AN ABSTRACT OF THE THESIS OF

CLINTON DALE GILLESPIE for the MASTER OF SCIENCE
(Name) (Degree)

in GEOLOGY presented on May 26, 1969
(Major) (Date)

Title: GEOLOGY OF THE CENTRAL BOND CREEK AREA, NABESNA, ALASKA

Abstract approved: Redacted for privacy
Cyrus W. Field

The central Bond Creek area is on the north slope of the Wrangell Mountains approximately 15 miles east of Nabesna, Alaska.

The entire area is underlain by plutonic rocks of the Monte Cristo batholith of probable Jurassic age. Early members of this complex are hornblende diorite, quartz diorite, and granodiorite of plutonic origin. Later members are hypabyssal porphyries ranging in composition from andesite to rhyolite. These form numerous dikes and plugs. Intrusion breccias and intrusive explosion-breccias are associated with these rocks.

Most large faults trend northwest and are defined by dikes. These faults are possibly related to regional faulting and folding. Fractures are abundant in all rock units and are randomly oriented. Foliation is common only in the youngest of the intrusive rocks such as the andesite, dacite, and rhyolite porphyries.

Hydrothermal alteration consists of both the propylitic and potassic types. Propylitic alteration is characterized by the formation of "white mica," epidote, chlorite, and calcite. Potassic alteration is restricted to breccias and areas of intense fracturing. It is characterized by biotite and orthoclase in the intrusive explosion-breccia, and quartz, "white mica," and orthoclase in the intrusion breccias and areas of intense fracturing.

Sulfide mineralization is most abundant in zones of potassic alteration. Pyrite is the most common sulfide, but chalcopyrite is locally abundant. Molybdenite is restricted to an area of stockwork veining.

Geology of the Central Bond Creek Area, Nabesna, Alaska

by

Clinton Dale Gillespie

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

June 1970

APPROVED:

Redacted for privacy

Professor of Geology
in charge of major

Redacted for privacy

Chairman of the Department of Geology

Redacted for privacy

Dean of Graduate School

Date thesis is presented May 26, 1969

Typed by Donna L. Olson for Clinton Dale Gillespie

ACKNOWLEDGEMENTS

The writer is especially grateful to his major professor, Dr. C. W. Field, for advice, guidance, and manuscript criticism. Appreciation is also extended to Drs. P. T. Robinson and E. M. Taylor for advice and editing of the manuscript.

Thanks are due Dr. W. H. Taubeneck for helpful discussions of breccias and Mrs. James Peters for editing of the manuscript.

The writer would like to express his appreciation to Bear Creek Mining Company for financial assistance during the field work. Special thanks are extended to Mr. Dave Snyder for his sincere interest in the support of this thesis.

The writer is also grateful to his fiance, Annie Leighton, for her encouragement and assistance in preparation of the thesis.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

GEOLOGY OF THE CENTRAL BOND CREEK AREA, NABESNA, ALASKA

INTRODUCTION

Location and Accessibility

The thesis area is on the north slope of the Wrangell Mountains approximately 50 miles west of the Canadian border and ten miles south of the confluence of Bond Creek and the Nabesna River. The area lies between parallels 62° and 62°20' North Latitude and meridians 142°40' and 143° West Longitude. Nabesna, 15 miles to the west, is joined to the Alaska Highway System by an unimproved dirt road. The thesis area is accessible only by helicopter.

Climate and Vegetation

The climate of the Bond Creek area is similar to that elsewhere in Alaska but modified by altitude and mountainous topography. Data from the weather recording station at Gulkana, 75 miles to the west, lists an annual average temperature of 25.2°F with an average low of -11.1°F in January and an average high of 52.1°F in August. Precipitation averages only 13.48 inches annually.

Vegetation is scarce and consists of small mountain flowers, tundra grass, and infrequent bushes. It is restricted to bench-like

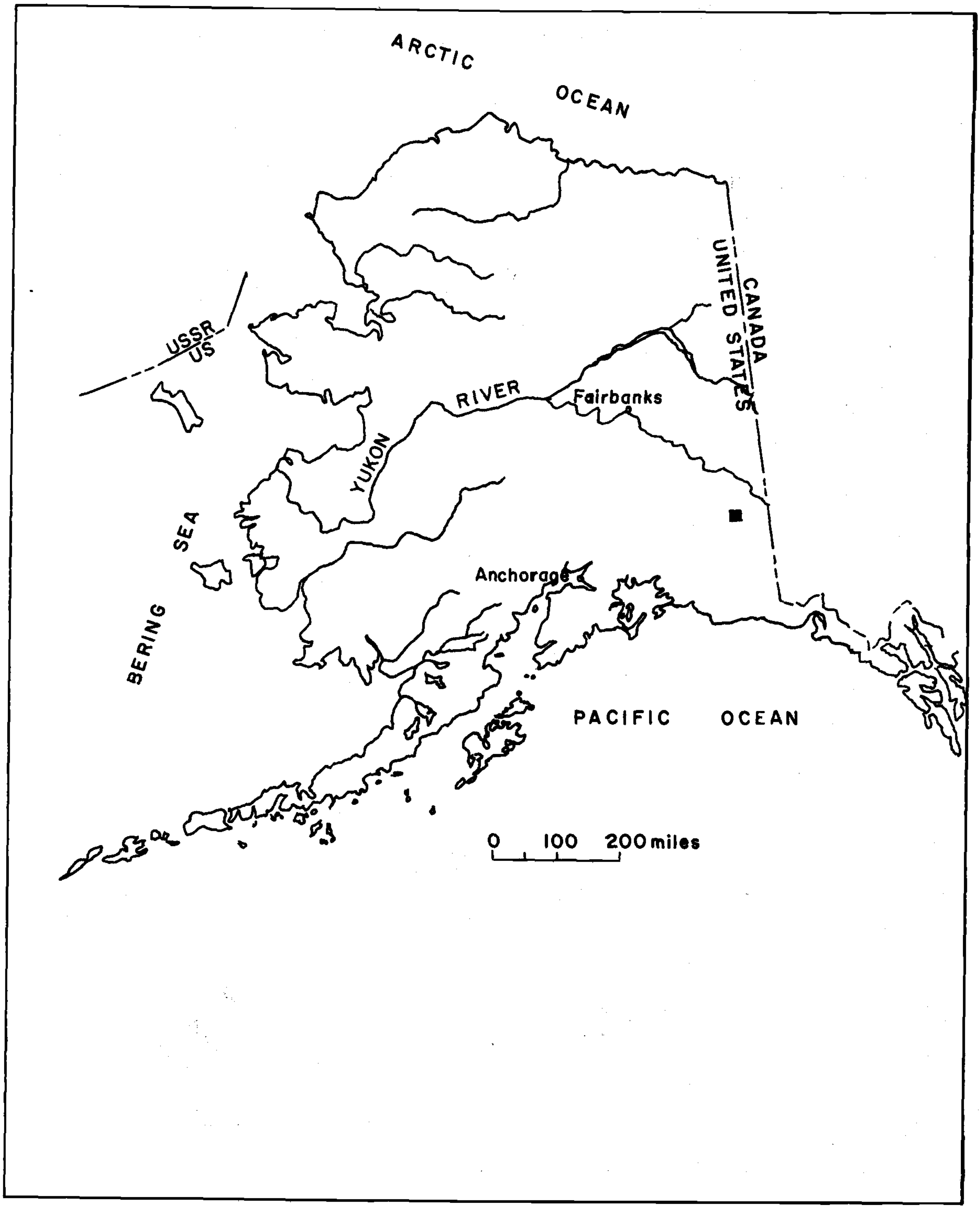


Figure 1. Index map of Alaska showing the thesis area as a black insert.

Figure 2. View of the central Bond Creek area. The thesis area is the central ridge bounded on the left by the Middle Fork and on the right by the West Fork of Bond Creek. Note the lateral moraines near the valley floors.

moraines between the valley floors and steep adjoining hill slopes.

Topography and Drainage

The thesis area is a steep ridge that noses out to the north at the confluence of the West and Middle forks of Bond Creek. The northwest-trending ridge has a total relief of 3,200 feet and ranges from 3,600 to 6,800 feet above sea level.

Recent glaciation is indicated by ridges of till along the valley walls up to 550 feet above the floors and by U-shaped valleys. The moraines are commonly obliterated by numerous talus streams.

The valley floors are flat and are underlain by gravel and boulders. Detritus-laden glacial streams continually shift their courses and deposit and redistribute the outwash. The volume of water in Bond Creek fluctuates widely in response to daily and seasonal temperature variations as well as to short term variations in precipitation. Drainage is perpendicular to the trend of the ridge and is largely obscured by talus streams.

Previous Work in the Area

The Nabesna-White River region was visited by Peters and Brooks in 1899 and by Schrader and Witherspoon in 1902. Moffit and Knopf, in 1908, examined the localities where copper and gold had been found previously. Their examination led them into the

Nabesna-White River region. The U.S. Geological Survey conducted these reconnaissance surveys but none reached the upper Bond Creek area.

Considerable work, undertaken in the Orange Hill area in 1946, led to a visit to the Bond Creek area by Chadwick in 1960. Reconnaissance geologic mapping in the Bond Creek area began in 1962 with detailed mapping in 1963 and 1964 by geologists of Bear Creek Mining Company. This work was done in the area immediately to the south of the thesis area. Wetherell (1967) visited the Bond Creek area and completed one geologic traverse within the thesis area.

Purpose and Methods of Investigation

The main purpose of this study was to produce a detailed geologic map. Igneous lithologies and their relationships to the localization and types of subsequent hydrothermal alteration were studied both in the field and in the laboratory.

Geologic mapping was done on enlarged aerial photographs at a scale of approximately 1: 6000. This was later transferred to topographic maps having a scale of 1: 4800. The field work was completed during the period June 11 to August 15, 1968.

Laboratory work involved petrographic studies of 100 thin sections and trace element analysis of two rocks. Modal analyses of representative samples were obtained with a mechanical stage and point counter. Traverses were made over the entire slide and 1,000 points were counted per slide. Rock color designations are in accord with Goddard, et al. (1948). The term "white mica" is used in lieu of a specific name for the phyllosilicate mineral that occurs as a common hydrothermal alteration product in the rocks of the thesis area. This phyllosilicate mineral is probably sericite, however, it cannot be differentiated from paragonite by optical means.

The classification of igneous rocks proposed by Travis (1955) is used in this thesis. The following table outlines the conventions used in naming porphyritic rocks:

Table 1. Proposed classification of porphyritic rocks. Modified from Travis (1955, p. 9).

Groundmass Texture	Percent Phenocrysts			
	Under 12	12-50	50-75	Over 75
Phaneritic	Diorite or Porphyritic diorite	Diorite porphyry	Diorite porphyry	Diorite
Aphanitic	Andesite or Porphyritic andesite	Andesite porphyry	Diorite porphyry	Diorite

REGIONAL SETTING

The oldest rocks exposed in the region are thick lava flows of Permian age. These are overlain by a series of clastic sedimentary rocks, with interbedded flows and limestones also of Permian age. These rocks crop out immediately south of the thesis area. They are not within it because of extensive erosion.

The sedimentary and volcanic rocks have been intruded by a complex batholith of diorite composition. This is the Monte Cristo batholith described first by Mendenhall and Schrader (1903) and later by Wayland (1943). Schrader believed this batholith to be pre-Permian in age, but Moffit (1910) suggested a Jurassic age. This is probably correct because it lies along the eastward extension of the Talkeetna geanticline and the Matanuska geosyncline of probable Jurassic age (Reed and Lanphere, 1969).

A quartz diorite phase of the Monte Cristo batholith occurs near its south contact and is the dominant rock type of the thesis area.

IGNEOUS ROCKS

Rocks of the thesis area consist chiefly of quartz diorites and silicic porphyries of the Monte Cristo Batholith. The individual members are lithologically distinctive but were probably derived from the same parent magma.

The earlier members of the plutonic complex are quantitatively more extensive in areal distribution and are slightly more mafic in composition than the later members. They are medium-grained and hypidiomorphic-granular in texture. The later intrusives, generally smaller in size and more silicic in composition, occur as dikes and plugs that have been emplaced along zones of structural weakness. These rocks are porphyritic and the phenocrysts exhibit late magmatic reactions, magmatic resorption, and zonation suggesting hypabyssal emplacement.

Contacts between the intrusive rocks are irregular and undulatory. They are variably defined between similar units and may range from transitional to sharp. Locally, intrusion breccias occur along normally transitional or sharp contact zones. Nearly all lithologies have been altered by hydrothermal fluids. The effects of hydrothermal alteration differ with the lithology and structure.

Hornblende Diorite

Distribution and Character

A medium-grained hornblende-rich diorite is exposed in the southwestern part of the thesis area. The rock is dark colored (5 PB 3/2) but grades into more leucocratic phases (5 Y 6/1) near contacts with the younger quartz diorite. Light colored dikelets are found near the contact with quartz diorite and are believed to be genetically related to the quartz diorite.

Lithology and Petrography

The hornblende diorite has a medium-grained hypidiomorphic-granular texture. The main constituents are plagioclase, hornblende, and orthoclase as given in the modal analysis (Table 2). Quartz may comprise as much as ten percent of the rock, but the average is less than two percent. Orthoclase, which is fresh and associated with quartz near fractures, is probably of secondary origin. Plagioclase is andesine (An_{41}). It is mottled white near hairline fractures because of selective bleaching and hydrothermal alteration and is generally altered to a shredded "white mica." Less abundant alteration products are calcite, kaolinite, epidote, and chlorite. Albite twin lamellae are commonly bent which indicate that the hornblende diorite has been subjected to post-consolidation

Table 2. Modal analysis of hornblende diorite sample A-3.[1]

Mineral	Percent
Quartz	3.6
Orthoclase	0.1
Plagioclase	55.1
Hornblende	31.6
Opaques	3.4
Apatite	0.1
Zircon	0.1
Sphene	0.2
Chlorite	3.9
Epidote	1.6
"White mica"	0.3
Total	100.0

[1](6,700E, 9,700S)

deformation possibly associated with intrusion of the quartz diorite. Primary biotite has been completely replaced by lavender colored chlorite and can be recognized by relic cleavage traces. Sphene and pleochloric epidote form linear aggregates along the cleavage traces of the chloritized biotite. Hornblende occurs both as large twinned subhedra that range from 0.5 to 4mm in length and as aggregates or clusters of anhedra that average 1mm in diameter and lack optical continuity because of their random extinction. The hornblende aggregates are common to all parts of the intrusion. The two distinct occurrences suggest that hornblende was stable over a long and interrupted sequence of crystallization. Late stage crystallization of hornblende was apparently more rapid and at multiple, closely spaced loci. These aggregates commonly are superimposed upon earlier and larger crystals. Alteration products of hornblende crystals are chlorite, calcite, epidote, and opaque iron oxides.

Disseminated pyrite and magnetite are the most abundant accessory minerals. Minor amounts of chalcopyrite, zircon, sphene, and apatite are present.

Age (Relative)

The hornblende diorite is believed to be the oldest unit in the thesis area despite the fact that it was observed to be intruded only by quartz diorite. The contact between these units is normally gradational. However, near the West Fork of Bond Creek (5,000E, 9,800S) the contact is marked by an intrusion breccia that contains large blocks of hornblende diorite engulfed in a matrix of quartz diorite. These blocks have distinctive reaction rims as much as three inches wide.

Quartz Diorite

Distribution and Character

A quartz-rich diorite is quantitatively the most abundant rock type in the thesis area. It is the host for all later plutonic intrusive phases. "Typical" exposures of this rock can be found along the ridge crest (6,400E, 7,800S). Intrusion by later plutonic phases caused multiple episodes of brecciation and hydrothermal alteration producing a great deal of variability in the unit. Outcrops are generally resistant but may be locally subdued. The quartz diorite is typically light olive-grey (5 Y 6/1) but may be yellowish-orange (10 YR 6/6) due to alteration of pyrite or yellowish-grey (5 Y 8/1) where quartz, "white mica," and gypsum are abundant.

Lithology and Petrography

The quartz diorite is a medium-grained hypidiomorphic-granular rock comprised of quartz, plagioclase, hornblende, and

Figure 3. Typical exposure of quartz diorite. Note the intense fracturing. Relative scale indicated by Dall sheep at base of outcrop.

chloritized biotite (Table 7). Quartz is present as interstitial grains and as fracture fillings. Dust trails formed by minute, unidentifiable particles are common in many crystals. Primary orthoclase occurs as anhedral crystals that envelop the other minerals. Secondary orthoclase is always fresh, pink, and localized along hairline fractures or as granular aggregates associated with quartz. Andesine crystals (An_{36-40}) are euhedral to subhedral in shape and average 3mm in length. These crystals have been partly altered to "white mica." Occasionally, the crystals are completely replaced and can be identified only by the "typical" feldspar shape. Epidote, chlorite, calcite, and kaolinite are other less abundant alteration products of plagioclase feldspar. Most of the primary biotite has been replaced by chlorite and lesser amounts of sphene and epidote. Dark green hornblende is the dominant mafic mineral. Individual crystals typically have ragged terminations due to late magmatic reactions. Pyroxene cores, described by Wilson (1964), were not found by the writer. Chlorite, that selectively replaces the interior of the hornblende crystals, is the most common alteration product.

Accessory minerals are pyrite, magnetite, zircon, sphene, and apatite. Alteration products of these constituents are limonite, hematite, and leucoxene.

Age (Relative)

Quartz diorite is intruded by all units within the thesis area except hornblende diorite. Contacts with intruding units are generally sharp or are marked by intrusion breccias.

Granodiorite

Distribution and Character

Dikes of granodiorite with prominant "quartz eyes," occur in the northern part of the thesis area (3,800E, 4,300S). Two isolated outcrops were also found in the center of the mapped area (5,200E, 6,300S) and on the West Fork (400E, 1,000S). The granodiorite is similar to rocks exposed along the East Fork of Bond Creek that were referred to as "quartz-eye" granite by Moerlein (1963) because of its large, rounded quartz phenocrysts. Dikes of this unit are light in color (5B 9/1), up to 150 feet wide, and irregular in shape.

Lithology and Petrography

The granodiorite is a locally porphyritic hypidiomorphic-granular rock composed chiefly of quartz, 30 percent; orthoclase, 10 percent; plagioclase, 50 percent; and mafic minerals, 10 percent. Rocks included in this unit range from granite to sodic quartz diorite in composition. The average grain size is 3 mm but some crystals range up to 8mm in diameter. Quartz forms large, fresh crystals that are often rounded and embayed. Orthoclase is present as subhedral crystals 1 to 5mm in diameter that are partly altered to kaolinite, "white mica," and calcite. Andesine (An_{30-32}) forms subhedral laths 1 to 8mm in length. It is commonly altered to "white mica," kaolinite, and calcite. The original mafic minerals have been replaced entirely by irregular aggregates and subhedral pseudomorphs of chlorite. Granular opaque iron oxides formed concomitantly with chloritization of the mafic minerals.

Locally, aphanitic aggregates of quartz, plagioclase, and orthoclase may make up as much as 15 percent of the rock. These aggregates extend irregularly between the larger crystals and are probably a chilled phase formed when only a small fraction of the granodiorite magma was still liquid.

Accessory constituents are pyrite, magnetite, sphene, zircon, and apatite.

Age (Relative)

The granodiorite was described by Moerlein (1964) as younger than the quartz diorite, but older than the quartz diorite porphyry. Contact relationships in the thesis area are limited to those with the quartz diorite, biotite diorite porphyry, hornblende andesite porphyry, needle andesite porphyry, and undifferentiated dikes. These contacts support the relative age of the granodiorite as originally interpreted by Moerlein.

Quartz Diorite Porphyry

Distribution and Character

A porphyritic quartz diorite was recognized and described by Moerlein (1964). In conformance with the classification used in this report, this unit is termed a quartz diorite porphyry by this author.

The quartz diorite porphyry is confined to the lower slope and creek bottom on the eastern flank of the ridge between 7,300E and 10,800E. As outcrops of this rock unit do not continue over the ridge, the observed distribution probably represents the truncated apex of this intrusion. Outcrops of quartz diorite porphyry are poorer than those of the nearby and more resistant quartz diorite because of intense fracturing. The outcrops are often stained red and yellow and are locally covered with grus. The rock has a characteristic "salt and pepper" appearance caused by green colored mafic minerals and white feldspar.

Lithology and Petrography

The porphyritic texture of this unit is not readily discernable in hand specimens because phenocrysts predominate and there is relatively little difference in the size and color between phenocrysts and groundmass. Phenocrysts average 0.5mm in diameter whereas the groundmass crystals average 0.1mm in diameter. The margins of the phenocrysts are granulated and embayed by the groundmass. Phenocrysts of quartz, plagioclase, and biotite comprise 60 to 70 percent of the total rock. A modal analysis for this unit is given in Table 3. Quartz makes up as much as 30 percent of this rock. It occurs as rounded and embayed anhedra. Andesine (An_{44}) forms euhedral to subhedral phenocrysts that exhibit normal zoning. Alteration to "white mica" is common along minute fractures within the crystals. Biotite is the only ferromagnesian mineral and it occurs as fine-grained aggregates of brown stubby sheets.

The groundmass is made up chiefly of anhedral crystals of quartz and plagioclase but orthoclase is present in quantities as great as three percent. Fibrous brown to green biotite is ubiquitous. Epidote, chlorite, and calcite are alteration products that commonly are present as aggregates in the groundmass.

Accessory minerals include pyrite, magnetite, apatite, sphene, and zircon.

Age (Relative)

Intrusion breccias, consisting of fragments of quartz diorite in

Table 3. Modal analysis of quartz diorite porphyry (sample CG 6-29-68-10).[1]

Mineral	Percent
Quartz	24.1
Orthoclase	0.5
Plagioclase	59.7
Biotite	10.9
Opaques	1.3
Zircon	0.2
Chlorite	1.3
Calcite	0.9
Epidote	0.7
"White mica"	0.4
Total	100.0

[1](9,400E, 8,500S)

a quartz diorite porphyry matrix, are characteristic of the contact between the quartz diorite and quartz diorite porphyry units. The quartz diorite porphyry is intruded by dikes of hornblende diorite porphyry, biotite diorite porphyry, hornblende andesite porphyry, and intrusive explosion-breccia.

Andesite Porphyry

Distribution and Character

Distinctive, although quantitatively minor, intrusions of porphyritic andesite crop out on both flanks of the ridge as isolated and discontinuous dikes (4,600E, 7,400S; 6,800E, 9,600S; and 5,600E, 3,200S). The andesite porphyry is very light in color (5 Y 7/1) and is distinguished by light colored talus "streamers."

Lithology and Petrography

The andesite is porphyritic with numerous phenocrysts of plagioclase and hornblende set in a pilotaxitic groundmass of the same composition (Table 4). Two sizes of phenocrysts exist; small phenocrysts, 1mm in length, and microphenocrysts, 0.1mm in length. The larger phenocrysts comprise 15.2 percent of the total rock and consist of quartz, plagioclase, and hornblende. Micro-phenocrysts comprise 26 percent of the andesite porphyry and are

Table 4. Modal analysis of andesite porphyry (sample CG 8-4-68-1).[1]

Mineral	Percent
Quartz Phenocrysts	0.2
Plagioclase Phenocrysts	33.3
Hornblende Phenocrysts	7.7
Opaques	3.0
Zircon	0.2
Apatite	0.1
Biotite	3.0
Calcite	1.0
"White mica"	0.1
Groundmass[2]	51.4
Total	100.0

[1](6,300E, 8,800S)

[2]Groundmass is composed of microcrystalline quartz and feldspar

exclusively plagioclase. Quartz phenocrysts are rare. Plagioclase feldspar occurs as phenocrysts of calcic andesine (An_{48-50}) and micro-phenocrysts of labradorite (An_{50-60}). The larger phenocrysts commonly exhibit normal zoning. Euhedral hornblende crystals average 1mm in length. These are enveloped by halos of green biotite and fine granular iron oxides presumably formed by deuteric alteration. Later hydrothermal alteration of the hornblende crystals formed a brownish aggregate of iron-stained clay, granular iron oxides, calcite, and chlorite.

The groundmass is composed of microcrystalline quartz, plagioclase, alkali feldspar, and biotite of possible deuteric origin.

Accessory minerals include magnetite, pyrite, apatite, and zircon.

Age (Relative)

The relative age of the andesite porphyry is unknown. This unit intrudes only the quartz diorite, however, rock fragments of the andesite porphyry are found in the intrusive explosion-breccia. Therefore, emplacement of the porphyry occurred after intrusion of quartz diorite and before formation of the intrusive explosion-breccia.

Hornblende Diorite Porphyry

Distribution and Character

This porphyritic diorite forms light colored (5 B 7/1) dikes and plugs that are restricted to the east side of the ridge. The most typical exposure is in the southeastern part of the thesis area (7,000E, 7,000S). Columnar jointing, modified by a longitudinal set of joints, is present in most outcrops.

Lithology and Petrography

Phenocrysts of quartz, plagioclase, biotite, and hornblende average 2mm in diameter and comprise 48 to 60 percent of this rock type. Fresh quartz is rounded and embayed. Andesine laths (An_{35}) are commonly broken and rounded by late magmatic resorption. A few crystals are zoned. Primary biotite, up to 2mm in diameter, is less abundant than the hydrothermal variety. Primary biotite is brownish in color and has been magmatically resorbed whereas hydrothermal biotite is greenish in color and euhedral in shape. Subhedral hornblende crystals average 1mm in length and commonly are altered to biotite and chlorite and lesser "white mica" and calcite.

The groundmass is composed principally of microgranular quartz, plagioclase, and alkali feldspar. Percentages of the

Table 5. Modal analysis of hornblende diorite porphyry (sample CG 8-10-68-1).[1]

Mineral	Percent
Quartz Phenocrysts	6.0
Plagioclase Phenocrysts	43.7
Hornblende Phenocrysts	9.0
Opaques	2.3
Zircon	0.1
Chlorite	1.2
Epidote	1.0
Biotite	0.7
Calcite	0.5
Groundmass[2]	35.5
Total	100.0

[1] (7,800E, 6,900S)

[2] Groundmass consists of microgranular quartz, plagioclase, alkali feldspar, opaques, and hydrothermal biotite

individual constituents and the compositions of the alkali feldspar could not be determined because of the small grain size and absence of distinguishing crystal shapes. The presence of alkali feldspar is suggested by the low relief of the groundmass and potassium cobaltinitrate stain. Hydrothermal biotite, pyrite, chlorite, epidote, calcite, "white mica," and sphene are abundantly distributed throughout the groundmass.

Age (Relative)

The hornblende diorite porphyry is older than the intrusive explosion-breccia, as indicated by the presence of fragments of this porphyry in the breccia. A dike of hornblende diorite porphyry has intruded the quartz diorite porphyry (7,800E, 4,800S) indicating that it is younger than the quartz diorite porphyry.

Biotite Diorite Porphyry

Distribution and Character

Exposures of biotite diorite porphyry are confined to the eastern flank of the ridge. This intrusive phase crops out chiefly as dikes in the southeastern part of the thesis area (9,600E, 9,600S) and as plugs in the northeastern part of the thesis area (4,800E, 2,800S).

The biotite diorite porphyry is similar to the hornblende diorite porphyry but is characterized by a darker color (5 PB 3/2) and a predominance of biotite over hornblende.

Lithology and Petrography

Phenocrysts of quartz, plagioclase, and biotite comprise 50 to 55 percent of the biotite diorite porphyry (Table 6). They are commonly broken, rounded and set in a microcrystalline groundmass that suggests violent emplacement at hypabyssal depths. Quartz crystals are normally embayed and rounded. Andesine (An_{40}) crystals commonly display normal zoning. Brown biotite may attain a maximum length of 5mm and is characteristically embayed, and altered to fine-grained secondary chlorite and biotite with lesser amounts of sphene and epidote. Hornblende crystals are typically replaced by fibrous aggregates of green hydrothermal biotite.

Microcrystalline quartz, plagioclase, and orthoclase comprise the light colored constituents of the groundmass. Orthoclase is also present as fracture fillings of the plagioclase phenocrysts. Primary disseminated opaques and brown biotite as well as secondary iron oxides and green biotite constitute approximately 30 percent of the groundmass. These minerals collectively are responsible for the dark color of the biotite diorite porphyry.

Accessory minerals are opaque iron oxides, zircon, sphene,

Table 6. Modal analysis of biotite diorite porphyry (sample CG 7-6-68-2).[1]

Mineral	Percent
Quartz Phenocrysts	2.7
Plagioclase Phenocrysts	34.1
Biotite Phenocrysts[2]	14.0
Hornblende Phenocrysts	0.1
Opaques	1.6
Zircon	0.2
Epidote	0.5
Chlorite	0.3
Calcite	0.1
Groundmass[3]	46.4
Total	100.0

[1] (7,300E, 6,900S)

[2] Hydrothermal biotite aggregates compose 12 percent of these phenocrysts

[3] Groundmass consists of microcrystalline quartz, plagioclase, orthoclase, opaques, and primary and secondary biotite

and apatite.

Age (Relative)

The biotite diorite porphyry intrudes hornblende diorite, quartz diorite, granodiorite, quartz diorite porphyry, hornblende diorite porphyry, and intrusive explosion-breccia. It is intruded by hornblende andesite porphyry, needle andesite porphyry, and rhyolite porphyry.

Hornblende Andesite Porphyry

Distribution and Character

The largest exposures of a hornblende-rich porphyritic andesite crops out on both the west flank (7,800E, 8,000S) and the east flank (2,000E, 6,700S) of the ridge. Columnar joints and resistant outcrops characterize this rock type. Dikes of this unit range from 3 to 150 feet in width and are light grey (5 B 7/1) to dark grey (5 PB 3/2) in color.

Lithology and Petrography

Phenocrysts of quartz, plagioclase, biotite, and hornblende make up 30 to 40 percent of the rock. Quartz crystals, 0.5 to 2mm in diameter, constitute 2 to 10 percent of the total phenocrysts.

Figure 4. Hornblende andesite porphyry dike intruding quartz diorite. Yellow color of the quartz diorite is due to oxidation of pyrite.

They are embayed and rounded. Euhedral crystals of plagioclase feldspar make up 65 to 75 percent of the total phenocrysts. These phenocrysts have been altered predominantly to calcite and solution of these calcite-replaced phenocrysts forms pock-marked surfaces in outcrop. Biotite, 5 to 10 percent of the phenocrysts, is extensively altered to chlorite and fine granular iron oxide. Individual plates of altered biotite are separated by dusty calcite that has entered along the cleavage planes, spread outward, and pushed the biotite flakes apart. Hornblende crystals that average 1mm in length make up 15 to 20 percent of the phenocrysts. The margins of many of these phenocrysts are replaced by a dark green, fibrous biotite that is believed to be of deuteric origin. Chlorite, calcite, and "white mica" are hydrothermal alteration products of hornblende.

The original mineral constituents of the microcrystalline groundmass have been largely destroyed by subsequent alteration. Typical alteration products include fine-grained granular iron oxide, calcite, chlorite, epidote, kaolinite, "white mica," sphene, and leucoxene. These minerals also fill polygonal micro-fractures or "cooling cracks" that are common in this unit.

Accessory minerals consist of apatite, zircon, sphene, pyrite, and magnetite.

Age (Relative)

Dikes of this unit intrude hornblende diorite, quartz diorite, granodiorite, quartz diorite porphyry, hornblende diorite porphyry, intrusive explosion-breccia, and biotite diorite porphyry. The hornblende andesite porphyry is in turn intruded by needle andesite porphyry and rhyolite porphyry.

Undifferentiated Dikes

Distribution and Character

Dikes of varying age and composition that could not be categorized into any of the previously described units were mapped as undifferentiated dikes. The largest exposures of these rocks occurs in the east-central part (6,600E, 6,000S) of the thesis area. The northwest trend of the dikes suggests a structural control. A dusky blue (5 PB 3/2) color and intense hydrothermal alteration characterize these rock types.

Lithology and Petrography

The undifferentiated dikes are normally porphyritic with phenocrysts (20 to 40 percent of the total rock) of altered plagioclase feldspar, pseudomorphs of chlorite that replace ferromagnesian minerals, and fresh quartz.

The bulk of the groundmass consists of microcrystalline quartz, "white mica," calcite, chlorite, epidote, biotite, and iron-stained clays.

Accessory minerals include pyrite, magnetite, sphene, zircon, and apatite.

Age (Relative)

Rocks of these dikes are of several different ages and probably represent extremely altered phases of more than one intrusive lithology. The relative ages of these dikes range from post-quartz diorite porphyry to pre-dacite porphyry.

Dacite Porphyry

Distribution and Character

An altered, silicic plug crops out at the ridge crest in the central part of the thesis area (5,300E, 6,000S). The single exposure of this porphyry is circular in shape and is approximately 180,000 square feet in area. The rock has a very light color (10 YR 8/2) due to extensive alteration and leaching. Outcrops commonly display a platy foliation that is random in orientation and attitude. The planes of foliation are spaced approximately two inches apart and are defined by subparallel alignment of elongate minerals.

Lithology and Petrography

The dacite porphyry contains approximately 20 percent phenocrysts that are set in an aphanitic groundmass. Phenocrysts of this rock type consist of quartz (25 percent), altered feldspar (70 percent), and altered ferromagnesian minerals (5 percent). Quartz crystals that average 1.5mm in length are the only fresh mineral constituents of this rock. Feldspar crystals have been extensively altered to "white mica," calcite, and kaolinite. However, a few crystals were noted that exhibited polysynthetic twinning which indicates that these feldspar crystals were originally plagioclase. The crystals are subhedral and range from 0.5 to 4mm in length. The original ferromagnesian minerals that are inferred to have been present have been completely replaced by chlorite.

The groundmass is made up largely of hydrothermal alteration products such as "white mica," chlorite, quartz, iron-stained clay, and calcite. Small aggregates of microcrystalline quartz are also present.

Accessory minerals include pyrite, magnetite, zircon, and sphene.

Age (Relative)

Because of limited exposures and juxtaposition only to quartz

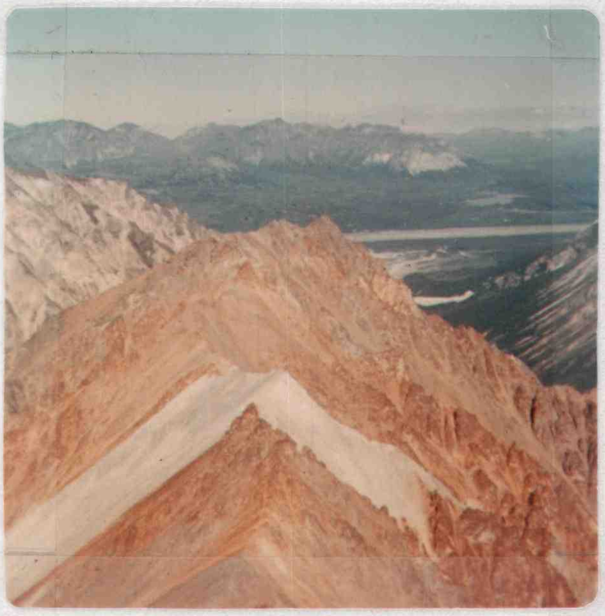


Figure 5. Light colored dacite porphyry plug exposed on the ridge crest (5,300E, 6,000S).

diorite, the relative age of this unit is inferred. Indirect evidence for the emplacement of this unit among the late intrusives are the following:

1) Copper and molybdenum sulfide mineralization is restricted to pre-hornblende andesite porphyry units. The dacite porphyry plug is unmineralized with respect to these sulfides.

2) Foliation caused by alignment of elongate minerals is characteristic of the youngest units in the thesis area. The dacite porphyry displays this foliation.

Needle Andesite Porphyry

Distribution and Character

Two andesite porphyry dikes that contain distinctive "needle-like" hornblende crystals are exposed in both the northwestern part (2,900E, 6,000S) and southwestern part (8,700E, 8,000S) of the thesis area. The bluish-grey (5 B 5/1) dikes are resistant and are readily defined by their linear topographic expression. Globular and wrinkled surfaces, concentric platy foliation, pilotaxitic texture, and devitrified groundmass suggest near-surface emplacement of these dikes.

Lithology and Petrography

Phenocrysts of plagioclase and hornblende comprise 25 percent of the rock and average 2mm in length. Plagioclase feldspar, whose anorthite content could not be determined because of extensive alteration, forms approximately 40 percent of the total phenocrysts. It occurs as brown subrounded crystals up to 5mm in length. Alteration products include kaolinite, "white mica," quartz, and chlorite. Hornblende crystals, modified by deuteric overgrowths of dark fibrous biotite, make up 35 percent of the total phenocrysts. These crystals have a subparallel alignment.

The groundmass has a pilotaxitic texture and consists of both primary and secondary constituents. Most of the groundmass is made up of hornblende, plagioclase, iron oxide, and deuteric biotite in a low relief background of brownish microcrystalline quartz and feldspar. Interstitial patches of zeolite, probably stilbite, and calcite are found throughout the groundmass and along hairline fractures.

Accessory minerals are sphene, magnetite, pyrite, zircon, and apatite.

Age (Relative)

Through-going dikes of needle andesite porphyry are intruded only by the rhyolite porphyry dike (8,300E, 6,800S).

Rhyolite Porphyry

Distribution and Character

A linear dike of altered silicic rock crops out for approximately two miles on the eastern flank of the ridge. This dike is very pale orange (10 YR 8/2) because of extensive bleaching and alteration of the mineral constituents. Foliation parallels the dike walls and is undulatory on planar surfaces. Foliation, devitrified glass groundmass, and trachytic texture indicate a near-surface emplacement of this dike.

Lithology and Petrography

Phenocrysts of quartz and pseudomorphs of calcite and muscovite after feldspar and biotite make up 25 percent of the total rock. Quartz crystals averaging 2mm in diameter form 30 percent of the total phenocrysts. The original plagioclase feldspar, and probably potassium feldspar as well, have been completely replaced by calcite which is readily dissolved, resulting in pock-marked outcrops. These calcite pseudomorphs comprise 40 percent of the total phenocrysts. Pseudomorphs of light brown silky muscovite that average 4mm in length have replaced octahedral flakes of biotite. Calcite has wedged apart the biotite along cleavage traces.

The groundmass is composed of anhedral quartz, fibrous "white mica," and altered feldspar in a background of iron-stained calcite and brownish devitrified glass.

Accessory minerals are zircon, sphene, magnetite, and apatite.

Age (Relative)

The rhyolite porphyry is believed to be the youngest rock unit in the area mapped. This dike intrudes all other intrusive phases except the dacite porphyry and andesite porphyry. Contacts between these units and the rhyolite porphyry were not observed. However, the through-going character as well as the inferred silicic composition indicate that the rhyolite porphyry is the youngest unit.

BRECCIAS

Two types of breccias are found in the thesis area. They are genetically classified as intrusive explosion-breccia and intrusion breccias. Intrusive explosion-breccias include those formed by gas explosion in confined spaces beneath the surface. Explosion may be followed by gas-streaming and formation of rounded boulders and with mobilization of the breccia (Wright and Bowes, 1963). Intrusion breccias are breccias caused by forcible intrusion of magma into country rock (Wright and Bowes, 1963).

Intrusive Explosion-Breccia

Distribution

An intrusive explosion-breccia is exposed as a small outcrop in the east-central part of the area (7,000E, 6,700S) and a large outcrop in the southeast part of the area (9,000E, 9,800S). The larger exposure of this breccia extends an unknown distance south of the thesis area.

Description

The small outcrop of breccia is irregular and elongate in shape and covers an area of approximately 15,000 square feet. The large outcrop is circular in shape and encompasses an area of approximately one-half square mile within the thesis area. This breccia can be divided into a dark colored (5 GY 2/1) core that forms the main body of the breccia and a lighter colored (5 Y 6/1) peripheral zone that forms a transition 100 to 500 feet wide into the quartz diorite. This peripheral zone is characterized by larger, more abundant, and more angular quartz diorite fragments than occur within the main body of the breccia.

Rock fragments in the intrusive explosion-breccia range from one-eighth inch to one foot in diameter, and the average is near one-half inch in diameter. The fragments are subrounded to rounded. They are evenly spaced within the matrix and rarely touch one another. Gradations of size and abundance can be found only in the peripheral zone. Quartz diorite comprises 90 percent of the rock fragments in the breccia. Other identifiable rock fragments are quartz diorite porphyry, andesite porphyry, hornblende diorite porphyry, "clots" of epidote, and teardrop-shaped aggregates of quartz and feldspar.

The matrix of this breccia is a dark, compact, heterogeneous mixture of broken plagioclase, quartz, and hornblende crystals and microcrystalline quartz, plagioclase, and orthoclase. Zircon, sphene, apatite, and pyrite crystals are present in minor amounts and are probably both "clastic" and primary. Hydrothermal alteration products of unbroken flakes of green biotite, pyrite, magnetite, "white mica," chlorite, epidote, calcite, and clay collectively impart a dark color to the matrix.

Age (Relative)

This breccia was formed after emplacement of the hornblende diorite porphyry and before intrusion of the biotite diorite porphyry shown by fragments of hornblende diorite porphyry included in the breccia and dikes of the biotite diorite porphyry that intrude the breccia.

Origin

An explosive and intrusive origin is postulated for this breccia. Crystallization of a magma at a shallow depth may have created a vapor pressure that exceeded the confining pressure of the overlying rocks. Sudden release of these volatiles, perhaps along fissure or fracture zones, is believed to have caused an explosion or series of explosions resulting in brecciation of the overlying quartz diorite. Volatiles escaped through the breccia, entraining and redistributing matrix material as well as rock fragments. The rock fragments were partially rounded during this "fluidization" process (Reynolds, 1954). After formation, the breccia was mobilized and intruded the quartz diorite. Such an origin for the intrusive explosion-breccia is suggested by the following features:

1) Rounded rock fragments.

2) Circular shape of the breccia body.

3) Included fragments of rock units that do not crop out in the immediate vicinity.

4) Matrix composed of fine-sized particles and broken crystals similar in composition to the quartz diorite and the biotite diorite porphyry.

5) Intrusive relationship to quartz diorite that is shown by formation of a peripheral breccia zone.

After brecciation, a residual crystal mush of the magma may have been forced upward through fractures into the breccia to form the dikes of biotite diorite porphyry. Similarities of mineral constituents, hydrothermal alteration, and environments of emplacement for both the breccia and the porphyry are consistent with this interpretation.

Intrusion Breccias

Distribution

Numerous intrusion breccias occur throughout the thesis area at contacts between the various plutonic units. The largest of these breccias are found near the contact between quartz diorite and quartz diorite porphyry.

Description

Intrusion breccias are tabular to circular in shape in the thesis area. They are rarely larger than 160,000 square feet in area. These breccias are normally light (10 YR 8/2) in color because of extensive alteration. Intrusion breccias generally form subdued outcrops as a consequence of later selective mechanical and chemical weathering. Less commonly, differential erosion may lead to the formation of small hoodoo-like exposures.

Fragments range from one-eighth inch to three feet in size. Shape varies from subangular to angular. The coherence of the matrix ranges from unconsolidated to indurated. Alteration with introduction of mineral constituents by the hydrothermal fluids has formed abundant "white mica," quartz, gypsum, pyrite, epidote, chlorite, calcite, clay, and orthoclase in the matrix.

Origin and Age (Relative)

Intrusion of magmas accompanied by fragmentation of adjacent host rocks created the intrusion breccias of the thesis area. Their relative ages range from pre-quartz diorite to post-hornblende andesite porphyry.

QUARTERNARY ALLUVIUM

Quaternary deposits consist of glacial moraines, talus, and river gravels. They are unstratified and composed of the coarser fractions of rock material. Because of the topographically steep terrain, the components are rarely less than pebble size in diameter.

Valley glaciers have formed small lateral moraines that interrupt the otherwise steep flanks of the ridge. The striated and rounded fragments that comprise these moraines range from less than one inch to greater than three feet in diameter and are angular to rounded in shape. The fragments consist of all rock units found in the Bond Creek area.

Talus streams fill depressions that extend down from the ridge. The material consists of rock units that are exposed immediately upslope.

Subrounded pebbles and boulders that represent a wide variety of lithologies fill the broad valley floors of Bond Creek (Figure 6).

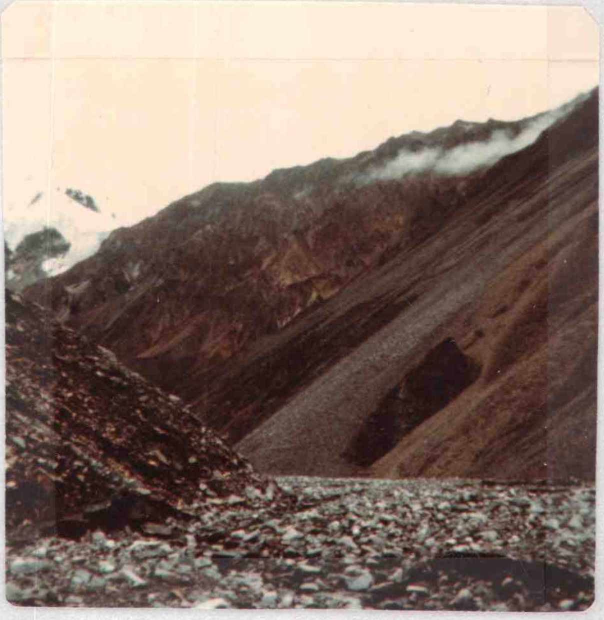


Figure 6. Typical river gravels in the valley floor of the Middle Fork of Bond Creek. Talus "streams" converge upon the valley floor from adjacent ridges.

STRUCTURE

Faults are numerous throughout the thesis area. Displacements could not be discerned in most cases because of the unstratified and homogenous character of all rock units. Where discernible, offsets were found to be minor and rarely exceeded three feet.

Fractures are ubiquitous in the rocks of the thesis area. They reflect cooling of the magma as well as post-consolidation and possibly tectonic movements of the intrusives. These fractures have been described by Moerlein (1964) as a "crackling" feature. Not infrequently, the fracturing is intense and the planes of breakage are closely spaced enough to cause complete mechanical disintegration of outcrops to grus. These fractures formed excellent conduits for the transportation of both hydrothermal fluids and later ground waters.

Dikes have been emplaced along many through-going faults and shear zones. Most dikes trend northwest and are nearly vertical. Their regularity suggests that the through-going faults are local manifestations of regional folding and faulting. In the rocks of the Nabesna-White River District, less than five miles from the thesis area, the prevailing trend of the folds and faults is northwest (Moffit and Knopf, 1910).

Columnar jointing is common in dikes of hornblende andesite

Figure 7. Structure controlled dikes of near-vertical attitude and undifferentiated composition that intrude quartz diorite. These dikes trend northwestward (north is toward the top of the photo). Location: 4,000E, 6,000S.

porphyry and hornblende diorite porphyry. The columns are oriented perpendicular to the nearest cooling surface although locally they may be modified by longitudinal joints that divide the columns into shorter posts.

Foliation, defined by parallel alignment of elongate minerals, is present in the dacite porphyry, needle andesite porphyry, and rhyolite porphyry and it is attributed to their near-surface epizonal origin. Foliation of the dacite porphyry is random whereas that of the rhyolite porphyry dike is undulatory and parallel to the adjoining walls. The needle andesite porphyry dike displays a concentric foliation of local distribution.

GEOMORPHOLOGY

Topography in the area is the result of recent glaciation, stream erosion, and landslides. Lateral moraines lie along the flanks of the ridge approximately 550 feet above the valley floors. The moraines commonly have been disrupted or overrun by talus streams. The wide, flat floors of Bond Creek also reflect recent glaciation. The intensely fractured nature of the rocks lead to their rapid disintegration and numerous talus streams cover the slopes.

HYDROTHERMAL ALTERATION AND MINERALIZATION

The classification of hydrothermal alteration proposed by Creasey (1959, 1966) is followed in this thesis. Creasey divided hydrothermal alteration into three principal types: propylitic, potassic, and argillic. Propylitic alteration is characterized by fixation of CaO in lime-bearing minerals such as epidote, calcite, and zeolites. It is the weakest type of alteration and commonly fringes the argillic or potassic types. Potassic alteration is distinguished by the formation of muscovite, biotite, and orthoclase and is accompanied by moderate leaching of CaO and Na_2O. The argillic type is characterized by the presence of kaolinite and montmorillonite and by strong leaching of CaO and usually Na_2O.

Propylitic and potassic alteration types are recognized in the thesis area.

Alteration and Gangue Minerals

Propylitic Alteration

The epidote-chlorite-"white mica" assemblage, typical of propylitic alteration, is the most common type throughout the thesis area. In general, the intensity of propylitic alteration increases from the northern end or "nose" of the ridge to the southwestern boundary of the thesis area. In this area, epidote is a ubiquitous mineral in rocks affected by propylitic alteration. It normally comprises less than two percent of the rocks and occurs as disseminated crystals, as aggregates up to one-half inch in diameter, and as veinlets. In the quartz diorite near the contact with intrusive explosion-breccia, it makes up nearly ten percent of the rock. Epidote typically replaces hornblende, biotite, and less commonly plagioclase feldspar, but its distribution is independent of rock type. Both hydrothermal and deuteric chlorite are present in the rocks of the area and distinction between them is usually difficult. Chlorite preferentially replaces biotite and commonly occurs as green radiating sheafs. The distribution of chlorite is controlled largely by the primary abundances of biotite and hornblende.

"White mica" is quantitatively the most abundant alteration product in the thesis area. However, this mineral cannot be used as an indicator of propylitic type alteration as it is found in all three alteration types described by Creasy. "White mica" generally forms by incipient replacement along cracks, cleavages, and crystal boundaries, most commonly in the plagioclase feldspars. "White mica" is most abundant in the hornblende andesite porphyry, dacite porphyry, and rhyolite porphyry. Calcite is commonly associated with "white mica" and is most abundant in the hornblende andesite porphyry and the rhyolite porphyry units. It replaces plagioclase feldspar and, more rarely, ferromagnesian minerals. It may also be found in veinlets.

Small amounts of kaolinite are locally present as a replacement of plagioclase feldspar.

Potassic Alteration

Potassic alteration is restricted to zones of intense fracturing and brecciation. These zones are enveloped by and gradational into zones of propylitic alteration. At Bond Creek potassic alteration has developed two separate mineral assemblages; quartz-"white mica"-orthoclase and biotite-orthoclase.

The quartz-"white mica"-orthoclase assemblage is characterized by the destruction of primary textures, stock-work veining, and a white bleached appearance of the host. Quartz and pink orthoclase feldspar occur both as veinlets and as disseminated granules. Both minerals are unaltered and perthitic intergrowths of albite and orthoclase are common. "White mica" forms a mat that completely replaces crystals of plagioclase feldspar. It is also disseminated within the quartz veinlets. Gypsum and calcite are commonly associated with the quartz-"white mica"-orthoclase alteration assemblage. They are generally localized in veinlets.

The biotite-orthoclase assemblage is distinguished from the quartz-"white mica"-orthoclase assemblage by the presence of hydrothermal biotite that imparts a dark color to the host rock.

Only moderate quantities of "white mica" and quartz are found associated with this assemblage. Hydrothermal biotite occurs as random disseminations within the host, as aggregates that replace original biotite and hornblende, and as disseminations in veinlets. The crystals of hydrothermal biotite are typically green and rarely exceed 0.1mm in length. Unaltered orthoclase is found as a fine-grained constituent of thin veins and as a disseminated microcrystalline component of altered rocks. The microcrystalline orthoclase is difficult to identify optically and, therefore, its abundance is largely inferred. Epidote and chlorite are associated with the biotite-orthoclase assemblage. They are believed to be relic minerals of an earlier stage of propylitic alteration because they generally occur as constituents of older included rock fragments within a breccia.

Sulfide Minerals

The close association of sulfide minerals to altered rocks clearly suggests that the processes of alteration and mineralization were both spatially and genetically related. Pyrite is ubiquitous to all rocks of the thesis area, but it rarely exceeds two percent by volume. It occurs as disseminated blebs and euhedral crystals, as smears along fractures, as disseminated grains in quartz veinlets, and as a cementing fraction in breccias. Fracture controlled pyrite is normally associated with quartz and "white mica". Disseminated pyrite shows a preference for secondary chlorite and epidote. Oxidation of pyrite produces limonite that probably includes the minerals hematite and jarosite. Chalcopyrite is commonly associated with pyrite. It occurs as disseminated blebs and grains and as fracture controlled smears. Supergene malachite, azurite, and dark copper oxides are derived from the surficial oxidation of chalcopyrite. Molybdenite is restricted to smears of very fine grains along the margins of quartz veins. The occurrences of molybdenite are rare.

Controls and Distribution

A complex overlapping of zones and episodes of hydrothermal alteration is present in the thesis area. This apparent complexity is believed to have developed because each intrusion may have emitted hydrothermal fluids that contributed to the alteration of the preceeding units. Nonetheless, distinct but generalized zones of propylitic and potassic alteration can be recognized locally within the area mapped.

Propylitic alteration is well developed and widespread throughout the area. It is controlled by fractures, joints, and foliation. These structures served collectively as a "plumbing" system for the circulation and distribution of hydrothermal fluids. Alteration effects are most prominent adjacent to veins. Intensive propylitic alteration of the dacite porphyry and rhyolite porphyry is attributed to hydrothermal fluids genetically related to these intrusives and controlled by the foliation in these shallow intrusions. This type of alteration grades transitionally into zones of potassic alteration where fracturing and brecciation are more intense.

Intense fracturing of the quartz diorite in the west-central part of the thesis area (4,600E, 6,400S) provided the necessary channelways for transport of fluids and space for deposition of the constituents of hydrothermal alteration and mineralization. Alteration of this area is of the potassic type and consists of a quartz-"white mica"-orthoclase mineral assemblage. Wetherell (1967) mapped these rocks as alaskite. Wilson (1964) described similar rocks to the south of the thesis area as S-K rock, a term used to denote an abundance of silica and K-feldspar. Modal and chemical analysis are presented in Table 7.

Intrusion breccias form a second mode of occurrence for potassic alteration characterized by a quartz-"white mica"-orthoclase assemblage. Channelways created by brecciation controlled the movement and deposition of hydrothermal minerals. Altered intrusion breccias are found throughout the thesis area and are most common at the contact between quartz diorite and quartz diorite porphyry.

The intrusive explosion-breccia constitute a third mode of

Table 7. Comparison of modal and trace element analysis of fresh quartz diorite A-2[1] and its altered phase JK-7[2]. (Trace element analysis by Rocky Mountain Geochemical Corporation).

Mineral	A-2	JK-7
Quartz	15.9	32.0
Orthoclase	--	15.9
Microperthite	--	0.3
Plagioclase	54.4	10.0
Hornblende	17.0	--
Opaques	1.3	1.4
Apatite	0.2	0.2
Zircon	0.1	0.2
Sphene	0.7	--
Chlorite	5.5	--
Epidote	4.3	--
"White mica"	0.5	39.6
Calcite	0.1	0.4
Total	100.0	100.0
Element	ppm	
Cu	55	+1000
Zn	110	255
Pb	10	50
Mo	1	120
Ag	0.2	2

[1](6,900E, 9,500S)

[2](4,700E, 6,450S)

occurrence for potassic alteration. The hydrothermal mineral assemblage of this breccia is biotite-orthoclase. Brecciation created a structurally favorable host for the transport and deposition of hydrothermal minerals.

Sulfide mineralization is largely associated with zones of potassic alteration. Copper and molybdenum minerals are most commonly associated with quartz-"white mica"-orthoclase alteration assemblage whereas pyrite is most abundant in the biotite-orthoclase assemblage. Sulfides are quantitatively less abundant in the propylitic type of alteration and they consist predominantly of pyrite.

Deposition of copper and molybdenum sulfides are restricted to rock units older than the hornblende andesite porphyry. Therefore, copper and molybdenum-bearing hydrothermal fluids were presumably derived from magmas that were pre-hornblende andesite porphyry in age. Later hydrothermal fluids were apparently deficient in copper and molybdenum.

GEOLOGIC SUMMARY

Plutonic rocks in the area all belong to a complex phase of the Monte Cristo batholith. Field relationships between the batholith and the surrounding rocks suggest a post-Permian age for the batholith, and it is believed to be Jurassic in age because of its similarity in composition and occurrence to other plutonic rocks of Jurassic age that crop out in southwestern and southeastern Alaska. Radiogenic age-dating and geologic mapping of the quartz diorite Kosina batholith in the Talkeetna Mountains of southwestern Alaska, indicate emplacement between early and late Jurassic time (Grantz and others, 1963). Potassium-argon determinations and geologic mapping of the Aleutian Range batholith, of intermediate composition, suggest emplacement between Early Jurassic and early Middle Jurassic time (Detterman and others, 1965). Potassium-argon ages determined for plutonic cobbles in the Kosina Conglomerate on the southwest side of the Wrangell Mountains indicate the plutonic rocks were emplaced in latest Early to earliest Middle Jurassic time (Grantz and others, 1966).

The Kosina and Aleutian Range batholiths and the plutonic cobbles in the Kosina Conglomerate are believed by Reed and Lanphere (1969) to be features formed as part of a major structural belt that extends from the Alaskan Peninsula to the Canadian border.

The principal tectonic elements of this belt are the Talkeetna geanticline and Matanuska geosyncline which are marked by Jurassic, Cretaceous, and Tertiary plutonic intrusions. The Monte Cristo batholith occurs within the eastward extension of these major tectonic elements, and it is suggested by the writer that the Monte Cristo batholith is related in time of emplacement to these tectonic events.

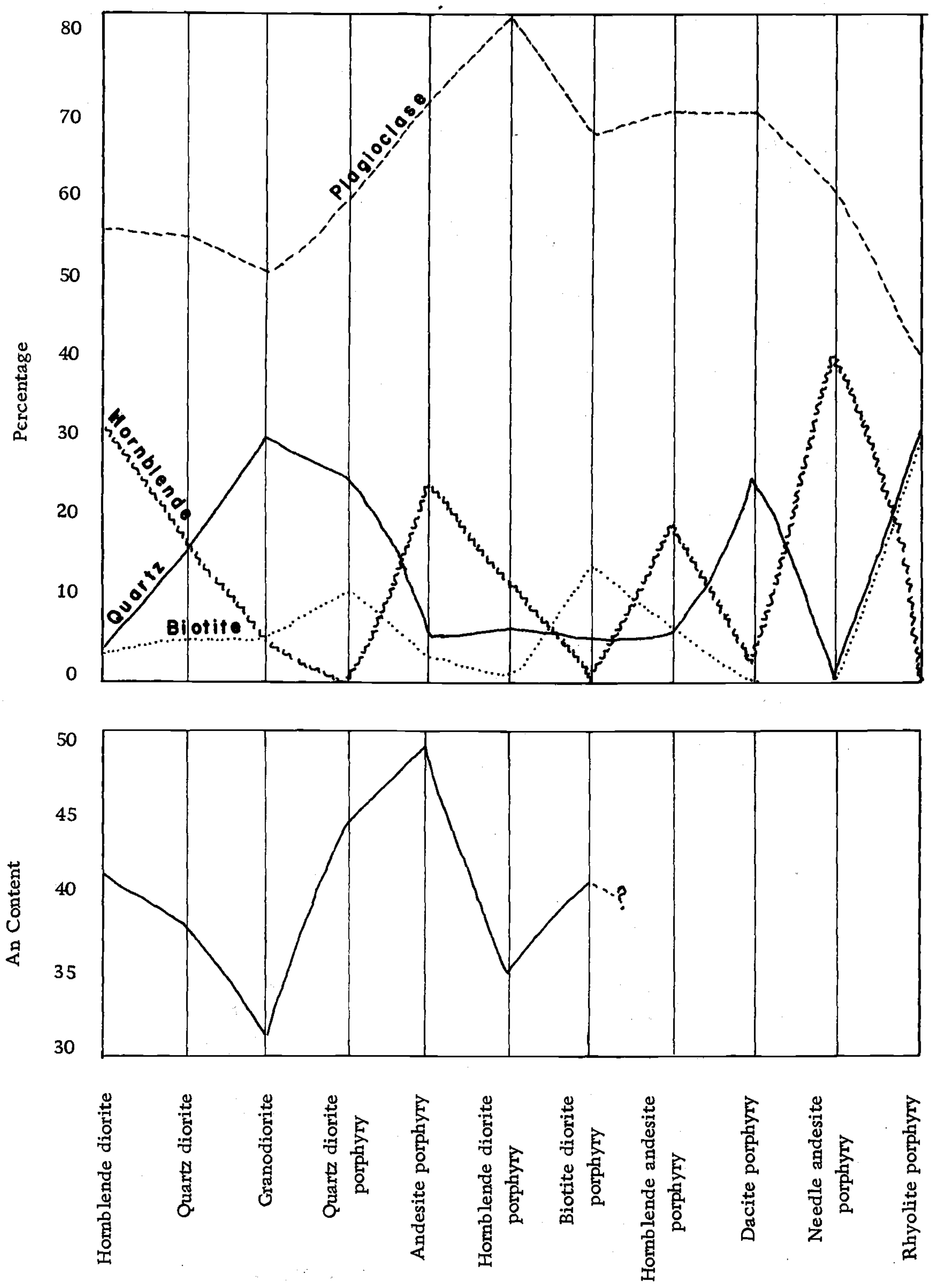
Batholiths at Klein Creek and White Mountain near Nabesna, Alaska, occur within a few miles of the Monte Cristo batholith. These batholiths are similar in composition and are also believed to be related in time to the emplacement of the Monte Cristo batholith. The quartz diorite batholith at White Mountain is known to intrude Upper Triassic Nabesna Limestone (Moffit, 1943). The batholith at Klein Creek intrudes rocks of undoubted Permian age. Moreover, rocks of Upper Triassic age are involved in the same structures and have undergone chemical alteration similar to that of the Permian rocks. There is also a conglomerate of Upper Jurassic age at Gravel Creek, near the Klein Creek batholith, that contains boulders that possibly were derived from the batholith at Klein Creek (Wayland, 1943).

A possibility of intrusives of both Jurassic and late Cretaceous or early Tertiary age, as described by Reed and Lanphere (1969) for batholiths of southwestern Alaska, exists in the Bond Creek area. These authors have found that potassium feldspar-rich plutonic rocks in southwest Alaska are predominant in the Cretaceous and Tertiary plutons but are subordinate in Jurassic plutons. Because of the extensive hydrothermal alteration of rocks within the thesis area, the abundance of potassium feldspar can only be inferred. The writer believes that the porphyries of the Bond Creek area contain more potassium feldspar than the older medium-grained equigranular diorites and granodiorite. Reed and Lanphere (1969) also state that mineralization is associated with the Cretaceous and Tertiary plutons. Although the earlier hornblende diorite, quartz diorite, and granodiorite of the thesis area are mineralized, the bulk of the mineralization is believed to have been introduced into these rocks at a later date. Reed and Lanphere (1969) suggest that Jurassic plutons were emplaced at greater depths than the younger plutonic rocks. This trend can be seen at Bond Creek as post-granodiorite intrusive rocks all display hypabyssal characteristics. However, definitive evidence for two or more ages of complex plutonism in rocks of the Monte Cristo batholith is lacking. Additionally, studies made by the writer were restricted to a small portion of the Monte Cristo batholith. Therefore, the writer has followed previous workers Moffit (1910), Wayland (1943), and Moerlein (1963), and tentatively assigned a Jurassic age to all plutonic rocks of the thesis area.

Early intrusive members of the Monte Cristo batholith within the Bond Creek area are hornblende diorite, quartz diorite, and granodiorite. Granular textures and medium-grained constituents suggest that these earlier members probably crystallized at considerable depths. The normally transitional contact between the hornblende diorite and quartz diorite suggests that intrusion of the quartz diorite occurred shortly after emplacement and prior to complete crystallization of the hornblende diorite. A normal sequence of magma differentiation is suggested by the order of intrusions consisting of mafic hornblende diorite followed by quartz diorite and finally silicic granodiorite. A decreasing anorthite content for plagioclase feldspars in the progressively younger members of this sequence also substantiates this differentiation trend. Table 8 illustrates the general mineralogical trends of this plutonic sequence.

A period of quiescence and accompanying erosion possibly occurred between emplacement of the granodiorite and the quartz diorite porphyry. Erosion may have removed enough surficial material during this interval of time to result in near-surface conditions for the emplacement of the later intrusive members. The later intrusions all display hypabyssal characteristics such as microcrystalline groundmasses and porphyritic textures. An interval of time between the early equigranular intrusives and later porphyritic intrusives is also suggested by the commonly brecciated contact between the quartz diorite porphyry and the older quartz

Table 8. Percentages of selected minerals and anorthite content for intrusive members of the Bond Creek area (generalized).



diorite. Formation of these intrusion breccias indicates that the older quartz diorite was completely crystallized before intrusion of the younger quartz diorite porphyry.

The post-granodiorite intrusives generally display sharp to brecciated contacts. This feature together with their apparent lack of consistent mineralogical trends as illustrated by Table 8, suggests that each intrusion was followed by an interval of time. The mineral percentages shown in Table 8 may be more inferred than real, however, as the compositions of the microcrystalline groundmass could not be determined and is therefore not included in the estimated percentages of the minerals. Additionally, identification and percentage determinations of original mineral constituents are affected by intense hydrothermal alteration.

Andesite porphyry and hornblende diorite porphyry followed emplacement of the quartz diorite porphyry. Formation of the intrusive explosion-breccia followed probably as a result of the expulsion of fluids from an underlying magma that was possibly related to the biotite diorite porphyry. After its formation, the breccia became sufficiently mobile to intrude the overlying cover. Biotite diorite porphyry magma moved upward through the breccia and other structurally weak zones to form dikes and small plugs throughout the area. Hornblende andesite was later emplaced along other structural zones of weakness.

Dacite porphyry, needle andesite porphyry, and rhyolite porphyry were emplaced as final members of this plutonic complex. These three youngest members exhibit near-surface characteristics that include phenocrysts in a microcrystalline groundmass, pilotaxitic textures, and foliation.

The emplacement of the intrusive members and the subsequent introduction, transport, and deposition of structure-controlled hydrothermal fluids caused the development of potassic alteration and fringing propylitic alteration. Pyrite, chalcopyrite, magnetite, and molybdenite were deposited from these fluids. Later hydrothermal fluids that followed intrusion of post-hornblende andesite intrusive members were deficient of copper and molybdenum as is suggested by the lack of copper and molybdenum sulfides in the dacite porphyry, needle andesite porphyry, and rhyolite porphyry.

The present day topography is a function of uplift, Pleistocene glaciation, and later stream erosion.

BIBLIOGRAPHY

Bateman, A. M. 1950. Economic mineral deposits. 2d ed. New York, Wiley. 916p.

Bryner, L. 1961. Breccia and pebble columns associated with epigenetic ore deposits. Economic Geology 56: 488-508.

Burnham, W. C. 1962. Facies and types of hydrothermal alteration. Economic Geology 57: 768-784.

Creasey, S. C. 1959. Some phase relations in the hydrothermally altered rocks of porphyry copper deposits. Economic Geology 54: 341-373.

Creasey, S. C. 1966. Hydrothermal alteration. In: Geology of the porphyry copper deposits, southwestern North America, ed. by S. R. Titley and C. L. Hicks. Tucson, University of Arizona. p. 51-73.

Detterman, R. L., B. L. Reed and M. A. Lanphere. 1965. Jurassic plutonism in the Cook Inlet region, Alaska. In: Geologic Survey Research 1965. Washington, D. C. p. D16-D21. (U. S. Geological Survey. Professional Paper 525-D)

Goddard, E. N. <u>et al</u>. 1948. Rock color chart. Washington, D. C. National Research Council. n. p.

Grantz, A., H. Thomas, T. W. Stern and N. B. Sheffey. 1963. Potassium-argon and lead-alpha ages for stratigraphically bracketed plutonic rocks in the Talkeetna Mountains, Alaska. In: Geological Survey Research 1963. Washington, D. C. p. B56-B59. (U. S. Geological Survey. Professional Paper 475-B)

Grantz, A., D. L. Jones and M. A. Lanphere. 1966. Stratigraphy, paleontology, and isotopic age of upper Mesozoic rocks in the southwestern Wrangell Mountains, Alaska. In: Geological Survey Research 1966. Washington, D. C. p. C39-C47. (U.S. Geological Survey. Professional Paper 550-C)

Mendenhall, W. C. and F. C. Schrader. 1903. The mineral resources of the Mount Wrangell district, Alaska. Washington, D. C. 71p. (U.S. Geological Survey. Professional Paper 15)

Moerlein, G. A. 1963. Northwest district report, Bond Creek examination and Orange Hill examination, Alaska. Spokane, Washington, Bear Creek Mining Company. 7 numb. leaves. (Unpublished)

Moerlein, G. A. 1964. Annual progress report, Bond Creek examination, Alaska (including a summary of Orange Hill results). Spokane, Washington, Bear Creek Mining Company. 20 numb. leaves. (Unpublished)

Moffit, F. H. and A. Knopf. 1910. Mineral resources of the Nabesna-White River district, Alaska. Washington, D. C. 64p. (U. S. Geological Survey. Bulletin 417)

Moffit, F. H. 1938. Geology of the Chitina Valley and adjacent area, Alaska. Washington, D. C. 137p. (U. S. Geological Survey. Bulletin 894)

Moffit, F. H. 1943. Geology of the Nutzotin Mountains, Alaska. Washington, D. C. p. 103-199. (U. S. Geological Survey. Bulletin 933-B)

Park, C. F., Jr. and R. A. McDiarmid. 1964. Ore deposits. San Francisco, Freeman. 475p.

Reed, B. L. and M. A. Lanphere. 1969. Age and chemistry of Mesozoic and Tertiary plutonic rocks in south-central Alaska. Bulletin of the Geological Society of America 80:23-43.

Reynolds, D. L. 1954. Fluidization as a geologic process and its bearing on the problem of intrusive granites. American Journal of Science 252: 577-614.

Titley, S. R. and C. L. Hicks (eds.). 1966. Geology of the porphyry copper deposits, southwestern North America. Tucson, University of Arizona. 287p.

Travis, R. B. 1955. Classification of rocks. Quarterly of the Colorado School of Mines 50: 1-98.

Turner, F. J. and J. Verhoogen. 1960. Igneous and metamorphic petrology. New York, McGraw-Hill. 694p.

Wayland, R. G. 1943. Igneous rocks. In: Geology of the Nutzotin Mountains, Alaska, by F. H. Moffit. p. 137-153. (U. S. Geological Survey. Bulletin 933-B)

Wetherell, C. E. 1967. Annual progress report, results of geological study at Bond Creek. Spokane, Washington, Bear Creek Mining Company. 7 numb. leaves. (Unpublished)

Williams, H., F. J. Turner and C. M. Gilbert. 1955. Petrography. San Francisco, Freeman. 406p.

Wilson, J. C. 1964. Coordinating unit report, final report on applied geochemical research studies in the Bond Creek-Orange Hill area, Alaska. Salt Lake City, Utah, Kennecott Copper Corporation Exploration Services Geologic Research Division. 41 numb. leaves. (Unpublished)

Wright, E. and R. Bowes. 1963. Classification of volcanic breccias: a discussion. Bulletin of the Geological Society of America 74: 79-86.