

STRATIGRAPHY AND STRUCTURAL GEOLOGY
OF THE GOAT RANGE AREA,
SOUTHEASTERN BRITISH COLUMBIA

by

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B.S. University of Massachusetts
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ABSTRACT

The Goat Range area encompasses 583 square kilometers (228 sq. mi.) of the eastern Selkirk Mountains and is underlain by Paleozoic and lower Mesozoic metasedimentary and igneous rocks. Lower Paleozoic rocks comprise quartzite and quartzofeldspathic gneiss of the Hamill Group; marble, calc-silicate gneiss and quartzofeldspathic gneiss of the Badshot-Mohican formations; and calcareous schist, pelitic schist and phyllite, tholeiite and grit of the Lardeau Group. The Upper Mississippian and Pennsylvanian Milford Group comprises three assemblages linked by their depositional relationship to the Lardeau Group. The eastern, sedimentary Davis assemblage and central volcanic and sedimentary Keen Creek assemblage both lie with angular unconformity on the Lardeau Group. The western McHardy assemblage consists mainly of siliceous argillite and contains conglomerate with boulders derived from the Lardeau Group. The McHardy assemblage is thrust eastward along the Stubbs fault over the Keen Creek assemblage. The Kaslo Group is composed of tholeiites and conodont-bearing cherty tuff that conformably overlie the McHardy assemblage and are repeated by the Late Permian to Middle Triassic Whitewater thrust fault which detached mainly along serpentinite basement. Diorite intruding the fault is overlain unconformably by the Upper Permian to Middle Triassic Marten Conglomerate in turn succeeded unconformably by Upper Triassic sedimentary rocks of Slocan Group. All map units and related thrust faults were folded by the Dryden anticline which was later cut by Schroeder fault before intrusion of Middle Jurassic granitic rocks. Metamorphism, characterized by the biotite zone and locally the oligoclase-garnet zone, culminated during intrusion of the granitic rocks.

The Lardeau, Milford and Kaslo groups are interpreted to have been deposited in an extensional or transtensional tectonic setting punctuated by compressional events in early Paleozoic and Late Permian to Middle Triassic time and most severely deformed during the initiation of the Columbian Orogeny in Early Middle Jurassic time. The Lardeau Group, Davis assemblage and Keen Creek assemblage constitute the Kootenay tectonostratigraphic terrane, deposited on attenuated continental crust of the ancient margin of western North America. The McHardy assemblage, Kaslo Group and Marten conglomerate form the Slide Mountain assemblage, which was deposited in an oceanic basin marginal to North America and is the basement for Quesnel terrane, represented by Slocan Group. This marginal oceanic terrane was thrust onto the continental terrane along the Stubbs thrust in Early Middle Jurassic time.

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Figure 1: View southeast along the crest of the Goat Range from Mount Marion. The peaks in the foreground are underlain by granite of the McKian Creek Stock, part of the Middle Jurassic Kuskanax Intrusives. Mount Cooper is the peak in the left middle distance.

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CHAPTER 1. INTRODUCTION

The western North American Cordillera is composed of a collage of crustal fragments from diverse tectonic settings (Davis et al., 1977; Coney et al., 1980). These fragments or "terranes" are fault-bounded entities with geological histories different from those of contiguous terranes. Monger and Berg (1984) combined rocks of the lower Paleozoic Lardeau Group and upper Paleozoic Milford Group into the Kootenay terrane and the upper Paleozoic volcanic rocks of the Kaslo Group and the lower Mesozoic clastic rocks of Slocan Group into the Slide Mountain and Quesnel terranes respectively. The Kootenay terrane is interpreted to have formed along the margin of Paleozoic North America (Price et al., 1985), but the Slide Mountain and Quesnel terranes are considered to have travelled far distances into their present position and to have accreted to North America in Middle Jurassic time (Monger, Price and Tempelman-Kluit, 1982).

The goal of this project was to produce a detailed geologic map of the Goat Range area which had previously only been mapped at reconnaissance scale. In the process of mapping, it was hoped that more could be learned about the geologic history and tectonic setting of each of these terranes and the timing and nature of accretion of each of these terranes to North America.

The major conclusions of this study are that the Slide Mountain terrane developed in an oceanic basin, probably in a transtensional setting adjacent to the Kootenay terrane and proximal to North America. Eugeoclinal rocks of the Slide Mountain terrane were telescoped in typical thrust-belt style in Late Permian to Middle Triassic time. Rocks of the Quesnel terrane lie unconformably on the deformed Slide Mountain rocks

and so the two assemblages actually constitute a single terrane. The combined Slide Mountain and Quesnel terranes were thrust eastward onto the Kootenay terrane between 190 and 180 Ma (Early to Middle Jurassic time).

LOCATION AND ACCESS

The Goat Range is in the south-central part of the Lardeau map area and north-central part of the Nelson map area, southeastern British Columbia (Fig. 2). The range lies between 5 and 20 km (3-12 mi) west of the northern end of Kootenay Lake. The mapped area (Figs. 3,4,5) of 583 square kilometers (228 sq. mi.) includes parts of the Poplar Creek (82 K/6), Roseberry (82 K/3), Lardeau (82 K/2), Slocan (82 F/14), and Kaslo (82 F/15) map-sheets.

The town of Kaslo is presently the principal community in the area. It is 66 km (41 mi) north of Nelson along Highway 31 and 187 km (116 mi) from Revelstoke via road and ferry. Highway 31 is along the southeastern margin of the area. Logging roads from Highway 31 provide access to the topographic benches east of Milford Peak. Highway 31A lies along the southwestern margin of the area. Good fire control roads provide access to Mount Buchanan and the Blue Ridge and join Highway 31A at Seven-Mile Creek. Mine roads can be used to reach the Empire property and Mount Jardine area from highway 31A at Ten Mile Creek. Mine roads and trails provide access to Rossiter Creek, Lyle Creek, and Whitewater Creek from Retallack. A logging road and unimproved trail reaches the Kane Creek headwaters from Highway 31A at Three Forks. Good logging roads and an unimproved trail permit access to the Wilson Creek valley south of Keen Creek from Highway 6, north of New Denver. From the Wilson Creek road, logging roads lead to

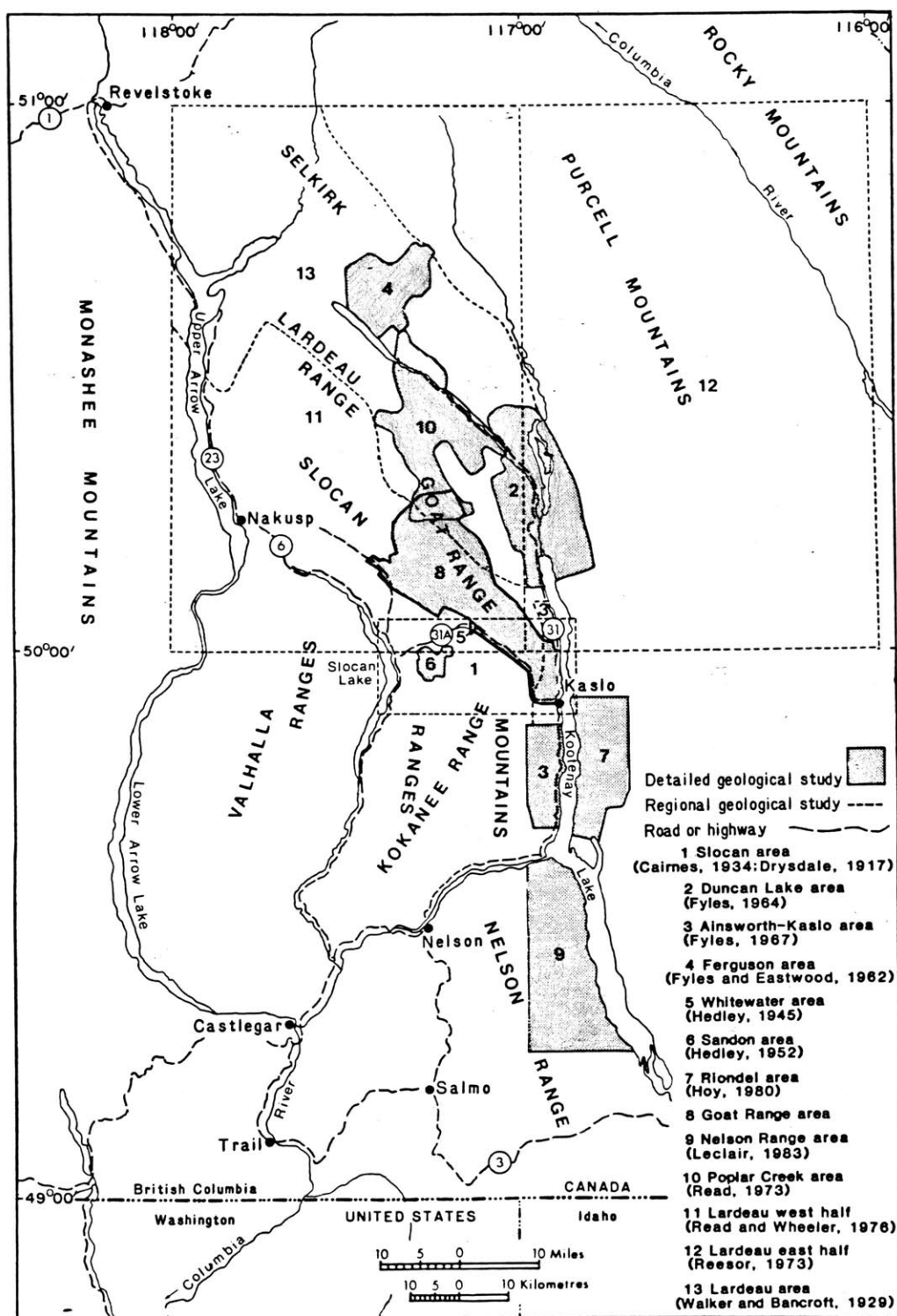


Figure 2: Index map showing the Goat Range area and adjacent map-areas.

the Mount Dolly Varden and Marten Mountain area. The crest of the Goat Range northwest of Mount Dryden is easily accessible only by helicopter via a twenty minute ferry from Nelson and twenty-five minute ferry from Revelstoke.

PHYSIOGRAPHY AND GLACIAL GEOLOGY

The Goat Range is one of the Slocan Ranges of the Selkirk Mountains, which is part of the Columbia Mountain system. The Blue Ridge is the southeast extension of the Goat Range. The highest peak in the study area is Mount Cooper (10135 ft., 3089 m) and the lowest elevation is at Kootenay Lake (1745 ft or 532 m) for a total relief of 2557 m (8389 ft). Commonly the elevation of the peaks is 2600 m to 2300 m (8530 ft to 7546 ft) and the valleys is 915 m to 1220 m (3000 to 4000 ft) for an average relief of 1380 m (4527 ft). The crest of the Goat Range forms the drainage divide north of Kaslo River, and streams flow northeast into the Kootenay Lake drainage and southwest into the Kaslo River and Slocan River drainages. Stream valleys are deeply incised, typically V-shaped and generally flow transverse to the geological trends. Kaslo River and Wilson Creek valleys are U-shaped. Abandoned cirques and alpine glaciers occur at the heads of the major drainages such as Kane Creek, Wilson Creek, and Cooper Creek. Active glaciers are most common on the northeast-facing slopes of peaks with elevations of 2590 m (8500 ft) or higher. Pleistocene glacial debris, especially kame terraces and lateral moraines, are common between elevations of 914 m and 1524 m (3000 ft and 5000 ft) and well developed at an elevation of 1125 m (3700 ft) along the southwest slope of the Blue Ridge.

HISTORY

The mineral resources of the Kootenay Lake Area were first exploited in the 1820's, when Indians and trappers from the Hudson Bay Company used lead ore from outcrops near Riondel for slugs for their muzzle-loading rifles. A period of prospecting activity occurred in 1868 in the Riondel area as prospectors stopped in the Kootenay Lake area on their way north to placer fields near the "big bend" of the Columbia river. However transportation costs were prohibitive and the Riondel lode remained unworked.

In the early 1880's, John C. and George J. Ainsworth, operators of a steamer on the Columbia River, established a railroad connecting the Columbia River and Nelson, at the outlet of Kootenay Lake. By 1888, several steamers operated on Kootenay Lake and mining camps grew up around the Hot Springs and Lulu claims at Ainsworth Hot Springs and the Bluebell Mine at Riondel.

During this period, prospectors reached the Goat Range and Kokanee Range near the present site of Sandon, and opened the Slocan Mining Camp. By 1892 the town of Kaslo had a population of four or five thousand, and sixteen properties were in operation in the Slocan Camp including large operations at Retallack and Zincton. In 1895, rail links between Kaslo and the Cody area and Sandon and Nakusp were completed. Smelters were built at Nelson in 1896 and at Trail in 1898 to process ores from the Rossland and Slocan camps. The Slocan area was struck by severe forest fires in 1894 and 1910.

Production in the district reached a peak during World War I, suffered a setback in the 1929 price drop, and increased again during the second

World War. Currently, mining activity in the Slocan district is restricted to a few mines that operate intermittently in the Goat Range and some mines east of Slocan City. The local economy is largely dependent on government services, forestry, and the tourist trade.

PREVIOUS WORK

The first geological work in the area was a reconnaissance survey by G.M. Dawson (1890) in 1888 along the shores of Kootenay Lake and Arrow Lakes. He correlated the high-grade gneisses and schists along the shore of Kootenay Lake with the Shuswap Series and the phyllite presently included in Slocan and Kaslo Groups with the Adams Lake series. McConnell (1897, 1898) mapped the west Kootenay district and together with Brock (1904) published the West Kootenay Sheet that covered an area as far north as about 51°N. They maintained the correlation with the Shuswap Series for high-grade rocks along the shore of Kootenay Lake, and designated rocks of the Ymir and Milford groups, Kaslo Group and Slocan Group as the Nisconlith Series, Lower Selkirk Series and the Slocan Series respectively. LeRoy (1909, 1910, 1911) did more detailed work in the Slocan District and his assistant, Drysdale, assumed charge of the project and published the results in 1917. Drysdale used the local designation, Kaslo Greenstone, instead of Selkirk Series for rocks of the Kaslo Group. Drysdale also recognized a conglomerate (now the Marten Conglomerate) at the base of the Slocan Series and correctly interpreted the Slocan Series as resting unconformably on Kaslo Greenstone and that the rocks were folded into a large anticline running the length of the Blue Ridge. Drysdale did not recognize the Schroeder fault or subdivide the Milford Group but in general his cross sections are remarkably similar to those of this report.

In 1917, 1920 and 1921 Bancroft reported on reconnaissance work in the eastern Goat Range and the Lardeau Range. Final results were published in 1929 (Walker and Bancroft, 1929). Bancroft interpreted the Kaslo Schists to be intrusive into the Milford and Slocan Series.

Cairnes (1934) published geologic maps of the Slocan district that reached as far as 50°3'30" north and provided the first detailed descriptions of lithologic units in the area. Fyles (1967) made a reconnaissance study of the slopes west of Kootenay Lake including the Blue Ridge as far north as Milford Peak, and he mapped in detail units south of True Blue Mountain along the west shore of Kootenay Lake.

Hedley (1945) made a detailed study of the Whitewater mine area and worked out the "Whitewater drag fold" in Upper Triassic limestone of the Slocan Group. Maconachie (1940) investigated the mineral deposits and mapped units in the headwaters of Whitewater and Lyle Creeks.

Ross and Kellerhalls (1968) mapped the ridges north and south of Kaslo, including the Blue Ridge to the Mount Jardine area. They proposed a structural interpretation that placed Kaslo Group rocks within the Lardeau Group.

Read (1973) mapped the northern section of the Goat Range, immediately north of and partially overlapping the area of this study. The main segment of the Goat Range was first mapped in reconnaissance by Read and Wheeler (1976). The present work is the first detailed mapping of the Goat Range north of Mount Jardine and south of Mount Marion and was preceded by three progress reports (Klepacki, 1983; Klepacki and Wheeler, 1985; Klepacki, Read and Wheeler, 1985).

FIELD WORK AND ACKNOWLEDGEMENTS

Six and a half months of field work were accomplished during the summers of 1982 to 1984. Mapping was done on standard 1:50,000 topographic base maps produced by the Surveys and Mapping Branch, Department of Energy, Mines, and Resources. Traverses were made from base camps located at the ends of logging roads, or at food caches set out by helicopter. Attitude data was obtained with the Brunton Compass. The assistance of L. Duchene and K. Jang in 1982, C. Klepacki, D. Orange, P. Vichert and A. Vichert in 1983, and B. Malahoff in 1984 is greatly appreciated. The writer is grateful for the hospitality of the people, merchants, and Post Officers of Kaslo. The supervision of J.O. Wheeler of the Geological Survey of Canada and B. C. Burchfiel of the Massachusetts Institute of Technology and the financial support of the Geological Survey of Canada, Massachusetts Institute of Technology, the Schlumberger Chair, and a National Science Foundation Grant (No. EAR-8314161) to B.C. Burchfiel is greatly appreciated. Many discussions, in the field and out of the field, with J.O. Wheeler, J.T. Fyles, A. Leclair, R. Parrish, P.B. Read and J.E. Reesor led to a much better understanding of the local and regional geology of the Kootenay Arc. Initial interest in the Kaslo Project was stimulated by R. Parrish and P.B. Read. P.B. Read provided an unpublished map of the Mount Buchanan-Milford Peak area that aided remapping of the area.

CHAPTER 2. REGIONAL GEOLOGICAL SETTING

STRATIGRAPHIC SETTING

The Goat Range lies within the Kootenay Arc, one of four geologic elements in southeastern British Columbia. From east to west, these elements are: 1) the Rocky Mountain-Foreland Fold and Thrust Belt, 2) the Purcell Anticlinorium, 3) the Kootenay Arc and 4) the Shuswap Metamorphic Complex (fig. 2). The Rocky Mountain-Foreland fold and thrust belt consists of Paleozoic to lower Mesozoic miogeoclinal and upper Mesozoic and lower Tertiary foreland sedimentary rocks that were deformed in Late Cretaceous to Early Paleocene time (Price, 1981). The Purcell Anticlinorium is a broad, northerly-plunging culmination mainly of Proterozoic clastic sedimentary rocks deposited on the ancient North American continental margin (Price, 1981; Harrison, 1972) and rare Paleozoic shallow water sediments (Root, 1983, 1985). The Kootenay Arc, first named by Hedley (1955), consists of an arcuate belt of lower Paleozoic and Mesozoic rocks on the west flank of the Purcell Anticlinorium. The limestone, dolomite, clastic sedimentary rocks and volcanic rocks of Paleozoic and early Mesozoic age in the Arc were intensely deformed during early Paleozoic and Middle Jurassic time (Read and Wheeler, 1976; Parrish and Wheeler, 1983; Archibald et al., 1983). The Shuswap Metamorphic Complex consists of high-grade metamorphic rocks west of the Kootenay Arc (Okulitch, 1984). The relationship of Archean (?) to Lower Jurassic rocks within the complex to the surrounding lower grade rocks is either an abrupt metamorphic transition or normal fault (Read and Brown, 1981).

ne normal faults

ne (54-50 Ma) alkaline granitic rocks and minor volcanic rocks

st faults of the Rocky Mountain system

aceous to Paleocene (100-64 Ma) granitic rocks

le Jurassic to Early Cretaceous clastic sediments of the Rocky
tain foreland sequence (Ferne Fm., Kootenay Gp., Blairmore Gp.)

le to Late Jurassic (180-150 Ma) granitic rocks

le to Late Jurassic normal faults

le Jurassic to Early Cretaceous thrust faults

Triassic to Lower Jurassic, mainly augite-porphry volcanics of
NEL TERRANE (Nicola Gp., Slocan Gp., Rosslund Gp.)

Triassic flyschoid sediments of QUESNEL TERRANE (Slocan Gp.,
Gp.)

oniferous eugeoclinal sediments and minor volcanics and Permian
anic rocks of the SLIDE MOUNTAIN TERRANE (McHardy assm.,
Roberts Fm., Anarchist Gp., Knob Hill Fm., Kaslo Gp.)

morphic rocks of the Okanagon and Grand Forks complexes: mainly
relative with SLIDE MOUNTAIN TERRANE and younger granitic rocks
nd Forks Gp., Scalping Knife Mtn. and Pinnacles Peak sequences
is Mary Ck. Gp., Trail and Castlegar gneisses, Valhalla Gneiss
lex)

oniferous successor sequence of limestone, clastic sediments and
anics (Milford Gp.: Davis and Keen Ck. assms., Pend d'Oreille River
ence)

nian to Triassic miogeoclinal limestone, sandstone and shale of the
y Mountain sequence (Cedared Fm., Harrogate Fm., Fairholme Gp.,
Forster Fm., Starbird Fm., Sassenach Fm., Palliser Fm., Banff Fm.,
le Gp., Rocky Mountain Gp., Spray River Gp.)



Lower Paleozoic clastics, calcareous sediments, and volcanics west of the Purcell Anticlinorium assigned to KOOTENAY TERRANE (Lardeau (Emerald member of Laib Fm., Ledbetter slate, Active Fm., Metallin limestone, Nelway Fm., Covada Gp.)



Lower Cambrian quartzite, carbonate, calcareous pelite and rare volcanics west of the Purcell Anticlinorium (Hamill Gp., Quartzit Fm., Addy quartzite, Gypsy quartzite, Reno Fm., Truman member of Fm., Mohican Fm., Maitlen phyllite, Reeves limestone, Badshot Fm.)



Lower Paleozoic miogeoclinal clastics and carbonates of the Rocky Mountain sequence (Gog Gp., Eager Fm., Chancellor Fm., Mt. Whyte Cathedral Fm., Stephen Fm., Eldon Fm., Pika Fm., Arctomys Fm., Ly Ottertail Fm., Canyon Ck. Fm., Glenogle Fm., Survey Pk. Fm., Outr Skoki Fm., Owen Ck. Fm., Mt. Wilson Fm., Beaverfoot Fm., Tegart F



Late Proterozoic mainly clastic sediments (Windermere Supergroup Horsechief Creek Gp., Miette Gp.)

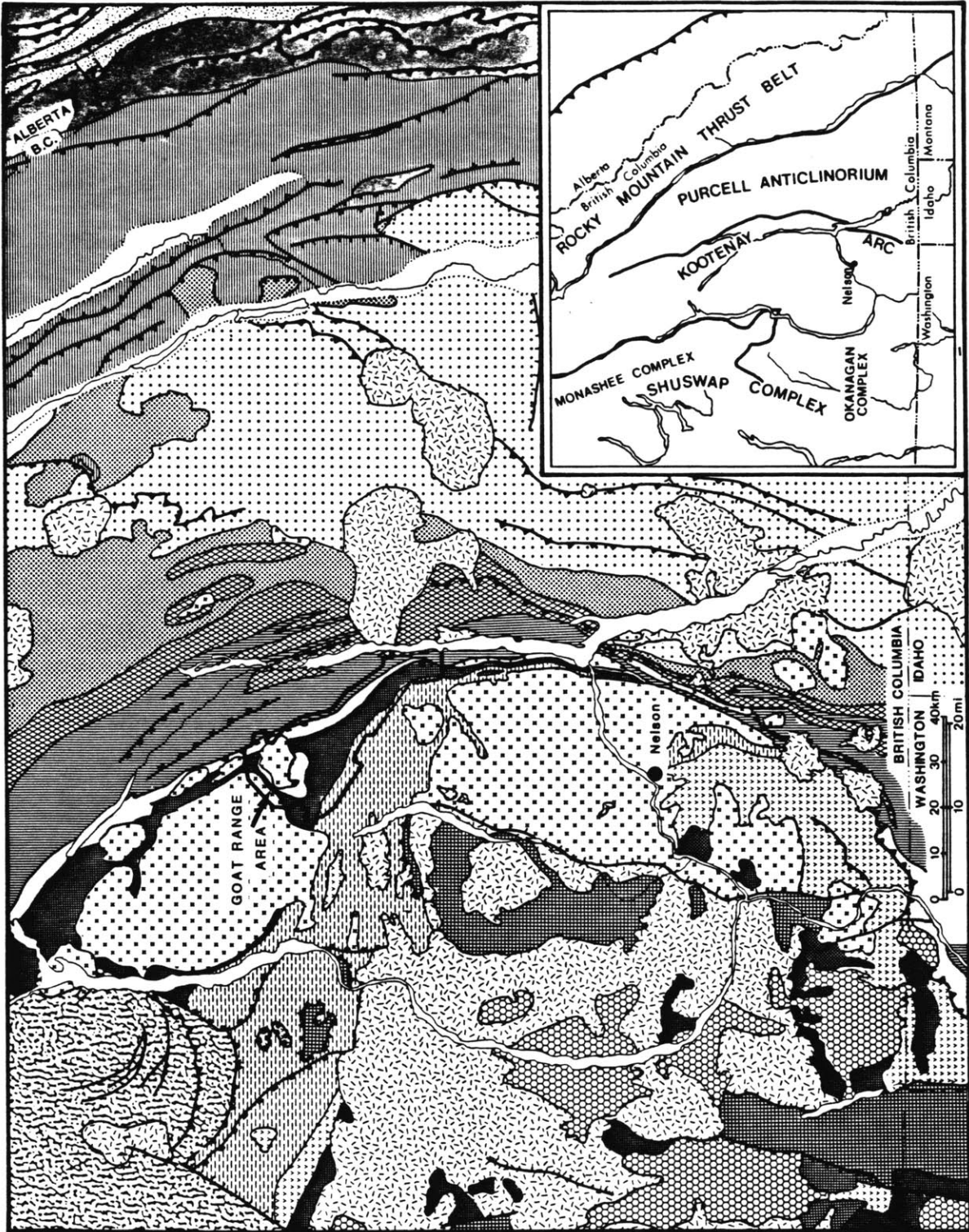


Middle Proterozoic sediments and basic intrusives of the Belt-Pur Supergroup



Archean to Paleozoic metamorphic rocks of the Monashee Complex

Figure 6: Geological map showing the regional setting of the Goat Range area.



The Purcell Supergroup is the oldest unit within the Kootenay Arc and Purcell Anticlinorium. It was deposited between 1500 Ma to 1350 Ma (McMechan and Price, 1982). East of the Rocky Mountain Trench, the Purcell Supergroup consists of shallow water shelf to supratidal deposits. West of the trench it comprises deep water turbidites that grade upwards to subtidal and supratidal strata at the top of the sequence (Hoy, in Brown et al., 1981, p. 336).

The Upper Proterozoic Windermere Supergroup of clastic sedimentary and local volcanic rocks unconformably overlies the Purcell Supergroup and may be as old as 827-918 Ma (McMechan and Price, 1982, p. 481) although recent work by Evenchick et al. (1984, p. 237) suggests the Windermere is no older than 730 Ma. The Purcell and Windermere supergroups form mainly clastic sedimentary continental terrace wedges of Proterozoic western North America.

The Lower Cambrian Hamill Group composed of quartzite with rare basic volcanic rocks apparently disconformably overlies the Windermere Supergroup in the northern Selkirk and central Purcell mountains (Wheeler, 1963; Reesor, 1973, pp. 34-37). The correlative Reno Quartzite and Quartzite Range Formation conformably overlie Windermere strata in the southern Kootenay Arc (Little, 1960). The Hamill Group is traced into the Gog Group of the Rocky Mountains in the Rogers Pass area (Wheeler, 1963), linking Purcell and Rock Mountain stratigraphy. Lower Cambrian archeocyathid-bearing limestone (Reeves limestone, Badshot Formation) conformably overlies the Hamill Group. It extends the length of the Kootenay Arc (250 km; Fyles, 1970, p. 96). The Hamill Group and Badshot Formation are thought to form the base of the Paleozoic Cordilleran miogeoclinal wedge (Bond and Kominz, 1984, p. 167; Devlin et al., 1985).

The Lardeau Group concordantly overlies the Badshot Formation (Reesor, 1973, p. 60). It consists mainly of calcareous metapelite and psammitic rocks in the central and southern Kootenay Arc (Hoy, 1980, p. 30; Leclair, 1983, p. 238). In the northern Kootenay Arc, the Lardeau Group comprises calcareous metapelite overlain by volcanic and gritty sedimentary rocks. The Lardeau Group may be correlative with fossiliferous Lower Cambrian and Ordovician slates in southern British Columbia and northern Washington (Little, 1960, p. 41) and possibly with Devonian volcanic rocks west of the Shuswap Metamorphic Complex (Brown et al., 1981, p. 369). In the northern Kootenay Arc the Lardeau Group is different from coeval calcareous and clastic sedimentary rocks east of the Purcell Anticlinorium (Reesor, 1973) which has led some workers (Monger and Berg, 1984, p. 8-15) to assign the Lardeau Group to a suspect terrane, the Kootenay terrane. The locally discontinuous distribution of the Badshot Formation at the base of the Lardeau Group is interpreted by Monger and Berg (op. cit.) to be the result of faulting along the terrane boundary. Other workers interpret the podiform distribution to attenuation during intense folding (Fyles, 1964, p. 24; Hoy, 1980, p. 26; Reesor, 1973, pp. 58-59). Recently, the difference in stratigraphy between the Lardeau Group and coeval units east of the Purcell Anticlinorium has been attributed to rapid facies changes across a transtensional continental margin in early Paleozoic time (Price et al., 1985, p. 3-28).

The Milford Group unconformably overlies the Lardeau Group in the eastern Goat Range (Wheeler, 1966; Read, 1975; Klepacki and Wheeler, 1985). A western part of the Milford Group may rest on oceanic basement. The Milford Group comprises siliceous argillite, metasandstone, limestone, volcanic rocks and conglomerate. The age range of the Milford Group is not

completely known, but most of the strata are Upper Mississippian to Lower Pennsylvanian in age (Orchard, 1985; Klepacki and Wheeler, 1985). The westernmost assemblage of the Milford Group is the base of the Slide Mountain terrane. Farther west, eugeoclinal strata that are correlated with the westernmost assemblage in the Goat Range comprise the Mount Roberts Formation (Little, 1982; p. 9) and the lower parts of the Anarchist, Kobau, Tenas Mary Creek and Chapperon groups. These units all consist of chert, pelitic rocks, limestone, conglomerate and greenstone (Peatfield, 1978, pp. 20-60). The Mount Roberts Formation in British Columbia and Anarchist Group in Washington are assigned by Monger and Berg (1984) to the Harper Ranch Subterrane of Quesnel terrane.

The Kaslo Group conformably overlies the westernmost assemblage of the Milford Group. It is composed mainly of Permian tholeiitic pillow basalts. Farther west greenstone of Permian age occurs near Greenwood (Little and Thorpe, 1965), and greenstone of the Kobau Formation and Upper Anarchist Series (Peatfield, 1978; p. 38) may be correlative. These western strata are assigned to the Okanagan subterrane (Monger and Berg, op. cit.).

Mesozoic strata in the northern and central Kootenay Arc consists of Upper Triassic sedimentary and minor volcanic rocks of the Slocan and Ymir groups whereas those in the southern part comprise the Lower Jurassic volcanic and sedimentary rocks of the Rossland Group. These strata together with the volcanic and sedimentary Nicola Group in the Okanagan Complex (Okulitch, 1979) constitute the Quesnel terrane in southern British Columbia. The Quesnel Terrane lies unconformably on the Slide Mountain terrane in the Kootenay Arc (Klepacki and Wheeler, 1985) and may also unconformably overlie the Harper Ranch and Okanagan subterrane (Smith, 1979, p. 120; Monger and Berg, 1984).

REGIONAL DEFORMATIONAL HISTORY

The oldest deformations recognized in southeastern British Columbia are a Middle Proterozoic (c. 1350 Ma) compressional event and a Late Proterozoic (c. 850 Ma) extensional event (McMechan and Price, 1982, p. 485). Down-to-basin normal faulting accompanied the development of the miogeocline in early Paleozoic time (Price, 1981, p. 431). Locally intense deformation of the Lardeau Group and older rocks preceded deposition of the Upper Mississippian part of the Milford Group. Deformation in early and middle Paleozoic time is based on regional unconformities (Wheeler, 1968; Klepacki and Wheeler, 1985; Struik, 1981) and Ordovician (c. 450 Ma) and Devonian (c. 380 Ma) isotopic dates (Okulitch, 1985). Unconformities in the Goat Range (Klepacki and Wheeler, 1985; this report) and at Dome Mountain near Okanagan Valley (Jones, 1959, p.29; Read and Okulitch, 1977, p. 616) indicate Late Permian to Middle Triassic, compressional deformation.

The major deformation in the Shuswap Complex (excluding the Monashee Complex) and Kootenay Arc occurred in Early to Middle Jurassic time and involved thrust imbrication of the Slide Mountain, Quesnel and Kootenay terranes (Read and Wheeler, 1976; Okulitch, 1984, p. 1186). Folding, metamorphism, local normal faults and the intrusion of granitic plutons accompanied this event (Read and Wheeler, 1976; Okulitch 1984, p. 1180; Klepacki and Wheeler, 1985). The youngest strata involved in the deformation are Early Toarcian (c. 190 Ma) (Tipper, 1984) and post-tectonic intrusions are dated as 180 ± 7 Ma (this report). Metamorphism apparently lasted a longer period of time in the southern Kootenay Arc, where K-Ar and $^{40}\text{Ar}/^{39}\text{Ar}$ data record temperatures in excess of $\sim 300^\circ\text{C}$ until 166-156 Ma (Archibald et al., 1983, pp. 1909-1910).

Plutonism and associated heating occurred between 115 Ma and 90 Ma (Archibald et al., 1984, p. 575; Parrish et al., 1985) when post-tectonic plutons were emplaced along much of the Kootenay Arc and Purcell Anticlinorium. The Middle Jurassic orogen and superposed middle Cretaceous magmatic belt were transported eastward at least 100 km during the Late Cretaceous-Paleocene shortening in the Rock Mountain belt (Price, 1981, p. 444). The Purcell Anticlinorium, Kootenay Arc and Shuswap Metamorphic Complex are thought to have attained their general configuration during this event. The Purcell Anticlinorium is interpreted as a ramp anticline with the Kootenay Arc forming its steeply-dipping western flank (Price, 1981, p. 436; Archibald et al., 1984, p. 578). Exposure of the Monashee Complex, part of the Shuswap Metamorphic Complex (Fig. 2), is also thought to be a product of ramping in basement rocks (Okulitch, 1984, p. 1188). In the southern Kootenay Arc (Archibald et al., 1984, p. 570-571) and Valhalla Range (Parrish et al., 1985, p. 86) gneissic Cretaceous granitoids may have been deformed and foliated at this time.

Crustal thickening and plutonism in the southeastern Canadian Cordilleran orogen are interpreted to have resulted from collisions between allochthonous terranes with the western margin of North America in Middle Jurassic and Late Cretaceous times (Monger, Price and Tempelman-Kluit, 1982). Westerly derived sedimentary units in the Rocky Mountain foreland record uplift in the active orogen commencing in Middle Jurassic time (Fernie Group; Poulton, 1984). Pulses of clastic sedimentation in the Late Jurassic-Early Cretaceous (Fernie Group and Kootenay Formation), middle Cretaceous (Blairmore and Fort St. John groups), and Late Cretaceous-Paleocene (Brazeau and Paskapoo formations) suggests deformation and uplift was more continuous along the eastern foreland than in the western

hinterland of the orogen (Price et al., 1985, pp. 3.12-3.15).

The distribution of Eocene deformation appears to be coincident with the area of Eocene plutonism in the southern Kootenay Arc and the Okanagan Metamorphic Complex. Eocene cooling dates correspond with the high-grade metamorphic culminations that occur near Kootenay Lake, and within the Valhalla Dome, the Monashee Complex, and Kettle River Dome (Archibald et al., 1984). Eocene normal faults have been mapped along Slocan Lake (Parrish, 1984; Parrish et al., 1985), the Kettle River Dome (Preto, 1970) and near the southern end of Kootenay Lake (Glover, 1978). Strike faults mapped along the western edge of Kootenay Lake (Fyles, 1967; Leclair, 1983, p. 239) may also have been active in Eocene time. Eocene deformation is interpreted as part of a regional extensional deformation that affected a large area of southern British Columbia and adjacent northern United States (Price, 1979; Ewing, 1981).

Table I. Table of formations.

ERA	PERIOD OR EPOCH	GROUP, FORMATION OR MEMBER	LITHOLOGY	THICKNESS		
CENOZOIC	PLEISTOCENE AND RECENT		Tufa, travertine			
			Till, gravel, sand, silt			
	EROSIONAL UNCONFORMITY					
	EOCENE?		Biotite-apatite lamprophyre and augite-biotite lamprophyre			
MESOZOIC	MIDDLE JURASSIC	Blue Ridge Intrusives	Felsite, hornblende leucogranite, feldspar porphyry, biotite leucogranite			
		Kuskawax Intrusives	Aegirine-augite leucogranite, leucocratic quartz monzonite, syenite			
	UPPER TRIASSIC-MIDDLE JURASSIC	Davis Ridge Diorite	Pyroxene-plagioclase diorite porphyry			
		Kaslo River Intrusives	Hornblende monzonite, quartz monzonite			
	INTRUSIVE					
UPPER TRIASSIC	SLOCAN GROUP					
	Limestone Member	Gray or black limestone		10-30m 33-98ft		
	Phyllite and Slate Member	Gray phyllite, slate, argillite, limestone, quartzite, calcarenite		12663m 17424ft		
EROSIONAL UNCONFORMITY						
	Marten Conglomerate	Conglomerate, limestone		60-119m 197-392ft		
EROSIONAL UNCONFORMITY						
MIDDLE TRIASSIC-UPPER PERMIAN		Whitewater Diorite	Light grey or green hornblende diorite, foliated diorite			
	INTRUSIVE					
PALEOZOIC	PERMIAN AND(?) PENNSYLVANIAN	KASLO GROUP				
		LOWER PLATE SEQUENCE		UPPER PLATE SEQUENCE		
		Upper Volcanic Member	Green tholeiitic basalt, amphibole-chlorite gneiss/schist 187-362m 614-1188ft	Upper Plate Volcanic Member	Green tholeiitic pillow basalt, greenstone, breccia, felsite tuff 820-1200m 2034-3937ft	
		Sedimentary Members	Green, grey and white cherty tuff, siliceous argillite, graywacke, conglomerate 20-170m 66-559ft	Upper Plate Sedimentary Members	Green, white and grey cherty tuff, graywacke, conglomerate 5-883m 16-2897ft	
		Lower Volcanic Member	Dark green tholeiitic basalt, pillow basalt 820-1060m 2690-3477ft	Ultramafic Member	Serpentinite, talc-carbonate schist 0-843m 0-2768ft	
		CONFORMABLE ON McHARDY ASSEMBLAGE				
			Kane Creek Diorite	Gray hornblende diorite, green plagioclase-chlorite-amphibole-epidote schist		
		INTRUSIVE				

ERA	PERIOD OR EPOCH	GROUP, ASSEMBLAGE AND MEMBER; LITHOLOGY; THICKNESS		
PALEOZOIC	PENNSYLVANIAN	MILFORD GROUP		
		SCHROEDER FAULT	Keen Creek assemblage	McHardy assemblage
			Siliceous Wacke Member	Volcanic Member
			Upper Limestone Members	Siliceous Argillite Member
			Upper Volcanic Member	Carbonate Member
			Banded Limestone Member	Copper Conglomerate
			Lower Volcanic Member	Tuffaceous Sandstone Member
			Basal Clastic Member	Calc-argillite Member
			Davis assemblage	
			Greenstone Member	Green tholeiitic basalt; Conglomerate 0-180m 0-590ft
Cherty Tuff Member	Green, white and purple cherty tuff 0-610m 0-2001ft			
Siliceous Argillite Member	Black, grey and white siliceous argillite; calcarenite; limestone; sandstone 120-780m 394-2362ft			
Sandstone and Phyllite Member	Gray phyllite, slate, siliceous argillite; light brown sandstone; gray calcarenite; limestone 0-1280m 0-4200ft			
Limestone Member	Blue-grey limestone, black argillaceous limestone 70-900m 230-2933ft			
EROSIONAL UNCONFORMITY		BASE NOT EXPOSED		

ERA	PERIOD OR EPOCH	GROUP OR FORMATION	LITHOLOGY	THICKNESS
PALEOZOIC	CAMBRIAN AND ORDOVICIAN	LARDEAU GROUP		
		Breadview Formation	Quartz-mica schist, phyllite, quartzite, quartz-feldspar granule grit, plagioclase-mica granulite	532-1337m 1745-4388ft
		Jowett Formation	Quartz-chlorite-plagioclase schist, amphibolite, pillow basalt	0-560m 0-1840ft
		Index Formation	Calcareous mica schist, quartz-muscovite-biotite-garnet schist, calc-silicate gneiss, marble, mica phyllite	~590m 1936ft
	LOWER CAMBRIAN	Badehot-Mohican Formations	Marble, calc-silicate gneiss, quartzofeldspathic muscovite-biotite gneiss	0-42m 0-140ft
HAMILL GROUP		White micaceous quartzite, quartzofeldspathic gneiss, blue-grey quartzite	300m 984ft	

CHAPTER 3. STRATIGRAPHY

The stratigraphy of the Goat Range has been established in part by previous workers and in part defined here (Table I). The stratigraphy defined here has been determined from structural position and stratigraphic superposition indicated by fossils, scour features, cross-bedding, and graded bedding in clastic rocks, and concavity of pillow structures in volcanic rocks. The stratigraphic sequence of the Goat Range is complicated by faults that juxtapose coeval strata (Figs. 3,7). The oldest rock units are present east of the Schroeder fault and comprise sedimentary and volcanic units of Hamill Group, Badshot Formation, Lardeau Group and the Davis assemblage of Milford Group. West of the Schroeder fault, clastic metasedimentary rocks of the Broadview Formation of the Lardeau Group and clastic metasedimentary, volcanic and limestone units of the Keen Creek assemblage of Milford Group are exposed in a structural window in the northern part of the map area. Clastic rocks, limestone and rare volcanic rocks of the McHardy assemblage, volcanic and ultramafic rocks of Kaslo Group and clastic sedimentary rocks and limestone of the Slocan Group comprise the Stubbs thrust sheet and occur in the western part of the area.

It is hoped the nomenclature developed in the Goat Range can be used in the more deformed areas along strike, so rock units are designated by the group name and informal lithologic members rather than numerical labels.

HAMILL GROUP

The oldest rocks in the Goat Range area are the Hamill Group. Walker and Bancroft (1929) first identified the Hamill Series from exposures of quartzites along the upper part of Hamill Creek. Reesor (1973, p. 55-57) redefined the unit as the Hamill Group with two reference

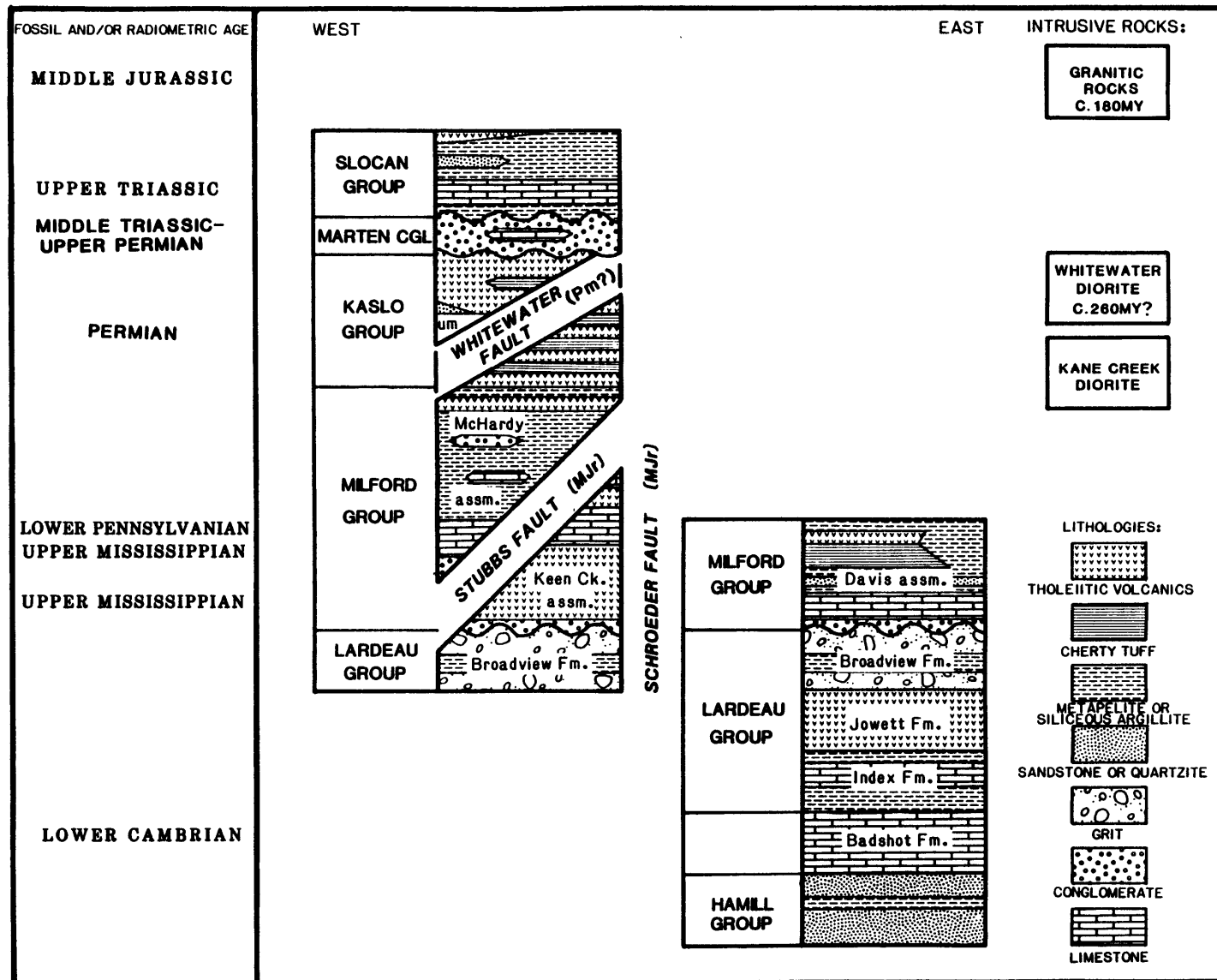


Figure 7: Generalized tectonic and stratigraphic relationships in the Goat Range area.

sections in the west-central Purcell Mountains. In general the Hamill Group consists of medium- to fine-grained white and grey quartzite and quartz-pebble conglomerate. Greenstone and mafic volcanic rocks also occur in the Hamill Group in the Selkirk Mountains (Wheeler, 1963, p. 3 and 1965, p. 10; Read and Wheeler, 1976).

In the Goat Range area, the Hamill Group outcrops in the southeastern part of the area above the shoreline of Kootenay Lake (Fig. 3). The unit consists of slabby, brown-weathering micaceous quartzite and overlying muscovite-biotite quartzofeldspathic gneiss with layers of white to water-blue quartzite 5-51 cm (2-20 in) thick.

The Hamill Group structurally overlies white marble of the younger Badshot Formation although the contact was not observed. The Index Formation, consisting of calc-silicate gneiss, marble, and muscovite-biotite quartzofeldspathic gneiss overlies Hamill Group strata east of Mount Buchanan. This contact is not exposed and the absence of mappable thicknesses of the intervening Badshot Formation suggests a faulted boundary. Pods of white marble along the contact zone also indicate a fault along the Hamill-Index contact at this location, as mapped by Fyles (1967, Figure 2).

Since the Hamill Group in the Goat Range is interpreted to form the core of the synformal Meadow Creek anticline identified in the Duncan Lake area (Fyles, 1964, p. 59), its outcrop width represents double its minimum thickness. The outcrop width of 400-600 m (1312-1968 ft) yields a minimum thickness of 200-300 m (656-984 ft). Reesor (1973; pp. 56-57) reports thicknesses of 4300 ft (1311 m) and 6500 ft (1981 m) at two typical sections.

The Hamill Group is reported to lie concordantly and perhaps disconformably upon Windermere strata (Reesor, 1973; pp. 37-38), and

conformably beneath the Badshot and Mohican formations (Reesor, op.cit.; Fyles, 1964, p. 26). The Badshot Formation is of Lower Cambrian age and the Hamill Group is assigned a Lower Cambrian age based on its relationship to the Badshot Formation.

Depositional Setting Of The Hamill Group

Strata of the Hamill Group are interpreted to represent quartz sands mixed with variable amounts of finer-grained clastic sediments. The source area for the Hamill Group was apparently to the east and southeast based on thickness changes and regional transgressive relationships (Reesor, 1973, p. 64). Recent stratigraphic and thermal modelling work (Bond and Kominz, 1984; Devlin et al., 1983, Devlin and Bond, 1984) suggests the Hamill Group was deposited in the final stages of rifting and initial stages of thermal subsidence of the late Precambrian to Early Cambrian west-facing continental margin. Mafic volcanics in the Hamill Group are interpreted as rift-related basalts.

BADSHOT-MOHICAN FORMATIONS

The Mohican Formation was named by Fyles and Eastwood (1962, p. 17), for interbedded limestone and schist exposed on Mohican Mountain in the Ferguson area 80 km (50 mi) north of the Goat Range. This sequence was previously mapped as Hamill Group (Walker and Bancroft, 1929). Crystalline limestone of the Badshot Formation overlies the Mohican Formation and was first named by Walker and Bancroft (1929, p. 10) from peak-forming exposures at Badshot Mountain known colloquially as the "Lime Dyke". In the Goat Range, the Badshot Formation outcrops along the shoreline of Kootenay Lake 3 km (2 mi) north of Kaslo. Fyles (1967, his Fig. 2) traced the unit farther north to the outlet of Schroeder Creek. Marble pods and

calc-silicate gneiss 1-3 meters thick and tens of meters in length occur along the contact between Hamill Group and the overlying Index Formation. These calcareous rocks have been included with the Index Formation although they may be the remnants of tectonically attenuated Badshot Formation.

In the study area, the Badshot and Mohican formations are mapped as one unit and consist of grey and white crystalline marble interleaved with calcite-plagioclase-diopside-amphibole-quartz gneiss and quartz-plagioclase-muscovite-biotite gneiss.

The greatest thickness of Badshot Formation in the study area occurs along the shore of Kootenay Lake where the 200 ft (61 m) cliffs expose a minimum thickness of 42 m (140 ft) of the Badshot.

No fossils have been found in the Badshot and Mohican formations in the Goat Range Study area. Archeocyathids have been recovered from the Badshot Formation in the Rogers Pass map-area (Wheeler, 1963, p. 6), from the northern Lardeau map-area (Wheeler et al., 1972b, p.48), and from the Reeves Limestone (Little, 1960, p. 34) in the Salmo area. A Lower Cambrian age is assigned to the Badshot Formation on this basis.

Depositional Setting Of The Badshot-Mohican Formations

The Badshot Formation in the Goat Range area is interpreted as shallow water, subtidal carbonate deposits with local archeocyathid-bearing bioherms, an environment analogous to that interpreted for a similar Early Cambrian sequence in southern California (Mount and Signor, 1985). The more pelitic composition of the intercalated Mohican Formation may represent local influx of mud, perhaps as sea level rose in the Early Cambrian (Bond and Kominz, 1984) and the sand/clay depositional interface migrated eastward with the shoreline.

LARDEAU GROUP

The Lardeau Group was originally mapped as the Shuswap series (Dawson, 1890; McConnell, 1897, p. 24A) from which the Lardeau series was separated out by Walker and Bancroft (1929) and divided into formations by Fyles and Eastwood (1962) with type-localities in the Ferguson area (Fig. 2). Read (1975, p. 29; Read and Wheeler, 1976) further refined the stratigraphy of the Lardeau Group. The basal Index Formation consists of calcareous phyllite in the east and includes a gritty facies to the west. Mafic volcanic rocks comprise the uppermost member of the Index Formation according to Fyles and Eastwood (1962). Overlying the Index Formation in the Ferguson area are massive siliceous phyllite of the lower Triune Formation and upper Sharon Creek Formation separated by quartzite of the Ajax Formation. These units grade westward into gritty units of the Index Formation. Read and Wheeler (1976) observed that the antithetic distribution of volcanic rocks within the Index Formation and those within the Jowett Formation, and repetition of facies similar to the intervening Triune-Ajax succession higher in the Broadview Formation suggest all volcanic rocks constitute a single lithostratigraphic unit. The Jowett Formation consists mainly of mafic pillow lava and greenschist, and is overlain by phyllite, grit and rare limestone of the Broadview Formation. Calcareous mica schist of the Early Bird Formation and quartz-garnet-mica-schist of the Princess Formation were named by Schofield (1920, p. 10) in the Ainsworth area. These units have been traced north (Fyles, 1967, p. 21-22) into the Goat Range area where they are correlated with the Index Formation. The Index Formation, and the southernmost occurrence of the Jowett and Broadview formations are exposed in the Goat Range.

Index Formation

The Index Formation was named by Fyles and Eastwood (1962, pp. 19-22) from exposures of grey and green phyllite, interbedded grey argillite and limestone, argillaceous limestone and volcanic rocks in the Index Creek basin in the Ferguson Area 80 km (50 miles) north of the Goat Range (Fig. 2). The succession in the Ferguson area consists of basal green phyllite overlain by a unit of grey phyllite or argillite with limestone at the base and at the top. Volcanic rocks succeed the upper limestone and may be a member of the Index Formation or alternatively the Jowett Formation. Carbonate beds in the upper part of the Index Formation were not recognized immediately northeast of the Goat Range in the Duncan Lake area (Fyles, 1964, p. 27).

In the Goat Range area the Index Formation occurs on the east side of the Blue Ridge from Kaslo River north to the south bank of Schroeder Creek (Fig. 3). The succession consists of basal green to grey calc-silicate gneiss and schist interlayered with mica schist and gneiss commonly containing garnet. Reddish-brown weathering impure marble pods are common in the basal hundred meters of the section. Calc-silicate gneiss contains the assemblage calcite-plagioclase-quartz-zoisite-actinolite ±diopside±microcline±sphene. Calc-schist commonly consists of quartz-calcite-biotite-plagioclase±muscovite. Opaques are granular and locally altered to leucoxene, indicating iron-titanium oxides. Biotite is commonly deep reddish brown. The basal calcareous section is overlain by rusty-weathering, dark grey mica schist and gneiss that also commonly contain garnet. These pelitic rocks are generally less quartz-rich than the overlying Broadview Formation.

Where the Jowett Formation overlies the Index Formation, brown-weathering crystalline marble at least 20 m (66 ft) thick is overlain by 10-20 m (33-66 ft) of mica-rich phyllite or schist, which is succeeded in turn by the Jowett Formation. This succession occurs on the 4500 ft bench north of Milford Creek and 2 km (1.2 mi) south of Mount Buchanan. Along the east side of the Blue Ridge south of Milford Creek and north of the Kaslo River the marble-schist-Jowett sequence is absent and the Broadview Formation overlies the Index Formation except where thin layers of biotite-amphibolite are present.

The lower contact of the Index Formation is not exposed but is mapped between outcrops of calc-silicate gneiss, calcareous schist, and marble and quartzite and quartzofeldspathic gneiss of Hamill Group. The upper contact is also unexposed. South of Mount Buchanan, silvery phyllite with quartzite beds is abruptly overlain by volcanic rocks of the Jowett Formation and is locally intruded by dykes of diorite and greenstone that feed the overlying volcanic rocks indicating an upright succession. North of Milford Creek, the contact between the Jowett Formation and upper Index Formation is intruded by a sill of the Kaslo River Intrusive Rocks. South of Milford Creek, the Jowett Formation is poorly developed (Fig. 3). In a 60 m (197 ft) thick interval rusty weathering, grey mica schist of the Index Formation becomes interbedded with grey quartzite beds 2-5 cm (0.8-2 in) thick, and near the top of the interval the abundance of green phyllite increases and these beds are mapped as Jowett Formation. As this gradational contact interval is traced south, the Jowett Formation apparently grades laterally into the Broadview Formation which then overlies the Index Formation. The Broadview-Index contact is also apparently gradational: quartz-rich schist and quartzite beds are



Figure 8: Calcareous schist and grey and black quartzites of the upper Index Formation. A calcareous bed traces out an F_1 fold which is cut by smaller F_2 structures abundant in this outcrop. This sequence may be lithologically correlative with the Triune-Ajax-Sharon Creek formations in the northern Kootenay Arc (Fyles and Eastwood, 1962). View to the northwest, north bank of Milford Creek.

interlayered with and underlain by rusty and red-weathering mica schist and gneiss. The interlayered zone is about 130 m (426 ft) thick.

The internal structure of the Index Formation is complex and its lower contact may be faulted, so thickness estimates only approximate stratigraphic thickness. The structural thickness of the Index Formation along Shetty and Wind creeks is about 590 m (1936 ft) after subtracting the thickness of intervening Kaslo River Intrusive Rocks.

No fossils have been found in the Index formation and its age must be assigned by correlation with fossiliferous rocks elsewhere. The Index Formation has been traced south to 10 km (6.2 mi) from the Laib Syncline in the Salmo Area, where it is correlated with the Emerald Member of the Laib Formation (Fyles, 1967, p. 61; Little 1960, pp. 34-35). The Emerald Member lies above the Lower Cambrian Reeves Limestone and below the Middle Cambrian Nelway Formation. The Index Formation also lies above the Lower Cambrian Badshot Formation. The Lardeau Group lies unconformably below the Upper Mississippian Davis assemblage of Milford Group. Thus the age of the Index Formation is lower Paleozoic and likely Lower Cambrian.

Jowett Formation

The Jowett Formation was named by Fyles and Eastwood (1962, p. 24-26) for volcanic and volcanoclastic sedimentary rocks occurring on Mount Jowett in the Ferguson Area. These volcanic rocks were considered by Fyles and Eastwood to be distinct from volcanic rocks in the upper Index Formation because of the intervening Triune Formation siliceous argillite, Ajax quartzite and Sharon Creek Formation argillite and quartzite. Read and Wheeler (1976) suggested that all the volcanic rocks in the middle part of

the Lardeau Group belong to the Jowett Formation and the lithologies of the Triune-Sharon Creek interval should be regarded as units in the upper Index (Fig. 8) and lower Broadview formations. The Jowett Formation, therefore, may intertongue with both Index and Broadview formations.

In the Goat Range area the Jowett Formation is mapped at an elevation of about 5000 ft (1524 m) south of Schroeder Creek and is traced south to an elevation of 4000 ft (1219 m) halfway between Milford and Kemball creeks (Fig. 3). It also occurs structurally above the Broadview Formation in the headwaters of Shuttery Creek and on the south slope of Mount Buchanan.

The Jowett Formation consists of quartz-chlorite-plagioclase schist and phyllite, amphibole-quartz-plagioclase greenstone and pillow lava (Fig. 9), and interbedded chlorite phyllite, grey mica phyllite and pyritic quartzite. Volcanic units north of Milford Creek have pseudomorphs of pyroxene and plagioclase in a finer grained greenstone matrix. Chloritic phyllite at the headwaters of Shuttery Creek and north of Milford Creek contains lenticular patches of dark greenish grey phyllite in a lighter matrix, suggesting a fragmental protolith. Intrusive rocks, interpreted as a feeder dyke for the Jowett volcanic rocks, occur between 3100 ft and 3400 ft (945-1036 m) elevation on the south face of Mount Buchanan. The basal contact of the foliated greenstone is discordant to the underlying grey phyllite and marble of the Index Formation. Carbonate xenoliths up to 10 m (33 ft) in diameter are present in the greenstones indicating the volcanic unit erupted through the underlying marble (Fig. 10). This relationship suggests the stratigraphic sequence is upright.

The composition of a pillow lava unit of the Jowett Formation located south of Mount Buchanan (Fig. 9) is a quartz-normative tholeiite (Table II). The CaO and MgO composition of this sample show the rock has been



Figure 9 (left): Flow
basalt of the Jowett Formation.
View to the north, southeast of
Mount Buchanan.

Figure 10 (below): Marble
xenolith of Index Formation
within a greenstone dyke of the
Jowett Formation. View north,
south slope of Mount Buchanan.

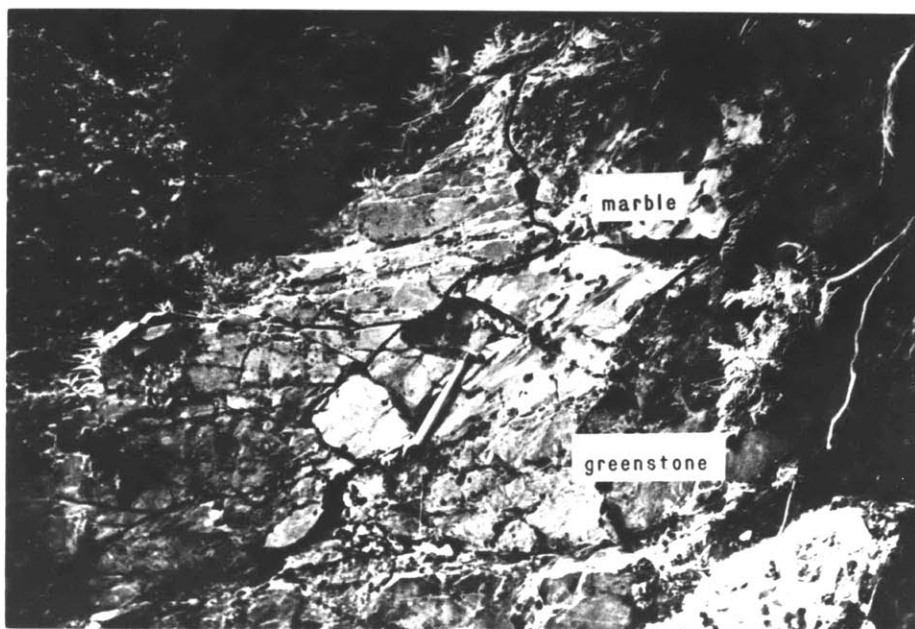


Table II: Chemical Analysis and Normative Composition of a Sample of Jowett Formation Pillow Lava

K83-14d			
weight percent		normative percent	
SiO ₂	46.6	Quartz	3.92
TiO ₂	1.80	Orthoclase	1.65
Al ₂ O ₃	11.7	Albite	15.23
Fe ₂ O ₃	3.7	Anorthite	23.02
FeO	7.4	Diopside	1.36
MnO	0.19	Hedenbergite	0.33
MgO	11.5	Enstatite	28.02
CaO	8.26	Ferrosilite	7.74
Na ₂ O	1.8	Forsterite	---
K ₂ O	0.28	Fayalite	---
		Magnetite	5.36
H ₂ O	4.9	Ilmenite	3.42
CO ₂	2.3	Apatite	0.46
P ₂ O ₅	0.20	Calcite	5.23
S	0.0	H ₂ O	4.90
Total	100.63	Total	100.64
		Normative Plagioclase:	
		Anorthite	60.18
		Albite	39.82

Analysis by the Analytical Chemical Section of the Geological Survey of Canada

K83-14d: 1.58 km at 163° from Mount Buchanan, 4770 ft elevation

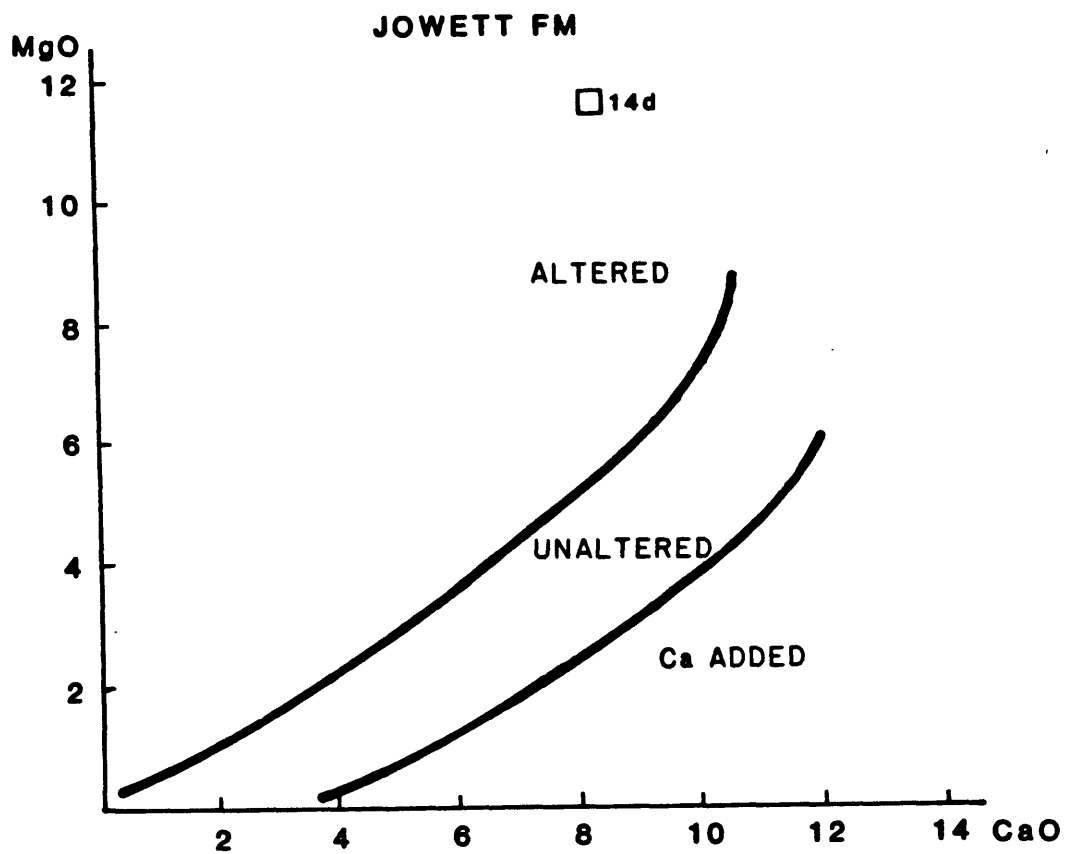


Figure 11: Weight percent MgO versus CaO plot of a sample of Jowett Formation pillow basalt indicating degree of alteration.

After De Rosen-Spence (1976, 1985).

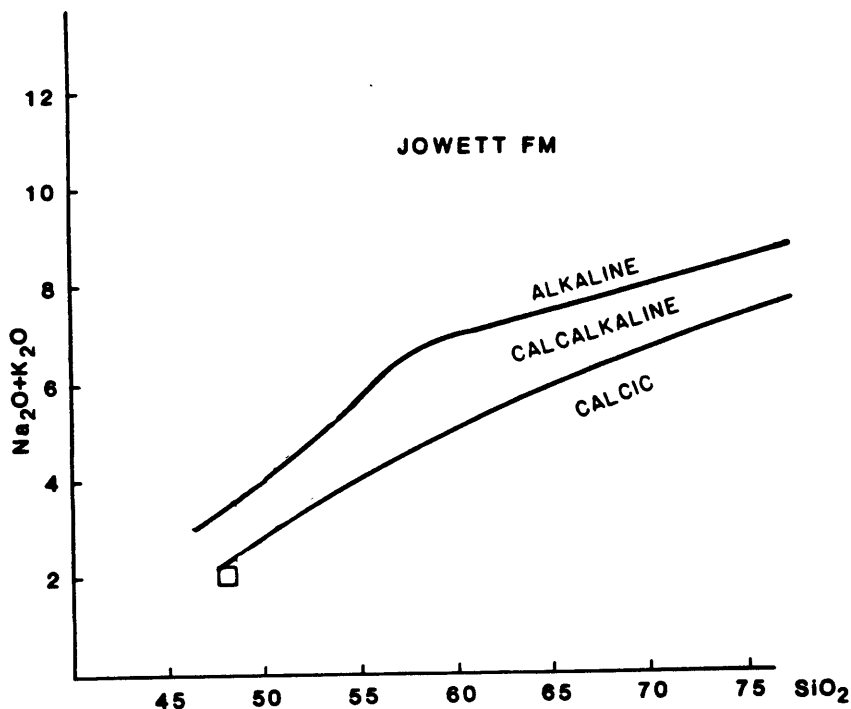


Figure 12: Weight percent Na₂O+K₂O versus SiO₂ plot of a sample of Jowett Formation pillow basalt indicating calcic affinity.

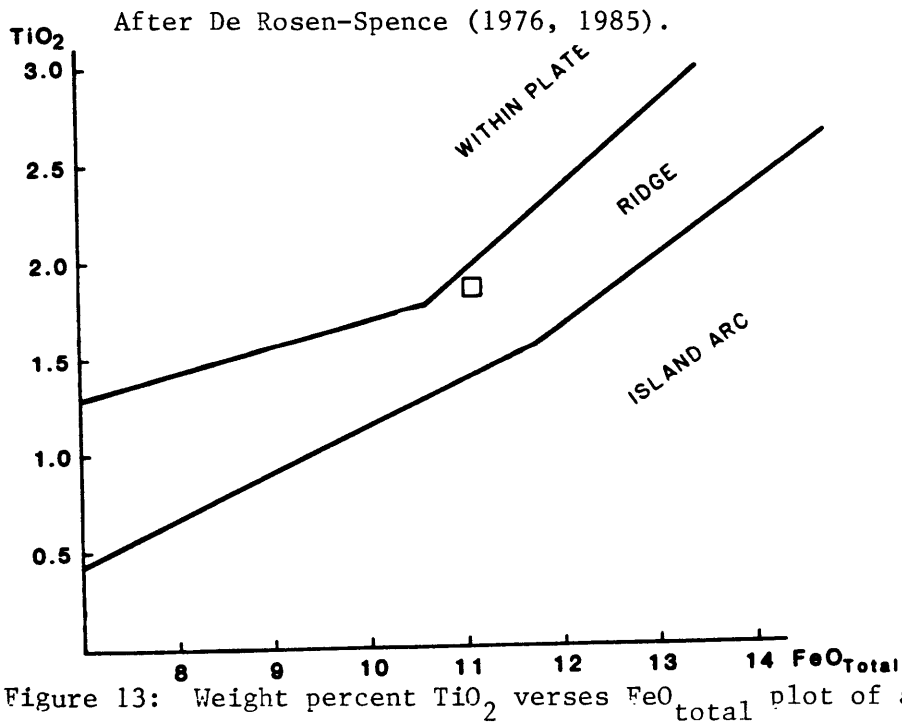


Figure 13: Weight percent TiO₂ versus FeO_{total} plot of a sample of Jowett Formation pillow basalt indicating ridge affinity, although this interpretation may be incorrect due to the alteration of the sample. After De Rosen-Spence (1976, 1985).

altered (Fig. 11). Alteration is also indicated from petrographic examination. Alkali: SiO_2 and TiO_2 : FeO total discrimination diagrams suggest the Jowett sample is of calcic affinity (Fig. 12) and a ridge-type basalt (Fig. 13) although these determinations are unreliable due to the alteration history of the rock.

The contact between the Jowett and Index formations is interpreted as conformable based on the intrusive relationship described above. Feeder dykes for the Jowett Formation were not recognized north of Milford Creek. The contact between the Jowett Formation and overlying Broadview Formation is not exposed but interpreted to be gradational. North of Milford Peak, green phyllite is interbedded on a scale of centimeters with pyritic bluish grey phyllite. The bluish grey phyllite is in turn interbedded with fine-grained quartzite and quartz granule grit characteristic of the Broadview Formation. This 40 m (131 ft) thick gradational sequence is correlative with the Triune-Ajax-Sharon Creek interval. South of Milford Creek, this sequence becomes dominated by grey phyllite and gritty quartzite. Green phyllite is absent 2 km south of Milford Creek. This relationship suggests an interfingering and gradational relationship between the Jowett and Broadview formations.

The thickness of the Jowett Formation is extremely variable. In the Ferguson Area, the estimated thickness ranges from 1500 to 3000 ft (457-914 m) (Fyles and Eastwood, 1962, p. 26). In the Goat Range, the Jowett Formation at Milford Creek is 560 m (1840 ft) thick and south of Mount Buchanan it is 400 m (1312 ft) thick. Between these localities, the unit pinches out along the Broadview Formation-Index Formation contact.

The age of the Jowett Formation is uncertain but is constrained between Lower Cambrian (Badshot Formation) and Upper Mississippian (Milford

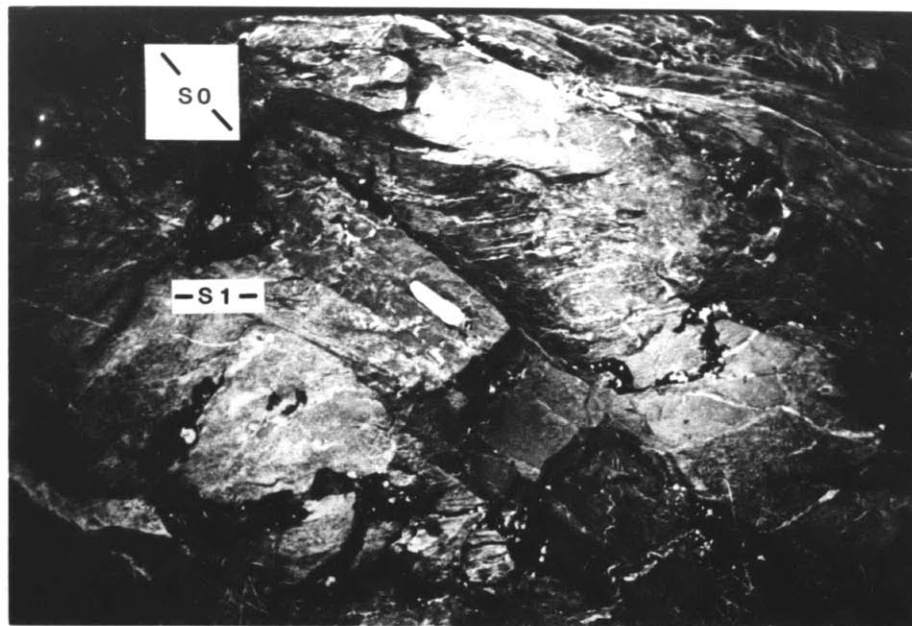


Figure 14: Grit and gritty phyllite of the Broadview Formation. Quartz-feldspar veinlets are mainly parallel to S1 foliation, here at a moderate angle to bedding. View east, south of McKian Creek Stock.



Figure 15: Quartz-pebble conglomerate and blue quartz-granule grit in the Broadview Formation. View west, southeast of Mount Buchanan.

Group). Read (in Brown et al., 1981, p. 352) interprets the age of deposition of the overlying Broadview Formation as 479 ± 17 Ma. Therefore the age of the Jowett Formation is lower Paleozoic and probably Cambro-Ordovician.

Broadview Formation

The Broadview Formation constitutes the uppermost formation of the Lardeau Group and was named by Fyles and Eastwood (1962, p. 27) from exposures of quartzite and poorly sorted quartz-granule clastic rocks (grits) along Broadview Creek and near the Broadview Mine in the Ferguson Area. The Broadview Formation generally consists of grey and green phyllitic grit and phyllite with characteristic thin veinlets, or "sweats" of quartz-feldspar along the foliation (Fig. 14). Gritty quartzites and feldspathic quartzites are present as well as minor recrystallized carbonate and calcareous phyllite (Read, 1973; pp. 10-16).

In the Goat Range, the Broadview Formation occurs along the eastern margin of the study-area north of Milford Peak. South of Milford Peak, the Broadview Formation occurs along the eastern slopes of the Blue Ridge. The Broadview Formation is also exposed west of the Spyglass and Schroeder faults along the edge of the McKian Creek stock in the headwaters of the Wilson Creek drainage and in the core of the northern segment of the Dryden anticline.

East of the Schroeder Fault and along the eastern slopes of the Blue Ridge, the Broadview Formation consists of grey to slightly rusty weathering quartz-muscovite-biotite-garnet schist and grit with secondary chlorite and muscovite, and rare plagioclase. Garnet porphyroblasts were not recognized above an elevation of 4100 ft (1250 m). Thick (to 2 m, 6.6

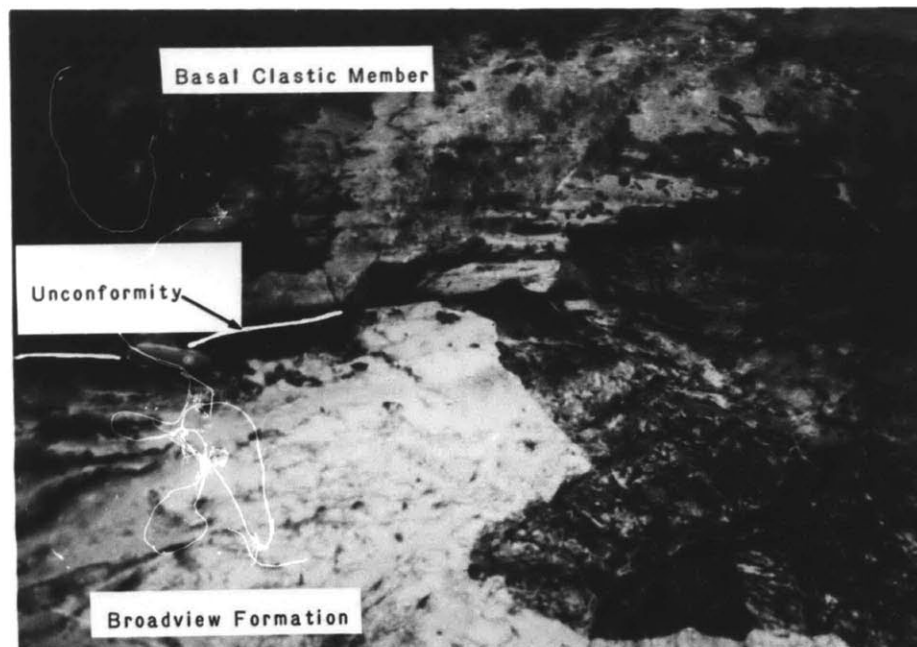


Figure 16: Exposure of the Milford Group - Broadview Formation unconformity. Metasandstone of the Basal Clastic Member of the Keen Creek assemblage unconformably overlies mica schist and feldspathic quartzite of the Broadview Formation which contains abundant quartz-feldspar pods and stringers. This exposure is found at 4362 ft (1330 m) elevation in Wilson Creek. View to the north.

ft) gritty quartzite beds are common. Quartz-pebble conglomerate and blue-quartz granule grit occurs 1 km (0.62 mi) east and 1.5 km (0.9 mi) southeast of Mount Buchanan (Fig. 5). The metamorphic grade of the Broadview Formation decreases with increasing elevation and to the northwest from Kaslo. Silvery phyllite interbedded with grit in the headwaters of Schroeder, Davis, and McKian creeks consists of opaque-rich (40 percent) quartz-muscovite-chlorite phyllite with rare biotite and subrectangular porphyroblasts containing fine-grained white mica. Gritty beds consist of quartz-rich (75 percent) muscovite-chlorite matrix with granules of quartz and rare albitic plagioclase porphyroblasts.

West of the Schroeder fault, in the core of the Dryden anticline and along the northern and southern margins of the McKian Creek Stock the Broadview Formation consists of quartz-rich biotite schist, bluish quartzite, and quartz-feldspar grit. Garnet occurs in pelitic rocks within 1 km (0.6 mi) of the McKian Creek Stock. A foliation (S1) defined by 1-2 mm (0.04-0.08 in) thick quartz-rich and biotite-rich layers is deformed into microfolds and is overgrown by micas with C-axes at a high angle to micas of the S1 fabric. These aligned micas define S2. About 5 percent of the micas overprint both S1 and S2 with an apparent random orientation. The randomly oriented micas are interpreted to be a hornfelsic recrystallization from intrusion of the McKian Creek Stock. The westernmost exposures of Broadview Formation consist of rusty-weathering quartz-rich biotite-muscovite-plagioclase schist, calc-schist, quartzite and grit with quartz and quartz-feldspar lenses and veinlets and occur along Wilson Creek northwest of McKian Creek Stock (Fig. 14). Garnet occurs in psammitic layers, and pyrite and pyrrhotite are common accessory phases. Calc-schist layers, consisting of bluish-to greenish-grey quartz-plagioclase-biotite ± carbonate are abundant in this area.

The contact of the Broadview Formation with the underlying Jowett Formation is apparently gradational as described above. Where the Jowett Formation is missing, the contact of the Broadview Formation with the underlying Index Formation is poorly defined. The contact was placed where rusty-weathering pelitic schist forms more than 50 percent of the sequence. Pelitic phyllite and schist of the Broadview Formation weather grey, wine-coloured, or only slightly rusty. This change in weathering colour coincides with a large increase in the amount of plagioclase or carbonate minerals, characteristic of the calcareous pelite of the Index Formation.

The contact of the Broadview Formation and overlying Milford Group is an angular unconformity (Wheeler, 1966; Read and Wheeler, 1976; Klepacki and Wheeler, 1985). East of the Schroeder fault the contact between the two units is commonly a fault. However exposures of the unfaulted contact are present along Davis Ridge, and in the headwaters of Schroeder Creek and Milford Creek. The upper part of the Broadview Formation contains quartz and quartz-feldspar stringers which are absent in the overlying Davis assemblage of the Milford Group. On the ridge 1.5 km (0.9 mi) at 030° from Mount Schroeder (Fig. 3) an early foliation restricted to the Broadview Formation is at a high angle the foliation present in the Davis assemblage. The basal carbonaceous argillite of the Davis assemblage contains pods of white vein quartz-pebble conglomerate, probable derived from quartz stringers in the Lardeau Group. West of the Schroeder fault, the Broadview Formation unconformably underlies the Keen Creek assemblage of Milford Group. In the core of the Dryden anticline, 4.3 km (2.7 mi) at 325° from Mount Stubbs, bedding and an S1 fabric restricted to the Broadview Formation are at a high angle to the S1 fabric in a tuffaceous conglomerate

at the base of the Keen Creek assemblage. The crenulation cleavage S2 fabric in the Broadview Formation has the same orientation as the S1 fabric in the younger Davis assemblage, therefore the S2 fabric in the Broadview Formation is the same s-surface as the S1 fabric in the Keen Creek assemblage. In a stream-washed outcrop in Wilson Creek at an elevation of 1330 m (4362 ft), siliceous plagioclase-rich metasandstone of Keen Creek assemblage contains subrounded, matrix-supported clasts of quartz and feldspar (Fig. 16). The metasandstone directly overlies grey and green mica schist and feldspathic quartzite of Broadview Formation. The Broadview Formation also contains abundant veinlets of quartz and feldspar conspicuously absent in the overlying metasandstone.

The thickness of the Broadview Formation can only be estimated: the lower contact with the underlying Index Formation was mapped only in the southeastern part of the map area and the upper contact is a pre-Late Mississippian thrust fault or the unconformity with overlying Milford Group. The maximum thickness of Broadview Formation in the Goat Range area occurs along Milford Creek where a structural thickness of 1337 m (4386 ft) can be measured. A minimum thickness of 532 m (1745 ft) is present along Wing Creek where both upper and lower contacts were mapped (Fig. 2).

The Broadview Formation has yielded no fossils. Read has obtained an Rb-Sr whole rock isochron of 479 ± 17 Ma from clasts derived from the Broadview Formation present in conglomerate of the Milford Group (Read and Wheeler, 1976; Brown et al., 1981, p. 352). Rb-Sr whole rock dates on meta-sedimentary rocks are difficult to interpret (Parrish, 1981, p. 954) and may represent an age range from the provenance of the sediments to the age of metamorphism. Read interprets this date as the age of deposition of

the Broadview Formation. This Lower to Middle Ordovician date is consistent with the pre-Upper Mississippian age necessary from relationships with the overlying Milford Group.

Depositional Setting Of The Lardeau Group

The stratigraphy of the Lardeau Group may be best understood in the context of a rift or transtensional setting. A rift environment has been postulated for the underlying Hamill Group (Bond and Kominz, 1984; Devlin et al., 1983, Devlin and Bond, 1984) and for Cambro-Ordovician strata similar to the Lardeau Group in the Selwyn Basin of southeastern Yukon and adjacent Northwest Territories (Gordey, 1981; Mortensen, 1982, p.9).

The Index Formation may represent fine clastic sediments deposited on a thermally subsiding carbonate shelf composed of the underlying Badshot-Mohican formations. Mafic volcanism constituting the Jowett Formation and coarse clastic grits of the Broadview and Index formations (Read, 1975, 1976) are interpreted as products of renewed rifting and clastics derived locally from a topographically high area created by faulting. This highland apparently lay to the west as Read (1975) noted a westward coarsening in grain size in the Broadview and Index formations.

MILFORD GROUP

The Milford Group east of the Blue Ridge was first included in the Shuswap Series by McConnell (1897, p. 25A) and mapped as the Niskonlith series by McConnell and Brock (1904). LeRoy, working with Drysdale (1917, p. 57) included the eastern belt of Milford Group rocks with the Slocan Series in the "Milford Syncline" and assigned a Cambro-Ordovician age to the series. Bancroft (1920, p. 42-43B) included strata presently assigned to the Slocan Group east of the Dryden anticline to the Milford Series, thought at that time to be of Jurassic age. Strata east of the Schroeder fault presently assigned to Milford Group were considered part of the Slocan Series and correlated with the main body of Slocan Series near Sandon. Cairnes (1934, p. 38) defined the Milford Group from exposures of the Milford Series and the eastern belt of the Slocan Series along Schroeder ridge and south along the eastern slopes of the Blue Ridge. The upper 762 m (2500 ft) of his section was later recognized as Slocan Group (Read and Wheeler, 1976). Cairnes (op. cit.) also mapped rocks of the McHardy assemblage that occur on the west slopes of Mount Buchanan as belonging to the Milford Group. Read and Wheeler (1976) mapped Carboniferous units on the southern, western and northern margins of McKian Creek Stock as Milford Group, expanding earlier mapping by Read (1973).

In general, the Milford Group consists of a basal limestone and argillaceous limestone sequence overlain by siliceous argillite, metasandstone, cherty tuff and volcanic rocks, all of Carboniferous age. Conglomeratic horizons have clasts of older metamorphic and igneous rocks and chert, sandstone, and limestone. Milford Group is exposed along the eastern slope of the Goat Range and underlies younger rocks to the west. It has been traced north from the Goat Range through the Lardeau

Range to northern shores of Upper Arrow Lake (Read and Wheeler, 1976) and south along the eastern Kokanee Range (Fyles, 1967) into the Nelson Range (Leclair, 1984). In the Goat Range (Klepacki and Wheeler, 1985; Klepacki, Read and Wheeler, 1985) the Milford Group consists of three assemblages in fault contact with each other (Fig. 7). The easternmost, Davis assemblage, occurs east of the Schroeder and Spyglass faults and consists dominantly of siliclastic rocks, limestone and tuffaceous rocks. The Keen Creek and McHardy assemblages lie west of the Schroeder fault. The Keen Creek assemblage occurs along the southern, western and northern margins of the McKian Creek stock and consists mainly of interbedded volcanic rocks and limestone. The McHardy assemblage is thrust over the Keen Creek assemblage along the Stubbs thrust fault and consists mainly of siliceous argillite. These three assemblages are linked by coeval uppermost Mississippian volcanic rocks and by deposition on or adjacent to the Lardeau Group (Klepacki, Read and Wheeler, 1985).

Davis Assemblage

Milford Group east of the Schroeder and Spyglass faults is assigned to the Davis assemblage. The succession is well exposed on Davis and Schroeder ridges (Fig. 17), the latter location includes the section of Milford Group described by Cairnes (1934, p. 38). In the central part of the Goat Range the Davis assemblage consists of, in ascending stratigraphic order, rare basal quartz-pebble conglomerate within fetid black argillaceous limestone; limestone; interbedded phyllite, limestone and metasandstone, cherty tuff and phyllitic greenstone overlain by grey siliceous argillite. In the southern Goat Range upper units are truncated by the Schroeder Fault and the assemblage consists of a basal limestone overlain by interbedded phyllite, limestone, and siliceous argillite. In

the northern part of the study area and the southern part of the Poplar Creek map area (Read, 1973), the Davis assemblage consists of a basal limestone, interbedded phyllite, metasandstone and siliceous argillite overlain by bedded siliceous argillite. The basal limestone overlies the Lardeau Group everywhere at the base of the Davis assemblage. Overlying units interfinger with each other or are truncated by the Schroeder fault. The thickness of the Davis assemblage is uncertain because the upper contact is a fault and because of structural repetition within the sequence. A maximum structural thickness of the Davis assemblage is present on the ridge south of Spokane Creek where 2100 m (6890 ft) of folded strata occur. A minimum thickness (of 100 m (328 ft) is present east of Mount Buchanan. A typical thickness of 1400-1450 m (4593-4757 ft) is found along Schroeder or Davis ridges. The Davis assemblage is Late Mississippian (Early Namurian) in age, based on conodonts from near the base and top of the sequence (Orchard, 1985, p. 294).

Limestone Member

The limestone member is the oldest mappable unit of the Davis assemblage and has long been recognized as an important part of the Milford Group (Drysdale and LeRoy's map, 1917). It is here mapped as an informal member of the Milford Group. The limestone extends the length of the map area and continues north into the Poplar Creek area (unit 14 of Read, 1973) and south into Kaslo-Ainsworth area (Fyles, 1967). The limestone member consists of bedded blue-grey and light to dark grey fine-grained limestone (Fig. 18). It weathers into flaggy fragments that commonly delaminate along parallel bedding surfaces. Bedding is typically 1-10 cm (0.5-2 inch) thick and is defined by colour contrast and pelitic partings with beds up to 2 cm (0.80 in) thick. Locally, the limestone is finely laminated with

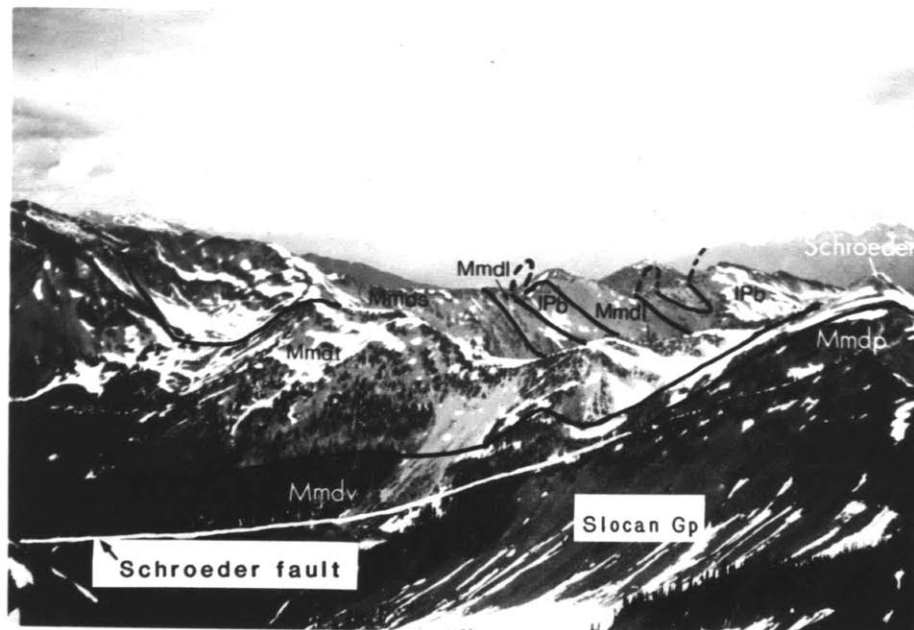


Figure 17: Panorama of the Mount Schroeder area. View northeast from Mount Jardine showing ridges underlain by Davis assemblage and Broadview Formation.



Figure 18: Limestone Member of the Davis assemblage. Note the well-bedded character and sill of(?) Kaslo River Intrusive. View northeast, north side of Wing Creek.

lamellae less than 1 mm thick and of contrasting colour. Pelitic material is dark grey to silvery phyllite. About 1.9 km (1.4 mi) north of Mount Schroeder approximately 20 m (66 ft) of fetid carbonaceous limestone occurs at the base of the member and contains lenses of clast-supported quartz-pebble conglomerate. Clasts are rounded and consist of polycrystalline quartz aggregates with grains up to 8 mm (0.3 in) in diameter. The limestone member unconformably overlies the Lardeau Group although the contact is in most places a fault. Unfaulted contacts occur where large scale F_2 folds are well developed, specifically at the headwaters of Schroeder Creek and in the Milford Creek-Kemball Creek area (see Fig. 3). The contact of the limestone member with the overlying sandstone and phyllite member is well exposed along Schroeder and Davis ridges and is gradational. Grey limestone is interbedded with grey siliceous argillite or phyllite; in a 10 m (33 ft) interval the rock varies from 70 percent limestone to 70 percent siliceous argillite or phyllite. The gradational interval is thicker to the north reaching 70 m (230 ft) thick north of Spokane Creek. The thickness of the limestone member varies from 70 m (230 ft) east of Mount Buchanan to 900 m (2953 ft) north of McKian Creek. A typical thickness of 220 m (722 ft) is present in the headwaters of Schroeder Creek.

The age of the limestone member of Davis assemblage has been established as Upper Mississippian (Early Namurian) on the basis of several conodont collections, mainly from the ridge 5 km (3.1 mi) east-northeast of Mount Cooper, and along the ridge 2.1 km (91.3 mi) north of Mount Schroeder (Orchard, 1985). Although crinoid parts, brachiopod valves, and gastropod debris are abundant in some layers, little work has been done on these fossils. Genera and species of conodonts identified in the limestone

member of the Davis assemblage are listed in table III. A brachiopod collection made in 1917 by M.F. Bancroft "from the ridge east of Cooper Mountain and obtained near the base of the group" was reported by E.M. Kindle (Bancroft, 1917, page 37) as including "Athyris sp. undtr. and Spirifer cf. marionensis. The presence of a spirifer which is either identical or closely related to sp. cameratus seems to place this horizon in the Pennsylvanian." Conodont collections from the same locality (Locality 1, table III) indicates the limestone here is of Late Mississippian age.

Sandstone and Phyllite Member

The sandstone and phyllite member of the Davis assemblage conformably overlies the limestone member. This unit comprises unit 15 (micaceous metasandstone) and unit 16 (limy micaceous metasandstone) of Read (1973, pp. 22-24) and part of uMmp (grey and brown phyllite and metasandstone) of Read and Wheeler (1976). The best exposures of the sandstone and phyllite member occur east of Mount Schroeder between 1829 and 2134 metres (6000 and 7000 feet) elevation (Fig. 19). Good exposures are also present 80-1800 m (2625-4921 ft) south of the summit of Mount Davis where pink- to light brown-weathering grey sandstone beds 1 cm to 1.5 m (0.4 in-4.9 ft) thick are interbedded with silvery grey phyllite. North of Cooper Creek sandstone beds decrease in thickness and abundance and light to dark grey calc-arenite and dark grey siliceous argillite constitute up to 70 percent of the rock sequence. East and south of Milford Peak the abundance of sandstone beds also decreases and the sandstone and phyllite member grades upward and laterally into bedded grey siliceous argillite and limestone of the overlying siliceous argillite member. In general, sandstone is most abundant in the lower hundred meters of the sandstone and phyllite member.

TABLE III - Conodont Age Determinations of the Milford Group
After Orchard, 1985

Assemblage, Member	Loc. GSC No.		Age	CAI ¹
Davis, Limestone	1 O-68715	X	Late Visean-Early Namurian	5-6
Davis, Limestone	1 C-87712	? ? X X X	Early Namurian	5-7
Davis, Limestone	1 C-87713	? X X X	Early Namurian	5-6
Davis, Limestone	2 O-93545	?	Carboniferous?	6
Davis, Limestone	3 C-87156	? X	Early Namurian	5-6
Davis, Limestone	4 C-103387	X	Late Visean-Early Namurian	5-6
Davis, Cherty Tuff	5 C-87155	X X	Early Namurian	5
Keen Ck, Banded Limestone	6 C-87160	X X	Early Namurian	6-7
Keen Ck, Banded Limestone	6 C-87161	? X	Early Namurian	6
Keen Ck, Banded Limestone	7 C-87165	X X	Early Namurian	6
Keen Ck, Banded Limestone	8 C-87714	X	Early Namurian	6
Keen Ck, Banded Limestone	8 C-87167		X Late Namurian- Wolfcampian	6-7
Keen Ck, Banded Limestone	8 C-87169		? X Late Namurian- Early Bashkirian	6-7
McHardy, Carbonate	9 C-116334		X Early-Mid Namurian	5
McHardy, Carbonate	9 C-116335	X	Early Namurian	5

Location Index:

- 1) Ridge 4.99 km at 080° from Mount Cooper, 7500 ft
- 2) Ridge separating Davis and Schroeder creeks, 7500 ft
- 3) 1.61 km at 250° from Mount Cooper, 7100 ft
- 4) 1.71 km at 082° from Mount Schroeder, 7400 ft
- 5) 0.23 km at 110° from Mount Schroeder, 7300 ft
- 6) 4.26 km at 294° from Mount Cooper, 8250-8300 ft
- 7) 4.31 km at 294° from Mount Cooper, 8100 ft
- 8) 1.6 km at 250° from Mount Cooper, 7100 ft
- 9) Old railway cut, 1.55 km at 131° from confluence of Keen Ck. and Kaslo R.,
2394 ft

¹Conodont Colour Alteration Index

The sandstone consists of fine-grained quartz-carbonate minerals -plagioclase-chlorite-muscovite with quartz comprising 65 percent of the rock. Opaques are rusted and produce wisps of insolubles parallel to the elongation direction of mineral grains. Phyllite consists of quartz-muscovite-chlorite-plagioclase-opaque phyllite. Biotite is present in the phyllite north of South Cooper Creek.

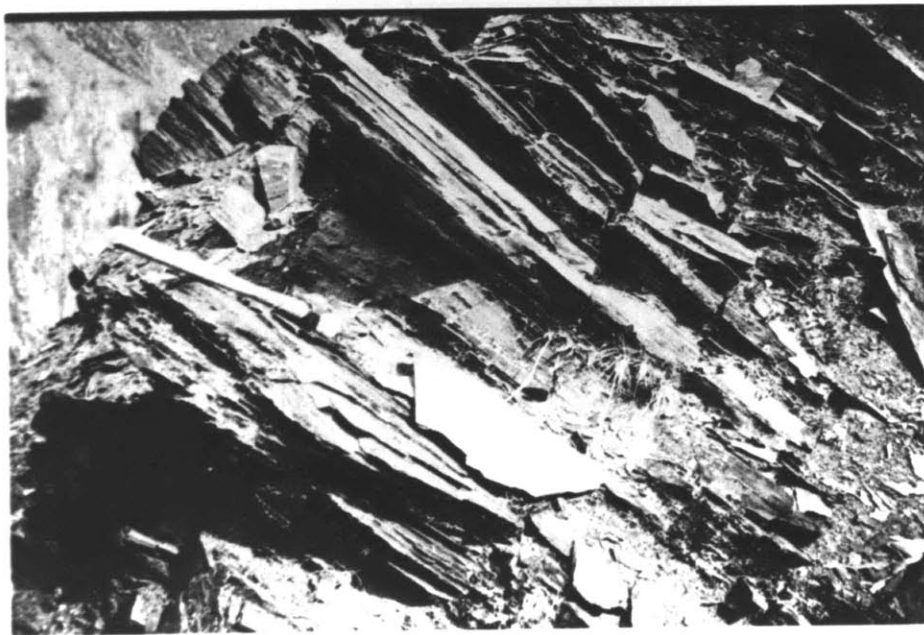
The contact of the sandstone and phyllite member with the underlying limestone member is gradational and is drawn where limestone constitutes more than 50 percent of the section. The contact with the overlying cherty tuff member south of South Cooper Creek and with the siliceous argillite member north of South Cooper Creek is also gradational. The contact with the cherty tuff member is well exposed 500 meters (1640 ft) north of Mount Schroeder at an elevation of 2134 m (7000 ft). Sandstone and phyllite grade upward into a black siliceous cherty argillite which, in turn grades into green siliceous slate and green and white cherty tuff. The gradational interval is about 1-2 meters (3.3-6.6 ft) thick. North of Cooper Creek the contact of the sandstone and phyllite member with the siliceous argillite member is difficult to define because grey to black siliceous argillite is abundant in both members. The contact is drawn where calcarenite beds comprise less than 30 percent of the section, or where white or light grey siliceous argillite or phyllite is a major constituent of the section.

Primary and secondary facing indicators are present in the sandstone and phyllite member. North of Mount Schroeder at an elevation of 2124 m (6970 ft), and at 2050 m (6725 ft) at 322° from Mount Schroeder, at an elevation of 2347 m (7700 ft), scour structures in the sandstone indicate these strata young to the west (Fig. 16). Bedding is commonly at an angle



Figure 19 (left): Sandstone and Phyllite Member of the Davis assemblage. Upper sandstone bed truncates lower sandstone bed indicating upright section in this view to southwest, headwaters of Rossiter Creek.

Figure 20 (below): Siliceous Argillite Member of the Davis assemblage. Flaggy dark pelitic phyllite and white and grey siliceous argillite. View northeast, ridge between Cooper Creek and South Cooper Creek.



to cleavage (S1 in Milford Group) and relationships generally show structural facing to the west, but locally strata are east-dipping and upright.

The apparent thickness of the sandstone and phyllite member varies from 0 south of Milford Peak to a maximum thickness of 1280 m (4200 ft) immediately north of Cooper Creek. The structural thickness of the unit in the area of Mount Schroeder is 700 m (2296 ft) although the rocks in this area contain well developed internal folds, a feature common in the sandstone and phyllite member. The age of the sandstone and phyllite member is Late Mississippian (Early Numerian) as Upper Mississippian conodonts have been recovered from the underlying limestone member and from the overlying cherty tuff member.

Siliceous Argillite Member

The siliceous argillite member occupies several stratigraphic levels in the Davis assemblage. In part it overlies and is laterally equivalent to the sandstone and phyllite and cherty tuff members. The siliceous argillite member is correlative with unit 17 (grey phyllite and impure meta-sandstone) of Read (1973, p. 24) and part of uMmp (grey and brown phyllite and meta-sandstone) of Read and Wheeler (1976). The siliceous argillite member is best developed on the ridges north and south of Spokane Creek. It generally consists of black, grey or white siliceous argillite commonly interbedded with light grey limestone or calcarenite or tan-weathering metasandstone (Fig. 20). The siliceous argillite member is distinguished from the sandstone and phyllite member by a greater (more than 50 percent) abundance of siliceous material rather than pelitic phyllite and the paucity (less than 30 percent) of beds of metasandstone.

North of South Cooper Creek, the siliceous argillite member contains abundant beds of limestone and calc-arenite within the basal 100 m (328 ft) of section and most of the overlying unit consists of well-bedded grey to white siliceous argillite. The well-bedded character helps to distinguish it from more massive siliceous argillite of the McHardy assemblage. South of South Cooper Creek, the siliceous argillite member interfingers with and overlies the cherty tuff and greenstone members. Green and white cherty tuff grade into grey and black siliceous argillite west of Mount Davis. On Mount Schroeder and in the headwaters of Davis Creek, dark to medium grey bedded siliceous argillite overlies the greenstone member. South of Milford Peak the siliceous argillite member overlies the limestone member. The boundary with the laterally equivalent sandstone and phyllite member is arbitrarily drawn at the northeast trending fault south of Milford Peak (Fig. 3). Siliceous argillite is more abundant than metasandstone south of this fault and a lateral facies change between the sandstone and phyllite member and siliceous argillite member is present near the fault. The siliceous argillite member south of Milford Peak contains 1 to 75 cm - (0.4 to 30 in) thick beds of metasandstone and limestone in its lower half, whereas its upper half is mainly grey and white siliceous argillite.

The contacts of the siliceous argillite member with the other members of the Davis assemblage are all conformable and gradational, although locally the contact with the cherty tuff and greenstone members is faulted. The upper contact along most of the outcrop area of the siliceous argillite member is the Schroeder Fault. North of Spokane Creek and south of Shuttery Creek the more massive siliceous argillite of McHardy assemblage is faulted against well-bedded siliceous argillite of the Davis assemblage. Additionally, the presence of foliated diorite dykes and sills distinguish

the McHardy assemblage. South of Cooper Creek and north of Kemball Creek the siliceous argillite member is faulted against slate and phyllite of the Slocan Group. The contrast between the more siliceous character of the siliceous argillite member and the more pelitic and foliated character of the Slocan Group help to define the presence of the Schroeder fault.

The thickest section of siliceous argillite member is present on the ridge between Cooper Creek and South Cooper Creek where 780 m (2560 ft) are exposed between the sandstone and phyllite and cherty tuff members. North of McKian Creek, the section is 720 m (2362 ft) thick although this sequence is truncated by the Spyglass fault. East of Mount Buchanan 120 m (394 ft) of the siliceous argillite member is preserved but this sequence is also truncated by the Schroeder fault.

The age of the siliceous argillite member is Late Mississippian as it overlies the Upper Mississippian limestone member and interfingers with the Upper Mississippian cherty tuff member. A younger age is possible for siliceous argillite that overlies the greenstone member.

Cherty Tuff Member

The quartz-rich cherty tuff member of the Davis assemblage was first recognized by LeRoy (Drysdale's Map, 1917). Bancroft (1920, p. 43B) noted that the local Indians used this flinty rock for arrowheads. Cairnes (1934, p. 40 and Map 273A) included the greenstone member with the cherty tuff member in the Milford Group. Read and Wheeler (1976) also mapped a chert unit that includes rocks that have been assigned here to the siliceous argillite member. The cherty tuff member is restricted to medium- to very fine-grained purple and green to white finely bedded cherts and tuffaceous argillites (Fig. 21). The unit is truncated by the Schroeder fault along the ridge between Cooper Creek and South Cooper

Creek. It is traced south to the headwaters of Shutty Creek where it is again truncated by the Schroeder fault. A typical section is exposed 200 to 500 m (565 to 1640 ft) north of Mount Schroeder. Grey siliceous slate 2 to 4 m (6 to 13 ft) thick is transitional from the sandstone and phyllite member and is overlain by about 150 m (492 ft) of purple slaty chert that forms the basal part of the cherty tuff member. The purple slaty chert is succeeded by 50 m (164 ft) of banded light green siliceous slate that is overlain by about 120 m (394 ft) of white and green finely laminated cherty tuff. The cherty tuff member is overlain by greenstone and pillow breccia of the greenstone member. In thin section the cherty tuff unit consists of about 70 percent fine-grained quartz with serrated boundaries. Plagioclase porphyroblasts, chlorite, muscovite, epidote, biotite and about 2 percent iron oxide minerals constitute the remainder of the rock. Cairnes (1934, p. 40) reports a whole rock analysis of the cherty tuff made by W.A. Jones that contained 92 percent silica. The member is named the cherty tuff member because of its proximal relationship to the overlying volcanic greenstone member and presence of feldspar porphyroblasts and certain layers which contain an abundance of chlorite and/or actinolite in addition to feldspar suggesting a mafic volcanic origin. The protolith of the cherty tuff is interpreted to be siliceous volcanic exhalatives (Cairnes, 1934, p. 40; Kalogeropoulos and Scott, 1983). Purple cherts of the cherty tuff member are restricted to the area between Davis Creek and Schroeder Creek. North and south of the sequence containing purple chert the member is composed mainly of finely layered white and green cherty tuff with rare, thin purple layers.

The cherty tuff member has a gradational contact with the underlying sandstone and phyllite or siliceous argillite members. The contact is well exposed 500 m (1640 ft) north of Mount Schroeder. The contact with the overlying greenstone member is also gradational and well exposed at Mount Schroeder and the ridge separating the headwaters of Rossiter Creek from Davis Creek. Green and white laminated chert at the top of the cherty tuff member includes beds of phyllitic greenstone and granular, epidote-rich volcanic metasandstone. The contact between the cherty tuff and greenstone members is placed along this 4 m (13 ft) thick transitional interval. Rocks of the transitional interval grade up into massive greenstone, pillow breccia, and volcanic conglomerate of the greenstone member.

The maximum thickness of the cherty tuff member is 610 m (2001 ft) on the ridge 3 km (1.9 mi) southeast of Schroeder Peak. A more typical thickness of 300 m (984 ft) is present in the Mount Schroeder-Davis Ridge area. The unit interfingers to the north with the siliceous argillite member and is terminated by the Schroeder fault to the south.

The age of the cherty tuff unit is Late Mississippian (Early Namurian). Wheeler collected conodonts from a lense of crinoidal limestone in the cherty tuff, 320 m at 110° from Mount Schroeder. They were identified by M.J. Orchard (Orchard, 1985) as Early Namurian.

Greenstone Member

The greenstone member of the Davis assemblage overlies the cherty tuff member. The unit was first recognized by Cairnes (1934, p. 40) who included it within his chert unit. Good exposure at the summit of Mount Schroeder reveals that the greenstone member comprises massive greenstone, pillow breccia, volcanic conglomerate, phyllitic greenstone and cherty tuff (Fig. 22). The greenstone member is truncated at its north end by the



Figure 21: Cherty Tuff Member of the Davis assemblage. Finely laminated green, white and purple cherty tuff. View northwest, northwest of Milford Peak.

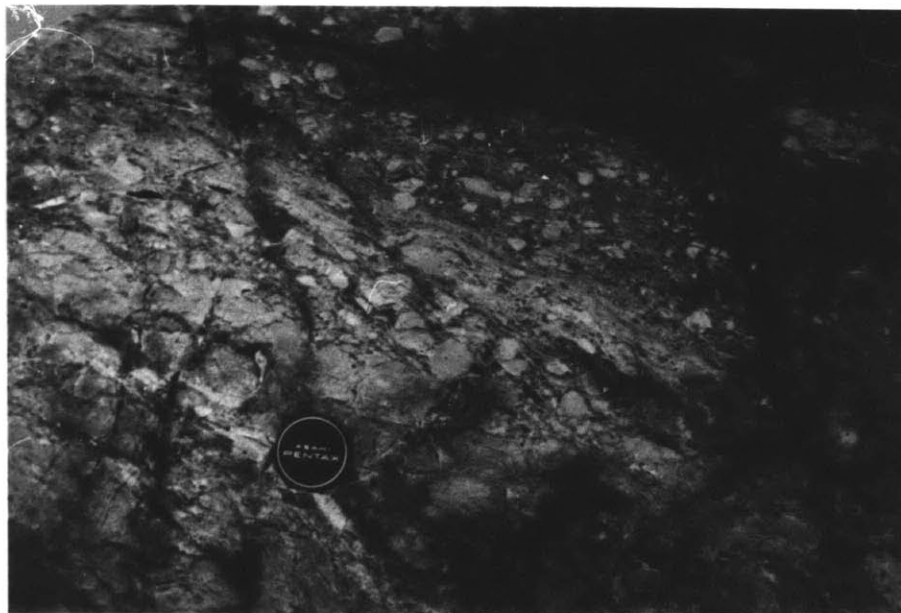


Figure 22: Greenstone Member of the Davis assemblage. Tholeiitic pillow breccia and volcanic conglomerate at Mount Schroeder.

Schroeder fault 1.5 km (0.93 mi) southwest of Mount Davis. It has been traced south to 1.3 km (0.81 m) southeast of Milford Peak. Massive greenstone is best developed at Mount Schroeder from where it continues 2.5 km (1.6 mi) to the northwest and 3 km (1.9 mi) to the southeast.

Pillow-like lenticular structures 20 cm (7.8 in) long and up to 8 cm (3.1 in) wide are present in some greenstone layers. The greenstone is composed of green and brown biotite, plagioclase, quartz, clinoamphibole, epidote and iron oxides. Rare quartz and carbonate veinlets traverse the rock and the plagioclase is mostly saussuritized.

A sample of massive greenstone collected from Mount Schroeder has the composition of olivine-normative basalt (Table IV). On a CaO:MgO diagrams (Fig. 21) the Mount Schroeder sample plots well within the altered basalt field. On an alkali ($\text{Na}_2\text{O}+\text{K}_2\text{O}$): SiO_2 diagram (Fig. 22) the sample plots on the boundary between the alkaline and calcalkaline fields. This determination may be valid despite the alteration history of the sample because the analysis plots among other Milford Group volcanic rocks. On a TiO_2 :FeO total diagram (Fig. 23) the Mount Schroeder sample plots within the island arc basalt field. The addition or subtraction of iron during alteration casts some uncertainty upon this determination, especially since other Milford Group samples fall within the within plate field. North and south of the belt of massive greenstone, the greenstone member is composed largely of volcanic conglomerate and cherty tuff. Volcanic conglomerate commonly contains clasts of greenstone, amygdaloidal basalt, and white chert pebbles. Serpentinite clasts are present at Mount Schroeder and at an elevation of 2164 m (7100 ft), 2.8 km (1.74 mi) at 299° from Mount Schroeder.

Table IV: Chemical Analyses (Weight Percent) and Normative Compositions (Percent) of Volcanic Rocks in the Milford Group

	MT SCH	K83-49h	K83-48e	K83-48e2	K83-45i	K83-48j	K83-43a
SiO ₂	48.8	48.1	48.6	48.2	48.7	52.3	46.7
TiO ₂	1.82	2.43	2.26	2.28	2.41	2.77	1.87
Al ₂ O ₃	13.6	14.3	16.3	15.8	13.6	13.1	13.4
Fe ₂ O ₃	2.1	4.1	2.9	3.1	5.6	5.3	5.3
FeO	10.9	7.9	7.9	7.7	6.3	7.9	9.0
MnO	0.25	0.18	0.16	0.16	0.18	0.18	0.27
MgO	8.61	6.33	6.33	6.10	7.07	5.12	6.89
CaO	5.48	9.62	9.74	9.67	10.4	6.94	8.89
Na ₂ O	3.7	3.0	3.8	3.6	3.1	4.7	2.4
K ₂ O	0.17	0.38	0.20	0.17	0.23	0.07	0.44
H ₂ O	4.5	2.3	1.4	1.3	1.9	0.7	3.6
CO ₂	0.2	0.5	0.1	0.0	0.3	0.1	0.4
P ₂ O ₅	0.18	0.32	0.29	0.27	0.29	0.38	0.20
S	0.01	0.08	0.00	0.04	0.11	0.02	0.45
Total	100.32	99.34	99.98	98.39	100.19	99.58	99.81
Quartz	---	2.12	---	---	2.67	4.52	2.78
Orthoclase	100	2.25	1.18	1.00	1.36	0.41	2.60
Albite	31.31	25.39	32.15	30.46	26.23	39.77	20.31
Anorthite	20.00	23.88	26.83	26.45	22.51	14.44	24.49
Diopside	2.37	10.71	10.41	10.97	17.38	9.74	9.13
Hedenbergite	1.52	4.31	4.99	5.05	2.64	3.89	4.01
Enstatite	13.86	10.80	3.09	5.76	9.55	8.24	12.93
Ferrosilicate	10.16	4.99	1.70	3.04	1.67	3.78	6.51
Forsterite	4.55	---	5.50	3.05	---	---	---
Fayalite	367	---	3.34	1.78	---	---	---
Magnetite	3.04	5.94	4.20	4.49	8.12	7.68	7.68
Ilmenite	3.46	4.62	4.29	4.33	4.58	5.26	3.55
Pyrite	0.02	0.15	---	0.07	0.21	0.04	0.84
Apatite	0.42	0.74	0.67	0.63	0.67	0.88	0.46
Calcite	0.45	1.14	0.23	---	0.68	0.23	0.91
H ₂ O	4.50	2.30	1.40	1.30	1.90	0.70	3.60
Total	100.33	99.34	99.98	98.38	100.16	99.58	99.79
Normative Plagioclase:							
Anorthite	38.98	48.48	45.48	46.48	46.19	26.64	54.67
Albite	61.02	51.52	54.52	53.52	53.81	73.36	45.33

Analyses by the Analytical Chemistry Section of the Geol. Survey of Canada
 MT SCH: Davis assemblage, Greenstone Member, Mount Schroeder, 7700 ft
 K83-49h: Keen Creek assemblage, Lower Volcanic Member, 3.22 km at 340°
 from confluence of Keen and Rossland creeks, 7380 ft
 K83-48e: Keen Creek assemblage, Lower Volcanic Member, 3.6 km at 321°
 from Mt. Stubbs, 7800 ft
 K83-48e2: As for K83-48e
 K83-45i: Keen Creek assemblage, Upper Volcanic Member, 1.8 km at 357°
 from Mt. Stubbs, 6478 ft
 K83-45j: Keen Creek assemblage, pillow lava in the Siliceous Wacke Member,
 2.24 km at 351° from Mt. Stubbs, 6842 ft
 K83-43a: McHardy assemblage, Volcanic Member, 3.17 km at 113° from
 Mt. McHardy, 7450 ft

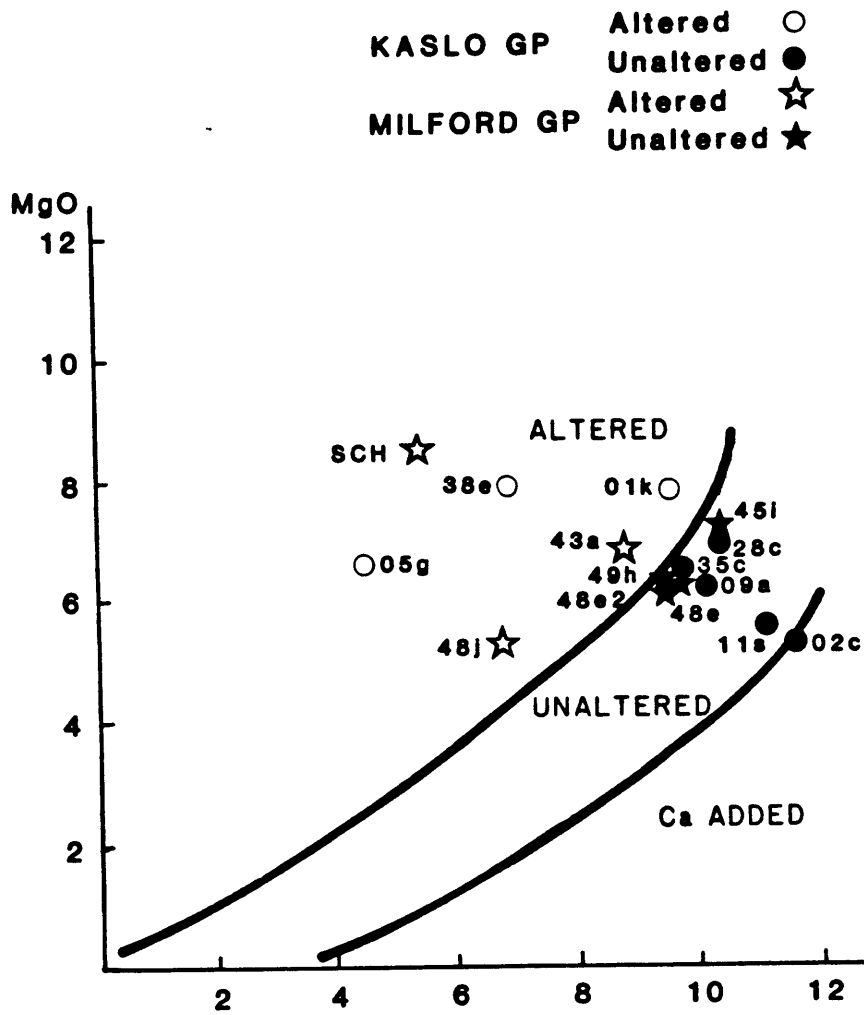


Figure 23: MgO versus CaO plot for analyzed volcanic rocks from the Milford and Kaslo groups, indicating degree of alteration. After De Rosen-Spence (1976, 1985).

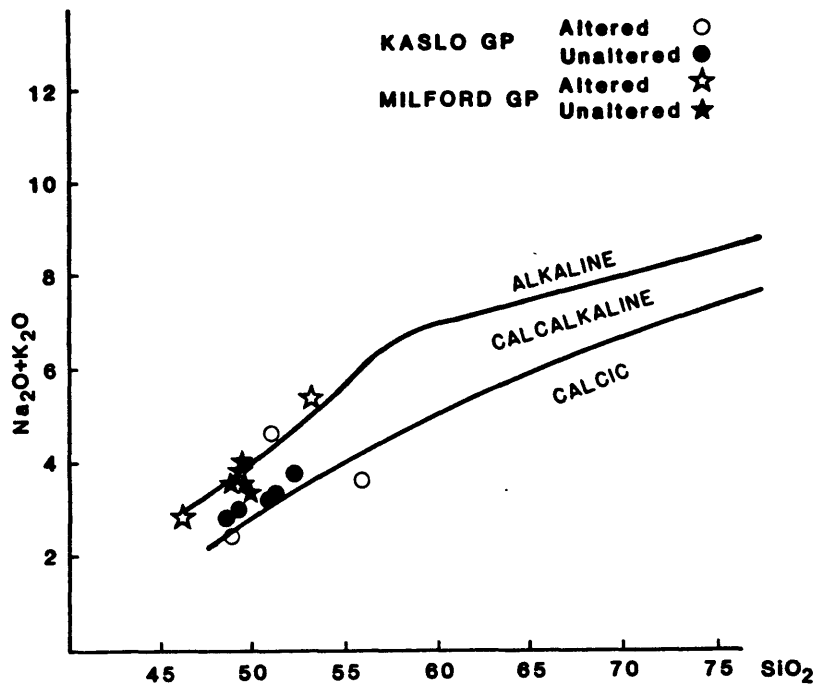


Figure 24: Weight percent $\text{Na}_2\text{O} + \text{K}_2\text{O}$ versus SiO_2 plot for analyzed volcanic rocks from the Milford and Kaslo groups, indicating alkaline,

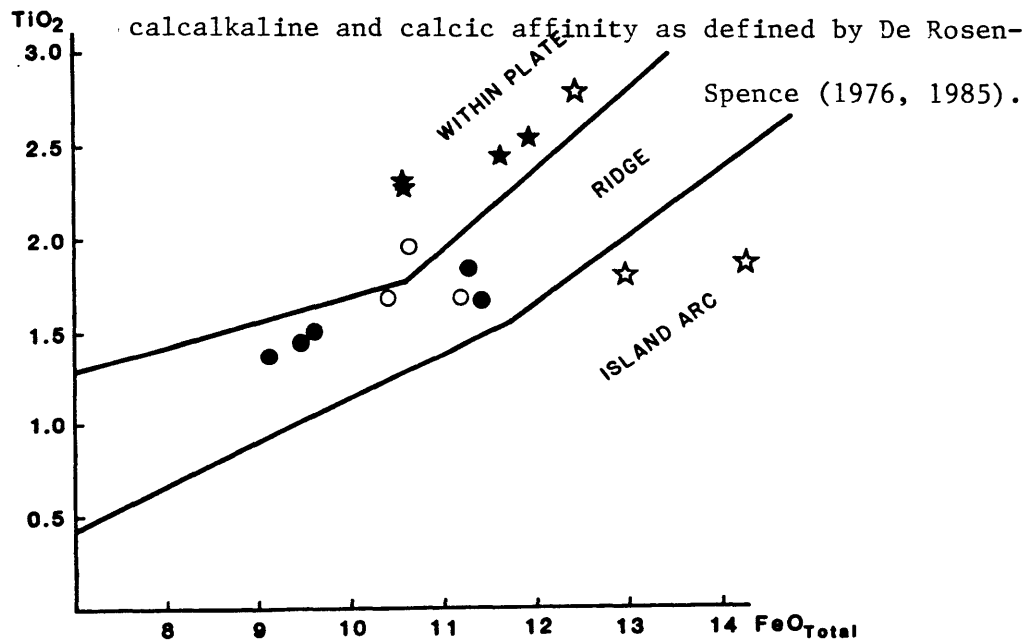


Figure 25: Weight percent TiO_2 versus $\text{FeO}_{\text{total}}$ plot for analyzed volcanic rocks from the Milford and Kaslo groups, indicating tectonic setting.

The greenstone member has a gradational contact with the underlying cherty tuff member. The interbedded green tuffaceous metasandstone and cherty tuff of the contact interval occupy about 4 meters (13 ft) of section. The top of the greenstone member consists of slaty green tuffaceous metasediment and green or white cherty tuff. Locally these rocks grade upward into dark and light grey siliceous argillite of the siliceous argillite member within about 2 m (6.6 ft). At Mount Schroeder this contact is faulted but at the saddle between the headwaters of Davis and Rossiter Creeks, a transitional contact is present.

The greenstone member of the Davis assemblage is 140 m (459 ft) thick at Mount Schroeder. On Davis Ridge it thins to 80 m (262 ft). South of the headwaters of Schroeder Creek, the greenstone member is locally absent along by the Schroeder fault, but attains a thickness of 180 m (590 ft) 1.5 km (0.93 mi) northwest of Milford Peak.

Because of the gradational contact with the underlying Upper Mississippian cherty tuff member, the greenstone member is also considered to be of Late Mississippian age. This assignment is supported by correlation of the volcanic greenstone member of Davis assemblage with Upper Mississippian-Lower Pennsylvanian basalt units in the Keen Creek assemblage.

Keen Creek Assemblage

The Upper Mississippian and Lower Pennsylvanian Keen Creek assemblage of the Milford Group lies in the northern quarter of the map area, west of the Schroeder fault and in the footwall of the Stubbs thrust fault. Its area of exposure is adjacent to the south, west, and north margins of the McKian Creek Stock (Fig. 26). The assemblage rests unconformably on the Broadview Formation and consists of sparse basal conglomerate or calcareous

rit overlain by tholeiitic basalt that is succeeded by Namurian limestone. The limestone is overlain by a heterogeneous sequence consisting of a tholeiitic basalt unit in the east that is interbedded with limestone layers and which grades upward and westward into a metasedimentary unit (the siliceous wacke member). The Keen Creek assemblage is thickest north of Rossland Creek where it is 2137 m (7014 ft) thick on the west limb of the Dryden anticline and is 2055 m (6742 ft) thick on the east limb. It is thinnest in the headwaters of Wilson Creek where the same stratigraphic interval is 547 m (1795 ft). Read and Wheeler (1976) included strata of the Keen Creek assemblage with the Milford Group, as did Read (1973). It is likely that the Keen Creek assemblage outcrops farther north in the Poplar Creek area.

Basal Clastic Member

The basal clastic member unconformably overlies schist, quartzite, and grit of the Broadview Formation and comprises rusty-weathering, matrix-supported, quartz-pebble conglomerate south of the McKian Creek Stock and feldspar and quartz porphyroblastic, bluish-grey, calcareous psammitic schist northwest of McKian Creek Stock. Good exposure of the rusty conglomerate occurs 2.5 km (1.5 mi) at 020° from the confluence of Keen Creek and Rossland Creek (Fig. 27). Rusty to yellowish green-weathering dark grey phyllite contains rare clasts of granular quartzite and disrupted metasandstone layers. In thin section the clasts consist of medium-grained, rounded quartz aggregates and mesoscopic layers consist of fine-grained quartz. Pelitic layers contain quartz-muscovite-biotite and 2 percent opaques. The rock is traversed by thin veinlets of hematite. Good exposure of the porphyroblastic schist occurs along Wilson Creek, from 1219 m to 1402 m (4000 ft to 4600 ft)

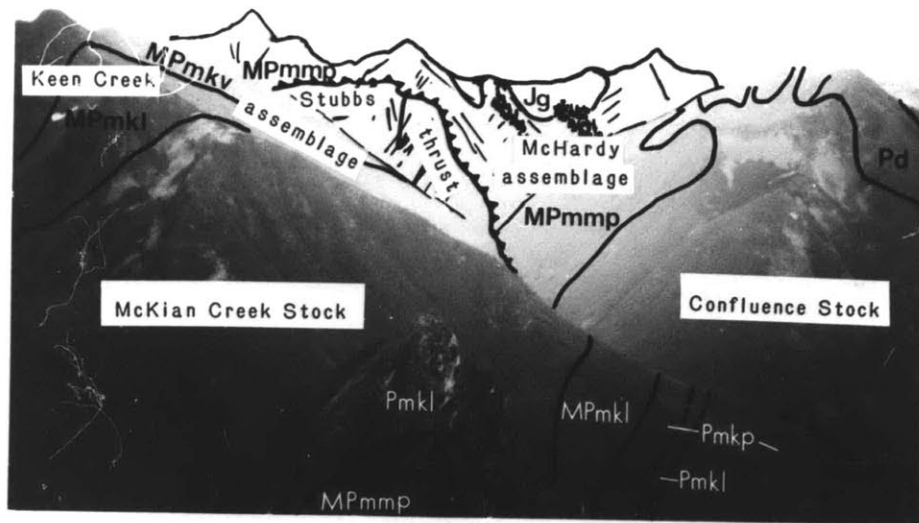


Figure 26: Panorama looking to the southeast, up Keen Creek, from west of Wilson Creek. The Keen Creek assemblage underlies the foreground and the northern valley wall of Keen Creek. The McHardy assemblage overlies the Keen Creek assemblage to the south with thrust fault contact.

elevation (Fig. 16). It consists of layered quartz-plagioclase-biotite-muscovite schist with isolated porphyroblasts of feldspar and quartz interpreted to be clastic debris derived from the underlying Broadview Formation. In places the basal clastic member along Wilson Creek is lithologically similar to the calcareous grits present in the Broadview Formation, however the Broadview Formation contains abundant quartz-feldspar veins that are absent in the basal clastic member, except where the member is adjacent to granitic bodies.

The contact of the basal clastic member with the underlying Broadview Formation is an unconformity. The contact is exposed in Wilson Creek at an elevation of 1329 m (4362 ft). Contorted beds of green and grey schist and grit with abundant quartz-feldspar veinlets are unconformably overlain by plagioclase-rich metasandstone with clasts of quartzite and feldspar and traversed by very rare quartz veinlets. The contact is not exposed south of the McKian Creek Stock but cleavage relationships demonstrate an unconformity. The Broadview Formation has two well-developed foliations, and the overlying basal clastic member of the Keen Creek assemblage has only the later of the two foliations (Klepacki and Wheeler, 1985; p. 284-285). This demonstrates deformation of the Broadview Formation prior to deposition of the basal clastic member.

The basal clastic member has a gradational contact with the overlying lower volcanic member. The basal clastic member along Wilson Creek grades upward into bluish grey quartz-plagioclase-biotite calc-schist that contains a few thin beds 1-2 cm (0.4-0.8 in) thick of granular chlorite-epidote schist. This sequence is abruptly overlain by epidote-rich greenstone and amphibolite of the lower volcanic member. Along the southern margin of McKian Creek Stock, rusty-weathering



Figure 27: Basal Clastic Member of the Keen Creek assemblage. Metaquartzite pebbles are stretched along southwest-dipping foliation. View to southeast, south of McKian Creek Stock.



Figure 28: Contact zone of the Lower Volcanic and Banded Limestone members of the Keen Creek assemblage. Carbonate is interstitial to pillow lava near the hammer. View to southeast, south of McKian Creek Stock.

conglomerate of the basal clastic member grades up into a chloritic phyllite, with grey phyllite clasts, that is interlayered with and overlain by chlorite-amphibole greenstone of the lower volcanic member.

The basal clastic member is of variable thickness. Along Wilson Creek it is about 46 m (151 ft) thick. South of the McKian Creek Stock it is absent in some places but it is up to 86 m (284 ft) thick in other places. No fossils have been recovered from the basal clastic member, but because Upper Mississippian strata lie unconformably on Lardeau Group in the Davis assemblage, and overlying rocks are Late Mississippian to Early Pennsylvanian in age, the basal clastic member is considered Late Mississippian in age.

Lower Volcanic Member

Tholeiitic pillow basalt (Table IV), massive greenstone, and amphibolite with epidote-quartz veinlets form the lower volcanic member. The member is well exposed along the northern valley wall of Rossland Creek, northwest of Mount Stubbs (Fig. 3). North of the McKian Creek Stock, the member is exposed 1.3 km (1 mi) at 219° from Mount Marion and can be traced westward 4.2 km (2.6 mi) where it is truncated by the Stubbs thrust fault. North of the McKian Creek Stock the member consists of foliated amphibolite with veinlets and clots of quartz and epidote. These rocks were included in unit 19 (coarse fragmental rocks) of Read (1973). The veinlets and clots constitute material originally interstitial to pillows in the lavas as they locally outline elongate pillow structures. The lower volcanic member is exposed on the west wall of Wilson Creek between 1372 m and 1524 m (4500 and 5000 ft) elevation, 6.5 km (4.0 mi) north of the confluence with Keen Creek. The largest outcrop area of the member occurs northeast of Keen Creek where it outlines the Dryden

anticline and associated folds (Fig. 3). Weakly altered pillow lava has phenocrysts of plagioclase and pseudomorphs of hornblende after pyroxene. Spherulitic rims on the pillows are common. Rare layers of foliated tuffaceous metasediment and weakly foliated greenstone are also present. Basalt in the member is altered, consisting of altered plagioclase (An₅, flat-stage perpendicular to 100 method), clots and large grains of hornblende with pyroxene habit, and a matrix of finer grained plagioclase, poorly-aligned hornblende grains, and minor amounts of biotite, chlorite, epidote and magnetite.

The lower volcanic member rests conformably on the basal clastic member and is conformably overlain by the banded limestone member. The upper contact is well exposed at several places north of Keen and Rossland creeks. The contact relationships are clear 3.5 km (2.17 mi) at 322° from Mount Stubbs where pillow lavas have intertices of limestone and pillow fragments are present in the lower 50 cm (19.7 in) of the overlying limestone (Fig. 28). North of McKian Creek Stock the lower volcanic member is about 300 m (984 ft) thick. South of the McKian Creek Stock, the member is about 425 m (1395 ft) thick although the unit is apparently thickened in the hinge of the Dryden anticline.

The lower volcanic member is probably, in part, Late Mississippian in age because it is overlain by the Late Mississippian to Early Pennsylvanian banded limestone member. It is also correlated with the greenstone member of the Davis assemblage, known to be Late Mississippian in age.

Banded Limestone Member

The banded limestone member conformably overlies the lower volcanic member and consists of well-bedded light grey limestone with thick (10-30 m; 33-98 ft) layers of bedded dark grey limestone. Read and Wheeler (1976) first mapped parts of the unit and Wheeler collected conodont samples that were identified by M.J. Orchard as Chesterian to Morrowan (Orchard, 1985). The member is best exposed along a southwest trending ridge that is 3.6 km (2.2 mi) at 328° from Mount Stubbs (Fig. 29). In addition to bedded dark and light grey limestone, this member contains several beds of biocalcirudite composed of brachiopod valves and crinoid columnals. Pyritic grey phyllite beds 1-50 cm (0.4-19.7 in) thick are common, whereas green and white siliceous phyllite beds are rare. White marble and dark grey marble beds with abundant actinolite grains up to 0.5 cm (0.19 in) long occur near contacts with granitic rocks. For example, actinolite is present near the apophysis of the McKian Creek Stock northwest of the confluence of Wilson and Keen creeks. Exposures of the banded limestone member north of the McKian Creek Stock consist of medium- to coarse-grained marble mapped as unit 14 (crystalline limestone and calc-silicate marble) by Read (1973). Northeast of Mount Stubbs, limestone members of the Keen Creek assemblage are truncated by the Stubbs fault. Directly below the fault surface a 30-50 m (98-164 ft)-thick zone of buff-weathering, hard, calc-silicate (quartz-zoisite-tremolite) rock and silicified limestone is present in the carbonate members, especially the banded limestone member.

The banded limestone member conformably overlies the lower volcanic unit. On the eastern flank of the Dryden anticline and north of the McKian Creek Stock the banded limestone member is overlain by a transitional sequence of green and white siliceous argillite and calc-silicate layers

that are in turn succeeded by a widespread green volcanic unit which forms the base of the upper volcanic member. The gradational contact is well exposed 3.6 km (2.2 mi) at 332° from Mount Stubbs.

The banded limestone member is truncated by granite along the north side of the McKian Creek Stock 1.3 km (0.8 mi) at 219° from Mount Marion. From there marble of the member can be traced for 1.9 km (1.2 mi) to the west gradually becoming more pelitic in composition and terminated by a lateral facies transition into calcareous greenschist of the adjacent volcanic members. The facies transition is mapped where calcareous beds of the banded limestone member are truncated by a lobe of granite and are not differentiated from adjacent metasediments of the upper volcanic member 250 m (820 ft) to the west on the west side of the lobe.

On the west side of the Dryden anticline the banded limestone member is overlain by pyritic biotite schist that is overlain by metasedimentary rocks. Both lithologies are included within the siliceous wacke member of the Keen Creek assemblage. The contact is gradational over an interval 10 m (33 ft) thick.

The banded limestone member apparently continues to the west bank of Wilson Creek, although poor exposure in the bottom of the valley does not permit the rocks to be traced continuously. On the west wall of Wilson Creek the banded limestone member stratigraphically interfingers with rocks of the upper limestone members.

South of the McKian Creek Stock and north of Keen Creek, the thickness of the banded limestone member varies from 774 m (2539 ft) on the west flank of the Dryden anticline to 144 m (472 ft) on the east flank of the Dryden anticline. North of the McKian Creek Stock the average thickness is 100 m (328 ft) although the member wedges out into the adjacent volcanic



Figure 29: Banded Limestone Member of the Keen Creek assemblage. The cliff face in the foreground has about 120 m (394 ft) of relief. Note the south-westerly verging F2 fold. View northeast, south of McKian Creek Stock.

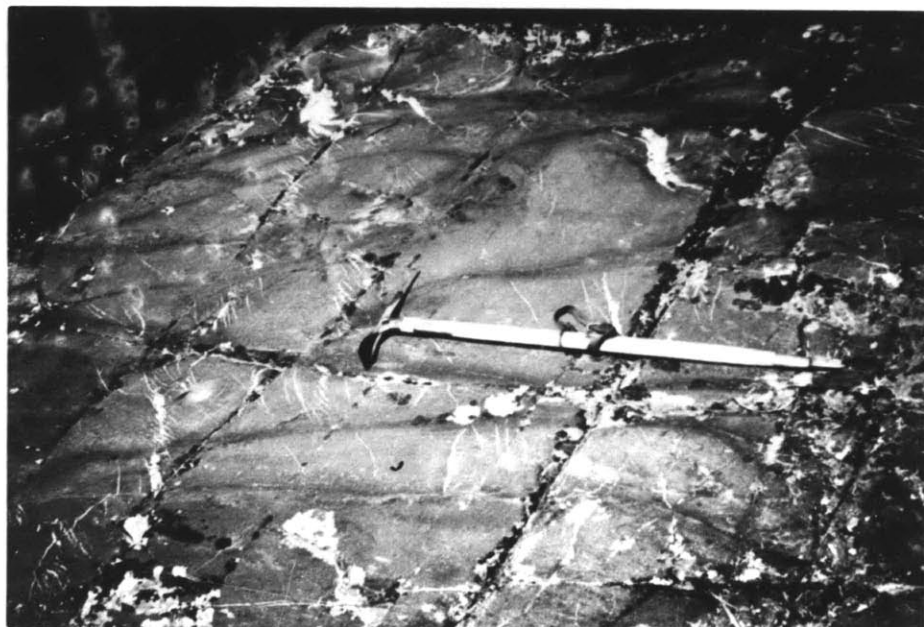


Figure 30: Pillow basalt of the Upper Volcanic Member of Keen Creek assemblage. Sigmoidal, quartz-filled tension fractures may be related to eastward movement along overlying Stubbs thrust. View east, Rossland Ck.

members to the west. West of Wilson Creek, limestone correlated with the banded limestone member is about 25 m (82 ft) thick.

Two localities in the banded limestone member have yielded identifiable conodonts. One locality of brachiopod and fossil hash beds, collected by Wheeler (Orchard, 1985, pp. 288-290) along a ridge at 2515 to 2530 m (8250 to 8300 ft) elevation and 4.26 km (2.65 mi) at 294° from Mount Cooper yielded Early Namurian (Late Mississippian) ages. This fossil locality has also yielded two collections of solitary corals that were examined by Bamber of the Geological Survey of Canada (Geological Survey of Canada fossil reports, localities C-87162 and C-87163). Both samples were described as "very poorly preserved solitary corals - probably Faberophyllum sp.... Faberophyllum is middle Late Visean in age. It ranges through the upper Mount Head Formation (Rundle Group) in southwestern Alberta and southeastern British Columbia and is found in the lower Milford Group at other localities."

The second conodont locality is on a spur of Mount Stubbs 1.61 km (1.0 mi) at 250° from Mount Cooper at an elevation of 2164 m (7100 ft) and was collected by Wheeler and Orchard (Orchard, 1985, p. 296). The samples yielded Early Namurian-Late Namurian conodonts (Late Mississippian-Early Pennsylvanian). Both conodont localities indicate that the banded limestone member is Late Mississippian to Early Pennsylvanian in age.

Upper Volcanic Member

Tholeiitic pillow lava, grey and green phyllite, and green amphibolite of the upper volcanic member overlies the banded limestone member on the eastern flank of the Dryden anticline and north of the McKian Creek Stock. A good section of the upper volcanic member is exposed in the northern

headwaters of Rossland Creek, where spherulitic pillow lava (Fig. 30), plagioclase-porphyry, and fine-grained greenstone overlies marble of the banded limestone member and underlies marble and calcsilicate of one of the upper limestone members. Along the southern margin of the McKian Creek Stock the pillow lava sequence includes green and grey pyritic phyllite. North of the McKian Creek Stock the upper volcanic member consists of green amphibolite with quartz-epidote clots and stringers that locally outline pillow structures. The upper volcanic member north of McKian Creek Stock was included in unit 19 (coarse fragmental rocks) of Read (1973).

Green hornblende-biotite schist probably equivalent to the upper volcanic member is interbedded with marble and conglomerate above the banded limestone member west of the Dryden anticline. These schists are only 5 m (16.4 ft) thick and could not be mapped separately at 1:50,000 scale so they are included in the overlying and interfingering siliceous wacke member.

The upper volcanic member rests conformably on the banded limestone member and is conformably overlain by one of the upper limestone members. The contact with the upper limestone member is well exposed 2 km at 232° from Mount Cooper. The change in lithology from volcanics to marble is abrupt, but local intercalations of the two rock types suggests the limestone was deposited on and in between mounds of pillow lava. North of the McKian Creek Stock, the upper volcanic member underlies an upper limestone member. It is exposed for 500 m (1640 ft) between granite of the McKian Creek Stock and the trace of the Stubbs thrust fault.

The upper volcanic member is 380 m (1247 ft) thick north of the McKian Creek Stock where the unit has stratigraphic contacts but is partially intruded by granite. The upper volcanic member varies in thickness from

148 m (485 ft) thick directly south of McKian Creek Stock, to 421 m (1381 ft) thick 2 km (1.2 mi) south of the Stock, and to 304 m (997 ft) thick directly northwest of the Stubbs fault. The average thickness is about 291 m (955 ft).

No fossils have been recovered from the upper volcanic member. Because of its conformable contact with the banded limestone member, the upper volcanic member is considered Early Pennsylvanian in age.

Upper Limestone Members

Carbonate beds mappable at 1:50,000 scale consisting of calcite marble, limestone, dolomitic marble and silicified limestone occur within and adjacent to the siliceous wacke member. The beds are discontinuous because of facies changes and probable unrecognized structural complexities, thus the relative stratigraphic position of the beds is uncertain and they are described collectively.

Carbonate rocks mapped as the upper limestone members are present in a number of places in the Keen Creek assemblage (Fig. 3). On the east flank of the Dryden anticline about 101 m (331 ft) of white actinolitic marble grades northwestward into bedded limestone. These rocks lie above the upper volcanic member. On the west flank of the Dryden anticline 1.7 km (1.1 mi) northeast of the confluence of Wilson and Keen creeks about 15 m (49 ft) of fine-grained grey marble occurs within the siliceous wacke member. North of the McKian Creek Stock, 25 m (82 ft) of grey marble mapped as part of unit 14 of Read (1973) is exposed for a distance of 500 m (1640 ft) under the Stubbs thrust fault 600 m (1968 ft) southwest of Mount Marion.

West of Wilson Creek, limestone and marble units occupy three stratigraphic positions. The lowest carbonate unit is correlated with the

banded limestone member and apparently merges with the middle carbonate unit. Where they merge their combined thickness is 72 m (239 ft). The combined marble unit is traced into an equivalent thickness of carbonate rocks, calcareous meta-argillite and sandstone farther north. The uppermost carbonate unit is about 121 m (399 ft) thick and is bounded by the Stubbs fault along most of its length and by the western lobe of the Confluence Stock to the south. In general the carbonate units west of Wilson Creek are fine- to medium-grained calcite marble. About 4 km (2.5 mi) northwest (322°) of the confluence of Wilson and Keen creeks, the carbonate units consist of silicified, buff-weathering, bedded calc-silicate or siliceous dolomitic marble.

The upper limestone members have gradational contacts with the surrounding metasedimentary rocks of the siliceous wacke member and underlying volcanic rocks of the upper volcanic member. The units are truncated by the Stubbs fault, typically along a knife-sharp contact.

The upper limestone members are considered to be Early Pennsylvanian or younger in age. No fossils have been recovered from the upper limestone members and their age assignment results from their stratigraphic position on top of the Upper Mississippian to Lower Pennsylvanian banded limestone member.

Siliceous Wacke Member

A heterogeneous unit of quartz-biotite-plagioclase-amphibole schist, calc-schist, amphibole- and biotite-rich metasandstone, metaconglomerate and pillowed amphibolite are interbedded with upper limestone members and are mapped as the siliceous wacke member. A distinctive stratigraphic succession of rock types was not recognized because the different rock

types are interbedded and lateral facies equivalents of each other. On the east flank of the Dryden anticline, pillowed amphibolite in the siliceous wacke member 2-3 km (1.2-1.9 mi) at 290° from Mount Cooper grades upward (to the east) and along strike into finely laminated (0.5-5 mm; 0.02-0.2 in) grey, green, and white amphibole-biotite-feldspar-quartz metasandstone (Fig. 31) with minor grey and green siliceous phyllite. The metasandstone contains microcline near the margin of the McKian Creek Stock. On the west flank of the Dryden anticline, quartz-biotite schist of the siliceous wacke member contains beds of green amphibolite, chloritic schist, feldspathic quartzite and quartz and biotite schist-pebble metaconglomerate (Fig. 32). Some quartz-biotite schist horizons are pyritic and rusty-weathering.

Wilson Creek Area

The metamorphic and stratigraphic differences between rocks of the Keen assemblage within Keen Creek and Rossland Creek valleys and those within the northern Wilson Creek valley are significant enough to warrant separate discussion. Intrusion of the Kuskanax Batholith, McKian Creek Stock and Confluence Stock apparently heated a septum of stratified rocks now exposed along the west wall of Wilson Creek and imparted higher grade metamorphic textures. The Keen Creek assemblage in the northern Wilson Creek valley is thinner than the assemblage farther east and mostly consists of the siliceous wacke member interbedded with the upper limestone members (Fig. 3). The siliceous wacke member extends from Keen Creek Valley to the west wall of the Wilson Creek Valley where it is mainly rusty-weathering quartz-biotite±muscovite schist with veinlets of quartz-feldspar. The schist contains beds of amphibolite, chloritic

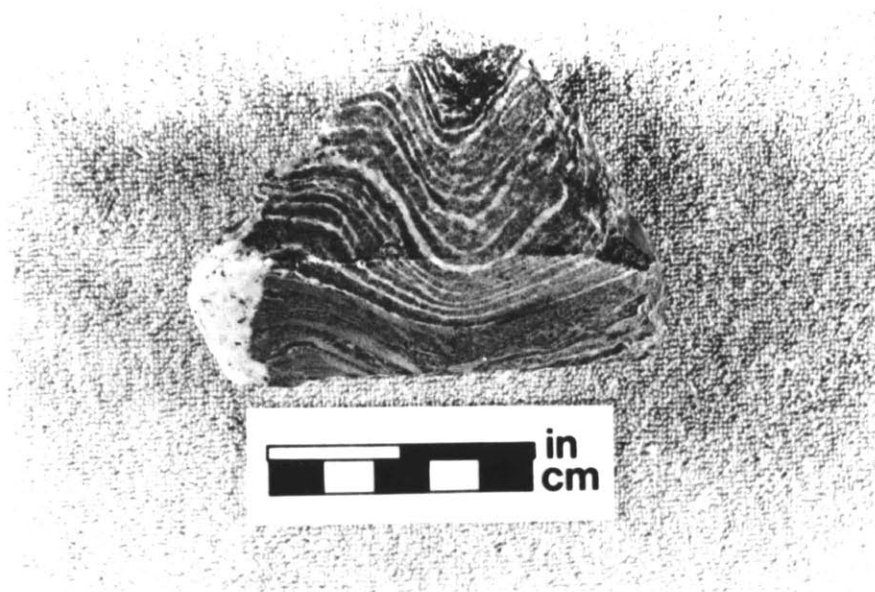


Figure 31: Striped metamorphosed volcanic sandstone of the Siliceous Wacke Member of Keen Creek assemblage. Compositional layering apparently represents bedding on the distal margin of volcanic flows. Sample from south margin of McKian Creek Stock.



Figure 32: Metaconglomerate of the Siliceous Wacke Member. Subangular quartzite fragments are in a quartz-biotite-plagioclase schist. View northeast near base of Keen Creek.

schist, and foliated white feldspathic quartzite. These lithologies are distinguished from the Broadview Formation (which also contains quartz-feldspar veinlets and quartzites) by amphibolite and the mafic composition of the schist. They also have continuity with similar lithologies on the north bank of Keen Creek where the stratigraphic sequence is certain. Pillow lavas within the siliceous wacke member west of Wilson Creek are overlain by and interbedded with rusty-weathering quartz-feldspar-biotite-muscovite schist 3.3 km (2.0 mi) at 344° from the confluence of Wilson and Keen creeks on the west wall of Wilson Creek at 1395 m (4586 ft) elevation. Two hundred metres (656 ft) south, at an elevation of 1474 m (4837 ft), the rusty mica schist grades laterally into plagioclase-actinolite-biotite schist and quartz-pebble conglomerate directly below a marble unit correlated with the banded limestone member. The conglomerate is interpreted as channel fill and truncations of underlying beds along the margin of the channel indicate tops are to the west in this west-dipping section. Clasts in the conglomerate consist of granular quartz pebbles and laminated quartzite with their lamination randomly oriented relative to foliation of the metasandstone matrix. Elsewhere, the contact of the rusty mica schist of the siliceous wacke member and marble units of the upper limestone members are gradational through a 1 to 20 metre interval (3.3 to 66 ft). The gradational sequence consists of quartz-feldspar-dolomite-biotite-actinolite schist and grey quartz-plagioclase-biotite schist.

The Keen Creek assemblage 6.2 km (3.8 mi) to 6.9 km (4.3 mi) north of the confluence of Wilson and Keen creeks is much thinner than the assemblage to the east, near Keen Creek. The thinner section consists of the basal clastic member, amphibolite greenstone with some marble beds

correlated with the lower volcanic member, rusty quartz-biotite-muscovite schist of the siliceous wacke member overlain by the uppermost limestone member. In the southern part of the upper Wilson Creek valley, the rusty mica-schist includes a calcareous unit correlated with an upper limestone member and the banded limestone member. These calcareous rocks are 80 m (262 ft) thick and consist of a basal marble overlain by crossbedded calcareous metasandstone, succeeded upward by calc-silicate schist, an upper marble and bedded plagioclase-biotite schist. The total thickness of the section to the base of the uppermost limestone member in the headwaters of the Wilson Creek is approximately 547 m (1796 ft). The same interval at the confluence of Keen and Wilson creeks is 1990 m (6529 ft) thick.

The siliceous wacke member has gradational contacts with the interbedded and overlying upper limestone members. Contacts are exposed along the small tributary creeks along the west wall of Wilson Creek north of Keen Creek.

The siliceous wacke member is in part Late Mississippian to Early Pennsylvanian in age because of the facies equivalence of the banded limestone member. The part of the siliceous wacke member above the banded limestone member is considered to be Early Pennsylvanian in age because of its stratigraphic position although a younger age is possible.

MCHardy Assemblage

The Carboniferous MCHardy assemblage of Milford Group is the westernmost of the three assemblages of Milford Group. It lies west of the Davis assemblage and the intervening Schroeder fault and is separated from the underlying Keen Creek assemblage by the Stubbs thrust fault. This assemblage was mapped by earlier workers (Cairnes, 1934; Fyles, 1967; Read, 1973; Read and Wheeler, 1976) as the Milford Group, and locally as the

Kaslo and Slocan Groups. The assemblage is named for outcrops on Mount McHardy, where siliceous argillite, the dominant lithology, is well exposed. The McHardy assemblage outcrops in the northwestern part of the Goat Range, and extends into the southern part of the Poplar Creek area (Klepacki, Read and Wheeler, 1985). It also occurs in the southern Blue Ridge, in the Mount Buchanan area (Fig. 3). Reconnaissance in the Ainsworth-Kaslo area (Fyles and Klepacki, unpublished, 1983) identified McHardy assemblage there, especially in unit 4d of Fyles (1967).

The McHardy assemblage, as mapped in the Goat Range consists of, in ascending stratigraphic order, calcareous phyllite and argillaceous marble, tuffaceous metasandstone, conglomerate, limestone and marble, and siliceous argillite with lenses of volcanic rock. It is now floored largely by the Stubbs thrust fault. Isotopic and regional evidence suggests it was deposited on oceanic basement. The assemblage is conformably overlain by the Kaslo Group.

Calc-argillite Member

The oldest unit mapped in the McHardy assemblage consists of a heterogeneous sequence of dark grey tremolitic limestone, dark grey siliceous phyllite and grey quartz-plagioclase-carbonate-mineral-mica schist. The sequence is well exposed in the core of the Cascade anticline, south of Cascade Mountain (Klepacki, Read and Wheeler, 1985; Fig. 33), where Read (1973) included it in his units 16 and 17. Grey limestone and dark grey limestone interbedded with buff-colored metasandstone in the faulted core of an anticline 1.8 km (1.1 mi) at 320° from Mount Cooper is assigned to the calc-argillite member. On the southwest side of Mount Buchanan, 500-1500 m (1640 ft-4921 ft) southeast of the confluence of Keen Creek (of the Slocan Sheet, 82 F/14) and Kaslo River, a sequence of

siliceous phyllite, mica phyllite, fine-grained marble and greenstone is intruded by dykes of foliated Kane Creek Diorite. This sequence apparently stratigraphically underlies the carbonate member of the McHardy assemblage to the east and thus is correlated with the calc-argillite member. Mica phyllite from this sequence contains quartz-carbonate-mineral-muscovite-chlorite-biotite phyllite with 1 percent flake-like opaques that are probably graphite.

The base of the calc-argillite member is not exposed in the map area. The member is conformably overlain by the tuffaceous sandstone member. The contact is well exposed in the core of the Cascade anticline and in the anticline 1.8 km (1.1 mi) northwest of Mount Cooper where grey and dark grey limestone beds 2-3 m (6.6-9.8 ft) thick are interbedded with equally thick metasandstone beds in an interval 20 m (66 ft) thick. The contact is placed where metasandstone comprises more than 50 percent of the section.

Only a minimum thickness of the calc-argillite member can be obtained from the Goat Range area because the base of the unit is not exposed. Half the outcrop width of the member exposed in the Cascade anticline is 175 m (574 ft) and is taken as a minimum thickness. No fossils have been recovered from the calc-argillite member so its age is uncertain. It lies below the Upper Mississippian carbonate member thus it is assigned a Late Mississippian age or older.

Tuffaceous Sandstone Member

The tuffaceous sandstone member conformably overlies the calc-argillite member and consists of pink to light grey, sandy weathering, bedded metasandstone. It is best exposed on the southern and eastern margins of the Cascade anticline (Fig. 34) and on the northwestern flank of

Mount Marion where Read (1973) included it in his unit 15 (micaceous metasandstone). The tuffaceous sandstone member also occurs in the core of an anticline on the ridge 1.7 km (1.1 mi) at 317° from Mount Cooper.

Northwest of Mount Marion, some grey- to light-brown weathering semipelitic beds 4-15 cm (1.6-5.9 in) thick and dark grey to white chert beds 1-5 cm (0.4-2.0 in) thick are interbedded with grey to pink metasandstone. Graded beds 2.0 km (1.2 mi) at 306° from Mount Marion and at an elevation of 2164 m (7100 ft) indicate the west-dipping section is upright. Metasandstone samples collected northwest of Mount Cooper and 100 m (328 ft) southeast of the southern margin of the McKian Creek Stock consist of fine-grained quartz-plagioclase-biotite-amphibole with 2 percent opaques and contains randomly-oriented clusters of tremolitic amphibole and medium-grained poikiloblastic plagioclase. Bedding is defined by biotite-rich layers 1-2 mm (0.04-0.08 in) thick generally at an angle to the foliation. The biotite- and plagioclase-rich composition suggests the protolith of the metasandstone was volcanic.

The contact of the tuffaceous sandstone member with the underlying calc-argillite member is gradational with intercalation of metasandstone and grey limestone of the calc-argillite member. The contact with the overlying Cooper conglomerate is also conformable and well exposed in the core of the Cascade anticline. Pink weathering metasandstone grades upward into grey metasandstone that contains pebble- to cobble-sized clasts of grit- and quartz-pebble conglomerate. South of the McKian Creek Stock and west of the Cascade anticline about 20 m (66 ft) of bedded metagreywacke lies between the metasandstone unit and the Cooper conglomerate.



Figure 33: Calc-argillite Member of the McHardy assemblage. Beds of crystalline limestone, calcsilicate schist, and (to right of backpack) siliceous argillite. View northeast, south side of Cascade Mountain.

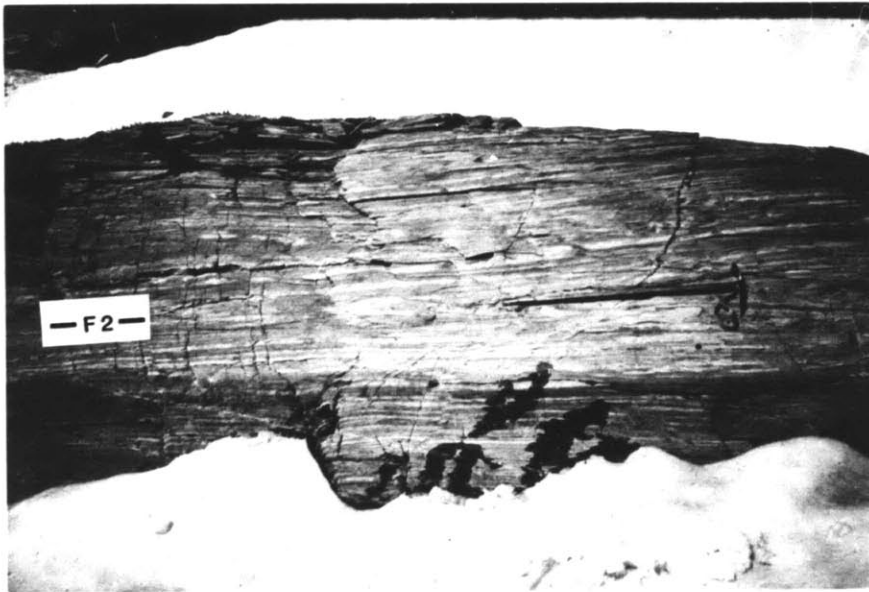


Figure 34: Tuffaceous Sandstone Member of McHardy assemblage. Note the attenuated bedding in the F_2 fold near the ice axe. View to the west, southwest flank of Cascade Mountain.

The thickness of the tuffaceous sandstone member is uncertain due to internal deformation in the unit. The least deformed sequence occurs in the footwall of the thrust fault in the Cascade anticline where the member is 85 m (279 ft) thick. In the hangingwall of this thrust fault, on the east flank of the anticline the member is 900 m (2953 ft) thick although this section contains numerous mesoscopic isoclinal folds and probable unrecognized thrust faults. Northwest of Mount Cooper and south of the McKian Creek Stock, moderately folded metasandstone is 110 m (361 ft) thick. A reasonable estimate of the average stratigraphic thickness of the tuffaceous sandstone member is 93 m (322 ft).

Because the tuffaceous sandstone member underlies the Upper Mississippian carbonate member of the McHardy assemblage, it is considered Late Mississippian in age or older.

Cooper Conglomerate

Metamorphosed conglomerate with granule- to boulder-sized clasts and grey metasandstone occurs near the base of the McHardy assemblage 1.5-2 km (0.9-1.2 mi) northwest of Mount Cooper and in the Cascade anticline between Cascade Mountain and Mount Marion. The unit was mapped northwest of Mount Cooper by Read and Wheeler (1976) as the Milford Group conglomerate. The present study shows the conglomerate there outlines a tight F₂ anticline (Figs. 3 and 4). Clasts are mostly pebble to boulder-sized (2-85 cm; 0.8-33 in) and consist of metadiorite (40%), mafic amygdaloidal volcanics (50%) and quartz monzonite (10%) (Fig. 35). These clasts are well rounded, commonly nearly spherical except in the hinge area of the fold, and supported by a weakly foliated matrix of fine grained quartz-biotite-plagioclase-sphene. The quartz monzonite and metadiorite cobbles yielded

zircons with a U-Pb concordia upper intercept age of 457^{+67}_{-33} Ma (Okulitch, (1985), interpreted as the age of crystallization of the plutonic rocks.

North of Mount Marion, conglomerate occurs in the hanging wall and footwall of the thrust fault folded by the Cascade anticline. In the hanging wall on the west flank of the anticline, a grey phyllite matrix contains clasts that are granule- to boulder-sized (as large as 2 m (6.6 ft) in diameter) and consist mainly of rusty-weathering quartz-pebble conglomerate with subordinate metagreywacke, metadiorite and rare mafic volcanic rocks and gneiss. The quartz-pebble conglomerate clasts, in turn, contain granule- to pebble-sized clasts of sugary quartzite and minor granules of watery-blue quartz.

In the core of the Cascade anticline pebble- to cobble-sized clasts consist mainly of foliated quartz-granule grit and quartz-pebble conglomerate derived from the Broadview Formation. Foliation in the clasts is randomly oriented with respect to the grey psammitic phyllite matrix (Fig. 36). The remaining clasts are rusty quartzite and rusty quartz-pebble conglomerate, metagreywacke, diorite, mafic volcanic rocks and gneiss. Metagreywacke clasts are apparently reworked from similar quartz-rich phyllite that occurs as the matrix of the conglomerate.

The base of the Cooper conglomerate commonly consists of several meters of foliated greywacke and grey sandstone which grades into the underlying tuffaceous sandstone member (Fig. 37). The conglomerate is overlain by a few meters of locally rusty-weathering grey sandstone that grades upwards through 5-10 cm (1.9-3.9 in) of calcareous sandstone into grey to white marble of the carbonate member. The contact is well exposed in the core of the Cascade anticline and in the core of the anticline 1.9 km (1.2 mi) at 347° from Mount Cooper (Fig. 38).



Figure 35: Cooper Conglomerate of the McHardy assemblage, northwest of Mount Cooper. Rounded boulders of mafic volcanics, diorite, and Ordovician granitic rocks are present in a quartz-biotite-amphibole-plagioclase matrix.



Figure 36: Cooper Conglomerate of the McHardy assemblage in the core of the Cascade Mountain anticline. Boulders of blue-quartz granule grit identical to Broadview Formation are abundant.

The Cooper conglomerate ranges from 10 to 50 m (33 to 164 ft) thick in the Cascade anticline and 100 to 150 m (328 to 492 ft) thick south of McKian Creek Stock. Given the large size of clasts in the Cooper conglomerate, it is likely the conglomerate is not areally extensive.

The Cooper Conglomerate directly underlies the Upper Mississippian Carbonate Member and is considered Late Mississippian in age or older.

Carbonate Member

White to grey marble, black fossiliferous limestone, and grey limestone constitute the carbonate member of the McHardy assemblage. The carbonate member outcrops extensively in the headwaters of Wilson Creek in the northernmost section of the study area, and along the southern margin of the McKian Creek Stock on the east flank of the Dryden anticline. Grey limestone that can be traced for 1.8 km (1.1 mi) north of the Kaslo River is included in the carbonate member. Most of the crystalline limestone and calc-silicate marble included in unit 14 of Read (1973) in the headwaters of Wilson Creek is correlated with the carbonate member of the McHardy assemblage.

The carbonate member generally consists of medium- to coarse-grained white to grey marble that contains dark grey to black bioclastic limestone beds and white marble with boulder-sized clasts of marble or siliceous argillite near its base. Beds of green to grey siliceous argillite 10 to 30 m (33 to 98 ft) are present within the carbonate member, commonly near the base and top of the member. Near the margins of these beds in the headwaters of Wilson and Rossland creeks, coarse-grained tremolite-dolomite-calcite-phlogopite-talc marble is present.

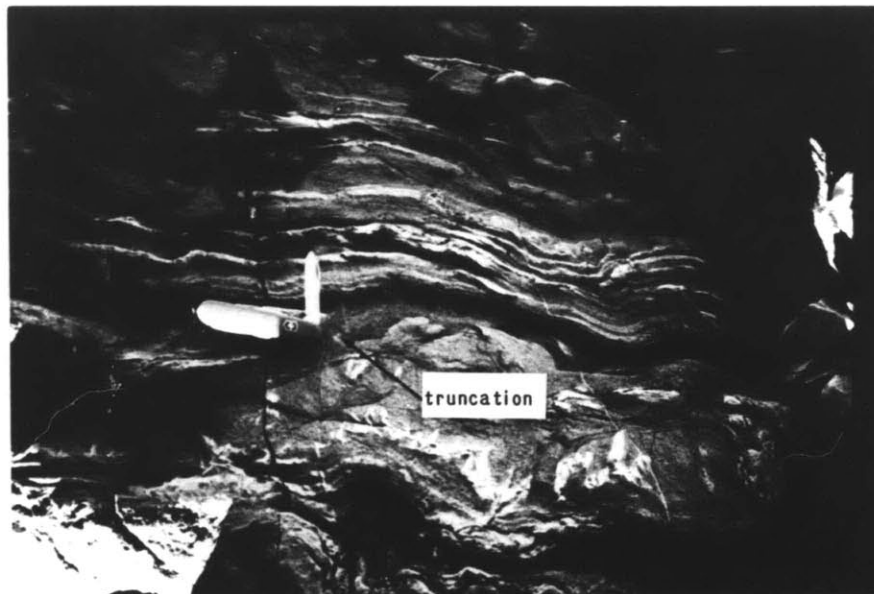


Figure 37: Greywacke in the Cooper Conglomerate of McHardy assemblage. Note truncated bed near knife indicating upright stratigraphic succession. View to east, northwest of Mount Cooper.



Figure 38: Gradational contact zone of the Cooper Conglomerate and overlying Carbonate Member of the McHardy assemblage. View to northeast, north of Mount Cooper.

North of the McKian Creek Stock, the carbonate member contains beds with crinoid debris and brachiopod valves in grey medium-grained marble 350 m (1148 ft) 216° from Mount Marion at an elevation of 2743 m (9000 ft). Crinoid debris and solitary corals are present in grey marble and black crinoidal crystalline marble in the core of the Cascade anticline 1650 m (5413 ft) 174° from Cascade Mountain at an elevation of 2210 m (7250 ft).

South of the McKian Creek Stock grey medium- to coarse-crystalline calcitic marble of the carbonate member is exposed in an anticline 1.2-2.2 km (0.7-1.4 mi) northwest of Mount Cooper. Black crystalline limestone lies at the base of the member, below a bed of siliceous argillite, and contains brachiopod and crinoid debris. Solitary corals occur at an elevation of 2199 m (7215 ft) 2.2 km (1.4 mi) at 018° from Mount Cooper.

Southwest of Mount Buchanan medium to dark grey limestone, locally well bedded but generally massive, is assigned to the carbonate member. Bedding is defined by grey and white color banding, graphitic phyllite partings or 1-2 cm (0.4-0.8 in) of pyritic limestone. Drysdale (1917, map 1667) and Cairnes (1934, p. 41) noted the carbonate unit where it crosses the Kaslo River, but they did not separate it out as a map unit. Many F₂ minor folds verge westward in the carbonate member north of Kaslo River and together with bedding/cleavage relationships, suggest the beds face east.

The carbonate member at the margins of the McKian-Creek Stock is conformably overlain by grey siliceous argillite. The contact is well exposed on the southwestern flank of Cascade Mountain and along the northwestern margin of the Mount Cooper Stock. An overlying transitional interval at the contact, 10-20 m (33-66 ft) thick, consists of light grey to green bedded amphibole-bearing calc-silicate or bedded plagioclase-biotite schist. The contact is placed at the top of the

uppermost marble bed. South of Mount Buchanan, the contact between the limestone and its adjacent members is not exposed, but the limestone contains more phyllite near its western margin, suggesting the contact with the underlying calc-argillite member is very close to these exposures. The intervening tuffaceous sandstone member and cooper conglomerate are apparently missing here.

The carbonate member south of Mount Buchanan is about 272 m (893 ft) thick. Northwest of Mount Cooper, it has an average thickness of 226 m (741 ft). North of the McKian Creek Stock the Carbonate Member averages 192 m (630 ft) thick east of Wilson Creek and thins to 125 m (410 ft) thick west of Wilson Creek.

Identifiable Late Mississippian conodonts have been recovered from the carbonate member at an elevation of 747 m (2450 ft), 3.3 km (2 mi) at 206° from Mount Buchanan (Orchard, 1985). No identifiable fossils have been recovered from the carbonate member in the northern part of the map area although the carbonate member there is also considered Late Mississippian in age because of its similar stratigraphic position below the siliceous argillite member.

Siliceous Argillite Member

Most of the outcrop area of the McHardy assemblage consists of dark to medium grey and green, dense siliceous argillite of the siliceous argillite member (Fig. 39). Bedding is generally expressed as color banding 1-3 cm (0.4-1.2 in) thick or more rarely by pelitic material. Extensive areas of massive siliceous argillite are also common. In general the siliceous argillite member is 60 percent fine-grained quartz with the remainder consisting of muscovite-biotite-chlorite with minor plagioclase and rare carbonate-tremolite-epidote. Graphite and iron oxides are common as opaques.

The siliceous argillite member was mapped in the Mount Buchanan area by Cairnes (1934, p. 39 and map 273A) and Read (1972, unpublished data) as the Milford Group. Read and Wheeler (1976) included most of the McHardy assemblage south of the McKian Creek Stock with the Kaslo Group and some parts with the Slocan Group. In the Poplar Creek area, Read (1973) included much of the siliceous argillite member in his units 13d (hornblende-plagioclase schist) and 15 (micaceous meta-sandstone).

The siliceous argillite member contains several variations in lithology. In the headwaters of Wilson Creek, it is more highly metamorphosed and generally occurs as light grey-to white-weathering bedded quartz-plagioclase biotite schist and calc-schist (Fig. 40). Calcareous phyllite is present at Mount McHardy and on the ridge southwest of the junction of Rossland and Keen creeks as beds within siliceous argillite. Local lenses of conglomerate are too thin and discontinuous to map separately at 1:50,000 scale. The conglomerate contains intraformational material as clasts of grey and green siliceous argillite are common. An important conglomerate bed is present near the base of the siliceous argillite member, along the border of the McKian Creek Stock and north of Spokane Creek. Clasts of angular white quartzite (metachert?), greenstone and metadiorite lie in a matrix of greenish-grey meta-sandstone. This conglomerate is important because the greenstone and metadiorite clasts may have originated from volcanics within the Davis and Keen Creek assemblages. White and black chert sharpstone conglomerate with a matrix of olive siliceous meta-sandstone is exposed 3.1 km (1.9 mi) at 112° from Mount McHardy (Fig. 41). Apatite-rich rocks, possibly representing metamorphosed phosphorites, occur in the siliceous argillite member in the core of the



Figure 39: Typical siliceous argillite of the Siliceous Argillite Member of the McHardy assemblage. View to west, ridge between Kane and Cooper creeks.



Figure 40: Metamorphosed Siliceous Argillite Member of the McHardy assemblage, consisting of layered quartz-plagioclase-biotite schist and calc-schist.

Dryden anticline at Mount Dryden at an elevation of about 1920 m (6300 ft) and the ridge east of Burkitt Creek at an elevation of 2073 m (6800 ft).

On the western slopes at the southern end of the Blue Ridge the siliceous argillite member consists of lineated siliceous phyllite. Micaceous minerals form lustrous surfaces that define the foliation planes. The rocks here are generally coarser grained than siliceous argillite exposures south of the McKian Creek Stock.

The siliceous argillite member is commonly bleached near the margins of intrusive rocks, especially near the Kane Creek Diorite. The bleached zones are relatively enriched in quartz+epidote+tremolite and minor sphene.

The lower contact of the siliceous argillite member is formed by the Stubbs thrust fault in some places but the depositional contact with the carbonate member is exposed in other places. The contact with the underlying carbonate member is conformable. The contact of the siliceous argillite member with the overlying lower volcanic member of the Kaslo Group is also conformable. It is well exposed in the core of the Dryden anticline in the headwaters of South Cooper Creek. On the southwest flank of the anticline pyritic grey slaty argillite grades upwards into siliceous green phyllite of the Kaslo Group. On the northeast flank of the anticline, pyritic grey argillite is overlain by 50 cm (19.7 in) of pillow breccia succeeded by pillow basalt.

The great distance between the carbonate member and Kaslo Group preclude an accurate estimate of thickness for the siliceous argillite member. Additionally, the siliceous argillite is complexly deformed and contains abundant intrusions of diorite. A relatively homoclinal section occurs along Keen Creek south of Rossland Creek and consists of 2900 m

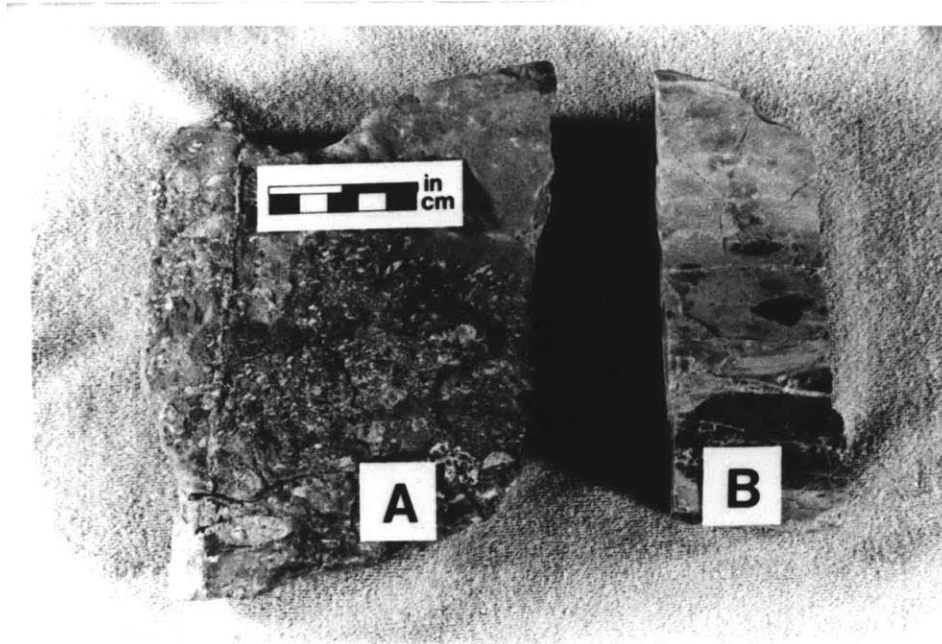


Figure 41: Conglomerates in the Siliceous Argillite Member of the McHardy assemblage. A: Metachert, diorite, and greenstone clasts in an arenaceous matrix. North valley wall of Spokane Creek. B: Chert sharpstone conglomerate in siliceous argillite and arenite matrix. Headwaters of Kane Creek.

(9515 ft) of siliceous argillite. The lower contact of this section is formed by the Stubbs thrust fault.

The age of the siliceous argillite member is bracketed by the underlying Upper Mississippian carbonate member and the overlying Lower to middle Permian Kaslo Group. Apatite-rich horizons near the upper part of the siliceous argillite member may correlate with Lower Permian phosphorites of the miogeocline (Norris, 1965; McGugan and Spratt, 1981).

Volcanic Member

Tholeiitic pillow basalt forms discontinuous but mappable lenses within the upper section of the siliceous argillite member. The lenses of the volcanic member occur along the western margin of the Spokane Creek Stock, at an elevation of about 2134 m (7000 ft) on the headwall of the Kane Creek Valley, and at the crest of Mount Buchanan on the southern Blue Ridge. Smaller, unmapped lenses are present at an elevation of 1402 m (4600 ft) 320° from Mount Buchanan.

The pillow lava is composed of fine-grained greenstone with pillow interstices of dark-green granular greenstone. Chemically, the volcanic rocks are similar to those in the overlying Kaslo Group (Tables IV and V). The MgO:CaO diagram (Fig. 23) shows the sample of volcanic member is altered. The sample is the most alkali and silica poor of the Milford Group analyses (Fig. 24) and plots near alkaline-calcalkaline border. It plots within the island arc field on a $TiO_2:FeO_{total}$ diagram (Fig. 25) separated from both the Milford Group and Kaslo Group clusters of analyses. A dyke of Kane Creek diorite feeds a pillow layer 3.9 km (2.4 mi) at 325° from Mount Dryden (Fig. 42). Kane Creek Diorite also feeds pillow lava of the Kaslo Group.

The contact relations of the volcanic member to the surrounding siliceous argillite member are well exposed only in the headwaters of Kane Creek. There, the pillow basalt grades laterally into green siliceous argillite. The basalt is overlain by grey pyritic (1-2 percent) siliceous argillite.

At Mount Buchanan the volcanic member is about 10 m (33 ft) thick and extends for about 750 m (2461 ft). In the Kane Creek headwaters the member varies from 5 to 10 m (16-33 ft) thick and two lenses have been traced for about 500 m (1640 ft) along strike. West of the Spokane Creek Stock, the volcanic member is 80-110 m (262-361 ft) thick and has been mapped along strike for about 1000 m (3281 ft).

The age of the volcanic of the McHardy assemblage is the same as that of the enclosing siliceous argillite member: Late Mississippian to Early Permian. Because of the chemical similarity of the volcanic member with the Early Permian Kaslo Group, it is likely the volcanic member is Late Pennsylvanian-Early Permian in age, but this correlation needs to be better established.

CORRELATION OF ASSEMBLAGES WITHIN THE MILFORD GROUP

The Davis, Keen Creek, and McHardy assemblages of the Milford Group are composed of similar lithologies that are in part coeval. In addition to general time equivalence, the assemblages are linked by their relationship to the Lardeau Group. The Davis and Keen Creek assemblages rest unconformably on the Lardeau Group. The McHardy assemblage contains boulders of Lardeau Group within the Cooper conglomerate. However, detailed correlation of lithologic units between assemblages is uncertain. Members of the Milford Group, especially within the Davis and Keen Creek assemblages, grade into each other along strike (e.g. relationships between

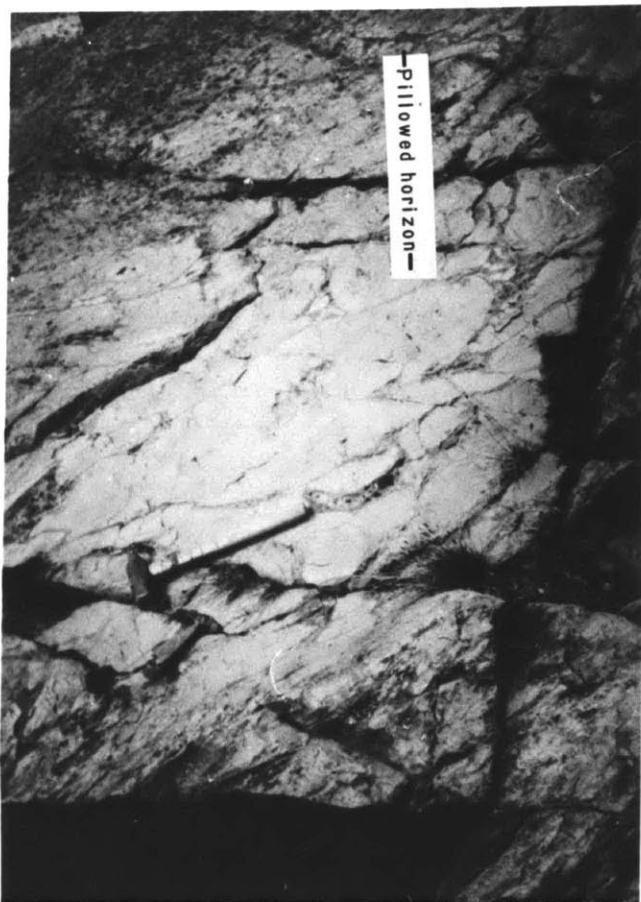


Figure 42: Pillowed top of a dyke of Kane Creek Diorite feeding the Volcanic Member of the McHardy assemblage. This outcrop is on the east limb of the southern segment of the Dryden anticline, Kane Creek headwaters. View northwest.



Figure 43: Pillow basalt typical of the volcanic members of the Kaslo Group. This outcrop is in the lower plate sequence of Kaslo Group, northeast of Mount Dryden. View to the northwest.

the siliceous argillite and cherty tuff members of the Davis assemblage south of South Cooper Creek and between the lower volcanic and banded limestone members of Keen Creek assemblage north of McKean Creek Stock). These units are probably also discontinuous from east to west. Fossils indicate that most of the Milford Group was deposited during Namurian time (Upper Mississippian-Lower Pennsylvanian; Orchard, 1985). The limestone member of the Davis assemblage is the oldest of the major carbonate units in the Milford Group within the Goat Range area, with some species indicating a Late Visean-Early Namurian age. The carbonate member of the McHardy assemblage is of Early Namurian to Early Mid-Namurian age. The banded limestone member of the Keen Creek assemblage is the youngest dated carbonate unit of the Milford Group, spanning Namurian time and possibly extending into the Bashkirian (Orchard, 1985). The correlation presented here (Fig. 44) is based on the assumption that the Upper Mississippian lower volcanic member of the Keen Creek assemblage is consanguineous with the greenstone member of the Davis assemblage. Volcanic clasts present in conglomerate of the siliceous argillite member of McHardy assemblage north of Spokane Creek are interpreted as products of this event.

Depositional Setting of the Milford Group

From stratigraphic, petrologic and regional considerations the three assemblages of Milford Group can be interpreted to have overlapped the boundary between oceanic crust and extended continental crust. The Davis and Keen Creek assemblages were deposited in a successor basin (King, 1969, p. 86). The basin is interpreted to have formed by the extension of the previously folded and foliated Lardeau Group and presumably, underlying rocks. The McHardy assemblage is interpreted to have been deposited on oceanic crust formed in a back-arc rift setting that was active from Middle Devonian to Early Pennsylvanian time.

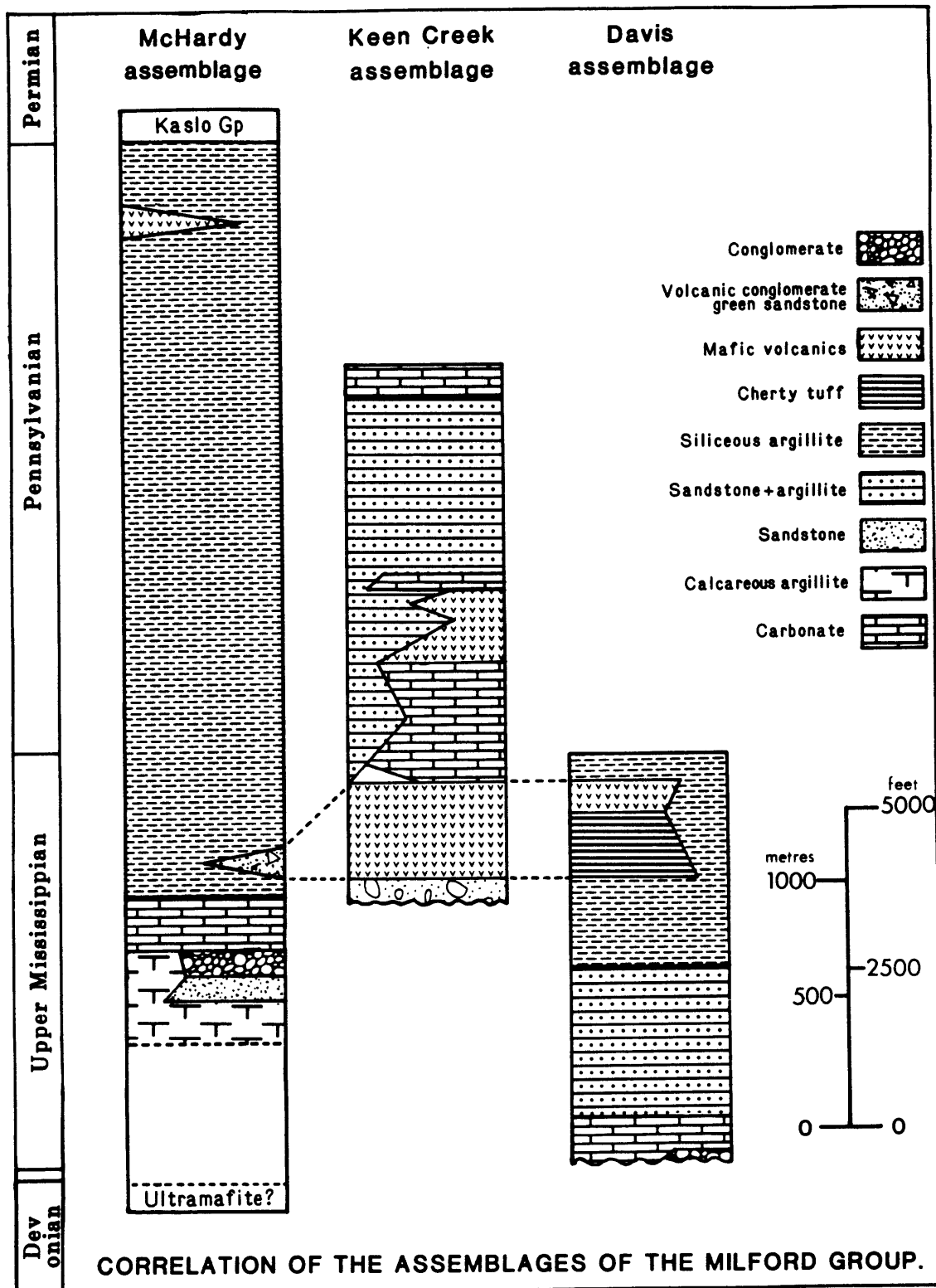


Figure 44: Correlation of the assemblages of the Milford Group. The datum plane is the Mississippian-Pennsylvanian boundary with a vertical dimension of lithologic thickness (scale at right).

Evidence in the Goat Range area for a rift environment comes from stratigraphic and petrologic data. Rapid facies changes between members and clastic rocks including conglomerate, grit and sandstone suggests a tectonically active environment of deposition. In particular, the tuffaceous sandstone and Cooper conglomerate members of the McHardy assemblage may have originated as clastic deposits proximal to an extensional fault scarp. The distribution of thicknesses of the Keen Creek assemblage indicates that it was deposited in a wedge-shaped basin, with the thickest strata deposited in the eastern part of the Keen Creek outcrop area. This thickness pattern can be interpreted as a rift-related half-graben. Chemical analyses of unaltered volcanic rocks in the Davis and Keen Creek assemblages (Fig. 25) indicates a rift or hot-spot setting for these rocks. The McHardy assemblage is intruded by the Late Permian to Middle Triassic Whitewater Diorite. Low $^{87}\text{Sr}/^{87}\text{Sr}$ ratios of about 0.7034 suggests the diorite did not interact with continental crust during intrusion (Faure and Powell, 1972, pp. 26-27). Additional evidence of an oceanic basement for the McHardy assemblage is provided by serpentinite lenses that outcrop along Crawford Creek 78 km (48 mi) northwest of the Goat Range area (Bancroft, 1921, pp. 111-112A; Read and Wheeler, 1976). These lenses are interpreted as slivers of altered oceanic crust along the trace of the Stubbs thrust fault that places the McHardy assemblage over the Davis assemblage at this locality.

The Davis and Keen Creek assemblages and members of the McHardy assemblage underlying the siliceous argillite member probably represent sequences deposited during or shortly after rift faults were active. Late Devonian to Early Mississippian fossils identified in the Milford Group along the western valley wall of Upper Arrow Lake (Orchard, 1985, p. 292)

are probably part of the McHardy assemblage. Orchard (1985, p. 298) proposed an eastward transgressive onlap of the Milford Group. This onlap may have occurred as rifting propagated eastward. The thick siliceous argillite member of the McHardy assemblage may have been deposited during the thermal phase of subsidence as the oceanic basement cooled.

Regional evidence for late Paleozoic rifting is present in other parts of the Canadian Cordillera. Work in southern Yukon and northern British Columbia (Mortensen, 1982; Gordey and Hills, 1985) shows that Middle Devonian to Mississippian volcanism, coarse clastic sedimentation and basin development are best interpreted by an extensional setting. Similar clastic sedimentary and mafic volcanic rocks are present in central British Columbia (Struik, 1985, p. 269 and 1981, p. 1769). Devono-Mississippian felsic to intermediate volcanic rocks and clastic sedimentary rocks from the Eagle Bay Formation 200 km (124 mi) northwest of the Goat Range area have been correlated with the Milford Group (Okulitch, 1979) and are interpreted as related to rifting (Preto and Schiarizza, 1985, p. 16-6). The ophiolitic lower sequence of the Fennel Formation includes sandstone, phyllite and chert and is of Early Mississippian to middle Permian age. This sequence correlates well with the McHardy assemblage and overlying Kaslo Group. The Fennel Formation is thrust onto the Eagle Bay Formation and results in a geologic configuration analogous to the Stubbs thrust sheet overlying Keen Creek and Davis assemblages. Elsewhere in southern British Columbia, late Paleozoic alkaline magmatism including carbonatites (White, as referenced in Pell, 1985), and Middle Devonian tholeiite (Root, 1985) may be associated with this apparently widespread rifting event.

KASLO GROUP

Mafic volcanic rocks, serpentinite, intrusives, and associated sedimentary rocks that outcrop along the west flank of the Blue Ridge were designated as the Kaslo schists by McConnell (1897, p. 24A) and Kaslo Group volcanic rocks by Drysdale (1917, p. 57). Cairnes (1934, pp. 43-49) presented a detailed description of the "Kaslo series" and included some grey siliceous metasediments on the west slope of Mount Buchanan that are here assigned to the McHardy assemblage of Milford Group.

The Permian and Carboniferous Kaslo Group is separated by the Late Permian to Middle Triassic Whitewater thrust fault into upper and lower plate sequences (Klepacki and Wheeler, 1985). The lower plate sequence lies conformably on the McHardy assemblage and consists of basal tholeiitic basalt intercalated with siliceous argillite and volcanic-derived sediments overlain by an upper tholeiitic basalt and greenstone member. The upper sequence is floored by an ultramafic unit that is overlain by volcanic rocks, siliceous sediments, conglomerate and wacke. Most of the upper plate sequence consists of tholeiitic pillow basalt and associated breccia. Pillow basalts of the upper and lower plate sequences of the Kaslo Group are texturally identical and generally consist of porphyritic plagioclase-pyroxene tholeiite (Fig. 43), although porphyritic plagioclase varieties are present. Pillow lava rims are commonly spherulitic (Fig. 45). The pillow lavas contain phenocrysts of pyroxene altered to amphibole and altered plagioclase that is commonly microlitic, set in a fine-grained matrix of amphibole-albite-epidote-quartz-chlorite-iron oxides-pyrite+biotite (Fig. 46). Plagioclase is altered to albite or oligoclase, quartz, epidote, carbonate, white mica, and rare zoisite and chlorite.



Figure 45: Spherulitic rims of pillows of Kaslo Group basalt. Spherules are composed of epidote, albite, quartz and minor carbonate. From the Upper Volcanic Member of the lower plate sequence on the southwest flank of Mount Brennan.

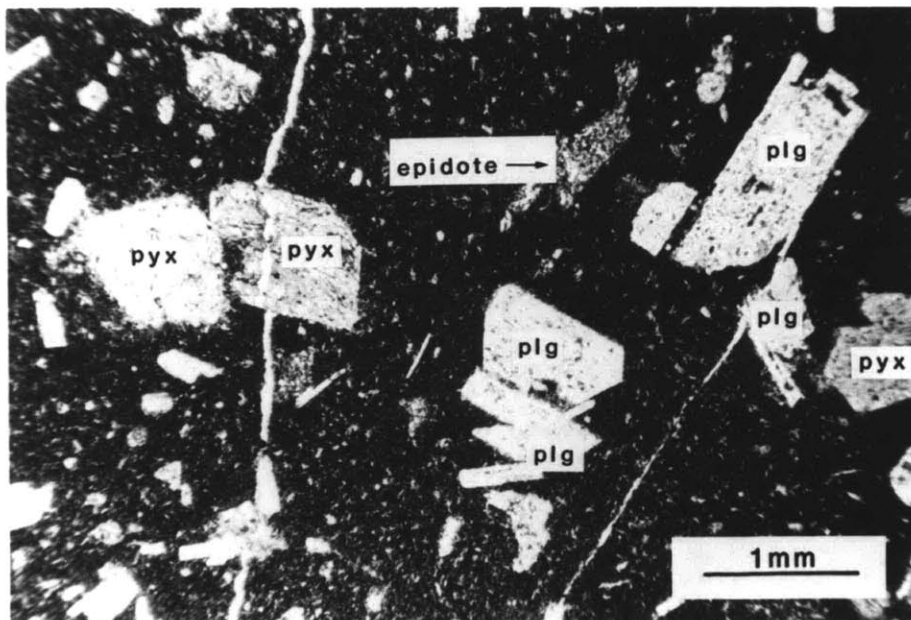


Figure 46: Photomicrograph of relict igneous texture in the Kaslo Group volcanics. Plagioclase (plg) microlites and pyroxene (pyx) pseudomorphs in a sample of Upper Plate Volcanic Member, Emerald Creek.

The Kaslo Group is best developed along the Blue Ridge from Mount Dryden south to Mount Jardine, where the sequence forms the crest of the Dryden anticline (Fig. 3). The Kaslo Group on the east limb of the anticline is truncated along the Schroeder fault and occurs as far north as Cooper Creek and as far south as Wing Creek. Along the west limb of the Dryden anticline, the Kaslo Group outcrops the length of the mapped area, and extends into the Ainsworth-Kaslo area to the south (Fyles, 1967). It is intruded by the Kuskanax Batholith directly northwest of the study-area (Read and Wheeler, 1976). The upper plate sequence has been recognized along the eastern margin of the Kuskanax Batholith in the Poplar Creek area (Read and Wheeler, 1976; Klepacki, Read and Wheeler, 1985).

The thickness of the Kaslo Group is variable because sections are truncated by the Whitewater fault and overlying unconformity surfaces. Representative thickness estimates for the lower and upper plate sequences are 1350 m (4429 ft) and 1210 m (3970 ft) respectively.

The Kaslo Group is unconformably overlain by the Upper Permian to Middle Triassic Marten Conglomerate and by the Upper Triassic Slocan Group.

Lower Plate Sequence

Lower Volcanic Member

The lower volcanic member is part of the lower plate sequence of the Kaslo Group and consists of dark green pillow lava, massive flows, flow and pillow breccia and tuffaceous greenstone. It conformably overlies argillaceous rocks of the siliceous argillite member of the McHardy assemblage. The lower volcanic member occurs on the northern slopes of Mount Brennan, northeast of Mount Dryden and east of the Whitewater fault on the southwestern slopes of Mount Dryden (Fig. 3). The lower volcanic

member also occurs on the southwestern slopes of Mount McHardy and along the Wilson Creek valley north of its confluence with Burkitt Creek.

Undivided volcanic rocks that overlie the McHardy assemblage and are present in the footwall of the Whitewater fault (Fig. 5, geologic section F-F') southeast of Ten Mile Creek contain rocks correlative lower volcanic member.

The lower volcanic member generally consists of amphibole pseudomorphs of pyroxene phenocrysts (1-10 percent) and altered plagioclase phenocrysts (0-20 percent) set in a fine-grained, poorly foliated matrix of amphibole, altered microlitic plagioclase, and opaques (1-5 percent of the rock). Light to dark green pleochroic actinolite and/or hornblende constitutes most of the amphibole after pyroxene pseudomorphs and is commonly rimmed with colorless cummingtonite. Hornblende (or actinolite) and cummingtonite grains occur in the matrix. Amphibole is commonly altered to chlorite and epidote and locally to talc or serpentine. Plagioclase is altered to albite, abundant epidote and clinozoisite, and locally carbonate minerals, chlorite and white mica. Spherulites and amygdules contain epidote, albite, quartz and chlorite. Opaques consist of hematite, magnetite, and rare pyrite. Amphibole and plagioclase constitute about 60 to 95 percent of the volcanic rock. Chlorite generally comprises less than 15 percent of the rock, although it may comprise as much as 20 percent of the tuffaceous lithologies. Lithic fragments in breccia and tuff are compositionally similar to their tuffaceous matrix and differ only in grain size. Chemically the volcanic rocks are tholeiitic basalt (Table V) and may be spillitic with a normative plagioclase composition of An_{37} to An_{45} and typical spillitic alteration products. The internal stratigraphy

Table V: Chemical Analyses (Weight Percent) and Normative Compositions (Percent) of Volcanic Rocks of the Kaslo Group

	K83-38e	K83-35c	K83-05g	K83-28c	K83-115	K83-01k	K82-2c	K83-09a
SiO ₂	48.9	50.9	53.3	48.5	48.8	48.9	50.7	47.6
TiO ₂	1.61	1.42	1.93	1.55	1.41	1.67	1.39	1.58
Al ₂ O ₃	14.5	14.9	14.3	14.8	15.6	14.2	15.7	15.6
Fe ₂ O ₃	4.2	3.2	2.7	2.1	3.3	2.4	3.2	2.8
FeO	6.6	6.5	8.0	9.2	6.1	8.7	5.9	8.5
MnO	0.19	0.18	0.20	0.23	0.17	0.20	0.19	0.20
MgO	7.82	6.66	6.68	6.98	5.37	7.79	5.02	6.12
CaO	6.94	9.90	4.67	10.5	11.3	9.67	11.7	10.2
Na ₂ O	4.0	3.5	3.4	2.6	3.1	2.2	3.1	2.8
K ₂ O	0.41	0.25	0.11	0.22	0.11	0.22	0.16	0.18
H ₂ O	3.4	1.9	4.1	3.1	3.0	3.9	1.7	3.5
CO ₂	1.2	0.1	0.7	0.4	1.9	0.3	0.1	1.0
P ₂ O ₅	0.16	0.12	0.22	0.13	0.12	0.16	0.13	0.16
S	0.32	0.00	0.00	0.01	0.12	0.00	0.00	0.18
Total	100.3	99.6	100.4	100.4	100.5	100.5	99.0	100.5
Quartz	---	0.82	11.28	---	4.09	5.89	3.37	0.94
Corundum	---	---	2.25	---	---	---	---	---
Orthoclase	2.42	1.48	0.65	1.30	0.59	12.00	0.95	1.06
Albite	33.85	29.62	28.77	22.00	26.23	21.15	26.23	23.69
Anorthite	20.40	24.21	17.30	28.06	28.36	23.98	28.45	29.47
Diopside	3.44	13.71	---	10.24	8.57	5.41	15.85	6.99
Hedenbergite	0.88	5.25	---	6.68	3.47	3.02	6.91	4.27
Enstatite	17.47	10.23	16.64	11.85	9.40	12.34	5.15	12.00
Ferrosilite	5.10	4.49	9.64	8.87	4.37	7.89	2.58	8.42
Forsterite	0.29	---	---	0.55	---	---	---	---
Fayalite	0.09	---	---	0.45	---	---	---	---
Magnetite	6.09	4.64	3.91	3.04	4.78	2.90	4.64	4.06
Ilmenite	3.06	2.70	3.67	2.94	2.68	1.67	2.64	3.00
Pyrite	0.60	---	---	0.02	0.22	0.02	---	0.34
Apatite	0.37	0.28	0.51	0.30	0.28	0.91	0.30	0.37
Calcite	2.73	0.23	1.59	0.91	4.32	0.23	0.23	2.27
H ₂ O	3.40	1.90	4.10	3.10	3.00	2.40	1.70	3.50
Total	100.18	99.54	100.32	100.33	100.37	99.81	99.0	100.39
Normative Plagioclase:								
Anorthite	37.60	44.98	37.56	56.05	51.95	53.13	52.03	55.43
Albite	62.40	55.02	62.44	43.95	48.05	46.87	47.97	44.57

Analyses by the Analytical Chemistry Section of the Geological Survey of Canada

K83-38e: Upper Volcanic Member of lower plate sequence, 1.72 km at 016° from the confluence of Burkitt and Wilson creeks, 3970 ft

K83-35c: Upper Volcanic Member of lower plate sequence, 2.35 km at 356° from the confluence of Burkitt and Wilson creeks, 6050 ft

K83-05g: Lower plate greenstone tectonite, 2.1 km at 187° from Milford Peak, 6265 ft

K83-28c: Upper Plate Volcanic Member, 2.25 km at 294° from Milford Peak, 6725 ft

K83-115: Upper Plate Volcanic Member, old railgrade cut, 2.7 km from Mount Buchanan, 2690 ft

K83-01k: Upper Plate Volcanic Member, 4.01 km at 221° from Milford Peak, 3180 ft

K82-02c: Upper Plate Volcanic Member, 1.1 km at 079° from confluence of Kaslo River and Emerald Creek, 3740 ft

K83-09a: Phyllitic tuff of the Upper Plate Volcanic Member, 2.6 km at 283° from Mount Buchanan, 2929 ft

of the lower volcanic member is unknown and consists of interfingering lens-shaped bodies of flows, pillow lavas, flow and pillow breccia, fine-grained tuffaceous greenstone and greenstone of undetermined origin. Near Mount Dryden one or two sedimentary units of cherty tuff and volcanic-lithic wacke intertongue with pillow lavas. Similarly intertonguing sedimentary units are mapped on the ridge separating Wilson and Burkitt creeks.

The lower volcanic member conformably overlies the siliceous argillite member of the McHardy assemblage and is itself conformably overlain by cherty tuff and siliceous argillite of the sedimentary members in the lower plate sequence of the Whitewater thrust fault. Contact relations are well exposed on the southwestern spur of Mount Brennan where siliceous argillite of the McHardy assemblage is interstitial to pillow lava through an interval of about 50 cm (20 in). A 90 m - (295 ft)-thick unit of cherty tuff is present about 200 m (656 ft) above the base of the lower volcanic member. The lower volcanic member is conformably overlain by green and purple siliceous argillite of the sedimentary members of the lower plate sequence of the Kaslo Group.

The lower volcanic member on the southwest spur of Mount Brennan is 1060 m (3477 ft) thick. Interbedded volcanic and sedimentary rocks on the ridge between Burkitt and Wilson creeks that are correlated with the lower volcanic member are 820 m (2690 ft) thick.

The age of the lower volcanic member is uncertain. The unit is younger than the Upper Mississippian carbonate member of the McHardy assemblage and older than the Late Permian to Middle Triassic Whitewater Diorite. Cherty tuff of the Kaslo Group in a structural horse along the Whitewater Fault has yielded fossils of Early to middle Permian age (Orchard, 1985 and personal communication, 1985). The lower volcanic

member is assigned a Permian age because of correlation with this fossiliferous sequence, but part of the sequence could be Pennsylvanian age.

Sedimentary Members

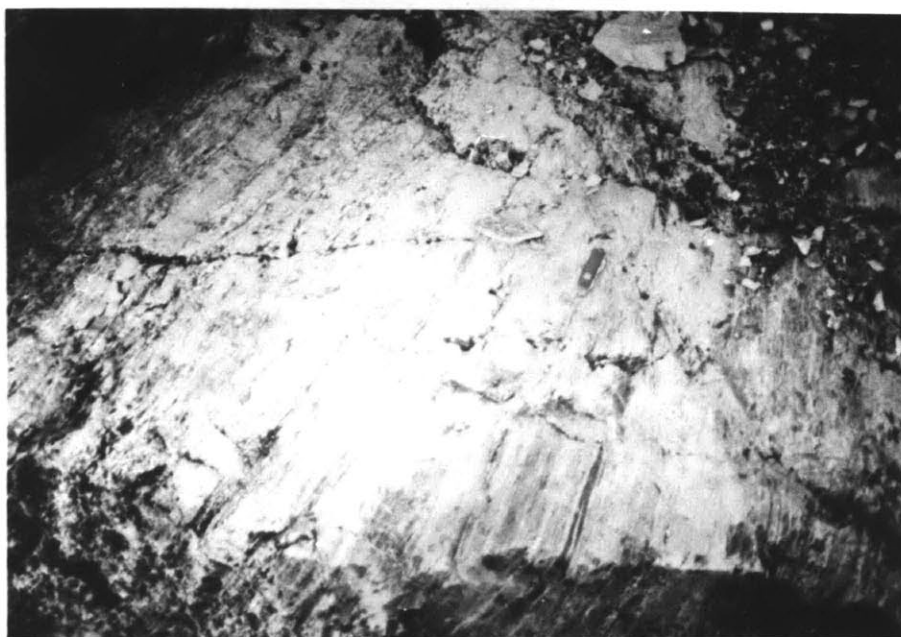
Green, grey and white laminated cherty tuff, purplish-grey siliceous argillite, and greywacke and conglomerate constitute the sedimentary units of the Kaslo Group in the lower plate sequence of the Whitewater fault. These lithologies occupy several stratigraphic levels within the lower plate sequence and were mapped collectively as sedimentary rocks. Thus they are described collectively as the sedimentary members. Cairnes (1934; p. 47) noted sedimentary rocks on Beaver Mountain which are part of the lower plate sequence. The sedimentary members are interbedded with the lower volcanic member at Mount Dryden, Mount Brennan and the ridge separating Burkitt and Wilson creeks. A relatively thick sequence of sedimentary rocks separate the upper and lower volcanic members of the lower plate sequence on the southwest slopes of Mount Brennan. These beds extend south to the western ridge of Beaver Mountain, southwest of Rossiter Creek, where they occupy the core of the Dryden Anticline (Fig. 47). The stratigraphic sequence of the belt of lower plate sedimentary rocks south of Mount Brennan consists of a basal purplish grey siliceous argillite overlain by green to grey slaty argillite and wacke and conglomerate that are in turn overlain by finely laminated green, white and black cherty tuff (Fig. 48). The conglomerate consists of granule- to cobble-sized clasts of greenstone, green siliceous argillite and grey to black chert set in a light grey wacke matrix. Locally, volcanic flows and tuffs are intercalated with the sedimentary rocks.

The sedimentary members have gradational contacts with the surrounding volcanic units. The transition from sedimentary to volcanic rocks commonly



Figure 47 (left): Grey slaty argillite and blocky-weathering conglomerate and wacke of the Sedimentary Members of the lower plate sequence of Kaslo Group. This is the crest of the Dryden anticline northwest of Mount Jardine, view to east.

Figure 48 (below): Laminated green, white and black cherty tuff of the Sedimentary Members of the lower plate sequence of Kaslo Group. View to the northwest, north valley wall of Rossiter Creek.



is marked by a few centimeters of green sandstone or argillaceous sandstone. The transition is well exposed at an elevation of 2255 m (7400 ft) on the ridge crest west of Mount Jardine. About 2.2 km (1.4 mi) at 023° from Mount Dryden, beds of green and white cherty tuff grade laterally into brecciated fragments that are inclusions within flows of pillow lavas. The tuffs were apparently deposited then disrupted by the flows.

The sedimentary members of the footwall sequence southwest of Mount Brennan are collectively about 170m (559 ft) thick. The sedimentary strata mapped around the Dryden Anticline in the Mount Dryden area varies in thickness from 20 to 100m (66 to 328 ft). On the ridge between Burkitt and Wilson creeks, the sedimentary members range from 53 m to 140m (174-459 ft) thick.

No fossils have been recovered from the sedimentary members of the lower plate sequence. The sedimentary rocks are correlated with fossiliferous Lower to middle Permian strata in the hanging wall of the Stubbs thrust fault and thus they are assigned a Early to middle Permian age.

Upper Volcanic Member

Tholeiitic pyroxene-plagioclase porphyritic pillow lava and breccia, greenstone, and chlorite phyllite that lies above the sedimentary members and below the Whitewater fault are assigned to the upper volcanic member of the lower plate sequence of the Kaslo Group. The member is present on the southwestern flank of Mount Brennan and on the ridge southeast of Rossiter Creek (Beaver Mountain). It also extends for 2 km (1.2 mi) between Wilson and Burkitt creeks.

Macroscopically and microscopically the lithology of the upper volcanic member is indistinguishable from the lower volcanic member of the lower plate sequence. In general the rock consists of phenocrysts of altered plagioclase and amphibole pseudomorphs after pyroxene set in a fine-grained matrix of amphibole, altered plagioclase, chlorite, abundant epidote and other alteration products. Flow and pillow interiors are medium-grained and more equigranular than the porphyritic and spherulitic rims.

The upper volcanic member rests conformably on sedimentary rocks of the lower plate sequence. Its upper contact is formed by the Whitewater fault thus thicknesses are minimum for the member. The thickness of the upper volcanic member northeast of Whitewater Creek is 187m (614 ft). At Lyle Creek it is 271m (890 ft) thick and at the ridge between Burkitt and Wilson creeks it is 362m (1188 ft) thick.

The upper volcanic member is considered Early to middle Permian in age based on correlation with fossiliferous Kaslo Group rocks in the upper plate of the Whitewater fault (Klepacki and Wheeler, 1985, p. 282; Orchard, 1985).

Upper Plate Sequence

Ultramafic Member

Serpentinite and talc-carbonate schist of the ultramafic member of Kaslo Group form discontinuous sheets which traverse the length of the study area (Fig. 3). The Whitewater thrust fault and splays off it form the floor of these sheets. The ultramafic member thus marks the base of the upper plate sequence of Kaslo Group.

McConnell (1897, p. 25A) first noted the presence of serpentinite in the Kaslo schists. LeRoy and Drysdale (Drysdale, 1917, Map no. 1667)

recognized the ultramafic unit on the southwest side of the Blue Ridge, and Cairnes (1934, p. 46 and Map 273A) mapped a second belt of serpentinite from Mount Jardine northwest to the southeastern slope of Mount Brennan. These two belts of serpentinite occur on the limbs of the Dryden anticline. The ultramafic member extends for 18 km (11.2 mi) along the northeastern limb of the Dryden anticline from South Cooper Creek to 2.5 km (1.6 mi) south of Milford Peak and for 41 km (25.5 mi) along the southwestern limb of the Dryden anticline, from 3.2 km (2.0 mi) northwest of Mount Buchanan northwestward to Fitzstubbs Creek (Fig. 3). The Whitewater fault bifurcates directly northwest of Lyle Creek creating an imbricated zone of ultramafic rock and greenstone extending northwest to Kane Creek (Fig. 3). Northwest of Kane Creek two discontinuous belts of ultramafic rock diverge and have been traced to the northeastern slopes of the Burkitt and Fitzstubbs creeks. Serpentinite lenses also occur in the Poplar Creek map-area (Read, 1973, p. 19; Klepacki, Read and Wheeler, 1985).

The ultramafic member consists of orange- or white-weathering olive-green to black serpentinite and light green talc-carbonate schist. Serpentinite breccia, with angular to rounded clasts of spotted serpentinite up to 4m (13 ft) in diameter, is common (Fig. 49), particularly along the southwestern belt from Rossiter Creek north to Whitewater Mountain. Bladed antigorite and fibrous chrysotile serpentine are well developed in the breccias. Bright green chrome mica (fuchsite) is locally abundant, especially in alteration envelopes adjacent to granitic dykes. In thin section rocks of the ultramafic member consists mainly of serpentine or talc+carbonate minerals. Chlorite, chromite, iron oxides and more rarely, biotite, constitute minor phases. Serpentine-talc-carbonate mineral assemblages are rare. Relict olivine occurs in the northeastern

belt 3.7 km (2.3 mi) at 132° from Mount Brennan. Bastite, formed by alteration of orthopyroxene, occurs southeast of Mount Brennan and at several places in the Whitewater Creek basin. Calcite is rare and carbonate minerals consist mainly of magnesite, ankerite and dolomite. Iron oxide is primarily magnetite, but hematite is locally abundant, especially at the confluence of Burkitt and Wilson creeks.

Anthophyllite-bearing talc schist occurs in the ultramafic member along the eastern margin of the Kuskanax Batholith west of Mount Marion.

The contacts of the ultramafic member with adjacent rocks are generally marked by faults. The lower contact is everywhere the trace of the Whitewater fault. The contact with the overlying upper plate sedimentary or volcanic members is generally sheared. Exposures of the contact with overlying lavas of the upper plate volcanic member occur at an elevation of 2150m (7054 ft) at 132° from Mount Jardine, in the old adit at the Emerald Mine on the eastern side of the upper Emerald Creek, and along the southwestern valley wall of Whitewater Creek. Greenstone above the contact consists of well-foliated layered flows and tuff overlying schistose serpentinite and serpentine-cobble breccia. The contact with overlying sedimentary rocks is also commonly sheared. An unfaulted contact is exposed at the crest of the Dryden anticline, 1000 m (3281 ft) at 165° from Mount Jardine. Serpentine breccia is locally overlain across a sheared and faulted contact by sheared schistose serpentine-pebble conglomerate (Fig. 50) that in turn is overlain by lithic wacke with clasts of volcanic rock and serpentinite. These relations suggest that the contact between the ultramafic member and overlying sedimentary and volcanic rocks of the upper plate sequence is apparently partly erosional.

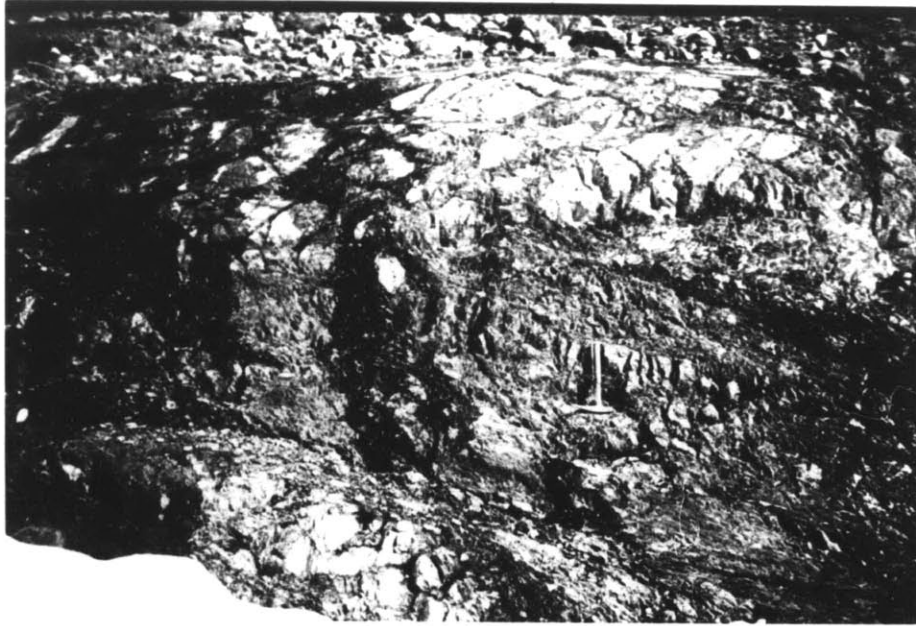


Figure 49: Serpentinite breccia of the Ultramafic Member, upper plate sequence of the Kaslo Group. View to the southwest, head of Whitewater Creek.

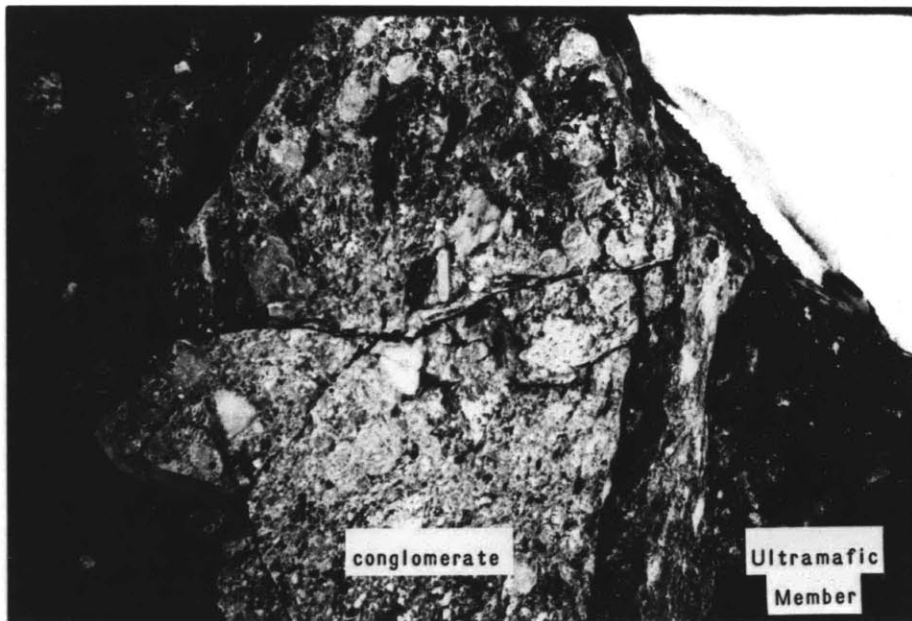


Figure 50: Conglomerate of the Upper Plate Sedimentary Members overlying brecciated serpentinite. The conglomerate contains clasts of serpentinite, volcanics and diorite. View northwest, north of Rossiter Creek.

The ultramafic member has an extremely variable thickness because the Whitewater fault, at the base of the upper plate sequence, locally eliminates the member. The maximum thickness of the member is present north of Whitewater Mountain where it is 843 m (2768 ft) thick, measured from cross sections. More commonly the unit is between a few tens and to a few hundreds of meters thick (66-984 ft).

The age of the ultramafic member is constrained only by overlying fossiliferous Lower to middle Permian sedimentary rocks of the upper plate sedimentary member. The ultramafic member is therefore Early Permian in age or older.

Upper Plate Sedimentary Member

The upper plate sedimentary members consist of green, white and dark grey cherty tuff, brown and grey wacke and conglomerate with clasts of volcanic rocks, diorite, serpentinite and chert. South of Kane Creek, the upper plate sedimentary rocks consist of thin (1-10m, 3-33 ft) lenses of conglomerate and wacke directly overlying the ultramafic member (Fig. 51). North of Kane Creek, on the southwest limb of the Dryden anticline, a belt of green, grey and white cherty, tuffaceous sedimentary rocks lie within a large thrust slice along the Whitewater fault (Fig. 52). Lenses of greywacke and volcanic conglomerate too small to map are present within the upper plate volcanic member.

Interbedded conglomerate, grey and green lithic wacke and sandstone, typical of the sedimentary rocks overlying the ultramafic member, occur 1000 m (3281 ft) at 165° from Mount Jardine. Clasts in the conglomerate and lithic wacke are granule- to pebble-sized and consist of light green tuff, greenstone, feldspar porphyry greenstone, and serpentinite (Klepacki, 1983, p. 233).

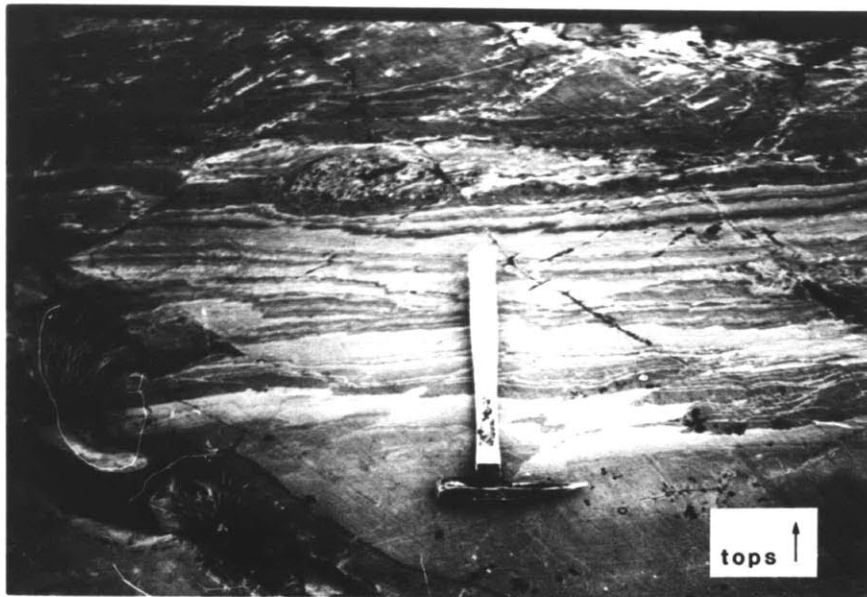


Figure 51 (above): Bedded greywacke of the Upper Plate Sedimentary Members of Kaslo Group. Note graded bedding (tops to west) and serpentinite limestone. View to the west, saddle between Mount Brennan and Whitewater Mountain.



Figure 52 (left): Cherty tuff of the Upper Plate Sedimentary Members of Kaslo Group. This unit yields Lower Permian conodonts. Note F_2 fold and disrupted beds. View to the southeast, northwest slope of Marten Mountain.

In thin section the wacke consists of clasts of plagioclase, quartz, actinolitic hornblende and quartz-carbonate mineral aggregates. The matrix contains muscovite-chlorite-quartz-plagioclase-carbonate minerals-epidote assemblage with carbonate minerals constituting up to 20 percent of the rock and opaques and chlorite defining well developed pressure-solution channels. Similar wacke and conglomerate beds, too thin to map, are intercalated with greenstone and serpentinite in a complexly slivered zone in the saddle between Mount Brennan and Whitewater Mountain. Here, brown-weathering beds of graded wacke include a few pebble- to cobble-sized clasts of serpentized gabbro and smaller clasts of greenstone (Fig. 51). Volcanic conglomerate at this locality contains clasts of greenstone, diorite, serpentized gabbro and serpentinite.

Northwest of Kane Creek the upper plate sedimentary member consists mainly of siliceous green argillite with beds 0.5 to 8 cm (0.2-3.1 in) thick of grey and white cherty tuff or sandy tuff (Fig. 52). In thin section the rock contains abundant quartz (35-50 percent) and muscovite (10-30 percent) with lesser amounts of chlorite, plagioclase and epidote. Carbonate minerals and hornblende are locally present. Conglomeratic lenses at Marten Mountain contain clasts composed of quartz aggregates, plagioclase, and serpentine. Locally, beds of white and grey cherty sedimentary rocks are transposed and fragmented in the hinges of tight F2 folds forming a pseudoconglomerate (Fig. 53).

The upper plate sedimentary member apparently rests unconformably on the ultramafic member and intertongues with volcanic rocks that locally rest on the ultramafic member. The upper plate volcanic member intertongues with and gradationally overlies the upper plate sedimentary member. Contact relations are well exposed at Marten Mountain where green

siliceous phyllite of the sedimentary member becomes increasingly granular and grades into porphyritic pyroxene-plagioclase pillow lava of the volcanic member. This transition takes place within 200 m (656 ft) laterally and 2 m (6.6 ft) vertically.

The thickness of the upper plate sedimentary member is variable. Siliceous sedimentary rocks northwest of Kane Creek are 883 m (2897 ft) although the section at Mount Dolly Varden that is 735 m (2413 ft) thick may represent a more typical thickness. Wacke and conglomerate, the predominant sedimentary rocks of the upper plate sequence southeast of Kane Creek, are rarely thicker than 30 m (98 ft) and are more typically 5 to 10 m (16 to 33 ft) thick.

Early Permian Neogondolella and middle Permian (Guadalupian-Wordian) Neogondolella serrata [Clark & Ethington] conodonts have been recovered from the siliceous sedimentary rocks 600 m (5249 ft) at 350° from Mount Dolly Varden at an elevation of 2240m (7350 ft) elevation (Klepacki and Wheeler, 1985, p. 282; Orchard, 1985, p. 294). Therefore the upper plate sedimentary member is assigned a Early to Middle Permian age.

Upper Plate Volcanic Member

The upper plate volcanic member comprises tholeiitic basalt flows and pillow lava, pillow and greenstone breccias and green tuff (Fig. 54). It has been traced the length of the map-area along the west limb of the Dryden anticline and from Cooper Creek to the headwaters of Wing Creek along its east limb. Greenstone breccia in a dark grey argillite matrix belonging to the volcanic member forms a belt on the east limb of the Dryden anticline from South Cooper Creek south to Ten Mile Creek.

In thin section the flow rocks contain amphibole pseudomorphs after pyroxene and altered plagioclase phenocrysts set in a fine-grained matrix of amphibole, albite, epidote, chlorite and iron oxides or pyrite (Fig.

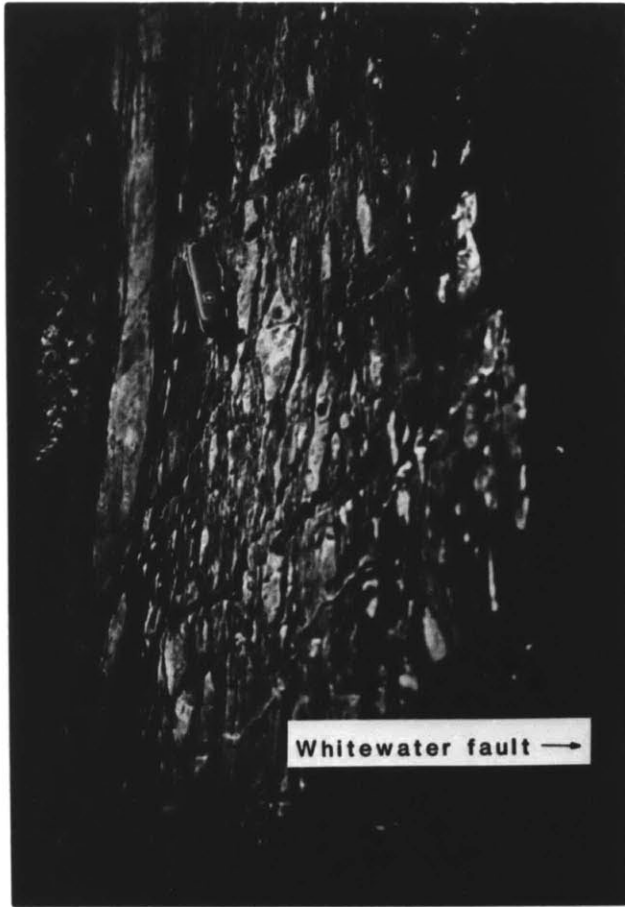


Figure 53 (left): Pseudoconglomerate formed from tectonically attenuated beds of cherty tuff. Adjacent to the Whitewater fault, west of Wilson Creek. View to the west.

Figure 54 (below): Basalt breccia common in the Upper Plate Volcanic Member of the Kaslo Group. Near flows and pillow lava at the top of the Kaslo Group, southwest of Inverness Mountain. View to the east.



46). Amygdules and spherulites contain albite and epidote. Actinolitic hornblende, cummingtonite, chlorite, albite, clinozoisite, carbonate minerals and abundant epidote are alteration products of the moderately altered basalts. Relict ophitic and subophitic textures are preserved although zoning of feldspars was not recognized. Tuffaceous rocks have a fine-grained equigranular matrix of albitic plagioclase-quartz-amphibole-chlorite-epidote-sphene. Crystal-lithic tuffs contain coarse-grained amphibole and plagioclase (albite) or lithic clasts of pyroxene(amphibole)-plagioclase porphyry. Chemically the upper plate volcanic rocks are quartz-normative basalts (Table V). Normative plagioclase ranges from 52 to 56 percent anorthite.

The volcanic rocks in the upper plate intertongue with sedimentary rocks and overlie the ultramafic member with an uncertain relationship. The upper plate volcanic member is unconformably overlain by the Marten conglomerate. On the northeast limb of the Dryden anticline the unconformable contact between the generally fragmental greenstone of the Kaslo Group and the overlying greenstone conglomerate of the Marten conglomerate is difficult to recognize. The unconformity is exposed on the southwest flanks of Whitewater and Inverness mountains where pillow lavas and pillow breccia are abruptly overlain by slightly rusty-weathering greenstone conglomerate with a light green phyllitic matrix.

Because the upper plate volcanic member interfingers with and overlies rocks of the Lower to middle Permian upper plate sedimentary member and is unconformably overlain by the Upper Permian to Middle Triassic Marten conglomerate, the upper plate volcanic member is Early to Middle Permian in age.

Depositional Setting of the Kaslo Group

The volcanic and sedimentary rocks of the lower plate sequence of Kaslo Group were deposited on the thick sedimentary section of the McHardy assemblage while similar rocks of the upper plate sequence were deposited on the ultramafic member which was probably oceanic crust (Gass et al., 1984). The age of the ultramafic member is uncertain but is probably Permian because feeder dykes to the overlying Permian volcanic rocks were not recognized within the ultramafic member, hence the ultramafic member itself is interpreted to be the altered magmatic source of the volcanic rocks. Chemical analyses of both lower and upper plate volcanic rocks (Table V; Figs. 23, 24, 25) are extremely similar and indicate the rocks are calcalkaline with TiO_2/FeO_x ratios typical of ocean ridge basalts. The upper plate sequence is interpreted as part of an oceanic ridge system perhaps within a back-arc setting similar to the present Andaman Sea (Hamilton, 1979, p. 67). The lower plate sequence is interpreted as the continent-ward margin of the rift volcanic field. There is no evidence for a late Paleozoic oceanic basin lying east of the Goat Range in the Paleozoic and Proterozoic supracrustal rocks of the Purcell and Rocky mountains. Therefore it is likely the "Kaslo basin" lay to the west and thrusting along the Permo-Triassic Whitewater fault that imbricated the upper and lower plate sequences of Kaslo Group was east-directed. Sedimentary rocks similar to the McHardy assemblage are present on the west side of the Okanagan Valley (lower Chapperon Group; Jones, 1959, Read and Okulitch, 1977; Okulitch, 1979) and are overlain by Permian volcanic rocks. The Kaslo basin either existed between the Goat Range area and the Okanagan Valley, or it may have been present west of the Okanagan Valley (in a reference frame relative to the Goat Range; restoring late Mesozoic-early

Cenozoic shortening would move both localities at least 100 km (62 mi) west.). If the Kaslo basin was west of the Okanagan Valley, tectonic transport of the hangingwall of the Whitewater fault would be about 200 km (125 mi). The similarity of the volcanic and sedimentary rocks in the footwall and hangingwall of the fault suggests the Kaslo basin was adjacent to the McHardy assemblage and east of the rock sequences in the Okanagan Valley.

MARTEN CONGLOMERATE

Greenstone conglomerate intercalated with limestone at the base of the Slocan Group, here informally named the Marten conglomerate, was first recognized by LeRoy and Drysdale (1917, Map 1667). Bancroft (1920, p. 45B) reinterpreted the conglomerate as an intrusive breccia but Cairnes (1934, p. 55,58) included it within the Slocan Group, implying a sedimentary origin for the unit. Read and Wheeler (1976) also included the conglomerate in the Slocan Group. Permian (?) conodonts are present in limestone beds in the conglomerate (Klepacki and Wheeler, 1985, p. 282) and recognition of a low angle unconformity with the overlying Slocan Group requires the Marten Conglomerate be separated as an unconformity-bounded stratigraphic unit distinct from either the Kaslo or Slocan groups.

The Marten conglomerate is typically exposed in the headwaters of Marten Creek on the southwestern slopes of Inverness Mountain and Mount Dolly Varden. It consists of clasts composed of greenstone, diorite and serpentinite set in a rusty-weathering, green calcareous phyllite matrix. It also includes beds of grey limestone with thin dark grey laminae. These beds form lenses up to 10 m (33 ft) thick and 150 m (492 ft) long although limestone beds 2-6 cm (0.8-2.4 in) thick and 1-2 m (3.3-6.6 ft) long are more common (Fig. 55). An easily accessible exposure of the Marten

conglomerate is present at a bend in Route 31A 7 km (4.3 mi) south of Retallack. Conglomerate clasts at this place are pancake-shaped and consist mainly of diorite and greenstone. On the eastern limb of the Dryden anticline, in the saddle between Mount Davis and Mount Brennan, the Marten conglomerate contains relatively undeformed clasts of greenstone and limestone (Fig. 56). In thin section the conglomerate matrix contains abundant albite plagioclase and chlorite, with carbonate minerals, epidote, amphibole, serpentine and opaques. Serpentinite clasts and serpentine generally constitute up to 5 percent of the matrix.

The contact between the Marten conglomerate and underlying Kaslo Group, Whitewater Diorite and Kane Creek Diorite is an unconformity. The Marten conglomerate is not intruded by either of the diorites and unconformably overlies the upper plate volcanic member - Whitewater diorite contact south of Mount Dolly Varden and Whitewater Mountain. In addition the conglomerate contains abundant diorite clasts. A precise position of the unconformity at the base of the conglomerate is difficult to recognize in most exposures. The underlying greenstone and diorite has a web of darker, rusty wisps that die out at depth and widen and contain rusty-weathering fine-grained matrix material within the conglomerate. This texture is interpreted as forming within a regolith and is well exposed at the Whitewater Diorite-Marten conglomerate contact on the ridge separating Marten and Dixie creeks (Fig. 57). A similar poorly-defined basal contact is present beneath most of the length of the Marten conglomerate along the east limb of the Dryden anticline. The contact of the Marten conglomerate and the overlying grey phyllite of the Slocan Group is also an unconformity; one which apparently spans 15 million years of geological time. The Marten conglomerate is absent between the Kaslo and



Figure 55 (left): Bedded limestone matrix and greenstone clasts of the Marten Conglomerate. Serpentinite clasts are found near this exposure. Limestone at this locality yields Permian conodonts. View northwest, southwest of Inverness Mountain.

Figure 56 (below): Greenstone and limestone clasts in a calcareous matrix in the eastern belt of Marten Conglomerate. Note relatively undeformed clasts. View to the west, saddle of Brennan and Davis mountains.



Slocan groups from Ten Mile Creek north to about 7.5 km (4.7 mi) south of Retallack, indicating the unconformity at the base of the Slocan Group cuts down into the Kaslo Group. Where exposed, the unconformity is knife sharp (Fig. 58).

Where present, the Marten conglomerate appears to maintain a relatively constant thickness of about 60 m (197 ft) along both limbs of Dryden Anticline. The thickest section lies between Rossiter Creek and the Kaslo River where it is 119 m (392 ft) thick.

The age of the Marten conglomerate is best constrained by the youngest strata of the underlying Kaslo Group, which are Wordian (middle Permian) in age and the oldest strata of the overlying Slocan Group, which are Carnian (Late Triassic) in age. Neogondolella and Ellisonia? conodonts recovered from a limestone bed at the ridge crest 1.9 km (1.2 mi) at 267° from Inverness Mountain were initially assigned an Early Permian age (Orchard, 1985, p. 297) but are now considered to be Late Permian (?) (M.J. Orchard, personal communication, 1985). The possibility that these conodonts are reworked from the underlying Kaslo Group cannot be ruled out. Additional faunal data are needed to better determine the age of the Marten conglomerate. Until such data are available the Marten conglomerate is assigned a Late Permian to Middle Triassic age.

Depositional Setting of the Marten Conglomerate

The Marten conglomerate is a locally derived coarse clastic and limestone sequence that overlaps fault slices of the Whitewater fault system. This post-tectonic deposit contains a record of subaerial erosion in the form of the pyritic paleosol sequences present at its base. The subrounded cobbles present in the conglomerate require local relief of a

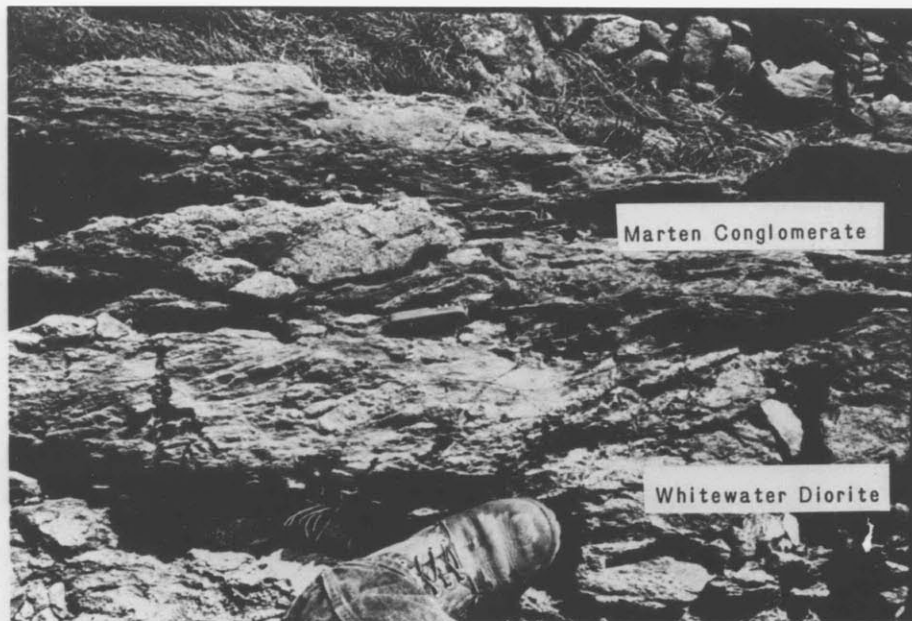


Figure 57: Gradational contact of the Marten Conglomerate and Whitewater Diorite interpreted as a regolith - an ancient C soil horizon.

Relatively coherent rock near foot of photograph grading up into foliated soil horizon in conglomerate. View west, near Mount Dolly Varden.



Figure 58: The unconformity between black argillite and slate (right) of the Upper Triassic Slocan Group and cobble conglomerate of the

Marten Conglomerate. View southeast, south of Whitewater Mtn.

source area. Limestone beds suggest the development of marine conditions. A possible scenario that accounts for the presence of erosion, conglomerate and limestone is the inundation of hilly post-tectonic terrain by the sea, creating islands with fringing reefs.

The amount of limestone in the Marten conglomerate appears to vary along strike. Limestone is most abundant in conglomeratic rocks exposed in the southeastern Goat Range area, on the western flanks of the Blue Ridge. The conglomerate was not recognized in the Ainsworth Area (Fyles, 1967), south of the Goat Range area, where carbonate units included in the Slocan Group rest directly on rocks correlated with the Kaslo Group and McHardy assemblage (Klepacki and Fyles, unpublished reconnaissance, 1983). Some of the carbonate may be the southward continuation of the calcareous Marten conglomerate.

The Marten conglomerate may be correlative with conglomerates that have a similar geologic setting elsewhere in southern British Columbia. Northwest of the Goat Range, conglomerate on the east and west slopes of Upper Arrow Lake (Read and Wheeler, 1976) may be equivalent to the Marten conglomerate, or may be equivalent to the Cooper conglomerate of the McHardy assemblage. Conglomerate that overlaps deformed late Paleozoic rocks is also present near Greenwood, British Columbia (Little, 1983) where sharpstone conglomerate of the lower Brooklyn Formation unconformably overlies the Knob Hill Group. A similar relationship exists at Dome Mountain near Okanagan Valley where Read and Okulitch (1977) report sub-Upper Triassic conglomerate unconformably overlying deformed late Paleozoic strata.

SLOCAN GROUP

Grey slate, limestone and quartzite that host the mineral deposits of the Slocan Mining Camp around Sandon were named the Slocan slates by McConnell (1897, p. 24A). Little (1960) called these strata the Slocan Group. Read and Wheeler (1976) separated Upper Triassic slate and limestone of the Slocan Group from Upper Mississippian rocks of the Milford Group on the east limb of the Dryden Anticline.

In the Goat Range, the Slocan Group forms three belts: a thin, discontinuous belt on the southeastern side of the Kuskanax Batholith in the Poplar Creek Map-area (Klepacki, Read and Wheeler, 1985); a belt on the east limb of the Dryden anticline from the ridge east of Mount Cooper southeastward to Kemball Creek; and a belt on the western edge of the map area which is continuous with the main body of Slocan Group of the "Slocan syncline" (Hedley, 1952).

The Slocan Group consists of dark grey slate and phyllite that is commonly massive, but is locally interbedded with limestone, limestone arenite, and minor quartzite. Limestone beds vary in thickness from a few millimeters to 30 m (98 ft).

The lithology of the Slocan Group seems to vary systematically. Cairnes (1934, pp. 54,58) and Hedley (1945, p. 9) noted that limestone is more abundant in the eastern Kokanee Range whereas quartzite is prevalent to the west. Fyles (1967, p. 33) described abundant limestone and dolostone that constitutes much of the Slocan Group in the Ainsworth-Kaslo area. This study corroborates the abundance of limestone beds in the southern part of the eastern belt of Slocan Group. Quartzite appears to be more common in the western outcrops of Slocan Group, especially northwest of Kane Creek. Two outcrops with crossbedded sandstone 2.5 km (1.5 mi) at

091° from Retallack at an elevation of 1305 m (4281 ft) indicate that paleocurrents came from the west-northwest. Tuffaceous beds that contain felsic volcanic debris were described by Hedley (1952, p. 22) and Cairnes (1934, p. 56).

Stratigraphy and structure within the Slocan Group is poorly known, thus its precise thickness is unknown. Cairnes (1934, p. 58) estimated a maximum thickness of 6800 ft (2073 m) based on cross-sections from his reconnaissance mapping. The maximum outcrop width in the study area is 3.2 km (2.0 mi) along Kane Creek that yields a thickness of 2663 m (7424 ft). This estimate surely includes internal structural duplication.

Phyllite and Slate Member

Grey phyllite and slate constitute most of the Slocan Group in the Goat Range area. The phyllite and slate is mostly massive, but bedding is locally present and defined by dark colour bands, sandy and calcareous layers, and bands that weather into differential relief because of slight compositional variations. Bedding varies from a few millimeters to about 4 meters (13 ft) thick and beds 2-8 cm (0.8-3.1 in) thick are most common. Beds of quartzite, calcarenite and limestone are common near the base of the Slocan Group along the eastern belt (Fig. 59). Pyrite cubes up to 5 mm (0.2 in) on a side are common and the phyllite is locally graphitic. In thin section the phyllite and slate consist of quartz-muscovite-chlorite with opaques of hematite, graphite, or pyrite. Biotite is rare but occurs in the eastern belt north of Cooper Creek, and in the western belt near the Marten Creek Stock, at London Ridge and along the lower part of Robb Creek, southeast of Retallack. Plagioclase is rare and where present is albite. Chloritoid occurs near the base of the member north of Rossiter Creek and altered andalusite occurs along the northeastern margin of the Marten Creek

Stock. Pressure solution features are abundant in the Slocan Group rocks and consist of wispy, anastomosing trails of rusty hematite, muscovite and chlorite that define the S₂ foliation. Detrital muscovite, tourmaline and zircon are common in sandy layers. Perthite occurs as detrital feldspar in quartzite beds along Wilson Creek 1300 m (4265 ft) south of the map area. The belt of Slocan Group that occurs along the eastern margin of the Kuskanax Batholith consists of bedded grey quartz-biotite-muscovite-sillimanite schist.

Limestone Member

Several different stratigraphic levels within the Slocan Group contain beds of grey to black microcrystalline limestone (Fig. 60) that are generally 10-30 m (33-98 ft) thick. Thinner beds of limestone were not mapped, but are especially abundant in the eastern belt of Slocan Group, southeast of Davis Creek. Individual limestone beds are generally massive, dense and weather yellowish grey to light grey. As noted by Cairnes (1934, p. 54) and Hedley (1945, p. 9) limestone beds grade abruptly across and grade abruptly across and along bedding into argillaceous or arenaceous rocks. The most prominent limestone bed in the study area is the 15 m (50 ft)-thick Whitewater limestone (Hedley, 1945) near Retallack. This limestone is folded by F₂ and F₃ folds into a complicated interference pattern north of Retallack (Fig. 4).

The Slocan Group rests with slight angular unconformity on the Marten conglomerate. The Marten conglomerate is missing, presumably due to erosion, for 4.5 km (2.8 mi) from Ten Mile Creek to 3.2 km (2.0 mi) southeast of the junction of Rossiter Creek and Kaslo River. Greenstone conglomerate with a grey phyllitic matrix similar to Slocan Group phyllite occurs 7 km (4.3 mi) south of Retallack. A lense of conglomerate lies



Figure 59 (left): Interbedded limestone, calcarenite, and slate of Slocan Group along the east limb of the Dryden anticline. View to the southeast at west-vergent, disharmonic F_2 folds. Saddle between Jardine and Schroeder mountains.

Figure 60 (below): A block of fossiliferous limestone from the Slocan Group. Rod-shaped features are extended Aulacoceridae cephalopods on a bedding plane. Saddle between Brennan and Davis Mountains.



within Slocan Group phyllite several centimeters above the Marten conglomerate a distance of 1850 m (6069 ft) at 251° from Whitewater Mountain at an elevation of 1951 m (6400 ft). These relationships indicate local reworking of Marten conglomerate during the beginning of Slocan deposition. The contact of the Slocan Group with overlying rocks is not exposed in the study area. Andesite, dacite, and augite porphyry basalt in the Nakusp area, 12-27 km (7.5-17 mi) west of the Goat Range area (Hyndman, 1968) are present at the top of the Slocan Group and are unconformably overlain by the Lower Jurassic Archibald Formation (Read and Wheeler, 1976).

The age of the Slocan Group is Late Triassic (Carnian-Norian) based on recent work with conodonts (Table VI; Orchard, 1985, p. 297). Numerous collections of macrofossils have been recovered from the Slocan Group and consist dominantly of pentacrinoïd columnals, ammonites, belemnites, and pelecypod shells (cf. Cairnes, 1934, p. 60; Drysdale, 1917, pp. 57; Fyles, 1967, p. 34; Bancroft, 1920, p. 42B). Plant fossils were reported by Bancroft (1920, p. 42B) at Reco Mountain, 5.5 km (3.4 mi) southwest of Retallack. Net-like structures resembling fenestrate bryozoans, but of undetermined origin (E.T. Tozer, personal communication, 1984) were recovered from metapelite and meta-arenite rythmites along a logging road at the ridgecrest 825 m (2707 ft) at 238° from the junction of Dixie and Monitor creeks. In addition, the author collected poorly preserved Aulacoceridae cephalopods from limestone of Slocan Group at the ridge between Mount Davis and Mount Brennan (Fig. 60). J.A. Jeletzky (personal communication, 1985) of the Geological Survey of Canada made the determination:

"The representatives of the order Aulacocerida Stolly 1919 are largely restricted to the Triassic. However they are known to occur more rarely in the Early to Early Late Jurassic and, even more rarely, in the Permocarboniferous...better preserved material is needed to rule out the also possible derivation of this lot from the Lower to Lower Upper Jurassic or Permocarboniferous rocks."

This locality is apparently the same as the belemnite locality reported by Bancroft within his Milford series map unit (Bancroft, 1920, p. 43B).

Depositional Setting of the Slocan Group

The slate, limestone, quartzite and volcanics of the Slocan Group are interpreted as part of a regionally extensive, north-south trending Late Triassic back-arc basin (Monger and Price, 1979). The sedimentary rocks of the Slocan Group have been traced northwest across the Shuswap Metamorphic Complex (Jones 1959; Little, 1960; Okulitch, 1979, 1985) and along the western margin of the complex as the "black phyllite belt" in central British Columbia (Campbell and Tipper, 1971; Campbell et al., 1972). The belt of Upper Triassic sedimentary rocks grades westward into the arc volcanics of the Nicola Group (Okulitch and Cameron, 1976; Okulitch, 1979). In the southern Kootenay Arc the Slocan Group is correlated with the lithologically similar Ymir Group (Little, 1960, p. 59) that in turn is thought to be equivalent to the Archibald Formation of Rossland Group (Little, 1982, p. 15). However, Read and Wheeler (1976) have shown the Archibald Formation to unconformably overlie the Slocan Group near Slocan Lake.

The lithologic distribution of Slocan Group sedimentary rocks in the north-central Kootenay Arc suggests they accumulated in a basin with a highland source to the west and carbonate bank to the east, near the present shore of Kootenay Lake. The abundance of quartzite west of the Goat Range area indicates a western source terrain. Detrital muscovite and

TABLE VI - Conodont Age Determinations of the Slocan Group
After Orchard, 1985

Rock Unit	Loc.	GSC No.			Age	CAI ¹
Lms in Phyl/Slt Mbr	1	C-103382	?	?	X Carnian	5
Lms in Phyl/Slt Mbr	2	O-93549	X	X X	Late Norian	5
Lms in Phyl/Slt Mbr	3	C-101305		X ?	Late Middle-Late Triassic	5
Lms in Phyl/Slt Mbr	4	C-101314		X	Middle-Late Triassic	5
Lms in Phyl/Slt Mbr	5	C-87154		X	Late Middle-Late Triassic	5
Lms in Phyl/Slt Mbr	6	C-87151		X	Middle-Late Triassic	5
Lms in Phyl/Slt Mbr	6	C-87153		X	Norian(?)	5
Whitewater limestone	7	O-93464	X	? ?	X Late Carnian-Norian	5-7
Whitewater limestone	7	O-93467a	X	X	Carnian-Norian boundary	5-6
Whitewater limestone	7	O-93467b	X	X	Middle Norian	5,7
Whitewater limestone	7	C-116333	X	X	Middle Norian	5-6
Whitewater limestone	7	C-116336	X	X	Carnian-Norian boundary	6-7

Location Index:

- 1) Logging road cut, 810m at 236° from junction of Monitor and Dixie creeks
1813 m (5950 ft) elevation.
- 2) 3.4 km at 227° from Mount Dolly Varden, 2141 m (7025 ft) elevation.
- 3) 2.1 km at 262° from Whitewater Mountain, 1783 m (5850 ft) elevation.
- 4) 2.3 km at 080° from Mount Brennan, 2149 m (7050 ft) elevation.
- 5) 0.48 km at 205° from Mount Schroeder, 2210 m (7250 ft) elevation.
- 6) 1.13 km at 205° from Mount Schroeder, 2225 m (7300 ft) elevation.
- 7) Road cut along highway 31A, 1.13 km west of Rossiter Creek, 945 m (3100 ft)
elevation.

¹Conodont Colour Alteration Index

perthite in the quartzite beds requires granitic or metamorphic rocks within the source terrain. Rhythmically bedded sequences of pelitic rocks, quartzite and calcarenite were probably deposited by turbidity flows although grading is rarely recognizable. A carbonate bank, built on a topographic high, probably existed in the Ainsworth area (Fyles, 1967) and perhaps farther east. Calcarenite-bearing sediment flows from the relatively shallower bank may account for the thin- to thick-bedded limestone deposits east of the Dryden anticline. Conodont distribution within the Slocan Group (Orchard, 1985, p. 298) supports such an environmental difference between the eastern and western parts of the Slocan basin.

CHAPTER 4. INTRUSIVE ROCKS

Intrusive rocks are common in the Goat Range and consist of dykes, sills and stocks of diorite, gabbro, granitic rocks and rare lamprophyre. The basic intrusive rocks occur along the length of the Goat Range whereas large discordant bodies of granitic rocks are present in the northwestern part of the area along the margin of the Kuskanax Batholith, one of the large Mesozoic intrusions characteristic of the southern Omineca crystalline belt (Wheeler et al., 1972a).

The oldest intrusive rocks in the Goat Range area are thin, discontinuous veinlets of quartz+feldspar ubiquitous in the Lardeau Group and older rocks. None of them are large enough to show on the map and will not be discussed further. Younger dioritic rocks are related to three plutonic events: 1) Intrusion of the Early to Middle Permian and Carboniferous Kane Creek Diorite, 2) Intrusion of the Late Permian to Middle Triassic Whitewater Diorite, and 3) Intrusion of the younger early Mesozoic Davis Ridge Diorite. All these diorites have a typical color index of 20-35, are hornblende bearing, and have a chemical composition of gabbro. Granitic rocks are Jurassic and (?) older in age and comprise the Kaslo River, Kuskanax and Blue Ridge Intrusive rocks. Lamprophyre dykes are possibly Eocene in age.

KANE CREEK DIORITE

Greenish-grey medium- to fine-grained hornblende diorite porphyry, microdiorite greenstone and plagioclase-porphyroblastic chlorite schist dykes constitute the Kane Creek Diorite (Figs. 61,62). The unit is named for abundant exposures of diorite in the headwaters of Kane Creek where at least two sills can be traced into pillowed flows of the volcanic member of the McHardy assemblage (Fig. 42). A hornblende-porphyry dyke also can be traced into a pillowed flow of the upper volcanic member of the lower plate sequence of Kaslo Group.

The Kane Creek Diorite is restricted to intrusions into the McHardy assemblage and Kaslo Group of the Stubbs thrust sheet. The largest single body of the Kane Creek Diorite is the 7.1 km² (2.7 mi²) Mount Cooper Stock. Smaller bodies are found in the McHardy assemblage from the Poplar Creek area to the Mount Buchanan area. The diorite also intrudes the Kaslo Group, but is difficult to distinguish from consanguineous flows. The Kane Creek Diorite consists of actinolite hornblende (30-50 percent) and altered plagioclase (20-35 percent) phenocrysts set in a matrix of amphibole-albitic plagioclase-epidote-chlorite-sphene. Minor quartz, biotite, and carbonate minerals also are present in the matrix. The texture of the diorite varies with deformation and alteration. In areas of weak to moderate deformation, Anastomosing bands of fine-grained foliated hornblende-chlorite-epidote-plagioclase greenstone surround lenses of massive diorite that are 0.5-1.5 m (1.6-4.9 ft) long and 10-100 cm (3.9-39.4 in) thick. These foliated bands represent local and more intensely deformed zones that cut through undeformed diorite. Fine-grained hornblende-chlorite-quartz-epidote schist with albitic plagioclase porphyroblasts represents thoroughly recrystallized diorite in the Mount Buchanan area of the Goat Range and fine- to medium-grained hornblende-plagioclase amphibolite represents a similar degree of deformation in the metadiorite along the margin of the Kuskanax Batholith. In relatively unaltered medium-grained Kane Creek Diorite, coarse-grained phenocrysts of hornblende are poikilitic with plagioclase inclusions and ophitic and subophitic texture of amphibole and plagioclase phenocrysts is preserved. With increased alteration hornblende is replaced by felted needles of actinolitic hornblende and cummingtonite and flakes of chlorite. Plagioclase is ubiquitously altered to albite+clinozoisite with additional epidote, or carbonate minerals and quartz.

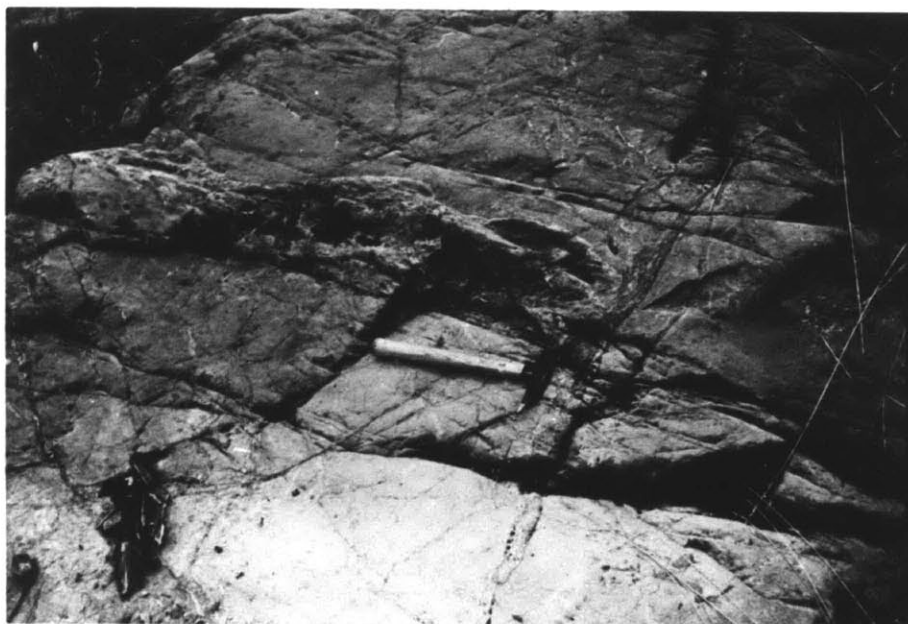


Figure 61 (above): Microdiorite phase of the Kane Creek Diorite containing a xenolith of Siliceous Argillite Member of McHardy assemblage. View northeast, upper reaches of Kane Creek.

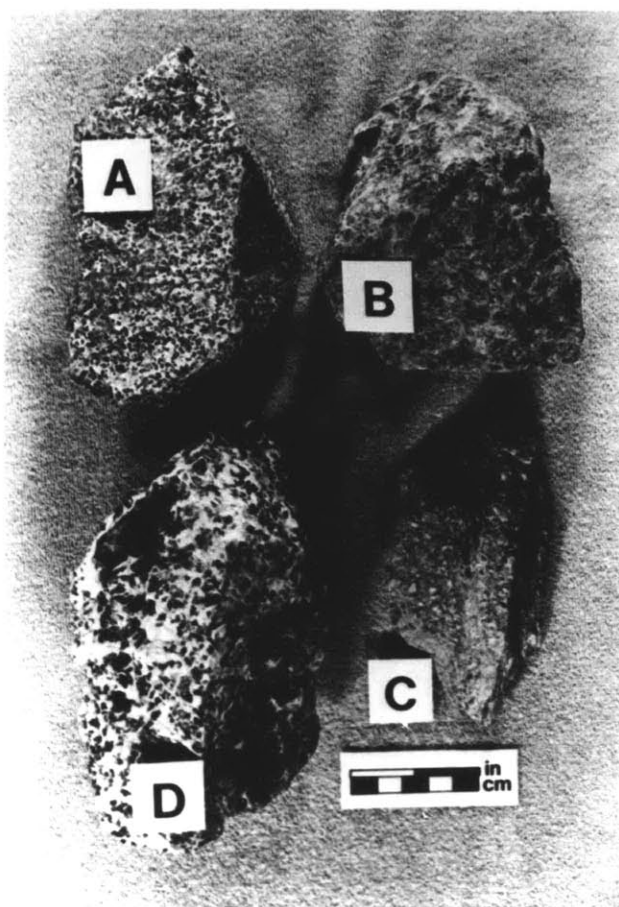


Figure 62 (left): Handsamples of Kane Creek and Whitewater Diorite. A: Typical Kane Creek Diorite. B: Kane Creek Diorite, Mount Cooper Stock. C: Foliated and altered diorite, Mount Buchanan area. D: Typical Whitewater Diorite, Marten Mountain.

Chemically the Kane Creek Diorite is a gabbro (Table VII) because it contains less than 50 percent silica and its normative plagioclase is greater than 50 percent anorthite. It is classified here as a diorite because of the moderate color index and presence of hornblende as the major mafic phase. The Kane Creek Diorite is distinguished from the similar Whitewater Diorite by its ophitic texture and distinctly greater color index (35-60 percent) and "dusty" appearance of its hornblende porphyry phase (Fig. 55).

The Kane Creek Diorite is assigned an Early to Middle Permian and Carboniferous age based on its relationship to the basalt units in the Lower to Middle Permian Kaslo Group and Pennsylvanian. Volcanic member of the McHardy assemblage.

WHITEWATER DIORITE

Equigranular, typically medium- to coarse-grained plagioclase-hornblende diorite is named the Whitewater Diorite from good exposures on Whitewater Mountain (Fig. 3). From Whitewater Mountain, a body 100 to 1200 m (328-3937 ft) wide continues northwest to Wilson Creek. Three other localities have mappable bodies of Whitewater Diorite: One intrusion mantles the Three Grizzlies Stock and extends southeast to Kane Creek, a second and larger body is present on the southeastern slope of Mount Brennan, the third locality contains several 1-3 km (0.6-1.8 mi) long bodies in the Mount Jardin area. Smaller dykes and sills are present near Mount Buchanan and southwest of Mount Cooper. The Whitewater Diorite commonly contains grains 1 cm (0.4 in) in length but locally grains may be 5 cm (2.0 in) in length. The diorite locally contains alternating hornblende-rich and plagioclase-rich layers 2-6 cm (0.8-2.4 in) thick. Anastomosing bands of fine-grained foliated diorite are more common in the Whitewater Diorite (Fig. 63) than similar foliated bands in the Kane Creek

TABLE VII: Chemical Analyses (Weight Percent) and Normative Compositions (Percent) of Diorites in the Goat Range Area

	K83-06c	K83-44b	K83-04g	K83-53	K83-40f	K82-30j
SiO ₂	49.5	49.7	47.1	49.8	49.0	54.0
TiO ₂	1.32	1.48	1.53	0.75	2.03	0.88
Al ₂ O ₃	17.2	16.2	14.1	15.8	14.2	15.1
Fe ₂ O ₃	3.4	2.5	1.4	2.4	2.5	2.0
FeO	5.5	6.6	8.6	5.1	9.9	6.7
MnO	0.16	0.19	0.19	0.15	0.21	0.17
MgO	5.88	7.79	6.27	9.23	6.04	5.96
CaO	11.3	11.0	8.24	11.6	9.79	7.56
Na ₂ O	2.7	2.9	3.1	2.6	1.7	2.5
K ₂ O	0.07	0.14	0.18	0.14	0.48	2.03
H ₂ O	2.9	1.8	4.1	2.5	3.6	2.4
CO ₂	0.1	0.1	5.4	0.1	0.3	0.1
P ₂ O ₅	0.11	0.11	0.18	0.09	0.18	---
S	0.00	0.01	0.06	0.06	0.08	0.39
Total	100.1	100.5	100.4	100.3	100.0	98.8
Quartz	3.02	---	11.01	---	6.12	5.89
Corundum	---	---	6.77	---	---	---
Orthoclase	0.41	0.83	1.06	0.83	2.84	12.00
Albite	22.85	24.54	26.23	22.00	14.39	21.15
Anorthite	34.61	30.77	5.57	31.03	29.70	23.98
Diopside	12.22	13.32	---	16.30	7.42	5.41
Hedenbergite	3.93	4.75	---	3.89	5.59	3.02
Enstatite	8.98	10.51	15.62	11.71	11.60	12.34
Ferrosilite	3.32	4.30	12.34	3.21	10.02	7.89
Forsterite	---	1.91	---	2.61	---	---
Fayalite	---	0.86	---	0.79	---	---
Magnetite	4.93	3.62	2.03	3.48	3.62	2.90
Ilmenite	2.51	2.81	2.91	1.42	3.86	1.67
Pyrite	---	0.02	0.11	0.11	0.15	0.91
Apatite	0.26	0.26	0.42	0.21	0.42	0.02
Calcite	0.23	0.23	12.28	0.23	0.68	0.23
H ₂ O	2.90	1.80	4.10	2.50	3.60	2.40
Total	100.17	100.53	100.45	100.32	100.01	99.81
Normative Plagioclase:						
Anorthite	60.23	55.63	17.50	58.51	67.37	53.13
Albite	39.77	44.37	82.50	41.49	32.63	46.87

Analyses by the Analytical Chemistry Section of the Geological Survey of Canada

- K83-06c: Kane Creek Diorite dyke, 3.92 km at 340° from Mount Buchanan, 1555 m (5100 ft) elevation.
- K83-44b: Mount Cooper Stock of Kane Creek Diorite, 2.5 km at 030° from Mount Cooper, 1865 m (6118 ft) elevation.
- K83-04g: Plagioclase-chlorite phyllite dyke of Kane Creek Diorite, along Buchanan Lookout Road, 2.85 km at 342° from Mount Buchanan, 1670 m (5480 ft) elevation.
- K83-53: Whitewater Diorite, 3.35 km at 294° from Mount McHardy, 2134 m (7000 ft) elevation.
- K83-40f: Davis Ridge Diorite, 3.94 km at 087° from Mount Cooper, 2377 m (7800 ft) elevation.
- K82-30j: Davis Ridge Diorite, along Schroeder Ridge, 1.8 km at 338° from Mount Schroeder, 2256 m (7400 ft) elevation.

Diorite. In general the Whitewater Diorite consists of phenocrysts of coarse-grained actinolitic hornblende with fine-grained (0.1 mm) plagioclase inclusions and phenocrysts of coarse-grained plagioclase altered to albite-epidote-white mica and rare amphibole. Locally a fine-grained matrix of albite-epidote-chlorite±green biotite is present. Opaques compose less than 1 percent of the rocks. The Whitewater Diorite has the chemical composition of a gabbro with a SiO₂ content of about 50 percent and normative plagioclase with an anorthite component of 58 percent (Table VII). The presence of hornblende and moderate color index of about 20 percent classify the rock as a diorite.

At Whitewater Mountain, the northeastern border of the diorite includes an intensely foliated dark green rock with white stringers of plagioclase and rare inclusions of bleached siliceous sedimentary rocks. Directly adjacent to serpentinite of the ultramafic member of Kaslo Group, the border phase consists of a chlorite-amphibole schist that contains angular fragments of foliated diorite in which the foliation is at an angle to the foliation of the matrix. In thin section both the intensely foliated diorite and chlorite-amphibole schist consist of green actinolitic hornblende altered to green chlorite and minor green biotite and granular albite, clinozoisite, and epidote. The serpentinite is coarser grained near the diorite contact and contains white rodingite dykes.

Greenish-grey phyllite with porphyroblasts of plagioclase and hornblende with intrusive relationships to the ultramafic and upper plate volcanic members is present 600m (1968 ft) southeast of Mount Jardine. Although the phyllite has a different texture from nearby bodies of Whitewater Diorite, it is considered to be Whitewater Diorite that was intensely foliated during the formation of the Dryden anticline.



Figure 63 (above): Anastomosing bands of fine-grained diorite in a coarser grained matrix within the Whitewater Diorite. These bands are interpreted as ductile shear zones which are themselves sheared in a sinistral sense by later shear zones (e.g. below hammer). View to east, headwaters of Keen Creek.



Figure 64 (left): Brecciated pyroxene (hornblende) - plagioclase porphyry phase of the Whitewater Diorite on the southeastern slopes of Mount Brennan. View north.

Whitewater Diorite outcrops as a stock in the basin on the southeastern slopes of Mount Brennan. The southeastern part of the body is a medium-grained equigranular hornblende diorite that grades northwestward into a pyroxene (pseudomorphed by hornblende)-plagioclase porphyry with a fine-grained, light greenish-grey matrix (Fig. 64). The porphyritic phase is brecciated and cut by epidote-rich veinlets. The southwestern margin of the stock contains abundant xenoliths of the lower plate sedimentary members of the Kaslo Group and lesser amounts of xenoliths of the volcanic members.

Good exposures of the Whitewater Diorite show it intrudes the Kaslo Group and Kane Creek Diorite. A large xenolith 420 m (1378 ft) long and 70 m (230 ft) wide a distance of 400 m (1312 ft) at 045° from Inverness Mountain contains the sheared contact between serpentinite and greenstone that is interpreted as the Whitewater fault (Fig. 65). This relationship indicates the Whitewater Diorite is younger than the Carboniferous(?) to Middle Permian Kaslo Group and movement along the Whitewater fault. The Whitewater Diorite is also nonconformably overlain by the Upper Permian to Middle Triassic Marten conglomerate. The unconformity is well exposed on the southern spur of Mount Dolly Varden (Fig. 57). The age of the Whitewater Diorite is therefore Late Permian to Middle Triassic as is the age of movement along the Whitewater fault.

Rubidium/Strontium Geochemistry of the Whitewater Diorite

Five localities of Whitewater Diorite were sampled for Rb/Sr analysis (Table VIII). Rock samples were crushed and analyzed at the Massachusetts Institute of Technology following the technique of Hart and Brooks (1977). Rb and K analyses were done on a 12-inch, 60° mass spectrometer and Sr analyses were done on a 9-inch, 60° mass spectrometer. Sr isotope

compositions are normalized to $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$ and reported relative to E & A $\text{SrCO}_3 = 0.70800$. Uncertainties for Sr isotopic compositions are two sigma of the mean and for K/Sr are about one percent. Results are presented in Figure 67. The whole rock data are scattered indicating the initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in the diorite were not uniform or the Rb-Sr isotopic system was disturbed by alteration. In thin section, the Whitewater Diorite contains evidence of significant alteration with plagioclase altered to albite, epidote, and white mica, also hornblende is locally altered to chlorite.

If the isotopic system is at equilibrium on the scale of the hand specimen and has not gained or lost Rb or Sr, then an isochron determined from the mineral constituents will yield the age of closure of the hand specimen (Faure, 1977, p. 84). This date can be related to the age of crystallization or the most recent metamorphic event. Three specimens were chosen for mineral separation: K82-16a, a coarse-grained, well altered specimen; K83-53a, a medium-grained, weakly foliated, slightly altered specimen and; K83-38c, a massive medium-grained relatively unaltered specimen. Hornblende separates for K82-16a and K83-38c yielded very poor analyses. Plagioclase from K82-16a also yielded a poor analysis. Plagioclase from K83-53a failed to produce a stable signal for measurement. Age determinations from two mineral analyses are poorly constrained but correspond to the geological history determined from other methods. Whole rock and plagioclase analyses from the relatively unaltered K83-38c gave an age of 263_{-104}^{+114} Ma. This date is in agreement with the Late Permian to Middle Triassic age for the Whitewater Diorite obtained from fossil evidence. Whole rock and hornblende analyses from K83-53a gave an age of 177_{-39}^{+45} Ma. K83-53a

Table VIII:

Whole Rock and Mineral Separate Rubidium-Strontium Isotopic Data
for the Whitewater Diorite

Sample	Sr (ppm)	Rb (ppm)	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$	$\pm 2\sigma$ error
K82-41j	220	0.09	0.001	0.70371	0.00003
K82-16a	152	0.19	0.004	0.70278	0.00003
K83-53a	99	8.59	0.250	0.70359	0.00004
K82-38c	218	3.22	0.043	0.70324	0.00003
K82-51a	94	1.91	0.058	0.70349	0.00004

Mineral Separate Rubidium-Strontium Isotopic Data for the Whitewater Diorite
P = Plagioclase Hb = Hornblende

Sample	Sr (ppm)	Rb (ppm)	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$	$\pm 2\sigma$ error
K82-16aP	34	0.16	0.013	0.70288	0.00007
K82-16aHb	3.8	0.05	0.036	0.70325	0.0004
K82-38cP	385	11.41	0.086	0.70340	0.00003
K82-38cHb	72	1.00	0.040	0.70358	0.0006
K83-53aHb	44	6.22	0.412	0.70399	0.00003

Location Index

K82-41j: 2.2 km at 248° from Marten Mountain, 2347m (7700 ft)
elevation

K82-16a: 1.5 km at 122° from Inverness Mountain, 1454m (4770 ft)
elevation

K83-53a: 3.5 km at 292° from Mount McHardy, 2164m (7100 ft)
elevation

K82-38c: 0.85 km at 135° from Whitewater Mountain, 2332m (7650 ft)
elevation

K82-51a: 0.86 km at 090° from Mount McHardy, 2463m (8080 ft)
elevation

was collected approximately 150 meters northeast of the margin of the Three Grizzlies Stock of the Kuskanax Intrusive Rocks. Zircon analyses indicate the Kuskanax intrusives are 168-187 Ma old (Parrish and Wheeler, 1983). The thermal aureole associated with the intrusion of the Three Grizzlies Stock apparently reset the Rb-Sr isotopic system of K83-53a yielding a Middle Jurassic age.

The most important result of the Rb-Sr whole rock analyses are the low $^{87}\text{Sr}/^{86}\text{Sr}$ values present in the Whitewater Diorite samples (0.70278-0.70371 with an arithmetic average of 0.70336). This suggests the Whitewater Diorite was derived from an upper mantle magmatic source with little or no contribution from the continental crust (Faure and Powell, 1972, pp. 26-27). This suggestion supports, but does not require an interpretation of an oceanic basement for the Kaslo Group, McHardy assemblage and older units into which the Whitewater Diorite intruded. The oceanic sequence was then thrust onto the continental crust that presently underlies the Goat Range (Monger and Price, 1979).

KASLO RIVER INTRUSIVE ROCKS

Several names have been applied to the deformed granitic sills and dykes along the west shore of Kootenay Lake and the grouping of these rocks may include granitic rocks of various ages. The local name, Kaslo River Intrusive Rocks is preferred for the lineated and foliated hornblende monzonite and quartz monzonite sills and dykes in the mapped area along the Kaslo River and on the eastern slopes of the Blue Ridge. The thick monzonite sill exposed in the Kaslo River west of the town of Kaslo (Figs. 3 and 5, section H-H') has been traced south into the Ainsworth area by Ross and Kellerhalls (1968, their Fig. 4) where it was previously included by Crosby (1960) with other granitic rocks in the "Kootenay Intrusives."

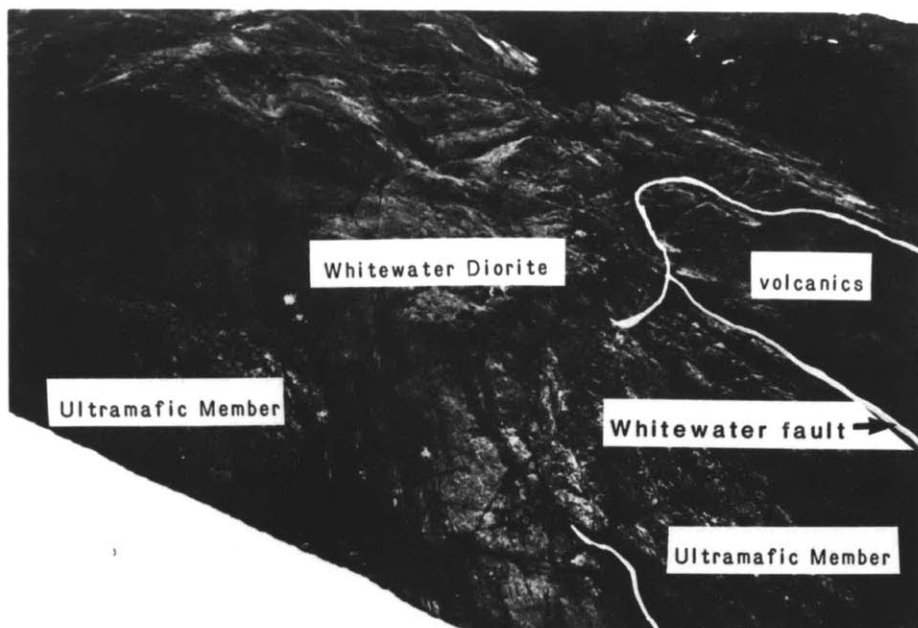


Figure 65 : A large xenolith within the Whitewater Diorite that contains the sheared contact of serpentinite and volcanics, interpreted as the Whitewater thrust fault. View east, northwest side of Kane Creek valley.

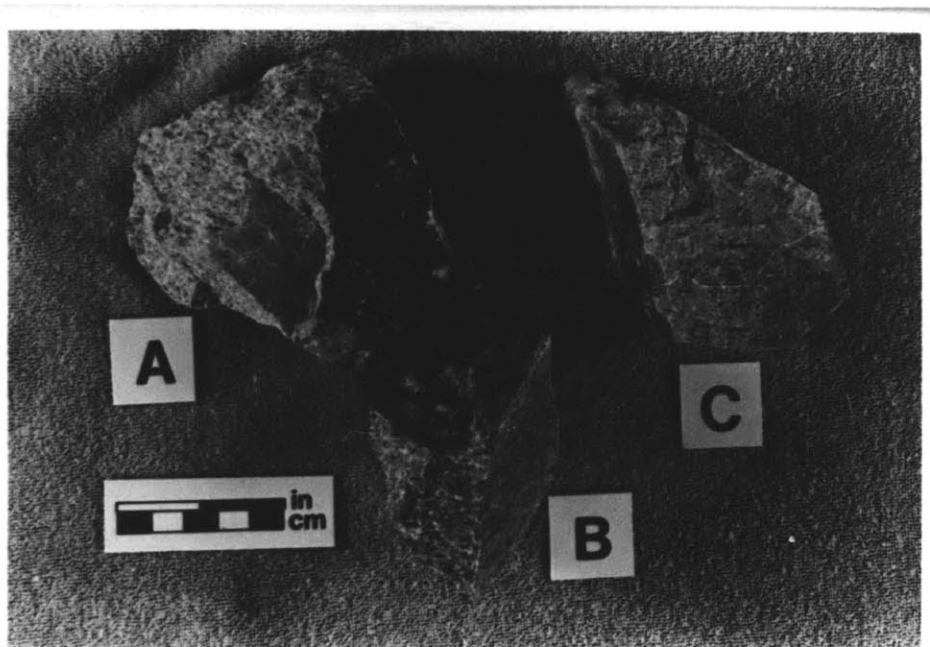


Figure 66 : Handsamples of the Kaslo River Intrusives. A: East of Mount Buchanan, 4100 ft elevation. B: Highway 31A. C: Southeast of Mount Buchanan, 3200 ft elevation. Note prominent lineation in all samples.

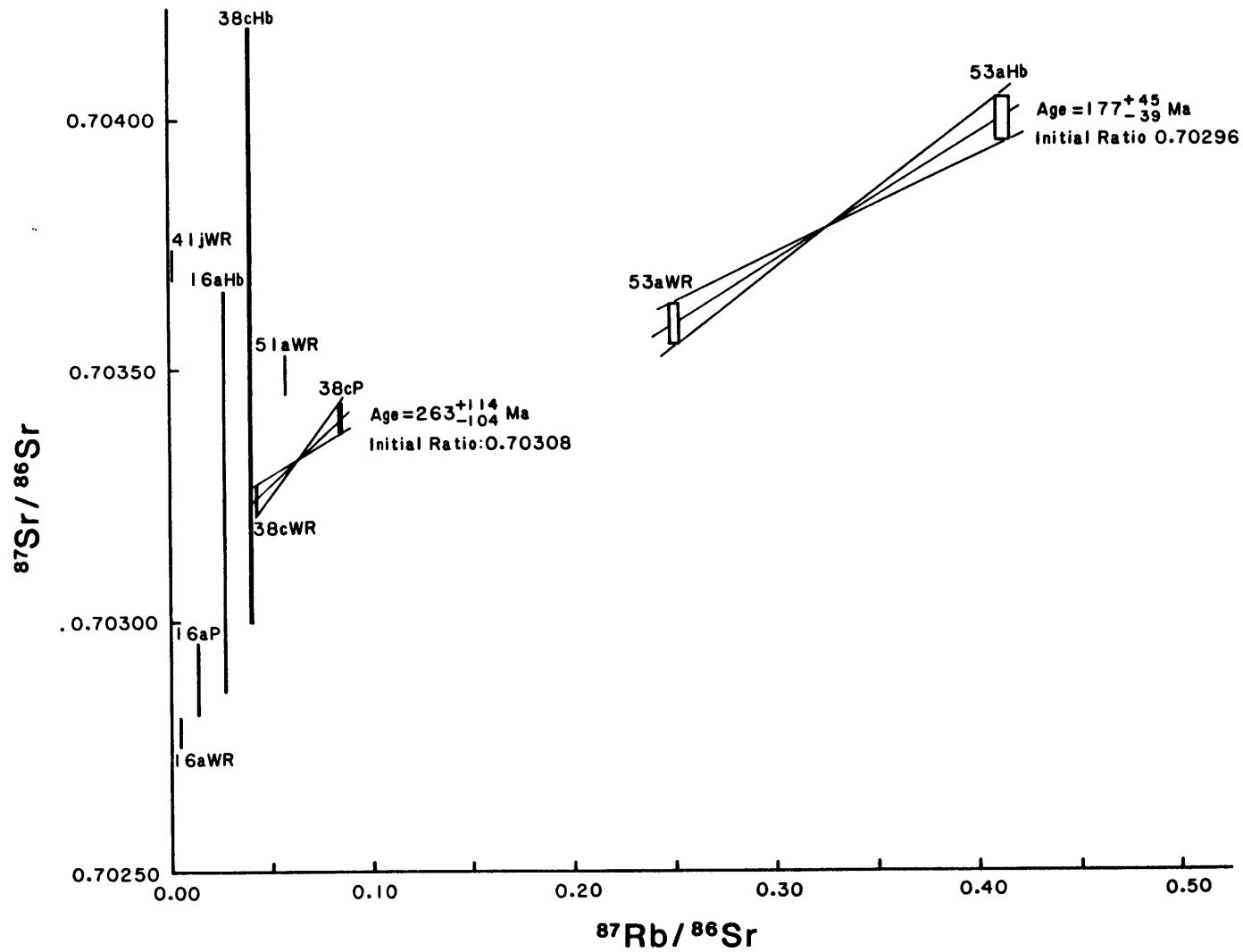


Figure 67: $^{87}\text{Sr}/^{86}\text{Sr}$ versus $^{87}\text{Rb}/^{86}\text{Sr}$ plot of whole rock and mineral separate analyses from the Whitewater Diorite.

Schofield (1920, p. 19) had described some of these sills in the Ainsworth camp as gneissic granite and these were later referred to by Rice (1941, p. 37) as the "Ainsworth granitic sills". Fyles (1967, his Fig. 3 and pp. 37-39) mapped "granitic sills and lenses" in the Ainsworth-Kaslo area, the northernmost of which is probably the southern continuation of the Kaslo River Intrusive Rocks. Fyles (1964, pp. 36-37) described similar felsite dykes and sills in the Duncan Lake area (Fig. 2).

The largest body of the Kaslo River Intrusive Rocks is the concordant intrusion of hornblende and quartz monzonite that outcrops along the Kaslo River 2-3 km (1.2-1.8 mi) west of its outlet into Kootenay Lake. This sill extends north to the limit of the mapped area south of Schroeder Creek (Fig. 3). A minor sill occurs at an elevation of 762 m (2500 ft) south of Milford Creek and possible correlative granitic rocks occur 1.5-2.0 km (0.9-1.2 mi) at 030° from Mount Schroeder.

The Kaslo River Intrusive Rocks consist of blocky, medium-grained light brown to light grey rocks that are generally rusty weathering (Fig. 66). Oligoclase or andesine plagioclase and slightly less microcline constitute 75 percent of the rock. Normative plagioclase is oligoclase (Table IX). Mafic components form less than 10 percent of the rock and consist of hornblende and minor biotite. Thin hornblende aggregates 1-10 mm (0.04-0.4 in) long define a well developed lineation and locally a foliation. The rest of the rock is fine-grained quartz, accessory zircon and apatite, and the alteration products epidote and carbonate minerals.

The sills vary from 1080 m (3543 ft) to a few centimeters thick. The main sill (see Fig. 3) is generally 400 m (1312 ft) thick. Dykes are 0.1-3 m (3.9 in-9.8 ft) thick. Dykes are recognized by their cross-cutting relationship to compositional layering in the metasedimentary rocks and are

commonly folded by F_2 folds. Sills are generally concordant to foliation within the surrounding metasedimentary rocks.

The Kaslo River Intrusive Rocks intrude rocks as young as Upper Mississippian and they are at least as old as the Middle Jurassic metamorphism and deformation. They are compositionally similar to the porphyritic phase of the Nelson Batholith (Cairnes, 1934, p. 63) and may be an early phase of this pluton (Archibald et al., 1983), a correlation that would make them Middle Jurassic in age.

DAVIS RIDGE DIORITE

Several large mafic sills and dykes are present on the southern ridge of Mount Davis and are called the Davis Ridge Diorite. The dykes and sills are commonly 2-10m (6.6-32.8 ft) thick and plugs are 100-300m (328-984 ft) in diameter. The diorite forms dykes intrusive into rocks of the Milford and Slocan groups on the east limb of the Dryden anticline north of Schroeder Creek and south of Spokane Creek (Fig. 68). In addition to Davis Ridge, the diorite is exposed on the ridge east of Mount Cooper and along Schroeder Ridge. A dyke of Davis Ridge Diorite occurs 900m (2953 ft) southeast of Whitewater Mountain (Fig. 3) where it intrudes Whitewater Diorite. Cairnes (1934, p. 72) recognized the "basic intrusives... intruding the Milford Group...with the general composition of hornblende diorite" east of the Dryden anticline, however he grouped these with rocks here recognized as the older Kane Creek Diorite.

The Davis Ridge Diorite generally consists of coarse-grained phenocrysts of altered pyroxene and plagioclase set in a fine-grained matrix. The diorite is locally foliated. Plagioclase phenocrysts (5-10 percent) are 1-3 cm (0.4-1.2 in) long and are altered to albite and epidote with minor carbonate minerals and white mica. Pyroxene phenocrysts (15-25

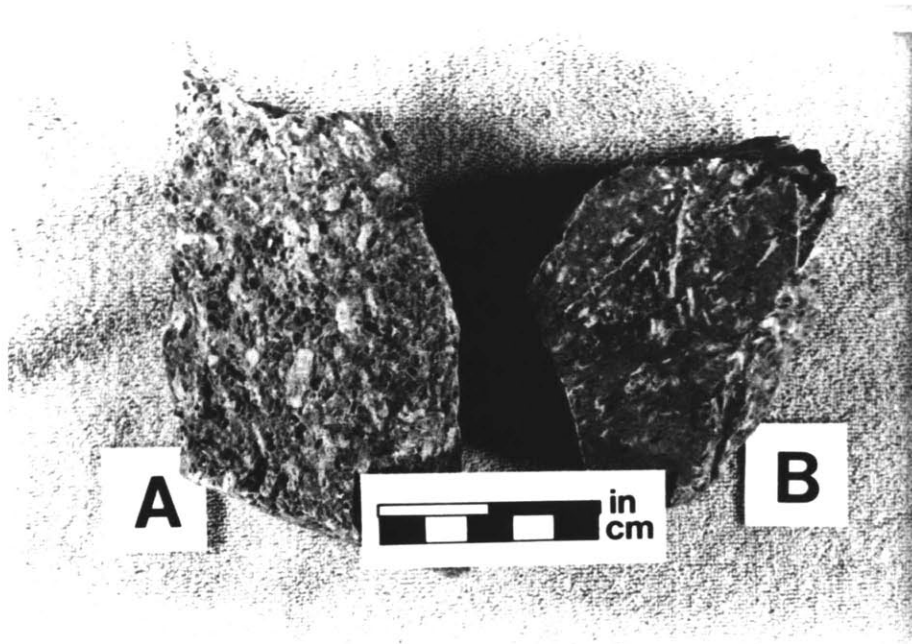


Figure 68: Handsamples of the Davis Ridge Diorite. Note abundant large phenocrysts of altered plagioclase and pyroxene altered to amphibole.

A: From Schroeder ridge. B: From ridgecrest east of Mount Cooper.



Figure 69: Mafic clots, characteristic of the Kuskanax Intrusives, within the Marten Creek Stock. View to the east.

percent) are 5-15 mm (0.2-0.6 in) long and mostly altered to hornblende and lesser amounts of green biotite and chlorite. The matrix of the Davis Ridge Diorite is fine-grained (less than 1 mm diameter) plagioclase (An₅), actinolitic hornblende with lesser amounts of chlorite, epidote and carbonate minerals as alteration products. Sphene is a common accessory mineral. Chemically, the Davis Ridge Diorite is a gabbro (Table VII).

The Davis Ridge Diorite intrudes rocks as young as the Upper Triassic Slocan Group. It is foliated along its margin and folded by F₃ folds and so is older than the Middle Jurassic deformation. These relations indicate the diorite is Late Triassic to Middle Jurassic in age.

KUSKANAX INTRUSIVE ROCKS

Fine- to medium-grained light-coloured to pinkish, mainly equigranular leucogranite, leucocratic quartz monzonite and syenite with characteristic lense-shaped mafic clots (Fig. 69) constitute the Kuskanax Batholith and neighboring satellite stocks (Fig. 62). The Kuskanax Batholith was named by Cairnes (1929, p. 104A-105A) from exposures in Kuskanax Creek. The Batholith and associated stocks were further described by Hyndman (1968, pp. 43-51), Read (1973, pp. 32-40), and Read and Wheeler (1976). Read (1973, p. 37) differentiated the locally foliated Kuskanax Batholith from its massive satellite stocks on the basis of deformational textures and feldspar mineralogy. Recent isotopic age determinations of the foliated batholith (Parrish and Wheeler, 1983) and massive satellite stocks (this report) yield the same values within analytical uncertainty, suggesting the batholith and stocks are part of the same alkalic magmatic event and differences in mineralogy and texture result from the local conditions of intrusion.

Kuskanax Batholith

The southeastern margin of the Kuskanax Batholith forms the northwestern boundary of the mapped area. In the headwaters of Poplar Creek, the margin of the batholith is distinctly foliated. A few kilometers southwest, on the ridge that separates Burkitt and Wilson Creeks, the margin of the batholith is unfoliated. Farther to the southwest, where the contact of the batholith crosses Fitzstubbs Creek, it contains a weak lineation defined by mafic minerals. In the Goat Range area, the Kuskanax Batholith mainly consists of pinkish-white equigranular leucogranite with fine-grained (<1 mm) phenocrysts of aegerine-augite. Granular epidote is an alteration product and occurs near Fitzstubbs Creek. Lense-shaped mafic clots composed of aegerine-augite, hornblende and biotite are common within the Kuskanax Batholith and are elongate parallel to foliation and polyhedral where foliation is absent. The Kuskanax Batholith is generally concordant with the structural trend and foliation produced by F2 folding in the mapped area although in detail it truncates map units and S₂ foliation (Fig. 70).

The crystallization age of the southeastern part of the Kuskanax Batholith, determined from U-Pb analysis of zircons, is 173₋₅⁺⁴ Ma (Parrish and Wheeler, 1983).

Satellite Stocks

Nine stocks in the mapped area consist of leucogranite and range in size from 0.8 to 132.7 square kilometers (0.3-51.2 square miles). Numerous smaller plugs, sills and dykes of similar leucogranite are also present. These plutonic bodies occur northwest of Kane Creek and Cooper Creek, in the northwestern third of the study area. Some of these were mapped as feldspar porphyries by Kead and Wheeler (1976).

Table IX: Chemical Analyses (Weight Percent) and Normative Compositions (Percent) of Granitic Rocks in the Goat Range Area and Related Rocks from Adjacent Areas

	K83-20b	K83-51g	K83-53a	K83-04a	Rapid Ck.		
					Stock ¹	Kuskanax ¹	Kuskanax ²
SiO ₂	67.4	69.8	68.9	69.1	71.9	71.8	65.6
TiO ₂	0.25	0.15	0.19	0.35	0.02	0.06	0.22
Al ₂ O ₃	16.9	15.3	16.0	15.4	15.0	15.4	16.6
Fe ₂ O ₃	0.5	0.8	1.0	1.6	0.7	0.9	1.0
FeO	1.3	0.6	0.5	1.2	0.5	0.4	0.89
MnO	0.04	0.04	0.05	0.07	0.02	0.03	0.06
MgO	0.24	0.14	0.23	0.78	<0.5	<0.5	0.90
CaO	1.87	1.10	1.43	0.56	1.3	1.1	1.5
Na ₂ O	5.5	5.7	5.4	5.6	6.0	6.0	5.3
K ₂ O	4.72	5.19	6.08	3.4	4.9	5.3	7.0
H ₂ O	0.3	0.2	0.2	0.6	<0.1	<0.1	0.24
CO ₂	0.2	0.3	0.1	0.1	---	---	---
P ₂ O ₅	0.06	0.04	0.04	0.07	---	---	---
S	0.03	0.01	0.00	0.11	---	---	---
Total	99.8	99.7	100.6	99.8	100.3	101.0	99.4
Quartz	13.01	15.57	12.23	21.53	15.29	16.51	4.61
Corundum	---	---	---	1.89	---	---	---
Orthoclase	27.89	30.67	35.93	20.09	31.32	28.96	41.37
Albite	46.54	48.23	45.69	47.39	49.71	49.88	44.85
Anorthite	7.49	0.83	1.46	1.69	---	---	0.83
Acmite	---	---	---	---	0.94	0.79	---
Diopside	0.03	0.75	1.24	---	1.07	1.07	4.33
Wollastonite	---	0.41	1.32	---	1.51	1.62	---
Hedenbergite	0.08	0.46	---	---	0.40	1.07	0.94
Enstatite	0.58	---	---	1.94	---	---	0.24
Ferrosilite	1.53	---	---	0.21	---	---	0.06
Magnetite	0.72	1.16	1.22	2.32	0.84	0.62	1.45
Hematite	---	---	0.16	---	---	---	---
Ilmenite	0.47	0.28	0.36	0.66	0.11	0.04	0.42
Pyrite	0.06	0.02	---	0.21	---	---	---
Apatite	0.14	0.09	0.09	0.16	---	---	---
Calcite	0.45	0.68	0.23	0.23	---	---	---
H ₂ O	0.30	0.20	0.20	0.60	0.05	0.05	0.24
Total	99.31	99.38	100.13	98.92	101.25	100.60	99.32
Normative Plagioclase:							
Anorthite	13.86	1.70	3.10	3.44	0.00	0.00	1.82
Albite	86.14	98.30	96.90	96.56	100.00	100.00	98.18

Analyses by the Analytical Chemistry Section of the Geological Survey of Canada

K83-20b: Kaslo River Intrusive, roadcut along highway 31A, 2.8 km at 278° from the outlet of Kaslo River into Kootenay Lake, 634m (2080 ft) elevation.

K83-51g: McKian Creek Stock, Kuskanax Intrusives, 3.3 km at 346° from confluence of Keen and Rosslund creeks, 2240m (7350 ft) elevation.

K83-53a: Three Grizzlies Stock, Kuskanax Intrusives, 3.4 km at 286° from Mount McHardy, 2195m (7200 ft).

K83-04a: Leucogranite of the Blue Ridge Intrusives, Buchanan lookout road, 2.85 km at 318° from Mount Buchanan, 1084m (3558 ft) elevation.

¹Rapid Creek Stock and Kuskanax Batholith analyses from Read, 1973, p. 38, the analyses were assigned 0.2 percent MgO and 0.05 percent H₂O for normative calculations.

²Kuskanax Batholith analysis from Hyndman, 1968, p. 64



Figure 70: Three phases of granitic dyke intrusion at the west side of the Wilson Creek valley. The country rock is foliated quartzite-pebble conglomerate of Siliceous Wacke Member, Keen Creek assemblage. All phases truncate S_2 foliation. Two dykes are folded by F_3 .



Figure 71: Augite-porphyrific lamprophyre intruded into granitic rock of the Kuskanax Intrusives in the Wilson Creek area. View to north.

All of the stocks and plugs consist of medium-grained mostly porphyritic leucogranite and commonly contain small clots of hornblende-biotite-epidote-plagioclase-zircon which, in hand specimen, are identical to mafic clots in the Kuskanax Batholith. The stocks and plugs are thus regarded as satellitic bodies of the batholith. The microcline phenocrysts (40-50 percent) in these bodies commonly contain inclusions and rinds of plagioclase and are perthitic. Some microcline phenocrysts in the McKian Creek Stock include a layer of quartz. Plagioclase phenocrysts (25-35 percent) are albitic (An₇₋₉) and commonly coated with perthitic microcline. Most stocks contain 3-5 percent aegerine-augite and accessory apatite and zircon. Marten and Monitor Creek stocks contain green hornblende and no augite, and the unnamed stock at the junction of Fitzstubbbs and Wilson creeks and the small plug where Cooper Creek crosses the belt of Slocan Group (Fig. 3) contain 2-4 percent green biotite as the mafic phase. Quartz occurs as anhedral interstitial grains and together with plagioclase and minor microcline forms a fine grained (0.5-2 mm) matrix. The stock at the junction of Fitzstubbbs and Wilson creeks is different from the other satellite stocks in that it consists of coarse-grained (5-10 mm) pink microperthite phenocrysts (30 percent) and lesser white plagioclase phenocrysts (20 percent) set in a light grey matrix; the rock is pink and grey and different from the more typical white to light grey varieties of this alkalic granitic suite. A 100 m (328 ft) thick ring dyke is present along the southern margin of the Cooper Creek Stock. It is composed of coarse-grained (1-2 cm; 0.4-0.8 in) trachytic syenite with coarse (5 mm) aegerine-augite phenocrysts.

The satellite stocks have suffered various degrees of secondary alteration. Compositional zoning was not recognized in the feldspars

indicating that magmatic zoning which was likely present has been obliterated. Feldspars in weakly altered stocks (McKian Creek, Three Grizzlys and Cooper Creek stocks) are dusted with minute grains of epidote and carbonate minerals. More altered stocks (Marten Creek and Monitor Creek stocks) commonly contain the assemblage epidote-carbonate minerals - muscovite±amphibole±chlorite.

The satellite plutons of the Kuskanax batholith are mainly discordant to structures and mapped units and they are generally unfoliated. Foliated rocks regarded as part of this intrusive suite do occur. A body of weakly foliated leucogranite interpreted as the northwesternmost lobe of the McKian Creek Stock underlies the headwaters of Wilson Creek (Fig. 3). Foliated dykes and sills folded by F_3 folds occur along the west wall of the Wilson Creek valley between the McKian Creek Stock and the Kuskanax Batholith (Fig. 70).

Zircons collected from samples across the discordant Cooper Creek Stock were analyzed by Peter Van der Heyden at the University of British Columbia. He obtained an age of $180.5_{-7.2}^{+6.6}$ Ma that overlaps ages determined for Kuskanax Batholith. The ages of the other satellite stocks are undetermined but their mineralogical similarity to the dated rocks suggests they are also Early Middle Jurassic in age.

U/Pb Zircon Geochronology

Samples from two satellite stocks of the Kuskanax Intrusive Rocks were taken for U/Pb analysis of zircons. Analyses were made by Peter Van der Heyden at the Geochronology Laboratory, University of British Columbia, following the procedures of Parrish and Wheeler (1983, p. 1753). Results are presented in Table X and Figure 72).

Zircons separated from the Cooper Creek Stock were described by Van der Heyden (personal communication, 1985) as "clear light-medium pink euhedral crystals. Some grains are cracked internally, and a few have somewhat rounded terminations. A few crystals have cloudy cores, probably xenocrystic." The zircons were separated into four splits that define a discordia with a lower intercept, interpreted as the age of crystallization of $180.5_{-7.2}^{+6.6}$ Ma. An upper intercept of $2097.8_{-277.4}^{+260.5}$ is interpreted to be the age of inherited zircons, presumably the xenocrystic cores. The 100-200 mesh nonmagnetic fraction was assigned a five percent error because of a high blank value incurred during zircon decomposition, resulting in the large error envelope on Figure 72.

Samples collected from the McKian Creek Stock gave two fractions with unreliable analyses. The 200-325 mesh, magnetic fraction is discordant and plots above the Cooper Creek Stock discordia and below the concordia curve. The 100-200 mesh, nonmagnetic fraction is only slightly discordant, however it lies above concordia in the uranium loss field (Faure, 1977, p. 209). Compositional and petrographic similarity of the McKian Creek Stock and the Cooper Creek Stock suggest the plutons are consanguineous. Thus the zircon analyses from the McKian Creek Stock should plot along the Cooper Creek Stock discordia. The two zircon fractions from the McKian Creek Stock were treated with hot hydrofluoric acid during the cleaning process (Parrish, personal communication, 1985). This treatment may have leached uranium from the zircons resulting in analyses which plot above the Cooper Creek Stock discordia and in the case of the 100-200 mesh fraction, above concordia. Thus, these analyses are considered unreliable because of their peculiar position on the concordia diagram and irregular preparation technique.

Table X Analytical results of the zircon analyses from the Goat Range area

	Mineral/Split Zircon	U (ppm)	Pb (ppm)	208	207	204	$\frac{206\text{Pb}}{204\text{Pb}}$ measured	Mole % blank Pb
K82-53h	100-200 NMG	1497	67.1	20.024	8.216	0.0934	869	1.18
Cooper Creek	200-325 NMG	1315.6	47.2	12.695	7.046	0.0337	3000	0.09
Stock	100-200 MG	1594.3	55.6	19.039	7.164	0.0906	1060	0.175
	200-325 MG	2110	71.9	17.237	7.045	0.0875	836	1.75
K83-51g	100-200 NMG	899.5	54.26	22.8426	6.3245	0.0719	1363	0.107
McKian Ck.	200-325 MG	1773.6	66.58	29.0947	6.7744	0.1076	916	0.107
Stock								
K82-38a	200-325 MG	1863.6	78.2	20.866	7.618	0.0309	2197	0.71
Blue Ridge Int.								
	Mineral/Split Zircon	$\frac{206\text{Pb}}{238\text{U}}$ ratio	$\frac{207\text{Pb}}{235\text{U}}$ ratio	$\frac{207\text{Pb}}{206\text{Pb}}$ ratio	$\frac{206\text{Pb}}{238\text{U}}$ date	$\frac{207\text{Pb}}{235\text{U}}$ date	$\frac{207\text{Pb}}{206\text{Pb}}$ date	
K82-53b	100-200 NMG	0.039912	0.378333	0.068751	252.28±12.78	325.74±24.11	890±100	
Cooper Creek	200-325 NMG	0.034618	0.313171	0.065600	219.42±1.97	276.62±2.72	793.5±5.2	
Stock	100-200 MG	0.031567	0.254480	0.058467	200.35±1.81	230.18±2.61	545.5±10.6	
	200-325 MG	0.000278	0.249542	0.057719	199.03±1.76	226.20±2.68	518.9±12.8	
K83-51g	100-200 NMG	0.053506	0.388902	0.052715	336.01±2.93	333.57±3.58	316.57 ^{+9.51} _{-9.57}	
McKian Creek	200-325 MG	0.031427	0.225204	0.051973	199.47±1.76	206.23±2.46	284.21 ^{+13.60} _{-13.71}	
Stock								
K82-38a	200-325 MG	0.037735	0.373360	0.071759	238.78±2.10	322.14±3.09	979.13 ^{+4.26} _{-4.27}	
Blue Ridge Int.								+79.2

Location Index:
 K83-53h: 0.9km at 203°, 2393 m (7850ft) elevation to 1.5km at 164°, 2134 m (7000ft) elevation, from Mount Stubbs
 K83-51g: 4.78km at 058° from confluence of Wilson and Keen creeks, 2240 m (7350ft) elevation
 K82-38a: 1.80km at 104° from Whitewater Mountain, 2194 m (7200ft) elevation
 $\lambda_{238}=0.155125 \times 10^{-9}/\text{yr}$, $\lambda_{235}=0.98485 \times 10^{-9}/\text{yr}$, $^{238}\text{U}/^{235}\text{U}=137.88$, Isotopic abundance $^{206}\text{Pb}=100$
 Isotopic composition of blank: $^{206}\text{Pb}/^{204}\text{Pb}=17.75$, $^{207}\text{Pb}/^{204}\text{Pb}=15.57$, $^{208}\text{Pb}/^{204}\text{Pb}=37.00$
 Common Pb correction ages: K83-53h=175Ma, K83-51g=170Ma, K82-38a=175Ma
 Isotopic composition of common Pb is based on the composition of Pb at the correction ages from the growth curve of Stacey and Kramers (1975); $^{206}\text{Pb}/^{204}\text{Pb}=11.152$, $^{207}\text{Pb}/^{204}\text{Pb}=12.998$, $^{208}\text{Pb}/^{204}\text{Pb}=31.23$ at 3.7Ga with $^{238}\text{U}/^{204}\text{Pb}=9.74$, $^{232}\text{Th}/^{204}\text{Pb}=37.19$

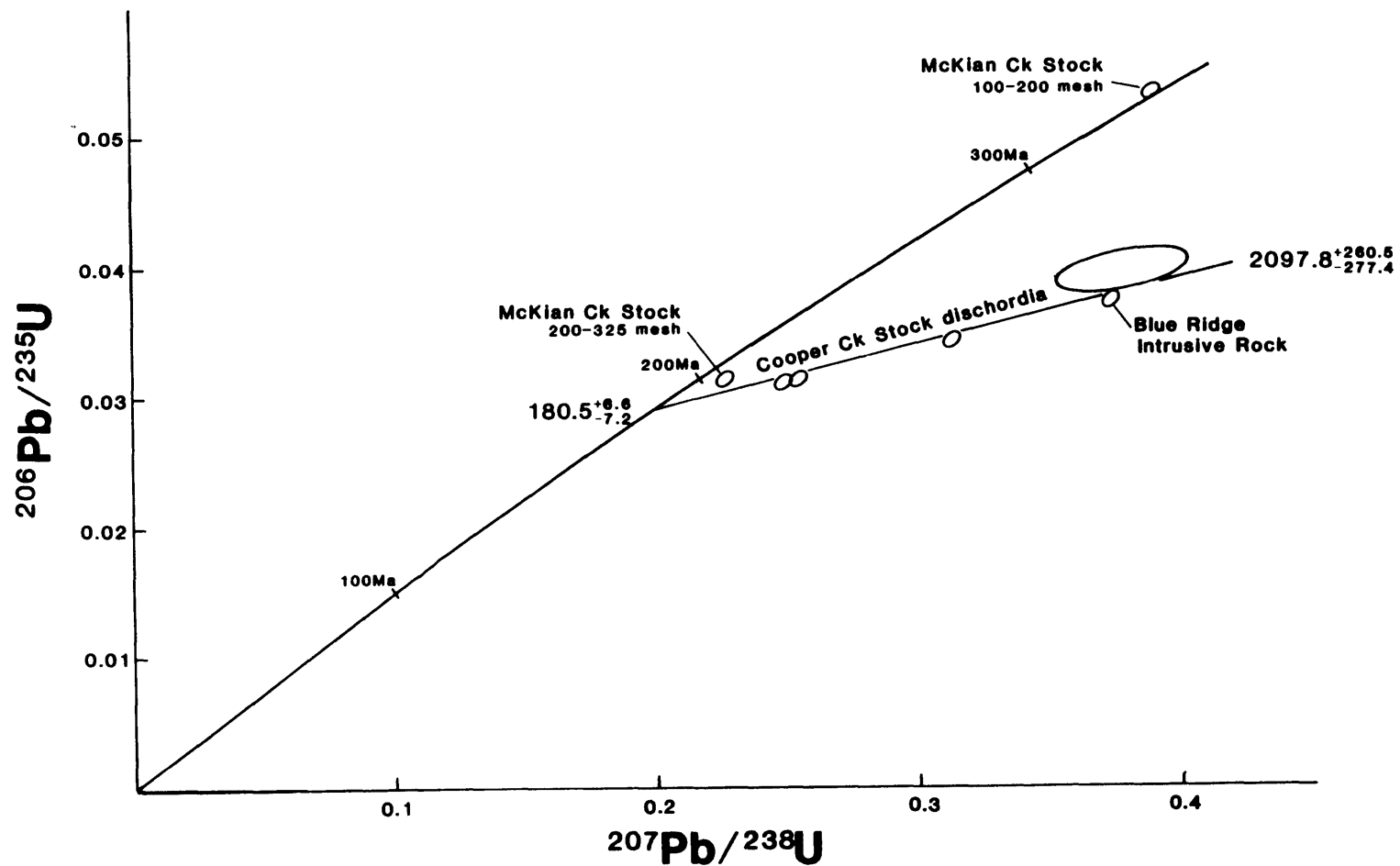


Figure 72: $^{206}\text{Pb}/^{238}\text{U}$ versus $^{207}\text{Pb}/^{235}\text{U}$ concordia plot for zircons from granitic rocks in the Goat Range area.

BLUE RIDGE INTRUSIVE ROCKS

Light colored felsite dykes and leucogranite occur along the Blue Ridge southeast of Kane Creek. These intrusive rocks were first described by Maconachie (1940, p. 27-28) and noted by Hedley (1945, p. 7). The felsite and feldspar porphyry dykes exposed in the pass between Whitewater and South Cooper creeks are typical of the Blue Ridge intrusive rocks. Leucogranite included the Blue Ridge intrusive rocks exposed at an elevation of 1067 m (3500 ft) on the Buchanan Lookout road and at an elevation of 1676 m (5500 ft) on the road to the Emerald and Voyageur mining properties. The felsite dykes are commonly 1m-10m (3.3-32.8 ft) thick and consist of fine-grained (0.5-2 mm) phenocrysts of microcline (35 percent) and albite (An₁) plagioclase (30 percent) set in a matrix (30 percent) of finer grained quartz and feldspar. Brown biotite and pyrite comprise 3-4 percent of the rock and are commonly corroded. Epidote, white mica and carbonate minerals form abundant alteration products. The dykes are pinkish-white felsite and white to light grey feldspar porphyry.

The leucogranite occurs as small weakly foliated stocks and discordant sheets, the largest of which covers an area of about 0.65 square kilometers (0.25 square miles). The rock consists of medium- to fine-grained (2-0.5 mm) phenocrysts of albite-oligoclase (An₉-An₁₅) plagioclase (25 percent) and pink-weathering microcline (20 percent) phenocrysts set in a fine grained (<1 mm) matrix of quartz (15 percent) and feldspar which is mainly plagioclase. Olive biotite and opaques constitute 2-3 percent of the rock. Hornblende was recognized only in the stock along the Buchanan Lookout road. Apatite is a common accessory mineral. Feldspar phenocrysts are moderately altered to epidote and white mica. Pyrite is common in the

leucogranite forming 1-2 percent of the rock. Quartz grains have undulose extinction accompanied by rare, broken plagioclase grains.

The leucogranite body at Emerald Creek apparently forms a discordant sheet dipping southeast at 26° that is 1891 m (6205 ft) long with a maximum thickness of 197m (647 ft) and abruptly tapered ends.

The Blue Ridge Intrusive Rocks are considered Early Middle Jurassic in age based on U-Pb analysis of zircons collected from a felsite dyke in the Whitewater Glacier basin. These zircons, which were analyzed by Peter Van der Heyden of the University of British Columbia (Table X), plotted on the discordia generated from zircons of the Cooper Creek Stock (Fig. 72). The lower intercept of this chord is $180.5^{+6.6}_{-7.2}$ Ma, interpreted as the age of crystallization of the stock and felsite dykes. Thus the Blue Ridge Intrusive Rocks are considered to be compositionally distinct but genetically related to the Kuskanax Intrusive Rocks.

LAMPROPHYRE DYKES

Two lamprophyre dykes were mapped by in the Goat Range area, and Hedley (1945, p. 15) noted the presence of other lamprophyre dykes near the Whitewater mine. In the headwaters of Kane Creek, 3250 m (2.02 mi) at 071° from Marten Mountain, a dyke 5 to 70 cm (2.0-27.6 in) thick of biotite lamprophyre intrudes granitic dykes of the Blue Ridge Intrusive Rocks. In thin section the rock consists of phenocrysts of zoned biotite (50 percent), slightly perthitic potash feldspar (10 percent) and euhedral apatite (15 percent) set in a matrix of carbonate and opaque minerals (25 percent). This type of lamprophyre was described by Cairnes (1934, p. 72) as minette.

A second lamprophyre dyke occurs 5.12 km (3.18 mi) at 351° from the junction of Wilson and Keen Creeks at an elevation of 1470m (4822 ft) where it intrudes granitic rocks of the Kuskanax Intrusive Rocks (Fig. 71). The unfoliated dyke consists of medium-grained (0.5-1 cm; 0.2-0.4 in) augite phenocrysts set in a dark grey, fine-grained (1-2 mm) matrix that contains biotite and feldspar. Similar dykes were described by Cairnes (1934, p. 71).

Eocene lamprophyre dykes are known in the Valhalla Range (Fig. 2; Parrish, 1981, p. 950 and Parrish et al., 1985, p. 84) and dykes that feed Eocene basic volcanics occur in the Monashee Mountains (Mathews, 1981, p. 1313). Lamprophyre dykes in the Goat Range are undeformed and hence post-date Jurassic deformation. The dykes are correlated with the Eocene lamprophyre dykes farther west.

CHAPTER 5. STRUCTURAL GEOLOGY

INTRODUCTION

The structure of the stratified rock units in the Goat Range area was interpreted from the map pattern of lithologic units and mesoscopic structural elements such as foliations, lineations, minor folds and drag folds near fault surfaces. Surface attitudes were projected along fold axes to construct a series of vertical structure sections (Fig. 5). The resulting geometry is interpreted to be the product of four or five superimposed deformational events that comprise four generations of folding and six episodes of faulting (Table XI). The deformational sequence presented here expands on similar chronologies presented by earlier workers (Read and Wheeler, 1976; Read and Brown, 1981, p. 1131; Okulitch, 1984, pp. 1183-1189).

GENERAL STRUCTURAL PATTERN

The structural pattern of the Goat Range area is illustrated in Fig. 73. The structure is dominated by the second generation (F_2) Dryden anticline, mainly outlined by the McHardy assemblage, Kaslo Group, Marten conglomerate, and Slocan Group. The base of discontinuous serpentinite sheets trace out the Whitewater thrust fault which is also folded by Dryden anticline. The Stubbs thrust fault occurs in the northern segment of the Dryden anticline, with the underlying Keen Creek assemblage and Lardeau Group exposed in a structural window that is intruded by the McKian Creek Stock. North of the McKian Creek Stock, the Dryden anticline is not recognized. The McHardy assemblage continues around the McKian Creek Stock into the Poplar Creek area (Klepacki, Read and Wheeler, 1985) where it is truncated to the east by the Spyglass fault. South of the McKian Creek Stock, the east limb of the Dryden anticline is truncated by the Schroeder

<u>Deformational Event</u>	<u>Structural Element</u>	<u>Metamorphic Event</u>	<u>Apparent Absolute age</u>
D1	F1 folds - Meadow Creek anticline Thrust east of Mt Buchanan	M1	Middle Ordovician(?)
D2	Whitewater thrust fault	--	Late Permian- Middle Triassic
D3	F2 folds - Dryden anticline Stubbs thrust fault F3 folds Schroeder-Spyglass fault Granitic intrusions	M2 M3	Middle Jurassic
Late D3 or D4	F4 and F4' folds NE-trending steep faults Bending of regional structural trends	M4?	Jurassic or Cretaceous
D4 or D5	Gouge faults	M4?	Eocene(?)

Table XI: Correlation of deformational episodes, fold phases, faults and metamorphism in the Goat Range area.

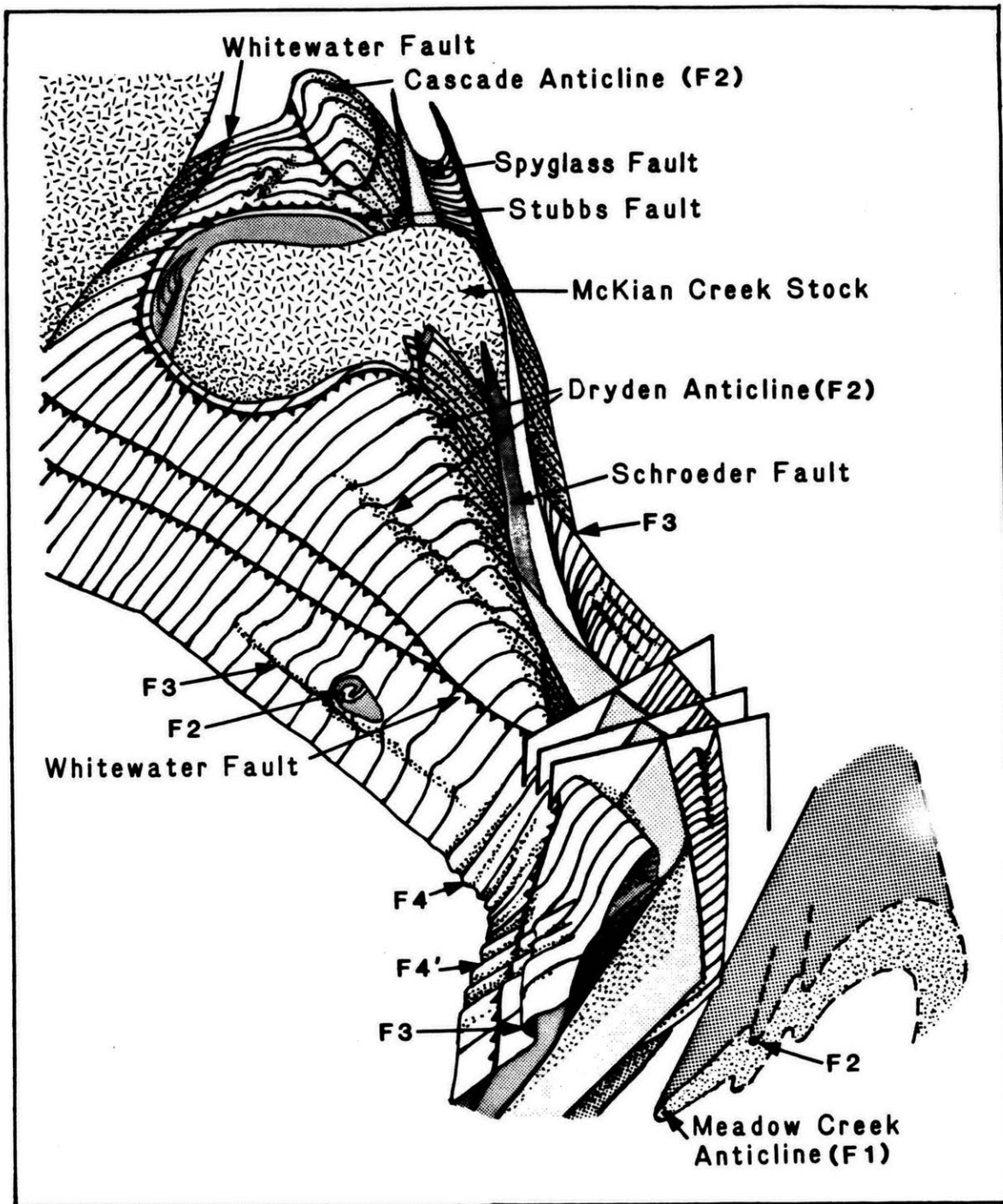


Figure 73: Schematic diagram of the major structures in the Goat Range area. North is at the top of the diagram.

SUBAREA	Pi axis* So+S ₂	F ₂ axis	1 sigma	F ₂ axial surface	1 sigma	F ₃ axis	1 sigma	F ₃ axial surface	1 sigma
1 N	338/45 22	338/45 3 164/15 2	12° -	169/71SW 3	4°	320/48 4	10°	053/40NW 1	-
2 N	004/54 12	298/32 1	-	116/70NE 1	-	300/28 1	-	122/66SW 1	-
3 N	325/21 41	322/25 7	8°	134/50SW 1	-	346/28 3	7°	153/62NE 3	*
4 N	130/15 48	120/11 7	8°	120/79NE 5	13°	095/56 3	27°	155/61NE 3	7°
5 N	097/45 15	094/62 2	-	085/86NW 2	-	-	-	-	-
6 N	347/30 40 2115/59	326/07 2	*	169/36SW 1	-	120/17 3	*	106/81NE 3	8°
7 N	294/20 112	290/08 9	17°	109/73SW 4	15°	284/24 5	32°	167/12SW 1	-
8 N	133/30 333	128/26 19	19°	132/89SW 12	8°	113/31 7	20°	126/84SW 3	23°
9 N	132/05 76	143/08 10	11°	143/68SW 3	3°	136/16 12	23°	140/80SW 4	18°
10 N	126/10 111	117/05 5	11°	117/87NE 5	14°	300/10 4	6°	152/12SW 4	6°
11 N	313/10 99	134/08 7	10°	120/29SW 3	3°	150/07 9	11°	143/10SW 8	22°
12 N	349/12 148	345/13 27	13°	009/53NW 6	19°	347/09 26	18°	142/31NE 11	16°
13 N	325/00 98	335/00 25	11°	141/31SW 12	10°	312/17 5	6°	142/37SW 1	-

*Visually estimated from stereonet scattergram

N = Number of data

¹Anticline in saddle between Cascade and Marion mountains

²Fit to data scatter interpreted to result from F₃ folding

Table XII: Structural data from F₂ and F₃ folds and Pi-axis diagrams of subareas in the Goat Range Area. Least-squares regression analyses are given where data are appropriately clustered. Where data are scattered because of conjugate folding, doubly plunging axis or along S-pole girdles, best-fit attitudes are visually estimated. One-sigma cones are given.

fault, correlated with the Spyglass fault. East of the Schroeder fault the west-facing Davis assemblage of the Milford Group unconformably overlies the upright, western limb of the Meadow Creek anticline. The Meadow Creek anticline is thought to be a first-phase, synformal anticline (Fyles, 1964, p. 59; Read and Wheeler, 1976).

The northwest-trending Dryden anticline bends about 50° near Milford Peak to a north trend. This "elbow-bend" marks a fundamental change in orientation from the northwest trend of the northern Kootenay Arc to the north trend of the central Kootenay Arc. The elbow-bend coincides with a zone of well-developed F_4 folds and a change in plunge of F_2 and F_3 structures from southeasterly plunging north of the bend to northerly plunging south of the bend (Table XII, Fig. 74). In general the configuration of rock units in the Goat Range area resembles a saddle that is bent, and truncated on its eastern side by the arcuate Schroeder fault.

STRUCTURAL ELEMENTS

Cross-cutting relationships of structures and rock fabrics were used to develop the relative chronology of folding and faulting events. The structural elements associated with the folding events are described in Table XIII. More detailed description of the structural elements of the Goat Range is presented below in relative chronological order.

F_1 Elements and the Meadow Creek Anticline

First generation structural elements are difficult to distinguish because they are commonly obliterated by second generation and younger features. A key feature useful in sub-garnet grade rocks of the Lardeau Group (especially the Broadview Formation) is the presence of quartz-feldspar veinlets along S_1 surfaces in most of exposures (Fig. 14). In rocks that are garnet grade or higher (in the Wilson Creek area between

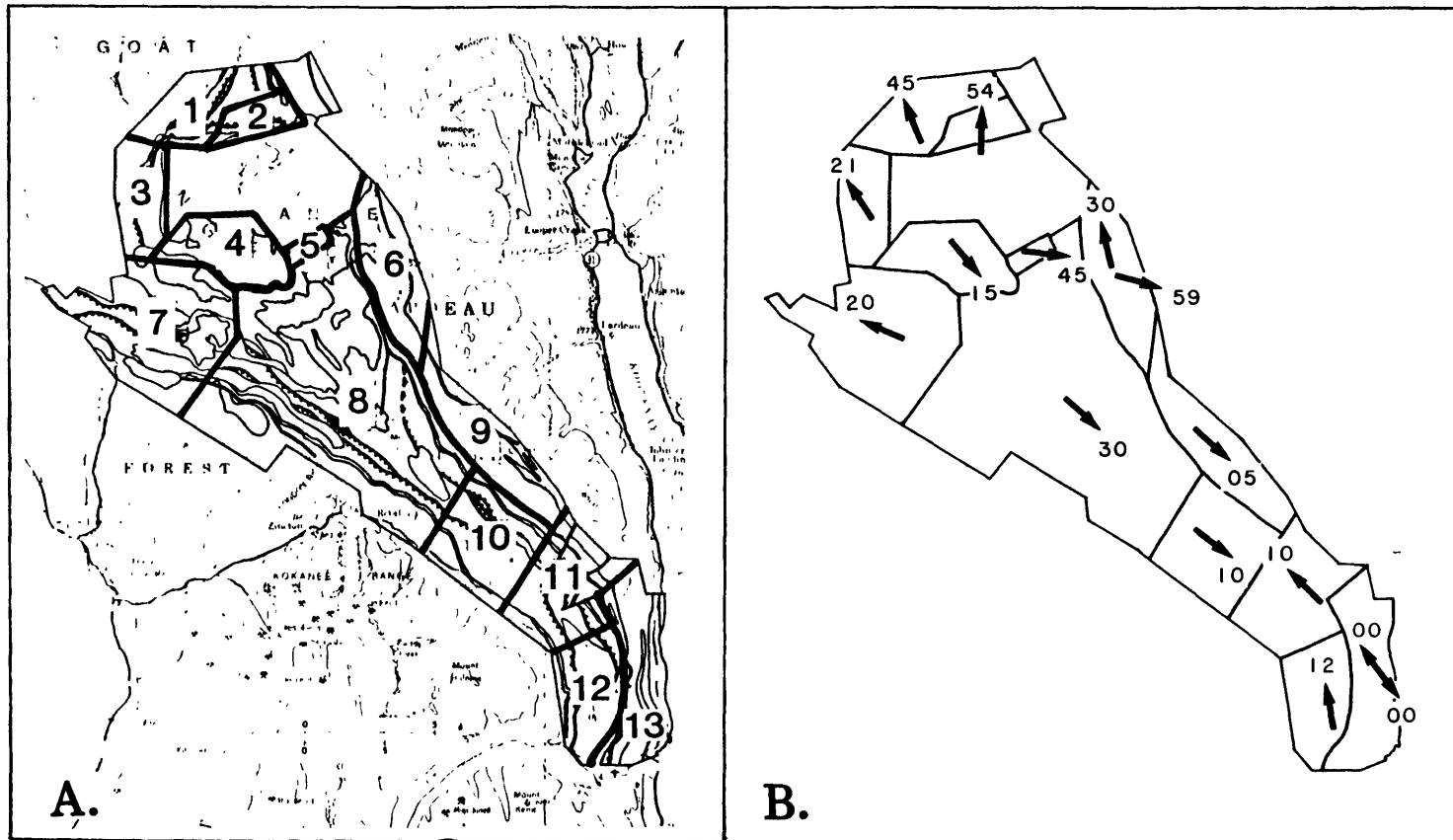


Figure 74: Structural subareas and axes from pi diagrams for bedding and S2 foliation in each subarea of the study area. A: Location of subareas. B: Pi axes from bedding and S2.

Table XIII: Description of bedding and foliations, minor folds and lineations associated with fold deformation in the Goat Range area.

Element	Definition/Characteristics	Typical Orientation
S ₀	Bedding: Defined by colour banding, compositional variation (e.g. calcareous vs. pelitic), grain size variation, elongate dimension of volcanic pillow structures.	Generally NW-SE strike, steep to moderate SW dip.
S ₁	Schistosity, phyllitic foliation, rare pressure solution cleavage. Axial planar to F ₁ folds. S ₁ is also defined by thin quartz±feldspar segregations. Occurrence restricted to Lardeau Group and older rocks.	Generally NW-SE strike, moderate SW or NE dip.
F ₁	Rare close to isoclinal mesoscopic similar folds in Lardeau Group and older rocks. Recognized from re-folded character and S ₁ axial planar foliation.	Gentle NW-SE plunge, Axial planes as for S ₁ .
L ₁	Positively identified only as an intersection lineation of micaceous minerals and quartz rodding of S ₁ on S ₀ surfaces of Lardeau Group and older rocks.	Gentle NW-SE plunge.
S ₂	Phyllitic foliation, slaty cleavage; schistosity in southeastern Blue Ridge and Wilson Creek areas. Gneissosity above west shore of Kootenay Lake. S ₂ is the dominant foliation in Milford Group and younger rock. Pressure solution textures common in quartz-rich phyllite and slate. In Lardeau Group and older rocks S ₂ is present as a crenulation cleavage or obliterates S ₁ .	NW-SE strike, moderate SW to steep NE dip, commonly subparallel to S ₀ .
F ₂	Close to isoclinal mesoscopic folds, open to tight macroscopic folds, with S ₂ as an axial-planar fabric. Folds are generally similar and easterly vergent.	Gentle to moderate NW-SE plunge, axial surfaces generally steep SW or NE dip, deformed by F ₃ .
L ₂	Intersection lineation of S ₂ on S ₀ , compositional streaks and ribbing of S ₀ on S ₂ , mineral lineation of amphiboles, quartz-rodding parallel to F ₂ axes. Crenulation lineation on S ₁ in Lardeau Group and older rocks.	Gentle to moderate NW-SE plunge.
S ₃	Rare crenulation cleavage present in Wilson Creek area and Mount Buchanan area. Locally conjugate.	NW-SE strike, gentle and steep SW and conjugate NE dips.

Table XIII: Description of bedding and foliations, minor folds and lineations associated with fold deformation in the Goat Range area (cont'd)

Element	Definition/Characteristics	Typical Orientation
F ₃	Open to close mesoscopic folds, locally conjugate with reclined and steeply west-dipping axial surfaces. Commonly west-vergent where not conjugate. Large scale (10's of meters), upright-structures are common in the northern Wilson Creek area.	Gentle to moderate NW-SE plunge, axial surfaces steeply dipping in northern and eastern part of area. Conjugate and reclined SW or NE in western and southern parts.
L ₃	Crenulation lineation on S ₁ or S ₂ with amplitude: wavelength ratio of 1:2 to 1:4 and hinge spacing of 0.5-8.0 cm (0.2-3.1 in). A corrugation produced by crenulation in siliceous phyllites is well developed in the southern Blue Ridge.	Generally shallow southeasterly or northerly plunge, commonly nearly colinear with L ₂ .
S ₄	Recognized only in the Wilson Creek area 5-7 km (3.1-2.7 mi) south of the confluence with Fitzstubb's Creek. Well developed crenulation cleavage nearly obliterates S ₂ .	070/40-80SE
F ₄	Commonly polyclinal, open parallel folds and reverse kink folds with kink surfaces 1 cm-2 m (0.4 in-3.3 ft) apart.	Axial surface attitude: 050-080/60-80SE Fold axes; 220-250/55-65.
L ₄	Rare chevron crenulations 1-5 mm (.04-.2 in) in amplitude and rounded kink band axes.	As for F ₄ fold axes.
S ₄ '	Well developed crenulation cleavage recognized only in the axial regions of F ₄ ' folds in Slocan Group adjacent to Kaslo River 0-2 km (0-1.2 mi) north of Seven Mile Creek.	~130/75SW.
F ₄ '	Northeasterly verging, close similar folds with amplitudes of 0.25-50 m (0.8-164 ft) and amplitude: wavelength ratios of 1:3-1:5.	Average axial surface attitude 108/84SW, average axis: 289/44
L ₄ '	Intersection lineation of S ₄ ' on S ₂ and crenulation cleavage, commonly rounded microfold axes spaced 1-5 mm (.04-.2 in) apart.	As for F ₄ ' fold axes.

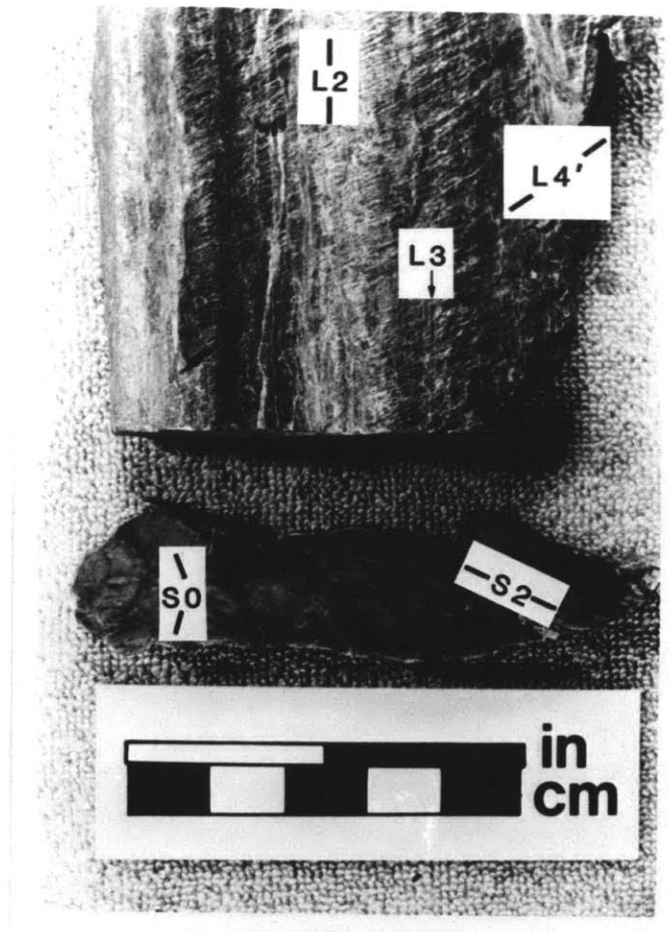


Figure 75: L_2 ribbing lineation and L_4' crenulation lineation in Siliceous Argillite Member of McHardy assemblage. The L_2 ribs are produced from the light quartz-rich and dark pelitic beds intersecting with S_2 foliation surfaces. L_3 microcrenulation lineation is barely visible and is subparallel to L_2 . L_4' , the prominent crenulation lineation, cuts all other fabrics at a high angle.

the Kuskanax Batholith and McKian Creek Stock and the area east of Mount Buchanan), quartz-feldspar segregations also occur along S_2 surfaces. S_1 generally parallels bedding except in the Broadview Formation where S_1 is locally at an angle to bedding. Wisps of darker, finer grained material extend along the foliation, suggesting that pressure solution may be involved in the formation of S_1 (Fig. 14). S_1 in the Broadview Formation commonly is defined by thin selvages of biotite or chlorite spaced 1-5 mm (.04-.2 in) apart. It is a more pervasive schistosity in other units of the Lardeau and Hamill groups. S_1 is axial planar to observed F_1 folds (Fig. 76) although good examples of this relationship are scarce. Locally, refolded F_1 minor structures are preserved (Fig. 8). The scarcity of unequivocal F_1 folds in the Goat Range area does not permit a satisfactory interpretation of the detailed geometry of the first generation of folding.

Meadow Creek Anticline

The belt of Hamill quartzite east of Mount Buchanan forms the core of an F_1 synformal anticline. This interpretation is based on correlation with a similar rock sequence north of the outlet of Davis Creek which Fyles (1964, Figure 3 and p. 59) mapped as the core of the first generation Meadow Creek anticline. However, Fyles (1967, Figure 2 and p. 23) later mapped the Hamill Group east of the Blue Ridge as an antiform, based in part on northerly plunging lineations. Lineation data analyzed in this study (Table XII) show no plunge for the area which includes the Hamill Group, allowing the simpler interpretation of the belt as a continuation of the Meadow Creek anticline.

Thrust Faults

On the ridge 1 km (0.6 mi) southeast of Mount Buchanan, structurally

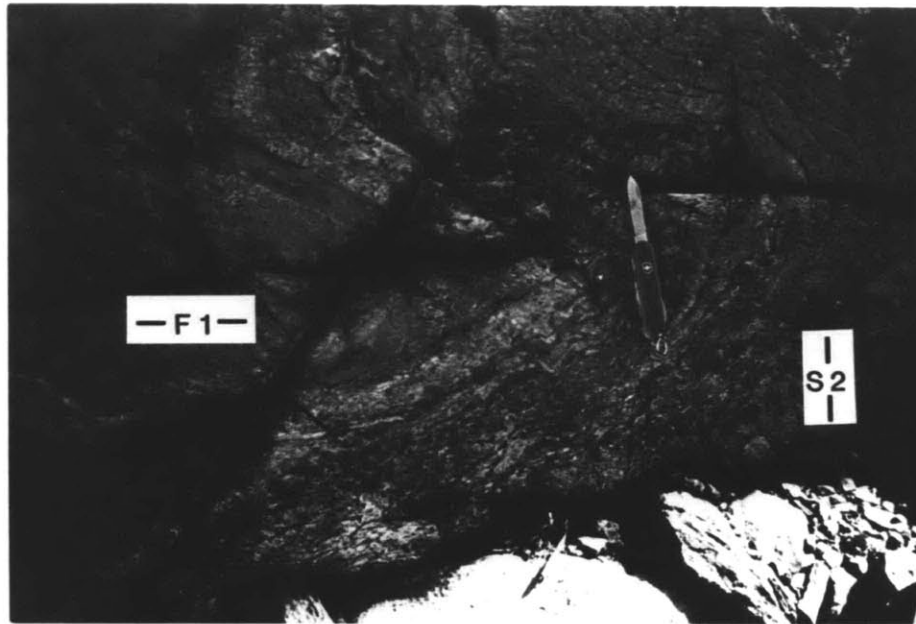


Figure 76: F_1 minor fold in grit of the Broadview Formation. S_1 axial planar cleavage is deformed by open crenulations (S_2) with axial surfaces upright, parallel to the knife. View to south, North of McKian Creek Stock.

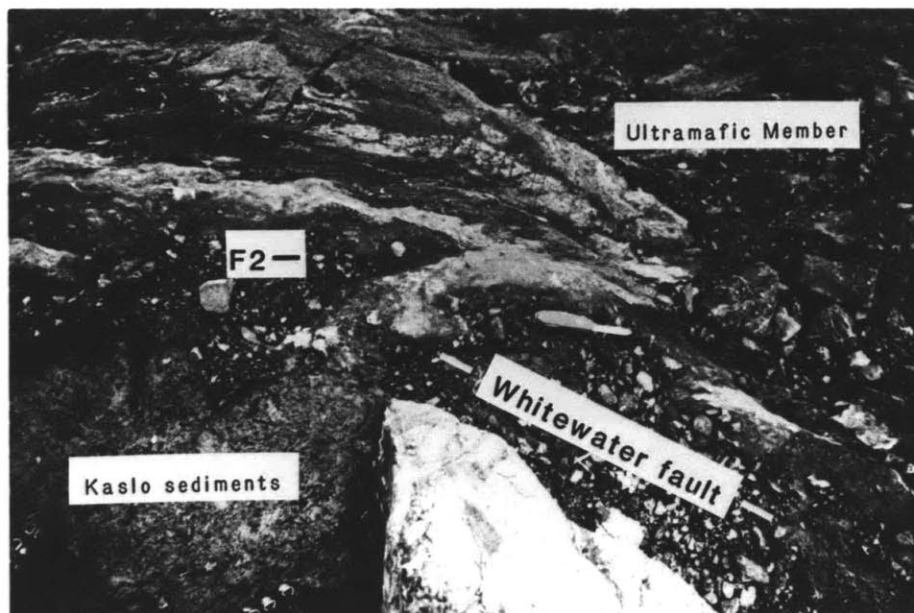


Figure 77: Splay of the Whitewater thrust fault folded by an F_2 minor fold. This splay is at the base of the main body of Ultramafic Member of Kaslo Group at the headwaters of Whitewater Creek. View to west.

upright upper Index Formation and Jowett Formation overlie the younger Broadview Formation in thrust geometry. The thrust is mapped at the Index or Jowett-Broadview contact and does not cut the Milford Group limestone member of Davis assemblage. Therefore this thrust is assigned to the pre-Mississippian, first phase of deformation. Units in the upper part of the Index Formation are truncated against the thrust fault in an apparent east-vergent drag fold. This vergence direction contradicts the westward-directed vergence of F_1 structures proposed for the Meadow Creek Anticline (Fyles, 1964, p. 53).

Age of First Generation Deformation

The age of first generation deformation is bracketed by the youngest strata involved in the deformation, the Ordovician Broadview Formation (Read and Wheeler, 1976) and the oldest strata not involved in the deformation, the Upper Mississippian Milford Group. On the basis of indirect, regional evidence such as plutonism (Okulitch, 1984, p. 1177) and regional unconformities (Price, 1981) the age of deformation may be Middle Ordovician.

Whitewater Fault

The Whitewater thrust fault occurs at the base of the upper plate of Kaslo Group. It is the oldest structural element recognized in strata younger than the Lardeau Group and is folded by F_2 folds, thus it formed between F_1 and F_2 fold phases. The fault is easily recognized at the base of the ultramafic member (Fig. 77) and is difficult to trace where the ultramafic rock is absent. The Whitewater fault was not recognized northwest of South Cooper Creek. This may be because it juxtaposes similar volcanic rocks of the lower and upper plates of Kaslo Group; alternatively, it may lie under slide debris in the valley of South Cooper Creek and become truncated by the Marten Conglomerate to the north.

The Whitewater fault comprises several anastomosing strands that outline horses (Boyer and Elliot, 1982, p. 1199) in the thrust system. These horses range in size from 3-10 m thick and 100-200 m long, as exposed east of the main body of serpentinite in the pass between Whitewater Mountain and Mount Brennan, to the slice between Lyle and Fitzstubb's creeks which is nearly 1500 m (4921 ft) thick and at least 23 km (9 mi) long. No folds associated with movement along the Whitewater fault are recognized. Locally a scaly fabric with lithons 1 mm to 5 cm (.04 to 1.9 in) thick is developed within the ultramafic member and is crenulated by S_2 . This relationship is best seen 1.6 km (1.0 mi) at 200° from Mount Jardine. The Whitewater fault cuts the Lower to Middle Permian Kaslo Group and is intruded by the Late Permian to Middle Triassic Whitewater Diorite, bracketing the age of movement and hence the second deformational episode, as Late Permian to Middle Triassic.

F₂ Elements: The Dryden Anticline and Related Structures

The second phase of folding dominates the map pattern in the Goat Range area. Second generation folds (F_2) are characterized by an axial planar foliation (S_2) which is the first cleavage and regional foliation in stratified rocks younger than Upper Mississippian (i.e. Milford, Kaslo and Slocan groups and Marten conglomerate). West of the Schroeder fault, the Dryden anticline and parasitic folds have northwest-trending, steeply dipping (Fig. 78) axial-planar foliation and gentle to moderate plunges. East of the Schroeder fault, eastward-vergent, northwest-trending folds up to 700 m (2296 ft) in amplitude occur in the Davis assemblage of Milford Group (Fig. 79) and also have the regional foliation as axial planar cleavage (Fig. 80). Folds on either side of the Schroeder fault are correlated on the basis of common regional axial-planar foliation, and similar style and orientation.

Figure 78: F_2 minor fold with steeply dipping S_2 axial planar foliation in the slate and phyllite member of Slocan Group. The slaty cleavage dips west in this view to the northwest, headwaters of Schroeder Creek.

Figure 79: Macroscopic, eastward-verging F_2 folds that deform the unconformity at the base of the Davis assemblage of Milford Group. The cliff exposure of the easternmost syncline of limestone member in the left-distances has a relief of about 61 m (200 ft). View is to the southeast, along the ridge east of Mount Schroeder.

Figure 80: The regional S_2 foliation with an axial planar relationship to F_2 minor folds in the sandstone and phyllite member of Davis assemblage of Milford Group. West-dipping slaty cleavage cuts the thick sandstone bed in the hinge area of this large F_2 minor fold. View is to the south, east of Mount Schroeder.

Figure 81: Mount Dryden and the Mount Dryden anticline viewed from the south. Volcanics and sedimentary rocks of the lower plate sequence of Kaslo Group are folded over siliceous argillite member of the McHardy assemblage.

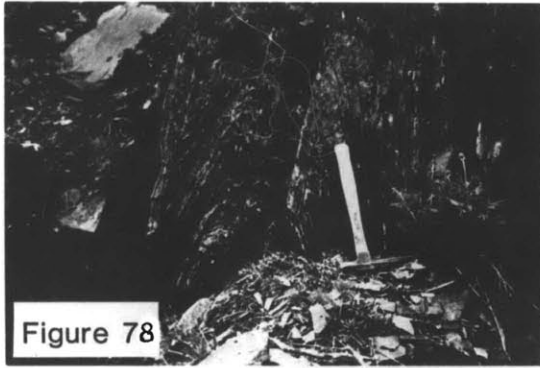


Figure 78



Figure 79



Figure 80

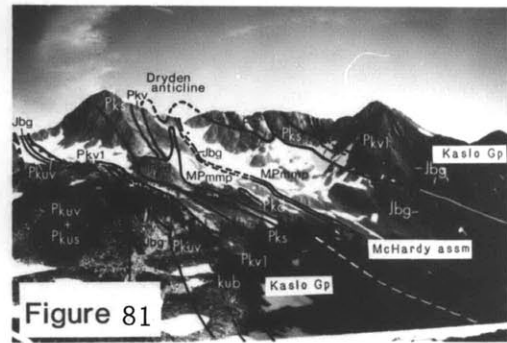


Figure 81

The Dryden anticline was first recognized at Mount Dryden (Fig. 81) and has been traced from the southern margin of the McKian Creek Stock to the elbow bend in trends southeast of Milford Peak. Southeast of Milford Peak the trace of the axial surface is defined by the symmetric distribution of map units and a zone of high-angle intersection between the bedding and S_2 foliation. However, this zone was not recognized south of the saddle north of Mount Buchanan and the axial trace is interpreted to be truncated by an inferred low-angle fault that cuts through the saddle (Figs. 3,4). The Dryden anticline consists of two en echelon segments: a southern segment that extends from Mount Dryden south along the Blue Ridge, and a northern one that extends from the southern headwaters of Cooper Creek northwest to the McKian Creek Stock (Fig. 4). The axial plane of the Dryden anticline is steeply dipping, both to the northeast and to the southwest, along the northern segment and along the southern segment to the Emerald Creek headwaters. The axial-planar cleavage becomes reclined, dipping southwest at $50-30^\circ$, southeast of the headwaters of Emerald Creek (Fig. 82) and the axial surface is interpreted to have a similar orientation. Along the steeply-dipping segments of the anticline, the foliation is at a high-angle to bedding in the hinge of the fold and near parallel to bedding along the limbs of the fold, resembling a downward-opening fan. The interlimb angle along the steeply-dipping segment is generally 60° and tightens to about 25° in the reclined segment south of Milford Peak. The Slocan Group on the west limb of the Dryden anticline contains folds that verge eastward and are parasitic to the Dryden anticline. An example is the "Whitewater Drag Fold" of Hedley (1945, his Fig. 2), a northwest-plunging, eastward-verging F_2 fold that is refolded by F_3 structures. The belt of Slocan Group east of the Dryden anticline contains westward-vergent F_2 folds (Fig. 59) and has

the general geometry of a faulted F_2 syncline. The synclinal form of the eastern belt of Slocan Group belt is clearly exposed on the ridge east of Mount Cooper.

Northwest of Mount Cooper, on the southern margin of the McKian Creek Stock, the limestone member and Cooper conglomerate of McHardy assemblage trace out a southeastward-plunging anticline. The anticline has axial-planar foliation and is assigned to F_2 . Similarly, north of McKian Creek Stock, the Cascade Mountain anticline (Klepacki, Read and Wheeler, 1985, p. 275) has axial-planar foliation and is assigned to F_2 .

In the southern part of the Blue Ridge near Mount Buchanan, the geometry of the F_2 folds is unknown. In the carbonate member of the McHardy assemblage north of Kaslo River, F_2 mesoscopic folds verge to the west. East of the Schroeder Fault in the southern Blue Ridge F_2 folds are tight similar folds with axial planes dipping southwest about 30° (Fig. 82). Mesoscopic F_2 folds in the Lardeau Group south of Schroeder Creek generally east verge and have similarly reclined axial surfaces, rounded hinges and deform S_1 . No major F_2 structures are recognized in the Lardeau Group although a belt of tight mesoscopic folds within the Jowett Formation north of Milford Creek (Fig. 83) are assigned to F_2 .

The first foliation to affect the rocks in the Milford, Kaslo and Slocan groups and Marten conglomerate (S_2) has many features indicative of formation by solution mass-transfer processes (pressure solution). These features include wisps of darker material of one bed intruding lighter material of the overlying bed (Fig. 84) and microscopic grains truncated by films of insolubles that suggest dissolution of material at interfaces of grains along solution channel-ways (Fig. 85; see Borradaile et al., 1982, pps. 310 and 331). In higher grade metamorphic rocks surrounding the

Figure 82: Reclined F_2 minor folds in the limestone member of Davis assemblage in the southern Blue Ridge. These east-vergent minor folds are accompanied by movement along shear surfaces parallel to the axial surfaces and are cut by associated small east-dipping antithetic riedel fractures. View is to the south, headwaters of Wing Creek.

Figure 83: F_2 minor folds deform S_1 foliation in the Jowett Formation near Milford Creek. Reclined, west-dipping axial surfaces are present in this extensive belt of folded green and grey phyllite and quartzite of the lower Jowett Formation. View is to the south.

Figure 84: Hand specimen of the McHardy assemblage with thin coloured wisps along S_2 foliation, suggesting a pressure solution mechanism for the formation of the cleavage. The S_2 fabric here is folded by typical open F_3 crenulations that have the effect of corrugating the S_2 surface. This specimen is from the Blue Ridge about 3 km (1.9 mi) north of Mount Buchanan.

Figure 85: Photomicrograph of graphite- and quartz-rich McHardy assemblage that shows truncated grains and opaque films along foliation, suggesting a pressure solution mechanism for the formation of the cleavage. Note the area of abundant dissolution in the left-center part of the photo. This sample is from the axial zone of the Mount Dryden anticline in the headwaters of South Cooper Creek.

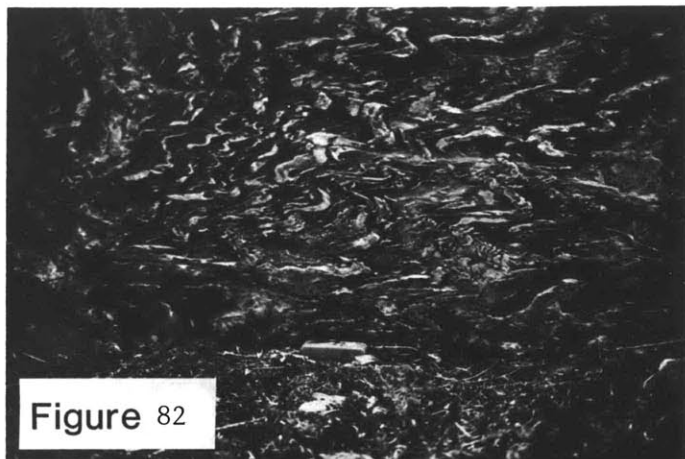


Figure 82



Figure 83

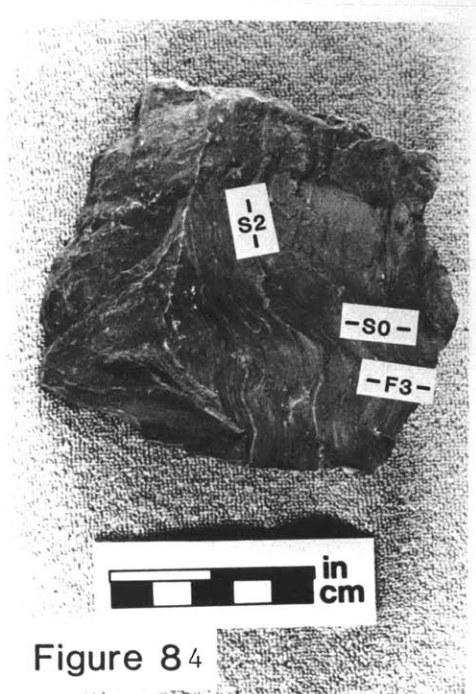


Figure 84

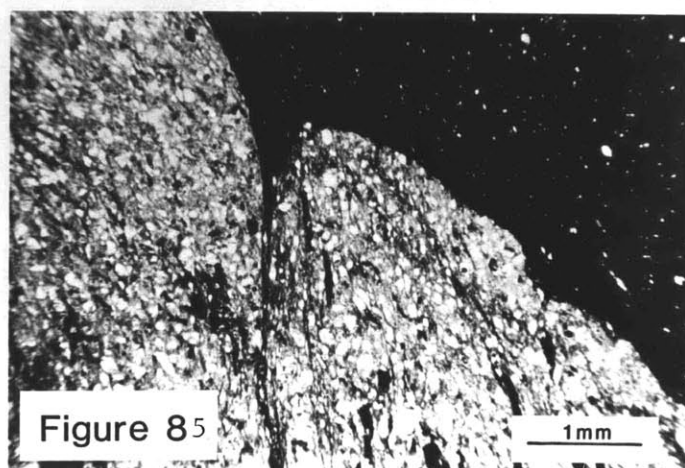


Figure 85

Kuskanax Batholith and McKian Creek Stock, and on the lower slopes of the Blue Ridge adjacent to Kootenay Lake, interlocking grains and the absence of opaque films indicate diffusion recrystallization and grain boundary sliding are the likely deformation mechanisms operative during S_2 formation. In rocks older than Milford Group, S_2 is commonly a crenulation cleavage superposed on the earlier S_1 cleavage.

F_2 folds affect the Upper Triassic Slocan Group rocks and are truncated by the 180 Ma Cooper Creek Stock. This constrains the age of F_2 folds to latest Triassic to Early Middle Jurassic. Strata of the Rossland Group that overlies the Slocan Group are apparently also deformed in the sequence of folds that includes F_2 (Little, 1979, p. 34), and is as young as Lower Toarcian. This brackets the age of the deformation of upper Paleozoic and lower Mesozoic strata that includes F_2 folds to ~185-180 Ma (Parrish and Wheeler, 1983, p. 1752).

The Stubbs Fault

On the northern face of Mount Stubbs, the McHardy assemblage is floored by a fault that truncates diorite dykes and sills and beds in the siliceous argillite member. The fault also truncates the members of the underlying Keen Creek assemblage and places Upper Mississippian rocks of the McHardy assemblage on top of Lower Pennsylvanian rocks of the Keen Creek assemblage. This fault, named the Stubbs thrust fault (Klepacki and Wheeler, 1985, p. 284), apparently moved northeastward, indicated by northeastward overturning of east-dipping banded limestone member in the footwall of the fault (Fig. 86). The thrust fault has been traced from Mount Stubbs northeastward to where it is truncated by the McKian Creek

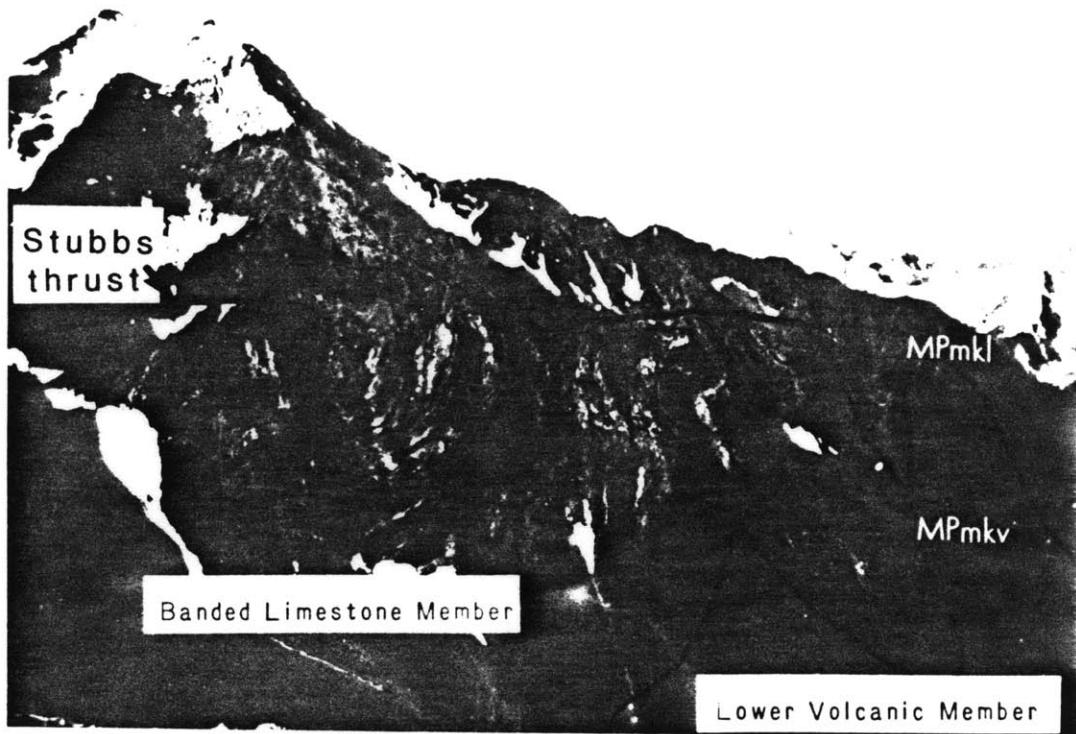


Figure 86: The Stubbs thrust fault at Mount Stubbs. Siliceous Argillite Member of the McHardy assemblage is thrust over the Banded Limestone and Lower Volcanic members of the Keen Creek assemblage. The east-dipping, upright, Banded Limestone Member is swept up into steep and locally overturned dips near the thrust surface in a dragfold that indicates movement to the east. View to the south across Rossland Creek.

Stock. It has also been traced northwestward, around the west margin of the McKian Creek Stock (Fig. 87), and then eastward, where the fault is truncated against the northern margin of the McKian Creek Stock (Klepacki, Read and Wheeler, 1985). The fault trace is generally knife-sharp (Fig. 88). In the headwaters of Wilson Creek 7.1 km (4.4 mi) at 359° from the confluence of Wilson and Keen creeks, the Stubbs fault consists of a 3 m (9.8 ft) zone of brecciated rock with miniature anastomosing fault traces, some of which outline duplex structures about 50 cm (20 in) thick in recrystallized limestone beds (Fig. 89).

On the south flanks of Cascade Mountain and north of Mount Marion, the Cascade Mountain anticline folds a thrust fault interpreted as a splay of the Stubbs thrust (Klepacki, Read and Wheeler, 1985, p. 275). The folded thrust repeats the lower part of the McHardy assemblage (Fig. 90) and is interpreted as an antiformal duplex structure (Boyer and Elliot, 1982, p. 1211).

Since the Stubbs thrust fault cuts beds folded by F_2 folds and is itself folded by the Dryden Anticline (Fig. 5, Section B-B'), the faulting is interpreted to have formed during F_2 formation of the folds, in Early Jurassic to early Middle Jurassic time.

F_3 Elements and Related Structures

Third generation folds deform S_2 and S_1 foliations, have shallow to moderate plunges, and commonly verge west within west-dipping strata. East-vergent mesoscopic folds occur locally, especially within east-dipping strata. Locally, polyclinal (box) folds with conjugate axial surfaces are developed that strike north to northwest and dip at a low angle to the southwest and at a moderate angle to the northeast (Fig. 91). F_3 folds are

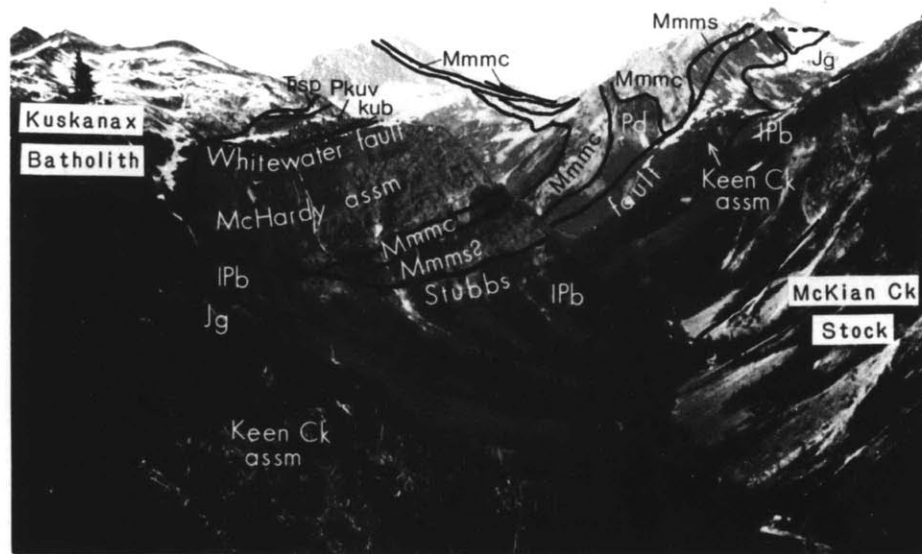


Figure 87: Panorama of the upper Wilson Creek valley showing the trace of the Stubbs thrust fault. The Kuskanax Batholith forms the ridge crest on the west (left) side of the valley and the McKian Creek Stock underlies the east (right) valley wall. Cascade Mountain is in the left distance and Mount Marion is in the right distance.



Figure 88: Close-up of the Stubbs thrust illustrating the sharp contact typical of most of the fault trace. Tuffaceous Sandstone Member(?) of the McHardy assemblage overlies the Lower Volcanic Member of the Keen Creek assemblage. View to the north, headwaters of Wilson Creek.

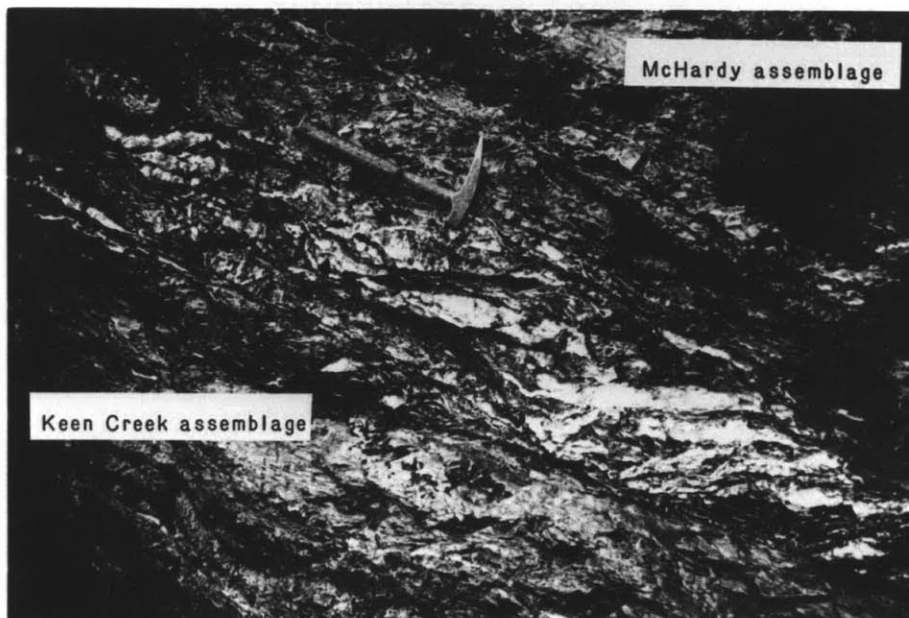


Figure 89: Breccia zone and duplex structure along the Stubbs fault trace in the upper Wilson Creek valley. A recrystallized limestone bed in Keen Creek assemblage forms the horses in the duplex. View to west.

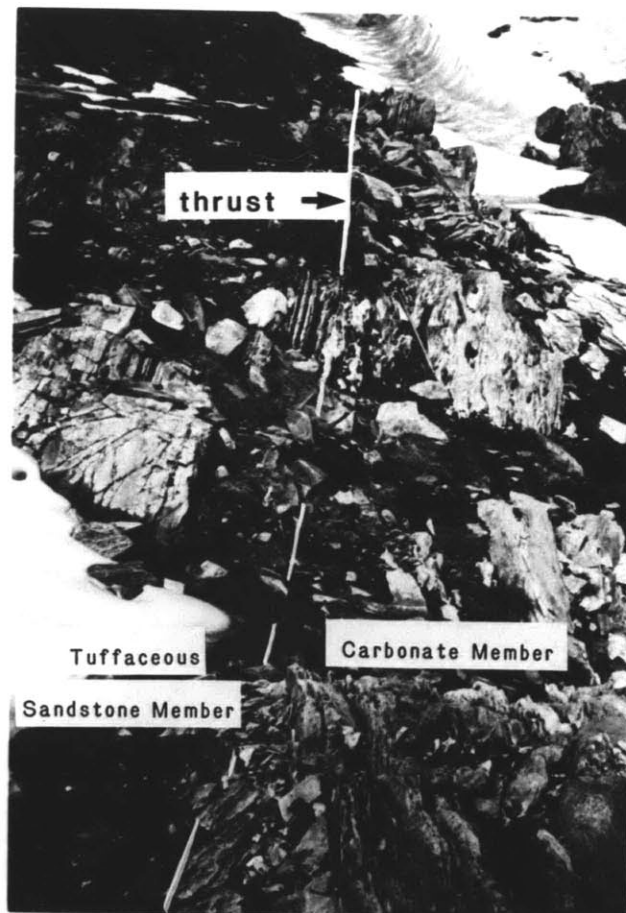


Figure 90: Thrust fault trace on the west flank of the Cascade Mountain anticline. Tuffaceous sandstone Member of McHardy assemblage is thrust onto Carbonate Member of McHardy assemblage. The thrust is folded by the Cascade Mountain anticline. View to the north from the saddle between Cascade and Marion mountains.



Figure 91: Conjugate F_3 fold that deforms S_2 foliation in the western belt of Slocan Group. Note the conjugate fold in the upper right part of the photo. View to the northeast, north of the foot of Emerald Creek.



Figure 92 : Tight F_3 fold that deforms the Upper Limestone Member of the Keen Creek assemblage and a dyke of the Kuskanax Intrusives. Axial surfaces dip to the southwest. View north, west of upper Wilson Creek.

close to tight in the headwaters of Wilson Creek (Fig. 92) and are open to close elsewhere. The orientation and style of F_3 folds varies throughout the Goat Range (Fig. 93).

Third generation folds warp upright, west-dipping strata into an overturned, northeast-dipping orientation. A major F_3 axial zone is present near Davis Creek and is defined by a change in dip and an increased abundance of F_3 minor structures. North of Davis Creek, foliation and bedding dips northeast (about 60°) and they trend more northerly (156°) than strata and foliation south of Davis Creek which has an average orientation of $128^\circ/40^\circ$ SW.

Third generation folding apparently coincided with intrusion of granitic rocks such that some granitic dykes are folded by F_3 folds (Figs. 70, 92) and F_3 axial surface traces are deformed and truncated by granitic bodies (e.g. southwest of Mount Marion on the northern margin of the McKian Creek Stock). Therefore the age of F_3 folding is about 180 Ma.

Schroeder-Spyglass Fault and Related Faults

Steeply dipping faults that parallel the trend of the F_2 and F_3 structures are present along the flanks of the Dryden anticline. On the west limb of the Dryden anticline, a fault is mapped in the Slocan Group from the headwaters of Goat Creek northwestward across Kane Creek and into Monitor Creek drainage. Drag-folds and slickenside step features exposed on the fault surface west of Inverness Mountain at an elevation of 2149 m (7052 ft) indicate oblique movement (right-lateral and west-side down).

On the east limb of the Dryden anticline steep faults occupy parts of the contacts between the Slocan Group and Marten conglomerate with the Kaslo Group; between the McHardy assemblage, Kaslo and Slocan groups and the Davis assemblage of Milford Group (the Schroeder fault), and the

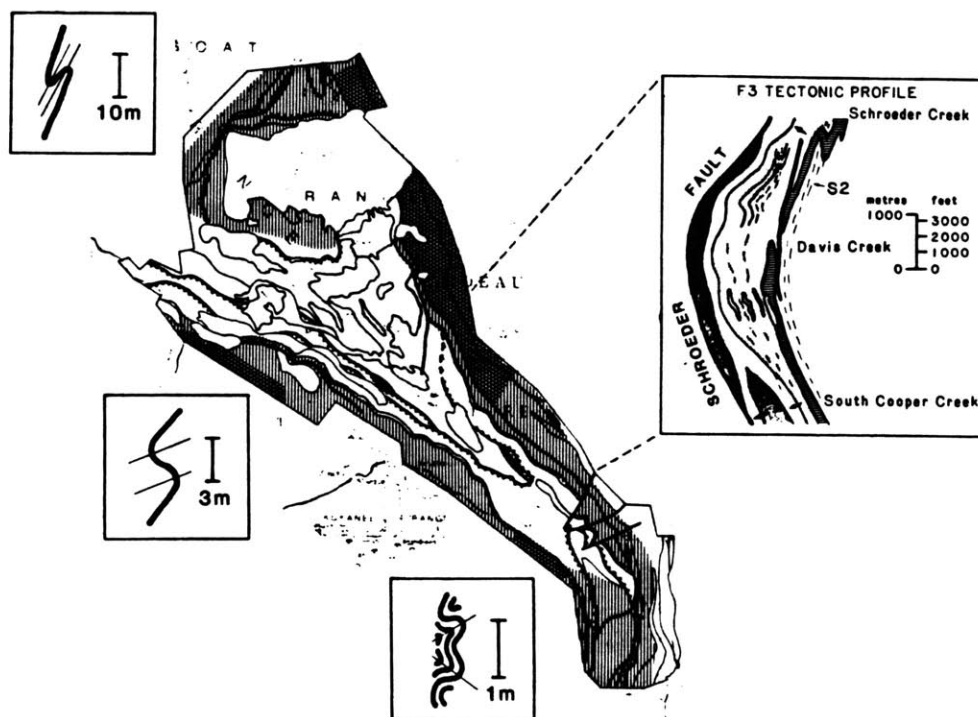


Figure 93: Distribution and style of F3 folds. The hatchured areas of the map indicate areas where F3 folds are developed, cross-hatched areas indicate northeast-dipping foliation and bedding on inverted limbs of F3 major folds. The tectonic profile inset is projected from strata in the Davis assemblage of Milford Group between South Cooper Creek and Schroeder Creek onto a plane perpendicular to the regional F3 axis of $145^{\circ}/20^{\circ}$. Other insets indicate profiles of typical F3 folds in the southern, west-central and northwestern parts of the Goat Range map area.

contact of Davis assemblage and Lardeau Group. The most important of these faults is the Schroeder fault (Fig. 94), which extends the length of the Goat Range area and is correlated with the Spyglass fault in the Poplar Creek area (Klepacki, Read and Wheeler, 1985). The Schroeder fault juxtaposes east-facing strata of McHardy assemblage, Kaslo and Slocan groups and Marten conglomerate against west-facing strata of the Lardeau Group and Davis assemblage (Fig. 93). The Schroeder fault is named for exposure of the fault trace along the west ridge of Mount Schroeder where the fault places phyllite of the Slocan Group against siliceous argillite member of the Davis assemblage (Fig. 95). At outcrop scale, the trace of the Schroeder fault generally parallels bedding and S_2 foliation. At Mount Schroeder, the fault is defined by a zone 3-4 m (10-13 ft) thick of interslivered sheets of siliceous argillite and pyritic phyllite that are 5-100 cm (2-39 in) long and 2-5 cm (0.8-2 in) thick. In the headwaters of Milford Creek, several strands of the Schroeder fault anastomose over a zone 6-10 m (20-33 ft) thick isolating slivers 1-3 m (3-10 ft) thick and 3-30 m (10-98 ft) long. Splays of the fault with normal (west-side-down) displacement are present in the hanging wall (Fig. 96). Undisrupted white quartz veins occur along the faulted area. Indirect evidence indicates west-side down displacement along the Schroeder fault. This evidence is:

- 1) an abundance of F_3 folds with a west-side-down vergence adjacent to the fault trace;
- 2) the juxtaposition of Upper Triassic Slocan Group strata against Upper Mississippian Davis assemblage, suggesting down-faulting of the younger strata; and
- 3) fault strands in the hanging-wall (Slocan Group) in the headwaters of Milford Creek are normal faults in their present orientation, which requires west-side-down movement.

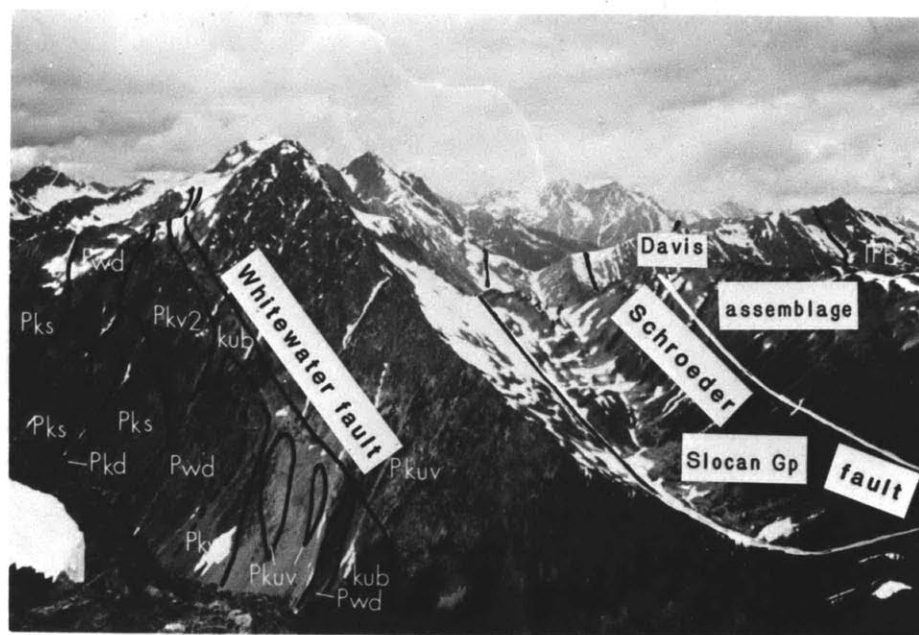


Figure 94: Panorama of the east flank of the Dryden anticline showing the trace of the Schroeder fault. Upper Triassic Slocan Group strata are juxtaposed against the Upper Mississippian Davis assemblage. View northwest across Rossiter Creek to Mount Cooper in the center distance.



Figure 95 (above): The Schroeder fault trace at Mount Schroeder. Outcrop on left (west) of Upper Triassic Slocan Group is faulted against Siliceous Argillite Member of Davis assemblage to right (east). View to northwest.

Figure 96 (left): The Schroeder fault trace with imbricate normal faults in the hanging-wall (Slocan Group). The Siliceous Argillite Member of Davis assemblage is in the footwall. Note the quartz vein along fault trace. View to the west.

An east-dipping fault occupies the contact between the Marten conglomerate and Slocan Group from the headwaters of Schroeder Creek northwest to Davis Creek. Drag folds and extended limestone beds within rocks of the Slocan Group along the fault trace in the saddle between Rossiter Creek and Davis Creek indicate this fault is extensional.

The contact between the Davis assemblage and the Broadview Formation is generally a fault where F_2 folds are absent. The contact is mainly a fault north of Davis Creek, probably continuous with the Emmens fault in the Poplar Creek area (Read, 1973). West-side-down displacement is inferred from juxtaposition of the Upper Mississippian Davis assemblage against the lower Paleozoic Broadview Formation.

The Schroeder fault apparently is associated with F_3 deformation because of the abundance of F_3 folds near the fault trace and the broad fold form of the fault in tectonic profile (Fig. 93) - an effect assigned to F_3 folding. However, the fault truncates F_3 minor folds on the northwest side of Mount Schroeder and truncates bedding and foliation at various angles (Fig. 5, Sections B-B', C-C', D-D', E-E') indicating the fault has not been folded along with the foliation, that is, it has not been affected by all of F_3 folding. This suggests that the formation of the fault post-dates the main pulse of F_3 folding, which is thought to have occurred during the early stages of granite intrusion. The Schroeder fault is intruded by the Spokane Creek and McKian Creek stocks that are members of the ~180 Ma Kuskanax Intrusive Rocks. Thus, the age of the north- to northwest-trending west-side-down faults in the Goat Range is about 180 Ma.

F₄ Elements and Related Structures

Fourth generation folds have two different orientations (see Table XIV) but their similar style and relative age relationships suggests both orientations of folds are synchronous. F₄ folds are well developed in the elbow-bend of the Blue Ridge while F₄' folds are well developed south of the bend, in the Mount Buchanan area (Fig. 97). Northeast-trending axial surfaces of F₄ folds apparently change orientation into a southeast trend in a region of poor exposure (about 30 percent exposure) 3.5-4.5 km (2.2-2.8 mi) north of the confluence of Kaslo River and Keen Creek of the Kokanee Range. A well-developed crenulation cleavage occurs with the F₄ folds just south of the map area, 5 km (3.1 mi) south of the confluence of Fitzstubbbs and Wilson creeks. Similar crenulation cleavage is common in F₄' fold hinges northwest of Mount Buchanan. F₄ folds are west-vergent with southeast-dipping axial surfaces or box folds (Figs. 98, 99). F₄' folds are northeast-vergent with steeply to moderately northwest-plunging axes (Fig. 100). Fourth generation folds deform gently plunging F₃ folds (Figs. 99, 101)

F₄ axial surfaces commonly contain faults or fractures. This feature, similarity of orientation, and concentration of F₄ folds in the elbow bend of the Goat Range are the basis for relating the F₄ folds with northeast-trending faults in the bend area. No direct evidence of displacement direction for these faults was recognized. An extensional component for displacement is interpreted from the increased outcrop area of the structurally higher Slocan Group within the northernmost and southernmost faults (Figs. 3,4). A northeast-trending lineament traced from the headwaters of South Cooper Creek to the ridge between South Cooper

Subareas	F ₄ Axis	one sigma	F ₄ Axial Surface	one sigma	F ₄ ' Axis	one sigma	F ₄ ' Axial Surface	one sigma
1-10 N	229/60 9	20°	078/70SE 5	28°	310/43 2	-	-	-
11 N	221/56 6	9°	059/78SE 6	10°	-	-	-	-
12-13 N	249/64 8	20°	054/60SE 9	23°	289/44 13	12°	108/84SW 8	13°

Table XIV: Average axes and axial surfaces from fourth generation folds determined from least squares regression. Fourth generation axes calculation include L₄ crenulation lineation and kink axes.

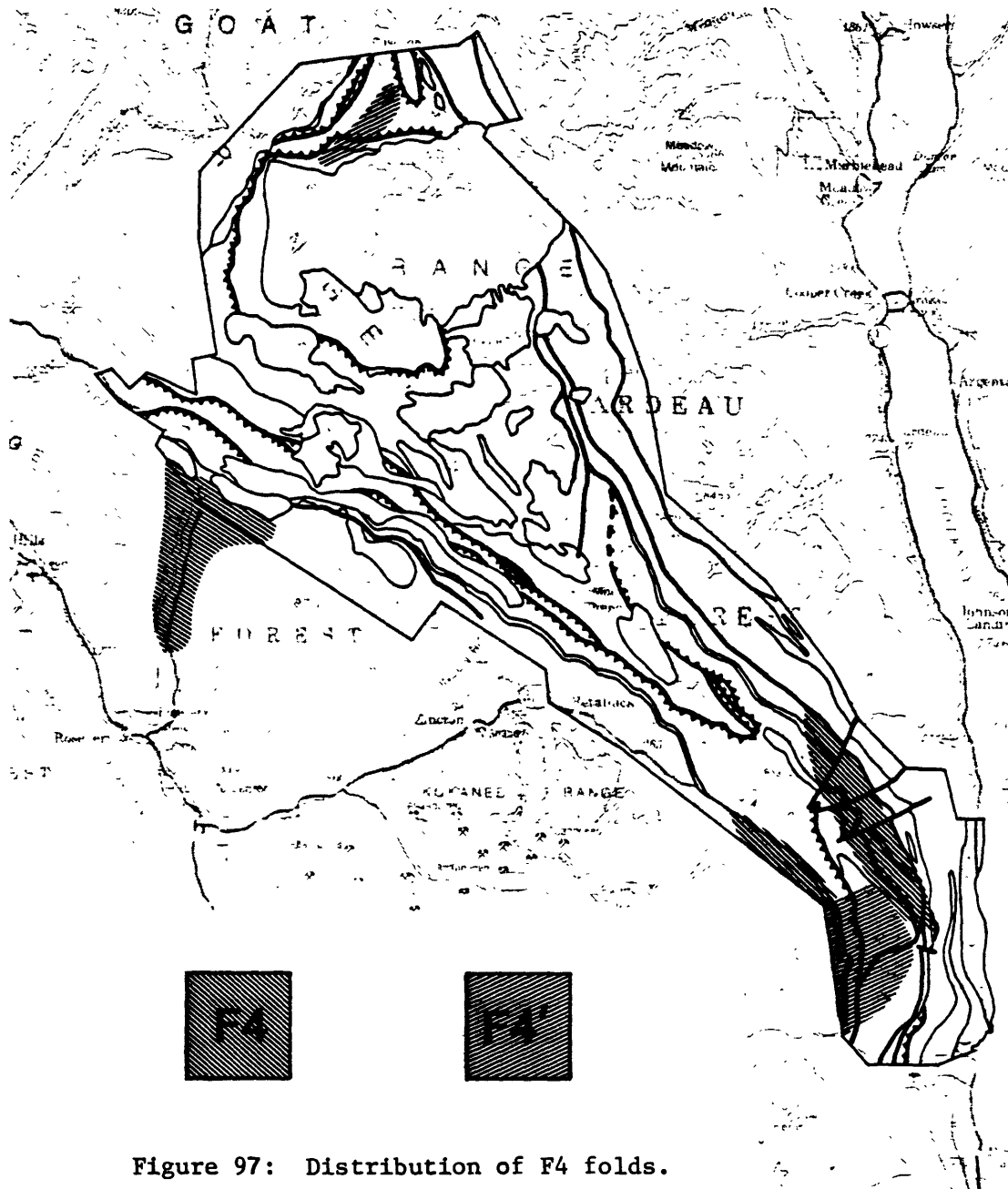


Figure 97: Distribution of F4 folds.

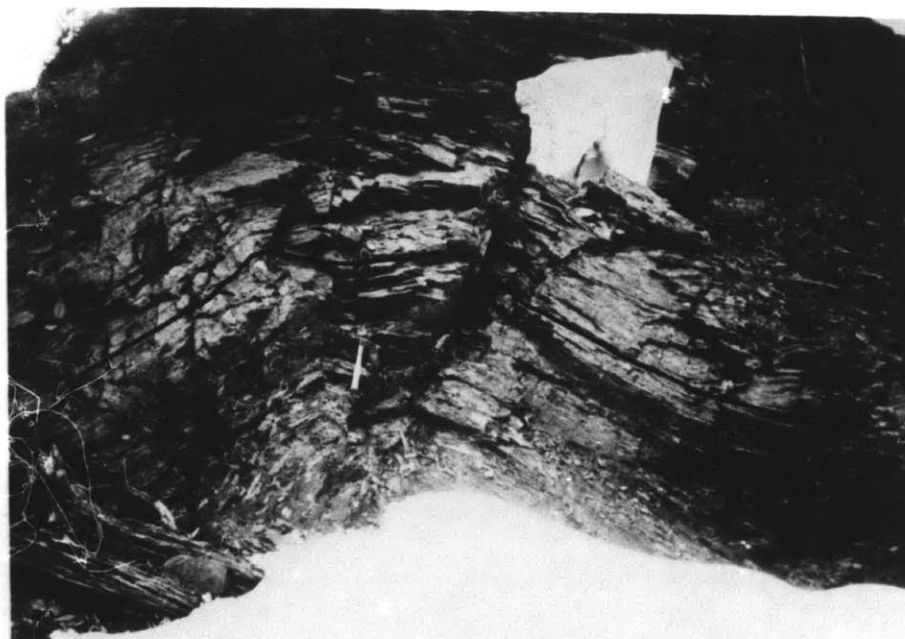


Figure 98 F₄ mesoscopic fold in the Slocan Group northwest of Milford Peak. Note box shape and conjugate axial surfaces occupied by fractures. View to west.

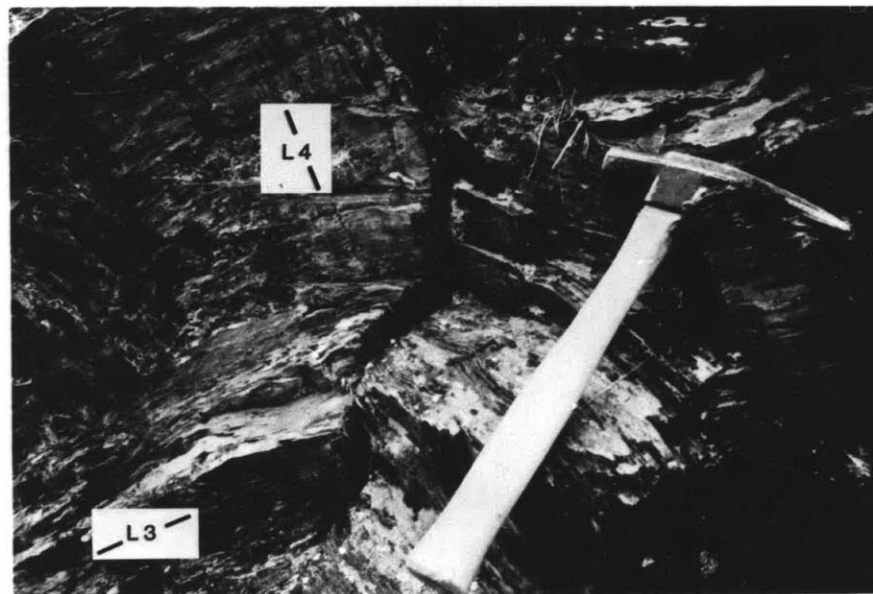


Figure 99: Hinge area of fold in figure 98 showing folded L₃ crenulation lineation, steeply southwest-plunging L₄ lineation and a fracture along the axial surface. View to the south.



Figure 100: F_4' folds with S_4' axial planar crenulation cleavage. The folded surface is S_2 foliation in Slocan Group. View southeast, Highway 31A north of Seven-mile creek.

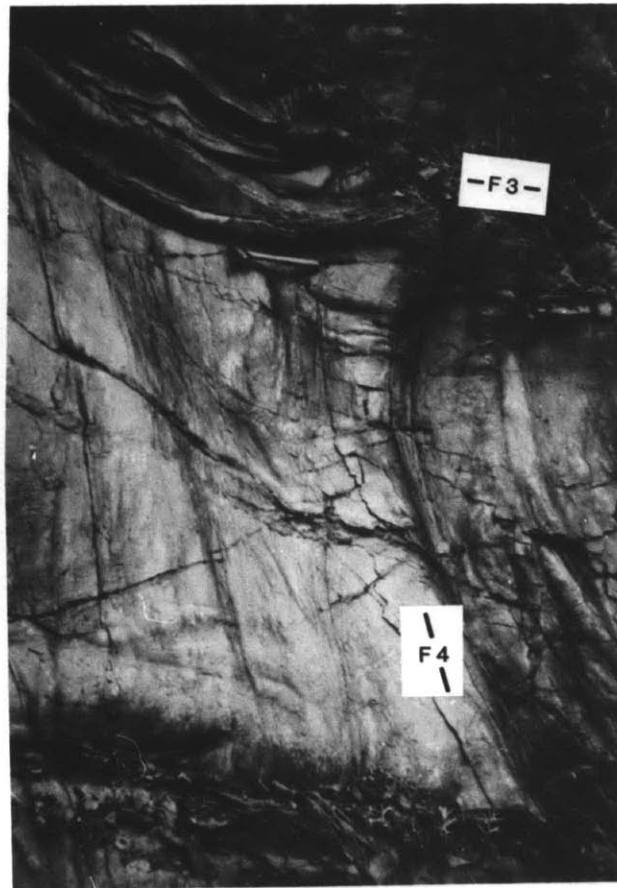


Figure 101: Gently plunging F_3 minor folds deformed by steeply plunging F_4 folds. The folded surface is S_2 foliation in Slocan Group. View east, near the confluence of Holmes Creek and Kaslo River.

Creek and Cooper Creek has a 1 m (3.3 ft) thick indurated crush zone indicating displacement, probably during the time of F_4 fold formation. A reverse fault with abundant complementary joints has an orientation similar to the axial surfaces of F_4 ' folds and occurs in the headwaters of Wing Creek. In general, the deformation that developed fourth generation folds apparently included both compressional features, such as reclined folds and crenulation cleavage, and extensional faults, especially on the outer arc of the bend defined by the Dryden anticline.

Northeast-trending steeply-dipping faults cut the Schroeder fault and related faults indicating that the faults associated with F_4 folds are younger than faults associated with the F_3 folds. A granite dyke of the Blue Ridge Intrusive Rocks in the headwaters of South Cooper Creek, 1.6 km (1.0 mi) at 147° from Mount Dryden is cut by a high-angle, northeast-trending fault. Similar granitic dykes are cut by northeast-trending faults 1 km (0.6 mi) at 259° from Mount Brennan. These relationships indicate that at least the faults associated with the fourth generation structures are younger than ~ 180 Ma. The younger age limit deformation is provided only by the overlap of fourth generation structures by glacial till.

Gouge Faults

Some northerly trending faults in the Goat Range area contain unindurated brecciated rock and clay gouge (Fig. 102). The gouge zones vary in thickness from a few centimeters (1-2 in) to several metres (10-16 ft). Faults with gouge were noted at an elevation of 948 m (3116 ft) along the Milford-Schroeder logging road, along a splay of the Schroeder fault 300 m (984 ft) northwest of the confluence of Kemp Creek and Kaslo River, and 4.5 km (2.8 mi) at 080° from Mount Cooper. The fault east of



Figure 102: Gouge fault near Milford Creek. Clay gouge about 9 cm (6 in) thick is present along the fault, which cuts pelitic schist of the Index Formation.



Figure 103. Gouge in a splay of the Schroeder fault near Kaslo River. About 1.5 m (4.9 ft) is present along the fault which separates Jowett Formation (hangingwall) from Index Formation (footwall). Note drag fold below hammer. View north, near confluence of Kemp Creek and Kaslo River.

Mount Cooper dips steeply to the east. The other faults dip 30-40° westward. Drag folds in the gouge of the splay of the Schroeder fault indicate west-side-down (normal) displacement (Fig. 103). Drag folds defined by a broken granitic dyke in the fault zone east of Mount Cooper indicate right-lateral displacement (Fig. 104). Displacement along faults marked by gouge in the Goat Range area was probably not large because the overall sequence of rock units is not interrupted.

The faults containing gouge disrupt the Middle Jurassic granitic dykes, and so are younger than Middle Jurassic, but older than undisrupted, mineral spring deposits and glacial alluvium. These faults are interpreted to post-date fourth generation structures because of the relatively fresh and unindurated nature of the gouge and regional correlation. The gouge faults may correlate with the Eocene brittle/ductile Slocan Lake extensional fault (Parrish, 1984; Carr, 1985, p. 94).

SUMMARY

First generation folds (F_1) are present in the lower Paleozoic Lardeau and Hamill groups and intervening Badshot-Mohican formations and have an axial planar cleavage (S_1) that is truncated at the unconformity with the upper Paleozoic Milford Group. An eastward-directed thrust fault is also apparently truncated at the unconformity. These folds and the thrust fault formed during the first deformational event in the Goat Range. Thrusting along the Whitewater Fault took place during the second deformational event and involved the McHardy assemblage and Kaslo Group and occurred during Late Permian to Middle Triassic time. The Whitewater Fault has several splays that detached along a basal ultramafic unit and outline horses and duplex structures typical of thrust belts (Boyer and Elliot, 1982).



Figure 104: Granitic dyke and the Limestone Member of the Davis assemblage deformed in dextral drag folds along a gouge fault. Several fault surfaces anastomose near the folded dyke. View is to the east, on the east end of the east spur of Mount Cooper.

The third deformational event began as early as the Late Early Jurassic and continued through the Early Middle Jurassic. Second (F_2) and third (F_3) generation folds and associated faults constitute this event. Second generation folds have an axial planar foliation (S_2) that is the primary foliation in the Milford, Kaslo and Slocan groups and the Marten conglomerate. The S_2 foliation also affects the dioritic rocks present in the Goat Range area. The second generation Dryden anticline controls the distribution of rock units west of the third generation Schroeder fault. East of the Schroeder fault, F_2 folds verge east. The McHardy assemblage, Kaslo Group, Marten conglomerate, and Slocan Group were thrust eastward over Keen Creek assemblage along the Stubbs thrust fault. The thrusting apparently occurred during the waning stages of second generation folding. Third generation folds are shallowly-plunging, broad folds with close and tight macroscopic and mesoscopic parasitic folds. The limbs of the broad folds are 500-2000⁺ m (1640-6562⁺ ft) in length. The third generation folds deform upright, west-dipping bedding and S_2 foliation into an overturned, east-dipping orientation. Third generation normal faults, that include the major Schroeder fault, parallel the regional structural trends and post-date the main pulse of third generation folding. These faults may be extension faults or steep reverse faults associated with the waning stages of third generation folding.

Fourth generation (F_4) folding may be part of the third deformational event or constitute a younger event. Fourth generation folds form two groups of mesoscopic folds with moderate to steeply plunging axes: 1) northwest-verging folds with northeast-trending axial surfaces and box

folds and 2) northeast-verging folds with southeast-trending axial surfaces.

The fourth generation folds and faults are associated with the northerly to northwesterly 50° bend in the regional structural trends near Milford Peak. Northeast-trending extensional faults in the bend area occur along the outer arc of the bend whereas fourth generation folds are present along the inner arc of the bend. The bend also coincides with a regional structural depression.

The young deformational event recognized in the Goat Range area resulted in north- to northwest-trending faults that have unindurated gouge zones. These faults have normal and/or right-lateral displacement and do not interrupt the general map pattern of the rock units. These faults are correlated with Eocene extensional faults recognized southwest of the Goat Range area (Parrish et al., 1985).

CORRELATION OF STRUCTURES OF THE GOAT RANGE

The four phases of folding in the Goat Range can be correlated with folds in the adjacent Poplar Creek (Read, 1973), Duncan Lake (Fyles, 1964), and Ainsworth (Fyles, 1967) map areas. The Riondel (Hoy, 1980) and Nemo Lakes (Parrish, 1981) areas are sufficiently well described to allow comparison with Goat Range structures also (Table XV). The key to resolving structural correlation problems in the Kootenay Arc is the distinction between the pre-Late Mississippian F1 folds and the post-Late Mississippian F2 folds. F2 folds are the first fold phase in the Milford Group and younger rocks and are characterized by the axial-planar regional foliation in these rocks. The most extensive fold phase that deforms this regional foliation is F3. F3 and F2 fold phases are difficult to

distinguish in Lardeau Group and older rocks as both phases deform the S1 foliation associated with F1 folding and locally obliterate it (Hoy, 1980, p. 48; Fyles, 1964, p. 43). In the Milford Group and younger rocks F2 and F3 phases are more easily defined. From application of the style and orientation of these phases to tectonic profiles of the Goat Range, Poplar Creek, and Duncan Lake areas a composite structural profile for the region can be constructed (Fig. 105). Major F1 folds with a common axial surface orientation in this scheme are named, from east to west: Howser syncline-Finkle creek syncline, Duncan anticline-Lake Creek anticline-Silvercup anticline, Saint Patrick syncline-Neil Creek synform, Meadow Creek Anticline-Riondel Nappe. Major F2 folds that have been named and are shown on the profile are, from east to west: Comb Mountain antiform, Glacier Creek synform, Kootenay Lake antiform-Stobbart Creek antiform. Several large folds present within the belt of Milford Group are second order to the major Kootenay Lake-Stobbart Creek antiform. These relationships are illustrated in figure 106.

The trace of the Stubbs thrust fault, which juxtaposes the McHardy assemblage, Kaslo Group, Marten conglomerate and Slocan Group against the Keen Creek and Davis assemblages of Milford Group, can be extrapolated north and south of the Goat Range area. In the northern part of the Goat Range area, the Stubbs thrust fault is apparently truncated at depth by the Schroeder-Spyglass fault. In the Poplar Creek area, north of the Goat Range area (Fig. 2), the trace of the Stubbs fault is interpreted to leave the Spyglass fault and is exposed along the western and northern margins of the Poplar Creek Stock, north of Cascade Mountain (see Read, 1973, Map 1277A) where it separates the Broadview Formation (Read's unit 9a) and

Goat Range	Poplar Creek (Read, 1973)	Duncan Lake (Fyles, 1964)	Ainsworth (Fyles, 1967)	Riodel (Hoy, 1980)	Nemo Lakes (Parrish, 1981)
F1	F1	F1	-	F1	-
F2	F2 and some F3	F2	F1	F2	F1
F3	F3 and some F4	F2	F2	F3?	F2
F4	F4	late folds	F3	-	-
F4'	some F3	?	F3	F3?	-

Table XV: Correlation of fold phases present in the Goat Range area with those described from nearby map-areas in the Kootenay Arc.

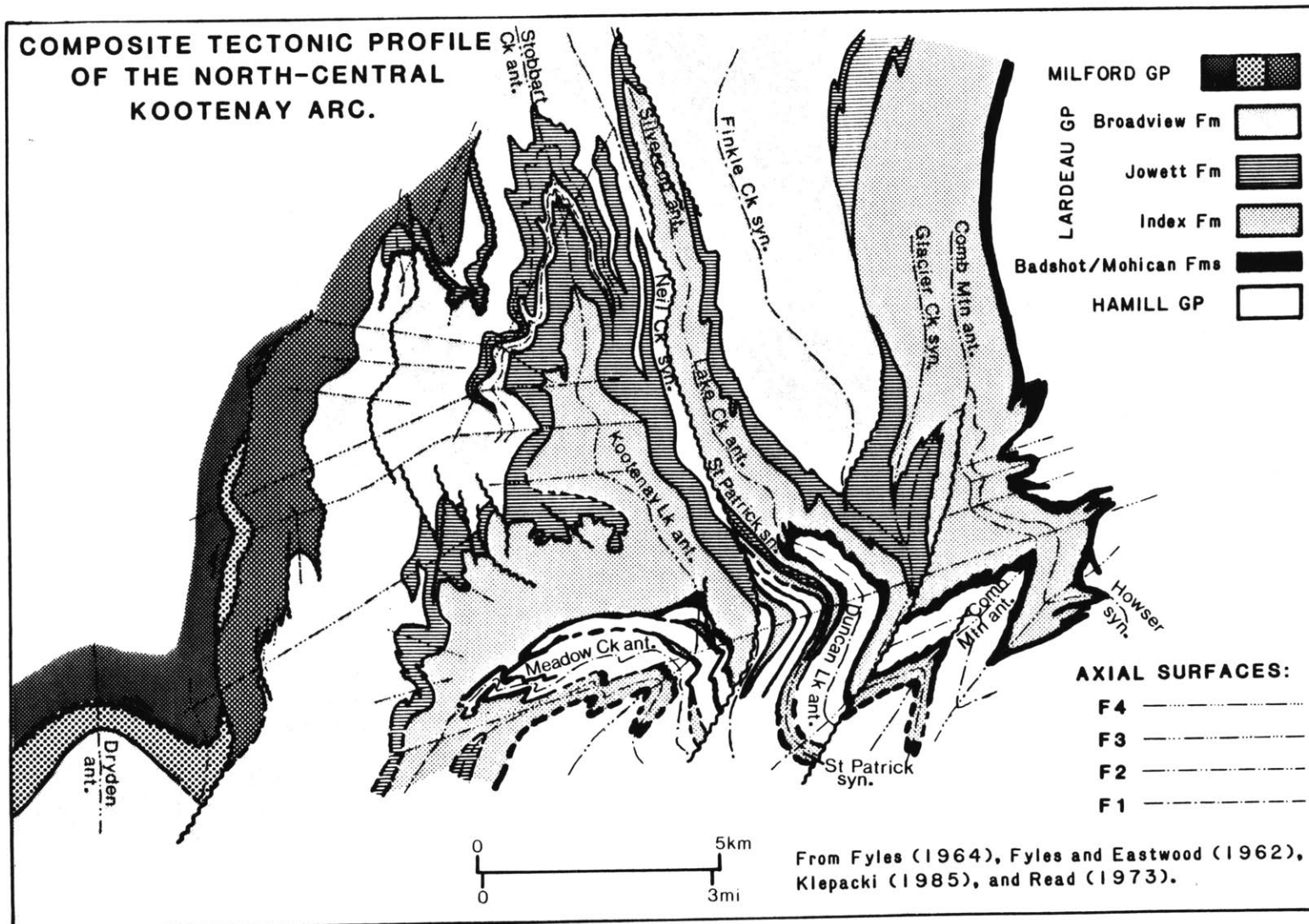


Figure 105: Composite tectonic profile of the north-central Kootenay Arc. The line of profile is located in the northern Goat Range and the north end of Kootenay Lake.

parts of the Milford Group from structurally higher parts of the Milford Group and the Kaslo and Slocan groups exposed along the eastern margin of the Kuskanax Batholith (Read and Wheeler, 1976). In the northwestern part of the Poplar Creek area, the Spyglass fault is interpreted to die out and the shallow-dipping fault mapped as the Spyglass fault directly east of Tenderfoot Lake (Read, 1973) is reinterpreted as the Stubbs thrust fault. This fault is interpreted to continue north of the Mount Hadow Stock where it separates units mapped by Read and Wheeler (1976) as undivided Lardeau Group to the west from Milford Group to the east. If the undivided Lardeau Group there is correlated with metasandstone, metavolcanic rocks and limestone of the McHardy assemblage instead of the Lardeau Group, then the structural sequence identified in the Goat Range area is preserved and the original correlation of these rocks (Read and Wheeler, 1975) is reinstated. Following this interpretation, the conglomerate reported west of Trout Lake City (Read, 1976, p. 95) can be correlated with the Cooper conglomerate and the Stubbs thrust fault can be inferred to lie along the eastern margin of the conglomerate and continue northwest, along Beaton Creek. The Stubbs thrust fault is interpreted to continue northwest of the northeast arm of Upper Arrow Lake and turn abruptly southwest down Crawford Creek. In the Crawford Creek valley serpentinite and talc schist mark the fault trace (Bancroft, 1921, p. 111-112A). These ultramafic rocks are interpreted as a sliver of the oceanic basement of the McHardy assemblage.

The Stubbs thrust fault is inferred to be truncated at depth by the Schroeder fault in the Goat Range area south of the McKian Creek Stock (Fig. 5) and in the northern part of the Ainsworth area (Fig. 2; Fyles, 1967). In the central part of the Ainsworth area unpublished

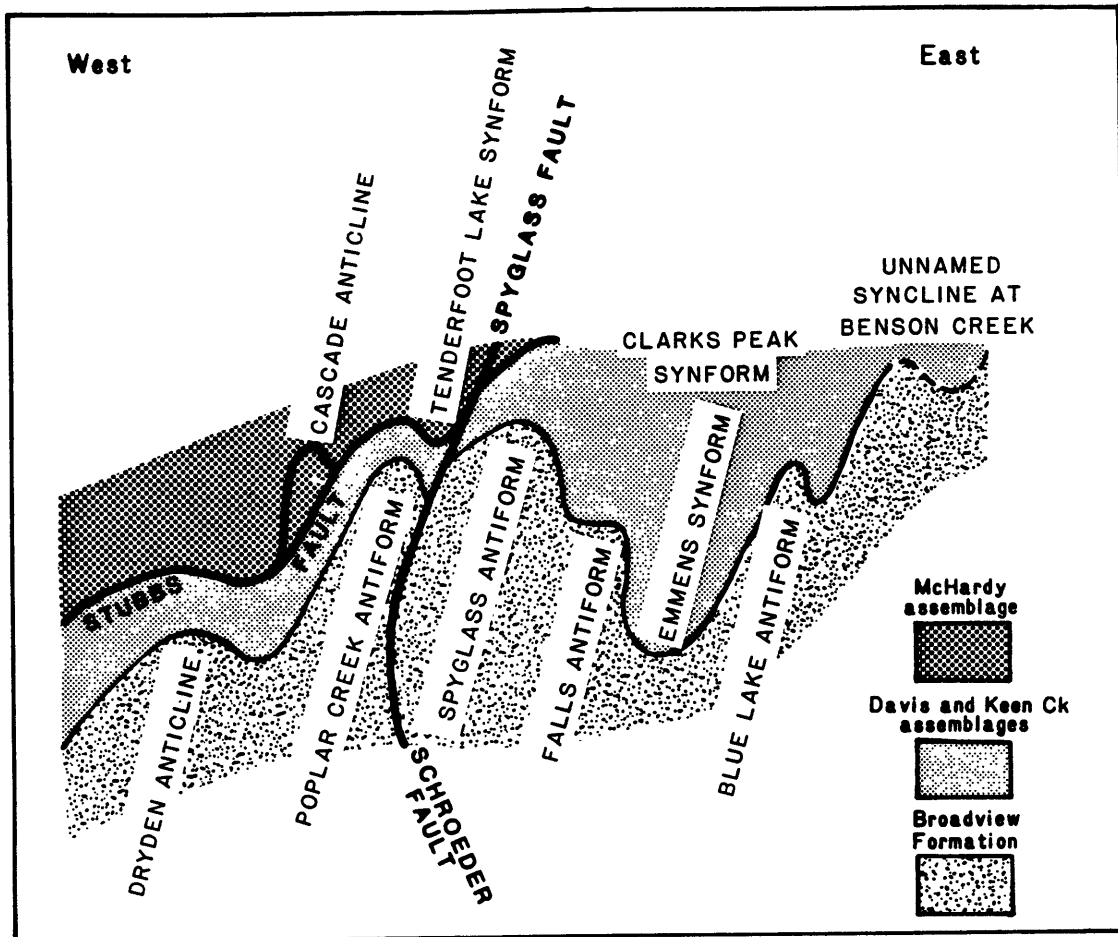


Figure 106: Schematic profile of folds along the Milford Group - Broadview Formation contact in the northern Goat Range and Poplar Creek areas. Structures from the Poplar Creek area are interpreted from geologic maps and sections of Read (1973).

reconnaissance work (Klepacki and Fyles, 1983) indicates the thrust fault may emerge from the Josephine fault trace near Fletcher Creek and continue south, through Loon Lake (Fyles, 1967, his Fig. 3). West of Loon Lake the Milford Group contains micaceous quartzites and hornblende schists that may be equivalents of siliceous argillite and diorite bodies characteristic of the McHardy assemblage in the Goat Range area.

If the Slocan Group is considered allocthonous because it is an element of the Stubbs thrust sheet then the Stubbs thrust fault can be inferred to continue along the eastern margin of the Slocan and correlative Rossland groups into the southern Kootenay Arc. The thrust trace probably lies within rock units correlated with the Milford Group (e.g., Leclair, 1983) and may connect with the Waneta fault near the United States border (Little, 1960).

CHAPTER 6. METAMORPHISM

MINERAL ASSEMBLAGES

Metamorphic minerals in the Goat Range area (Table XVI) are characteristic of the biotite zone of the greenschist facies and oligoclase-almandine garnet zone of the lower amphibolite facies (Turner, 1981, p. 360). Most of the study area lies in the biotite zone of the greenschist facies (Fig. 107). The biotite zone includes the assemblage quartz-white mica-chlorite-albite-epidote (Table XVI, assemblage 2), characteristic of the chlorite zone. However, biotite-bearing assemblages occur within close proximity, locally within the same outcrop as assemblage 2, indicating biotite-absent assemblages are probably the result of local compositional variation. Mafic igneous rocks of the Kaslo Group, Milford Group and diorite intrusives in the biotite zone commonly contain two clinoamphiboles; an optically negative amphibole with γ pleochroism deep green to olive green, and an optically positive, nearly colourless amphibole with γ =pale green, identified as cummingtonite. Cummingtonite needles occur on the margins of actinolitic hornblende prisms and have indistinct grain boundaries with the main mass of actinolitic hornblende. Immiscibility gaps between hornblende and cummingtonite, actinolite and hornblende, and actinolite and cummingtonite have reported elsewhere (Klein, 1969; Oba, 1980; Cameron, 1975; Ross et al., 1969). It is likely that detailed examination of the amphibole mineralogy in greenstones of the Goat Range will reveal three phases of clinoamphibole.

The oligoclase zone is defined by the absence of albite plagioclase and presence of a single plagioclase feldspar phase with an oligoclase composition (anorthite component 10-30 percent; Crawford, 1966; Grapes and Otsuki, 1983). At temperatures lower than those attained in the oligoclase

Composition	Biotite Zone	Oligoclase-Garnet Zone
Pelitic	1) White mica-quartz-chlorite-biotite-albite-epidote±carbonate	8) White mica-quartz-biotite-garnet-oligoclase±chlorite
	2) Quartz-white mica-chlorite-albite-epidote	
	3) White mica-quartz-biotite-chlorite-andalusite-graphite-albite	
	4) Quartz-chlorite-white mica-chloritoid-albite	
Carbonate	5) Carbonate mineral-quartz-white mica±chlorite±albite±epidote	9) Carbonate mineral-tremolite±quartz carbonate-quartz-tremolite-clinozoisite±oligoclase
		10) Carbonate mineral-quartz-actinolite-phlogopite-epidote-oligoclase
		11) Carbonate mineral-quartz-oligoclase-zoisite-microcline-actinolite-biotite-diopside-sphene
Mafic	6) Actinolite hornblende-cummingtonite-chlorite-albite-epidote±clinozoisite±stilpnomelane	12) Hornblende-oligoclase-biotite-chlorite-quartz-epidote
Ultramafic	7) Talc-serpentine-carbonate±quartz	13) Talc-anthophyllite
		14) Talc-serpentine±olivine±carbonate

Table XVI: Metamorphic mineral assemblages found in the Goat Range area. Mineral components of the assemblages are in mutual contact, with smooth grain boundaries. Albite plagioclase contains less than 7 percent anorthite component, oligoclase contains between 20 and 34 percent anorthite.

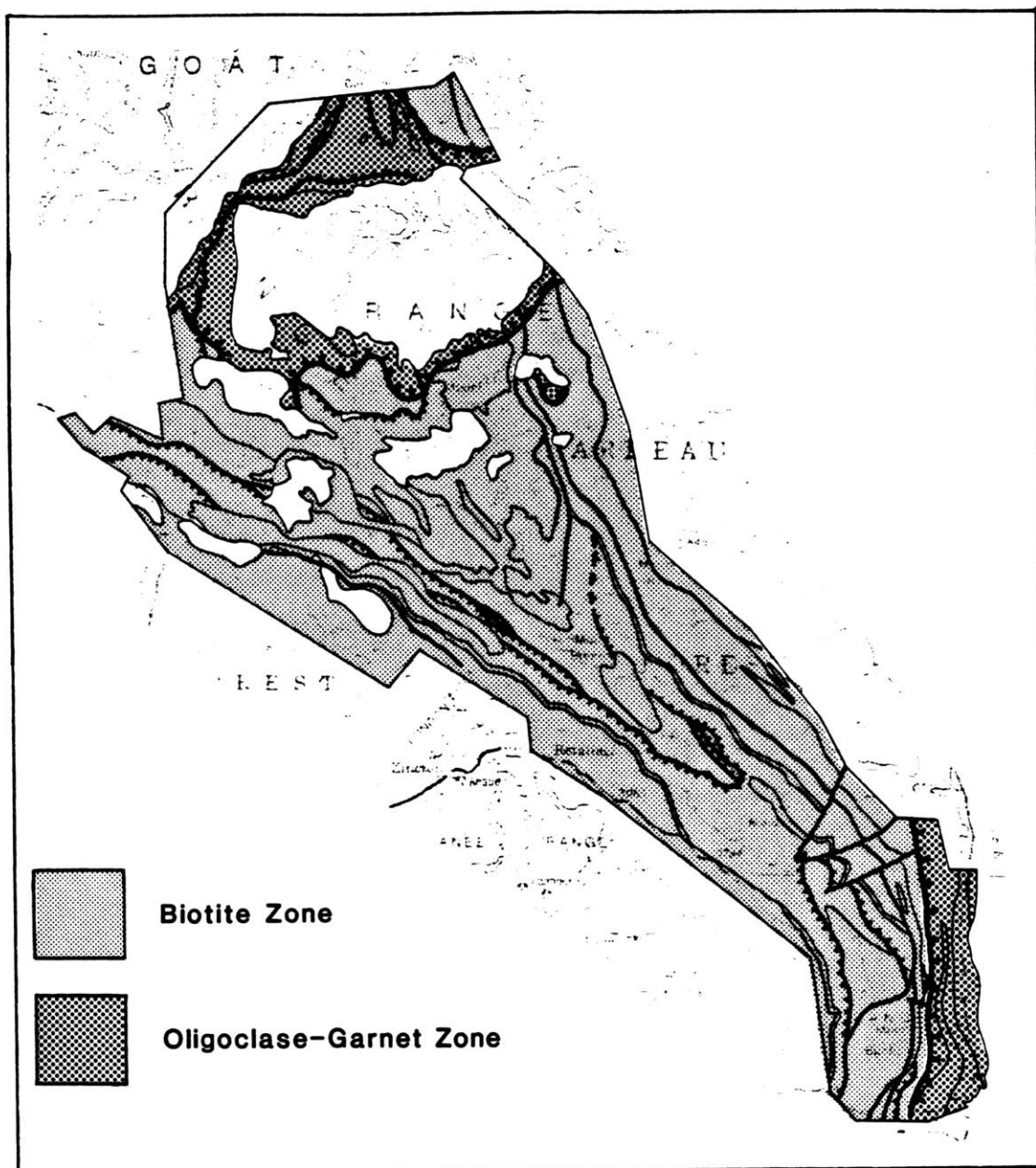


Figure 107: Distribution of metamorphic zones in the Goat Range area. Delineation of the metamorphic zones has been determined from petrographic examination of samples from 114 widely distributed localities.

zone and above the single feldspar (albite) field, a two-feldspar, albite+oligoclase field occurs which defines the plagioclase peristerite solvus. The first appearance of oligoclase is thought to result from reactions involving the breakdown of clinozoisite and possibly sphene. In the Goat Range, the oligoclase zone contains oligoclase with compositions (determined optically) of An₂₀-An₃₄. Plagioclase in rocks of the biotite zone is commonly An₀-An₇ with a typical composition of An₅. Anomalous compositions were found in three localities and probably represent conditions within the peristerite solvus, which is apparently poorly represented in the Goat Range area. Two of these samples (An₉ and An₂₃) fall within the biotite zone and one sample (An₅) falls within the oligoclase-garnet zone. The first appearance of garnet in pelitic rocks closely follows the first appearance of oligoclase, however the scarcity of pelitic compositions in the mapped area makes the first appearance of oligoclase a more easily mapped metamorphic indicator than the first appearance of garnet. Where garnet-bearing pelitic rocks are present, garnet occurs in association with biotite and with chlorite (especially near the biotite zone). Chlorite is absent from white mica-quartz-biotite-oligoclase±garnet assemblages in schist and gneiss found at an elevation less than 1067 m (3500 ft) on the east slope of the southern Blue Ridge. Carbonate rocks in the oligoclase-garnet zone commonly contain tremolite or actinolite. Mafic igneous rocks apparently contain a single dark-green to brown clinoamphibole, identified as hornblende. Anthophyllite occurs in ultramafic rocks in the oligoclase-garnet zone on southeast margin of the Kuskanax Batholith.

Metamorphic grade apparently increases from the crest of the Blue Ridge to the shore of Kootenay Lake. Fyles (1967, pp. 21-22 and Figure 3)

reports staurolite in the Lardeau Group just south of Kaslo and kyanite along the west shore of Kootenay Lake north of Kaslo. Pegmatite and aplite veins and segregations occur in rocks below 2600 ft elevation on the west shore, indicating local conditions near the granite solidus.

TIMING OF METAMORPHISM

Microscopic textures indicate four episodes of mineral growth in the rocks of the Goat Range. The first stage of mineral growth occurred during the development of F_1 folds during the first deformational event and consisted of the growth of micas along S_1 foliation. Two fabrics are present in thin section in Lardeau Group and older rocks. Adjacent to the unconformity at the base of the Milford Group it is clear that the earlier of these fabrics is S_1 and the later is S_2 . Within the oligoclase-garnet zone east of the Blue Ridge, rocks of the Lardeau Group contain porphyroblasts formed with S_1 (Fig. 108). If porphyroblast growth in Lardeau Group and older rocks is associated with F_1 (an early Paleozoic event) then a metamorphic break should occur at the unconformity with Milford Group. Although quartz±feldspar veins are restricted to Lardeau Group, no difference in metamorphic grade was recognized from thin section study of adjacent samples of Milford and Lardeau groups. Two hypotheses can be proposed for the development of metamorphic fabrics east of the Blue Ridge:

- 1) The earlier fabric is S_1 and porphyroblasts, mainly garnet, developed during this event (F_1). The later fabric, characterized by aligned quartz and moderately crenulated micas is S_2 .

- 2) S_1 is obliterated and the earlier fabric and porphyroblast growth are associated with F_2 and the later fabric is S_3 , associated with F_3 .

The age of porphyroblast growth in Lardeau Group is

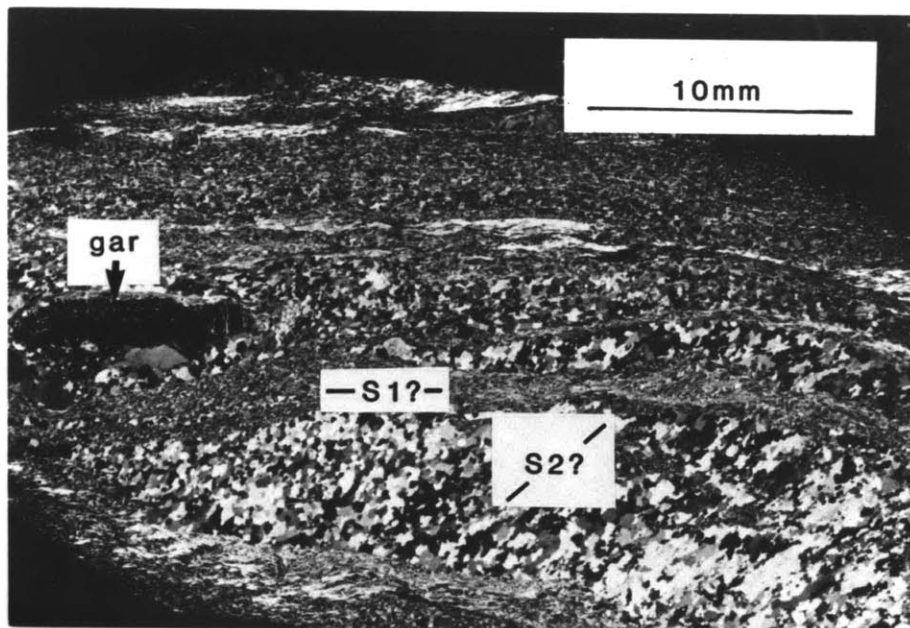


Figure 108: Photomicrograph of Broadview Formation schist from the oligoclase-garnet zone. Note the elongate garnet with an internal fabric parallel to $S_1(?)$ and a later crenulation cleavage in the matrix ($S_2?$). See text (Timing of metamorphism) for a discussion on relative fabric ages. Photo is taken with crossed nicols.

uncertain in the Goat Range area although metamorphism of lower Paleozoic rocks in the southern Kootenay Arc appears to be of Mesozoic age based on isotopic age determinations (Archibald et al., 1983).

The second episode of metamorphic mineral growth occurred the third deformational event in association with F_2 folds. This episode is the first regional metamorphic event recognized in rocks of the Milford, Kaslo and Slocan groups, Marten conglomerate and diorite plutons. The S_2 foliation is the dominant fabric element developed during this event and formed largely by solution transfer processes (Figs. 84,85). This foliation is overprinted by porphyroblasts that grew during the third episode of metamorphic mineral growth (Fig. 109). Porphyroblasts are best developed near the margins of granitic stocks (Fig. 110). The distribution rocks within the oligoclase-garnet zone closely follows the margins of the the McKian Creek Stock and Kuskanax Batholith. This relationship suggests that the Middle Jurassic intrusive activity accompanied the highest grade metamorphic conditions in the Goat Range area. Porphyroblasts are rotated and extended along S_4 foliation surfaces that are locally developed and have no associated mineral growth.

The fourth episode of metamorphism is characterized by the partial to complete alteration of porphyroblasts to randomly oriented grains of muscovite and chlorite. The absolute age of this event is unknown.

CONDITIONS OF METAMORPHISM

An estimate of the pressure-temperature conditions of metamorphism can be made by comparing the observed mineral assemblages with stability fields of mineral assemblages determined from experimental, geothermometry, and geobarometry studies (Fig. 111). Conditions within the biotite zone are constrained by the lower stability limit of talc and the upper stability limit of antigorite serpentine. Andalusite porphyroblasts are locally

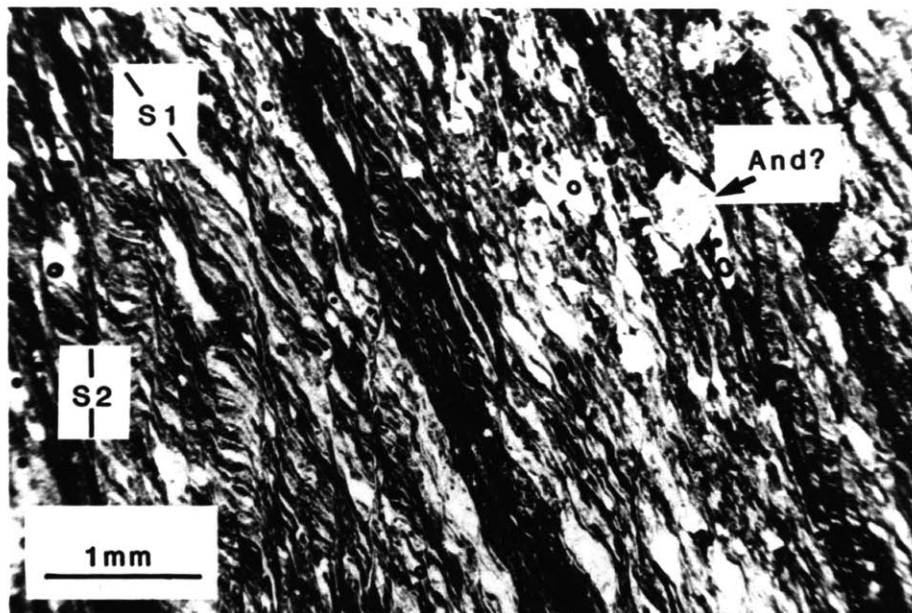


Figure 109: Photomicrograph of Broadview Formation phyllite, adjacent to the unconformity with Milford Group, showing S_1 foliation and S_2 crenulation cleavage overprinted by andalusite(?) porphyroblasts of the third phase of metamorphism.

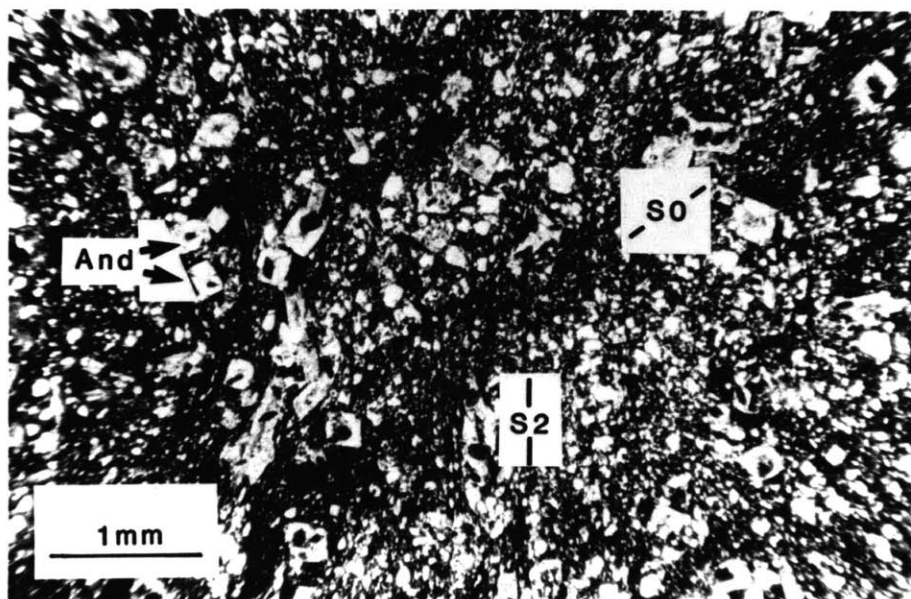


Figure 110: Andalusite porphyroblasts in Slocan Group phyllite along the margin of the Martin Creek Stock. Note that the porphyroblasts overgrow the pressure solution fabric (S_2).

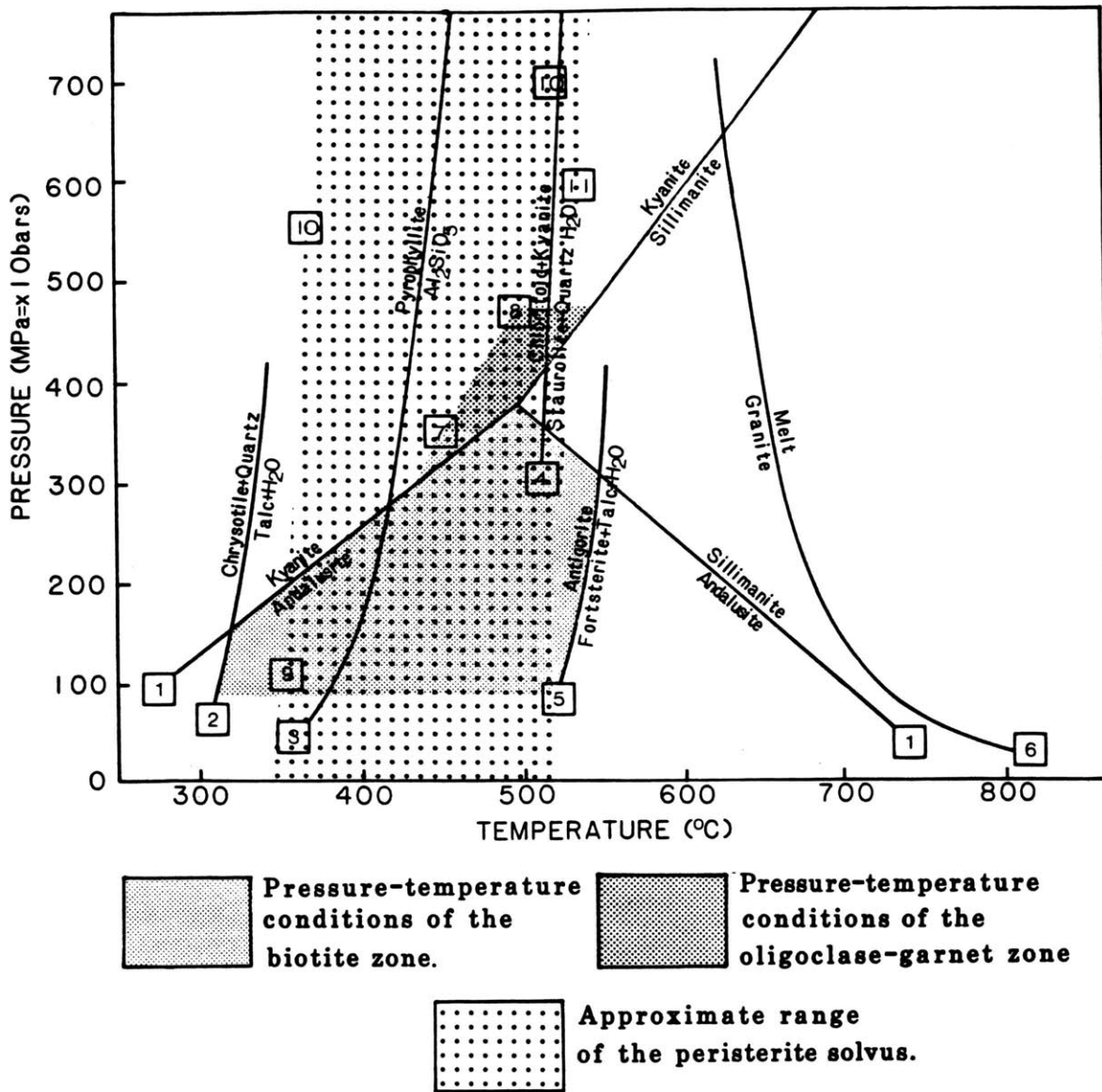


Figure 111: Approximate pressure-temperature conditions for the biotite and oligoclase-garnet metamorphic zones in the Goat Range area. Mineral assemblage data are from (numbers correspond to reaction numbered above): 1) Holdaway, 1971. 2) Johannes, 1969. 3) Kerrick, 1968. 4) Ganguly, 1972. 5) Evans et al., 1976. 6) Luth et al., 1964. "Garnet-in" P-T conditions are from: 7) Ferry, 1980; 8) O'Neil and Ghent, 1975. Boundary conditions of the Peristerite field are from: 9) Nord et al., 1978; 10) Grapes and Otsuki, 1983; 11) Crawford, 1966.

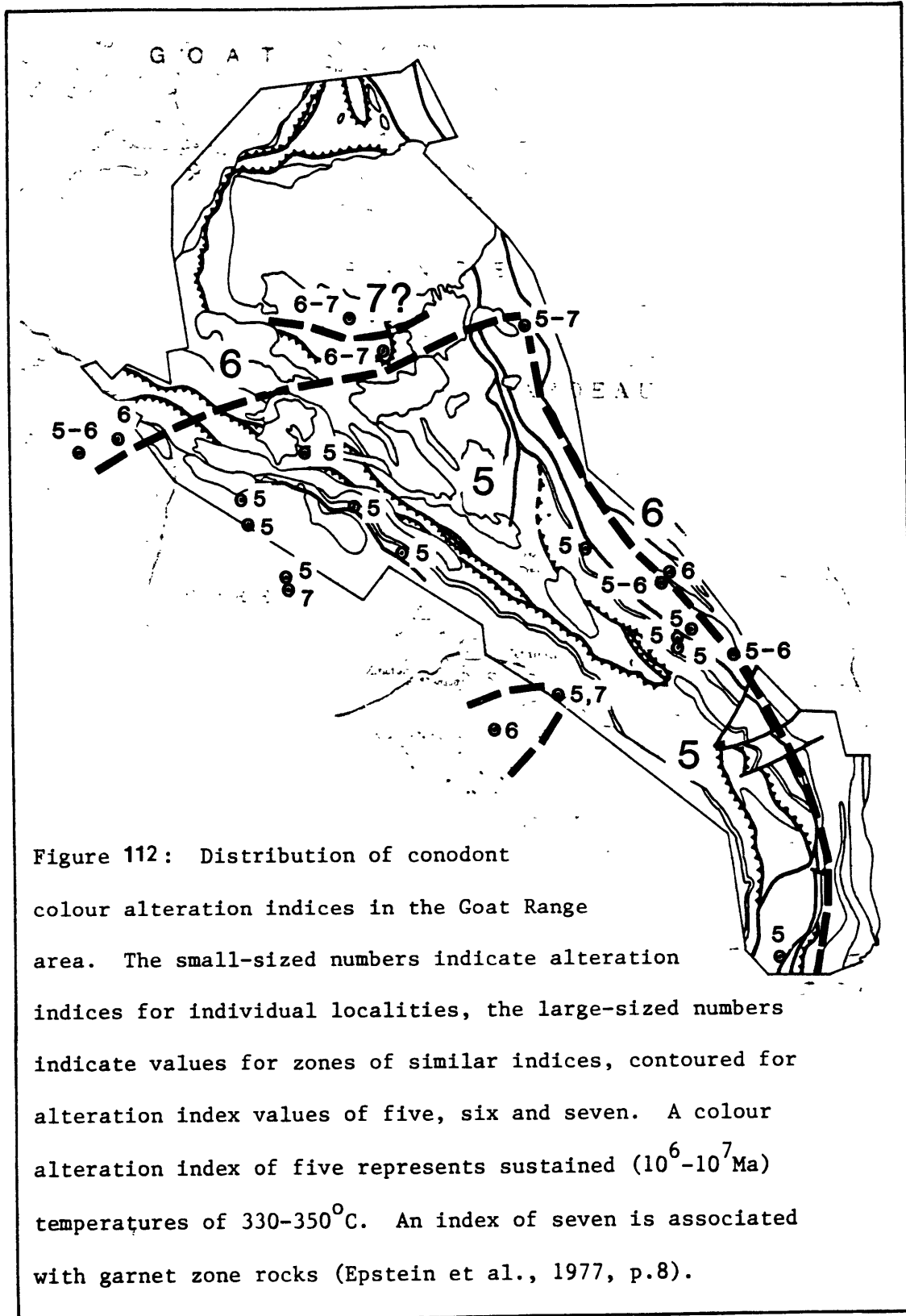
developed (Figs. 109,110) and provide an additional constraint on conditions within the biotite zone. However, white mica is present in many localities areas and may include pyrophyllite, and the occurrence of andalusite may be restricted to local thermal anomalies. With these considerations metamorphic conditions in the biotite zone are estimated to range in temperature from 320°C to 540°C and up to 3.5 kb (350 MPa) pressure.

The metamorphic conditions present in the oligoclase-garnet zone are poorly constrained. The stability field of oligoclase plagioclase and the peristerite solvus over a range of pressures is poorly known. Nord et al. (1978) report subsolvus unmixing at about 350°C and 1 kb (100 MPa). Grapes and Otsuki (1983) estimated the first appearance of oligoclase to have occurred at about 370°C and 5.5 kb (550 MPa), and the closure of the solvus (the oligoclase isograd) at 510°C and 7 kb (700 MPa). Crawford (1966) estimated conditions for the oligoclase isograd at 550°C. The coincidence of the first appearance of oligoclase and garnet requires that either the stability field of garnet is expanded to lower temperatures relative to other metamorphic belts, or that the field of epidote is expanded, pushing oligoclase-producing reactions to higher temperatures.

Several mineral reactions that produce garnet are reported and involve chlorite, chloritoid, muscovite and quartz (Karabinos, 1985; Thompson, 1976, pp. 406-407). Plagioclase may also be involved (Crawford, 1966). These reactions are complex and experimental data (e.g. Hsu, 1968) yield unnaturally high temperatures. Several studies using geothermometry and geobarometry from exchange reactions and stable isotope fractionation approximately place the garnet isograd. Ferry (1980) reports the first occurrence of garnet at about 440°C at 3.5 kb (350 MPa). O'Neil and Ghent

(1975) report the first occurrence of garnet at about 460°C and 4.5 kb (450 MPa), and Hodges and Spear (1982) report the presence of garnet near the aluminosilicate triple point (550°C, 3.5 kb, 350 MPa; Holdaway, 1971). These relationships suggest conditions of metamorphism in the oligoclase-garnet zone are at least 460°C and 3.5 kb (350 MPa). In the Poplar Creek area and northern part of the Goat Range area, Read (1973, pp. 80-81) reports the presence of staurolite, indicating conditions there of at least 4 kb (400 MPa) and 515°C.

The thermal conditions of metamorphism are also indicated by the alteration colour of conodonts recovered from the Goat Range area (Epstein et al., 1977). Conodonts in the Goat Range have color alteration indices (CAI) of five to seven (Orchard, 1985). A CAI of five can be produced from heating for 1 million years at 350°C or 10 million years at 330°C. Shorter periods of time at higher temperatures can also produce a CAI of five, but the conodont alteration in the Goat Range is interpreted to be a result of regional metamorphism that apparently occurred on a time scale of 10^8 to 10^6 Ma (Archibald et al., 1983, 1984). The distribution of color alteration "isograds" generally follows the pattern of metamorphic mineral zones (Fig. 112). Mixed values from a single locality, for instance five and seven values from the Whitewater limestone southeast of Retallack, can be attributed to local thermal aberrations such as dykes or, in the case of the Whitewater limestone, hot spring alteration. Epstein et al. (op. cit.) noted that conodonts with a CAI of six may be produced by a narrow temperature range transitional from CAI five to CAI seven. CAI seven conodonts are found in garnet zone rocks (Epstein et al., 1977, p. 8).



CHAPTER 7. SUMMARY OF THE TECTONIC HISTORY OF THE GOAT RANGE

The age of the rocks present in the Goat Range represents a small part (about 200 Ma) of Phanerozoic time. Regional deformation occurred during at least four episodes in the Phanerozoic and left complex deformational features within the rocks. A tectonic history constructed for the Goat Range is necessarily incomplete because of the incomplete rock record and the imperfect analysis of data from that record.

The Hamill Group and Badshot-Mohican formations probably represent quartz sand and carbonate rocks that transgressed eastward onto the Windermere High (Reesor, 1973, pp. 63-79), probably as the High subsided during early Paleozoic rifting along the western margin of North America (Bond and Kominz, 1984). Recent work in the Hamill Group has produced stratigraphic evidence for syndepositional rifting (Devlin and Bond, 1984). The overlying Lardeau Group consists of pelite, calcareous pelite, grit, volcanic and carbonate rocks that are interpreted to have been deposited during continued rifting and subsidence in Cambro-Ordovician time. The volcanic rocks of the Jowett Formation can be interpreted to be the product of tholeiitic volcanism associated with rifting and the grit of the Broadview Formation can be interpreted to be a graben fill deposit in this scenario. It is likely that the western source of clastic material in the Broadview Formation (Read, 1975) is the western margin of the rift basin or an intra-basinal horst. The Lardeau Group and older rocks were deformed into large, westward-closing folds and cut by possible eastward-directed thrust faults during early or middle Paleozoic time (Read and Wheeler, 1976; Okulitch, 1984, p. 1177). This is the first deformational event recognized in the Goat Range area and is associated with the oldest metamorphic fabric recognized in the pre-Mississippian rocks. The presence

of Ordovician granitic boulders in the Late Mississippian Cooper conglomerate and an Ordovician orthogenesis in the Monashee Complex (Okulitch, 1985, p. 1416) supports the interpretation of Okulitch (1984) of an Ordovician age for the deformation.

The three assemblages of Milford Group are of late Paleozoic age and are linked together by their relationship to the Lardeau Group. The eastern Davis and Keen assemblages rest with angular unconformity on the Lardeau Group and the western McHardy assemblage contains material derived from the Lardeau Group. Rifting that apparently began in Middle Devonian time and culminated in Mississippian time is documented in northern British Columbia (Mortensen, 1982; Gordey and Hills, 1985) and is interpreted to have formed basins in southern British Columbia in which the Milford Group was deposited (Fig. 113). The McHardy assemblage consisting of siliceous argillite, calcareous pelite, limestone, conglomerate and volcanic rocks is of Late Devonian to Early Mississippian age along the west shore of Upper Arrow Lakes (Figs. 2,6; Orchard, 1985, p. 292) and Late Mississippian to Early Permian age within the Goat Range area. The McHardy assemblage is interpreted to rest on oceanic basement created during late Paleozoic time based on low $^{87}\text{Sr}/^{86}\text{Sr}$ values for diorite that intrudes the assemblage and regional correlations where equivalent strata are underlain by serpentinite and ophiolite. The thick siliceous argillite member of the McHardy assemblage may record thermal subsidence of the oceanic crust. The Davis and Keen Creek assemblages are interpreted to have accumulated in half-grabens formed in extended Lardeau Group and older rocks.

The Davis assemblage is the easternmost assemblage of Milford Group and consists of pelite, arenite, limestone, cherty tuff, tholeiitic volcanic rocks and sparse conglomerate, all of Late Mississippian age.

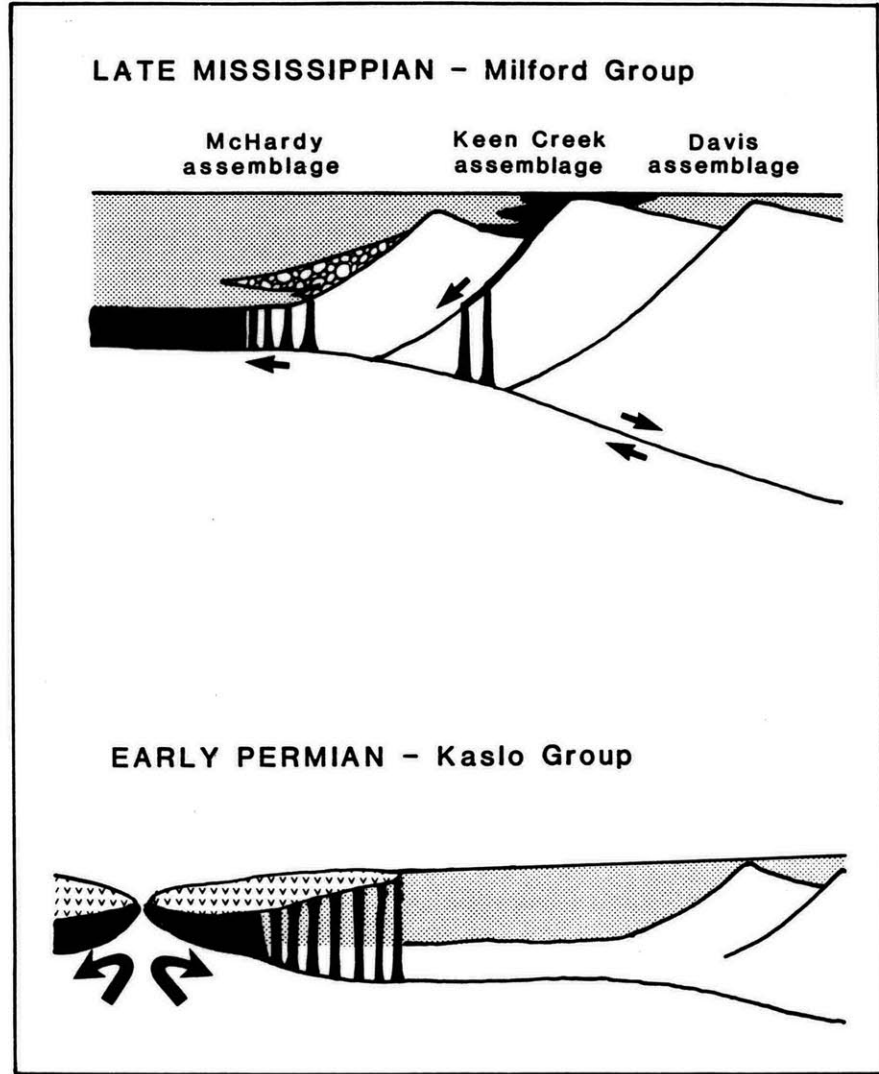


Figure 113: Extensional depositional models for the Milford and Kaslo groups.

The Keen Creek assemblage lies to the west of the Davis assemblage and is in fault contact with the Davis assemblage in the Goat Range area. In the northwestern Poplar area (Read, 1973), the Davis and Keen Creek assemblages appear to interfinger. Intraplate tholeiitic basalt of Late Mississippian age in the Keen Creek assemblage is interpreted to be equivalent to basalt near the top of the Davis assemblage and conglomerate containing volcanic clasts near the base of the siliceous argillite member of McHardy assemblage.

The Lardeau and Milford groups are assigned to the Kootenay terrane (Table XVII; Silberling and Jones, 1984), separated from adjacent North American rocks to the east on the basis of stratigraphic dissimilarity with coeval North American rocks and the presence of Paleozoic tectonism that is not recognized in the North American miogeocline. The boundary between the Kootenay terrane and North American rocks is interpreted to lie along an inferred fault contact between the Badshot and Index formations. The western boundary of the Kootenay terrane has been interpreted to be the upper contact of the Milford Group (Silberling and Jones, 1984). Work in the Goat Range indicates this terrane boundary is better located along the Stubbs thrust fault. This interpretation separates oceanic rocks to the west which include the McHardy assemblage of Milford Group, from rocks of the Kootenay terrane that have a more continental derivation. Therefore the Kootenay terrane contains the Davis and Keen Creek assemblages of Milford Group and the Slide Mountain assemblage of the Quesnellia terrane contains the McHardy assemblage of the Milford Group.

The Kootenay terrane is considered part of the North American continental margin, at least by Late Mississippian time. The stratigraphic

Table XVII: Stratigraphic and terrane correlations and interpreted tectonic settings of Goat Range Stratigraphy

Age	Goat Range Area	Lithologies	Correlative (coeval, laterally continuous) Units	Interpreted Tectonic Setting	Terranes
Upper Triassic	Slocan Group	Pelitic rocks, limestone, quartzite, volcanics at top	Nicola Group (Okulitch, 1974), Ymir Group (Little, 1960)	Back arc basin	Queensella
Permian	Marten Conglomerate	Calcareous greenstone conglomerate	Brooklyn Formation, Rawhide Formation (Little, 1983) Conglomerate at Dome Rock Mtn. (Okulitch, 1979)	Detritus shed after closure of Kaslo basin	Slide Mountain assemblage*
	Kaslo Group	Basalt, cherty sediments, wacke	Knob Hill Group (Little, 1983), Greenstone of the Anarchist Group (Little, 1961), Greenstone of the Chapperon Group (Read and Okulitch, 1977), Upper Fennell Formation (Schiarizza, 1983), Antler Formation (Struik, 1981). Old Tom Formation (Read and Okulitch, 1977)	Marginal rift basin (e.g. Andaman Sea)	
Carboniferous	McHardy Assemblage	Siliceous argillite, limestone, conglomerate volcanics	Mt. Roberts Fm. (Little, 1960, 1982), Lower Anarchist Group (Little, 1961), Lower Chapperon Group (Read and Okulitch, 1977), Tenas Mary Creek sequence (Parker and Galkins, 1964), Attwood Formation (Little, 1983), Bradshaw, Independence Shoemaker Formations (Bostock, 1941; Read and Okulitch, 1977), Kobau Group (Little, 1961) Lower Fennell Formation (Schiarizza, 1983)	Western strata of a marginal transitional (?) rift basin, deposited on Devono-Mississippian oceanic crust	
	Davis and Keen Creek assemblages	Pelite, limestone, sandstone, volcanics, conglomerate	Grass Mountain, Pend O'reille, Flagstaff Mountain Sequences (Yates, 1964, 1971), Eagle Bay Formation (Schiarizza et al., 1984), Greenberry and Alex Allen formations (Orchard and Stuik, 1985)	Successor basin strata deposited on folded then rifted (attenuated) continental crust	Kootenay
Cambro-Ordovician	Lardeau Group	Pelite, grit, volcanics, limestone	Emerald Member of the Laib Formation; Nelway Formation, Active Formation, Maitlen Phyllite, Metaline Limestone, Ledbetter State (Little, 1960), Covada Group of Snook et al. (1981)	Rift assemblage on distal margin of N. American miogeocline	

*The term assemblage is used here instead of terrane because of the stratigraphic, not structural, contact between Slocan Group and underlying units

dissimilarity of Lardeau Group with miogeoclinal rocks of the North American shelf sequence can be attributed to rapid facies changes along a rifted continental margin. If the Kootenay terrane (Lardeau Group) does contain elements that are allochthonous with respect to North America (Hamill Group and Badshot Formation) these elements were incorporated into the North American margin during the pre-Milford compressional deformation. This is indicated by the presence of the S_1 cleavage and F_1 folds in the Lardeau Group, Badshot Formation and Hamill Group (Fig. 105) and absence of these features in the unconformably overlying Milford Group (Davis and Keen Creek assemblages).

The Kaslo Group of Permian and (?) carboniferous age consists of two sequences separated by the Whitewater thrust fault. Both sequences are composed of tholeiitic basalt of oceanic ridge affinity, cherty tuff, greywacke and conglomerate. The lower sequence has a gradational contact with the underlying McHardy assemblage and the upper sequence is floored by ultramafic rock interpreted to be oceanic crust. Intrusive stocks, dykes and sills of the Permian and (?) Carboniferous Kane Creek Diorite fed the volcanic rocks of the lower sequence. The upper sequence was thrust onto the lower sequence and partly onto the McHardy assemblage along the Whitewater fault. The fault generally detached within ultramafic rocks and contains horses and duplex structure typical of fold and thrust belts. The McHardy assemblage, Kaslo Group and Whitewater fault are intruded by the Whitewater Diorite. The Kaslo Group and Whitewater Diorite are unconformably overlain by the Marten conglomerate that consists of greenstone conglomerate, commonly with a green phyllite or calcareous matrix. The age of the thrust faulting, the Whitewater Diorite and the Marten conglomerate are constrained by the youngest strata of the Kaslo

Group which are middle Permian in age, and the oldest strata of the unconformably overlying Slocan Group which are Early Late Triassic in age. This Late Permian to Middle Triassic compressional deformation and dioritic magmatism is the second deformational event recognized in the Goat Range area. It is named the Whitewater event from exposure of its various tectonic elements near Whitewater Mountain. Since the Lardeau Group and older rocks are basement for the late Paleozoic strata east of the Goat Range and no indication of a late Paleozoic oceanic basin exists there, it is likely that the oceanic sequence present in the hanging wall of the Whitewater fault was thrust from the west.

The Whitewater event may be part of a widespread Late Permian to Early Triassic compressional deformation that affected central and southeastern British Columbia. Read and Okulitch (1977) described extensive pre-Upper Triassic deformation in southern British Columbia. Jones (1959, p. 29) reported a slight angular unconformity at Dome Mountain, west of Okanagan Valley, of Permian or older age. In northern British Columbia, Harms (1985) reported a Late Permian zircon age for a tonalite that intrudes thrust faults within the late Paleozoic oceanic Sylvester allochthon. This setting is very similar to relations in the Goat Range area where the Whitewater diorite intrudes the Whitewater fault.

The Kaslo Group is interpreted to have been deposited within a Permian back-arc rift basin (Fig. 113), similar in tectonic setting to the present day Andaman Sea. This basin was closed by thrust faulting during the Late Permian to Middle Triassic Whitewater event. The tectonically thickened units provided a source for detritus in the Marten conglomerate.

The Upper Triassic Slocan Group consists of grey metapelite, limestone and quartzite and unconformably overlies the Marten conglomerate and Kaslo

Group. The Marten conglomerate is locally missing along the unconformity. Limestone and dolomite abundant in the eastern part of the Slocan Group and quartzite and arenite that contains detrital muscovite and rare perthite are abundant in the western part. This suggests a western source for the quartzite and arenite that included plutonic or metamorphic rocks. The Slocan Group is interpreted to have been deposited in the eastern part of a back-arc basin behind the Nicola volcanic arc near Okanagan Lake (Monger and Price, 1979, p. 780).

The Kaslo Group is assigned to the upper volcanic part of the Slide Mountain terrane (Monger and Berg, 1984). The McHardy assemblage is part of the Milford Group that is assigned to the Kootenay terrane. However the McHardy assemblage is better correlated with the lower sedimentary part of the Slide Mountain terrane because it stratigraphically underlies Kaslo Group and is separated from the rest of the Milford Group by the Stubbs thrust fault. Boulders derived from the Lardeau Group of Kootenay terrane are present in Slide Mountain terrane (Cooper conglomerate of McHardy assemblage) and provide a provenance link between the two terranes. Therefore, the Slide Mountain terrane accumulated adjacent to the late Paleozoic North American continental margin. The Kaslo Group is separated in two parts by the Whitewater thrust fault, but the similarity of volcanic and sedimentary rocks in the upper and lower plates of the thrust fault is also interpreted as a provenance link, thus they are not considered to be separate terranes.

The Slocan Group is a characteristic unit of the eastern part of Quesnellia terrane (Monger and Berg, 1984). In central British Columbia, where the Quesnellia terrane was first identified, it has been thrust onto the Slide Mountain terrane along the Eureka thrust fault. In the Goat

Range area, however, the Slocan Group rests unconformably on the Marten conglomerate and Kaslo Group of Slide Mountain terrane. Terranes are defined as fault-bounded entities (Howell and Jones, 1983, p. 6) so some revision in terminology that incorporates the stratigraphic continuity between units of the Slide Mountain and Quesnellia terranes is necessary. The name Slide Mountain assemblage of Quesnellia terrane is proposed to maintain a consistent definition for terranes.

The most intense deformation that occurred in the Goat Range area was the third deformational event which occurred in the initial Middle Jurassic part of the Columbian Orogeny. The Columbian Orogeny is interpreted to have begun after the deposition of the Early Toarcian, upper part of the Hall Formation present about 190 km (118 mi) south of the Goat Range (Tipper, 1984; Parrish and Wheeler, 1983). The third deformational event formed the F_2 and F_3 folds and the associated faults. Eastward-vergent folds formed before and during eastward movement along the Stubbs thrust fault. F_2 folds include the major Dryden anticline that is present along most of the length of the study area. The regional foliation, S_2 , formed at this time as an axial-planar cleavage to F_2 folds by pressure solution and metamorphic recrystallization. Monzonite to quartz monzonite of the foliated Kaslo River Intrusive Rocks was intruded during F_2 folding. During this event, the Stubbs thrust fault placed the McHardy assemblage, Kaslo Group, diorite plutons, Marten conglomerate and Slocan Group in its hanging wall over Keen Creek assemblage and Broadview Formation.

Westward vergent, commonly open F_3 folds formed synkinematically with steeply dipping faults that have an apparent normal displacement; these faults, however, may be locally overturned reverse faults. The Schroeder-Spyglass fault is the major fault of this type. It separates the

Davis assemblage of Milford Group and Lardeau Group to the east from the Lardeau Group and Keen Creek assemblage, and rocks of the Stubbs thrust sheet, to the west. The faults were intruded by aegerine-bearing granite and leucogranite of the Kuskanax Intrusive Rocks emplaced at 180 ± 7 Ma. Locally these intrusive rocks were foliated and folded by F_3 folds. The locally foliated Blue Ridge Intrusive Rocks were intruded contemporaneously with the Kuskanax Intrusive Rocks, but dykes that belong to this suite were not folded. F_3 folds predate much of the intrusive activity but also formed during the first stages of intrusion, thus they are in part Early Middle Jurassic in age.

A simple kinematic model relates F_2 and F_3 folds to thrust faults during the beginning of the Columbian Orogeny (Fig. 114). The F_2 folds are interpreted to have resulted from eastward-directed shear associated with an eastward-vergent thrust system that included the Stubbs thrust fault. Deeper and younger faults in this system, perhaps the East and West Bernard faults east of Kootenay Lake (Hoy, 1980), may have carried the Goat Range rocks over a buried thrust ramp west of the present Goat Range. As strata moved through the fault bend at the base of the ramp, west-vergent F_3 folds and reverse faults (e.g. the Schroeder fault) may have formed in response to stress concentration there (Berger and Johnson, 1982). The folds and reverse faults would then be carried to higher structural levels as displacement up the ramp continued. Rotation of originally east-dipping F_3 axial surfaces into their present west-dipping orientation can be interpreted to have resulted from structurally deeper thrust imbrication east of and under the ramp during the formation of an antiformal stack (Boyer and Elliot, p. 1211). Further westward rotation may have occurred

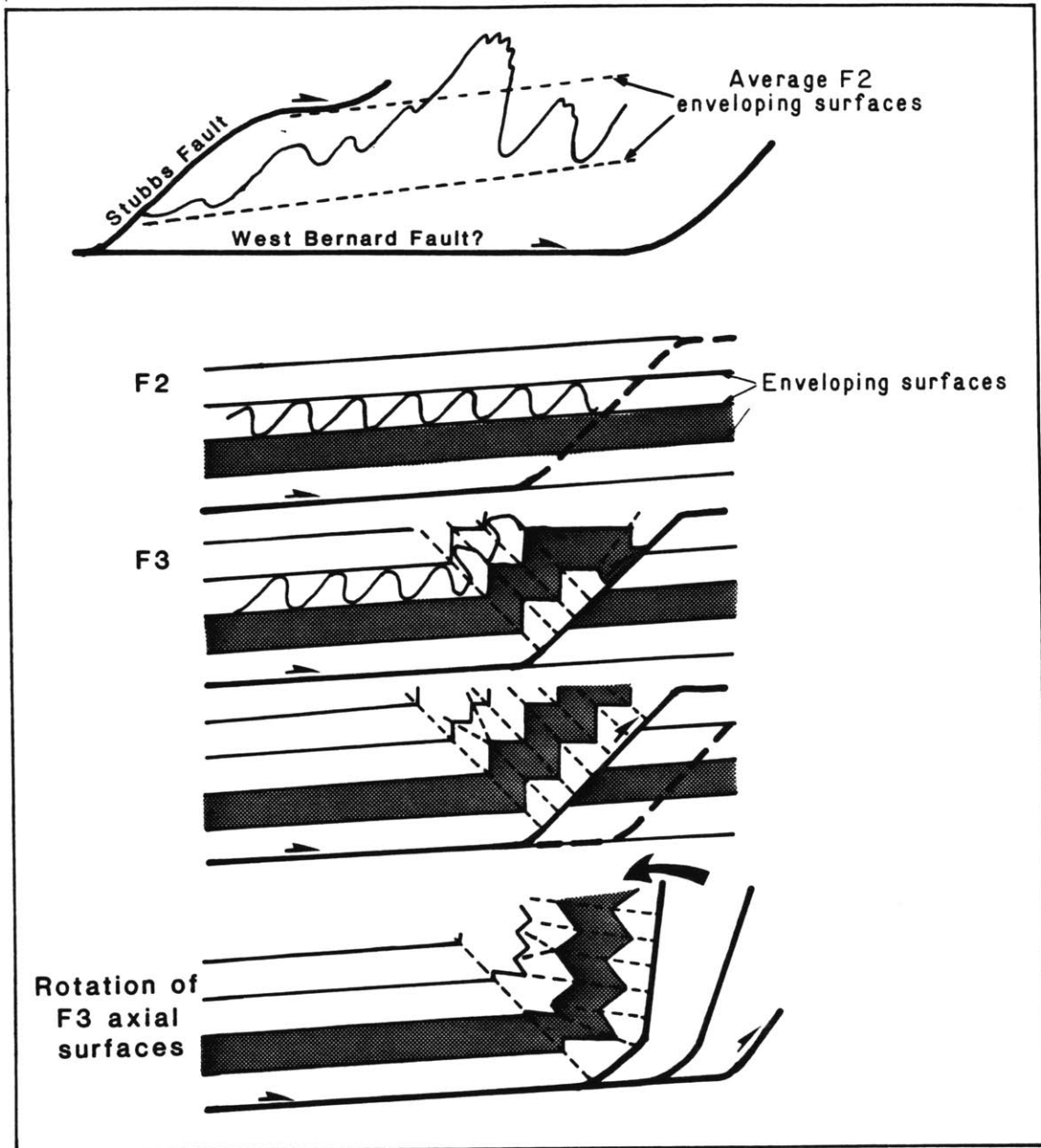


Figure 114: Kinematic model for the development of F2 and F3 folds. The upper diagram depicts the F2 fold and thrust geometry in the north-central Kootenay Arc. The lower four diagrams schematically present the development of F3 folds from "back folding" at the base of a thrust ramp.

in Late Cretaceous and Paleocene time when the Purcell anticlinorium farther east formed as a large ramp-anticline (Archibald et al., 1984).

Metamorphism culminated during the intrusion of granitic rocks during the initial phases of the Columbian Orogeny. About 80 percent of the Goat Range area lies in the biotite zone of greenschist facies metamorphism. Higher grade rocks in the oligoclase-garnet zone of the lower amphibolite facies are present in the northwestern part of study area, associated with the granitic plutons, and in the southeastern part of the study area, adjacent to Kootenay Lake. Although metamorphic recrystallization occurred during the development of F_2 folds, the most elevated thermal conditions were reached slightly later, during granitic intrusion. Metamorphic conditions for the biotite zone at this time are estimated to have been about 350°C and 3 to 4 kb (300-400 MPa) based on mineral assemblages and conodont alteration colour. Widespread retrograde alteration of metamorphic minerals occurred at a later, unknown time.

F_4 folds and faults may have been the final structures formed during the third deformational event or they may constitute a separate, younger fourth deformational event. F_4 folds and faults are interpreted to be related to the bend in regional structures near Milford Peak. The bend in structural trends also coincides with a structural depression, creating a configuration like that of a bent saddle. F_4 folds are of two kinds - a northeast trending set concentrated on the concave side of the elbow area of the bend and a northwest-trending, northeast-vergent set concentrated in the southwesternmost part of the study area. F_4 faults are concentrated along the convex side of the elbow area of the bend. This distribution of folds and faults can be related to bending of the relatively less ductile

Kaslo Group volcanic rocks in a manner similar to a flexed beam, with F_4 extensional faults occurring along its outer arc and with F_4 compressional folds along its inner arc (Fig. 115). F_4 folds with a northwest trend may be the result of general northeastward-directed compression that created the bend in the Kootenay Arc in its northern segment. F_4 folds and faults may have occurred as the Kootenay Arc was carried eastward about 100 km during Late Cretaceous-Paleocene thrust faulting in the Rocky Mountains (Price, 1981).

The last deformation in the Goat Range produced faults characterized by clay gouge. The southern part of the Schroeder fault was reactivated during this deformation. These late faults are correlated with Eocene extensional deformation reported along Slocan Lake (Parrish et al., 1985) southwest of the Goat Range. Intrusion of lamprophyre dykes in the Goat Range area is also probably of Eocene age.

Pleistocene glaciation was extensive in the Goat Range, and kame terraces and erratics are common, especially in the southern part of the area. Active glaciers appear to be receding, leaving unvegetated outwash sediments and moraines at higher elevations. Active mineral spring deposits of tufa and travertine are present in the Goat Range, although some tufa deposits are covered by several centimeters of soil.

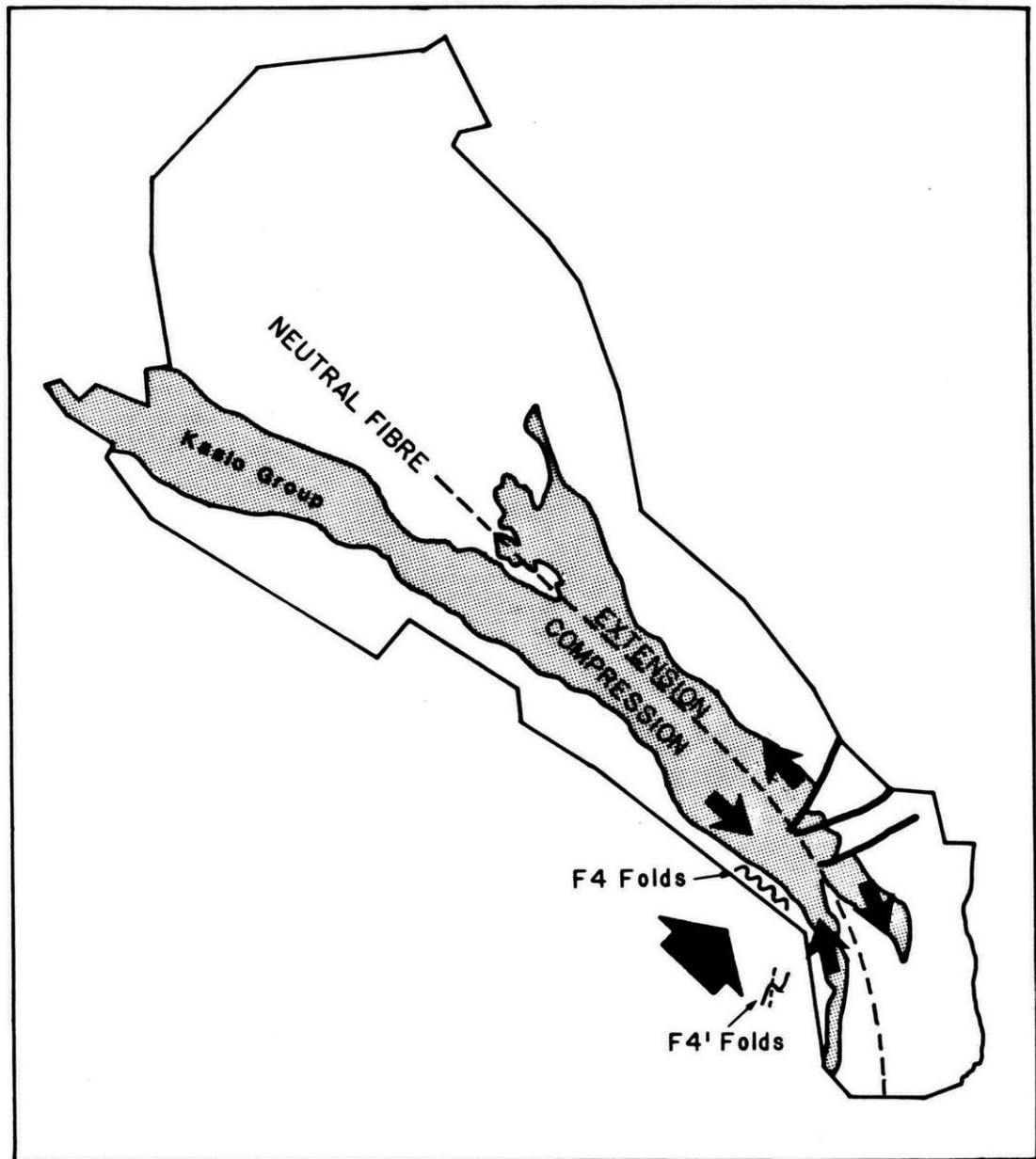


Figure 115: Kinematic model for the development of F4 folds. An initially straight Dryden anticline, outlined by the Kaslo Group, is bent about 50° by northeastward-directed compression. The relatively stiff volcanic rocks of Kaslo Group behaved as a bending beam with extension along its outer arc, resulting in extension faults, and compression along its inner arc, resulting in abundant F4 folds.

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