GEOLOGY OF THE FRASER RIVER VALLEY BETWEEN LILLOOET AND BIG BAR CREEK

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ABSTRACT

An area of 550 square miles between Lillooet and Big Bar, B.C. was mapped by the author using the scale of one mile to the inch.

In the southern part of the Bowman Range four members are recognized in the Middle (?) and Upper Permian Marble Canyon formation which is partly composed of reefal limestone. This formation forms a northwesterly trending anticlinorium overturned to the northeast. The cherts, argillites, limestones, and volcanic rocks west of the Bowman Range, originally referred to the Permo-Pennsylvanian Cache Creek group are shown to be Permo-Triassic and are here assigned to the Pavilion group, a new group which is made up of two Divisions. Microscopic and stratigraphic evidence is given that the cherts of this group are of radiolarian origin.

The Lower Cretaceous Lillooet group here is subdivided into three units. Divisions A and B are shown to form a northwesterly trending anticline.

Three members are now recognized in Division A of the Lower Cretaceous Jackass Mountain group.

The Lower Cretaceous Spences Bridge group is subdivided into several local and stratigraphic units. Two units previously assigned to the Spences Bridge group are correlated with the Kingsvale group on the basis of new fossil collections.

Some volcanic and sedimentary rocks originally referred to the Miocene Kamloops group are here correlated with Miocene to Pleistocene rocks of the Quesnel map-area.

West of Lillooet a belt of serpentinite was mapped that has structural and lithological similarities to the Upper Triassic ultrabasic intrusions of the Shulaps Range. Granitic rocks of three ages are recognized and range from early Lower Cretaceous or older to mid-Lower Cretaceous.

It had earlier been shown that the Fraser River fault zone consists of several normal faults with relative downward movement to the east. East of these faults the author recognizes another fault with relative downward movement to the west. Lower Cretaceous and early Tertiary rocks thus occupy a graben between Permo-Triassic units to the northeast and to the southwest. This graben probably controlled the deposition of Divisions B and C of the Jackass Mountain group. The faulting may be related to the isostatic rise of adjacent granitic masses. Evidence is given that the latest movement on one of the faults took place in mid-Tertiary time.

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INTRODUCTION

1. Location and Access

The area mapped, elongate and irregular, lies along the Fraser River between Lillooet and French Bar Canyon and includes the adjacent Bowman Range and parts of the Pavilion Mountains, the Camelsfoot Range, and Fountain Ridge.

The eastern side of the Fraser River, and the west side in the vicinity of Lillooet, are served by highway, the Pacific Great Eastern Railway, and secondary roads and trails. In the central and northern parts of the map area the west side is accessible by a cable car near Pavilion and a ferry at the mouth of Big Bar Creek. From these two crossings only pack trails and a few wagon roads provide further access to the western parts of the map area.

2. Previous Geological Work

The earliest geological work in the area was done in 1871 by J. Richardson and A.R.C. Selwyn. The Cache Creek group and the Jackass Mountain group are named and described for the first time in Selwyn's report (1872).

In 1877 G.M. Dawson (1877-78) mapped the Kamloops area on a scale of eight miles to the inch. Further studies were carried out in the seasons of 1888, 1889, and 1890, and in 1895 a report and a map on a scale of 4 miles to the inch were published. Dawson established all of the major rock units

of the present map area, and his map and report are still the only source of information for some of the northern parts of the Kamloops Area.

In 1918 and 1919 Leopold Reinecke (1920) who examined the mineral deposits adjacent to the Pacific Great Eastern railway between Lillooet and Prince George described a few deposits in the present map area.

A reconnaissance survey from the Fraser River to Taseko Lake was carried out in 1920 by J.D.McKenzie whose map and report cover the west side of the Fraser River between Watson Bar Creek and French Bar Creek.

From 1945 to 1947 S. Duffell and K.C.McTaggart remapped the Ashcroft area on a scale of 4 miles to the inch. Their most important contributions to the geology of the present map area concern the Lower Cretaceous sedimentary rocks, and the Fraser River fault zone.

In 1955 J. McCammon and H. Nasmith (1956) studied possible dam sites in the northern part of the map area. They discovered several faults which proved to be northern extensions of the Fraser River fault zone.

Some of the northwestern parts of the area mapped are here described for the first time.

3. Field Work

Field work was carried out for a total of 9 months during the summers of 1957 and 1958 and for one week in 1959.

The dry climate and good accessibility of the area allowed uninterrupted work. In most of the area the geology was plotted on base maps on a scale of 1/2 mile to the inch. Near the Fraser River base maps on scales of 1000 feet and 500 feet to the inch were available. Locations were established by cross bearings, altimeter readings, and pace and compass traverses. The geology of the Bowman Range was plotted on air photographs and, by means of radial plotting, transferred to base maps showing photo centers.

4. Physiography and Pleistocene Geology

Three major elements of the topography can be distinguished: Mid-Tertiary and older mountain ranges, Middle or Late Tertiary upland surfaces and Pleistocene and Recent valleys.

The main mountain ranges of the map area are the Pavilion Mountains and the Bowman Range in the east underlain by the Upper and (?) Middle Permian Marble Canyon formation, and the Camelsfoot Range and Fountain Ridge in the west, underlain by Lower Cretaceous sedimentary rocks.

The Bowman Range and the Pavilion Mountains consist mostly of parallel ridges formed by steeply dipping limestones. In the northern part of the Bowman Range a plateau-like topography has been produced by gently dipping limestone beds. As in this arid climate limestone is very resistant to weathering the highest mountains of the map-area are found in this belt (Mount Bowman 7360 feet).

The Camelsfoot Range is underlain by moderately dipping lithic sandstones and conglomerates that are highly resistant to weathering. It has steep slopes, and is transected by numerous valleys, some of which are deeply incised and narrow. Fountain Ridge is a narrow remnant of the same mountain mass. In the present map area the elevations of the Camelsfoot Range are mostly between 4500 and 5500 feet but rise up to 6900 feet. The altitudes of Fountain Ridge range from 4200 to 5500 feet.

Mount Martley, whose rounded top reaches an altitude of 6700 feet at the southeastern edge of the present map area, is formed by highly resistant granitic rocks.

The steeply dipping but weakly resistant sedimentary and volcanic rocks of the Pavilion group form hilly tracts or mountains of lesser height which rarely rise above 5000 feet.

Gently dipping Cretaceous and early Tertiary volcanic rocks, not very resistant to weathering form a belt of low mountains that only in the northern part of the area rise to elevations of more than 6000 feet.

Flat lying sedimentary and volcanic rocks of Middle or Late Tertiary age form small plateaus at altitudes ranging approximately from 3000 to 4000 feet near Pavilion, between McKay Creek and Watson Bar Creek, and on Big Bar Creek. North of Pavilion, south of Watson Bar Creek, and in the vicinity of Big Bar Creek some of these depositional surfaces are continuous with younger gently sloping erosional surfaces, which are covered only with a thin veneer of unconsolidated Pleist-

ocene and Recent deposits. These Middle or Late Tertiary surfaces are parts of the floor of a valley that possibly extended from Glen Fraser to Big Bar Mountain and was connected along Big Bar Creek with the extensive plateau east of the Bowman Range. The valley partly coincides with the present Fraser River valley but has not been recognized south of Glen Fraser.

The present valley of the Fraser River is younger than these Middle or Late Tertiary surfaces and was probably developed in Pleistocene time. In most of the area it is approximately parallel to the strike of the rocks and to the Fraser River fault zone, except for a peculiar S-shaped turn near Fountain. It might be suggested that the River originally flowed along Fountain valley but was diverted into the Bridge River.

The Pleistocene valley bottom probably coincided approximately with the present surface of the river which lies between 900 and 650 feet above sea level. This valley was filled, probably in the latest Pleistocene, with more than 1000 feet of unconsolidated materials ranging from boulder gravel to mud (See Plate IV). The stratigraphy of these deposits changes over short distances and their history is complicated. Much of the material showing deltaic cross-bedding appears to have been deposited by braided streams. Some of the extensive silt deposits between Pavilion and Big Bar Creek may have been laid down in glacial lakes. Mudflows appear to have been deposited on alluvial fans of tributaries.

In Recent time the river has been rejuvenated and has cut through the unconsolidated sediments into bedrock. This rejuvenation probably was caused by a decrease of the detrital load in post-glacial time. (Thornbury, 1954, p. 144).

Although the area was covered by glaciers (Duffell and McTaggart, 1953, p. 69) glacial erosion is slight and till very rare. Probably no rapid movements took place in this region which lies only some 50 miles to the south of a major glacial divide (Geol. Assn. of Canada, 1958; W.H.Mathews, 1941, p. 64).

A thin layer of Recent volcanic ash has been found in the vicinity of Big Bar and Jesmond. W.H.Mathews (oral communication) suggests that the ash was ejected by a cinder cone on the upper Bridge River. H. Nasmith (oral communication) reports Recent volcanic ash in the vicinity of Pavilion. Bridge River Ash ca. 2400 years

5. Climate, Vegetation, Wild Life

The area lies in the "dry belt" of the Interior of British Columbia which is sheltered from rain and snow by the Coast Mountains. The average annual precipitation at Lillooet over 41 years was 12.35 inches. The summers are warm and the winters cool. The extremes at Lytton, some thirty miles south of the map area in 1956 were -9° in January and 106° in July; the extremes recorded within 30 years are -25° and 112°. (Province of B. C. Dept. of Agriculture, 1957).

The vegetation is relatively sparse. Some parts of the area are covered by forests, some are park-like, and others

open grass-land. The slopes of the western part are more densely forested than those of the eastern part. Most of the trees are pines (lodge-pole pine, ponderosa pine); white spruce, balsam fir and Douglas fir, are common only in the higher and cooler areas that receive more precipitation. Only a few mountains rise above timber line which lies near 6500 feet. Valley flats are characterized by sage brush, bunch grass and cactus.

The area is noted for big game. Deer, moose, and black bears are common in the Bowman Range and on the west side of the Fraser River; goats were observed on the west side of the river, southwest of Pavilion.

6. Industries

The main industry of the area is cattle ranching. The soils of the Fraser River valley, particularly wind blown silts, which were seen in many localities, are very fertile, but the raising of cattle feed depends on irrigation, and only a few creeks carry water all summer.

Logging is second in importance. In 1956 and 1957 only forests on the east side of the Fraser River near Pavilion, Kelly Lake, and Jesmond were logged but preparations for the exploitation of the west side were being made.

Mining is relatively unimportant. In 1958 only two placer mines were operating, one on the Fraser River, opposite Fountain (M3) and the other one on Watson Bar Creek. Some exploration work was done on the claims of the Monty group (M2), southwest of Ward Creek.

Tourism and big game hunting provide another source of income for local people.

A power dam on the Fraser River would help the local industries greatly by providing cheap electricity, allowing extensive irrigation, and by attracting tourists (Warren, 1959).

CHAPTER I

GENERAL GEOLOGY

Introductory Statement

The general geology of the area is summarized on the following table of formations. The term Division was used for certain units by Duffel and McTaggart (1952). The usage is followed here and the term is applied to other units that are roughly equivalent to formations but not well enough known to justify formational names. Local units of somewhat uncertain stratigraphic position are termed "assemblage" and designated by the name of the area in which they occur.

TABLE OF FORMATIONS

Succession	System	Series	Stage	Group	Formation or Division	Assemblage	Member	Lithology and Contacts
Cenozoic	Quaternary	Recent and Pleistocene						Alluvium, volcanic ash, river gravel, sand, and silt, mudflows, tuff, conglomerate, glacial outwash and till.
								- unconformity -
	Tertiary	Middle or late Tertiary						olivine basalt, minor andesite. - conformable contact - lithic arenite, conglomerate, minor shale
								- angular unconformity -
		Eocene Oligocene or younger						tuff, felsite, andesite, basalt, minor coal.
								- conformable contact -
		Eocene-Oligocene			French Bar Formation			conglomerate, volcanic arenite, minor siltstone, plant seams.
								- unconformity -
Cenozoic or Mesozoic		Pre-Oligocene post early Lower Cretaceous				Ward Creek assemblage		andesite, dacite, felsite, tuff, minor basalt, volcanic arenite, coal.
								- not in contact -

Succession	System	Series	Stage	Group	Formation or Division	Assemblage	Member	Lithology and Contacts
Cenozoic or Mesozoic	Lower Cretaceous or younger							gabbro and diabase dykes
								- not in contact -
Mesozoic	Cretaceous	Lower Cretaceous	Albian? or	Spences Bridge Group ? or Kingsvale Grp. ?		Fountain Valley assemblage	C	andesite, minor volcanic arenite, volcanic breccia, plant seams
							B	felsite
							A	andesite, felsite, minor conglomerate.
								- not in contact -
			Aptian?	Spences Bridge Grp. lower Div. or Kingsvale Grp. Div. B.		Glen Fraser assem.		andesite, dacite.
								- contact not exposed -
			Albian?	Kingsvale Grp.	Div.B			andesite, dacite, minor tuff, volcanic arenite.
								- conformable contact -
					Div. A			volcanic arenite, conglomerate, minor siltstone, plant seams.
								- unconformity -

Succession	System	Series	Stage	Group	Formation or Division	Assemblage	Member	Lithology and Contacts
Mesozoic	Cretaeous	Lower Cretaeous	Aptian?	Spences Bridge Group	Upper Division			andesite, minor dacite, volcanic arenite, siltstone.
								- not in contact -
					Lower Division	Gibbs Creek assemblage	C	andesite, minor dacite, volcanic arenite, siltstone.
							B	andesite, felsite, volcanic arenite, siltstone, conglomerate, argillite, tuff, agglomerate.
							A	andesite
								- not in contact -
					Lower Division		Basal mem.	andesite, dacite, tuff, andesitic breccia.
								- angular unconformity with Pavilion Group -

Succession	System	Series	Stage	Group	Formation or Division	Assemblage	Member	Lithology and Contacts
Mesozoic	Cretaceous	Lower Cretaceous	Barremian(?)					porphyritic quartz-diorite dykes and sills.
								- intrusive contact -
				Jackass Mtn. Grp,	Div. C			volcanic arenite, argillite, conglomerate; minor plant seams.
								- conformable contact -
					Div. B			conglomerate, volcanic arenite, minor argillite.
								- local unconformities -
					Div. A		AIII	siltstone, volcanic arenite argillite, minor limestone.
							AII	volcanic arenite, minor siltstone, argillite, conglomerate.
							AI	conglomerate, tuffaceous sandstone, volcanic arenite, minor plant seams.
								- unconformity -

Succession	System	Series	Stage	Group	Formation or Division	Assemblage	Member	Lithology and Contacts
Mesozoic	Cretaceous	Lower Cretaceous	Neocomian?	Lillooet Grp.?	Div. C			volcanic arenite (tuffaceous), conglomerate, siltstone, argillite.
								- fault contact with Division B, angular unconformity? -
								porphyritic quartz-diorite dykes and sills and a small quartz-diorite pluton.
								- intrusive contact -
				Lillooet Grp.	Div. B			volcanic arenite, siltstone, argillite, conglomerate.
								- gradational contact -
					Div. A			argillite, siltstone, volcanic arenite, minor coal.
								- not in contact -

Succession	System	Series	Stage	Group	Formation or Division	Assemblage	Member	Lithology and Contacts
Mesozoic	Lower Cretaceous or older							quartz-diorite, diorite, granodiorite stocks and porphyritic dykes and sills.
								- intrusive contact with Pavilion group -
	Triassic (?)	Upper Triassic (?)						serpentinized peridotite and carbonate - silica alteration.
								- intrusive contact with Pavilion group -
				Pavilion Grp.	Div.II	Pavilion assem.		tuff, volcanic arenite and greywacke, volcanic flows, argillite, chert, limestone; minor breccia, siltstone, amphibolite, hornfels, meta-quartzite.
								- not in contact -
						Big Bar assem.		tuff, lithic sandstone, argillite, chert, volcanic flows.
								- gradational contact -
Mesozoic and/or Paleozoic	Triassic and/or Upper Permian			Pavilion Grp.	Div.I			chert, argillite, minor tuff, limestone, volcanic flows.
								- gradational contact -

Succession	System	Series	Stage	Group	Formation or Division	Assemblage	Member	Lithology and Contacts
Paleozoic	Permian	Upper Permian		Cache Creek Group	Marble Canyon Formation	Southern Bowman Range	IV	chert, argillite, limestone, tuff, volcanic flows.
							III	limestone
		Upper Permian and/or Middle Permian					II	chert, argillite, limestone, tuff, volcanic flows.
							I	limestone with interbedded ribbon chert.
								- conformable contact -
		Middle Permian and/or Older		"	Mt. Soues Div.			chert, argillite, tuff, volcanic flows, limestone.

1. SEDIMENTARY AND VOLCANIC ROCKS

CACHE CREEK GROUP

Introduction

The Cache Creek group was first described by Selwyn, in 1872, who divided it into a lower and an upper part. The lower part, studied in outcrops along the Cariboo Highway between Martel and Clinton, was said to contain limestone, black shale, rocks rich in epidote and chlorite associated with talc and serpentine, diorite, and felsitic porphyries. Brachiopods from this unit indicated an age somewhere between the oldest Devonian and the youngest Permian. The upper part, investigated between Clinton and Pavilion, was found to contain limestone, marble, dolomite, chloritic and epidotic rocks, and black shales. Foraminifera from the Marble Canyon limestone were misidentified by W.J. Dawson as Loftusia and considered to be Eocene or Cretaceous in age.

G.M. Dawson's report on the Kamloops area (1895) contains the first comprehensive description of the Cache Creek "formation" of the type area. Dawson described the distribution of major lithological units as follows: the Marble Canyon limestones, shown as a separate map unit, form a northwesterly trending belt, that extends from the Cornwall Hills to the northwestern extremity of the map area but is concealed by Tertiary rocks in the vicinity of Hat Creek. Immediately to

the east of the limestone, in the area of Cattle Valley, McLean Lake, and Medicine Creek, volcanic rocks associated with limestone are dominant. Farther east, on Bonaparte River and Thompson River, cherty quartzites and argillites are most abundant. To the west of the limestone belt, in the Edge Hills, in the western part of the Pavilion Mountains, and on Mount Martley, chert and argillite are dominant; farther west, on Pavilion Creek and Leon Creek, most of the rocks are volcanic. Dawson, as did Selwyn, considered the Marble Canyon limestones to be the upper part of the formation but stressed their stratigraphic continuity with the underlying rocks.

As the limestone belt is flanked to the east and west by "older" rocks he thought that the regional structure was a major syncline modified by numerous minor folds. His summary of the stratigraphy of the Cache Creek group is based on a composite section through the eastern limb of that "syncline" (1895,p.46B):

		Feet
1.	Massive limestones (Marble Canyon limestone) with some minor intercalations of volcanic rocks, argillites and cherty quartzites. At least 1000 feet seen in some single exposures. Total thickness probably at least	3000
2.	Volcanic materials and limestones, with some argillites, cherty quartzites, etc., Minimum thickness about	2000
3.	Cherty quartzites, argillites, volcanic materials and serpentines with some limestone. The thickness of these beds, or of a part of them, was roughly estimated in two places as between 4000 and 5000 feet. Minimum total thickness say	4500
		9500

Dawson retained the original identification of Loftusia but because of accompanying fusulinids referred it to the Carboniferous and defined the Cache Creek as an essentially Carboniferous formation.

As more information about the fusulinids accumulated, Dawson's age determination was revised. Dunbar (1932), Thompson and Wheeler (1942), and Wickenden (Duffell and McTaggart, 1952, p. 23) all agreed on a Permian age but disagreed on the specific position in that period.

Duffell and McTaggart called the Cache Creek a group and the Marble Canyon limestones a formation. Their report is in close agreement with Dawson's but offers two alternative hypotheses about the major structure and stratigraphic order within the group. The first is Dawson's concept that two major units are arranged in a syncline; the second that the "group consists of two successions of argillites, cherts, greenstones, minor limestones, and quartzites, separated by the thick series of the Marble Canyon limestones." (p. 17). According to the first hypothesis the Cache Creek group is approximately 10,000 feet thick, according to the second hypothesis 20,000 feet. The latter thickness is comparable, as Duffell and McTaggart have pointed out, to a section of 24,000 feet measured by Armstrong in the Fort St. James area (1949) that includes three limestone units and four separate chert successions.

In an attempt to solve the problems resulting from the earlier work the Marble Canyon Formation was studied in some detail. Fossils from the upper part of that formation are

assigned by W.R. Danner to the Upper and (?) Middle Permian. In the southern part of the Bowman Range the Marble Canyon formation is approximately 6000 feet thick and contains chert, argillite, tuff, volcanic flows, and about 2500 feet of limestone. It here forms a northwesterly trending anticlinorium that is overturned to the northeast. In the core of the anticlinorium, on the south slope of Mount Soues an older unit, about 1500 feet thick containing little limestone is exposed which is here called Mount Soues Division. The rocks to the west of Bowman Range and Pavilion Mountains appear to overlie the Marble Canyon formation conformably. A fossil found in these rocks is probably of Triassic age. As the Cache Creek group has been defined as a Permo-Pennsylvanian unit (Armstrong, 1949, p. 50) the Permo-Triassic rocks overlying the Marble Canyon formation are assigned to a new unit, the Pavilion group.

MOUNT SOUES DIVISION

On the southeast slope of Mount Soues ribbon chert, argillite, volcanic flow-rocks mostly of basic composition, tuff, and limestone are exposed. The assemblage differs from rocks of the Pavilion group in two respects: the presence of limestones that are interlaminated with ribbon chert, and the relative abundance of basic volcanic flows. The outcrop zone is about two miles wide and pinches out to the northwest. The thickness of the unit which is overlain conformably by the Marble Canyon formation is estimated as approximately 1500 feet. The rocks are folded and faulted and seem to occupy the core of an

anticlinorium formed by the basal member of the Marble Canyon formation. As the Marble Canyon Formation is Middle (?) and Upper Permian the Mount Soues Division probably is Middle Permian and/or older.

MARBLE CANYON FORMATION

1. Distribution

In the present map area the Marble Canyon formation underlies the Bowman Range and the central part of the Pavilion Mountains. In the Bowman Range where the formation has been mapped in its full width it occupies a belt approximately 8 miles wide.

2. Lithology and Thickness

Because of facies changes, complications by faulting and folding, and the scarcity of marker beds, bedding attitudes, and stratigraphic top determinations it has been almost impossible to work out the structure and stratigraphy of the Marble Canyon formation. An attempt to establish a stratigraphic sequence could be made only in the southern part of the Bowman Range. Four members I, II, III, IV are distinguished here, and a fifth IIIa is recognized in the central and northern parts of the area. The stratigraphy described on the following pages is valid only for the southern part of the Bowman Range; it is impossible, for example, to recognize the same members in the Marble Canyon.

Member I, approximately 200 to 300 feet thick is composed of limestone and ribbon chert. The limestone is partly massive, and partly interlaminated with ribbon chert. Laminae of chert are one to three inches thick. Most of the laminae are extensive but at some localities they form short units one to several feet long. The limestone seems to be continuous over most of the area, but in the vicinity of Fifty-Seven Creek it apparently forms discontinuous lenses that interfinger with chert. No fossils were found in the unit.

Member II, which overlies I is poorly exposed. It comprises chert, argillite, tuff, small lenses and beds of limestone, and volcanic flow rocks. Although the member appears to be 3200 feet thick it probably has been repeated by folding, and the true thickness perhaps lies between 500 and 1000 feet.

Member III, is composed mainly of limestone but locally contains small amounts of interbedded chert and argillite. The member forms a high ridge, about 13 miles long, that culminates in Mount Bowman (Plate V). South of Porcupine Creek the limestone is approximately 1000 feet thick; south of Two-Mile Creek it tapers and finally disappears. North of Porcupine Creek the structure probably is complicated by faulting and folding and neither the full strike-length nor the stratigraphic thickness of the limestone mass are certain. The limestone masses on Mount Kerr (about 2500 to 3000 feet thick) are perhaps in the same stratigraphic position as the ones on Mount Bowman but the two are not connected by outcrop; possibly these bodies are

lenticular. Most of the limestone is pure and massive and shows no bedding. In some localities, however, alternating light grey and dark grey layers are visible that are from a few millimeters to one centimeter thick. Under the microscope the layers are seen to differ in grain size and in the proportion of minute inclusions in the carbonate. Some of the rocks are calcarenites and show graded bedding, ripple marks, and intraformational breccias. (Plate VI). Breccias made up of fragments that range from a few millimeters to one inch in size locally occur within the massive limestone. In the northern part of the map area some rocks that may be correlative with member III contain oolites. Fossils are relatively rare; remains of colonial corals, of crinoids, echinoids, algae, and fusulinids have been found at a few localities.

In the syncline on Mount Kerr the thick massive limestone of member III is overlain by a bed of limestone, approximately 500 feet thick, that contains laminae of chert. A sheet of interlaminated limestone and chert forms the crest of the Bowman Range between Mann Creek and Jesmond Creek. Scattered outcrops of a similar type occur between Jesmond Creek and the northern extremity of the Bowman Range. These rocks are tentatively referred to <u>member IIIa</u>, but it is not certain whether all of them are in the same stratigraphic position.

> A thin-section of chert from this unit consists of anhedral quartz grains showing undulose extinction that range from a few microns to .2 mm in diameter. Some spherical aggregates with a diameter of .08 mm and a few spine-like structures about .4 mm long and .05 mm wide composed of very fine-grained silica are visible; they are probably of radiolarian origin.

> A hand specimen of limy chert consists of fine blue grey stringers, that are one to two centimeters long and a few millimeters thick, embedded in a light grey groundmass. The stringers are crenulated and fractured. Under the microscope they are seen to consist of fine-grained silica, dominantly quartz with undulose extinction, and small amounts of chalcedony. The light grey matrix comprises about 50% carbonate grains part of which, showing rhombohedral habit, are probably dolomite, and 50% quartz and chalcedony. Silica and carbonate are uniformly distributed. A spherical structure, about .2 mm in diameter is made up of fine-grained silica in the center and relatively coarse-grained quartz with undulose extinction at the periphery.

Member IV consists of argillite, chert, limestone, tuff, tuffaceous sandstone, and volcanic flow rocks, but only the limestones are well exposed. The latter occur in lenses and beds ranging from a few hundred feet to 8 miles in strike length. Some are of fairly constant thickness, others vary considerably in thickness along strike. A mass on Pavilion Mountain, for example, that is about 2 miles long, ranges from 200 feet to about 2000 feet in thickness. Most of the limestones do not show bedding. In a few localities oolites were noticed, and in others fusulinids, algae, corals, pelecypods, and echinoderms (?). In the vicinity of intrusions the limestone has recrystallized to a fine-grained marble which locally shows a foliation in the form of fine dark layers rich in carbonaceous matter. The thickness of this member is uncertain because its structure could not be worked out. On the west side of the Bowman Range it occupies a belt one mile to 1-1/2 miles wide. The thickness of the unit is perhaps between 3000 and 6000 feet.

The succession in the Marble Canyon formation in the south-western part of the Bowman Range may be summarized as follows:

Member	IV	3000-6000 feet.	Chert, argillite, limestone, tuff, volcanic flows.
"	III	1000 "	Limestone
"	II	500-1000 "	Chert, argillite, limestone, tuff, volcanic flows.
"	I	200- 300 "	Limestone with interbedded ribbon chert.
		4700-8300 feet.	

The Marble Canyon formation in this area then is approximately 6000 feet thick and contains perhaps 2500 feet of limestone. As the limestone forms conspicuous cliffs and the other rocks are mostly concealed by overburden the proportion of limestone in the formation has been overestimated by previous workers.

3. Structure

Because of facies changes, lack of marker beds, and the scarcity of bedding attitudes and stratigraphic top determinations (related to the reefal character of the limestones) the whole structural picture has not been worked out. Some success, however, was achieved in the southern part of the Bowman Range, and the information obtained in this area may be sufficient to establish the age relation of the Marble Canyon formation to the Pavilion group.

The following three criteria have been used for the recognition of folds:

The most important criterion are bedding attitudes. However, systematic changes in strike and dip could not be observed in all of the postulated folds.

A V-shaped or U-shaped limestone outcrop visible on air photographs is suggestive of the nose of a plunging fold because the limestones in most localities form conspicuous outcrops whereas the other rock types, which are less resistant to weathering, are mostly covered by overburden. However, this criterion alone, is not used to establish a fold because the same outcrop situation could be produced by the differential weathering of a solid mass of limestone or by facies changes.

The third criterion is faulting in the crestal areas of anticlines or in the troughs of synclines. Apparently the folding was accomplished by very little flowage and much fracturing of the strata. In the extreme case a box-type of fold is produced with steeply dipping limbs, a flat lying crest, and faults between the crest and the limbs. (Plate IX) However, in most localities the crests or troughs are characterized by irregular contortions.

In the southern part of the Bowman Range Member I appears to form a northwesterly plunging anticlinorium which is overturned to the northeast and is composed of at least five anticlines and the corresponding synclines. (Cross-section F-F'). (Plate VII) A few faults, modifying the anticlinorium are shown on the map; others are probably concealed by overburden.

The only fold recognized with assurance in the central part of the Bowman Range is an upright, broad, open syncline on

Mount Kerr, which plunges to the southeast and fits between two northwesterly plunging anticlines outlined by Member I. (Plate VIII) A change in the direction of dips and strong distortions are well displayed in the central part of the syncline which is formed by the interlaminated limestone and chert of Member IIIa.

In the northern part of the Bowman Range the dips of the strata are mostly moderate to low; their directions are uniform within small areas but change abruptly from one area to another. No folds could be outlined. A few faults are shown on the map. It is believed that many others are hidden by overburden. It seems that the strata here are broken into numerous fault blocks tilted into various directions. The dominance of faulting over folding in the northern part of the map area probably is due to the great thickness of the strata, to their lenticular (?) shape and to low heat and pressure during the time of deformation.

4. Mode of Origin

The absence of coarse-grained clastic rocks and the dominance of biological, chemical, or fine-grained clastic material suggests that the source area was of low relief or at a great distance from the basin of deposition.

Three types of limestone can be distinguished. The first type is interlaminated with ribbon chert (member I and IIIa). These deposits are moderately thick, ranging from 200 to 500 feet in thickness and may cover as much as 100 square miles. As they are associated with chert that is possibly of

radiolarian origin, an analogous origin is suggested for the limestone: it may have formed by the accumulation of free floating calcareous organisms, possibly foraminifera. However, no fossils have been found in these rocks. Perhaps the sediments were deposited very slowly and subjected to solution and recrystallization on the sea floor. The alternative is inorganic precipitation, but it is uncertain whether the conditions for such a process existed.

The second type of limestone deposit is extremely thick (up to 2500 feet) but probably narrow. Corals, algae, bryozoa and echinoids (together with fusulinids) have been found in these rocks. The fossils and the shapes of the deposits suggest that they are reefs. However, Lowenstam (1950) argues that not any mass of fossiliferous limestone showing reef like dimensions should be called a reef and requires evidence that sediment binding organisms were present which were able to erect wave resistant structures. Certain colonial corals such as Waagenophyllum (?) which are locally fairly abundant may have been reef builders of the type required. The thick limestone masses in the vicinity of Mount Kerr are believed to be reefs.

A third type, occurring in the members II and IV is lenticular or pod-like and ranges from one hundred feet to several miles in strike length. Many of these bodies have dimensions similar to those of reefs but most of them are lacking in fossils. Perhaps some were reefs composed of algal structures that are no longer recognizable. The origin of these deposits is uncertain.

Calcarenites and breccias in the members III and IIIa indicate local current activity. Some of the beds containing oolites may have been deposited at shallow depth in the zone of wave action (Illing, 1954, pp. 35-44).

The origin of the ribbon chert is a controversial subject. According to modern experimental work (Krauskopf, 1956) both fresh-water and sea-water are highly undersaturated with respect to silica and neither changes in p.H. (below a p.H. of 9) nor in salinity appreciably affect the solubility of that substance. Only three of the various hypotheses for the origin of chert seem reasonable in view of the required chemical conditions established by Krauskopf: the deposition of colloidal silica from siliceous solutions that may be related to volcanism (Davis, 1918; Cairnes, 1924b, p. 41); the leaching and redeposition of silica from vitric tuff, a material that dissolves much faster than mineralic matter (Goldstein and Hendricks, 1953) and the accumulation of debris from siliceous organisms (Bramlette, 1946). Both volcanic flows, and tuffs are present in the Marble Canyon formation. There is however, no striking association of chert and volcanic flows and the relatively small proportion of tuff appears insufficient as source of the much larger volume of chert. However, thin-sections of chert show spine-like and nodular structures that could be of organic origin. Better preserved specimens of the same type have been found in greater quantity in the cherts of Division I of the Pavilion group. Therefore it is believed that the chert of the Marble Canyon Formation is largely of organic origin.

5. Age and Correlation

Fossils collected at 11 localities in the Bowman Range (see Geological Map) were identified by W.R.Danner:

F1 Locality: On ridge, about 1 mile east of Jesmond road, 1.25 miles northwest of Porcupine Creek, upper part.

Member IV

Yabeina sp.

Schwagerina sp.

Verbeekina sp.

Glomospira sp.

Gyroporella sp.

associated: algae, coral, small fusulinids

Age: Upper Permian.

F2 Locality: On ridge, about 1 mile east of Jesmond road, 2 miles southeast of Mt. Bowman.

Member III

Yabeina sp.

one small *Verbeekina* type fusulinid foraminifera, one similar to *Pachyploia*

Tetrataxis sp.

Gyroporella sp.

associated: echinoid debris, mollusc shells, and a coral.

Age: Upper Permian. The assemblage could be slightly older than those from the other localities.

F3 Locality: On ridge about 2 miles east of Jesmond road, 2 miles northeast of head of Porcupine Creek

Member: III

Yabeina minuta

Schwagerina acris

Condonofusinella sp.

Textularia sp.

Age: Upper Permian.

F4 Locality: Two miles southeast of Mt. Kerr, .7 miles northwest of Fifty-seven Creek.

Member III

Yabeina columbiana

?Neoschwagerina sp.

?Verbeekina sp.

Associated: other foraminifera (?), corals, algae, coarse plates of echninoderms, crinoid stems, a bryozoan fragment, and oolites.

Age: Upper Permian.

F5 Locality: 1.5 miles west of Mt. Kerr

Member III

Yabeina minuta

Schwagerina acris

Condonofusinella sp.

Age: Upper Permian.

F6 Locality: 3.2 miles east of Mt. Bowman, .2 miles north of Mann Creek

Member III?

Yabeina sp.

Condonofusinella sp.

Glomospira sp.

Age: Upper Permian

F7 Locality: 3.5 miles east-northeast of Mt. Bowman, .5 miles north of Mann Creek.

Member III?

?Waagenophyllum sp.

Associated: at least two Permian type fusulinids.

Age: Permian.

F8 Locality: 2 miles east of Mt. Bowman, .5 miles southwest of head of Mann Creek

Member III?

Yabeina sp.

Age: Upper Permian

F9 Locality: about 5 miles east of Jesmond, 1 mile northeast of head of Jesmond Creek

Member III?

Two bryozoan fragments, corals (?), primitive fusulinids (?) algal remains (?), oolites.

Age: unknown but probably Upper Paleozoic.

F10 Locality: About 1/2 mile north northwest of F9

Member III?

Corals, foraminifera, echinoid stems.

Age: unknown.

F11 Locality: Eastern bank of Big Bar Creek, about 2.5 miles northwest of Jesmond.

Member IV

Fusulinids, pelecypods, coral, algae or echinoderms.

Age: Permian.

W.R.Danner states that most of the collections contain fusulinids common to the American and Asiatic Tethys sea. "The association of Yabeina-Schwagerina-Condonofusinella is typical as far as is known for the uppermost fusulinid zone in North America and is considered to be Upper Permian". According to Danner collection #2 might be slightly older than the others but the fusulinids are too recrystallized to establish whether they are Neoschwagerina and hence a zone lower in the Upper Middle Permian.

All fossils were collected in the members III and IV or in rocks that are believed to be correlative with these members. Both members therefore appear to be mostly Upper Permian; but the lower part of III may be Upper Middle Permian. The members I and II are perhaps Middle Permian.

PAVILION GROUP

Introduction

The Permo-Triassic Pavilion group is composed of chert, argillite, volcanic flow-rocks and tuff, volcanic sandstones, limestone, siltstone, conglomerate, sedimentary breccia and the metamorphic equivalents of these rocks. Two Divisions are distinguished. Chert and argillite are dominant in the lower part (Division I) and volcanic rocks and sandstones in the upper part (Division II). The top of the Upper Permian Marble Canyon limestone marks the boundary of the Pavilion group with the Permo-Pennsylvanian Cache Creek group. The rocks now assigned to the Pavilion group were formerly included with the Cache Creek group.

DIVISION I

1. Distribution and Thickness

Division I extends from the southeastern to the northern extremity of the map-area. On Big Bar Creek, where the Division is continuously exposed and its boundaries with the underlying and overlying formations are well exposed, it forms a zone about 5-1/2 miles wide. Its thickness may be anywhere between 1000 and 5000 feet and is possibly in the vicinity of 3000 feet.

2. Lithology

Division I consists dominantly of chert and argillite

and their metamorphic equivalents and some limestone, tuff, and lithic sandstone. Volcanic flows are rare or absent.

Large bodies of tuff and limestone, locally accompanied by lithic sandstone, are found only in the vicinity of the Fraser River between Kelly and Butcher Creeks. They probably belong in the upper part of Division I. Small masses of tuff, limestone, and rarely lithic sandstone occur at various localities and probably occupy different stratigraphic positions.

The chert varies from light grey to bluish black in color. It mostly occurs as "ribbon chert", that is in layers which are in the order of one to three inches thick and are separated by thin sheets of argillite or phyllite. The chert layers have a characteristic swelling and pinching cross-section. Cherty argillites or cherts that contain a high proportion of argillaceous material are mostly massive.

Light grey chert is composed dominantly of quartz, and to a small proportion of chalcedony and "clay", that is clay-sized minerals of the chlorite-epidote-and mica-groups. Dark chert contains small amounts of carbonaceous matter. The quartz is present in anhedral grains which range from a few to approximately 30 microns in diameter and show undulose extinction. The quartz either forms a structureless mosaic or nodules. These nodules are coarser grained than the "mosaic" and have a higher content of chalcedony and a lower content of "clay". The nodules are spherical or elliptical in section and range from .03 to .3 mm in diameter; the average diameter probably lies between .15 and .2 mm. A few nodules

show a radiating pattern around the margin; one has a spine-like projection (Plate X, XI). They bear a close resemblance to radiolarian cherts in well preserved specimens of California (Jenkins, 1943, pp. 315, 319). Chert of this type was seen in 13 out of 18 thin-sections of specimens from various localities. Most sections contain numerous minute veinlets of quartz and carbonate. Carbonate also occurs in isolated grains within the chert.

The argillite is bluish black and laminated to massive. Under the microscope minute crystals of mica, chlorite, carbonate, and particles of carbonaceous matter are seen to be embedded in a groundmass of low birefringence that is too fine-grained for identification. The organic matter is dispersed throughout the argillite but in phyllitic specimens it is concentrated in parallel layers. Some of the argillite contains massive or nodular aggregates of fine-grained silica and grades into chert. Most of the argillite has a silt-fraction, composed largely of feldspar fragments.

The tuffs do not form beds but lenticular masses which in most localities are associated with limestone.

> A hand specimen of a little altered tuffaceous rock is brownish green and composed of angular or lenticular fragments ranging from a fraction of a millimeter to about 3 mm in diameter. The section consists dominantly of fine-grained highly altered grains of volcanic rocks some of which are vesicular or amygdaloidal, a smaller proportion of chlorite, which may represent altered volcanic glass, and a few percent of quartz, feldspar, hornblende, clino-pyroxene, and "iron ore". The tuffaceous origin of the rock is apparent from two features: the clino-pyroxene, a

mineral which has not been observed by the writer as a detrital mineral in any sedimentary rock of the map-area, shows subhedral to euhedral forms; and the quartz has inclusions and rims of extremely fine-grained volcanic rock, probably rhyolite or dacite. As the tuff was deposited in water it may have incorporated some detrital material.

A specimen from the slope north of the upper part of Siwash Creek probably represents a sheared and altered limy tuff. The hand specimen is bluish green and contains light to dark colored, rather angular fragments in a light green groundmass. The fragments range from one centimeter to about one millimeter in size. The thin section shows fragments of volcanic rocks embedded in an abundant matrix of chlorite and carbonate. The fragments are porphyritic and vitrophyric and mostly amygdaloidal. They show lath-like microlites and broad prisms of plagioclase in a groundmass that is altered to chlorite and very fine-grained deep brown carbonate. The carbonate of the cement is strongly twinned, in some places in a feathery fashion. The chlorite of the groundmass occurs in narrow stringers and large patches made up of radiating sheaves or felted masses.

The limestones of Division I form pods and lenses. Short beds were observed in only a few localities. The largest of the lenticular masses is located on the slope north of the upper part of Siwash Creek and has been mapped as a separate unit. Except for gastropods, no fossils have been found in these limestones. Some of the limestones contain oolites and pisolites that range from a fraction of a millimeter to several millimeters in diameter. Most of them are ellipsoidal; less commonly they are spherical or spindle-shaped. The oolites are made up of concentric layers of very fine-grained carbonate. Radial structures are rarely developed. The centre of the oolites is occupied by coarse-grained calcite, in some specimens by a single crystal or, less commonly, by chlorite and chert nodules (Plate XII).

Most of the limestones are associated with tuffs, and near the contacts the two rocks are mixed. Some of the limestone near the contacts contains greenish or brownish weathering stringers of chlorite which in some specimens are associated with chalcedony. Angular fragments of limestone or irregular blebs with rounded outlines are incorporated in the tuff. The size of these inclusions ranges from tens of feet to a fraction of a centimeter.

The lithic sandstones occur with tuff, argillite, and chert. At some localities they show graded bedding and are similar in appearance to those of Division II.

3. Metamorphism

Where rocks of Division I are in contact with Coast Intrusions they are highly metamorphosed. Most of the metamorphism is related to the pluton between Kelly Creek and Leon Creek and the best exposures are on both banks of the Fraser River near the mouth of Kelly Creek where a migmatite complex consisting of dioritic dykes, amphibolites and banded hornfelses has been mapped as a separate unit. It is not certain, however, if all of the rocks belong to Division I; some of the rocks on the west shore may be part of Division II.

Near the mouth of Kelly Creek, a facies of Division I rich in tuffaceous rocks has been intruded by dioritic dykes. The contact between the dykes and the host rock is generally gradational and the host rock is cut by numerous lenses and veinlike stringers rich in quartz and feldspar. (Plate XIII)

> A typical specimen of the transition rock, a blue-grey, fine-grained, massive amphibolite is cut by fine greyish white quartz-feldspar veinlets that are from one to a few millimeters wide. A thin-section from this rock contains approximately 75% of hornblende (grain size approximately .05-.5 mm) associated with "iron ore" and a trace of biotite, and 25% of finer grained (.005-.25 mm) quartz and feldspar. The plagioclase, calcic andesine, is partly anhedral, partly subhedral, and mostly twinned. A large proportion of the feldspar is water-clear.

A part of the rocks on the western bank of the Fraser River in the same area are finely layered amphibolites and hornfelses. The rocks belong in the hornblende-hornfels facies (Fyfe, Turner and Verhoogen, 1958, p. 209), and may originally have been phyllites or strongly jointed argillites.

> A specimen of these foliated rocks is composed of light grey and black layers ranging from one millimeter to 1.5 centimeter in thickness that show fine crenulations. The dark layers consist mainly of subhedral hornblende crystals, about .1 mm long that are strongly pleochroic (z: bluish green; y: green, x: pale brownish green). The light colored layers are made up of cloudy, partly twinned calcic oligoclase with a grain size of approximately .05 mm, and a little quartz. Hornblende and plagioclase are present in approximately equal proportions.

A grey, massive, very fine-grained specimen showing some medium-sized grains of feldspar is characteristic of another large group of rocks on the west side of the Fraser River, opposite the mouth of Kelly Creek. The original nature of the rock, which now belongs in the epidote-albite hornfels facies, is uncertain; perhaps it was an acidic volcanic flow.

> It consists of approximately 50% of feldspar, 42% of quartz, 5% of epidote, 2% of chlorite, 1% of carbonate and traces of sphene and "iron ore". The groundmass is a tightly interlocked aggregate of anhedral quartz, and subhedral to anhedral feldspar, both ranging approximately from .05 to .5 mm in size, that is cut by stringers of epidote, chlorite, and carbonate. The feldspar consists mostly of twinned sodic albite; potassic feldspar is rare or absent. The albite of the groundmass is cloudy with inclusions of epidote; the larger crystals, forming anhedral, twinned grains up to 1.5 mm long contain inclusions of quartz, but not of epidote. The fine-grained cloudy feldspar of the groundmass and some of the quartz are thought to be original constituents of the rocks; the inclusion-free plagioclase, and some of the quartz may have been introduced.

4. Structure

The contact between Division I and the Marble Canyon formation is exposed only in the vicinity of Sallus Creek and Keatley Creek, north of Pavilion Lake, and on Big Bar Creek. In these localities neither an unconformity nor a major fault was observed although the contacts between limestone beds and argillite are locally sheared. The contact is gradational and the proportion of interbedded limestone increases in an eastward direction. As Division I is in contact with the uppermost part of the Marble Canyon formation one might conclude that it overlies the limestones. However the westward transition from limestone to chert and argillite could represent a facies change in isoclinally folded strata, and in this case Division I would be partly contemporaneous with the upper Marble Canyon Formation.

In most localities the strata of Division I strike northwesterly and dip steeply. Marker beds are scarce and stratigraphic tops could be determined only at a few localities. Judging from the well stratified and plastic nature of the rocks they are tightly folded; the pattern of folding may be similar to that of the younger Lillooet group, which has a comparable lithology. Dragfolds are developed only in the vicinity of faults and are here of very varied plunge. In some localities the limestones show a lineation in the form of grooves, but the plunges of these lineations are also irregular. Division I is partly bounded by faults (see page 57) but no extensive internal faults were recognized. However, there are broad areas underlain by sheared rocks that are crossed by numerous minor irregular faults. The most extensive of these shear zones is exposed between Moran and Kelly Creek. Other shear zones of this type were seen on the slope north of Gibbs Creek, in High Bar Canyon, and on the slopes above Big Bar Creek, near the mouth of Stable Creek. In addition to these large zones shown on the map there are numerous small ones that have not been indicated. Almost all contacts between massive rocks, such as limestone, tuff or lithic sandstone on the one hand, and laminated argillite and chert on the other hand are sheared. Some of the distortions may have been caused by differential movements of sedimentary strata during folding, others seem to be related to movements of Coast Intrusions.

5. Mode of Origin

Remnants of radiolarian skeletons in the chert suggest that Division I was laid down in a marine environment. The presence of carbonaceous matter indicates a "restricted" environment (Krumbein and Garrels, 1952). The scarcity of coarse-grained clastic sediments and the dominance of fine-grained clastic and bioclastic sediments indicates that the source area was of low relief or at a great distance from the site of deposition. There was little volcanic activity in the area. The environment of Division I appears similar to that of the Marble Canyon formation, except that conditions for the growth of reefs were rare or lacking. If Division I is partly contemporaneous with the Marble Canyon formation it probably was deposited seaward from the reef zone.

The origin of the chert, tuff, and limestone, pose special problems.

Microscopic examination shows that the cherts are composed of a considerable proportion of nodules that resemble the radiolarian remains of relatively well preserved (Compare Jenkins, 1943, pp. 315, 319) rocks. A few of these nodules show radiating spine-like structures around the margins that are strongly suggestive of an organic origin. Because of the microscopic evidence and the scarcity of volcanic centers in the area it is believed that the chert is of organic origin. The alternations of chert and argillite may be due to seasonal changes that governed the life of the siliceous organisms or

the deposition of the associated inorganic matter.

The lenticular shape of the tuff bodies and features of brecciation near their margins indicate that the tuffs were deposited by currents, perhaps density currents that originated when the tuffaceous material entered the water.

The origin of the limestone in Division I is a difficult problem.

The big, pod-like mass north of Siwash Creek is reef-like in shape, but no fossils have been found in it. Regarding the smaller bodies two consistent features may be of genetic significance: the association of the limestone with tuffs, and the signs of current activity such as oolites and certain features of brecciation. These relations could be explained in different ways. The limestones may be inorganic and their precipitation could have been caused by the currents that carried the tuffaceous matter. The solubility of calcium carbonate in sea water (Revelle, 1934) depends on the carbon dioxide content of the water, on its temperature, pressure and pH. The currents descending from the surface may have warmed up the bottom waters and thus caused the precipitation of some calcium carbonate. However, the amount of limestone produced by such a process would be relatively small. It is also possible that the currents collected unconsolidated limy material from the sea bottom and swept it along together with the tuffaceous material. A third possibility is that the deposition of both tuff and limestone was controlled by depressions on the sea floor. The limestone may have been de-

posited in such depressions owing to biological or physico-chemical conditions and the density currents may have dropped their load here because of dynamic factors.

6. Age

The structural relations show that Division I is either contemporaneous with the upper part of the Marble Canyon formation or younger. It is overlain by Division II which is probably Triassic. Therefore it is Upper Permian and/or Triassic in age.

DIVISION II

1. Distribution and Thickness

Rocks assigned to Division II underlie two separate areas. They have been correlated because of their similar lithology but they may not be exactly of the same age.

The outcrops of the Big Bar assemblage form a zone about 3 miles long and up to 1-1/2 miles wide in the vicinity of the lower part of Big Bar Creek. Their thickness is of the order of 2500 feet.

The Pavilion assemblage underlies an area about 10 miles long and up to three miles wide situated mostly on the west side of the Fraser River between Sallus Creek and Moran. The unit is bounded by faults, and so little is known about its internal structure that an accurate statement of the thickness cannot be given. Several thousand feet of strata are probably present.

2. Big Bar Assemblage

A. Lithology

Because of facies changes and lack of outcrop the stratigraphy of the Big Bar assemblage has not been worked out.

A broad belt of lithic sandstone with interlaminated argillite extends from the west slope of Mount Kostering across Big Bar Creek to the south slope of Big Bar Mountain. The contacts of this belt are gradational. The rocks show graded bedding and abundant contortions that apparently were produced before the lithification of the sediments. To the east of this belt in the vicinity of Big Bar Creek, flows of andesite and dacite are exposed. The other parts of the area are underlain by tuff, ribbon chert, argillite, and limestone. The limestone occurs in beds, not exceeding half a mile in strike length, in lenses and pods associated with tuff, or in thin layers interlaminated with argillite.

A typical specimen of interlaminated argillite, siltstone, and sandstone from the west-slope of Mount Kostering weathers brownish green. Its laminae of argillite are from one centimeter to a fraction of a millimeter thick; a layer consisting mostly of sandstone and siltstone is about 3 centimeters thick. Approximately two thirds of the argillite consist of clay-sized minerals, one third of silt-sized carbonate, feldspar, and quartz, and a small fraction of carbonaceous matter. The sandstone and the siltstone are made up dominantly of carbonate, feldspar, and quartz, and a smaller proportion of clay. The specimen shows graded bedding and some cross-bedding.

A graded unit ranges from very fine-grained sandstone at the bottom through siltstone to argillite. The contact between two graded units is marked by a concentration of carbonaceous matter and flutings in the argillite, and by an abrupt change in grain-size.

The volcanic flow rocks weather greenish grey and are mostly porphyritic. Two specimens of altered andesite consist dominantly of albite which forms microlites and phenocrysts, and a smaller proportion of epidote, (largely pistacite), chlorite, and carbonate; one specimen shows replacement by prehnite. The lack of zoning, the albitic composition, and the abundance of epidote, indicates that the plagioclase has been altered.

> In a thin-section of meta-dacite, phenocrysts of calcic albite are embedded in a fine-grained groundmass consisting largely of albite and quartz. The plagioclase has relatively few inclusions. The partly jagged outlines of the crystals and undulose extinction indicate recrystallization. The rock is veined by quartz and epidote.

B. Structure

The southwestern contact of the Big Bar assemblage, exposed near the road to the High Bar ferry probably is faulted. The rocks are strongly sheared, and the transition from tuff to chert and argillite is abrupt. The northeastern contact is gradational. No major fault is visible here, but the contacts between masses of tuff and chert and argillite are locally sheared and altered. In the southeast the unit tapers and forms a nose. The northwestern contact is not exposed. The

strata strike approximately N 40° W and dip moderately to steeply northeast. At many different localities in the southwestern half of the unit the stratigraphic tops were found to face the northeast. At three localities in the northeastern half they were seen to face the southwest. It appears that the strata form a syncline which is overturned to the southwest and probably plunges to the northwest. In the central part of the unit on the slope north of Big Bar Creek gently dipping strata were seen that appeared to lie upside down. It is uncertain whether these anomalous attitudes were produced by disturbances before or after the lithification of the rocks. The folding of the unit probably was accompanied by much differential slippage on bedding planes which may explain the sheared and faulted contacts. A schistosity which strikes northwesterly and dips steeply to the northeast was only observed in the central parts of the Big Bar assemblage, that is near the axial plane of the inferred syncline.

3. Pavilion Assemblage

A. Lithology

Approximately two thirds of the Pavilion assemblage are made up of volcanic rocks, mostly tuffs and less flows, and about one third consists of lithic sandstone, argillite, limestone, siltstone, breccia, and conglomerate.

The tuffs are greenish weathering massive rocks which show fine, angular fragments only on fresh surfaces. Tuffs rich in lithic material can hardly be distinguished from

volcanic greywacke. The vitric fragments are altered to chlorite or finely recrystallized; shard-like outlines are rarely preserved. The crystal fraction consists mostly of twinned plagioclase and a small proportion of quartz; hornblende is rare. Some pyroclastic crystals are euhedral, others are broken; they are fresher looking and less rounded than detrital grains in the sedimentary rocks.

The volcanic rocks of the Pavilion area range from basalt to felsite. Many of them contain phenocrysts of quartz.

> A greyish green weathering aphanitic (tholeitic) basalt contains approximately 8% of quartz, 3% of endiopside (+2v moderate; n_y 1.673) which forms micro-phenocrysts, and 10% of chlorite and fine-grained alteration minerals; the balance is made up of twinned and zoned plagioclase microlites which range from calcic labradorite to sodic bytownite in composition. The rock is crossed by narrow zones of mylonite and by veins of carbonate and chlorite.
>
> A blue grey porphyritic aphanitic flow rock of felsitic composition comprises about 40% of fractured and corroded phenocrysts (grain size 2 mm - .5 mm) in an extremely fine-grained partly glassy groundmass (grain size approximately 1 - 5 microns). Most of the phenocrysts are of quartz; a smaller number consists of zoned and twinned andesine, and a few grains are of "iron ore", which probably has replaced a mafic mineral. The groundmass is too fine-grained for identification. Besides quartz and feldspar minerals of the chlorite and mica groups are abundant. The specimen includes a few fragments of relatively coarse-grained acidic flow rocks. It is veined and replaced by quartz, carbonate, and radiating chlorite.
>
> A greyish porphyritic volcanic rock which apparently has been metamorphosed has about 30% of plagioclase phenocrysts (grain size .5 mm - 3 mm) and a mosaic-like groundmass composed of anhedral quartz, plagioclase, and potassic feldspar. The phenocrysts, unzoned but twinned albite are re-

> placed around the margins by the groundmass and contain numerous inclusions of quartz, epidote, and minor feldspar. Some very fine-grained aligned inclusions of quartz resemble myrmekitic intergrowths. Quartz probably has been introduced into the rock. The specimen is veined by minerals of the epidote group, mostly pistacite.

A belt of laminated lithic sandstone with some argillite, conglomerate, breccia, and siltstone is exposed in the vicinity of the railroad between Pavilion and Moran. As the contacts of this belt are gradational and poorly exposed it could not be mapped as a separate unit. The rocks show graded bedding and contortions formed before the lithification of the sediments.

The lithic sandstone weathers brownish green and is grey on fresh surfaces. Three specimens analyzed contain approximately 10-40% of feldspar, 1% of quartz, 45-85% of lithic fragments and chlorite, and less than 1% of "iron ore" and epidote. The feldspar is mostly twinned and zoned plagioclase that has not been albitized. The lithic fragments are mostly derived from volcanic rocks (dominantly of intermediate composition) and some from chert and argillite. Some specimens show graded bedding and are well sorted but in others the sorting is poor. A comparatively unaltered rock has only a small content of clay matrix (less than 10%), and its particles are rounded or subrounded. Others are too highly altered to determine the original roundness and clay content. These rocks are classified as volcanic arenites.

A sedimentary rock transitional from coarse-grained greywacke to granule conglomerate has the following composition:

plagioclase	10%
quartz	1%
chlorite and epidote	1%
hornblende and "iron ore"	-1%
volcanic fragments	67%
limestone	20%
chert	1%

The fragments are embedded in a clay matrix which probably makes up more than 10% of the rock. Both rounding and size sorting are poor. The grain size ranges from 4 mm to .1 mm.

Associated with the lithic sandstone and conglomerate are breccias that are made up of the same components but locally contain a larger fraction of limestone, chert, and argillite. These breccias are between 2 and 20 feet thick and can be traced along strike for a few hundred feet. In most breccias the fragments do not exceed a few centimeters in diameter. However, on the ridge north of Keatley Creek, about 2 miles northeast of Glen Fraser, a section was measured that contains several very coarse breccias or conglomerates.

Thickness in Feet	Lithology
	Top of measured section
4	Lithic sandstone with granules and sand-sized grains of limestone.
3	Laminated sandstone and siltstone showing some cross-bedding.
12	Lithic sandstone with fragments of limestone up to one inch long.
3	Lithic sandstone with abundant argillaceous matrix and a smaller proportion of sand than normal.

Thickness in Feet	Lithology
24	Limy conglomerate, consisting mostly of limestone cobbles, about 4 inches in diameter, some fragments of lithic sandstone and chert, and one lens of argillite, about 6 inches long. Laminated sandstone and siltstone locally show graded bedding. The conglomerate is closely packed and the fragments are well rounded and size-sorted.
2	Covered interval.
2	Calcarenite and granule conglomerate with limy fragments in a matrix of lithic sandstone.
2	Calcarenite and granule conglomerate consisting of limestone fragments in a matrix of lithic sandstone.
1	Covered interval.
2	Lithic sandstone.
2	Fine-grained calcarenite.
8	Lithic sandstone with granules of limestone grading downward into cobble conglomerate containing dominantly fragments of limestone and minor argillite. Towards the top of the layer the sand grains become scarcer and the matrix more argillaceous.
12	Dominantly argillite mixed with marl and lithic sandstone. The upper 6 feet contain well rounded cobbles of limestone and argillite about 6 inches in diameter.
4	Lithic sandstone.
6	Granule conglomerate. One third of the fragments are of limestone and two thirds of chert. The matrix consists dominantly of limestone.
6	Lithic sandstone.
5	Covered interval.
16	Breccia consisting dominantly of limestone pebbles, approximately 1 inch in diameter, and a few fragments of argillite about 6 inches long in a matrix of lithic sandstone.

Thickness in Feet	Lithology
6	Coarse limestone breccia. Most of the limestone is blue grey, some brownish fragments may be dolomitic. Some boulders are angular others rounded. A small fraction of the fragments ranging up to 6 inches in length are composed of chert. The matrix consists of lithic sandstone.
6	Lithic sandstone with scattered granules of limestone.
6	Lithic sandstone.
6	Argillite.
1	Covered interval: fault?
32	Coarse breccia composed mostly of limestone and some chert. The size of the limestone fragments ranges from pebbles 1/2 inch in diameter to a boulder 8 feet long, 4 feet wide. Most fragments are well rounded, the larger ones mostly ellipsoidal. The matrix is lithic sandstone; the granule grade is poorly represented.
4	Lithic sandstone.
1	Fine breccia. Fragments dominantly of limestone and minor chert, argillite, and volcanic rocks are embedded in a matrix of lithic sandstone. The fragments are up to one inch in diameter and mostly well rounded.
	Fault.
18	Lithic sandstone with granule to pebble sized fragments of limestone.
1	Argillite.
48	Lithic sandstone that is mostly massive but shows bedding in the form of bluish, silty or argillaceous laminae near the contact with the overlying argillite. Contains a few ellipsoidal fragments of argillite and some limestone pebbles.
68	Covered interval.
5	Fine-grained diorite sill.

Thickness in Feet	Lithology
3	Fossiliferous limestone containing corals, gastropods, brachiopods, gastropods, and echinoids and some oolites. The limestone is intermittently exposed for about 200 feet. In some places lithic sandstone and tuffaceous material is interlaminated.
4	Ribbon chert.
	Bottom of measured section
323 feet	

Limestone, a minor component of this Division, occurs in pods or lenses that do not exceed two hundred feet in length. The greatest concentration of such bodies occurs near Pavilion Creek about 1/2 mile east of the Fraser River. At only two localities fossils were found. Crinoid stems were collected on the east side of the Fraser River about one mile south of the mouth of McKay Creek, and fragments of corals, pelecypods, gastropods and echinoids about two miles northeast of Glen Fraser (F12).

B. Metamorphism and Alteration

As the Pavilion assemblage is intruded by numerous dioritic bodies a considerable proportion of the rocks show contact metamorphism. Both the hornblende-hornfels and the albite-epidote hornfels facies are represented. Some specimens are transitional between these two groups. (See Table 1).

Most of the metamorphic rocks are dark green, fine-grained (grain-size .01 - .15 mm) massive or weakly foliated amphibolites which may have been derived from tuffs, lithic

sandstones, and basalts. In some of the specimens an original fragmental character can still be detected under the microscope, but pyroclastic rocks cannot be distinguished from sedimentary rocks. All of these rocks contain more than 40% of amphibole and most of them have 20-45% of plagioclase. In rocks of a moderate grade of metamorphism the amphibole is represented by hornblende. The mineral varies in habit from broad to slender prismatic and is strongly pleochroic (z: blue-green; y: green or greenish with a brown tint; x: pale brownish green or pale brown.) In a specimen showing retrogressive metamorphism the hornblende is partly replaced by chlorite. A low-grade metamorphic rock consists dominantly of acicular, pleochroic (z: blue-green) actinolite. The plagioclase, ranging in composition from calcic andesine to albite, is anhedral, full of inclusions of epidote and amphibole, and partly twinned. Epidote appears in appreciable quantity only in rocks of intermediate to low grade of metamorphism. Quartz forms up to 30% of some specimens. As accessories "iron ore", sphene, and apatite are present.

Some metamorphosed lithic sandstones have the same mineral associations as these amphibolites but are relatively poor in amphibole. Where lithic sandstone was interlaminated with argillite, alternations of hornblende-rich and felsic layers are visible which in some localities show boudinage structures.

Two greyish, fine-grained, massive rocks consisting dominantly of feldspar (albite in one specimen; albite and

orthoclase in the other), quartz, and small amounts of chlorite, epidote, "iron ore", and carbonate apparently have been metamorphosed under conditions of the albite-epidote hornfels facies. The porphyritic texture of one specimen and the fine-grained lath-like habit of the plagioclase in the other one indicate that they were (acidic) volcanic flow rocks.

Near intrusions the ribbon cherts have been metamorphosed to quartzite and the limestones to marble.

As the unit is bounded by major faults and broken internally by numerous minor ones, brecciation and mylonization are common in these rocks. Associated with the dynamic metamorphism is alteration by carbonate, epidote, chlorite, and quartz.

TABLE 2

Mineral-composition of some metamorphic rocks, Pavilion Group, Division II.

Spec. No.	Determination of Plagioclase	% An	% of Plagioclase	% of Quartz	% of Hornblende	% of Actinolite	% of Epidote	% of Iron Ore	Metamorphic Facies
58-M3 1	(+)2v ⊥ 010, x' ∧ 010 (maximum = 24°) nx' on (001) 1.5485	An_{44}	46	.5	49		minor	minor	Hornblende-hornfels
58 M5 4	(-)2v nx' on 001 = 1.538	An_{20}	22	28	41		minor	10	Hornblende-hornfels
58 M3	(+)2v ⊥ 010, x' ∧ 010 =14° max.	An_{8}	47	minor	50		3	minor	Hornblende-hornfels transitional to albite-epidote hornfels
57 Au-104			minor	minor	75% but partly replaced by chlorite		25	minor	Retrogressive from hornblende-hornfels to albite-epidote hornfels
58 M5-3	(+)2v ⊥ 010 x' ∧ 010=14° (Maximum?)	Albite	32	minor	?	50	10	8	Albite-epidote hornfels

C. Structure

To the west the Pavilion assemblage is inferred to be in fault contact with Lower Cretaceous volcanic rocks. The contact is nowhere exposed but is believed to be a fault because the Lower Cretaceous strata seem to dip under those of the Cache Creek group. (Plate XXIII) The rocks of the Pavilion assemblage in the vicinity of this contact are sheared, brecciated, and locally altered.

To the east the assemblage is in contact with Division I. The nature and exact location of this boundary are only partly known. The contact is well exposed only on the slope north of Pavilion Creek. Here an abrupt break from amphibolites in the southwest to ribbon chert in the northeast can be seen. The chert adjacent to the contact is strongly sheared and partly carbonatized; the amphibolite is sheared and altered in some places and apparently little disturbed in others. Between this locality and the slope above Moran the boundary of the two units is covered by overburden. It seems to cut across the regional strike of the strata in a northwesterly direction. Southeast of Moran the contact is not exposed but can be located within a few hundred feet. The appearance of the rocks on either side of the contact is the same as on Pavilion Creek. It seems to be certain therefore that between Pavilion Creek and Moran the boundary between the two Divisions is a fault. There are almost no outcrops between the railroad and the Fraser River in this vicinity. On the west side of the Fraser River, approximately two miles down-

stream from the mouth of Kelly Creek, a sharp break was noticed from hornfelsic rocks in the northeast to little metamorphosed sedimentary and tuffaceous rocks in the southwest. The contact between the two rocks is not exposed. The hornfelses near the contact appear little disturbed but the sedimentary and tuffaceous rocks are in some places schistose and carbonatized. This contact approximately lines up with the fault southeast of Moran and may be its continuation. However, it is not entirely certain whether the metamorphic rocks belong to Division I.

South of Pavilion Creek the contact is poorly exposed. Only on the ridge north of Keatley Creek can it be located with accuracy, but its nature is uncertain. The lack of a transition zone between lithic sandstone, tuff, and amphibolite in the west and chert and argillite in the east, the unusual narrowness of Division I which is here only about one mile wide and the orientation of the stratigraphic tops which face the northeast suggest a fault contact.

Because of the scarcity of marker beds, insufficient exposure, and the difficulty to determine the relative position of the stratigraphic tops in sheared and altered areas, the internal structure of Division II is little understood.

Between Pavilion and Moran the general strike of the strata is 5° - 10° west of north, and the dips are steep. A marker bed of chert shows extreme local distortions but a uniform trend over large distances. A few stratigraphic tops in the eastern part of the area face the east and at one

locality in the western part the west.

A great number of zones composed of rusty or schistose rocks are exposed between Pavilion and Moran. Most of these zones, probably faults, are parallel to the regional strike. A few of the larger ones are shown on the map.

4. Mode of Origin

Fossils indicate a marine environment, and the presence of carbonaceous matter in the argillite shows that it was of the "restricted" type in which the carbonaceous matter has not been oxidized. Graded bedding and the deposition of breccias are attributed to turbidity currents. Contortions that probably formed before the lithification of the sediments are probably due to submarine slumping. Both turbidity currents and slumping may be related to tectonic movements that were probably accompanied by volcanic activity. The presence of acidic volcanic flows suggests that some of the volcanic centers lay in the vicinity of Pavilion and Big Bar.

5. Age and Correlation

The Big Bar assemblage appears to overlie Division I conformably. As Division I overlying the uppermost Permian fusulinid zone is Upper Permian and/or Triassic, Division II may be Triassic. The Pavilion assemblage which is in fault contact with Division I has been correlated with the Big Bar assemblage lithologically. It is believed to be contemporaneous or younger.

Helen Duncan of the United States Geological Survey reports on a few corals found in the Pavilion Assemblage on the ridge north of Keatley Creek, near the contact with Division I, as follows: (F12)

> The corals in lots A8 F 1a and A8 F1H are very much recrystallized and corroded, but I am virtually positive they are hexacorals. So far as I can tell, they look like things that have been identified as Montlivaultia by Squires and in the literature. The specimens certainly are not the type of thing I should expect to find in the Permian, so I think a Triassic assignment is the best possibility on the evidence available.

The Pavilion group cannot be correlated with the Upper Triassic Nicola group of the Ashcroft map-area because no ribbon chert has been reported in that unit. As the Pavilion group is intruded by Upper Triassic (?) ultrabasic dykes it may be older than Upper Triassic. (See p. 145).

LILLOOET GROUP

1. Distribution and Thickness

The Lillooet group is exposed in the vicinity of the Fraser River between the mouth of the Bridge River and the town of Lillooet. It has been subdivided into three divisions, A, B, and C. Because of folding and faulting the true thicknesses of these units are not known. The base of division A, which appears in the centre of an anticlinorium, is not exposed. In the present map-area it is probably less than 3000 feet. Division B has a minimum thickness of 2500 feet. C does not directly overlie B but is in fault contact with that Division.

The exposed thickness of C is approximately 900 feet. The concealed part of Division C may be of considerable thickness.

2. Lithology

Division A

Division A consists mostly of argillite that is massive or interbedded with silty argillite, siltstone, and fine-grained lithic sandstone. Individual laminae range from a few millimeters to a few centimeters in thickness. Graded bedding and crenulations attributed to deformations of the sediments before their lithification are common features; cross-bedding is rare. Locally the argillite contains limy concretions.

The argillite is dark blue grey. It contains about 10% of carbonaceous matter and a few percent of silt in a clay matrix. The carbonaceous matter in many specimens is concentrated in layers a fraction of a millimeter thick along which joints are developed. The silt fraction consists of feldspar, chlorite, quartz, and carbonate.

Lithic sandstone and granule conglomerate are rare in Division A. About 2 miles south of Seton Creek on the west side of the Fraser River a few feet of volcanic arenite and a seam of coal are interbedded with the argillite. The arenite has approximately the following composition:

feldspar	30%
lithic fragments	43%
chlorite and mica	2%
carbonate and "iron ore"	5%
quartz	20%

The feldspar is mostly albite. The lithic fragments are largely from volcanic rocks and highly altered; some are probably chert. The fragments are of medium to fine sand grade, subangular to subrounded, and fairly well sorted. Their cement consists of rusty weathering carbonate and iron oxide.

Division B

Division B consists of lithic sandstone, siltstone, argillite, and conglomerate. The lowest beds of sandstone or conglomerate in the Lillooet group that are at least a few feet thick, mark the base of that Division. Argillite is the most common rock in the lower part, but higher in the section lithic sandstone becomes dominant, and the proportion of pebble conglomerate increases.

A stratigraphic section measured in the upper part of Division B near the mouth of Bridge River on the west shore of the Fraser River shows the increase of coarser sediments upwards. (Percentages of rock-types are based on rapid estimates).

Feet	
	Top of measured section.
26	Lithic sandstone, blue-grey, blue grey to green weathering, mostly fine-grained, pyrite, thick-bedded to laminated, graded bedding, resistant; grades downward into siltstone, light grey to blue-grey, light-grey to blue grey weathering; siltstone grades into argillite, dark bluish grey, dark bluish grey weathering, recessive; siltstone and argillite laminated to thin-bedded; pene-contemporaneous deformations. ss. 90% st: 5% arg: 5%
7	Lithic sandstone, medium to very coarse-grained, grades downward into granule conglomerate, includes fragments of argillite, up to 2 feet long.
9	Lithic sandstone, mostly fine-grained, thick-bedded to laminated, siltstone with pyrite, argillite. ss: 50% st: 45% arg: 5%
8	Covered interval
1.5	Lithic sandstone, medium-grained, laminated.
1	Argillite, grading downwards into siltstone, pyrite.
	Fault, contortions.
10	Lithic sandstone, medium to fine-grained, siltstone, argillite; thin-bedded. ss, st: 90% arg: 10%
	Fault.
10	Conglomerate, volcanic pebbles and granules, rounded to sub-angular, matrix of lithic sandstone, poorly sorted, massive, cliff-forming.
8	Lithic sandstone, mostly fine-grained, siltstone, argillite; thin-bedded to laminated. ss: 50% st: 30% arg: 20%
7	Lithic sandstone, fine to medium-grained, pyrite, fragments of argillite 2 mm long, massive.
2	Siltstone, thin-bedded to laminated.
5	Argillite, massive, strongly contorted.

Feet	
45	Lithic sandstone, fine to medium-grained, massive.
1	Argillite, medium-bedded.
16	Siltstone, mostly massive, partly thin-bedded to laminated, argillite massive. st: 60% arg: 40%
7	Siltstone, argillite; thin-bedded to laminated. st: 80% arg: 20%
2	Siltstone and argillite as above, sheared and carbonated.
	Fault.
1	Lithic sandstone, thick-bedded, strongly carbonated.
1	Siltstone, argillite, thin-bedded to laminated, carbonated. st: 50% arg: 50%
1.5	Lithic sandstone, medium-grained, carbonated.
4.5	Siltstone, massive.
1	Siltstone, argillite; thin-bedded to laminated, carbonated. st: 60% arg: 40%
4	Siltstone, argillite; thin-bedded to laminated. st: 90% arg: 10%
15	Lithic sandstone, fine-grained, mostly massive.
20	Siltstone, argillite, lithic sandstone; medium-bedded to laminated, pene-contemporaneous deformations. st: 40% arg: 40% ss: 20%
12	Lithic sandstone, fine to medium-grained, massive.
10	Siltstone, argillite; thin-bedded to laminated. st: 90% arg: 10%
4	Lithic sandstone, fine- to medium-grained, thin-bedded to laminated.

Feet	
4	Siltstone, argillite; thin-bedded to laminated st: 90% arg: 10%
17	Conglomerate, mostly granules, partly pebbles of volcanic rocks, poorly to moderately sorted and rounded, large fragments of siltstone and argillite forming intraformational breccia; massive.
4	Siltstone, argillite, lithic sandstone, medium-grained; thin-bedded to laminated. st: 85% arg: 10% ss: 5%
	Fault.
6	Siltstone, lithic sandstone, coarse- to fine-grained, argillite; thin-bedded to laminated. st: 50% ss: 40% arg: 10%
11	Siltstone, argillite, lithic sandstone, fine-grained; thin-bedded to laminated. st: 60% arg: 30% ss: 10%
5.5	Diabase sill.
25	Siltstone, argillite, lithic sandstone, coarse- to fine-grained; thin-bedded to laminated, graded bedding. st: 65% arg: 30% ss: 5%
1	Siltstone, argillite, lithic sandstone, coarse- to fine-grained; medium-bedded, graded bedding. st: 65% arg: 30% ss: 5%
14	Siltstone, argillite, lithic sandstone, fine-grained; thin-bedded to laminated. st: 50% arg: 40% ss: 10%
3	Argillite, massive, platey jointing.
4	Lithic sandstone, medium- to fine-grained, siltstone, argillite; medium-bedded to laminated, graded bedding. ss: 50% st: 30% arg: 20%
12	Siltstone, massive.
26	Lithic sandstone, medium to coarse-grained, massive.
5.5	Lithic sandstone, fine-grained, argillite, siltstone; thin-bedded to laminated, pene-contemporaneous deformations. ss: 40% arg: 40% st: 20%
2.5	Diabase sill.

Feet	
.5	Siltstone, argillite; thin-bedded to laminated, strongly indurated by sills.
1.5	Diabase sill.
13	Lithic sandstone, fine- to medium-grained, siltstone, argillite; medium-bedded to laminated, graded bedding. ss: 50% st: 35% arg: 15%
5	Argillite, silty, massive.
8	Lithic sandstone, fine- to medium-grained, massive.
24	Lithic sandstone, fine-grained, siltstone, argillite; medium-bedded to laminated, graded bedding pene-contemporaneous deformations. ss: 50% st: 30% arg: 20%
18	Covered interval.
2	Lithic sandstone, medium- to coarse-grained, thick-bedded.
12	Lithic sandstone, medium- to fine-grained, siltstone, argillite; thick-bedded to laminated, graded bedding. ss: 50% st: 40% arg: 10%
4	Lithic sandstone, mostly medium-grained, mostly thin-bedded, locally massive.
13	Siltstone, lithic sandstone, fine-grained, argillite; medium-bedded to laminated, pene-contemporaneous deformations. st: 60% ss: 20% arg: 20%
7	Lithic sandstone, coarse-grained, with granules and pebbles of altered volcanic rock and fragments of argillite up to 2 in. long; massive.
14	Siltstone, argillite, lithic sandstone, fine-grained; thin-bedded to laminated. st: 55% arg: 25% ss: 20%
2	Diabase sill.
4	Lithic sandstone, fine-grained, siltstone; medium- to thin-bedded. ss: 80% st: 20%
9	Siltstone, argillite, lithic sandstone, fine-grained; thin-bedded to laminated. st: 40% arg: 40% ss: 20%

Feet	
3	Lithic sandstone, medium- to fine-grained, siltstone, argillite; thin-bedded to laminated. ss: 80% st: 10% arg: 10%
20	Argillite, lithic sandstone, coarse- to fine-grained, siltstone, argillite; thin bedded to laminated, graded bedding. arg: 40% ss: 30% st: 30%
3	Lithic sandstone, medium- to coarse-grained, massive.
15	Siltstone, argillite, lithic sandstone, mostly fine-grained; thin-bedded to laminated, upper part carbonated.
5	Lithic sandstone, mostly fine-grained, siltstone, argillite; thick-bedded to laminated, graded bedding. ss: 80% arg: 10% st: 10%
20	Lithic sandstone, mostly fine-grained, siltstone, argillite; mostly thin-bedded to laminated, a few beds one foot thick. ss: 40% arg: 30% st: 30%
5.5	Lithic sandstone, coarse-grained, grades downward into pebble-conglomerate, includes fragments of laminated siltstone and argillite; massive.
6.5	Lithic sandstone, medium- to fine-grained, siltstone, argillite; medium-bedded to laminated, pene-contemporaneous deformations, graded bedding. ss: 50% arg: 30% st: 20%
6	Lithic sandstone, fine-grained, partly thick-bedded, siltstone, argillite; thin-bedded to laminated, all strongly carbonated. ss: 70% st: 20% arg: 30%
5.5	Siltstone, lithic sandstone, fine-grained, argillite; thin-bedded to laminated, carbonated. st: 40% ss: 30% arg: 30%
4	Lithic sandstone, fine-grained, thick-bedded to laminated, siltstone, argillite; thin-bedded to laminated, all carbonated. ss: 70% st: 20% arg: 10%
5.5	Lithic sandstone, fine-grained, siltstone, argillite; thin-bedded to laminated, graded bedding, carbonated. ss: 40% st: 40% arg: 20%
2	Lithic sandstone, fine-grained, massive, carbonated.

Feet	
1.5	Siltstone, argillite, lithic sandstone, fine-grained; thin-bedded to laminated, carbonated. st: 50% arg: 30% ss: 20%
4	Lithic sandstone, fine-grained, massive, carbonated.
4	Siltstone, argillite, lithic sandstone, fine-grained; thin-bedded to massive, carbonated. st: 50% arg: 30% ss: 20%
10	Lithic sandstone, coarse-grained, locally grading into granule conglomerate, siltstone, argillite; lithic sandstone mostly massive; siltstone and argillite thin-bedded to laminated.
20	Siltstone, argillite, lithic sandstone, fine-grained; thin-bedded to laminated, graded bedding, pene-contemporaneous deformations.
3	Lithic sandstone, coarse-to fine-grained, siltstone, argillite; medium-bedded to laminated. ss: 90% st: 5% arg: 5%
16	Lithic sandstone, mostly fine-grained, siltstone, argillite; thin-bedded to laminated; one bed of argillite with strong pre-lithification contortions. ss: 40% st: 40% arg: 20%
3.5	Lithic sandstone, medium- to fine-grained, medium- to thin-bedded.
15	Siltstone, argillite, lithic sandstone, mostly fine-grained; medium-bedded to laminated, pene-contemporaneous deformations, graded bedding. st: 60% arg: 30% ss: 10%
	Fault. Bottom of measured section.
685	

The lithic sandstones are blue grey. Six specimens analyzed contain 10 to 40% of feldspar and 1 to 5% of quartz. The balance consists dominantly of volcanic fragments, a small proportion of chlorite, and a clay matrix.

In unaltered specimens the matrix constitutes only a

few percent of the rocks; in many altered specimens the clay content seems to be higher. But in these rocks the matrix cannot be distinguished from the margins of altered volcanic fragments, and the results of point counter analyses that range up to 20% of clay content are probably too high.

The lithic fragments are mostly volcanic but include particles of argillite ranging from sand to pebble size, probably derived from contemporaneous sediments.

The volcanic fragments are fine-grained and highly altered. They consist largely of plagioclase and chlorite but also contain potassic feldspar, quartz, "iron ore", and secondary minerals such as carbonate, sericite, epidote, chlorite and zeolites. The largest number of fragments resemble original andesites or keratophyres; smaller proportions seem to be derived from basalts or spilites, from dacites or quartz-keratophyres, and from felsitic rocks. Some completely chloritized fragments may be altered volcanic glass. Some of the detrital feldspar and quartz may have formed phenocrysts in such rocks. The fragments are mostly subangular. The sorting is better than in typical greywackes but poorer than in typical quartz arenites.

The conglomerates are made up of granules or pebbles. In many localities the fragments are rather angular. They seem to have been derived from the same source as the sandstones but are richer in lithic fragments and poorer in feldspar and quartz.

Division C

Division C separated from B by a fault, is made up essentially of the same rock types as B but contains a larger proportion of the coarser grades and is mostly massive. Lithic sandstone is the dominant rock-type and granule and pebble-conglomeratescomposed of rather angular fragments are not uncommon in the lower part of the Division. Siltstone and argillite which form only a small fraction of the exposed rocks are present in laminae and thin beds. A covered interval of 350 feet in the upper part of the Division may contain a higher proportion of these rocks.

The following stratigraphic section was measured on the west side of the Fraser River, approximately one mile north of the mouth of Bridge River. Percentages of rock types are based on rapid estimates.

Top of Measured Section:

Member AIII, Jackass Mountain Group

Feet	
61	Lithic sandstone, light bluish grey, greenish grey, locally brownish grey weathering, medium- to fine-grained, mostly massive with a few thin interbeds of siltstone, light grey, greenish grey weathering, and argillite, dark bluish grey, dark bluish grey weathering.
	Fault.
23	Lithic sandstone as above, upper 3 feet carbonated.
1	Lithic sandstone, fine-grained, siltstone, argillite; medium-bedded to laminated. ss: 70% st: 20% arg: 10%
9	Lithic sandstone, coarse- to fine-grained, partly massive, partly thin-bedded to laminated, includes a 1 foot lens of volcanic pebble conglomerate.
3	Siltstone, argillite, lithic sandstone, coarse- to fine-grained; thin-bedded to laminated, strongly sheared. st: 50% arg: 30% ss: 20%
16	Lithic sandstone, very coarse-grained, granule conglomerate, one inch fragments of argillite, some pebbles of volcanic rocks, poorly sorted, massive.
370	Covered interval.
38	Lithic sandstone, fine- to coarse-grained, massive; thin interbeds of siltstone and argillite. ss: 98% st: arg: 2%
4	Covered interval, recessive.
44	Lithic sandstone, fine- to coarse-grained, massive.
2	Lithic sandstone, fine-grained, siltstone, argillite; thin-bedded to laminated.
8	Covered interval, recessive.
33	Lithic sandstone, fine- to coarse-grained, massive, thin interbeds of siltstone and argillite forming less than 1% of the unit.

Feet	
47	Lithic sandstone, coarse- to fine-grained, with some granules and pebbles of volcanic rock and fragments of argillite, mostly massive, partly thin-bedded, a few thin interbeds of siltstone and argillite. ss: 95% st: arg: 5%
4	Lithic sandstone, siltstone; medium- to thin-bedded, recessive. ss: 60% st: 40%
40	Lithic sandstone, coarse- to fine-grained, upper part fine-grained, massive, some granules and pebbles of volcanic rocks, poorly sorted.
7	Lithic sandstone, coarse- to fine-grained, grading upward into siltstone, siltstone grades upwards into argillite; mostly massive, thin-bedded in upper part. ss: 60% st: 30% arg: 10%
40	Lithic sandstone, coarse- to fine-grained, coarser in lower part, massive.
8	Lithic sandstone, coarse- to fine-grained, siltstone, argillite, thin-bedded to laminated, graded bedding. ss: 40% st: 30% arg: 30%
32	Conglomerate, volcanic pebbles and granules, rounded to sub-angular, matrix of lithic sandstone and siltstone, with fragments of siltstone and argillite 2 inches to 5 feet long; poorly sorted, massive.
3	Lithic sandstone, fine-grained, siltstone, argillite; thin-bedded to laminated, upper part fissile, pene-contemporaneous deformations. ss: 40% st: 30% arg: 30%
2.5	Lithic sandstone, coarse- to fine-grained, thin-bedded to laminated, graded bedding.
2	Lithic sandstone, fine-grained, siltstone, argillite, thin-bedded to laminated. ss: 60% st: 30% arg: 10%
8	Lithic sandstone, lower part very coarse-grained, with granules, massive, upper part medium- to fine-grained, partly massive, partly medium-bedded to laminated.
1	Argillite, fissile, siltstone; thin-bedded. arg; 70% st: 30%

Feet	
1.5	Sandstone, medium- to fine-grained, grades upward into siltstone and argillite; medium-bedded to laminated.
.5	Siltstone, argillite, lithic sandstone, fine-grained; thin-bedded to laminated. st: 40% arg: 40% ss: 20%
2	Lithic sandstone, fine-grained, medium-bedded to laminated. ss: 98% st: 2%
1	Covered interval, road.
8	Lithic sandstone, fine-grained, grades upward into siltstone; mostly massive, partly thin-bedded to laminated.
1	Argillite, siltstone, lithic sandstone, fine-grained; thin-bedded to laminated. arg: 40% st: 40% ss: 20%
20	Lithic sandstone, lower part coarse-grained, upper part medium- to fine-grained, mostly massive, upper part thin-bedded; lens of limestone 3X 0.5 feet, light grey, brownish weathering, fine-grained.
1.5	Siltstone, lithic sandstone, medium- to fine-grained, argillite; thin-bedded to laminated. st: 50% ss: 30% arg: 20%
4	Lithic sandstone, mostly fine-grained, mostly thin-bedded to laminated, partly medium-bedded; some interlaminated siltstone.
2.5	Lithic sandstone, coarse- to fine-grained, siltstone, argillite; thin-bedded to laminated, graded bedding, pene-contemporaneous deformations. ss: 55% st: 30% arg: 15%
4	Lithic sandstone, medium- to fine-grained, thin-bedded to laminated.
1	Limestone, light grey, greyish buff weathering, grains of silt-size.

Feet

27.5 Lithic sandstone, mostly fine- to medium-grained, partly coarse-grained, mostly massive, partly thin-bedded, siltstone, argillite, both thin-bedded to laminated.

At 20 feet from bottom lens of limestone 7X 0.75 feet, medium grey, light greenish-grey weathering, very fine micro-crystalline, pyrite.
ss: 99% st: arg: 1%

---

881 Bottom: water-level of Fraser River

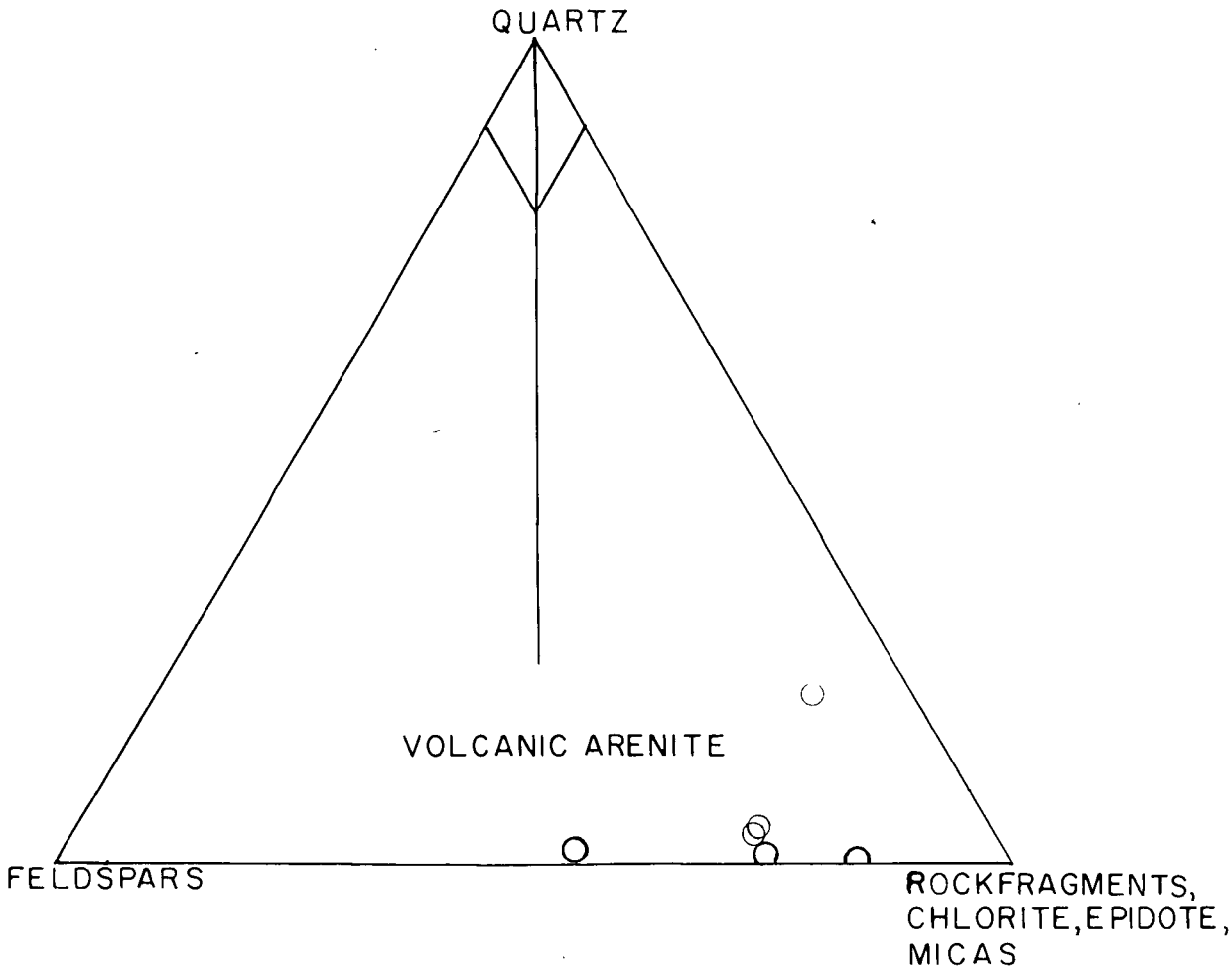
A typical granule-conglomerate contains approximately 10% of feldspar, largely albite, 40% of volcanic rock fragments, and 10% of chlorite; the clay matrix makes up about 40% of the rock. Some of the sandstones and conglomerates carry highly altered tuffaceous material.

This unit shows a high degree of alteration to albite, chlorite, and carbonate, the alteration apparently being related to several branches of the Fraser River fault zone.

Figure 2 shows the relative proportion of three components of these rocks: feldspar, quartz, and lithic fragments together with chlorite and mica. In the framework of Gilberts classification (Williams, Turner, Gilbert, 1955, p. 293) the rocks would be classified as volcanic arenites. A few volcanic greywackes may be represented, but the content of original clay matrix in these rocks is uncertain.

3. The Problem of Albitization

As pointed out by Duffell and McTaggart (1952, p. 37) most of the feldspar is plagioclase and has the composition of



COMPOSITION OF FRAGMENTS, SANDSTONES, LILLOOET GP.

CLASSIFICATION ADAPTED FROM GILBERT, (1955)

FIGURE 2

sodic albite, although one grain observed by the author in 1 out of 17 thin-sections is zoned from An_6 to An_{10}. Abundant inclusions of epidote, and the zonal distribution of sericite in some grains indicate that the albite was derived from more calcic plagioclase by alteration.

The albitization may have occurred in any of three periods: as alteration by hydrothermal solutions soon after the formation of the lavas from which the arenites are derived, by metamorphism of these volcanic rocks, or by albitization of the derived sedimentary rocks.

Late magmatic albitization is suggested by the following observation. In one thin-section an amygdule in a scoriaceous volcanic fragment is filled with water-clear plagioclase which is probably albite; but no such plagioclase can be seen in fractures or cavities of the sedimentary rock.

Another thin-section contains both albite and zoned calcic plagioclase which indicates that the albite in this rock is detrital.

On the other hand, a sill intruding the Lillooet group near a major fault has been prehnitized (Duffell and McTaggart, 1952, p. 92), and the gabbros west of Lillooet which are spatially close to the strata of the Lillooet group have been albitized and prehnitized. Probably the sedimentary rocks were exposed locally to the same altering solutions.

The relative importance of each of the three possible periods of alteration remains uncertain.

4. Structure

The beds of Divisions A and B strike northwesterly and dip steeply. Judging from the distribution of rock types and a few determinations of stratigraphic tops their major structure is an isoclinal anticline which is in part overturned to the southwest. In Division A the major anticline is modified by a greater number of minor folds that are indicated by the relative directions of the stratigraphic tops. A few folds near the lower part of Dickey Creek are shown on the map. The thickness of their limbs probably is of the order of a few hundred feet. The more competent beds of Division B do not show this pattern of tight secondary folding.

To the west the rocks are probably in fault contact with basic and ultrabasic intrusions. The contact is not exposed. To the east they are in fault contact with flat lying or gently dipping strata of Division C and of the Jackass Mountain group.

Division C, probably of marine origin, is overlain by the continental member AI of the Jackass Mountain group. The transition from marine to continental deposits suggests an unconformity but an angular discordance between the two groups has not been observed.

5. Mode of Origin

The presence of Aucella indicates that Division A was deposited in a marine environment, and the association of

carbonaceous matter with the sediments shows that it was at times of the restricted type in which reducing conditions prevail. As most of the rocks show graded bedding the sediments were probably deposited by turbidity currents. The thickness of uniformly laminated rocks is remarkable. Contortions and crenulations in the rocks apparently formed before the lithification of the sediments suggest that some of these turbidity currents are related to submarine slumping. The causes of such slumping may be tectonic disturbances of the basin.

The same conditions apparently persisted during the deposition of Division B. The gradual transition in this unit from argillite to sandstone and conglomerate however, suggests an uplift of basin or source area. A small seam of coal in Division B probably originated in a continental or near-shore marine environment.

Divisions A and B are tightly folded and intruded by numerous dykes and sills whereas Division C and the overlying strata of the Jackass Mountain Group lie almost horizontally and are cut by very few intrusive rocks. These relations suggest that the folding and the intrusion took place shortly after the deposition of Division B, and that B and C are separated by an angular unconformity. But as B and C are in fault contact, and the strata between them are not exposed such an unconformity can only be inferred and not observed.

After a period of uplift and erosion the area was again submerged; the belemnites in Division C indicate a marine environment. As this unit consists mostly of sandstone and some

conglomerate, the sediments were probably deposited not far from the shore. The tuffaceous material in these rocks suggests contemporaneous volcanism.

At the end of the time represented by the Lillooet group the area again rose above sea level. The basal conglomerate of the Jackass Mountain group probably was laid down in a continental environment.

6. Age and Correlation

The Lillooet group was first defined and described by Duffell and McTaggart. Specimens found by these authors in the lower part of the group were identified by J.A. Jeletzky as "Aucella sp. ind. (ex aff. crassicollis) Keyserling" and considered to be early Lower Cretaceous (Lower Neocomian) in age. (Duffell and McTaggart, 1952, p. 39).

Some fossils found during the present investigation in Division B (F13) are according to Jeletzky "indeterminate true belemnoids of general Jurassic or Cretaceous age". Similar but very poorly preserved specimens were noticed in Division C.

Duffell and McTaggart have correlated the Lillooet group with Division A of the modified Dewdney Creek group of the Princeton area and with the Dewdney Creek group of the Coquihalla area. The correlation is based mainly on lithology and stratigraphic position of the respective units.

If the unconformity between Divisions B and C were proved Division C should be treated as a separate unit or

included with the Jackass Mountain group. However, since at this time its presence can only be inferred, these rocks, following earlier workers, have been left in the Lillooet group.

JACKASS MOUNTAIN GROUP

1. Distribution and Thickness

Duffell and McTaggart have subdivided the Jackass Mountain group into three stratigraphic units called Division A, Division B, and Division C. In the present work three lithological units, members AI, AII, and AIII are distinguished in Division A.

Division A underlies the lower and intermediate levels of Fountain Ridge and of the north side of the Fraser River between Fountain and the mouth of Bridge River. Division B forms conspicuous cliffs on the higher levels of the same area. Division C, underlies large parts of Fountain Ridge and of the Camelsfoot Range.

Member AI has an approximate thickness of 150 feet. On the north slope of Fountain Ridge AII is about 2500 feet thick but possibly repeated by faulting. On the south slope of the Camelsfoot Range, 1-1/2 miles northeast of the mouth of Bridge River, AIII comprises approximately 1000 feet of strata.

About 1-1/2 miles north of Fountain on the north side of the Fraser River Division B is about 1000 feet thick and on Fountain Ridge approximately 1500 feet. Duffell and McTaggart

state (p. 40) that the Division is 1750 feet thick on the west slope of the Camelsfoot Range near the northwestern edge of the Ashcroft map area outside of the present map area.

The top of Division C is removed by erosion. According to Duffell and McTaggart at least 5000 feet of strata are represented (p. 91).

2. Lithology

Division A

Member AI

Member AI comprises conglomerate and lithic sandstone that carries some plant remains. The conglomerate is exposed only for one mile along the shores of the Fraser River in the western part of the area underlain by Division A. It disappears further east, probably because of a gentle dip to the east. The sandstone with plant remains extends to the eastern boundary of Division A but where the conglomerate is lacking Member AI is difficult to distinguish from AII.

The following stratigraphic section of AI was measured on the north side of the Fraser River about 1 mile northeast of the mouth of Bridge River. Percentages of rock types are based on rapid estimates.

Feet	Top of section
8	Conglomerate, brownish green weathering, volcanic pebbles, 1-3 in., well rounded, matrix of lithic sandstone, massive.
9	Conglomerate, granules and fine pebbles, well-rounded to subrounded, massive.
16	Conglomerate, volcanic pebbles, mostly 1-4 in., well rounded, abundant matrix of lithic sandstone, strongly carbonated.
8	Lithic sandstone, light bluish grey, greenish grey to brownish grey weathering, scattered lenses of pebble conglomerate; massive, strongly carbonated.
2	Conglomerate, 15 feet lens, volcanic pebbles, mostly 1-3 in., well rounded.
2	Lithic sandstone, medium-grained, comparatively loosely cemented, lenses of pebble-conglomerate, thin beds of argillite; strongly carbonated.
3	Lithic sandstone, medium-grained, thin-bedded, comparatively loosely cemented.
1	Lithic sandstone, siltstone, light bluish grey, greenish-grey weathering, argillite, dark bluish-grey, dark bluish grey weakening, thin-bedded to laminated, strongly sheared and laminated.
8	Lithic sandstone, medium- to fine-grained, massive.
1	Conglomerate, volcanic pebbles, well rounded, mostly .5-2 in.
4	Lithic sandstone, fine- to medium-grained, massive, lenses of volcanic pebble and granule conglomerate.
2	Conglomerate, volcanic pebbles, well rounded, mostly .5-2 in.
1	Lithic sandstone, medium-grained, massive.
3	Conglomerate as above.
1	Lens of lithic sandstone as above.
12	Conglomerate as above.

Feet	
4	Conglomerate, granules and pebbles of volcanic rocks, comparatively loosely cemented, massive.
15	Lithic sandstone, medium- to fine-grained, mostly massive, a few thin beds very loosely cemented, probably tuffaceous, a few thin interbeds of siltstone and argillite; strongly carbonated.
	Fault, continuity of section uncertain.
15	Lithic sandstone, medium- to coarse-grained, massive, a few thin interbeds of argillite and siltstone, strongly sheared.
10?	Lithic sandstone, medium- to fine-grained, massive; thickness uncertain because of faulting.
	Fault.
5?	Lithic sandstone, medium- to fine-grained, massive, with a few thin interbeds of siltstone and argillite; thickness uncertain because of faulting.
4	Lithic sandstone, fine-grained, siltstone, argillite; medium- to thin-bedded. ss: st: 80% arg: 20%
11	Lithic sandstone, medium- to coarse-grained, tuffaceous, with fragments of plant-matter, some coaly wood, a few granules and pebbles of volcanic rocks, loosely cemented, mostly thin-bedded, partly massive; recessive.
____	Bottom of section : top of Div. C., Lillooet Group.
145	

The strata change considerably over distances as short as one hundred feet.

The round-stones of the conglomerate are mostly made up of light grey weathering massive aphanitic rocks some of which show a few fine-grained phenocrysts. Two typical specimens examined in thin-section are quartz-keratophyres.

They contain micro-phenocrysts of albite and chlorite associated with "iron ore" pseudomorphous after a pyribole. The groundmass consists dominantly of plagioclase microlites, some quartz, and minerals too fine-grained for identification. The plagioclase is altered by sericite and carbonate.

Relatively weak cementation and the presence of plant-matter, mostly remnants of stems, are characteristic of some of the lithic sandstones associated with the conglomerate. The lithic sandstones contain little quartz (1% or less) and feldspar (3% or less) and are composed mainly of volcanic fragments and chlorite. Some of the fragments show shard-like outlines, others appear to be vesicular and probably many of them are of tuffaceous origin. As the volcanic fragments are highly altered they cannot be distinguished easily from the original clay matrix.

The fragments are subrounded to subangular and moderately well sorted. In their roundness and sorting the sandstones resemble volcanic arenites.

> A carbonatized lithic sandstone from the vicinity of Fountain station is of very fine sand grade, fairly well sorted and contains fragments that are subrounded to subangular in shape but replaced at the margins by chlorite. The rock contains approximately 30% of feldspar, 15% of quartz, and 7% of recognizable rock fragments. Chlorite, mica, epidote, and clay make up about 20% of the rock. The balance consists of carbonate and derived "iron ore" which has replaced the original clay matrix to a large extent. The feldspar, mostly plagioclase is partly clear, partly altered and rich in epidote. All grains of plagioclase determined have the composition of albite.

Member AII

Member AII strongly altered, faulted, and poorly exposed consists largely of lithic sandstone but contains beds of conglomerate that are a few feet thick, seams of plant matter in the lower part of the section, and an increasing proportion of interbedded siltstone in the upper part. On the west slope of Fountain Ridge, east of the railroad bridge near Lillooet the typical greenish weathering massive lithic sandstone is underlain by dark siltstone of considerable thickness.

The typical lithic sandstone is massive, blue grey on fresh surfaces, and greenish on weathered faces. Six specimens analyzed contain 3 to 10% of feldspar, mostly albite, 2 to 5% of quartz, and a few per cent of epidote and mica; the balance consists dominantly of volcanic fragments. The fragments are fairly closely packed. Interstices are filled by chlorite. The fragments are altered on the outside to "clay". Minor constituents are "iron ore" and carbonaceous matter. Some of the lowest beds of the member show greyish laminae about one millimeter thick and spaced a fraction of a centimeter apart. Microscopic examination shows that they are layers rich in pyrite. As the mineral is moderately well rounded it probably is of detrital origin.

The particles are mostly subrounded, of fine grade, and better sorted than in any other unit of the Jackass Mountain group. The lithic sandstone of Member AII can be classified as "volcanic arenite" (Gilbert, 1955).

Member AIII

Member AIII consists of argillaceous siltstone, laminated argillite, lithic sandstone and lenses and beds of limestone that are a few feet thick.

A section measured on the south slope of the Camelsfoot Range can be summarized as follows:

Feet	
520	Siltstone, dark blue grey, dark blue grey weathering, partly concretionary, lithic sandstone, grey, greenish weathering, fine- to coarse-grained, argillite, dark blue grey, dark blue grey weathering, lenses and beds of limestone, light grey, light grey weathering; massive to laminated. st: 50% ss: 35% arg: 10% lms: 5%
450	Siltstone, as above with argillite fragments, fossiliferous, belemnites, pelecypods, mostly massive, with a few lenses and beds of limestone as above.
970	

The strata vary considerably over distances of a few miles, and lithic sandstone and limestone are not present in every section.

> A typical massive argillaceous siltstone is made up of about 50% of silt sized minerals, mostly feldspar, quartz, epidote, mica, and chlorite. The matrix consists largely of clay but includes a few percent of carbonaceous matter. The specimen contains approximately 40% of spherical or elliptical pellets of argillite that are darker colored and richer in carbonaceous matter than the siltstone.
>
> A typical laminated specimen is composed mainly of layers of dark argillite ranging from a few millimeters to one centimeter in thickness and a smaller fraction of laminae of greyish silty argillite that are one millimeter or a few millimeters thick. The dark argillite contains about 8% of siltsized minerals and 5% of carbonaceous matter,

> and the balance consists of clay-sized material. The greyish argillite comprises approximately 45% of silt, 3% of carbonaceous matter and 52% of clay. The silt fraction consists of feldspar, mica, epidote, chlorite, and carbonate. The specimen is well size-sorted and shows graded bedding. The dark color is produced by the carbonaceous matter.

Division B

In the present investigation Division B of the Jackass Mountain group was examined only briefly. Few additions can be made to the account given by Duffell and McTaggart.

The Division consists, in the order of abundance, of conglomerate, lithic sandstone, argillite, and siltstone.

The conglomerate is made up mostly of cobbles and partly of boulders and pebbles. Granule conglomerate is comparatively rare. Most of the roundstones are derived from granitic rocks others from volcanic rocks, chert and argillite. They are embedded in an abundant matrix of lithic sandstone and fairly well sorted with respect to size. Imbricate structures are very rare. In some localities the long axes of the roundstones seem to lie in the plane of bedding, but exact bedding attitudes cannot be measured in these rocks. In a section measured by Duffell and McTaggart on Jackass Mountain the conglomerate beds range in thickness from 5 to 100 feet, most of them being 8 to 20 feet thick. They are not conspicuously lenticular but can be traced for scores of feet.

The lithic sandstone weathers greenish, is medium- to fine-grained, and resembles the sandstone of Division C. The rocks show no internal stratification. On Jackass Mountain

the sandstone beds are from 1 foot to 50 feet thick and have an approximate thickness of 10 feet.

The interbedded siltstones and argillites are similar to the ones in member AII. In the present map area only a few poorly exposed strata were seen.

In the present map area the lowest beds of conglomerate in most places rest conformably on 200 to 300 feet of lithic sandstone. Only at the road-cut west of Fountain and at two localities on Fountain Ridge were they seen to overlie dark siltstone and argillite, at least ten feet thick, with erosional unconformity.

Lithic sandstone makes up perhaps one quarter of the middle and upper part of Division B. It becomes more abundant in the upward direction and is dominant in the basal part of Division C. The lithic sandstone is continuous with the matrix of the conglomerate, and the relation between the two rock types in most localities is conformable. The only example of a cut-and-fill structure in the present map area was noticed on the south slope of the Camelsfoot Range where conglomerate overlies a bed of argillite with erosional unconformity.

Division C

According to Duffell and McTaggart (p. 43) Division C of the Jackass Mountain group has approximately the following composition:

greywacke, i.e. lithic sandstone	60-70%
argillite	25-35%
conglomerate	4%

The following stratigraphic section of a part of Division C was measured by the author on the east slope of Fountain Ridge, about 1 mile southwest of the Indian settlement of Fountain Valley.

Feet	Top of section.
100	Lithic sandstone, light bluish grey, greenish grey weathering, fine- to coarse-grained, massive, siltstone, argillite; laminated to thin-bedded. ss: 98% st, arg: 2%
215	Covered inverval, slightly recessive.
500	Lithic sandstone, as above, mostly massive. At 430 feet from the bottom lithic sandstone fine to very fine-grained, laminated; 80-85 feet lithic sandstone with scattered, poorly sorted pebbles and cobbles, well rounded, mostly granitic, partly volcanic; at 45 feet from bottom of unit a few laminae of siltstone and argillite.
80	Lithic sandstone, as above, grading upwards into siltstone and argillite, scattered cobbles and pebbles, well rounded, mostly granitic.
850	Lithic sandstone, as above, mostly massive. At 700 feet from the bottom a few laminae of lithic sandstone fine to very fine-grained; at 650 feet a 5 feet lens of conglomerate, pebbles mostly of volcanic rocks, well rounded; at 330 feet a few laminae of siltstone and argillite; at 140 feet from the bottom laminae of lithic sandstone fine to very fine-grained and siltstone.
1745	

The typical lithic sandstone is massive, light bluish grey, and weathers greenish. Four specimens analyzed contain

feldspar	10 - 42%
quartz	3 - 14%
mica	4 - 5%
epidote	1 - 2%
rock fragments and chlorite	15 - 55%
"iron ore", carbonaceous matter, apatite, sphene	trace

As the lithic fragments are mostly altered around their margins the content of original clay matrix is very difficult to determine.

All feldspar crystals examined are of sodic albite. Most of the rock fragments are volcanic and some are metamorphic. Angular fragments of argillite ranging up to pebble size and pebbles of other rocks are present in some beds in small amounts. The fragments are subrounded to subangular. The sorting is poorer than in Member AII of Division A but better than in typical high rank greywackes. All specimens examined are of fine- or medium sand grade.

In sections measured by Duffell and McTaggart the beds of lithic sandstone average 60 feet in thickness.

Argillite is interbedded with the lithic sandstone in discontinuous stringers, up to three feet long, or in more extensive laminae that are one to two inches thick. The argillite commonly contains a relatively large fraction of sand and silt which in one specimen studied consists of feldspar, quartz and epidote.

In composition the conglomerate of Division C closely resembles the conglomerate of Division B. In most localities the beds are not thicker than thirty feet; but a conglomerate underlying the slopes southwest of Ward Creek may be several hundred feet thick.

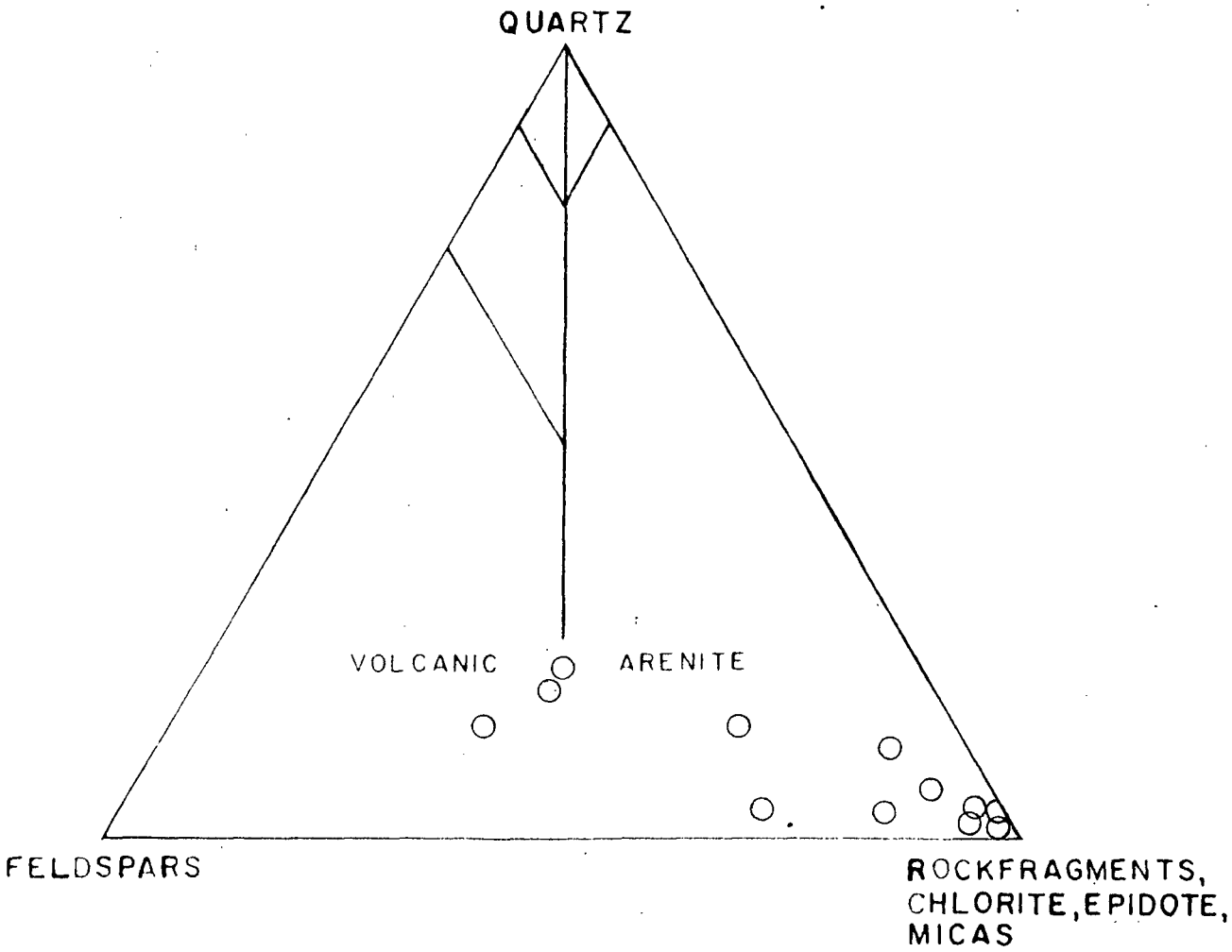
Near the mouth of Fountain Creek a few hundred feet of continental beds are exposed. The rocks consist mostly of lithic sandstone but also comprise beds of pebble and cobble

conglomerate that are a few feet thick and several seams of fossil plant matter. Three characteristic specimens of a fine-grained lithic sandstone contain 4 to 18% of feldspar, mostly albite, and 3 to 7% of quartz. The balance consists mostly of fine-grained, highly altered volcanic fragments, less chlorite, and small amounts of epidote and mica. The particles are subrounded to angular. The proportion of original clay matrix cannot be determined.

> A specimen of volcanic arenite has approximately the following composition:
>
> | | |
> |---|---|
> | feldspar (mostly albite) | 36% |
> | quartz | 19% |
> | mica, epidote, and chlorite | 4% |
> | lithic, dominantly volcanic fragments | 31% |
> | carbonate and "iron oxide" | 10% |
>
> The grains are of fine sand grade and angular to sub-rounded. The cement consists of carbonate and "iron oxide" which may have been introduced by hydrothermal solutions as these beds are near a major fault zone.

Seams of plant matter interbedded with lithic sandstone are also exposed on the western banks of the Fraser River, near Fountain. Strata containing a small percentage of plant remains were found near the mouth of Sallus Creek at a few localities in the vicinity of Lee Creek and Blackhill Creek.

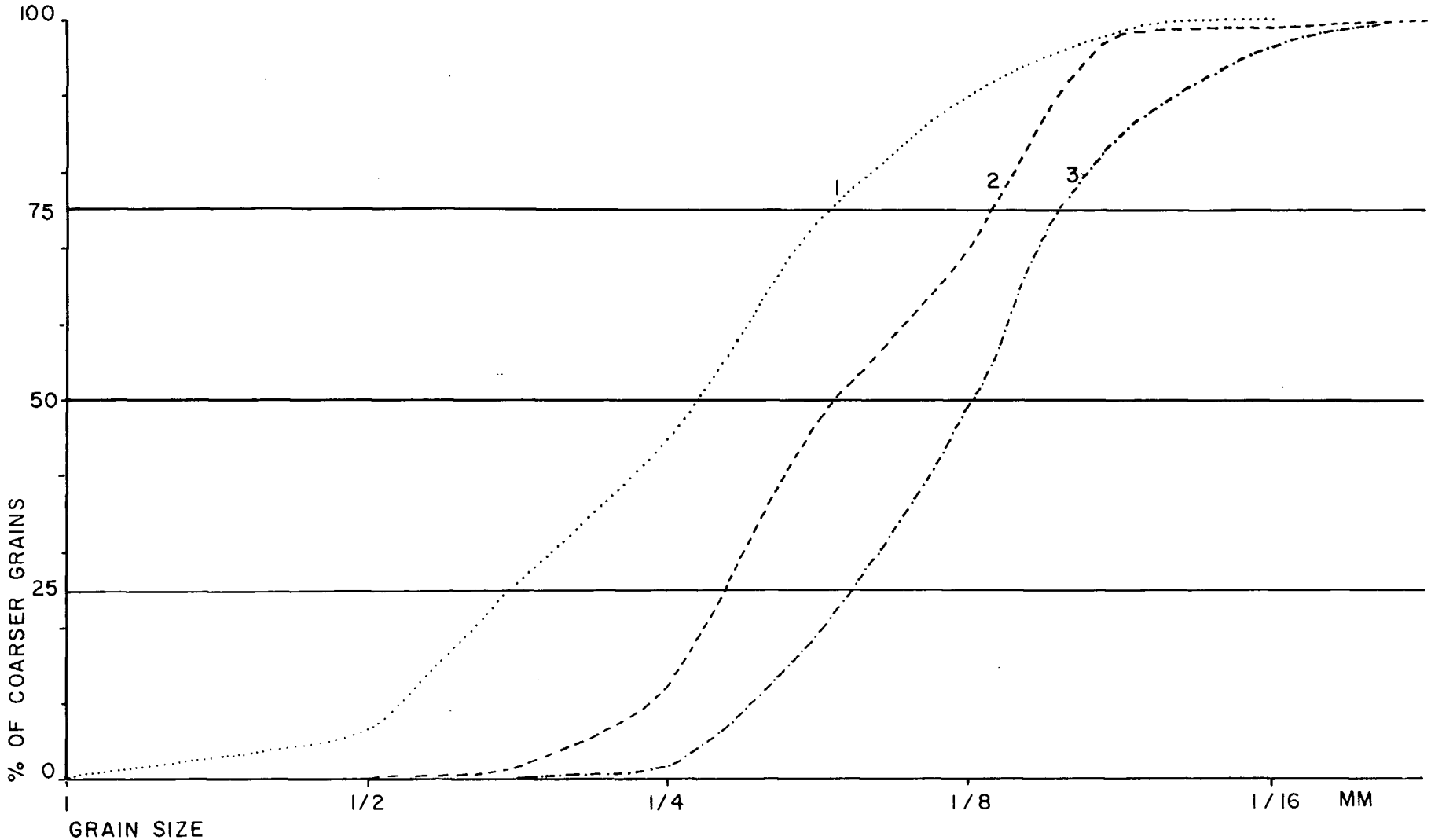
Figure 3 shows the relative proportion of quartz, feldspar, and lithic fragments with their alteration products in 12 specimens from the Jackass Mountain group. All specimens are in the range assigned by Gilbert to volcanic arenite, volcanic wacke, or volcanic greywacke. According to the fair sorting and relatively close packing most of the



COMPOSITION OF FRAGMENTS, SANDSTONES,
JACKASS MOUNTAIN GROUP

CLASSIFICATION ADAPTED FROM GILBERT, (1955)

FIGURE 3



SIZE DISTRIBUTION IN SAND- AND COARSE SILT-GRADE,

THIN-SECTION ANALYSIS OF 3 × 400 GRAINS, AFTER PACKHAM, (1955)

1) DIV. C , MD = .23MM SO = 3.2
2) DIV. C , MD = .17MM SO = 2.8
3) MEMBER AII, MD = .12MM SO = 2.2

FIGURE 4

rocks are arenites rather than wackes or greywackes.

In Figure 4 the size distribution in the sand and coarse silt grades of three characteristic specimens from Member AII and Division C is shown. (Plate XIV). The maximum sectional diameter of 400 grains was measured and the cumulative size distribution curve obtained was reconstructed with the aid of tables given by Packham (1955).

The sorting coefficient of the specimen from AII is 2.2; the two specimens of Division C have sorting coefficients of 2.8 and 3.2 respectively.

On the basis of 170 sediments from many different types of environments Trask (1932, pp. 71-72) obtained the following distribution of sorting coefficients (So):

So	less	than	1.9	- 10%
"	"	"	2.5	- 25%
"	"	"	4.5	- 75%
"	"	"	5.0	- 90%

The extremes are 1.26 and 9.4. The mode is 2.9. He concludes: If So is less than 2.5 the sample is well sorted; if it is greater than 4.5 the sediment is poorly sorted; and if it is about 3.0 the deposit is normally sorted.

According to Trask's classification the specimen from member AII would be well sorted and the specimens from Division C are normally sorted. However, compared with studies by Krumbein and Tisdel (1940), and Hough (1942) the results obtained are too high. Krumbein and Tisdel found that crystalline rocks which have disintegrated in place have a coefficient of sorting

that places them into the range of Trask's well sorted sediments. Hough points out that most near-shore marine sediments have sorting coefficients between 1.0 and 2.0.

The subjects of size analysis from thin section and sorting coefficients of greywackes and related rocks need more investigation. (Compare also Greenman, (1951), Krumbein (1953), Rosenfeld, Jacobsen, and Fern (1953)).

3. The Problem of Albitization

The plagioclase in the Jackass Mountain group consists dominantly of albite although a few grains of oligoclase were noted. As adjacent strata of the younger Spences Bridge and Kingsvale groups and the older Pavilion group are not albitized the albite of the Jackass Mountain group appears to be detrital. From different observations Duffell and McTaggart arrived at the same conclusion (p. 92f). The problem remains, however, whether the albite was produced by spilitization or by regional metamorphism of the source rocks.

4. Structure

The strata of the Jackass Mountain Group lie mostly flat or dip at low angles. In the vicinity of major faults, however, they have been tilted into almost vertical positions. On the northern part of Fountain Ridge the three divisions form a shallow syncline. As the contacts here are all strongly altered and sheared the folding probably was accompanied by

much differential slippage on bedding planes. The group is broken by several longitudinal and transverse faults that will be discussed in a later chapter.

5. Mode of Origin

Information about the mode of origin of the Jackass Mountain group can be obtained from three sources: from the texture and composition of the sedimentary rocks, from the included fossils, and from the history of the Fraser River fault zone.

Member AI containing conglomerate, much plant matter, and no marine fossils probably was laid down in a continental environment. Volcanic eruptions resulting in the deposition of tuff probably took place at the same time.

Fossils indicate a marine environment for members AII and AIII, and associated carbonaceous matter shows that the basin was "restricted". As the grain size in these members is comparatively fine the sediments were laid down relatively far from the shore or were derived from a source area without pronounced relief.

The relatively coarse grain size in the beds of the lower part of Division B is suggestive of a near-shore environment of deposition or uplift of the source area.

The origin of the conglomerate in Division B poses several problems.

The great thickness of the conglomerate suggests a rapid uplift of the source area and may have been caused, as

Duffell and McTaggart suggested, (p. 47) by early movements of the Fraser River fault zone. The present study of this fault zone indicates that before the deposition of the Spences Bridge group a graben had formed which controlled the sedimentation of Division C and perhaps also of Division B of the Jackass Mountain group. The present fault zone is complex and comprises at least four major longitudinal faults with relative downward movement of the eastern fault block and one fault with relative downward movement of the western block. In the southern part of the area the fault-zone has a width of approximately 7 miles and the graben itself of approximately one mile. The graben has been traced throughout the whole map area and probably extends much farther to the northwest and to the southeast. The latest movements on one of the faults took place in early or middle Tertiary.

The faults visible now may not coincide with the faults of the early Lower Cretaceous. But the present situation perhaps gives a picture of the conditions in the past. There may have existed a narrow, elongate trough which was perhaps in the order of ten miles wide and more than one hundred miles long. The conglomerate of Division B is found in the western part of the present fault zone and perhaps was laid down along the western margin of the inferred trough. The stratigraphic equivalents of the conglomerate in the middle and eastern part of the area are not exposed. Because of the scarcity of bedding attitudes and complications by faulting not enough information could be obtained about the variations in the thickness of the

conglomerate. But it was mentioned that the conglomerate on the northwestern edge of the Ashcroft map area is perhaps 750 feet thicker than opposite Fountain. These scanty data suggest an increase in thickness to the northeast.

Division B is the oldest known stratigraphic unit in the present map area that contains a major proportion of granitic material.

Some argillite interbedded with conglomerate contains marine fossils, but it is uncertain whether the basin was permanently or only temporarily flooded by the sea. The lack of plant matter perhaps supports the theory of a permanently marine environment.

If the environment was marine the detrital material may in part have been rounded by transportion in streams which descended from the bordering mountains with a steep gradient and in part by wave action on beaches. A problem is the mechanism of distribution in the basin over a width of more than one mile. It may be assumed that currents were active. The erosion surfaces locally observed may have been produced by such agents. The nature and origin of the postulated currents, however, are uncertain. The sediments of Division B do not resemble the turbidity current deposits of the Lillooet group or the Cache Creek group. Laminations, graded bedding, slump structures, and intraformational breccias are inconspicuous or lacking. Perhaps the distribution of the gravel was greatly aided by relatively steep submarine slopes produced by faulting. The areas of greatest depression also may have

shifted laterally in the basin.

In order to explain the great width of the conglomerate, Duffell and McTaggart suggested deposition on a floodplain that was only at times inundated by the sea. They mention, however, that such characteristic features of a flood plain as cut-and-fill structure and lenticular shape of the deposits are uncommon.

Some of the strata of Division C containing conglomerate and plant matter were deposited in a continental or near shore marine environment. Others, including invertebrate fossils, are of marine origin. Carbonaceous matter associated with the argillite indicates that the environment at times was reducing. The rocks rarely show structures suggestive of current action. A fairly continuous uplift of the borderland can be inferred from the generally coarse-grain size of the sediments. The source area was underlain dominantly by volcanic rocks and a smaller proportion of Coast Intrusions.

In summary it can be stated that Division C and probably also Division B were deposited in a narrow elongate trough that subsided rapidly with respect to bordering highlands but fluctuated with respect to sea level. At times it may have been connected with the open sea, more often it formed a restricted marine environment and temporarily it may have been a continental valley that was possibly occupied by a large river.

6. Age and Correlation

The name "Jackass Mountain Conglomerate Group" was given by Selwyn to the sandstone, quartzite, shale, and pebble conglomerate of Jackass Mountain. He recognized that the rocks are younger than the Cache Creek group.

Dawson refers to the rocks as "Queen Charlotte Island" group which he assigned to the Cretaceous.

Duffell and McTaggart applied the name Jackass Mountain Group and established a mid-Lower Cretaceous age. On ground of lithological and paleontological correspondences they correlate Divisions A, B, and C of the Jackass Mountain group with Divisions B, C, and D of the Dewdney Creek group of the Princeton area, the Pasayten group of the Similkameen River district, and "Lower Cretaceous" rocks of the Coquihalla map area.

Fossils found during the present mapping and identified by J.A. Jeletzky confirm the mid-Lower Cretaceous age of the Jackass Mountain group.

In Member AII on the northwestern slope of Fountain Ridge about 1/2 mile east of the mouth of the Bridge River the following fossils, identified by J.A. Jeletzky, were found (F14):

Pseudomelania ? sp. indet.
(a gastropod)

"*Pterocera*"? sp. indet.
(a gastropod)

Ostrea sp. indet.

Pecten (*Entolium*) sp. indet.

Mytilus sp. indet.

Astarte ? sp. indet.

According to Jeletzky the collection "cannot be dated beyond a tentative suggestion that its gastropods and pelecypods show some similarity with those of the undescribed mid-Lower Cretaceous (Barremian or ? Aptian) faunas of the Quatsino Sound, Vancouver Island.

Jeletzky identified a fossil found approximately 1-1/2 miles due north of the mouth of Bridge River in Member AIII (F15) as:

Ancyloceras (*Helicancylus*) c.f. *aequicostatum* Gabb

This ammonite "is characteristic of the Aptian rocks (so called Alderson and Argonaut zones of Anderson, 1938, G.S. A. Sp. Paper 16, p. 65-66, table 2). The state of preservation of the only specimen available is, however, too poor to exclude its reference to other allied forms of *Ancyloceras*, which range down into Upper Barremian rocks in California and elsewhere. The writer prefers therefore to date the lot here discussed as of Upper Barremian (?) or Aptian age in terms of the international standard stages.

In British Columbia, faunas of similar and slightly older mid-Lower Cretaceous age have been known for some time from the rocks of the Jackass Mountain group of the Ashcroft area (see Duffell and McTaggart, 1952, pp. 48-52) and from the Dewdney Creek group of the Princeton area (see Rice, 1947, p. 18-19)".

A fossil collected on the south slope of the Camelsfoot Range, at an elevation of 1700 feet, approximately 1-1/2 miles northeast of the mouth of the Bridge River (F16) was identified by Jeletzky as

Acroteuthis sp. indet.

He states: "This belemnite genus is restricted to the early mid-Lower Cretaceous rocks not older than the Berriasian (= Infravalanginian) and not younger than the Barremian stages of the international standard. It is not known to range into the Aptian stage either in North America or in Eurasia."

An "indeterminate (phylloceratid?) ammonite" found on the north side of the Fraser River opposite the mouth of Fountain Creek (F17) "can only be dated as of the general Jurassic or Cretaceous age" but indicates a marine environment.

SPENCES BRIDGE GROUP

Introduction

A belt of intercalated volcanic and sedimentary rocks is exposed between the southeastern extremity of the map area and the slopes north of McKay Creek. Dawson included these rocks with his "Lower Volcanic Group" which he considered to be Miocene. Drysdale (1914) renamed this group Spences Bridge group, and F.K. Knowlton regarded plant fossils found by Drysdale to be Lower Cretaceous but with Jurassic affinities. Bell referred the same fossils and new collections made by Duffell and McTaggart to the early Upper Lower Cretaceous

(Aptian stage). New fossils found during the present investigation show that some of the rocks are late Lower Cretaceous (Albian) and therefore correlative with the Kingsvale group. Consequently the volcanic rocks have been subdivided into several units. Some units have been correlated with the Spences Bridge group, others with the Kingsvale group. The age and correlation of several units isolated by faulting are unknown.

LOWER DIVISION

A. Basal Member

Between Sallus Creek and Gibbs Creek are two isolated small areas underlain by volcanic rocks.

The northern outcrops, located approximately 1 mile north of Gibbs Creek, consist of aphanitic and aphanitic-porphyritic andesite, of andesitic flow-breccia, tuff and dacite. A layer of tuff contains remnants of plant stems. The contacts between two flows dip 70° to the northeast.

The other area, situated about 1/2 mile to the southeast, is made up of porphyritic dacite. In the eastern half of the area the dacite weathers reddish brown and locally shows fine flow layering and parallel orientation of plagioclase phenocrysts. Some of these flow layers show strong contortions. In the western half the dacite is uniformly greenish grey and contains coarse phenocrysts. In a few localities the plagioclase phenocrysts form flow layers that generally have constant attitudes over several hundred feet; but in one place a tight anticline of flow layers, about 2 feet across was seen. The dips of the flow layers range

from 80° to 25° and the strikes from northeast to northwest.

> A specimen of the grey porphyritic dacite consists dominantly of plagioclase, and chloritized palagonite or chlorophaeite, and contains approximately 10% of quartz, 15% of chlorite, and small proportions of "iron ore", biotite, and apatite. Most of the phenocrysts are plagioclase, but a few consist of quartz or biotite. A grain of plagioclase showing oscillatory normal zoning has an approximate composition of An_{42} in the core and An_{30} at the margin. Both plagioclase and quartz phenocrysts include fine-grained minerals of the groundmass. The quartz phenocrysts are surrounded by rims of feldspathic material, and some include plagioclase crystals of intermediate size. No flow structures are apparent in the rock.

The contacts of these volcanic rocks are not exposed but topography and structure suggest that they overlie Division I of the Pavilion group unconformably. Near the margin of the southern outcrop area remnants of a breccia, one or a few inches thick were seen to overlie bed-rock of chert and argillite. The breccia is composed of the same rock types (chert and argillite), cemented by carbonate, and traversed by veinlets of quartz. It probably originated on the Lower Cretaceous erosion surface and locally underlies the volcanic flows.

According to Duffell and McTaggart the Spences Bridge group locally rests unconformably on the Cache Creek group. (p. 54). Therefore these rocks are thought to represent the basal unit of the Spences Bridge group.

B. Gibbs Creek Assemblage

1. Distribution and Thickness

The unit underlies the ridge south of Gibbs Creek and small areas north of that creek. It has been subdivided into

three members. The base of A, the lower member, is not exposed. It has a minimum thickness of 200 feet. On the slope immediately south of Gibbs Creek member B is approximately 700 feet thick but it thins to the south and disappears about one mile south of Gibbs Creek. The top of member C has been removed by erosion; its minimum thickness is 500 feet.

Lithology

Member A

Member A is very uniform consisting only of dark grey or greenish weathering porphyritic andesite with medium- to coarse-grained phenocrysts of plagioclase and medium- to fine-grained phenocrysts of augite. No directional textures were seen.

> About 50% of a typical specimen consists of plagioclase phenocrysts, ranging approximately from 2 mm to .1 mm in size. The plagioclase, complexly twinned and zoned, ranges from intermediate oligoclase to calcic andesine. The mineral is much altered and has inclusions of sericite, carbonate and chlorite. Crystals of augite form a smaller fraction of the phenocrysts. The augite has an approximate composition of $Ca_{41}Mg_{48}Fe_{11}$. (ny - 1.684). The mineral is partly to completely replaced by chlorite. The groundmass consists mostly of very fine-grained plagioclase microlites and small amounts of chlorite, "iron ore", augite and quartz. Cavities are lined by chlorite and filled by quartz and carbonate. Clots of an extremely fine-grained mineral of high birefringence and high relief are dispersed through the rock. The mineral is possibly a carbonate.

Member B

Member B is composed of sedimentary and pyroclastic beds and of volcanic flows. Its composition varies within

small areas and the contacts with the underlying and overlying rocks are mostly gradational.

The sedimentary rocks are most abundant in the vicinity of Gibbs Creek, particularly in the northeastern part of the area. A section here contains approximately 450 feet of sandstone, siltstone, silty argillite, and conglomerate.

Intercalated volcanic flow rocks range from andesite to rhyolite in composition. Light colored flow rocks form conspicuous cliffs around the ridge south of Gibbs Creek and mark the upper boundary of member B. A few specimens examined in thin-section have the composition of dacite, quartz-latite, and rhyolite. They all are very poor in biotite, chlorite, and "iron ore" and contain 10% or more of quartz which in some specimens forms phenocrysts or microphenocrysts. Significant mineralogical differences exist only in the composition of the feldspar. The dacite contains only plagioclase which forms zoned phenocrysts ranging from oligoclase to calcic andesine and microlites of oligoclase. The quartz-latite contains sodic oligoclase and potassic feldspar which both form microphenocrysts. The rhyolite has phenocrysts of sodic andesine and a groundmass consisting dominantly of potassic feldspar. The rock forms a flow breccia and shows under the microscope a spherulitic texture. Most of the spherulites are made up of radiating fibres but one shows concentric differentiation.

The andesites of member B resemble the ones found in the members A and C.

Pyroclastic rocks are widely distributed but form only a small proportion of the total assemblage.

> A tuff from the north side of the lower part of Gibbs Creek weathers light greyish green but contains dark fragments that are up to five millimeters long. It consists of approximately 50% of large partly broken crystals of plagioclase that have the appearance of phenocrysts. They show complex twinning and in many instances fine zoning. (Plate XV) A grain exhibiting the typical oscillatory zoning is sodic labradorite in the core and sodic andesine at the outer margin. Some grains have abundant inclusions of relatively coarse-grained apatite and of "iron ore". A small number of crystals are of clinopyroxene. Lithic fragments constitute a little less than half of the rock. Most of them are from volcanic rocks of intermediate composition but some are from metamorphic rocks, including carbonaceous siltstone and fine-grained meta-quartzite.
>
> Crystals and lithic fragments are embedded in a matrix of glass shards and dust-like glassy matter. Cavities are filled with radiating or felted aggregates of chlorite and carbonate.

Member C

Member C consists mostly of porphyritic andesite, less dacite, and a small proportion of intercalated sandstone and siltstone.

The andesite is uniform in composition and texture. It is dark grey, porphyritic, and lacking in flow-structures. The phenocrysts in the order of their abundance are of plagioclase, clino-pyroxene, and hornblende. The plagioclase is twinned and zoned and ranges in composition from intermediate oligoclase to calcic andesine. Some grains have a spongy or skeletal structure and contain inclusions of sericite, carbonate, chlorite, and volcanic glass. The clinopyroxene, partly replaced by chlorite, is twinned. Some grains have a lower

birefringence around the margins. The composition of the minerals lie in the boundary field of augite, endiopside, and diopside. (n_y = 1.6875, 2v = 53.5°; Fe_{13} Ca_{44} Mg_{43}, augite; n_y = 1.6755, 2v = 49°, $Fe_6Ca_{38}Mg_{56}$, endiopside; n_y = 1.683, 2v = 54°, $Fe_{10}Ca_{44}Mg_{46}$, augite).

The groundmass is very fine-grained and consists dominantly of oligoclase microlites with minor "iron ore" and chlorite. Other mafic minerals and glassy matter may be present but are difficult to identify. Some rocks contain a low percentage of quartz. Apatite is a common accessory.

The rocks are dominantly altered by carbonate and chlorite. Veins are filled with quartz, carbonate, and zeolites, (too fine-grained and too scarce for further identification.)

3. Structure, Correlation, Mode of Origin

The rocks dip uniformly at moderate angles to the northwest. To the west they are inferred to be in fault contact with the Fountain Valley assemblage (see below). Unless the unit is separated from the rocks to the north by a concealed fault, member A is correlative with the basal member of the Spences Bridge group which appears to rest unconformably on a Lower Cretaceous land surface. The problem of correlation has not been solved. Neither has evidence for such a fault been obtained nor have underlying rocks of the Pavilion group been observed south of Gibbs Creek. Perhaps the Lower Cretaceous erosion surface sloped down to the south. The unit is tentatively referred to the lower Division of the Spences Bridge group.

Upper Division

1. Distribution

The rocks referred to the uppermost part of the Spences Bridge group are exposed on the west side of the Fraser River between the mouth of Lee Creek and the slopes north of McKay Creek. South of Leon Creek they are concealed by overburden and overlying middle or late Tertiary olivine basalts. As the structure of these rocks is mostly unknown their thickness is uncertain.

2. Lithology

The unit consists mostly of andesite; basalt, rhyolite and tuff are less common.

The andesites are grey or red and apahanitic or aphanitic-porphyritic. The phenocrysts are of finer grain than in the Gibbs Creek assemblage. Flow structures are rare.

The phenocrysts consist mostly of plagioclase but in some thin-sections crystals or clinopyroxene, hornblende, or biotite or their altered equivalents are present. In some rocks transitional to dacite, a few of the phenocrysts are of quartz.

The groundmass consists dominantly of plagioclase microlites, a few percent of "iron ore", and varying amounts of glass.

In most specimens the plagioclase is calcic andesine or andesine-labradorite zoned over a narrow range. Plagioclase phenocrysts are mostly twinned; the groundmass micro-

lites are in part untwinned. The mineral is replaced by carbonate, sericite, and an unidentified zeolite. The mafic phenocrysts are partly or completely replaced by chlorite, "iron ore" and chalcedony. Other minerals present as alteration or cavity filling are prehnite, chalcedony and zeolites.

The textures are intergranular, trachytic or hyalophitic. Some specimens are flow breccias.

> A typical specimen of basalt is brownish grey, aphanitic, and vesicular. Macroscopically it can hardly be distinguished from the andesites of the unit. A thin-section contains approximately 80% of plagioclase; the remainder consists dominantly of clinopyroxene and some "iron ore". The plagioclase is euhedral or subhedral and forms lath-like crystals. It is twinned and shows fine zoning, the composition ranging from An_{45} to An_{70}. The clinopyroxene is euhedral, subhedral, or anhedral and partly zoned. The composition of the larger grains was determined as $Fe_7\ Ca_{43}\ Mg_{50}$, endiopside, (ny = 1.679, 2v - 53°).
>
> A specimen of rhyolite is light buff, porphyritic-aphanitic, and lacking in flow structures. The phenocrysts are up to 2 millimeters long and consist of plagioclase, andesine, quartz, and a few smaller crystals of biotite. The andesine is clear, untwinned, fractured, and includes quartz, biotite, and plagioclase crystals of fine to intermediate size. The plagioclase has an approximate composition of An_{33}. Most grains are twinned. The plagioclase has inclusions of sericite and glass and one grain is replaced by a zeolite which is possibly laumontite. Some grains have a spongy structure. The quartz is rounded and embayed by minerals of the groundmass. The crystals are rimmed by fibrous intergrowths of feldspar and silica that are oriented approximately perpendicular to the faces. The groundmass consists dominantly of fibrous partly spherulitic intergrowths of silica and potassic feldspar, of quartz, and small amounts of biotite. Apatite and "iron ore" occur as accessories.

3. Structure, Age, and Correlation

Near the mouth of Slok Creek the rocks dip at low angles to the southeast and seem to underlie the Kingsvale group. To the west they are inferred to be in fault contact with the Jackass Mountain group and to the east with the Cache Creek group.

As the unit underlies sedimentary rocks of Albian age it probably is Aptian.

KINGSVALE GROUP

1. Distribution and Thickness

Sedimentary and volcanic rocks on the east side of the Fraser River about 1-1/2 miles north of Glen Fraser formerly included with the Spences Bridge group are now correlated with the Kingsvale group. The rocks have been subdivided into two Divisions, A, and B. Division A is approximately 700 feet thick. Although the top of B has been removed by erosion, more than 700 feet of volcanic rocks are still present. (Reinecke, 1912, p. 12).

2. Lithology

Division A

Division A consists dominantly of volcanic arenite that grades into both pebble conglomerate, and siltstone. Conglomerate forms perhaps one third of the sequence, siltstone is comparatively rare.

Most of the volcanic arenite is grey but some beds are red. The rocks consist dominantly of volcanic fragments, of less than 50% of plagioclase and small amounts of quartz, "iron ore", and biotite. The lithic fragments are mostly andesitic in composition, some are basaltic and felsitic. Where the grains are not replaced by the groundmass they are subrounded to rounded. In one specimen neither carbonate nor "iron oxide" nor quartz can be detected as cement. Another specimen contains approximately 50% of rusty weathering carbonate as matrix. Perhaps the carbonate was introduced by hydrothermal solutions and has replaced some of the sedimentary material.

Most rocks are well bedded and size-sorted. Locally the "iron ore" is concentrated in thin laminae. In some localities graded bedding and cross-bedding can be observed.

A cobble conglomerate on the east side of the Fraser River, near the hidden contact with the Spences Bridge group consists dominantly of volcanic roundstones but also contains some granitic cobbles.

Division B

Division B consists dominantly of andesite, a few flows of dacite, and several thin layers of tuffaceous and sedimentary rocks.

The andesite is dark grey, light grey, or red brown. Most of the rocks are aphanitic-porphyritic but some are aphanitic.

Most of the phenocrysts are twinned and zoned plagioclase that ranges in composition from intermediate andesine to intermediate labradorite; the average composition seems to be calcic andesine. Some rocks also contain phenocrysts of oxyhornblende. In the groundmass, which is in most specimens very fine-grained, abundant microlites of plagioclase and a few percent of "iron ore" can be recognized. Mafic silicates, too fine-grained for identification and volcanic glass are present in small amounts. Apatite occurs as an accessory. Light colored rocks that are transitional to dacite contain fine-grained quartz in the groundmass. The rocks are altered by sericite, chlorite, and carbonate.

Some specimens have a trachytic texture.

A specimen of dacite is porphyritic-aphanitic and contains elongate prisms of amphibole in a light greenish grey groundmass.

> Microscopic examination shows that the amphibole is oxyhornblende. In the groundmass a few micro-phenocrysts of plagioclase, lath-like plagioclase microlites, a small fraction of "iron ore", and very fine-grained interstitial quartz can be identified. The microlites are sodic andesine; the micro-phenocrysts are zoned and range in composition from sodic to calcic andesine.

3. Structure

The contact of Division A with the Spences Bridge group is not exposed. The presence of cobble conglomerate near the base of Division A suggests an unconformity. Division B probably overlies A conformably. To the west the

Kingsvale group is in fault contact with the Jackass Mountain group, to the east in fault contact with the Pavilion group and possibly with rocks of the Spences Bridge group overlying the Cache Creek group. In the vicinity of the fault contacts the strata dip steeply, elsewhere the dips are low to moderate.

4. Mode of Origin, Age, and Correlation

The well sorted and generally coarse-grained character of the sediments of Division A indicates deposition by running water, and the abundance of plant matter a continental environment. Apparently they were laid down on the flood plain of a stream that drained a terrain underlain by volcanic rocks, mostly andesites.

Plant fossils found in the lower half of member A (F18) were identified by Professor G.E. Rouse as follows:

Menispermites (cf. with Bell (1957), p. 130))	Upper Blaimore-Whitemud (Albian-Maestrichtian)
Celastrophyllum (celastrinites?) (acutidens)	(Albian-Basal Eocene)
Trochodendroides (Cercidiphyllum?) (cf. potomacensis	Upper Blairmore (Albian)
Platanus sp.	(Albian through Tertiary)
cf. Myrtophyllum boreale or: cf. Magnoliaephyllum	(Albian-Tertiary) (Upper Cretaceous)
Cissites sp.	(Albian of Portugal) (Patapsco of Maryland (Lower Cretaceous) (Upper Cretaceous of U.S.Rockies)

Professor Rouse states in his report that "four and possibly five of the six species have been recorded in the (Albian) Kingsvale by Bell, but none of these is found in the Spences Bridge (Aptian) ... the material ... is younger than Aptian and hence younger than the Spences Bridge group."

Duffell and McTaggart state that the Kingsvale group in the Ashcroft map area has a sedimentary unit at its base which is locally 800 to 1000 feet thick and consists of arkose, grit, mudstone, conglomerate, and argillite. Outcrops of these rocks extend for 16 miles along Nicola River. Many of the beds on Nicola River contain fragments of stems and leaves, and the mudstones carry well preserved plant fossils. One of the fossils collected near Glen Fraser, Menispermites, was also found in the belt on Nicola River (Duffell and McTaggart, 1952, p. 57-58). These relations suggest that Division A at Glen Fraser and the sedimentary belt on Nicola River are perhaps correlative and may represent the same flood-plain. However, as these are continental deposits of possibly small extent the correlation is not certain.

SPENCES BRIDGE GROUP OR KINGSVALE GROUP

Flows of andesite and dacite which could be assigned either to the Spences Bridge or Kingsvale groups are exposed immediately northeast of Glen Fraser, on the east side of the road to Pavilion.

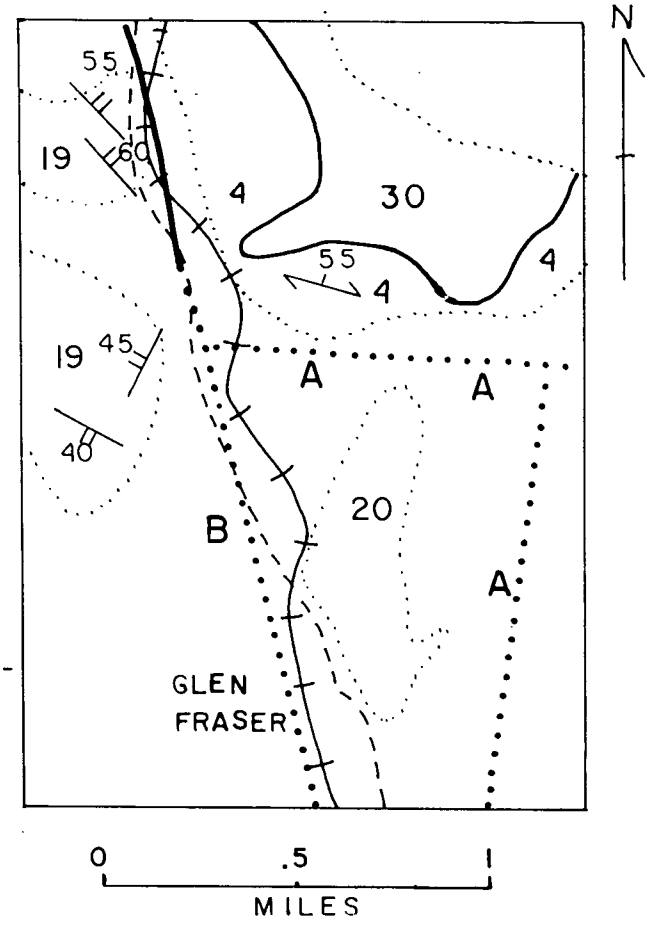
> A specimen of andesite transitional to basalt contains coarse phenocrysts of plagioclase and completely chloritized pyriboles and a very fine-grained groundmass in which plagioclase microlites and "iron ore" can be identified. The plagioclase of the phenocrysts has a spongy structure, is twinned and zoned, and ranges in composition from andesine-labradorite to labradorite-bytownite. The microlites are of andesine-labradorite. The rock shows carbonate and chlorite alteration.

The dacite weathers light grey and forms flow breccias which contain fragments of dark colored volcanic rocks.

> A specimen has phenocrysts of calcic andesine that are twinned, zoned, and strongly altered, of a pyribole that is completely replaced by chlorite and "iron ore", and of quartz. The groundmass contains plagioclase, a relatively high proportion of quartz and a low proportion of "iron ore" and chlorite. Apatite is relatively coarse-grained and abundant. Some of the phenocrysts are replaced near cleavages by a mineral with a low negative relief and low birefringence which is either orthoclase or a zeolite. No orthoclase could be identified in the groundmass.

The outcrops are separated from cliffs of Division B of the Kingsvale group by an expanse of overburden about one half mile wide.

The stratigraphic position of these rocks is uncertain because the location of the boundary fault between the Pavilion group and the Kingsvale group in this area is unknown. If this longitudinal fault is not offset by a transverse fault it continues under the overburden in the vicinity of the Pavilion road and the rocks belong to the lower Division of the Spences Bridge group which overlies the Pavilion group. However, the rocks in the vicinity of the road show no signs of alteration and shearing. The longitudinal fault may be



LEGEND

FAULT, LOCATION KNOWN

A, B ALTERNATIVE CONTINUATIONS OF FAULT

CONTACT

OUTCROP BOUNDARY

ATTITUDE, SCHISTOSITY, LAYERING OF VOLCANIC ROCKS

30 QUARTZ-DIORITE

20 KINGSVALE GP., DIV. B, OR SPENCES BRIDGE GP., LOWER DIV.

19 KINGSVALE GROUP, DIVISION B

4 PAVILION GROUP, DIVISION II

ROAD

RAILROAD

FIG. 5: GEOLOGY OF GLEN FRASER AREA

offset by a transverse fault along the southern border of the stock south of Pavilion in which case the volcanic rocks would be part of Division B of the Kingsvale group. The alternatives are shown on Figure 5.

FOUNTAIN VALLEY ASSEMBLAGE

1. Distribution and Thickness

The Fountain Valley assemblage made up largely of volcanic rocks, is exposed on both sides of the Fraser River east of Fountain Creek. It has been subdivided into three members, A, B, and C. The base of Member A, which is in fault contact with the Jackass Mountain group, is not exposed. Member A has a minimum thickness of 1200 feet. Member B is lenticular; its thickness ranges from 600 feet to 2500 feet. The upper part of Member C which is in inferred fault contact with the Gibbs Creek assemblage is not exposed. The member is about 1000 feet thick.

2. Lithology

Member A

Member A consists mostly of interlayered felsitic and andesitic rocks. About 1000 feet southwest of the long railroad tunnel near Gibbs Creek a short lens of conglomerate is intercalated with the volcanic flows.

Successions of andesitic rocks form units about one hundred feet thick, and individual felsitic flows range up to 20 feet in thickness.

The felsitic rocks are light grey to buff, aphanitic, and lacking in flow structures.

> A thin-section of a dacite consists mainly of andesine microlites, 10 to 15 percent of quartz and small amounts of "iron ore" and volcanic glass. The microlites show subparallel orientation. The rock is altered by carbonate and chlorite.

Other specimens examined are probably latite or quartz latite and rhyolite; but the exact composition of these rocks cannot be determined because of their extremely fine grain size.

> A typical specimen of andesite is reddish brown, aphanitic and forms a flow-breccia. In thin-section a few micro-phenocrysts of plagioclase are visible in a groundmass that consists mostly of microlites of andesine. Within small areas of the thin-section the microlites show parallel alignment. Incorporated fragments have the same mineral composition as the matrix but differ in grain size and in the orientation of the microlites. Cavities are filled by very fine-grained quartz and chlorite. The section is stained by "iron oxide".

Member B

Member B, a conspicuous, cliff-forming unit, is made up of acidic volcanic flows ranging from dacite to rhyolite. It seems to consist of a multitude of flows but the boundaries between individual flows are difficult to determine. The rocks are light grey on fresh surfaces and reddish or brownish buff on weathered surfaces and aphanitic or aphanitic-porphyritic. In some localities the plagioclase phenocrysts are aligned and probably oriented parallel to the layering of the flows.

A thin-section of a porphyritic-aphanitic dacite consists of about 30% of phenocrysts, and 70% of groundmass. Most of the phenocrysts are of plagioclase; a few consist of biotite, "iron ore" that has replaced biotite, and quartz. The plagioclase, which has the composition of calcic andesine, is twinned and zoned. The plagioclase phenocrysts show a spongy structure which is due to replacement by minerals of the groundmass and carbonate. The biotite is replaced inwards from its margins and cleavages. The groundmass consists dominantly of lath-like sodic oligoclase. About 10 to 15% of the groundmass is made up of anhedral quartz. Smaller fractions are formed by "iron ore", biotite and volcanic glass. Potassic feldspar is rare or absent. Apatite occurs as an accessory mineral.

A specimen of rhyolite weathers brownish buff and is light greyish buff on fresh surfaces. Under the microscope fine-grained phenocrysts of andesine and quartz are visible in a microfelsitic groundmass. The minerals of the groundmass, probably intergrowths of potassic feldspar and cristobalite (?) are fibrous and form aggregates most of which show a radiating structure. Undulating, brecciated flow layers made up of relatively fine-grained aggregates alternate with layers of coarser aggregate size. Fractures in the specimen are filled with "iron oxide".

Member C

Only the lowest part of Member C is exposed. It consists of andesite, andesitic flow breccia, and a few feet of lithic sandstone that contains seams of plant matter.

A typical andesite specimen from the east shore of the Fraser River weathers purple to greyish green. The rock is aphanitic-porphyritic and contains a small percentage of plagioclase phenocrysts that are largely replaced by carbonate. The groundmass is made up dominantly of microlites of sodic andesine, and a few percent of "iron ore" and chlorite. The microlites show sub-parallel orientation. The rock contains veinlets of carbonate, quartz, and chlorite.

3. Structure, Mode of Origin, Age

The volcanic flows strike approximately N 20° W and dip at moderate to steep angles to the northeast. At one locality near the contact of the members A and B a felsitic flow of B includes fragments of a more basic rock probably from member A; the stratigraphic tops therefore probably face to the northeast.

The unit seems to occupy a graben between older rocks to the west and to the east. The fault contact with the Jackass Mountain group to the west is exposed at several localities on both sides of the Fraser River. The contact with the lower part of the Spences Bridge group is covered by an expanse of overburden; a fault between these two units is suggested by cross section B-B' (Figure 1). This inferred fault perhaps is connected with the normal fault that forms the western boundary of the Cache Creek group in the central and northern parts of the map area.

The association of these volcanic rocks with conglomerate and with sandstone carrying seams of plant matter indicates a continental origin.

The structure suggests that the Fountain Valley assemblage is younger than the Gibbs Creek assemblage. Its age may lie anywhere between the Aptian stage of the Lower Cretaceous and the early or middle Tertiary.

WARD CREEK ASSEMBLAGE

1. Distribution and Thickness

Volcanic rocks of Cretaceous or early Tertiary age form a narrow elongate belt on the west side of the Fraser River between Leon Creek and the northwestern extremity of the map area. As the belt is in fault contact with other units on two sides, and as its internal structure is largely unknown no accurate statement of its thickness can be given; several thousand feet of volcanic rocks may be present.

2. Lithology

The unit is made up dominantly of andesite, less dacite and felsitic rocks and minor tuff, basalt, lithic sandstone, and coal.

The andesite weathers dark grey or purple and is mostly massive. Flow-banding and porphyritic textures were rarely seen.

> A thin-section of a typical andesite-flow breccia is made up dominantly of microlites of calcic andesine, about .05 mm long, and a few crystals of biotite in an extremely fine-grained, partly glassy groundmass. Although the mineral composition is uniform throughout the slide individual breccia-fragments can be distinguished by the variation in the orientation of the microlites. The section is veined by chalcedony.

In a few localities flow-banded dacite (?) was observed. Macroscopically the rocks are finely layered and porphyritic. The flow layers range from purple to cream in color and are

a few millimeters thick. They show small flow folds one or a few feet across and fine crenulations.

> Under the microscope phenocrysts are seen to consist of plagioclase, quartz, and biotite. The plagioclase, mostly sodic andesine, is twinned, zoned and has inclusions of glass. The quartz phenocrysts are partly embayed and corroded by minerals of the groundmass. The groundmass consists of minute microlites of plagioclase, and very small crystals of quartz and biotite embedded in a matrix of glass. The microlites form flow-layers that curve around the phenocrysts. Some flow layers, more coarse-grained than most of the groundmass, are relatively rich in quartz.
>
> A specimen of basalt from the upper part of Trimble Creek is very dark on fresh surfaces, weathers dark green and is aphanitic. It contains microphenocrysts of plagioclase and clino-pyroxene. The plagioclase, sodic bytownite in composition, is lath-like, twinned and finely zoned. Some of the clino-pyroxene, diopside-augite, (n_y=1.6835, 2v-55°, $Ca_{45}Mg_{46}Fe_{9}$) shows twinning, and a few grains have rims of lower birefringence. Some of the crystals are replaced by chlorite. The groundmass consists dominantly of minute plagioclase microlites, some "iron ore", chlorite and other mafic minerals too fine-grained for identification, and volcanic glass.

The rocks of this unit show no signs of metamorphism but are locally altered. Some are veined or partly replaced by carbonate, chlorite, chalcedony or epidote. Felsitic rocks in the shear zone southwest of the Big Bar ferry contain crystals of pyrite, the amygdules in an andesite flow are filled with quartz and pistacite.

3. Structure

The Ward Creek assemblage lies approximately on strike with parts of the Kingsvale group, the Spences Bridge group,

and the Fountain Valley assemblage, and like these it is believed to occupy a graben. Between Leon Creek and Big Bar Creek the unit is in fault contact with the Pavilion group to northeast. North of Big Bar Creek it is unconformably overlain by the French Bar formation. To the southwest the rocks are inferred to be in fault contact with Division C of the Jackass Mountain Group. They are separated from the DIVISION of the Spences Bridge group by overburden and overlying middle or late Tertiary olivine basalt.

About one mile southwest of the Big Bar ferry a zone of shearing and alteration is exposed for approximately 1000 feet. The schistosity of this zone dips steeply to the west. The shear zone possibly is part of a more extensive fault that may terminate the French Bar formation on the east side of the Fraser River. However, the possible continuations of the shear zone to the north as well as to the south are covered by expanses of overburden.

Little is known about the internal structure of the Ward Creek assemblage because determinations of attitudes and stratigraphic tops in most localities are difficult to obtain. Between Watson Bar Creek and Big Bar Canyon the rocks in the western part of the volcanic belt dip steeply and strike approximately N 35° W. The stratigraphic tops face to the northeast. At several localities northwest of Big Bar Canyon moderate northeasterly dips were observed.

4. Mode of Origin, Age and Correlation

The presence of coal seams indicates a continental environment.

The unit is older than the unconformably overlying French Bar formation. It may be correlative with the upper Division of the Spences Bridge group, with parts of the Kingsvale group or Early Tertiary volcanic rocks of the Quesnel map-area. Its age may lie anywhere between the Aptian stage of the Lower Cretaceous and the Oligocene.

McKenzie (1920) referred these rocks to his Oligocene Taseko formation. However, as this formation also includes olivine basalts it probably comprises rocks ranging from Early to Middle or Late Tertiary and may have to be redefined.

FRENCH BAR FORMATION

The French Bar formation extends from Big Bar Creek to the northwestern extremity of the map area near French Bar Canyon. Near Big Bar Creek it is at least 2100 feet thick. The formation consists mostly of cobble-pebble- and granule-conglomerate, less volcanic arenite, and small amounts of siltstone. (Plates XVI, XVII).

Beds of arenite and conglomerate are mostly from one to twenty feet thick, and individual beds of arenite and conglomerate can be traced for several hundred feet. A unit composed dominantly of volcanic arenite and some interbedded conglomerate is exposed for about 1-1/2 miles.

The rocks weather yellowish or brownish and conglomerate strata are darker colored than arenite. The sediments all seem to have been derived from volcanic rocks that were mostly of andesitic composition. The conglomerates consist almost entirely of volcanic fragments. The arenites in addition to the volcanic fragments, contain a small amount of feldspar, quartz, biotite, and "iron ore". The siltstones are made up of the same minerals and chlorite. Rounding and sorting vary considerably, but in general the beds are moderately well size-sorted and the fragments subrounded. Conglomerates and arenites have a matrix of silt-sized rock-flour and are partly cemented by "iron oxide" and rarely carbonate. Some arenites are very poorly consolidated. Locally the arenite contains seams of fossil plants.

Graded bedding and cross bedding are rare and were observed only where the sandstone is interlaminated with silt-stone.

The French Bar formation overlies the Ward Creek assemblage unconformably. It is overlain by a volcanic sequence that is in fault contact with the Pavilion group. The strata strike uniformly about N 25° W and dip steeply or moderately to the northeast. In the southeastern part near the boundary fault of the Pavilion group the dips are approximately 80° and in the northwest they are close to 45°. Near Big Bar Creek exposures of the conglomerate end abruptly. Possibly the formation here is cut off by a fault; a strong

shear zone that may be part of such a fault is exposed in the volcanic rocks on the west side of the river. Alternatively, the basin of deposition may have ended here. The formation is intruded by numerous basaltic dykes and sills.

The associated plant matter indicates a continental environment for the formation. The generally rounded nature of the fragments and local laminations suggest deposition by running water. Beds that show poor sorting and rounding may have been deposited as mudflows. The coarse size of the fragments is indicative of steep gradients. These gradients may be related to contemporaneous volcanism or tectonism.

Plant fossils found in the upper part of the formation, near Big Bar Creek were identified by Professor G.E. Rouse as follows:

DIVISION	SPERMATOPHYTA	
Class	GYMNOSPERMAE	
Order	CONIFERALES	
1.	Metasequoia occidentalis (Newb.) Chaney.	Paleocene-Miocene
2.	? Sequoia nordenskioldi Heer.	Paleocene-Eocene
Class	ANGIOSPERMAE	
Sub-Class	DICOTYLEDONAE	
3.	Cinnamomum sp. - cf. affine Lg	Upper Cretaceous-Eocene.
4.	Carpinus grandis Unger.	Tertiary
5.	? Salix sp. - cf. S. wyomingensis Kn. and Cock	Paleocene-Miocene
6.	? Laurophyllum sp. - cf. L. laraminum (DN) Bell	Paleocene
7.	Tetracera sp. - cf. T. castaneafolia Mac G.	Eocene

8. Hamamelis ? clarus Hollick Paleocene-Eocene
9. Alnus sp. cf. A. cremastogynoides Berry Eocene-Oligocene

Rouse states in his report:

"As can be noted, the determinations indicate a definite Tertiary age for the strata, with a preference towards an Eocene dating. However, it is possible that the beds are either earlier Tertiary or Oligocene; a more definite age determination cannot be based on the relatively poorly preserved fragmentary remains. It is the writer's considered opinion that the Big Bar flora is closely contemporaneous with those from other Tertiary basins in B.C. e.g. Chu-Chua, and Princeton. The ages of these latter sediments have been variously ascribed as Eocene to Miocene. The closest more probable age would seem to be Upper-Eocene or Oligocene for the Big Bar flora."

In 1920 McKenzie described and defined the French Bar formation as follows: (p. 76 A - 77 A)

"This formation is well exposed on upper French Bar Creek, and underlies the country westward across the ridges in which Yalakom river heads as far as upper Churn Creek drainage basin. It may have a considerable extension in the area southeast of that just described."

"The French Bar formation is made up of very coarse conglomerates with lenticular sandstone beds in subordinate amounts. The rocks are much less indurated than any of the sediments of those included in the Eldorado series" (Lower

Cretaceous), and the pebbles and boulders easily weather out of their sandy matrix. The formation is characterized by a high percentage of large, well rounded boulders of the plutonic rocks of the Coast Mountains .... The conglomerate beds range from 10 to 100 feet thick, and the formation as a whole gives the impression of being of fluviatile origin." ...

"The thickness of the French Bar formation as exposed near the creek of that name is approximately 2000 feet."

"On lithologic and structural grounds, this formation is tentatively correlated with the Coldwater group of Dawson, supposedly of Oligocene age".

As the conglomerate and arenite on the Fraser River lie only approximately 6 miles to the east of the French Bar formation and as they have a comparable lithology, sedimentary structure and thickness they are tentatively correlated with that formation. The granitic boulders reported by McKenzie are probably of local origin and were not transported into the Big Bar area. The deposits appear to be older than the Tertiary sedimentary rocks on Big Bar Creek, on Leon Creek, and near Pavilion because they are much stronger deformed.

VOLCANIC ROCKS OVERLYING THE FRENCH BAR FORMATION

The French Bar formation is overlain by a minimum of 2000 feet of tuff, andesite, basalt, felsite, and minor seams of coal.

The andesite is generally greyish brown, aphanitic, and mostly massive. A specimen of basalt weathers greyish brown and has a vesicular, aphanitic texture.

> It consists of abundant microphenocrysts of plagioclase and augite in a groundmass of very fine-grained plagioclase, clino-pyroxene, "iron ore", and volcanic glass and its alteration products. The plagioclase microphenocrysts, intermediate to sodic labradorite, are lath-like, twinned, and show oscillatory normal zoning. They have a sub-parallel orientation. Some of the augite phenocrysts (ny=1.6905 2v-52°; $Ca_{43}Mg_{41}Fe_{16}$) also show twinning.
>
> A thin-section of a whitish relatively light felsitic rock contains a few corroded phenocrysts of plagioclase and quartz in a vesicular glassy groundmass.

To the northeast the volcanic rocks are in fault contact with the Pavilion group. This contact is not exposed but a fault can be inferred from the fact that the Pavilion group strikes into the Tertiary volcanics, from the steep dips near the contacts, and from shearing and alteration.

MIDDLE OR LATE TERTIARY SEDIMENTARY AND VOLCANIC ROCKS

1. Sedimentary Rocks near Pavilion

A. Distribution and Thickness

Middle or Late Tertiary outcrops near Pavilion lie in a northeasterly trending zone that is approximately 5 miles long and 1-1/2 miles wide. The exposures are confined to narrow zones along hill sides. The elevation of the lowest outcrops is 3200 feet at the northeastern extremity and nearly 4000 feet at the southwestern extremity. Individual exposures do not exceed 200 feet in thickness but the vertical range of the deposits on the slope south of Pavilion Creek is greater than 500 feet. On the north side of the same valley

however, the rocks are less than one hundred feet thick.

A small outcrop of similar rock was noted at approximately 4000 feet elevation on the slope above Moran, and another one lies immediately northeast of the railroad crossing near Glen Fraser.

B. Lithology

The rocks consist of lithic arenite, conglomerate, and a small proportion of carbonaceous shale. The contacts between these rock types are well defined, but the rocks show no pronounced internal stratification. The rocks and the soil derived from them are brick-red. In hand-specimens of conglomerate and arenite, argillite, chert, quartz, and rarely chlorite fragments can be recognized. These particles range from sand to cobbles. The weakness of their cement has resulted in the formation of numerous caves, and in a major land slide about one mile east of Pavilion.

Three specimens of lithic arenite examined under the microscope contain 10-35% quartz, 0-9% feldspar, 11-35% chert, and 20-50% lithic fragments, mostly of argillite and a small proportion of other sedimentary and metamorphic rocks. Minor detrital constituents are carbonate, muscovite, and tourmaline.

The fragments in most specimens are well size-sorted. Originally they were subrounded to rounded but they have partly been replaced by the matrix which consists of carbonate and "iron oxide".

C. Structure

The unit overlies unconformably strata of the Pavilion group and small bodies of igneous rocks assigned to the Coast Intrusions. The beds lie horizontally or dip at angles of less than ten degrees and appear nearly everywhere little disturbed. An isolated outcrop by the Pavilion Mountain road, however, has pronounced jointing, possibly parallel to bedding, that dips 55 degrees east.

Although the exposures of the Tertiary rocks on the slope north of Pavilion Creek terminate at the fault contact between Division I and II of the Cache Creek group, there is no evidence that the Tertiary sedimentary rocks were displaced by that fault. It is more likely that the contact formed a topographic control of deposition. The amphibolites to the west of that contact which are indurated by a dioritic intrusion are probably more resistant to weathering than the ribbon cherts to the east. In Tertiary time they may have formed the margin of a basin and received no sediments.

D. Mode of Origin

The sediments appear to be derived mostly from rocks of the Cache Creek and Pavilion groups and to minor extent from Coast Intrusions. As they consist of relatively coarse, well sorted material they probably represent a flood plain. The red color of the rocks indicates oxidizing conditions which prevail only in well drained areas. The black shale, however, shows that locally swamp conditions existed.

The original limits of the deposits are only partly known. On the northeast they lap against a pluton which rises above the Tertiary beds, and north of Pavilion Creek they become thin and probably disappear. They may have been laid down in a valley that was connected with the area south of Leon Creek and partly coincided with the present Fraser River valley.

E. Age

Dawson correlated the sediments with the sandstones underlying the basalt plateau on Leon Creek and placed them in the middle Miocene. (Dawson, 1895, p. 212B). Duffell and McTaggart include them with the Coldwater Beds (?) of the Kamloops group which is considered to be Miocene or earlier. (p.66)

Although the rocks near Pavilion are similar in lithology to those on Hat Creek they differ in structure. The strata on Hat Creek dip at angles up to 60° whereas the beds near Pavilion lie almost horizontally.

Dawson's correlation of the sediments near Pavilion with those south of Leon Creek is supported by several features. Both strata are approximately at the same elevation, both seem to be undisturbed and both appear to be older than the latest volcanic rocks of the area. It will be mentioned that the strata south of Leon Creek probably underlie Middle to Late Tertiary olivine basalts. The sediments on Pavilion Creek are at a slightly lower elevation than an isolated remnant of Tertiary andesite situated about 1-1/2 miles to the northeast on the plateau on Pavilion Mountain. Duffell and McTaggart

pointed out that the sedimentary outcrop near Glen Fraser is cut by two dykes. (p. 65p). Such dykes may well be related to the latest volcanic activity.

The upper surface of the sedimentary rocks near Pavilion is continuous with a well preserved erosion plain on Pavilion Mountain of approximately 20 square miles. It is believed that surfaces of this type are not older than Miocene. (Thornbury, 1954, p. 26).

2. Sedimentary Rocks Associated with the Olivine Basalts near Leon Creek and Big Bar Creek

About two miles south of Leon Creek and one mile west of the Fraser River poorly consolidated sediments are exposed for about one mile along the steeply sloping margin of a plateau at an elevation of approximately 3500 feet. The thickness of the exposed strata is less than one hundred feet, but the unit may be much thicker. The rocks, mostly brownish and reddish, range from sandstone to boulder conglomerate and are in part well bedded. Different layers can be distinguished by color or grain size. The beds are from one to ten feet thick. The detrital material consists mainly of chert and argillite, and some granitic fragments. Pebbles and sand grains are poorly rounded. The cement consisting of carbonate and "iron oxide" is mostly weak. The beds rest unconformably on quartz diorite. A low dip has probably been produced by recent slumping. The sediments seem to have been derived from rocks of the immediate vicinity. They probably underlie olivine

basalt but may only be slightly older than that volcanic rock.

At many localities around the margins of the Tertiary basalt the soil contains unusually well rounded pebbles and cobbles. These roundstones are probably derived from conglomerates which underlie the basalts but are hidden by the abundant talus that surrounds their cliffs at the margins. Such conglomerates would be correlative with the outcrop described above and with the sedimentary rocks near Pavilion.

Flat lying sedimentary rocks, 200 to 300 feet thick are exposed for approximately one mile along the upper margin of the plateau north of Big Bar Creek. To the east they interfinger with olivine basalt, and to the west their contact is covered. The rocks are mostly pebble- or cobble-conglomerate but include boulder-conglomerate, sandstone, and minor amounts of mudstone. The roundstones are made up of chert, argillite, limestone, and greenstone, all derived from the Cache Creek or Pavilion groups and from granitic rocks, and highly vesicular Tertiary basalts. The fragments are well rounded and fairly well sorted and cemented by carbonate. The strength of the cement varies irregularly throughout the rock. The sediments seem to have been deposited by running water and apparently are contemporaneous with the olivine basalts. They are probably slightly younger than the Tertiary sedimentary rocks near Leon Creek and near Pavilion.

3. Olivine Basalt

A. Distribution and Thickness

The outcrops of Middle or Late Tertiary olivine basalts are confined to two narrow zones. One is situated on the west side of the Fraser River between McKay Creek and Watson Bar Creek; (Plate XVIII), the other one, located approximately 10 miles to the north, extends along the lower part of Big Bar Creek. The elevation of the upper surface of the first zone gradually drops from 4400 feet in the south to 3900 feet in the north over a distance of approximately 10 miles; the upper surface of the second zone drops from 3900 feet in the west to 3600 feet in the east over a distance of approximately 5 miles. These upper surfaces seem to represent the original top of the volcanic flows because they are of great regularity and marked by coarse vesicles. They are overlain only by a thin veneer of soil and form plateaus which are well expressed on topographic maps. The elevations of the lower contacts are known with less accuracy because they are hidden by talus and because the outer margins of the volcanic plateaus have slumped almost everywhere. Probably the basalts are nowhere thicker than 200 feet. The sheet south of Leon Creek seems to thin out to the west; the flows on Big Bar Creek appear to be thicker in the west than in the east where they interfinger with sediments. Individual flows are from 10 to 50 feet thick. Some of them were traced along the margin of the plateaus for several hundred feet but they may be much more extensive.

B. Lithology

The rocks are red-brown and some of them are relatively coarse-grained. Dark green crystals of olivine about one to two millimeters long can be detected with the unaided eye. The upper parts of the flows are highly vesicular. Columnar jointing is a common feature. North of Big Bar Creek ellipsoidal structures about one foot or a few feet thick that resemble pillows were seen.

Seven specimens studied in thin-section consist approximately of 50-60% plagioclase, 7-22% olivine, and 3-5% "iron oxide". The balance is made up dominantly of clinopyroxene. Orthopyroxene, not identified in all of the specimens, forms less than 1% of the rock. Apatite, zircon (?), and an unknown mineral occurring as very fine-grained needle-like inclusions in the plagioclase are present only in minute proportions. (Plate XIX).

The plagioclase forms euhedral to subhedral microlites that exhibit Carlsbad and albite twinning. The other twin laws are less commonly represented. The mineral shows zoning, mostly of the normal type, and has an average composition near An_{60}. It is little altered.

Some crystals of olivine are subhedral, but most of the grains are anhedral. The composition of the mineral ranges from Fo_{84} to Fo_{72} and averages Fo_{80}. In several specimens the olivine is partly altered to brownish "iron oxide". The alteration is strongest around the outer margins of the grains and near fractures but also occurs in their interior.

The orthopyroxene is subhedral and colorless unless altered. In one specimen its composition was determined as En_{79} (n_y=1.685, - 2v). In some specimens the mineral is altered by "iron oxide."

The clinopyroxene forms very fine-grained subhedral or anhedral grains the composition of which is difficult to identify. Most of the clinopyroxene seems to be augite but some pigeonite may be present. In one specimen the augite has an approximate composition of $Ca_{41}Mg_{44}Fe_{15}$ (n_y=1.689).

Of the "iron ore" minerals ilmenite is much more abundant than magnetite.

The texture of the rocks is seriate and intergranular. In some specimens the plagioclase microlites show subparallel alignment. The size of the essential minerals in a relatively coarse-grained specimen ranges approximately from 2mm to .02 mm and in a fine-grained rock from 1 mm to .015 mm. Two types of texture may be distinguished: either olivine alone forms the large grains (type I) or the large grains consist of plagioclase and orthopyroxene as well as olivine (type II). The intermediate range is dominated by plagioclase but also contains some olivine and clinopyroxene. The finest grade is made up of mostly clinopyroxene and small amounts of plagioclase.

TABLE 3

MINERAL COMPOSITION OF 7 SPECIMENS OF OLIVINE BASALT

Specimen #	% plagioclase	% clinopyroxene	% orthopyroxene	% olivine	% iron oxide alter-	% iron ore	nx' of (001) cleavage fragments of plagioclase	Composition in % of An ± 2% 2*	n_y of olivine	Comp. in% Fo ± 1%	Texture
1c	51	17	0	16	13	3	1.5587 ± .001	61	1.6855 ± .002	84	II
1b	59	22	1	14		4	1.5584 ± .001	60	1.6893 ± .002	82	II
1a	60	20	0	15		5	1.5584 ± .001	60	1.6900 ± .002	81.5	II
2c	57	32	trace	8		3	1.5585 ± .001	60	1.6991 ± .001	77.5	II
2b	50	25	0	15	6	4	1.5586 ± .001	61	1.7100 ± .001	72.5	I pilotaxitic
2a	50	25	0	8	14	3	1.5590 ± .002	62	1.6900 ± .001	81.5	I trachytic
3	49	40	0	7		4	1.5581 ± .001	59	1.6910 ± .002	81	I

2* R.M. Crump and N.B.Kettner, (1953) (3) A. Poldervaart, (1950)

Specimen 1a, b, and c, are taken from three successive flows of the plateau south of Leon Creek, and specimen 2a, b, and c, are from three successive flows from the plateau north of Leon Creek. The two localities are approximately 2 miles apart. Specimen 3 is from north of Big Bar Creek.

The present sampling indicates no systematic variation in composition. The presence of orthopyroxene in some flows probably is not significant because the mineral occurs only in small quantities. The one flow (2b) that contains an olivine comparatively rich in iron shows no deviation from the average in the composition of its plagioclase. This lack of correlation between olivine and plagioclase may perhaps be explained by the fact that the texture of the rock is of type (I) and approaches that of an olivine porphyry.

C. Structure

The basalts rest unconformably on rocks of the Pavilion group and on poorly consolidated Tertiary sediments. Their upper surface slopes about 50 feet per mile to the north corresponding to a dip of less than one degree. They overlie the Fraser River fault zone without any signs of disturbance.

Being relatively resistant to weathering the basalts form cliffs and have produced uncommonly steep profiles in the underlying rocks which they protect. Apparently these weaker rocks are not able to support the load of the basalts at such slopes and yield by slumping. The margins of the basalt plateaus are also characterized by numerous fractures along which openings from a few feet to tens of feet wide develop.

The terrace-like fault blocks around the basalt plateaus near Leon Creek are visible on air-photographs. (Plate XX)

D. Mode of Origin

There can be little doubt that the four outcrop areas between McKay Creek and Watson Bar Creek are remnants of a continuous sheet of volcanic flows which originally filled a valley. Some of the mountain slopes that bounded this valley on the west are still preserved. The slopes are underlain by rocks of the Jackass Mountain group and of the Ward Creek assemblage. The valley in which the basalts were laid down apparently contained sands and gravels that may have been partly of fluviatile origin.

The distribution of the basalts on Big Bar Creek, their association with fluviatile sediments, and the presence of possible pillow structures suggesting submerged deposition indicate that these flows like the underlying Tertiary sediments, also occupied a valley.

Because of the uniformity of lithology and elevation and the similarity of environment it is probable that the basalts along Big Bar Creek were connected with those south of Watson Bar Creek.

As no basalts are preserved between Watson Bar Creek and Big Bar Creek such a connection must have underlain areas that have subsequently been eroded down to elevations lower than 3900 feet; therefore it must have occupied a narrow zone along the line of the present valley of the Fraser River.

It was mentioned that the upper surface of the northern outcrop zone dips at a gradient of approximately 50 feet per mile to the north and that the upper surface of the flows on

Big Bar Creek slope with a similar gradient to the east. One is tempted to conclude that the source of the volcanic flows was located not far from the southern extremity of their present outcrops and that they flowed northward and eastward along valleys that coincide in part with the present valleys of Fraser River and Big Bar Creek. The fact, however, that the upper surfaces of the basalts south of Watson Bar Creek and north of Big Bar Creek have the same elevation of 3900 feet ± 50 feet and that no gradient is noticeable indicates that some tilting has occurred since the deposition of the flows. The direction of tilt and therefore the original slope of the ancient valleys are unknown.

These basalts are the oldest volcanic rocks in the present map-area that contain olivine. Their appearance marks the end of the phase dominated by andesite. It is generally thought that such flows are derived from a basaltic layer in the earth's crust and rise through deep reaching fractures. As the flows overlie one or two major faults they may well have ascended through fractures associated with the Fraser River fault zone but after they ceased to be active.

This conclusion conforms in a general way with Dawson's concept that the flows are of local origin (Dawson, 1895,p.216B).

E. Age

Dawson included the basalts in his "Upper Volcanic Group" which he placed in the Upper Miocene. Duffell and McTaggart correlated them with the Kamloops group considered as

Miocene or earlier. However, in the Kamloops area the olivine basalts rest unconformably on the Kamloops group (W.H.Mathews, personal communication).

As Dawson remarked "their present appearance represents a very great amount of river erosion since the date of their formation." (1895, p. 216B). The depth of erosion since their deposition is more than 3000 feet. As the Fraser River contains Pleistocene deposits it is improbable that the volcanic rocks are younger than early Pleistocene.

On the other hand, they are younger than the French Bar conglomerate because unlike that formation they have not been affected by movements of the Fraser River fault zone. Their possible age then ranges from Oligocene to early Pleistocene. Within that span a relatively young age is probable because they present an original surface of fair extent preserved under conditions of rapid erosion. For these reasons a Pliocene or late Miocene age is suggested. (Compare Thornbury, 1954 p. 26). With respect to lithology and geomorphic environment the rocks closely resemble basalts of the Quesnel map-area assigned by (Tipper 1959) to the Miocene, Pliocene, and possibly Pleistocene.

2. INTRUSIVE ROCKS

ULTRABASIC INTRUSIONS

ULTRABASIC ROCKS NEAR LILLOOET

1. Distribution

A belt of ultrabasic rocks lies between Triassic or

older rocks to the west and the Lillooet group to the east in the vicinity of Lillooet. Although outcrops are scarce the serpentinites appear to be one half mile wide. The belt probably extends beyond the present map area to the northeast and may be linked with the ultrabasic rocks of the Shulaps Range.

2. Lithology

All specimens examined are serpentinized harzburgite. In most of them medium-to-coarse-grained light green enstatite or bastite is set in a black or dark olive-green groundmass

> A partly serpentinized specimen has approximately the following composition of primary minerals:
>
> | | |
> |---|---|
> | olivine | 66% |
> | enstatite | 30% |
> | clinopyroxene | 3% |
> | chromite | 1% |
>
> The texture of the rock is allotriomorphic-seriate.
>
> The olivine is anhedral and relatively fine-grained, ranging approximately from .5 to .2 mm in sectional diameter. The composition of the mineral is Fa_{10} (n_y - 1.674). Some grains contain inclusions of chromite.
>
> The enstatite En_{91} (n_y - 1.670) is subhedral or anhedral and ranges in grain size approximately from one centimeter to one half millimeter. It has inclusions of clinopyroxene that are oriented parallel to the optic plane of the host. Two types of inclusions can be recognized: lamellae of uniform width (.025 mm x .5 mm) and spindle-shaped or irregular patches (e.g. .4 x .8 mm). All inclusions within a single grain have the same crystallographic orientation. The orientation of the inclusions is not the same as that of the host but in certain sections the extinction position of guest and host coincide. The birefringence of the inclusions decreases from their centre toward

their outer margin; as many as ten different zones of distinct interference color can be observed.

Clinopyroxene also occurs as individual grains that probably have the composition of diopside, (n_y = 1.678). The grains are subhedral to anhedral and of smaller size than the orthopyroxene. Their sectional diameter lies between one and one half millimeter.

The chromite is opaque or brownish translucent and anhedral. It is relatively fine-grained, ranging from about one quarter to one eighth of a millimeter in sectional diameter.

3. Serpentinization

Most of the ultrabasic rocks are strongly or completely serpentinized; the least altered specimen seen consists of about 65% serpentine.

The three main silicates are affected differently by the serpentinization. The diopside is little altered. Some completely serpentinized crystals of enstatite contain unaltered inclusions of diopside.

Most of the enstatite is partly or completely replaced by antigorite. The serpentinization has progressed from the margin and from cleavages and the blades of antigorite lie approximately parallel to the cleavage of the host.

The olivine is strongly affected by the serpentinization. Replacement from the margin and from fractures has produced two types of mesh structures. In the first type "serpophite" is surrounded by a few blades of antigorite. In some specimens the antigorite shows very roughly a preferred orientation which may be the result of stress, (Leech, 1953, p. 32). In others the serpophite is surrounded by one or several layers of very

fine fibres that grow perpendicularly to the walls of the serpophite core. The fibres (length slow, low birefringence) are possibly "chrysotile". The interstices between chrysotile layers contain material that is isotropic or has low birefringence together with grains of an opaque mineral which is probably secondary magnetite. These grains range from a fraction of a micron in size to larger, vein-like aggregates ranging up to .4 mm in length and .02 mm in width.

The "serpophite" and some of the fibrous serpentine contain minute acicular inclusions which range from .005 to .03 mm in length and are approximately .001 mm thick. The inclusions are also found in the marginal zones of olivine grains but never in the core of that mineral. These outer zones apparently have been altered as they show a lower birefringence than the inner part of the grains.

The refractive indices of the mineral lie between 1.51 and 1.53. It may be sepiolite, a mineral which occurs in serpentine. Sepiolite associated with talc was synthesized by Bowen and Tuttle at temperatures around 350° C and a pressure of 15,000 lbs./in. (Bowen and Tuttle 1949, p. 443).

4. Carbonate-Silica-Alteration

On the ridge northeast of Town Creek the serpentinized ultrabasic rocks have been replaced by carbonate and quartz. The altered rocks form conspicuous, rusty weathering cliffs. In some specimens from these outcrops remnants of serpentine are preserved but in others only the presence of chromite indicates that the rocks originally were ultrabasic.

The composition of the carbonate lies near the boundary of magnesian dolomite and parankerite (ng-1.699). It is present in a network of veinlets that encloses quartz and nodules of carbonate some of which include a few fine grains of "iron ore". The centre of the veinlets contain much secondary "iron oxide". In some specimens the carbonate is cut by veinlets of quartz. (Plate XXI).

5. Age and Origin

Because of insufficient exposure the nature of the contacts and the internal structure of the ultrabasic rocks are unknown. However, the following observations may have some bearing on their age and origin.

(1) The ultrabasic rocks occupy a zone between Triassic or earlier rocks to the west and the Lillooet group to the east which south of the present map area are in fault contact. (Duffell and McTaggart, 1953, p. 27).

(2) Other ultrabasic intrusions in the map area occur only in rocks of the Pavilion group.

(3) The serpentinites are on strike and possibly continuous with the ultramafic complex of the Shulaps Range to which they bear a close lithological resemblance. Leech found that the main mass of the intrusions in the Shulaps Range cuts Upper Triassic strata, and he observed chromite, probably derived from these intrusions, in Lower Jurassic sediments. (p.39). He inferred that the ultrabasic rocks were emplaced in the Upper Triassic.

(4) Intrusions of similar lithology are wide spread in British Columbia and attributed by White to the Upper Triassic Cassiar orogeny (White, 1959).

Because of the last three points it is thought that the serpentinites west of Lillooet are of an original Upper Triassic age. Their association with the regional fault can be explained in two ways. Either they are in intrusive contact with Cache Creek-type of rocks to the west and in fault contact with the Lillooet group to the east and antedate the faulting, or the ultrabasic rocks, originally emplaced in the Triassic, were remobilized in or after the Lower Cretaceous and squeezed into the fault. "Cold intrusions" have been described by Taliaferro (1943, p. 205) and Thayer, (1948, p. 64-65), and the concept was referred to the Fraser River fault zone by Duffell and McTaggart (1953, p. 76), and to the Shulaps Range by Leech, (1953, p. 39).

PERIDOTITE INTRUDING THE PAVILION GROUP

At a few localities serpentinized dykes were seen to intrude Divisions I and II of the Cache Creek group.

> A hand specimen from a dyke exposed on the east bank of the Fraser River, approximately one mile north of the mouth of Siwash Creek, is reddish brown on weathered surfaces, black to olive green on fresh surfaces, and fine-grained.
>
> About 15% of the primary minerals are clinopyroxene (endiopside ? n_y - 1.675), the balance consists of forsterite (+2v larger than 87°) and a small amount of a brownish opaque mineral which is probably chromite. The endiopside is subhedral and the olivine and the chromite are anhedral. The grain size is near .5 mm.

Serpentinization has produced a mesh structure consisting of olivine or serpophite cores surrounded by relatively broad blades of antigorite that lie in subparallel orientation. The clinopyroxene has been affected by the serpentinization to a much lesser extent than the olivine. There is also some carbonate replacement.

As these dykes cut rocks that are possibly of Lower Triassic age but have not been seen in the adjacent Lower Cretaceous strata their age may lie anywhere between those limits. Lithologically they are not identical with the ultrabasic rocks west of Lillooet. But as the emplacement of ultrabasic rocks is a rare event in the history of a small area it is likely that these dykes are contemporaneous with the masses near Lillooet and in the Shulaps Range. Therefore they are tentatively referred to the Upper Triassic.

COAST INTRUSIONS

1. EARLY LOWER CRETACEOUS OR OLDER

1. Distribution

In the present area dioritic rocks considered to be early Lower Cretaceous or older are the most abundant of the igneous rocks assigned to Coast Intrusions.

A stock underlies Mount Martley on the southeastern edge of the map area. (see Figure 6) Another, about 5 miles

long and up to 2 miles wide, extends from the mouth of Kelly Creek to Leon Creek. Parts of a small stock are exposed south of Pavilion. The present map (Figure 1) suggests that it is less extensive than indicated on previous maps, and instead of one large mass a number of small intrusions are shown. Some of these may be off-shoots of a stock or batholith hidden at depth. A zone of small intrusions extends from Pavilion to Kelly Creek. A relatively small plug underlies the slopes at the north end of Pavilion Lake. In the northern part of the area the Coast Intrusions are represented only by a dyke-like mass on the lowest part of Big Bar Creek which is about one mile long and a few hundred feet wide.

2. Lithology

The intrusions are composed of diorite, quartz diorite, granodiorite, and dacite. Quartz diorite is the commonest rock type. The plutonic rocks have a hypidiomorphic equigranular texture and are mostly medium-grained. Many of the dyke rocks are porphyritic.

The essential minerals present are plagioclase, quartz, hornblende, and biotite; augite was noticed only in one specimen. "Iron ore" constitutes up to 2% of the rock. Apatite is comparatively common as an accessory mineral, and zircon and sphene are rare. One dyke rock contains muscovite but no mafic silicates.

The plagioclase is mostly subhedral, zoned, and twinned; the zoning is most commonly of the normal oscillatory type. The mineral contains inclusions of sericite, epidote, and carbonate. Potassic feldspar, if present at all, forms less than one per cent of the rocks.

The hornblende is subhedral and some grains are twinned. It shows pronounced pleochroism being dark green in the z-direction and pale brownish green in the x-direction. The biotite is anhedral or subhedral and brown or green in color.

Both hornblende and biotite contain inclusions of "iron ore" and apatite and are in many specimens partly or completely replaced by chlorite.

The quartz is anhedral and most grains are free from inclusions.

Table 4 shows the range in the composition of the rocks. It seems to be true in a general way that the plagioclase becomes more sodic and that the percentage of mafic minerals decreases as the content of quartz increases; but there are exceptions.

Near the contacts with rocks of the Pavilion group the Coast intrusions are locally contaminated and contain a relatively high proportion of hornblende.

TABLE 4

MINERAL COMPOSITION OF 8 SPECIMENS FROM COAST INTRUSIONS, EARLY LOWER CRETACEOUS OR OLDER

Locality	Composition of plagioclase	% of Quartz	% of mafic minerals	Classification of rock
Dyke on lower Big Bar Creek	Calcic andesine, zoned	0	35	diorite
South of mouth of Kelly Creek	Zoned from calcic oligoclase to sodic labradorite	5	26	diorite
Pluton, southeast of Pavilion, east side	altered to albite	8	27	diorite, transitional to quartz-diorite
Dyke near Moran	Calcic andesine, zoned	11	25	quartz-diorite
Pluton between Leon Creek and Kelly Creek	Intermediate andesine, zoned	23	12	quartz-diorite
Stock southeast of Pavilion, west side	Zoned from sodic to intermediate andesine	33	22	quartz-diorite
Mount Martley Stock	Zoned from calcic oligoclase to sodic andesine	30	19	quartz-diorite, transitional to granodiorite
Stock at north end of Pavilion Lake	Zoned from calcic oligoclase to sodic andesine	32	13	quartz-diorite transitional to granodiorite

3. Associated Mineralization

Small sulfide deposits are associated with these intrusions in many localities but only the Big Slide Mine (M1) near the mouth of Kelly Creek which operated for a few months in 1887 has been of some economic importance. The property was inspected by G.M. Dawson in 1887 and by A.M. Richmond of the B.C.Department of Mines in 1932. A compilation of all previous reports was given by Duffell and McTaggart (p. 103 f.). The mineralization here consists of pyrite, pyrrhotite, arsenopyrite, chalcopyrite, marcasite, limonite, native gold, and carbonate in two pinching and swelling quartz veins that are up to 4 feet wide and have an average thickness of eight inches. The host rock is a small dioritic mass that intrudes chert, argillite, and minor volcanic rocks of Division I of the Pavilion group. South of Kelly Creek, in the same vicinity, another small deposit was explored by a shaft and two short levels. The writer noted some pyrite, bornite, malachite and azurite in an abundant gangue of quartz and carbonate on a surface dump.

Disseminated pyrite and arsenopyrite form rusty zones in the diorite outcrops on Tiffin Creek and in chert, argillite, and diorite on the upper part of Sallus Creek.

A specimen of bornite shown to the writer was said to have been collected on the upper part of Siwash Creek near the contact between granitic dykes and limestone. Small amounts of copper minerals have been found in the pluton south of Leon Creek.

4. Structure, Mode of Origin

Although elongate masses are parallel to the strike of the host rocks the intrusions locally cut across the pre-existing structures. Foliations and lineations are rarely apparent. The major regional faults pass around the plutonic masses, but minor zones of shearing and alteration are present locally.

That the quartz-diorite has been emplaced by intrusion and not by processes of granitization is suggested by the crosscutting relation of the granitic rocks and the very low grade of regional metamorphism in the country rocks suggesting a shallow depth of emplacement. Crystallization from a magma is also indicated by the oscillatory normal zoning of the plagioclase.

5. Age

The rocks intrude Divisions I and II of the Cache Creek group and therefore they are not older than Triassic. They were not observed in intrusive contact with the Spences Bridge group or the Kingsvale group of mid-Lower Cretaceous age. It is also probable that they were emplaced before the earliest movement on fault "e" of the Fraser River fault zone, (see Figure 6, p.168) which is thought to have taken place in the early Lower Cretaceous.

In the present map-area this group of Coast Intrusions cannot be distinguished lithologically from the early Lower Cretaceous quartz-diorite that intrudes the Lillooet group. McTaggart and Duffell, however, correlate them with the Mount

Lytton batholith and present structural studies support this correlation (see page 176). Duffell and McTaggart suggest that the Mount Lytton batholith is older than the intrusions west of the Fraser River and perhaps contemporaneous with the Guichon Creek batholith, and refer it to the Jurassic (p. 81).

II. EARLY LOWER CRETACEOUS

1. Distribution

The Coast Intrusions known to be early Lower Cretaceous occur as dykes and sills in the Lillooet group. The largest of these intrusions is a lenticular pluton about 1/2 mile long and several hundred feet wide which is exposed on the east side of the Fraser River near the railroad bridge in the vicinity of Lillooet.

2. Lithology

All specimens examined are quartz-diorite or dacite. Coarse or medium-grained rocks have a hypidiomorphic granular texture but porphyritic types consist of medium- to coarse-grained phenocrysts in a fine-grained or aphanitic groundmass. Some rocks are entirely aphanitic.

A specimen from the lenticular sill-like pluton near the railroad bridge northeast of Lillooet is composed of the following primary minerals:

Feldspar	70%
quartz	21%
hornblende	8%
biotite	1%
"iron ore", apatite, sphene	trace

The feldspar consists dominantly of subhedral sodic andesine that is twinned and shows normal or oscillatory normal zoning. Orthoclase which is subhedral or anhedral makes up only a small fraction of the total feldspar. Some of the feldspar is strongly sericitized.

Most of the hornblende is subhedral. The mineral is dark green in the z-direction. The biotite is subhedral or anhedral and pleochroic in browns. The quartz is anhedral and relatively free from inclusions.

As alteration minerals sericite, carbonate, and chlorite are fairly abundant.

The texture of the rock is granitic and the size of the essential minerals ranges from 2.5 mm to 1 mm.

The phenocrysts of dyke rocks consist of plagioclase which commonly is zoned andesine. Hornblende and quartz are rare as phenocrysts. The groundmess of the porphyries contains in addition to these minerals biotite, and in some specimens muscovite.

Highly altered rocks found in the vicinity of major faults are rich in chlorite, muscovite, carbonate, and prehnite.

3. Age

Granitic dykes are abundant in the lower and middle part of the Lillooet group which are tightly folded but lacking in the flat lying upper part, Division C, and very scarce in the Jackass Mountain group. It is possible that the intrusion took place shortly after the deposition of the sediments and was

nearly contemporaneous with the main period of folding. The age of these quartz-diorites probably is early Lower Cretaceous.

III. LATE BARREMIAN

1. Distribution

The Coast Intrusions of this group occur only as dykes or small plugs in the Jackass Mountain group. In the southern and central parts of the map area they are rare. A few dykes are exposed on the north side of the Fraser River opposite the mouth of Fountain Creek. Between Fountain and the mouth of Bridge River several zones of carbonate alteration are visible on the shores of the Fraser River some of which are associated with small granitic dykes. Similar zones of alteration in the vicinity of Lee Creek and Blackhill Creek that apparently are not related to major faults may indicate intrusive bodies at greater depth. In the northern part of the map-area, in the vicinity of Watson Bar Creek, granitic rocks are more abundant. The largest of these intrusions is shown on Figure 1.

2. Lithology

Lithologically these dykes do not differ from the two other groups of Coast intrusions in the area; they are porphyritic quartz-diorites. A typical specimen has coarse phenocrysts of zoned andesine and a fine-grained groundmass consisting of plagioclase, quartz, hornblende, biotite, and minor orthoclase. "Iron ore" and apatite were noted as accessories.

Secondary minerals present are sericite, epidote, chlorite, and carbonate.

A dyke which probably lies in the immediate vicinity of fault "d" of the Fraser River fault zone has been altered completely. The plagioclase has been altered to albite and epidote and the mafic minerals to chlorite. The rock is extensively replaced by carbonate.

3. Associated Mineralization

On the upper part of Stirrup Creek four small (epithermal?) deposits of stibnite, cinnabar, gold, wehrlite, and barite (Professor H.V.Warren, personal communication) is associated with porphyritic quartz diorite that has intruded lithic sandstone of Division C of the Jackass Mountain group (M2). The minerals occur in quartz veins that cut bleached porphyritic quartz-diorite and strongly carbonatized country rock. Occurrences of this type are probably the source of the numerous gold placers on Stirrup Creek (outside the map area).

4. Age

As these dykes intrude Division C of the Jackass Mountain group but have not been found in the Spences Bridge group or Kingsvale group they probably were emplaced in the late Barremian. They are the youngest Coast Intrusions known in the general area.

GABBRO AND DIABASE NEAR LILLOOET

1. Distribution, Structure

Gabbros and diabases are exposed for about 6 miles between a point on the west bank of the Fraser River about 2 miles southeast of Lillooet and the head of Town Creek on the ridge northwest of Lillooet. The outcrops are mostly small and separated by expanses of overburden; larger masses are exposed only in the vicinity of the power house on Seton Creek.

It is not known whether the outcrops are connected and thus form one large intrusion or whether they represent numerous small intrusions.

The belt as a whole strikes approximately N 30° W and forms the eastern margin of a zone occupied dominantly by ultrabasic rocks. To the east the intrusions are possibly in fault contact with the Lillooet group, but this contact is nowhere exposed.

2. Lithology

The rocks on the east shore of the Fraser River, outside of the map-area have not been studied during the present investigation. According to Brock (1956) they are hypersthene gabbros that show differentiation.

The intrusions on the west side are greyish green, medium- to fine-grained, and show no stratification. They are highly altered, and their original composition is recognizable only in a few specimens that range from bronzite gabbro to augite diorite.

All specimens contain augite which shows no systematic variation in composition. In one thin-section the augite has "hour glass" structure. In two out of nineteen specimens orthopyroxene was recognized. In one specimen it was bronzite in the other one hypersthene, but the two minerals probably do not differ in composition by more than 5% of the enstatite molecule. In some of the other rocks orthopyroxene may have been present originally but probably has been replaced by minerals of the chlorite group. Only in two specimens the original plagioclase appears to be preserved. In the bronzite gabbro its composition lies near An_{60}. In the augite diorite it is zoned from calcic andesine to calcic oligoclase. But as the cores of many plagioclase crystals in this rock are highly altered they may have had a more calcic composition originally. Although most of the rocks contain hornblende perhaps only in the augite diorite is this mineral of primary origin.

The differences between the basic and acidic types is apparent in the following table:

bronzite-gabbro	
plagioclase	50%
augite	37%
bronzite	5%
chlorite group, replacing (bronzite ?)	6%
"iron ore"	2%

augite diorite	
plagioclase	60%
augite	30%
hornblende	8%
chlorite group	1%
"iron ore"	1%

Table 5 shows the determinations of the main primary minerals in 4 characteristic specimens.

It is apparent that these gabbros are not uniform in composition but owing to the lack of exposure and the high degree of alteration the trends and mechanisms of differentiation could not be worked out.

The outcrops north of Lillooet are of medium- to fine-grained gabbro and have a hypidiomorphic granular texture. Most of them are equigranular, but some are seriate. In some of the specimens the augite appears strained. The original texture of the rocks has been obliterated to a large extent by alteration.

In the outcrops on Seton Creek the degree of alteration is even higher. Some rocks seem to have been fine-grained gabbros with a hypidiomorphic granular texture. Two specimens resemble original diabases; one of them shows a variolitic texture.

TABLE 5

MINERAL COMPOSITION OF 5 SPECIMENS OF ALTERED GABBROIC AND DIORITIC ROCKS

Spec.	Ortho-pyroxene, comp. x	Measurements	Augite Composition +	Measurements	Hornblende	Plagioclase Composition ✱	Measurement
14	En 89 ± 1% bronzite	(+) high 2v n_y=1.672±.001	$Ca_{41}Mg_{44}Fe_{15}$ ±2%	n_y=1.684± .002 2v=49°	Absent	An_{61}± 2%	nx' = 1.559± .001
16	Magnesian hypersthene	(-)2v close to 90°	$Ca_{37}Mg_{49}Fe_{14}$ ±2%	n_y=1.685± .002 2v=44°	present but probably secondary	An_{40} probably altered	nx' 1.5472± .001
13	absent or completely altered		$Ca_{40}Mg_{46}Fe_{14}$	n_y=1.686± .003 2v=48°	absent	completely altered	
12	absent or altered		$Ca_{41}Mg_{47}Fe_{12}$ ± 2%	n_y=1.685± .002	present replacing augite	Zoned An_{25}-An_{45}	nx'= 1.554-1.540

x H.H.Hess and H.A.Phillips, (1940)

+ H.H.Hess, (1949)

✱ R.M. Crump and K.H.Kettner, (1953)

3. Metamorphism and Alteration

In 17 out of 19 specimens the plagioclase has been altered to albite and minerals of the epidote group among which pistacite seems to be abundant. The orthopyroxene has been replaced partly or completely by minerals of the chlorite group. A mineral of that group showing bladed habit, low birefringence, and positive elongation probably is antigorite. The augite is better preserved than the other minerals but partly replaced by minerals of the chlorite group, by hornblende, or "iron ore".

The rocks are replaced by prehnite, carbonate, and less commonly by tremolite and possibly the amphibole nephrite. As vein filling prehnite, carbonate and albite occur.

One specimen is mylonitized; in others the augite appears to be strained and bent.

4. Age

The contacts of the gabbros were not seen. An indication of their age is given by the following observation. East of Fountain Creek, in the vicinity of fault "d" a specimen was collected that is composed of chloritized clinopyroxene and hornblende in a matrix of prehnite and shows a strong schistosity. It resembles the highly altered gabbros or diorites west of Lillooet. The occurrence of these rocks suggests that they were intruded into major fault zones and

therefore are early Lower Cretaceous or younger. Their alteration may have been produced by late magmatic solutions.

ANDESITIC AND BASIC DYKES

All rock units, except for the Middle or Late Tertiary olivine basalts are intruded by andesitic, diabasic or basaltic dykes. These dykes may range in age from early Mesozoic to Late Tertiary. They are too small to be shown on the accompanying map.

CHAPTER II

THE FRASER RIVER FAULT ZONE

1. Introduction

Although Dawson (1895) considered the structure of the Fraser River area as a series of tight folds he noticed the shattered and altered nature of the rocks in many localities and suggested that some of the major contacts are faults. He described, for example, the structure in the vicinity of Stein Creek as follows:

"but in this vicinity, on both sides of the river entire masses of the rocks have become reddened and decomposed by action subsequent to their deposition. The beds are all much shattered, and lines of faulting in this place undoubtedly run along the valley one of which apparently bounds the Cretaceous trough on the east side of the valley." (p. 147 B, f.)

He stated of the contact of the Jackass Mountain group with the rocks of the Spences Bridge group (which he considered to be Tertiary) between McKay Creek and Leon Creek:

"The boundary between the Cretaceous rocks on the west and volcanic Tertiary rocks, is here remarkably distinct and straight, and follows a well-marked valley which is nearly parallel to that of the Fraser. There is some reason to suppose that this boundary may be a faulted one, but this is not so certain." (p. 215B.)

In 1912 N.L.Bowen in a reconnaissance survey of the Fraser River valley from Lytton to Vancouver observed that the Cretaceous strata south of Lytton occupy a grabben between granitic rocks:

"The average strike of the Cretaceous beds is about N 15° W and the beds are commonly at low angles, but close to the granites the attitude may be nearly or quite vertical. The granite does not, however, give any evidence of being intrusive. The relation shown is due to the down faulting of the Cretaceous beds. This part of the Fraser Valley is, in fact, excavated along a belt of comparatively soft sedimentaries themselves preserved by graben faulting. The strips of Paleozoic rocks, too, probably owe their present position to this faulting, for the strike of their beds makes a sharp angle with the elongation of the strips."

Duffell and McTaggart corroborated Bowen's observation that in the southern part of the Ashcroft area the Fraser River Cretaceous belt occupies a graben. North of Cinquefoil Creek however, they noted a series of faults in which the rocks to the west have been elevated relative to those in the east. They gave evidence of intermittent activity from Lower Cretaceous to post-Eocene time and showed that carbonate, prehnite, and albite alteration are associated with the fault zone. As the probable cause of the faulting they suggested uplift and tilting of the Coast Mountains.

Leech (1953) mapped a fault zone in the Yalakom area

that is probably connected with a major fault discovered by Duffell and McTaggart near Lillooet.

McCammon and Nasmith (1956) during a study of possible dam sites on the Fraser River observed several faults in the northern parts of the present map-area which they considered to be possible extensions of the Fraser River fault zone of the Ashcroft area.

The present study has added the following information:
(1) Those faults of the Ashcroft sheet (Duffell and McTaggart 1953) that are situated in the present map area have been mapped in greater detail but without major changes.
(2) It is shown that the western contact of the Pavilion group is another fault of the Fraser River fault zone. The movement on this fault is in the opposite sense to that of the other faults of the zone, showing a relative downward movement of the western block. The structure of the present map area therefore appears to be a complex graben. It is suggested that fault movements on this graben controlled the deposition of Divisions B and C of the Jackass Mountain group.
(3) Another longitudinal fault, the nature of its movement unknown, has been mapped within the Pavilion group.
(4) It is shown that the latest movement on one of the longitudinal faults probably took place in Middle Tertiary time.

2. Description of the Fraser River Fault Zone

The main branches of the Fraser River fault zone are shown on Figure 6. The main faults of the zone trend north-

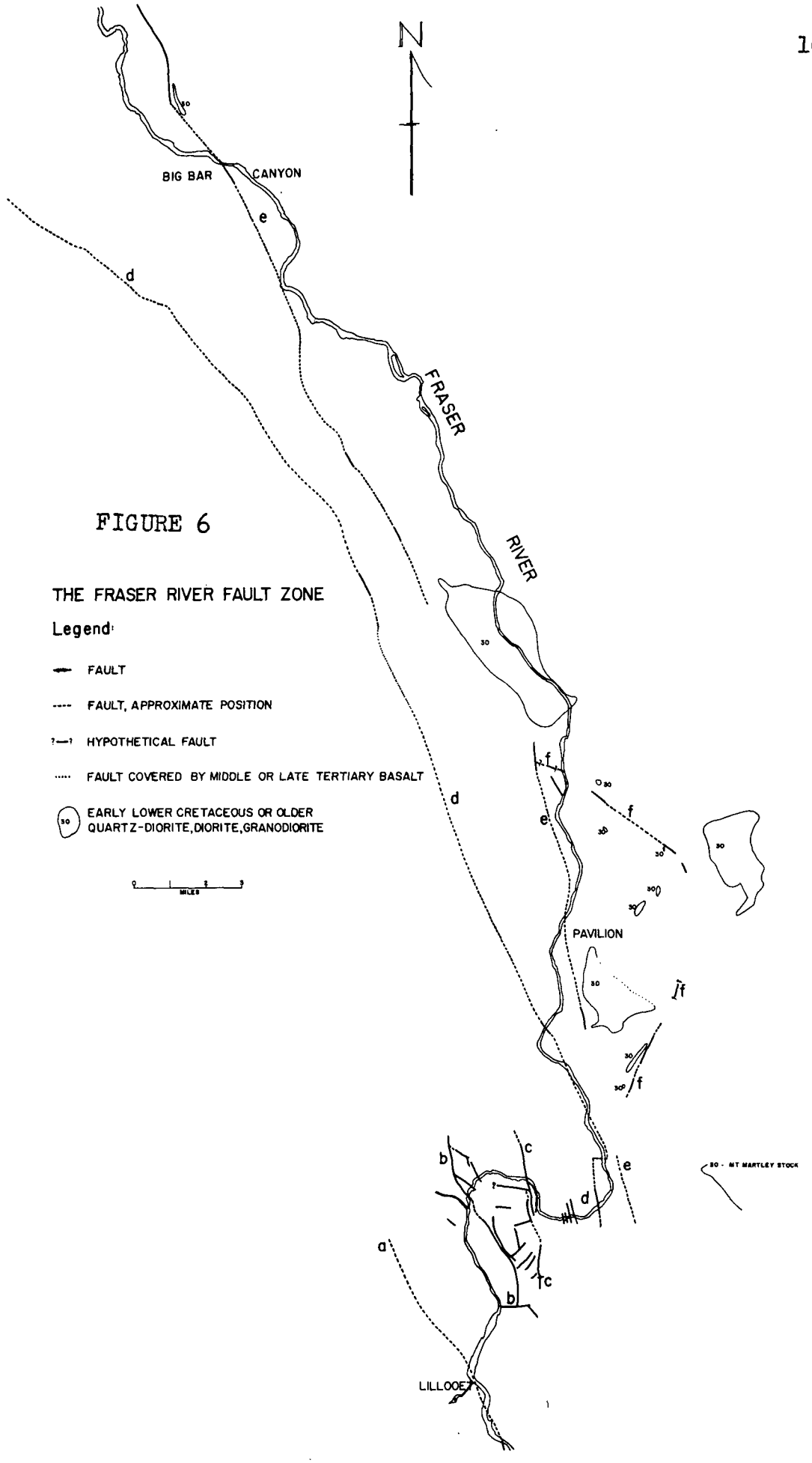

N
BIG BAR
CANYON
FRASER
RIVER
PAVILION
LILLOOET
a
b
c
d
e
f
30
30 - MT MARTLEY STOCK
THE FRASER RIVER FAULT ZONE
Legend:
FAULT
FAULT, APPROXIMATE POSITION
HYPOTHETICAL FAULT
FAULT COVERED BY MIDDLE OR LATE TERTIARY BASALT
EARLY LOWER CRETACEOUS OR OLDER
QUARTZ-DIORITE, DIORITE, GRANODIORITE
MILES

FIGURE 6

westerly to northerly and are referred to as longitudinal faults. Faults trending westerly, in part apparently offsetting the longitudinal faults, are referred to as cross-faults.

Six major longitudinal faults have been recognized in the map area. At least two of them are continuous throughout the area and some of them have been shown to extend far to the south. It is assumed that other faults exist but have not been recognized because of thick overburden and lack of obvious offset in the formations transected. The longitudinal faults strike northwesterly to northerly, and, judged by their lack of deflection on the map in crossing ridges or valleys, dip steeply.

Fault "a" (see Figure 6) separates the Lillooet group on the east from Triassic or older rocks to the west. The fault is not exposed in the map-area but has been seen farther south (Duffell and McTaggart, 1953) and is probably continuous to the north with a major fault in the Yalokom area (Leech, 1953). In the present map-area it has associated with it serpentinized ultrabasic intrusions, gabbros and diabase which either localized the break or intruded the fault zone.

Fault "b" brings the Lillooet group into contact with the Jackass Mountain group. It has several branches near the mouth of Bridge River that seem to converge to a single break to the south and to the north. The fault is poorly exposed and has no topographic expression on the western slopes of the Camelsfoot Range and of Fountain Ridge. Where the individual branches cross Fraser River, the strata are disturbed

over widths up to several hundred feet.

Fault "c" divides the Jackass Mountain group into two main blocks. All three divisions of the group are exposed in the western block but only Division C in the eastern block. Near Fountain Station three closely spaced branches were observed or inferred but elsewhere only one could be established. The eastern branch is indicated by a narrow belt of steeply dipping and distorted strata east and northeast of Fountain Station along the west shore of the Fraser River. The western branch is marked by intensely stained and sheared cliffs a few hundred feet above the road west of Fountain Station. The central branch is exposed only on the shore of the river but probably continues to the south. It truncates Division B and brings it into contact with a fault slice of Division C.

Fault "d" forms the contact of Division C of the Jackass Mountain group with volcanic rocks of the Fountain Valley assemblage, the upper Division of the Spences Bridge group, and the Ward Creek assemblage. The fault zone is exposed east of Fountain Creek at the south shore of the Fraser River, and again northeast of the mouth of Blackhill Creek. Several minor faults parallel with fault "d" occur near the mouth of Fountain Creek. Between the mouths of Gibbs Creek and Blackhill Creek, on the west side of the Fraser River, the strata of Division C, commonly flat-lying or gently dipping, have been tilted into almost vertical attitudes for distances of at least one-half mile west of the fault zone (Plate XXII). Minor branches of the zone are exposed at the mouths of Sallus and Blackhill

Creeks. In this vicinity, the main fault seems to have controlled the course of the Fraser River. Between the upper part of McKay Creek and Leon Creek the fault is covered for about 2-1/2 miles by flat-lying Miocene or Pliocene (?) basalts that apparently have not been offset by the fault. To the north, on Watson Bar Creek, the fault is marked by intense carbonate alteration in the lithic sandstones and the volcanic rocks.

Fault "e" the western boundary fault of the Pavilion group is well exposed on a cliff in Big Bar Canyon, where the fault dips about 75° to the southwest. (Plate XXIV) The trace of the fault plane on the cliff is straight, suggesting little variation in dip. The foot-wall here consists of ribbon chert that lies approximately parallel to the fault plane and contains numerous veinlets of quartz and carbonate. The hanging wall is andesite that has been converted into a layer of gouge about 40 feet thick.

Between Watson Bar Creek and French Bar Canyon the existence of a fault contact is indicated by the steep dips of the otherwise flat lying or moderately dipping volcanic rocks. From Watson Bar Creek to McKay Creek the rocks adjacent to the contact are poorly exposed. Between McKay Creek and a locality about one mile northwest of Glen Fraser the fault is not exposed but indicated by anomalous dips (Plate XXIII) and signs of shattering and alteration. Immediately north of Glen Fraser the location of the fault is uncertain. From Glen

Fraser to the mouth of Gibbs Creek the eastern contact of the Pavilion group is covered by overburden. Southwest of the mouth of Gibbs Creek a fault between the lower Division of the Spences Bridge group and the Fountain Valley assemblage was inferred from a cross section (B-B'). This inferred fault probably is continuous with the eastern boundary fault of the Pavilion group traced from northwest of Glen Fraser to north of Big Bar Creek.

Fault "e" lies close to the western margin of several granitic masses. No major plutons in the present map area are exposed to the east of this fault.

Fault "f" forms the contact between Division I and Division II of the Pavilion group. The fault is exposed on the slope north of Pavilion Creek and indicated by shearing and alteration south of Moran. The northwestern continuation of the contact is obscured by lack of outcrop and metamorphism (see p. 58). South of Pavilion Creek the contact is very poorly exposed. On Keatley Creek a fault relation was inferred from an abrupt lithological change, from the unusual narrowness of Division I and an anomalous stratigraphic top near the contact.

The faults "a", "b", "c", and "d" appear to be normal faults with relative downward movement of the eastern block; fault "e" is a normal fault with relative downward movement of the western block. These five longitudinal faults form a complex graben. The sense of movement on fault "f" is uncertain.

Cross-faults, approximately normal to the longitudinal faults, seem to be comparatively short and to show small offsets. Although horizontal and vertical displacements can be established in some places, in others offsets cannot be recognized at all and faulting is indicated only by abrupt changes in attitude. The cross-fault zones consist of single breaks or, as on Fountain Ridge, of a series of closely spaced faults. One of the cross faults offsets a longitudinal fault but others appear to stop at them.

3. Associated Alteration

The most common alteration associated with the Fraser River fault zone is carbonatization. The carbonate weathers rusty brown. In an altered rock from Big Bar Canyon it has the composition of magnesiodolomite (n_o=1.6795). In conglomerates, sandstones, and siltstones the carbonate replaces mostly the matrix, but in the other rocks it occurs in veinlets and irregular patches. In many localities veinlets of quartz are associated with the carbonate.

Igneous rocks and lithic sandstones near major faults show signs of low grade or retrogressive metamorphism. Calcic and intermediate plagioclase have been converted to albite and epidote and the mafic minerals to chlorite. Chlorite and epidote in many of these rocks form veinlets and apparently have been redistributed by solutions. Duffell and McTaggart have pointed out that in many localities the albitization is accompanied by prehnitization. The prehnite appears in veinlets

or replaces the plagioclase of the host. In the present map area the mineral was found in the gabbroic belt west of Lillooet, in a dioritic dyke near the mouth of Bridge River, in a gabbroic or dioritic dyke and a lithic sandstone east of Fountain Creek and in the diorite mass southeast of Pavilion. All these localities are in the vicinity of major fault zones. It is possible that the altering solutions and the gabbroic dykes ascended through such fractures and that dykes and solutions are related in origin. West of Lillooet the gabbros are also veined by tremolite and possibly the amphibole nephrite.

4. History of the Fraser River Fault Zone

The history of the Fraser River fault zone probably is a long and complex sequence of intermittent movements. The evidence for the earlier movements is incomplete, indirect, and lies mostly in the stratigraphic record. Only the latest movements can be established directly from the present structure.

Cross section C-C^1 shows that the faulting is younger than the folding of the Lillooet group which probably took place in the Neocomian.

The earliest indication of the existence of the fault zone is the conglomerate of Division B (Barremian) of the Jackass Mountain group. The great thickness of coarse sediments in this unit suggests rapid uplift of the source area which may have been accomplished by normal faulting.

There is also some evidence that the fault zone was active during the deposition of Division C (Barremian) or at the end of that time.

About one mile north of the mouth of Gibbs Creek volcanic rocks of the Spences Bridge group apparently overlie the Pavilion group with unconformity. About one mile to the west strata of Division C, several thousand feet thick are exposed. The units are probably separated by two faults the latest movement on which took place in the middle (?) Tertiary. (Cross-section C-C'). The situation can be explained in two ways. Either the strata of the Jackass Mountain group never extended to the locality where the Spences Bridge group was laid down later; or the eastern part of Division C was removed by uplift and erosion before the deposition of the Spences Bridge group. In the first case the sediments of Division C must have been deposited in a rapidly subsiding trough whose eastern boundary approximately coincided with the present fault. The second explanation implies a rapid uplift of great magnitude immediately to the east of the present fault zone. Both explanations suggest movements of the present fault zone; in the first case it would have taken place in the mid-Lower Cretaceous (Barremian); in the second case slightly later (early Aptian?). If the rocks north of Gibbs Creek are not correlative with the basal unit of the Spences Bridge Group in the type area, but younger, the faulting might be middle or late Aptian.

Middle and Upper Cretaceous and early Tertiary move-

ments cannot be established, but perhaps the volcanism of this time is related to the Fraser River fault zone. (Compare Cloos, 1939).

The youngest rocks disturbed by fault movements are the volcanic flows and tuffs that overlie the French Bar formation (Eocene-Oligocene). The Middle or Late Tertiary olivine basalts overlie fault "d" without signs of disturbance, and topographic evidence of Pleistocene or Recent faulting has not been found.

5. Causes of Faulting

Duffell and McTaggart have related the movement on faults a, b, c, and d, which show relative depression of the eastern blocks, to uplift and tilting of the Coast Mountains in the west. By analogy fault "e", showing relative depression of the western block could be related to uplift of the plutonic masses situated immediately to the east. Perhaps these plutons are part of a larger mass hidden at greater depth that is connected with the Mount Lytton batholith.

On the other hand Hans Cloos (1930) has suggested that the greatest grabens of the world probably were produced by broad domal uplifts and are the result of tension. An uplift of the Fraser River area in the Lower Cretaceous is indicated by the gradual shift from marine to continental conditions.

Perhaps both processes are related.

CHAPTER III

Geological History of the Area

In the Permian and Triassic the area was part of a somewhat restricted marine basin in which carbonaceous matter was not oxidized. In the Upper Permian a reef zone extended through the present Bowman Range and Pavilion Mountains. To the west of the reefs alternating layers of mud and radiolarian debris were laid down. The conditions were moderately stable but some volcanic eruptions took place. In the Triassic the area became tectonically active. Tectonic movements resulting in sub-marine slumping and turbidity currents were accompanied by strong volcanism. The deposits of this epoch consisted of lithic sand, tuff, volcanic flows, argillaceous mud, radiolarian debris, lime, and silt. The tectonic activity may have culminated in the Cassiar orogeny (White, 1959). However, in the present map area the only intrusions marking that event are Upper Triassic (?) ultrabasic intrusions west of Lillooet and east of the Fraser River.

No sedimentary or volcanic rocks of the time interval between Triassic and Lower Cretaceous are exposed. The Lower Cretaceous sediments, however, were derived from volcanic rocks that probably were deposited during this interval. These volcanic rocks were rich in albite and probably belong to the

spilite-keratophyre suite. They were possibly Jurassic and exposed to the northeast and/or southwest of the Fraser River fault zone. The source rocks may have been related to the Middle Jurassic keratophyres exposed near Harrison Mills, B.C. (Burley, 1954).

Intrusion of granitic rocks into the Pavilion group may have taken place in the Jurassic.

In the earliest Lower Cretaceous during the deposition of Divisions A and B of the Lillooet group the area was part of a restricted marine basin which was tectonically unstable. The mud of Divisions A and B and an increasing proportion of lithic sand in Division B were deposited by turbidity currents that were accompanied by submarine slumping. During the deposition of Division B the area gradually rose and then was folded, intruded by dioritic dykes, elevated above sea level, and eroded. The uppermost part of the Lillooet group, Division C, consisting of tuffaceous lithic sandstone, granule conglomerate and a small proportion of argillite was deposited in a marine environment perhaps under near-shore conditions. At the end of that time (Neocomian?) the area again rose above sea-level, and the basal conglomerate of the Jackass Mountain group was laid down in a continental environment. Associated tuffaceous matter indicates contemporaneous volcanism.

During the deposition of the members AII and AIII of Division A and of the basal part of Division B of the Jackass Mountain group (Barremian) the area was part of a restricted

marine basin. The sediments of AI consisted dominantly of fine sand, those of AII of mud, silt and fine sand, and the basal part of Division B was composed of medium-grained sand. This change in grain size may reflect a relative depression of the basin followed by a gradual rise.

The thick conglomerate of Division B is the earliest evidence of activity on the Fraser River fault zone which continued intermittently to the Middle Tertiary. The faulting may be related to the isostatic rise of Coast Intrusions to the east and to the west or an uplift of the whole area. A complex graben structure was produced which probably controlled the sedimentation of Divisions B and C of the Jackass Mountain group. Divisions B and C consisting of conglomerate, lithic sandstone, and minor argillite probably were laid down in a narrow elongate trough which subsided rapidly with respect to the bordering mountains but fluctuated with respect to sea level. At times it may have been connected with the open sea, more often it formed a restricted marine basin, and temporarily it may have been a continental valley occupied by a large river. Graded bedding and slump structures are very rare, and in this respect these "post tectonic" rocks differ markedly from the older geosynclinal facies. The sediments were mostly derived from albite rich volcanic rocks and to a lesser extent from granitic intrusions.

Rocks younger than the early Lower Cretaceous are only found to the east of the Lower Cretaceous sedimentary belt, and all of them are of continental origin.

In the middle and late Lower Cretaceous volcanic rocks of great thickness consisting dominantly of andesite were deposited that are locally intercalated with continental sediments. Perhaps the volcanic flows ascended through fractures of the Fraser River fault zone.

Because of the lack of fossils the Upper Cretaceous and Paleocene-Eocene history of the Fraser River valley is uncertain. Probably the volcanic activity continued.

In Eocene-Oligocene time gravel and lithic sand of great thickness derived from volcanic rocks were laid down on a flood plain between Big Bar Creek and the French Bar Canyon. The river deposits were overlain by another series of volcanic rocks ranging from basaltic to felsitic compositions. These volcanic flows and tuffs are the youngest rocks found in the area that have been disturbed by movements of the Fraser River fault zone.

Between the Miocene and earliest Pleistocene lithic sands were deposited on flood plains near Pavilion, south of Leon Creek, and on Big Bar Creek. Possibly these deposits were connected and formed in a valley that partly coincided with the present Fraser River valley. These sediments were succeeded by olivine basalts which may have risen through fractures associated with the Fraser River fault zone. Their appearance marks the end of a long period of volcanic activity dominated by andesitic rocks.

Although the area was covered by glaciers in the Pleistocene apparently little glacial erosion took place.

Probably at the end of the last glaciation the valley was occupied by braided streams and glacial lakes and more than 1000 feet of gravel, sand, silt, and mud flows were deposited. In Recent time the Fraser River has been rejuvenated and has cut through the unconsolidated material into bed rock. The northwestern and central part of the area received thin deposits of volcanic ash.

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APPENDIX I: DETERMINATION OF MINERAL COMPOSITIONS

The following optical properties and references have been used.

High-temperature plagioclase: extinction angles in zone normal to (010); van der Kaaden, 1951, Where extinction angles could not be measured, the Tsuboi-index, n_x' of 001 - cleavage fragments was used; Crump and Kettner, 1952.

The Tsuboi indices have been worked out, so far, only for low-temperature plagioclases. But in the present study it was found that determinations based on Crump and Kettner's curves do not deviate far from those based on van der Kaaden's extinction angle curves.

Low-temperature plagioclase: Tsuboi-indices; Crump and Kettner 1952, Extinction-angles; Winchell and Winchell, 1951.

Owing to the uncertainty about the optical properties of plagioclase the determinations probably have an accuracy only of ± 2-5%. However, the curves used have been interpreted as closely as possible.

Clinopyroxene: n_y, 2v; Hess, 1949.

Orthopyroxene: n_y, optical sign; Hess and Phillips, 1940, Poldervaart, 1950.

Olivine: n_y optical sign; Poldervaart, 1950.

Carbonates: n_o; Winchell and Winchell, 1951.

The Tsuboi-indices have been determined with an accuracy of approximately ± .001, other indices with an accuracy of approximately ± .002.

APPENDIX II

PLATES

PLATE I

The Fraser River Valley near Fountain. View to the southwest.

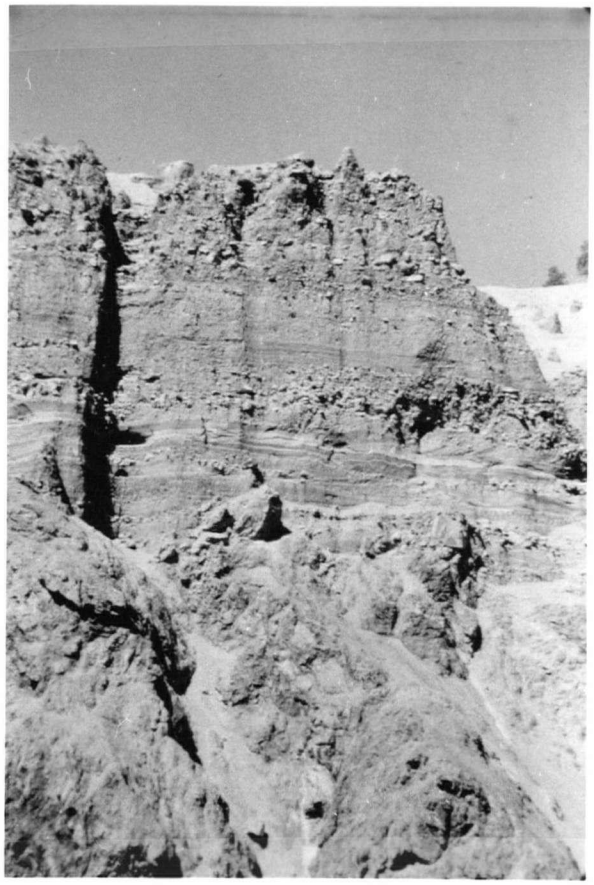
PLATE II

The Fraser River Valley near Moran.
View to the northeast.

PLATE III

The Fraser River Valley between
Siwash Creek and Leon Creek.
View to the northwest.

PLATE IV



Unconsolidated Pleistocene sediments resting on chert and argillite of the Pavilion group, Division I, Upper Permian or Triassic.
Lower part of Kelly Creek.
View to the north.

PLATE V

Mount Bowman. View to the south.

PLATE VI

Calcarenite, thin-bedded to laminated. At close inspection the rock shows graded bedding and intraformational brecciation. Marble Canyon formation, member III, Upper Permian. About two miles northwest of Mount Bowman.

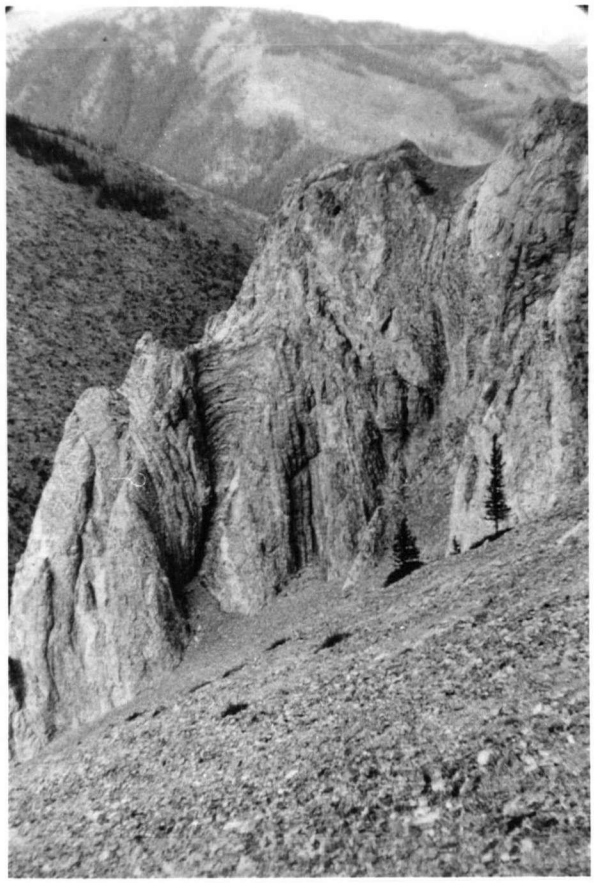
PLATE VII

Mount Soues. View to the north.

PLATE VIII

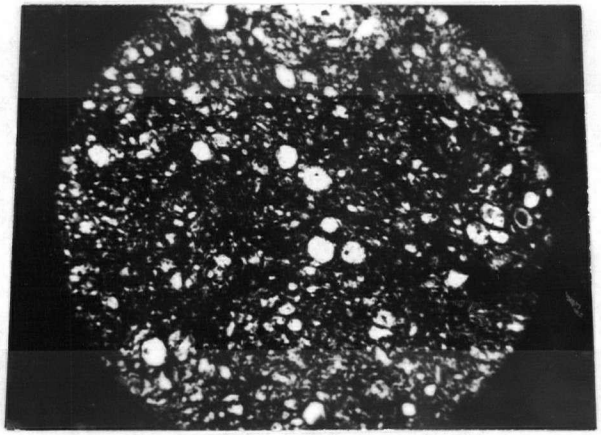
Syncline on Mount Kerr. View to the northwest.

PLATE IX



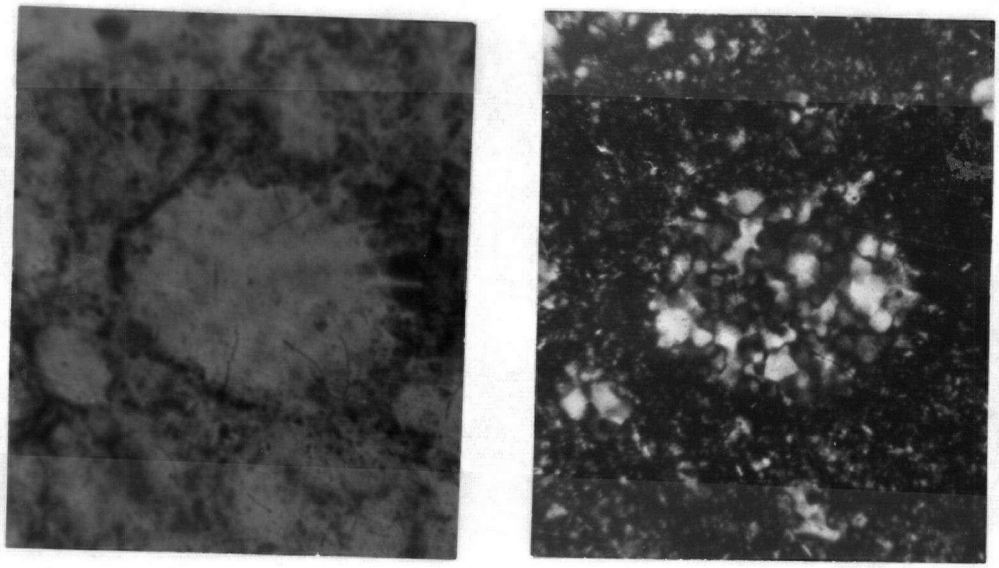
Interbedded limestone and chert, showing box-type of folds. Marble Canyon formation, member IIIa, Upper Permian. About one mile west of Mount Kerr. View to the northwest.

PLATE X



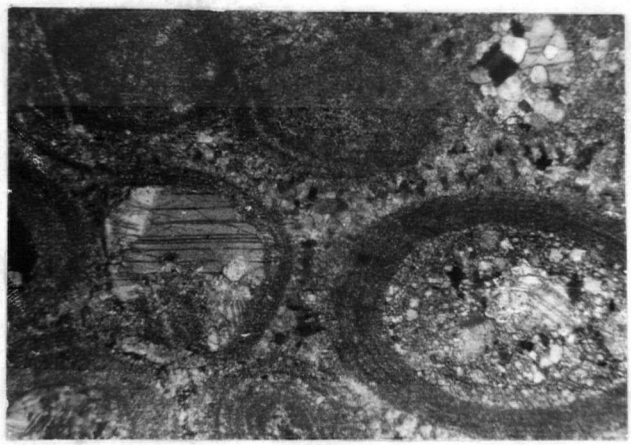
Radiolarian chert nodules in argillaceous matrix. Argillaceous chert from Pavilion group, Division I, Upper Permian or Triassic.
Crossed nicols x25.

PLATE XI



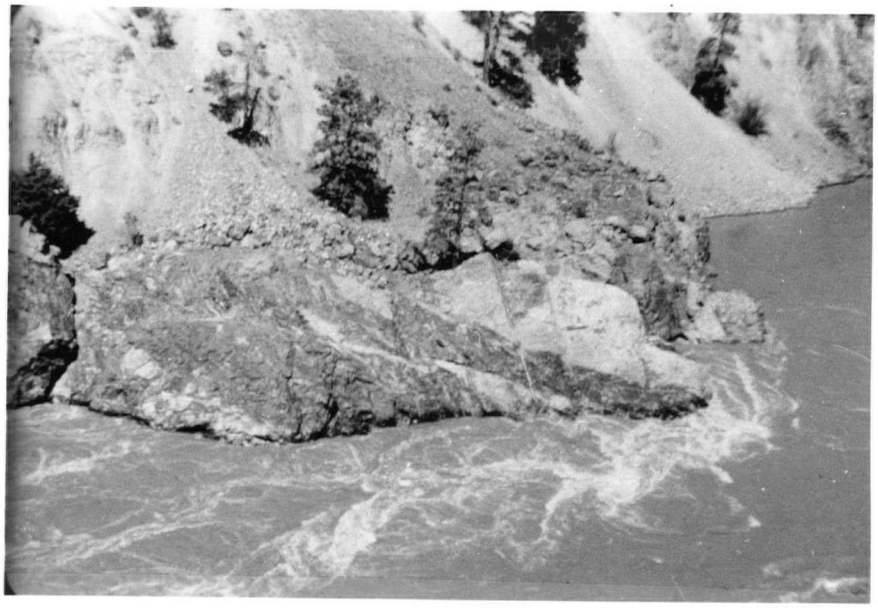
Radiolarian chert nodule, showing radiating spines. Pavilion group, Division I, Upper Permian or Triassic. Left: ordinary light, right: crossed nicols x190.

PLATE XII



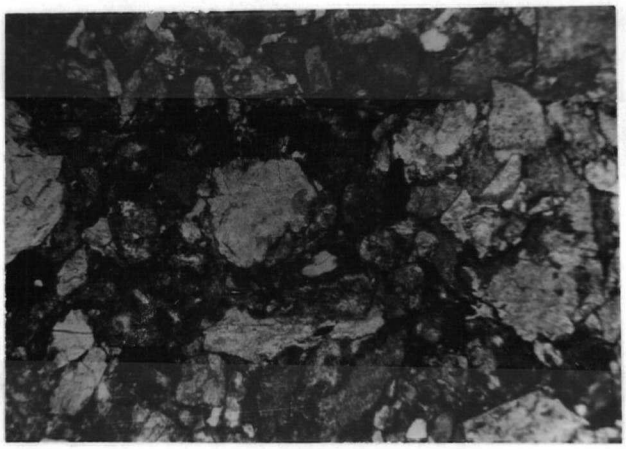
Oolitic limestone. Oolites and pisolites show external concentric structure and some relatively coarse twinned crystals of calcite in the interior. Pavilion group, Division I, Upper Permian or Triassic.
Crossed nicols x35.

PLATE XIII



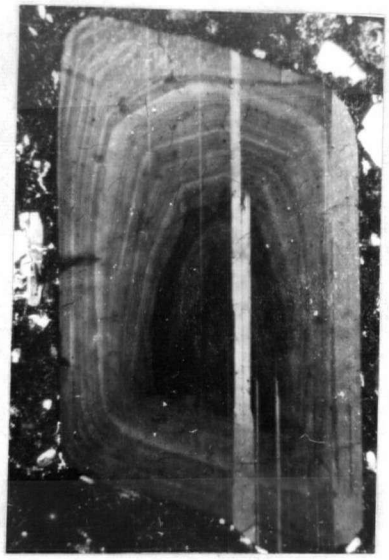
Migmatite consisting of hornblende hornfels and dioritic intrusions. West shore of Fraser River, opposite the mouth of Kelly Creek. View to the northwest.

PLATE XIV



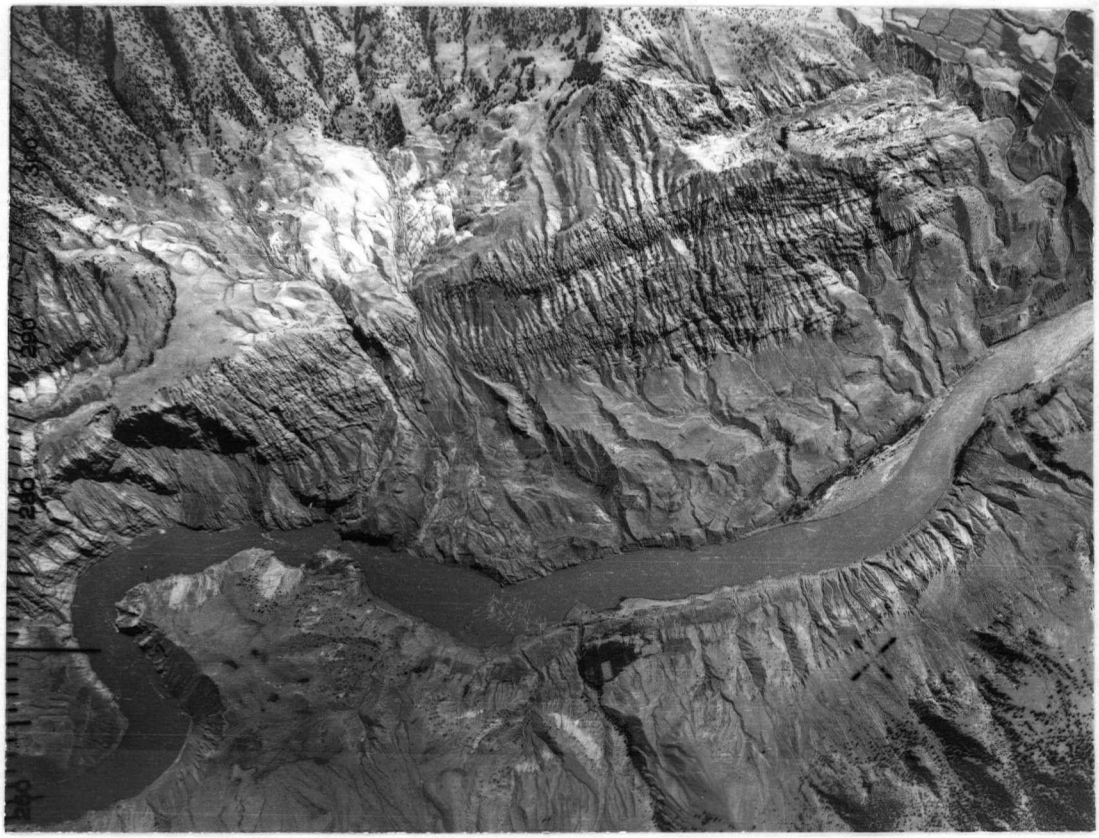
Volcanic arenite, fine-grained.
A few clear grains are of quartz,
the light grey grains are mostly
of plagioclase. Specimen 2 of
figure 4. Jackass Mountain group,
Division C, Barremian.
ordinary light x32.

PLATE XV



Plagioclase crystal, showing twinning and oscillatory normal zoning, from tuff, Spences Bridge group, Gibbs Creek assemblage, member B, Aptian.
Crossed nicols x30.

PLATE XVI



The French Bar formation, Upper Eocene or Oligocene, near French Bar Canyon. Air-photograph.

PLATE XVII

Conglomerate of the French Bar formation, Upper Eocene or Oligocene, near Big Bar Creek.

PLATE XVIII

Olivine basalt, Middle or Late Tertiary. About 2 miles north of McKay Creek. View to the north.

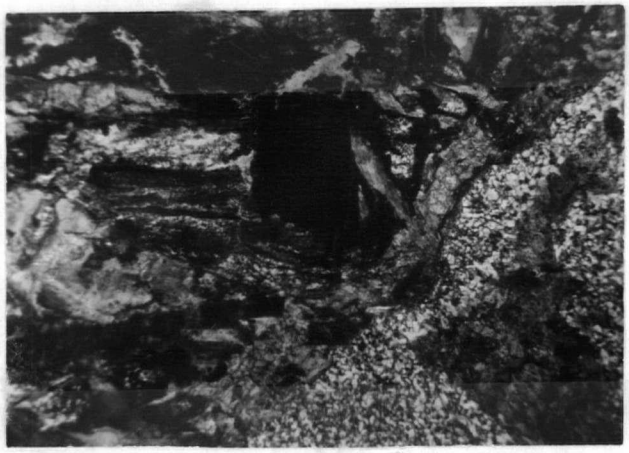
PLATE XIX

Olivine basalt, showing large, corroded crystals of olivine, lath-like, twinned plagioclase, and fine crystals of clinopyroxene and iron ore. The texture is seriate inter-granular.
Crossed nicols x32.

PLATE XX

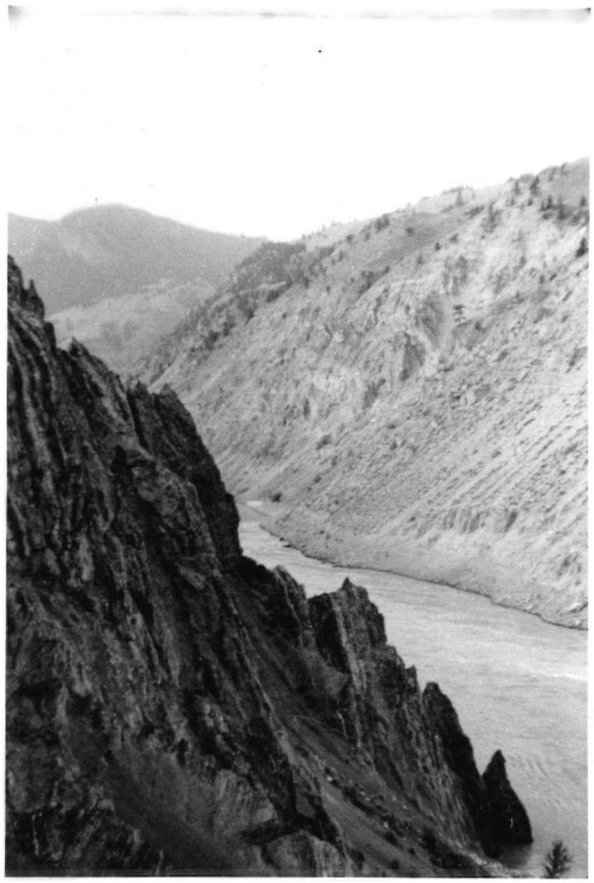
Slide of Middle or Late Tertiary
olivine basalt near Leon Creek.
Air-photograph.

PLATE XXI



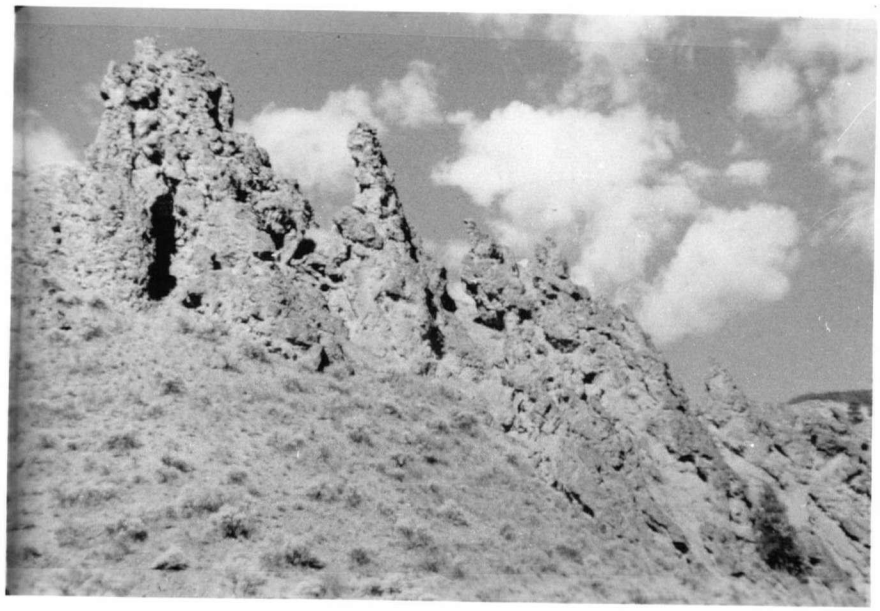
Altered ultrabasic rock. A grain of chromite, (dark), some parankerite, (medium grey to dark), partly pseudomorphous after enstatite and partly altered to limonite, and veins of very fine-grained quartz, (mostly light grey). Ultrabasic belt west of Lillooet, Upper Triassic (?) Crossed nicols x32.

PLATE XXII



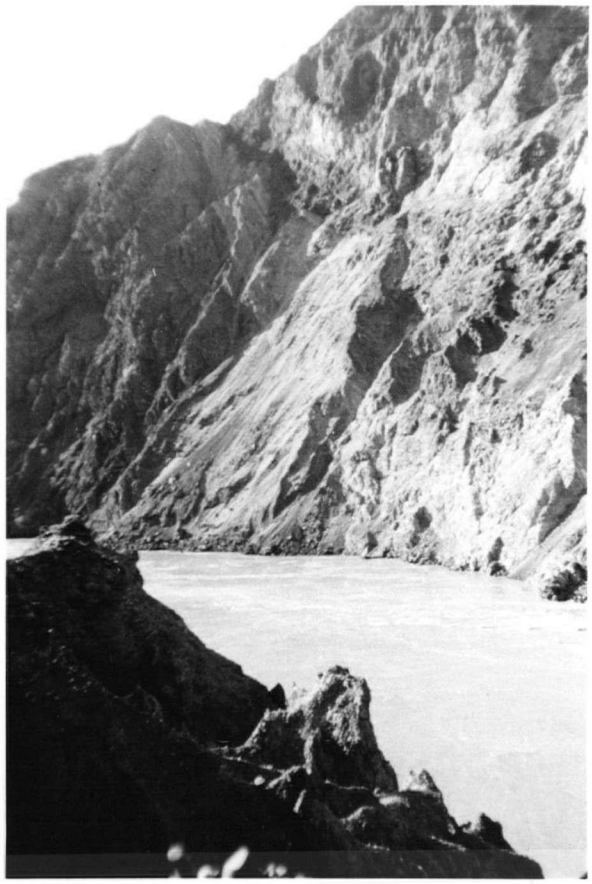
Steeply dipping strata of the Jackass Mountain group, Division C, Barremian, near fault "d" on the east side of the Fraser River, between Sallus Creek and Gibbs Creek; view to the southwest.

PLATE XXIII



Andesite and basalt of the Spences Bridge group, Upper Division, Aptian, dipping steeply to the northeast near fault contact with Pavilion group, Division II, Triassic, (fault "e"). Lower part of McKay Creek. View to the northwest.

PLATE XXIV



Fault "e" in Big Bar Canyon. View to the southeast. On the northeast side of the fault chert and argillite of the Pavilion group, Division I, Upper Permian or Triassic; on the southwest side basalt and andesite of the Ward Creek assemblage, Cretaceous or early Tertiary. The fault plane dips about 75° to the southwest.