GEOLOGY OF THE EUREKA CREEK AREA, EAST-CENTRAL ALASKA RANGE

By
James H. Stout

GEOLOGIC REPORT 46

STATE OF ALASKA

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By James H Stout[1]

ABSTRACT

Geologic investigations in portions of the Mt. Hayes A-4, A-5, B-4, and B-5 quadrangles near Eureka Creek reveal a folded and faulted succession of predominantly volcanic rocks ranging in age from pre-Pennsylvanian(?) to Late Triassic. Pre-Pennsylvanian amphibolites and greenschists exposed south of the Denali Highway are unconformably overlain by the Pennsylvanian and Permian Tetelna Complex, a sequence of subaerial dacitic to andesitic volcanics and volcaniclastic sediments. These rocks apparently grade into the predominantly marine limestones and shales of the Mankomen Group exposed at Rainy and Eureka Creeks. Collectively, the Upper Paleozoic rocks are approximately 15,000 feet thick.

A very thick succession of basaltic to andesitic flows and related volcaniclastics of the Amphitheater Group unconformably(?) overlie the uppermost Permian strata. Three formations are recognized. The Paxson Mountain Basalt consists of approximately 9500 feet to subaerial basalts recrystallized to greenstone. The Tangle Lakes Formation consists of approximately 13,000 feet of andesite flows, volcanic tuffs, and tuffaceous sediments. Its marine environment of deposition is evidenced by thin tuffaceous limestones that locally contain Late Triassic pelecypods, and by abundant pillows in the flows. The Boulder Creek Volcanics consist of at least 18,500 feet of slightly recrystallized gray-green basalt interlayered with distinctive amygdaloidal zones. Collectively, the three formations comprise over 40,000 feet of predominantly volcanic rocks accumulated during Triassic time. These rocks form part of a belt along the south flank of the Alaska Range that correlates in age and lithology with similar sequences in the Wrangell Mountains, at Kluane Lake (YT), and on Vancouver Island.

This thick sequence is separated in both time and space from Late Jurassic to Cretaceous argillaceous sediments and volcanics which are correlative with the Gravina-Nutzotin belt elsewhere in Alaska. These rocks in the Eureka Creek area have been regionally metamorphosed to the sillimanite zone in the Late Cretaceous and are part of the Maclaren metamorphic belt. The contact between the relatively unmetamorphosed pre-Jurassic terrane and the highly metamorphosed younger sediments is the Broxson Gulch Thrust fault, a major structural break that extends for a minimum distance of 50 miles along the south flank of the Alaska Range. Stratigraphic and structural arguments suggest that the contact is a faulted unconformity.

Dunite and other ultramafic intrusives of probable Tertiary age along the Broxson Gulch Thrust fault and along the Denali Fault east of the Delta River suggest that faulting and intrusions were broadly contemporaneous–perhaps as recently as post-Late Oligocene. Fossiliferous Late Oligocene(?) sandstones and conglomerate are highly deformed along the Broxson Gulch Thrust fault, and younger conglomerates contain abundant clasts from the ultramafic rocks.

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INTRODUCTION

GEOGRAPHY

The Eureka Creek area covers approximately 500 square miles between the Denali Highway and the south flank of the central Alaska Range. The area is bounded on the east by the Richardson Highway and on the west by the Maclaren River. It encompasses major portions of the Mt. Hayes A-4, A-5, B-4, and B-5 30-minute quadrangles.

The topography is varied. Terrane north of Eureka Creek is characterized by steep unvegetated ridges separated by active valley glaciers. The most notable of these is the Maclaren Glacier, the East Maclaren Glacier, and several smaller, unnamed glaciers at the headwaters of Eureka Creek. Each of these produces substantial runoff during the summer months and renders the glacial streams impassable by foot. Drainage from the East Maclaren Glacier bifurcates into the east-flowing Eureka Creek and into the west-flowing Maclaren River (East Fork). The latter finds egress to the Gulf of Alaska by way of the Susitna River, whereas the former joins the Delta River, which flows north to the Tanana and Yukon Rivers and eventually to the Bering Sea. The lofty peaks that form the crest of the Alaska Range north of the map area attain elevations of 9,000 to 10,000 feet (fig. 1).

In contrast, the topography south of Eureka Creek is more subdued. The Amphitheater Mountains, contained entirely within the map area, are characterized by less severely dissected ridges flanked by broadly sloping talus and glacial deposits. Maximum elevations are near 6,000 feet. There is no active glaciation. However, the evidence for previous glaciation is strikingly preserved in the several U-shaped watergaps that extend in a north-south direction across the regional trend of

Figure 1. South flank of the central Alaska Range as viewed from the Amphitheater Mountains. Eureka Creek and the West Fork Glacier are in the middle ground. Photo looking north.

the Amphitheater Mountains. Most notable of these are Landmark Gap and the Delta River valley. Small glacial cirques are common above 4,000 feet.

South of the Amphitheater Mountains and the Denali Highway, the topography is gentle, consisting predominantly of glacial deposits that mantle all but a few isolated bedrock localities. A notable exception is Paxson Mountain, which rises to 5,500 feet in the southeastern corner of the map area (pl. 1).

Vegetation in the area is sparse. Conifers are present at elevations below 3,000 feet and are abundant only along the Delta River and Rainy Creek. Scattered brush exists locally up to 4,000 feet. At higher elevations, the low-lying tundra vegetation is predominant.

Convenient access to the marginal portions of the map area is achieved by automobile on the Richardson and Denali Highways. These roads cross the Maclaren River and the Delta River, both of which may be navigated by riverboat. Fixed-wing support, on wheels or floats, is available at Summit Lake and Susitna River. Numerous lakes are accessible by float plane south of Eureka Creek, but none are large enough for safe operation further north. A landing strip at Broxson Gulch provides fixed-wing access north of Eureka Creek—as do several outwash plains at the base of the Maclaren and East Maclaren Glaciers. The entire area is accessible by foot.

HUMAN HISTORY

Evidence of early man in the Eureka Creek area is scanty, but apparently occasional bands of Indians frequented the Landmark Gap area in the Amphitheater Mountains in search of rock suitable for tool working. Several sites at Landmark Gap and Tangle Lakes have been identified by abundant chips of siliceous tuff which outcrops locally. These are presently under investigation by an archeological group from Alaska Methodist University.

More recently, the quest for gold and copper has attracted prospectors and mining companies at various times to this otherwise uninhabitated area. Gold placers at Broxson Gulch and Rainy Creek (Brooks, 1918; Martin, 1920) were worked successfully as early as 1903. The operation at Broxson Gulch has been active in recent years. Numerous claims exist elsewhere, notably on Rainy Creek, where copper and nickel sulfides are present in a gabbro porphyry, and in the eastern part of the Amphitheater Mountains, where copper-sulfide bearing quartz veins and joint surfaces are common. Other than those employed by occasional mining interests, the only inhabitants are seasonal residents at Tangle Lakes and Maclaren River.

PREVIOUS INVESTIGATIONS

The earliest geologic reports on the Eureka Creek area deal mainly with the general geology and its bearing on the early economic development of Alaska resources. The earliest account seems to be that of Mendenhall (1900) who, with a military expedition in 1898, followed a route to Tangle Lakes (pl. 1) and along the east side of the Delta River. Four years later, Mendenhall and Schrader (1903) returned to make a reconnaissance topographic and geologic map of a large area that included a portion of the area around the Delta River. The discovery of placer gold on Valdez Creek in 1903 generated further interest in the surrounding bedrock geology. The first definitive geologic map, still accurate in many respects, is that of Moffit (1912). He described that part of the Alaska Range in the vicinity of the Delta River and Eureka Creek as consisting of a belt of Carboniferous and post-Carboniferous sedimentary and igneous rocks lying between older schists to both the north (north of the McKinley strand of the Denali fault) and the south (south of the present Denali Highway). He considered the structure as a simple synclinorium, but recognized the possible complexity due to faulting.

A compilation by Moffit (1954) of his own work in the Alaska Range from 1912 and of others since then contains only minor changes in his 1912 version of the Eureka Creek area. Geologic mapping programs since then have been undertaken by the Alaska Division of Geological and Geophysical Surveys and the University of Alaska. Reconnaissance studies by Rose (1965, 1966) and Stout (1965) provide the basis on which additional mapping was completed as part of this study north of Eureka Creek. Additional mapping efforts by Rose (1966b) and Rose and Saunders (1965) in the Amphitheater Mountains, and Moffit (1912) provided the only existing geologic maps for the area south of Eureka Creek prior to this study.

ACKNOWLEDGMENTS

I acknowledge with pleasure the financial and logistic support of the Alaska Division of Geological and Geophysical Surveys during the course of this study. In particular, Dr. T.E. Smith afforded fixed-wing and helicopter support for access to the more remote areas. Drs. Jonathon Callender, University of New Mexico, and J.B. Brady, Harvard University, provided me with able assistance in 1971, when a portion of the map area north of Rainy Creek was investigated. Mssrs. R.J. Beltrame, Gary Gaynor and J.E. Quick, all of the University of Minnesota, provided assistance during the 1973 field season. To them I express my gratitude.

GEOLOGIC SETTING

The oldest known rocks in the Eureka Creek area consist of fossiliferous bedded sandstones, siltstones, and silty limestones of Early Pennsylvanian age (Rowett, 1969) exposed north of Rainy Creek and along the Delta River and Phelan Creek in the northeast corner of the map area (fig. 2 and pl. 1). The section is underlain by unfossiliferous dacite crystal tuff and volcanic breccias believed also to be of Pennsylvanian age (Stout, 1965). These rocks are faulted against younger metamorphic rocks of the Maclaren Belt (Smith, 1971; Smith and Lanphere, 1971) to the north. The only evidence for an older basement is south of the Denali Highway near Tangle Lakes, where well-foliated greenschist and amphibolite of possible pre-Carboniferous age (Rose and Saunders, 1965) are found. The precise age of these rocks is not known.

The predominantly subaerial pyroclastics and flows of Pennsylvanian age grade into fossiliferous Permian limestones and volcanics (Petocz, 1970). The rocks are predominantly marine, and represent the youngest known Upper Paleozoic sediments in the Alaska Range. The entire Upper Paleozoic sequence is apparently correlative with similar rocks in the Chulitna district (Clark, Clark and Hawley, 1972) south of Mt. McKinley. They are also reported east of the present area near Gulkana Glacier and in the Nabesna area (Richter and Jones, 1970). These authors interpret the stratigraphic relationships as a record of an island arc developed directly on oceanic crust followed by subsidence to a shallow-water platform.

Overlying these rocks south of Eureka Creek (pl. 1) is a thick section of mafic volcanics and pyroclastics believed to be Triassic. Mofitt (1912) first correlated these rocks with the Nikolai Greenstone of the Chitina Valley now considered to be late Middle to early Late Triassic in age (MacKevett, 1969). Most of the Amphitheater Mountains are underlain by these mafic volcanics now referred to as part of the Amphitheater Group (Smith, 1974a, b). The central axis of the Amphitheater Mountains is the axial trace of a broad syncline (hereafter referred to as the *Amphitheater syncline*) that repeats the volcanic section to the south. Hence that portion of the stratigraphic section younger than Middle or Late Triassic is not exposed.

Younger Mesozoic sedimentary and volcanic rocks in the Eureka Creek area are tectonically separated from older rocks by the Broxson Gulch Thrust fault (Rose, 1965). The argillites, siltstones, and silty limestones

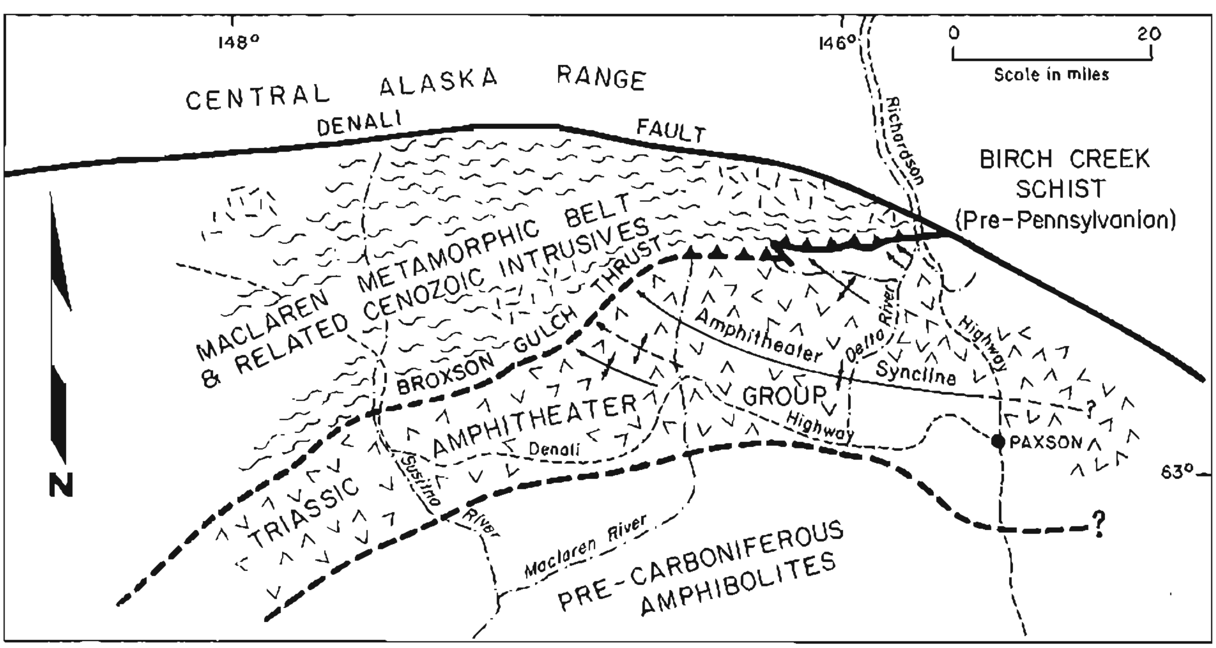

Figure 2. Generalized geologic map of the central and east-central Alaska Range. Sources of data are referenced in text.

north of Eureka Creek are part of the Maclaren metamorphic belt (Smith, 1970b; Smith and others, 1972; Smith and Turner, 1973). The crystalline schists of this belt were first recognized in the Eureka Creek area by Rose (1965, 1966) and subsequently studied by Stout (1972). The low-grade parts of the belt in the Clearwater Mountains are apparently post-Upper Triassic, but not younger than Late Jurassic (Smith and Lanphere, 1971). Fossils recently discovered by Smith (1974a) from conglomerate exposures in the Maclaren Belt are Upper Jurassic. The widespread argillites and their metamorphosed equivalents in the Maclaren metamorphic belt are lithologically equivalent to rocks in the Gravina-Nutzotin belt near Mentasta Pass (Richter, 1967) and therefore may be as young as late Early Cretaceous (Berg and others, 1972). The marine flyschlike argillites, graywackes, and interbedded volcanics of the Gravina-Nutzotin belt depositionally overlie Upper Paleozoic and Triassic rocks elsewhere in Alaska and are interpreted by Berg, Jones, and Richter (1972) as part of a deformed upper Mesozoic magmatic arc.

Radiometric dating of metamorphic biotite and hornblende from schists of the Maclaren belt yield regional metamorphic ages from 66 to 57 m.y. (Smith and Turner, 1973) and confirms its Late Cretaceous development.

Supracrustal rocks of the Maclaren belt have been intruded by numerous stocks and stills ranging in age from 143 m.y. for alkali gabbro (Smith and Lanphere, 1971) to approximately 30 m.y. for granodiorite and quartz monzonite (Smith and Turner, 1973). None of these intrusive rocks can be directly correlated with rocks intruded into the tectonically separated Mesozoic and Paleozoic sections to the south. The felsic intrusives do seem to correlate, however, with two of the three main intrusive epochs of the Alaska-Aleutian Range batholith (Reed and Lanphere, 1970, 1973). The latter are Late Cretaceous—Early Tertiary and Middle Tertiary.

South of the Broxson Gulch Thrust, granodiorite intrusive into basalts of the Amphitheater Group is dated at 125 m.y. (Smith and Turner, 1973). Numerous ultramafic rocks, including dunite and peridotite, are younger than the granodiorite but have not as yet been dated by direct means.

The intrusive ultramafic rocks are apparently of different ages. A layered sequence of peridotite and dunite south of Eureka Creek (fig. 2) may be pre-Jurassic, whereas the massive dunites along the base of the Broxson Gulch Thrust appear to be Tertiary (Stout, 1965). The latter rocks define a northeast-striking belt that extends to the Denali Fault, and then east-southeast along that great lineament (Stout, 1972).

Tertiary conglomerate, coal-bearing sandstone, and a few volcanic flows (all probably post-Oligocene) unconformably overlie all older rocks. They are broadly folded in most areas, but are strongly deformed and faulted near the Broxson Gulch Thrust. This suggests that motion on the thrust fault—and perhaps on the Denali Fault as well—is as young as Middle to Late Tertiary.

STRATIGRAPHY

The pre-Tertiary stratified sedimentary and volcanic rocks of the Eureka Creek area are divided into two suites: 1) Pre-Jurassic sedimentary and volcanic rocks south of the Broxson Gulch Thrust, and 2) Jura-Cretaceous metamorphic rocks north of the Broxson Gulch Thrust.

This division facilitates comparison of the lithology and geologic history of rocks separated by the Broxson Gulch Thrust.[1] It also serves to illustrate the fundamental tectonic and stratigraphic differences between these two suites. Both are unconformably overlain by Tertiary sediments and deposits of glacial origin. A summary of the stratigraphic succession is given in table 1.

PRE-PENNSYLVANIAN(?) GREENSCHISTS AND AMPHIBOLITES

Well-foliated greenschists and amphibolites are exposed in the low-lying hills south of the Denali Highway near Tangle Lakes (pl. 1). These rocks are part of the 'Carboniferous(?) greenstone, schist, and limestone' unit recognized by Moffit (1912, 1954) and Chapin (1918) north of the west fork of the Gulkana River. The west-trending belt extends from the Richardson Highway to at least the Susitna River, a distance of over 100 miles. Rose and Saunders (1965) later examined these rocks south of Paxson Mountain and, based on their higher rank metamorphism relative to the Triassic Amphitheater Group, concluded that they are probably pre-Triassic. They are probably the oldest rocks exposed in the Eureka Creek area.

At the most northerly outcrops near Tangle Lakes (pl. 1), interlayered rusty schists and greenschists dip steeply to the north. These are fine-grained rocks with a well-developed metamorphic fabric. Some deeply weathered diorite or granodiorite sills penetrate the schists at this locality. They appear to be unmetamorphosed.

Further south, amphibolites become common and the rusty-weathering units are absent. Thin-section examination of representative amphibolite samples (table 2) reveals a pale blue-green hornblende with apparently unreacted cores of colorless clinopyroxene (fig. 3). Biotite is common in the finer-grained varieties. Epidote and actinolite or very pale hornblende occurs in a few calcmagnesian layers.

Most of the thin sections of amphibolites have approximately 5 volume-percent magnetite. This prob-

[1] Usage of *thrust* will apply loosely to all low-angle faults in the zone of movement (pl. 1).

Table 1. *Stratigraphic summary of layered rocks in the Eureka Creek area.*

Quaternary:	*Glacial till:* Largely unconsolidated ground moraine
	UNCONFORMITY
Oligocene:	*Tertiary:* Consolidated gravel and coal-bearing sandstone. Correlative with Gakona Formation elsewhere.
	UNCONFORMITY (Mid-Oligocene)
Jurassic: (Cretaceous?):	*Jura-Cretaceous* Mildly to severely metamorphosed argillite, graywacke, volcanic flows, and conglomerate. Correlative with rocks of the Gravina-Nutzotin belt elsewhere.
	FAULT CONTACT (Broxson Gulch Thrust)
Triassic	*Amphitheater Group:* Mildly metamorphosed pillow basalts and andesites with interbedded siliceous tuffs and volcaniclastic rocks. Correlative with Nikolai Greenstone elsewhere.
Permian	*Mankomen Group:* Marine mudstone and siltstone overlain by fossiliferous limestone and shale.
Pennsylvanian:	*Tetelna Complex:* Thick sequence of mildly to unmetamorphosed siliceous volcanics, dacitic volcaniclastics, tuffaceous sediments, and limestone.
Pre-Pennsylvanian	*Pre-Pennsylvanian Greenschists and Amphibolites:* Interlayered greenschists and amphibolites.

ably accounts for the high aeromagnetic intensity observed by Andreason and others (1964) over this poorly exposed terrane.

Careful examination of the foliation and attitudes of primary compositional layering shows that the rocks

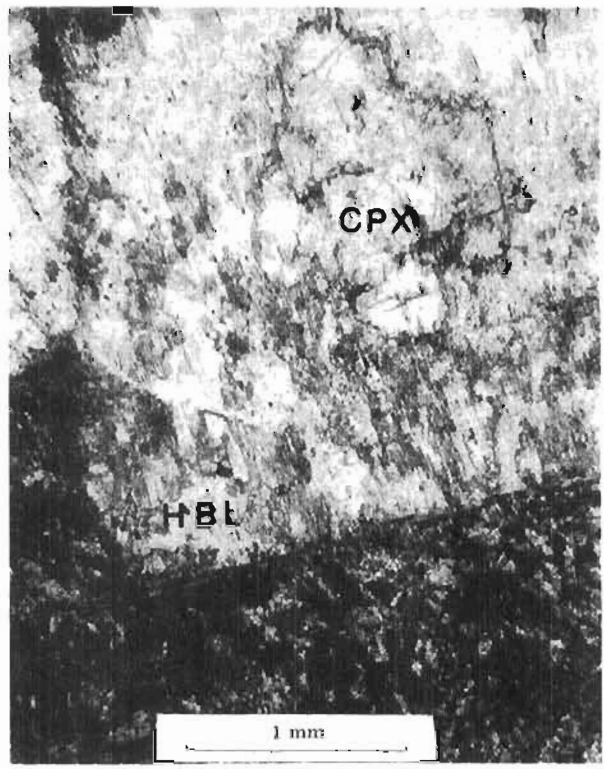

Figure 3. Photomicrograph of amphibolite from pre-Pennsylvanian(?) terrane near Tangle Lakes. Hornblende porphyroblasts (HBL) have relict clinopyroxene (CPX) cores. Specimen A4-3-1.

Table 2. *Modes of representative specimens from Pre-Pennsylvanian(?) greenschists and amphibolites from near Tangle Lakes.*

[Modes are from thin section by visual estimate.]

Specimen No.	A4-3-1	JS-801A	JS-801B	JS-802	A5-1-1
	Modes				
Actinolite	-	-	-	10	-
Biotite	5	20	20	-	10
Chlorite	-	10	25	30	10
Epidote	2	-	-	10	10
Hornblende	70	30	10	-	-
Hematite	-	-		-	10
Magnetite	5	4	5	5	-
Plagioclase	-	35	40	5	-
(An content)	-	30	30	20	-
Pyroxene	10	-	-	-	-
Quartz	-	-	-	35	30
Sericite	-	-	-	5	30

have been intensely folded on an outcrop scale. This observation is noted here because it contrasts markedly with the rather uniform dips of the Triassic Amphitheater Group exposed north of the Denali Highway. There, the metavolcanics are only weakly recrystallized and dip at low to moderate angles to the north. Unfortunately, the contact is covered by an extensive region of glacial drift in the vicinity of Tangle Lakes. There is sufficient outcrop to conclude, however, that the thick Pennsylvanian and Permian sections discussed elsewhere in this paper are missing. A fault or an unconformity or both are possible interpretations. There is some basis for preferring an unconformity because of the absence of Lower and Middle(?) Triassic rocks elsewhere in Alaska.

TETELNA COMPLEX

Outcrops of Pennsylvanian sedimentary and volcanic rocks define a wedge-shaped area (fig. 2) bounded on the north by the Jura-Cretaceous Maclaren metamorphic belt and on the south by the Permian Mankomen Group. The best exposed regions are in the deeply dissected canyons west of the Delta River and along the east side of the Richardson Highway. The section extends westward beyond Broxson Gulch, where it is faulted out between imbricate thrust faults (pl. 1).

Several attempts have been made to divide the Pennsylvanian rocks into mappable units. Stout (1965) originally defined eight informal formations on the basis of differences in lithology. These are, in order of decreasing age:

1. Andesite flow unit
2. Interbedded siliceous tuff and tuffaceous limestone unit
3. Siltstone and mudstone unit
4. Crystalline limestone unit
5. Graywacke and dark tuffaceous sandstone unit.
6. Dacite quartz porphyry
7. Calcareous shale and siltstone unit
8. Volcanic breccia and dacitic tuff.

Collectively, the exposed section is between 9,000 and 10,000 feet thick. These are the oldest rocks exposed in the Eureka Creek area and are a part of an extensive volcanic-rich sequence east of the Delta River near Rainbow Mountain (Hanson, 1963). There, nearly 4,000 feet of dacitic tuffs and volcanic breccias intercolated with grey-green siltstone and mudstone of probably volcanic origin are overlain by approximately 3,300 feet of bedded sandstone, siltstone, and silty limestone. Rowett (1969) estimates an aggregate thickness of approximately 8,000 feet.

A detailed stratigraphic study of the Pennsylvanian section east of the Delta River by Bond (1970, and personal communication, 1974) indicates that units 1 through 5 described by Stout (1965) and listed above are probably correlative with the lower Tetelna Complex of Atokan or Desmoinesian age, or both. The nomenclature is based on Mendenhall's (1905) original usage and that adopted by Richter (1966) for several thousand feet of subaerial volcanics in the Slana district, 100 miles to the east. Units 6 through 8 listed above lithologically correlate with Bond's Richardson Highway pyroclastics; consequently, that usage will be adopted here. This formation contains fossils of Missourian(?) and Virgilian(?) age (Rowett, 1969, 1971) and its top is taken as the boundary between Pennsylvanian and Permian strata. A recent study by Rowett and Timmer (1973) of a varied fauna of rugose corals collected near milepost 212 on the Richardson Highway establishes a lower Middle Pennsylvanian (Atokan or Desmoinesian) age for these rocks.

Rose (1965, 1966) further attempted to subdivide the Paleozoic strata. He distinguished the following sequence of six mappable units in order of decreasing age:

1. Andesite, dacite, and graywacke
2. Limestone
3. Intrusive andesite and dacite
4. Rainy Creek basalt
5. Limestone associated with Rainy Creek basalt
6. Tuff and sediments associated with Rainy Creek basalt.

Field mapping as part of the present study (pl. 1) indicates that Rose's sequence and Stout's (1965) sequence are broadly correlative. Comparison of Rose's stratigraphy with that of Stout (above) reveals that Rose's units 1 and 2 correlate with Stout's units 1 through 5. Both sets of units appear to correlate with Bond's lower Tetelna Complex. For future usage and formal nomenclature, it seems appropriate at this time to adopt the formation name *Tetelna Complex* in place of the informal units of Rose (1965, 1966) and Stout (1965).

The dacite quartz porphyry of Stout (1965) and the intrusive andesite and dacite of Rose (1966) are taken in this study as the contact between Bond's lower Tetelna Complex and his Richardson Highway pyroclastics. Extrapolation of Bond's contact (personal commun., 1974) across the Delta River to Ann Creek (pl. 1) indicates that Stout's units 7 and 8 correlate with the Richardson Highway pyroclastics.

The contact between the Pennsylvanian and Permian sections in the Eureka Creek area is not well defined because of an absence of diagnostic fossils. Rowett (1971) has found lower Wolfcampian fossils in thin, bioclastic limestones that are interbedded in a predominantly volcanic sequence that stratigraphyically overlies the Richardson Highway pyroclastics. These rocks correspond to the sparsely exposed volcaniclastics and flows between Ann Creek and Rainy Creek. They are also apparent stratigraphic equivalents to Rose's (1965, 1966) units 4-6, listed earlier. Rose's Rainy Creek basalt and associated limestone and tuffaceous sediments appear from their structural position (pl. 1) to stratigraphically overlie the uppermost units mapped by Stout (1965). They also underlie the fossiliferous limestones and shales of the Mankomen Group. Hence they are likely to be of lower Permian age.

Bond (personal commun., 1974) has mapped the equivalent succession of rocks east of Phelan Creek as the *upper Tetelna Complex*. This nomenclature is adopted here because the formation includes a wide range of lithologic types that are conveniently mapped (pl. 1) as a single unit. None of the thin limestones or individual volcaniclastic beds observed as part of this study could be traced laterally for more than a few hundred feet.

Adoption of Bond's nomenclature is further justified because of the difficulty in recognizing discrete lithologies near the west fork of Rainy Creek and Broxson Gulch. There, the presumed lower Permian rocks are strongly altered by hypabyssal intrusives. Dacite porphyry, gabbro, and dunite have locally recrystallized the host rocks so that even their primary bedding is obscured. Thin-section and hand-specimen examination of representative rocks reveal pyrite, calcite, sericite, chlorite, and epidote as the most common alteration products.

Recognition of distinct lithologies is further complicated by intense deformation due to faulting. At the base of the Broxson Gulch Thrust (fig. 2 and pl. 1), thrust tectonites (Stout, 1965) are locally developed. They are generally fine grained and possess a distinctive 'metamorphic' fabric that is absent a few hundred yards from the thrust zone. A photomicrograph of a deformed andesite from the lower Tetelna Complex is shown in figure 4. Both the formal nomenclature of the Tetelna Complex as applied to the Eureka Creek area and its approximate stratigraphic thicknesses are summarized in figure 5.

Petrographic observations of several representative thin sections (table 3) as well as hand specimen observations indicate that nearly the entire Tetelna Complex is volcanic or volcaniclastic in origin. Approximately 75 percent of the section, or 7,000 feet, consists of pyroclastic rocks of predominantly dacitic composition. Approximately 20 percent of the section consists

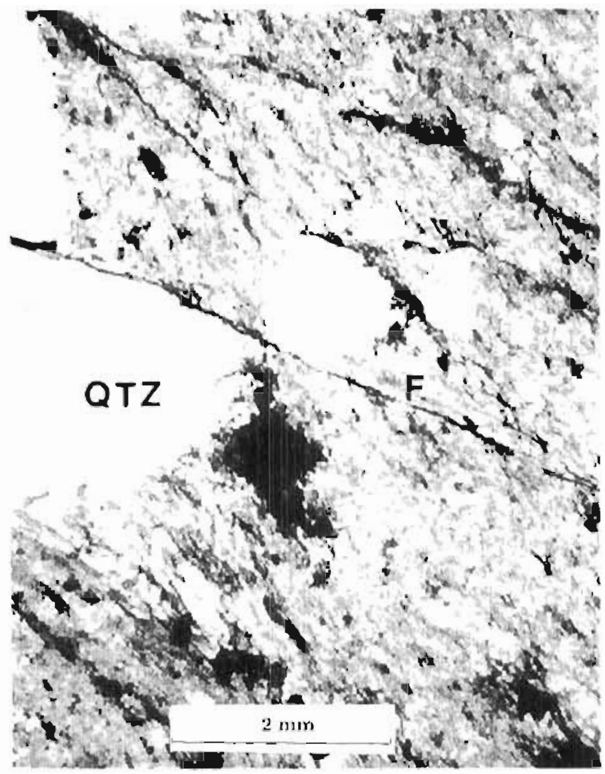

Figure 4. Photomicrograph of highly deformed andesite at the base of the Broxson Gulch Thrust. Quartz phenocrysts (QTZ) are broken by microfaults (F), and a pervasive metamorphic fabric is developed. Specimen JS-193.

Table 3. *Modes of representative specimens from the Pennsylvanian and Permian Tetelna Complex.*
[Specimens JS-190, 193, 210, 327, and 377 from the lower Tetelna Complex; remaining specimens from the upper Tetelna Complex.]

Specimen No.	JS-336	JS-377	JS-280	JS-327	JS-210	JS-382	JS-190	JS-381	JS-193
	Modes								
Actinolite	-	40	-	-	-	-	-	30	-
Chlorite	-	5	-	2	5	10	20	-	-
Epidote	5	3	-	1	-	-	-	-	10
Magnetite	5	-	10	-	-	2	-	-	-
Opaque material	40	10	10	1	-	15	-	20	10
Plagioclase	20	15	10	55	7	13	10	30	-
Quartz	30	5	20	25	20	40	30	-	40
Sericite	-	22	10	12	40	20	40	-	40
Volcanic rock fragments	-	-	40	6	28	-	-	20	-

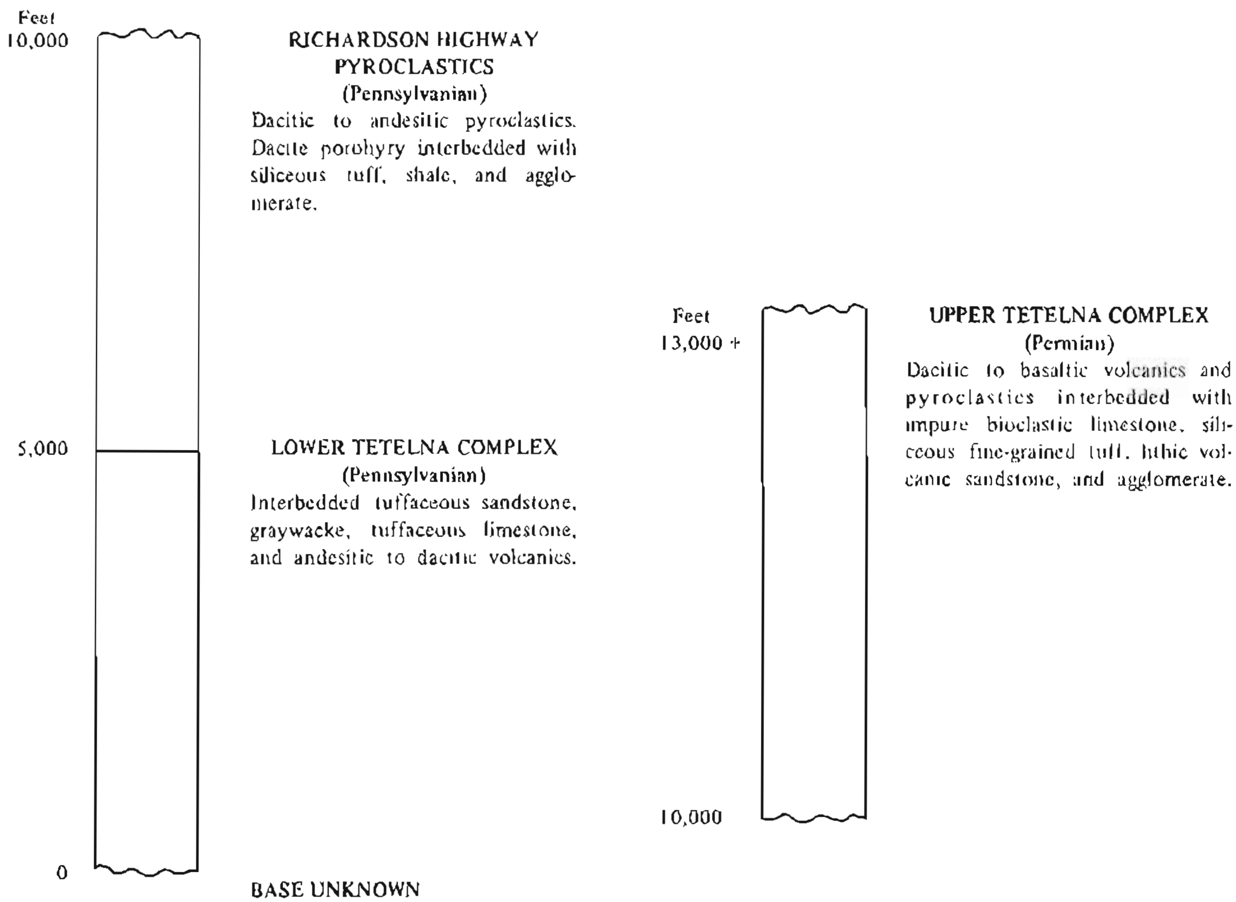

Figure 5. Summary of stratigraphy within the Pennsylvanian and Permian Tetelna Complex.

of volcanic flows whose compositions appear in hand specimen to range from dacite to basalt. The rest of the section consists of limestone, tuffaceous limestone and sediments, and feldspathic sandstone (graywacke). These results support Bond's (1970) interpretation that the upper Paleozoic stratigraphic succession records an ancient island-arc environment.

MANKOMEN GROUP

Marine strata of lower Permian age are well exposed in Eureka Creek and in Rainy Creek near the northeast corner of the study area. There appears to be a gradational contact between subaerial lavas and pyroclastics of the Tetelna Complex to the north and marine shales or argillites and limestones that constitute the basal part of the Mankomen Group to the south. The south-dipping section is approximately 2,000 feet thick on Rainy Mountain (pl. 1) and is cut by numerous faults of unknown displacement. The contact between the Mankomen Group and the presumed base of the Triassic Amphitheater Group is exposed 3 miles northwest of Rainy Mountain.

The lithology and biostratigraphy of the Mankomen Group on Rainy Mountain and along the Delta River has been studied extensively by Petocz (1970) and will only be summarized here. The most distinctive rocks are thick, fossiliferous limestones, which constitute approximately 80 percent of the strata. Brachiopods, bryozoans, crinoids, and both solitary and colonial rugose corals are common. Interbedded black shales and thin, bioclastic limestones are prominently exposed along the north-facing bluffs on Rainy Creek. Eighteen species of fusulinids studied by Petocz (1970) from these rocks indicate a lower Permian age.

Coral zonation (Rowett, 1970) indicates that the massive bioclastic limestones at the top of the section on Rainy Mountain may have been deposited in Leonardian time. According to Rowett, an eastward marine transgression commenced at this time and ultimately inundated the Tetelna volcanic pile that was simultaneously accumulating in the Slana district.

The stratigraphy of the Mankomen Group south of Rainy Mountain is less well understood. A thick section of fossiliferous limestone and interbedded shale in the lower gorge of Eureka Creek south of Rainy Mountain (pl. 1) was noted by Moffit (1954) and Rose (1965), but was not studied in detail. Examination of fossils collected from the limestone between Eureka and Rainy Creek as reported by Rose (1965, p. 10) indicates a probable post-Wolfcampian age. Field mapping as part of this study (pl. 1) in the gorge of Eureka Creek indicates that this is the same limestone-shale sequence as exposed on Rainy Mountain. The limestone is typically coarsely bedded and displays dark-blue, gray, or buff weathered surfaces. Crinoid parts, brachiopods, and corals are abundant—just as they are on Rainy Mountain. Interbedded black to gray shales range from 2 to 40 feet thick. Locally they contain abundant bryozoans.

The apparent stratigraphic sequence as observed between Rainy Mountain and Eureka Creek is shown in figure 6. In addition to the interbedded limestone and black shale, two formations of brown to maroon amygdaloidal basalt occur within the sequence north of Eureka Creek. The basalts are lithologically identical, but they differ in thickness. The basalt nearest Eureka Creek is approximately 1,000 feet thick, whereas the basalt nearest Rainy Creek is approximately 3,400 feet

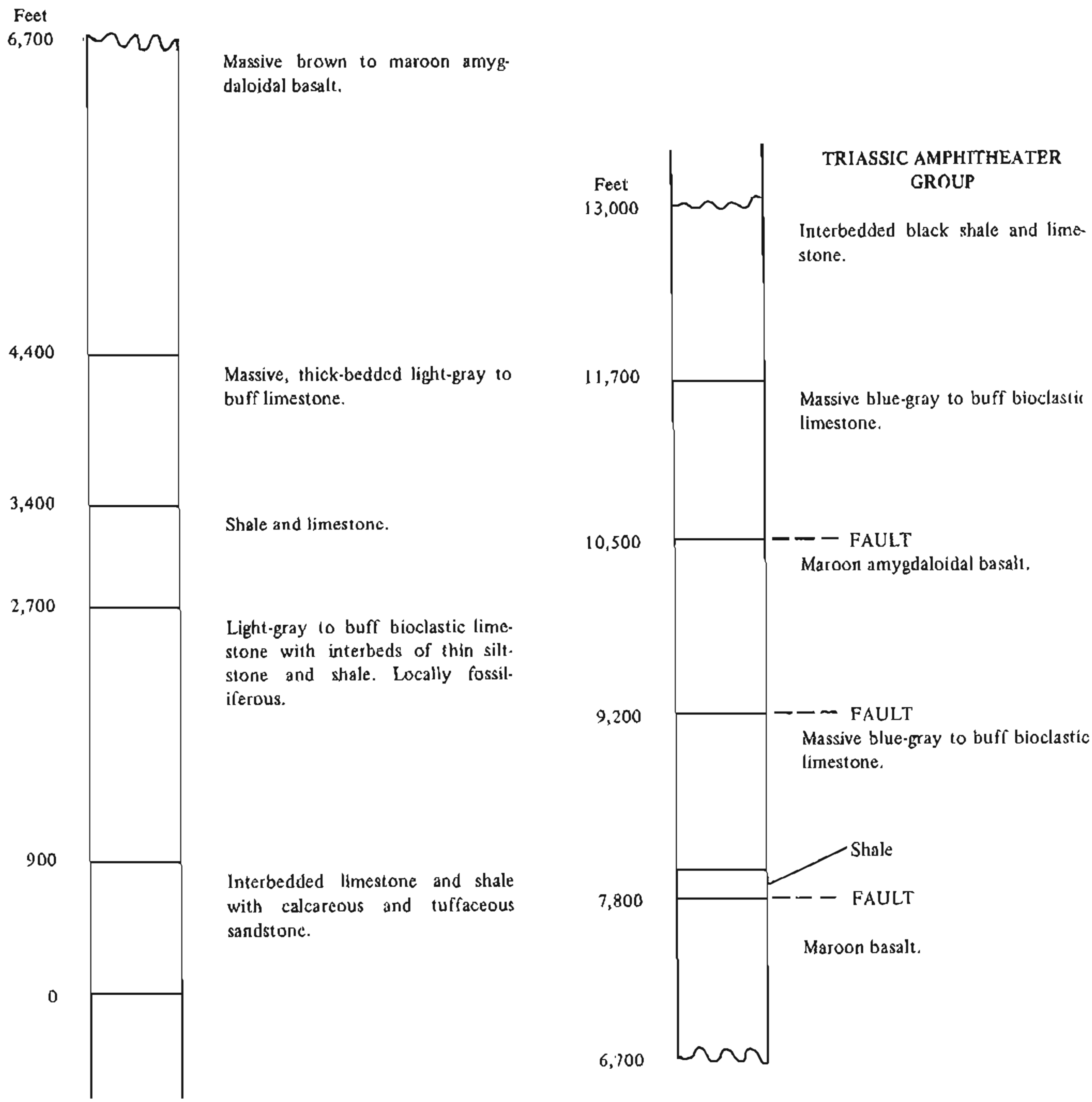

Figure 6. Summary of stratigraphy within the Permian Mankomen Group.

thick. The base of the latter is exposed within 1 meter of interbedded limestone and shale on the north-facing slope 3 miles northwest along strike from Rainy Mountain. As there is no evidence for faulting, it is interpreted as a primary depositional contact.

The similarities of the shale-limestone-basalt sequences shown in figure 6 suggest that faulting may be responsible for the repetition. The aggregate stratigraphic thickness from the base of the Mankomen Group north of Rainy Mountain to the base of the extensive basalt terrane (Triassic Amphitheater Group) south of Eureka Creek is approximately 13,000 feet. The massive fossiliferous limestones are near the base of the apparent section, whereas they are near the top of Permian sections elsewhere in Alaska (Mendenhall, 1905; Moffit, 1954). This further suggests that the Mankomen Group as exposed on Rainy Mountain is repeated in Eureka Creek because of faulting.

In view of this interpretation, the 3,000-foot section of brown to maroon amygdaloidal basalt exposed between Rainy Creek and Eureka Creek is considered here as the base of the Triassic Amphitheater Group. This interpretation must be considered tentative inasmuch as amygdaloidal basalts have been described elsewhere within Permian rocks (Capps, 1916; Moffit, 1943, 1954; Richter and Matson, 1969). The basalts recognized by Richter (1966) and Rowett (1971) within the Permian section near Slana are all included within the Tetelna Complex, however.

In the absence of diagnostic fossils at the presumed base of the Amphitheater Group, there is little evidence that exists within the Eureka Creek area to document the Permian-Triassic unconformity recognized elsewhere (Force, 1973). The oldest Triassic fossils in the overlying Amphitheater Group are Middle-Late Triassic (Moffit, 1912; Smith and Lanphere, 1971), but there are several thousand feet of lavas stratigraphically below the fossiliferous horizons.

AMPHITHEATER GROUP

Weakly metamorphosed basalt, andesite, and tuffaceous rocks of the Amphitheater Group are well exposed in the Amphitheater Mountains north of the Denali Highway (pl. 1). The rocks were first mapped on a reconnaissance basis by Moffit (1915), who recognized their distribution as a band, 15 to 20 miles wide, extending from the Susitna river east to the Richardson Highway. The rocks were also described by Chapin (1918) and Ross (1933) as consisting of metamorphosed basalt and andesite flows, breccias, and tuffs referred to collectively as *greenstone*. Both Moffit (1915) and Martin (1926) recognized the similarities with the Nikolai Greenstone (MacKevett, 1969) in the Chitina Valley and suggested their correlation. The Nikolai Greenstone is Middle to Late Triassic and is probably correlative with extensive basalt sequences of the same age elsewhere; these include presumed Amphitheater Group equivalents east of Slana and along the international border (Richter, 1967), the Mush Lake Group near Kluane Lake (Muller, 1967) and the Karmutzen Group on Vancouver Island (Surdam, 1968). Hence the section exposed in the Amphitheater Mountains and elsewhere along the south side of the central Alaska Range may represent a portion of a belt that extends for more than 1500 miles.

Specific studies in the Amphitheater Mountains did not commence until the reconnaissance mapping effort by Rose (1966b). Rose and Saunders (1965) applied the name 'Amphitheater basalt' to the metabasalts exposed to Paxson Mountain south of the Denali Highway (pl. 1). These rocks dip to the north and are overlain by andesitic tuffs and agglomerates that Rose (1966b) includes as part of the 'Amphitheater formation'. Smith (1974) subsequently elevated the entire unit to group status because of its varied lithology and complexity.

Geologic mapping as part of this study reveals that the Amphitheater Group in the Amphitheater Mountains and vicinity consists of three distinctive lithologic sequences (fig. 7). They are given formational status because of their lateral continuity and importance in understanding the regional stratigraphy. Collectively, the three formations are approximately 40,000 feet thick.

PAXSON MOUNTAIN BASALT

This formation is named after Paxson Mountain in the southeast corner of the map area (pl. 1), where the characteristic olive-gray to dark-green matabasalts are well exposed and readily accessible. It is the oldest formation in the Amphitheater Group, and on Paxson Mountain and nearby hills it dips at moderate angles to the north. Near Rainy Creek, 20 miles to the north, the Paxson Mountain basalt directly overlies the Permian Mankomen Group and dips at moderate to steep angles to the south. The intervening structure, the Amphitheater syncline, is responsible for the present distribution of the formation. It is discussed on pages 26-27.

South of Paxson Mountain, the Permian section is apparently missing. Instead, the Paxson Mountain Basalt overlies, perhaps unconformably, the well-crystallized greenschists and amphibolites considered by Moffit (1954) as among the oldest rocks of the Copper River Basin. In the map area of plate 1, these presumed pre-Carboniferous metamorphic rocks are exposed only in the low-lying hills south of the Denali Highway near Tangle Lakes.

The oldest rocks recognized in the Paxson Mountain Basalt are brown to maroon amygdaloidal basalts exposed between Rainy Creek and Eureka Creek (pl. 1). They appear more strongly altered than similar rocks

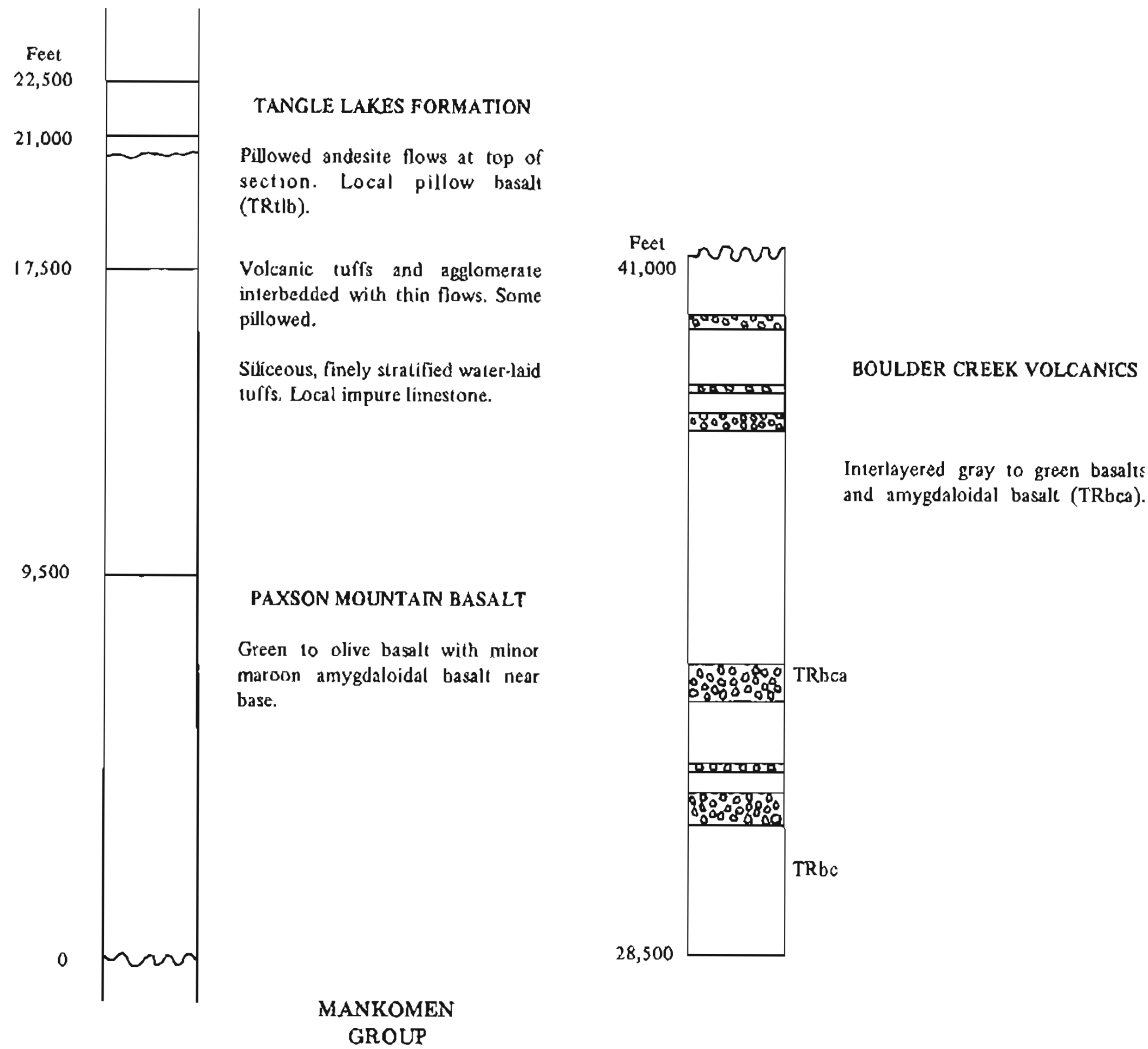

Figure 7. Summary of the nomenclature and stratigraphy of the Triassic Amphitheater Group.

higher in the section as evidenced by their relative softness and secondary mineralogy. The maroon color in many outcrops is due to fine-grained hematite or limonite contained in the aphanitic groundmass. Porphyritic varieties are present, but the plagioclase is invariably albite and has a distinctive pale-green color owing to fine-grained secondary epidote and chlorite. These alterations commonly impart a splotchy red-and-green aspect to the rock on fresh surfaces that is rather distinctive.

South of Eureka Creek and on Paxson Mountain, the more abundant dark-green to olive-gray basalts that occur higher in the formation form massive, resistant outcrops. These rocks are finer-grained and harder than those lower in the section. This is perhaps due to the sparse occurrence of amygdular zones in contrast to the older basalts. The amygdular zones are the only reliable indicators of primary layering, and when they are absent (such as on Paxson Mountain), structural relationships are difficult to determine.

Many of the outcrops on Paxson Mountain and elsewhere in the formation appear quite fresh and little altered. Thin-section examination in every case, however, reveals that the plagioclase feldspar is completely recrystallized to albite. Commonly, the primary augite has reacted to form chlorite or actinolite, but in some sections it retains its original chemistry despite the plagioclase alteration. The opaque oxides, mainly ilmenite and magnetite, are usually skeletal and highly oxidized.

The secondary mineralogy of the amygdules (fig. 8) is rather distinctive. The amygdules are typically zoned

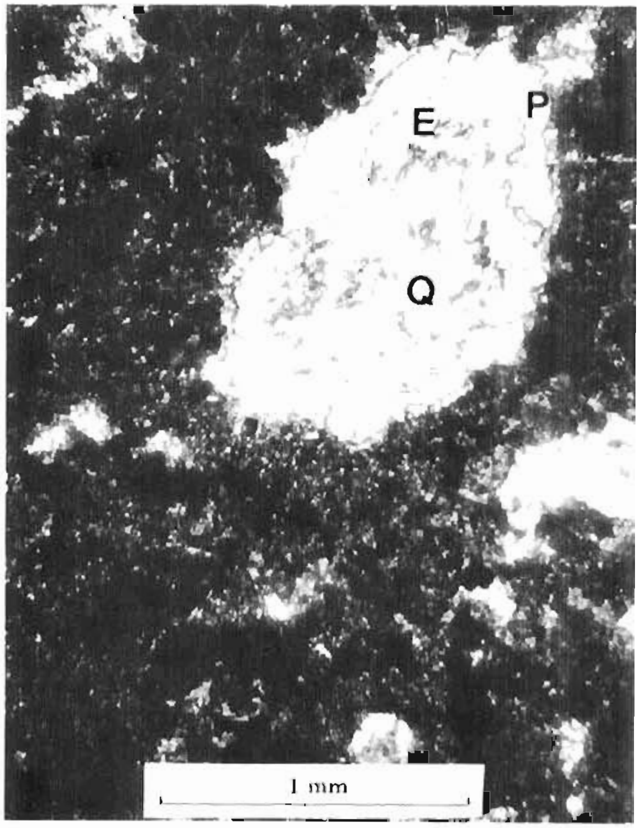

Figure 8. Photomicrograph of amygdaloidal basalt within the Paxson Mountain Basalt near Rainy Creek. Amygdules consist of pumpellyite (P), epidote (E), and quartz (Q) set in a groundmass of magnetite, partly recrystallized augite, and secondary minerals. Specimen A5-8-4B.

in a radial manner, and the sequence of phases from rim to core is varied. The most common sequence is chlorite-epidote-pumpellyite-prehnite-quartz; but calcite, laumontite, clinozoisite, and albite also occur in some cases. Rarely, the amygdules will contain malachite (and once, bornite). The most remarkable observation is that the mineralogy and sequence of phases is practically the same throughout the entire thickness of the Amphitheater Group where amygdules are found. Similar observations elsewhere in the Amphitheater Group (Smith, 1974), in the Nikolai Greenstone (MacKevett, 1965), and in the Karmutsen Group (Surdam, 1968) on Vancouver Island suggest that the amygdule mineralogy is inherent to the rock and not necessarily related to local thermal gradients. The latter interpretation is invoked by Smith and Turner (1974) to account for the prehnite and pumpellyite in the Amphitheater Group at the base of the Maclaren metamorphic belt in the Clearwater Mountains. This problem is currently under investigation as part of a separate study.

The total thickness of the Paxson Mountain Basalt can only be bracketed owing to incomplete exposure. South of Eureka Creek, the amygdaloidal maroon basalts apparently grade into the more typical dark-green to olive basalts over a stratigraphic distance of about 5,000 feet. At Fish Lake, the basalts are apparently in fault contact with the Fish Lake ultramafic complex (pl. 1). On the southeast limb of the Amphitheater syncline, a maximum of 10,000 feet of basalt is exposed mainly on Paxson Mountain and in the low hills to the north. Reliable attitudes are scanty in this area, however, so the possibility of faulting or folding cannot be ruled out. Representative modes of the Paxson Mountain Basalt are given in table 4.

TANGLE LAKES FORMATION

The type locality for the Tangle Lakes Formation is on the south limb of the Amphitheater syncline near Tangle Lakes and the upper Delta River. The characteristic andesites, agglomerates, and siliceous tuffs dip at moderate angles to the north at the type locality, but become west dipping in the hinge zone of the syncline. These well-layered and unmistakable volcanics can be traced almost continuously around to the north limb of the syncline, where the formation is apparently faulted against the Fish Lake ultramafic complex to the north. At this locality, only the uppermost members of the formation are exposed.

On the south limb of the Amphitheater syncline just west of the Tangle Lakes (pl. 1), a maximum thickness of 11,500 feet is inferred from the uniformly north-dipping attitudes. Of this, a maximum of 3,000 to 4,000 feet could be accounted for by diabase and diorite sills that penetrate the strata. These intrusives are very abundant south and east of Sugarloaf Mountain (pl. 1), where they occupy up to 75 percent of the outcrop.

Rose (1966b) was the first to describe the andesitic volcanics exposed on Sugarloaf Mountain. He referred them to his informal Amphitheater formation but recognized that they were overlain by a thick sequence of metabasalts (*Boulder Creek Volcanics* of this report). Rose incorrectly inferred the presence of a fault east of Sugarloaf Mountain, which facilitated his tentative correlation of the overlying basalts with the lithologically similar Paxson Mountain Basalt. These two basalt sequences are now known to be different.

Several distinct lithologies are represented in the Tangle Lakes Formation. The more prominent of these are summarized in figure 7. At the base of the formation, several thousand feet of well-bedded siliceous tuffs and tuffaceous fine-grained sediments are exposed. The most continuous section of these rocks is found just north of Round Tangle Lake (pl. 1) along the west side of the upper Delta River. The distinctive gray to green bands commonly observed on weathered surfaces range from 0.5 to 3 cm wide. Thin-section examination (table 4) reveals the banding due to alternating silica-rich and plagioclase feldspar-rich layers. In both types,

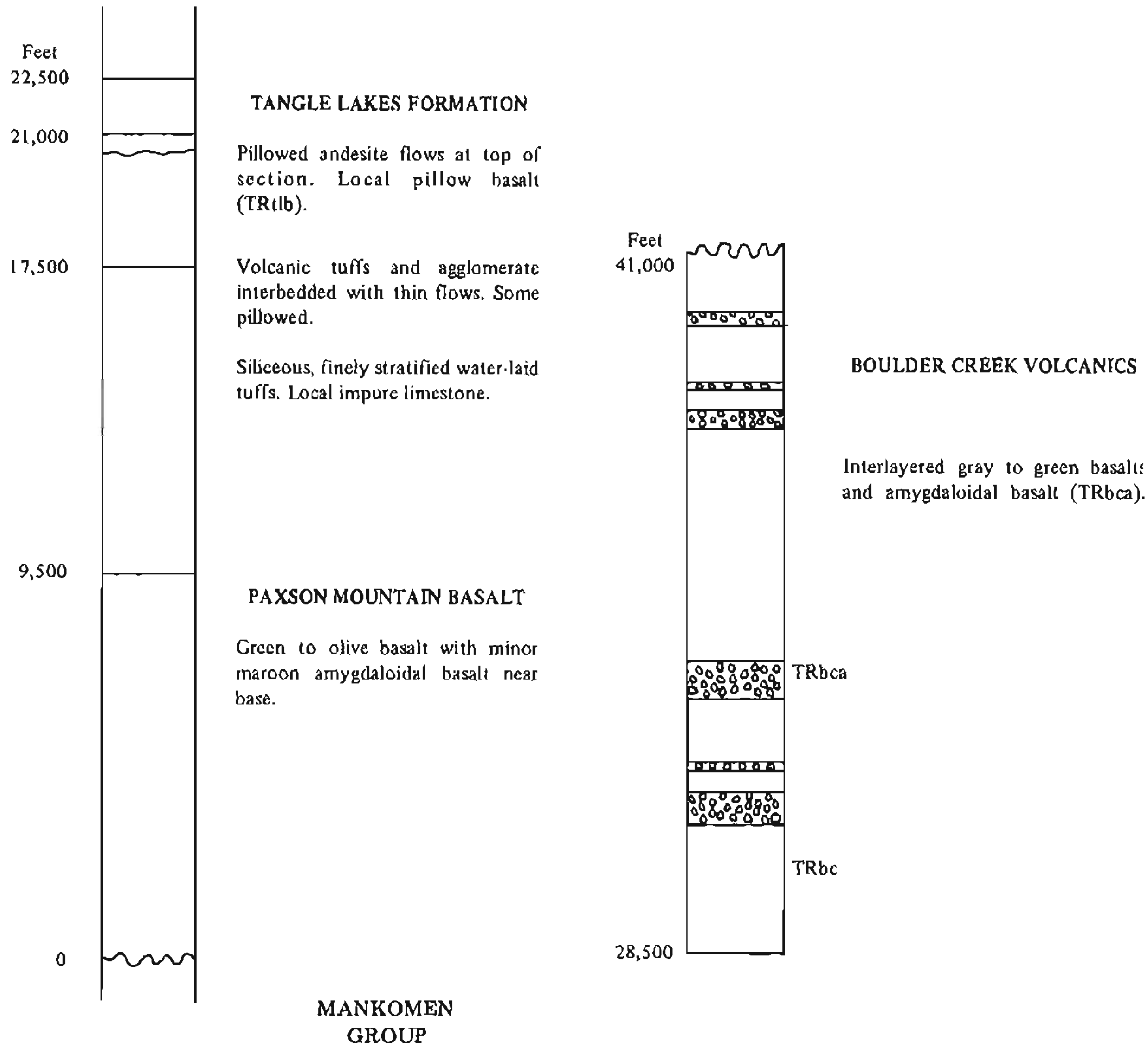

Figure 7. Summary of the nomenclature and stratigraphy of the Triassic Amphitheater Group.

higher in the section as evidenced by their relative softness and secondary mineralogy. The maroon color in many outcrops is due to fine-grained hematite or limonite contained in the aphanitic groundmass. Porphyritic varieties are present, but the plagioclase is invariably albite and has a distinctive pale-green color owing to fine-grained secondary epidote and chlorite. These alterations commonly impart a splotchy red-and-green aspect to the rock on fresh surfaces that is rather distinctive.

South of Eureka Creek and on Paxson Mountain, the more abundant dark-green to olive-gray basalts that occur higher in the formation form massive, resistant outcrops. These rocks are finer-grained and harder than those lower in the section. This is perhaps due to the sparse occurrence of amygdular zones in contrast to the older basalts. The amygdular zones are the only reliable indicators of primary layering, and when they are absent (such as on Paxson Mountain), structural relationships are difficult to determine.

Many of the outcrops on Paxson Mountain and elsewhere in the formation appear quite fresh and little altered. Thin-section examination in every case, however, reveals that the plagioclase feldspar is completely recrystallized to albite. Commonly, the primary augite has reacted to form chlorite or actinolite, but in some sections it retains its original chemistry despite the plagioclase alteration. The opaque oxides, mainly ilmenite and magnetite, are usually skeletal and highly oxidized.

The secondary mineralogy of the amygdules (fig. 8) is rather distinctive. The amygdules are typically zoned a gray to pale-green aphanitic matrix is common.

Several varieties of volcanic agglomerate are interbedded with the finer-grained tuffs. They consist of angular volcanic clasts up to 3 feet in diameter, but dimensions in the range of a few inches are more common. The enclosed fragments all appear to be of local derivation. They include siliceous tuffs, andesite flow rocks, other agglomerates, and rare tuffaceous limestone (fig. 9). Plagioclase phenocrysts can occassionally be discerned within the light- to dark-green aphanitic groundmass. The overall bulk composition appears to be andesitic or dacitic.

Approximately 8,000 stratigraphic feet from the base of the section, andesite flows and interbedded red cherts and black, siliceous argillite or shale are predominant. Thin tuffaceous limestone and dolomitic limestone are also present. The latter rocks occur as discontinuous lenses up to 3 feet thick that can be traced no more than a few tens of feet along strike. The andesite flows are generally fine grained and distinctly lighter colored than the basalts in the overlying and underlying formations. Thin-section examination (table 4) of the light-gray to light-green porphyritic varieties show tiny 'swallowtail' plagioclase phenocrysts (fig. 10) embedded in a fine-grained to aphanitic groundmass.

The only fossil evidence for the age of the Tangle Lakes Formation comes from a small hill 1 mile east of VABM TANGLE east of Tangle Lakes. There, a black calcareous argillite contains sparse fragments of a small pelecypod tentatively identified as *Monotis Subcircularis*. Pending confirmatory identification, the enclosing beds are assumed to be late Upper Triassic.

An Upper Triassic age for the Tangle Lakes Formation seems reasonable in view of its lithologic similarity to fossiliferous rocks of the same age elsewhere in the Alaska Range. Moffit (1912) identified *Monotis Subcircularis* near the presumed top of the

Figure 9. Photomicrograph of volcanic agglomerate from the Tangle Lakes Formation. Large volcanic rock fragments (RF) are imbedded in a volcaniclastic matrix consisting of plagioclase phenocrysts (P), smaller volcanic debris, and possibly devitrified glass.

Table 4. *Modes of representative specimens from the Amphitheater Group*

[The first four specimens are basalts from the Paxson Mountain Basalt. The second four specimens are andesites and andesitic agglomerate (A5-4-21) from the Tangle Lakes Formation. The remaining specimens are basalts from the Boulder Creek Volcanics.]

Specimen No.	B4-3-14	B4-3-12	JS-260	JS-261	A5-4-21	JSP-5	A5-4-20	A5-8-21	A5-8-4A	A5-8-4B	A5-8-40	A5-8-12	A5-4-25	A5-8-16
	Modes													
Actinolite	-	-	-	-	-	-	-	-	-	-	-	-	-	20
Calcite	-	3	-	-	-	3	3	-	-	-	-	-	2	-
Chlorite	25	10	5	5	-	-	10	-	5		-	-	10	20
Epidote	10	7	10	10	-	5	-	10	15	5	6	12	2	2
Hematite	3	5	-	-	-	-	-	-	-	-	-	-	-	-
Ilmenite[1]	-	-	1	2	-	-	-	-	-	-	-	-	-	-
Magnetite[1]	2	5	2	3	-	2	2	-	8	12	15	10	3	8
Opaque material	10	10	-	-	35	60	40	15	12	30	-	-	-	-
Plagioclase[2]	40	30	55	50	5	20	-	20	30	20	30	30	30	15
(An content)	< 5	< 5	50	5-40	< 5	< 5	-	5-15	< 5	< 5	< 5	< 5	< 5	< 5
Prehnite	5	-	-	-	-	-	-	-	-	-	3	-	-	-
Pumpellyite	5	-	-	-	-	3	30	-	-	3	3	3	10	-
Pyroxene	-	30	25	30	-	2	15	50	30	30	40	45	40	35
Quartz	-	-	-	-	10	5	-	5	-	-	3	-	3	-
Volcanic rock fragments	-	-	-	-	50	-	-	-	-	-	-	-	-	-

[1]Plagioclase is albitized and contains secondary epidote, sericite, and clay.
[2]Commonly altered to leucoxene minerals and hematite.

Triassic section near Windy Creek in the Clearwater Mountains. He describes "Banded slates, black slates, red-weathering slates or shales, graywackes or fine tuffs, tuffaceous conglomerate..." that overlie a thick sequence of greenstone or basalt.

At the very top of the Tangle Lakes Formation is a distinctive pillow andesite that attains a maximum thickness of 1,500 feet. The pillows are superbly developed (figs. 11, 12) and provide positive evidence for the submarine origin of the rocks. Nested pillows in several localities were sufficiently well developed that stratigraphic 'tops' could be determined. The attitudes in each case are consistent with the Amphitheater syncline. Elsewhere in the Amphitheater Group, pillows are not as easily recognized because of severe jointing and lichen growth. Only a few hundred feet along strike from the outcrop of figure 11, the pillows can be discerned only with difficulty because of the pervasive jointing.

The top of the pillow andesite member is taken as the upper contact of the Tangle Lakes Formation. There is a sharp contact with overlying pillow basalt, the basal member of the Boulder Creek Volcanics. One or two thin (less than 200-foot-thick) pillow basalts do occur immediately below the pillow andesite member on the north side of the Amphitheater syncline, but cannot be traced in the field for more than a few hundred feet.

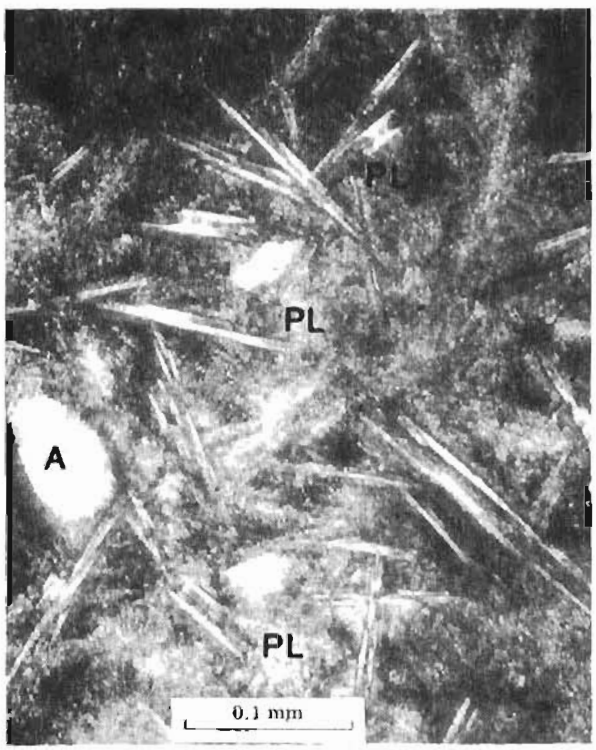

Figure 10. Photomicrograph of fine-grained andesite flow showing small laths of plagioclase (PL) with swallowtail morphology. Aphanitic groundmass is mostly opaque material, probably devitrification products. Tiny amygdules (A) are filled with radiating pumpellyite needles.

BOULDER CREEK VOLCANICS

The type locality of the Boulder Creek Volcanics is in the low mountains just north of Boulder Creek and Sevenmile Lake[2] in the west-central part of the map area (pl. 1). There, approximately 18,500 feet of interlayered green basalt and amygdaloidal basalt is exposed above the pillow andesite member of the Tangle Lakes Formation. These outcrops lie in the northern limb of the Amphitheater syncline. The section is present, but not as well exposed on the south limb of the syncline north of Glacier Lake and the Denali Highway.

Because of the low-angle plunge of the Amphitheater syncline to the west, even higher portions of the Boulder Creek Volcanics should be exposed west of the Maclaren River. The thickness stated above should thus be considered minimal.

The predominant lithology in the formation is a green to olive basalt that bears striking similarities to the upper portion of the Paxson Mountain Basalt. Amygdaloidal zones, however, are much more common in the Boulder Creek Volcanics and locally attain thicknesses of nearly 3,000 feet. They are mapped as separate members on the geologic map of the area (pl. 1). These differences and the overall continuity of the Paleozoic and Mesozoic sections on the limbs of the Amphitheater syncline demonstrate that the two predominantly basaltic formations are different. Minor differences exist in the petrography of the rocks (table 4), but at this time they cannot be used as distinguishing criteria.

The amygdaloidal members are the most distinctive in the formation and are critical to defining the folded structure of the rocks in the western part of the map area. The rocks consist of alternating layers (fig. 13) of varying bulk chemistry. This is apparent from the variation in concentration of amygdules, their size, and their mineralogy. Some layers only a few inches thick consist of 75 percent amygdules, whereas adjacent layers of the same thickness may have less than 10 percent. Single amygdules range up to an inch in diameter and may be sparsely distributed through the rock. Thin-section examination (table 4) shows their mineralogy to consist of epidote, quartz, pumpellyite, chlorite, prehnite, and calcite.

The origin of the amygdaloidal basalts is somewhat

[2]Sevenmile Lake has been known by the local residents for many years as Boulder Lake. Boulder Creek drains west into the Maclaren River.

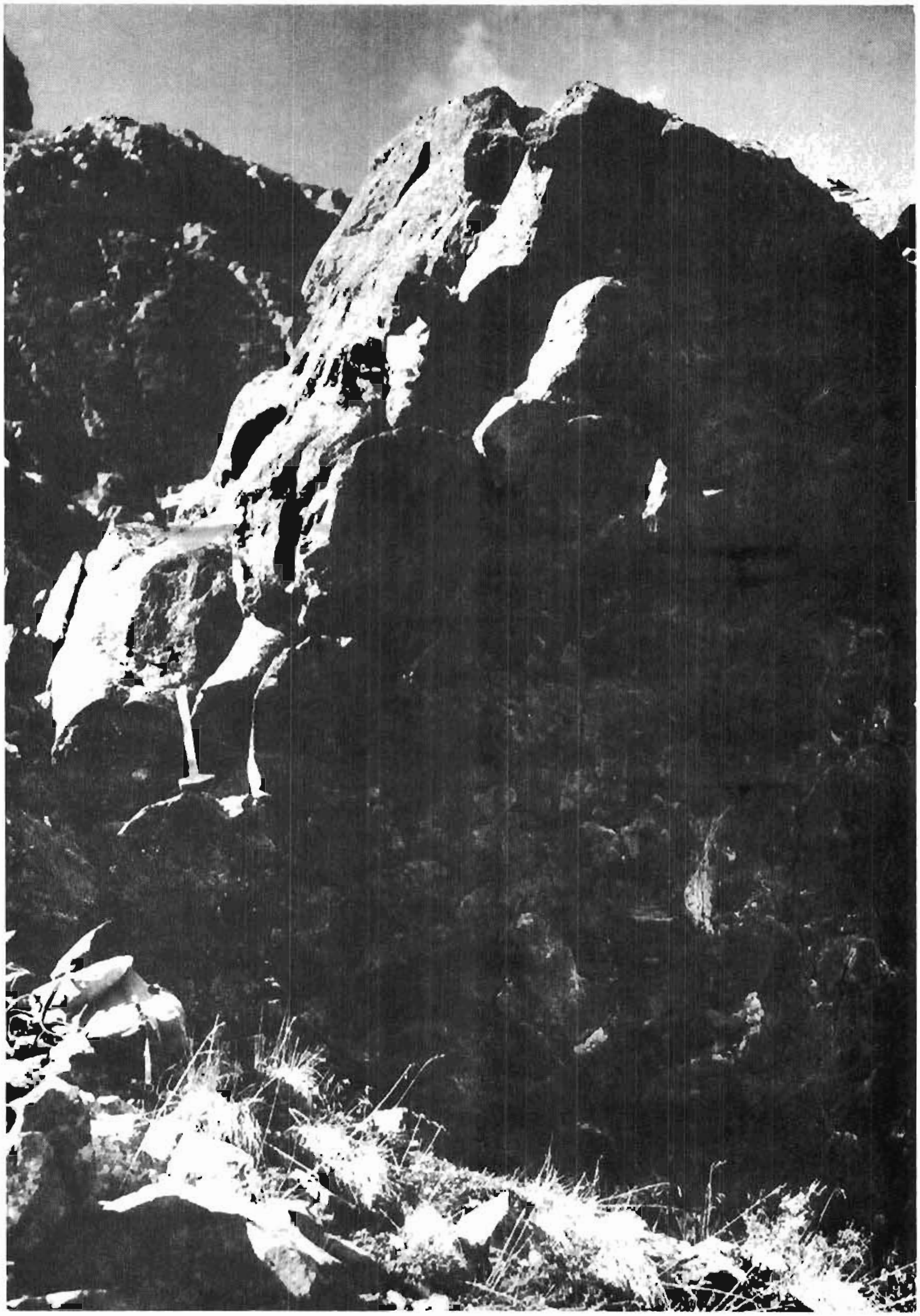

Figure 11. End view of well-developed pillows in andesite of the Tangle Lakes Formation. Tops are to the left.

Figure 12. Longitudinal view of pillow tubes in andesite of the Tangle Lakes Formation.

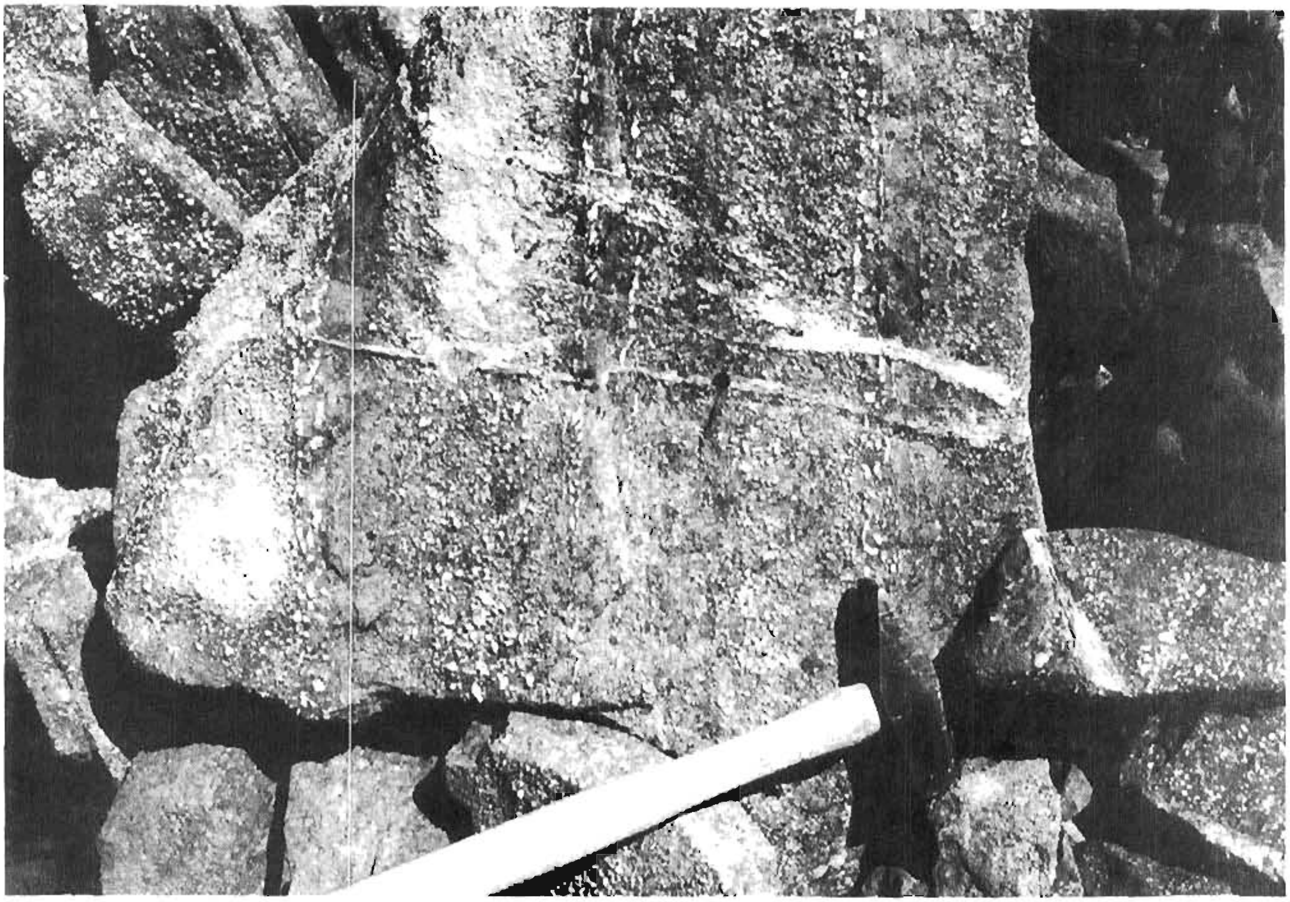

Figure 13. Typical layering of amygdaloidal flows within the Boulder Creek Volcanics. Amygdules may be equidimensional or elongate parallel to bulk compositional layering. Late veinlets of epidote and quartz are common.

problematic, particularly with respect to their remarkable layering. Individual layers only an inch thick can be traced in the field for over 100 feet without any detectable deviation in attitude. These must represent highly vesiculated individual flows that were capable of flowing with little resistance. Commonly, individual amygdules will be stretched out parallel to the primary layering (fig. 14), which may indicate flow during cooling from magmatic temperatures. The only instance where amygdules are elongated normal to flow surfaces is near the chilled rinds of pillows found at the base of the formation.

JURA-CRETACEOUS METAMORPHIC ROCKS

A progressively metamorphosed and highly deformed sequence of argillite, graywacke, volcanic flows, and minor conglomerate of Jurassic and probably Cretaceous age are exposed north of the Broxson Gulch Thrust fault (pl. 1). Where observed as part of this study, these rocks—even in their lowest grade portion—are noticeably more deformed and recrystallized than any of the older sedimentary and volcanic rocks previously de-

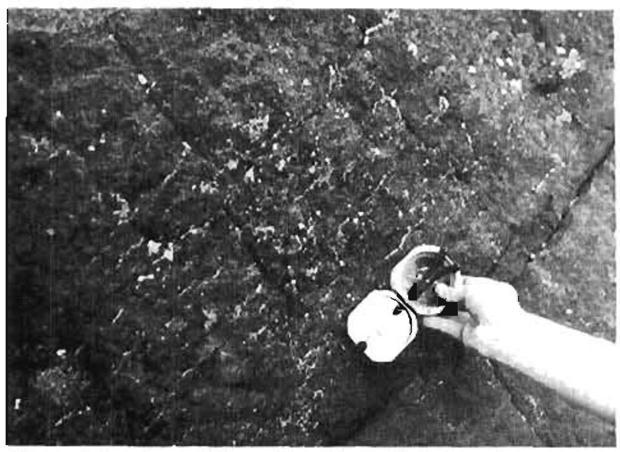

Figure 14. Amygdules aligned parallel to primary compositional layering in the Boulder Creek Volcanics.

scribed. The rocks occupy a linear belt extending from the region west of the Susitna River (fig. 2) to the Delta River, where it is truncated by the Denali Fault (Stout, 1972). Because of this unique character and history, they are now referred to as the *Maclaren metamorphic belt* (Smith, 1970a,b).

Only the lowest grade portions of the Maclaren metamorphic belt are exposed in the present study area. Along the northern margin of plate 1, greenschist and phyllite are the predominant lithologies. Thin-section examination (table 5) reveals that the parent volcanic flows or tuffs and argillaceous sediments have recrystallized in the chlorite zone. The low-grade rocks are intensely deformed, however. Isoclinal folds on the scale of hand specimens and on the scale of 1 mile have been observed. Axial surfaces and metamorphic foliation dip uniformly to the north.

Maclaren River (pl. 1) is part of the Broxson Gulch Thrust. The evidence for estimating the magnitude of displacement along the thrust is discussed on pages 28-29, but it is highly probable that the structural discontinuity extends west to the Clearwater Mountains.

The confirmatory evidence for at least a Jurassic age of the pelitic sediments is provided by a new Jurassic fossil locality (Smith, 1974a) north of the tectonic contact in the Clearwater Mountains. The fossils are reportedly Upper Jurassic and from conglomerate beds in the low-grade portion of the Maclaren metamorphic belt. Similar conglomerates with interbedded, unfossiliferous limestone occur in the present study area just east of the Maclaren River, where they are overlain by the more common black phyllites and greenschists.

Detailed studies by Stout (1974) within the Maclaren terrane near the Delta River indicates that the de-

Table 5. *Modes of representative phyllites and greenschists from the Maclaren metamorphic belt*

Specimen No.	JS-2	JS-13	JS-541	JSA-35	JSA-36	JSA-37	JSA-38	JS-562	JS-563	JS-232	JS-388
	Modes										
Actinolite	1	3	15	-	-	-	-	-	-	-	16
Calcite	1	-	5	-	2	2	1	-	-	4	-
Carbonaceous material	20	5	5	15	10	15	15	15	5	-	-
Chlorite	-	-	-	35	20	40	15	20	14	53	46
Epidote	6	12	8	4	10	5	1	-	-	17	15
Plagioclase	15	10	20	5	10	10	10	10	10	25	23
(An content)	8	10	16	<5	<5	<5	2	30	<5	12	10
Quartz	30	30	32	20	25	13	42	33	60	1	-
Sericite	27	40	15	20	20	15	15	20	10	-	-
Sphene	-	-	-	-	-	-	1	-	-	-	-
Stilpnomelane	-	-	-	1	3	-	-	2	1	-	-

Beyond the northern boundary of the map area, the greenschists and phyllites are progressively metamorphosed to calc-magnesian gneisses and pelitic schists or gneisses, respectively (Stout, 1965, 1974). The highest grade gneisses are in the sillimanite zone at the eastern end of the belt, but are in the kyanite zone at the western end (Smith, 1970; Smith and Turner, 1973). Erratics of coarse-grained sillimanite gneisses derived from the high-grade portion of the belt are common in the glacial outwash along Eureka Creek and even south of the Amphitheater Mountains.

The depositional age of the metamorphic rocks is Jurassic and possibly Cretaceous. Stout (1965) and Rose (1965, 1966) originally considered them to be pre-Devonian because of their high rank of metamorphism (compared with older rocks in the Alaska Range). Smith (1970, 1971) concluded that the pelitic sediments were younger than the middle Late Triassic Amphitheater Group that they apparently overlie, but older (at least in part) than a Late Jurassic alkali gabbro that intrudes them. The nature of the Triassic-Jurassic contact in the Clearwater Mountains is now in doubt (Smith and Turner, 1973) as a result of continued mapping since 1970. The contact in the vicinity of the

positional thickness of the argillaceous sediments is over 15,000 feet. Because the Late Jurassic conglomerates are near the base of the section, this thick sequence of predominantly marine strata is believed to be younger. Comparison with late Jurassic and younger rocks of similar composition elsewhere in Alaska strongly suggests a correlation with the Gravina-Nutzotin belt (Berg and others, 1972). This belt, located in the eastern Alaska Range, is approximately 20,000 feet thick and consists mainly of dark-gray argillite, siltstone, graywacke, and conglomerate in its lower part, overlain by andesitic fragmental rocks and flows of the Chisana Formation (Richter and Jones, 1972). The rhythmically alternating graded beds of gray to dark-gray argillite, siltstone, and graywacke that constitute the major part of the lower part of the section correlate well with the banded phyllites shown in plate 1. Despite the strong axial-plane cleavage developed in these low-grade rocks, the graded bedding is remarkably well-preserved.

The age of the Gravina-Nutzotin belt in the eastern Alaska Range is from Late Jurassic (Oxfordian) to Early Cretaceous (Barremian) (Berg and others, 1972). These ages are consistent with the Late Cretaceous—Early

Tertiary metamorphic age of the Maclaren metamorphic belt, independently determined by radiometric dating techniques (Smith and Lanphere, 1971; Smith and Turner, 1973).

TERTIARY ROCKS

Conglomerate, coal-bearing sandstone, and shale of probable Late Oligocene and younger age are found in scattered outcrops throughout the Eureka Creek area. Moffit (1912) first described the Tertiary sediments near the Delta River as the western extension of Mendenhall's (1905) Gakona Formation. The rocks are in general poorly exposed owing to their easy erosion and to the extensive cover of younger glacial drift. In this study, the distinction between the Tertiary deposits and the lithologically similar Quaternary deposits is based on the degree of consolidation and association with coal-bearing sandstones. The Tertiary conglomerates are poorly to well consolidated, whereas the overlying gravels of presumed Quaternary age are generally unconsolidated deposits.

The Tertiary sediments in the region have not been sufficiently studied to establish the stratigraphic relationships between the various lithologies. The lowermost beds in the section are usually coarse-bedded conglomerates that unconformably overlie all older rocks. But at several localities (pl. 1) on the flanks of the Amphitheater Mountains, a fine-grained olivine basalt is the lowermost rock. It typically occurs in light-colored, frost-heaved outcrops that are easy to overlook. Examination of a single thin section shows 10 percent olivine phenocrysts embedded in a fine-grained groundmass of 70 percent labradorite (An_{65}), 10 percent calcic clinopyroxene, 7 percent euhedral magnetite, and 3 percent dark-brown biotite (fig. 15).

The basal conglomerates are usually interbedded with coal-bearing sandstones. A notable exception is 2 miles east of the outwash plain of the West Fork Glacier, where at least 100 feet of dunite conglomerate unconformably overlies the Permian upper Tetelna Complex. Moffit (1912) first noted the outcrops because of the huge landslide on the east slope of the mountain. It contains blocks of conglomerate up to 25 feet in diameter. The rock consists of coarse conglomerate (fig. 16) with up to 90 percent dunite cobbles and boulders interbedded with coarse sandstone. Cobbles of granodiorite, porphyritic volcanic flows, and siliceous tuff are found in subordinate amounts. Thin-section examination of three sandstone specimens (fig. 17) shows serpentinized olivine grains with occassional grains of compositionally zoned plagioclase, microcline, clinopyroxene, and spinel.

Without exception, all of the clasts observed in the conglomerate and sandstone can be identified with a local source area. In particular, the dunite cobbles and olivine and spinel grains must be derived from the dunite

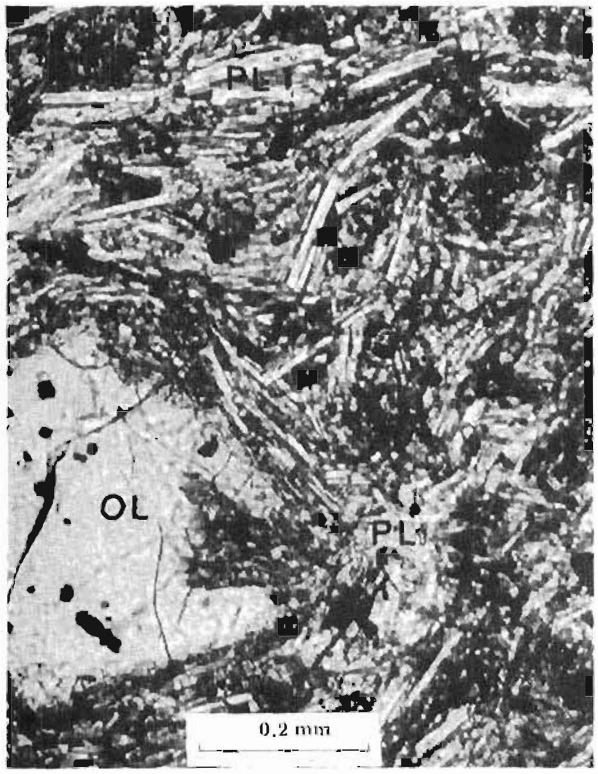

Figure 15. Photomicrograph of porphyritic olivine basalt of Tertiary age. Olivine phenocrysts (OL) are embedded in a fine-grained groundmass of labradorite (PL), magnetite, and clinopyroxene.

Figure 16. Dunite conglomerate in outcrop east of Broxson Gulch.

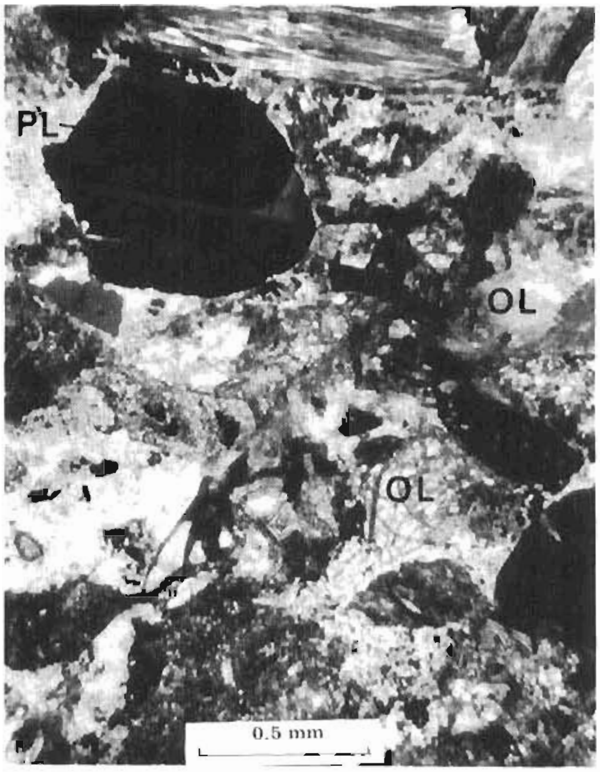

Figure 17. Photomicrograph of coarse sandstone interbedded with dunite conglomerate near Broxson Gulch. Serpentinized olivine grains (OL) and zoned plagioclase (PL) derived from nearby granodiorite are present.

bodies (pl. 1) that are found only along the Broxson Gulch Thrust, less than 1 mile away. The granodiorite cobbles and feldspar grains have compositions identical with nearby granodiorite intrusives. The remaining volcanic rock fragments could easily be derived from the underlying Tetelna Complex.

A notable exclusion from the suite of clasts are metamorphic rock types from the Maclaren metamorphic belt. The latter rocks are well exposed in the southern drainage of the Alaska Range; in fact, pebbles and cobbles of most metamorphic lithologies are abundant in the present-day stream gravels that pass over the older conglomerates. A diligent search was made of each of several conglomerate outcrops extending from Ann Creek (near the Delta River) to Broxson Gulch, and not a single clast of Maclaren belt rock was found. A possible interpretation is that the Maclaren metamorphic belt was faulted into its present position after the conglomerates were deposited (p. 28).

The precise age of the Tertiary beds is still problematic owing to the lack of detailed studies on the well-preserved flora. Plant megafossils collected from the coal-bearing sandstones between Broxson Gulch and the West Fork Glacier are currently being studied by J.A. Wolfe of the U.S. Geological Survey, but as of this writing, no final conclusions had been made. A diverse conifer flora seems to be represented, and may include *Metasequoia*. Other forms resembling *Alnus evidens* (Holl.) are also present and are suggestive of a Late Oligocene age (Wolfe, 1966, 1972).

A Late Oligocene or younger age for the Tertiary rocks is further suggested by the absence of older Tertiary rocks elsewhere in the Alaska Range. The base of the Tertiary near the Nenana River is the Healy Creek Formation, which is no older than Late Oligocene (Wahrhaftig and others, 1969). This formation is apparently correlative with approximately 2,000 feet of poorly consolidated sandstone, shale, and conglomerate with numerous interbedded coal layers in the Jarvis Creek coal field (Wahrhaftig and Hickcox, 1955). These rocks are on the northern flank of the Alaska Range and unconformably overlie the pre-Pennsylvanian(?) Birch Creek Schist terrane.

QUATERNARY DEPOSITS

More than 50 percent of the Eureka Creek area is covered by glacial till, outwash, and related deposits. Most of this is ground moraine that forms a rather uniform veneer over the glacially scoured bedrock below. These deposits consist of unconsolidated, unsorted glacial debris, mostly gravel. Where the deposits overlie poorly consolidated conglomerates of possible Tertiary age such as around Fielding Lake (pl. 1), incorrect age assignments may be easily made.

Unconsolidated to poorly consolidated sands and gravel of problematic age are exposed along the banks of Eureka Creek. The unit weathers to a distinctive orange and forms impressive hoodoos in several localities. The unit is well bedded and has a horizontal attitude except near underlying bedrock. In such cases, the bedding conforms to the bedrock topography.

In the second drainage east of Broxson Gulch (pl. 1), similar but better consolidated gravels contain abundant lignite and partially coalified wood. The relatively lightweight, woody character of these organic layers suggests that they are younger than the Tertiary conglomerates and associated black coal seams. At this locality, the beds dip north at 15 degrees and are unconformably overlain by 3 feet of gray unconsolidated till.

A distinctive morainal topography characterizes all of the valleys on the south side of the Alaska Range that now have active glaciers. The lateral moraines are the most obvious, and can extend for several miles beyond the present ice front. Ponds dammed by terminal moraines are present at the terminus of the East Maclaren Glacier.

A widespread but more subdued morainal topography provides abundant evidence for an earlier, more extensive glaciation. Beautiful U-shaped watergaps in the Amphitheater Mountains with terminal lobes that close to the south demonstrates that in probable Wisconsin time an ice sheet extended from the southern flank of the Alaska Range southward through and beyond the Amphitheater Mountains. The best evidence for the direction of ice flow is from the distribution of pelitic gneiss cobbles and erratics derived from the Maclaren metamorphic belt. This distinctive and unmistakable lithology has been observed in the glacial deposits all along the southern flank of the Amphitheater Mountains and as far south as Paxson Mountain (pl. 1). This suggests that Wisconsin ice in the Eureka Creek area found egress to the Copper River Basin to the south rather than through the Delta River valley to the north.

The periglacial environment of the region is also expressed by several well-developed rock glaciers (pl. 1). The largest of these are on east-facing slopes near Lower Tangle Lake and Landmark Gap Lake. They are generally several hundred feet wide and up to one-half mile long. Their terminal regions are quite steep and up to 50 feet high.

Other Quaternary deposits of note in the Eureka Creek area are landslides. Two in particular are impressive because of their areal dimensions and the house-sized blocks contained within them. Houseblock Valley, just south of the west end of Sevenmile Lake, is over 1 mile long and has blocks of basalt from the Boulder Creek Volcanics with dimensions up to 30 feet.

The other locality is that described by Moffit (1912, pl. IVA) on a northern tributary of Eureka Creek near Broxson Gulch. This slide approaches 1 mile in its greatest dimension and is notable for its unusual blocks of dunite conglomerate (p. 19). At the bottom of the hills, the blocks are overlain by extensive alluvial fans that originate on the opposite slope. Because the slide is unglaciated, its age is between the last Pleistocene advance and the present erosional epoch.

Alluvial deposits—mostly fans and aprons along the lower flanks of most ridges—and talus are distinguished on plate 1. Much of the bedrock in the Amphitheater Mountains is severely frost heaved, and in many instances the distinction between talus and bedrock is arbitrary.

INTRUSIVE ROCKS

The intrusive rocks in the Eureka Creek area range in bulk composition from quartz monzonite to dunite. The known time span of the intrusive history is from 125 m.y. to approximately 30 m.y. (Smith and Lanphere, 1971; Smith and Turner, 1973; Turner, personal commun., 1973). To facilitate their interpretation within the stratigraphic and tectonic history of the region, the intrusive rocks are discussed in two categories corresponding to the areas north and south of the Broxson Gulch Thrust fault (pl. 1). Only one intrusive rock—the dacite porphyry dikes—are believed common to both areas. These are described in the region south of the Broxson Gulch Thrust (below) because of their greater abundance there.

INTRUSIVE ROCKS SOUTH OF THE BROXSON GULCH THRUST FAULT

Most of the intrusive igneous rocks in this region appear to be temporarily and spatially related. Rose (1966b) first studied these rocks and noted the preponderance of gabbro and mafic gabbro associated with dunites and peridotite near Fish Lake in the center of the map area (pl. 1). Rose also describes a few felsic varieties, including granite and leucogabbro. Geologic mapping as part of this study reveals that this suite of intrusive rocks defines a belt extending from the east side of the West Fork Glacier southeast through Fish Lake and on into the Amphitheater Mountains. There, the suite has a generally arcuate distribution that conforms to bedding trends in the Amphitheater syncline. Near Fourteenmile Lake north of the Denali Highway in the southeastern corner of the map area (pl. 1), the belt appears to swing around to the west. Isolated outcrops of dunite and peridotite on both sides of Tangle Lakes on the south limb of the syncline suggests that the trend continues to the west. In general, the rocks intrude both the Paxson Mountain Basalt and the Tangle Lakes Formation. The main body of intrusive rocks lie 'stratigraphically' between these two formations.

At its northwestern end, where the rocks are predominantly dunite, the belt appears to be truncated by the Broxson Gulch Thrust fault system. At its southern and southwestern end, the belt is covered by glacial till. Because of their spatial and apparent genetic relationships, this suite of rocks will hereafter be referred to as the *Fish Lake Complex*.

The mafic and ultramafic rocks of the Fish Lake Complex are typically exposed as brown to red rubble (fig. 18) on small hills usually isolated from outcrops of older host rock. Despite the poor outcrops, however, a crude compositional layering can often be detected, which suggests that the Complex is a differentiated layered sill. A preferred orientation of plagioclase laths in some gabbros—particularly near Fourteenmile Lake (pl. 1)—further indicates that the rocks were capable of flow during intrusion.

At least the gabbroic portions of the Complex were hot enough during intrusion to locally bake the country rock. Near Eureka Creek, a tremolite-bearing skarn (fig. 19) is locally developed in the Tangle Lakes Formation, where it is in contact with the gabbro. Thin-section examination (table 6) of the skarn (specimen A5-7-1) reveals coarse tremolite laths up to 1 inch long embedded in a matrix of recrystallized calcite and graphite. The gabbro (specimen A5-8-31) contains ser-

Table 6. *Modes of representative mafic and ultramafic intrusive rocks from the Amphitheater Mountains and vicinity*

[All but the first and last entries are from the Fish Lake Complex.]

Specimen No.	A5-7-1	A5-8-31	A4-5-1	A4-5-2	A4-5-4	A4-5-9	A4-6-14	A4-6-15	A4-6-16	A4-6-17	A4-6-18	A5-6-19	A5-4-27	A5-4-31
	Modes													
Augite	-	30	35	25	10	28	10	60	5	45	5	-	45	-
Biotite	-	-		-	-	-		10	-	-	-	5	-	-
Calcite	55		-	-	-		-	-	-	-	-	-		-
Chromespinel	-	-	-	-	-	-	-	-	3	-	2	-	-	-
Hornblende		-	20	10	-	10	30	3	2	-	5	5	-	25
Magnetite	5	5	3	-	15	2	-	3	10	5	2	-	5	5
Microcline		-	-	-	-	-	-	-	-	-	-	40	-	-
Olivine	-	30		-	-	-		-	40	30	70	-	-	-
(Fo content)	-	80	-	-	-	-	-	-	90	88	85	-	-	-
Opaque material	10		-	5	5	-	10	4	-	-	-	-	-	-
Orthopyroxene		-	-	20	-		-	-	-	-	-	-	-	-
Plagioclase	-	30	40	40	10	60	20	-	-	-	-	-	-	-
(An content)	-	65	60	60	55	60	10	-	-	-	-	20	50	70
Quartz	-	-		-		-		-	-	-	-	10	50	55
Serpentine		5	2	-	-	-	-	20	40	20	15	-	-	-
Tremolite	30		-		-			-	-	-	-	-	-	-

pentinized olivine, chrome spinel, saussuritized calcic plagioclase, and clinopyroxene.

An additional indication of the temperature of intrusion is given by Quick (1974), who studied the partitioning of Fe^{+2} and Mg between olivine and spinel in the dunites exposed at Fish Lake. His results suggest an equilibration temperature of 450° to 500°C, which could be interpreted to indicate subsolidus intrusion or reequilibration during a later metamorphic event.

Figure 18. Typical outcrop surface of dunite and peridotite within the Fish Lake Complex.

The main body of dunite exposed in the low hills around Fish Lake consists of olivine (Fo_{80-90}), secondary serpentine minerals, and chrome spinel. Layering in this body seems to be due in part to variations in grain size and perhaps to differing degrees of serpentinization. Several distinct clinopyroxene-bearing lay-

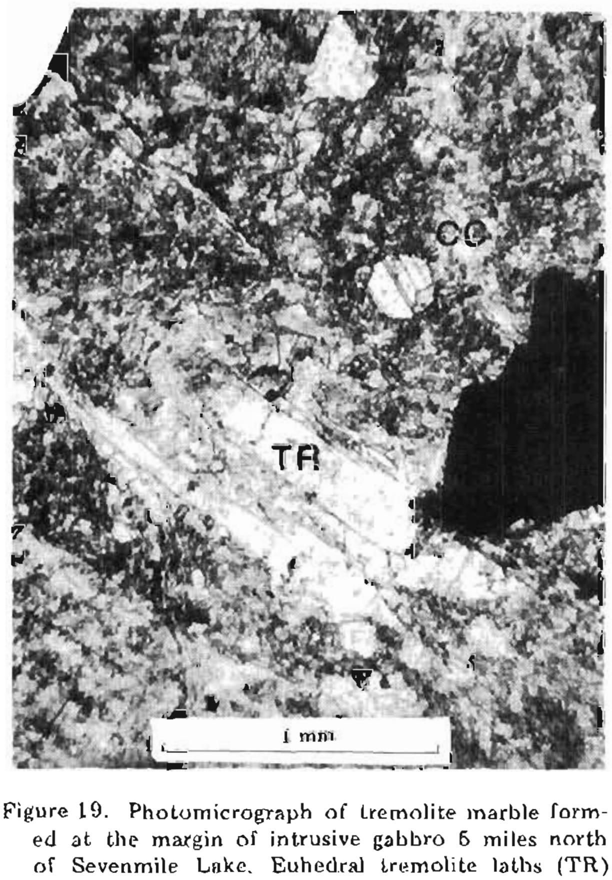

Figure 19. Photomicrograph of tremolite marble formed at the margin of intrusive gabbro 5 miles north of Sevenmile Lake. Euhedral tremolite laths (TR) and large grains of recrystallized calcite (CC) are common.

ers up to 12 inches thick were noted, however. There is little variation in mineralogy of the dunites for 15 miles between Fish Lake and the last exposures on the west side of the West Fork Glacier. The dunites elsewhere in the Complex (pl. 1) are less extensive and are more commonly associated with pyroxene-bearing varieties.

The dunites appear to be least serpentinized in the central portions of the outcrops; some dunites there are virtually unaltered. Nearer the covered contacts, however, the dunite is commonly completely serpentinized. Hand-lens inspection of weathered surfaces clearly show subhedral grains of serpentine pseudomorphed after olivine.

Felsic intrusive varieties occur less commonly in the Complex, but are notable in the vicinity of Fourteenmile Lake (pl. 1). The low color index in some outcrops is due to secondary alteration of augite to actinolite and the saussuritization of plagioclase. Quartz-bearing varieties (table 6) do occur, however, and could be derived as differentiates of a more mafic parent.

There are several satellitic dikes of gabbro intruded into the Tangle Lakes Formation that appear genetically related to the Fish Lake Complex. Specimen A5-4-27 (table 6) is typical. The dikes have a uniform north-northwest trend and clearly cut across the primary compositional layering of the host rocks. The dikes range up to several hundred feet thick. At a locality 1 mile east of Lower Tangle Lake, a gabbro dike on the south side of Sugarloaf Mountain was followed continuously into a much more extensive body that is part of the Fish Lake Complex.

The field relationships seem to indicate that the Fish Lake Complex is younger than the Late Triassic rocks they apparently intrude. There is some evidence, however, to suggest that the Complex was emplaced prior to the deformation that produced the Amphitheater syncline. The generally folded form of the main body of the Complex and the localization of the intrusive rocks along the contact between the Paxson Mountain Basalt and the Tangle Lakes Formation are certainly suggestive of this. There is also the systematic variation in trend of the presumably related gabbro dikes that is suggestive of folding. North of Sevenmile Lake on the northern limb of the syncline, gabbro dikes and sills strike N. 70° W., whereas in the vicinity of Lower Tangle Lake and Sugarloaf Mountain, the dikes have a nearly north-south trend. The age of folding is problematic, but as discussed on page 55, there is evidence that indicates it is possibly pre-Late Jurassic.

The minimum age assignment from field relationships is provided by the Tertiary deposits of probable Late Oligocene or younger age that appear to unconformably overlie the Fish Lake Complex. On the broad rounded hills 4 to 5 miles north of Sevenmile Lake, the porphyritic olivine basalt described earlier overlies dunite and gabbro. On the hill (elev. 4320) 1 mile east of the terminal moraine of the West Fork Glacier, the projected dips of tertiary conglomerate, sandstone, and shale extend well above the Fish Lake Complex, which begins only one-half mile to the south.

The only radiometric date that bears on the age of the Fish Lake Complex is a 125-m.y. date on hornblende granodiorite (Smith and Turner, 1973) in the Mt. Hayes A-6 quadrangle. The rock intrudes the Amphitheater Group and is clearly older than any intrusive rocks north of the Broxson Gulch Thrust fault. Any relationship between this body and the Fish Lake Complex can only be considered speculative at this time.

The only intrusive rocks south of the Broxson Gulch Thrust fault that are apparently unrelated to the Fish Lake Complex are dacite porphyry dikes. These bodies are numerous in the Amphitheater Mountains and are found along north-south-trending fracture zones (pl. 1); unlike the gabbro dikes discussed above, they show no variation in trend that could be attributed to folding.

The noteworthy fact about the dacite porphyry dikes is that they are found in the Jura-Cretaceous terrane north of the Broxson Gulch Thrust fault. They clearly cross-cut a massive dunite east of Broxson Gulch that is probably Tertiary. There, the dikes retain the north-south trend exhibited further south. Small boulders of the same rock were observed as part of the lateral moraines on the West Fork Glacier and on the glacier at the headwaters of Broxson Gulch, indicating that the dikes intrude the metamorphic terrane. At these localities, the dikes were not found in place.

Petrographically, the dacite porphyry dikes are quite distinctive (fig. 20). Two specimens were examined, one from near Landmark Gap Lake (A5-4-31) south of the Broxson Gulch Thrust fault and one from the west side of Broxson Gulch (B5-2-40) north of the thrust. The two rocks are identical (table 6). Both are characterized by strongly zoned green to brown euhedral hornblende phenocrysts up to 1 mm long. These are surrounded by strongly zoned plagioclase feldspar laths interspersed with tiny magnetite octahedra.

There are at least two other north-south-trending dikes in the Amphitheater Mountains that bear similarities to the dacite porphyry dikes. These occur in the small U-shaped valley just south of the east end of the Sevenmile Lake. Dike rock there has the same tiny hornblende needles, but has strongly zoned plagioclase phenocrysts up to 0.5 inch in diameter.

INTRUSIVE ROCKS NORTH OF THE BROXSON GULCH THRUST FAULT

The intrusive rocks in this region include not only those north of the Broxson Gulch Thrust fault but also those that are intruded or faulted within the thrust zone itself. The rocks range from quartz monzonite to dunite, and trend east-west along the northern margin of the map area (pl. 1). Unlike the intrusive rocks south of the

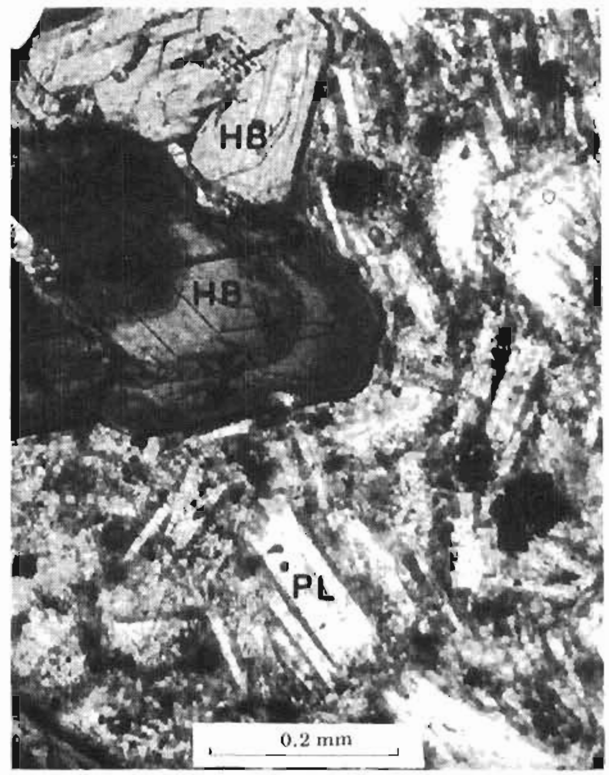

Figure 20. Photomicrograph of dacite porphyry dike. Euhedral zoned hornblende (HB) and zoned plagioclase phenocrysts (PL) are contained within a groundmass of finer grained plagioclase, augite, and magnetite.

Broxson Gulch Thrust fault, they are post-Late Cretaceous, and in the case of the dunites, probably Tertiary.

Felsic intrusive rocks, mainly quartz monzonite and granodiorite (table 7), underlie a considerable portion of the map area. The unvegetated pink- to orange-weathered ridges between the Maclaren Glacier and Broxson Gulch consist of quartz monzonite. The rock is intensely sheared and altered by secondary solutions, which have produced fracture fillings of oxidized pyrite and limonite throughout. The degree of alteration is so severe in some outcrops that the identity of the rock can be ascertained only with difficulty. Less-altered specimens (B5-3-16 and B5-3-17, table 7) show in thin section euhedral plagioclase grains up to 3 mm diameter strongly altered to sericite, epidote, and opaque clay minerals. Microcline is much less altered. Quartz is abundant and fresh, but highly strained with sutured grain boundaries. The primary mafic minerals, biotite and hornblende, are almost completely altered to chlorite, epidote, and opaque iron oxides. The amount of quartz and microcline are variable over the area mapped as quartz monzonite and locally, the rocks are granodioritic to quartz dioritic.

The contacts between the quartz monzonite and the surrounding country rock are moderately well exposed. The southern contact with Permian upper Tetelna Complex and Tertiary conglomerate is a low-angle, north-dipping thrust fault that is interpreted as part of the Broxson Gulch Thrust fault system. The red to orange staining so common in the altered quartz monzonite is well developed in the fault zone and in the adjacent andesitic volcaniclastics and flows. The northern contact in two localities (pl. 1) is also a north-dipping thrust fault. Between the Maclaren Glacier and the East Maclaren Glacier, the quartz monzonite is in thrust contact with phyllites of the Maclaren metamorphic belt; just east of the East Fork Glacier the thrust contact is with serpentinized dunite.

In the northeastern corner of the map area, a quartz monzonite stock exhibits intrusive contacts with pelitic schists of the Maclaren metamorphic belt. Locally, there has been contact metamorphism of the previously metamorphosed Jura-Cretaceous sediments, and regional isograds predate the intrusion (Stout, 1974). The quartz monoznite here is typically coarse grained and has no directed fabric. Inclusions of surrounding country rock are common (fig. 21). Thin-section examination (specimens JS-96, JS-361A) reveal microcline, quartz, oligo-

Table 7. *Modes of representative felsic intrusive rocks north of and within the Broxson Gulch Thrust fault*

[The first four specimens are quartz monzonite; the last four specimens are granodiorite and quartz diorite.]

Specimen No.	B5-3-16	B5-3-20 •	JS-96	JS-361A	B5-3-17	JS-241A	JS-386	JS-51
	Modes							
Biotite	-	-	-	-	-	-	-	-
Chlorite	10	3	5	7	-	1	1	1
Epidote	2	2	-	-	-	1	4	12
Hornblende	-	-	-	-	30	25	33	18
Microcline	20	25	35	35	-	15	14	-
Opaque alteration	4	5	-	-	-	7	14	35
Plagioclase	30	30	22	25	60	33	25	6
(An content)	25	30	12	28	40	25·	32	28
Quartz	35	35	37	25	10	16	2	23
Sericite	2	-	1	11	-	2	7	5

Figure 21. Intrusive breccia formed by country rock of pelitic schist contained within quartz monzonite.

clase, biotite, and (locally) muscovite as the main constituents. This body differs from the quartz monzonite (described above) by the presence of muscovite and the lack of secondary alteration.

The other mappable unit of felsic intrusive rocks is granodiorite and quartz diorite north of the quartz monzonite body between the Maclaren Glacier and Broxson Gulch. This unit corresponds to the Compass Creek intrusive and the Landslide Creek granodiorite of Rose (1966). These rocks extend up to the thrust contact with the Maclaren metamorphic belt. At the contact, the quartz diorite along the east side of the Maclaren Glacier is locally sheared and foliated.

The contact of quartz diorite with quartz monzonite is distinct and can be mapped within a covered zone less than 20 feet wide along the west side of the East Maclaren Glacier. At several localities, the quartz diorite is intruded by and is in fault contact with serpentinized dunite.

Several smaller bodies of granodiorite and quartz monzonite are exposed east of Broxson Gulch. Three elongate masses of granodiorite are probably in thrust-fault contact with low-grade phyllites of the Maclaren metamorphic belt north of Ann Creek in the northeastern corner of the map area. These rocks are foliated near their margins and are similar to hornblende granodiorite described by Hanson (1963) in the Rainbow Mountain area east of the Delta River. Specimens JS-241A and JS-386 are typical. A small body of quartz diorite (specimen JS-51) is located north of Ann Creek near its confluence with the Delta River.

Petrographically, the granodiorite and quartz diorite of this unit consist of altered plagioclase, quartz, hornblende, and sparse microcline (table 7). Epidote, chlorite, sericite, and opaque iron oxides are present in subordinate amounts.

The felsic intrusive rocks in the vicinity of the Broxson Gulch Thrust fault are clearly younger than the Permian volcaniclastics and andesitic flows of the upper Tetelna Complex that they intrude. However, they must be older than both the serpentinized dunites and a period of major movement on the Broxson Gulch Thrust fault. Several lines of reasoning (p. 30) argue that this movement is post-Late Cretaceous or Early Tertiary and possibly pre-Late Oligocene. The general absence of felsic intrusive rocks in the presumed Late Oligocene and younger sediments favors this interpretation.

The quartz monzonite stock within the Maclaren metamorphic belt in the northeast corner of the map area has a preliminary K-Ar age of approximately 30 m.y. (Turner, personal communication, 1973). It is not known whether this age represents the 25-30 m.y. epoch of intrusion known elsewhere in Alaska (Lanphere and Reed, 1973) or the resetting of an earlier date due to movement on the Denali Fault (Stout, 1972).

Mafic and ultramafic intrusive rocks underlie a substantial portion of the study area, particularly in the eastern half of the map area along the Broxson Gulch Thrust fault system. Dunite and mafic gabbro predominate. The dunite was first described in the Delta River area by Stout (1965), who mapped the main body as far west as Rainy Creek. Rose (1965, 1966) followed the belt along the Broxson Gulch Thrust fault as far as the East Maclaren Glacier, where only dikes of the ultramafic rock are exposed. Kaufman (1964) reports an isolated occurrence of dunite in the headwaters of the West Fork of the Maclaren River, 10 miles further west. In all, the ultramafic belt extends at least 20 miles in an east-west direction (fig. 2). Further east along the Denali Fault, similar dunites occur near the Canwell Glacier (Kleist, 1973) and near Mentasta Pass (Richter, 1967).

The dunite body at Rainy Creek occupies approximately 5 square miles. The outcrops are distinctive for their reddish-brown or dun-red weathered surfaces. All but the marginal portions, however, are relatively fresh dunite (table 8) and consist of olivine (Fo_{86-90}) and minor spinel. The exposed margins of the body are variably serpentinized, and in several localities (pl. 1) are faulted against the adjacent Pennsylvanian to Permian volcanics. Thin-section examination of several specimens (table 8) reveal an equilibrium texture between olivine grains and abundant deformation lamallae in some grains. Serpentine, where present, is interstitial and associated with abundant secondary magnetite.

Several smaller outcrops of dunite occur as isolated outcrops along the Broxson Gulch Thrust fault. Some of these, for example on the west side of East Maclaren Glacier, are wholely serpentinized. These bodies are

Table 8. *Modes of representative mafic and ultramafic intrusive rocks north of and within the Broxson Gulch Thrust fault*

[The first three specimens are dunite from Rainy Creek and Broxson Gulch. The last three specimens are pyroxene-bearing dunite and mafic gabbro from southwest of Rainy Creek.]

Specimen No.	B5-2-30	JS-450	JS-55	JS-368	JS-337	JS-341
	Modes					
Augite	-	-	-	10	48	56
Chrome spinel	1	-	-	-	-	-
Magnetite	4	-	1	1	1	3
Olivine	70	99	60	85	-	-
(Fo content)	88	82	88	82	-	-
Opaque alteration	-	-	-	-	5	15
Orthopyroxene	-	1	-	-	20	15
Plagioclase	-	-	-	-	25	10
(An content)	-	-	-	-	60	55
Serpentine	25	-	39	4	1	1

typically elongate in an east-west direction as much as 20 to 1 and are commonly bounded on their north and south sides by north-dipping thrust faults. The central portions of a few of these smaller bodies are relatively unaltered dunite, which substantiates the relationship between degree of serpentinization and the proximity to fault contacts.

Numerous bodies of gabbro and mafic gabbro are associated with the dunites. The largest of these is south of the Rainy Creek dunite east of Broxson Gulch. It is intrusive into both the Pennsylvanian dacites and andesites and the Permian Mankomen Group between Rainy Creek and Eureka Creek. Local contact metamorphism can be observed, particularly in limey beds, near well-exposed contacts.

Contacts between the gabbro and the dunite appear to be sharp over a distance of 10 to 20 feet but nowhere were the field relationships sufficiently clear to determine relative ages. Both dunite and gabbro are younger than the Permian rocks they intrude, and cobbles of both are found in the Late Oligocene conglomerates that mantle the older bedrock. The almost exclusive occurrence of the dunites in the Broxson Gulch Thrust zone and their extension southeast along the trace of the Denali Fault suggests that the thrusting and ultramafic emplacement are coeval.

No radiometric age determinations are as yet available for the hornblende and biotite-bearing felsic intrusives that are in turn intruded by dunite. Correlation of the quartz monzonite north of Ann Creek within the Maclaren metamorphic belt with the quartz monzonite east of the Maclaren Glacier implies that the dunites are younger than 65 m.y. If the Late Oligocene age assignment to the dunite conglomerates is correct, the ultramafics can be no younger than about 25 m.y.

The only other direct age determination that bears on the age of the dunites was made by Kleist (1973). The granodiorite exposed along the south side of the Canwell Glacier (fig. 2) is intruded by dunite. An examination of the body by this writer during the summer of 1972 indicates that it is identical with the Rainy Creek dunite in its outward appearance. A biotite separate from the intruded granodiorite yields a K-Ar date of 83 m.y. (Kleist, 1971).

STRUCTURAL GEOLOGY

The most important structural features in the Eureka Creek area are folds and faults. Both are spectacularly exposed. In the following discussion, continual reference is made to the geologic map of the area (pl. 1) and to the structural sections (pl. 2).

FOLDING

Previous attempts (Rose, 1965, 1966a,b) to understand the folded nature of the layered Paleozoic and Mesozoic sequence in the study area were unsuccessful because of an incomplete understanding of the stratigraphy. The stratigraphic relationships ascertained as part of the present study indicates that the entire sequence through the Triassic Boulder Creek Volcanics is folded about axes that trend approximately N. 75° W. The folds plunge at low angles (<20°) to the west.

The most notable of these folds is the Amphitheater syncline (pl. 1 and pl. 2). The trace of its axial surface extends from the western margin of the map area, near the Maclaren Glacier, east to at least Sugarloaf Mountain east of Lower Tangle Lake---a distance of over 20 miles. Extrapolation of the folded Paxson Mountain Basalt further east suggests that the axial trace of the fold passes beneath the Tertiary and Quaternary deposits near Fielding Lake and Summit Lake. A reconnaissance mapping trip into the Amphitheater Group west of the Maclaren Glacier in the Mt. Hayes A-6 and B-6 quadrangles indicates that the N. 70° W. trend continues until probable termination against the western extension of the Broxson Gulch Thrust fault. Geologic field

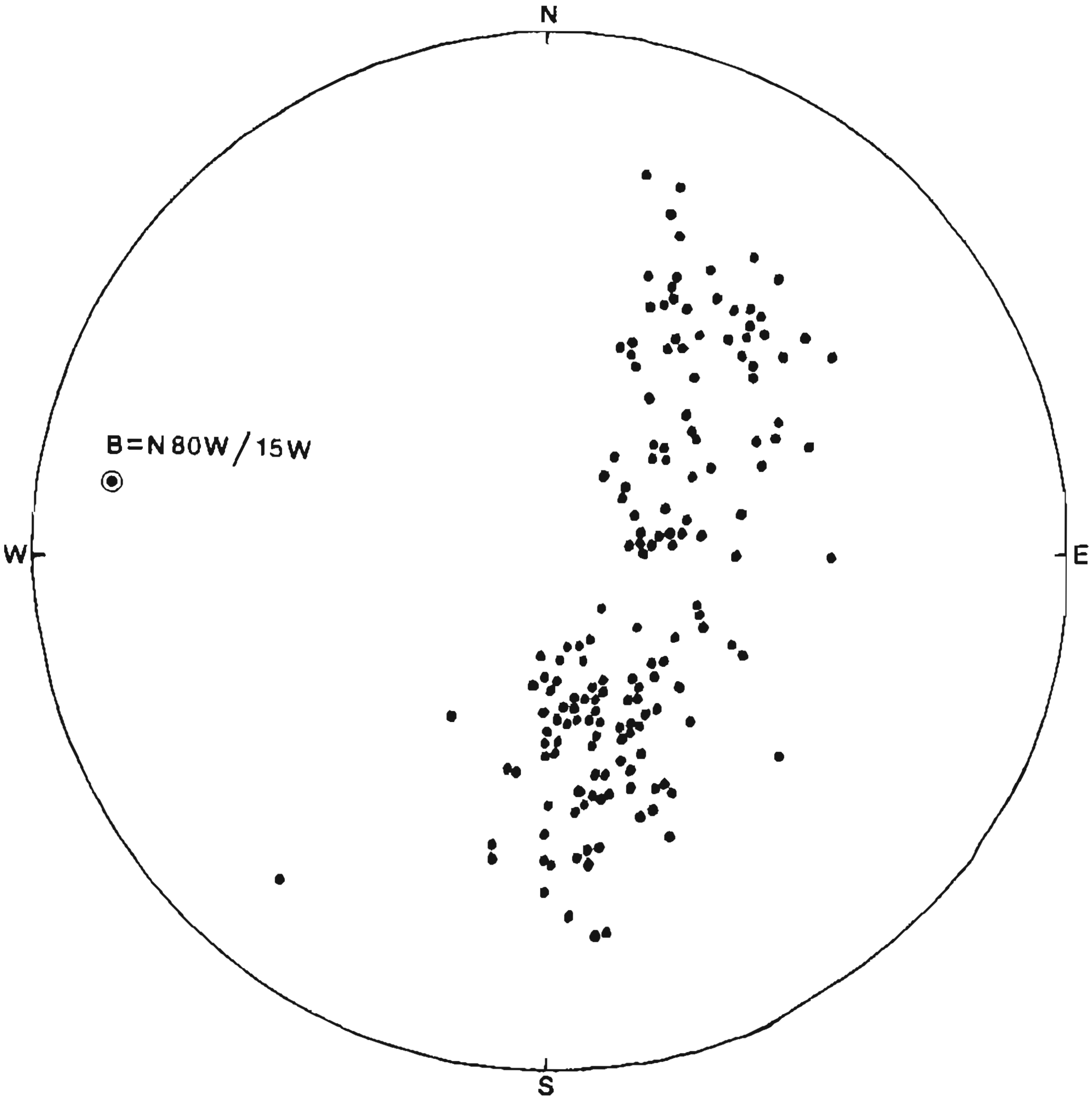

Figure 22. Poles to 167 compositional layers and bedding planes in the Amphitheater syncline.

mapping by Smith (1974c) in the Mt. Hayes A-6 quadrangle also suggests that other east-west-trending folds in the Amphitheater Group are terminated at the structural discontinuity between Late Triassic rocks and Late Jurassic rocks.

The folded form of the Amphitheater syncline is apparent from the areal distribution of formations and their attitudes. Poles to measured attitudes on compositional layering and bedding around the syncline are represented in figure 22. These show that the fold is approximately cylindrical over a distance of 20 miles, and has a gentle plunge to the west. A down-plunge view of the fold is readily obtained by viewing the geologic map at 15 degrees to the horizontal in a N. 80° W. direction. The average bearing and plunge of the fold axis (fig. 22) lie in a near-vertical plane with an average axial trace taken from plate 1. Therefore, the axial plane of the Amphitheater syncline is essentially vertical.

The north limb of the Amphitheater syncline becomes the south limb of an adjacent anticline north of

Eureka Creek (pl. 1 and pl. 2). There, the Pennsylvanian and Permian Tetelna Complex are involved in the folding. The bearing of the axial trace of the anticline is approximately N. 60° W. and the plunge is about 30° to 35° to the west. In the Broxson Gulch area, it is quite clear that the axial trace of the anticline is terminated against the east-west-trending Broxson Gulch Thrust fault. The northwest- to west-trending folds are also found in the area around Ann Creek in the northeastern corner of the map area. Several northwest-plunging anticlines and synclines were first mapped there by Stout (1965). These folds are unquestionably truncated by the Broxson Gulch Thrust fault in this area.

The northwest- to west-trending set of folds is restricted to Triassic and older rocks. In contrast, the folds developed in the metamorphosed Jura-Cretaceous terrane north of the Broxson Gulch Thrust fault have a totally different form and orientation. Throughout the belt in the Eureka Creek area, folds are isoclinal to subisoclinal and have their axial surfaces uniformly inclined to the north. Where measured, hinge lines plunge at low to moderate angles to the west (pl. 1). Structural and petrological studies by Stout (1974) reveal evidence for two periods of folding in the pelitic schists. An early period is related to the Late Cretaceous metamorphic event. The later period is coaxial with the first, but differs from it by having vertical instead of inclined axial planes. This deformation may also be related to the metamorphism, or alternatively, to either the 30-m.y. intrusive event or movement on the Denali Fault.

These data and arguments place definite constraints on the time of folding both in the pre-Jurassic terrane and in the younger rocks. In the former, the evidence seems to favor a post-Late Triassic—pre-Late Jurassic age for the formation of the Amphitheater syncline and other folds related to it. On the other hand, the evidence clearly indicates that the folding north of the Broxson Gulch Thrust fault is later than their Jura-Cretaceous depositional age, and is probably contemporaneous with the Late Cretaceous regional metamorphism.

There is scanty evidence in the Eureka Creek area for a folding event that postdates the Late Oligocene and younger conglomerates and coal-bearing sandstones. Gentle (but opposing) dips on Tertiary beds northwest of Fielding Lake (pl. 1) suggest an axial trace that extends through Dude Lake. East of the Delta River and Phelan Creek, the Tertiary beds are also folded (Bond, personal commun., 1973). Moffit (1954) and Wahrhaftig and Hickcox (1955) describe the folding in Tertiary conglomerates and coal-bearing sandstone on the north side of the Alaska Range. These authors conclude that the age of folding could be as young as post-Pliocene.

Figure 23. The Broxson Gulch Thrust Fault (F) as viewed from the Richardson Highway near milepost 218. Note the truncation of mafic dikes (D) in the underlying Tetelna Complex.

FAULTING

Several faults of probably large displacement have been mapped in the Eureka Creek area (pl. 1). The largest of these is the Broxson Gulch Thrust fault. It was first recognized in the Delta River area by Stout (1965), who followed its east-west trace as far as Rainy Creek. Rose (1965) simultaneously recognized the fault at Broxson Gulch and in fact named it after the geographic landmark. Rose (1966) extended the trace of the fault to the East Maclaren Glacier. The results of the present study show that the Broxson Gulch Thrust and related faults extend uninterrupted from the Delta River to the Maclaren Glacier, a distance of 25 miles.

Studies by Stout (1972) indicate that the eastern extension of the Broxson Gulch Thrust is terminated by, or is an extension of, the Denali Fault. This juncture (fig. 2) is on the east side of the Delta river near the Canwell Glacier. The fault may extend to the west along the Triassic-Jurassic boundary as far as the Susitna River (Smith and Turner, 1973; Smith, personal commun., 1973). The apparent truncation of the axial traces of pre-Jurassic folds along this line (fig. 2) and the general absence of Lower and Middle Jurassic rocks here and elsewhere in Alaska (Moffit, 1954; Berg and others, 1972) indicates that the boundary is both a fault and an unconformity. If the fault interpretation west of the Maclaren Glacier is correct, the length of the Broxson Gulch Thrust fault is at least 50 miles and hence must rank as one of the major structural breaks in the Alaska Range.

The Broxson Gulch Thrust fault as herein referred actually consists of several imbricate faults that occupy a zone of deformation that ranges from several yards to 2 miles wide. The major break defines the northern margin of the zone and places the Jura-Cretaceous Maclaren metamorphic belt on top of the Permian Tetelna Complex (fig. 23). A discontinuity in lithology and metamorphic grade across the fault is apparent everywhere. Inbricate faults to the south lie wholely within the pre-Jurassic terrane.

Without exception, all faults within the zone of deformation dip at low to moderate angles to the north. In some localities (fig. 24), individual fault surfaces may even be horizontal. Commonly, a white to reddish zone (fig. 24) up to 50 feet wide marks the trace of the fault. This zone consists in some cases of finely ground, clay-rich gouge material similar to that observed along the Denali Fault (Stout and others, 1973). In other cases, the whitish zone is weathered, serpentinized dunite.

In contrast to the low-angle faults of the Broxson Gulch system, several large northwest-trending vertical faults exist in the map area. The most notable of these is at Broxson Gulch, where the Broxson Gulch Thrust fault has an apparent offset of approximately 6 miles. Rose (1966) recognized the displaced phyllites of the Maclaren belt and postulated his Eureka fault beneath the Quaternary gravels in Broxson Gulch. The actual fault (pl. 1) is well exposed east of Broxson Gulch, where it extends through highly deformed and thrust-faulted Permian volcanics. Its eastern extension may correspond in part to Rose's (1965) Pioneer fault, separating the Permian Mankomen Group from the Permian Tetelna Complex near Rainy Creek.

Other northwest-trending vertical faults are postulated between Rainy Creek and Eureka Creek. The horizontal slip on these are unknown, but the vertical slip must account for several thousand feet of repeated Permian strata. Northwest-trending vertical faults are also present north of Rainy Creek in the northeast corner of the study area. Stout (1965) interpreted these as older than the north-dipping thrust faults on the basis of cross-cutting relationships.

The other possibly large northwest-trending vertical faults in the area are those that bound the Fish Lake Complex on the north limb of the Amphitheater syncline. These faults are not exposed, but the degree of serpentinization and the intense shearing in the peripheral outcrops suggest at least some fault movement along the contacts. The displacement on these faults

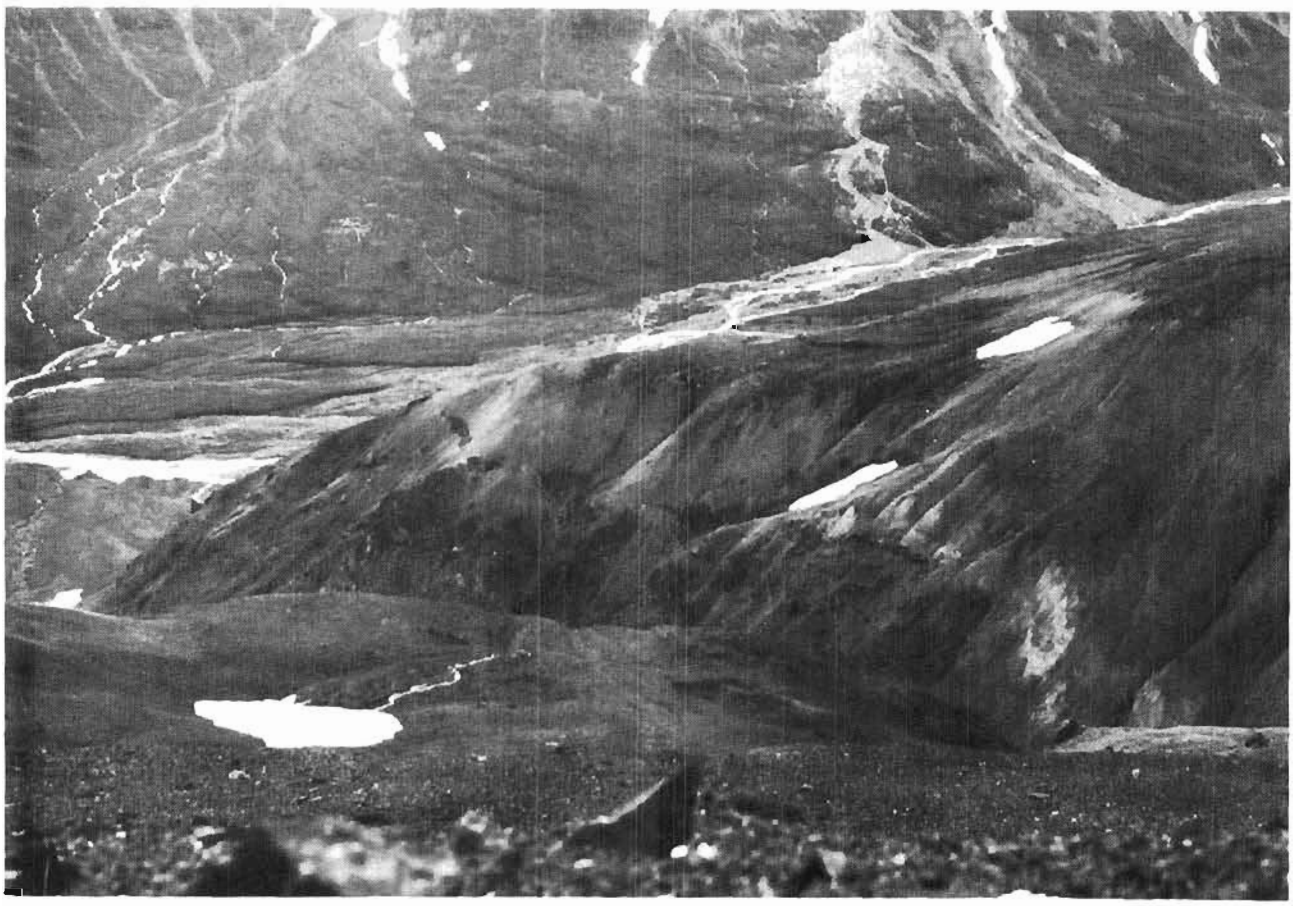

Figure 24. A near-horizontal thrust fault near Broxson Gulch which places Jura-Cretaceous phyllite (on right) on top of Permian volcanics (on left).

is not known.

In the Amphitheater Mountains, there is evidence for only one set of faults. These appear to be vertical, and have a north-northwest trend. Apparent offsets of several hundred feet are common, and displacement of up to 1 mile is possible.

The age of faulting in the Eureka Creek area is bracketed by the following considerations. All rocks older than Quaternary are faulted. This includes the presumed Late Oligocene conglomerates and coal-bearing sandstones. In the small drainages that disect Tertiary rocks midway between the East Maclaren Glacier and Broxson Gulch, Late Oligocene rocks are tectonically overlain by deformed quartz monzonite and Permian volcanics. The two faults that are exposed dip approximately 30 degrees to the north and appear to correlate with a similar pair of thrust faults near the terminus of the East Maclaren Glacier (pl. 1). The coal-bearing beds in the underlying plate dip 70 degrees to the north. The associated conglomerates in this steeply dipping section are noteworthy because of their lack of dunite clasts. A diligent inspection of all cobble lithologies failed to reveal types characteristic of the Maclaren metamorphic belt.

One mile to the west, the relationship between the dunite conglomerates and the east-west-trending thrust faults differs. There, one thrust fault that separates gabbro from Permian volcanics is unconformably overlain by the conglomerate. This suggests the possibility that the dunite conglomerates are younger than the Late Oligocene coal-bearing sandstones, and that thrusting took place between the times of their deposition. The absence of dunite cobbles in the older conglomerates could be interpreted to mean that the dunites had not been emplaced by Late Oligocene. However, their presence in the possibly younger conglomerates only 1 mile away and absence in the thrust-faulted older conglomerates further suggests that the thrust faults and the dunite emplacement are closely related in time.

There is independent regional evidence (Stout, 1972) that indicates the likelihood of simultaneous thrusting and dunite emplacement during the Tertiary. The age of movement on the Denali Fault that must be postulated to explain the separation of the Maclaren metamorphic belt and its possible extension in the Ruby Range, 250 miles to the east (Forbes and others, 1973; Turner and others, 1974), is younger than the regional metamorphism. It is also younger, at least in part, than the 30-m.y.-old quartz monzonite that is intruded into the belt. The dunite bodies along the Denali Fault at Gillett Pass, Mentasta Pass, and the Canwell Glacier are not found along the Denali Fault further west than the Delta River. Instead, the untramafic belt follows the Broxson Gulch Thrust fault in a diverted, east-west direction. These relationships can be interpreted to mean simultaneous movement on the Broxson Gulch Thrust fault and the Denali fault east of the Delta River. It was at this time, perhaps after the Late Oligocene, that the dunites were emplaced into their present position.

JOINTS

The only other structural features of note in the Eureka Creek area are the well-developed joint sets in the Amphitheater Mountains. Many of these are shown on plate 1. A northwest-trending set that dips steeply to the north is the most prominent. These joints maintain their attitude on both limbs of the Amphitheater syncline, indicating that they postdate the pre-Jurassic folding event. The other prominent joint set trends to the northeast; joints dip at moderate to steep angles, variably to the north and south. Quartz veins are rather common along this set and are locally mineralized.

ECONOMIC GEOLOGY

Occurrences of disseminated copper and iron sulfides are common in the Eureka Creek area. In the Amphitheater Mountains, the only occurrences that justify further investigation at this time are found in quartz veins that occupy the north- to northeast-trending fracture systems described earlier. The quartz veins range in thickness from less than an inch to 12 inches, and contain chalcopyrite, bornite, malachite, azurite, and minor calcite. The chalcopyrite and bornite occur as massive pods up to 1 inch thick near a northern tributary of Boulder Creek and on the west side of Lower Tangle Lake (pl. 1). At the latter locality, malachite-coated nuggets are scattered through the stream gravels in the drainage basin of a small cirque in that area.

The several localities shown on plate 1 are notable insofar as they are apparently restricted to the Boulder Creek Volcanics. All but one of the occurrences are located on the northern limb of the Amphitheater syncline. The exception is at Lower Tangle Lake, where the northeast-trending veins are at approximately the same stratigraphic position in the sequence but in the crest of the fold.

A linear extrapolation of this linear belt of mineralization extends across the Maclaren River to just beyond the western boundary of the map area to the Kathleen-Margaret (KM) copper deposit. This is the richest known prospect in the area, and has apparently been active at various times since 1918 (Martin, 1920). The deposit is described by Chapman and Saunders (1954) and MacKevett (1964) as consisting of north-striking copper-bearing quartz veins. The veins range in thickness a few inches to about 20 feet. The principal ore minerals are bornite and chalcopyrite, both commonly coated with malachite. The surrounding country rock consists of interlayered basalt (greenstone) and amygdaloidal basalt that dips to the south. There is no doubt that these rocks, too, are a part of the Boulder

Creek Volcanics, and that they are situated on the north limb of the Amphitheater syncline.

The age of the copper mineralization is bracketed by the following considerations. The quartz veins have formed in the north-northeast-trending set of joints that have been mapped (pl. 1) over the entire area. The joints and the quartz veins cut across the folded limbs of the Amphitheater syncline with no variation in altitude that can be attributed to folding. Hence, they are younger than the pre-Late Jurassic folding event. The dacite porphyry dikes described in earlier (p. 28) occupy the same set of joints both north and south of the Broxson Gulch Thrust fault. Although no mineralization associated with the dikes has been observed, they may have an origin common with the copper-bearing quartz veins. If so, the mineralization may be Tertiary and perhaps as young as Late Oligocene.

Several nickel-copper occurrences are known in the Eureka Creek area. All of them are associated with the Tertiary ultramafic rocks in the vicinity of the Broxson Gulch Thrust fault. The localities visited by this writer are described in some detail by Rose (1965, 1966). The most notable of these is the Pioneer claim on the upper part of Rainy Creek (pl. 1). There, a light-colored gabbro porphyry contained enough disseminated chalcopyrite to justify a preliminary drilling operation in the summer of 1974 (Mark-Anthony, personal commun., 1973). This deposit, like the others in the area associated with the ultramafic belt and the low-angle faulting, are Tertiary.

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