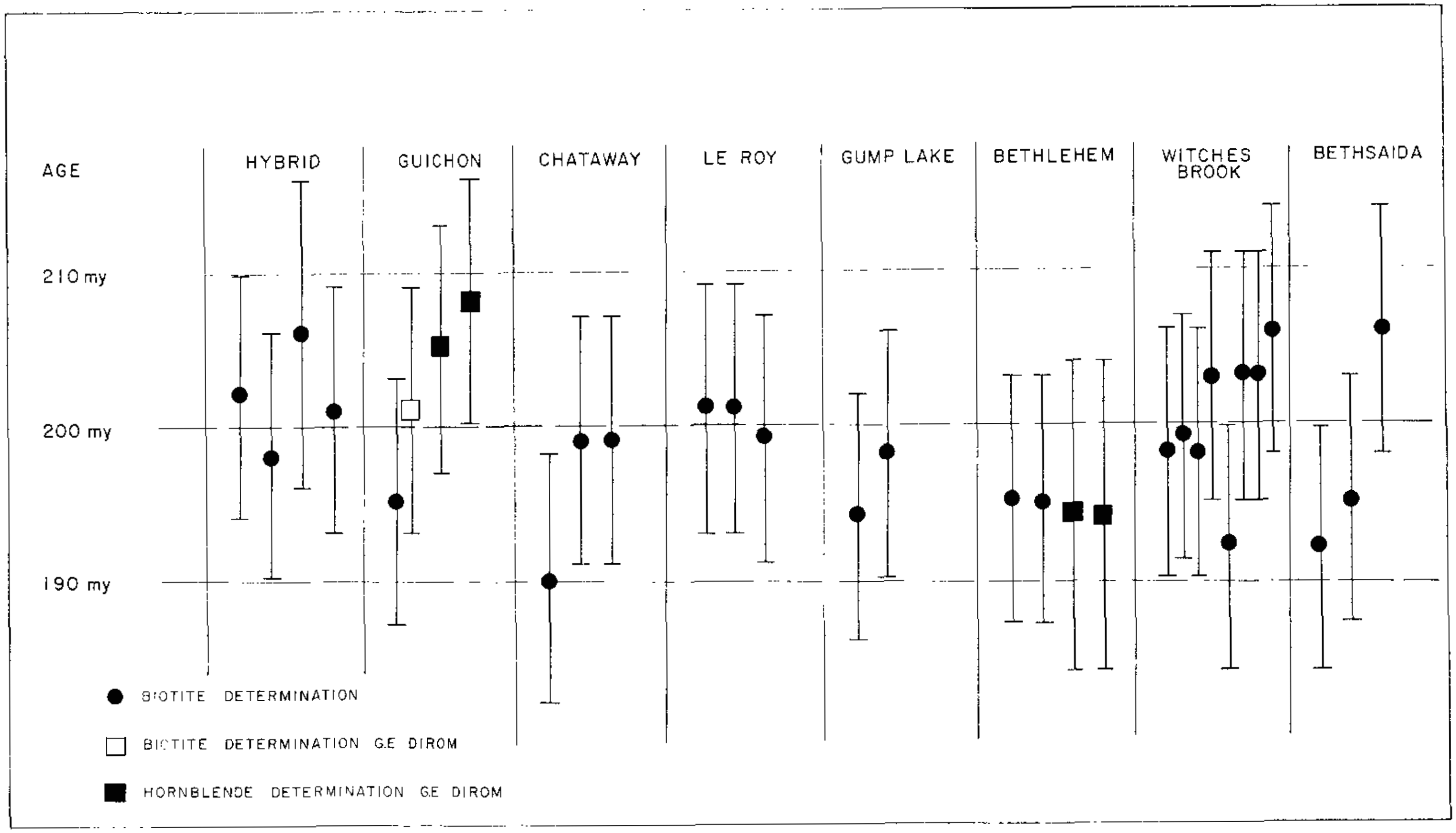

Fig. 11. Graphic representation of K/A age determinations with phases listed in order of decreasing age by geologic considerations.

The figure shows it is not possible to differentiate among various phases on the basis of K/A apparent ages because variations are within analytical limits of uncertainty of the techniques used. Biotite of the major phases began retaining argon at approximately the same time, clustered around 198±8 million years ago. The Iona Breccia, a breccia pipe occurring on the Bethlehem property, containing hydrothermal(?) biotite, the youngest biotite observed on the batholith, also gave a similar isotopic age of 199±8 million years (*see* White *et al.*, 1967, p. 686).

There are at least two possibilities to explain the remarkable uniformity of isotopic ages obtained for the various phases of the Guichon Creek batholith:—

(1) The phases of the batholith are all older than 198 million years but underwent regional metamorphism at that time, which reset the argon^{40} " clocks " in biotite.

(2) The phases of the batholith were emplaced during a short period of time before 198 million years, so that they were all relatively hot at the same time and began to retain argon at about the same time.

The first possibility is inconsistent with geological evidence within the batholith and the Nicola Group rocks which it intrudes. The Nicola Group country rock has been thermally metamorphosed at contacts with the intrusive rocks but does not show the same degree of metamorphism a few hundred feet away from the contacts. It would be expected that a regional metamorphic event of sufficient intensity to allow all argon to escape from biotite and hornblende would affect the older rock around the batholith.

Table VII.—Potassium Analytical Data

Sample No.	Phase	Mineral	Per Cent Potassium with Standard Deviation and Number of Samples Analysed
K63-13	Hybrid	Biotite	4.49±0.02 (4)
K64-156a	Hybrid	,,	6.73±0.01 (6)
K63-223	Guichon	,,	5.77±0.02 (4)
K64-116a	Chataway	,,	5.24±0.04 (4)
K64-220	Chataway-LeRoy	,,	5.20±0.02 (4)
K63-37	LeRoy	,,	6.42±0.03 (4)
K64-101	LeRoy	,,	5.16±0.05 (4)
K64-98-I	Gump Lake	,,	5.95±0.01 (4)
K63-115	Bethlehem	,,	5.90±0.07 (4)
K64-102	Witches Brook	,,	4.91±0.03 (4)
K64-105-I	Witches Brook	,,	6.53±0.04 (4)
K63-171	Witches Brook	,,	6.59±0.06 (4)
K64-203	Witches Brook	,,	4.42±0.02 (4)
K64-17	Witches Brook	,,	3.59±0.02 (4)
K63-187	Bethsaida	,,	4.48±0.02 (4)
K63-231	Bethsaida	,,	5.86±0.07 (4)
K63-114	Fragmental Rhyolite	,,	6.99 (2)

Table VIII.—Argon Analytical Data and Radiometric Age

Sample No.	Phase	A^{40} rad / A^{40} total	A^{40} rad (10^{-5} cc STP/g)	A^{40} rad / K^{40}	Radiometric Dates and Assigned Error (m.y.)
K63-13	Hybrid	0.85	3.795	0.01249	202± 8
		0.91	3.716	0.01223	198± 8
K64-156a	Hybrid	0.52	5.785	0.01270	206±10
		0.93	5.659	0.01243	201± 8
K63-223	Guichon	0.87	4.689	0.01201	195± 8
K64-116a	Chataway	0.80	4.155	0.01171	190± 8
K64-220	Chataway-LeRoy	0.77	4.358	0.01239	201± 8
		0.92	4.325	0.01230	199± 8
K63-37	LeRoy	0.30	5.390	0.01241	201± 8
		0.78	5.385	0.01240	201± 8
K64-101	LeRoy	0.90	4.295	0.01231	199± 8
K64-98-I	Gump Lake	0.37	4.817	0.01196	194±10
		0.91	4.919	0.01222	198± 8
K63-115	Bethlehem	0.90	4.307	0.01199	195± 8
		0.90	4.788	0.01196	195± 8
K64-102	Witches Brook	0.87	4.055	0.01221	198± 8
		0.91	4.077	0.01228	199± 8
K64-105-I	Witches Brook	0.90	5.442	0.01230	198± 8
		0.93	5.536	0.01253	203± 8
K63-171		0.75	5.263	0.01181	192± 8
K64-203		0.64	3.759	0.01257	203± 8
		0.79	3.750	0.01254	203± 8
K64-17		0.74	3.093	0.01272	206± 8
K63-187		0.80	3.590	0.01184	192± 8
		0.88	3.648	0.01204	195± 8
K63-231		0.86	5.044	0.01272	206± 8
K63-114		0.88	1.389	0.002935	49± 3
		0.83	1.433	0.003032	51± 3

NOTE.—Constants: $\lambda e = 0.58 \times 10^{-10} yr^{-1}$
$\lambda B = 4.72 \times 10^{-10} yr^{-1}$
$^{40}K/K = 1.181 \times 10^{-4}$

Table IX.—Potassium Data from the Bethlehem Property (Dirom, 1965)

Sample No.	Phase	Mineral	% K	No. Samples Analysed
G.D. 12	Guichon	Biotite	5.56	(2)
		Hornblende	0.424	(2)
G.D. 4	Guichon	Hornblende-amphibole	0.169	(3)
K63-115	Bethlehem	Hornblende	0.387	(2)
G.D. 11a	Bethlehem	Hornblende-amphibole	0.162	(2)
K63-222	Witches Brook	Biotite	7.16	(2)
G.D. 2	P_3 Porphyry	Hornblende-amphibole	0.140	(3)
G.D. 10	P_3 Porphyry	Hornblende-amphibole	0.292	(2)
G.D. 5	Dacite Porphyry	Biotite	5.56	(2)
K63-240	Iona Breccia	Biotite (W. H. White)	5.60	(4)

Table X.—Argon Data from the Bethlehem Property (Dirom, 1965)

Sample No.	Phase	A^{40} rad / A^{40} total	A^{40} rad (10^{-5} cc STP/g)	A^{40} rad / K^{40}	Radiometric Dates and Assigned Error (m.y.)
G.D. 12	Guichon	0.83	4.663	0.01239	201± 8
	Guichon	0.60	0.3629	0.01264	205± 8
G.D. 4	Guichon	0.60	0.1474	0.01285	208± 8
K63-115	Bethlehem	0.39	0.3121	0.01192	194±10
G.D. 11a	Bethlehem	0.44	0.1305	0.01193	194±10
K63-222	Witches Brook	0.87	5.903	0.01218	198± 8
G.D. 2	P_3 Porphyry	0.24	0.09845	0.01041	170±12
		0.39	0.09879	0.01044	171±12
G.D. 10	P_3 Porphyry	0.53	0.2432	0.01230	199± 8
G.D. 5	Dacite Porphyry	0.50	4.717	0.01253	203± 8
K63-240	Iona Breccia (W. H. White)	0.84	4.643	0.01225	199± 8

There is no evidence of metamorphism of intrusive rock 200 million years ago of sufficient intensity to release all argon from all biotite and all hornblende throughout the batholith. Original rock textures and structures seem to be unchanged. The intrusive rock retains flow structure shown by preferred orientation of mafic minerals and plagioclase.

Concordant ages in hornblende and biotite are considered by some to be evidence that the rock has not undergone a later metamorphic event (*see* Aldrich *et al.*, 1960). It is hardly conceivable that failing recrystallization of older rock and complete loss of argon that both biotite and hornblende could have lost the proper ratio of argon by heating to result in concordant ages of 198 million years.

The second possibility, that 198±8 million years represents the time that crystallization and cooling of all phases had progressed sufficiently to retain radiogenic argon, is consistent with geologic evidence. No interval of time can be given for period of emplacement of the batholith. It can be said, however, that

(1) paucity of chilled contacts indicates most phases of the batholith were hot at approximately the same time;

(2) biotite of the major phases began retaining argon at approximately the same time clustered around 198±8 million years ago;

(3) no significant metamorphic event has affected the rocks of the Guichon Creek batholith since that time;

(4) geological evidence shows that emplacement of the batholith occurred after Karnian time. Argon must have begun to accumulate in biotite and hornblende well before Middle Jurassic because pebbles of the batholith occur in conglomerate of this age.

CHAPTER IV

Petrogenesis

ENVIRONMENT OF EMPLACEMENT

Buddington describes criteria indicative of emplacement of plutons in progressively deeper environments or zones of increasing pressure, temperature, and wallrock mobility. These zones are called "epizone," "mesozone," and "catazone" (*see* Buddington, 1959, p. 676). Plutons of the epizone are probably emplaced at a shallow depth between 0 and 6 miles with wallrock temperature below 300 degrees centigrade. Plutons of the mesozone are considered to be emplaced between 4 and 10 miles of the surface with wallrock temperatures ranging between 250 and 500 degrees centigrade. Plutons of the catazone are emplaced between 6 and 12 miles depth with wallrock temperatures the order of 600 to 700 degrees centigrade (op. cit., pp. 676–677).

According to Buddington's criteria, the Guichon Creek batholith would be classed as mesozonal to epizonal. Mesozonal features are characteristic of the older phases at the outer margin of the batholith. Complex discordant, and in part concordant, emplacement relationships occur. The surrounding country rock has been metamorphosed to albite-epidote or hornblende hornfels facies. The contact aureole is small, generally one-eighth to one-half mile. Assimilation of country rock appears to have been significant. No effects of chilling are apparent at the outer margin of the batholith or at contacts between border phases. The phases at the margin of the batholith have a fairly well-developed planar foliation of mafic minerals and a well-developed preferred orientation of euhedral plagioclase crystals. This foliation and preferred orientation is crosscut by younger units. There is no apparent direct relationship between plutons and volcanic rocks.

A number of features of young central phases suggest emplacement in a shallower environment than the older phases. The Bethsaida phase has no obvious lineation or foliation. Late stage aphanitic and porphyritic dykes are common. There are some chilled contacts between the Bethsaida and the Bethlehem, and commonly the late porphyry dykes are chilled at their contact with Bethsaida, Bethlehem, and Highland Valley phases. Pipe breccias are common in the younger phases in the centre of the batholith, and where they do occur in older phases near the batholith margin, they are always in association with porphyries or bodies of younger phases.

It is possible that the oldest phases were emplaced in a mesozonal environment while erosion was in progress. Perhaps successive phases of the batholith were emplaced at progressively shallower depths as a result of the erosion of overlying Upper Triassic (Karnian) formations. This would require erosion of from 5,000 to 15,000 feet of overlying strata. Thereby, epizonal features of younger phases were superimposed on earlier mesozonal features. The possibility that erosion of overlying sediments took place during emplacement of the Guichon Creek batholith is suggested by absence of Lower Jurassic sediments. Middle Jurassic conglomerate unconformably overlies the batholith and Upper Triassic (Karnian) rocks. If post-Karnian–pre-Middle Jurassic rocks were ever deposited, they must have been eroded before Middle Jurassic. In order to have deposition of Lower Jurassic sediments, it would be necessary to postulate a basin of deposition occurring simultaneously above shallow forceful emplacement of the batholith.

An alternate explanation for the apparent environmental change is that the batholith penetrated en masse successively higher into the crust during intrusion of younger central phases. The overlying uplifted material was eroded and resulted in epizonal conditions during emplacement of late phases. Although faulting and shearing have occurred in older rocks of the Nicola and Cache Creek Groups near the margin of the batholith, there is little evidence that faulting was a major mechanism of emplacement of the batholith.

Carr (1963, p. 44) illustrates grabens almost completely surrounding the batholith. A large northwesterly trending graben lies a few miles to the west of the exposed batholith margin. The grabens are apparently pre-Middle Jurassic because they were filled by marine Middle Jurassic and younger strata to the east of which was " a high landmass in which the Guichon batholith, not long emplaced, was bared to erosion " (*see* Carr, 1963, p. 44). The grabens apparently had little to do with emplacement of the Guichon Creek batholith because the first sediments to appear within them contain pebbles and cobbles of the batholith.

Fault breccias at the west margin of the batholith commonly contain a few granitic fragments, which are indicative of movement after crystallization of the magma. Some upward movement of older crystallized phases at the margin of the batholith probably occurred during emplacement of younger central phases. There is, however, no intense shearing of the Hybrid phase at the batholith margin to indicate that intrusion of crystallized outer phases of the batholith into successively higher levels of the crust was a major mechanism of emplacement of the batholith. The hypothesis which encounters the least number of difficulties is that erosion during intrusion changed the environment of emplacement from mesozonal to epizonal depths.

According to Curtis *et al.* (1958), dating of the Sierra Nevada batholith suggests an interval of approximately 2 million years between successive intrusions. Most intrusions appear to have been almost completely crystallized before succeeding intrusions were emplaced. The suggested interval of 2 million years for emplacement and crystallization of each intrusion is in fair agreement with Larsen's estimate of 1 million years (*see* Larsen, 1945, p. 415).

If a period of 4 million years were required for emplacement and crystallization of the Hybrid and Highland Valley phases of the Guichon Creek batholith, a rate of erosion of 1 foot every 250 to 800 years would change the environment of emplacement from mesozonal to subvolcanic before intrusion of the younger phases.

MODE OF EMPLACEMENT

Emplacement of the Guichon Creek batholith by granitization of older stratified rocks does not seem probable; first, because foliation of mafic minerals of the

Hybrid and Guichon rocks and preferred orientation of plagioclase in all but the youngest phases suggests movement of partially crystallized magma during emplacement. Minerals late to crystallize in the Hybrid and Guichon rocks and platy mafic minerals in phases of intermediate age show no preferred orientation as would be expected if alignment of plagioclase in these rocks were simply the result of stress. Second, all phases can be seen in intrusive contact with other phases or older stratified rock. The contacts are " sharp " and occur between large intrusive masses, small irregular dyke-like bodies, dykes with regular fine-grained margins, and contact breccias. Third, a narrow halo of low-grade thermal metamorphism suggests magmatic rather than metasomatic origin. Such a contact is said to be disharmonious and indicative of emplacement by magma (*see* Walton, 1955, pp. 8–9). According to Walton, " The only adequate means as yet known of introducing a large, localized source of heat into a relatively shallow, unmetamorphosed sedimentary environment is by introducing an adequate amount of hot material with high heat capacity—or to put it bluntly, by intrusion of hot, mobile rock material—or even more bluntly, by hot magma" (*see* Walton, 1955, p. 10).

For the above reasons, the Guichon Creek batholith is considered to have been emplaced as intrusive magma.

Process of Emplacement

Phases of the Guichon Creek batholith appear to have been emplaced in a roughly concentric series by pulses of partly crystallized magma. Emplacement was affected by a combination of wallrock stoping, assimilation of stratified country rock, forceful intrusion, and possibly partly as a result of differential gravitational effects on the granitic material relative to surrounding country rock.

Magmatic stoping is suggested by the presence of xenoliths, which are abundant in the older phases for a distance of several hundred feet inward from the batholith margin. Paucity of xenoliths in younger central phases is not easily explained, but perhaps the xenoliths were completely assimilated and incorporated in the magma before they reached the present erosion level in the batholith. Possibly the magma at the top of the magma chamber was enriched in volatile constituents and was sufficiently reactive to assimilate and homogenize most of the inclusions.

Assimilation and incorporation of wallrock material may be indicated by inhomogeneities in texture and composition near the outer contact, as compared with relatively homogeneous composition in the middle part of the batholith. The Hybrid phase grades outward across the batholith margin from only slightly contaminated intrusive rock to highly contaminated rock charged with xenoliths, to recrystallized pre-batholith rock or metasomatized epidote-albite to hornblende hornfels, to relatively unmetamorphosed stratified country rock. Marked textural and compositional differences in intrusive rock at the batholith margin may be a result of compositional differences in assimilated material. Xenoliths, most abundant within one-quarter mile of the outer contact, show a gradation in degree of recrystallization, metasomatism, and assimilation grading from relatively unchanged older rock showing sharp contacts to dark mafic-rich clots with indistinct outlines in intrusive rock. Degree of metamorphism, recrystallization, and assimilation of xenoliths are thought to be a function of their reactivity, composition, size, pressure-temperature conditions within the magma, amount of volatile constituents present, and length of time of immersion in the magma (*see* Lovering, 1955, p. 269). Hybrid rocks farther from the contacts are more homogeneous in texture and composition as a result of complete mixing of assimilated material. In view of the width of the contaminated zone, particularly on the west side of the batholith, assimilation appears to have played an important role in the development of the batholith.

Table III, Average Modes of Phases and Varieties, and Figure 3 show that the plagioclase and biotite content is fairly uniform. There is, however, an increase in amount of opaque minerals (magnetite largely), hornblende, and augite in Hybrid rocks. Although all phases have similar plagioclase content, plagioclase of the Hybrid rocks is richer in calcium. Hybrid rocks contain less orthoclase and quartz than phases near the middle of the batholith. No chemical analyses were made of the rocks, so no direct compositional comparisons can be made between Hybrid rocks and the Highland Valley phase, which is thought to represent closely the composition of the original magma. Mineralogical differences between Highland Valley and Hybrid phases suggest that Hybrid rocks have been enriched in calcium, iron, magnesium, hydroxide and are poorer in silicon, potassium, and possibly sodium.

The process of emplacement of a partly crystallized magma by assimilation of presumably more basic materials cannot easily be explained. Addition of any basic material should raise temperature of crystallization. Any addition of basic material to a partly crystallized magma should result in rapid crystallization. Bowen (1956, pp. 175–223) has shown that any minerals high on the continuous or discontinuous reaction series added to an acidic melt will cause an exothermic reaction and will be made over into phases in equilibrium with the melt. Contamination of magma can be brought about in a quantitatively important amount of exchange of materials between magma and wallrock if an exchanging medium of volatile-rich solutions are present (*see* Nockolds, 1933, pp. 561–583). Nockolds (1933, p. 584) pointed out that contamination of magma is increased by disintegration of wallrock and xenoliths and incorporation of released minerals into the magma. It is suggested that volatile constituents may have diffused and concentrated at the margin of the batholith, in an environment of lower temperature and pressure, in order to equalize the partial pressure of volatile constituents throughout the magma (*see* Kennedy, 1955, pp. 489–503). Additional volatile constituents may have been derived from stratified pre-batholith rocks. The presence of volatile constituents is suggested by the relative abundance of hydrous hornblende in rocks on both sides of the batholith's outer contact. Volatile constituents would not only provide a medium of exchange of other material from magma to inclusions and country rock, but would also lower temperature of crystallization and further assist the process of assimilation.

It is possible that forceful intrusion also played an important role in emplacement of the batholith, but it is a difficult process to demonstrate. Sharp contacts of apophyses of younger phases, irregular dyke-like bodies, breccia at the batholith margin, irregular dykes with chilled margins, and pipe breccias may have been caused by forceful intrusion of magma. Nicola rocks are in semi-concordant contact on the east and west sides of the batholith, dipping away from its outer margin, an attitude that is suggestive of being forced upward and outward by magmatic pressure. This apparent semi-concordant relationship could, however, be the result of late deformation in grabens flanking the batholith. A few miles south of Ashcroft, Middle Jurassic rocks which unconformably overlie the batholith have similar attitudes. According to Walton (1955, p. 7), salt domes demonstrate clearly how light mobile material impelled by nothing more than gravity can punch its way through tens of thousands of feet of overlying strata. Apparently structural deformation produced by such processes is scarcely noticeable beyond a few hundred metres from the edge of the intrusive mass and is evident only when the deformed rocks are well stratified and not otherwise deformed. The specific gravity of uncontaminated phases is lower than country rock. In general the specific gravity of the intrusive rocks increases with increasing amount of contamination. It is possible that the effect of gravity on the different densities of magma and surrounding country rock played some part in emplacement of the Guichon Creek batholith.

MAGMATIC PROCESSES

Textural and compositional differences between phases and the intrusive nature of internal contacts suggest that the magma was emplaced as a series of pulses. Magmatic pulses may result from cyclic diffusion of volatile constituents until partial pressure is high enough to overcome confining pressure. The major control would be the rate of diffusion of water in the magma (*see* Kennedy, 1955, p. 495).

While successive pulses of magma were being emplaced, differentiation was taking place in the main magma chamber. Differentiation is shown by the modes of phases shown on Tables II to IV and on Figure 3. Plagioclase and biotite content remains fairly uniform among phases, but the composition of plagioclase is less calcic toward the core of the batholith. There is an increase in amount of orthoclase in younger phases, but this increase is not regular. Figure 3 shows that the Gump Lake and Witches Brook phases contain the highest concentrations of orthoclase. The spread of orthoclase values for fine-grained Witches Brook phase is thought to represent a true range of orthoclase content within the phase. The range of values in the coarse-grained porphyritic Gump Lake phase in which orthoclase occurs as large (>1 inch) irregularly spaced clots could be partly a result of sampling error. The higher values obtained from stained slabs are believed most representative of the amounts of orthoclase in this phase and are probably a result of differentiation of magma. Figure 3 shows an increase in quartz in younger phases and is thought to be a result of differentiation. The wide range of values for quartz content in porphyritic Bethsaida phase may in part be due to sampling error. Hornblende content in general decreases toward the core of the batholith or with decreasing relative age of the phases.

The variation in composition within the Hybrid phase and the difference in average composition of this and the Highland Valley phase are probably not the result of differentiation but are thought to be largely the result of contamination by wallrock. Thereby, marginal phases at the batholith are richer in hornblende, augite, magnetite, and calcium-rich feldspar than the central phases.

During early stages of crystallization of phases near the batholith margin, there may have been a tendency for more basic materials to crystallize first in accordance with the general order of crystallization of Bowen's reaction series (*see* Bowen, 1956, p. 60). Crystallization of basic materials at the batholith margin by a process of diffusion over short distances, aided by convection, may have enriched the remaining magma in more acidic material.

A second form of differentiation, to some extent, may have an opposite effect. There may be a tendency for volatile constituents accompanied by alkalis and silica to diffuse upward and outward through the magma and concentrate within the crystalline inner edge of the batholith and in cupolas. Kennedy (1955, p. 490) has shown that volatile constituents, in an effort to reach uniform partial pressures, tend to diffuse upward and outward to cooler, lower pressure places in the magma chamber. Walton (1955, pp. 2–3) suggests that the phyllosilicate and tectosilicate structures which they form favour the cooler, lower pressure areas. The orthoclase- and quartz-rich variety of Witches Brook phase and leucocratic dykes and irregular bodies cutting older phases may be evidence of accumulation of such differentiated magma. If the confining pressure and strength of overlying rock is exceeded, the magma and its concentration of alkalis, followed by less differentiated magma, break through the outer, already crystalline phases of the batholith. Upon fracturing, emplacement of already partly crystalline magma in cooler enclosing rock is accompanied by a decrease in pressure and probable loss of volatile constituents. The result is rapid crystallization resulting in fine grain size. It is believed that such processes occurred during emplacement of the Bethlehem-Witches Brook phase. These processes account for the widespread occurrence of irregular dyke-like bodies of Witches Brook phase in all older phases, for its great variations in composition and for its fine-grained seriate texture.

SUGGESTED HISTORY OF EMPLACEMENT OF THE GUICHON CREEK BATHOLITH

Mesozonal Environment

The magma was emplaced to approximately the present level of the Guichon Creek batholith by a combination of magmatic stoping, assimilation, differential gravitational effects between magma and country rocks, and forceful intrusion by magmatic pressure. Depth of burial at this stage would have been 4 to 6 miles deep in the mesozone. During this period, much wallrock was dislodged and assimilated. Outward diffusion of volatile constituents from the magma to marginal zones and inward diffusion of volatile constituents from country rock to the magma possibly lowered the temperature of crystallization and aided in assimilation of basic material. Crystallization of the more basic components of the magma effectively left the remaining magma more acidic. A period of quiescence followed emplacement of the batholith, during which crystallization proceeded inward from the margin, gradually slowing as volatile pressures began increasing (*see* Fig. 12A).

The volatile pressure finally exceeded the confining pressure and resulted in breakthrough of magma locally to emplace the Highland Valley phase in the Hybrid phase and stratified older rocks. There was local brecciation and some assimilation of Hybrid and older rocks, which resulted in a gradation in composition at outer contacts. A long period of quiescence followed crystallization of Highland Valley phase (Guichon and Chataway varieties), during which there was again steady

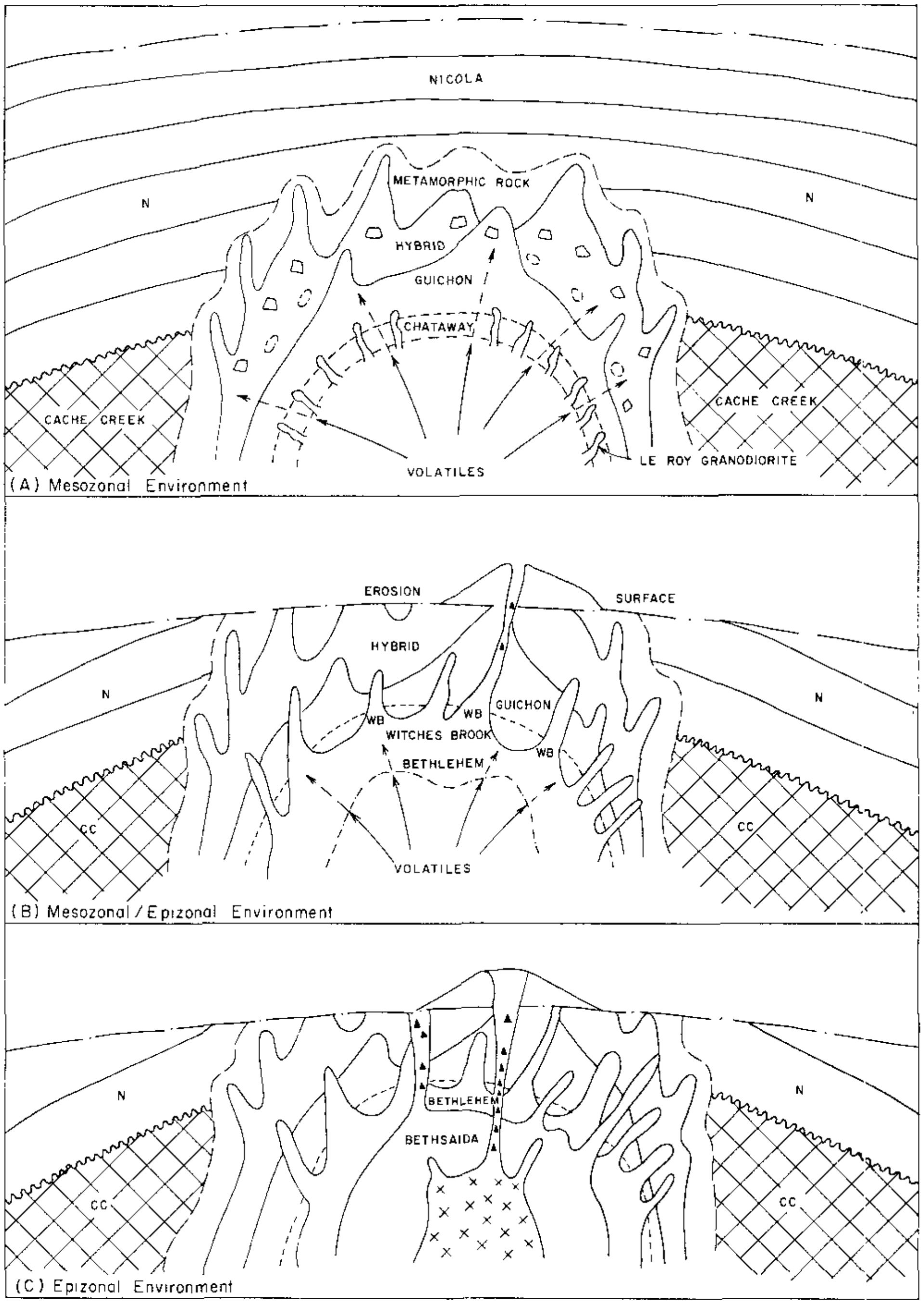

Fig. 12. Diagrams showing the suggested sequence of events during emplacement of the Guichon Creek batholith.

increase of volatile pressures and an accompanying slowing of crystallization. Confining pressure and strength of overlying rock was again exceeded, causing fracturing in cooler crystalline phases and emplacement of LeRoy granodiorite as fine-grained irregular dyke-like bodies. Fracturing of cooler rock was accompanied by loss of pressure and volatile constituents, which resulted in rapid crystallization of an already partly crystallized magma.

After emplacement of the Highland Valley phase, the Gump Lake phase was emplaced on the east side of the batholith. Its emplacement is unexplained. Possibly this phase is an offshoot of the Nicola batholith, which lies to the east. Emplacement of the Nicola batholith may have preceded the Guichon Creek batholith in time and was at a later stage of differentiation.

A long quiescent period allowed the maximum outward diffusion of volatile constituents, which were accompanied by alkalis and silica. These materials apparently collected in cupolas and apophyses along the inner crystalline border of the batholithic magma. Volatile pressure increased, possibly accompanied by renewed magmatic pressure from below, until the confining pressure was exceeded. Extensive fracturing of older crystalline phases occurred throughout the batholith. Differentiated alkali, quartz, and metal-enriched magma of the Witches Brook phase entered the fractures in country rock forming irregular dyke-like bodies and large irregular masses. Loss of pressure and volatile constituents caused rapid crystallization of the magma and resulted in a fine grain size. Copper deposits associated with the Witches Brook phase were formed at this time. Meanwhile, crystallization of the Bethlehem phase occurred in the main magma chamber. Bethlehem and Witches Brook phases and their varieties are probably very closely related and may be variations of one phase (Fig. 12B).

Epizonal Environment

Emplacement and crystallization of Hybrid, Highland Valley, and Bethlehem phases was accompanied by erosion of older rock overlying the batholith. Environment of emplacement of magma gradually changed from mesozonal conditions to epizonal subvolcanic conditions by the time the Bethlehem phase had crystallized. Volatile constituents and associated materials again collected at the inner crystalline margin. As volatile pressure built up and locally exceeded the confining pressure, porphyry dyke swarms were emplaced and pipe breccias were also formed by explosive release of pressure. Volatile constituents and associated materials were deposited in fractures in outer crystalline phases. These solutions were copper-rich, and many more mineral deposits, such as Bethlehem, Trojan, and Krain, were formed at this time, accompanied by hydrothermal alteration.

Erosion continued downward; crystallization of the Bethsaida phase occurred in the main magma chamber. Volatile material diffused and there was build-up of vapour pressure. When the confining pressure was again exceeded, there was local emplacement of Bethsaida into older phases. Outer crystalline phases were at this time cooling more rapidly in a shallower environment, causing chilling of Bethsaida against older phases (*see* Fig. 12C). Mineral deposits such as O.K., Lornex, and others associated with Bethsaida phase were formed at this time, possibly accompanied by emplacement of the Gnawed Mountain porphyries. The last differentiated magma to crystallize formed aplite and alaskite dykes and small irregular masses. Erosion proceeded to the present level.

APPENDIX

Geochronology

A. SAMPLING METHODS

Representative samples weighing 50 to 100 pounds were collected for each phase to be analysed. The sample-sites were chosen on the basis of contact relationships, accessibility, and freshness of rock. Sample-sites are shown on Figure 2. Samples of older phases were taken as distant as possible from contacts with younger phases to minimize the danger of loss of argon from biotite. For the same reason, near-surface samples in forest-fire areas were avoided. Fresh rock was obtained by breaking through weathered surfaces of outcrops with a sledge hammer. Wherever possible, samples were taken from fresh cliff faces, from excavations for power pylons, and from road cuts. The degree of alteration of biotite was determined in thin-sections of the rock and by binocular microscopic examination of biotite separates. A number of samples were discarded as too intensely altered to give reliable age determinations.

B. BIOTITE SEPARATION

The amount of sample necessary to give approximately 25 grams of biotite was crushed to less than one-half inch diameter by using, in turn, a jaw crusher and cone crusher. The crushed rock was then passed through a disk pulverizer and sieved into four size fractions roughly the grain size of the mafic minerals, -28 to $+100$ Tyler mesh, so that biotite would be released and a minimum of composite grains would remain. Each size fraction was washed in a vertical-column water classifier. For most samples a rough biotite concentrate could be made by the classifier. The samples were dried by heating to less than 100 degrees centigrade under a heat lamp. Each washed and dried size fraction was passed through an electrostatic separator (Dings Magnetic Separator, Company Model 2LAB) set to give a rough biotite concentrate. Magnetic grains were removed from concentrates with a hand-magnet. Clean biotite concentrates were obtained by a combination of additional processes, including heavy liquid separation using bromoform, tetrabromoethane, and diiodomethane, isodynamic (magnetic) separation, and by rolling the concentrate down paper towels, electrostatically charged plastic sheets, and, finally, by hand-picking until an acceptable purity was obtained. The purified biotite concentrates were washed several times with acetone to remove traces of heavy liquids.

The final concentrates contain more than 95 per cent biotite or chloritized biotite. Chloritic alteration in biotite is revealed by lower potassium values. Samples containing less than 4 per cent potassium are considered unreliable for age determinations.

C. POTASSIUM ANALYSES

The potassium content of biotite was determined by flame photometric techniques using a Baird Atomic model KY-1 clinical flame photometer which uses a lithium internal standard. Results were recorded on a two-second response, 10-millivolt, zero-centre Weston recorder connected in series with the photometer meter. Instrument instability was reduced by use of propane as fuel and by installation of an external voltage regulator on the photometer power supply-line and by sensitive pressure regulating valves (*see* Dirom, 1965, p. 18).

Care was taken to guard against contamination of samples and standard solutions. Glassware was treated with Siliclad at frequent intervls and was soaked, after use, in hot HNO_3 and rinsed in pure water. Distilled water, further purified by being passed through an ion exchange column, was used to rinse glassware and for making up to volume standard and biotite sample solutions. Standard and biotite sample solutions were stored in 1-litre air-tight polyethylene bottles. Blanks, containing all chemicals and solutions added to biotite sample solutions, run at intervals during the analyses, indicated that the level of potassium contamination was negligible.

Biotite solutions were prepared and analysed according to the procedures described by Cooper (1963). Four samples weighing between 0.5 and 1.0 gram were split from the stock concentrate. The second halves of the last two splits were retained for argon analyses. Biotite samples were decomposed at temperatures less than 100 degrees centigrade in a solution of 3 millilitres of concentrated H_2SO_4, 35 millilitres of 49 per cent HF, and 2 millilitres of concentrated HNO_3 finally evaporated down to about 3 millilitres. The residual solutions were brought up to exactly 1,000 millilitres with pure water and 100 millilitres of stock solution containing 2,000 p.p.m. lithium and 5,000 p.p.m. sodium prepared from reagent grade LiCl and Na_2SO_4. The potassium content of biotite sample solutions was determined by comparing unknown solutions with standard solutions containing 200 p.p.m. lithium, 500 p.p.m. sodium, and an appropriate amount of potassium. Standard solutions were prepared by dissolving weighed quantities of dessicated, reagent grade K_2SO_4 in pure water. One hundred millilitres of the same lithium and sodium stock solution used to prepare the biotite sample solutions was added to the standard solution and was then made up to 1,000 millilitres with pure water. Most biotite analyses were in quadruplicate, using different weights of biotite sample digested and analysed in two completely separate runs (*see* Dirom, 1965, p. 19).

D. ARGON ANALYSES

Argon Extraction and Measuring Equipment

The argon extraction and measuring system was designed by G. P. Erickson, built and operated by Erickson, assisted by J. E. Harakal. A brief description is given by White *et al.*, 1967, page 683.

Argon content of biotite was measured statically by an MS10 mass spectrometer (Associated Electrical Industries). The method of isotope dilution was used, employing a known quantity of A^{38} as a tracer or spike and correction for contamination by atmospheric argon based on A^{36} concentration in the gas sample. The same type of mass spectrometer is successfully being used in the Geophysics Laboratory at the University of Toronto. The operational characteristics of the MS10 have been described by Farrar *et al.* (1964). The method used by Erickson and Harakal at the University of British Columbia for fusion of biotite, clean-up of argon, addition of A^{38} spike, and introduction of the sample into the mass spectrometer is similar in principle to that used at the University of Toronto but differs in procedure.

Figure 13 is a diagram of the argon extraction and analytical system used at the University of British Columbia (*see* White *et al.*, 1967, p. 684). It consists of four sections: fusion section, spike and air calibration section, clean-up and inlet section, and analytical section. Each section can be isolated from the other by ultra-high-vacuum metal valves. Fusion and " clean-up inlet " sections are outgassed by mercury diffusion and rotary vacuum pumps. The air-A^{38} spike calibration section is outgassed by a rotary vacuum pump and the analytical section is outgassed by an ion pump. Pressures in all sections are monitored by pirani gauges.

An A^{38} reservoir, containing A^{38} of known purity and a small volume between two ultra-high-vacuum metal valves, forms the A^{38} spike system. The amount of A^{38} introduced by each spike is determined by an air-argon calibration system (Fig. 13). The A^{40}/A^{36} ratio of atmospheric argon is measured several times, and amounts are calculated at standard temperature and pressure. Several more comparisons are then made of the amounts of atmospheric A^{36} and A^{40} and A^{38} from each addition of spike. The amount of A^{38} spike is calculated at standard temperature and pressure. A^{38} calibrations were made at frequent intervals between runs of unknown samples, and a graph was prepared to show the amount of A^{38} spike at standard temperature and pressure released into the system by each addition of spike.

Immediately preceding each analysis, a leak test of the argon line was made by opening each section in turn to the mass spectrometer and by observing the mass 40 and mass 28 signals.

Fusion of between 0.7 and 1.0 gram of sample in an alundum-jacketed molybdenum crucible is accomplished by a 6-kilowatt radio frequency generator and an induction coil which encircles the fusion jar (Fig. 13). A spike of A^{38} is released into the fusion section when the temperature of the sample reached 1,000 degrees centigrade during fusion. A final temperature of about 1,500 degrees centigrade, maintained for at least 10 minutes, was found to be sufficient to fuse completely the sample and release all argon. The pressure within the fusion section was controlled by lowering the temperature of the hot titanium sponge to absorb impurities and by placing dry ice on a cold trap to remove water (*see* Dirom, 1965, p. 25).

During purification of argon samples, argon can be temporarily stored on charcoal at the temperature of liquid nitrogen, and the remaining gases pumped off. Impurities are adsorbed on titanium by cooling the titanium furnaces from 750 degrees centigrade and in cold traps at the temperature of dry ice. Any number of purification cycles could be carried out by alternating the gas back and forth between fusion and clean-up introduction sections (*see* Dirom, 1965, p. 26).

Argon is monitored into the mass spectrometer through a variable leak valve to give conveniently measurable signals of A^{40}, A^{38}, and A^{36}, the A^{40} signal being between 5 and 10 volts. The average of 10 scans for both the 40/36 and 40/38 ratios was used to determine the correction necessary for atmospheric argon in the 40/38 ratio (*see* Dirom, 1965, p. 27).

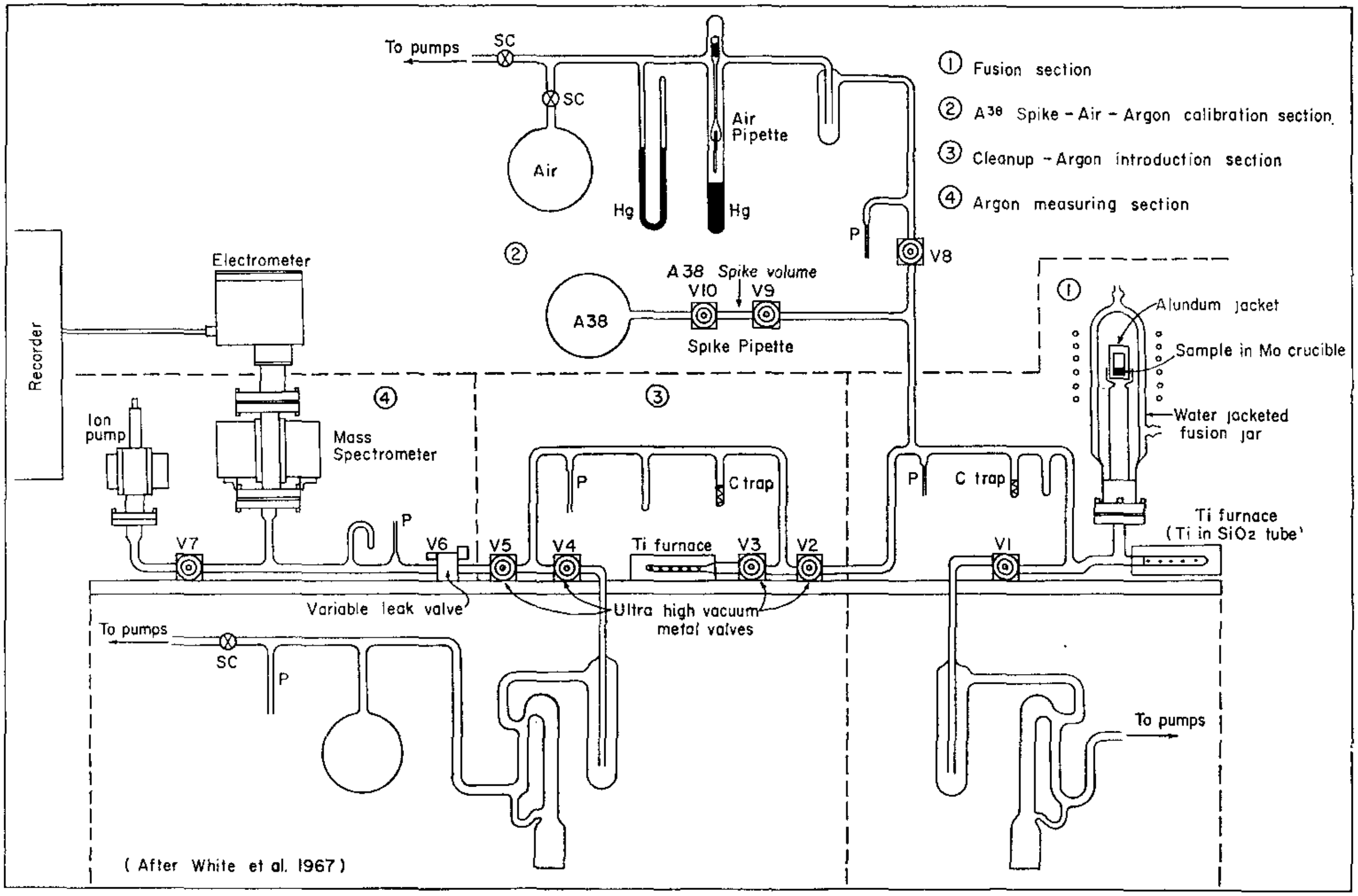

Fig. 13. University of British Columbia K/A laboratory and analytical system.

Operational Characteristics

It was found that the fusion section did not require outgassing by baking if outgassed for periods greater than 12 hours before making an analysis. The mass spectrometer analytical and clean-up inlet sections were kept constantly at a high vacuum. It was also found that there was no detectable memory effect resulting from argon being adsorbed on tubing, metal valves, etc., and bake-out of this section was unnecessary. Similar findings are reported by Farrar *et al.* (1964) for the MS10 in use at the University of Toronto.

Systematic changes in observed ratios during analyses were negligibly small, so that it was not necessary to extrapolate the ratios to time of admission to the mass spectrometer.

For each analysis a check was made to determine the fraction of the total quantity of gas actually admitted to the spectrometer so that fractionation effects at the leak valve could be evaluated. The small volume between V_5 and V_6 (*see* Fig. 13), approximately 10 per cent of the volume of the purification inlet section, was used for that purpose. In all analyses less than 10 per cent of the total volume of gas was used. For biotite 200 million years old, 0.7 to 1.0 gram of sample gives more than adequate argon for measurement by the MS10.

Corrections for fractionation at the valve and for discrimination in the mass spectrometer were made on the measured A^{40}/A^{36} and A^{40}/A^{38} ratios. These corrected values were used in age calculations.

Precision and Accuracy

Duplicate and replicate analyses that have been made of samples from the Guichon Creek batholith and interlaboratory standard samples give a measure of precision for both potassium and argon analyses at the University of British Columbia K/A laboratory. These data are listed on Tables XII to XV.

The average precision of potassium analyses is 0.78 per cent and of $argon^{40}$ radicle is 1.04 per cent (*see* Tables XI and XII).

Accuracy is estimated from interlaboratory comparisons of analyses of the same material. The University of British Columbia results for potassium and argon on three interlaboratory standard micas are compared with those of other laboratories on Tables XIII and XIV. Accuracy of the University of British Columbia potassium analyses is within 1 per cent. Accuracy of the University of British Columbia argon analyses is within approximately 3 per cent. The limits of error are therefore set at ± 4 per cent of the calculated age for samples containing less than 50 per cent atmospheric argon.

Table XI.—Potassium Analyses Precision

Sample No.	Number of Analyses	$\overline{X}$	S	Per Cent
Interlaboratory Standards				
GE2060	22	6.81%K	0.10	1.46
P207	5	8.61	0.04	0.46
Guichon Creek Batholith Samples				
K63-13	4	4.49	0.02	0.45
K63-156a	6	6.73	0.01	0.15
K63-223	4	5.77	0.02	0.35
K64-116a	4	5.24	0.04	0.76
K63-220	4	5.20	0.02	0.38
K63-37	4	6.42	0.03	0.48
K64-98-I	4	5.95	0.01	0.17
K63-115	4	5.90	0.07	1.19
K64-186a	4	1.87	0.01	0.53
K64-102	4	4.91	0.03	0.61
K64-101	4	5.16	0.05	0.97
K64-105-I	4	6.53	0.04	0.61
K63-171	4	6.59	0.06	0.91
K64-203	4	4.42	0.02	0.45
K64-17	4	3.59	0.02	0.56
K63-187	4	4.48	0.02	0.47
K63-231	4	5.86	0.07	1.19
	K—Analyses weighted average of precision=0.78			

Constants used in calculation of radiogenic ages (K/A method):—

$\lambda e = 0.58 \times 10^{-10}\ yr^{-1}$

$\lambda B = 4.72 \times 10^{-10}\ yr^{-1}$

$^{40}K/K = 1.181 \times 10^{-4}$

Table XII.—Argon Precision

Sample No.	Number of Samples	$\frac{Ar^{40} rad}{Ar\ total}$	Ar^{40} rad (10^{-5} cc STP/g)
Interlaboratory Standards			
P207 Muscovite	(6)		2.779 2.806 2.855 2.787 2.745 2.826 $\overline{X}$=2.800 DM±0.029=±1.04%
GE2060 Biotite	(3)		5.484 5.438 5.423 $\overline{X}$=5.448 DM±0.027=±0.49%
Guichon Creek Batholith			
K63-13	(2)		3.795 3.716 $\overline{X}$=3.755 DM±0.040=±1.07%
K64-156a	(2)		5.785 5.659 $\overline{X}$=5.722 DM±0.063=±1.10%
K63-220	(2)		4.358 4.325 $\overline{X}$=4.341 DM±0.017=±0.39%
K63-37	(2)		5.390 5.385 $\overline{X}$=5.387 DM±0.003=±0.06%
K64-98-I	(2)		4.817 4.919 $\overline{X}$=4.868 DM±0.051=±1.05%
K63-115	(2)		4.307 4.788 $\overline{X}$=4.547 DM±0.240=±5.28%
K64-102	(2)		4.055 4.077 $\overline{X}$=4.066 DM±0.011=±0.27%
K64-105-I	(2)		5.442 5.536 $\overline{X}$=5.489 DM±0.047=±0.86%
K64-203	(2)		3.759 3.750 $\overline{X}$=3.754 DM±0.005=±0.14%
K63-187	(2)		3.590 3.648 $\overline{X}$=3.669 DM±0.021=±0.57%
K63-114	(2)		1.389 1.433 $\overline{X}$=1.411 DM±0.022=±1.56%
			Weighted DM ±1.04%

Table XIII.—Interlaboratory Results

Standard No. and Mineral	Laboratory Analyst	Potassium	$\frac{A^{40} \text{ rad}}{\text{Total } A^{40}}$	A^{40} rad (in 10^{-5} cc STP/g)
GE2060—biotite	*Columbia:*			
	Erickson, G. P.	6.92% I	0.97	5.579
		6.91% I	0.90	5.628
	McDowell, F.	6.89% P		$\bar{X}$ 5.603
	Yale:			
	Armstrong, D.	6.81% P		
		6.82% P		
		$\bar{X}$ 6.87%		
	U.B.C.:			
	Northcote, Dirom, White, Harakal (20)	6.81%±0.10	0.95	5.484
			0.63	5.438
			0.83	5.423
			0.48	5.394
				$\bar{X}$ 5.435

K—U.B.C. differs from mean value of other labs by −0.06 or −0.87%.
A—U.B.C. differs from mean value of other labs by 2.99%.

P207—muscovite	Lanphere & Dalrymple, 1965	8.58%±0.12	......	2.840±.063
	U.B.C.:			
	Northcote, Dirom, Harakal	8.61%±0.04	0.77	2.742
			0.90	2.666
			0.66	2.722
				$\bar{X}$ 2.710

K—U.B.C. differs from mean value of other labs by +0.03 or +0.35%.
A—U.B.C. differs from mean value of other labs by −4.57%.

B3203—biotite	Summary, Hurley *et al.*, 1962	....	......	38.77±0.14
	U.B.C.:			
	Harakal, J. E.	....	0.72	38.37

A—U.B.C. differs from mean value of other labs by −1.03%.

Table XIV.—Summary of Accuracy of Potassium and Argon Analyses

Potassium: U.B.C. values within 0.62% (weighted average).

Argon: U.B.C. values within 3.10% (weighted average) of average values obtained from other laboratories.

E. Description of Biotite Used for K/A Age Determinations

K64-102 Witches Brook Phase, Variety B

Greater than 95 per cent biotite and chlorite with less than 15 per cent chloritic alteration (visual estimate).

Light brown/black, many grains mottled by silvery to light silvery-green chloritic alteration. Scattered grains of biotite, poikilitic, enclosing quartz and plagioclase. Few scattered grains of hornblende and light-green actinolite(?). Traces of iron oxide cementing several quartz grains together.

K63-171 Witches Brook Phase, Variety A

Ninety-eight per cent biotite and chlorite with less than 5 per cent chloritic alteration (visual estimate).

Mottled black and light golden brown, several grains showing silvery-green chloritic alteration. Few grains of biotite poikilitically enclosing plagioclase. Traces of iron-stained grains, presumably oxidized magnetite.

K64-116a Chataway Variety

Greater than 95 per cent biotite and chlorite with less than 10 per cent chloritic alteration (visual estimate).

Black, mottled by golden brown, scattered grains of silvery-green chloritic alteration.

K63-223 Guichon Variety

Approximately 95 per cent pure biotite, less than 5 per cent chloritic alteration (visual estimate).

Dark-golden brown/black, resinous lustre with a few grains of silvery-green chloritic alteration, trace of feldspar grains.

K64-203 Witches Brook Phase, Variety A

Approximately 98 per cent biotite and chlorite, 15 per cent chloritic alteration (visual estimate).

Medium to dark brown, many grains showing silvery-green chloritic alteration, few grains of quartz and feldspar.

K63-220 LeRoy Granodiorite

Greater than 95 per cent biotite and chlorite with about 10 per cent showing chloritic alteration (visual estimate).

Dark brown-grey, medium golden brown, scattered grains show mottling with silvery-green chloritic alteration. Less than 5 per cent poikilitic hornblende.

K63-115 Bethlehem Phase

Approximately 95 per cent biotite and chlorite, about 15 per cent chloritic alteration (visual estimate).

Black, mottled by golden brown and mottled by silvery-green chloritic alteration. Less than 5 per cent hornblende, trace of actinolite, few grains of plagioclase and quartz, trace of epidote.

K63-231 Bethsaida Phase

Approximately 95 per cent biotite and chlorite, of which 10 to 15 per cent is chlorite (visual estimate).

Dark golden brown and black biotite. Silvery-green chlorite grains. Trace of hornblende, scattered grains of plagioclase feldspar and quartz, some forming composite grains with biotite.

K63-13 Hybrid Phase

Approximately 95 per cent biotite showing abundant chloritic alteration (visual estimate).

Dark brown-grey, golden brown and black mottled by light brown and light silvery-brown chloritic alteration. Less than 5 per cent composite grains of quartz, plagioclase, and hornblende.

K64-101 LeRoy Granodiorite

Greater than 95 per cent biotite and chloritized biotite (visual estimate).

Black and dark grey-brown, mottled by light golden brown. Abundant light silvery-tan and silvery-brown chlorite. Less than 5 per cent composite grains of plagioclase, quartz, and hornblende.

K63-187 Bethsaida Phase

Greater than 95 per cent chloritized biotite, approximately 30 per cent chloritic alteration (visual estimate).

Dark brown-grey mottled by golden brown and by light silvery-green chloritic alteration. Few composite grains of chloritic biotite, quartz, plagioclase, and bornite.

K64-98-I Gump Lake Phase

Approximately 98 per cent chloritized biotite containing less than 10 per cent chlorite (visual estimate).

Dark brown-grey to black, mottled by light golden brown and tan. Slight mottling by light silvery green/tan chloritic alteration. Few grains of chlorite. Few grains of biotite poikilitically enclosing plagioclase.

K63-67 LeRoy Granodiorite

Approximately 98 per cent slightly chloritized biotite showing approximately 5 per cent chloritic alteration (visual estimate).

Black, glistening, lighter golden brown on thin flakes. Less than 2 per cent scattered grains of hornblende. Trace of sphene, trace of biotite grains poikilitically enclosing plagioclase.

K64-156a Hybrid Phase

Greater than 95 per cent unaltered biotite (visual estimate).

Black and dark golden brown, medium to light golden brown on thinner flakes, resinous lustre. Scattered composite grains containing hornblende, quartz, and plagioclase.

K64-105-I Witches Brook Phase, Variety B

Greater than 95 per cent chloritized biotite showing less than 10 per cent alteration (visual estimate).

Black, dark brown-grey, mottled by golden brown on thin edges. Less than 10 per cent chlorite. Scattered grains of amphibole (hornblende?) and composite grains containing quartz and plagioclase.

INDEX

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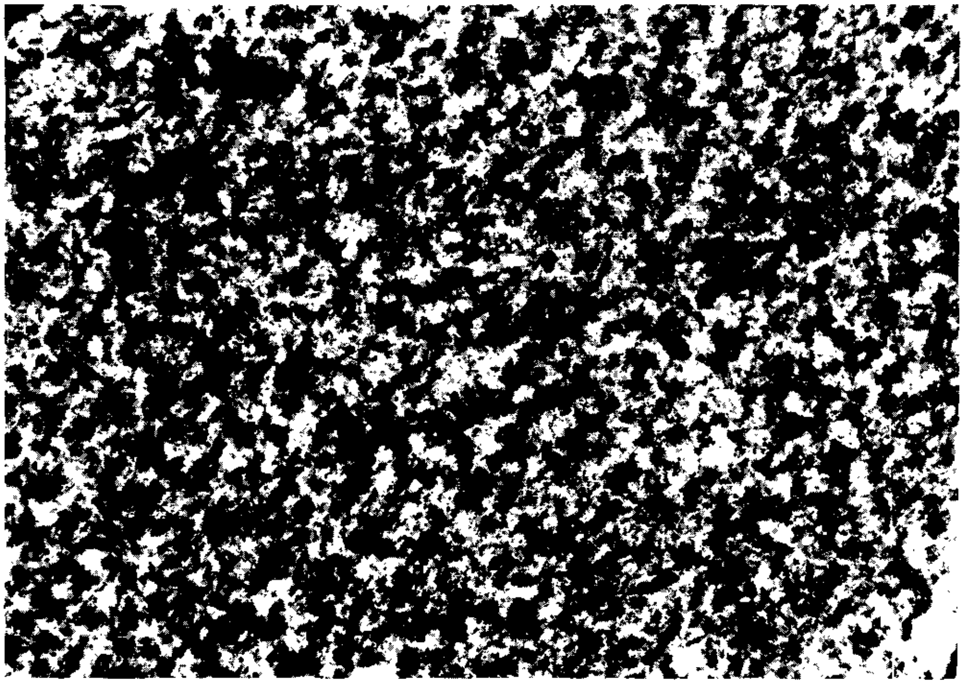


Plate I. Hybrid phase (twice natural scale).

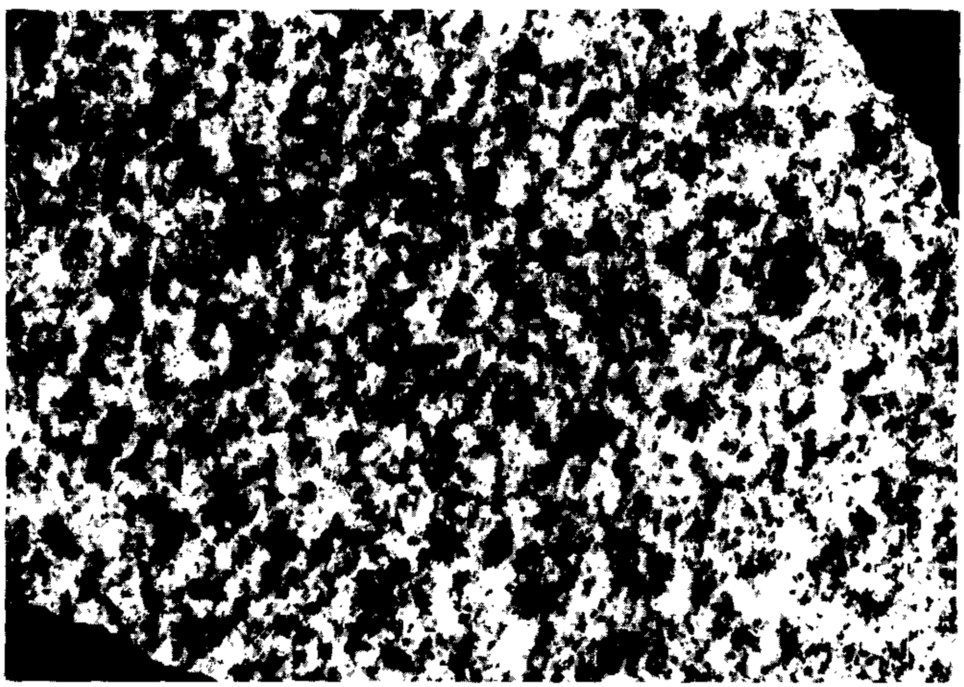


Plate II. Hybrid phase (twice natural scale).

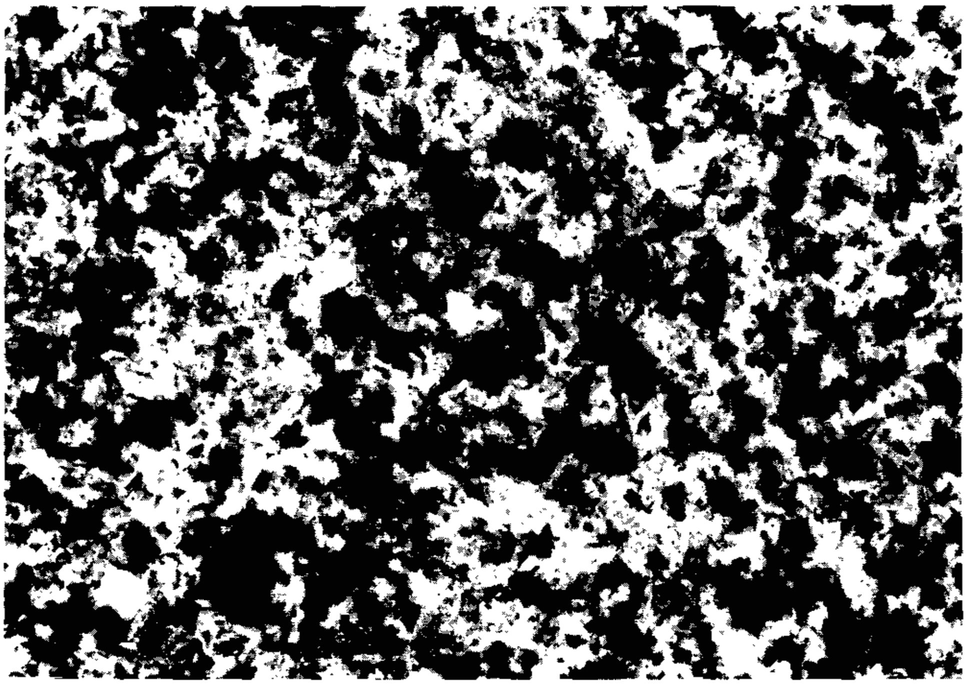


Plate III. Guichon variety (twice natural scale).

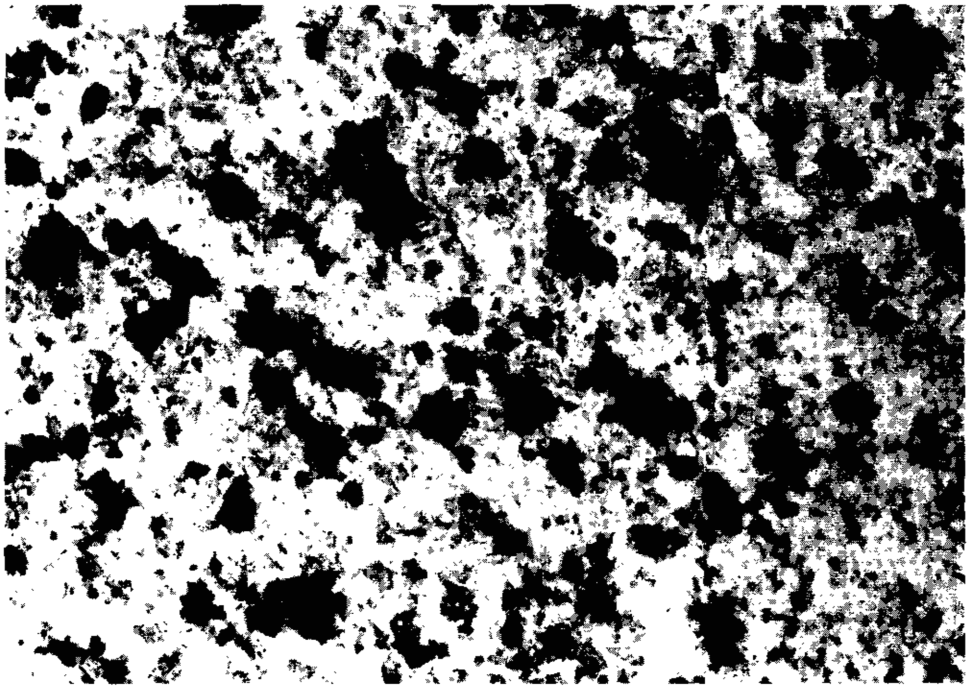


Plate IV. Chataway variety (twice natural scale).

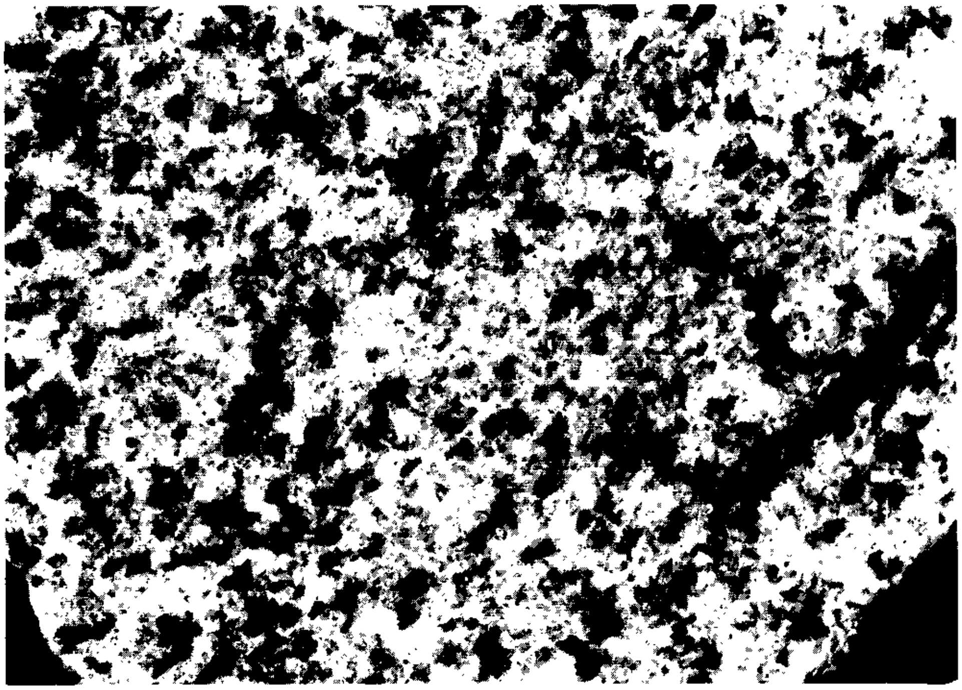


Plate V. LeRoy granodiorite (twice natural scale).

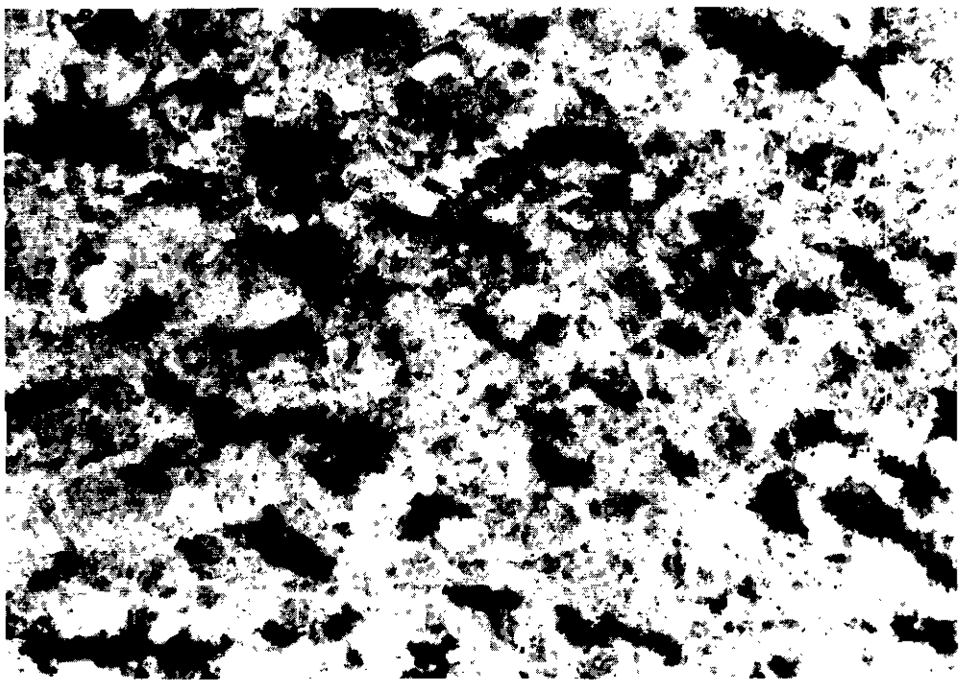


Plate VI. Gump Lake phase (twice natural scale).

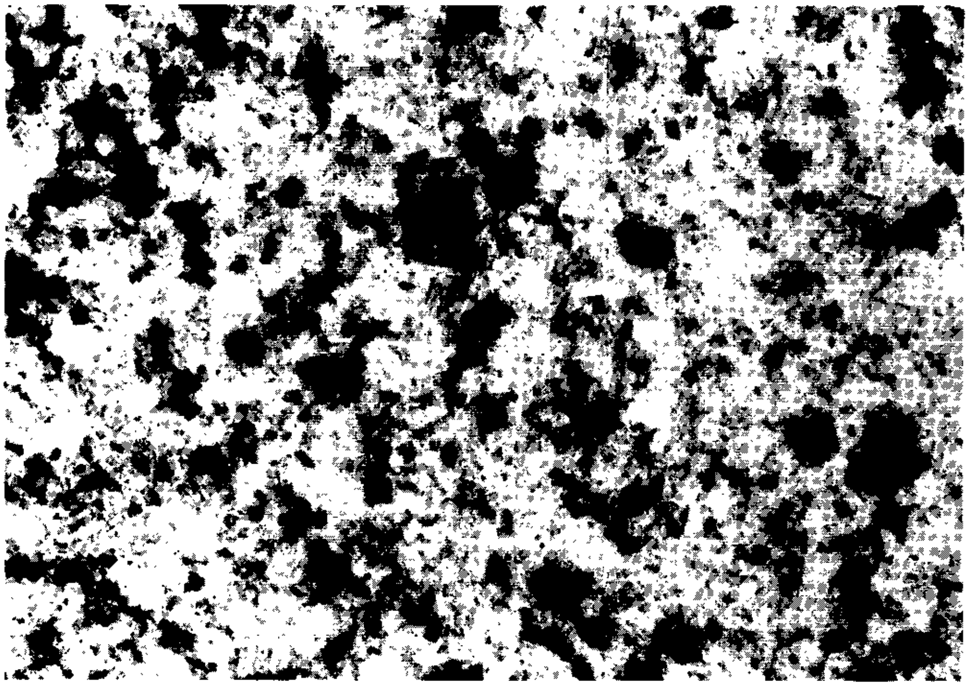


Plate VII. Bethlehem phase (twice natural scale).

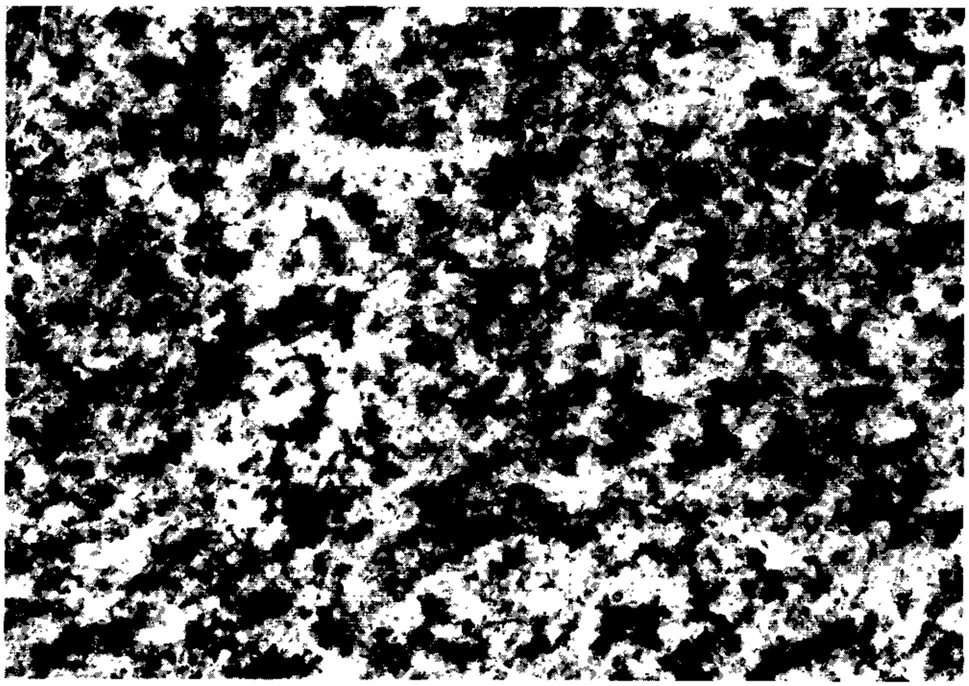


Plate VIII. Witches Brook Variety A (twice natural scale).

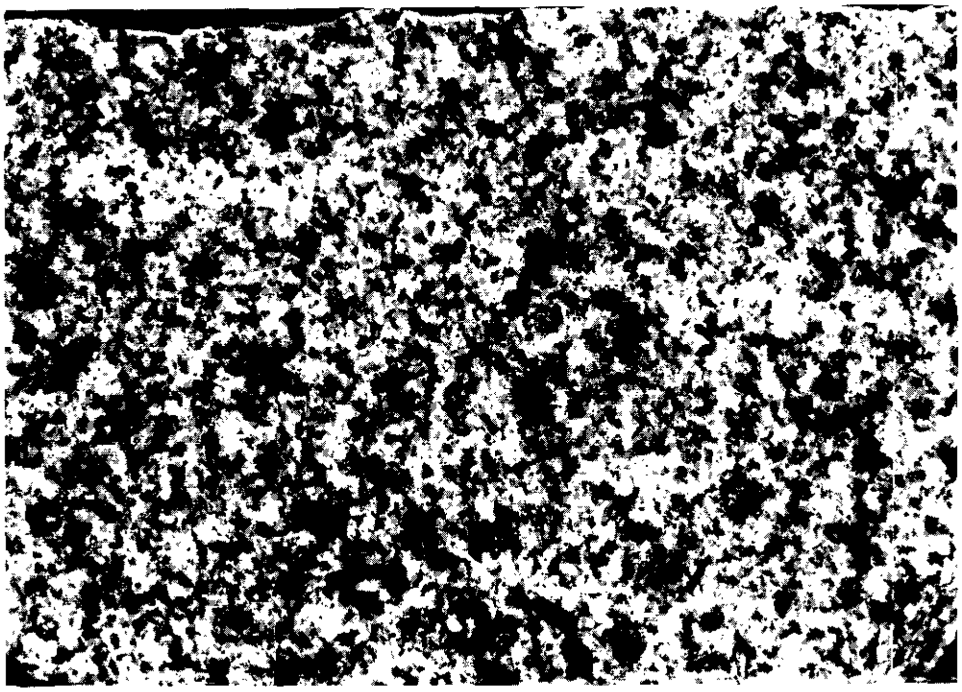


Plate IX. Witches Brook Variety B (twice natural scale).

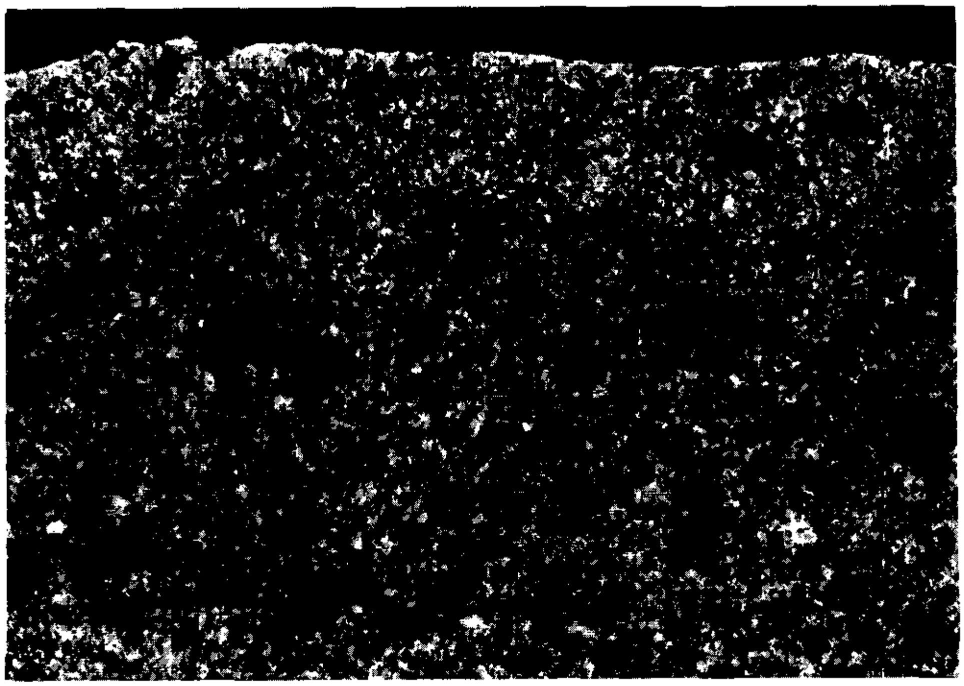


Plate X. Witches Brook Variety C (twice natural scale).

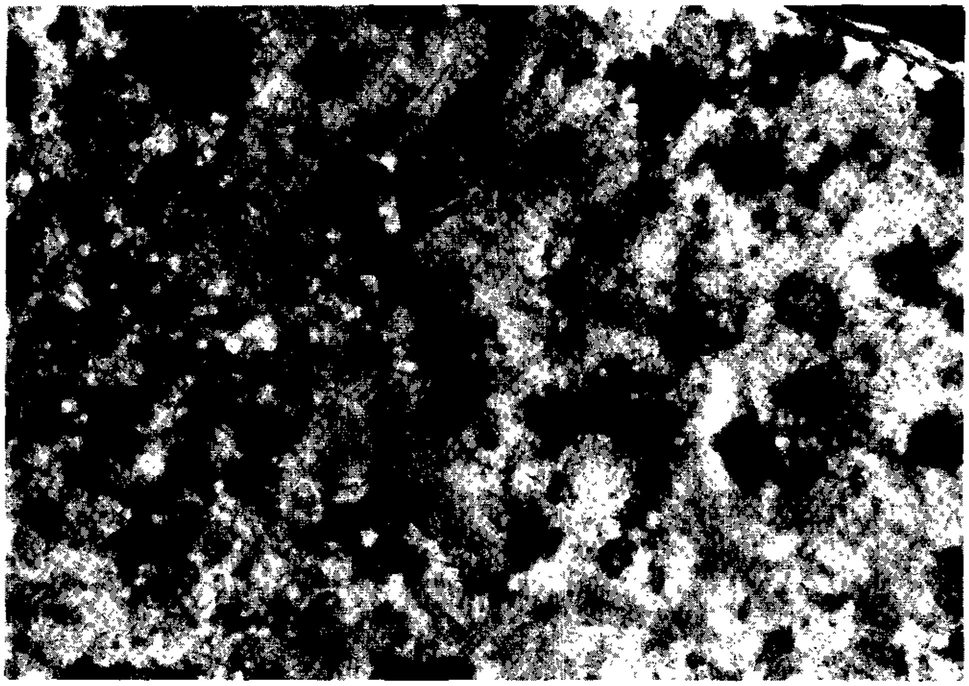


Plate XI. Bethsaida phase (twice natural scale).

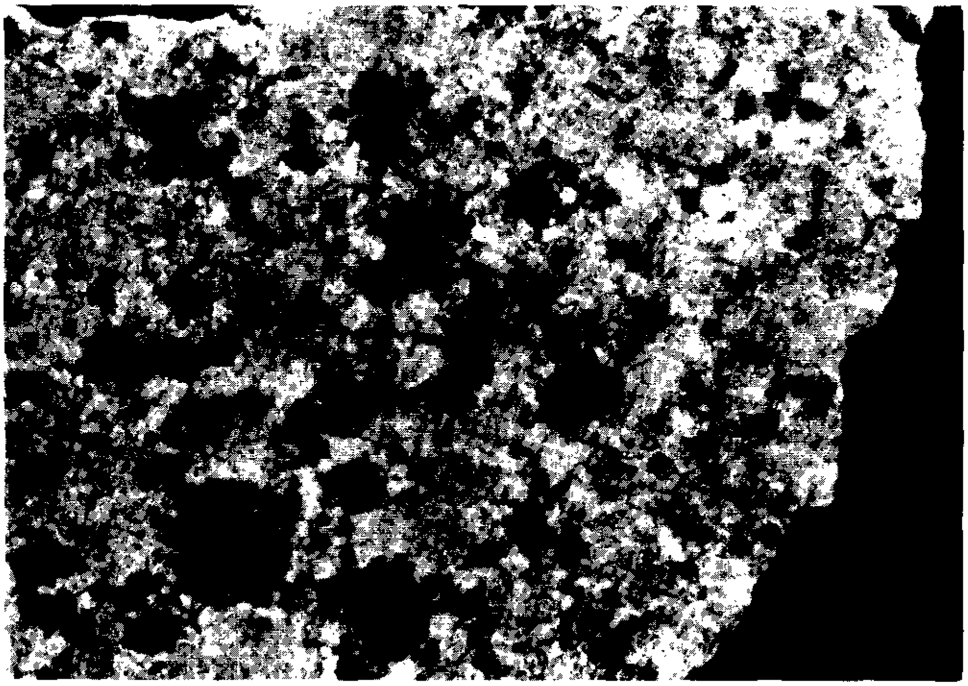
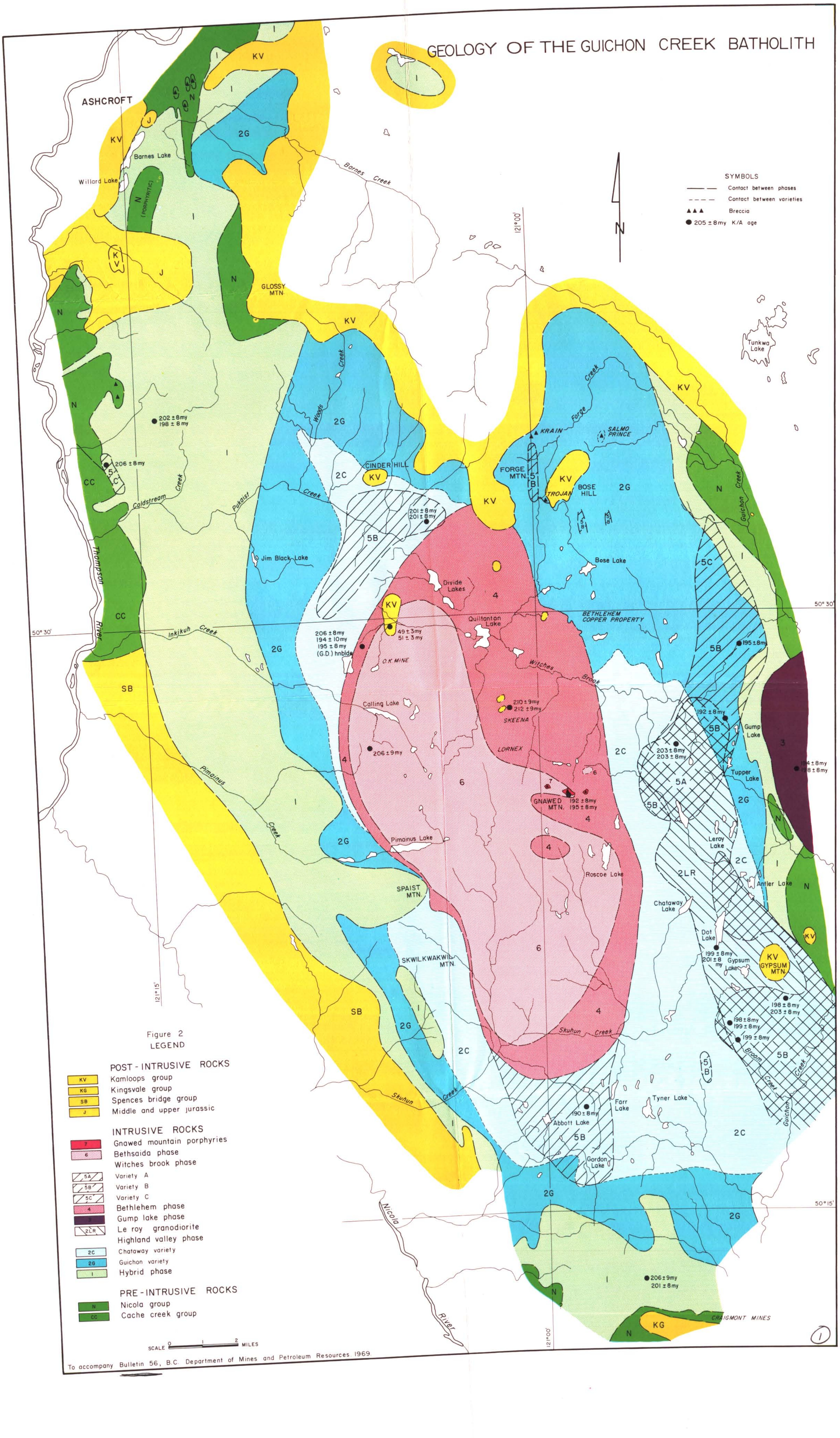
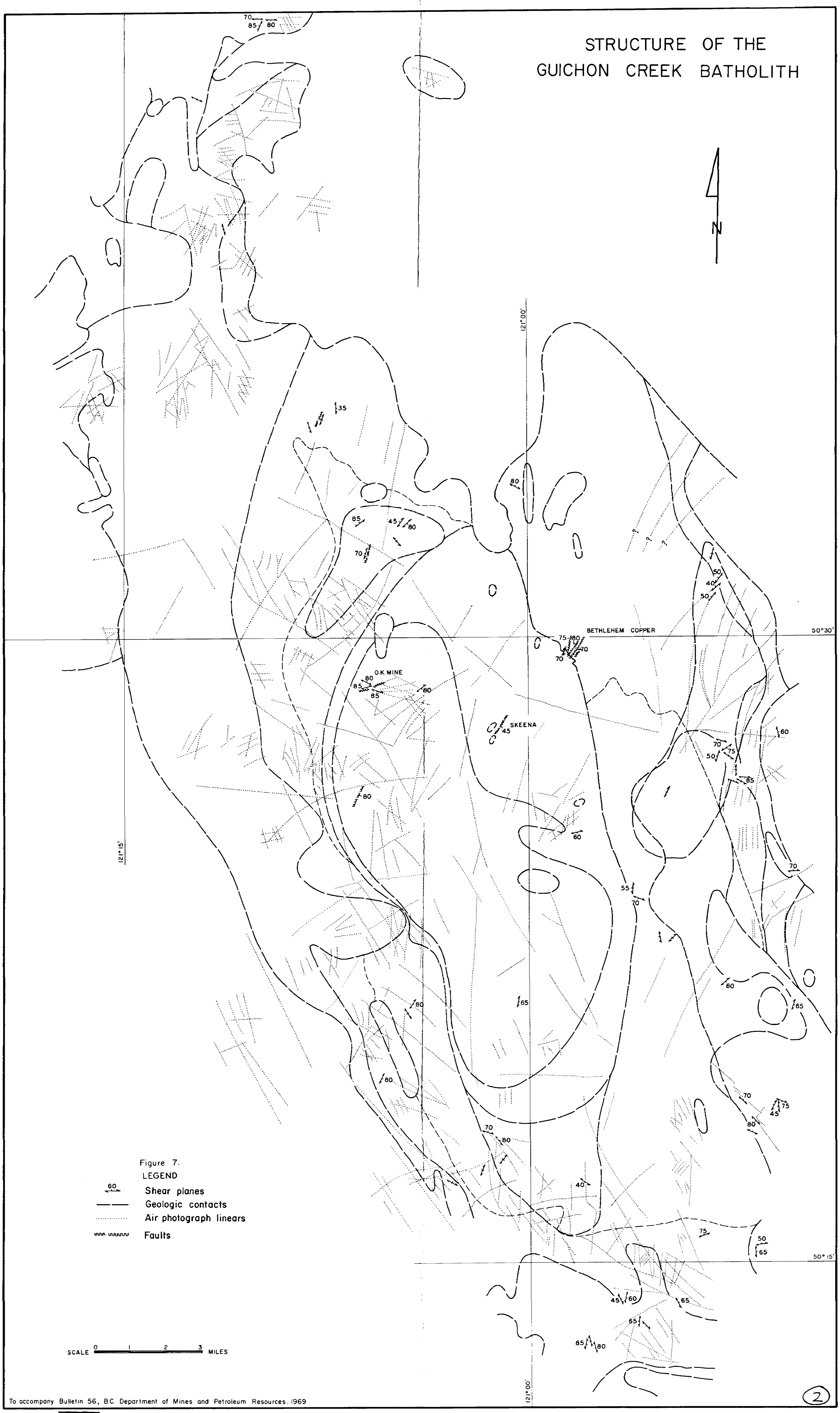


Plate XII. Bethsaida phase, Gnawed Mountain variety (twice natural scale).


GEOLOGY OF THE GUICHON CREEK BATHOLITH
SYMBOLS
Contact between phases
Contact between varieties
Breccia
205 ± 8my K/A age
Figure 2
LEGEND
POST - INTRUSIVE ROCKS
KV Kamloops group
KG Kingsvale group
SB Spences bridge group
J Middle and upper jurassic
INTRUSIVE ROCKS
7 Gnawed mountain porphyries
6 Bethsaida phase
Witches brook phase
5A Variety A
5B Variety B
5C Variety C
4 Bethlehem phase
3 Gump lake phase
2LR Le roy granodiorite
Highland valley phase
2C Chataway variety
2G Guichon variety
1 Hybrid phase
PRE - INTRUSIVE ROCKS
N Nicola group
CC Cache creek group
SCALE 0 1 2 MILES
To accompany Bulletin 56, B.C. Department of Mines and Petroleum Resources 1969
ASHCROFT
Barnes Lake
Willard Lake
GLOSSY MTN.
Barnes Creek
Tunkwa Lake
CINDER HILL
FORGE MTN.
BOSE HILL
KRAIN
SALMO PRINCE
TROJAN
Bose Lake
Jim Black Lake
Divide Lakes
Quiltanton Lake
BETHLEHEM COPPER PROPERTY
O.K. MINE
Witches Brook
SKEENA
LORNEX
Calling Lake
GNAWED MTN.
Pimainus Lake
Roscoe Lake
SPAIST MTN.
SKWILKWAKWIL MTN.
Skuhun Creek
Gump Lake
Tupper Lake
Leroy Lake
Antler Lake
Chataway Lake
Dot Lake
Gypsum Lake
GYPSUM MTN.
Farr Lake
Tyner Lake
Abbott Lake
Gordon Lake
Broom Creek
Guichon Creek
Thompson River
Nicola River
Inkikuh Creek
Coldstream Creek
Pukaist Creek
Pimainus Creek
Woods Creek
Forge Creek
CRAIGMONT MINES
50°30'
50°15'
121°00'
121°15'
1


STRUCTURE OF THE GUICHON CREEK BATHOLITH
N
Figure 7.
LEGEND
Shear planes
Geologic contacts
Air photograph linears
Faults
SCALE 0 1 2 3 MILES
BETHLEHEM COPPER
O.K. MINE
SKEENA
121°00'
121°15'
50°30'
50°15'
To accompany Bulletin 56, B.C. Department of Mines and Petroleum Resources. 1969
2