THE STRATIGRAPHY AND STRUCTURE OF THE TYPE-AREA OF THE CHILLIWACK GROUP, SOUTHWESTERN BRITISH COLUMBIA

by

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JAMES WILLIAM HERON MONGER. THE STRATIGRAPHY AND STRUCTURE OF THE TYPE-AREA OF THE CHILLIWACK GROUP, SOUTHWESTERN BRITISH COLUMBIA.

Supervisor: Dr. W. R. Danner.

ABSTRACT

The stratigraphy and structure of Upper Palaeozoic and Mesozoic sedimentary and volcanic rocks, and of amphibolitic rocks of unknown age, were studied in an area of about 140 square miles in the Cascade Mountains of southwestern British Columbia.

The amphibolitic rocks are probably of diverse origins; their stratigraphic relationship to the other rocks is not known, although they may, in part, be equivalent to pre-Devonian rocks in northwestern Washington.

Upper Palaeozoic rocks comprise the Chilliwack Group. The base is not exposed. Oldest rocks are volcanic arenites and argillites which are overlain by an argillaceous limestone, about 100 feet thick, in which Early Pennsylvanian (Morrowan) fusulinids occur. Apparently conformably overlying the limestone is a succession of argillites, coarse volcanic arenites, minor conglomerate and local tuff, which contains both marine and terrestrial fossils and ranges in thickness from 450 to 800 feet. A cherty limestone, generally about 300 feet thick, in which there is an Early Permian (Leonardian) fusulinid fauna, is conformable upon the clastic sequence. Altered lavas and tuffs are in part laterally equivalent to this Permian limestone, and, in part, overlie it; these volcanic rocks range in thickness from 700 to 2,000 feet.

Disconformably above the Permian volcanic rocks are argillites and volcanic arenites of the Cultus Formation. This formation is apparently about 4,000 feet thick, contains Late Triassic, Early and Late Jurassic fossils and no stratigraphic breaks have been recognized within it.

All of these rocks underwent two phases of deformation between Late Jurassic and Miocene time. The first phase, correlated with mid-Cretaceous deformation in northwestern Washington, was the most severe, and thrusts and major, northeast-trending recumbent folds were formed. These structures subsequently were folded and faulted along a northwest trend, possibly in response to differential uplift of the Cascade Mountains.

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INTRODUCTION

Purpose and scope of investigation

The stratigraphy of many sedimentary and volcanic rock assemblages in the Western Cordillera, particularly those of Palaeozoic age, is very poorly known. This is due to several factors, among which are the priority given by the various geological surveys to reconnaissance mapping, to terrain which is commonly rugged and inacessible, and to the generally complex structures encountered in the region. Therefore, W.R. Danner suggested that the writer make an intensive study of the Upper Palaeozoic Chilliwack Group in the small, readily accessible area in southwestern British Columbia where the group had first been investigated by R.A. Daly (1912), with the object of obtaining as much information as possible on its stratigraphic composition.

As the investigation proceeded it became evident that the structural complexity of the area was such that if any definite statement was to be made on the stratigraphy of the Chilliwack Group, more emphasis would have to be placed on structural geology than was originally intended. Consequently, this thesis is a study of the stratigraphy and structure of the area in which the Chilliwack Group was first described, rather than an account of the Chilliwack Group alone. The general nature and relationships between rock stratigraphic units of formational status are described. Palaeontological study is largely restricted to identification of fusulinids in Palaeozoic rocks, and cephalopods in Mesozoic rocks, these fossils providing the most precise stratigraphic dates. As the interpretation of the structure of the area is based partly on a study of minor structures, these are described in some detail.

Location and accessibility of the type-area of the Chilliwack Group

In 1912, Daly described four stratigraphic sections, which provided the basis for his "Chilliwack Series", or Chilliwack Group, as it is now designated. As these sections were measured in, and just south of the valley of Chilliwack River, it is justifiable to regard this valley as the type-area of the Chilliwack Group.

Chilliwack Valley is located in southwestern British Columbia, approximately 70 miles east of Vancouver, about 6 miles southeast of the town of Chilliwack, and about 6 miles north of the International Boundary (Figure 1). It lies within the Skagit Range, on the western flank of the Cascade Mountains of British Columbia, which are the northerly extension of the Northern Cascade Mountains of northwestern Washington (Smith and Calkins, 1904, p.14, Fenneman, 1931, p.422, Holland, 1964, p.44 and map).

The area investigated by the writer includes much of Chilliwack Valley, and is bounded on the west by Cultus Lake Valley, on the northwest by Fraser Lowland (Holland, 1964, p.36), on the east by Cheam Range and roughly by the divide between Slesse and Nesakwatch Creeks, and on the south by the International Boundary. This area is referred to subsequently as the Chilliwack Valley map-area.

Access to most parts of the map-area is good. A largely unpaved all-weather road from the settlement of Vedder Crossing, which is just west of the map-area, continues parallel to Chilliwack River as far as Chilliwack Lake, east of the map-area (Plate 1). Logging roads, in various

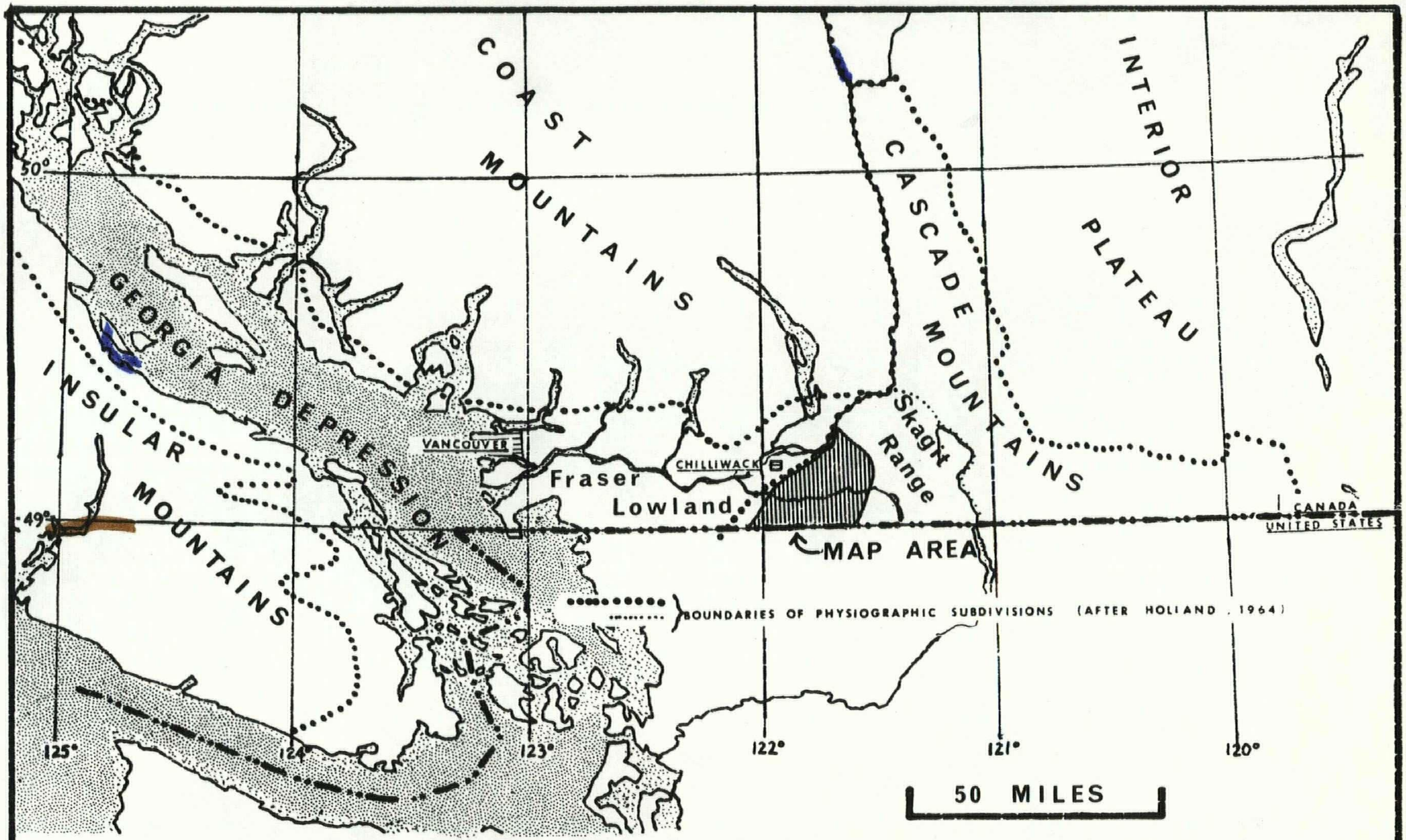


FIGURE 1: Index Map showing location of Chilliwack Valley Map Area, southwestern British Columbia.

states of repair, follow most of the major tributary streams of Chilliwack River and ascend several of the mountains. In the north and northwest parts of the map-area, logging roads go up the mountains directly from the flood plain of Fraser River. A few British Columbia Forest Service trails run into some of the more inaccessible areas. No permission is needed to gain access to most of the map-area, as it lies largely within Chilliwack Provincial Forest.

Climate and vegetation

The climate is mild, with moderate precipitation. At Cultus Lake, on the west side of the map-area, the average annual mean temperature, over a period of 10 years, is 49° Fahrenheit, and the average annual total precipitation, over a period of 24 years, is 58 inches (British Columbia Department of Agriculture, 1957). Accumulated winter snow persists on some mountain slopes down to an altitude of 5,000 feet, until late June or early July. During the two full field seasons (1962, 1963) spent in the map-area, steady rain and low cloud hampered field work during much of June, and early July; fine weather predominated in late July, August and early September.

Below 5,000 feet altitude forest vegetation is prolific (*see* Figure 2). Where virgin forest is present it contains the typical Coast Forest flora with predominant Douglas fir (*Pseudotsuga*), hemlock (*Tsuga*) and cedar (*Thuja*). Balsam (*Abies*) is common at higher altitudes. Destruction of this forest by extensive logging operations and forest fires has resulted in the development of dense second growth over most of the lower slopes of the mountains. Travel in this second growth is extremely

Figure 2: Chilliwack Valley. View looking east, from the northeast side of Church Mountain.

arduous and time consuming, in contrast to the relative ease of travel in the mature, virgin timber. Above an altitude of 5,000 feet alpine meadowland predominates; above 6,000 feet vegetation is sparse.

Physiography

Physiographically the map-area is in the southwestern part of the Cascade Mountains of British Columbia (Holland, 1964). The topography of the map-area is rugged, with an average relief of about 5,000 feet. The mountains rise steeply from the flood-plain of Fraser River, of approximately 100 feet elevation, to heights of about 4,500 feet in the west and northwestern parts of the map-area, and increase in height eastward to a maximum of about 7,000 feet on the eastern margins of the map-area.

The map-area lies within the drainage basin of Chilliwack River, with the exception of the slopes of the mountains in the northwestern part of the map-area, which form the south side of Fraser Valley, and which are drained by streams running directly into Fraser River. Orientation of many creeks and the rectangular drainage pattern developed in parts of the map-area, reflect structural control. Creeks may run parallel to either a northeasterly or a northwesterly structural trend.

Both valley and alpine glaciation have had a marked effect on topography. Major stream valleys are relatively straight, with truncated spurs, and of modified U-shape (<u>see</u> Figure 2). Daly (1912, p.595) considered the glacier once occupying Chilliwack Valley to have been the longest valley glacier along the International Boundary in the Cordillera, having a length of at least 30 miles, and a maximum thickness of 4,000 to 5,000 feet. Some minor tributaries, such as Pierce and Borden Creeks, occupy hanging valleys. Cirques, some of which contain tarns, are found on the northerly sides of peaks and ridges, and a few higher peaks carry small, permanent snow fields. Valley floors are commonly overlain by deposits of fluvio-glacial origin. Surficial deposits in the western part of the map-area have been mapped and classified by Armstrong (1960).

Orthography

In this thesis the spellings of names of natural and man-made features follows those given on the Geological Survey of Canada topographic map-sheets 92 H/4, East and West. In some cases such spellings differ from those in local usage or those used on contiguous United States Geological Survey maps.

Previous work

Two geologists, G. Gibbs and H. Bauerman, were attached to the International Boundary Commission, which determined the boundary between Canada and the United States across the Cordillera in 1859-1861. Gibbs (1874, p.342) noted limestone and collected crinoid fragments and corals of Devonian or Carboniferous age from limestone float in Chilliwack River. Bauerman (1884) published a more detailed report in which he made no differentiation between Palaeozoic and Mesozoic rocks, but estimated that there were 24,000 feet of shaly beds, with limestone in the higher parts, along Chilliwack Valley, between Schweltza (Cultus) Lake and Chilukweyuk (Chilliwack) Lake. These strata were considered to be equivalent to shales and limestones along the Fort Hope road, and the limestones thought to be similar to those of Vancouver Island. Bauerman mentioned finding Cretaceous fossils in Chilliwack Valley, but gave a geological cross-section through this area showing the rocks to be of Palaeozoic age.

Smith and Calkins (1904) made a geological reconnaissance of the Northern Cascade Mountains in Washington. They noted the presence of strata probably ranging in age from Early Palaeozoic to Jurassic in the vicinity of Mount Baker, a few miles south of the map-area. The supposed Palaeozoic rocks were predominantly sandstones and slates, with some volcanic rocks. Sandstones, less metamorphosed than the supposed Palaeozoic rocks, contained Upper Jurassic pelecypods and cephalopods.

During 1901 and 1906, R.A. Daly did geological mapping in the Chilliwack Valley area and his final report was published in 1912. Daly's report is the most detailed work yet published on the geology of this area and he is responsible for all stratigraphic nomenclature, incorporated in the literature, which is applied to rock units in the area. He gave the name "Chilliwack Series" to sedimentary rocks exposed in Chilliwack Valley between the Chilliwack batholith on the east and a point 2 miles west of the junction of Tamihi Creek with Chilliwack River. Andesitic rocks, which he believed were present in the upper part of the "Chilliwack Series" and which crop-out on the International Boundary west of Tamihi Creek he called the "Chilliwack Volcanic formation." The term Cultus Formation was applied to fine clastic rocks of supposed Triassic age, that occur on the west side of Cultus Lake, and, according to Daly (1912, p.516) are in fault contact with the "Chilliwack Series."

Daly described in some detail four stratigraphic sections from the "Chilliwack Series", measured respectively on Church Mountain, east of

Cultus Lake and immediately south of the International Border, on the west slope of Mount McGuire, and on the north side of Chilliwack Valley north of the mouth of Slesse Creek valley. These four sections were combined to give a tentative columnar section for the "Chilliwack Series", having a total thickness of more than 6,780 feet (see Table 1). Faunal collections were examined by Girty (in Daly, 1912, p.515); he considered them to be correlative, in part, with the fauna of the Nosoni Formation of California, then believed to be of Upper Carboniferous age.

Daly (1912, p.516, p.544) indicated that he was aware of the structural complexity of the area, and made a rough interpretation of the structural geology. He suggested that the Chilliwack River between Tamihi and and Slesse Creeks flows along the core of a "broken anticline", whose axis plunges eastward at a low angle. The southern limb of this anticline is the northern limb of a "broken syncline" capping Mount McGuire. Probable repetition of a limestone unit on the north side of Chilliwack Valley was ascribed to normal faulting. Daly believed that the Cultus Formation was bounded on the east and west by possible normal faults, and that the volcanic rocks on Liumchen Mountain were overthrust northward (Daly, 1912, p.516, and Map 89A).

Table 1: General columnar section of the "Chilliwack Series", according to Daly (1912, p.514)

Top, erosion surface at plane of unconformity with Cretaceous (?) rocks

1.	50 + feet-----	Quartzitic sandstone.
2.	20 " -----	Dark grey argillite.
3.	50 " -----	Light grey limestone, containing corals and crinoids.
4.	60 ± " -----	Grey calcareous quartzite and argillite.
5.	2,000 + " -----	Andesitic flows, tuffs, and agglomerates (pillow lava probably in this member where locally developed). This member may for convenience be referred to as the Chilliwack Volcanic formation.
6.	200 " -----	Grey and brownish shale and sandstone, with thin conglomerate bands; shales crumbling and thin-bedded; highly fossiliferous, with plant fragments, corals, crinoids, bryozoans, brachiopods, pelecypods and cephalopods (?).
7.	600 ± " -----	Light grey, massive, generally crystalline limestone, often crinoidal, with corals and bryozoans.
8.	90 " -----	Shale, sandstone and grit.
9.	110 ± " -----	Massive light grey limestone, with large crinoid stems and brachiopods, bryozoans, and echinoderms.
10.	300 ± " -----	Dark grey and brown shales, with fossils.
11.	100 " -----	Massive, hard sandstone.
12.	1,400 ± " -----	Hard sandstones and black and red shales with bands of grit and thin beds of conglomerate; thickness very roughly estimated.
13.	800 ± " -----	Hard, massive sandstone with gritty layers.
14.	1,000 + " -----	Dark grey to black, often phyllitic argillite with quartzitic bands.
	6,780 feet	

Base concealed.

N.L. Bowen (1914, pp.112-113) noted Chilliwack-type rocks on both sides of Fraser River, north of the map-area. He suggested that a northeasterly trend in Fraser Valley indicated the existence of a Palaeozoic mountain system oriented in this direction. On this earlier trend northwesterly trending faults and granitic intrusions were superimposed in Mesozoic time.

No further work was published on this area until 1930, when C.H. Crickmay (1930a) discussed the structural connection between the Coast and Cascade Mountain systems. Crickmay worked mainly on Mesozoic rocks around Harrison Lake, north of the map-area, and gave no detailed description of the Palaeozoic rocks. He traced the structure and some lithological units south across Fraser River to the vicinity of Mount Baker in northern Washington. Unlike Daly, who considered all rocks between the Chilliwack batholith on the east and Church Mountain on the west as Palaeozoic, Crickmay assigned rocks in the eastern third of the Chilliwack Valley area to his Slollicum "Series" of possible Triassic age.

Crickmay described a major fault, the Harrison Lake fault, whose trace largely lies beneath Harrison Lake. Palaeozoic rocks east of the lake are in fault contact with Mesozoic rocks to the west. The fault plane dips steeply to the east. The southward continuation of this fault was believed to mark the western limit of Palaeozoic rocks in the Chilliwack Valley (<u>see</u> map, Crickmay, 1930a, <u>opp</u>. p.487). Crickmay considered that rocks of the area immediately east of Cultus Lake, described by Daly as Cultus Formation, were <u>schuppen</u> of Carboniferous and Lower Cretaceous rocks.

Structural trends were observed by Crickmay to be roughly parallel to the boundaries of the "Jurassic Coast Range Batholith" and he suggested that the Cascade Mountains were formed by compression of the geosynclinal sedimentary accumulation against the resistant mass of the batholith.

In 1944 the Geological Survey of Canada published the Hope Sheet (Map 737A) on a scale of 4 miles to 1 inch. This geological map was a compilation by C.E. Cairnes, with the geology shown for Chilliwack Valley being taken directly from Daly's map of 1912. The term Chilliwack Group, rather than Chilliwack Series, appeared for the first time on this map, but no explanation for the change was made.

A brief, general review of the geology of the northern Cascade Mountains of Washington State published by P. Misch (1952) was the first comprehensive synthesis of the geology of the region, although no detailed stratigraphic information was included.

D.N. Hillhouse (1956) studied the geology of the area around Cultus Lake, and concluded (p.23) that most of the limestones he observed in the Chilliwack Group are probably of Wolfcampian age, but that an age range from Mississippian to Triassic is possible.

W.R. Danner (1957), who worked mainly in northwestern Washington, to the southwest of the map-area, divided the Chilliwack Group into two formations on the basis of lithologies and extensive faunal collections. These formations are the Red Mountain Formation of probable Early Pennsylvanian to Late Mississippian age, and the Black Mountain Formation of Wolfcampian age (Danner, 1957, p.115). The type-localities of these proposed formations are a few miles southwest of the Chilliwack Valley area.

Misch (1960) briefly described two major westward and northwestward overthrusts in this region. The lower or Church Mountain thrust-fault transported Palaeozoic rocks over Jurassic and lower Cretaceous rocks. In the Chilliwack Valley map-area this fault is shown (Map, Geological Discussion Club, 1960) to follow approximately the southward extension of Crickmay's Harrison Lake fault. Recumbent folds within this Palaeozoic thrust-plate were observed in the map-area by Misch (1960). The upper or Shuksan thrust-fault (Misch, 1960, 1962) brings low grade metamorphic rocks of pre-Jurassic age over the Upper Palaeozoic rocks. Both fault movements are of middle (?) Cretaceous age (see Miller and Misch, 1963, p.107). The thrust-faults have been subsequently folded in Tertiary (early Eocene ?) time (Misch, 1960, Miller and Misch, 1963).

C.L. Smith (1962) studied the Red Mountain Formation of Danner, and correlated limestone at several localities in northern Washington with this unit.

W.S. Moen (1962) mapped and described the geology of the northern part of the Van Zandt quadrangle, immediately southwest of the map-area in northern Washington. This area contains the type-localities of Danner's (1957) proposed formations. According to Moen (1962, p.57) the Chilliwack Group was initially folded and faulted prior to deposition of Lower Mesozoic rocks, although he presented no evidence to support this conclusion. Deformation during middle Cretaceous time produced northeast trending folds and faults and large-scale thrusts. North trending folds and associated east trending faults were formed during middle Eocene time. Epeirogenic movement in Pliocene time superimposed structures similarly oriented to those produced in Eocene time.

Field work

Field work by the writer was done in 1962, 1963, and 1964. Data was plotted directly on maps of scale 4 inches to 1 mile, enlarged from 1:50,000 Canadian National Topographic Sheets, 92 H/4 West and East. Air photographs, obtained from the British Columbia Department of Lands and Forests, gave almost complete stereographic coverage of the map-area, and were comparable in scale to the enlarged maps. Locations on the map were determined with the aid of the air photographs and a Taylor altimeter, calibrated in 25 foot intervals.

In addition to mapping lithologies and contacts of rock-stratigraphic units of known age, note was made of the geometry, orientation, sense of movement and relative age of any secondary structures present. Information from these minor structures, combined with a knowledge of the spatial distribution of rock units of known age, allows an interpretation to be made of the geology of the area.

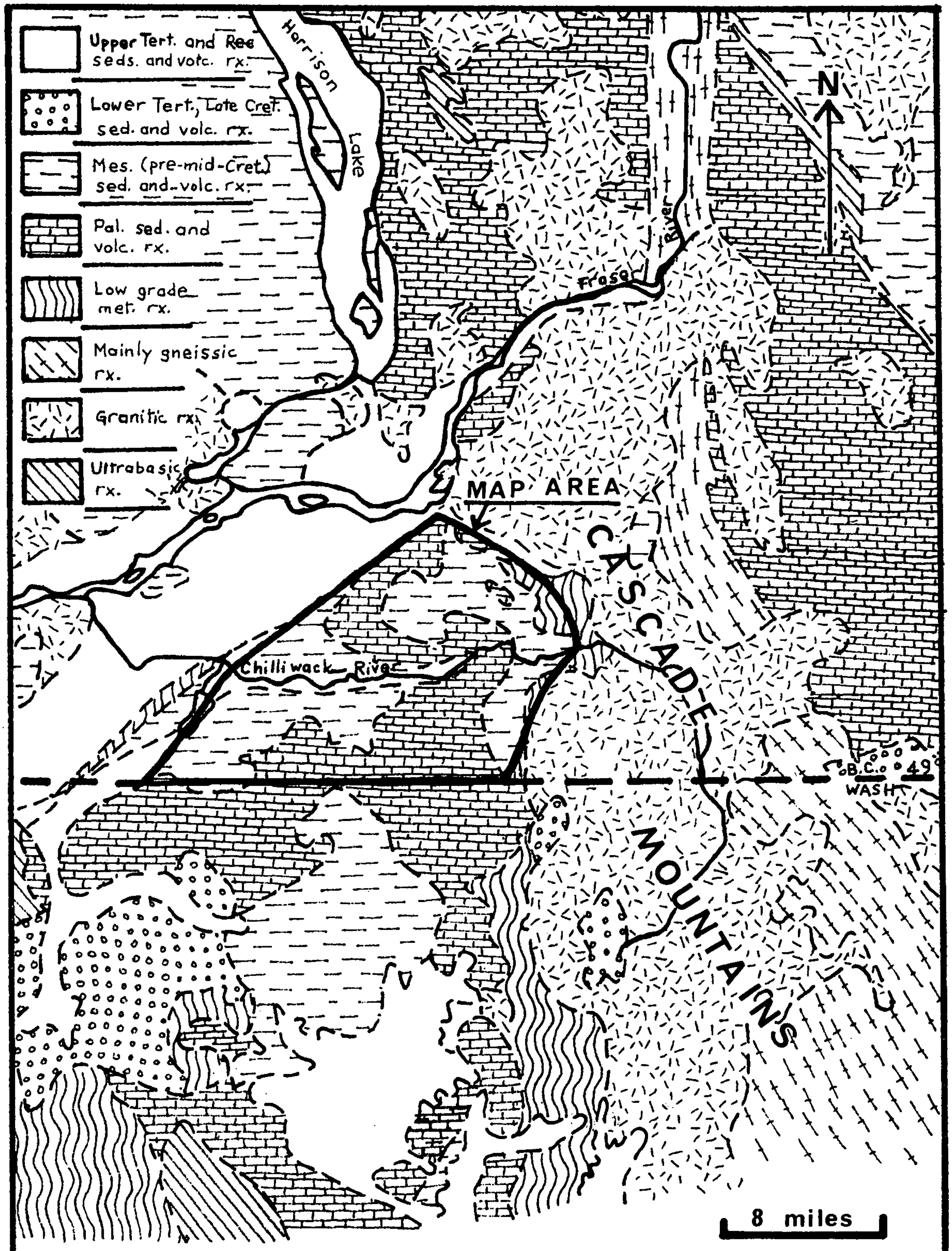
The size of the map-area was not fixed, but instead governed by two opposing considerations. Mapping had to be done in sufficient detail to enable possibly complex structures to be elucidated. On the other hand, the area mapped had to be large enough to allow demonstration of both the continuity, or otherwise, of rock-stratigraphic units and the magnitude of any major structures controlling the present distribution of these units. More field time was spent in the central part of the map-area, than towards the periphery.

GEOLOGICAL SETTING

The Cascade Mountain system in northwestern Washington and southern British Columbia consists of a central, north-northwest trending, gneissic and granitic core, flanked on the east and west by belts of sedimentary and volcanic rocks which locally have been subjected to low-grade regional metamorphism (Figure 3; Map, Geological Discussion Club, 1960; Huntting et al., 1961). The type-area of the Chilliwack Group is situated at the northern end of the western belt of sedimentary and volcanic rocks, contiguous to the core of the mountain system, which here consists of the intrusive granodioritic Chilliwack batholith and the Custer Gneiss (Daly, 1912). To the north of the map-area, across Fraser River Valley, intrusive granitic rocks predominate in the apparent extension of the system, and the Cascade Mountains adjoin the Coast Mountains (Geological Discussion Club, 1960; Little, 1962).

The belt of sedimentary and volcanic rocks on the west side of the Northern Cascade Mountains has been the site of intermittent deposition since at least Middle Devonian time. Volcanic rocks, and sedimentary rocks derived from them, are the predominant deposits, although limestones are of local importance. Younger sedimentary rocks tend to be arkosic, but still contain much material of volcanic origin (Danner, 1960a, pp.1,2).

Middle Devonian rocks lie unconformably upon an amphibolitic gneiss complex cut by dioritic rocks in the San Juan Islands, some 40 miles southwest of the map-area (Danner, 1960b). Amphibolitic and granitoid rocks of minor areal extent exposed west and south of the Chilliwack Valley



(Map taken from Guidebook of Geol. Discussion Club, Vancouver, B.C., with modifications)

FIGURE 3 : Sketch map showing the geological setting of map area.

map-area (Moen, 1962, p.49, Miller and Misch, 1963, p.166) and within the easternmost part of the map-area are possibly equivalent to the pre-Middle Devonian rocks in the San Juan Islands.

Limestones of Devonian age cropping-out immediately southwest of the map-area are included by Moen (1962, p.15) within his undifferentiated Chilliwack Group, and correlated by Danner (1960a, p.3) with Middle Devonian volcanic and clastic rocks and limestones of the San Juan Islands (Danner, 1957, p.54).

No Mississippian rocks are recognised in this region (Danner, 1960a, p.3). Lower Pennsylvanian (?) rocks lie with apparent conformity (Danner, 1957, p.88) upon Devonian rocks in the San Juan Islands. Limestones of Early Pennsylvanian age, and associated clastic rocks present within the map-area and to the south of it, form the lower part of the Chilliwack Group as presently established. These Pennsylvanian rocks are widely distributed in northwestern Washington (Smith, 1962).

Lower Permian clastic rocks, limestones and volcanic rocks disconformably overlie the Pennsylvanian rocks in and to the southwest of the map-area and comprise the upper part of the Chilliwack Group as presently established. These rocks are overlain disconformably in the map-area by Upper Triassic rocks. Overlying Lower Permian rocks in the San Juan Islands, however, are Upper Permian rocks; the latter are also present farther south in Washington in the Cascade Mountains (Danner, 1957, 1960a).

During Late Triassic time, volcanic rocks and limestones were laid down west of this region on Vancouver Island, and to the east in the Southern Interior of British Columbia (McLearn, 1953). In the map-area predominantly fine clastic rocks of marine origin, belonging to the Cultus

Formation, were deposited. These range in age from Late Triassic to Early Jurassic, with no recognised break. Middle Jurassic volcanic rocks crop-out both north and south of the map-area (Crickmay, 1930b, p.35), Danner, 1960a, p.4) and may be present within it. Upper Jurassic clastic rocks are recognised in the eastern part of the map-area, and clastic rocks of Upper Jurassic age grade up into the Lower Cretaceous rocks to the north and south of the map-area (Crickmay, 1930b, p.35, Miller and Misch, 1963, p.167).

Middle Devonian to Lower Cretaceous clastic rocks of this sedimentary belt are derived generally from source areas in which volcanic rocks were predominant. The presence of volcanic rocks, not uncommonly accompanied by limestone, and contemporaneous with the clastic rocks, suggests that many source areas were active volcanic centres, within the mobile belt now occupied by the Western Cordillera.

Although Miller and Misch (1963, p.167) suggested that metamorphism took place during Late Palaeozoic and Early Mesozoic time in this region, no evidence of any orogenic activity of this age has been observed within the map-area. Available data indicates that stratigraphic breaks between Lower Permian and Upper Triassic rocks, and possibly between Lower Pennsylvanian and Permian rocks are due to non-deposition, surficial erosion and possibly non-deformative, epeirogenic (?) uplift. The earliest, post-Devonian, evidence of deep erosion, such as would presumably accompany orogeny, is the presence of granitic cobbles in a Lower Cretaceous conglomerate in the Harrison Lake area (Crickmay, 1962). The major post-Devonian orogenic event in the region happened about mid-Cretaceous time (Miller and Misch, 1963, p.167). Within the Chilliwack Valley map-area, and contiguous areas to the southwest (Moen, 1962, p.57), northeast trending folds and thrusts were formed, and many of the rocks were subjected to very low-grade regional metamorphism. The northeast trend of these structures is of unknown areal extent and stands in marked contrast to the regional north-northwest trend of both Cascade and Coast Mountains.

Immediately southwest of the map-area, rocks of Late Cretaceous and Paleocene age lie with marked unconformity on Palaeozoic and Mesozoic rocks (Miller and Misch, 1963, p.167). The younger rocks are predominantly continental arkoses, although they still contain much volcanic detritus (Danner, 1960a, p.2). To the west, on Vancouver Island, Upper Cretaceous marine rocks are transitional into these continental sediments. Deposition in this region, from post-mid-Cretaceous time to the present, has occurred in restricted basins, whose positions correspond approximately to present day topographic depressions and lowland areas.

A second period of deformation took place in the region in early Eocene time (Miller and Misch, 1960, p.170). In the map-area, northwest trending structures normal to the trend of structures produced during mid-Cretaceous deformation, were possibly formed at this time.

Middle Eocene and younger rocks are continental arkosic rocks which lie with angular unconformity on the lithologically similar Paleocene rocks. To the west and southwest of the map-area these rocks are merely tilted or gently warped (Daly, 1912, p.520, Miller and Misch, 1963, p.171). However, downfaulted middle Eocene (G.E. Rouse, oral communication) conglomerates at Hope, 20 miles northeast of the map-area, have the form of a syncline with steeply dipping limbs (Cairns, 1924, p.70).

Intrusion of the Chilliwack batholith, forming a part of the crystalline core of the Cascade Mountains immediately east of the map-area, apparently took place 18 million years ago (Baadsgaard _et_ _al_., 1961, p.697), in Miocene time (Kulp, 1961).

STRATIGRAPHY

Preliminary statement

Rock-stratigraphic units are described below in order of decreasing age. Where possible, the descriptions given are of formations or undesignated rock-stratigraphic units of comparable status. These rock-stratigraphic units, their ages and lithologies are summarised in Table 2.

Structural and stratigraphic data provide evidence for the presence within the map-area of at least three major tectonic units or nappes, separated by flat-lying faults. These structures were formed by deformation subsequent to deposition of all rocks in the map-area. In some cases, parts of the same rock-stratigraphic unit are present in two or more nappes. Such parts were originally separated by unknown distances but are now superposed. Consequently, unless such a rock-stratigraphic unit is of remarkably uniform nature, the unit may display quite different characteristics within the relatively small dimensions of the map-area, as the result of superposition during deformation. Most descriptions of formations, or undesignated rock-stratigraphic units of comparable status, therefore are subdivided into discussions of the unit as present in different tectonic units. Where this subdivision is made, the formation is described in order of decreasing structural level.

To make the subsequent discussion easier to follow, a brief summary of these tectonic units which includes the names given to them and the rocks composing them, is given below in Table 3. These structures are discussed in the structure section of the thesis. A schematic representation of their form and relations to one another is shown in Figure 4, and their distribution within the map-area in Figure 5.

Where possible, correlation of rock-stratigraphic units within a single tectonic unit was achieved by tracing-out lithologies. Correlation of formations exposed in different tectonic units was made by demonstrating the presence of a similar lithology in a comparable stratigraphic succession.

Table 2: Rock-stratigraphic units
(Stratigraphic names established in the literature are in capital letters).

Age		Name and apparent thickness (feet)	Lithology
Late Jurassic Middle Jurassic Early Jurassic Late Triassic		CULTUS FORMATION 4,000	Fine to medium grained volcanic arenites, argillites and slates; very minor flows
		disconformity	
Early Permian (Leonardian)	CHILLIWACK GROUP (as presently established)	Permian volcanic sequence 2,000 - 700 (conformable)	Altered basic to intermediate flows, tuffs, minor chert and minor argillite
Early Permian (Leonardian)	CHILLIWACK GROUP (as presently established)	Permian limestone 300 (conformable)	Limestone, typically cherty; in part laterally equivalent to the Permian volcanic sequence
Permian and (?) Pennsylvanian	CHILLIWACK GROUP (as presently established)	Upper clastic sequence 800-450 (conformable)	Coarse to medium-grained volcanic arenites, argillites, local conglomerates, tuffaceous towards top. This sequence may include one or more disconformities
Lower Pennsylvanian (Morrowan)	CHILLIWACK GROUP (as presently established)	Red Mountain Limestone (restricted from Danner, 1957) 100 (conformable)	Limestone, typically argillaceous
Lower Pennsylvanian (?)	CHILLIWACK GROUP (as presently established)	Lower clastic sequence 2,500	Argillites, fine to medium-grained volcanic arenites
		-BASE NOT RECOGNISED-	
Unknown age (Possibly equivalent in part to pre-Middle Devonian basement of Danner and Misch)		Amphibolitic rocks	Rocks of possible diverse origin and age

Table 3: Tectonic units of the Chilliwack Valley area

STRUCTURAL TOP

Name of tectonic unit	Description
Unnamed	Permian rocks and amphibolitic rocks which overlie Mesozoic rocks in easternmost part of the map-area
FLAT LYING FAULT	
McGuire Nappe	Recumbently-folded sedimentary and volcanic rocks which range in age from Late Jurassic to Early Pennsylvanian
FLAT LYING FAULT	
Liumchen Nappe	Thrust sheet (in part?) composed of volcanic rocks of Early Permian age, with overlying Mesozoic rocks. In the extreme northeastern part of the map-area, this tectonic unit may include older sedimentary rocks.
FLAT LYING FAULT	
Autochthon (No lateral translation of these rocks, for any great distance, can be demonstrated)	Folded sedimentary and volcanic rocks of slightly lower metamorphic grade than rocks in all higher tectonic units. Age of rocks ranges from Early Pennsylvanian to Middle Jurassic

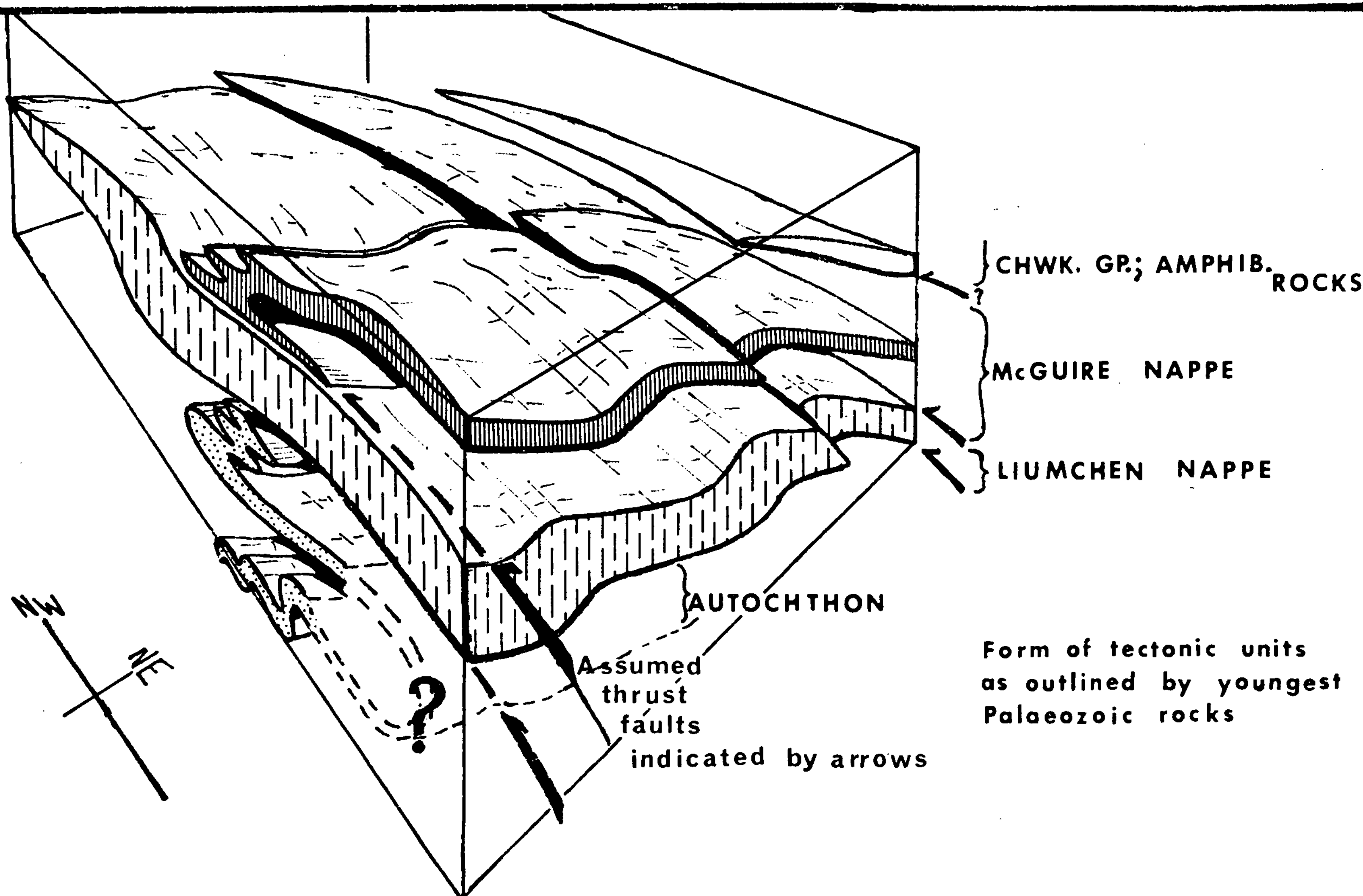


FIGURE 4 : Schematic representation of form and relationships of tectonic units in the map-area

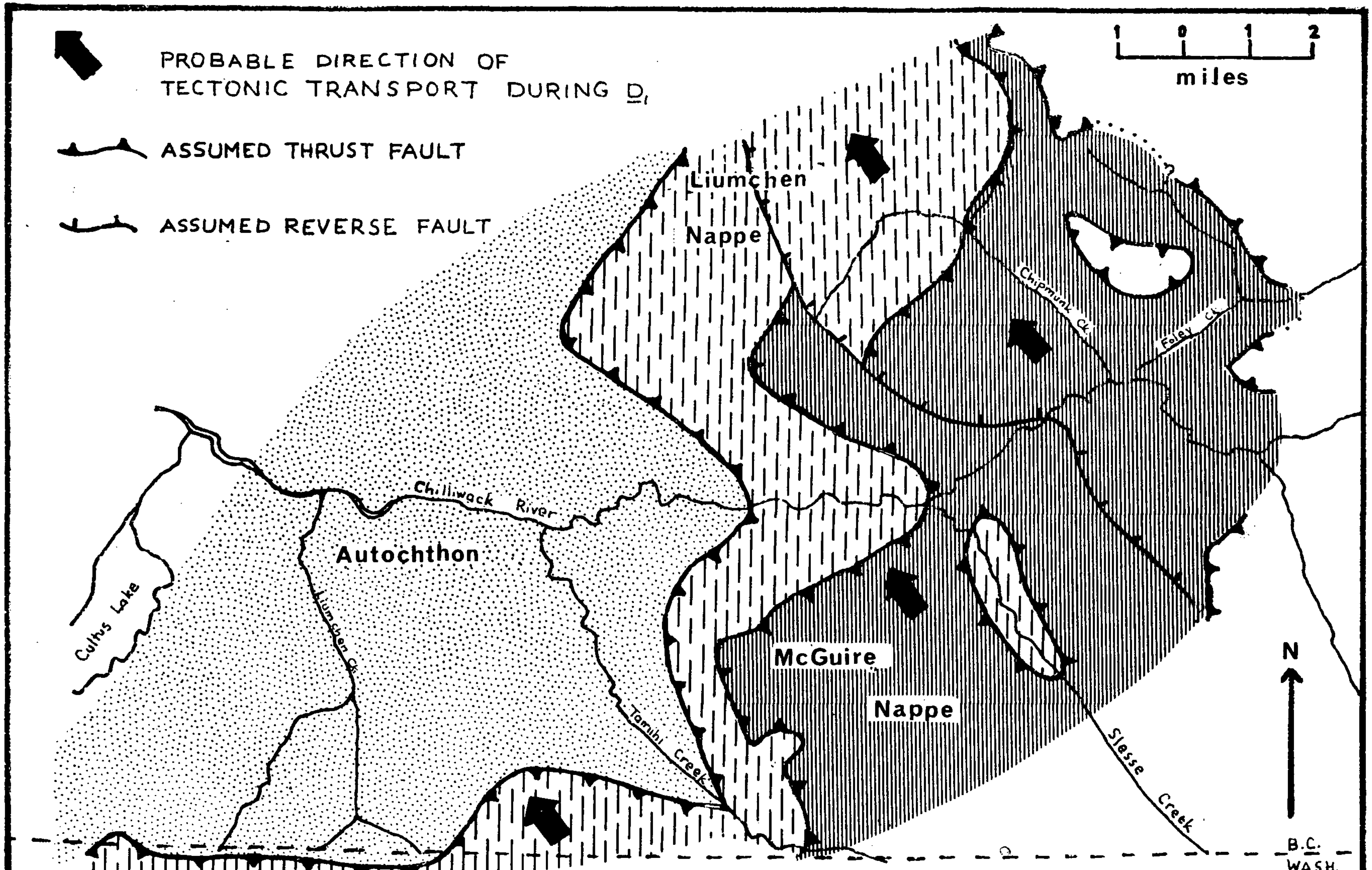


FIGURE 5 : Areal distribution of tectonic units in the map area

Amphibolitic rocks

Rocks that vary widely in texture, less widely in composition and which are probably of diverse origins, but which invariably contain abundant amphiboles, are grouped for the purposes of description under the heading of amphibolitic rocks. These rocks have not been completely mapped and petrological examination was restricted to a few specimens from scattered localities. More work is necessary to demonstrate whether their inclusion under a common heading is justified.

The amphibole-bearing rocks crop-out at the eastern and southeastern limits of the map-area. They appear to form a belt which extends in a north-northeasterly direction from the southern end of Slesse Creek, near the International Boundary, to Airplane Creek Valley, just west of the Cheam Range (Plate 1). Present mapping has not established the continuity, or otherwise, of this belt of amphibolitic rocks. As the rocks exhibit somewhat different characteristics in the northern, central and southern parts of the belt, rocks from each of these locations are described separately.

North of Chilliwack River

Amphibolitic rocks form prominent cliffs on the east side of Airplane Creek Valley and to the south, at an altitude of 4,000 feet, on the ridge between Foley Creek, and Chilliwack River. At the latter locality, Daly (1912, p.544) noted the presence of rocks that he described as a sill or great dyke, similar lithologically to gabbroic rocks on Mount Pierce to the south of Chilliwack River.

Amphibolitic rocks in these localities are typically fine-grained, even-textured, hard, massive, grey-green weathering, dark greyish-green to black rocks. In a few places, small euhedral feldspars are present, scattered through the fine grey-green matrix. Relatively rare coarser equivalents of the above rocks, in hand specimens, typically have an estimated composition of about 70% amphibole and 30% feldspar. One rock examined in the field resembles a fine-grained diorite, being composed of approximately equal percentages of amphibole and feldspar. A coarse-grained rock of granoblastic texture, composed entirely of amphiboles, apparently comprises a dyke within the predominant fine-grained rocks. All coarser grained rocks examined from this area have isotropic fabric.

Microscopically, the fine-grained rocks consist of a groundmass of finely granular epidote (replacing plagioclase laths ?), and small subhedral to anhedral hornblende crystals exhibiting brown to green pleochroism and comprising 20% to 30% of the whole. Chlorite is present throughout the groundmass. Pyrite and pyrrhotite are the most abundant opaque minerals, although skeletal ilmenite crystals partly altered to semi-opaque leucoxene and finely granular sphene (?) are common. Rare feldspar phenocrysts up to 2mm. in length show all stages of alteration to epidote. Fabric of all ~~fine-grained~~ rocks examined is isotropic.

The composition of the few rocks examined in detail suggests that they belong to the quartz-albite-epidote-biotite subfacies of the greenschist facies (Fyfe, Turner and Verhoogen, 1958, p.224).

The amphibolitic rocks on the ridge between Foley Creek and Chilliwack River appear to form a thick, tabular body, roughly conformable with the underlying, eastward dipping, sedimentary rocks. Apparent thickness of these rocks is nearly 1,000 feet. Rocks on the east side of Airplane Creek Valley may be of even greater thickness.

In Airplane Creek Valley, and on the ridge between Foley Creek and Chilliwack River, amphibolitic rocks overlie Mesozoic slates, argillites, and siltstones which are no more metamorphosed than stratigraphically equivalent, lithologically similar, rocks further west in the map-area. The contact has not been observed, but can be located to within about 200 feet in the lower part of Airplane Creek Valley.

Rocks of the Chilliwack Group are exposed above amphibolitic rocks on the east side of Airplane Creek Valley, although the contact has not been investigated. White (1949, p.A215) reported limestones and clastic rocks of the Chilliwack Group on the southernmost peak of the Cheam Range, about 1,500 feet above the top of the amphibolitic rocks on the east side of Airplane Creek, and limestone pods and volcanic rocks probably belonging to this group are present on the west side of the range, farther to the north.

The relationship between amphibolitic rocks in Airplane Creek Valley, and Permian limestones and volcanic rocks that cap Mount Laughington, just west of Airplane Creek is not known. These Permian rocks overlie Mesozoic rocks identical to Mesozoic rocks below the amphibolitic rocks in Airplane Creek. If the Permian rocks on Mount Laughington are the westward extension of the limestones and volcanic rocks in the Cheam Range, which overlie amphibolitic rocks of Airplane Creek, then the amphibolitic rocks must thin very rapidly to the west.

On the ridge south of Foley Creek, argillites and slates of unknown age immediately overlie amphibolitic rocks. The assumed continuation of these rocks in the bottom of Chilliwack Valley are dark grey to black, quartz-rich sericitic slates and argillites, locally thermally metamorphosed by the adjacent Chilliwack batholith to cordierite-biotite hornfelses. These rocks are somewhat similar lithologically to the "pre-Jurassic phyllites" reported by Miller and Misch (1963, p.166). These rocks are possibly the basal part of the Chilliwack Group, by analogy to the relative positions of the rocks on the east side of Airplane Creek.

Mount Pierce and Nesakwatch Creek Valley

Cliffs of amphibolitic rocks on the west side of the northern end of Nesakwatch Creek Valley, were mapped by Daly (1912, p.532) as Slesse Diorite. He regarded the Slesse Diorite as an intrusive, stock-like body of post-Carboniferous age, which was cut by the Tertiary Chilliwack batholith.

Amphibolitic rocks at this locality are generally coarser than amphibolitic rocks to the north, although all grain sizes are present. They range from dark grey-green to black rocks, composed of 100% amphibole, to grey-green rocks containing about 50% feldspar.

Microscopic examination of one coarse-grained specimen, composed of about equal proportions of feldspar and amphibole, revealed fairly fresh andesine associated with large fibrous hornblende crystals with ragged terminations and curved cleavage planes. Pleochroism of the hornblende ranges from greenish-yellow to blue-green. Small elongate amphibole crystals within the feldspars show very strong blue-green pleochroism and are possibly actinolite.

Rocks forming the cliff on the west side of Mount Pierce appear to be part of the same body as the amphibolitic rocks in Nesakwatch Creek, although continuity is not definitely established. Daly (1912, p.543) described from near this locality a body of dyke-like form, which was not seen by the writer, composed of serpentine, olivine, and magnetite and dyke-like bodies of amphibolite transitional to coarse-grained gabbro. One rock examined by the writer from this locality appears similar to the diorite-like rock from north of the Chilliwack River (p.20) but has an indistinct lineation produced by roughly aligned hornblende crystals. In a thin section this rock was seen to be composed of about 40% hornblende (with blue-green to greenish-brown pleochroism) set in a groundmass of finely granular epidote (Figure 6). Sphene and apatite are present in minor amounts, the sphene being coarse-grained, drop-like in shape, and not associated with any opaque minerals.

Overall form of the amphibolitic rocks in this part of the map-area is not known. The amphibolitic rocks on Mount Pierce appear to have the form of a tabular body, conforming to bedding and foliation in underlying Mesozoic argillites and slates.

No rocks were seen to overlie the amphibolitic rocks in the Nesakwatch Creek and Mount Pierce localities. However, rust-coloured bluffs on the east side of Nesakwatch Creek Valley are composed of dark-grey, quartz-rich slates and argillites; these rocks are lithologically similar to rocks above amphibolitic rocks on the divide between Chilliwack River and Foley Creek.

Figure 6: Photomicrograph (thin section, plane light, X40) amphibolitic rock from Mount Pierce, composed largely of hornblende and fine granular epidote. Sphene (high relief) is visible at top centre.

Southern end of Slesse Creek Valley

Amphibolite forms cliffs on the east side of Slesse Creek Valley, about one mile north of the International Boundary at an altitude of 3,500 feet. These rocks are fine-grained, massive, hard and superficially resemble the amphibolitic rocks in Airplane Creek. However, they are composed of an interlocking mesh of fine, needle-like, blue-green actinolite crystals. Biotite is present in minor amounts and minute, red-brown garnets were observed in one specimen.

Due west of this locality, on the west side of Slesse Creek Valley, at altitudes ranging from 2,000 to 2,500 feet, grey to grey-green weathering rocks crop-out. Some of these rocks, with a well-developed foliation which is cut by a later planar structure, closely resemble certain rocks in the amphibolitic-diorite complex underlying Devonian rocks in the San Juan Islands (W.R. Danner, oral communication). One specimen of this foliated rock examined in thin section consists largely of an irresolvable, finely granular groundmass containing muscovite that is oriented parallel to the early foliation. Scattered through the groundmass are actinolite and biotite crystals, mimetic to both the early foliation and later planar structures. These rocks crop-out about one mile from the western margin of the Chilliwack batholith, which is exposed on the east side of Slesse Creek Valley, immediately south of the International Boundary. Contact metamorphism may well be responsible for the development of garnet, biotite and blue-green actinolite, which cross-cut all planar structures.

The overall form of the bodies of amphibolitic rock at the southern end of Slesse Creek Valley, and their relationship to other rock units in the map-area is unknown.

Correlation

Rocks of similar lithology to the amphibolitic rocks in the map-area have been reported by other workers in the region, and are briefly mentioned below. However, until the amphibolitic rocks in the map-area have been mapped and described in detail, any attempt at correlation remains speculative.

Danner (1960b) reported an amphibolitic complex cut by dioritic rock which is unconformably overlain by Middle Devonian rocks in the San Juan Islands. As noted above, amphibolitic rocks from the southern end of Slesse Creek lithologically resemble certain of these pre-Devonian rocks.

The Shuksan thrust, mapped by Misch (1960, 1962) in northern Washington, brings phyllites and greenschists of pre-Jurassic age over Palaeozoic rocks. Underlying the sole of the Shuksan thrust in the Mount Larrabee area, immediately southwest of where Slesse Creek crosses the International Boundary, are crystalline rocks, to which Misch has ascribed a pre-Devonian age, on the basis of their lithological similarity to amphibolitic-dioritic rocks of the San Juan Islands. These rocks, called the Yellow Aster Complex (Miller and Misch, 1963, p.166), are hornblende-rich diorite and gabbro, amphibolite and acidic granitoid rock. Misch (oral communication, February, 1965) has observed amphibolitic rocks on the ridge south of Mount Pierce, which are similar lithologically to some of his pre-Devonian crystalline rocks south of the International Boundary.

Daly mapped the Vedder Greenstone on Vedder Mountain, just west of the map-area. He considered it (Daly, 1912, p.523) to be an altered basic diorite or gabbro, possibly related to volcanic rocks of the Chilliwack Group, although originally he believed it to be part of a basal crystalline series. The similarity between the Vedder Greenstone and rocks near the summit of Mount Pierce was remarked on by Daly (1912, p.544).

Moen (1962, pp.50-56) described metadiorites, amphibolites and diopsidite from just southwest of the map-area, in northern Washington, to the south of Vedder Mountain. He gave a pre-Devonian age to these rocks; presumably because of their lithological similarity to the rocks in the San Juan Islands.

Crickmay (1930a, p.488) mapped rocks he called "Triassic volcanics", north of the map-area, about 10 miles due north of amphibolitic rocks mapped by the writer in Airplane Creek. These Triassic (?) volcanic rocks cross the Fraser Valley and crop-out to the east of Harrison Lake. Cairns (1944, Geol. Surv. Canada, Map 737A) showed bodies of serpentine, diorite, gabbro, amphibolite, hornblendite and pyroxenite in localities corresponding to Crickmay's Triassic (?) volcanic rocks.

Conclusions

Further mapping and systematic sampling is necessary to demonstrate the nature and field relationships of these amphibolitic rocks. It is not even known whether they form a single unit such as could be included under the stratigraphic term "complex." The following conclusions are to be regarded as speculative.

Rocks grouped under the heading "amphibolitic rocks" may well be of completely different origins. Some, such as the foliated rocks exposed at the southern end of the Slesse Creek Valley are possibly of pre-Devonian age, on the basis of their lithological similarity to rocks underlying Devonian rocks in the San Juan Islands. Others, such as the predominantly non-foliated fine-grained rocks north of the Chilliwack River, may correspond to the "pre-Jurassic greenschists" of Misch. It may be possible to obtain direct evidence of the age of the latter rocks from the northeastern part of the map-area, where amphibolitic rocks are exposed below Chilliwack Group rocks at the southern end of the Cheam Range.

Amphibolitic rocks on Mount Pierce, and to the north on the ridge between Foley Creek and Chilliwack River, and in Airplane Creek, lie on top of Mesozoic slates and argillites. The spatial relationship of these two lithologies, and their geographical position relative to that of the Shuksan thrust of Misch (1960, 1962) suggests that the amphibolitic rocks may have been emplaced along the northerly continuation of the Shuksan thrust of Misch.

Finally, there is enough doubt about the limits and nature of the Slesse Diorite, considered by Daly to be an intrusive body, to warrant its re-investigation.

Devonian rocks of northwestern Washington

No Devonian rocks have been identified in the Chilliwack Valley area.

Middle Devonian volcanic and clastic rocks, cherts and limestones, designated the President Channel Formation (Danner, 1957, p.54), are present in the San Juan Islands, where they apparently lie unconformably on an amphibolitic complex cut by dioritic rock (Danner, 1960b). Danner (1960a, p.3) correlated rocks in the President Channel Formation with

Devonian limestones reported from several localities in northern Whatcom County, immediately southwest of Chilliwack Valley, (Danner, 1960a, p.1; Moen, 1962, p.15). At one locality in northern Whatcom County (south end of Silver Lake Valley), a conglomerate containing granitic cobbles appears to underlie the Devonian limestone (W.R. Danner, oral communication). Some of these Devonian limestone bodies are in fault contact with meta-diorites believed to be part of the basement complex (Moen, 1962, p.16).

No Mississippian rocks are known in this region (Danner, 1960a, p.3). It is not known at present whether a hiatus exists, or whether Mississippian rocks have not been reported because of the absence of a recognized Mississippian fauna.

Pennsylvanian and Permian rocks in the map-area

Daly distinguished three separate fossiliferous limestones within the Chilliwack Group in the type-area (Table 1), but made no attempt to differentiate their ages. Girty (in Daly, 1912, p.515) considered these fossiliferous rocks to be Upper Carboniferous. However, Daly noted that certain unfossiliferous rocks included in his "Chilliwack "Series" could well belong to older systems.

From investigations of Palaeozoic rocks cropping-out immediately southwest of the Chilliwack Valley map-area Danner (1957, p.113) suggested that the Chilliwack Group was divisible into one formation of Late Mississippian to Early Pennsylvanian age and one of Early Permian age. His formations were based on two fossiliferous limestones, and included associated, but undifferentiated, clastic and volcanic rocks. The name "Red Mountain Formation" (Danner, 1957, p.113) was applied to the older formation and the name "Black Mountain Formation" (Danner, 1957, p.147) to the younger. These proposed formations have not been formally described and incorporated in the literature.

Two limestone units are distinguished by the writer within the Chilliwack Valley map-area. Fossil content of these limestones indicates their approximate time-equivalence to the limestones described by Danner. They do not completely correspond to any two of the limestones in the composite section of Daly reproduced as Table 1 in this thesis.

These two limestones are the only units recognised within the Chilliwack Group as presently established, whose continuity, distinctive lithology, and characteristic fossil content enables them to be used as stratigraphic markers across much of the map-area. Therefore the stratigraphic position of all other units in the Chilliwack Group is made relative to them. However, these limestones are not ideal marker units. The upper, Permian, limestone varies considerably in thickness and is, in part, a facies equivalent to volcanic rocks in the map-area. Fortunately, it invariably contains a distinctive fusulinid fauna, which enables precise stratigraphic dating to be made. The lower, Pennsylvanian, limestone is thin and locally absent, and Early Pennsylvanian fusulinids have been recognised within it only in the eastern part of the map-area. However, this limestone generally contains very large crinoid columnals, which are useful as rock components for correlating. The crinoid columnals cannot be used to demonstrate time-equivalence of the Pennsylvanian limestone across the map-area, although according to Smith (1962) and Danner (oral communication) they are characteristic of Pennsylvanian rocks in the Northern Cascade Mountains.

Lower clastic sequence

A sequence of dominantly fine-grained clastic rocks which lies stratigraphically below the Pennsylvanian limestone, is called, for reference purposes, the lower clastic sequence. In its lithological homogeneity and mappable nature this sequence is of formational status, although it cannot formally be designated as a formation, partly because its stratigraphic base is not recognised. Relative to Mesozoic rocks, this sequence is of limited areal extent within the map-area.

Daly (1912, p.512) described a sequence of sandstones and shales below limestone containing large crinoid stems. Daly regarded this clastic sequence as the basal part of his "Chilliwack Series" (see Table 1). Danner (1957, p.119) noted that Pennsylvanian limestone in northern Whatcom County conformably overlies thin bedded cherty argillites. Smith (1962, p.32) gave a more detailed description of these clastic rocks.

McGuire Nappe

Clastic rocks stratigraphically (and structurally) below the Pennsylvanian limestone crop-out in the south, southeast and northeast parts of the area bounded on the west by Tamihi Creek, on the north by Chilliwack River, on the east by Slesse Creek and on the south by the International Boundary. They are also present below Pennsylvanian limestone on the east side of Slesse Creek Valley. These rocks form the structurally lowest part of the core of the McGuire Nappe in the map-area.

The sequence consists of massive beds of tan-weathering, medium to fine-grained sandstones somewhat sparsely and irregularly distributed through dominant, thinly bedded, rhythmically graded and laminated, hard, very fine sandstones, siltstones and argillites. The argillites probably comprise the greater part of the sequence. Conglomerate horizons are present, but are rare.

Coarser beds are dark grey to dark grey-green in colour, hard, and composed of poorly sorted grains, whose maximum size rarely exceeds 3 mm. Determinable clasts in hand specimens are grey to green chert, rare volcanic rock fragments and argillite fragments. Large argillite fragments are common in some horizons. Although the texture is preserved in these rocks, in hand specimens grain boundaries commonly are indefinite and blurred, and the only clasts with sharp boundaries are argillite fragments.

Very fine-grained sandstones and siltstones commonly form thin beds ranging in thickness from 1 inch to 4 inches, within dominant argillites. The fine granularity of these rocks, generally does not allow grading, as shown by overall range in grain size within a bed, to be directly observed in hand specimen, but it is apparent as a hue change from medium to dark grey as grain size becomes smaller and argillite content increases. In some beds grading may be repeated several times, with the formation of irregularly spaced laminae. Load casts, many of which are minute, and small cut-and-fill structures are common.

One conglomerate bed about 6 feet thick within this graded sequence is composed of well-rounded cobbles of feldspar porphyry with euhedral feldspars in a pale grey to green felsitic groundmass; the cobbles are scattered through a poorly sorted sandstone matrix.

In the coarser clastic rocks, a crude foliation, roughly parallel to bedding, is present. In the fine rocks this foliation is present, but is extremely difficult to distinguish from bedding.

Microscopic examination of the common finer grained rocks shows them to be poorly sorted, below a certain maximum size of about 0.5 mm. Where alteration is not extensive, the rocks consist largely of plagioclase feldspar, which is mainly albite, and low-birefringent chloritic (?) matrix. Quartz grains are rare or absent, but fragments of argillite are common. In most places, however, alteration of grains in these rocks is so extensive that their original composition cannot be directly determined, but can only be inferred by analogy with partly altered grains. Alteration or replacement of plagioclase clasts is commonly to calcite, less commonly to brown, semi-opaque clay minerals and rarely to fine-grained aggregates of quartz (Figure 7).

Clastic rocks of this sequence which are coarser than argillites are called altered plagioclase arenites or volcanic arenites (after Folk, 1961; see Appendix A), largely on the basis of the composition of the few little-altered rocks within the sequence.

The proportion of finer grained material in the succession increases towards the stratigraphic top. Just below the contact with the overlying limestone the sequence is composed entirely of thinly-bedded, black, rusty-weathering, argillites.

Apparent thickness of this succession exposed on the south side of Spencer Peak, above Tamihi Creek, is more than 2,500 feet; in Slesse Creek Valley the thickness is less than 1,000 feet. These estimates of thickness do not take into account duplication of bedding by folding, which is locally directly observed, and commonly indicated by repeated inversions of graded bedding.

The upper contact is well exposed on the south side of Spencer Peak, above Tamihi Creek, at an altitude of approximately 5,000 feet. In this locality the contact is gradational. Several thin beds of limestone are present within argillites of the clastic sequence immediately below the contact with the main limestone body.

The stratigraphic base of this sequence has not been seen in the map-area. On the southwest side of Spencer Creek, and in Slesse Creek Valley the sequence overlies Lower Permian volcanic rocks and minor Lower Permian limestone. The lower contact has not been observed, but is the assumed flat-lying fault on the base of the McGuire Nappe.

Autochthon

One and one half miles southwest of the peak of Church Mountain black cherty argillites are in contact with the structural base of limestone containing Lower Pennsylvanian fusulinids. These rocks are lithologically similar to rocks of the lower clastic sequence stratigraphically below Pennsylvanian limestone in the McGuire Nappe. However, more detailed mapping is necessary in this part of the map-area before they can be correlated with rocks of the lower clastic sequence in the McGuire Nappe, as the structural interpretation of this part of the map-area, based on present mapping, indicates that they are part of the upper clastic sequence. Similar black cherty argillites are also associated with Pennsylvanian limestone in Liumchen Creek Valley.

Fossils

Fossils are rare in this clastic sequence. Organic hieroglyphs (worm markings) have been observed. Small, acute conic, hollow structures up to about 3 cm. long, referred to as belemnite-like fossils by Smith

(1962, p.17, p.32 etc.), are present in clastic rocks associated with Pennsylvanian limestone on the northeast side of Mount McGuire and to the southwest of the summit of Church Mountain (Fossil Localities 32 and 49, Plate 1). These structures are of unknown origin; according to J.A. Jeletzky (oral communication, July 1964) they are not belemnites, but may be related to pteropods. Poorly preserved, unidentified pelecypods and gastropods are present in rocks of this sequence in Liumchen Creek, in the vicinity of the Pennsylvanian limestone.

Daly (1912, p.513) in his Section 3 on the west side of Mount McGuire, reported brachiopods, echinoderms and bryozoans in shales below the limestone, believed by the present writer to be of Pennsylvanian age. None has been found by the writer from what appears to be Daly's locality.

Age

As these rocks underlie limestone of probable Lower Pennsylvanian age, and are gradational with it, they are in part, of probable Lower Pennsylvanian age. As no stratigraphic base of the sequence is seen, the age of rocks in the lower part of the sequence is not certain. No Mississippian rocks are known from the map-area, although Devonian rocks are present immediately to the southwest (Moen, 1962, p.15). Further mapping in the Liumchen Creek area, and to the southwest of it, may reveal the relationship between this sequence and the Devonian limestones.

Environment of deposition

No unequivocably marine fossils have been found by the writer within the lower clastic sequence. The uppermost part, gradational into limestone containing crinoid columnals and corals, is presumably of marine origin. Daly (1912, p.513, Section 3) reported brachiopods, bryozoans and echinoderms from what is possibly this sequence, just below crinoidal

(Pennsylvanian ?) limestone. The remainder can only be inferred to be of marine origin.

Overall fineness of grain and poor sorting indicates that these rocks were laid down in a predominantly low-energy environment. Graded bedding indicates deposition by turbidity currents, and although some finely laminated beds may have been produced by settling-out of very fine grains widely distributed by "normal" marine currents, load casts and cut-and-fill structures suggest that most beds were laid-down by the former mechanism. The rare conglomerate horizons have a high matrix to grain ratio, with cobbles suspended in a poorly sorted matrix whose largest grains are sand-sized, a fabric typical of turbidite sequences. Rounding of cobbles is presumably due to abrasion prior to final transport and deposition.

The abundance of plagioclase grains in the less altered rocks, presence of volcanic clasts, and low quartz content of these rocks suggests that volcanic rocks predominated in the source area. No evidence of distance from source was obtained, although the gradual overall decrease of grain size upwards may indicate relative lowering of the source area, or else increase in distance of the source from the site of deposition.

Red Mountain Limestone

Limestone of Pennsylvanian age stratigraphically overlies the clastic sequence described above. Although this limestone is a relatively thin unit of minor areal extent within the map-area, it is one of the principal stratigraphic markers within the Chilliwack Group as presently defined.

It is proposed that the term "Red Mountain Formation", originally applied by Danner (1957, p.115) to Pennsylvanian limestone and associated but undifferentiated clastic rocks which crop-out just southwest of the map-area be restricted to Red Mountain Limestone. The Pennsylvanian limestone described by Danner is correlative with that in the map-area. The geographic term "Red Mountain" is retained as the limestone is well-developed, excellently exposed and readily accessible in a quarry on Red Mountain in northern Washington. It has been described in some detail from this locality by Smith (1962, p.15-17), who measured a total thickness of $582\frac{1}{2}$ feet. Danner's original "Red Mountain Formation" has been restricted to Red Mountain Limestone as the limestone alone is a distinctive and readily mappable unit over a wide area. In contrast, the associated clastic rocks are rarely fossiliferous, commonly covered, and so similar in lithology to units of other ages in the region, that their relationship to the Pennsylvanian limestone must be seen directly before their stratigraphic position is certain.

On the basis of faunal collections, Danner (1957, p.136) ascribed an age of Late Mississippian to Early Pennsylvanian to the limestone cropping-out on Red and Black Mountains, which lie about 5 miles southwest of the map-area. Further studies have lead the above author to believe that an Early Pennsylvanian age is most probable (Danner, oral communication, November, 1964).

Smith (1962) described five sections of this limestone at five different localities in northern Washington. He correlated these sections using lithologies, stratigraphic relationships between the limestone and contiguous units, and certain fossils used as rock components rather than biostratigraphically.

Danner (oral communication) collected fusulinids from limestone about one and one half miles southwest of the peak of Church Mountain (Fossil Locality 49, Plate 1), in the southwestern part of the map-area. These fusulinids were considered by J.W. Skinner to be of Morrowan age, and the limestone to be correlative with Pennsylvanian limestone on Black Mountain.

As no other fusulinids capable of providing a precise age have been found in the Pennsylvanian limestone elsewhere in the map-area, several other criteria, similar to those employed by Smith (1962) are used in correlating this limestone within the map-area. The limestone commonly contains very large crinoid columnals (Figure 8), which seem to be restricted in this region to Lower Pennsylvanian rocks (Smith, 1962, p.82, W.R. Danner, oral communication). In addition, "belemnite-like" fossils of Smith, 1962, (possibly pteropods) have only been found in association with Pennsylvanian limestone in northern Washington (Smith, 1962, p.82) and are present in the map area in similar association. The limestone in the map-area is not uncommonly argillaceous, in contrast to the typically cherty Permian limestone. It stratigraphically overlies, and is partly gradational with, fine clastic rocks, and is commonly overlain stratigraphically by a coarse clastic sequence. These criteria, when taken together, enable reasonable confidence to be placed in correlation of this unit across the map-area. Correlation by tracing out lithology can only be done locally as the limestone in many places occurs as a series of discrete lenses.

McGuire Nappe

The Red Mountain Formation is part of the core of the McGuire Nappe. The formation is well-exposed on Spencer Peak, two and one half miles

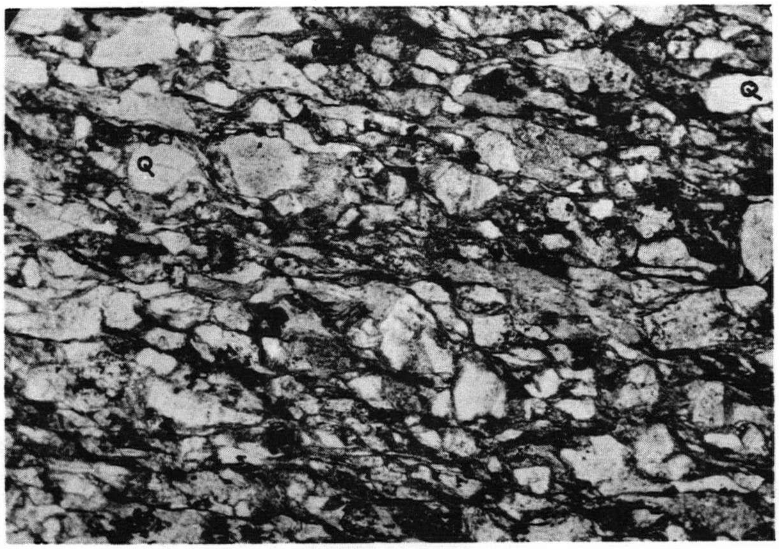


Figure 7: Photomicrograph (thin section, plane light, X40) of poorly sorted, fine-grained sandstone of the lower clastic sequence. Most grains visible are feldspar, commonly altered to brownish clay minerals (?) and carbonate. Rare quartz grains (Q) are present. Groundmass is composed of chlorite, carbonate and wisps of argillaceous material. Note crude (left to right) foliation.

Figure 8: Large crinoid columnals in Red Mountain Limestone in Liumchen Creek, about ½ mile north of International Boundary.

southeast of the summit of Mount McGuire, and crops-out on ridges north and east of this peak, on both sides of Slesse Creek Valley at altitudes between 2,000 and 3,000 feet, and at a few localities on the north side of Chilliwack River.

The Red Mountain Limestone is typically medium to dark grey in colour and weathers tan or grey-white. It is locally divisible into three units of approximately equal thickness, although commonly deformation and recrystallization are too great to allow any differentiation to be made. The lowest unit is thin to medium bedded with irregular bedding surfaces, which are separated by calcareous shale laminae. Above this there is a massive unit, and the top unit is similar to the lowest one. Chert nodules are rare in this limestone, in marked contrast to their abundance in the Permian limestone.

Recrystallization has usually destroyed or obscured original textures. Where textures are preserved, these rocks are either argillaceous fossiliferous micrudites (after Folk, 1959) or, less commonly, biomicrudites. Locally, the limestone consists of large crinoid stems, commonly an inch or more in diameter and up to almost 1 foot long in a matrix containing smaller crinoidal material (Figure 8). Although the matrix of these crinoidal limestones is invariably recrystallized, the poor sorting, and the lack of observed orientation in the primary fabric, indicates they are crinoidal biomicrudites. Even where the limestone is coarsely recrystallized, the large crinoid stems remain visible. The crinoid stems do not appear to be confined to any particular horizon within the limestone. On Spencer Peak they are present in a separate bed of limestone about 18 inches thick, within argillites just below the main limestone body. Elsewhere they occur within the massive unit. Scattered oolites have been observed at the structural base of limestone containing large crinoid stems, on the north bank of Chilliwack River, north of Slesse Creek Valley.

The apparent thickness of this limestone in the McGuire Nappe is nowhere greater than 200 feet, and is usually less than 100 feet. It is locally absent, the limestone appearing as a series of discrete lenses, which appear to lie on the same structural plane. It is not known at present whether this lateral discontinuity is a primary depositional feature, or whether it is due to subsequent deformation.

The lower contact is partly gradational with stratigraphically underlying rocks, a few thin beds of limestone being present at the top of the underlying fine clastic sequence. The limestone is stratigraphically overlain by a succession in which coarse clastic rocks are prominent.

Liumchen Nappe

About half a mile east of Bridal Falls in Fraser Valley, and at the base of the north side of Mount Cheam, in the northernmost part of the map-area, crystalline limestone is quarried. It is briefly described from this locality by Mathews and McCammon (1957, p.40). The limestone can be traced up the mountain to the west and is overlain and underlain by fine clastic rocks. This limestone is not siliceous and contains crinoid stems. It may be equivalent to the Red Mountain Limestone farther south in the map-area, and is possibly a part of the Liumchen Nappe.

Autochthon

An isolated outcrop of limestone containing fusulinids of Lower Pennsylvanian age is present about one and a half miles southwest of the peak of Church Mountain. Limestone containing large crinoid ossicles is interbedded with fine clastic rocks in Liumchen Creek Valley about three-quarters of a mile north of the International Boundary. Further mapping is necessary before the structural relationship between these two limestones is established, although they are believed to be the same formation.

Fossils

Small fusulinids collected by W.R. Danner and identified by J.W. Skinner (written communication to W.R. Danner, October, 1964) from the limestone southwest of the summit of Church Mountain are identified as *Eostaffella* and *Millerella*. Rare endothyroid foraminifera are the only other foraminifera that have been observed in this limestone elsewhere in the map-area. Small, unidentified horn corals and rare colonial corals are present, and appear to be restricted to the shaly phase of the limestone, as do rare fucoidal markings on bedding planes. Bryozoan and brachiopod fragments have been observed in thin sections. Crinoid columnals of all sizes are ubiquitous.

Daly (1912, p.513, Section 3) collected brachiopods and bryozoans from what is probably the Pennsylvanian limestone on Spencer Peak. These fossils were not found by the author at this locality. Girty (*in* Daly, 1912, p.515) noted that this collection seemed to differ considerably from other faunas obtained by Daly from Palaeozoic rocks in the Chilliwack Valley area. This difference is presumably because rocks at other localities from which Daly obtained diagnostic fossils are Permian rather than Pennsylvanian in age.

Age and correlation

Age of the Red Mountain Limestone in the map-area is based on the presence of the fusulinids *Eostaffella* and *Millerella*, which J.W. Skinner considers to be of probable Morrowan, (Early Pennsylvanian) age. Skinner has also identified similar forms from limestones at the Red Mountain type-locality in northern Washington, just southwest of the map-area. These fusulinids are considered by Skinner to establish correlation of the Pennsylvanian limestone from the Chilliwack Valley-Red Mountain localities with the Coffee Creek Formation of Suplee, Oregon, and with limestones at Harper Ranch, northeast of Kamloops, British Columbia.

Danner (1960a, p.3) and Smith (1962, p.84) correlated Pennsylvanian limestones from the Red Mountain locality with limestone at several other localities in northern Washington, using both palaeontological and rock-stratigraphic evidence. Limestone containing both large and small crinoid ossicles crops-out in the east side of the south end of Harrison Lake, to the north of the map-area (Crickmay, 1930b, pp.35,38). This limestone was considered by Crickmay to be of Pennsylvanian age, and is thus believed by the writer to be possibly equivalent to the Red Mountain formation in the map-area.

Environment of deposition

The marine origin of the Red Mountain Limestone is demonstrated by the presence within it of corals and echinoderm fragments. Sparse oolites have been observed in the limestone at only one locality, and the common argillaceous content and textures seen in limestone that has been little recrystallized, suggests deposition in a low-energy environment. The base of the limestone is gradational with the underlying clastic sequence, and the lower part of the limestone is argillaceous; massive limestone occurs in the middle part of the unit, and the upper is again argillaceous. The limestone may have been deposited largely because the supply of clastic sediments ceased, possibly a continuation of the trend evident in the underlying clastic sequence, which generally becomes finer upwards. When clastic deposition was renewed, the carbonate particles became too dispersed to form a discrete, lithologically homogenous unit.

Upper clastic sequence

A sequence of clastic rocks separating the Pennsylvanian and Permian limestones in Chilliwack Valley area is called, for reference purposes, the upper clastic sequence. It is an areally extensive, major part of the Chilliwack Group in the map-area. Although the upper clastic sequence is of roughly similar composition to the previously described lower clastic sequence, it contains a far higher proportion of coarse sand-sized clastic rocks and is partly composed of the products of contemporaneous vulcanism.

Exact age of this sequence is problematical. It is believed to contain both Lower Pennsylvanian and Lower Permian rocks, and to include a hiatus, or hiatuses, possibly representing Middle and Late Pennsylvanian time. Division of the sequence into Pennsylvanian and Permian rocks has not been effected at present because neither diagnostic fossils, nor an unconformity or unconformities, have been recognized.

On Mount Laughington and Cheam Range

Altered volcanic arenites associated with Permian limestone on Mount Laughington structurally overlie Mesozoic rocks of the McGuire Nappe. These volcanic arenites are lithologically similar to rocks stratigraphically below Permian limestone in the McGuire Nappe, and are considered to be part of the same sequence. Fine cherty argillites contiguous to Permian limestone on Mount Cheam (Fossil Locality 9) may possibly belong to the same sequence.

McGuire Nappe

Rocks comprising this sequence are present on Mount McGuire, on the east side of Slesse Creek Valley and on both sides of Chilliwack Valley between the junctions of Slesse Creek and Chipmunk Creek with Chilliwack River. These rocks form the upper part of the core of the McGuire Nappe.

The upper clastic sequence in the McGuire Nappe consists of a basal few feet of argillite which is stratigraphically overlain by massive to thick-bedded, locally cliff-forming sandstones and minor tuff and conglomerate, interbedded with argillaceous rocks. The latter are much less prominent topographically and are commonly poorly exposed but probably comprise the greater part of the succession.

Within this sequence are present three different types of clastic rocks composed of predominantly sand-sized grains; to some extent these three types grade into one another.

Clastic rocks of the first type are quartz-poor volcanic arenites and are the most common. They are typically olive-grey to tan weathering, and green, grey-green, or grey in colour. These rocks are unsorted and composed of angular clasts of all sizes, the largest clasts being granules or pebbles. There is no sharp differentiation between grains and matrix. The finer grained rocks occur as thin, graded beds. More massive and coarser grained beds are of uniform texture for much of their thickness, with markedly coarser clasts present only at the base of the bed. All of these rocks commonly have a crude foliation, with clasts being flattened and grain boundaries blurred and indistinct, as a result of later deformation. They are composed of varying proportions of altered volcanic rock fragments, plagioclase feldspars and minor fragments of argillite. The volcanic fragments megascopically resemble grey or green chert, but microscopically have tuffaceous textures or are composed of small, inter-locking feldspar laths. Although these fragments are commonly altered to saussurite, chlorite, or clay minerals, original textures are still discernible. White or pale green albite or oligoclase, showing varying degrees of alteration to sericite, semi-opaque, low-birefringent clay minerals, or, less commonly, calcite, is present in amounts of up to 30% of the rock. Chlorite is present throughout and quartz is very rare, or absent (Figure 9). Rocks of this first type are lithologically similar to rocks from the Miocene of Papua described as greywackes by Edwards (1950, p.146). For reasons given in Appendix A, the writer prefers to use Folk's terminology, and these rocks are called altered volcanic arenites. There may be some admixture of effectively contemporaneous volcanic material, but this cannot be demonstrated, and the rocks are considered to have been derived from a pre-existing volcanic terrane.

In contrast to the above rocks, in which quartz is minor or absent, sandstones of the second type, which are much less abundant, are maroon, pale green or silvery-white in colour and contain up to 10% of angular to rounded, clear quartz grains. Apart from very rare, unaltered albite clasts, quartz is the only unaltered material; the remainder of the grains are completely altered to semi-opaque, low-birefringent material or calcite, and contain chlorite, epidote and sericite. Some clasts are composed of altered shards. The maroon sandstones owe their colour to disseminated grains of hematite. Origin of these quartz-bearing rocks is unknown. Quartz-bearing vitric-crystal tuffs are common in the volcanic sequence which stratigraphically overlies the Permian limestone, which is above this upper clastic sequence. Similar tuffs were possibly produced by vulcanism outside the map-area during the time that the upper clastic sequence was being deposited. These quartz-bearing tuffs may have been mixed with the more common volcanic arenites during deposition.

Rocks of the third type are true lithic tuffs, composed largely of rock fragments, with very minor amounts of feldspar and quartz (Figure 10). These tuffs are present locally near the top of the upper clastic sequence. They differ from the more common volcanic arenites in having a higher matrix to grain ratio, and in containing shard-shaped to pumiceous clasts, now largely altered to chlorite. They are interbedded with argillites containing molds of crinoid columnals and bryozoans and grade vertically downwards into volcanic arenites.

A cobble conglomerate, within the upper clastic sequence and about 20 feet thick, crops-out on the west side of the ridge north of Spencer Peak, above the Pennsylvanian limestone. It is composed of rounded cobbles of altered basic to intermediate volcanic rocks and cherts, set in a matrix of smaller, angular clasts of similar composition. The matrix to grain ratio of this cobble conglomerate is high.

Apparent thicknesses of the upper clastic sequence in the McGuire Nappe are variable. The sequence is more than 800 feet thick on the east side of Slesse Creek. Due north of Spencer Peak it is not more than 450 feet thick. It is not known whether this variation in thickness is primary, or is due to an unconformity within the sequence, or is the result of deformation.

The lower contact of the sequence is conformable with Pennsylvanian

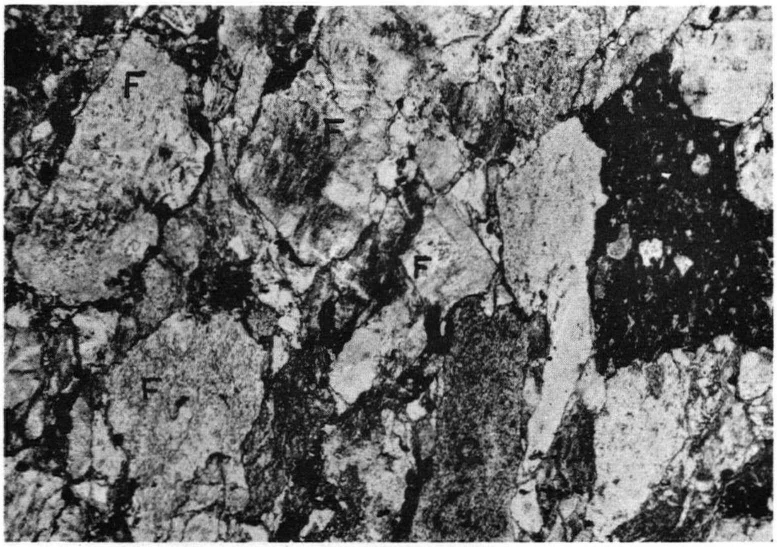


Figure 9: Photomicrograph (thin section, plane light, X40) of coarse-grained volcanic arenite of the upper clastic sequence, exposed on the east side of Slesse Creek Valley. Most grains are feldspar (some denoted by F); others are saussuritic volcanic rock fragments (dark), or "chert" (C); chlorite is interstitial. Foliation is poorly shown in thin section, but is apparent from the oriented long axes of grains.

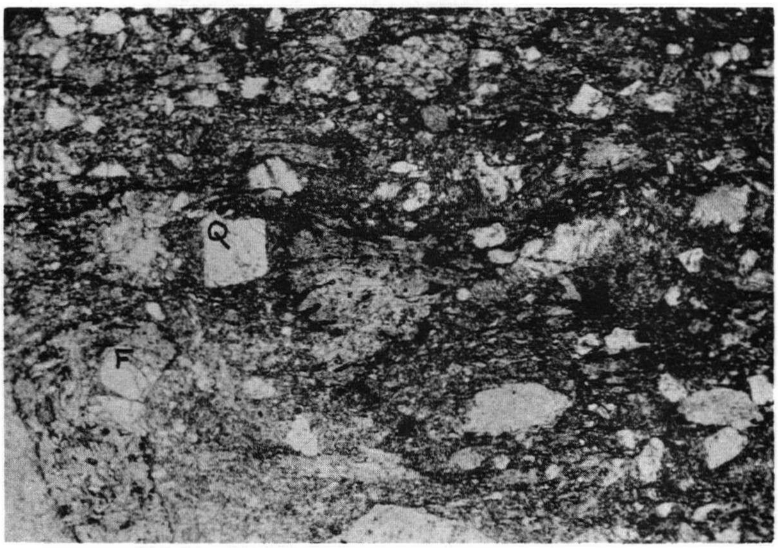


Figure 10: Photomicrograph (thin section, plane light, X40) of lithic tuff at the top of the upper clastic sequence, exposed $1\frac{1}{2}$ miles northeast of Mount McGuire Peak. Grains are mainly altered lithic fragments; rare feldspars (F) and quartz (Q) grains are present. Rock has a much higher matrix to grain ratio than the volcanic arenite (see Figure 9).

limestone. A few feet of argillite, the basal part of the sequence, separatesthe limestone from overlying coarse volcanic arenites. Permian limestone conformably overlies the sequence, with a similar transition from coarse volcanic arenites, or tuffs, through a few feet of dark argillaceous rocks, to limestone. This contact is visible and readily accessible in the road at the confluence of Slesse Creek with Chilliwack River.

Liumchen Nappe

Volcanic arenites, probably part of the Liumchen Nappe, are lithologically similar to those of the Mount McGuire Nappe and crop-out above Permian limestone at an elevation of 2,000 feet, three miles west of Mount Cheam, and one mile southwest of Bridal Falls. Due south of this locality at an altitude of 4,000 feet similar rocks underlie Permian limestone. The association of these clastic rocks with Permian limestone, and their lithological similarity to rocks of the upper clastic sequence in the McGuire Nappe suggest they are part of the same stratigraphic unit.

Autochthon

Coarse-grained, massive, tan weathering, dark grey to grey-green volcanic arenites, conglomerate and interbedded shales structurally overlie inverted Permian limestone just west of the summit of Church Mountain, and are apparently overlain by Pennsylvanian limestone, although further mapping is needed to verify the latter relationship. The stratigraphic equivalence of these clastic rocks to the upper clastic sequence in the McGuire Nappe is shown both by their lithological similarity and also by their relationship to the Permian limestone.

The sandstones are composed of volcanic rock fragments and fairly fresh feldspars (albite to oligoclase), with very minor quartz and intergranular chlorite (Figure 11). The grains are angular and sorting poor. In contrast to rocks of the equivalent sequence in the McGuire Nappe, these clastic rocks are much less altered; the grains are fresher, and there is no penetrative foliation developed through the rock.

A conglomerate bed within the sequence, reported earlier by Hillhouse, (1956, p.14) and Danner (1957, p.119), consists of well-rounded boulders and cobbles of altered intermediate to basic lavas, chert and some limestone, set in a green to grey volcanic or plagioclase arenite matrix. The grain to matrix ratio is variable, but in many outcrops rounded cobbles of volcanic rock are dispersed through green to grey volcanic sandstone, and the rock is a sandstone containing cobbles, rather than a conglomerate. The conglomerate outcrops extensively on Church Mountain, and has a thickness of about 100 feet.

Thickness of all clastic rocks of this sequence on Church Mountain is estimated to approach 600 feet.

Fossils

Argillites of the upper clastic sequence in the McGuire Nappe contain molds of small crinoid columnals, fenestellate bryozoans and brachiopod fragments, but these fossils are relatively rare. One graded bed on the northeast side of Mount McGuire (Fossil Locality 33) contains bellerophontid gastropods, pteropods (?) and fragmental brachiopods. A similar faunal assemblage is reported by Smith (1962, p.29) in clastic rocks interbedded with Pennsylvanian limestone in northern Washington. West of Spencer Peak (Fossil Locality 40) shales contain straight nautiloids, brachiopod fragments and pteropods (?).

Plant fragments are present in volcanic arenites on Church Mountain

(Fossil Locality 50). Identifiable fossils are largely stem fragments of Calamites and less commonly Lepidodendron. No identifiable associated microflora has been found. Pteropods (?) similar to those present in rocks of the equivalent sequence in the McGuire Nappe are associated with these plant remains.

Age and correlation

Exact age of the upper clastic sequence is not known. No fossils identified are sufficiently diagnostic to demonstrate whether the sequence is either Pennsylvanian or Permian in age. Plant fossils found in the sequence in the map-area indicate a possible Pennsylvanian or Early Permian age (G.E. Rouse, oral communication). In central Oregon, a flora is present in clastic rocks overlying Pennsylvanian limestone (Merriam and Berthiaume, 1943). This limestone is correlated by J.W. Skinner, on the basis of fusulinids, with the Pennsylvanian limestone on Church Mountain, which also probably stratigraphically underlies plant-bearing rocks of the upper clastic sequence. However, even if it is assumed that the identical stratigraphic positions of floras in the Chilliwack Valley and central Oregon allow the floras to be correlated, the Oregon flora can still only be dated as Pennsylvanian (Maymay and Read, 1956, p.227).

In all localities in this region from which plant fossils are known, they are present in clastic rocks associated with Early Pennsylvanian limestone (Danner, 1957, p.127, Smith, 1962). As no report has been made of any plant fossils in rocks associated with Permian limestone alone, an Early Pennsylvanian age would seem likely for these clastic rocks.

However, lithological evidence appears to contradict this conclusion. Danner (1960b) suggested that a stratigraphic break existed in the region between rocks of Early Pennsylvanian and Early Permian age, with Early Permian coarse clastic rocks lying disconformably on top of Pennsylvanian limestones. Erosion of possible Pennsylvanian rocks is indicated by the presence of a rounded limestone cobble containing either Pennsylvanian or Permian corals in conglomerate between Pennsylvanian and Permian limestone on Black Mountain in northern Washington (Danner, 1957, p.147). In the map-area, a stratigraphic break may be indicated by the sudden appearance of coarse clastic rocks, apparently conformable on a few feet of fine clastic rocks overlying Pennsylvanian limestone, and the continued deposition of similar coarse clastic material until the overlying Lower Permian limestone was laid-down. Tuffs in the upper part of this clastic sequence may be related to Early Permian vulcanism, which is partly contemporaneous with the Lower Permian limestone.

No direct evidence for a hiatus in this sequence can be given, although the sequence seems very thin to represent all of the time between Early Pennsylvanian and Early Permian, particularly as the type of sedimentation indicated by textures of these rocks is commonly typical of thick, rapidly accumulated sequences. As the apparent thickness of this sequence varies, even within one tectonic unit, unconformities may be present within it. Possibly turbidity flows and slides caused erosion of previously deposited unconsolidated material. Available evidence can only suggest that rocks ranging from Early Pennsylvanian to Early Permian in age are present in the sequence, possibly separated by one or several hiatuses, which may represent much of this time.

Correlation of these rocks, with similar rocks in northern Washington has been made (Danner, 1957, Smith, 1962), and they may also correlate with plant-bearing rocks in Oregon (see above). Crickmay (1930b, p.35) reported a clastic sequence containing conglomerate, from the Harrison Lake area. Some pebbles in the conglomerate are fossiliferous Pennsylvanian limestone, and Crickmay dated the conglomerate as post-Pennsylvanian, pre-Early Jurassic. This conglomerate is possibly equivalent to conglomerate in the upper clastic sequence in the map-area, although the only basis for this correlation is the general lithological similarity of these conglomerates.

Environment of deposition

A marine origin for some of these rocks is demonstrated by the presence of crinoid columnals and bryozoans in argillaceous rocks of the sequence in the McGuire Nappe. Because pteropod-like fossils, occurring with nautiloids and brachiopods in rocks of this sequence in the McGuire Nappe, are associated with plant fossils in clastic rocks of the autochthon, the latter rocks may well be of marine origin. Daly (1912, p.511) reported the occurrence of plant fossils associated with brachiopods, bryozoans, echinoderms, and clams in what are possibly rocks of this sequence in the autochthon. Available evidence therefore suggests that all rocks of the upper clastic sequence are of marine origin.

No current bedding has been observed in any rocks of this sequence. The presence of graded bedding suggests that turbidity flows were the final transporting mechanism for some of the beds. However, this sequence is not the rhythmic alternation of graded beds and shales seen in typical turbidite sequences (see Kuenen, 1964, p.20). Beds composed of coarse clasts are commonly poorly graded, or not graded at all, and were possibly deposited by the mechanism akin to both turbidity flows and sliding proposed by Dzulynski *et al.*(1959, p.1114). Conglomerates, containing well-rounded cobbles, generally have a high matrix to grain ratio, with cobbles dispersed through a volcanic arenite matrix. This kind of texture can result only from transport and deposition by a medium of relatively high viscosity, such as a turbidity flow or slide (*see* Pettijohn, 1957, p.228). As rounding of the cobbles must have occurred prior to final transport by such a mechanism, material forming these conglomerates appears to have been transported initially and rounded by stream action, temporarily laid-down and then finally deposited by turbidity flows or slides. Stream transport history was only of sufficient length to allow the largest clasts to become rounded, and sand-sized clasts remained angular (*see* Pettijohn, 1957, p.63). Such conglomerates, deposited by turbidity flows, can be widespread. Dzulynski *et al.* (1959, p.1113) report a conglomerate bed which was traced for 30 km. with little change in boulder size, although the thickness of the bed was observed to diminish. Danner (1957, p.119) stated that a cobble conglomerate 150 feet thick separates Pennsylvanian limestone from Permian limestone on Black Mountain in northern Washington. The stratigraphical position of this conglomerate is identical to that of the lithologically similar, but thinner, conglomerate on Church Mountain. If these conglomerates are the same bed, then the conglomerate bed is possibly comparable to conglomerates of Dzulynski *et al.*, as the Black Mountain and Church Mountain localities are (now) 8 miles apart.

These clastic rocks were derived from a source area composed largely of volcanic rock, with minor limestone. Absence of any metamorphic, or granitic detritus indicates that no deep erosion of the source area took place, and that uplift of the source area was probably not great, and was relatively short lived. The extent to which vulcanism contemporaneous with deposition contributes to the sequence is not established, although primary tuffs are present in the upper part of the sequence in the McGuire Nappe. Altered quartz-bearing clastic rocks, interbedded with volcanic arenites, are possibly the product of direct deposition from showers of volcanic ejectaon.

The following depositional history is proposed by the writer. Fine clastic rocks were laid down prior to, and immediately after deposition of Pennsylvanian limestone, and the limestone may merely represent a cessation of clastic supply. Conformably above the few feet of argillaceous rock overlying the limestone are coarse clastic rocks, interbedded with argillaceous rocks. The change in overall grain size of these clastic rocks, from predominantly fine-grained rocks below the Pennsylvanian limestone to coarser clastic rocks above, indicates accelerated growth of the primary source area above sea level, following deposition of the Pennsylvanian limestone. With this accelerated growth, presumably a delta or shelf was repeatedly constructed from material deposited by streams or along-shore currents. This accumulated material was then periodically transported by slides and turbidity flows from this secondary source area to the final site of deposition. The area above sea level must have been large enough to allow a primary transport history of length sufficient to enable cobbles and pebbles to become rounded, and stable enough to permit a flora to become established. Evidence of continued uplift of the source area is given by the presence of a rounded limestone cobble, containing either Pennsylvanian or Permian corals, in the conglomerate on Black Mountain, northern Washington (Danner, 1957, p.147). Sediment supply to the basin of deposition was supplemented by sporadic vulcanism, particularly in the latest part of the time represented by the sequence. Possibly uplift of the source area was related to subsequent extensive Lower Permian volcanic activity in the region.

Permian limestone

Lower Permian limestone conformably overlies the upper clastic sequence, and is in part a facies equivalent to, and in part underlies, volcanic rocks of the Chilliwack Group. As this limestone is present in most parts of the map-area, may readily be differentiated on the basis of lithology from overlying and underlying rocks, and is the most prominent single unit in Chilliwack Valley, forming characteristic grey-white weathering cliffs, it is the most useful stratigraphic marker in the map-area. In addition, it is the only unit so far recognized in the Chilliwack Group in the map-area which contains a widely distributed fauna capable of providing an unequivocable and precise age. As this limestone is distinctive, mappable and of lithological homogeneity and is an important part of the Chilliwack Group in the map-area, it is clearly of formational status. However, formal designation of a formation requires the description of a type-section. Further work is necessary before this can be done, even though most other details necessary for the establishment of a formation are known. Therefore, the writer feels that no useful purpose is served in applying a formational name to this rock unit until a type-section is described in detail. This unit is accordingly called the Permian limestone in this report.

Daly (1912, p.512) found limestone containing bryozoans, brachiopods and Fusulina elongata Shumard just southwest of the map-area, in northern Washington. Girty (in Daly, 1912, p.515) suggested that this fauna probably correlated with that in the Nosoni Formation of northern California, now regarded as Lower Guadalupian in age (Dunbar et al., 1960). Thompson et al. (1946, p.11) regard F. elongata Shumard as probably belonging to the genus Parafusulina, which would give either a Leonardian or Guadalupian age to this limestone in the map-area. Therefore, discovery of F. elongata Shumard is the earliest recorded evidence of Permian rocks in the area, although Daly made no attempt to differentiate rocks in the Chilliwack Group on the basis of age.

Hillhouse (1956, p.15) noted fusulinid-bearing limestone on the south end of International Ridge in the southwestern part of the map-area, but gave no description of the fusulinids.

Danner (1957, p.153) applied the term Black Mountain Formation to Permian limestone and associated, but undifferentiated, clastic and volcanic rocks on Black Mountain in northern Washington. This limestone contains an abundant fusulinid fauna, considered by Skinner (in Danner, 1957, p.151) to be of Wolfcampian age.

The stratigraphy of the Permian limestone in the map-area has not been studied in detail sufficient to establish whether or not it contains distinct lithological units. Unfortunately, such units are not apparent from macroscopic investigation; they would have to be based on the original petrology of the limestone, which has commonly been destroyed or obscured by subsequent recrystallization or silicification. Therefore a general description can only be given, with more detailed information from specific localities.

The Permian limestone is commonly light grey in colour, but may locally be dark grey, and forms prominent buff, grey or white weathering cliffs. In contrast to the Pennsylvanian limestone it is only locally shaly, and many horizons have a high silica content, manifested either as large black to light grey chert nodules, oriented parallel to bedding, or as a rough weathering surface produced by silica disseminated through the limestone. Fossils are abundant in certain horizons but are generally sparse or absent, although this absence is possibly due partly to subsequent recrystallization.

Although recrystallization has commonly obscured or destroyed the original texture of the limestone, the texture may in some cases be inferred from the relationships of preserved allochems to the recrystallized matrix. Fossils are generally the sole allochems; these were locally silicified, whereas the matrix remained as carbonate, and although subsequent recrystallization has destroyed any original textures and structures in the matrix, the silicified fossils are not affected. If it can be assumed that generally all fossils are preserved where silicification has taken place, then the common paucity of silicified fossils relative to the abundance of the matrix indicates that the matrix was originally micrite, rather than sparite and that these rocks were originally fossiliferous micrites (<u>see</u> Folk, 1961, p.141). A few highly fossiliferous horizons present in the upper part of the limestone contain abundant randomly oriented fossils, which show no evidence of size sorting, in a microsparite matrix. These rocks were presumably originally biomicrudites. Where no fossils are present, and alteration has not progressed beyond recrystallization of the matrix to microsparite, the rocks were presumably originally micrites.

On Mount Laughington and Mount Cheam

Pods of recrystallized limestone containing poorly preserved, silicified, Lower Permian fusulinids are present on the summit of Mount Laughington, and on the western ridge of Mount Cheam at an altitude of 6,000 feet (Fossil Localities 9 and 11). As this Permian limestone overlies Mesozoic rocks which in turn overlie Permian rocks of the McGuire and Liumchen Nappes, it is considered to belong to a separate and higher tectonic unit.

McGuire Nappe

Permian limestone in the McGuire Nappe is extremely prominent and is well exposed over a wide area. It outlines a large recumbent anticline with an attenuated or missing lower limb. The axis of this major fold plunges at a low angle towards the northeast. The peak of Mount McGuire is composed of limestone forming the hinge of this major structure, and digitations on this hinge are exposed as discontinuous limestone cliffs on the north side of the mountain. The limestone cliffs appear at progressively lower altitudes towards the northeast, occur by Chilliwack River at its confluence with Slesse Creek and are present on the north side of Chilliwack Valley on Mounts Thurston and Mercer. Limestone comprising the upper limb of the recumbent anticline caps ridges due east of Mount McGuire summit, and its eastward continuation crops-out at an altitude of about 4,000 feet, on the east side of Slesse Creek Valley. From the latter locality the limestone outcrops can be traced into Chilliwack Valley where they decrease in altitude to the east, and occur on the valley floor near the junction of Foley Creek with Chilliwack River. Northward continuation of limestone forming this upper limb is present on the south side of Mount Mercer, and in Chipmunk Creek. Local limestone lenses overlying Permian volcanic rocks southeast of the peak of Mount McGuire, and above Permian volcanic rocks exposed in a window at the north end of Slesse Creek Valley outline the lower limb of this recumbent anticline.

Thickness of Permian limestone in the McGuire Nappe varies considerably across the map-area. Below the summit of Mount McGuire it is more than 2,000 feet thick, a thickness which is due in part to visible repetition of bedding by folding. In localities where the limestone is seemingly little deformed and continuous, such as high on the east side of Slesse Creek Valley, the apparent thickness is in the order of 200 to 300 feet. Elsewhere, particularly near the eastern limit of exposure of Permian limestone in the McGuire Nappe, the limestone forms discrete, commonly thin, lenses. It is not known whether these lenses are of depositional origin or result from deformation.

The Permian limestone in the McGuire Nappe conformably overlies volcanic arenites, lithic tuffs and argillites. The transition from coarse volcanic arenites, through dark-grey argillites to limestone is abrupt, taking place over a few feet. It is stratigraphically overlain by Permian flows, tuffs, cherts and rarely, argillaceous rocks. At some localities, such as just north of the peak of Mount McGuire, the fossiliferous, stratigraphic top of the Permian limestone contains fragments of volcanic rock, commonly tuff, up to one cm. in diameter. In some cases, the top of the limestone is marked by a calcareous tuff composed of volcanic clasts in a calcareous matrix; the latter contains a few, unbroken fossils. These tuffaceous limestones and calcareous tuffs locally form a horizon at the extreme top of the Permian limestone, marking the transition to overlying volcanic rocks.

Liumchen Nappe

The Liumchen Nappe in Chilliwack Valley is composed largely of Permian volcanic rocks. A limestone bed, a few feet thick, on the southwest side of Mount McGuire (Fossil Locality 41) lies within the dominant lavas and minor tuffs comprising the Liumchen Nappe. This limestone contains fusulinids which although not well preserved, appear to be identical with fusulinids in the stratigraphic top of the Permian limestone in the McGuire Nappe, about 1,000 feet vertically above this locality. If this limestone bed can be considered to be time-equivalent to the top of the Permian limestone of the McGuire Nappe, then part of the volcanic sequence of the Liumchen Nappe is a facies equivalent to at least part of the Permian limestone.

Pods of Permian limestone, probably belonging to the Liumchen Nappe, are exposed at an altitude of 4,000 feet on the south side of Fraser Valley, about two miles west of Mount Cheam (Fossil Localities 5 and 8). They are overlain by chert and crystal tuffs and overlie clastic sedimentary rocks. To the north and west of this limestone, at an altitude of about 2,000 feet, limestone of probable Permian age overlies volcanic rocks and underlies volcanic arenites similar to those of the upper unnamed clastic sequence.

Autochthon

Permian limestone of the autochthon is exposed on the east side of the summit of Church Mountain, in scattered outcrops west and southwest of the summit and in Liumchen Creek.

Limestone on Church Mountain is inverted; it is overlain by the upper clastic sequence, and overlies volcanic rocks. At the structural base of the limestone, tuffaceous limestone and calcareous tuff mark the transition to structurally underlying Permian volcanic rocks. In Liumchen Creek Valley, insufficient mapping has been done to clarify structure, but pods of limestone containing Permian fusulinids overlie volcanic rocks and are interfolded with them.

A limestone of unknown age is in contact with Upper Triassic rocks in Liumchen Creek. Because it is overlain by, and gradational with, Permian volcanic rocks, and overlies Upper Triassic rocks with a sharp contact, it is possibly of Permian age, the succession here being inverted.

Apparent thickness of limestone east of the summit of Church Mountain is about 500 feet. Repetition by visible folding is responsible for much of this thickness. Permian limestone west of this locality is much thinner, possibly less than 100 feet.

Fossils

Fossil content of the Permian limestone in the McGuire Nappe varies considerably. Fossils are abundant in a few horizons but in most are either absent or very rare. This paucity may be due, in part, to destruction of fossils by recrystallization.

A well defined fauna found at the stratigraphic top of the Permian limestone where the limestone is thick, may persist for a few feet into overlying tuffaceous beds gradational with the top of the limestone. This same fauna is also present at some localities, such as Chipmunk Creek, where the Permian limestone occurs only as local, thin pods underlying volcanic rocks. Fusulinids, generally silicified, are the commonest fossils in this fauna and the genera Parafusulina and Pseudofusulinella have been identified (Figures 12, 13). These fossils are associated with rhombopo-roid bryozoans, crinoid columnals and rare gastropods and brachiopod frag-ments. As this fauna is of restricted vertical range, contains fossils which enable precise stratigraphic dating to be made, and is present almost everywhere in the map-area at the stratigraphic contact between rocks of markedly differing lithologies, it appears to be an ideal strat-igraphic marker. However, as the fauna is found only at the contact of the limestone with volcanic rocks some environmental control is possible; the horizon it marks may therefore be diachronous, perhaps over a restrict-ed time-range. Its presence only at the stratigraphic top of the Permian limestone, where it is thick, enables structural inversion of the lime-stone to be demonstrated in many localities.

Medium sized fusulinids of the genus Schwagerina (Figure 14) are present within the limestone, away from the base and top. The distance at which they occur above the base of the limestone is not known, but these forms have only been found where the limestone is relatively thick, never in the thin lenses. Associated with this Schwagerina are large horn cor-als, superficially similar to Dibunophyllum (E.C. Wilson, written commun-ication, July, 1962).

An abundant fauna observed half a mile east of the peak of Mount McGuire (Fossil Locality 42) occurs in a stratigraphic horizon close to the horizon in which the medium sized Schwagerina is found. The fauna contains the tabulate coral Michelinia, small poorly preserved horn corals, and the brachiopods Rhipidomella (very abundant), Rhynchopora, Neospirifer (?) and some large poorly preserved, fragmental brachiopods with costellate

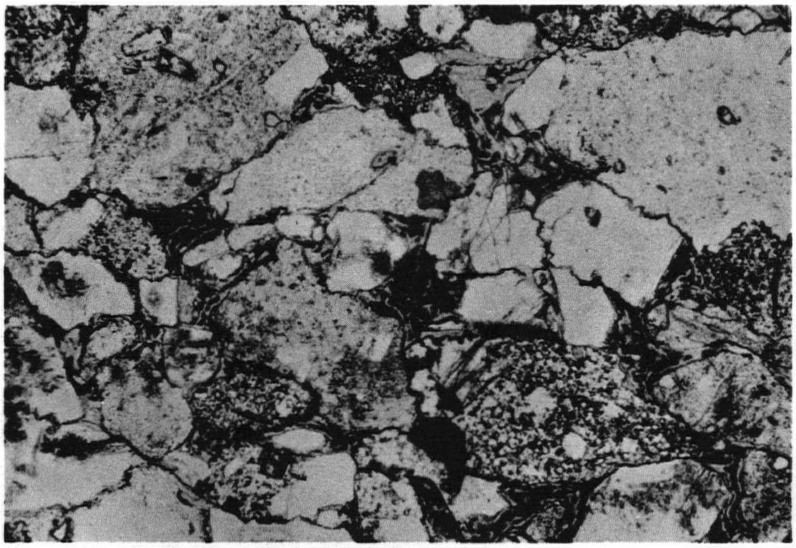


Figure 11: Photomicrograph (thin section, plane light, X40) of coarse-grained volcanic arenite of the upper clastic sequence on Church Mountain. Rock composed of fairly fresh albite and lithic volcanic fragments, with interstitial chlorite. Note the freshness, and absence of any marked orientation of the grains, in comparison to Figure 9.

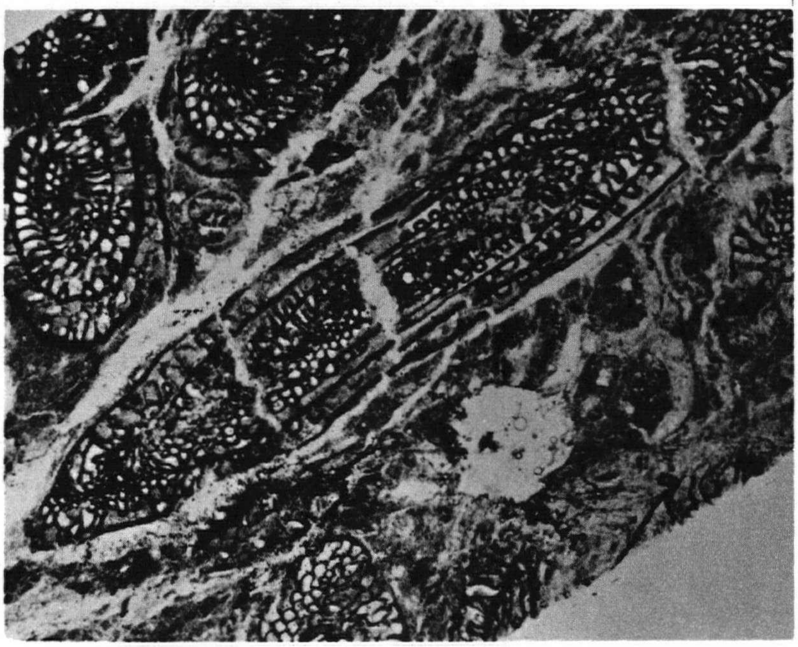


Figure 12: Near axial section of *Parafusulina* (X7) in Permian limestone from the southeast side of Mount Thurston.

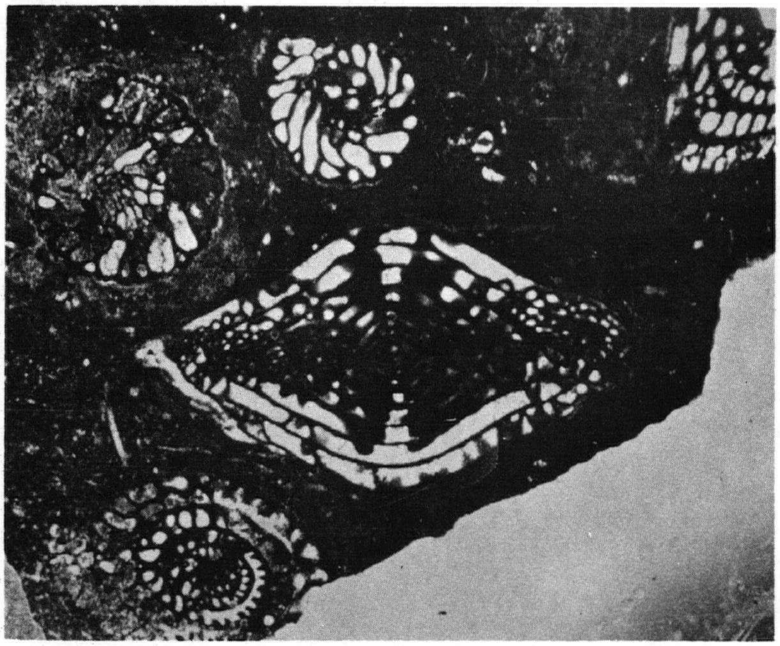


Figure 13: Axial section of Pseudofusulinella (X12) in fusulinid biomicrudite of Permian age, from Liumchen Creek.

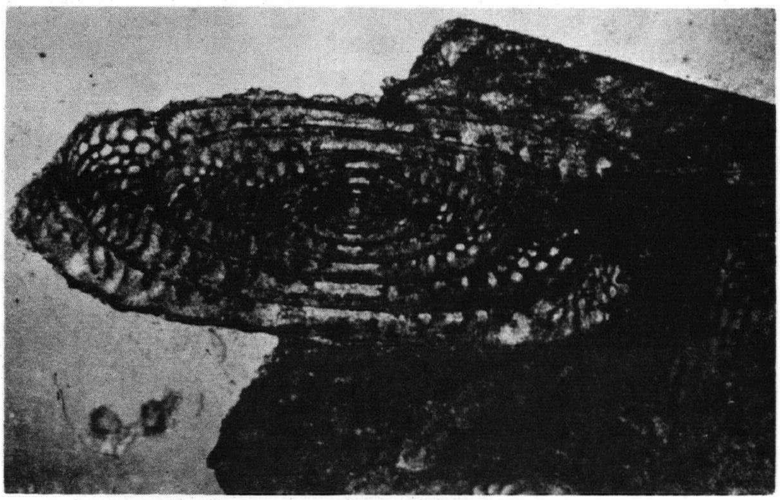


Figure 14: Near axial section of silicified Schwagerina (X10) in Permian limestone, west side of Pierce Creek.

ornamentation. Colonial corals, tentatively identified as Heritschioides by E.C. Wilson (written communication, July, 1964) were found one mile northeast of the peak of Mount McGuire (Fossil Locality 44), in what is probably a similar stratigraphic horizon. Fucoid markings are also present on some bedding planes.

Silicification is responsible for preservation of almost all of these fossils. Quality of preservation by silicification varies considerably. Fusulinid microstructures are commonly well preserved, whereas many large horn corals may only be partly silicified and thus poorly preserved. Where silicification has not occurred, commonly the only recognizable fossils are crinoid columnals, standing out as round patches of coarse white crystalline calcite against the more finely crystalline matrix.

Small unidentified horn corals, large horn corals, possibly *Dibunophyllum*, and compound corals, probably *Heritschioddes*,are present in Permian limestone of the autochthon. Crinoid columnals of various sizes are ubiquitous. Some small silicified fusulinids, probably *Schwagerina*, were found in float. Calcareous volcanic breccias and tuffaceous limestones, at the structurally lower contact of the limestone on the east side of Church Mountain summit (Fossil Locality 51), contain well preserved *Parafusulina* and *Pseudofusulinella* and some smaller forms which superficially resemble *Parafusulina* but are possibly large schwagerinids. *Parafusulina* and *Pseudofusulinella* are present in limestones on the east side of Liumchen Creek, due west of Church Mountain.

Age and correlation

The limestone is dated on the basis of its fusulinid content. Two horizons containing different fusulinid faunas are known. Fusulinids of the genus Schwagerina occur in one horizon within the limestone. The other horizon is at the extreme top of the unit and contains Parafusulina, Pseudofusulinella and possibly some large, unidentified schwagerinids.

All examples examined of Schwagerina (Figure 14) are silicified, and although some details of the structure have been destroyed, preservation is good enough to allow identification to be made. This is a new species, with septal evolution advanced to a level where some of the outer chamberlets are elongate and appear about to form cuniculi. It is similar to Schwagerina crassitectoria Dunbar and Skinner in size, general morphology, and evolutionary level, but different in overall shape and in possession of a smaller proloculus. S. crassitectoria occurs in the lower part of the Leonard Formation of Texas (Ross, 1963, p.13) and is closely related to, and occurs with, S. guembeli, which has reached the same level of septal evolution (see Dunbar and Newell, 1946, p.402). These two genera occur in Nevada (Knight, 1956, Rich, 1961) where they are regarded as being of Leonardian age. Mills and Davies (1962, p.45) have described S. missionensis, a form related to S. guembeli, from northeastern Washington and believe it to be of Leonardian-Guadalupian age. McGugan (1963) has described a schwagerinid of similar evolutionary level, from southeastern British Columbia, which again he regards as being on the border of Lower to middle Permian age. Largely on the basis of degree of septal evolution, the medium sized Schwagerina from the Permian limestone of Chilliwack Valley is regarded by the writer as being basal Leonardian in age.

The large Parafusulina (Figure 12) occurring with Pseudofusulinella at the extreme top of the Permian limestone is a new species, in general morphology close to Parafusulina nosonensis Wheeler and Thompson, but in size very similar to the larger species, P. californica (Staff). These forms are common in the lower Guadalupian Nosoni Formation of northern California. Therefore this fusulinid may be as young as Guadalupian in age. However, the poorly developed cuniculi indicate that it probably is of Leonardian rather than Guadalupian age.

The Pseudofusulinella (Figure 13) occurring with Parafusulina in Chilliwack Valley is probably the form described by Skinner (written communication to W.R. Danner, April, 1964) as Pseudofusulinella danneri Skinner and Wilde, from the Black Mountain locality in northern Washington. Although Skinner (in Danner, 1957, p.131) considered the Black Mountain fauna to be of Wolfcampian age he has recently recorded a primitive Parafusulina from this locality and now considers it to be possibly lower Leonardian in age (written communication to W.R. Danner, April, 1964).

A third species occurring with Parafusulina and Pseudofusulinella on Church Mountain appears to be a large Schwagerina or small Parafusulina. Because this form has not been observed elsewhere in the Chilliwack Valley area its presence may well suggest the closer relationship of the Church Mountain fauna to the predominantly schwagerinid fauna of Black Mountain, rather than to those equivalent faunas found elsewhere in Chilliwack Valley. As the large Parafusulina from the Chilliwack Valley area appears to be more advanced than any form reported from Black Mountain, the Permian limestone may be diachronous, over a fairly restricted range. These possible age differences between parts of the Permian limestone in different tectonic units may be enhanced by tectonic superposition or juxtaposition of parts of the formation which were laterally separated prior to deformation.

No other reported occurrence of this limestone has been made from the region. Mathews and McCammon (1957, p.43) have reported a limestone near Agassiz, on the north side of Fraser River north of the map-area, which underlies light grey-green siliceous tuff. This tuff is lithologically similar to certain of the volcanic rocks overlying Permian limestone in the Chilliwack Valley map-area. On the basis of this association, the Agassiz limestone is possibly a northerly equivalent of the Permian limestone of the Chilliwack Valley.

Environment of deposition

All evidence seen suggests that deposition of the Permian limestone took place in a marine low-energy environment, because all limestones examined were probably, or are, micrite, fossiliferous micrite or biomicrudite.

Vulcanism, contemporaneous with deposition of the limestone, may be partly responsible for precipitation of micritic carbonate by the various mechanisms suggested by Kania (1929) and also a possible cause of the characteristically siliceous nature of the limestone (see Bissel, 1959, p.182).

The following suggestions on conditions extant during deposition of the Permian limestone are little more than speculative. More information is needed on the original textures of limestone comprising the formation and also on Permian stratigraphy from surrounding areas.

Available evidence indicates that the clastic sequence below the Lower Permian limestone was largely deposited by slides, slumps and turbidity currents. Such mechanisms would tend to deposit sediments in deeper parts of the basin. Uplift, possibly related to Lower Permian vulcanism, may have elevated isolated areas of the sea floor, which previously received clastic sediments, to positions still below wave base, where they were no longer able to receive sediments by turbidity flows or slides (see Heezen, 1963, p.754, Kuenen, 1964, p.6). The only materials these elevated areas could then receive would be precipitated carbonates, clay-sized clasts carried in suspension, and aerially transported material such as volcanic ash. Sediments formed by the latter two agencies are possibly represented by the few feet of shale, and local lithic tuff, which are present stratigraphically below the Permian limestone. Subaqueous effusion of lavas, by changing the chemical environment in the sea (see Kania, 1929) might result in chemical precipitation of limestone in the vicinity of a volcanic centre.

The predominant lithologies of Permian rocks in the autochthon, Liumchen Nappe, and McGuire Nappe are believed to indicate the existence of such a volcanic centre, flanked by areas of limestone deposition. Prior to Cretaceous deformation, during which rocks of these three tectonic units were transported to the northwest, rocks of the McGuire Nappe, now structurally the highest of these three tectonic units, lay southeast of rocks of the Liumchen Nappe, which in turn were southeast of rocks of the autochthon, the structurally lowest rocks in the map-area. The Liumchen Nappe, composed in large part of flow rocks and tuff, with minor limestone containing Leonardian fossils, separated laterally rocks of the autochthon from rocks of the McGuire Nappe. In the latter tectonic units Permian rocks are Leonardian limestones, overlain by relatively thin lavas and tuffs.

Cessation of limestone deposition possibly was the result of a change from relatively quiet effusion of lavas, to pyroclastic activity whose products so diluted any carbonate being deposited that it was no longer apparent as a discrete, homogenous unit.

Permian volcanic sequence

An areally extensive sequence of Lower Permian volcanic rocks is present in most parts of the map-area. In some places these volcanic rocks lie conformably on the Permian limestone; elsewhere they are a partial facies equivalent of this unit. The sequence is overlain disconformably by clastic rocks of Late Triassic age. Lithologies within the sequence vary between basic to intermediate flows, tuffs, and minor cherts and argillites. These rocks provide a more sensitive index of metamorphic grade than any other rocks of the map-area. Thicknesses of the different lithological types, and thus the thickness of the sequence as a whole, vary considerably across the map-area.

Daly (1912, p.521) called these volcanic rocks the "Chilliwack Volcanic formation." As it is a readily mappable, lithologically distinct part of the Chilliwack Group in the type area it is clearly of formational status according to modern stratigraphic principles. However, where these volcanic rocks are typically developed in the map-area, (as in the Liumchen Nappe) the basal contact of the sequence is tectonic and not stratigraphic; where both upper and lower stratigraphic contacts are present (as in the McGuire Nappe) the sequence is thin and somewhat atypical. Therefore, as no type section can be given by the writer which would adequately represent this succession, these rocks are not designated a formation and are called, instead, the Permian volcanic sequence.

Several earlier workers in the region have mentioned these rocks. Daly described his "Chilliwack Volcanic formation" as consisting of altered augite and hornblende andesites, with interbedded pyroclastics. He believed these rocks were of Upper Carboniferous age, and formed much of the upper part of his "Chilliwack Series" (see Table 1). Crickmay (1930, p.488) mapped Daly's "Chilliwack Volcanic formation" as Triassic volcanic rocks, separating the Chilliwack Group from Crickmay's "Slollicum Series." Brief descriptions of some of these volcanic rocks were given by Hillhouse (1956, p.10) and Danner (1957, p.113), both of whom believed the rocks to be part of the Chilliwack Group. Moen (1962, p.34) mapped the lateral continuation of this volcanic sequence, to the southwest of the map-area, and included it in the Chilliwack Group.

On Mount Laughington and Cheam Range

Green, massive, basic flow rocks crop-out on the south side of Mount Laughington at an altitude of 4,000 feet. These rocks are amygdaloidal, consist of a felted mass of saussuritized feldspar microlites, with augite and albite phenocrysts, and are very similar to other basic lavas in the map-area described below. Chlorite and pumpellyite are present in vesicles. Thin bedded silicified tuffs and cherts present near the summit of Mount Laughington are associated with Lower Permian limestone. All of these rocks structurally overlie Mesozoic rocks of the McGuire Nappe.

Greenstones cap Lady Peak, near the northern end of Cheam Range. They are composed of clear albite laths, minor fibrous hornblende, epidote, minor quartz and chlorite. Ilmenite, leucoxene and sphene are present in the groundmass. Vesicles in these rocks contain chlorite. The age of these greenstones is uncertain. They overlie argillites containing a limestone pod, in which a few small crinoid stems have been found. Permian limestone containing fusulinids, present to the north of this locality on the western ridge of Mount Cheam, is possibly part of the same tectonic unit, and overlies Mesozoic rocks.

McGuire Nappe

Rocks of the Permian volcanic sequence in the McGuire Nappe are interfolded with Permian limestone on the north side of Mount McGuire, and overlie Permian limestone high on the east side of Slesse Creek Valley, in the Chilliwack Valley east of the junction of Slesse Creek with the Chilliwack River, and in Chipmunk Creek.

Rocks of the Permian volcanic sequence in the McGuire Nappe are of variable lithology. Thin bedded grey, green to white cherts, jasper and siliceous tuff, locally with shaly interbeds, overlie the limestone in some localities. Elsewhere the overlying rock is a quartz-bearing crystal tuff, similar to that described more fully below. A dark green, altered feldspar porphyry is present stratigraphically above the Permian limestone just west of Pierce Creek, and in a similar stratigraphic position north of this locality, on the north side of Chilliwack River near its junction with Slesse Creek. This feldspar porphyry is composed of small, glass-clear albite phenocrysts in a very fine-grained, dark green matrix, consisting of saussuritized feldspar microlites, small diopsidic augites, and chlorite.

Dark, gabbroic dykes, cutting the Pennsylvanian and Permian limestones and clastic rocks of the Chilliwack Group, are present on Mount McGuire, and are possibly feeders to the Permian volcanic sequence.

Thickness of volcanic rocks in the McGuire Nappe is probably nowhere more than 200 feet, and is locally considerably thinner.

The Permian volcanic sequence is overlain by fine-grained siltstones and argillites of Upper Triassic age. No angular relationship has been detected between the bedding of the volcanic rocks and that of overlying Triassic rocks. Commonly a breccia rarely greater than 25 feet thick, and composed of angular clasts up to 6 inches long of volcanic rock, chert and minor limestone, marks the contact. Composition of volcanic rock clasts in the breccia is identical to that of underlying Permian volcanic rocks. Poorly preserved, silicified, medium-sized fusulinids of probable Early Permian age were found in a limestone clast from the breccia above the east side of Slesse Creek Valley. As the breccia is invariably present at this stratigraphic contact in the McGuire Nappe, forms a continuous stratigraphic horizon of relatively constant thickness, and contains randomly oriented, angular, unsorted, clasts it is believed to result from a submarine slide.

The lower contact of the volcanic sequence is to some extent gradational with underlying Permian limestone. The contact, where seen, generally is marked by an abundant fusulinid fauna. East of Pierce Creek and in Chipmunk Creek the limestone is locally thin and forms a series of discrete lenses. Where the limestone is absent the distinction of tuffaceous rocks of this volcanic sequence from underlying volcanic arenites is difficult and in many cases arbitrary.

Liumchen Nappe

The Liumchen Nappe in the map-area is composed largely of the Permian volcanic sequence. Permian volcanic rocks form the summit of Liumchen Mountain and crop-out west of this locality on the south end of International Ridge. East of Liumchen Mountain, volcanic rocks underlie most of the north and west sides of Mount McGuire and are exposed in a window at the north end of Slesse Creek Valley. Volcanic rocks forming the probable northerly continuation of the Liumchen Nappe underlie the south, west and northwest slopes of Elk Mountain. Scattered outcrops, northeast of Elk Mountain on the south side of Fraser Valley, are believed to belong to this volcanic sequence in the Liumchen Nappe.

Permian volcanic rocks are largely flow-rocks on Liumchen Mountain, the west side of Mount McGuire and in the window at the north end of Slesse Creek. Two principal rock types are recognized; a dominant altered augite-bearing intermediate to basic rock, and a relatively rare hornblende andesite.

The augite-bearing flow-rocks are massive and not uncommonly form cliffs. Generally, it is not possible to obtain bedding measurements from these rocks, largely because of their massive nature, although interbedded pyroclastic material and compositional variations, enable bedding to be discerned locally. Pillow lavas have been recognized on the southwest side of Mount McGuire. These flow rocks are typically grey-green, but vary through yellow-green and brownish-grey to dark green. They are commonly very fine-grained and altered, so that accurate field identification is not possible. Rare, coarse-grained equivalents, possibly conformable intrusions within the sequence, are of uniform texture and consist of about 70% randomly oriented, interlocking grey-green altered feldspar laths, with interstitial ferro-magnesian minerals. Chlorite and calcite amygdales are common, and concentrically arranged chlorite-filled vesicles have been observed at several localities where no pillows were recognized. The composition of these rocks, determined microscopically, varies from about 60% to 80% altered plagioclase feldspar, 10% to 20% diopsidic augite, at least 10% chlorite and various amounts of ilmenite and its alteration products (Fig.15). Altered, subhedral, randomly oriented plagioclase feldspar laths are invariably of uniform size in any one specimen. The longest laths seen are about 3mm. long, the smallest are microlites, and the commonest sizes range from 0.4 to 0.2mm. in length. Generally, the plagioclase laths are completely saussuritized and their original nature can only be inferred from textural relationships, and by analogy with crystals which are part saussurite, and in part feldspar whose optical properties can be determined. Optic axial angles of partially altered feldspars are 83° to 84°, and measurements of x'$\wedge$010 give an average of about 15° (obtuse extinction), and the feldspars are therefore albite of composition about An_8. The diopsidic augite is porphyritic or interstitial and may display an ophitic or sub-ophitic relationship with the altered feldspar laths, and is commonly fresh, but may be highly fractured and show alteration to chlorite. Chlorite, generally with anomalous blue birefringence, occurs interstitially, fills vesicles where it not uncommonly forms radiating aggregates, and is present in veinlets. Pumpellyite is present in many of these rocks, having the form of very fine acicular crystals, often in radial clusters and occurring typically with chlorite in veinlets and vesicles (Figure 16). Calcite is found in vesicles and rarely as patches in the groundmass. Skeletal ilmenite (?), displaying all stages of alteration to leucoxene and finely granular sphene, occurs in amounts up to 10%. In some examples small granules of sphene are scattered through the rock. Fine-grained hematite is disseminated through some rocks, these rocks in hand-specimens being brownish-grey.

A distinctive feldspar porphyry, within tuffaceous rocks on the north side of Chilliwack River, is composed of pale green altered feldspar phenocrysts, up to 7mm. long, set in a darker matrix. The feldspars were

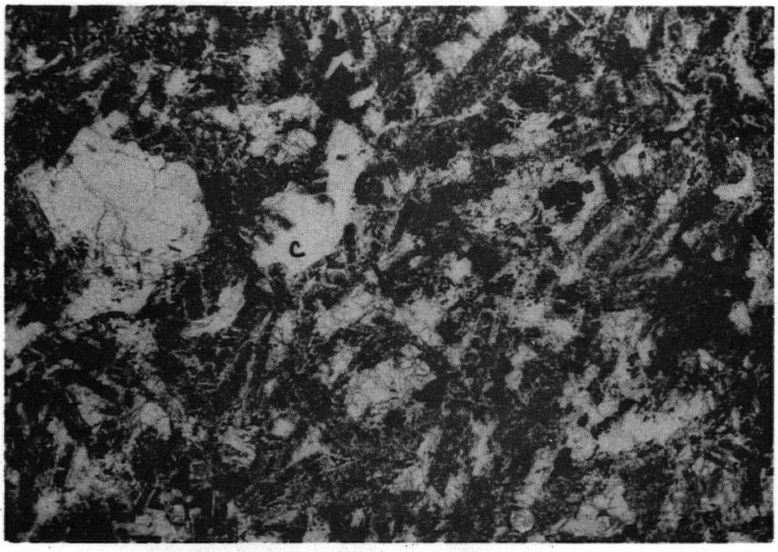


Figure 15: Photomicrograph (thin section, plane light, X40) of typical altered flow rock in the Permian volcanic sequence from the north end of Slesse Creek Valley. Groundmass of dark, saussuritized feldspar laths, with diopsidic augite, opaque grains and chlorite (C).

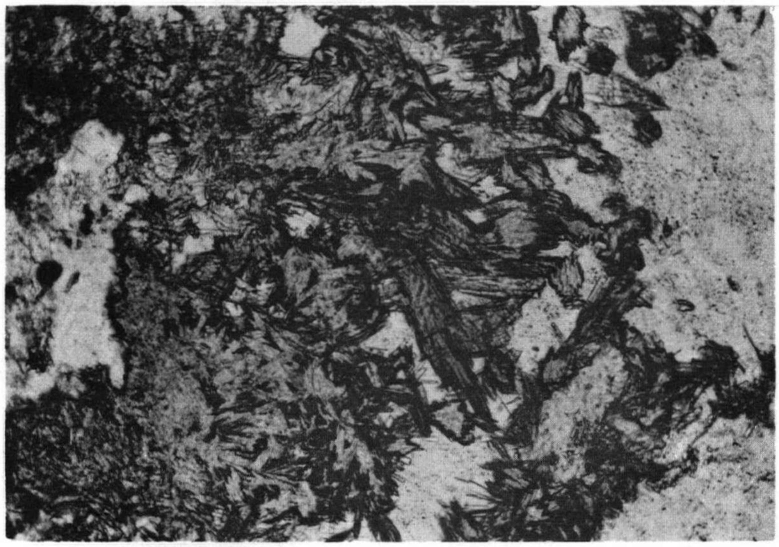


Figure 16: Photomicrograph (thin section, plane light, X100) of pumpellyite crystals in a quartz veinlet in altered flow rock of the Permian volcanic sequence, from the north end of Slesse Creek Valley.

originally zoned, but are now entirely saussuritized and set in a matrix of fine saussuritized feldspars, augite and interstitial chlorite. Ilmenite (?), and its alteration products, leucoxene and sphene, are present.

Precise petrographic nomenclature of the flow rocks described above is difficult to establish because of the invariable alteration of the plagioclase feldspars. The original composition of these rocks has to be inferred from existing textures and mineral associations. As noted above, augite may display an ophitic and subophitic relationship with altered feldspar laths. In many of these rocks chlorite is present between the feldspar laths, a texture known as intersertal (Williams, et al., 1954, p.22). Williams (1954, p.93) in referring to andesites, states:

> "...intersertal and ophitic textures are exceptional save in varieties transitional to basalts."

Well-aligned feldspar laths were not seen in any specimens from Chilliwack Valley. Moen (1962, p.35) noted trachytic texture in specimens from the lateral continuation of these volcanic rocks to the southwest of the map-area, although he stated that rocks with this texture were not common. Trachytic texture is common in many andesites, but is exceptional in basalts. Textures of these altered extrusive rocks are therefore indicative of their original basaltic nature. In addition, Williams, et al. (1954, pp.95.47) note that ilmenite (skeletal crystals of which are common in Chilliwack flow rocks) is rare in pyroxene andesites but occurs in basalts. Moen (1962, p.35) measured extinction angles of unaltered feldspars in lavas of the Chilliwack Group from localities southwest of the map-area, obtained compositions intermediate between oligoclase and andesine, and called these rocks augite andesites. Moen also stated that altered feldspars had extinction angles suggestive of albite and oligoclase, and mentioned that spilites are present in the volcanic sequence. Daly (1912, p.52) called these rocks augite andesites, noted that they were altered, but did not give any feldspar compositions. All feldspar determined by the writer from these augite-bearing flow rocks of the Chilliwack Group is albite. Although mineralogical assemblages of many of these flow rocks are those of spilites, sodium does not appear to have been introduced into the rock. Instead, saussuritic alteration of the anorthite part of the plagioclase molecule has left albite pseudomorphs containing saussurite. Textures and existing mineral associations therefore are believed by the writer to indicate that these augite-bearing flow rocks are altered basalts or altered andesitic basalts.

Hornblende andesites, present in this volcanic sequence on Liumchen Mountain and Mount McGuire, are very minor in relation to the augite-bearing rocks and in contrast to them are fresh. These rocks are porphyritic and contain elongate hornblende phenocrysts, and slightly altered feldspar phenocrysts, some of which show zoning. The composition of the feldspar phenocrysts ranges from low andesine to oligoclase. The matrix consists of small, sub-equant crystals of feldspar and hornblende. Magnetite and apatite are accessory minerals. Freshness of these rocks suggests that they may be later than, and intrusive into the Permian volcanic rocks.

Volcanic rocks forming the Liumchen Nappe north of Chilliwack River are largely pyroclastic rocks, and of these, very pale green to olive-green, quartz-bearing, crystal vitric tuffs are probably the most common, and certainly the most prominent. These rocks are hard, massive, and composed of about 40% to 60% pale green, altered euhedral to subhedral feldspars, about 5% to 10% quartz and a variable but subordinate amount of lithic and vitric fragments, in a matrix of similar composition. The clasts are unsorted, but generally have an upper size limit of about 2mm. Maximum grain size is commonly uniform throughout a single massive bed, although grading has been observed in some medium to thinly bedded crystal tuffs interbedded with the more common massively bedded rocks. In some of these graded beds, as the clasts became finer upwards, the crystal tuff grades upwards into pale green silicified tuff, resembling chert. Quartz clasts are very conspicuous in thin section. Many are euhedral crystals, and show the sub-equant, sub-rectangular outline associated with high temperature, bipyramidal quartz (<u>see</u> Folk, 1961, p.68). Commonly these grains are partly rounded and show rounded embayments, suggesting magmatic resorbtion. Some quartz grains are both angular and rounded, and are clearly fragments of euhedral crystals. All other clasts in these rocks are invariably altered in some degree. Altered plagioclase feldspars are in part albite with compositions ranging from An_6 to An_8 (as determined by X$\wedge$010 method), and in part a semi-opaque very fine-grained material with a faint brown colour. Some of these altered feldspars contain various amounts of a brown fibrous material, with a moderate birefringence masked by the brown colour (Figure 17). This mineral was identified as lawsonite on X-ray examination by R.M. Thompson. Remaining clasts are altered to chlorite or semi-opaque clay minerals and have vesicular textures or are of shard-like shape, suggesting that they are altered vitric fragments. The groundmass consists of finer clasts of generally similar composition to those above, together with chlorite and chert. Minor amounts of calcite, epidote and pumpellyite are present. Rarely, the whole rock, with the exception of the quartz grains, may be calcitized. Epidote and pumpellyite are rare, the latter, when present, occurring as acicular crystals in veinlets.

Owing to alteration of the feldspars, the nomenclature of these rocks is difficult to establish. The presence of lawsonite together with albite in the feldspar crystals, suggests the crystals were originally plagioclase more calcic than albite. Moen (1962, p.40) described similar volcanic rocks from the Chilliwack Group to the southwest of the map-area, and called them dacites. Textures and mineral associations suggests that these quartz-bearing rocks in Chilliwack Valley are altered dacite crystal tuffs.

Lithic tuffs appear to be more common in other tectonic units and are described in detail under the appropriate headings. They may be more abundant in the Liumchen Nappe than is realized at present, as they are commonly relatively soft and more easily eroded than the massive lavas and quartz-bearing crystal tuffs with which they are interbedded, and tend to be covered.

Silicified fine tuffs, resembling grey to pale green cherts are present in the volcanic sequence but are nowhere abundant. All gradations exist between these rocks and coarser grained quartz-bearing crystal tuffs (Figure 18). Thin bedded to massive jasper is locally present. No typical ribbon cherts have been seen in the volcanic sequence in the Liumchen Nappe.

Apparent thickness of volcanic rocks of the Liumchen Nappe exposed on Liumchen Mountain is nearly 2,000 feet. Volcanic rocks exposed in the window at the north end of Slesse Creek are about 700 feet thick. Although

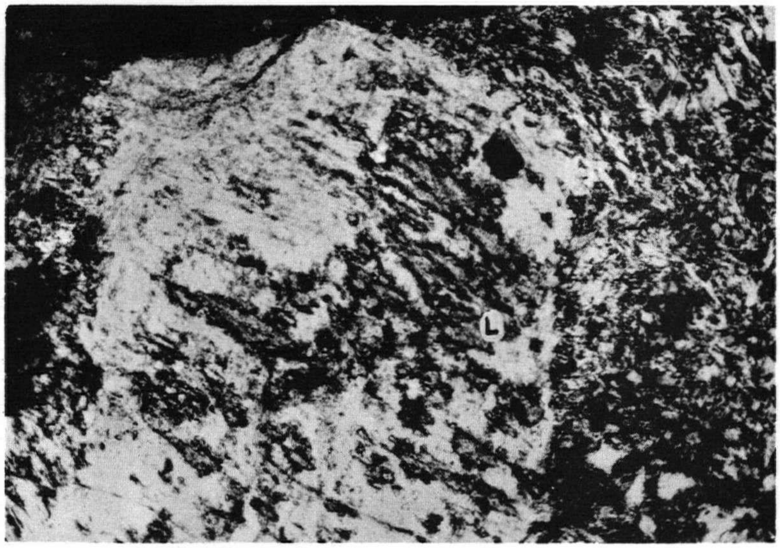


Figure 17: Photomicrograph (thin section, crossed nicols, X100) of an altered plagioclase feldspar crystal containing lawsonite (L), in crystal tuff of the Permian volcanic sequence, from the southeast side of Mount Thurston.

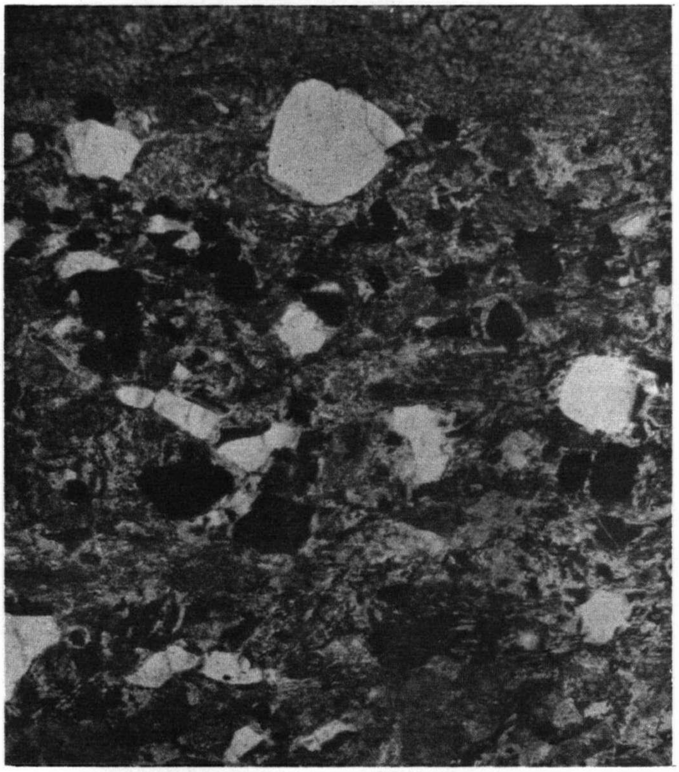


Figure 18: Photomicrograph (thin section, plane light, X40) of base of crystal vitric tuff bed, from Permian volcanic sequence, just west of Bridal Falls. The tuff is composed largely of volcanic quartz and semi-opaque altered vitric fragments. Note fine-grained silicified tuff at base, which is the top of the underlying tuff bed.

the base of volcanic rocks on Elk Mountain is not seen, the exposed thickness approaches that on Liumchen Mountain.

Quartz-bearing crystal tuffs of the Liumchen Nappe are overlain, apparently disconformably, by fine clastic rocks of Upper Triassic age on Elk Mountain. Other contacts of the volcanic sequence in the Liumchen Nappe in Chilliwack Valley are structural rather than stratigraphic. On Mount McGuire and at the north end of Slesse Creek Valley these volcanic rocks are overlain by Upper Palaeozoic limestones and clastic rocks of the McGuire Nappe. This contact is assumed to be a flat-lying fault.

Daly (1912, Map 89A) showed volcanic rocks of his Chilliwack volcanic formation to be overthrust upon both Mesozoic and Palaeozoic rocks in the Church Mountain area, and Moen (1962), working to the southwest of the map-area mapped the continuation of Daly's thrust in northern Washington. Because volcanic rocks of the Liumchen Nappe lie on Mesozoic rocks at the south end of International Ridge, on Palaeozoic rocks on Church Mountain, and overlie Mesozoic rocks on the northwest side of Mount McGuire, the lower contact of volcanic rocks in the Liumchen Nappe is believed to be a thrust fault.

Autochthon

Lavas and tuffs structurally below and partly gradational with Lower Permian limestone are exposed on the north and east sides of the summit of Church Mountain, and pyroclastic rocks, cherts and minor flows are present in Liumchen Creek Valley.

Permian flow rocks in the autochthon are similar to those described previously, being grey-green to maroon, amygdaloidal, altered basic lavas. Pillow lavas are exposed in Liumchen Creek Valley.

The pyroclastic rocks vary in size from coarse volcanic breccias, with clasts up to 6 inches in diameter, to very fine-grained tuffs, and range in colour from various shades of green to maroon. They are composed of variable percentages of altered vitric to lithic fragments. The vitric fragments are commonly altered to semi-opaque clay minerals and chlorite, and their original composition can only be inferred by the vesicular nature or shard-like outlines of the clasts. The lithic fragments typically contain relict microlites, or rarely, large, randomly oriented, altered feldspar laths, set in a chlorite matrix and some lithic fragments contain chlorite amygdales. Quartz is absent or rare in these rocks. Alteration of these rocks is commonly so extensive, that microscopic examination is made under plane polarized light alone, as with crossed nicols the rocks appear as a mass of chlorite and carbonate in which textures cannot be distinguished. W.R. Danner collected a fine-grained, dark grey to green banded rock from Liumchen Creek, composed entirely of altered shards, oriented and flattened parallel to bedding (Figure 19). The texture suggests that it is a welded tuff.

On Church Mountain this volcanic sequence structurally underlies Lower Permian limestone. The contact is gradational, and marked by calcareous pyroclastic rocks containing fusulinids. The volcanic rocks structurally overlie Mesozoic rocks on the east side of Church Mountain and are interfolded with them to the north of the summit. Rocks on both sides of this folded contact appear to be conformable. Volcanic rocks in Liumchen Creek are overlain partly by Lower Permian limestone and partly by older clastic rocks, and pass structurally downwards into limestone of unknown age, which conformably overlies Upper Triassic siltstones and argillites. Elsewhere in Liumchen Creek Valley, volcanic rocks are interfolded with Triassic rocks, but the sequence appears to be conformable.

Metamorphic grade

The only altered basic volcanic rocks composed of a well-defined metamorphic mineral assemblage are the greenstones forming the summit of Lady Peak, which belong to the quartz-albite-muscovite-chlorite sub-facies of the greenschist facies of Fyfe, Turner and Verhoogen (1958, p.219). In other volcanic rocks of the Chilliwack Group, particularly the massive lavas and crystal tuffs, textural and mineral reorganization resulting from metamorphism appears to be relatively slight and superficially little more than diagenetic. Feldspars in the altered basic lavas retain their original form, although altered to saussurite and albite, and augite phenocrysts are generally unaltered. In the quartz-bearing crystal tuff, the feldspars are partly altered to incipient lawsonite, so fine-grained and of such atypical form that it could only be determined using X-rays. Chlorite is ubiquitous and pumpellyite is present in many rocks. Zeolites or prehnite have not been found in these rocks.

As Fyfe, Turner and Verhoogen (1958, p.226) state that lawsonite is known only in the glaucophane schist facies, some of these rocks belong to this facies as defined by these authors. Lawsonite has been found only in altered feldspars in crystal tuffs and not in feldspars in altered basic lavas, even where these rock types are apparently lateral equivalents and present in the same structural horizon. This, together with the atypical form of the mineral, suggests that the lawsonite present in these rocks was formed very close to the lower limits of its stability range and that its presence in the crystal tuff is due to slightly more favourable internal physico-chemical conditions in the tuff rather than to any differences in external conditions. True glaucophane schists have been reported from the Northern Cascades in Washington by Smith and Calkins (1904, p.52) and P. Misch (oral communication) but their structural and stratigraphic relationships to rocks in the Chilliwack Valley is not known at present.

Seki (1961) demonstrated that pumpellyite is a useful indicator of metamorphic grade in low-temperature regional metamorphism. He believed that metamorphism producing pumpellyite could be divided into two types, the glaucophanitic and non-glaucophanitic type, the former representing "higher solid pressure" during metamorphism than the latter. Pumpellyite in altered volcanic rocks in Chilliwack Valley has been produced by the former type of metamorphism. Seki also suggested that four mineral facies, the pumpellyite-chlorite, pumpellyite-prehnite, chlorite and zeolite facies span the gap between the greenschist and diagenesis. Metamorphism at relatively "low solid pressure" would cause successive changes from diagenesis, respectively through the zeolite, pumpellyite-prehnite and greenschist facies and at relatively higher solid pressure through the zeolite, chlorite, pumpellyite-chlorite and glaucophane schist facies. Metamorphic mineral assemblages suggest that metamorphism in Chilliwack Valley area has followed the latter path, and that these rocks belong to Seki's pumpellyite-chlorite facies, transitional to the glaucophane schist facies.

Fossils and age

Fusulinids of Leonardian age are found in calcareous pyroclastic rocks at the base of the volcanic sequence present in the autochthon, in thin limestones intercalated with volcanic rocks in the Liumchen Nappe, and in limestone associated with volcanic rocks on Mount Laughington.

Belemnites, similar to Dictyoconites groenlandicus Fischer, from the Late Permian of Greenland (similarity confirmed by J.A. Jeletzky, oral communication, July, 1964) are present in lithic tuffs of the sequence in Liumchen Creek (Figure 20).

No other diagnostic fossils are known. This volcanic sequence is therefore partly Leonardian in age, and as the upper age limit is not known, some later Permian rocks may be included.

Environment of deposition

Fossils in volcanic rocks comprising the Permian volcanic sequence and in contiguous rock units gradational into these volcanic rocks, together with rare pillow lavas, suggests that some of these rocks were laid down in a marine environment. The welded tuff texture of an altered vitric tuff from Liumchen Creek indicates that this and perhaps other volcanic rocks of this sequence were deposited subaerially.

It has been suggested in the discussion on environment of deposition of the Permian limestone that basic lavas were quietly extruded and consolidated around the vent(s) of a volcanic centre, whilst contemporaneous limestone deposition took place peripherally to this. Rocks of the volcanic centre now form the Liumchen Nappe, whereas the sites of limestone deposition are now the subjacent autochthon and superjacent McGuire Nappe. A subsequent change to a more siliceous magma resulted in explosive ejection of predominantly quartz-bearing crystal tuff which spread over the area, terminating limestone deposition. This tuff was possibly partly aerially transported directly to the site of deposition. Unconsolidated crystal tuffs on the flanks of the volcanic centre may have been transported to the final site of deposition by subaqueous pyroclastic flows (Fiske,

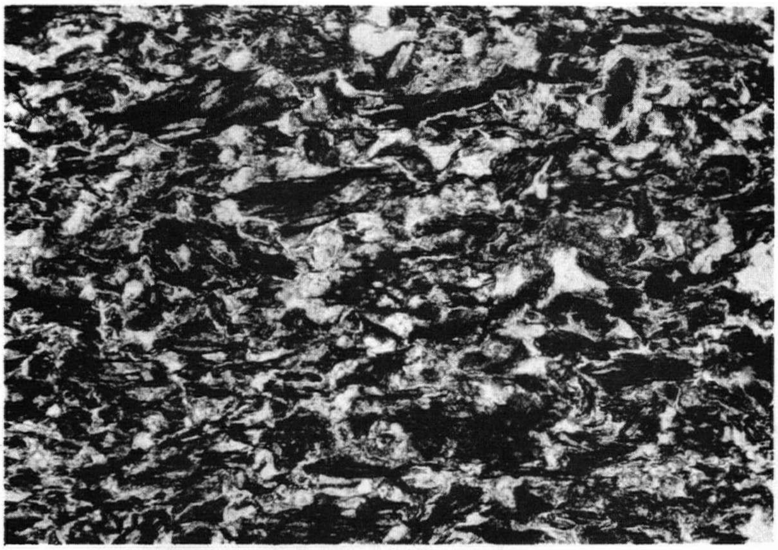


Figure 19: Photomicrograph (thin section, plane light, X40) of welded tuff (?) composed entirely of flattened, altered vitric fragments. Specimen collected by W.R. Danner from Liumchen Creek.

Figure 20: Photomicrograph (thin section, plane light, X18) showing a cross-section of a ribbed belemnite similar to Dictyoconites groenlandicus Fischer, in a lithic tuff of Permian age from Liumchen Creek Valley (Fossil Locality 55).

1963). This mode of transport would be compatible with the massive, unsorted, non-graded nature of much of the crystal tuff. Grading in some of these tuffs suggests they were possibly deposited by turbidity flows.

In the Liumchen Nappe, an apparent lateral transition takes place from a sequence of predominant lavas to a sequence of crystal tuff with minor lava. Although no precise time horizon can be drawn through both of these facies, that they are at least partly contemporaneous is shown by interbedded lavas and crystal tuffs on the north side of Mount McGuire, and therefore the change from a sequence of basic lavas, to an overlying sequence of quartz-bearing crystal tuff appears to have been gradational rather than abrupt.

Stratigraphic relationship between Permian and Triassic rocks

As conditions in the basin of deposition during and following Permian vulcanism have some bearing on the stratigraphic relationship between Permian and Triassic rocks, this topic is introduced here, rather than in the discussion of Mesozoic rocks. Although Moen (1962, p.67) stated the Chilliwack Group southwest of the map-area in northern Washington was initially folded and faulted prior to deposition of Lower Mesozoic rocks, he gave no direct evidence to support his statement. No evidence of Permo-Triassic deformation is recognized in the map-area.

The Permian volcanic sequence is stratigraphically overlain by rhythmically graded, fine volcanic arenites and argillites of Upper Triassic age. Existence of a stratigraphic break between these sequences is indicated by the following factors. At some localities in the map-area less than 100 feet of crystal tuff separates lower limestone with Leonardian fusulinids from overlying Upper Triassic rocks. The lithology of the Triassic sequence above the contact is markedly different from that of underlying Permian rocks, with no gradation between the two. The contact is marked by a breccia horizon, composed of clasts of identical lithology to underlying Permian rocks. Early Permian fusulinids were found in one clast in the breccia. This breccia is believed to result from a submarine slide, and although not necessarily marking erosion of Permian rocks in the map-area, represents erosion of Permian rocks in the region.

All evidence indicates that a disconformity exists between Permian and Triassic rocks in the map-area. Bedding of contiguous Permian and Triassic rocks is conformable. Although rocks within the map-area covered a much wider area prior to tectonic superposition, everywhere the stratigraphic Permo-Triassic contact is seen, it is underlain by Permian volcanic rocks. Variation in thickness of the Permian volcanic sequence may be partly due to erosion, but from the nature of the sequence, this variation could well be original. Structural evidence shows that both Permian and Triassic rocks have undergone the same number of periods of deformation, and that any differences in degree of metamorphism are between rocks of different tectonic units and not between Permian and Triassic rocks of the same tectonic unit. The breccia at the contact demonstrates that erosion of Permian rocks did take place and therefore this stratigraphic break is probably a regional unconformity, although only a disconformity can be demonstrated in the map-area.

Dott (1961) has discussed the existence of extensive Late Permian and probable Early Triassic vulcanism and the common lack of recognition of Lower and Middle Triassic rocks over much of the Western Cordillera. He linked these two factors, suggesting:

> ". . . as a working hypothesis that the rate of Permian sedimentary and volcanic accumulation exceeded subsidence and so built up to or slightly above sea level by Early Triassic. . . . . Isostatic adjustment to this volcanic pile by slow subsidence lagged until Late Triassic when vulcanism had diminished somewhat. The belt then again subsided more uniformly below sea level, or sea level rose eustatically allowing widespread marine transgression."

A modified form of Dott's hypothesis is adopted to explain the nature of the contact between Permian and Triassic rocks in the Chilliwack Valley.

During Permian time, rate of accumulation of volcanic rocks in the map-area may have exceeded the sum of their rates of erosion and subsidence, resulting in the growth of a volcanic island above sea level. Support for this proposal is provided by the welded tuff from Liumchen Creek, as it is difficult to conceive how such a texture could be formed in a subaqueous environment. Once the supply of volcanic material had ceased, erosion and subsidence would lower the volcanic island below wave base. The breccia, at the contact between Permian and Triassic rocks, may result from erosion of a still-elevated contiguous part of the volcanic island, deposited by submarine sliding (also causing erosion?) on the already submerged Permian volcanic rocks of the map-area.

By Late Triassic time, volcanic activity in southwestern British Columbia was concentrated west of the map-area on Vancouver Island and to the northeast, in the Nicola area in the Interior of British Columbia. Upper Triassic sediments in the map-area, mainly graded bedded volcanic arenites and argillites, appear to have been deposited by turbidity currents in a trough between these volcanic centres.

Following the reduction of the volcanic island to wave base, it would stand as a slowly subsiding isolated high area on the sea-floor, surrounded by the lower sea-floor on which material was being deposited by turbidity currents. It would be able to receive only pelagic sediments until it reached the general level of the basin by subsidence and possibly by the accumulation of turbidites in the surrounding lower areas, if accumulation exceeded subsidence in these areas, (see Heezen, 1963, p.754, Kuenen, 1964, p.6). By Late Triassic time, there was little or no difference in elevation between the level of the old volcanic centre and the general level of the basin floor and turbidites were deposited over the whole area.

As no pelagic sediments have been recognized, the interval between general cessation of vulcanism and subsequent erosion, and deposition of Upper Triassic rocks, may have been relatively short.

Validity and present status of the term Chilliwack Group

The term Chilliwack Group is derived from Daly's Chilliwack Series, which is informally defined by modern standards. Because stratigraphic names are now defined according to the Code of Stratigraphic Nomenclature (1961) an examination of the validity and present status of the term Chilliwack Group is essential.

The geographical name Chilliwack must be retained for reasons of priority and usage although the term Chilliwack Valley would be more applicable by modern standards. The change from Series to Group first appeared in 1944 on the geological map of the Hope area (Geol. Surv. Canada Map 737A) although no explanation was given for this alteration. Danner, (1957, p.113) observed that the usage of Group here is correct according to modern stratigraphical practice.

As defined by the Stratigraphic Code, a group consists of two or more associated formations and is defined in order to demonstrate the natural relationship between formations with significant features in common. Although formations within the Chilliwack Group were proposed by Danner (1957, p.114) not enough was known of the composition of these units to define them formally, and they have not been incorporated within the literature, and the present usage of the term Chilliwack Group is informal. Temporary use of "group" in this instance is presumably acceptable as the Stratigraphic Code notes noncommittally that it has been used for reconnaissance work for sequences that appear divisible into formations but which have not as yet been divided. Therefore the term Chilliwack Group provides a useful interim stratigraphic classification and will eventually become formal when all formations within it have been defined.

As noted above, a group is established formally in order to demonstrate the natural relationship between formations. The Permian limestone and the Permian volcanic sequence, both of which are of formational status, are gradational into one another and are possibly genetically related, either directly by chemical precipitation of the limestone by contemporaneous vulcanism, and/or indirectly, by vulcanism elevating part of the sea floor above the general level and thus making it a suitable site for limestone deposition. Restriction of the term Chilliwack Group to include these units alone would emphasize such relationships and would also allow the group to be defined formally. In addition, this restricted usage would be ideal as these two formations are the predominant Palaeozoic rocks in the Chilliwack Valley. However, the upper clastic sequence underlying the Permian limestone may be partly or almost wholly Lower Permian in age and is possibly separated from the underlying Lower Pennsylvanian rocks by a hiatus of unknown duration. If such a stratigraphic break can be demonstrated, then a more logical division might be to include all of the clastic rocks above the hiatus in the Chilliwack Group; the presence of tuffs in this clastic sequence indicates a possible genetic relationship between these rocks and the Permian volcanic sequence. Older rocks would be combined into a new group composed of clastic rocks below such a stratigraphic break, the Red Mountain Limestone (restricted from Danner, 1957) and clastic rocks below the Pennsylvanian limestone. These older rocks are a minor part of the Chilliwack Group as presently established in the type-area and are seemingly better exposed just southwest of the map-area in northern Washington.

These changes in terminology are summarized on the following page, in Table 4.

TABLE 4: Synopsis of terminology applied to rocks of the Chilliwack Group and contiguous units

AGE	Daly, 1912	Crickmay, 1930a, 1962 (mainly Harrison Lake area)	Danner, 1957, 1960a (mainly north-west Washington)	This thesis: NW part of map-area	This thesis: SE part of map-area
Cretaceous	Tamihy Series	Various formations	Nooksack		
		near	Group	Mica-bearing sandstones	
Jurassic		Harrison Lake Harrison Lake volcs.	Nooksack volcanics	M. Jurass? volcs.	
Triassic	Cultus formation	Slollicum Series Triassic volcanics		Cultus Formation	
Permian			Chilliwack Gp.: Limestone of Black Mtn. Fm.	Chilliwack Group: Permian volcanic sequ. Permian limestone Upper	
Pennsylvanian	Chilliwack series (U. Carb.): Chilliwack Volcanic fm.	Chilliwack Series	Plant bearing clastics Limestone of Red Mtn. Fm.	clastic sequence Red Mountain Limestone Lower clastic sequence	
Mississippian	--(none known in region)				

Mesozoic rocks of the map-area

In contrast to the lithologically diverse Palaeozoic rocks, Mesozoic rocks are of relatively uniform lithology, rarely have any strong topographic expression and are generally poorly exposed. They therefore cannot be readily subdivided into smaller rock-stratigraphic units. Moreover, although Upper Triassic, Lower Jurassic and Upper Jurassic fossils have been found, these fossils are too scarce to allow biostratigraphic units to be defined. Therefore the Mesozoic rocks are discussed under one heading.

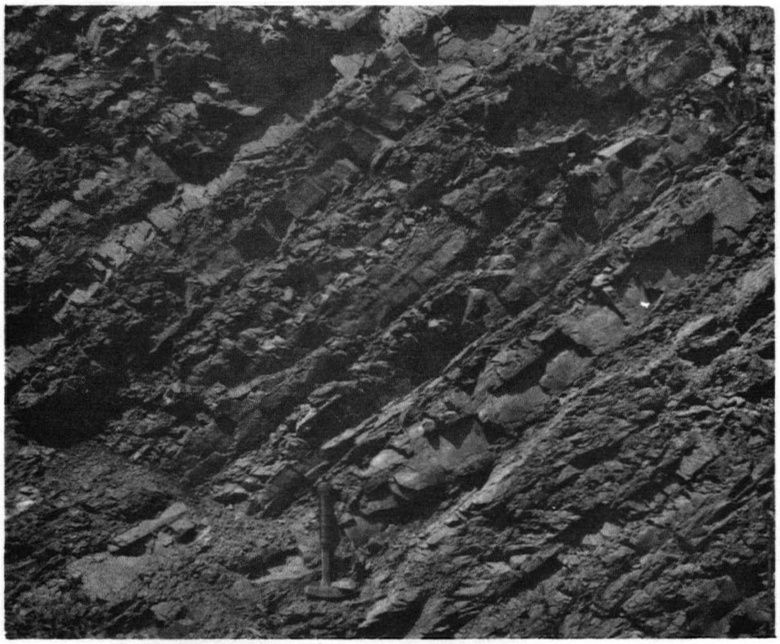
Several previous workers have described these rocks. Daly (1912, pp.516-518) reported argillites and associated coarser clastic rocks, containing Triassic cephalopods, from the east side of Cultus Lake, and named these rocks Cultus Formation. He also gave the name Tamihy Series to clastic rocks present near the south end of Tamihi Creek, just south of the map-area, and on the basis of field relations concluded that these rocks were younger than both the Chilliwack Group and the Cultus Formation, and believed their age to be possibly Cretaceous. Crickmay (1930a, map) showed Triassic rocks overlying Palaeozoic rocks in the eastern part of the map-area, where Daly and other authors (e.g. Cairns, 1944) believed rocks of Palaeozoic age to occur. Crickmay named these rocks the Slollicum Series, correlating them with similar rocks on the east side of Harrison Lake, north of the map-area. Frebold (1953, p.1232) considered that Daly's Triassic ammonites probably belonged to the lower part of the Lower Jurassic, although he stated that beds of Triassic age may be present in the Cultus Formation. Hillhouse (1956) mapped Mesozoic rocks around Cultus Lake, and followed Frebold in concluding they were of Lower Jurassic age. Misch (1963, p.167) used the term Nooksack Group for clastic rocks varying in age from Late Jurassic to Early Cretaceous which crop-out south of the map-area; these rocks include some of those in Daly's Tamihy Series.

Mesozoic rocks are widespread in the map-area. They form International Ridge, the north side of Church Mountain, and crop-out both in the northern part of Tamihi Creek Valley, and in Chilliwack River two miles east of its confluence with Tamihi Creek. Five miles northeast of Cultus Lake, Mesozoic rocks are exposed in road cuts in the Ryder Lake area. To the north of Chilliwack Valley and on the east side of Slesse Creek Valley, Mesozoic rocks crop-out above Palaeozoic rocks. The eastward continuation of these Mesozoic rocks on Mount Laughington and west of Mount Cheam is overlain by Palaeozoic rocks.

Mesozoic rocks of Chilliwack Valley map-area are typically rusty-brown, dark grey or buff weathering shales, argillites, slates, siltstones and very fine-grained sandstones. Of these, argillaceous rocks are probably predominant. Coarser sandstones and fine breccias are present in this sequence but are relatively uncommon. Thicknesses of individual beds range from siltstone laminations in predominant argillites up to about 4 inches in beds composed partly of coarse sand-sized clasts. Rarely, bedding thicknesses are much greater. Graded bedding is typical of these rocks, with regular alternations taking place between shales and coarser clastic rocks. Variation in grain size may be difficult to see in finer beds but may be recognized by hue changes from light grey to dark grey to black as the grain size becomes finer and the content of argillaceous material increases. Small load casts are common at the base of individual graded beds and convoluted and cross-bedded laminae are observed rarely at the top of some beds. These rocks form a typical turbidite sequence (see Kuenen, 1964) of graded, regularly alternating fine sandstones and argillites (Figures 21, 22).

Sand-sized rocks of this sequence are unsorted, with no sharp distinction into grains and matrix. They are composed of various proportions of angular volcanic rock fragments, plagioclase feldspars, shale chips and minor amounts of limestone fragments. Rocks in which feldspar grains are more abundant than volcanic rock fragments tend to be light grey in colour, and where volcanic fragments predominate the rocks are dark grey or grey-green. Some rocks with sand-sized textures contain shale "microbreccias" or intraformational conglomerates.

Microscopically, some volcanic fragments show relict tuffaceous textures and are commonly altered to low birefringent, semi-opaque clay minerals, chlorite or less commonly calcite; others are fragments of altered basic or intermediate lavas and consist of an altered (saussuritized ?) groundmass of feldspar microlites that encloses plagioclase phenocrysts. Clasts which are single feldspar crystals are common, and show varying degrees of alteration. Unaltered feldspars are albite, and altered feldspars, particularly in Mesozoic rocks of the autochthon, are composed of albite associated with calcite or, by analogy with partly altered grains, altered entirely to calcite. In Mesozoic rocks of tectonic units higher than the autochthon a typical alteration product of the feldspar laths is a brownish, fine-grained mineral (incipient lawsonite ?) or fibrous lawsonite (identified by X-ray methods). Some clastic calcite grains are of organic origin, for they possess the microstructure characteristic of



<u>Figure 21</u>: Typical exposure of rocks of the Cultus Formation in the autochthon, showing thin-bedded argillites, interbedded with thicker bedded, graded volcanic arenites. Exposure in logging road, west side of Liumchen Creek Valley.

<u>Figure 22</u>: Thin-bedded altered volcanic arenites and argillites of Norian age; Cultus Formation, north side of Church Mountain.

echinoderm skeletons (<u>see</u> Moore, Lalicker and Fischer, 1952, p.575). Typically, quartz is absent or rare, but rounded, clear, volcanic quartz grains are locally common in the groundmass, and epidote is present, but rare. These rocks are typical volcanic arenites.

Fine-grained Mesozoic rocks in the autochthon exhibit a fracture cleavage developed during probable mid-Cretaceous deformation and the coarser-grained rocks are jointed but otherwise unaffected. By contrast, fine-grained rocks of the Mesozoic sequence in all higher tectonic units possess a slaty cleavage, with marked mineral and textural anisotropism being developed, and coarser rocks have a crude, penetrative foliation.

There is some variation of lithology in this sequence of predominantly graded volcanic arenites and argillites. Hard argillaceous cherts and cherty argillites, which are generally thin-bedded but occasionally massive, are present near the contact with Palaeozoic rocks on the north side of Chilliwack Valley, west of Mount Cheam, on Church Mountain and in the vicinity of Pierce Creek. These rocks are invariably fine-grained and no graded bedding has been observed in them. On the southwest side of Elk Mountain, at an altitude of 4,000 feet, a thin, sparsely fossiliferous, shaly limestone to calcareous shale bed is interbedded with these cherty argillites (Fossil Locality 2). Minor argillaceous limestones in Mesozoic rocks also crop-out on the Foley Creek road, and are exposed in creek beds on the south side of Mount Laughington.

Variolitic lavas in the extreme northwestern part of the map-area, at an altitude of 500 feet on the Ryder Lake road, overlie fine clastic rocks which contain Lower Jurassic fossils and are themselves overlain by massive, micaceous sandstones. These lavas occur as pillow-like masses, with dark green chloritic material between the pillows. Pale green variolites set in dark green chloritic material are visible near the borders of the pillows; these variolites become more numerous and coalesce towards the centre of the pillows, where the whole rock is pale green. Thin sections reveal that the rock is composed of radiating aggregates, up to one mm. in diameter, of oligoclase or albite. Chlorite patches within the rock simulate the shape of pyroxene phenocrysts and contain relict pyroxene cleavages. Chlorite occurs in vesicles, and with calcite, fills veins. Minor amounts of pumpellyite are associated with the chlorite.

The massive micaceous sandstone overlying the variolitic lavas contains up to 10% angular quartz fragments, feldspars, volcanic rock fragments and fairly abundant muscovite and biotite. Its composition differs, by the presence of detrital micas, from all other known Mesozoic clastic rocks in the map-area, but resembles clastic rocks cropping-out on the east side of Vedder Mountain, just west of the map-area (W.J. McMillan, oral communication, February, 1965).

The lower stratigraphic contact of these rocks was described previously in the discussion of the Permo-Triassic boundary. Bedding at the base of the Mesozoic sequence is conformable with that in the stratigraphically underlying Permian rocks. The contact in many places is marked by a breccia, derived largely from underlying Permian volcanic rocks.

No upper stratigraphic contact of the Mesozoic sequence is known from the map-area. Although rocks of latest Cretaceous or possible Paleocene age crop-out on the north side of Chilliwack River, immediately west of the map-area (Crickmay and Pocock, 1963, p.1933), exposure is so poor at this locality that the structural and stratigraphic relationships of these rocks to older Mesozoic rocks was not determined. The youngest Mesozoic rocks known are of Late Jurassic age; these rocks crop-out in the south-eastern part of the map-area and are overlain structurally by amphibolitic rocks of uncertain age.

The apparent thickness of Mesozoic rocks in the map-area probably exceeds 4,000 feet. Lack of distinctive marker horizons, folding and relative paucity of outcrops makes it impossible to give any estimate of the original thickness.

Fossils and age of the Mesozoic sequence

Fossils are not very common in Mesozoic rocks from Chilliwack Valley. Bottom dwelling forms are represented by rare clams, snails and crinoid ossicles, the latter being found only in the shaly limestone bed on Elk Mountain, or as detrital fragments of unknown age in clastic rocks. Trace fossils, such as worm borings and trails, are present throughout the sequence but are never abundant. Ammonites and belemnites have been found at a few, scattered localities.

Fossils diagnostic of the Upper Triassic (upper Karnian and early Norian), Early Jurassic (Sinemurian) and Late Jurassic (late Oxfordian-early Kimmeridgian) have been collected from Mesozoic rocks in the map-area.

Daly (1912, p.517) obtained fossils from a locality just south of the International Boundary to the southwest of the map-area which were considered to be of Triassic age. These fossils were identified as the ammonite Arniotites vancouverensis Whiteaves? and Aulacoceras ? sp., a belemnoid resembling A.Carlottense Whiteaves. Ammonites of late Early Jurassic or early Middle Jurassic age were found on the Ryder Lake road by J.E. Armstrong (Hillhouse 1956, p.33).

A molluscan fauna was found by the writer in Mesozoic rocks on the east side of Liumchen Creek, not far from the contact of these rocks with Palaeozoic rocks (Fossil Locality 53). The most abundant fossil is the small ammonite Hannaoceras c.f. H. (Sympolycyclus) nodifer (Hyatt and Smith) (Figure 23). Fragments of a larger ammonite, possibly Discotropites, and a large Halobia (H.superba ?) were found associated with Hannaoceras. E.T. Tozer (written communication, December, 1964) confirmed this identification of Hannaoceras but stated that the identifications of Discotropites and Halobia are not very satisfactory owing to their poor preservation. From near this locality a belemnite, possibly Atractites c.f. A. drakei Smith, some small unidentified pelecypods and a medium-sized, orthostropic gastropod were collected. This fauna appears to be representative of the Tropites subbulatus zone, and is uppermost Karnian in age.

Poorly preserved Halobias were collected on the north side of Church Mountain (Fossil Locality 52). These were tentatively identified by G.E.G. Westermann (written communication, February, 1964) as Halobia dilata Kittl ?, probably of lower, possibly of middle, Norian age.

Fragmentary ammonites and large, ribbed, belemnites were found in shaly limestone on the southwest side of Elk Mountain (Fossil Locality 2). The belemnites (Figure 24) were identified as Aulococeras c.f. A. Carlottense Whiteaves. J.A. Jeletzky (oral communication, July, 1964) confirmed this identification and considers that Aulacoceras is restricted to the Upper Triassic. The ammonites from this locality were too poorly preserved to be identified.

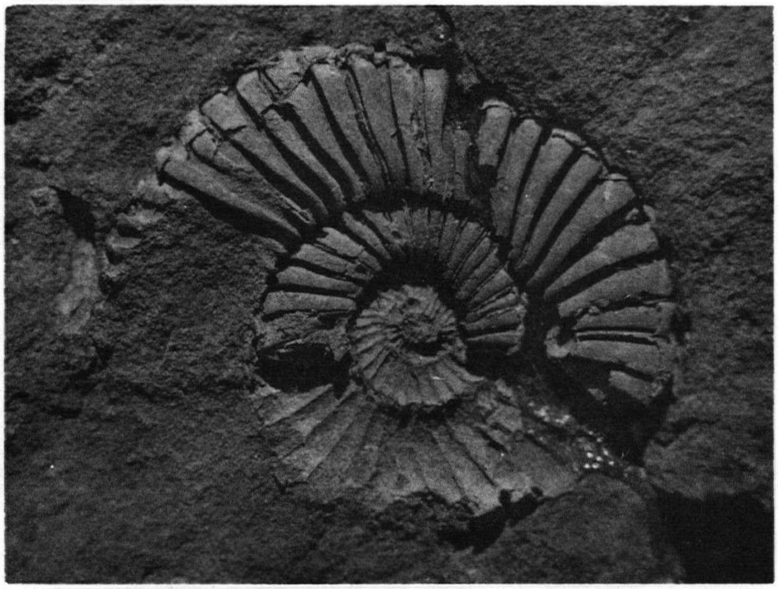


Figure 23: Hannaoceras c.f. H. (Sympolycyclus) nodifer (Hyatt and Smith), X3, an ammonite of upper Karnian age, from lower part of Cultus Formation, Liumchen Creek (Fossil Locality 53).

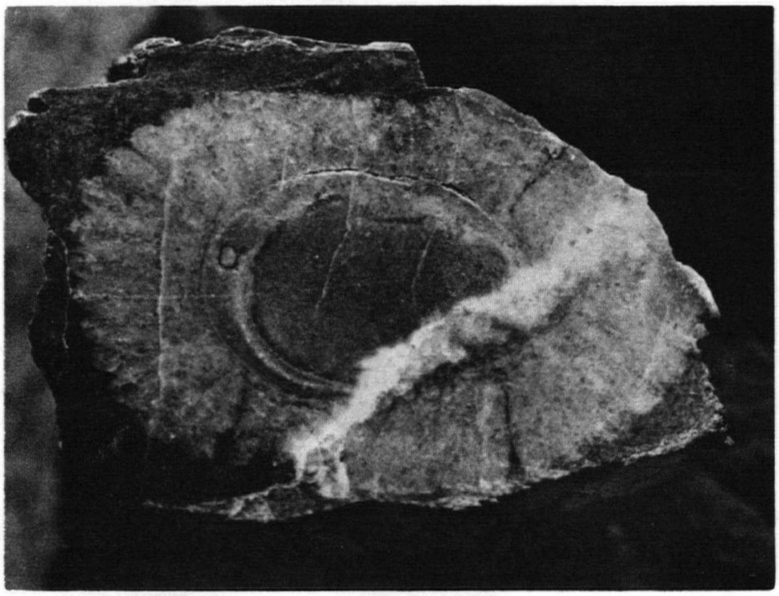


Figure 24: Cross-section of Aulacoceras c.f. A. Carlottense Whiteaves, X3, a ribbed belemnite of Upper Triassic age, from shaly limestone of the lower part of the Cultus Formation, on Elk Mountain (Fossil Locality 2).

The Upper Triassic age of Aulacoceras raises some doubt as to the age of Daly's collection (1912, p.517) which contained, in addition to Aulacoceras, ammonites identified as Lower Jurassic by Frebold (1953, p.1232).

A poorly preserved ammonite, collected from Mesozoic rocks on the logging road between Mount Mercer and Mount Thurston, was identified by H. Frebold (written communication, November, 1963) who writes:

> "The poorly preserved specimen resembles specimens collected by Dr. Armstrong some years ago, and by me in the summer of 1963. I am including these specimens in the Arnioceratidae and will probably identify them with Melanhippites. I have also made collections from the Harrison Lake area some years ago and last summer, which indicate the presence of the same genus. The age of the beds concerned, which also includes pelecypods, is Sinemurian."

Similar forms to this were found in the Ryder Lake road, probably from the locality where they were first collected by J.E. Armstrong (oral communication, 1964).

No Middle Jurassic fossils are known from the map-area. Daly (1912, p.519) noted that Stephanoceras ? and Aucella erringtoni, respectively of Middle and Upper Jurassic age, had been obtained from a locality not far south of Tamihi Creek in northern Washington.

Poorly preserved pelecypods found in talus below the north face of Mount McFarlane in the upper part of Pierce Creek Valley (Fossil Locality 29) were identified by J.A. Jeletzky as Buchia ex. gr. concentrica (Sowerby). Jeletzky in a written communication (August, 1964) states:

> "Most specimens are distorted beyond recognition. However, two left valves are strongly suggestive of Buchia ex. gr. concentrica (Sowerby) (= B. bronni Lahusen, non ? Rouillier, 1847). All representatives of this species group are restricted to the upper Oxfordian-lower Kimmeridgian stages of the Upper Jurassic throughout North America and northern Eurasia. This is, accordingly, the most probable age of this slaty facies of the Nooksack Group. The same Buchia fauna, although much better preserved, occurs in

the lower part of the type Nooksack Group in northwestern Washington."

Correlation

Rocks of Upper Triassic age are common in this region. To the southwest of the map-area, the Karnian to Norian Haro Formation of the San Juan Islands consists of clastic sedimentary rocks, derived largely from volcanic sources, and some limestones (Danner, 1957, p.304). On Texada Island, in the Strait of Georgia, about 130 miles west-northwest of the map-area, the ammonite Hannaoceras is present in limestones interstratified with volcanic rocks (Mathews, 1947, p.36). Crickmay (1930b, p.35) noted possible Triassic sedimentary rocks on the west side of Harrison Lake and also (Crickmay, 1930a, p.488) showed Triassic argillites, schists and greenstones, which he called the Slollicum Series, cropping-out on the east side of Harrison Lake, and continuing to the south across Fraser River, into the eastern part of Chilliwack Valley map-area. No fossils were reported as evidence of age of the Slollicum Series. About 80 miles to the northeast, on the east side of the Cascade Mountains, the Nicola Group contains fossils of Late Triassic age, and consists mainly of volcanic rocks, with lesser amounts of limestone and clastic sedimentary rocks, (McLearn, 1953, p.1217).

The only known rocks from near the map-area which contain Lower Jurassic fossils are from Harrison Lake (see Frebold, written communication, above). Lower Jurassic rocks are known from Vancouver Island, from Parson Bay, which is about 200 miles northwest of the map-area, (Jeletzky, 1954, Crickmay, 1928) and from the Tyaughton Lake area, over 100 miles north of the map-area (Cairns, 1943).

Volcanic rocks of Middle Jurassic age, the Harrison Lake Formation of Crickmay (1962, p.3), crop-out on the west side of Harrison Lake. These rocks are correlated by Danner (1960a, p.4) with volcanic rocks at the base of the Upper Jurassic to Lower Cretaceous Nooksack Group which crops-out south of the map-area in northern Washington. Variolitic flow rocks over-lie rocks containing Lower Jurassic fossils in the northwestern part of the map-area. Possibly these volcanic rocks can be correlated with the other Middle Jurassic volcanic rocks in the region.

Upper Jurassic clastic rocks of Chilliwack Valley map-area are dominantly fine-grained, and are of similar lithology to Crickmay's Agassiz Prairie Formation (1962, p.6) of comparable age. According to Jeletzky (written communication, above) these rocks in the map-area are a slaty facies of the Nooksack Group. Misch and Armstrong (in Hillhouse, 1956, pp.38-39) have suggested that sedimentary rocks on the east side of Vedder Mountain immediately west of the map-area are equivalent to Misch's Upper Jurassic-Lower Cretaceous Nooksack Group. The mica-bearing sandstone above the (Middle Jurassic ?) volcanic rocks in the northwestern part of the map-area is lithologically similar to some of the rocks on the east side of Vedder Mountain.

Environment of deposition

All evidence suggests that Mesozoic clastic sedimentary rocks in Chilliwack Valley map-area were deposited by turbidity currents, or related processes, well below wave base. These rocks are typically graded; the only cross-bedding laminations observed are confined to the uppermost part of individual graded beds, and according to Kuenen (1964, p.27) these may be produced by fluctuations of turbidity currents. The presence of worm borings and trails in these clastic rocks, indicates that the sediments possibly accumulated at a depth of water greater than that to which light can penetrate (Seilacher, in Trumpy, 1960, p.874).

Cherty argillites in the sequence near the contact with Palaeozoic rocks may have been formed in the following manner. The silica content of the sea water in the basin may have been high as the result of contemporaneous (Upper Triassic) vulcanism. Unless clastic sedimentation were restricted to very fine material, slowly deposited from suspension, then precipitated silica would be so diluted by clastic material rapidly deposited from turbidity currents, that its presence would not be obvious. These cherty argillites may have been deposited on local highs on the sea floor, possibly remnants of the Permian volcanic island, on which material could not be laid-down by turbidity currents (see Heezen, 1963, p.754, Kuenen, 1964, p.6), but which could be covered by very fine clastic material originally carried in dilute suspension by "normal" marine currents.

With the possible exception of mica-bearing sandstone in the extreme northwest of the map-area, Mesozoic rocks in Chilliwack Valley area were largely derived from volcanic rocks. As noted above, Upper Triassic volcanic rocks are present, both to the west on Vancouver Island, and to the northeast, on the other side of the Cascade Mountains. It is suggested that during Late Triassic time conditions in these areas northeast and west of the map-area were analogous to conditions in the map-area during Early Permian time. The areas were highs on the sea floor resulting from volcanic accumulation exceeding subsidence. Upper Triassic rocks in the map-area, composed largely of clasts of volcanic origin and deposited by turbidity currents, probably accumulated in a trough between the highs, and were derived from them. The lithology of Upper Triassic and Lower Jurassic rocks in the map-area is identical, and no stratigraphic break can be detected between them. Presumably conditions extant in Late Triassic time continued into the Jurassic.

Volcanic rocks within the map-area of possible Middle Jurassic age, and Middle Jurassic volcanic rocks just to the north of the map-area near Harrison Lake, record the migration of volcanic centres back to the vicinity of the map-area again, during Middle Jurassic time.

Little can be said of the source of the slates containing the only Upper Jurassic fossils known in the map-area. The mica-bearing sandstone above the (Middle Jurassic ?) volcanic rocks in the Ryder Lake area is lithologically similar to rocks on Vedder Mountain, some of which were reported to contain granitic clasts (Hillhouse, 1956, p.34). Therefore the mica-bearing sandstone in the map-area may be partly derived from granitic or high-grade metamorphic rocks. Lower Cretaceous conglomerate containing granitic clasts has been reported from north of the map-area in the Harrison Lake area (Crickmay, 1962, p.7).

Nomenclature of Mesozoic rocks in the map-area

Daly (1912, p.516) gave the name Cultus Formation to presumed Triassic rocks east of Cultus Lake. Later work has shown both Upper Triassic and Lower Jurassic fossils to be present in the sequence. No stratigraphic break or marked lithological variation is known in this sequence and the term Cultus Formation is retained. Although "Slollicum Series" was applied by Crickmay (1930a) to rocks of supposed Triassic age cropping-out in the eastern part of the map-area, these rocks are lateral equivalents of the Cultus Formation in the Cultus Lake area and the term "Slollicum Series" can be rejected on grounds of priority, insufficient lithological description and lack of fossils cited as evidence of age. As no stratigraphic break or lithological variation has been detected between Upper Jurassic rocks in the southeastern part of the map-area and Upper Triassic and Lower Jurassic rocks elsewhere, these rocks can only be regarded as part of the Cultus Formation, stratigraphically equivalent to the Agassiz Formation of Crickmay (1962) or part of the Nooksack Group of Misch (Miller and Misch, 1963). In the northwestern part of the map-area, three distinct rock types are present. These are, Lower Jurassic argillites of the Cultus Formation, volcanic rocks, which, if of Middle Jurassic age, are possibly part of the Harrison Lake Formation of Crickmay (1962), and micaceous sandstones, which crop-out above the lavas and may be equivalent to the Nooksack Group or the Peninsula Formation of Crickmay (1962).

STRUCTURAL GEOLOGY

Preliminary statement

The effects of what appear to be two phases of one period of deformation are recognized in rocks whose ages range from Pennsylvanian to Late Jurassic. The first phase, hereafter denoted $\underline{D}_1$, took place after Late Jurassic time and before the Miocene, and it is correlated with the probable mid-Cretaceous deformation of Misch (Miller and Misch, 1963, p.167). Major northeast-trending overturned and recumbent folds and thrusts were formed at this time. Minor folds, denoted $\underline{F}_1$, and associated structures formed during $\underline{D}_1$ are used in establishing the style, sense of movement, and orientation of the major structures. During the second phase, denoted $\underline{D}_2$, northwest-trending structures were superimposed upon the earlier structures. The time during which the second period of deformation took place can only be established as post-$\underline{D}_1$ and pre-Miocene. Major structures formed during $\underline{D}_2$ are not prominent relative to those formed during $\underline{D}_1$, but minor structures produced during this period of deformation are common.

A general description of structural elements is given below; this is followed by more specific descriptions of both minor and major structures.

Structural elements

Any one or combination of the following structural elements may be present in a single outcrop.

Planar structures

Bedding, denoted $\underline{S}_0$, is commonly an easily recognized planar structure, which, acting as a marker in folded rocks, enables the style of folds formed during $\underline{D}_1$ to be distinguished. Bedding is discerned in individual outcrops of clastic sedimentary rocks by variations in grain size, or, in the fine-grained clastic rocks such as interbedded siltstones and argillites, by variations in hue. Clastic sedimentary rock sequences in which neither of the above can be seen are not common. Bedding is recognized in limestone outcrops, even where recrystallization has been extensive, from the presence of chert nodules parallel to bedding, or from shaly interbeds. However, bedding in massive lavas and some crystal tuffs may not be distinguishable in single outcrops and in many cases can only be determined by mapping lithological units.

Planar structures, denoted $\underline{S}_1$, are those produced during $\underline{D}_1$. Their presence in a particular rock and their exact nature depend in part upon both the competancy of the rock during deformation and also the metamorphic environment in which deformation has taken place (<u>see</u> De Sitter, 1956, p.77).

The earliest secondary planar structure recognized which results from deformation of both Palaeozoic and Mesozoic fine-grained clastic rocks in the western parts of the map-area (Subarea 1, Plate 3) is either a fracture or strain-slip cleavage. In outcrops both of these cleavages are visible typically as a set of closely spaced fractures commonly oriented at low angles to bedding. Strain-slip cleavage is developed when bedding, $\underline{S}_0$, is closely and regularly spaced and the rock is fine-grained, as in laminated siltstone and argillite sequences (Figure 25), whereas fracture cleavage occurs when $\underline{S}_0$ is more widely and less regularly spaced and/or the rocks are coarser grained (Figure 26). In a single graded bed this fracture cleavage may be in the upper part, composed of clay-to silt-sized clasts, but not the lower part containing medium or coarse sand-sized clasts.

Both fracture cleavage and strain-slip cleavage are oriented roughly parallel to the axial planes of minor folds of the same style in this (western) part of the map-area. For this reason, and because bedding is the only planar structure cut by either the fracture or strain-slip cleavage, they are considered to be equivalent planar structures which were formed during $\underline{D}_1$, and both are denoted by the same symbol, $\underline{S}_1'$. Their differing characteristics are seemingly due to differences of the primary nature of the rocks in which they are developed.

Slaty cleavage, denoted by $\underline{S}_1''$, is the earliest secondary planar structure recognized which results from deformation in all fine-grained clastic rocks in the remaining, major, eastern part of the map-area. In the field, it is difficult locally to distinguish this cleavage from bedding, as the two are commonly nearly parallel. However, microscopic examination invariably reveals that slaty cleavage, $\underline{S}_1''$, has been developed (Figure 27). A penetrative planar structure of metamorphic origin is also present in coarse-grained clastic rocks in this part of the map-area. In volcanic arenites containing granule or coarse sand-sized grains, this planar structure is a somewhat irregular foliation (Figure 28), which becomes more regular as grain size decreases, and appears to grade into slaty cleavage. Individual grains in the coarse clastic rocks appear flattened and many

Figure 25: Strain-slip cleavage, $\underline{S}_1'$, in laminated siltstones and argillites of the Cultus Formation; exposed in Liumchen Creek. Dip of cleavage is to southeast.

Figure 26: $\underline{F}_1$ fold in medium to thin-bedded, fine-grained clastic rocks showing poorly developed axial plane fracture cleavage, $\underline{S}_1'$, (parallel to dashed line). Cultus Formation, in side of logging road, north side of Church Mountain. Dip of axial plane of fold is to the southeast.

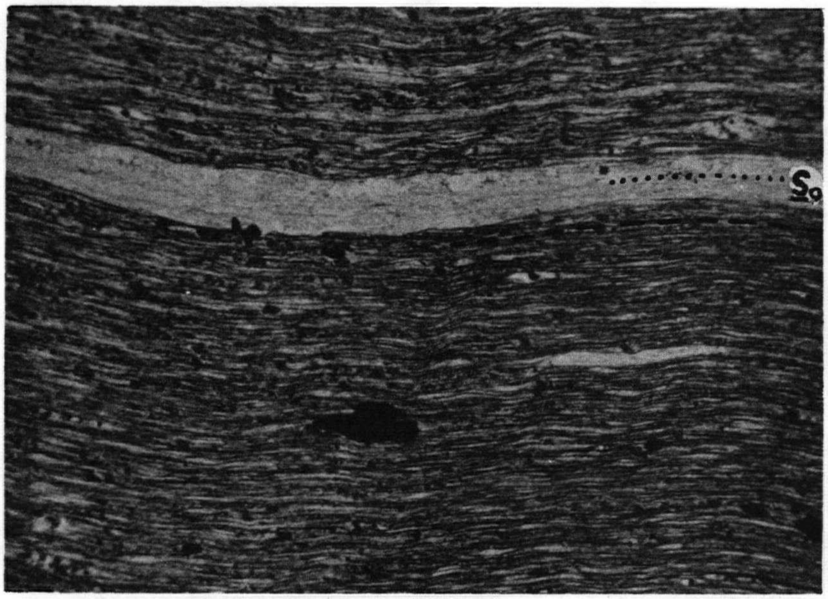


Figure 27: Photomicrograph, (thin section, plane light, X30) of fine-grained clastic rock from basal part of the Mesozoic sequence in Foley Creek showing slaty cleavage, $\underline{S}_1''$ (parallel to dashed line), parallel to compositional banding, $\underline{S}_0$. $\underline{S}_1''$ and $\underline{S}_0$ have both been gently folded.

Figure 28: Coarse volcanic arenite of the upper clastic sequence on the south side of Mount Mercer, showing the penetrative foliation, $\underline{S}_1''$, (parallel to dashed line) cross-cut by kink-bands (parallel to dotted line). Dip of plane of kink-bands is to the southwest.

grain boundaries are indistinct (Figure 30B). This foliation is approximately parallel to slaty cleavages in contiguous fine-grained rocks, and is the earliest recognized planar structure of metamorphic origin in the coarse-grained rocks. It is therefore considered to be an analogous structure to the slaty cleavage, and is also denoted by the symbol $\underline{S}_1''$.

Where the relationship is seen between slaty cleavage in fine-grained clastic rocks, and its seeming equivalent, the foliation in coarser clastic rocks, and minor $\underline{F}_1$ folds, these planar structures are axial plane cleavages (e.g. Figure 29A).

Both $\underline{S}_1'$ and $\underline{S}_1''$ are the earliest planar structures resulting from deformation and bear the same relationship to minor folds in their respective parts of the map-area, and are thus considered to be analogous structures, both of which were produced during $\underline{D}_1$. In addition, clastic rocks in both parts of the map-area are stratigraphically equivalent and were originally of similar character. Therefore, the differing natures of $\underline{S}_1'$ and $\underline{S}_1''$ are due presumably to different metamorphic conditions extant during their production. As $\underline{S}_1''$ involves reorganization of rock-material (to produce slaty cleavage), in contrast to $\underline{S}_1'$, and as it is also developed in coarse clastic rocks, unlike $\underline{S}_1'$, it appears to have been produced under more intense metamorphic conditions than $\underline{S}_1'$.

Planar structures, denoted by $\underline{S}_2'$ and $\underline{S}_2''$, cut $\underline{S}_0$, $\underline{S}_1'$ and $\underline{S}_1''$ and were formed during $\underline{D}_2$. Unlike the earlier two secondary planar structures which are ubiquitous, in certain rock types, in their respective parts of the map-area, planar structures formed during $\underline{D}_2$ are irregularly distributed on outcrop scale, although present throughout the map-area.

Planar structures designated by $\underline{S}_2'$ are typically associated with fine

FIGURE 29: Minor structures. With the exception of B, all examples shown of minor structures were traced directly from sawn surfaces of hand specimens. The specimens are oriented in a near-vertical plane, with the azimuth of the plane indicated approximately.

A Isoclinally folded laminations in a slate/siltstone rock. Slaty cleavage, S_1'', is effectively parallel to the axial planes of these minor folds. Specimen is from lower clastic sequence, east side of Slesse Creek.

B Conjugate fold, in thin but irregularly bedded argillaceous rocks of the Cultus Formation, northeast side of Church Mountain.

C Conjugate fold, in cherty argillite, developed on limb of pre-existing fold. Triassic rocks, near summit of Elk Mountain.

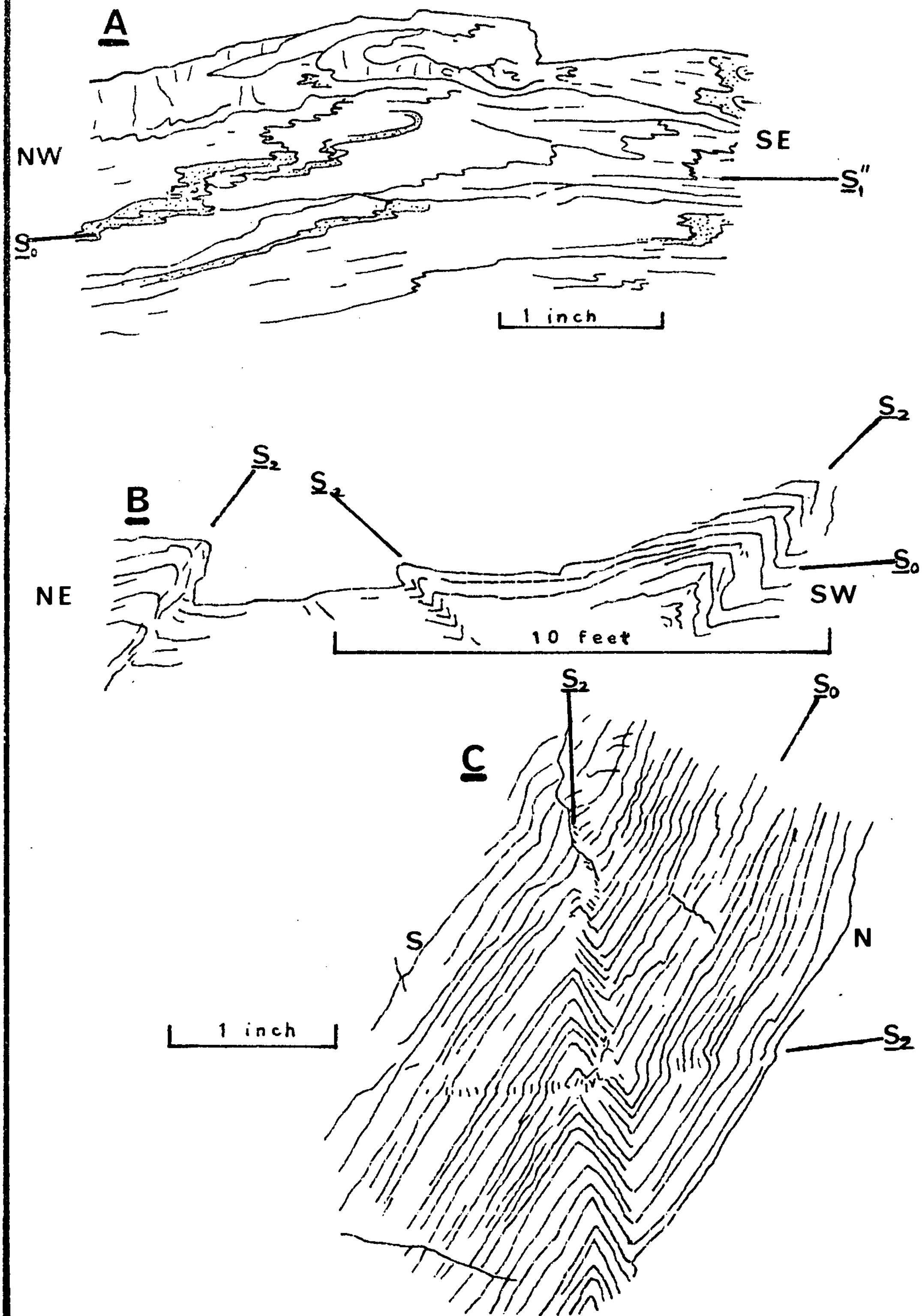


FIGURE 29: Minor structures

FIGURE 30: Minor structures. All examples are traced directly from sawn surfaces of hand specimens. The specimens are oriented in a near vertical plane with the azimuth of the plane indicated approximately.

A Planar fractures (S_2') associated with crinkles, in a slate. Specimen from basal part of Mesozoic sequence, Foley Creek.

B Crudely foliated volcanic arenite, showing flattening of clasts parallel to S_1'', cross-cut by kink bands, parallel to S_2'. Specimen from upper clastic sequence, south side, Mount Mercer.

C Curved fractures (S_2') in a foliated fine tuff or volcanic arenite. Variation in grain size across specimen is responsible for curving of fracture planes. Specimen from upper clastic sequence, Slesse Creek gorge.

D Minor D_2 fold, associated with kink bands, in foliated tuff or volcanic arenite of upper clastic sequence, Slesse Creek.

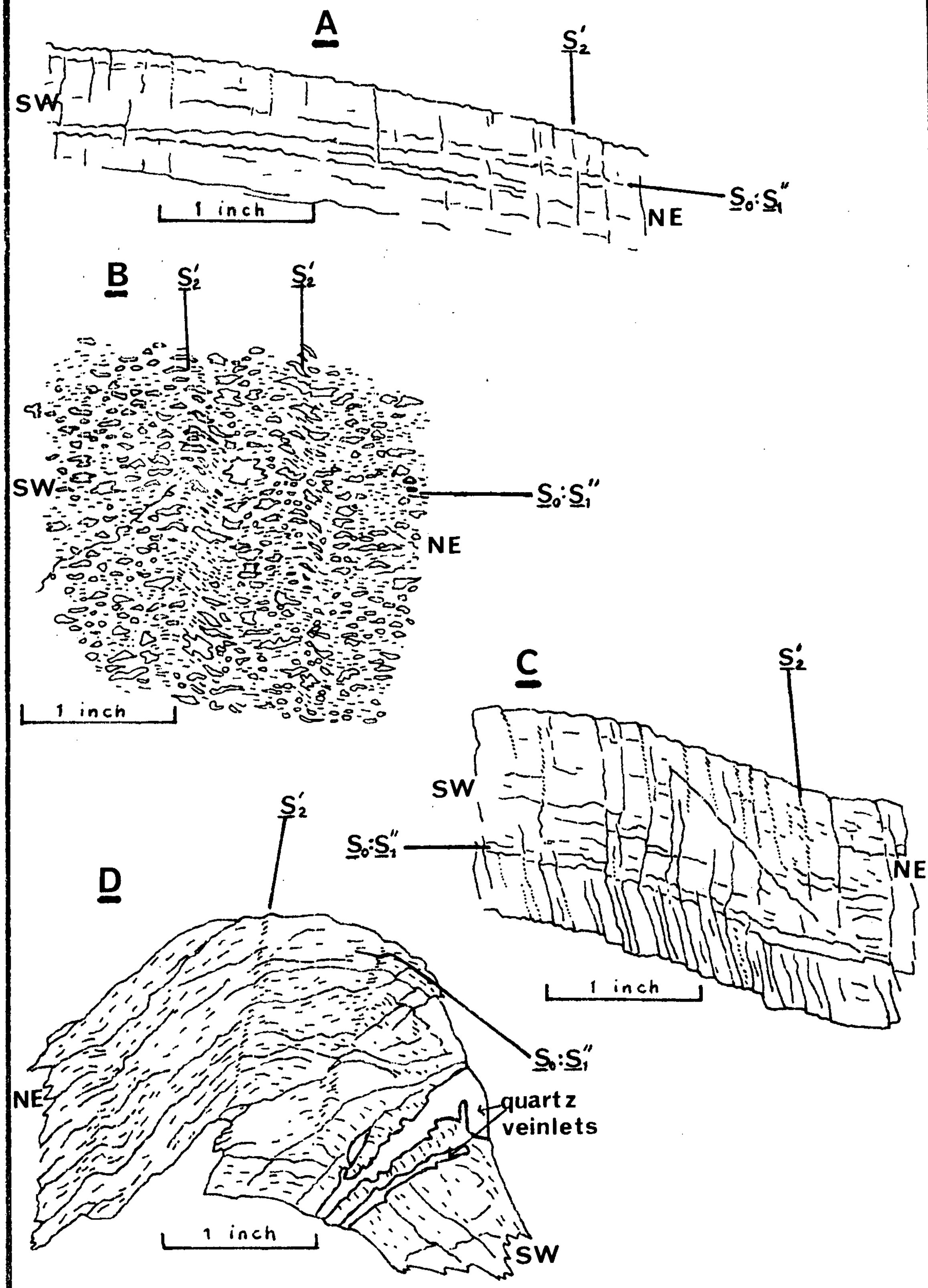


FIGURE 30 : Minor structures

parallel crinkles locally developed on $\underline{S}_0$ and $\underline{S}_1''$. These crinkles are common in rocks in which $\underline{S}_0$ and $\underline{S}_1''$, generally subparallel, dip eastwards at low to moderate angles, and $\underline{S}_2'$ is described below as it occurs in rocks with this eastward dip. The fine parallel crinkles are irregularly distributed and may be either solitary or in groups in which they are spaced as closely as 10 crinkles per inch. Where closely spaced, the crinkles typically have the form of regularly repeated, minute, asymmetric, step-like folds, with a short limb generally dipping steeply eastwards, a longer limb dipping either gently eastwards, horizontal or gently westwards, and an angular hinge. Fractures, denoted $\underline{S}_2'$, may be present instead of the steep short limb, and are approximately normal to the general dip of $\underline{S}_0$ or $\underline{S}_1'$ and thus dip steeply westwards (Figure 30A). In rocks of uniform lithology, these fractures are planar (Figure 30A) but in rocks where the grain size varies they are curved (Figure 30C). The fractures divide the rock into a series of slices, with each slice elevated successively above its eastern neighbour, so that the overall dip to the east of $\underline{S}_0$ and $\underline{S}_1''$ is apparently steepened. Apart from this local apparent steepening and warping of $\underline{S}_0$ and $\underline{S}_1''$ where crinkles associated with $\underline{S}_2'$ are well developed, no folds have been observed associated with this planar structure.

Structures developed in rocks other than fine-grained clastic rocks cut $\underline{S}_0$ and $\underline{S}_1''$ planes, are similarly oriented to $\underline{S}_2'$ planes in contiguous fine-grained rocks and are believed to be analogous. Joint drags (Flinn, 1952, p.266) or kink bands (Ramsay, 1962, p.523) are developed in less well-foliated and generally coarser grained rocks than the fine clastic rocks in which the crinkles occur. Geometry of these kink bands is similar to that of the crinkles in the fine-grained rocks, but they are of greater amplitude, more angular, and are not as closely spaced or as regularly repeated (Figures 28, 30B). The kink bands are typically present in rocks that dip gently eastwards. Orientation of the plane of kinking is roughly normal to $\underline{S}_0$ or $\underline{S}_1''$ and is approximately parallel to $\underline{S}_2'$ in contiguous fine-grained rocks. Local, closely spaced fractures in shaly limestones are parallel to $\underline{S}_2'$ in adjacent shales. In massive rocks, particularly massive, hard, quartz-bearing crystal tuffs, zones of en-echelon quartz-filled fractures, with each fracture up to 1 foot long, are locally present. The plane of the zone containing these fractures is roughly parallel to $\underline{S}_2'$ planes in associated foliated rocks.

Planar structures designated $\underline{S}_2''$ occur typically in fine-grained clastic rocks and are developed on the short limb of asymmetric folds (Figure 31), which superficially resemble the oblique-shear or chevron folds of De Sitter (1956, p.183). Commonly, these folds are oriented so that $\underline{S}_0$ or $\underline{S}_1''$, defining the longer, plane, limb, dips east at low to moderate angles. $\underline{S}_2''$ is oriented at about 45° to $\underline{S}_0$ or $\underline{S}_1''$ and thus dips eastward at a fairly steep angle. The shorter, western limb is divided into a series of slices by $\underline{S}_2''$ planes; $\underline{S}_0$ and $\underline{S}_1''$ in each slice is folded, and the overall effect is to produce a "limb" which dips westward or is nearly horizontal. Less common are folds believed analogous to those described above in which $\underline{S}_0$ and $\underline{S}_1''$ are deformed and in which $\underline{S}_2''$ is poorly developed (Figure 30D) or absent (Figure 32). Furthermore, $\underline{S}_2''$ planes are displayed in some rocks, with no recognizable fold-forms. Rarely folds similar in form to those described above occur where $\underline{S}_0$ or $\underline{S}_1''$ dip steeply westwards, and $\underline{S}_2''$ is nearly horizontal.

Although $\underline{S}_2'$ and $\underline{S}_2''$ have never been seen at the same location, and

Figure 31: Asymmetric "fold" produced during $\underline{D}_2$, with eastward dipping, longer limb, and short western "limb" cut by $\underline{S}_2''$ (parallel to dashed line). In upper clastic sequence (?) by logging road, west side of Mount Cheam.

Figure 32: Asymmetric fold, with eastern dipping longer limb, believed analogous to fold in Figure 31, but with no development of $\underline{S}_2''$ planes. Lower clastic sequence, in logging road, south end of Slesse Creek.

thus their relationship cannot be directly observed, several lines of evidence suggest they are related structures produced during the same phase of deformation, $\underline{D}_2$. The main difference between them appears to be their angular relationship with earlier planar structures; $\underline{S}_2'$ is oriented at roughly 90° to $\underline{S}_0$ or $\underline{S}_1'$, and $\underline{S}_2''$ at about 45°.

Both $\underline{S}_2'$ and $\underline{S}_2''$ have been formed under similar metamorphic conditions. They both cut $\underline{S}_0$ and $\underline{S}_1'$ or $\underline{S}_1''$ and are associated with fold forms which commonly have angular hinges and which appear to result from deformation under which the rocks generally behaved in a brittle manner. In every example of $\underline{S}_2'$ and $\underline{S}_2''$ studied microscopically, the reorientation of minerals parallel to $\underline{S}_2'$ and $\underline{S}_2''$ is mechanical and restricted to the immediate vicinity of the planar structures. Because there is no reorganization of rock material, these structures were presumably produced at a lower metamorphic grade than that under which slaty cleavage ($\underline{S}_1''$) was formed. To allow for such a decrease in metamorphic grade there must have been a relatively long interval between the time when $\underline{S}_1''$ was produced ($\underline{D}_1$) and the time when $\underline{S}_2'$ and $\underline{S}_2''$ were formed ($\underline{D}_2$).

Conjugate folds (Figure 29B) are present in the map-area and appear to have been produced under similar metamorphic conditions and at a similar time to $\underline{S}_2'$ and $\underline{S}_2''$, as both $\underline{S}_0$ and $\underline{S}_1'$ or $\underline{S}_1''$ are deformed in these conjugate folds, and as the folds have angular hinges and seem to be the result of brittle deformation. The relationship between conjugate folds and planar structures formed during $\underline{D}_2$ has not been observed by the writer in the map-area, but the relationships between these structures may be inferred from the studies done elsewhere by Paterson and Weiss (1962) and Ramsay (1962).

Conjugate folds and kink bands have been produced experimentally by compression of phyllite. Where the direction of compression is contained within the foliation of the phyllite so conjugate folds are formed by the symmetrical intersection of two sets of kink planes. The sets of kink bands are asymmetric where the direction of compression is not contained in the foliation, and only one set is developed when the direction of compression is at 25° to 45° to the foliation (Paterson and Weiss, 1962, pp.1046-1047).

Ramsay (1962) discussed the form and geometry of conjugate folds and their relation to stress directions, and noted that bedding planes frequently contain the maximum stress direction ($\underline{P}max$) where conjugate folds have been formed in thinly bedded rocks. Where the maximum (and minimum stress) directions are oriented at about 45° to bedding planes, then kink bands or joint drags are produced (Ramsay, 1962, pp.521-522).

In the Chilliwack Valley area conjugate folds are rare, but were presumably produced when $\underline{P}max$ was contained in $\underline{S}_0$ or $\underline{S}_1$ (Figure 33A). The angular relationships of the axial planes of these folds to $\underline{S}_0$ or $\underline{S}_1$ are the same or very similar to the angular relationships between $\underline{S}_2''$ and $\underline{S}_0$ or $\underline{S}_1$ in the "oblique-shear" type folds. It is suggested that $\underline{S}_2''$ is formed when $\underline{P}max$ was nearly but not quite contained within the plane of $\underline{S}_0$ or $\underline{S}_1$, thus producing an asymmetrical fold, corresponding to one of the folds of a conjugate pair (Figure 33B). $\underline{P}max$ oriented at about 45° to the foliation, however, produced $\underline{S}_2'$ in fine-grained rocks, and kink bands in coarser and less well-foliated rocks oriented at roughly 90° to the foliation (Figure 33C). Thus, the different $\underline{S}_2$ planar structures are believed to have been formed during the same phase of deformation ($\underline{D}_2$) by stress

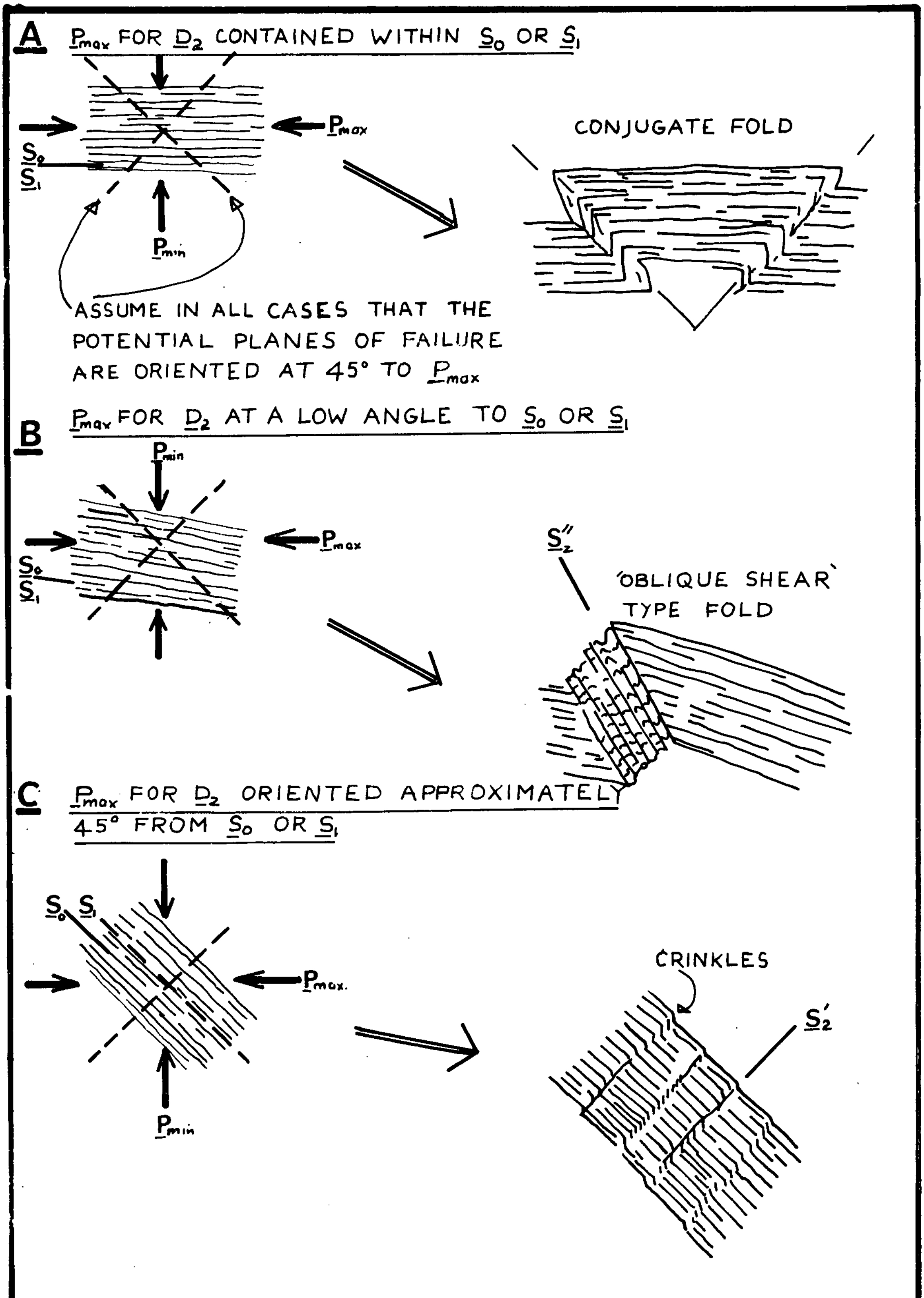


FIGURE 33 : Suggested relationship between D_2 planar structures

fields oriented differently with respect to the earlier planar structures, $\underline{S}_0$ or $\underline{S}_1$.

Linear structures

Linear structures denoted $\underline{L}_1$ were produced during $\underline{D}_1$ and are the intersection of $\underline{S}_1'$ or $\underline{S}_1''$ with $\underline{S}_0$, or the rarely observed crinkling of $\underline{S}_0$ in the slices associated with strain-slip cleavage, $\underline{S}_1$. $\underline{L}_1$ is parallel to the axes of minor folds, denoted $\underline{F}_1$, formed during $\underline{D}_1$ (Figure 34A).

Linear structures produced during $\underline{D}_2$ are of several types. Crinkles or crests of kink bands, parallel to the intersection of $\underline{S}_2'$ with $\underline{S}_0$ or $\underline{S}_1$, are denoted $\underline{L}_2'$ (Figure 34B). Both the crests of chevron folds, denoted $\underline{F}_2$, and the intersection of $\underline{S}_2''$ with $\underline{S}_0$ or $\underline{S}_1$ are denoted $\underline{L}_2''$ (Figure 34C). The crests of conjugate folds are denoted $\underline{L}_2$. Intersecting sets of $\underline{L}_2$, each set being parallel to the fold axes of the small paired monoclinic folds and producing a rhombic pattern of kinks on $\underline{S}_0$ or $\underline{S}_1$ have been observed at a few localities (Figure 34D).

Minor folds

The following criteria distinguish $\underline{F}_1$ from $\underline{F}_2$ folds in the field. $\underline{F}_1$ folds are the result of deformation of $\underline{S}_0$ alone. They are commonly tight with angular to rounded hinges, and, in rocks of suitable composition, have an axial plane cleavage $\underline{S}_1'$ or $\underline{S}_2''$ which is present throughout the fold (e.g. Figures 26, 35, 37). $\underline{F}_2$ folds deform $\underline{S}_0$ and $\underline{S}_1$ and are either conjugate or are of asymmetric "oblique-shear" type. Cleavage, $\underline{S}_2''$, where present, is restricted to the short limb of these folds (Figures 29B, 31, 32).

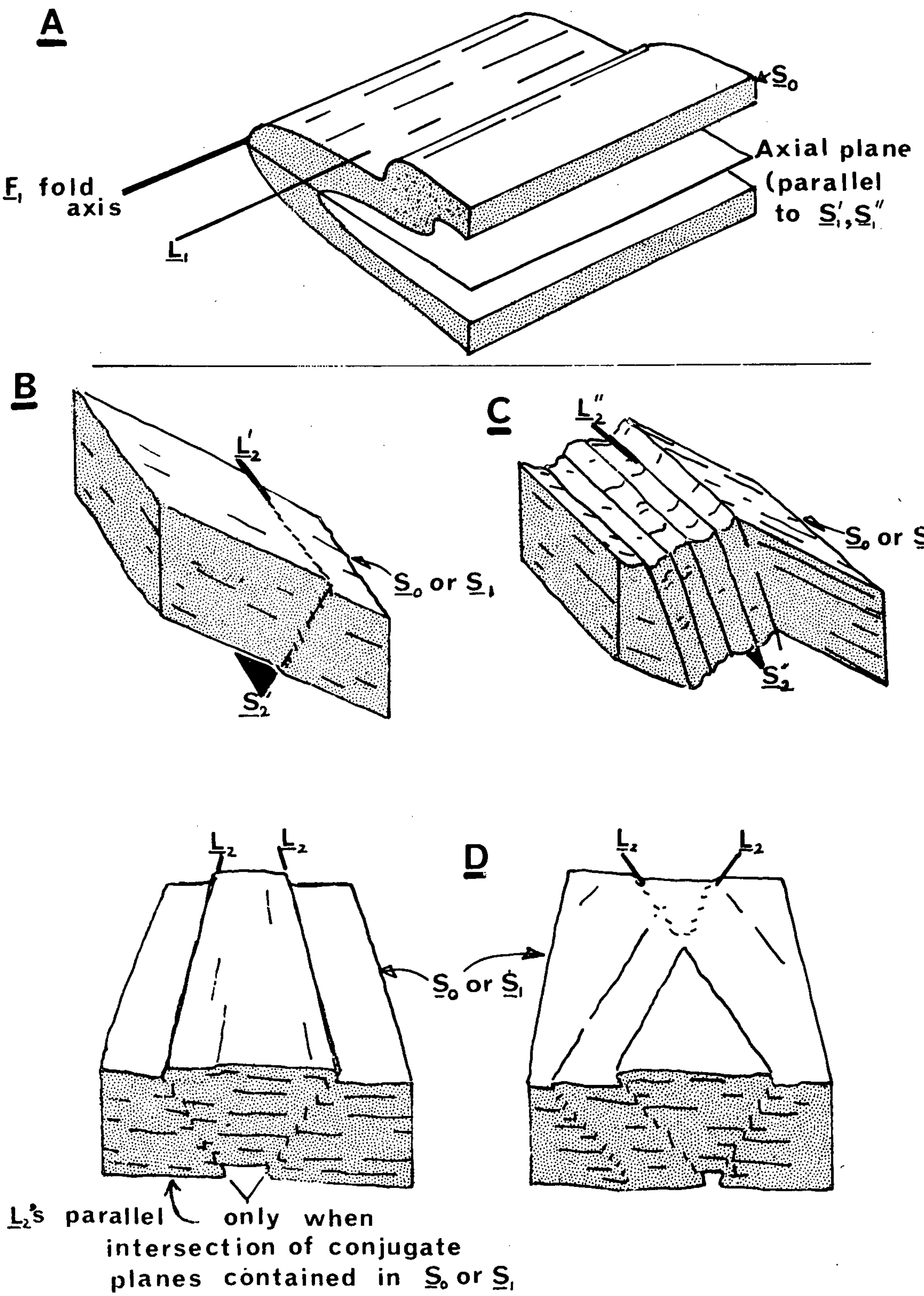


FIGURE 34 : Relationship of linear structures to other minor structures

It is sometimes difficult to relate folds with the style of those shown in Figure 36 and 40 to either $\underline{D}_1$ or $\underline{D}_2$, when these folds are present in rocks in which $\underline{S}_1$ is poorly developed, such as the cherts in Figure 40. Where such folds cannot be related to the complimentary fold of a conjugate pair and where their axes are conformable with those of neighbouring $\underline{F}_1$ folds, they are considered to be $\underline{F}_1$ folds.

Structural synthesis

The map is divided into eight subareas, from each of which the orientation of the above structural elements is plotted on a equal-area net (Plate 3). Choice of these subareas is in part arbitrary, depending upon outcrop distribution, and in part based on tectonic units, particular tectonic units being further subdivided perpendicular to the direction of plunge.

Subarea 1

This subarea is bounded on the west by Cultus Lake Valley, on the north by Chilliwack River, and on the east by the eastern limit of Mesozoic rocks in the northern part of Tamihi Creek Valley (Plate 3). The southern limit is the contact between both Palaeozoic and Mesozoic rocks and overlying Permian volcanic rocks of the Liumchen Nappe.

Rocks of this subarea are less metamorphosed than those elsewhere in the map-area, and the fine-grained clastic rocks contain fracture cleavage or strain-slip cleavage ($\underline{S}_1'$) rather than the slaty cleavage ($\underline{S}_1''$) present in equivalent rocks in the remainder of the map-area. No cleavage formed during $\underline{D}_1$ has been observed in coarse sand-sized rocks of the Cultus

Formation, in coarse clastic rocks of the Chilliwack Group, or in Palaeozoic limestones and volcanic rocks of this subarea.

Minor folds (denoted $\underline{F}_1$) in medium-to-thin-bedded, predominantly fine clastic rocks of the Cultus Formation on the east side of the south end of Cultus Lake are overturned to the northwest, and have horizontal fold-axes trending 050° and axial planes dipping 35° to the southeast. These folds are generally tight, with rounded hinges, and fine-grained rocks have a well-developed fracture cleavage, $\underline{S}_1'$, approximately parallel to their axial planes. Many $\underline{F}_1$ folds occur in thin-bedded rocks of the Cultus Formation and thin-to-medium-bedded volcanic rocks at the stratigraphic top of the Chilliwack Group in Liumchen Creek Valley. These folds are tight to nearly isoclinal (Figure 35), have angular to rounded hinges, and fold-axes of variable orientation. Because fold-hinges are commonly angular in thinly bedded rocks and rounded in more massive rocks, their form appears to be largely a function of competancy. The folds are overturned in a northerly or northwesterly direction, with axial planes dipping generally southerly at moderate angles but rarely as steeply as 80°. Tight $\underline{F}_1$ folds present in rocks of the Cultus Formation on the north sides of Church Mountain (Figures 26, 36), are invariably overturned to the north. No folds have been observed in coarse clastic sedimentary rocks of the Chilliwack Group exposed to the west of the summit of Church Mountain. Permian limestone, forming cliffs east of and immediately below the summit of Church Mountain, is deformed into large folds, also overturned to the north.

Minor structures produced during $\underline{D}_2$ are commonly chevron folds or kinks related to these, but the planar structure, $\underline{S}_2''$, which is associated

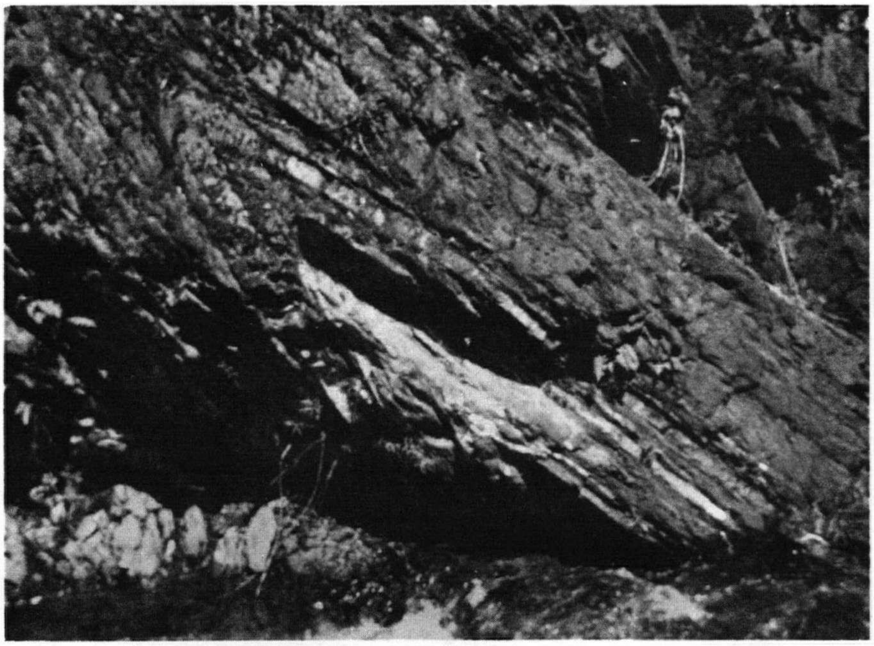


Figure 35: Tight to nearly isoclinal $\underline{F}_1$ fold, with south-east dipping axial plane, and fold axis plunging north-eastward at a low angle, in fine-grained clastic rocks of the Cultus Formation, not far above the contact with Permian limestone exposed in inlier, east side of Liumchen Creek.

Figure 36: Tight ($\underline{F}_1$?) fold, with southeast dipping axial plane and fold axis plunging southwest at a low angle, in thin-bedded clastic rocks of the Cultus Formation, in side of logging road, north side of Church Mountain.

with chevron folds elsewhere in the map-area, apparently is not well developed in this subarea. Crenulations or structures related to $\underline{S}_2'$ and conjugate folds are relatively rare. All of these later structures in this subarea are of very irregular form, in comparison to analogous structures elsewhere in the map-area. Ramsay (1962, p.517) has noted that conjugate folds are most commonly developed in thin bedded or closely laminated rocks and only rarely in strata where the beds exceed 10 cm. in thickness. Possibly the more regular form of $\underline{D}_2$ structures found in rocks elsewhere in the map-area is the consequence of the slaty cleavage ($\underline{S}_1''$) in these rocks being a more perfect foliation than the fracture cleavage ($\underline{S}_1'$) characteristic of rocks of Subarea 1.

Stereographic projection of the above structural elements shows the effects of more than one period of deformation, as plots of $\underline{L}_1$ lie on a (poorly defined) great circle and poles to $\underline{S}_0$ are scattered (Plate 3). If it can be assumed that prior to $\underline{D}_1$, $\underline{S}_0$ was horizontal, $\underline{D}_1$ deformation would then produce $\underline{F}_1$ folds with horizontal fold axes. The orientation of $\underline{L}_1$, when horizontal, is 060°, and presumably indicates the trend of $\underline{F}_1$ folds prior to $\underline{D}_1$ deformation. Poles to $\underline{S}_0$ form a diffuse maximum corresponding to a strike of 060°, and a dip of 40°; possibly this is some reflection of the orientation of the average limbs, and thus the axial plane prior to $\underline{D}_2$ deformation. During $\underline{D}_2$ deformation $\underline{D}_1$ structures were deformed, so that $\underline{L}_1$ lineations when plotted lie on a great circle, and poles to $\underline{S}_0$ no longer form a regular pattern. The presence of even a diffuse concentration of poles to $\underline{S}_0$ remaining after this deformation may indicate a bias in sampling, and/or that the effects of the second period of deformation were localized, and the orientation of many early structures were little altered by the later period of deformation. The irregular distribution on outcrop scale of minor structures produced during $\underline{D}_2$ (in contrast to the ubiquitous fracture or strain-slip cleavage formed during $\underline{D}_1$ in all fine clastic rocks) gives some basis to the latter suggestion. Most planar structures formed during $\underline{D}_2$ which were measured from this subarea are $\underline{S}_2''$ structures; they are thus of little value in determining the orientation of axes of the stress system which produced them (see Figure 33B). However the orientation of stress axes can be determined from rarely observed conjugate folds. In one conjugate fold (Figure 29B), the intersection of the axial planes of the pair of asymmetric folds comprising the conjugate fold is approximately horizontal, with an azimuth of 150°. This intersection is parallel to the intermediate stress axis (Pint) of the stress system producing the fold. According to Ramsay (1962, p.520) the correct bisector giving Pmax can always be determined from the shape of the fold. In the case of the fold in Figure 29B, Pmax is approximately horizontal and has an azimuth of 240° (60°). The possible orientation of $\underline{F}_1$ fold axes prior to $\underline{D}_2$ deformation was 060° and horizontal; this corresponds to Pint for $\underline{D}_1$. Thus Pmax for $\underline{D}_2$ appears to coincide with the possible orientation of Pint for $\underline{D}_1$. In summary, minor folds formed during $\underline{D}_1$ possibly had horizontal fold axes, trending about 060°, and axial planes dipping 40° to the southeast. These folds were deformed during $\underline{D}_2$. The orientation of Pmax during $\underline{D}_2$ was parallel to the possible position of undeformed $\underline{F}_1$ fold axes, or Pmax during $\underline{D}_2$ was parallel to Pint for $\underline{D}_1$.

Further mapping of lithological units is necessary before the major structure of Subarea 1 is known. Permian volcanic rocks in the bottom of Liumchen Creek Valley are interfolded with Mesozoic rocks. The contact is probably stratigraphic; rocks are conformable on both sides of it and fossils of Upper Karnian age, the oldest known Mesozoic fossils in the map-area, are found close to the contact. Palaeozoic rocks capping Church Mountain are inverted. The structural succession, from the top down, consists of the upper clastic sequence, exposed west of the peak, Permian limestone transitional downward to Permian volcanic rocks, exposed below the east side of the peak, and finally, Mesozoic rocks. North of the peak of Church Mountain, Permian rocks are interfolded with Mesozoic rocks, with a stratigraphic contact between them. This interfolding of Mesozoic and Permian rocks and the overturned sequence on Church Mountain suggests that overturned folding rather than thrusting is responsible for the presence of Palaeozoic rocks on top of Mesozoic rocks. Possibly the Palaeozoic rocks on Church Mountain form the inverted limb of a large recumbent anticline, with a southerly (?) dipping axial plane. The structural relationship between the inverted Palaeozoic sequence capping Church Mountain and the rocks in Liumchen Creek is not known. As Pennsylvanian limestone is present in Liumchen Creek, not far north of the International Boundary and also 3,000 feet higher, roughly along strike, southwest of the summit of Church Mountain, the relationship between the two may be complex. In degree of metamorphism (including development of fracture cleavage) no detectable difference exists between rocks in Liumchen Creek and those on Church Mountain. This uniformity is in contrast to the higher degree of metamorphism (including development of slaty cleavage) in all, structurally higher, rocks in the map-area, and suggests that rocks of Subarea 1 should be considered as a single unit.

Rocks in Subarea 1 are considered to be autochthonous. There is no evidence that rocks in the western part of this subarea have undergone any considerable lateral translation. The axial planes of F_1 folds near Cultus Lake and in Liumchen Creek dip at moderate (rarely steep) angles to the southeast. If the attitude of these overturned minor folds reflects that attitude of large-scale structures, as in the overlying McGuire Nappe, where the minor recumbent folds reflect the attitude of the major structure, then it is unlikely that these rocks have been displaced laterally to any great extent. However, Palaeozoic rocks overlie Mesozoic rocks in the eastern part of the map-area. As all rocks in Subarea 1 have undergone the same amount of metamorphism, and as there is evidence of folding of the rocks on Church Mountain rather than overthrusting, the Palaeozoic rocks are possibly parautochthonous. The hypothetical relationship of rocks in this subarea to each other and to other rocks in the map-area is indicated in Figure 4 and Plate 2, section 8 - 8.

Subarea 2

Subarea 2 lies south of Chilliwack River and east of Borden Creek. It is bounded on the west by Mesozoic rocks of Subarea 1, and includes volcanic rocks lying west of Tamihi Creek and south of Subarea 1. Its southern boundary is the limit of mapping.

This subarea is composed mainly of volcanic rocks and limestones of Permian age, and also includes older clastic rocks and Pennsylvanian limestone. Massive Permian volcanic rocks are exposed on the west and northwest slopes of Mount McGuire and overlie rocks of Subarea 1. Structurally overlying the volcanic rocks and forming the peak of the mountain is Permian limestone, which is partly stratigraphically equivalent to the underlying rocks. Minor volcanic rocks, stratigraphically above the Permian limestone, are exposed on the north side of the peak. The upper clastic sequence, Pennsylvanian limestone and the lower clastic sequence, all stratigraphically below the Permian limestone, crop-out southeast of the peak.

Minor structures produced during $\underline{D}_1$ are common in sedimentary rocks of this subarea. Large, recumbent, near-isoclinal $\underline{F}_1$ folds, overturned to the northwest, with northeast trending axes, are visible in Permian limestone cliffs northeast of the peak of Mount McGuire (Figures 37, 38). Tuffs, thin-bedded cherts and argillites of the volcanic sequence stratigraphically overlying the Permian limestone, are infolded into the limestone west of the peak, and form angular, tight, recumbent, "zig-zag" $\underline{F}_1$ folds, of a smaller scale than the $\underline{F}_1$ folds in the limestone. Few $\underline{F}_1$ folds have been recognized, however, in the extensive area of limestone outcrops east of the peak of Mount McGuire because such folds in massive limestone are too large to be visible in most outcrops. No $\underline{F}_1$ folds have been seen in massive volcanic rocks possibly because $\underline{S}_0$ planes are difficult to recognize in these rocks, and no $\underline{S}_1'$ planes have been seen in these rocks. The massive volcanic rocks nonetheless are locally highly faulted, and contain shear zones which in a few cases are parallel to tuff horizons in the predominant flow rocks. Clastic rocks, southeast of the peak of Mount McGuire show a crude $\underline{S}_1'$ foliation but folds are not common in these rocks. Repeated inversion of graded bedding in graded rocks of the lower clastic sequence stratigraphically below Pennsylvanian limestone, southeast of Mount McGuire peak, is due to small-scale $\underline{F}_1$ folding.

Minor structures formed during $\underline{D}_2$ are not common in rocks of this subarea, possibly because of the massive nature of most rocks in the

Figure 37: Recumbent $\underline{F}_1$ fold, overturned to the northwest, in cliffs of Permian limestone on the north side of the north ridge of Mount McGuire. Axis of fold is nearly parallel to cliff-face.

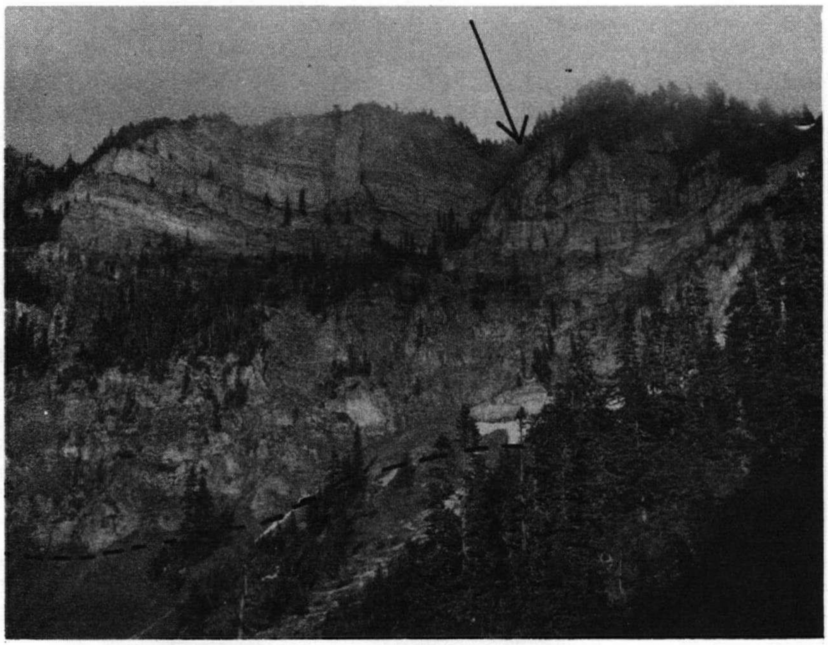


Figure 38: Recumbent $\underline{F}_1$ fold, overturned to the northwest, in cliffs of Permian limestone in cirque north of peak of Mount McGuire. Arrow points to fold; dashed line indicates contact between limestone and stratigraphically higher, structurally lower, tuffs and cherts of the Permian volcanic sequence.

subarea. Crinkles occur in some (rare) foliated volcanic rocks in Tamihi Creek, and rare $\underline{F}_2$ "chevron" folds in fine-grained clastic rocks south-east of the summit of Mount McGuire. Steep, closely-spaced, local jointing in Permian limestone is approximately parallel to $\underline{S}_2'$ planes in fine clastic rocks of the subarea east of Subarea 2.

Information recorded of all structural elements, except $\underline{S}_0$, is sparse from this subarea. The few recorded $\underline{L}_1$ lineations trend 040°, and have shallow plunges to the northeast or are horizontal. Poles to $\underline{S}_0$ lie on a great circle, whose pole corresponds approximately to the orientation of $\underline{L}_1$ lineations. Too few $\underline{D}_2$ structural elements have been recorded to be of any value.

Two explanations for the structure of Subarea 2 are considered below. The first is that the structure consists of two nappes, major tectonic units separated from each other and from underlying rocks by thrust (?) faults. The lower tectonic unit is a thrust sheet and is called the Liumchen Nappe. The upper unit is characterized by a recumbent anticline, with a thin, partly preserved lower limb cut out by a thrust or lag fault, and is designated the McGuire Nappe. The second explanation is that the structure consists of a single recumbent fold, with the lower limb being the Liumchen Nappe proposed above.

Rocks forming the proposed Liumchen Nappe in this subarea underlie the lower parts of the west and northwest sides of Mount McGuire and extend westwards across Tamihi Creek to Liumchen Mountain. The nappe in this subarea is composed of massive Permian volcanic rocks, mainly flows. Evidence that the basal contact of this nappe is a low-angle thrust fault is provided by the map-pattern. A continuous body of Permian volcanic rocks extends from about 9 miles southwest of the map-area (Moen, 1962, Plate 1) and crosses the International Boundary at the south end of International Ridge, where it lies on Mesozoic rocks. East of this locality, the volcanic rocks continue parallel to, and just south of the Boundary, still lying on Mesozoic rocks (Daly, 1912, Map 89A) and recross the Boundary again, to form the summit of Liumchen Mountain, north of which they lie on Palaeozoic rocks. The volcanic rocks of Liumchen Mountain extend to the east across Tamihi Creek and are exposed on Mount McGuire, where they again overlie Mesozoic rocks. Overthrusting would account for the overstepping of this Permian volcanic unit from Mesozoic volcanic rocks in the west, on to Palaeozoic rocks north of Liumchen Mountain, and back on to Mesozoic rocks on Mount McGuire, and seemingly provides the basis for Daly's (1912, Map 89A) and Moen's (1962, p.61, and map) interpretation of the lower contact of this body of Permian volcanic rocks as a thrust. Supporting evidence for overthrusting is provided by the differing nature of $\underline{S}_1$ planar structures in certain rocks, apparently originally of the same composition, below and above this fault. Slaty cleavage is developed in all fine-grained clastic rocks and a foliation in coarser clastic rocks above this overthrust, whereas below the overthrust, strain-slip cleavage or fracture cleavage is present in fine-grained clastic rocks, with no corresponding cleavage in coarser rocks. De Sitter (1956, p.98) concluded that fracture cleavage could develop into slaty cleavage. The apparent lack of any transition between the two in the map-area, is additional support for a structural discontinuity. The upper contact of this tectonic unit will be discussed in the following description of the McGuire Nappe.

Rocks forming the McGuire Nappe in this subarea underlie the summit of Mount McGuire and extend eastwards as far as the limb of the subarea. The nappe is composed of Permian limestone, overlain stratigraphically by minor Permian volcanic rocks and underlain by clastic rocks and Pennsylvanian limestone. Permian limestone forming the peak of Mount McGuire outlines a large recumbent anticline, overturned to the northwest, whose lower limb is partly missing (Plate 1, Plate 2, section 6-6'). The axis of this major structure trends 040° and plunges northeast at about 5°, and the axial plane dips generally eastward at shallow angles. The conformity of the geometry of $\underline{F}_1$ folds in cliffs north of the summit of Mount McGuire (Figure 38) with that of the major structure demonstrates that the major structure was formed during the same period of deformation, $\underline{D}_1$, as the minor folds. Permian limestone at the peak of Mount McGuire is the hinge of this major recumbent anticline and forms digitations, which north of the peak enfold younger tuffs and argillites of the Liumchen Mountain Formation. Limestone outlining the upper limb of the major fold forms a prominent ridge east of the peak of Mount McGuire; this upper limb may extend at least 4½ miles to the southeast as Misch (oral communication, February, 1965) has mapped limestone overlain by volcanic rocks on Border Peak. The lower limb of this major recumbent fold is thin and represented only by Permian limestone forming a low east-west ridge southeast of the peak of Mount McGuire and scattered limestone pods, further south, which lie on Permian volcanic rocks of the underlying Liumchen Nappe. Clastic rocks, stratigraphically below the Permian limestone, together with Pennsylvanian limestone form the core of this recumbent anticline and crop-out southeast of the peak of Mount McGuire. Rocks of the upper clastic sequence are in contact with Permian limestone and extend stratigraphically down to Pennsylvanian limestone exposed near Spencer Peak, below which are rocks of the lower clastic sequence. This latter sequence contains the oldest rocks of reasonably certain age in the map-area; these lie directly on Permian volcanic rocks of the Liumchen Nappe (Plate 2, section 6-6'). The fact that no rock sequences in the core of the McGuire Nappe are inverted and that the oldest rocks in the nappe lie directly on Permian volcanic rocks, is evidence for the existence of a flat-lying fault between the McGuire Nappe and the underlying Liumchen Nappe.

The alternative explanation for the structure of this subarea, which is equally compatible with the evidence from minor structures, is that rocks of this subarea are part of one tectonic unit, a large recumbent anticline overturned to the northwest, instead of the two tectonic units postulated above. The lower limb of the single tectonic unit is composed of the Permian volcanic sequence, and the hinge and upper limb consists partly of Permian limestone and minor volcanic rocks, together with Mesozoic rocks which stratigraphically and structurally overlie Permian rocks east of this subarea. Older rocks lie in the core of this recumbent fold. As the Permian volcanic sequence is at least partly stratigraphically equivalent to the Permian limestone, a rapid facies change must take place across the hinge of this postulated major fold, from a sequence composed of Permian volcanic rocks to a predominantly sedimentary sequence. However, if these rocks do form a large recumbent fold, it is difficult, if not impossible, to give any structurally consistent explanation for the absence of an inverted sequence of Pennsylvanian to Permian clastic rocks, with interbedded Pennsylvanian limestone, in the core of the fold, as the oldest known rocks in this tectonic unit are clastic rocks, stratigraphically and structurally below Pennsylvanian limestone, which lie on Permian volcanic rocks of the postulated lower limb. No evidence for or against inversion of the volcanic sequence in the lower limb has been obtained from this subarea, and good evidence exists that the position of the volcanic sequence above rocks of Subarea 1 is due to overthrusting, rather than overturned folding. However, the hinge of this postulated major recumbent fold as marked by Permian limestone on Mount McGuire, is at least 5 miles southeast, in a direction normal to the trend, and contained within the axial plane, of any possible hinge marked by the contact between the Permian volcanic rocks and stratigraphically overlying Mesozoic rocks. Maximum thickness of the Permian volcanic rocks immediately below Permian limestone marking the hinge is 2,000 feet. If it is assumed that no thickening occurs at the hinge of the major recumbent fold, then the contact between Mesozoic rocks and Permian volcanic rocks on the hinge would only be 2,000 feet northwest of the hinge as marked by Permian limestone. The actual distance to any possible hinge is ten times this, which strongly suggests that there is a structural discontinuity between the lower, volcanic sequence and the upper, predominantly sedimentary sequence (Figure 39).

However, there are certain objections to the structural interpretation proposed by the writer that there are two separate tectonic units, each underlain by a flat-lying fault. North of this subarea, north of the Chilliwack River, Mesozoic rocks stratigraphically and structurally overlie Permian volcanic rocks which are the northerly continuation of the Liumchen Nappe in Subarea 2. Therefore, if the McGuire Nappe had been thrust over the Liumchen Nappe, as suggested by its geometry, Mesozoic

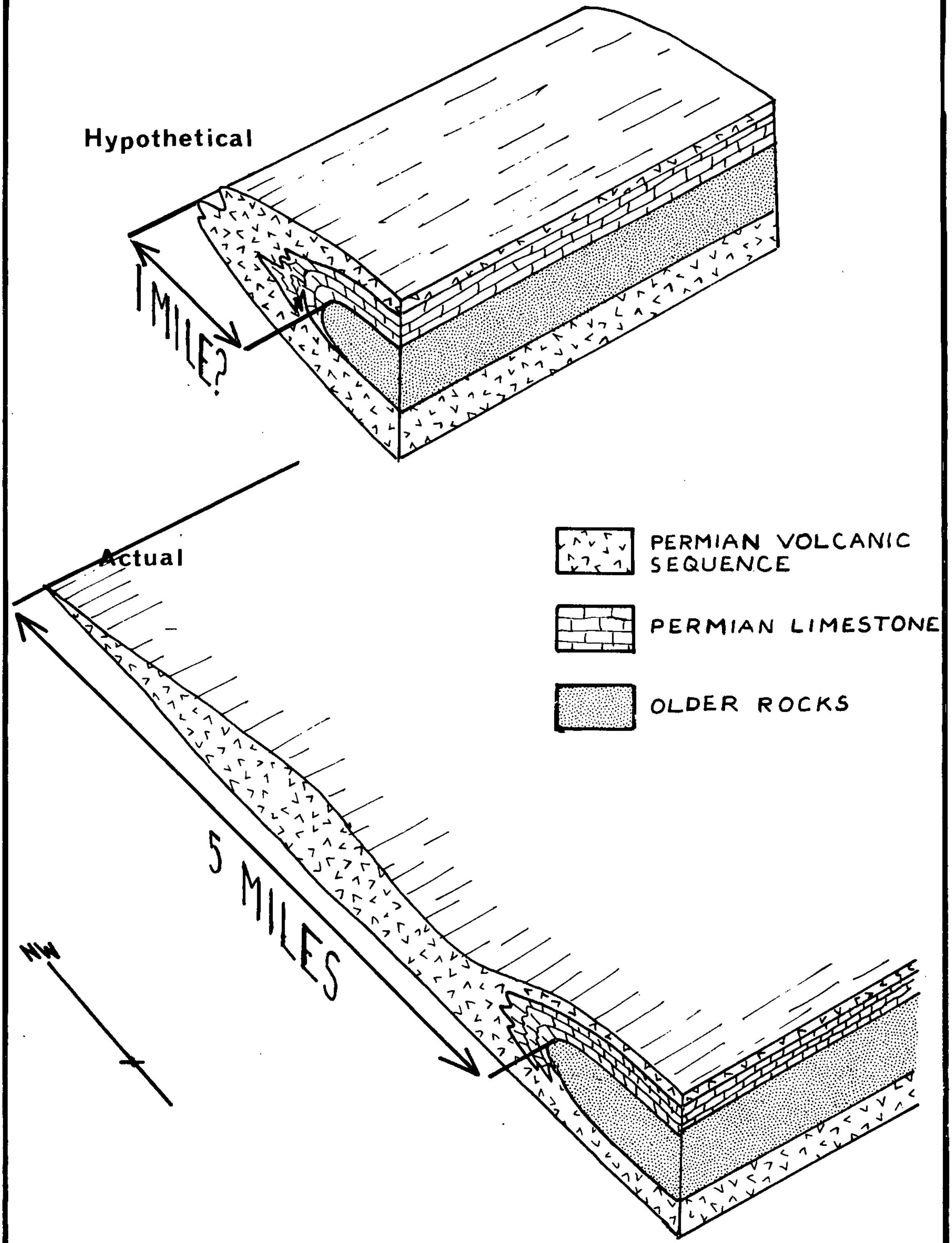


FIGURE 39: Comparison of hypothetical and actual forms of postulated recumbent fold forming McGuire Nappe

rocks should separate the two tectonic units in Subarea 2, which is not the case. A possible explanation for this apparent anomaly is that the flat-lying fault separating the two tectonic units is a lag or lag-fault rather than a thrust. A lag, as originally defined by Bailey (1934, p.467) is a fault formed in close causal connection with folding, which replaces the normal (upper) limb of a recumbent structure. A lag-fault (Hills, 1963, p.191) is a low angle fault with normal fault displacement, which originates from the upward movement of the footwall block in a general region of thrusting. In this case, the hanging wall is the McGuire Nappe which has lagged behind the movement of the footwall, or Liumchen Nappe. (A lag, as used in Bailey's sense, cannot be proven in this example.) The geometry of the overlying first order nappe is apparently anomalous, but may be a relict of its initial form (see below). This lagging behind of the McGuire Nappe, in the general forward movement could account for the absence of Mesozoic rocks between the two tectonic units, and is compatible with the presence of Permian volcanic rocks of the Liumchen Nappe at least 6 miles northwest of the hinge of the McGuire Nappe.

Subarea 3

This subarea is bounded on the west by a north-south line along Borden Creek, on the north by the Chilliwack River and on the east by Slesse Creek. The southern limit is the limit of geological mapping in this direction (Plate 3).

Most rocks in this subarea are stratigraphically below the Permian limestone, with the exception of Permian limestone and minor volcanic rocks which crop-out in the north of the subarea, Permian limestone in the centre, and Permian volcanic rocks in the bottom of Slesse Creek Valley.

Minor folds formed during $\underline{D}_1$ are visible in the limestone bluff at the confluence of Slesse Creek with Chilliwack River, and in fine clastic rocks on the west side of Slesse Creek Valley about 3 miles south of the above locality. Slaty cleavage $\underline{S}_1''$ is developed in the fine clastic rocks, but as this cleavage is sub-parallel to bedding in this subarea, it is difficult to distinguish the two. Coarse clastic rocks, particularly those which are tuffaceous, show a crude foliation, parallel to $\underline{S}_1''$ in finer, contiguous rocks.

Structures formed during $\underline{D}_2$ are very well developed in this subarea, possibly because of the predominance of well-foliated fine clastic rocks. Crinkles and associated planar structures ($\underline{S}_2'$), "oblique shear" type folds associated with $\underline{S}_2''$, and folds probably related to "oblique shear" type folds with no development of $\underline{S}_2''$ (Figure 32), are common, particularly in the vicinity of Pennsylvanian limestone on the west side of Slesse Creek Valley. Locally this limestone, which is shaly, shows closely spaced fractures parallel to $\underline{S}_2''$.

Projection of the above information shows the effects of two periods of deformation. Most poles to $\underline{S}_0$ are concentrated in a similar area to those in the plot of Subarea 2, but an additional weak maximum is developed in the northeast quadrangle. Orientation of the few $\underline{L}_1$ lineations is variable, but they are confined to the northeast-southwest quadrangles, and vary in plunge from horizontal to 45°.

Structures related to $\underline{D}_2$ provide more information. According to Ramsay (1962, p.521) structures similar to kink bands are produced when

Pmax and Pmin are oriented at about 45° to bedding planes (or foliation) and of the two shears produced one will cut the bedding planes at a high angle, and the other may lie so close to bedding that shear movements are dissipated by slip on bedding surfaces. Where $\underline{S}_2'$ is present, associated with crinkles or kink bands, and oriented at about 90° to $\underline{S}_0$ (or $\underline{S}_1$), then if it can be assumed that the other conjugate shear is nearly parallel to $\underline{S}_0$ (or $\underline{S}_1$), intersection of $\underline{S}_2'$ with $\underline{S}_0$ (or $\underline{S}_1$) will give a rough approximation of the orientation of Pint (Figure 33C). Direction of displacement along $\underline{S}_2'$ will indicate which bisector of the angle between $\underline{S}_0$ (and $\underline{S}_1$) and $\underline{S}_2'$ contains Pmax. The average Pint determined from the intersection of $\underline{S}_0$ ($\underline{S}_1''$ is effectively parallel to $\underline{S}_0$) with $\underline{S}_2'$ is oriented at about 170° and plunges at 10° to the south, Pmax plunges 25° in a direction 075°, and Pmin plunges at 65° in a direction 260°. The development of a west dipping limb, (Plate 3) is presumably due to the imposition during $\underline{D}_2$ of the above stress field on previously folded rocks.

Most rocks in this subarea lie in the core of the McGuire Nappe. The limestone bluff at the confluence of Slesse Creek with Chilliwack River is the hinge of a syncline overturned to the west-northwest, which lies between digitations of Permian limestone on the nose of the McGuire Nappe. The general northeasterly trend and plunge of these digitations from the peak of Mount McGuire to this limestone bluff is readily apparent from the spatial distribution of Permian limestone, forming cliffs, on the north side of Mount McGuire. Permian limestone in the central part of the subarea, north of Spencer Peak, and possibly limestone overlain by volcanic rocks on Canadian Border Peak south of the subarea (P. Misch, oral communication, February, 1965), are part of the upper limb of this nappe.

Strongly foliated, amphibolitic rocks cut by $\underline{S}_2$ planes crop-out in the west side of the Slesse Creek Valley, about 2 miles south of this subarea. Their position relative to the distribution of dated rock units as presently known, suggests they lie in the core of the McGuire Nappe. Further mapping in the southern end of the Slesse Creek Valley and on Border Peak is necessary before this is confirmed.

Volcanic rocks, largely lavas, are exposed in the bottom of the north end of the Slesse Creek Valley. These volcanic rocks lie below fine clastic rocks which are stratigraphically below Pennsylvanian limestone exposed on both sides of Slesse Creek Valley. The composition, degree of alteration, and structural position of these volcanic rocks is identical to that of volcanic rocks of the Liumchen Nappe which structurally underlie fine clastic rocks stratigraphically below Pennsylvanian limestone to the south of the peak of Mount McGuire. The volcanic rocks exposed at the northern end of Slesse Creek Valley are therefore believed to belong to the Liumchen Nappe, and are exposed in a window or fenster in the McGuire Nappe (Plate 1, Plate 2, section 4-4'). As the dip of the rocks immediately west of this window is predominantly to the west, the present exposure of these lavas is believed to be partly due to their position in the core of an antiform related to the second period of deformation, which trends roughly parallel to Slesse Creek (Plate 2, section D-D').

Apart from this antiform, the present spatial distribution of these rocks in this subarea is governed largely by structures formed during the first period of deformation and the present topography.

Subarea 4

Subarea 4 is bounded on the west by Slesse Creek, on the north by Chilliwack River and to the east and south by the limit of mapping (Plate 3).

The steep sides of Chilliwack Valley and the Slesse Creek Valley, respectively on the north and west of this subarea, are underlain by Palaeozoic rocks, and the tips of the ridges by Mesozoic rocks (Figure 40).

Slaty cleavage ($\underline{S}_1''$) is ubiquitous in fine-grained clastic rocks and is parallel to the foliation of coarser clastic rocks; both generally nearly parallel to bedding ($\underline{S}_0$). Crinkling and associated $\underline{S}_2''$ cleavage and kink bands are locally common.

Stereographic projection shows that most poles to $\underline{S}_0$ form a single maximum, corresponding to bedding orientation of strike 155° and dip 25° to the southwest. A second, weak maximum, located in the northeast quadrangle, corresponds in relative position to a weak maximum developed in a similar position in the projection from Subarea 3. Plots of $\underline{L}_1$ are located in the northeast quadrant, and the majority trend about 060° and plunge about 40°.

Stress axes for $\underline{D}_2$, as approximately determined from the intersection of $\underline{S}_0$ (and $\underline{S}_1''$) with $\underline{S}_2'$ are, $\underline{P}$max trending 150° and horizontal, $\underline{P}$min trending 140° and plunging at 70° and $\underline{P}$int at 320° and plunging 20°. The position of $\underline{P}$int indicates that the presence of two maxima of poles to $\underline{S}_0$ in the northeast, and southwest quadrants is due to $\underline{D}_2$.

Rocks in Subarea 4 largely belong to the McGuire Nappe; exceptions are volcanic rocks of the underlying Liumchen Nappe which are exposed in

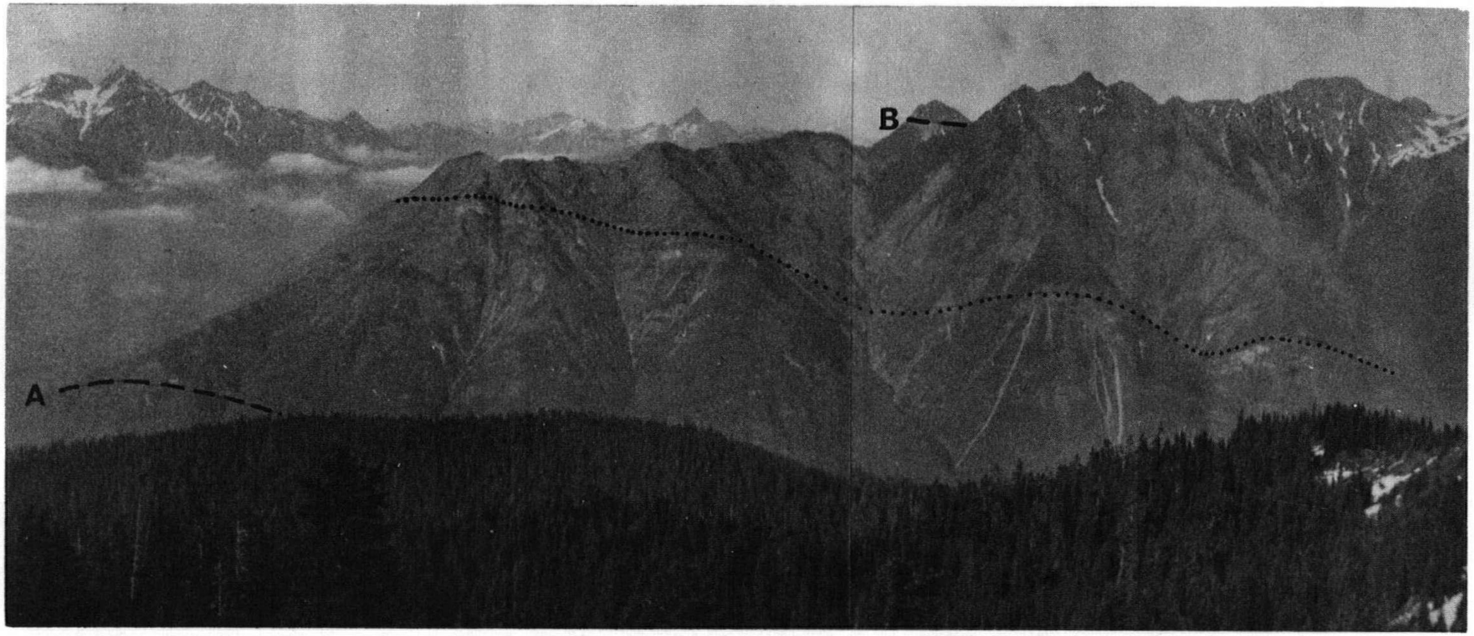


Figure 40: View of east side, north end, Slesse Creek Valley with Chilliwack Valley to left; most of these rocks are part of the McGuire Nappe; exceptions are, rocks below the dashed line A, which are Permian volcanic rocks of the Liumchen Nappe exposed in a window, and rocks above the dashed line B, which are amphibolitic rocks on Mount Pierce. Contact between Mesozoic and underlying Palaeozoic rocks in the McGuire Nappe is indicated by the dotted line ; with fairly continuous cliffs of Permian limestone exposed not far below the contact.

a window at the bottom of Slesse Creek and amphibolitic rocks structurally overlying Mesozoic rocks of the McGuire Nappe on Pierce Mountain (Figure 40). Thickness of Palaeozoic rocks forming the McGuire Nappe is about 2,000 feet; thickness of Mesozoic rocks in the McGuire Nappe is about 3,000 feet between the top of the Palaeozoic rocks, and the overlying amphibolitic rocks.

The contact between Palaeozoic and Mesozoic rocks is higher on the east side of Pierce Creek than the west side. As no local marked change of orientation of $\underline{D}_1$ structures has been found along this creek, this difference in elevation is believed to be due to high-angle reverse faulting which occurred during $\underline{D}_2$ (Plate 2, Section D-D').

Subarea 5

Subarea 5 is bounded on the west by a line southward from the summit of Mount Thurston, on the south by Chilliwack River, on the east by Chipmunk Creek and to the north by the Mount Thurston-Mount Mercer ridge.

Palaeozoic rocks occupy the southern slopes, and Mesozoic rocks the upper parts of Mounts Mercer and Thurston.

Folds developed during $\underline{D}_1$ are readily recognized in many rocks in this subarea. On the southeast side of Mount Thurston, volcanic rocks and cherts are interfolded with Permian limestone. The thin bedded cherts are locally deformed in tight, overturned, zig-zag, folds with planar limbs and sharp, angular hinges (Figure 41), which are in marked contrast to the far less regular deformation present in contiguous limestones. As the cherts overlay the limestone prior to deformation, and so presumably had the same initial orientation, and as both have been subjected to the same

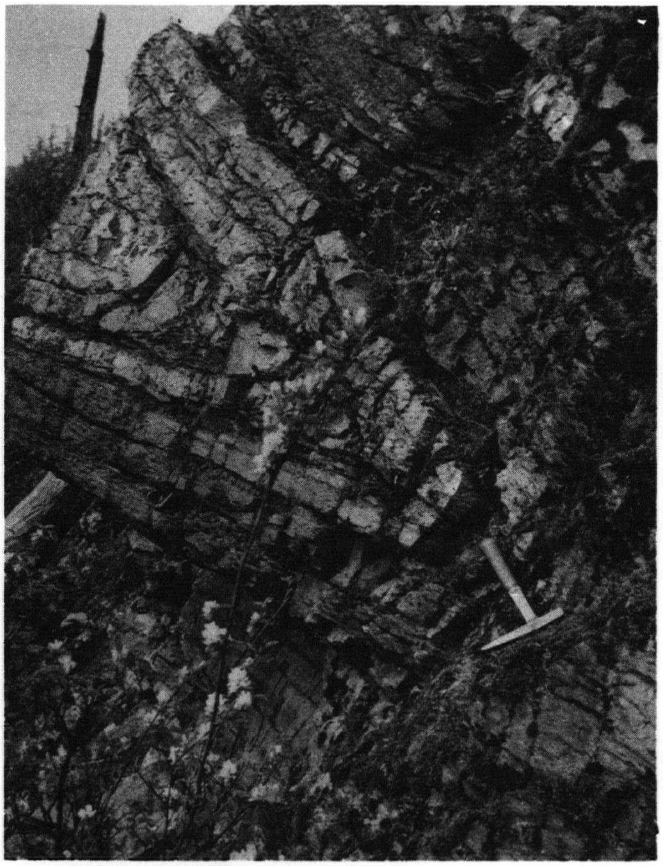


Figure 41: Minor $\underline{F}_1$ fold on southeast side of Mount Thurston, in thin-bedded silicified tuff and chert.

metamorphic conditions, the differing styles of deformation are seemingly due to the differing competancies of the cherts and limestones. Elsewhere, near-isoclinal recumbent folds, commonly of small size, occur in cherts and argillites; a slaty cleavage ($\underline{S}_1''$) is present in fine clastic rocks; this is parallel to the penetrative foliation in contiguous coarse clastic rocks shown in Figure 28.

Structures produced during $\underline{D}_2$ are well developed in the clastic rocks. Gradations exist from crinkles associated with $\underline{S}_2'$ planes in fine-grained clastic rocks, to kink bands in the coarse clastic rocks. Planes which contain kink bands are roughly parallel to $\underline{S}_2'$ planes in associated fine clastic rocks. Chevron folds are present but do not appear to be as common as other structures produced during $\underline{D}_2$.

Projection of poles to $\underline{S}_0$ shows a scatter. A maximum is developed corresponding to bedding with a strike of 120° and dip of 25° to the northeast. Plots of $\underline{L}_1$ are present in both northeast and southwest quadrants and trend about 060°. Poles to $\underline{S}_1''$ are scattered, but are in the vicinity of the maximum of poles to $\underline{S}_0$.

Stress axes, approximately determined from the intersection of $\underline{S}_0$ (and the parallel $\underline{S}_1''$) with $\underline{S}_2''$ give the trend and plunge of $\underline{P}$max as 225° at 15°, of $\underline{P}$min as 010° and 70°, and $\underline{P}$int as 130° and 15°. If it is assumed that prior to $\underline{D}_2$, $\underline{L}_1$ was horizontal, then the position of $\underline{P}$int for $\underline{D}_2$ relative to that of $\underline{L}_1$ and poles to $\underline{S}_0$ on the projection, suggests that the position of $\underline{L}_1$ and poles to $\underline{S}_0$ result from rotation of these structures about $\underline{P}$int for $\underline{D}_2$.

Rocks in Subarea 5 are part of the McGuire Nappe. Permian limestone on the southeast side of Mount Thurston and northwest of the junction of

Slesse Creek with Chilliwack River is deformed into a large recumbent anticline with tuffaceous clastic rocks in the core. This fold, formed during $\underline{D}_1$, has a northeast trending axis, and is the northeasterly continuation of the recumbent anticline outlined by Permian limestone on Mount McGuire. Digitations outlined by Permian limestone on the hinge of this fold on Mount Thurston interfinger with stratigraphically overlying cherts, crystal tuffs and minor argillite, and the limestone itself is both overlain and underlain by lavas and crystal tuffs.

A second recumbent fold, again delineated by Permian limestone, is visible on the south side of Mount Mercer, about 2 miles east of the fold on Mount Thurston and appears to be an additional recumbent structure developed during $\underline{D}_1$ which structurally overlies that fold on the southeast side of Mount Thurston. Mesozoic rocks, present to the south of the saddle between Mounts Mercer and Thurston thus seem to lie in a recumbent syncline between the two recumbent anticlines formed of Permian rocks. However, field relations between rock units on the south side of Mount Mercer and the present spatial distribution of rock units along the trend of these folds, on Mount McGuire to the southwest, and Chipmunk Creek to the northwest make this explanation improbable. The second recumbent fold on Mount Mercer is believed to be the northeastward extension of the fold on Mount Thurston, elevated to its present position during $\underline{D}_2$ and thus simulating a second higher recumbent structure formed during $\underline{D}_1$ which appears to structurally overlie the northeast projection, along plunge, of the fold on Mount Thurston (Figure 42, Plate 2, Sections 3-3', C-C'). The nature of this displacement is not certain but is believed to be due to faulting during $\underline{D}_2$. No predominant dip of bedding in a westward direction

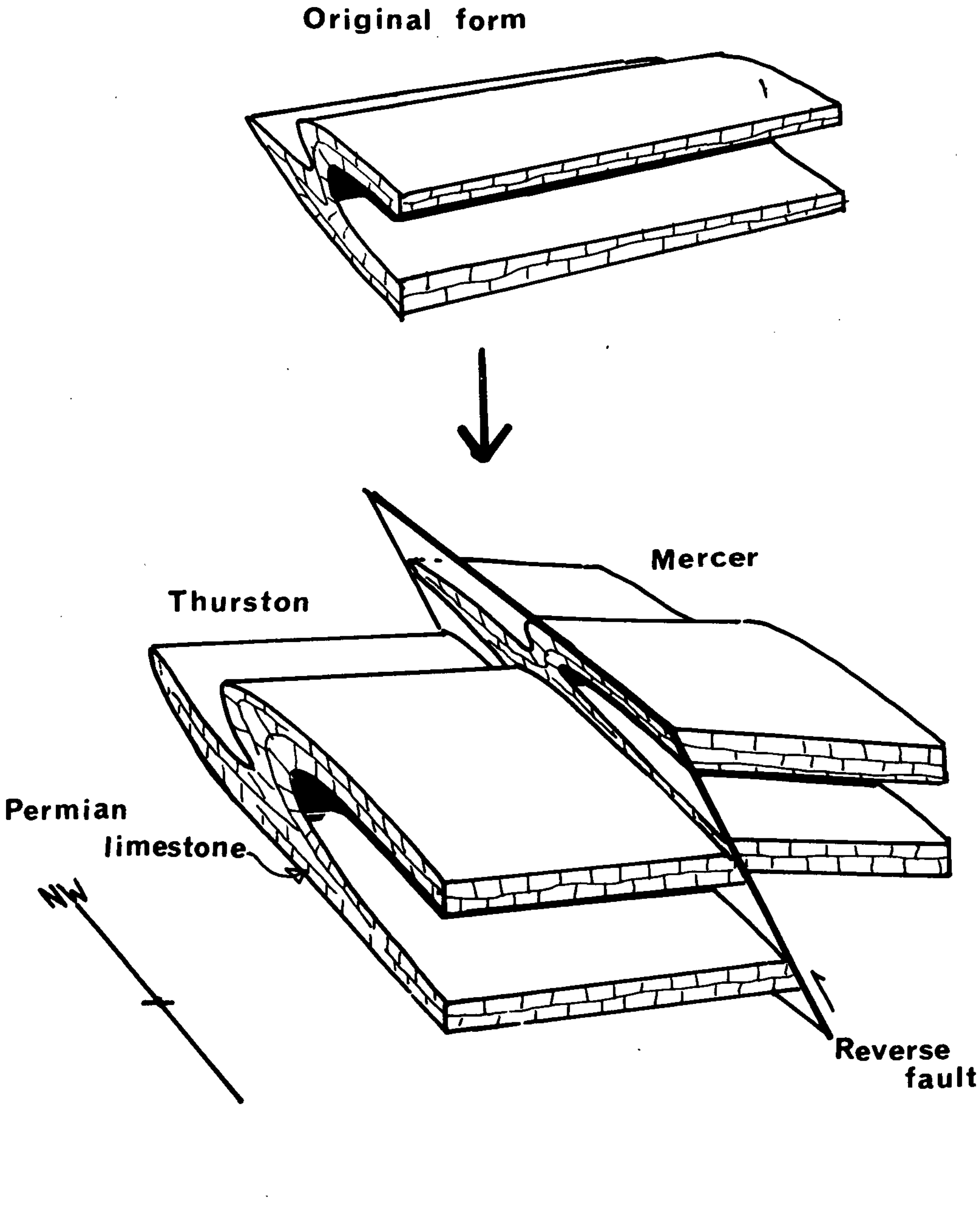


FIGURE 42: Relation between recumbent anticlines on Mounts Mercer and Thurston

has been seen on the southwest side of Mount Mercer, which would be expected if folding was the mechanism. In addition, Mesozoic rocks which lie in the apparent recumbent syncline noted above, structurally and stratigraphically overlie Permian volcanic rocks on Mount Thurston and are in contact with both Permian volcanic rocks and the stratigraphically lower Permian limestone on Mount Mercer. The latter contact can only be explained by a fault between Mesozoic and Palaeozoic rocks. De Sitter (1956, p.223) has discussed the association of chevron-folding with thrusting. In the map-area "chevron" or "oblique shear" type folds are one manifestation of $\underline{D}_2$, and as the spatial distribution of rocks associated with the probable fault suggests that it is a high-angle thrust with an eastward-dipping fault plane which strikes in a similar direction as $\underline{P}$int for $\underline{D}_2$, this faulting is believed to have taken place during $\underline{D}_2$. The continuation of this fault to the south may be responsible for the elevation of Palaeozoic rocks on the east side of Pierce Creek above those on the west described under Subarea 4.

Subarea 6

Subarea 6 is the western part of Mount Thurston and Elk Mountain. Its eastern limit is a line south from the summit of Mount Thurston, and it is limited to the northeast and southwest by drift covered areas.

Permian volcanic rocks, mainly tuffs with minor flows and intercalated limestones outcrop on the lower, southwestern slopes of Mount Thurston and Elk Mountain and are overlain by predominantly fine-grained clastic rocks of Mesozoic age.

Slaty cleavage ($\underline{S}_1''$), generally parallel to bedding, is developed in the fine clastic rocks of Mesozoic age on Mount Thurston and Elk Mountain, and coarser clastic rocks in this sequence are foliated. Minor $\underline{F}_1$ folds have not been recognized in the volcanic rocks of this subarea, but are present in overlying fine clastic rocks near the summit of Elk Mountain. Crinkles and chevron folds produced during $\underline{D}_2$ are present but are not common. The structural data which has been obtained is mainly from a few widely scattered outcrops of Mesozoic rocks, and little data has been obtained from the predominant, commonly massive, Permian volcanic rocks. The projection of poles to $\underline{S}_0$ shows a spread, in which bedding corresponding to the principal maximum, strikes due north and dips 15° east. Recorded $\underline{L}_1$ lineations strike almost due east or northeast. Small conjugate folds (Figure 29C) locally developed on the limbs of minor, upright $\underline{F}_1$ folds (Figure 43) have an intermediate stress axis which trends 102° and plunges 5°, almost parallel to the axis of the earlier folds. These conjugate folds presumably result from the tightening of the earlier $\underline{F}_1$ folds along the same axis, under metamorphic conditions of lower grade than those at which the original folding took place.

Rocks of this subarea are believed to be part of the Liumchen Nappe. In both lithology and age the volcanic sequence, representing the Palaeozoic in this subarea, is far closer lithologically to the thick Permian volcanic sequence of the Liumchen Nappe than to the Pennsylvanian-Permian, limestone, clastic rock and volcanic rock sequence of either the overlying McGuire Nappe or the underlying autochthon. The differences between the Permian volcanic rocks of this subarea and those of the Liumchen Nappe are believed to be the result of facies changes. A transition takes place from Liumchen Mountain and the west side of Mount McGuire, where the rocks

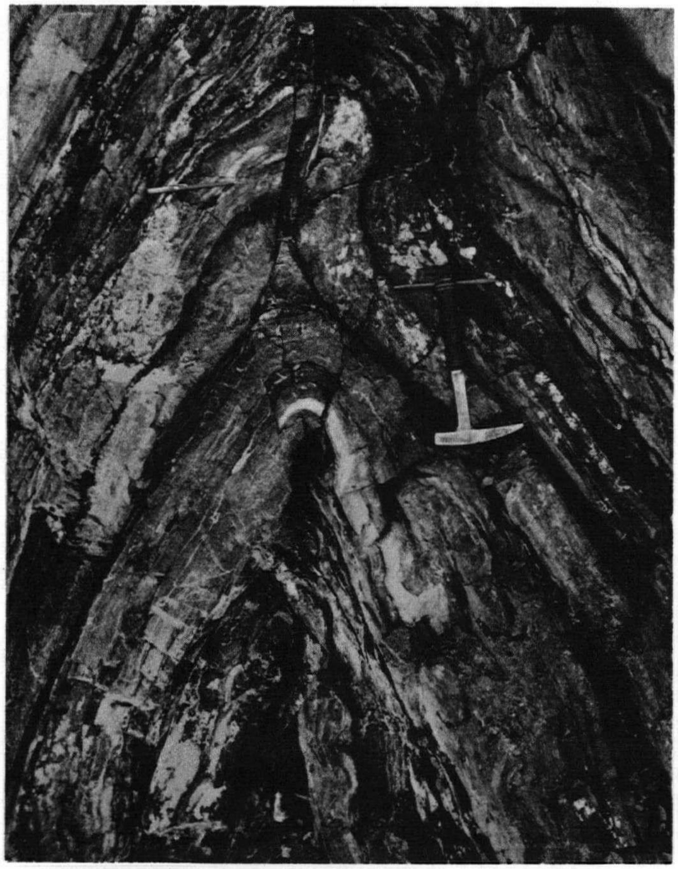


Figure 43: Upright $\underline{F}_1$ fold with east trending, horizontal axis in thin-bedded cherty argillites on Elk Mountain, with still smaller $\underline{F}_1$ fold on southern (right) limb. The fold has been tightened by later deformation, producing fracturing at hinge, and the small conjugate folds (illustrated in Figure 29C) on the limbs. Minor flat-lying shears are visible just above pens.

are largely flows, through interbedded flows and quartz-bearing crystal tuffs on the north side of Mount McGuire and south side of Mount Thurston to the predominant tuffs on Elk Mountain.

The lower contact of the Liumchen Nappe on the north side of Chilliwack River can only be located approximately, owing to lack of exposure, and is the northerly extension of the thrust-fault separating Permian volcanic rocks from underlying Mesozoic rocks on the northwest side of Mount McGuire. Supporting evidence for existence of the thrust-fault in this subarea is provided by the presence of slaty cleavage ($\underline{S}_1''$) in Mesozoic rocks on Elk Mountain; fine-grained clastic Mesozoic rocks on the south side of Fraser Valley, west of Elk Mountain contain fracture cleavage, and underlie Permian volcanic rocks of this nappe.

The upper contact of this nappe is drawn below the lowest digitation of Permian limestone marking the hinge of the McGuire Nappe on the southeast side of Mount Thurston, largely by analogy with the contact at the base of this nappe south of the summit of Mount McGuire, 5 miles to the southwest along the trend of the structure. This basal contact of the McGuire Nappe descends the north side of Mount McGuire, crosses the Chilliwack River just west of its confluence with Slesse Creek and comes into contact with Mesozoic rocks south of the summit of Mount Thurston (Plate 1). It is to be emphasized that although the nose of the McGuire Nappe, and the underlying Liumchen Nappe are visible in cross-section on the southeast side of Mount Thurston, no Mesozoic rocks separate these structures, and there is no great difference in altitude between the upper part of the McGuire Nappe as marked by the thin Permian volcanic sequence above the Permian limestone, and the structurally underlying Permian volcanic rocks of the Liumchen Nappe (Plate 2, section 4-4'). As there is evidence on Mount McGuire that a structural discontinuity does exist between these two proposed nappes, the absence of Mesozoic rocks between these structures can only be explained if the structural discontinuity between the nappes is a lag-fault. This explanation is compatible with the presence of Permian volcanic rocks of the Liumchen Nappe 5 miles northwest of the hinge of the McGuire Nappe marked by the Permian limestone on the southeast side of Mount Thurston.

Subarea 7

Subarea 7 includes Foley Creek Valley, from its confluence with Chilliwack Valley to as far as Foley Lake, Mount Laughington and the divide between Foley Creek and Chilliwack River.

Fine-grained Mesozoic rocks predominate in this subarea. They stratigraphically overlie Palaeozoic rocks in the western part of the map-area, and are overlain by amphibolitic rocks on top of the ridge between Foley Creek and Chilliwack River and on the east side of Airplane Creek near Foley Lake. Permian rocks overlie Mesozoic rocks on top of Mount Laughington.

The fine-grained Mesozoic clastic rocks have well developed slaty cleavage ($\underline{S}_1''$) commonly nearly parallel to bedding (Figure 27), with $\underline{L}_1$ produced by the intersection of these two surfaces. Although repeated inversion of bedding suggests the presence of folds in the sequence, only a few ($\underline{F}_1$) folds have been seen. These are near-isoclinal, recumbent structures, whose axes plunge northeast, parallel to $\underline{L}_1$ lineations. Coarser Palaeozoic clastic rocks are foliated, the foliation being approximately parallel to $\underline{S}_1''$ in the finer rocks. No structures have been observed in massive amphibolites in this subarea.

Structures produced during $\underline{D}_2$ are well developed, and are predominantly local, closely spaced crinkles ($\underline{L}_2'$), and planar structures ($\underline{S}_2'$) associated with these.

Poles to $\underline{S}_0$ are scattered and lie on a great circle, whose pole corresponds to the maximum concentration of $\underline{L}_1$. A maximum on this great circle corresponds to bedding oriented at strike 140° with dip 25° to the northeast. An isolated second concentration is present in the northeast quadrangle, and is analogous in position to similarly isolated concentrations in projections for Subareas 3 and 4. $\underline{L}_1$ lineations are scattered, but the average orientation of the greatest concentration trends 050° and plunges 30°. Presumably the spread of poles along the great circle, centred on $\underline{L}_1$ is due to the first period of deformation.

Intersections of $\underline{S}_1''$ and $\underline{S}_2''$ gives the approximate orientation of stress axes for $\underline{D}_2$, with $\underline{P}$max trending 238°, and plunging 6°. If it is assumed that $\underline{F}_1$ fold axes or $\underline{L}_1$ lineations were originally horizontal, then the overall northeast dip of bedding, with a few beds dipping to the southwest is believed to result from the rotation of $\underline{S}_0$ about $\underline{P}$int for $\underline{D}_2$.

Mesozoic and minor Permian rocks of the McGuire Nappe are overlain in this subarea by amphibolitic rocks and Permian rocks which presumably belong to a higher tectonic unit. The Mesozoic rocks and minor Permian rocks in Foley Creek Valley and in the sides of Mount Laughington are the farthest known extension to the northeast of the McGuire Nappe. Permian rocks on the summit of Mount Laughington, amphibolitic rocks in Airplane Creek Valley and on the ridge between Foley Creek and Chilliwack River appear to occupy the same structural plane and thus to belong to the same tectonic unit, which structurally overlies the McGuire Nappe. To the north, Palaeozoic rocks near the summit of Mount Cheam and Lady Peak are possibly part of this unit. The relationship between the Permian rocks on Mount Laughington, to amphibolitic rocks in Airplane Creek is not known, although the latter are overlain by Palaeozoic rocks at the south end of Cheam Range. Possibly the Palaeozoic rocks form a partial envelope around a core of amphibolitic rock. Further mapping is necessary to establish relations and to determine whether the emplacement of these rocks above Mesozoic rocks of the McGuire Nappe is due to thrusting related to $\underline{D}_1$ or $\underline{D}_2$.

Subarea 8

Subarea 8 includes the northwest side, summit, and south side of Mount Cheam, Lady Peak, and the northern part of the Mount Laughington ridge. The subarea is isolated as there is a paucity of exposures between it and other subareas.

Palaeozoic volcanic rocks, limestones and clastic sedimentary rocks crop-out on the northeast side of Mount Cheam. These are overlain by Mesozoic rocks, which are in turn overlain by Palaeozoic rocks near the summit of Mount Cheam.

Rare recumbent isoclinal $\underline{F}_1$ folds are visible in Palaeozoic rocks in the northwest side of Mount Cheam. Slaty cleavage, commonly subparallel to bedding, occurs in fine-grained clastic rocks, and coarser clastic rocks are foliated. Chevron folds, joint drags and crinkles are present locally.

Projection of poles to bedding shows a lack of recognizable pattern, apart from a general eastward dip of bedding. The few $\underline{L}_1$ lineations obtained have an average azimuth of 025° and plunge about 20°. Not enough measurements of $\underline{S}_2'$ and $\underline{S}_1''$ intersections have been made to determine the orientation of $\underline{D}_2$ stress axes. However, the orientations of $\underline{S}_2$ and $\underline{L}_2$ are not very different from that in the rest of the map-area; the $\underline{D}_2$ stress system is probably similar to that elsewhere.

The spatial distribution of Palaeozoic rocks exposed on the south side of Fraser Valley, 2 miles west of Mount Cheam, suggests they form part of a recumbent fold. Permian limestone and minor volcanic rocks exposed to the west of Mount Cheam at an altitude of 4,000 feet are overlain stratigraphically by Mesozoic rocks, and themselves overlie a sequence of coarse to fine-grained clastic rocks, in part lithologically similar to the upper clastic sequence elsewhere in the map-area. A bed of limestone of possible Pennsylvanian age is present in this clastic sequence. Still lower on the mountain side, coarse-grained clastic rocks overlie probable Permian limestone, which is structurally above volcanic rocks exposed at the base of the mountain, west of Bridal Falls. If these rocks do form a recumbent fold, its relationship to other tectonic units in the map-area is not known. Trend of $\underline{L}_1$ lineations in rocks forming this possible fold, suggests that it was formed during $\underline{D}_1$.

It is proposed that the Palaeozoic rocks on the west side of Mount Cheam are part of the Liumchen Nappe, although this suggestion is to be regarded as tentative. Volcanic rocks of the Liumchen Nappe on Elk Mountain, are of similar lithology to those at the base of the west side of Mount Cheam, 5 miles northeast of Elk Mountain. Rocks at both localities are predominantly pale green, quartz-bearing crystal-vitric tuffs and silicified tuffs. Although exposures on the south side of Fraser Valley between Elk Mountain and Mount Cheam are extremely poor, a few scattered outcrops of pale green silicified tuff near the valley floor indicate that there is continuity between the two areas. If this is so, volcanic rocks at the base of Mount Cheam belong to the Liumchen Nappe. In addition, the Liumchen Nappe is the only one of the three lower nappes in which Palaeozoic rocks are directly observed to extend as far north as Fraser Valley. As the trend of the south side of Fraser Valley between Elk Mountain and Mount Cheam is roughly parallel to the northeast-southwest trend of $\underline{D}_1$ structures in the map-area, the Liumchen Nappe could extend northeast from Elk Mountain to Mount Cheam, with no major change of trend.

On the other hand, in lithology, stratigraphy and structure, the Palaeozoic succession on the west side of Mount Cheam, above the basal volcanic rocks, resembles that of the McGuire Nappe rather than the Liumchen Nappe. Furthermore, the contact between Permian and Mesozoic rocks at an altitude of 4,000 feet to the west of Mount Cheam can be traced almost continuously along Chipmunk Creek, as far as Chilliwack Valley, where it appears as the contact between Permian and Mesozoic rocks of the McGuire Nappe. However, the structural continuity between rocks on Mount Cheam and those of the McGuire Nappe in Chilliwack Valley may be more apparent than real, as no marked break has been observed between rocks of the Liumchen Nappe and the McGuire Nappe where they are particularly well-exposed on the southeast side of Mount Thurston. Also, the hinge of the McGuire Nappe as delineated by Permian limestone on Mounts Thurston and Mercer is at least 5 miles due south of any possible hinge as marked by Permian limestone in the apparent recumbent fold on Mount Cheam. Assuming the rocks on Mount Cheam belong to the McGuire Nappe, then the only possible explanation for such a discrepancy is that later deformation was responsible for a northwesterly translation of the hinge of the recumbent fold, from a position it occupied on the northeasterly extension along strike of the McGuire Nappe, to its present position on Mount Cheam. If folding were responsible for such a translation an abrupt change of trend of $\underline{L}_1$ lineation would be expected in the area between Mounts Thurston and Mercer and Mount Cheam. No such change has been recorded; the rare $\underline{L}_1$ lineations trend northeasterly with no marked change of direction. If strike-slip faulting were responsible, lateral movement would have to be considerable; no evidence of such movement is evident from the map-pattern. Therefore, available evidence suggests that the predominantly sedimentary Palaeozoic succession above volcanic rocks on the west side of Mount Cheam can only belong to the Liumchen Nappe. If this is in fact so, a rapid facies change must occur from the predominantly volcanic sequence on Elk Mountain to the predominantly sedimentary sequence on Mount Cheam.

Evidence for a reverse fault related to $\underline{D}_2$ has been found in the vicinity of Pierce Creek, and in the saddle between Mounts Mercer and Thurston (Plate 1); the northwesterly extension of this fault is believed to be responsible for the elevation of Permian rocks cropping-out two and a half miles east-northeast of Elk Mountain above contiguous Mesozoic rocks to the west. Major structures formed during $\underline{D}_1$ have a general plunge to the northeast in Chilliwack Valley. However, Permian rocks of the Liumchen Nappe crop-out at an altitude of 3,000 feet on Elk Mountain; equivalent Permian rocks of presumably the same tectonic unit are present to the northeast at an altitude of 4,000 feet on Mount Cheam. This apparent anomaly is believed to be due to faulting which has elevated Palaeozoic rocks to the northeast above their western equivalents. Lithologies of scattered outcrops indicate that the trace of this fault crosses the ridge $2\frac{1}{2}$ miles east-northeast of Elk Mountain. If this is so, then the fault appears to be the northerly continuation of the reverse fault present further south in the map-area between Mounts Thurston and Mercer. As the strike of the fault plane is approximately parallel to Pint for D_2 as determined from minor structures, it was possibly formed during D_2.

Permian rocks crop-out above Mesozoic rocks near the summit of Mount Cheam and are present further south in Cheam Range. The structural relationship of these rocks to underlying rocks is not known at present; they may lie above a thrust, and presumably belong to the same tectonic unit as the Permian rocks overlying Mesozoic rocks on Mount Laughington, further south in the map-area.

Structural history of the map-area

All recognized deformation in the map-area took place after deposition of Upper Jurassic rocks and prior to intrusion of the Chilliwack batholith, an event, dated radiometrically, which took place 18 million years ago (Baadsgaard et al., 1961, p.697), in Miocene time (Kulp, 1961). The same maximum number of structural elements is developed in rocks ranging in age from Early Pennsylvanian to Late Jurassic. Earlier rocks are not noticeably more metamorphosed than later ones, and incipient metamorphism of the glaucophane-schist type is present in both Palaeozoic and Mesozoic rocks. Stratigraphic breaks between Permian and Triassic rocks, and probably between Lower Pennsylvanian and Lower Permian rocks, are believed to result from uplift with no associated deformation, non-deposition, and possibly erosion. Clastic rocks of known Early Pennsylvanian to Late Jurassic age are derived from volcanic and sedimentary rocks; there has been no deep erosion, with clastic detritus derived from plutonic or high-grade metamorphic rocks, such as would be expected to accompany a major period of mountain building.

Misch, working just south of the map-area in northern Washington, has recognized two periods of post-Upper Jurassic deformation. According to Misch, thrusting to the west and northwest took place along two major thrust faults in about mid-Cretaceous time in this region (Misch, 1960, Miller and Misch, 1963). The lower, Church Mountain thrust, corresponds in part to that thrust below the Liumchen Nappe of the writer, and was considered to carry Upper Palaeozoic rocks over Jurassic and Lower Cretaceous rocks; the upper, Shuksan thrust, brought low-grade metamorphic rocks over Palaeozoic rocks; its northerly continuation in the map-area may correspond to that contact mapped by the writer between amphibolitic rocks and underlying Mesozoic rocks in the eastern part of the map-area. Following this deformation, continental arkosic rocks of latest Cretaceous-Paleocene age were deposited in the region and subsequently folded into moderately tight to open folds (Miller and Misch, 1963, p.167, p.171). These rocks are overlain with angular unconformity by middle and/or upper Eocene rocks of similar lithology, which have been subsequently warped rather than folded (Miller and Misch, 1963, p.167, p.173).

The effects of two phases of deformation have been recognized by the writer in Pennsylvanian to Jurassic rocks in the map-area. There is little doubt that the structures formed during the first phase, $\underline{D}_1$, partly correspond to the mid-Cretaceous thrust plates of Misch. The second phase of deformation, $\underline{D}_2$, took place prior to intrusion of the Miocene Chilliwack batholith, as unoriented biotite and cordierite porphyroblasts, in thermally metamorphosed rocks close to the contact, grow across minor structures ($\underline{S}_2''$ planes) produced during $\underline{D}_2$. This dates $\underline{D}_2$ as pre-Miocene and is the only way of obtaining a minimum age for both periods of deformation. Further work is necessary to demonstrate whether $\underline{D}_2$ corresponds to the early Eocene deformation of Miller and Misch. The following structural history of the map-area is tentatively suggested.

Palaeozoic and Mesozoic rocks were initially deformed into northeast trending folds. During folding, slaty cleavage ($\underline{S}_1''$) was developed in rocks of appropriate composition towards the middle of the orogenic belt, and now in the McGuire Nappe, and fracture cleavage ($\underline{S}_1'$) in rocks of similar composition to the northwest, now forming the autochthon. Nothing has been observed to relate the incipient glaucophane-schist type metamorphism present in both Palaeozoic and Mesozoic rocks in the map-area to any period of deformation. Following Fyfe et al. (1958, p.177), this metamorphism may have resulted from the deep burial of sediments with high water content in a region of low thermal gradient; in the map-area metamorphism of the glaucophane-schist type therefore may have taken place before or in the earliest stages of $\underline{D}_1$ deformation.

The cause of the northeast trend of $\underline{D}_1$ structures, which are oriented nearly normal to the Cordilleran trend in the region, is not known. This northeast trend is extensive; Bowen (1914, p.112) reported northeast trends from north of Fraser River, north of the map-area, and Moen (1962, plate 1) has shown this trend continuing for several miles southeast of the map-area.

Crickmay (1930a) suggested that this anomalous trend was due to the geosynclinal accumulation being wrapped around the southern end of the "Coast Range Batholith." As granitic rocks were present north of the map-area in Lower Cretaceous time (Crickmay, 1962), they may have acted as a buttress during mid-Cretaceous deformation and thus controlled this anomalous trend. Alternatively, if $\underline{D}_1$ structures were formed in response to basement deformation, then possibly the orientation of these structures may be controlled by an old, pre-Devonian, northeasterly trend in the basement rocks. Although the location of probable basement rocks at the southern end of Slesse Creek suggests they lie in the core of the recumbent anticlinal structure which is the McGuire Nappe, and thus possibly controlled the formation of this nappe, further mapping is needed before the relationship of these basement rocks to the sedimentary rocks is known. Misch (1962) suggested that similar rocks, mapped south of the locality in Slesse Creek, are part of a pre-Devonian basement complex, which moved up along the root of his Shuksan thrust-fault, and became imbricated with Palaeozoic rocks in the upper part of his Church Mountain thrust plate. The upper part of Misch's Church Mountain thrust plate seemingly is roughly equivalent to the McGuire Nappe.

As deformation continued, so the northeast-trending folds became overturned to the northwest, thrusting took place, and the Liumchen Nappe and Mount McGuire Nappe were formed. Presumably these two nappes were initially discrete folds, relicts of which are preserved as the recumbent anticline on Mount McGuire, and the recumbent anticline in the possible northeasterly extension of the Liumchen Nappe, to the west of Mount Cheam. Rocks of the McGuire Nappe, closer to the centre of the orogenic belt than rocks of the Liumchen Nappe, were initially thrust over rocks of the Liumchen Nappe, and became a recumbent anticline whose lower limb was partly removed by thrust-faulting. With continuing deformation, the greater competancy of the thick volcanic sequence forming the Liumchen Nappe resulted in this underlying nappe being moved relatively further forward; the structural discontinuity separating the Liumchen and McGuire Nappes is thus a lag fault rather than a thrust. The postulated development of these structures is shown in Figure 44.

Structures formed during $\underline{D}_2$ were then superimposed upon the earlier structures. Deformation during $\underline{D}_2$ is believed to be responsible for the common dip of bedding to the northeast at low to moderate angles, for the production of large-scale open folds such as the antiformal structure at the north end of Slesse Creek, and for reverse faults with northeast-dipping fault planes. The style of minor structures formed during this period of deformation suggests they are the result of brittle deformation; this contrasts with the folds produced during $\underline{D}_1$. In addition, $\underline{D}_2$ planar structures do not involve the reorganization of rock material necessary to produce the slaty cleavage formed during $\underline{D}_1$ in parts of the map-area. Therefore, structures formed during $\underline{D}_2$ appear to have been formed at a somewhat lower metamorphic grade than that extant during $\underline{D}_1$ in parts of the map-area. This lowering of metamorphic grade indicates that there is some time difference between $\underline{D}_1$ and $\underline{D}_2$ structures.

The genetic relationship between $\underline{D}_1$ and $\underline{D}_2$ structures is not known. If it is assumed that prior to $\underline{D}_1$, bedding was horizontal, then the fold axes of $\underline{F}_1$ folds,(parallel to $\underline{L}_1$), produced during $\underline{D}_1$ would be horizontal and parallel to Pint for $\underline{D}_1$. If this is so, then Pint for $\underline{D}_1$, prior to $\underline{D}_2$

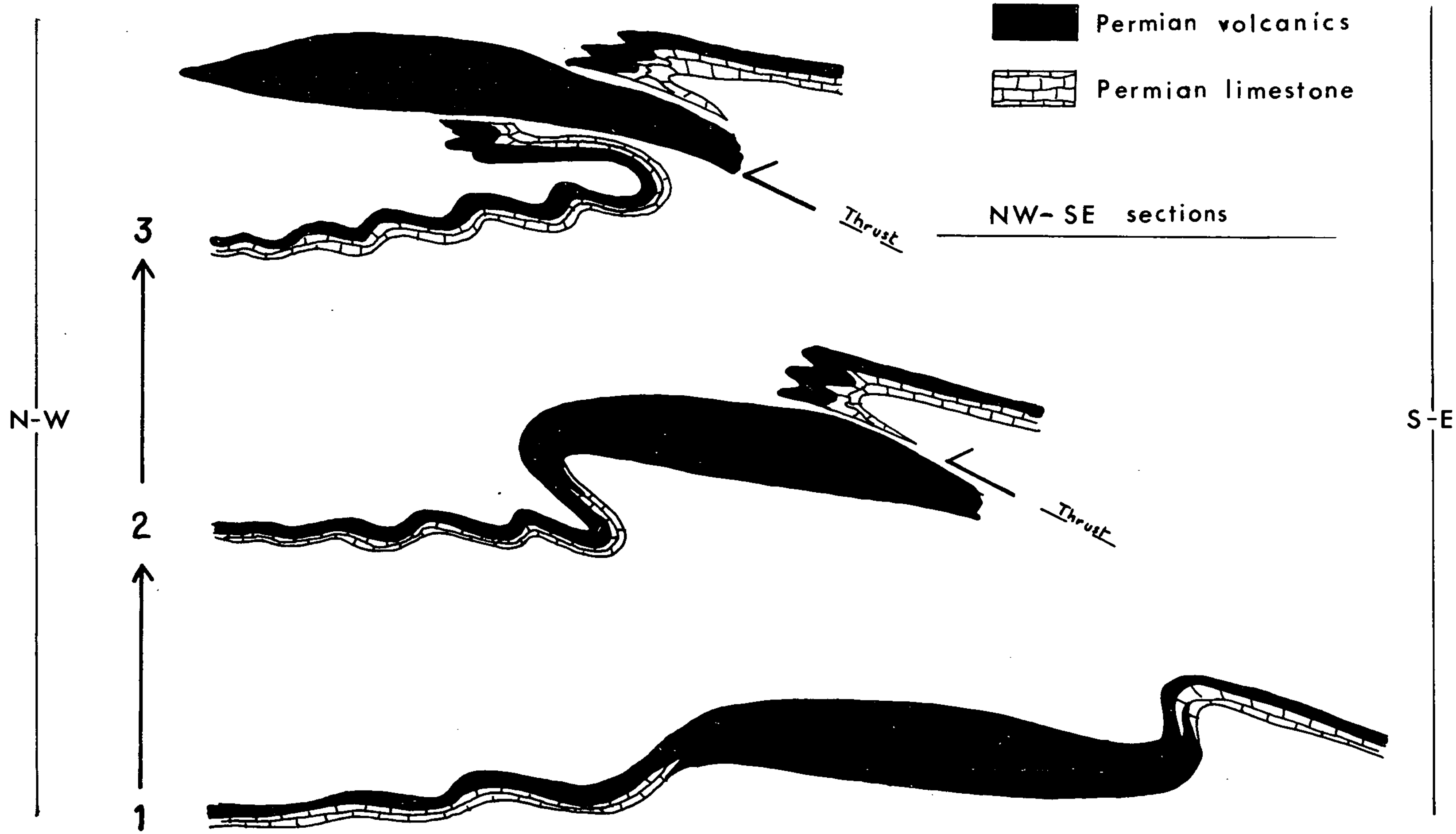


FIGURE 44: Postulated development of D_2 major structures

deformation appears to have coincided with Pmax for $\underline{D}_2$, and was normal to Pint for $\underline{D}_2$ (compare diagrams B and C, Plate 3). Orientation of Pint for $\underline{D}_2$ appears to coincide with the direction of tectonic transport during $\underline{D}_1$ as indicated by the form and orientation of $\underline{D}_1$ structures. Similar relationships, invariably developed in environments where thrusting is important, have been discussed by other workers. Cloos (1946, pp.127-128) gave examples of lineations and folding normal to the regional trend, developed in areas in which thrusting is important in Scotland and Scandinavia. Kvale (1953) discussed linear structures and their relationship to movement in the Caledonides of Western Europe, and concluded (p.61) that where compression and resultant folding predominate in orogenic belts, so axes of the folds are perpendicular to the direction of compression and lineations parallel to the fold axes; where overthrusting is the predominant process, lineations and small scale folds are formed parallel to the direction of movement. Johnson (1956, 1957) described conjugate and monoclinic folds with fold-axes parallel to the direction of movement on the Moine Thrust. Style of these folds (Johnson, 1956, p.346, Text-fig.1, 1957, p.252, fig.5, in part) is directly comparable to that of minor folds formed during $\underline{D}_2$ in the Chilliwack Valley map-area. Johnson (1956, p.349) considered these folds to be accomodation structures formed by stresses within the thrust zone during movement, and not a reflection of the direction of forces applied externally to the whole rock mass. However, as these structures were produced concomitantly with thrusting, and as the $\underline{D}_2$ structures in the map-area appear to be later than $\underline{D}_1$ movements, they do not appear to be analogous. There does not appear to be any direct genetic relationship between $\underline{D}_2$ and $\underline{D}_1$ structures in the map-area.

Structures produced during $\underline{D}_2$ may be the result of differential up-lift of the Cascade Mountain system, which resulted in the earlier structures slipping sideways with the production of antiforms, reverse faults and brittle type minor structures, as suggested in Figure 45. The sense of movement indicated by most of the "oblique shear" type minor folds is to the southwest, and the reverse faulting attributed to $\underline{D}_2$ has the same sense. The apparent symmetry of these $\underline{D}_2$ structures with respect to $\underline{D}_1$ structures may result from their orientation being in part controlled by the earlier structures. As indicated earlier, deformation of this type probably ceased before intrusion of the Chilliwack batholith. A comparison of $\underline{D}_2$ structures in the map-area, with those produced during the early Eocene deformation of Miller and Misch (1963) might enable the $\underline{D}_2$ movements to be dated more precisely.

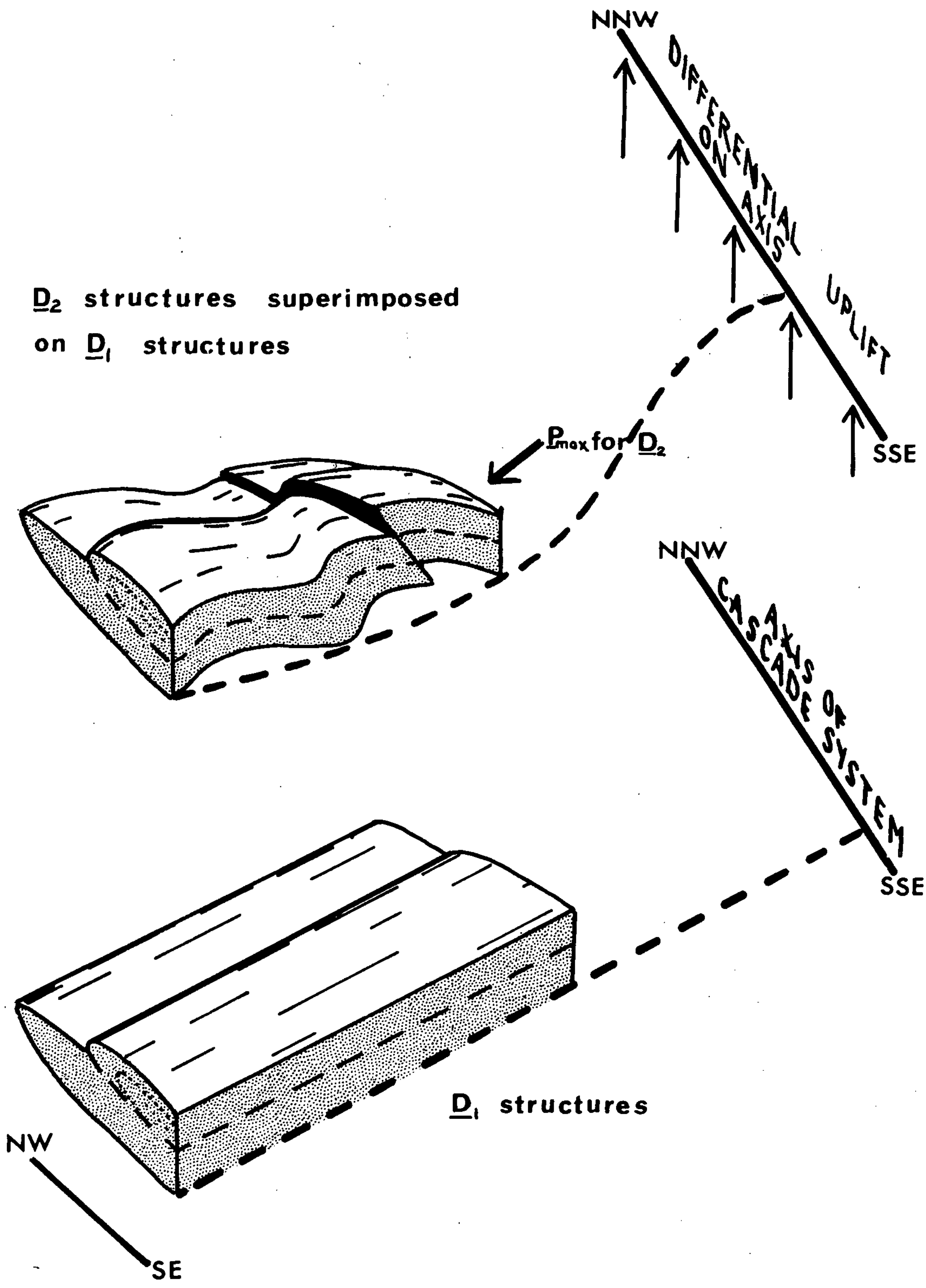


FIGURE 45: Postulated development of $\underline{D}_2$ structures

CONCLUSIONS

Geological history of the map-area

Late Palaeozoic and Mesozoic history of this region is dominated by migrating volcanic centres, whose proximity to the map-area have governed to a large extent the type of deposition within it. No evidence has been found to demonstrate that any deformation took place in the map-area between Early Pennsylvanian and Late Jurassic time, and the major period of deformation was in mid-Cretaceous time, subsequent to deposition of all rocks in the map-area.

The lithological similarity between some amphibolitic rocks exposed in the eastern part of the map-area to Devonian rocks in the San Juan Islands suggests they are of this age, and are thus basement rocks on which all later rocks in the map-area were deposited. However, the stratigraphic relationship between these rocks in the map-area and the Palaeozoic and Mesozoic rocks is not known.

The oldest rocks of reasonably certain age are predominantly fine-grained clastic rocks of the lower clastic sequence, which were derived from a source area composed largely of volcanic rocks, and deposited in part by turbidity currents, presumably in a marine basin.

Lower Pennsylvanian limestone, the Red Mountain Formation, was laid down on top of this clastic sequence. It is locally gradational with the underlying sequence and its presence as a discrete lithologically homogenous unit may be partly due to a cessation of clastic supply to the basin, a trend indicated by the overall decrease in grain size towards the top of the underlying clastic sequence. The limestone is locally shaly and preserved textures indicate that it was laid down in a low-energy environment. As this limestone is regionally widespread, occurring in all tectonic units in the map-area and at several localities in northern Washington, its presence is perhaps indicative of a period of tectonic quiesence.

Clastic rocks of the upper clastic sequence were laid down on top of the Red Mountain limestone. Initially, fine-grained clastic sediments accumulated to a depth of a few feet; these were succeeded by coarse-grained unsorted sandstones, minor conglomerates and argillites, derived largely from a volcanic terrane and deposited by sub-aqueous sliding and turbidity currents. This sediment supply was supplemented by sporadic vulcanism outside of the map-area, which contributed lithic and crystal tuffs, particularly to the upper part of the sequence. The coarse nature of sediments in the sequence is possibly the result of rapid uplift related to this vulcanism. A sparse, marine fauna was present in the basin of sedimentation. Fragmental plant material, found in rocks of this sequence in the autochthon, demonstrates the presence of land in the region at this time. The source area of this clastic sequence was large enough to permit a primary transport history of sufficient length to enable cobbles to become rounded, and stable enough to permit a flora to become established. Age of this clastic sequence is not certain; it appears to span Early Pennsylvanian to Early Permian time, as no stratigraphic breaks are known.

By Early Permian time, a volcanic centre, represented by basic lavas in the Liumchen Nappe, had migrated to the map-area. Permian limestone, now in the autochthon and Liumchen Mountain Nappe, was deposited in a low-energy environment northwest and southeast of the volcanic centre, on top of the upper clastic sequence. Transition between the underlying coarse clastic rocks laid down by turbidity flows and slides, and the overlying limestone, takes place over a few feet, and is marked by fine clastic rocks and lithic tuffs. Possibly the sea floor was locally elevated above the general basin level by the advent of vulcanism, to a position still below wave base, but where it could no longer receive clastic sediments carried by turbidity flows or slides.

Cessation of Permian limestone deposition may have been caused by a change of magma from a basic one, which was relatively quietly extruded, to a more siliceous magma which resulted in pyroclastic activity, the products of which blanketed the area of limestone deposition. Quartz-bearing crystal tuffs with minor flows overlie the Permian limestone; these tuffs were probably deposited both directly, and also by sub-aqueous sliding and turbidity currents. The volcanic centre was possibly elevated above sea level during this period of pyroclastic activity.

Cessation of vulcanism resulted in erosion of this volcanic pile to wave base, where it stood as an elevated area above the general level of the sea floor, and was possibly surrounded by a low area in which sediments were deposited by turbidity flows. By Late Triassic time this local high no longer existed and fine clastic rocks were deposited by turbidity currents right across the map-area.

Deposition of rocks by turbidity currents continued from Late Triassic to Late Jurassic time across much of the map-area, with no detected stratigraphic break. Rocks of Late Triassic and Early Jurassic age derived largely from pre-existing volcanic rocks, which apparently accumulated in a trough or basin between volcanic highs then existing to the west on Vancouver Island and to the northeast in the Interior of British Columbia. Volcanic centres were located just north and south of the map-area in Middle Jurassic time, and one may be represented by flows of possible Middle Jurassic age in the northwestern most part of the map-area. In the eastern part of the map-area, sedimentation of the type present in the Early Jurassic continued until the Late Jurassic.

Sometime after deposition of the Upper Jurassic sediments, probably in mid-Cretaceous time, all of these rocks were strongly deformed. Northeast trending folds were initially produced and were overturned to the northwest. With continuing deformation they developed into recumbent structures and related thrusts. No evidence has been found to demonstrate that minerals characteristic of glaucophane-schist type metamorphism found in certain rocks in the map area is related to this deformation and the metamorphism may merely be the result of deep burial prior to this period of deformation.

Following this first period of deformation these rocks were again deformed. Structures produced trend northeast and may be the result of movement to the southwest, caused by differential uplift of the Cascade Mountain system.

Outside of the map-area, arkosic Late Cretaceous to Paleocene sediments of molasse-type were deposited, and sedimentation of this type has effectively continued until the present day in the region.

BIBLIOGRAPHY

Armstrong, J.E., 1960, Surficial geology, Chilliwack (west half); Geol. Surv. Can., Map 53-1959.

Baadsgaard, H., Follinsbee, R.E., and Lipson, J., 1961, Potassium argon dates of biotites from Cordilleran granites; Bull. Geol. Soc. Amer., vol. 72, p. 689-701.

Bailey, E.B., 1934, West Highland tectonics: Loch Lomen to Glen Roy; Geol. Soc. London Quart. Jour., vol. 78, p. 82-131.

Bauerman, H., 1884, Report on the geology of the country near the forty-ninth parallel of north latitude, west of the Rocky Mountains; Geol. and Nat. Hist. Surv. Can., Rept. Prog. 1882-83-84.

Bissel, H.J., 1959, Silica in sediments of the Upper Palaeozoic of the Cordilleran area; Silica in sediments, Soc. Econ. Paleontologists and Mineralogists,Special Pub. No. 7, p. 150-185.

Boswell, P.G.H., 1960, The term graywacke; Jour. Sed. Petrology, vol. 30, p. 154-157.

Bowen, N.L., 1914, A geological reconnaisance of the Fraser River valley from Lytton to Vancouver, British Columbia; Geol. Surv. Can., Summ. Rept. 1912, p. 108-114.

Cairns, C.E., 1924, Coquihalla Area, British Columbia; Geol. Surv. Can., Mem. 139.

Cairns, C.E., 1944, Hope Sheet; Geol. Surv. Can., Map 737A.

Carozzi, A.V., 1960, Microscopic Sedimentary Petrography; John Wiley and Sons Inc., New York and London.

Cloos, E., 1946, Lineation-a critical review and annotated bibliography; Geol. Soc. Amer., Mem. 18.

Crickmay, C.H., 1928, Stratigraphy of Parson Bay, British Columbia; Calif. Univ. Pub., Dept. Geol. Sci. Bull., vol. 18, p. 51-70.

Crickmay, C.H., 1930a, The structural connection between the Coast Range of British Columbia and the Cascade Range of Washington; Geol. Mag., vol. 67, p. 482-491.

Crickmay, C.H., 1930b, Fossils from Harrison Lake area, British Columbia; Geol. Surv. Can., Museum Bull. 63, p. 33-113.

Crickmay, C.H., 1962, Gross stratigraphy of Harrison Lake area, British Columbia; Published privately by author, available at Evelyn de Mille Books, 616 - 3rd St. S.W., Calgary, Alberta.

Crickmay, C.H. and Pocock, S.A.J., 1963, Cretaceous of Vancouver, British Columbia, Canada; Am. Assoc. Petroleum Geologists Bull., vol. 47, p. 1928-1942.

Daly, R.A., 1912, Geology of the North American Cordillera at the Forty-Ninth Parallel; Geol. Surv. Can., Mem. 38.

Danner, W.R., 1957, Stratigraphic reconnaissance in the northwestern Cascade Mountains and San Juan Islands of Washington State; Unpub. Ph.D. thesis, Univ. of Washington.

Danner, W.R., 1960a, An introduction to the stratigraphy of southwestern British Columbia and northwestern Washington; Guide Book for Geological Field Trips in Southwestern British Columbia, prepared by Geological Discussion Club, Vancouver, p. 1-6.

Danner, W.R., 1960b, Paleozoic eugeosynclinal sequence of southwestern British Columbia and northwestern Washington; (abstract) Bull. Geol. Soc. Amer., vol. 71, p. 2055.

Dapples, E.C., Krumbein, W.C., and Sloss, L.L., 1953, Petrographic and lithological attributes of sandstones; Jour. Geology, vol. 61, p. 291-317.

De Sitter, L.U., 1956, Structural Geology; McGraw Hill Book Co., Inc., London, New York, Toronto.

Dott, R.H.R., 1961, Permo-Triassic diastrophism in the Western Cordilleran region; Amer. Jour. Sci., vol. 259, p. 561-582.

Dunbar, C.O., and Newell, N.D., 1946, Marine Early Permian of the Central Andes and its fusuline faunas; Amer. Jour. Sci., vol. 244, pt. 1, p. 377-402, pt. 2, p. 457-491.

Dunbar, C.O., Chairman, 1960, Correlation of the Permian formations of North America; Bull. Geol. Soc. Amer., vol. 71, p. 1763-1806.

Dzulynski, S., Ksiazkiewicz, M., and Kuenen, Ph. H., 1959, Turbidites in flysch of the Polish Carpathian Mountains; Bull. Geol. Soc. Amer., vol. 70, p. 1089-1118.

Edwards, A.B., 1947, The petrology of the Miocene sediments of the Aure trough, Papua; Proc. Royal Soc. Victoria, new ser., vol. 57, p. 123-148.

Fenneman, N.M., 1931, Physiography of the Western United States; McGraw Hill Book Company, New York, 534 p.

Fisher, R.V., 1961, Proposed classification of volcaniclastic sediments and rocks; Bull. Geol. Soc. Amer., vol. 72, p. 1409-1414.

Fiske, R.S., 1963, Subaqueous pyroclastic flows in the Chanapecosh Formation, Washington; Bull. Geol. Soc. Amer., vol. 74, p. 391-406.

Flinn, D., 1952, A tectonic analysis of the Muness Phyllite block of Unst and Uyea, Scotland; Geol. Mag., vol. 89, p. 263-272.

Folk, R.W., 1954, The distinction between grain size and mineral composition in sedimentary rock nomenclature; Jour. Geol., vol. 62, p. 344-359.

Folk, R.W., 1956, The role of texture and composition in sandstone classification; Jour. Sed. Petrology, vol. 26, p. 166-171.

Folk, R.W., 1961, Petrology of sedimentary rocks; Hemphills (Publishers), Austin, Texas.

Frebold, H., 1953, Correlation of the Jurassic formations of Canada, Bull. Geol. Soc. Amer., vol. 64, p. 1229-1246.

Fyfe, W.S., Turner, F.J., and Verhoogen, J., 1958, Metamorphic reactions and metamorphic facies; Geol. Soc. Amer., Mem. 73.

Geological Discussion Club, Vancouver, B.C., 1960, Guidebook for geological field trips in southwestern British Columbia; prepared for meeting of Cordilleran Section of Geol. Soc. Amer.

Gibbs, G., 1874, Physical geography of the northwestern boundary of the United States; Jour. Am. Geographical Soc. New York, vol. 4, p. 298-415.

Hay, R.L., 1952, The terminology of fine grained detrital volcanic rocks; Jour. Sed. Petrology, vol. 22, p. 119-120.

Heezen, B., 1963, Turbidity currents; in The Sea, vol. 3, Interscience Publishers, p. 742-775.

Helmbold, R., Trans. by Van Houten, F.B., 1958, Contributions to the petrography of the Tanner greywacke; Bull. Geol. Soc. Amer., vol. 69, p. 301-314.

Hillhouse, D.N., 1956, Geology of the Vedder Mountain (Silver Lake) Area; unpub. M. Sc. thesis, University of British Columbia.

Hills, E.S., 1963, Elements of Structural Geology; Methuen and Co. Ltd., London.

Holland, S.S., 1964, Landforms of British Columbia; B.C. Dept. Mines and Pet. Resources, Bull. 48.

Huntting, M.T., Bennett, W.A.G., Livingston, V.E.R., and Moen, W.S., 1961, Geologic Map of Washington; State of Washington, Div. of Mines and Geology.

Jeletzky, J.A., 1954, Geological history of west coast of Vancouver Island and Quatsino Sound; (abstract) Bull. Geol. Soc. Amer., vol. 65, p. 1269-1270.

Johnson, M.R.W., 1956, Conjugate fold systems in the Moine thrust zone in the Lochcanon and Coulin Forest areas of Western Ross; Geol. Mag., vol. 93, p. 345-350.

Kania, J.E.A., 1929, Precipitation of limestone by submarine vents, fumaroles and lava flows; Amer. Jour. Sci., 5th ser., vol. 18, p. 347-359.

Klein, G. de V., 1963, Analysis and review of sandstone classification in the North American Geological Literature; Bull. Geol. Soc. Amer., vol. 74, p. 555-576.

Knight, R.C., 1956, Permian fusulines from Nevada; Jour. Paleontology, vol. 30, p. 773-792.

Kuenen, Ph. H., 1964, Deep-sea sands and ancient turbidites; Turbidites, Elsevier Pub. Co., Amsterdam, London, New York, p. 3-33.

Kulp, J.L., 1961, Geologic time scale; Science, vol. 133, p. 1105-1114.

Kvale, A., 1954, Linear structures and their relation to movement in the Caledonides of Scandinavia and Scotland; Geol. Soc. London Quart. Jour., vol. 109, p. 51-73.

Little, H.W., 1961, Geological map of British Columbia, Geol. Surv. Can., Map 932A.

Mathews, W.H., 1947, Calcareous deposits of the Georgia Strait area; B.C. Dept. Mines, Bull. 23.

Mathews, W.H., and McCammon, J.W., 1957, Calcareous deposits of southwestern British Columbia; B.C. Dept. Mines, Bull. 40.

Maymay, S.H., and Read, C.B., 1956, Additions to the flora of the Spotted Ridge Formation in Central Oregon; U.S. Geol. Surv., Prof. Paper 274-1.

McGugan, A., 1963, A Permian brachiopod and fusulinid fauna from the Elk Valley, British Columbia; Jour. Paleontology, vol. 37, p. 621-627.

McLearn, F.H., 1953, Correlation of the Triassic formations of Canada; Bull. Geol. Soc. Amer., vol. 64, p. 1205-1228.

Merriam, C.W., and Berthiaume, S.A., 1943, Late Palaeozoic formations of Central Oregon; Bull. Geol. Soc. Amer., vol. 54, p. 145-171.

Miller, G.M., and Misch, P., 1963, Early Eocene angular unconformity at western front of Northern Cascades, Whatcom County, Washington; Amer. Assoc. Petroleum Geologists Bull., vol. 47, p. 163-174.

Mills, J.W., and Davies, J.R., 1962, Permian fossils of the Kettle Falls area, Stephens County, Washington; Contr. Cush.Found. Foram. Research, vol. 13, p. 41-51.

Misch, P., 1952, Geology of the Northern Cascades of Washington; The Mountaineer, vol. 45, p.No. 13, p. 4-22.

Misch, P., 1960, Large overthrusts in the northwestern Cascades near the 49th Parallel, Whatcom and Skagit Counties, Washington, and Lower Tomyhoi Creek area, British Columbia; (abstract) Bull. Geol. Soc. Amer., vol. 71, p. 2069.

Misch, P., 1962, Unusual imbrication patterns displayed by pre-Devonian crystallines and Upper Palaeozoic rocks below Mount Shuksan overthrust in Mount Larrabee (Red Mountain)-Tomyhoi Peak area of northwestern Cascades, Whatcom County, Washington; Geol. Soc. Amer., sp. pap., Abstracts for 1962, p. 53.

Moen, W.S., 1962, Geology and mineral deposits of the north half of the Van Zandt Quadrangle, Whatcom County, Washington; Washington Div. of Mines and Geology, Bull. 50.

Moore, R.C., Lalicker, C.G., and Fischer, A.G., 1952, Invertebrate Fossils; McGraw Hill Book Co. Inc., New York, Toronto, London.

Oriel, S.S., 1949, Definitions of arkose; Amer. Jour. Sci., vol. 247, p. 824-829.

Packham, G.H., 1954, Sedimentary structures as an important factor in the classification of sandstones; Amer. Jour. Sci., vol. 252, p. 466-476.

Paterson, M.S., and Weiss, L.E., 1962, Experimental folding in rocks; Nature, vol. 195, p. 1046-1048.

Pettijohn, F.J., 1957, Sedimentary Rocks; Harper and Brothers, New York.

Ramsay, J.G., 1962, The geometry of conjugate fold systems; Geol. Mag., vol. 99, p. 516-526.

Rich, M., 1961, Stratigraphic section and fusulinids of the Bird Spring Formation near Lee Canyon, Clark County, Nevada; Jour. Paleontology, vol. 35, p. 1159-1180.

Ross, C.A., 1963, Standard Wolfcampian Series (Permian), Glass Mountains, Texas; Geol. Soc. Amer., Mem. 88.

Seki, Y., 1961, Pumpellyite in low-grade metamorphism; Jour. Petrology, vol. 2, p. 407-423.

Smith, C.L., 1962, Stratigraphy of the Red Mountain Formation (Lower Pennsylvanian?) of northwestern Washington; unpub. M. Sc. thesis, University of British Columbia.

Smith, G.O., and Calkins, F.C., 1904, A geological reconnaissance across the Cascade Range near the forty-ninth parallel; U.S. Geol. Surv., Bull. 235.

Thompson, M.L., Wheeler, H.E., and Hazzard, J.C., 1946, Permian fusulinids of California; Geol. Soc. Amer., Mem. 17.

Trumpy, R., 1960, Paleotectonic evolution of the Central and Western Alps; Bull. Geol. Soc. Amer., vol. 71, p. 893-908.

Van Andel, T.H., 1958, Origin and classification of Cretaceous, Paleocene and Eocene sandstones of Western Venezuela; Am. Assoc. Petroleum Geologists Bull., vol. 42, p. 734-763.

Williams. H., Turner, F.J., and Gilbert, C.M., 1954, Petrography; W.H. Freeman and Company, San Francisco.

White, W.H., 1949, Minister Mines, British Columbia; Annual Rept., p. A214-A216.

APPENDIX A

Choice of clastic sedimentary rock classification

Where the original composition of the clastic sedimentary rocks of the Chilliwack Group and Cultus Formation can be determined, then these rocks are seen to consist mainly of fragments of volcanic rocks and plagioclase feldspars. Quartz grains and fragments of sedimentary and metamorphic rocks are rarely abundant and commonly absent. These clastic rocks are quite variable in hue, generally being dark when volcanic fragments predominate and light when feldspar fragments are more abundant. Sorting is poor and rhythmically graded sequences are common. These rocks present two problems, the first being one of nomenclature and classification, and the second, the difficulty of distinguishing some of them from true pyroclastic deposits.

Most workers in the region (e.g. Misch, 1952, Danner, 1957, and Moen, 1961) have called these rocks greywackes. The term "greywacke" has been variously defined by different modern authorities and has no universally accepted meaning at present. According to Boswell (1960, p.154) the term greywacke originally had a largely textural connotation, although Naumann's classical definition (1858, in Klein, 1963, p.571) included both compositional and textural elements. If it is believed that a very general concept of the term "greywacke" is sufficiently exact, then the clastic rocks of the Chilliwack Group and Cultus Formation could well be called greywackes. Their somewhat restricted compositional nature would allow the term "greywacke" to be qualified by the adjective "volcanic" as is done by Edwards (1947a) for rocks very similar in composition to these. Boswell (1960, p.154) suggested that the term greywacke should be abandoned completely, or else given a precise connotation; and Pettijohn, (1960, p.627) has similarly recommended that the meaning should be restricted to be of any value, and should take into account the original or type material (recently described by Helmhold, translated by Van Houten, 1958).

Modern authorities have made two-fold attempts to obtain both a universal sandstone classification and precision in definition. Modern sandstone classifications usually include both the term "arkose", classically defined on the basis of mineralogical composition (Oriel, 1949), and also "greywacke", in which, classically, texture is an important factor, if not the main one. Therefore, in order to retain some semblance of the original meaning of the terms "greywacke"and "arkose", these classifications must be based on both textural properties and mineralogical composition. Krynine (1948), Dapples, Krumbein and Sloss (1953) have employed the concept of mineralogical composition paralleling textural maturity in their classifications. Folk (1956, p.170) and Van Andel (1958, p.745) have demonstrated that this is too simple an approach, and have shown that as texture and mineralogical composition are strictly two independent parameters, only one of these parameters can be chosen as a basis for classification, and the two cannot be combined.

Two objections can be made to the choice of texture as a basis for classification. One is demonstrated by the classification of Pettijohn (1957) and Packham (1954) who placed primary emphasis on texture, or genetic factors interpreted largely from texture, but apparently found it necessary to include the mineralogical classification as texture alone is too imprecise a property on which to define a sandstone class. However, the main objection to texture as a basis for classification is that raised by Folk (1954, p.352) who states,

> "Rock types, ----, must be set up on the firm basis of mineral composition, not on the insecure basis of clay content of the sediment, which is a reflection largely of the vicissitudes of the local environment."

and both Folk (1954) and Van Andel (1958) base their classification soley on the mineralogical composition of the rock. Gilberts' classification (1954) has both a textural and mineralogical basis, and the nomenclature applied to the rock will thus partly depend on "the vicissitudes of the local environment."

For a complete description Folk (1954) proposes a tripartite nomenclature, with a rock name derived from the mineralogical composition, and separate terms for textural maturity and grain size. Klein (1963, p.572) recommends that Folk's approach to sandstone classification be followed but has also stated (1963, p.572) that the classical conceptions of the various types will not be invalidated by this approach. This is incorrect, the greywacke of Folk being very different from the classical greywacke, so different that possibly the term should not be used in the classification and should be abandoned, as suggested by Boswell (1960, p.154).

The ternary diagram for mineral composition proposed by Folk (1954, p.354) and extended by Folk (1961, p.111) is used in this report. The three poles, each with their respective mineral and rock fragment groups, derived from source areas of igneous, sedimentary and metamorphic rocks, give rise, respectively, to arkoses, orthoquartzites and greywackes. Sediments at the igneous pole are differentiated into "arkose" derived from plutonic (predominantly granitic) source rocks, which is close to the classical arkose, and volcanic or plagioclase arenites derived from volcanic sources (Folk, 1961, p.117). Moen (1962, p.14) has noted that greywackes (composed largely of rock fragments) grade into arkoses (composed largely of feldspars) in Chilliwack Group rocks southwest of the map-area. All evidence indicates that these rocks were derived from the same volcanic source-area, and the use of Folk's classification thus avoids the necessity of using two terms, classically of very different meaning, for genetically related rocks. Unfortunately, these volcanic arenites are very susceptible to alteration by diagenetic or metamorphic processes and in many cases the exact composition cannot be determined. Identification can then only be made by comparison with less altered but identifiable rock, in the same sequence.

There may be considerable difficulty in distinguishing these volcanic arenites, derived from pre-existing, but probably nearly contemporaneous volcanic terranes, from true pyroclastic rocks, particularly when the pyroclastic rocks have been deposited by submarine pyroclastic flows (Fiske, 1963, p.392). Hay (1952) considers that all reworked pyroclastic material, even though the remaking may be essentially contemporaneous with deposition, as is the case with submarine pyroclastic flows, should be designated volcanic sandstone. The opposite view is taken by Fisher (1961) who believes all material moved prior to lithification, from its original place of deposition, should be called pyroclastic. Carozzi (1960, p.112) believes shards or pumiceous fragments constitute direct proof of pyroclastic origin, but these would tend to be readily removed by any sorting processes, and are easily destroyed by metamorphism.

Generally tuffs tend to be greener in colour than volcanic arenites and the latter are commonly graded. In practice, there is probably little chance of a tuff being recognized in a sequence of volcanic arenites, unless shards are found, and conversely, in a sequence of flows, most volcanic arenites would probably be called tuffs, even though shards are not seen.

APPENDIX B

Fossil localities of the Chilliwack Valley Map-Area

Fossil localities are given on Plate 1. The brief descriptions below indicate lithology of the fossiliferous rocks and their fossil content. Most localities known are listed; others not listed occur in the immediate vicinity of given localities, and can be found by tracing out the same horizon.

Locality 1: Argillites in side of road ascending plateau south of the settlement of Ryder Lake, altitude 100 feet.

Fossils: Poorly preserved arnioceratid ammonite of Early Jurassic age; similar specimens were collected earlier from this locality by J.E. Armstrong and H. Frebold.

At an altitude of 400 feet on the same road, just north of the first road junction, unidentified clams are present in coarse clastic rocks in roadside.

Locality 2: Shaly limestone within dominant cherty argillites, on the southwest side of Elk Mountain, altitude just over 4,000 feet.

Fossils: *Aulacoceras* cf. *A. Carlottense* Whiteaves, 1889, of Late Triassic age, and two unidentified, poorly preserved ammonite genera.

Locality 3: Limestone, siliceous, on ridge top, 2½ miles northwest of Elk Mountain, altitude 4,800 feet.

Fossils: Rare, medium sized fusulinids, closely resembling the common *Schwagerina* seen elsewhere, of Early Permian age.

Locality 4: Limestone, in side of logging road on south side of ridge mentioned in Locality 3, about 1 mile northwest of Locality 3, altitude

4,000 feet.

Fossils: Large, recrystallized fusulinids, probably Parafusulina of Early Permian age.

Locality 5: Limestone, in side of logging road, just north of saddle, 2½ miles south of Bridal Falls, altitude 4,000 feet.

Fossils: Poorly preserved Parafusulina, and Pseudofusulinella of Leonardian age, both well and poorly preserved, with large horn corals (Dibunophyllum?) and crinoid columnals.

Locality 6: Limestone, in side of, and below, logging road on top of bluff, 1 mile southwest of settlement of Bridal Falls, altitude 2,200 feet.

Fossils: Small crinoid columnals; limestone float containing poorly preserved fusulinids was found in the bed of the logging road, near this locality.

Locality 7: Limestone, in creek, at end of old logging road, about 1 mile southeast of Bridal Falls, altitude 1,650 feet.

Fossils: Abundant medium sized crinoid columnals.

Locality 8: Limestone, siliceous, interbedded with chert and jasper, above logging road, about 2 miles south-southeast of Bridal Falls, altitude 3,800 feet.

Fossils: Abundant, fairly well preserved, partly silicified, Parafusulina and Pseudofusulinella?, rhomboporoid bryozoans, and small crinoid columnals, of Leonardian age.

About 1 mile north of this locality, at an altitude of 3,200 feet, limestones containing poorly preserved Parafusulina and small colonial corals, are the northerly extension of the limestone at Locality 8.

Locality 9: Limestone on south side of western ridge of Mount Cheam, just below ridge top, altitude 5,850 feet.

Fossils: Rare, poorly preserved Parafusulina, of Leonardian age.

Locality 10: Limestone pod, on the west side of Lady Peak, altitude 6,250 feet.

Fossils: Small crinoid columnals.

Locality 11: Limestone, cherty, on ridge of Mount Laughington, altitude 5,500 feet.

Fossils: Poorly preserved, silicified Parafusulina, rare horn corals, crinoid columnals, of Leonardian age.

Locality 12: Limestone pod, on west side of Chipmunk Creek, altitude 1,900 feet.

Fossils: Medium sized, recrystallized fusulinids (Schwagerina?) of Early Permian age.

Locality 13: Limestone, by logging road leading into Foley Creek.

Fossils: Rare, recrystallized large fusulinids (Parafusulina?) of Early Permian age.

Locality 14: North side of limestone knoll above Chilliwack River.

Fossils: Medium sized to small crinoid columnals.

Locality 15: Talus, below limestone cliff on the southeast side of Mount Mercer, altitude of 3,000 feet.

Fossils: Abundant, medium sized Schwagerina?, completely silicified or recrystallized, of Early Permian age.

Locality 16: Shaly base of limestone cliff, on the southeast side of Mount Mercer, altitude 3,750 feet.

Fossils: Poorly preserved but identifiable Parafusulina, large horn corals (Dibunophyllum?) and rhomboporoid bryozoans, of Leonardian age.

Locality 17: Limestone, southeast of summit of Mount Mercer, altitude 4,600 feet.

Fossils: Partially silicified, poorly preserved horn corals, small crinoid columnals, and recrystallized medium sized fusulinids (Schwagerina?) of Early Permian age.

Locality 18: Talus, below limestone cliff, and above old logging road, on south side of Mount Mercer, altitude 2,300 feet.

Fossils: Abundant silicified Schwagerina, large horn corals (Dibunophyllum?), of Early Permian age.

Locality 19: Shales in side of logging road ascending to saddle between Mounts Mercer and Thurston, altitude 4,000 feet.

Fossils: Poorly preserved arnioceratid ammonite, identified by H. Frebold as Melanhippites of Sinemurian age.

Locality 20: Limestone on north bank of Chilliwack River, just over 1 mile east of the junction of the Chilliwack River with Slesse Creek.

Fossils: Large crinoid stems.

Locality 21: Contact of limestone with underlying shales and volcanic rocks, just north of old logging road, and ½ mile northwest of the confluence of Slesse Creek with the Chilliwack River, altitude 1,200 feet.

Fossils: Parafusulina, Pseudofusulinella and rhomboporoid bryozoans, of Leonardian age.

Locality 22: Volcanic arenites, tuffs? and shales below limestone cliffs, above and to north of Locality 21, altitude 2,600 feet.

Fossils: Molds of crinoid columnals, fenestellate bryozoans.

Locality 23: Limestone, on south side of Mount Thurston, altitude 2,300 feet.

Fossils: Parafusulina, Pseudofusulinella of Leonardian age.

Locality 24: Limestone, in creek bed, altitude 2,300 feet.

Fossils: Parafusulina.

Locality 25: Beds of limy chert, within dominant thin bedded cherts, on divide between two creeks, just above their junction, south side of Mount Thurston, altitude 1,850 feet.

Fossils: Abundant, partly silicified Parafusulina, rhomboporoid bryozoans, small crinoid columnals, of Leonardian age.

Several other fossil localities containing the same fauna, occur in limestone in the vicinity of Localities 21, 23, 24, 25, but are not listed, as they are readily located by tracing out the same horizon along the hillside.

Locality 26: Limestone, argillaceous and cherty, on the west side of knoll, east side of Borden Creek, near its confluence with Chilliwack River and immediately south of the main road in Chilliwack Valley, altitude 850 feet.

Fossils: Parafusulina, of Leonardian age.

Locality 27: Limestone pods, on the east side of Pierce Creek, altitude 3,500 feet.

Fossils: Large, poorly preserved fusulinids, probably Parafusulina.

Locality 28: In limestone talus, at base of large north-facing limestone cliff, west side of Pierce Creek, altitude 3,600 feet.

Fossils: Silicified Schwagerina, of Early Permian age.

Locality 29: Argillites, in talus slope below north face of Mount McFarlane, altitude 5,000 feet.

Fossils: Distorted clams, identified by J.A. Jeletzky as Buchia ex. gr.

concentrica Sowerby, of Late Oxfordian-Early Kimmeridgian age.

Locality 30: Limestone, in creek on east side of Slesse Creek Valley, altitude 1,740 feet.

Fossils: Large crinoid stems.

Locality 31: Limestone, in creek bed on northeast side of Mount McGuire, altitude 3,100 feet.

Fossils: Large crinoid columnals.

Locality 32: Limestones and clastic sedimentary rocks in side of old logging road, northeast side of Mount McGuire, altitude 2,900 feet.

Fossils: Large crinoid columnals in limestone; pteropods? in clastic rocks in contact with the limestone.

Locality 33: Calcareous, badly weathered, clastic rock in side of old logging road, northeast side of Mount McGuire, altitude 2,750 feet.

Fossils: Bellerophontid gastropods, brachiopod fragments, pteropods?

Locality 34: Limestone float, below limestone cliff, north end of ridge on east side of Borden Creek, altitude 4,000 feet.

Fossils: Poorly preserved Schwagerina, Early Permian age. Just below this locality, fenestellate bryozoans and crinoid columnal molds are present in argillites.

Locality 35: Shales in side of Borden Creek, altitude 3,450 feet.

Fossils: Molds of small crinoid columnals and fenestellate bryozoans.

Locality 36: Shaly horizon in limestone cliff, northwest of Spencer Peak, altitude about 5,000 feet.

Fossils: Brachiopod fragments, fenestellate bryozoans, crinoid columnals, and endothyroid foraminifera of Lower Pennsylvanian? age.

Locality 37: Limestone, on ridge, northwest of Spencer Peak, altitude

5,000 feet.

<u>Fossils</u>: Large crinoid columnals, of Lower Pennsylvanian? age.

<u>Locality 38</u>: Limestone cliff southwest side of Spencer Peak, altitude 5,100 feet.

<u>Fossils</u>: Small horn corals; large crinoid columnals are present in bed below main body of limestone on north side of this peak; of Lower Pennsylvanian? age.

<u>Locality 39</u>: Limestone cliff, due north of Spencer Peak.

<u>Fossils</u>: Large crinoid columnals; small horn corals in cliff on southwest side; of Lower Pennsylvanian? age.

<u>Locality 40</u>: Tuffaceous?, shales on north side of ridge, below limestone.

<u>Fossils</u>: Orthoconic nautiloids, bellerophontid gastropods, pelecypods?, pteropods?.

<u>Locality 41</u>: Limestone bed, in predominant volcanic rocks, in creek bed on southwest side of Mount McGuire, altitude 4,000 feet.

<u>Fossils</u>: <u>Parafusulina</u> of Leonardian age.

<u>Locality 42</u>: Limestone, due east of peak of Mount McGuire, and just northwest of saddle in central east-west ridge, altitude 5,100 feet.

<u>Fossils</u>: Small horn corals, tabulate corals (<u>Michelinia</u>), compound corals, and brachiopods, the most abundant being <u>Rhipidomella</u>; all fossils are silicified and preservation varies considerably; of Early Permian age.

<u>Locality 43</u>: Below cliff on the east side of the peak of Mount McGuire, altitude 5,700 feet.

<u>Fossils</u>: Silicified, medium sized <u>Schwagerina</u> of Early Permian age.

<u>Locality 44</u>: Limestone, south side of north ridge of Mount McGuire, altitude, 4,800 feet.

Fossils: Crinoid columnals, coral Heritschioides, of Early Permian age.

Locality 45: Limestone, northwest ridge of Mount McGuire, altitude 5,000 feet.

Fossils: Silicified brachiopods.

Locality 46: Rock composed of volcanic fragments in a calcareous mátrix, north side of north ridge of Mount McGuire, base of limestone cliff, altitude 4,800 feet.

Fossils: Parafusulina, of Leonardian age.

Locality 47: Tuffaceous and agglomeratic limestone, bioclastic limestone, at contact with infolded cherts, argillites and volcanic rocks, north of peak of Mount McGuire, altitude 6,000 feet.

Fossils: Parafusulina, Pseudofusulinella, schwagerinid?, rhombopo-roid bryozoans of Leonardian age.

Locality 48: Shales, shaly limestone on ridge 1 mile north of the summit of Liumchen Mountain. This is possibly the locality from which Daly (1912, p.510) made his collections # 1512, 1514.

Fossils: Abundant brachiopods, fenestellate and rhomboporoid bryo-zoans, clams?.

Locality 49: Limestone, capping knoll about 1½ miles southwest of the summit of Church Mountain.

Fossils: Fucoid markings, fusulinids Eostaffella, Millerella collected by W.R. Danner from this locality, and identified by Skinner; poorly preserved corals, crinoid columnals, of Lower Pennsylvanian age.

Locality 50: Clastic rocks, on east side of knoll about 3/4 miles due west of the summit of Church Mountain.

Fossils: Fragments of Calamites, Lepidodendron, pteropod ?-like fossils.

Locality 51: Tuffaceous limestone, base of limestone cliff on east side of summit of Church Mountain.

Fossils: Parafusulina, Pseudofusulinella, large Schwagerina? and rhomboporoid bryozoans; Dibunophyllum? and crinoid columnals are present in limestone cliff above this locality; of Leonardian age.

Locality 52: Shales, in side of logging road, northeast side of Church Mountain, altitude 2,900 feet.

Fossils: Pelecypods collected from this locality were identified by G.E.G. Westermann as Halobia dilatata Kittl? of Norian age.

Locality 53: Shales, in side of old logging road, above and to east of main logging road in Liumchen Creek.

Fossils: Hannaoceras nodifer (Hyatt and Smith), Discotropites?, Halobia? of Upper Karnian age.

Just north of this locality, above creek flowing northwestwards into Liumchen Creek, belemnites, Atractites cf. A.drakei, small clams and a gastropod were found in similar shales.

Locality 54: Coarse clastic rocks, in side of old logging road above fork in Liumchen Creek.

Fossils: Plant fragments.

Locality 55: Tuff, in Liumchen Creek.

Fossils: Belemnite, cf. Dictyoconites groenlandicus Fischer 1947, and crinoid columnals; of Permian age.

Locality 56: Limestone, on east side of Liumchen Creek Valley.

Fossils: Parafusulina, Pseudofusulinella, of Leonardian age.

Locality 57: Limestone, in bed of Liumchen Creek.

Fossils: Large crinoid columnals.

<u>Locality 58</u>: Limestone, in volcanic rocks on the south end of International Ridge.

<u>Fossils</u>: Fusulinids, <u>Parafusulina</u>?, of Early Permian age.

<u>Locality 59</u>: Shales, in dominant volcanic arenite sequence, on north side of north ridge of Mount McGuire, altitude 4,900 feet.

<u>Fossils</u>: Fenestellate bryozoans, small brachiopods, <u>Hustedia</u>?

PLATE 1: Geological map of Chilliwack Valley area

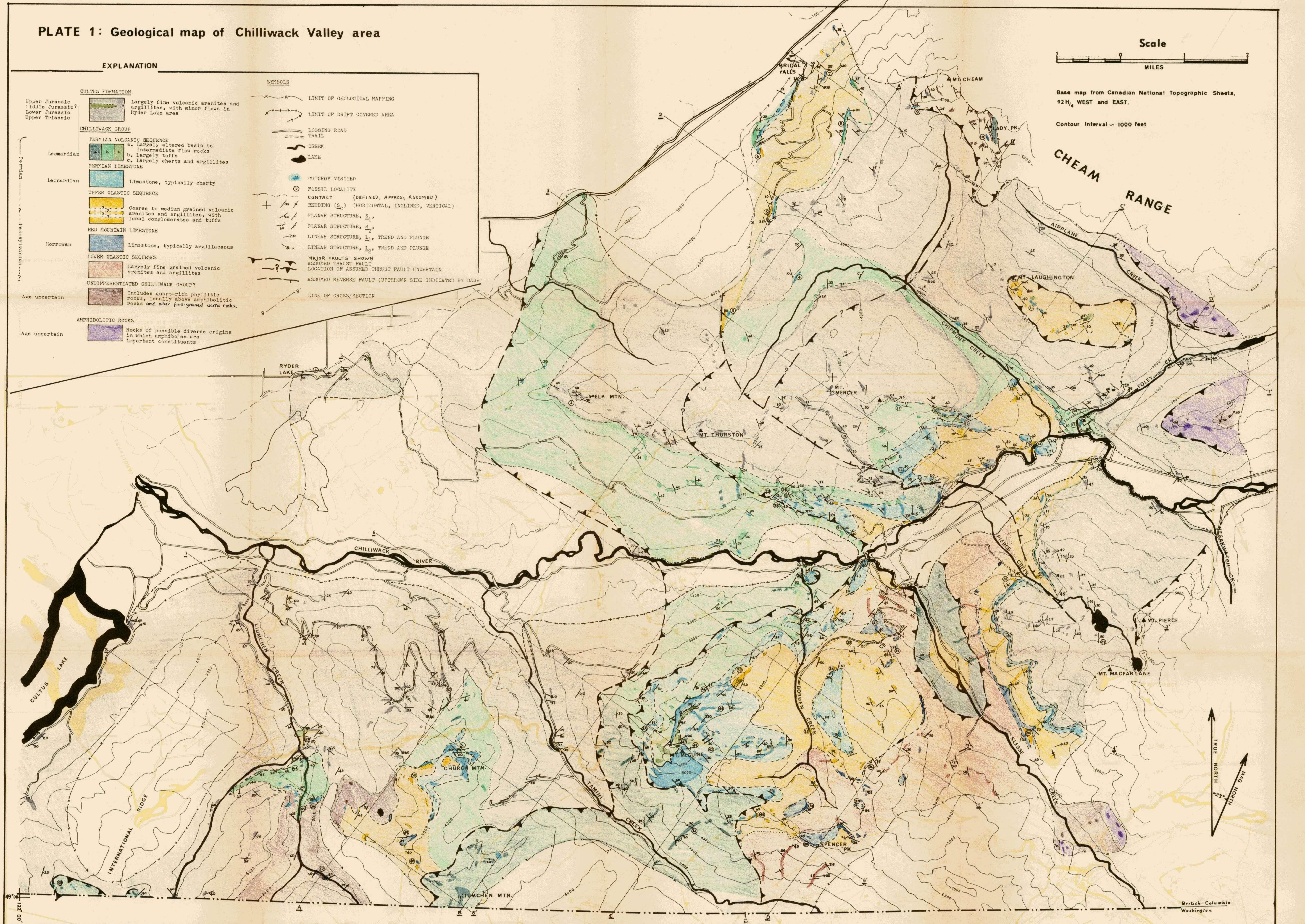


PLATE 2: Geological cross-sections of Chilliwack Valley area