STATE OF ALASKA

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DIVISION OF MINES AND MINERALS

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GEOLOGIC REPORT NO. 2

Bedrock Geology of the Rainbow Mountain Area, Alaska Range, Alaska

An M. S. thesis prepared by Larry G. Hanson
of the University of Alaska in cooperation
with the Division of Mines and Minerals

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FOREWORD

This report is the result of one of the projects of a cooperative graduate student geologic mapping program between the State of Alaska Division of Mines and Minerals and the University of Alaska College of Earth Sciences and Mineral Industry. In this program, the Division contracted with the University to finance the expenses of selected graduate geology students in field work and thesis preparation for advanced degrees. The Division made the final payment for each project only if the completed thesis was acceptable to the College as qualifying the student for the degree and acceptable to the Division as contributing new geologic information of use and benefit to future searches for and development of economic mineral deposits. The College authorized the Division to publish the qualifying theses as Division publications.

We are proud to present this excellent thesis by Larry Hanson. It will be found by technical persons to be a highly worthwhile contribution to the economic geology of the State, and of value in future development of the State's mineral resources.

James A. Williams, Director
Division of Mines and Minerals
November 6, 1963

ERRATA

Page 47 (line 17).....Change: Separated by a major fault (I)...
to: Separated by a major fault (K)...

Table 2 (p. 51; last listed brachiopod).....

Change: *Leiorhynchus* cf. *L*. *rockymontanus* (Marcou) F-2
to: *Leiorhynchus* cf. *L*. *rockymontanus* (Marcou) F-1

Plate 3 (in pocket; index map).....

Change: Fault I
to: Fault K

CONTENTS

Faulting

ILLUSTRATIONS

(Plates in pocket)

ABSTRACT

The Rainbow Mountain area is located along the Richardson Highway adjacent to and south of the Denali fault. The Paleozoic and Mesozoic sedimentary and igneous units of the study area contrast the Birch Creek schist which underlies the area immediately north of the fault.

Pre-Mississippian low grade metamorphic rocks (phyllites, greenschists and marbles) with included ultramafic dikes and sills occur in several fault blocks which border the Denali lineament. Rainbow Mountain is for the most part underlain by detrital rocks ("graywackes"), limestones, andesitic and dacitic pyroclastics and minor andesite flows of the Mississippian (?) McCallum Creek and Pennsylvanian Rainbow Mountain sequences. These have been intruded by massive porphyritic andesite sills, hornblende granodiorite and quartz diorite plutonic masses and a variety of dike rocks. A dunite intrusion and a belt of quartz diorite gneiss outcrop near the Denali fault.

The paleontologically dated Carboniferous sequences have been deformed during at least three distinctive cycles of deformation of probably late Mesozoic to early Tertiary age. Following the intrusion of the andesite sills, these sequences were folded and locally overturned and overthrust to the southwest. Intrusion of the hornblende granodiorite pluton was succeeded by a cycle of vertical block faulting which subparallels the trend of the Alaska Range. Subsequent to the mineralization of the quartz veins and the intrusion of the diabase swarm, a system of north to northeast striking faults of dominantly lateral movement were developed. Each cycle of faulting may reflect

movement along the Denali fault. Uplift, tilting and minor vertical faulting have proceeded since the time of the last major cycle of faulting.

The three principal types of mineralization which occur are: (1) copper-lead in quartz veins, (2) nickel-copper associated with serpentinite, (3) disseminated sulfides in andesite "sills" and units of the Rainbow Mountain sequence. Although no economically important deposits were found, further investigation of some occurrences is reccommended.

INTRODUCTION

Description of the study area

Location

The Rainbow Mountain area is located in the east central Alaska Range just north of Isabel Pass and east of the Delta River. The location and approximate limits of the study area are shown in figure 7.

Access roads

The main access road, the Richardson Highway, is the western boundary of the area. Three spur roads penetrate the general area from the highway: (1) a three mile long private road leaves the highway approximately one mile south of Miller's Roadhouse, (2) a microwave station maintenance road follows McCallum Creek upstream for two miles, (3) a road also leads to the terminal area of Gulkana Glacier from the highway, at the Richardson Monument.

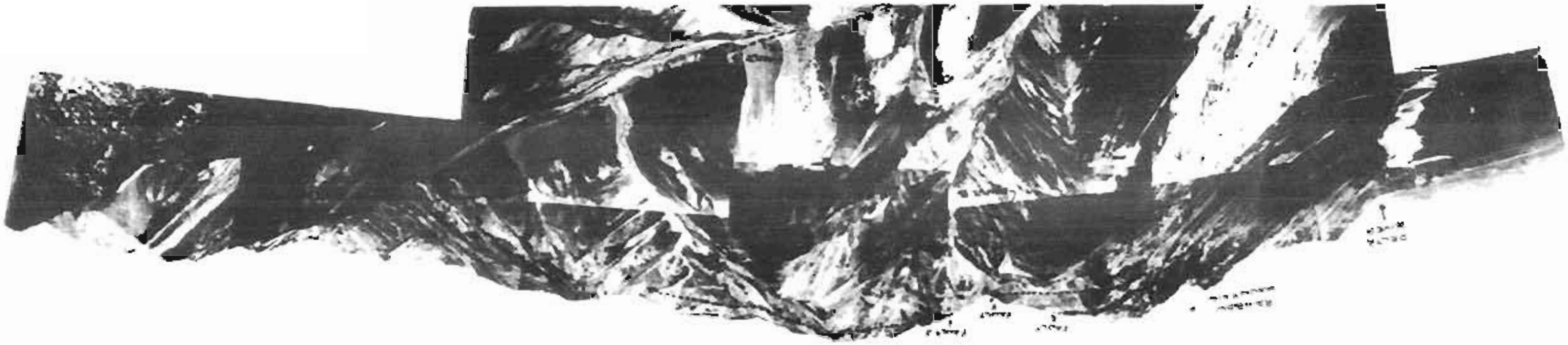
Physiography

Relief and drainage

Elevations within the area range from approximately 2500 feet along the Delta River to more than 7000 feet near the eastern boundary; greater than 4500 feet relief.

The principle topographic elements are: (1) the north to northwest trending ridge of Rainbow Mountain which rises abruptly more than 4200 feet above the valley floor of the Delta River (figs. 2 and 3),

[illegible]



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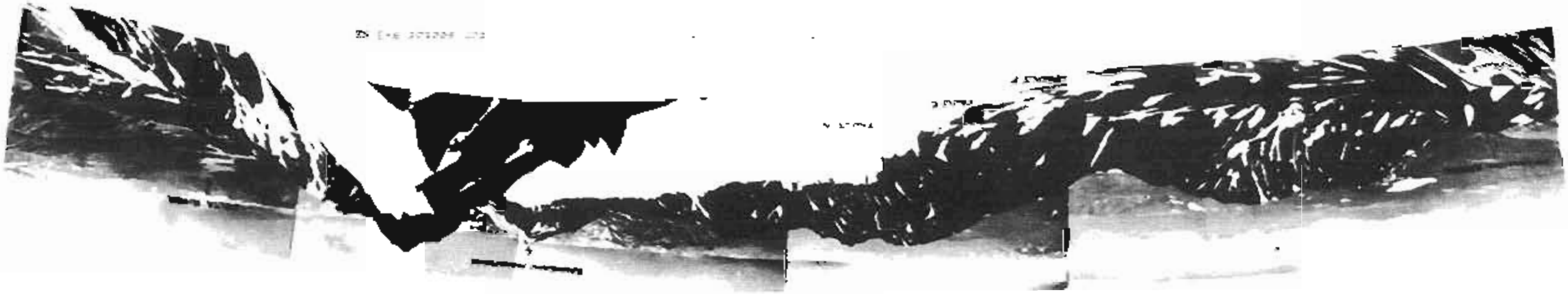

and (2) the high branching ridge trending east and southeast from the highest peak of Rainbow Mountain (fig. 4).

The major streams which drain the area include: (1) McCallum and Phelan Creeks to the south and west and (2) the Canwell Glacier system (Miller Creek) to the north; both systems tributary to the Delta River.

Physiographic form

Quaternary glaciation has produced typical alpine topographic features. Sharp arêtes are characteristic of the high ridges. Many abandoned cirques occur between 4500 and 5500 feet elevation. Above 5500 feet, cirques and valleys are still occupied by glaciers. Moraine and outwash materials mantle the valley sides and floors of most drainages. A complex of modified side glacial channels occurs along the northwest and southwest flanks of Rainbow Mountain.

Structural control of topography:

The ridge of Rainbow Mountain is essentially a strike ridge and much of the western slope approximates a dip slope (figs. 5 and 39). Resistant layers in the McCallum Creek and Rainbow Mountain sequences form small ridges as do some units of the Pre-Mississippian metamorphic rocks. Many basic and intermediate dikes and sills are also minor ridge formers.

The topography underlain by plutonic rocks is generally more serrate than that underlain by sedimentary and metamorphic units. The traces of most major faults coincide with prominent valleys or other topographic lows (e. g., the Denali Fault beneath Canwell Valley and faults G, O, Q, S, W, and X, each underlying a linear topographic low (see plate 4).

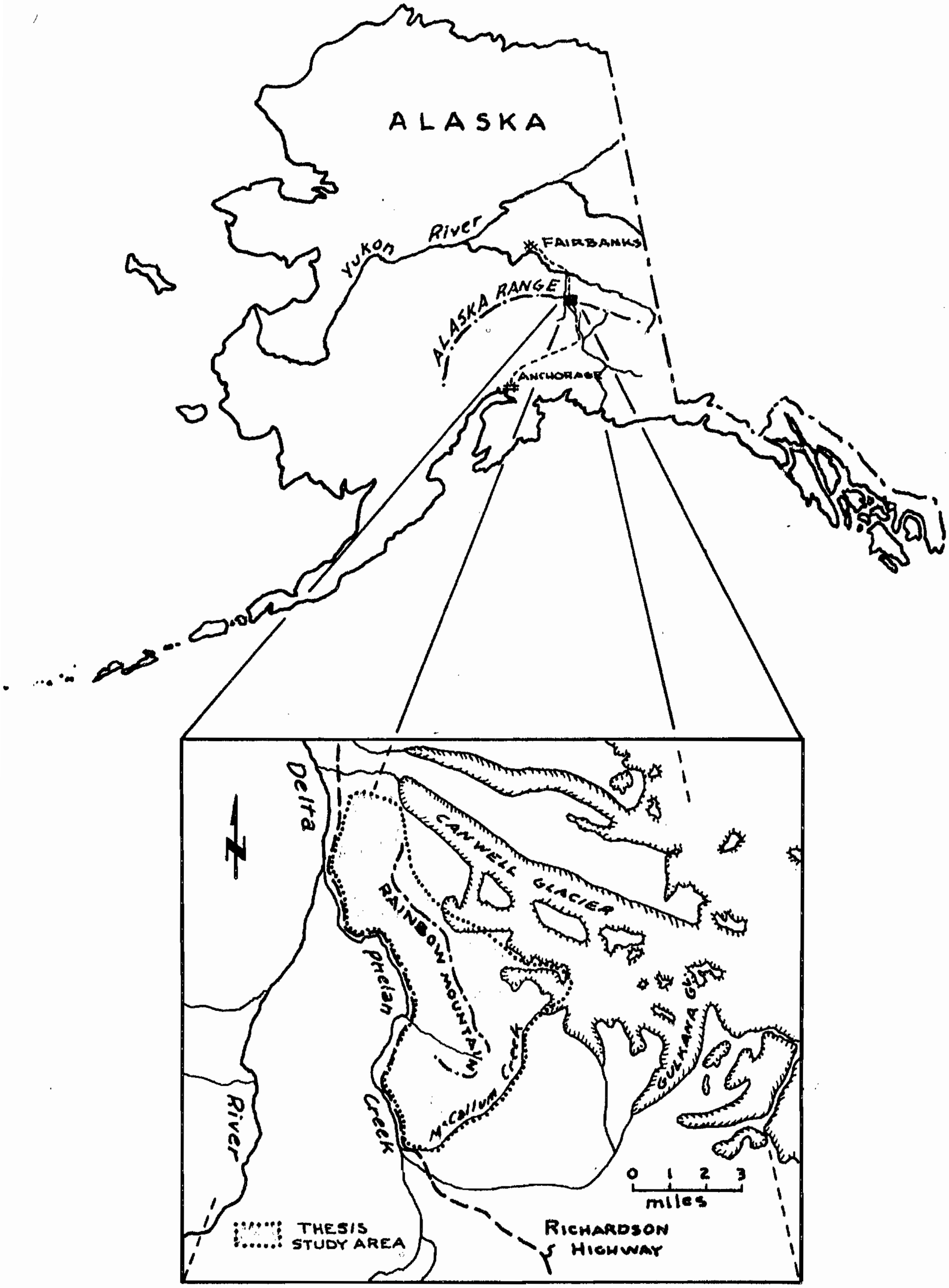

Fig . 7.--Location map, Rainbow Mountain area.

Figure 5: The crest of Rainbow Mountain; a view to the north from sector B-3(WC). The strike ridge form is typical with dip slope to the west.

Figure 6: The southern area of Rainbow Mountain; a view to the south from sector B-3(WC). Fault J separates the McCallum Creek sequence(MCS) from the Rainbow Mountain sequence(RMS).

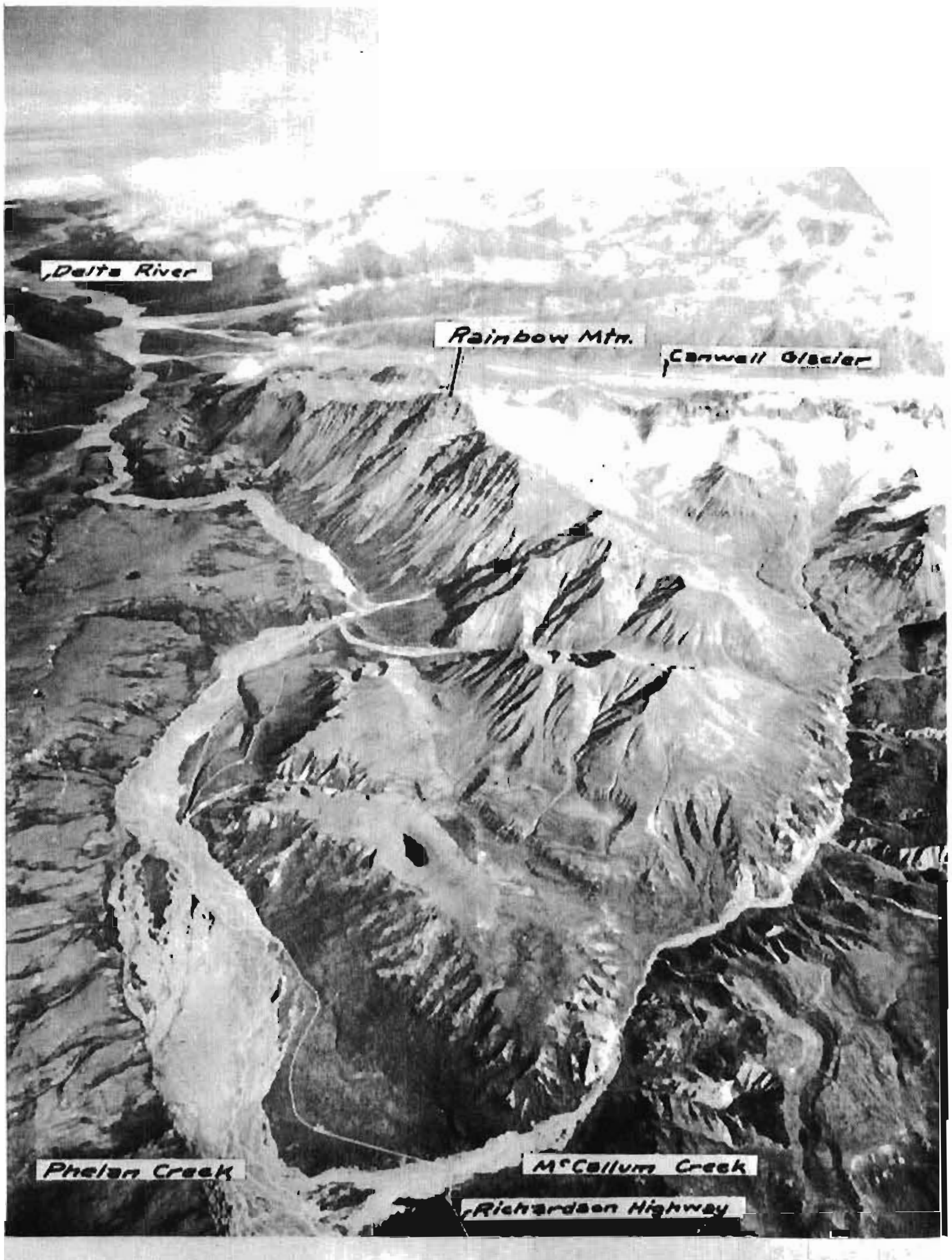

Figure 1: The Rainbow Mountain area; an air view from the south. (Air photograph by the U. S. Navy)

Research objectives and Techniques

The following factors influenced the selection of this area for study:

1. Known nickel and copper minerals occur in the northern part of the area and suggest other possible occurrences.

2. Fossiliferous stratigraphic sections which are important to a better understanding of the geology of the Alaska Range are well exposed over much of the area.

3. One of the most prominent structural features in the Range--the Denali Fault--bounds the area on the north.

4. It is situated adjacent to the Gulkana Glacier area where related bedrock and physiographic studies are in progress.

5. Relatively easy access to the area is possible.

Research objectives

The Rainbow Mountain study has attempted to:

1. Define the petrology and structure of major bedrock units exclusive of the Tertiary sedimentary rocks.

2. Determine the age of these units and geologic history of the area.

3. Obtain a general understanding of the stratigraphy of the Paleozoic sequences.

4. Relate mineralization to the various geologic factors as a key to exploration and utilization.

Techniques

Field data were collected during the 13 weeks of the summer field season in 1962. Operations were staged from a base camp located near the Richardson Highway. Four major trail camps were established at scattered localities near the crest of Rainbow Ridge.

The area was mapped on a scale of 1:20,000. Air photographs of scale 1:52,000 and 1:40,000 aided in the investigation.

Previous investigations

Mendenhall (1900), in his report of a reconnaissance traverse across the Alaska Range at Isabel Pass, was the first to geologically describe parts of the Rainbow Mountain area. He noted the thick succession of tuffs exposed along the Phelan Creek near the Delta River. He also recorded the association of porphyritic rhyolite flows with these tuffs. Later, Mendenhall (1905) correlated these tuffaceous beds with the Chisna formation exposed 25 miles to the east, which he believed to be of Carboniferous age; this dating was based on analogous structural and lithologic evidence.

Moffit has done considerable work in the Alaska Range east of the Delta River. Two of his reports (1912 and 1942) discuss the Rainbow Mountain area in part.

Regarding these rocks, Moffit (1912) notes:

> East of Phelan Creek and west of Delta River northward from Eureka Creek to Canwell Glacier, the high mountains consist of slates, tuffaceous beds, quartzitic sediments and local limestone beds associated with diabase flows or intrusions and with light gray or greenish gneisses that probably represent metamorphosed diorite intrusions. These beds are much folded and in

> places a schistose structure has been developed....The same rocks [implying all lithologies] extend eastward to the Chistochina River region, where they were named the Chisna formation by Mendenhall and westward on the north side of Eureka Creek to at least as far as the glacier at the head of the main fork of Maclaren River.

In his latest report, (1954), which summarizes most of his work in the eastern Alaska Range, Moffit suggests that the tuffs along Phelan Creek may be of Permian age.

Acknowledgements

The investigations reported here were supported under provisions of geologic mapping program of the State of Alaska, Division of Mines and Minerals, in cooperation with the University of Alaska.

I am indebted to Dr. R. B. Forbes for his valuable assistance and advice during field and laboratory studies and in the preparation of this manuscript.

Drs. D. M. Ragan, M. J. Andresen, C. L. Rowett and T. L. Péwé of the University of Alaska read much of the manuscript and offered many helpful suggestions.

The fossil identifications of Drs. A. G. Unklesbay of the University of Missouri, H. E. Wheeler of the University of Washington, and C. L. Rowett are appreciated.

I am grateful to Charles F. Herbert, mining engineer of Newmont Exploration Limited, for his cooperation during the field investigations.

The U. S. Army of Fort Greely made possible the helicopter transportation of supplies to the more remote areas of Rainbow Mountain.

The many comments of my field assistant, Donald Mortensen and fellow students Gerard Bond, Donald Morrison and Richard D. Reger were particularly helpful.

GEOLOGIC SETTING

Rock units

Moffit's geologic map (1954) (see figure 8) indicates the general distribution of rock types in the eastern Alaska Range.

Birch Creek schists and gneisses with associated plutonic rocks crop out north of the Rainbow Mountain area and underlie most of the area along the northern flank of the range. These rocks are separated from the dominantly Paleozoic-Mesozoic rocks of the southern Alaska Range by the Denali fault.

Units of Devonian through Triassic age are probably represented in the southern fault block. Lithologically these consist primarily of graywackes, limestones, basic to intermediate volcanics, acidic to intermediate intrusives and rare ultramafics. Low grade metamorphic rocks are typical of most pre-Devonian units, but medium and high-grade metamorphic rocks of unknown age also occur in the general area; among these are the migmatites, gneisses and schists which underlie much of the catch basin of Gulkana Glacier (D. M. Ragan, personal communication). Tertiary conglomerates and sandstones with coal occur at the lower elevations in areas both north and south of the Denali fault.

The Denali fault

In the east central area of the Alaska Range, the Denali fault is expressed topographically as a well defined lineament. This lineament is occupied by segments of some of the largest glaciers in the region (Susitna, Black Rapids, Canwell, Gulkana and Chistochina Glaciers).

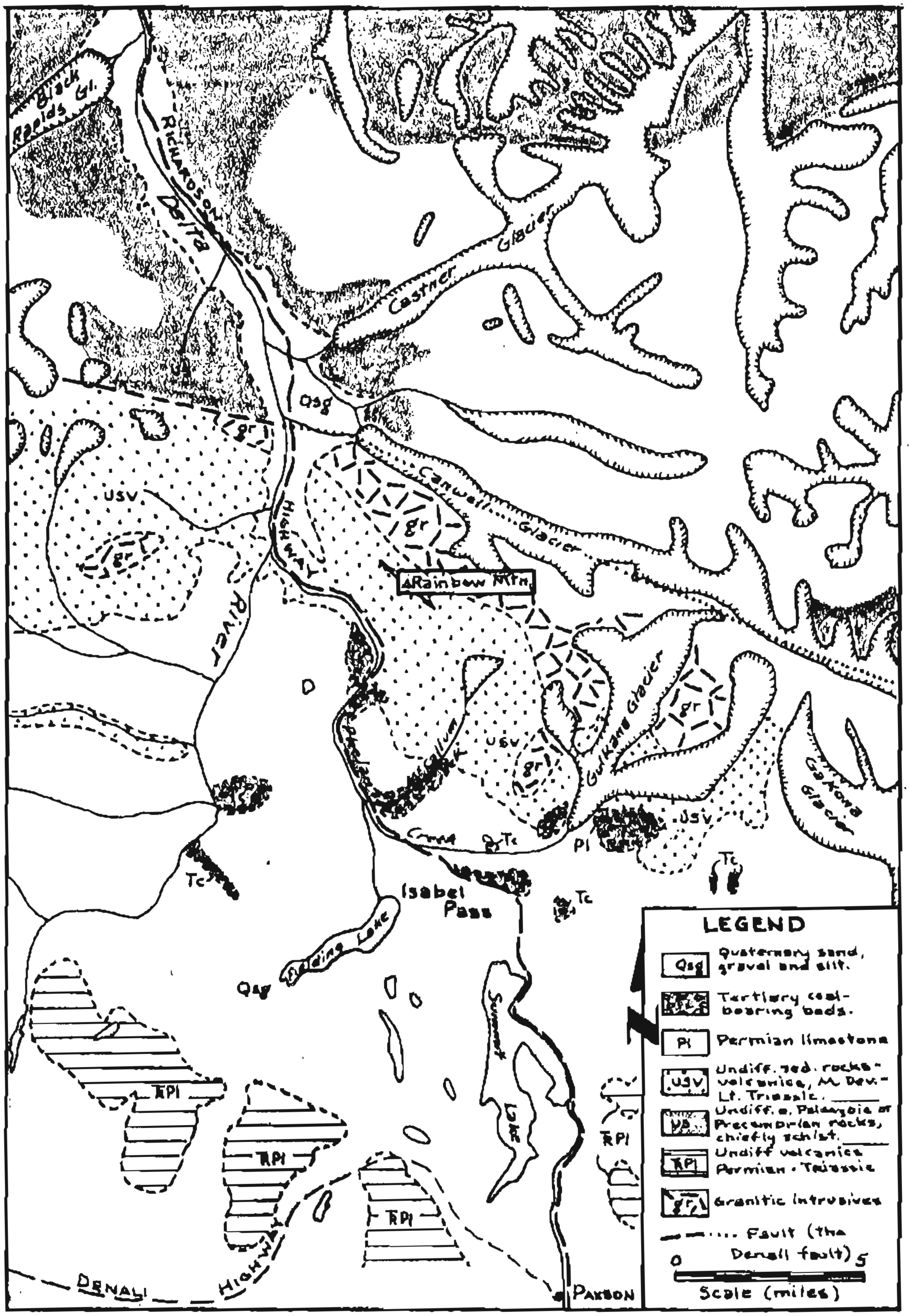

Fig. 8.--Generalized geologic map of the Rainbow Mountain-Gulkana Glacier area (taken from geologic map of eastern Alaska Range by Moffit (1954).

It can be traced without major interruption to the southeast along the Alaska Range into Canada, and is believed by many to continue south through Chatham Strait in Southeastern Alaska.

The magnitude and direction of displacement along this "great fault" are controversial. A right lateral displacement of 150 miles has been proposed by St. Amand (1957). This has been sharply contested by some, who believe that lateral displacement does not exceed 20 miles. Muller (1958) suggests that the fault is a thrust, at least in the western Yukon and eastern Alaska. He holds that the southern block has been overthrust to the north and northeast. Wahrhaftig (1954) believes that the Denali is a reverse fault and that the northern block is upthrown.

Regional Geologic History

According to Payne (1951) the area occupied by the present Alaska Range was the site of a major geosynclinal trough during early Paleozoic time (Cambrian-Silurian). This geosyncline was receiving sediments primarily from volcanic sources to the south. The environment was chiefly eugeosynclinal. The miogeosynclinal portion of the trough lay to the north, and was accumulating more pelitic sediments derived from a stable continental mass, which was then located near the present Arctic Ocean.

Thousands of feet of graywackes, limestones, tuffs and lava flows were probably deposited throughout much of the area which is now the Alaska Range, but these rocks have been eroded and obscured by metamorphism, and there is little direct evidence of their presence. An orogenic disturbance during early Devonian time folded and recrystallized these pre-Devonian rocks. Following uplift and erosion, the reactivated geosyncline continued to migrate northward, enclosing the entire Alaska Range area in the unstable eugeosynclinal phase. During late Paleozoic time, thousands of feet of basic volcanics, graywackes, tuffs and carbonates were deposited. The extrusion of lavas increased in frequency through Permian time, reaching a maximum during early Mesozoic time in the east central Alaska Range (Moffit, 1954).

The single linear geosyncline became less well defined during Triassic and Jurassic time, and various segments of the Alaska Range subsided at different times to form dependent (?) geosynclines. These received sediments and basic volcanics from adjoining volcanic island arcs (Payne, 1951).

According to Payne (1955), major deposition ended with the early Cretaceous (Late Neocomian-Aptian) orogeny. Renewed deposition of marine sediments followed with the subsidence again in Albian-Cenomanian time. The ensuing Turonian orogeny was followed by erosion over most of the Alaska Range. Continental deposition continued in many areas during Late Cretaceous and Tertiary times. Several early Tertiary orogenic pulses resulted in further deformation of the Alaska Range geosynclinal belt and Nutzotin segment (fig. 9). Epeirogenic (?) uplift of the Alaska Range continued throughout Tertiary and Quaternary periods to the present.

PETROLOGY OF ROCK UNITS

Pre-Mississippian metamorphic rocks

Field Occurrence

This unit includes the phyllites, calc-phyllites, greenschists and impure marbles which occur in the extreme northwest part of the map area (see sectors C-5 and D-5, plate 1). These rocks occur in three distinct fault-bounded blocks (see plate 1), which contact to the south the rocks of the Pennsylvanian Rainbow Mountain sequence, along one fault and the quartz diorite gneiss along a second fault. To the north outcrops of phyllite and calc-phyllite can be traced to the southern margin of the Canwell Glacier, where they are covered by moraine. The Pre-Mississippian metamorphic rocks probably lie in fault contact (the Denali Fault) with the medium grade crystalline schists of the Birch Creek complex, which compose the ridge north of the Canwell Glacier. These possible relationships are, however, covered by ice of the Canwell Glacier.

A number of serpentinized ultramafic dikes have been intruded into the phyllites and greenschists in the southern fault block (see plate 1). This area is mapped separately; as the Serpentinite complex.

Delicate intercalations of phyllites, calc-phyllites and minor impure marbles and greenschists characterize the rocks of the two north fault blocks. In contrast, greenschists are major while calc-phyllites are subordinate and impure marbles rare in the south fault block. The

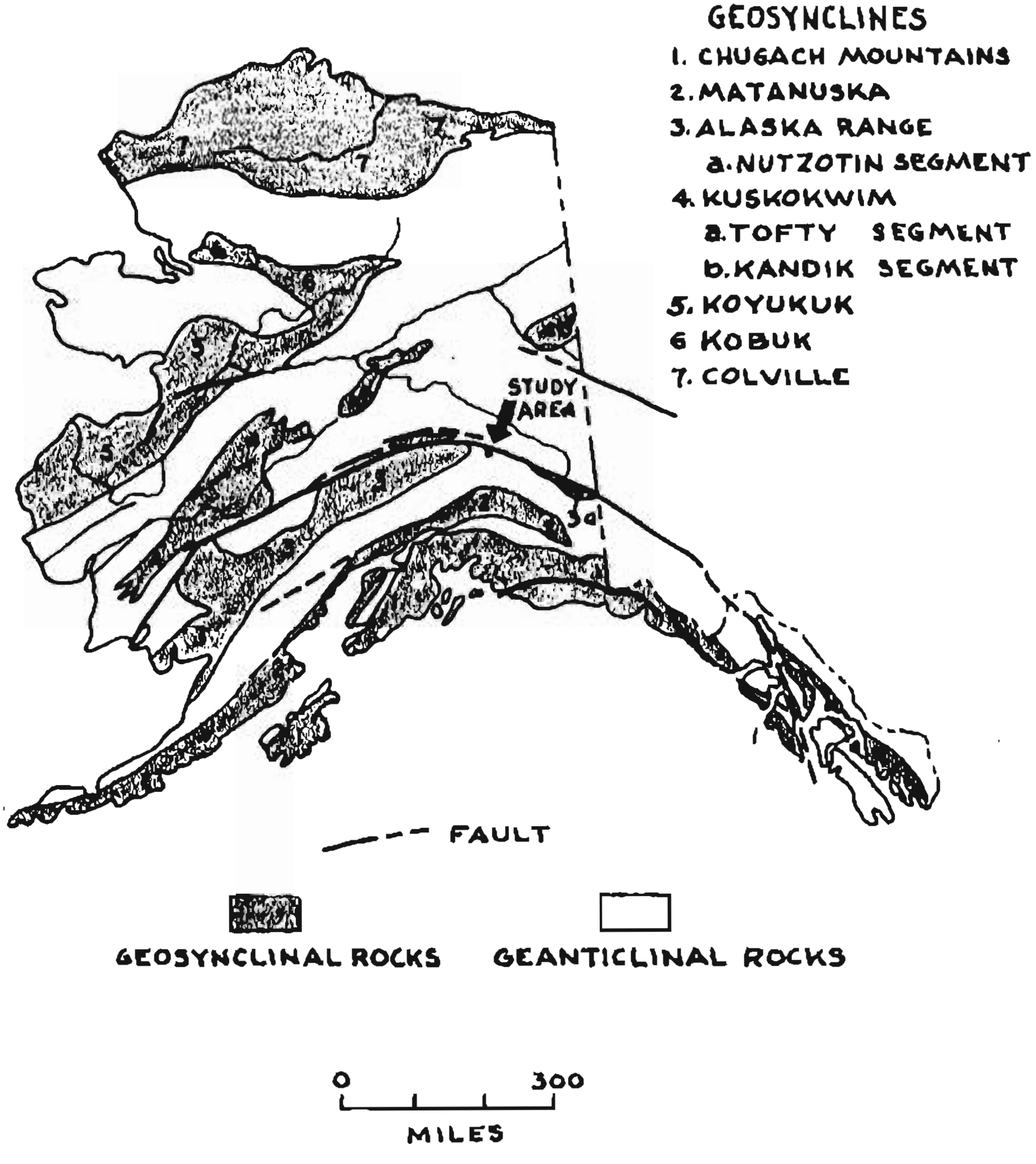

Fig. 9.--Late Mesozoic geosynclinal rocks of Alaska. (taken from Gates and Gryc, 1963)

thicknesses of the interbedded phyllites and greenschist layers vary between 2 and 10 feet in this part of the section.

Petrography

Phyllites and Calc-phyllites

Mineralogy.--Quartz, albite, chlorite (clinochlore), sericite, and carbonate are the major constituents in these rocks. Stilpnomelane, carbonaceous matter, epidote (clinozoisite) and actinolite are often present as minor or accessory constituents. Magnetite and leucoxene are common accessory minerals. Quartz and albite are the most abundant minerals in the phyllites; and carbonate is the dominant mineral in many calc-phyllites. With an increase in actinolite, epidote, stilpnomelane and chlorite, the phyllites and calc-phyllites grade into greenschists and carbonate-bearing greenschists.

Representative equilibrium metamorphic mineral assemblages from the phyllites and calc-phyllites are listed below:

phyllites	(sericite-chlorite-albite-quartz ((stilpnomelane-chlorite-quartz-albite ((sericite-chlorite-calcite-albite-quartz
calc-phyllites	(chlorite-carbonate-albite-quartz ((stilpnomelane-sericite-carbonate-albite-quartz

Fabric.--The grain size in the phyllites and calc-phyllites ranges from .05 to .2 mm. Porphyroblasts are generally rare. However, on the north margin of the north fault blocks (near Canwell Glacier), the units exhibit megascopic albite-oligoclase porphyroblasts. The anorthite content of these porphyroblasts is high for a true low grade phyllite, and these rocks may represent transitions between phyllites and medium grade schists.

Two and commonly three s-surfaces are present in the fabric of these rocks. Compositional layering (s_1), is probably bedding inherited from the parent sediments; s_2, a crystallization foliation, defined by the preferred orientation of platy minerals, usually parallels compositional layering; and s_3 is an incipient axial plane foliation defined by platy and prismatic minerals (quartz and feldspar) in some areas. s_1 and s_2 are tightly folded and s_3 typically transects these at the fold axes (fig. 10).

Greenschists

Mineralogy.--The major mineral constituents of the greenschists include actinolite, chlorite (pennine and clinochlore) and albite. Quartz, carbonate and epidote (clinozoisite) and stilpnomelane are usually present and are only major constituents in some greenschists. Magnetite, leucoxene and pyrite occur as accessories.

Only a few greenschists were examined petrographically; this was insufficient to establish the modal variation of these rocks. Equilibrium metamorphic mineral assemblages of probably representative greenschists are listed below:

(chlorite-calcite-albite-actinolite
(
greenschists (clinozoisite-quartz-albite-chlorite-actinolite
(
(stilpnomelane-actinolite-calcite-clinozoisite-chlorite

Fabric.--The greenschists exhibit a range in average grain size similar to that of the phyllites. Some layers, however, contain large subhedral plagioclase porphyroclasts which appear to be relicts from the fabrics of igneous parent rocks. These particular layers are more homogeneous than the more typical greenschist units which are composed of laminations of greenschist and chlorite phyllite.

The greenschist fabrics also contain s_1, s_2, and s_3 surfaces as previously described in the phyllites and calc-phyllites. The s_2 and s_3 surfaces of the greenschists are defined by the preferred orientation of actinolite, chlorite and stilpnomelane and similarly represent two stages of penetrative movement with s_2 being tightly crumpled.

Marbles

Mineralogy.--Minerals found in most marbles include carbonate (calcite), albite and albite-oligoclase, quartz, carbonaceous material, sericite, magnesian chlorite, clinochlore, sphene and magnetite. The purer marbles characteristic of the northern occurrence of the unit contain accessory albite and sericite. The impure marbles which are more typical of the rocks of the southern fault blocks have carbonate, albite, quartz and generally clinochlore as major constituents. Other chlorites, sericite and carbonaceous materials are usually minor with sphene and magnetite as accessories. Marbles gradational to calc-phyllites are common. Sericite and usually clinochlore are major constituents of these rocks.

Examples of marbles which appear typical are:

(carbonaceous-chlorite-sericite-quartz-albite-calcite
(
marbles (sericite-quartz-chlorite-albite-calcite
(
(quartz-albite-calcite

Fabric.--The marble units in both north and south fault blocks display essentially complete recrystallization and the development of a crystallization foliation in the impure varieties (fig. 11).

Grain size generally ranges from .05 mm to .2 mm; similar to other rocks of the sequence. The mean size of carbonate grains, however, is commonly larger (.2 mm to .4 mm) than other constituents in many marbles. Porphyroblasts (.2 mm to .5 mm) of albite and albite-oligoclase in some of the extreme northern occurrences are common. Albite twinning of the albite-oligoclase porphyroblasts is displayed in these rocks along the northern limit of the sequence.

Fabric surface s_1, s_2, and s_3 are well developed in the impure marbles as they are in the phyllites and greenschists. Surfaces s_2 and s_3 are defined by the preferred orientation of sericite, carbonaceous material and the chlorites (fig. 11).

An anomalous carbonate occurrence

A restricted occurrence of incompletely recrystallized and brecciated limestone which is associated with quartz diorite gneiss and phyllites and greenschists of the pre-Mississippian rocks outcrop along the crest of the ridge in sector D-5(C). This unit can be traced across the canyon to the east, sector D-5(EC), where it topographically overlies the phyllites and greenschists with apparent structural conformity. The incomplete recrystallization of this carbonate unit as compared to the phyllites and greenschists is not understood.

These carbonates are in part dolomitic. Thin lenses and layers of chert and quartzo-feldspathic aggregates (a few millimeters in thickness) occur as impurities. Fossil fragments (?) and clastic carbonate (intraclasts) (?) embedded in a fine grain clastic matrix are typical constituents.

The primary sedimentary structures and textures are generally obscured by the fine degree of brecciation which is characteristic of these rocks. Brecciation appears to be a result of local shearing. The fragmented particles are coated with ferric oxide which imparts a rust color to the outcrops.

Petrogenesis

The Pre-Mississippian metamorphic rocks are composed of low grade crystalline schists derived from a succession of interbedded argillaceous, calc-argillaceous and impure carbonate rocks. The delicate compositional layering and high carbonate content of many greenschist layers implies a sedimentary rather than igneous parentage. The massive greenschists containing relict phenocrysts were derived from basic igneous rocks.

The metamorphic mineral assemblage from representative crystalline schists are typical of the low grade zone of synkinematic metamorphism. There appears to be, however, a slight increase in grain size of these rocks to the north, from phyllites to phyllitic schists. This suggests a possible corresponding increase in metamorphic grade. The average grain size of sericite increases, although coarse grained muscovite does not occur; and the phyllitic calc-schists and impure marbles which occur near the southern margin of Canwell Glacier exhibit coarse, twinned albite-oligoclase grains. These, however, may not be porphyroblasts but relicts, instead, from parent sedimentary rocks (porphyroclasts).

The relationships between the crystalline schists and parent rocks are shown in the table below:

argillaceous sediments → phyllites
calc-argillaceous sediments → calc-phyllites
calc-magnesian argillaceous sediments → greenschists
basic igneous rocks → greenschists
impure carbonates → marbles (impure)

Serpentinite complex

Field occurrence

A network of serpentinized periodotite and serpentinite dikes and sills, intrude the phyllites and greenschists of the Pre-Mississippian metamorphic rocks.

The complex is confined in outcrop to a prominent north-south trending ridge located in sector D-5(EC) (see plate 1). It occupies a one-quarter square mile area of the southern fault block of the Pre-Mississippian metamorphic rocks

The ultramafic dikes and sills average from 5 to 10 feet in thickness. Some bodies are as thin as a few inches and several others appear to be more than several hundred feet wide. The layers of phyllite and greenschist which separate individual intrusions consist of narrow (a few feet), discontinuous lenses which are minor in the unit volume.

The majority of the dikes and sills are parallel to subparallel and strike in a northwest to westerly direction; however, a few strike to the west to southwest. Dips vary from a low of 20° to 25° to the more common 70° to 90°. The foliation of the serpentinites generally parallels these attitudes although sharp deviations in strike of as much as 90° in a few inches are common.

Petrography

Limited microscopic analyses of these rocks indicate that dominantly serpentinized peridotite compose the dikes and sills. Serpentinites, however, probably represent a major portion of this network. Olivine (Fo70), enstatite (En90-95) and antigorite are the major mineral constituents. Minor constituents of some rocks include chrysotile, "iddingsite," magnetite and clinopyroxene (diopsidic?). Carbonate, chlorite, chromite and phlogopitic mica (?) occur as accessories.

Modal analyses of two specimens of serpentinized peridotite showed:

Mineral	Per cent	
	(1)	(2)
olivine	25	32
enstatite	15	22
antigorite	41	28
chrysotile	13	22
opaques (mainly magnetite)	3	7
"iddingsite"	-	5
clinopyroxene	2	2
accessories	1	1

Olivine grains are subhedral and average one to two millimeters in size. Orthopyroxene occurs interstitial to olivine as large (2 mm to 4 mm) anhedral grains.

Secondary deformation textures are cataclastic in origin. Primary olivine grains have been granulated and alteration has concentrated along the fractures.

A foliation has been developed in some phases of the dikes and sills. The origin and microscopic characteristics of this structure have not been determined.

The petrography of the phyllites and greenschists discussed in reference to south fault block occurrence of the Pre-Mississippian metamorphic sequence applies equally well to the corresponding rock types of the Serpentinite complex.

Petrogenesis

On the basis of the partial examination, two equally likely events can explain these rocks:

1. intrusion into non-metamorphic succession with serpentinization occurring during metamorphism.

2. serpentinization occurring during emplacement.

The McCallum Creek and Rainbow Mountain sequences

The Mississippian (?) McCallum Creek sequence and the Pennsylvanian Rainbow Mountain sequence are lithologically very similar. The distinction between these is based primarily on fossil content (different ages indicated) and the succession of strata. The two units are separated by a fault (J) (see plate 1).

In the following sections, the field occurrence of each of these units is discussed separately. A combined study of both McCallum Creek and Rainbow Mountain lithologies (Petrography) then follows. The succeeding chapter deals with the stratigraphy and paleontology of these units.

Field Occurrence

McCallum Creek sequence

The McCallum Creek sequence includes the altered Mississippian (?) sedimentary and pyroclastic rocks which occupy the extreme southern portion of the area and are well exposed in the canyon of lower McCallum

Creek. The geologic map (pl. 1) illustrates the areal distribution, contact relationships and general lithologic character of the sequence.

Field studies of Gerard Bond in 1963 (personal communication) indicate that this unit extends for at least three miles southeast from McCallum Creek beyond this study area. The possible distribution of the sequence to the northwest beyond Phelan Creek was not investigated. To the northeast the McCallum Creek sequence contacts the Rainbow Mountain sequence along a major fault. A porphyritic andesite mass bounds the McCallum Creek sequence to the southwest (a fault contact (?)) in the Rainbow Mountain area.

Several other sill-like bodies of porphyritic andesite intrude the sequence. One of these andesite layers (southeast corner of sector C-2) may be a flow; this relationship, however, is not established.

Rainbow Mountain sequence

The Pennsylvanian sedimentary and volcanic rocks of the Rainbow Mountain sequence occur north of the McCallum Creek sequence and underlie most of the main ridge of Rainbow Mountain. The distribution of the major lithologies and contact relationships are shown on the geologic map, plate 1.

The Carboniferous (?) rocks exposed west of Phelan Creek have not been definitely assigned to this unit. Granodiorite and quartz diorite plutonic rocks bound the sequence to the east and northeast. Both intrusive (sector A-3 (WC)) and fault contact (sectors B-3(SE) and B-4(SW)) relationships with these intrusives are mapped. The southeastern limit of the sequence is not defined with this study.

Petrography

For discussion purposes, the rocks of the McCallum and Rainbow Mountain sequences are divided into three groups which are: (1) detrital sedimentary rocks ("graywackes"), (2) limestones, and (3) volcanics.

Detrital sedimentary rocks ("graywackes")

According to Folk (1954) there are five important variables in the description of sedimentary rocks. These are: (1) grain size, (2) cementing material, (3) textural maturity, (4) miscellaneous transported constituents, and (5) clan designation. A rock described using this system might be: fine sandstone; siliceous, submature, glauconitic orthoquartzite. The system of Folk outlined above is used in this report for all variables except the restricted clan designation.

There is no classification scheme which adequately defines most of the clastic detrital rocks encountered in the study area. The rocks are of graywacke-like occurrence, but they are not graywackes (or arkoses) intended in such classification schemes as Pettijohn (1957), Krynine (1948), Folk (1954), or Hubert (1960). Therefore, the term "Graywacke" is used only in a broad sense to apply to all volcanic derived rocks, and there is no specific mineral composition implied as in other classifications. In addition, the variations in mineral composition are presented in tabular form and the reader may interpret these data in any way he chooses.

The granular fraction of breccias, finer grained clastics and pebble conglomerates of the Carboniferous sequence are as follows:

Breccias and finer grained clastics

Grains--detrital particles larger than .03 mm

1. Volcanic rock fragments

   andesitic-porphyritic andamygdaloidal porphyritic

   dacitic

   basaltic (minor)

2. Plagioclase--oligoclase and andesine

3. Quartz

4. Limestone fragments in some zones or interbeds

5. Minor constituents

   amphibole

   pyroxene (rare)

   chlorite

   epidote

   magnetite

   leucoxene

Matrix--detrital particles less than .03 mm

1. plagioclase
2. quartz
3. chlorite
4. epidote
5. sericite
6. clay minerals

Cement

1. generally siliceous
2. calcareous common to rocks associated with limestone

Pebble conglomerates

Grains

1. chert
2. siltstone ("graywacke" composition)
3. tuff fragments

The remaining material is the same as that in the breccias and finer grained clastics.

The mineral composition of the sandstones and coarser rocks in the study area is such that there are complete transitions from rocks having the composition listed above to both limestones on the one hand and tuffs on the other, and at any place on the continuum, either rock fragments or feldspar may be volumetrically prominent. Tuffaceous rocks are locally abundant and are usually massively bedded. Highly calcareous rocks are commonly interbedded with limestones. Rocks intermediate between these are typified by graded bedding and appear to be "classic graywackes."

The detrital clastic rocks of the study area typically are dense and siliceous. Secondary alteration of the mafic constituents (mainly rock fragment components) to chlorite, and the common epidotization of the feldspar fraction have caused a characteristic green-gray color (magascopic). Alteration to epidote has generally been concentrated in layers of the fine clastics (siltstones and fine sandstones). The resultant pale yellow-green color of these strata contrasts with the epidote-poor darker green of the coarse clastic layers. This contrast produces a striking stratification.

Most silicate constituents are angular to subrounded in form. Carbonate and other soft mineral grains are round to subround. Medium to coarse clastics are poorly sorted as indicated by the high matrix content (4% to 20% in most layers) and a correspondingly low cement content.

Most "graywacke" units are well bedded in layers which generally vary from a few inches to 3 feet in thickness. Graded bedding is common; each layer exhibits a gradation from coarse sandstone or pebble breccia-conglomerate to siltstone or fine sandstones. Other layers are more massive or thickly bedded. Laminated (non-graded) units are also common (fig. 14).

Examples of the more typical lithologies encountered in the study area are listed in table 1.

Limestones

The most abundant limestones in the study area are composed of a poorly sorted mixture of fossil fragments and rounded grains of clastic limestone (intraclasts) set in a matrix of microcrystalline ooze (chemically precipitated calcite analogous to matrix in a detrital rock). Feldspar, quartz, and volcanic rock fragments are major impurities in most limestones, and magnetite, chlorite, clay, hematite, and pyrite are minor impurities.

Silty autochthonous (entirely chemically precipitated) limestone is a major lithology in unit f of the Rainbow Mountain sequence (fig. 26). These rocks contain abundant hematite which imparts a

TABLE 1.--Typical detrital rocks ("graywackes") of the McCallum Creek and Rainbow Mountain sequences.

Specimen Number	Textural Class	Cement	Textural Maturity	Miscellaneous Transported Constituents	Structure and Alteration	Modal Analysis (%)					
						V*	P*	F*	Q	O	M
8-17-1	coarse siltstone medium sandstone	siliceous	immature	-	graded bedding sausseritized	8		63	2	10	17
7-24-31	fine-very fine sandstone	siliceous	-	-	graded bedding sausseritized	36		38	1	15	10
8-2-15	fine-coarse sandstone	siliceous	immature-submature	-	laminated graded bedding	72	?	15	2	3	8
7-17-1	pebbly coarse sandstone	calcareous siliceous	immature	tuffaceous fossiliferous	stratified epidotized	13 ?	12	18	18	39	10
8-17-2	sandy pebble conglomerate	siliceous	immature-submature	tuffaceous	graded bedding chloritized	53		8	6	8	15
8-15-4	silty, fine-coarse sandstone	siliceous	immature	tuffaceous	laminated chloritized	2		41	26	11	20
6-11-7	coarse sandstone	calcareous siliceous	immature-submature	fossiliferous tuffaceous	massive silicified	8		46	-	31	15
6-8-26-2	silty coarse sandstone	calcareous siliceous	immature	fossiliferous tuffaceous	massive silicified	48 ?	7	9	3	21	12
8-16-14	pebble conglomerate	siliceous	immature	-	massive epidotized	77 ?	?	2	1	10	10
6-21-18	very coarse sandstone	siliceous calcareous ferruginous	immature-submature	glass	stratified	29		50	6	7	8
9-4-2	sandy fine pebble conglomerate	siliceous	immature	tuffaceous	massive silicified	76		7	-	8	9

*includes secondary alteration products

V = volcanic flow rock fragments
≻ combined where indistinguishable
P = pyroclastic rock fragments
F = feldspar grains
Q = quartz grains
O = other, (includes carbonate, chert and other granular constituents)
M = matrix and cement, (cement constitutes no more than 3 per cent of any of these rocks)

maroon color. In other units autochthonous limestones are minor and are usually intercalcated with allochthonous (clastic) limestones and transitional varieties.

The allochthonous (clastic) limestones consist of fossil fragments and intraclasts cemented by sparry clacite. This variety also exhibits impurities of volcanic origin (e. g., plagioclase and volcanic rock fragments).

A discussion of the aspects of paleontology related to the dating of the units is contained in the following chapter. In general, however, the fauna contributing the fossil fragments common to most limestones are principally: (1) crinoids, (2) brachiopods, (3) bryozoans, (4) corals, and (5) foraminifers. Some layers particularly in unit f, are crinoidal limestones. Brachiopod-bryozoan-crinoid coquinas are confined to thin (less than 2 feet) layers in limestones of the Rainbow Mountain sequence.

The clastic grains composing most limestones range between .1 mm and 2 mm in size. Intraclasts are rounded. Silicate impurities are subrounded to subangular.

The limestones of the McCallum Creek sequence are apparently more silicified than most carbonates of the Rainbow Mountain sequence. A few exceptions are noted, however, and this silicification probably relates more to lithologic association (e. g., silica source in the volcanics) than to structural position and age differences. Most limestones are slightly silicified although non-silicified types and those in which only allochems are silicified are common.

The ratio of transported chemical fragments to cement varies greatly within any one major limestone unit. Layers composed almost totally of transported chemical fragments contrast with adjacent layers of predominantly chemically precipitated ooze. Stratification (thin bedded to laminated) is defined in part by this variation of the allochem-orthochem ratio.

Some of the more common limestone lithologies of the McCallum Creek and Rainbow Mountain sequences are listed below in approximate order of decreasing abundance:

Rock name

intramicrudite-_intramicrite_*

volcanic detritus bearing, fossiliferous.

(fossiliferous, sandy calcarenite-calcirudite).

intramicrite-_intramicrudite_*

fossiliferous (fossiliferous calcirudite-calcarenite).

biomicrite-_biomicrudite_*

intraclast bearing (highly fossiliferous calcarenite-calcirudite with some coquina).

intraparudite-_intrasparite_*

volcanic detritus bearing, fossiliferous.

(fossiliferous, sandy calcarenite-calcirudite).

_micrite_*

fossiliferous.

(fossiliferous lithographic limestone)

_micrite_*

(lithographic limestone)

---

*Classified according to Folk (1959).

Volcanics

Various pyroclastic rocks comprise a major part of the Carboniferous sequences. Andesite flows also occur in association with some pyroclastic units but are minor in the sequence in general.

Pyroclastics.--Pyroclastics of two major compositions occur in both the McCallum Creek and Rainbow Mountain sequences. These are: (1) dacite and (2) andesite.

Dacite tuffs:--There appears to be little mineralogical variation within the thick beds of these pyroclastics. They are primarily crystal tuffs and crystal lapilli tuffs. Lithic lapilli tuffs are minor.

The most common variety of tuffs include approximately equal quantities of coarse grained quartz and plagioclase with minor mafic minerals and rock fragments. These are embedded in a fine-grained sericite and chlorite-rich quartzo-feldspathic matrix (fig. 18).

Alteration of some constituents is locally severe. Plagioclase grains have been decalcified (An_{30-35}), with the development of alteration sericite, epidote, carbonate and clay minerals (?). The primary mafic constituents (hornblende?) have been altered to chlorite. Lithic fragments of porphyritic dacite are major constituents in the coarser phases (dacite lapilli tuffs). These fragments are highly altered to aggregates of chlorite, sericite, epidote, and minor carbonate.

The matrix is composed of predominantly fine grained ($<$ 0.1 mm) quartz, plagioclase, sericite and chlorite. Epidote, carbonate, magnetite, leucoxene, sphene, clay minerals (?) and volcanic glass fragments are minor.

All gradations in particle sizes from ash to lapilli are common to these dacitic pyroclastics. Blocks and bombs are constituents in some layers.

Quartz grains occur as euhedral to subhedral dipyramidal forms with embayed surfaces. Straining and fracturing is characteristic of most of these grains; separation along these fractures is rare, however. Myrmekitic intergrowths are present but uncommon.

The coarse plagioclase grains are generally subhedral. Polysynthetic albite and pericline twinning is common.

Sericite and chlorite aggregates display a subparallel preferred orientation which in part defines a planar structure characteristic of these rocks. This structure in some areas represents a primary depositional feature--a bedding. Elsewhere it is the result of post-alteration shearing. In these layers, aggregates of alteration chlorite and sericite (derived from lithic fragments) have been "smeared out" coincident with bedding plane slip.

In outcrop, the rock is friable and has a gross appearance of weathered gneissic granitic rock. The volcanic-clastic fabrics (microscopically visible) and the interbedded relationships of these rocks with "graywackes" and impure limestones indicate the origin.

Andesite tuffs.--Pyroclastic beds of andesite lithic tuffs and lapilli tuffs occur as massive and stratified layers associated with dacitic tuffs and as isolated pyroclastic successions in mainly the units of the McCallum Creek sequence.

Andesite lithic fragments, most of which are amygdaloidal, predominate over plagioclase grains as the major constituents. Combined with minor pyroxene and other altered mafic grains (hornblende?), these constituents are set in in fine grained matrix of devitrified glass fragments and plagioclase along with minor quartz. Abundant pennine chlorite, sericite, and epidote are principally alteration products of the primary lithic, mafic, and plagioclase (oligoclase-andesine) fraction.

The lithic fragments are subangular to rounded and flattened masses which are usually oriented parallel to bedding as are the contained discoid aggregates of chlorite. These features probably represent, at least in part, a post-depositional flattening of the particles.

Flows.--The recognized flows consist dominantly of andesites, mostly porphyritic and amygdaloidal. These rocks appear similar in texture and mineralogy to the massive andesitic "sills" described in the following section.

One flow of basalt (labradorite, augite and minor olivine) was found associated with the andesitic volcanics (sector D-4(NC)). Basic flows may be more prevalent than implied in the discussion since fragments of these are common in many "graywackes." No dacitic flows were noted even though dacite pyroclastics are abundant in both sequences.

The typical andesite flow rocks contain altered plagioclase (An_{35}) and subordinate hornblende phenocrysts (20% to 35%) embedded in an aphanitic and partly vitric groundmass of plagioclase, hornblende, glass, and magnetite. These primary constituents have been partially altered to sericite, epidote, clay (?) (from plagioclase), and pennine, epidote and magnetite (from mafic constituents). Augitic pyroxene is a minor constituent of some flows as is quartz in others.

Amygdules compose less than 20% of these flow rocks and contain chlorite and commonly calcite and silica as fillings.

Atypical flows and flow phases are non-porphyritic and amygdule-free but otherwise similar in mineralogy and fabric.

Phenocrysts of porphyritic flows grade from .5 mm to 2 mm (an average maximum). These grains are typically euhedral to subhedral with plagioclase (decalcified andesine) displaying polysynthetic twinning as well as normal zoning (defined in part by magnetite inclusion patterns (fig. 20).

Flow structure, defined by the preferred orientation of lath shaped phenocrysts and slight compositional variations, is characteristic of zones of some flows. Columnar jointing is weakly defined with most flows. Other structural features (if present) and contact zones of flows are difficult to recognize in the field owning to the intense alteration, fracturing, and weathering of most volcanic layers.

Petrogenesis

The history of post depositional modifications of these units is complex. The determinations of origin and sequence of the diagenetic events which have brought about the many changes in the mineralogy and fabric of these rocks requires elaborate petrographic and stratigraphic studies beyond this study. In general the processes of silicification, chloritization, pyritization and other mineralization and replacement have been noted as being effective in modifying primary lithologies. Whether these changes represent one or more cycles of deuteric, hydrothermal or regional metasomatic processes has not been determined.

Hypabyssal rocks

Many hypabyssal masses have intruded the metamorphic, plutonic, and Paleozoic sedimentary rock units in the area. Five separate occurrences are defined. Each of these display distinctive mineral compositions.and petrogeneses. Those included can be classified as: (1) porphyritic andesite, (2) porphyritic rhyolite, (3) basalt-gabbro, (4) alkali gabbro, and (5) porphyritic dacite. Several other dike varieties apparently unrelated to these five types have been recognized; however, the field relationships of these as groups have not been adequately determined.

Porphyritic andesite

Field occurrence

This unit is volumetrically the most important hypabyssal occurrence in the area. These andesites are confined as sill-like intrusions into rocks of the McCallum Creek and Rainbow Mountain sequences. Although these bodies have sill-like form when examined on a large scale, each mass exhibits local discordancies and small dike offshoots (fig. 28). Several major "sills" (thicknesses varying to more than 1000 square feet) and many minor "sills" (less than 200 feet thick) have been mapped (see plate 1).

It is possible that some of the thin, poorly defined layers of andesite indicated as being of hypabyssal origin are effusive instead. All the major andesite bodies, however, display xenolithic layers and dike like offshoots along both contact surfaces which indicate their hypabyssal emplacement.

Petrography

Several slight variations in mineralogy and texture are noted among the prophyritic andesites. The more typical andesite exhibits both plagioclase (1 mm to 2 mm) and subordinate hornblende (1 mm to 3 mm), as phenocrysts (modal 25% to 30%) set in an aphanitic groundmass of primary plagioclase and mafic minerals (hornblende? and others) with abundant secondary sericite, epidote, carbonate, and chlorite (fig. 21). Quartz is minor or absent altogether.

The less typical andesite variations common to some "sills" show differences in (1) the volume of phenocrysts, (2) the ratio of hornblende to plagioclase in the phenocrysts, (3) the size of phenocrysts, and (4) the occurrence of amygdules.

In the McCallum Creek sequence (sectors B-2(SW) and C-2(SE)) an amygdaloidal andesite variety containing characteristically abundant (modal 45%) large (to 4 mm) plagioclase phenocrysts, crops out with a hornblende phenocrystal type as lithologies in a large, in part discordant, intrusion.

Several megascopic textural variations occur within the extensive andesite occurrences which underlie much of the high ridge in the eastern part of the area (sector A-3). Both phenocryst-rich (plagioclase) and phenocryst-poor rocks are common. This highly altered andesite probably composes more than one layer; several of these may be flows. The intrusion of the granodiorite pluton has statically metamorphosed a zone several hundred feet wide within this andesite complex. The andesites have been recrystallized to actinolite-epidote-chlorite-albite rocks (greenstones). Igneous textures are preserved.

The intensity of alteration varies within this general andesite unit. The contact zones of individual bodies show generally the greatest effects. The alteration assemblage of chlorite, epidote, sericite, and hematite causes a characteristic purplish green color in hand specimens. Toward the interior of these intrusions less intense alteration is apparent from the pale green color of these rocks.

A broad transition zone of andesite, rich in xenoliths (in varying degrees of digestion), marks the contact zones of most of the thicker "sills" (greater than 100 feet wide). These zones average 10 to 20 feet in thickness in most "sills", and some are more than 200 feet wide.

Porphyritic rhyolite

Field occurrence

Parts of two ridges in sectors C-5 and D-5 are underlain by porphyritic rhyolite (see plate 1). These occurrences, separated by a covered valley, are probably related. This dike-like intrusion pinches out to the west after attaining a maximum thickness of 500 feet.

The intrusion(s) crosscuts rocks of the Rainbow Mountain sequence and appears to be intruded by porphyritic andesite of the unit just described.

Petrography

These rhyolites are characteristically porphyritic. Euhedral to subhedral, quartz, and altered potassium feldspar phenocrysts (varying 1 mm to 5 mm in size) are contained in a matrix of aphanitic to fine-grain phaneritic potassium feldspar, quartz, some plagioclase, and alteration sericite, epidote, carbonate, and clay minerals. Abundant fine grain chlorite (from the alteration of pre-existing mafic constituents) colors these rhyolites an anomalous dark green.

Basalt-gabbro

Field occurrence

Two occurrences of basalt-gabbro (diabase primarily) are distinguished. One consists of a single swarm of near vertical dikes which cross cut all pre-Tertiary conglomerate rock units. Many of the thickest of these (greater than 5 feet) are shown on the geologic map (pl. 1). The dikes of the swarm which are subparallel in orientation trend eastwest in the eastern part of the area and swing to a northwestern trend in the northern part of the area. Individual dikes are relatively uniform in thickness and can be traced for several miles. Most dikes are less than 10 feet wide; however, several of thicknesses greater than 100 feet were mapped.

The second and most unusual occurrence of diabase intrusives cross cuts rocks of the McCallum Creek sequence in the southern part of the area (see plate 1). In map view this occurrence consists of a series of small, approximately circular bodies with diameters varying from 100 to 300 feet. These plug-like intrusions display more intensely altered mineral assemblages than do the dikes of the swarm but otherwise appear compositionally related to them.

No structural connection between these occurrences, however, was established.

Petrography

The mineral compositions of these basalt-gabbro intrusives vary slightly between bodies. A clinopyroxene and labradorite assemblage is characteristic of most dikes. Augite (commonly titaniferous) is the common pyroxene. Pigeonite is locally a major constituent. Another variety of dike, a gabbro, contains hornblende and decalcified andesine-labradorite as major constituents. All mafic constituents are at least partially altered to chlorite, and feldspars are moderately saussuritized and weathered to clay minerals. An uncommon amphibole (pale green hornblende) is altered to actinolite as well as chlorite.

Alkali Gabbro

Field occurrence

A few alkali gabbro dikes (less than 25 feet in thickness) intrude the Pre-Mississippian metamorphic rocks. These dikes are further cross cut by the diabase dike swarm.

A compositionally similar but possibly unrelated dike intrudes a porphyritic andesite hypabyssal (?) body in the southern part of the area and crops out along lower McCallum Creek (sector B-1(NE)).

Petrography

These dikes are distinguished in outcrop by a relatively high specific gravity, a dark green color, and fine grained equigranular texture.

Hornblende and subordinent (?) diopsidic pyroxene predominate over plagioclase and interstitial potassium feldspar and quartz as the major mineral constituents. Biotite is a significant mineral in the dike rocks of the northwestern occurrence. The mafic constituents have been chloritized. Feldspars are altered to sericite. Plagioclase shows additional alteration epidote and carbonate. Grains of primary constituents range up to 7 millimeters in size.

Dacite

Field occurrence

Several small, isolated but apparently related, lenses of porphyritic dacite crop out along major fault traces (faults "E," "F," and "N") in sectors B-3(SW and WC) (see plate 1). This relationship suggests that these bodies were intruded along the zones of structural weakness.

Petrography

Plagioclase (An_{36+}) and minor quartz occur as coarse (5 mm maximum) subhedral phenocrysts in a fine dark green groundmass of primarily feldspar, quartz, and chlorite. Locally potassium feldspar is included as a major phenocrystal and groundmass constituent. Rocks of these latter phases are best classified as rhyodacites.

The minor primary mafics, confined to the matrix, have been thoroughly chloritized. Epidote (from plagioclase) and sericite (from potassium feldspar) are additional alteration products of minor abundance.

Other hypabyssal rocks

Several thin (1 ft to 4 ft) dikes of light colored porphyritic andesite cross cut the Rainbow Mountain sequence and most of the associated hypabyssal units. These bodies which appear to be randomly oriented are unrelated to the major porphyritic andesite "sills" which were injected earlier.

Other light colored dikes contain abundant altered potassium feldspar in addition to major plagioclase and quartz as phenocrysts in a comparable groundmass. These thin scattered intrusions appear to be quartz latites.

Petrogenesis

These rocks were intruded following the deposition of the Carboniferous sediments. The porphyritic andesite "sills" were emplaced prior to the Mesozoic (?) orogeny which caused the major folding of these sedimentary units. The principle dike units were injected concurrently with or following this orogeny. The intrusion of the porphyritic rhyolite and porphyrite dacite dikes preceded that of the diabase dike swarm. The rhyolites and/or dacites may be related to the hornblende granodiorite pluton which appears to have been intruded during a corresponding geologic period (Cretaceous). The relationships of the alkali gabbro dikes to the orogenies following the "sill" intrusion are unknown.

The leucocratic dikes (porphyritic andesite and quartz latites) are among the latest of intrusions.

The summary of the geologic history (table 4) relates some of these intrusions to other geologic events.

Plutonic rocks

General statement

Several granitic bodies representing one or more plutonic intrusions are recognized within the Rainbow Mountain-Gulkana Glacier area: (1) a mass of medium grained relatively fresh quartz diorite (the Gulkana phase) underlies much of the floor of Gulkana Glacier, (2) quartz diorite also crops out along the south side of Canwell Glacier in sectors B-4, C-4, and C-5 (pl. 1), (3) north of the Denali lineament and principally west of the Delta River another granitic mass has been intruded, (4) a distinctive, highly altered quartz diorite gneiss of probable plutonic origin crops out chiefly in a linear pattern near the northern limit of the map area in sectors C-5 and D-5, and (5) a granodiorite mass occupies much of the area just east of the ridge of Rainbow Mountain.

No areal limits of any of these bodies have been examined in detail nor are the relationships between them known. The quartz diorite gneiss and the granodiorite mass are located in part within the study area and are discussed in the following sections.

Quartz diorite gneiss

Field occurrence

Quartz diorite gneiss occurs in a northwest trending fault block or wedge in sector C-5 and D-5 (see plate 1). Another faulted (?) segment crops out in the canyon wall (sector D-5(C and NC)) for a distance of one-half mile south of fault U (pls. 1 and 4). In the latter occurrence the mass is partially capped (fault or unconformity) by Pre-Mississippian metamorphic rocks.

Petrography

Andesine, quartz, hornblende, pennine chlorite, and clay (?) minerals are major constituents in most of these gneisses.

For the most part, the composition of the gneiss is narrowly quartz dioritic. Quartz poor (dioritic) phases occur locally. Plagioclase (in slightly decalcified grains, An_{30-35}) is altered to epidote (clinozoisite) carbonate and sericite, and highly weathered to clay (?) minerals. Alteration and weathering products commonly constitute more than 50 per cent of original plagioclase volume. Grains are inequigranular (1 mm to 3 mm), anhedral, and slightly elongate. Albite twinning is preserved in many grains. Quartz has a similar habit and grain size variation. Leucocratic constituents in many gneisses are distinctly serrated in form. The mafic minerals associated with the dark components of the gneiss are alteration or retrograde products from the conversion of hornblende. These minerals include pennine chlorite, pistacite, and minor actinolite. In some phases very little primary hornblende is relict; elsewhere it is abundant. Apatite and magnetite are common accessories. No potassium feldspar was observed in this gneiss.

The following shows the variation in the mode of constituents for five specimens.

mineral	specimen number				
	(1)	(2)	(3)	(4)	(5)
plagioclase	18	33	42	32	39
quartz	12	37	3	15	4
hornblende	20	-	2	1	5
epidote (pistacite)	11	3	14	13	12
chlorite (pennine)	18	5	15	4	22
carbonate	3	3	2	5	6
sericite	11	4	4	8	7
clay (?) minerals	6	14	17	10	4
accessories	1	1	1	2	1

The gneiss exhibits an equigranular xenoblastic texture. Foliation is defined by the coarse to fine, subparallel minerals which occur as elongate anhedral (amoeboid-like) grains (fig. 25). All mineral constituents have been affected by the cataclasis and partial recrystallization which have been responsible for the gneissic fabric. Compositional layering (parallel to foliation) is pronounced in some gneisses. In most phases, however, the gneiss is massive.

Petrogenesis

The narrow compositional limits over a fairly large area suggest that the quartz diorite gneiss was derived from a preexisting igneous mass.

Of a number of possible origins, two seem most likely:

1. A marginal portion of one of the Mesozoic quartz diorites (e.g., Canwell phase, see figure 24) was deformed during or after intrusion. Foliation banding, recrystallization and cataclasis would then be products of this event. The apparent transition from directionless Canwell quartz diorite to gneiss with just a few apparently small displacements supports this view (R. B. Forbes, personal communication), as does the mineralogic similarity of these bodies.

2. The quartz diorite intrusion and its metamorphism were both pre-Mississippian events, perhaps related to the metamorphism of the pre-Mississippian sediments. This view is supported by the observation that: (1) there is an absence of deformed and schistose post-Mississippian sediments and igneous rocks in the area and (2) the occurrence of quartz diorite gneiss of virtually identical composition to the quartz diorite gneiss in question has been recognized in a definitely pre-Mississippian higher grade schist-gneiss-migmatite complex located 4 miles farther to the east (D. M. Ragan, personal communication).

Hornblende granodiorite

Field occurrence

The granodiorite mass is intruded into sediments, flows and some hypabyssal rocks of the Rainbow Mountain sequence.

The occurrence is separated into two linear belts. R. B. Forbes (personal communication) has mapped hornblende granodiorite in a narrow belt along the southern margin of Canwell Glacier, (see pl. 1), sectors B-9, B-5, and C-5. This belt is separated from the main occurrence of the granodiorite, sectors A-3, B-3, and B-4, by a mass of quartz diorite and dunite also mapped by Forbes.

To the west, the pluton has been faulted into contact with the Rainbow Mountain sequence (along faults G and Y (pl. 4)). Intrusive contacts are noted along the southeastern margin of the granodiorite.

The eastward limit of the granodiorite body has not been conclusively determined.

The granodiorite body forms fresh, sharp, light colored outcrops and yields coarse blocky talus as a result of the uniform well developed joint sets. Reddish iron oxidation staining darkens the joint surfaces of the rocks in zones adjacent to major faults.

Petrography

Only minor variations in mineralogy and texture occur throughout the mass of hornblende granodiorite. The major primary mineral constituents include andesine and quartz. Hornblende and potassium feldspar are minor with zircon and magnetite as common accessories.

A representative modal analysis shows:

plagioclase-andesine (decalcified An_{40}) with alteration products (epidote, carbonate, sericite and clay minerals)	54%
quartz	34%
potassium feldspar-orthoclase (?) with sericite and clay minerals as alteration	6%
amphibole-hornblende, plus alteration chlorite, epidote and biotite	5%
accessories-zircon and magnetite	1%

Andesine occurs in subhedral to anhedral grains which are moderately to highly altered primarily to epidote and clay minerals and minor carbonate and sericite. Grains vary in size to a maximum of 5 mm. Albite twinning is common and normally zoned plagioclase grains are typical of some granodiorite phases.

Most quartz grains are uniquely coarse and equidimensional in form but show irregular margins which identify the interstitial habit. Other grains are small and amoeboid in form (fig. 23).

Potassium feldspars form anhedral to euhedral grains; the former are interstitial. These grains have been highly sericitized.

The primary mafic constituents have been altered to chlorite, epidote, and biotite in part. Relict hornblende grains are scattered in subhedral aggregates. Accessory magnetite is primarily an alteration product.

Glomeroporphyritic masses of mafic mineral-rich aggregates are typically scattered throughout the intrusion. Many exhibit a diameter of as much as 10 cm to 20 cm; however, most vary from 1 cm to 3 cm. Xenoliths of andesitic and sedimentary rock composition derived from the country rock are abundant along some intrusive contacts.

The granodiorite is readily distinguished in the field from other plutonic varieties by the nature of the coarse grained texture of quartz and the relatively low color index (5-10).

Petrogenesis

A normal sequence of crystallization of the constituent minerals is indicated. The early crystallization of plagioclase was accompanied in part by the development of the mafic constituents. More calcic plagioclase grains crystallized initially and were compounded by the addition of progressively more albitic rims. Potassium feldspar partially crystallized later to form fine euhedral-subhedral grains. Quartz formed during the last stages of crystallization as interstitial masses. A late magmatic or pneumatolytic origin of some of the irregular interstitial potassium feldspar is likely. A similar origin for the albite rims of the andesine grains is possible. The post-magmatic alteration of these rocks (probably deuteric, possibly hydrothermal) has accounted for the development of the secondary minerals, pennine chlorite, sericite, epidote, carbonate, and clay (?) minerals.

The physical relationships of the hornblende granodiorite mass with the Canwell phase or Gulkana phase of the quartz diorite have not been established. The fabric and mineralogy within each of these bodies varies little; no gradation from one to the other has been noted. Although the apparent similarities in gross chemical composition suggest that these masses represent individual phases of one major pluton, field evidence supports the postulation that two separate and distinct plutons exist.

It is probable that the granodiorite intrusion is middle to late Cretaceous in age. This dating is based on: (1) correlation with a similar granodiorite pluton occurring to the east which has been dated as 105 million years (lead-alpha method), (2) relative age with respect to the local sequence of deformation, and (3) correlation with regional orogenic movements.

STRATIGRAPHY AND PALEONTOLOGY

Stratigraphy

Description

This section is confined to a discussion of the McCallum Creek and Rainbow Mountain sequences. The variations in gross lithology and areal distribution of these units are shown on plate 1.

Plate 3 illustrates stratigraphic sections and general lithologic descriptions of the McCallum Creek and Rainbow Mountain sequences which were compiled from the geologic map and structure sections. No detailed sections were measured in the field and, therefore, all stratigraphic thicknesses are approximate.

The McCallum Creek and Rainbow Mountain sequences are similar in terms of general lithology and structural style. There are, however, differences in the sequence of strata and certain structural aspects and faunal content which give cause for the separation of units.

McCallum Creek sequence

The McCallum Creek sequence is separated by a major fault (I) into two principle fault blocks (pl. 3). The lithologic and general stratigraphic similarity of the lower 1000 feet of section from the southern fault block, and the upper 1000 feet of the northern fault block suggests the possible correlation of these intervals. If this correlation is correct, which seems likely, then the sequence displays a minimum stratigraphic thickness of approximately 5600 feet (pl. 3).

Rainbow Mountain sequence

The Rainbow Mountain sequence is transected by two major fault sets (D-E-F and W-M) into three principle fault blocks. The stratigraphy in each block has been determined. Correlation of the sections between these blocks, however, has not been accomplished. Generalized stratigraphic columns for each block are shown in plate 3.

Paleotectonic setting

Payne (1951) indicates that much of southern Alaska, including the present Alaska Range, was the site of the magmatic (eugeosynclinal) portion of a major geosynclinal belt during late Paleozoic time. This interpretation may or may not be supported by the present study of the Rainbow Mountain area. Since the study area is relatively small and extensive, regional correlations of units have not been made, an interpretation of the major tectonic setting is reserved.

The thick sections of volcanic "graywackes," tuffs, and flows that characterize both the Rainbow Mountain and the McCallum Creek sequences indicate deposition in an active tectonic environment. It is also evident that volcanic activity provided the chief source of materials.

The physical succession of rock types exposed in this area appears to reflect cyclical tectonic and volcanic activity; represented in the following stages:

1. volcanism with the extrusion of andesitic and dacitic flows and accumulation of pyroclastic sediments.

2. erosion and partial redistribution by currents and wave action of volcanic debris to form thin bedded to massive "graywackes."

3. recurrent uplifts that resulted in slumping of sediments and further redistribution of clastic materials. Deposition from turbidity currents produced thick sequences of graded "graywackes."

4. volcanic quiescence and relative stability, during which thin limestones accumulated.

A completed cycle usually shows 150 to 300 feet (average) of deposits. Cycles of much thicker accumulation, however, do occur.

The sequence of the cycle was complicated by numerous local factors, and interruptions and reversals of stages have been recognized locally. It is clear that topography, proximity to volcanic source, and depth of water are among the factors that affected the areal distribution, thickness, and vertical succession of deposits.

Well developed graded bedding suggests that much of the section was deposited from turbidity currents. Oscillation ripple marks, mudcracks, cross bedding, and similar sedimentary structures usually indicative of shallow water are in general absent. However, many layers are characterized by small scale deformational features such as slump and flowage structures that apparently were formed penecontemporaneously.

Most tuffs and volcanic flows are interbedded with limestones and appear to be of marine origin, but the possibility of subareal accumulation of some of these deposits is recognized. No clear evidence that would resolve this problem has been obtained.

A comprehensive study of the sedimentary structures and physical facies relations of rocks in the Rainbow Mountain area is needed for a detailed interpretation of the paleotectonic setting. Combined with biostratigraphic study, these data would ultimately permit reconstruction of the paleogeography of this part of Alaska.

Paleontology

Fossils were collected from 12 localities in the Rainbow Mountain sequence and in the McCallum Creek sequence. Fossil localities are shown by plate 3. Identified fossils from each locality are listed in table 2.

Age

Fossils indicate that rocks of both Mississippian (?) and Pennsylvanian age are present in the Rainbow Mountain area. The designation McCallum Creek sequence (Mississippian ?) and Rainbow Mountain sequence (Pennsylvanian) is based primarily upon paleontological differences of the two sequences.

A preliminary study of the fossil invertebrates has been made by C. L. Rowett, paleontologist at the University of Alaska. Rowett notes the following:

> A Pennsylvanian age is indicated for the exposures at localities F-1 and 3 through 9. The rocks at localities F-10 and 11 are pre-Pennsylvanian and probably Mississippian in age.
>
> In particular, the presence of *Pseudoparalegoceras* n. sp. and *Spirifer* cf. *S. rockymontanum* at locality F-1 suggests that these strata are lower Pennsylvanian (pre-Desmoinesian) in age. Similarly, the occurrence of the fusilinids *Wedekindellina*? and *Fusulinella*? at locality F-3 requires a post-Morrow, pre-Missouri age for these strata. An unidentified Neoicoceratidian cephalopod and fusiform

TABLE 2. Fossils from McCallum Creek and Rainbow Mountain sequences

Fauna	Locality, F-											
	1	2	3	4	5	6	7	8	9	10	11	12
Foraminifera:												
Wedekindellina? sp.			X						X			
Fusulinella? sp.			X						X			
fusiform fusilinids, genus undet.		X										
Anthozoa												
Aulophyllid coral, genus undet.	X											
Lithostrotionellid coral, genus undet.						X	X	X				
Bothrophyllum n. sp.								X				
Cyathopsid coral, genus undet.				X		X	X	X	X			
Amplexizaphrentis n. sp.				X								
Michelinia cf. *M. referta* Moore and Jeffords				X				X				
Cladochonus cf. *C. texasensis* Moore and Jeffords	X											
Brachiopoda												
Schizophoria sp.					X							
Leptaena cf. *L. analoga* (Phillips)										X	X	
Schuchertella sp.										X		
Composita sp.	X											
dictyoclostid brachiopod					X				X			
Linoproductus (sensu stricto) sp.	X											
Buxtonia sp.								X	X			X
Echinoconchus sp.	X											
Brachythyris cf. *B. subcardiformis* (Hall)											X	
Spirifer cf. *S. rockymontanus* Marcou	X											
Spirifer spp.	X				X			X				
Leiorhynchus cf. *L. rockymontanus* (Marcou)		X										
Gastropoda:												
Pleurotomariacian gastropod, genus undet.				X								
Pelecypoda:												
Aviculopecten sp.	X											
Cephalopoda:												
Pseudoparalegoceras n. sp.	X											
Neoicoceratidian cephalopod, genus undet.									X			
Trilobita:												
Phillipsid trilobite, genus undet.	X											

> fusilinids from locality F-9 likewise suggest a lower Pennsylvanian (post-Morrow) age. The overall aspect of the fauna corresponds most nearly to Atokan faunas elsewhere.
>
> It is notable that the fossil assemblage from locality F-1 has no counterpart at any other locality; this may be due to a slight difference in age, or more probably, a lateral difference in the environment of deposition.
>
> The exposures at locality F-10 and 11 are pre-Pennsylvanian in age. Numerous specimens of *Leptaena* were collected at these localities. These appear to be referable to *L. analoga* (Phillips), which is a Mississippian form. In addition, a single specimen of *Brachythyris* was collected at locality F-11 that appears to correspond stratigraphically to the strata at locality F-10. This scanty evidence, plus the absence of definitive Devonian forms, supports a tentative assignment to the Mississippian System.

Regarding the collection of fusilinids from localities F-3 and F-9, H. E. Wheeler states:

> Among these, only the fusilines appear to be diagnostic. Only the sub-family, Fusulininea appears to be represented; some appear assignable to *Wedekindellina* and some possibly to *Fusulinella*. The abundance of these in the pre-Missourian Pennsylvanian, together with the absence of more advanced forms strongly suggests that the strata are either Des Moinesian or earlier Pennsylvanian.

Wheeler also infers a post-Morrowan age for these fauna in his discussion.

The fusiform fusilinids collected from locality F-2 are similar in external form to those from localities F-3 and 9. However, only a few poorly preserved specimens were obtained. The distinctive "maroon" limestone rubble at locality F-2 is believed to represent a landslide mass derived from unit f of the Rainbow Mountain sequence (fig. 36), which is of similar lithology. On this basis, unit f is tentatively dated as Pennsylvanian. A Pennsylvanian age is also assigned, tentatively, to the remaining succession in this fault block on evidence of the apparent conformity of the section with respect to unit f and the general similarities between these units in faunal aspect.

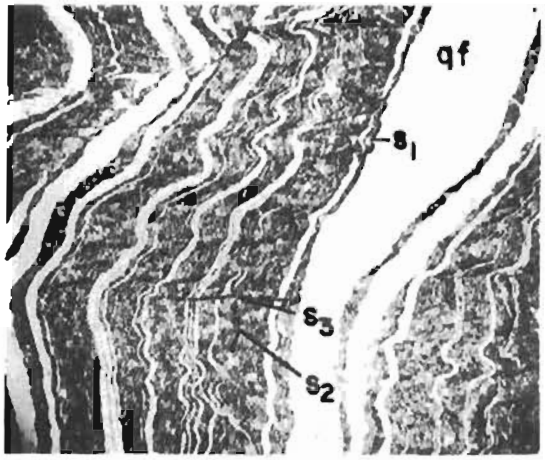

Figure 10: Crumpled phyllite from the Pre-Mississippian metamorphic rocks (specimen SCF/v/5). Delicate intercalations of quartzo-feldspathic layers (qf) and carbonaceous chlorite phyllite show s-surfaces (s_1, s_2 and s_3). Plain light, X40.

Figure 11: Finely layered impure marble from the Pre-Mississippian metamorphic rocks (specimen SCF/v/1-2). Alternating quartz-albite-calcite (c) and carbonaceous chlorite-sericite-quartz-albite (f)-calcite layers define s_1 with foliation (s_2) subparallel. Plain light, X40.

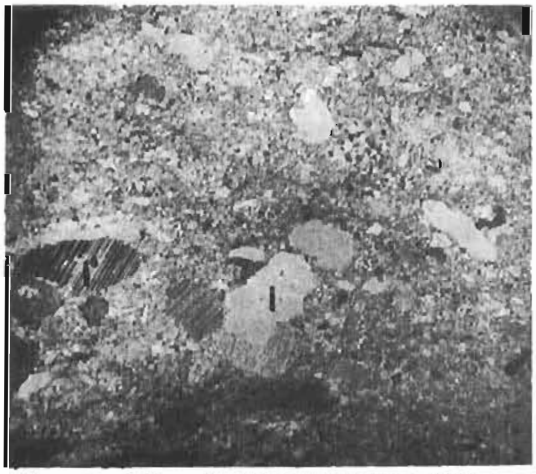

Figure 12: Intrasparite from the Rainbow Mountain sequence (specimen 9-5-6). Poorly sorted intraclasts (i) are cemented by sparry calcite. Crossed nicols, X40.

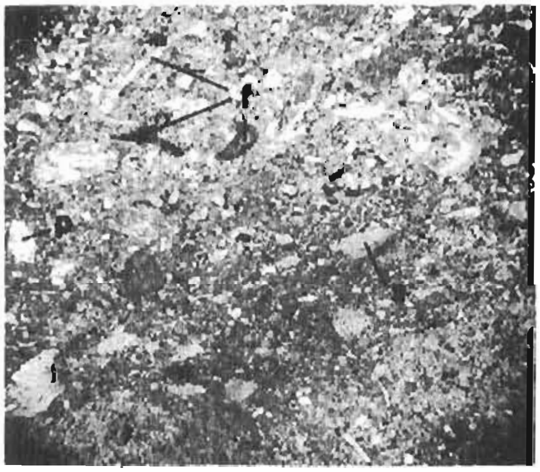

Figure 13: Feldspathic biomicrite from the McCallum Creek sequence (specimen 8-2-17). Dominantly fossil fragments (f) and other clastic grains (plagioclase (f) and siltstone (s)) are embedded in microcrystalline ooze (fine-grained, dark). Plain light, X40.

Figure 14: Typical stratified siltstone and lithic sandstone ("graywacke") from McCallum Creek sequence (specimen 8-2-15). Volcanic rock fragments (v) predominate over plagioclase (f) in poorly sorted sandstone layers. Plain light, X40.

Figure 15: Feldspathic sandstone ("graywacke") from Rainbow Mountain sequence (specimen 6-21-18). Poorly sorted subangular (subhedral) plagioclase (f), quartz (q) and sub rounded volcanic rock fragments (v) are volcanic derivatives. Crossed nicols, X40.

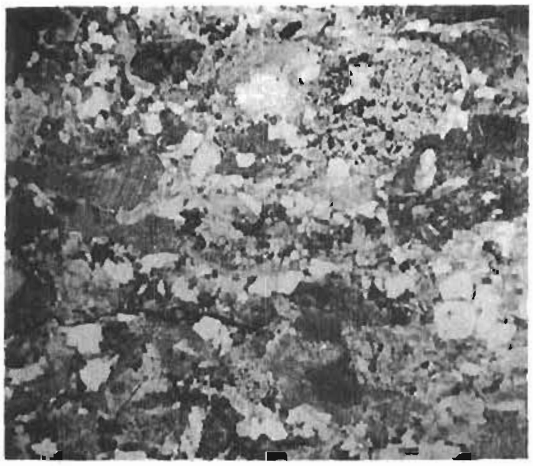

Figure 16: A common transitional (limestone-volcanic "graywacke") sandstone from the Rainbow Mountain sequence (specimen 6-8-26-2). Volcanic rock fragments (v), limestone fragments, plagioclase and quartz dominate the assemblage. Plain light, X40.

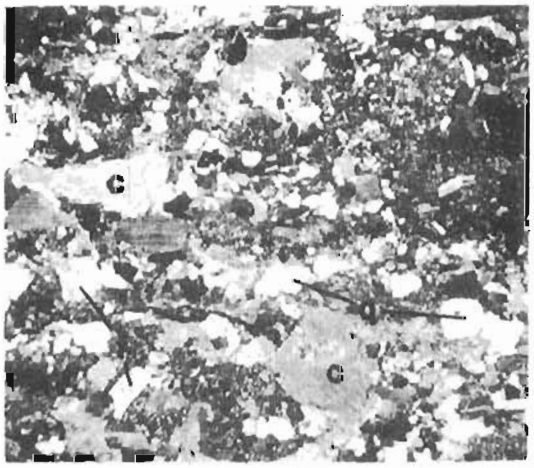

Figure 17: As Figure 16; plagioclase (f), limestone fragments (c) and quartz (q) are indicated. Crossed nicols, X40.

Figure 18: Dacite crystal tuff from the Rainbow Mountain sequence (specimen 5-31-2). Euhedral quartz (q) and andesine (f) are embedded in a fine chlorite-rich ash matrix displaying flow structure. Crossed nicols, X40.

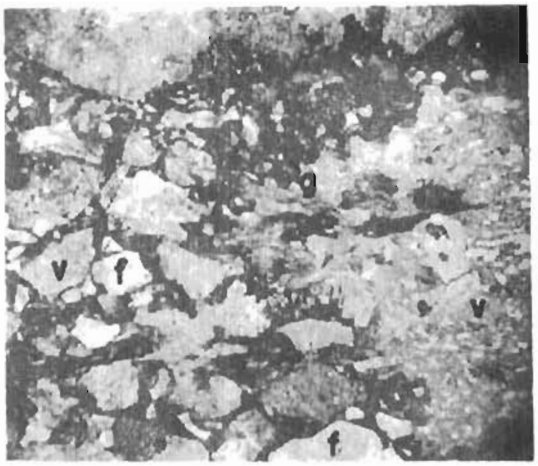

Figure 19: Andesine lithic tuff from McCallum Creek sequence (specimen 8-4-7). Flattened amygdaloidal andesites (v) occur with andesine (f) in glass-rich matrix (g). Plain light, X40.

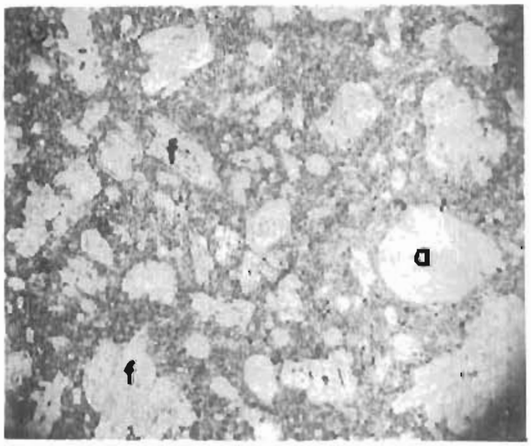

Figure 20: Typical amygdaloidal (a) porphyritic andesite flow rock from Rainbow Mountain sequence (specimen 8-14-1). Note magnetite inclusion patterns in zoned plagioclase. Plain light, X40.

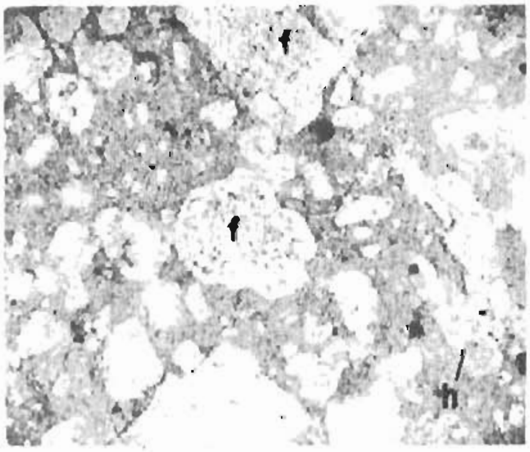

Figure 21: Typical porphyritic andesite from "sill" in Rainbow Mountain sequence (specimen 8-1). Inclusion-rich andesine (f) and minor hornblende (h) phenocrysts are highly altered. Plain light, X40.

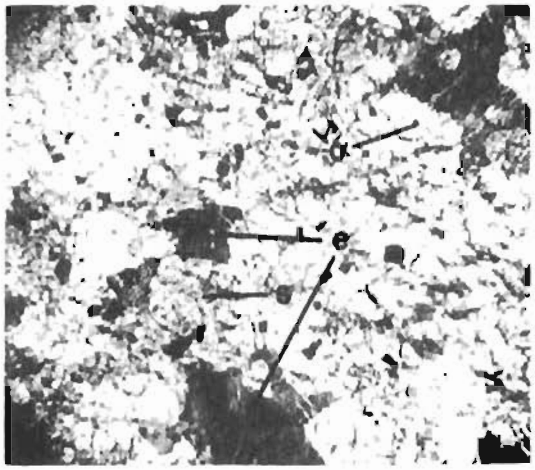

Figure 22: Serpentinized enstatite (e), olivine (o) peridotite from dike in serpentinite complex (specimen 6-22-10). Serpentine minerals (antigorite and chrysotile) (s) are products from primarily olivine alteration. Plain light, X40.

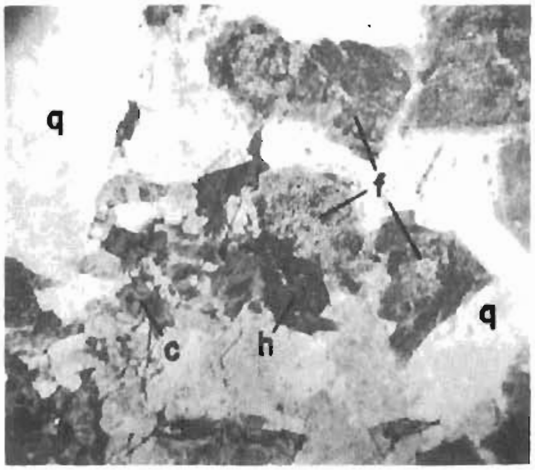

Figure 23: Typical texture and mineralogy of hornblende granodiorite from pluton (specimen 7-26-12). Saussuritized plagioclase (f) and chloritized (c) hornblende (h) occur with interstitial quartz and potassium feldspar. Plain light, X40.

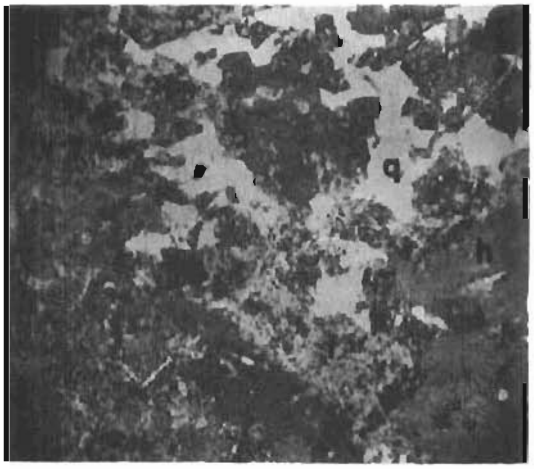

Figure 24: Typical coarse grain variation of quartz diorite (Canwell phase) (specimen SCF 8-1). Mode and texture of quartz (q) and altered plagioclase (f) and hornblende (h) appear similar to those relict in the gneiss (Fig. 25). Plain light, X40.

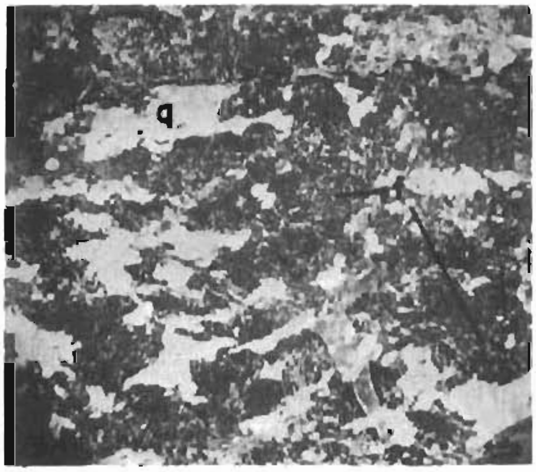

Figure 25: Typical quartz diorite gneiss (specimen GDNS). Foliation is weakly defined by elongate plagioclase (f) and amoeboid quartz. Intense weathering and alteration of plagioclase is common. Plain light, X40.

Future study

The need for further careful biostratigraphic study of this area is apparent. Only a few fossiliferous horizons have been collected, and it is on this basis that much of the section in the Rainbow Mountain area is tentatively dated. Further collecting from the McCallum Creek sequence as well as study of the stratigraphy are also required.

Most limestone beds within these units are fossiliferous to some degree and, although the recovery of fossils is difficult from silicified zones, these layers should be examined in greater detail.

Figure 26: Laminated to thinly bedded, "maroon" (dark), silty limestone underlying massive "graywacke" conglomerate; unit f of Rainbow Mountain sequence.

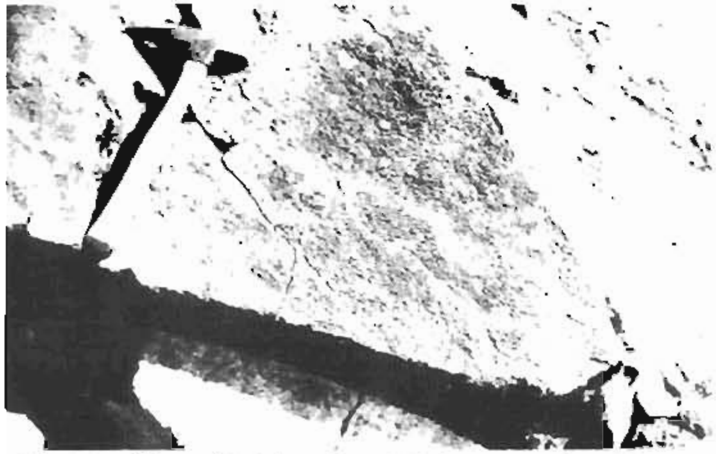

Figure 27: Highly fossiliferous clastic limestone of Rainbow Mountain sequence showing typical weathering and thick bedded character.

Figure 28: Upper intrusion contact of xenolith-rich porphyritic andesite "sill" (right) into "graywacke" siltstones-sandstones of Rainbow Mountain sequence.

Figure 29: Massive "graywacke" pebble-cobble conglomerate of the Rainbow Mountain sequence near western margin of glacier (sector B-3(WC)).

STRUCTURE

In this discussion continual reference is made to the structure map, plate 4 (a foldout at the end of this chapter) and structure sections, plate 2 (in pocket).

Folding

Pre-Mississippian metamorphic rocks

Units of the Pre-Mississippian metamorphic rocks show a variety of megascopic and microscopic structures. The microscopic features have been previously discussed in conjunction with the petrology of the unit.

The Pre-Mississippian metamorphic rocks are found in three fault blocks in the northwestern part of the area. These blocks are separated by two major vertical faults (T and U), both of which have been active in post-metamophic times (see plate 4). The southernmost fault block of the three blocks displays structures which are slightly different from those of the two northern blocks.

Northern fault blocks

Deformation of the rocks in the northern fault blocks has been more intense. Folds are isoclinal to sub-isoclinal and are upright to slightly overturned to the north. Fold axes trend approximately 280 degrees (subparallel to the general trend of this segment of the Alaska Range). Fold axes plunge steeply (30° to 70°) toward the southwest to northwest.

Folded s_1 (bedding) and subparallel foliation s_2 are cut at the hinges of the folds by an axial plane foliation (s_3). Minor folds (and corresponding foliation s_3) are well developed on the limbs of the major folds.

A detailed examination of the geometry and size of the major metamorphic structures of these rocks as well as those of the southern fault block was not attempted largely because of the limited exposures. Several major folds, however, are believed to occur in the one-quarter mile wide outcrop belt.

At several localities north to northeast trending lineation was noted.

Southern fault blocks

Rock units of the southern fault blocks are more variable in structure. Folds are generally open to subisoclinal and are upright. They trend approximately due north and plunge in this direction (30° or less).

Compositional layering (s_1) and subparallel foliation (s_2) strike from 315 to 30 degrees. These surfaces have been folded, and locally axial plane foliation s_3 is developed where shear fold dislocations have formed an incipient axial plane schistosity. S_3 typically transects s_2 and s_3.

Metamorphic rocks of the Gulkana Glacier area

Schists, gneisses and magmatites crop out in the upper basin of Gulkana Glacier (to the east)(D. M. Ragan, personal communication). There is no lithologic similarity between these rocks and those of the pre-Mississippian unit of the map area and the structural relationships between them are not known. Folds of the gneisses trend 270 degrees and show very little plunge. A prominent lineation parallels the trend of fold axes.

Carboniferous sequences

The folding in the McCallum Creek and Rainbow Mountain sequence is similar in general style and orientation but differs slightly in certain detailed aspects. Both units consist of a series of dominantly northwest trending subisoclinal to open anticlines and synclines (see plates 2 and 4). Folds in the McCallum Creek sequence, however, are typically more tightly appressed and more numerous than are those in the Rainbow Mountain sequence to the northwest. Subisoclinal folds are common in the McCallum Creek sequence. These are generally overturned to the southwest (pl. 2 and fig. 33).

Details of the McCallum Creek sequence

The McCallum Creek sequence, exposed in the southern part of the area, consists structurally of five major subparallel folds which trend 310 degrees northwest. The traces of the axial planes are shown on plate 4. These folds constitute a synclinorium in which the central fold (syncline III) is flanked to the northeast and southwest by syncline-anticline pairs (I-II and IV-V). Only syncline III can be traced across the area; the smaller folds on the flanks of this syncline are discontinuous. The flanking folds are symmetrical and open as exposed along McCallum Creek. Tracing northwest each pair becomes a monocline before the flexure dies out completely (pl. 2). Along several segments, syncline-anticline I and II are subisoclinal and slightly overturned to the southwest. Axial planes of all folds are commonly vertical to inclined 70 degrees to the north.

Traced from southeast to northwest, syncline III varies from a symmetrical subisoclinal to slightly asymmetric relatively open fold.

Although not examined in detail, slight culminations and depressions of several of these folds are apparent. In general plunges to the southeast (less than 35°) are common, and plunges to the northwest are less common and do not exceed 10 degrees.

Details of the Rainbow Mountain sequence

A number of major folds occur in the Rainbow Mountain sequence, but none can be correlated across several high angle faults which cut the unit into three principle blocks. These blocks are referred to as: (1) the south, (2) the north, and (3) the northwest blocks, and are separated by fault sets D-E-F, and M-W, respectively (pl. 4).

The south fault block.--Rocks in the lower plate of thrust fault D-F are the most intensely deformed part of the unit. Here two small anticlines (one-quarter mile apart) with an intervening syncline can be traced across the area from sector B-2(NC) toward the northwest (shown on plate 4--no symbol). These folds are open and upright to slightly overturned with axial planes dipping northward (70°). On the limbs of these folds, several small, sharply crested folds are developed (fig. 38). All of these folds die out along the strike. The geometry of the northernmost anticline in the vicinity of fault I suggests superimposed drag folding.

The north fault block.--The rocks above thrust fault D-E are monoclinal along much of the central Rainbow Ridge area. These southwest dipping beds appear to be the east limb of a major syncline (VI), the trough of which is covered along the lower western flank of the central ridge area.

In the northern Rainbow Ridge area the trough is exposed in trace from sector C-4(C) to D-5(SE). The syncline here is open and symmetrical. Further north the fold becomes asymmetric (axial plane dipping as low as 60° west) and plunge steepens from 5 to 45 degrees (320° to 315° direction). Correspondingly, the syncline broadens until at the northern limit of the trace, sector D-5(SE), the fold is all but completely flattened (fig. 40).

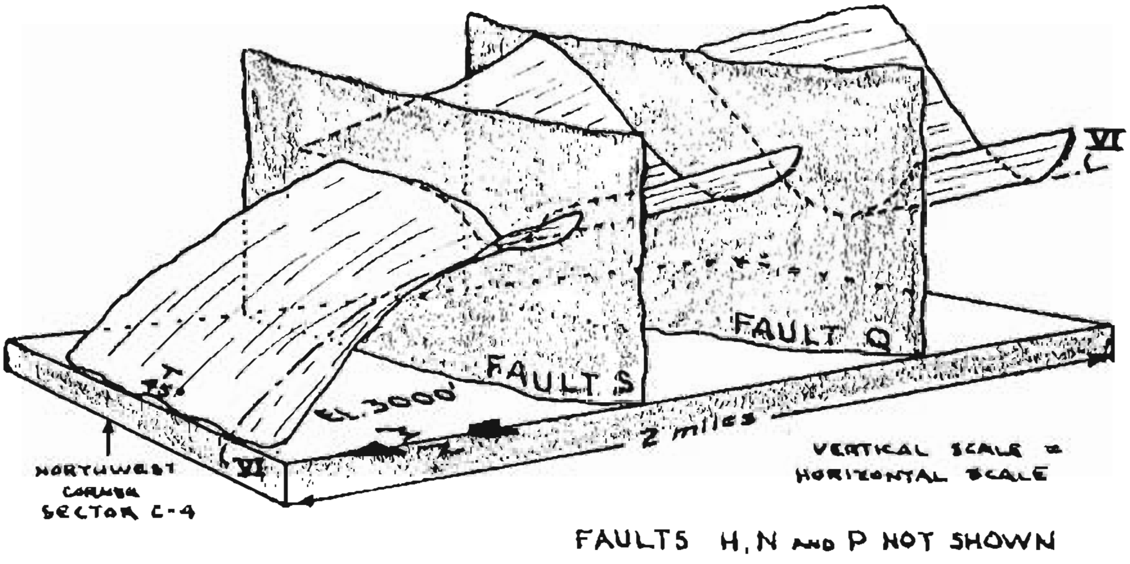

Fig. 40.--Geometry of major fold of Rainbow Mountain sequence in northern fault block.

The eastern limb of the syncline (the monocline in part) contains numerous minor folds subparallel to syncline VI (320°) and is discontinuous. The most prominent examples are located near the high peak of Rainbow Mountain (sector C-4(SE)).

The northwest fault block.--The structure of the northwestern fault block (bounded by faults W and X) contrasts somewhat with the style displayed in the other two fault blocks.

No major fold is believed to be present (see plate 2). Instead the thick succession of units forms a dominantly high angle subparallel trending structure which varies only in dip in the following manner. Along the southern margins of the fault block in the mapped area the units are upright, strike 270 degrees and dip 35 degrees north (sector D-4(SE)). Northward, the dip steepens to 90 degrees and strike swings to 315 degrees. Still further north, the units are overturned (dips 44° southwest). The only complication of this general structure occurs in sector D-4(SE), where several small sharp crested folds are developed--an anticline and syncline.

Faulting

The major faults which cross cut the map area are shown in plate 4, structure map. The characteristics of these are summarized in table 3.

The relationships of individual faults with: (1) other faulting, (2) folding, (3) plutonic intrusion, and (4) hypabyssal intrusion, indicate that the faults of the area are grouped into systems which

TABLE 3.--Characteristics of major faults of the Rainbow Mountain area.

Classification	Symbol	Approximate Attitude Strike, Dip	Separation or Slip	Remarks
Low angle reverse (thrust faults)	A	300°, 0°-15° N.	overthrust southwest, slip 0'-100' (max.)	faults related to isoclinal overturned folds, overthrusting in the direction of overturning.
	B	300°, 5°-15° N.	overthrust southwest, slip 0'-200' (max.)	
	C	300°, $< 20^{\circ}$ N.	overthrust southwest, slip 0'-200' (+)	
	D	280°-300°, 50°-60° N.	overthrust southwest thrust separation 7400'(+)	accumulative magnitude based on stratigraphic separation
	E	300°-320°, 35°-50° N.	overthrust southwest	
	F	300°-320°, 35°-45° N.	overthrust southwest	
Normal or reverse separation fault (slip fault?)	G	305°, 80° N.	dip separation unknown	weak evidence to indicate relative movement of blocks. A major strike slip component is unlikely

TABLE 3--Continued

Classification	Symbol	Approximate Attitude Strike, Dip	Separation or Slip	Remarks
Near vertical, dip separation faults (slip faults?)	H	328°, vertical (±)	dip separation 20'-50', north block down	minor strike slip possible
	I	306°, vertical (±)	dip separation 300'-400', north block down	only minor strike slip possible
	J	302°, vertical (±)	dip separation unknown north block down (?)	major strike slip highly unlikely
	K	298°, vertical (±)	dip separation (greater than 400') probably, north block down	dominantly vertical but may possibly have moderate strike separation
	L	345°, vertical (±)	separation unknown (less than 100'?), south block down (?)	evidence weak for dip slip
Normal separation faults (slip faults?)	M	345° ±, 70°±10° W.	vertical separation unknown	major strike separation possible but not likely. Dip separation only apparent
	N	298°, vertical to 80° S.	dip separation 100'(±)	only minor strike slip possible
	O	65°, 65° W.	dip slip 25'	a minor strike slip is noted (<5')

TABLE 3--Continued

Classification	Symbol	Approximate Attitude Strike, Dip	Separation or Slip	Remarks
Right separation faults (right slip?)	P	5°, near vertical	150' right separation	major vertical separation possible but not likely
	Q	20°, $80^{\circ} \pm 10^{\circ}$ E.	1500' separation	less than 200' dip separation possible
Left separation faults (left slip?)	R	within 0°-45°, high angle	left 1000' separation	less than 500' dip separation possible
	S	25°, high angle	left separation 300'-500'	probably an oblique slip with strike separation greatest
Faults of unknown separation	T	35°, high angle	?	strike separation noted on union parallel (associated?)
	U	270°-300°, near vertical	?	faults of probably great magnitude (in thousands of feet)
	V	298°, near vertical	?	
	W	$345^{\circ} \pm 10^{\circ}$, high angle (?)	?	probably of major magnitude greater than 5000')
	X	345°, near vertical	?	probably of major magnitude greater than 500'
	Y	$300^{\circ} \pm 10^{\circ}$, high angle	?	probably dip slip primary if continuous with fault G
	Z	315°,-60° S.	?	movement less than 100' probably

demonstrate relative age and tectonic setting. The sequence of tectonic events in relation to other geologic events is outlined in the following chapter (Geologic history).

Thrust faults

The earliest recognized Mesozoic (?) development consists of those faults that are associated with the major cycle of folding. These faults (A, B, C, D, E, and F) are thrust dip (?) faults.

A, B, and C are faults of minor displacement (less than 300 ft thrust slip). Each is associated with the lower limb of a subisoclinal to isoclinal fold overthrust to the southwest and can be related to an anticline which has been overturned to the southwest (see plate 2).

Thrust faults E and F join to form thrust D to the west. Overthrusting of this set is probably toward the southwest with a combined separation of most likely more than 7400 feet.

High angle faults

High angle faults can be subdivided into three groups based on orientation and relative movement. These are: (1) dip slip (?) faults of northwest strike, (2) strike slip (?) faults of dominantly 0 to 25 degrees strike, and (3) others.

Dip slip (?) faults of northwest strike

This group, consisting of dominantly dip slip faults, strikes between 290 degrees and 320 degrees. Included in this group are faults G, H, I, J, N, and probably Y and Z. Most of these faults are nearly vertical. Faults H, I, J, and K belong to an en échelon group with the northern blocks of each downthrown. Faults G and Y are post-granodiorite intrusion in age and probably represent one continuous fault (mostly covered). All faults in this set cut folds of the earlier deformation. This fault system is further cut or intruded by: (1) most hypabyssal units including at least the diabase dike swarm and the porphyritic dacite lenses and (2) the high angle faults of the system striking 0 to 25 degrees.

Strike slip (?) faults

The high angle (near vertical) faults of trend 0 to 25 degrees display a prominent lateral component of displacement and are believed to be primarily strike slip faults. The similarity of trend and strike movement on these faults (P, Q, R, and S) suggests a single period of movement. Faults R and S are probably segments of the same fault.

Both left and right lateral slip (?) faults are represented in this system. These faults offset folds and faults of the northwest trending systems described previously and also offset dikes of the diabase swarm.

Others

Fault T may belong to the strike slip system (above) since it truncates dikes and several major faults of a north-northwest strike (M, W, and probably L and X) and also subparallel faults P-S. Furthermore, fault T is probably older than system P-S since T is truncated by fault V which is also cut by U which is similarly offset by fault R. Each of these could be primarily strike slip but only slip of P-S is known.

Several other faults (M, W, L, and X) do not readily relate to the systems described above since the displacement is not known. These faults occur in pairs M-W and L-X, both of which are subparallel in strike (approximately 345°). Only the fault planes of M and L are exposed. They are high angle with a suggestion of vertical separation. The structural discontinuity across fault W suggests a major displacement for this fault. The existence of fault W has not been conclusively indicated.

Faults M and probably X are truncated by fault T which dates this pair as pre-faulting (P, Q, R, and S). The relationship of faults M and X to the dike swarm is not clear although the continuity of dikes across the faults appears real. If this relationship is true, then faults M and W and perhaps L and X correlate with the dip slip (?) faults of the northwest trend (H, I, J, etc.). Faults M-W and L-X may also represent a separate system.

Many faults of relatively small displacement (i.e., less than 50 ft) occur in the area. These can usually be related to one of the major fault systems described above in terms of strike and/or slip. Only a few of these are shown on the geologic map. One (fault O) is shown on the structure map. The fault zone and fault drag fold aspects of this fault in outcrop are typical of those of most minor faults (fig. 37).

The Denali fault

The Denali fault underlies the prominent lineament defined by Canwell Glacier along the northern margin of the map area. No observations were made that would directly indicate the direction or magnitude of movement of this fault.

The sequence of fault movements of the Rainbow Mountain area, however, suggest that a similar history of movement may relate to the genesis of the Denali fault. Two sequential events are suggested:

1. The Denali fault subparallels the northwest dip slip (?) fault system. This suggests that there may have been similar movement (dip slip) on the Denali when these smaller faults were active.

2. Lateral slip faulting recognized in the Rainbow Mountain area may indicate lateral slip (?) on the Denali fault. Several of the north to northwest trending strike slip faults approximate the position and movement of one of the possible second order wrench fault systems of Moody and Hill (1959) which ideally develop secondary to a primary wrench fault (the Denali fault in this case). Although right lateral movement is implied, much more work is required to confirm this since there are anomalous movements indicated on some of these "secondary" faults. In general, however, the fault patterns in the Rainbow Mountain area are not incompatible with right lateral slip movement postulated by many for the Denali fault.

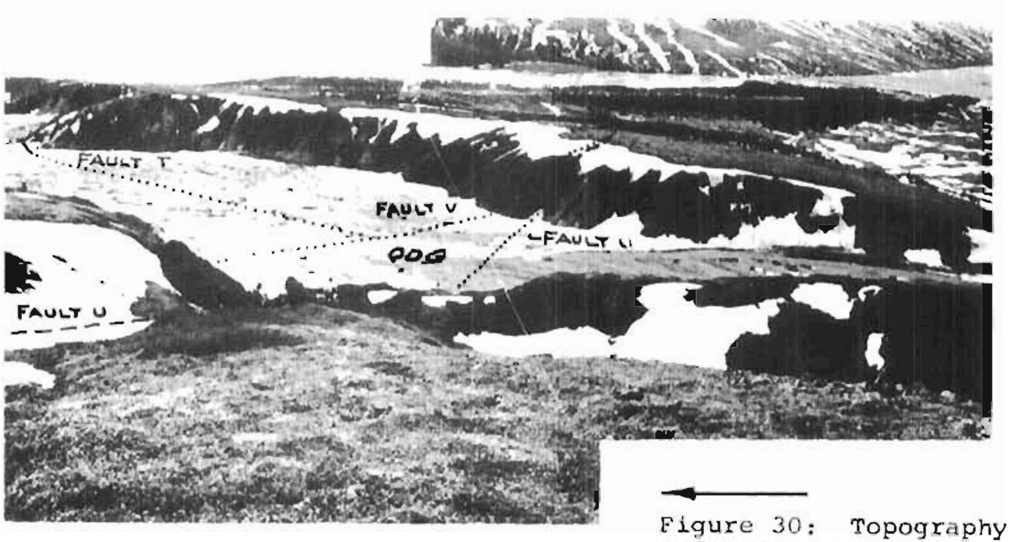

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Figure 30: Topography and major unit contacts of northwestern part of map area; a view to the west from sector C-5(NW). SC=Serpentine complex, QDG=Quartz diorite gneiss, PMMR=Pre-Mississippian metamorphic rocks.

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Figure 31: Outcrop of Pre-Mississippian metamorphic rocks in canyon wall near highway (sector D-5(EC)). Interlayered phyllites (p) and greenschists (g) are cut by several serpentinite dikes (s).

Figure 32: Crumpled phyllites of the Pre-Mississippian metamorphic sequence.

Figure 33: Subisoclinal folding (overturned to 45°) in McCallum Creek sequence, (sector B-2(NC & NW)); a view to the east.

Figure 35: Typical outcrop form of porphyritic andesite "sills"; defined by well developed joint sets.

Figure 34: Thrust fault B in McCallum Creek sequence (sector B-2(NW)); a view to the west.

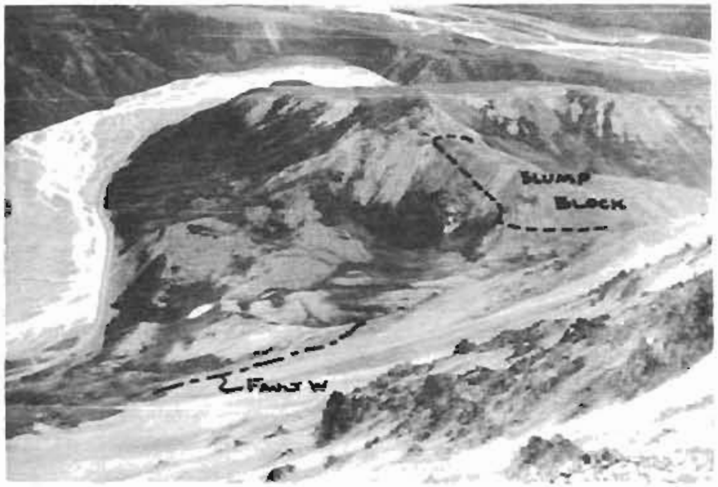


Figure 36: Major slump block and characteristic topography of the Rainbow Mountain sequence of "northwestern fault block" (west of fault W); a view west from sector C-4(SC).

Figure 38: Sharp synclinal flexure in "graywackes" of the Rainbow Mountain sequence near fault O (Fig. 37).

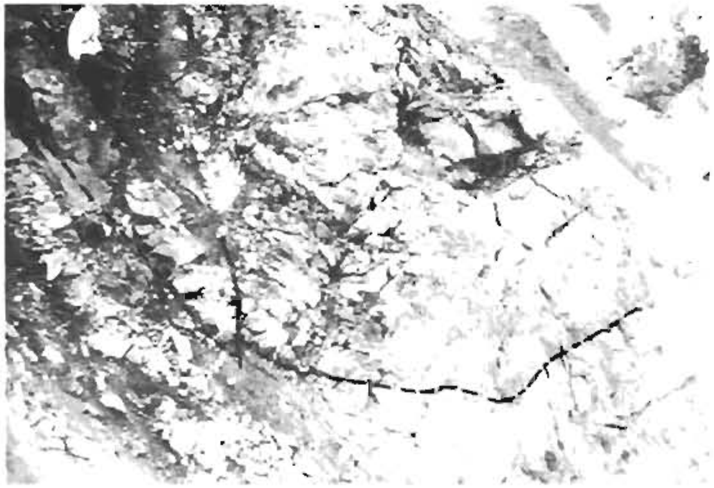
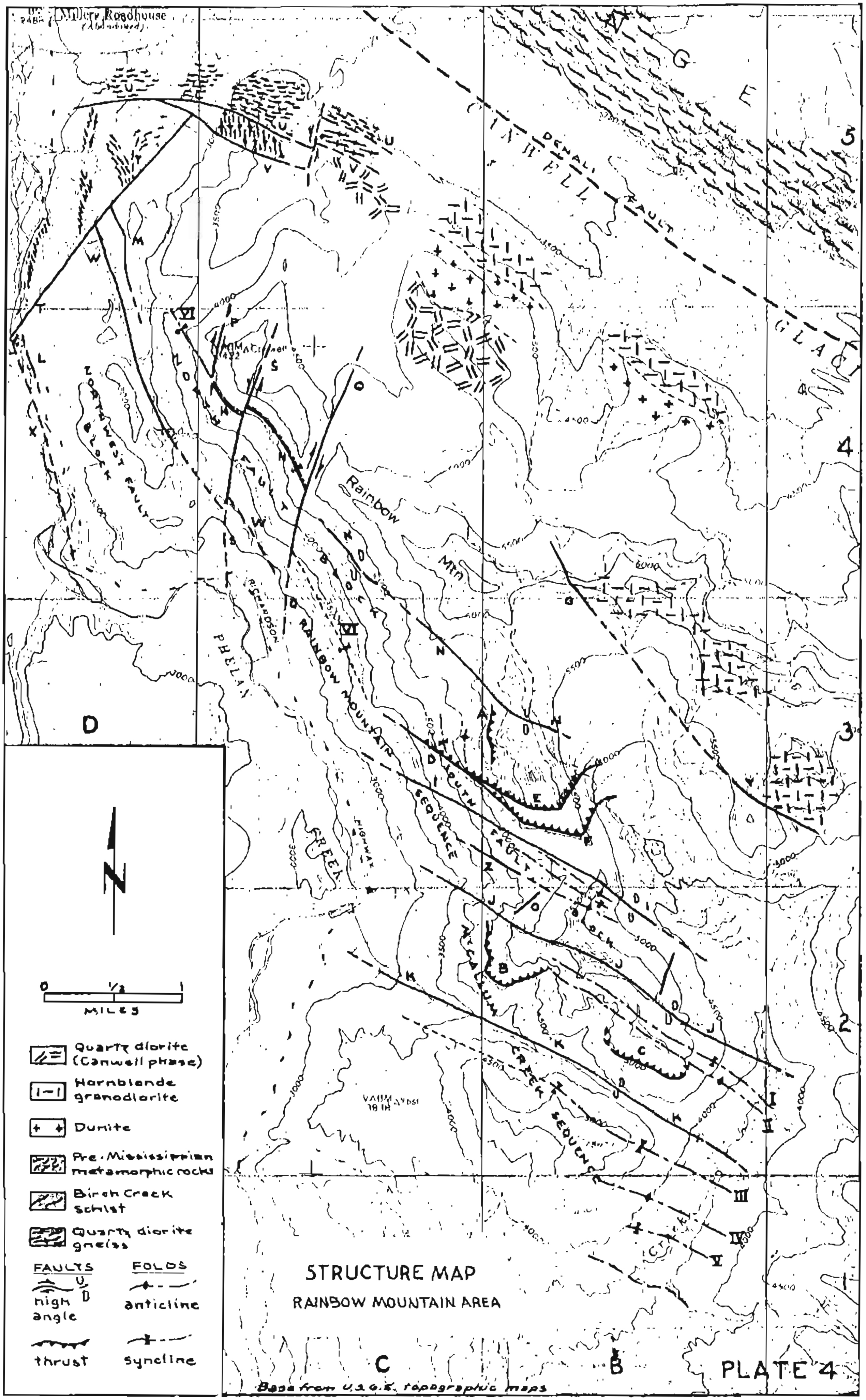


Figure 37: Fault O separating rocks of the Rainbow Mountain sequence (sector B-2(NW)). The approximate vertical separation is shown.

Figure 39: Uniformly dipping beds of "graywackes" (foreground) and limestones (high peak) along prominent strike ridge of Rainbow Mountain sequence at headwall of cirque in sector B-3(SC).



STRUCTURE MAP

RAINBOW MOUNTAIN AREA

PLATE 4

MINERALIZATION

Previously known deposits

Sulfide mineralization in the Rainbow Mountain area has been known since the arrival of the earliest prospectors. The presence of much of this mineralization is evident from the heavy residual of iron oxide stain which covers large surface areas of "Rainbow" Mountain. Mining interests, concerned with copper mineralization, have investigated many of these deposits.

Three different modes of mineralization have previously been recognized within the area. These are: (1) nickel-copper, associated with ultramafic intrusions, (2) quartz veins with copper, lead, silver and gold, and (3) disseminated sulfides (chiefly pyrite) in silicified volcanics and sedimentary rocks.

Nickel and copper mineralization in association with ultramafic dikes was first discovered by Mr. Rollie Emerick of Delta Junction, Alaska, within the Serpentinite complex (sector D-5(EC)) in the early 1950's. Chalcopyrite-galena bearing quartz veins with values in gold and silver have been previously known to outcrop in the canyon walls (sector D-5(EC and SE)). These veins cross cut pyroclastics, "graywackes," and limestones of the Rainbow Mountain sequence.

Deposits of disseminated pyrite and other sulfides of possible economic importance occur in many areas of Rainbow Mountain. Some of the most prominent of these are shown in sectors C-4(C), C-4(WC), B-3(SW), and B-3(SE), plate 5.

Many of the previously known mineral deposits have been studied by geologists and mining engineers of the Alaska State Division of Mines and Minerals, and the U. S. Bureau of Mines. This information is readily available to the public from these agencies.

Mineral deposits representing significant discoveries made during this investigation are discussed in the following section.

New discoveries

These deposits can be subdivided on a basis of lithology-mineralogy (genesis inferred) into: (1) quartz veins, (2) mineralized conglomerate, (3) silicified diorite-serpentinized peridotite, (4) silicified granodiorite, (5) mineralized greenstone, and (6) dunite. The nature of these is discussed below.

Quartz veins

Sulfide-bearing quartz veins have been discovered at 13 localities, shown on plate 5. The characteristics of these are listed in table 5.

The following assays for copper, lead, gold and silver were run by Mr. I. W. Mitchell, Alaska State, Division of Mines and Minerals, on specimens collected from most of these veins (table 6).

Most of these veins strike from 325 to 360 degrees with a few orientations in other directions. This strike approximates that of the veins discovered earlier by others in sector D-5. The common strike subparallels the major fault-joint set in the area. In addition, many other barren veins of similar attitude cut the Rainbow Mountain sequence.

TABLE 5.--Location, distribution, and mineralogy of sulfide bearing quartz veins.

Locality	Location (sector)	Principal Ore minerals	Altitude	Remarks
1	D-5(EC)	Chalcopyrite galena	355°, 45° E.	several 2"-3" veins in small swarm
2	D-5(SE)	Chalcopyrite	270°, 65° S.	1.5' replacement zone bordering vein.
3	D-4(NC)	Chalcopyrite galena, pyrite, dunite	irregular, low-high angle	thin (< 6"), discontinuous, scattered mineralization.
4	D-4(WC)	Chalcopyrite pyrite	irregular, near vertical	small veins, random orientation, area of patchy azurite-malachite stain.
5	C-4(SW)	Chalcopyrite galena	355° 70°-80° W.	6" veins with a few smaller in subparallel set.
6	C-3(EC)	Chalcopyrite	330°, 55° E.	a swarm of subparallel veins 0.2'-1' in thickness, 10 in number, mineralization in some only, scattered in these
7	B-3(SW)	Chalcopyrite pyrite	N.-S., vertical	swarm in dacite intrusives along thrust 1'-8' veins, mineralization scattered.
8	B-3(SW)	Chalcopyrite galena, pyrite	355°, 83° W.	two veins 2' in thickness, several smaller, truncated by fault to north.
9	B-3(SW)	Pyrite chalcopyrite	326°, vertical-70°S. W.	mostly quartz veins (2') with a calcite vein (3' to 6').
10	B-2(NC)	Chalcopyrite galena	20°, vert.	along fault, several small irregular veins, scattered mineralization in these
11	B-2(EC)	Chalcopyrite	var. 343°-45°, near vertical	a few 0.5'-1' veins near fault, patchy mineralization.
12	B-3(SE)	Chalcopyrite pyrite, galena	270°-340°, vertical	an area of scattered concentrations of small veins.
13	B-3(SE)	Chalcopyrite pyrite	60°, 40° S.	Several 6" and many smaller irregular veins. Scattered chalcopyrite and galena.

TABLE 6.--Assays of samples from quartz veins.

	Percentage of		Ounces per Ton	
Locality	Copper	Lead	Gold	Silver
1	1.6 - 1.7	2.0 - 2.1	Trace	2.4
3	0.2 - 0.3	0.4 - 0.5	Trace	Trace
4	9.9 - 10.0	0.4 - 0.5	Trace	Nil
5	3.99	Not analyzed	0.02	1.40
6	0.7 - 0.8	0.3	Trace	Trace
8	0.3 - 0.4	0.5 - 0.6	Trace	Trace
10	0.3 - 0.4	2.5 - 2.6	Trace	1.4
12	0.4 - 0.5	0.4 - 0.5	Trace	Nil

South of fault J (in the McCallum Creek sequence) no mineralized veins have been found nor are barren quartz veins common. Immediately north of this fault and in most areas underlain by the Rainbow Mountain sequence, veins (many mineralized) are common. The concentration of quartz veins near the thrust set D, E, F, and a similar relationship of veins to major fault W suggests that these faults may represent the principle avenues of mineralizing solutions. It is possible also that faults D and W are segments of the same fault.

Brecciated carbonate veins of similar orientation and mineralization have been noted by R. B. Forbes in sectors B-4, C-5, and D-5. Carbonate veins also occur at widely scattered localities along Rainbow Ridge proper. Some of these have been found in association with quartz veins.

Assays indicate that free gold is contained in most veins although it was not detected megascopically.

The following summary cites the discoveries and economic observations made by R. B. Forbes and D. M. Ragan during reconnaissance of the Rainbow Mountain area in the vicinity of Canwell Glacier during parts of the 1962 and 1963 field seasons. Several different associations of mineralization were recognized.

Mineralized conglomerate

One occurrence of mineralized graywacke-type conglomerate was discovered near the base of an abrupt canyon in sector D-5(SE) (see plate 5). This rock type of the Rainbow Mountain sequence is exposed along several hundred yards of this canyon; however, mineralization is limited to a small body a few hundred square feet in area. Pyrite and minor chalcopyrite are the important sulfides. The typical oxidation stain from the weathering of pyrite defines these mineralized bodies. An assay of the mineralized conglomerate showed gold (0.12 ounces per ton) and no silver.

Silicified diorite cut by ultramafic dikes

Two nickel-copper deposits (discovered by R. B. Forbes in 1962) occur along a northwest trending fault controlled draw, one-quarter mile south of Canwell Glacier (sector C-5(C), pl. 5). In the largest showing, nickeliferous pyrrhotite and perhaps other complex nickel sulfide mineralization occurs in and is associated with a network of serpentinized peridotite dikes. These cut silicified diorite in a shear zone which is largely covered but can be roughly defined by a mineralized zone measuring approximately 25 feet long and a maximum of three feet wide.

The second occurrence consists of lenses of pyrrhotite which are exposed in a small area 50 feet southwest of the largest showing. The percentage of sulfide in each showing varies from approximately 20 per cent to greater than 50 per cent; these sulfides are disseminated in massive aggregates closely associated with quartz. The following assays by Mr. I. W. Mitchell, Alaska State, Division of Mines and Minerals, were run on samples from these showings:

	Percentage of		Ounces/Ton
Location	Copper	Nickel	Gold
northeast occurrence	6.0	1.1	0.4
	1.9	1.5	Trace
	2.0	1.2	Trace
southwest occurrence	1.1	6.6	0.04

Silicified granodiorite

Pyrite and minor arsenopyrite bearing, silicified granodiorite occurs in isolated zones in the granodiorite pluton (sector B-4(EC)) (pl. 5). These zones are marked by iron oxide stain derived from the weathering of pyrite. Assays of the sulfide bearing granodiorite from this location showed a trace of gold.

This occurrence and others of disseminated pyrite and in one instance chalcopyrite in granodiorite (sector B-3(EC)) indicate that sulfide deposits may be associated with the granodiorite intrusion.

Chalcopyrite and pyrite bearing greenstone, (float)

Greenstone float containing chalcopyrite and pyrite is common in the medial and east lateral moraines of the glacier located in sector A-4(WC). An unsuccessful attempt to locate the source of this float was made in the spring of 1963. The source is believed to lie near the granodiorite-greenstone contact at the head of the cirque in the area of sector A-3(NC and NW).

Dunite

A body of dunite crops out in a one-half mile wide linear pattern near and parallel to the Canwell Glacier (sectors B-4, B-5, and C-5 (see geologic map, pl. 1). This mass is only slightly serpentinized. Near the northern margin, however, small veinlets of cross fiber chrysotile are common. No commercial occurrence of asbestos has been found. The dunite contains a trace of chromite. Samples submitted for chemical and spectroscopic analysis by Bruce Thomas of the U. S. Bureau of Mines, showed traces of nickel and cobalt.

A small basic igneous body (diorite-gabbro?) crops out along the northern margin of the dunite. Much of this basic intrusion is covered, and its relationships with the dunite are not clear. It contains disseminated pyrrhotite at several localities and deserves further investigation.

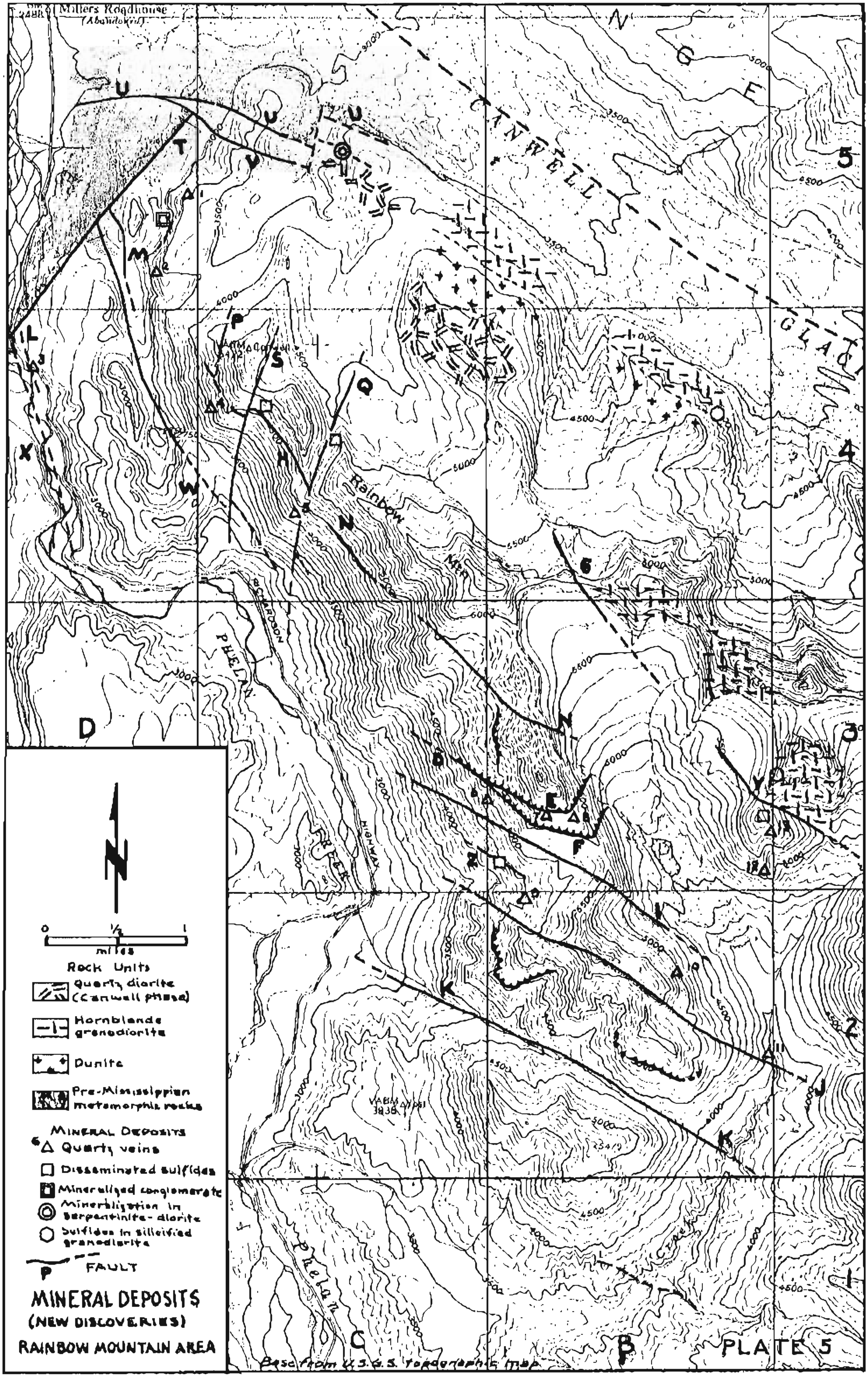
Summary and recommendations

Mineralized quartz veins are found along Rainbow Mountain (in the Rainbow Mountain sequence) for a distance of 7 miles south of the area in which similar mineralization has been previously recorded. Many of these areas, such as those near faults D-E-F, W and Y, merit further examination.

The occurrence of disseminated pyrite, chalcopyrite and trace gold in one conglomerate unit of the Rainbow Mountain sequence suggests that similar values may be present in the other sulfide dissemination deposits in this unit. These are exposed in many areas along Rainbow Mountain. Many porphyritic andesite "sills" are also pyritized and may reflect other more important sulfides mineralization. These deposits deserve further examination.

The nickel and copper mineralization associated with ultramafic dikes and silicified diorite near Canwell Glacier may persist at depth to the northwest under valley fill. These deposits also warrant detailed investigation.

Some evidence suggests that sulfide mineralization may be at least in part associated with the hornblende granodiorite intrusion. The contact zones of this pluton are probably worthy of further prospecting.



MINERAL DEPOSITS

(NEW DISCOVERIES)

RAINBOW MOUNTAIN AREA

PLATE 5

GEOLOGIC HISTORY

The sequence of events recorded in the Rainbow Mountain area can be arranged in relative order as shown in table 4. The paleontologic dating of several of these events is supplemented by regional correlation to permit dating of the entire sequence.

The record of early Paleozoic as well as possible Pre-Cambrian sedimentation and tectonism in the entire Alaska Range is not clear. No rocks of Cambrian, Ordovician or Silurian age are recognized in the eastern part of the range (Moffit, 1954). From the scarcity of lower Devonian rocks in Alaska, Smith (1938) suggests that this was a time of a major orogeny. Also, since middle and upper Devonian rocks are only locally schistose and distinctly less metamorphosed than the earlier rocks mapped in the eastern Alaska Range the postulation of a lower Devonian orogeny is supported.

From this evidence, the Pre-Mississippian metamorphic rocks probably represent sediments deposited in pre-Devonian time and the deformation may be dated as lower Devonian since the degree of deformation of this unit does not compare with the rocks believed metamorphosed during pre-Devonian orogenies.

No definite ages are assigned to the cycles of deformation during which the Carboniferous sequences were deformed. None of the intrusions which accompanied the tectonism in this area have been positively dated. Ages of the movements, including the intrusions can, however, be postulated from correlation with known tectonic activity in the Alaska Range. These correlations are based on the intensity, style and sequence of movements.

Moffit (1954) suggests in regard to the eastern Alaska Range that "Permian beds were folded and at least in places raised above the sea...followed by resubmergence in late Triassic time."

Payne (1955) records instead that the first Mesozoic orogeny involving the Alaska Range geosyncline, including the Nutzotin segment to the east (fig. 9), occurred during late Jurassic time. He dates the orogeny of the most intense Mesozoic folding and thrusting as mid-Cretaceous (late Neocomian-Aptian). The three major orogenies that followed are dated as: (1) Turonian, (2) post-Paleocene, and (3) post-Eocene.

Moffit (1954) postulates that the granitic plutons which intrude the area of the eastern Alaska Range range in age from earlier than late Upper Jurassic to Post-Eocene. One of these, a granodiorite, lies approximately 50 miles east of the Rainbow Mountain area in the Kuskulana River area. This mass has been dated at 105 million years (Matzko _et al._, 1958). The similarity in composition and structural position between this mass and the granodiorite of the Rainbow Mountain area suggests that the latter may also be of similar age. If this is true then the hornblende granodiorite intrusion would correlate with the Turonian orogeny. This is supported by field evidence.

In table 4, the episodes of deposition, orogeny, and intrusion in the Rainbow Mountain area are correlated with the sequence of events as recorded by Payne (1955) and others as noted above.

TABLE 4.--Geologic history of Rainbow Mountain area.

Sequence of Events	Event	Age	Remarks
17	Continued uplift; during glacial and interglacial stages.	Quaternary	At least three major glaciations recorded in this area, (Péwé 1953 and 1961).
16	Uplift, tilting and minor vertical block faulting.	Post-Eocene	Tertiary sediments faulted (?) into contact with pre-Tertiary units; Tertiary deformation evident from minor faulting within unit and common northeast dip of 15°-20° in Rainbow Mountain area. In Gulkana Glacier area, a broad anticline exists; a prominent fault separates unit from pre-Tertiary.
15	A continental deposition of sands and gravel and organics (Tertiary conglomerate unit).	Tertiary (Eocene or Miocene?)	Dated from plant fossils as Eocene (Wahrhaftig, 1958) in central Alaska Range; may be as young as Miocene according to some.
14	Intermittent high angle faulting of dominantly lateral movement. Coincident lateral movement along Denali fault possible.	Early Tertiary*(?) - Quaternary (?)	Many faults related to probably the same or consecutive orogenies; only a few show direction or movement (dominantly lateral). All (?) offset or truncate: (1) diabase dikes, (2) high angle, dominantly vertical northwest striking system, and (3) fold structures of event #7. Orientation of fault system favorable in part as secondary wrench fault group (Moody and Hill, 1956) related to theoretical right lateral movement on Denali fault.
13	Intrusion of diabase dike swarm.	Late Cretaceous-early Tertiary* (?)	Dikes cut or intrude: (1) mineralized quartz veins, (2) dacite lenses, (3) high angle northwest striking faults, (4) hornblende granodiorite, (5) thrust faults and associated folds, and (6) all major bedrock units in the area.
12	Principle quartz vein development and mineralization.	Upper Cretaceous* (?)	Most veins fill fractures parallel to major northwest fault system. One vein swarm cuts dacite lens along thrust fault E.
11	Intrusion of dacite dikes.	Upper Cretaceous (Turonian)* (?)	Intrusion along major faults in: (1) high angle northwest striking set and (2) thrust systems D, E, and F.
10	Block faulting; dominantly vertical movement. Similar movement along Denali fault possible.	Upper Cretaceous (Turonian) (?)	Faults cut major folds in Carboniferous sequences. Granodiorite faulted into contact with Carboniferous sequence along fault(s) subparallel to system. Movement continues on several of these faults following dacite intrusion of #11.
9	Intrusion of hornblende granodiorite pluton.	Post-Aptian and pre-Turonian* (?)	Pluton cuts folded belt of fold-thrust orogeny; possibly late orogenic (of event 8) (later than peak of folding).
8	Deformation, major folding and thrust faulting; overturning and overthrusting of Carboniferous rocks.	Mid-early Cretaceous (late Neocomian-early Aptian)* (?)	First recognizable deformation since deposition of Pennsylvanian sediments and andesite intrusion; northeast-southwest compression; overturning of folds and overthrusting toward the southwest; probably correlates regionally with major compressional (fold-thrust) orogeny of the Alaska Range*.
7	Intrusion of porphyritic andesite "sills" (in rocks of McCallum Creek and Rainbow Mountain sequences.	Post-Mississippian and pre-Cretaceous orogeny	"Sills" intrude only Carboniferous units. Pre-orogenic age indicated by pattern of hypabyssal layer involvement in folding, also folding of #7 most intense where andesites are missing and none of the sills have been controlled by structural weaknesses as a result of #7. Lithologic similarity of "sills" to Pennsylvanian volcanics suggests that sills may be Pennsylvanian also.
6	Accumulation of sediments and volcanics (McCallum Creek and Rainbow Mountain sequences).	Mississippian (?) and Pennsylvanian	Dated from fossils; McCallum Creek possibly Pennsylvanian in part; Mississippian (?) section tentative from fossils; sequences separated by fault; may be stratigraphically conformable, however.
5	Synkinematic metamorphism of sediments and volcanics (?) (Pre-Mississippian metamorphic sequence). Also cataclasis and partial recrystallization of quartz diorite of pluton (development of gneiss).	Early Devonian (?)	Dated pre-Carboniferous because of non-metamorphic character of Carboniferous units. Early Devonian believed to be time of major orogeny (Smith, 1938); this event probably correlative; may be older or conceivably later Devonian.
4	Intrusion of ultramafic dikes and sills into units of the Pre-Mississippian metamorphic rocks.	Pre-Devonian (?)	Gneiss possibly formed instead during a later orogeny from the deformation of quartz diorite (Canwell phase).
3	Intrusion of quartz diorite pluton (later, quartz diorite gneiss).	Pre-Devonian (?)	Pre-metamorphism (cataclasis) of unit and probably intrusion into sedimentary unit of event #1.
2	Accumulation of sediments and volcanics (?) (later, Pre-Mississippian metamorphic rocks).	Pre-Devonian (?)	Probably younger than sediments of Birch Creek schist origin but may be equivalent to these or conceivably older.
1	One or more periods of metamorphism; the development of the: (1) Birch Creek schist (north of Canwell Glacier) and (2) schists-gneisses-migmatites (Gulkana Glacier catch basin).	Precambrian (?)	May include metamorphism of Pre-Mississippian metamorphic rocks--Birch Creek schist--dominantly quartz-muscovite schist (just north of glacier). May be Paleozoic in age, or possibly Mesozoic: schists-gneisses-migmatites most likely Precambrian.

*Dating based in part on Payne (1955).

CONCLUSIONS

The Paleozoic-Mesozoic igneous and sedimentary rock units which dominate the Rainbow Mountain area (south of the Denali fault) contrast the Precambrian (?) Birch Creek schist which underlies much of the area north of the fault.

The following major rock units occur within the study area:

1. Pre-Mississippian metamorphic rocks (low grade) include phyllites, greenschists and marbles and occupy several fault blocks marginal to the Denali fault. A concentration of ultramafic sills and dikes defines the associated Serpentinite complex.

2. Mississippian (?) McCallum Creek and Pennsylvanian Rainbow Mountain sequences are composed of graywacke-like detrital rocks, andesitic and dacitic tuffs and volcanic breccias, a few andesite flows and subordinate fossiliferous limestones. These have been dated from paleontologic evidence. These sequences demonstrate a minimum total thickness of 5600 feet and 8000 feet respectively.

3. Separate systems of dikes and sills composed of: (1) andesite, (2) rhyolite, (3) basalt-gabbro, (4) dacite, (5) alkali gabbro, and several others cut most sedimentary and metamorphic rock units.

4. A pluton of hornblende granodiorite intrudes the Carboniferous sedimentary rocks and andesites and may be related to the quartz diorite (Canwell phase) mass which outcrops beyond the study area. A dunite intrusion separates two occurrences of these granitic rocks.

5. Quartz diorite gneiss representing a sheared and partially recrystallized pluton (?) is found in association with the Pre-Mississippian metamorphic rocks.

At least four major and distinctive cycles of deformation are recorded in the area:

1. The early or middle Paleozoic (?) synkinematic metamorphism of the Pre-Mississippian metamorphic rocks has produced generally subisoclinal to isoclinal folds of north to northwest trend and low grade equilibrium mineral assemblages.

2. The first major deformation of strong intensity following Pennsylvanian deposition and andesite sill intrusion caused open to subisoclinal folding and local overturning and overthrusting to the southwest (structural trends northwest).

3. Vertical block faulting along subparallel faults trending northwest followed the intrusion of the hornblende granodiorite plutonic rocks.

4. High angle north to northwest trending system of lateral slip (?) faults succeeded the intrusion of the diabase dike swarm and major quartz vein mineralization.

These last three cycles are probably late Mesozoic to early Tertiary in age and may reflect corresponding movement on the Denali fault. No further evidence was collected that might suggest the direction or magnitude of movement on "the great fault."

Sulfide mineralization, although sparse throughout the area, does occur in several concentrations which warrant further investigation. These are primarily nickel-copper deposits associated with ultramafic dikes. Other deposits of possible economic importance are: (1) the north to northwest trending copper-lead bearing quartz veins which cut principally the Rainbow Mountain sequence and (2) disseminated sulfides in principally the rocks of the Rainbow Mountain sequence and associated andesite sills and the granitic plutonic rocks.

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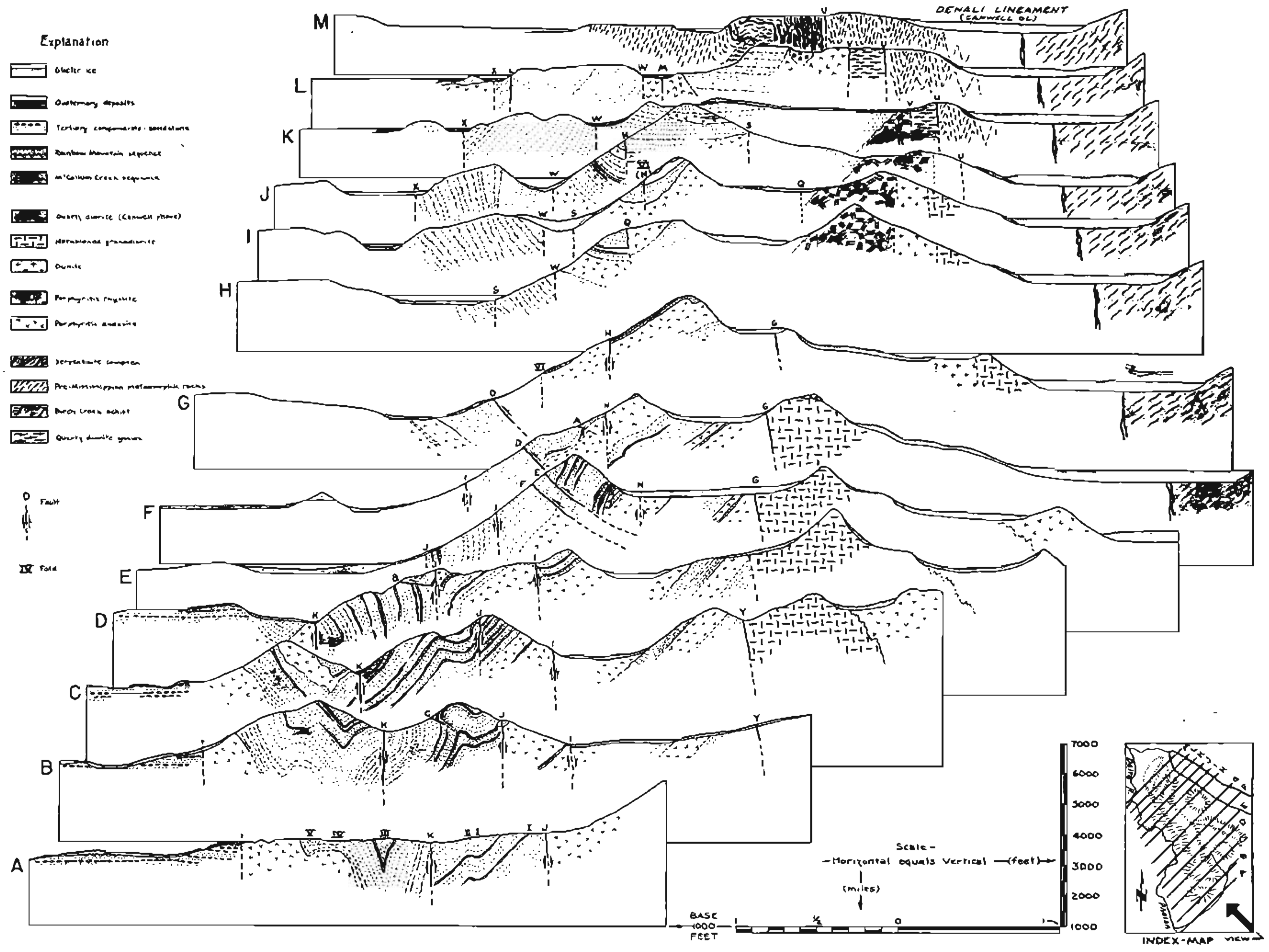

STRUCTURE SECTIONS, RAINBOW MOUNTAIN AREA.

PLATE 2