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STRATIGRAPHIC AND STRUCTURAL RELATIONS OF THE MILFORD, KASLO AND SLOCAN GROUPS, GOAT RANGE, LARDEAU AND NELSON MAP AREAS, BRITISH COLUMBIA

Project 790041

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Abstract

Mapping of upper Paleozoic rocks was continued in order to understand the relationships between the Cordilleran accreted terranes and ancestral North America. The Upper Mississippian and Lower Pennsylvanian Milford Group comprises three assemblages linked by Early Namurian limestones. The eastern, sedimentary Davis assemblage and the central, tholeiitic Keen Creek assemblage both lie with angular unconformity on the lower Paleozoic Lardeau Group. Siliceous argillite of the western, McHardy assemblage is thrust eastward along Stubbs Fault over the Keen Creek assemblage. The overlying tholeiites and conodont-bearing cherty tuff of the Lower Permian and (?)Carboniferous Kaslo Group are repeated by the Early Permian Whitewater Thrust Fault. Diorite intruding the fault is overlain unconformably by the Lower Permian Marten conglomerate in turn succeeded by Upper Triassic sediments of the Slocan Group. All map units and related thrust faults were folded by Dryden Anticline which was later cut by Schroeder normal fault before intrusion of Middle Jurassic granites.

Résumé

On a continué de cartographier les roches du Paléozoïque supérieur afin de mieux comprendre les liens qui existent entre les terrains accumulés dans la Cordillère et l'Amérique du Nord primitive. Le groupe de Milford du Mississipien supérieur et du Pennsylvanien inférieur se compose de trois assemblages reliés par les calcaires du Namurien ancien. L'assemblage sédimentaire de Davis, à l'est, et l'assemblage tholéiitique de Keen Creek, au centre, reposent en discordance angulaire sur le groupe de Lardeau du Paléozoïque inférieur. L'argilite siliceuse de l'assemblage de McHardy, qui est situé à l'ouest, a été poussée vers l'est sur l'assemblage de Keen Creek, le long de la faille de Stubbs. Les tholéiites et les tufs siliceux à conodontes sus-jacents du groupe de Kaslo du Permien inférieur et du (?)Carbonifère sont reproduits par la faille chevauchante de Whitewater du Permien ancien. La diorite qui a fait intrusion dans la faille est recouverte en discordance par le conglomérat de Martin du Permien inférieur qui, à son tour, est recouvert par les sédiments du groupe de Slocan du Trias supérieur. Toutes les unités cartographiques et les failles chevauchantes connexes ont été plissées par l'anticlinal de Dryden que la faille normale de Schroeder a par la suite recoupé avant l'intrusion des granites du Jurassique moyen.

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Introduction

The Milford, Kaslo, and Slocan groups comprise sedimentary and volcanic assemblages deposited along and west of the North American continental margin from late Paleozoic to early Mesozoic time. The volcanic, ultramafic and related sedimentary rocks of Kaslo Group form part of the Eastern Assemblage of Monger et al. (1982) where they form the leading edge of the Cordilleran accreted terranes. Phyllite, limestone, calcareous flysch, and quartzite of Slocan Group are part of Quesnellia terrane lying directly west of the Eastern Assemblage. The purpose of this project is to examine in central Kootenay Arc the stratigraphic and structural relationships between the leading edge of the accreted terranes and the autochthonous rocks of ancestral North America.

Mapping from the 1982 field season (Klepacki, 1983) in the Goat Range study area (Fig. 36.1) was extended southeast in 1983 to connect with Ainsworth area (Fyles, 1967) and to the northwest, nearly to the Poplar Creek map area (Read, 1973). This report incorporates ages of rock units assigned from microfossils identified by M.J. Orchard (Orchard, 1985) from collections made by J.O. Wheeler in 1965, 1967, 1980 and 1981, by A.V. Okulitch in 1976, by P.B. Read in 1976 and 1978, by M.J. Orchard in 1981 and by D.W. Klepacki in 1982 and 1983.

The principal results of the 1983 field season include:

1. Milford Group can be divided into three structurally discrete, stratigraphic assemblages; an eastern (Davis) assemblage of limestone, clastic and volcanic rocks, a central (Keen Creek) assemblage of limestone, pillowed tholeiitic volcanics and volcaniclastic rocks, and a western (McHardy) assemblage of cherty sediments and minor volcanic rocks and limestone (Fig. 36.2).
2. A panel comprising the McHardy assemblage and the Kaslo and Slocan groups has been thrust along the Stubbs Fault over the Keen Creek assemblage which lies unconformably on the Lardeau Group.
3. A thrust fault within the Lardeau Group places Index and Jowett formations on top of the Broadview Formation and this thrust is truncated by the unconformity at the base of the Milford Group (Davis assemblage).
4. Thrusting within Kaslo Group and intrusion of diorite bodies occurred in Early Permian time.
5. Fault panels mapped in Ainsworth area (Fyles, 1967) contain stratigraphy similar to that identified in the study area, and faults bounding these panels splay off the Schroeder Fault.

Stratigraphy

Hamill Group

The oldest and structurally lowest rocks of the study area are pegmatitic mica schist and gneiss, grey quartzite, and micaceous quartzite mapped as Lower Cambrian Hamill Group by Fyles (1967). This unit occurs along the shore of Kootenay Lake, at the southeastern edge of the study area (Fig. 36.3).

Badshot Formation

Coarsely crystalline white marble mapped as Badshot Formation outcrops sporadically at low elevations east and north of Mount Buchanan. Fyles (1967) mapped this unit as Lower Cambrian Badshot Formation because it overlies quartzite of the Hamill Group and underlies calcareous schist of Lardeau Group.

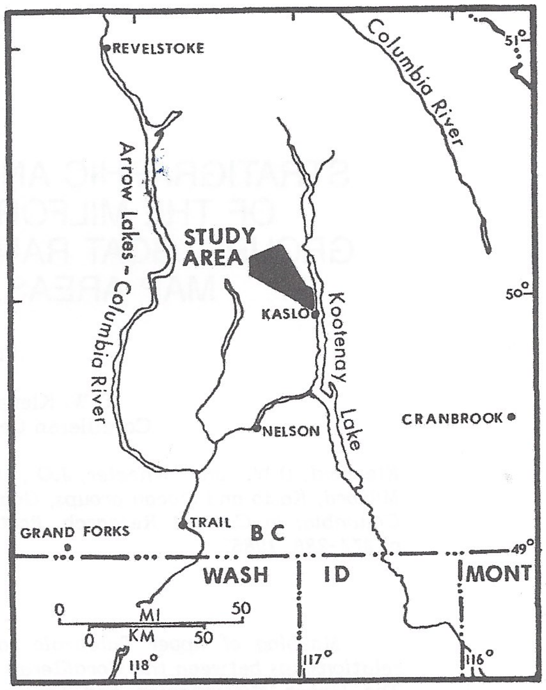

Figure 36.1. Location map of the Goat Range study area.

Lardeau Group, Index Formation

The stratigraphy of Lardeau Group is based on work farther north (Fyles, 1964; Read and Wheeler, 1976). Indicators of stratigraphic tops are scarce in the Lardeau Group in the study area but, where present, support the stratigraphic order outlined by earlier workers. Calc-silicate gneiss, quartzofeldspathic biotite-muscovite schist, and garnet-biotite schist and gneiss form the Index Formation. A white marble underlying the volcanic Jowett Formation is interpreted as Index Formation but may be Badshot marble. Index Formation is mapped along the southeastern margin of the study area.

Lardeau Group, Jowett Formation

Pyroxene-porphyry pillow lava, greenstone, and chlorite phyllite and schist are mapped as Jowett Formation. The unit forms two discontinuous belts: an upper belt which lies below the unconformity at the base of Milford Group and is locally truncated by it; and a lower belt which outcrops along the 5000-foot high ridge extending northeast from Milford Peak, 7.5 km north of Mount Buchanan. The Jowett Formation contains xenoliths of the underlying white marble thereby demonstrating that the strata face west.

Lardeau Group, Broadview Formation

Grey mica phyllite and schist, quartz-pebble conglomerate and blue-quartz-granule grit make up the Broadview Formation. The unit outcrops along the northeastern margin of the study area and northwest of Mount Cooper below the Keen Creek assemblage of Milford Group.

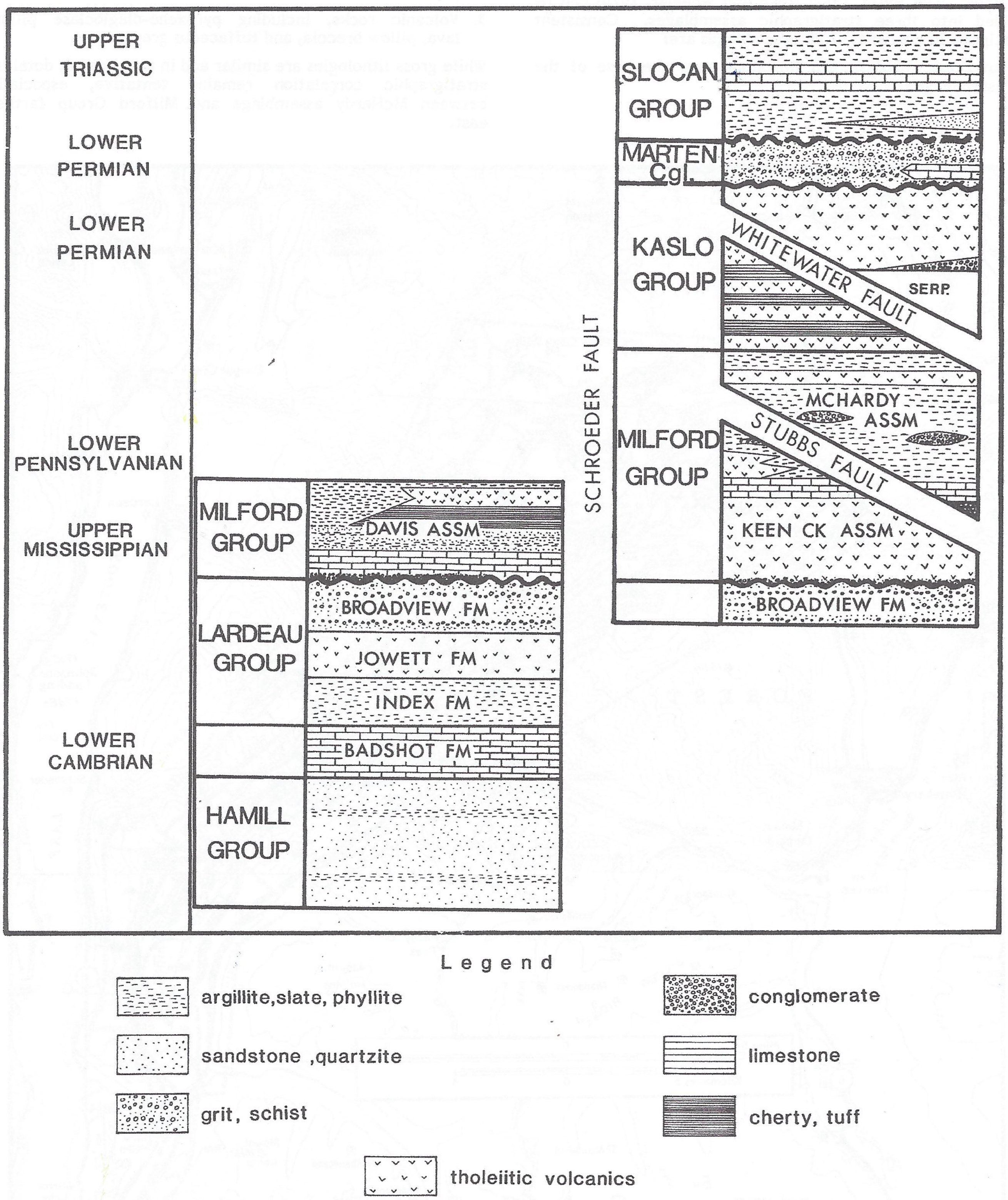

Figure 36.2. *Tectonic and stratigraphic relationships of stratified rocks in the Goat Range. Stratigraphic ages determined from fossil collections are shown on the left margin.*

Milford Group

Rocks previously mapped as Milford Group (Cairnes, 1934; Fyles, 1967; Read and Wheeler, 1976) can be divided into three stratigraphic assemblages. Consistent stratigraphic elements of all assemblages are:

1. An Upper Mississippian limestone near the base of the assemblage.
2. Siliciclastic rocks consisting of bedded cherty argillite, chert or quartz-pebble conglomerate, and slate or mica phyllite.
3. Volcanic rocks, including pyroxene-plagioclase pillow lava, pillow breccia, and tuffaceous greenstone.

While gross lithologies are similar and in part coeval, detailed stratigraphic correlation remains tentative, especially between McHardy assemblage and Milford Group farther east.

Figure 36.3. Generalized geological map of the Goat Range study area from work of the 1982 and 1983 field seasons. Contour interval is 500 feet.

Milford Group, Davis assemblage

The eastern belt of Milford Group lies unconformably upon grits and volcanics of Lardeau Group. This belt is informally named Davis assemblage because of good exposure of the sequence on Davis Ridge. This assemblage consists, in ascending stratigraphic order, of: rare basal quartz-pebble conglomerate, limestone, interbedded phyllite, limestone and metasandstone, cherty tuff and local phyllitic greenstone, overlain by grey siliceous argillite. The Davis assemblage forms a west-facing panel truncated to the west by the Schroeder Fault. Upper Mississippian (Early Namurian) conodonts have been obtained from the lower limestone and from a limestone lens in the cherty tuff unit (Orchard, 1985).

Milford Group, Keen Creek assemblage

The Keen Creek assemblage is exposed in the core of the Dryden Anticline, south of the McKian Creek Stock. Psammitic schist, quartzite, grit and quartz-pebble conglomerate, correlated with Broadview Formation of Lardeau Group, are unconformably overlain by a lower unit of sparse conglomerate and volcanics. The pyroxene-plagioclase pillow lavas, greenstone and green tuffaceous rocks are in turn overlain by a middle unit of light and dark grey banded limestone which has yielded Upper Mississippian (Early Namurian) and Lower Pennsylvanian (Late Namurian) conodonts (Orchard, op. cit.). The upper unit of the assemblage is composed in the east chiefly of pillow lavas

LEGEND for Figure 36.3

Geological Boundary: ——— Fault: ———

Axial Surface, Dryden Anticline:

UPPER TRIASSIC

TRSp — SLOCAN GROUP: Slate/phyllite, limestone, sandstone

~~~ Disconformity ~~~

LOWER PERMIAN

PMc — MARTEN Conglomerate: Greenstone conglomerate

~~~ Unconformity ~~~

PERMIAN AND(?) CARBONIFEROUS

PKv — KASLO GROUP: Tholeiitic volcanics

PKub — KASLO GROUP: Ultramafic Unit

UPPER MISSISSIPPIAN AND PENNSYLVANIAN

MPM — MILFORD GROUP — McHardy assemblage: Siliceous argillite, diorite tholeiitic volcanics, limestone

Stubbs Thrust Fault

MPK — Keen Creek assemblage: Tholeiitic volcanics, limestone, clastics

MPD — Davis assemblage: Siliciclastics, limestone, tholeiitic volcanics

~~~ Angular Unconformity ~~~

LOWER PALEOZOIC

lPL — LARDEAU GROUP: Calcareous schist, mafic volcanics, grit

LOWER CAMBRIAN

lЄB — BADSHOT FORMATION: White marble, calc-silicate gneiss

lЄH — HAMILL GROUP: Mica Schist, quartzite, micaceous quartzite

INTRUSIVE ROCKS

MIDDLE JURASSIC

Jg — KUSKANAX-NELSON Granitic rocks: Hornblende-biotite granite, aegerine granite feldspar porphyry

LOWER PERMIAN

Wwd — Whitewater diorite: Medium- to coarse-grained foliated diorite

PERMIAN AND(?) CARBONIFEROUS

PKd — feeder diorite: Medium-grained porphyritic hornblende diorite
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and volcaniclastics which grade westward into tuffaceous rocks and then into meta-wacke, quartz-pebble (meta-chert?) conglomerate and grey siliceous phyllite. Conglomerate clasts are matrix supported. The matrix is a fine grained dark grey hornblende-biotite hornfels.

Milford Group, McHardy assemblage

The McHardy assemblage is separated from the underlying Keen Creek assemblage by the undulating Stubbs Fault. This assemblage was mapped earlier as Milford Group and, in part, as Kaslo and Slocan groups (Cairnes, 1934; Fyles, 1967; Read and Wheeler, 1976) and as Grey Siliceous Argillite Unit (Klepacki, 1983). The lowest unit is grey limestone and dark grey calcareous sandstone overlain by tuffaceous sandstone in turn overlain by a mostly matrix-supported boulder conglomerate. Clasts are boulder- to pebble-sized and consist of diorite, amygdaloidal and pyroxene-porphyry volcanics, and rare granite. The granite boulders have yielded an Ordovician isotopic date (U-Pb, zircons; Okulitch et al., in prep.). Exposure of this conglomerate unit is restricted to a tight, northeast-trending fold cut off by McKian Creek Stock northwest of Mount Cooper. This conglomerate is overlain by limestone succeeded by thick, complexly folded grey siliceous argillite with rare calcareous beds and conglomerate. Conglomerate beds contain clasts of chert, diorite and volcanic rocks. Near the top of the McHardy assemblage, but within siliceous argillite, are thin (3-5 m) beds of pyroxene-plagioclase porphyry pillow lava of tholeiitic composition. McHardy assemblage is also distinguished by numerous dykes and sills of hornblende diorite porphyry which feed overlying volcanic rocks.

Similar grey siliceous phyllite, cut by dykes and sills of hornblende porphyry, near Mount Buchanan also belongs to the McHardy assemblage. There the phyllite is apparently underlain by a limestone which has yielded Upper Mississippian (Early Namurian) conodonts (Orchard, op. cit.). This limestone may be correlated with that northwest of Mount Cooper.

Kaslo Group, ultramafic unit

Serpentinite breccia, talc schist, or talc-chlorite schist outline a discontinuous sheet traversing the length of the study area (Fig. 36.3). The Whitewater Fault, marked near Whitewater Mountain by a complicated sliver zone, occurs at the base of the ultramafic unit thereby dividing the Kaslo Group into two plates. Northwest of Whitewater Mountain, however, a splay off the Whitewater Fault creates a third plate within the Kaslo Group, intermediate in character between the upper and lower plates by virtue of containing important amounts of cherty tuff. Because the intermediate plate is floored by ultramafic rocks, it probably represents a repetition of the upper plate. North of Mount Buchanan, the ultramafic unit rests on McHardy assemblage. The ultramafic unit is interpreted as oceanic floor basement to the upper plate of the Kaslo Group (Klepacki, 1983).

Kaslo Group, lower plate units

The lower plate units at Whitewater Mountain comprise tholeiitic pyroxene-porphyry pillow lava, flows, and tuffaceous greenstone interbedded with green and white cherty tuff. This sequence lies with depositional contact on the McHardy assemblage. Within the intermediate plate of Kaslo Group northwest of Marten Mountain a cherty tuff sequence which lithologically resembles the lower plate sequence has yielded Lower Permian conodonts (Orchard, op. cit.). Zircons recovered from the top of the cherty tuff yielded a single discordant point with U-Pb ages of 245.58 ± 7.08 Ma (U^{238}-Pb^{206}) and 269.60 ± 12.70 Ma (U^{235}-Pb^{207}) (P. van der Heyden, R.L. Armstrong; personal communication, 1983). These dates provide a minimum age of the zircons present in this sequence and should not be interpreted as the age of the unit without additional data. Kaslo Group is assigned a Permian and(?) Carboniferous age in accordance with the structural position of fossil data.

Kaslo Group, upper plate units

The upper plate of the Kaslo Group is predominantly pillow lava. Sedimentary rocks are rare and consist of greywacke and volcanic conglomerate with clasts of volcanics, diorite, and serpentinite. The upper plate is floored by the ultramafic unit and overlain stratigraphically by the Marten conglomerate.

Marten conglomerate

Rusty-weathering greenstone conglomerate with clasts of pyroxene-porphyry pillow lava, diorite, limestone, and in two localities, serpentinite, overlies the Kaslo Group with angular unconformity. This mappable unit is well exposed in the headwaters of Marten Creek southwest of Inverness Mountain. The matrix of the conglomerate is commonly calcareous green or grey phyllite or limestone and is locally pyritic. The conglomerate also contains sparse lenses of limestone a few centimetres to 10 metres thick, one of which has yielded Lower Permian conodonts.

Slocan Group, phyllite-limestone-sandstone unit

The youngest sedimentary rocks in the study area comprise a thick unit of grey phyllite or slate, locally rhythmically bedded with grey quartzite and limestone layers. Limestone beds are up to 20 metres thick, although most are only a few centimetres thick. Limestone has yielded Upper Triassic (Carnian/Norian) conodonts (Orchard, op. cit.), shell and crinoid fragments, molluscs and cephalopods (Cairnes, 1934). Sandstone beds containing detrital mica occur southwest of Retallack and require granitoids or metamorphic rocks in the source terrane. Previous work (Cairnes, 1934; Klepacki, 1983) suggests a source area to the west.

Intrusive rocks

Three major types of intrusive rocks occur in the study area. These are: synvolcanic diorite, syntectonic diorite, and granitic rocks. Synvolcanic diorite is medium- to fine-grained foliated hornblende diorite porphyry commonly containing ductile shear zones, mineralized quartz-epidote ± carbonate veins, and breccia with mineralized fractures. Glomerophyric hornblende is common but not ubiquitous. Dykes of synvolcanic diorite can be traced into tholeiitic volcanics of the McHardy assemblage and the Kaslo Group. Accordingly, in the field, the synvolcanic diorite was referred to informally as the "feeder diorite". It is considered, therefore, to be of Permian and (?)Carboniferous age. Large bodies of "feeder diorite" occur at Mount Cooper and southeast of Mount McHardy.

Syntectonic diorite or "Whitewater diorite" is difficult to distinguish from "feeder diorite" where crosscutting relationships or glomerophyric textures characteristic of the "feeder diorite" are lacking. In general, Whitewater diorite is medium- to coarse-grained equigranular diorite with a lower colour index than "feeder diorite". Locally Whitewater diorite is intensely sheared with fine grained, mylonite-like ductile shear zones which suggest syntectonic emplacement. The unit is best exposed at Whitewater Mountain where it invades the Whitewater Fault and overlying Kaslo volcanics.

North of Marten Mountain, it includes large xenoliths of serpentinite and volcanics, including a body with the serpentinite-volcanic contact, interpreted as representing the Whitewater Fault. Because the Whitewater diorite intrudes the Kaslo Group of Lower Permian and (?)Carboniferous age and is unconformably overlain by the Marten conglomerate of Lower Permian age, the age of the diorite is Early Permian. The Whitewater diorite is restricted to the McHardy assemblage and the Kaslo Group.

Granitic rocks consist of hornblende and/or biotite granite and leucogranite, aegerine granite, and feldspar porphyry plugs and dykes. Isotopic dates farther north (Read and Wheeler, 1976; Parrish and Wheeler, 1983) and south (Nguyen, Sinclair and Libby, 1968) on Kuskanax and Nelson suite granitic rocks, and preliminary zircon analyses in the study area, suggest the granitoids are Middle Jurassic. Granitic bodies postdate folding events and plug all major faults, but are locally cut by faults with minor displacement (100 m).

Major structures and deformation

The distribution of Mississippian and younger rocks in the study area is controlled by four major structures: Whitewater Fault, Stubbs Fault, Dryden Anticline, and Schroeder Fault (Fig. 36.4). Pre-Mississippian rocks experienced additional deformation not associated with these structures. This earlier deformation is manifested as thrust faults and a pre-Mississippian foliation probably associated with folding. Northwest of Mount Cooper, two foliations are present in Broadview Formation of Lardeau Group, whereas only one occurs in the overlying Keen Creek assemblage of Milford Group(Fig. 36.5, 36.6, 36.7). Pebbles of quartzite in basal conglomerate of Keen Creek assemblage are stretched along the foliation associated with the Dryden Anticline. This foliation is present as crenulation cleavage in the underlying Broadview Formation. Southeast and east of Mount Buchanan, structurally upright marble and overlying Jowett Formation volcanics lie structurally on top of Broadview Formation in apparent thrust contact. The thrust

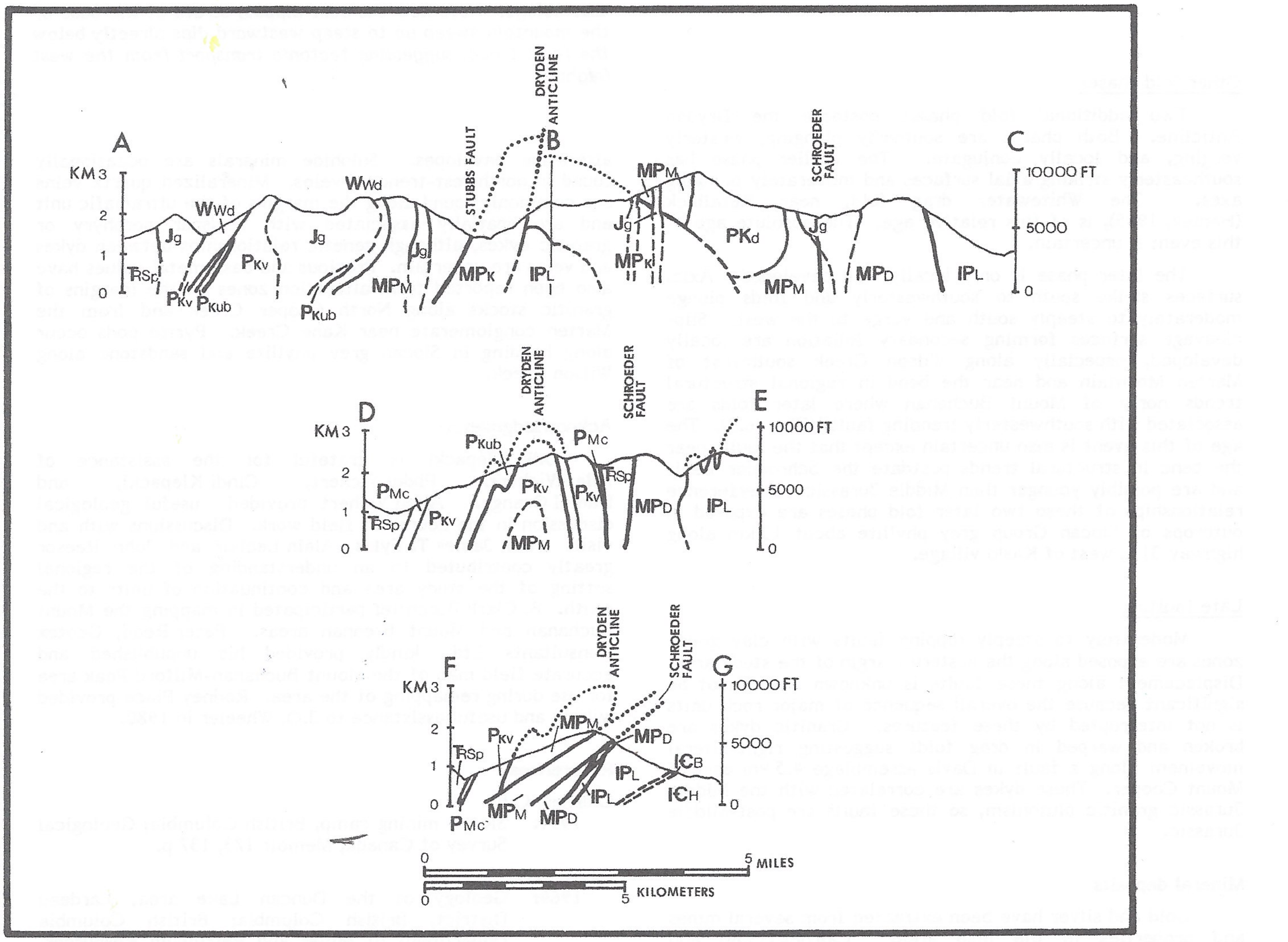

Figure 36.4. Vertical geological sections from the Goat Range study area. Location of the sections is keyed to Figure 36.3, with A-B-C the most northerly section and F-G the most southerly section. No vertical exaggeration.

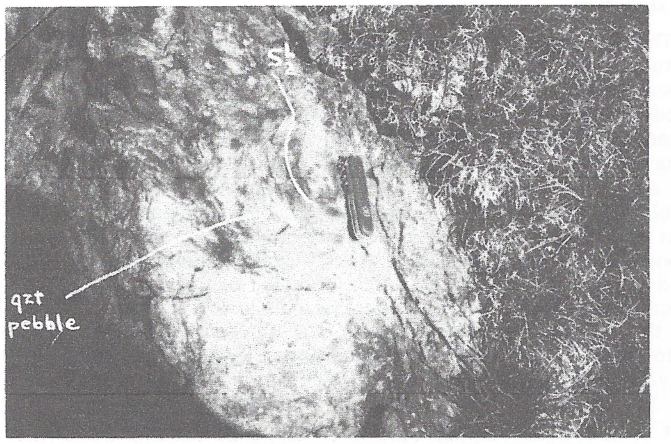

Figure 36.7. *Outcrop of conglomerate in rusty-weathering tuffaceous sediments at the base of Keen Creek assemblage. Clasts of quartzite are stretched out along foliation which dips southwest and is equivalent to* S_2^{L}*). This fabric is the primary foliation in Keen Creek assemblage.*

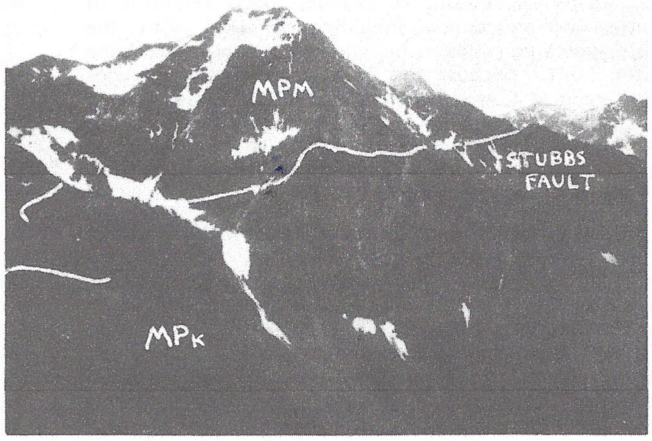

Figure 36.8. *Mount Stubbs and the Stubbs Fault viewed from the northeast. The fault truncates the layered limestone unit. The footwall contains limestone and volcanics of Keen Creek assemblage. The hanging wall contains siliceous argillite and diorite of McHardy assemblage. Note how the east-dipping strata at the base of the mountain sweep up to steep westward dips directly below the fault trace, suggesting tectonic transport from the west (right).*

Other fold phases

Two additional fold phases postdate the Dryden Anticline. Both phases are southerly plunging, westerly verging, and locally conjugate. The earlier phase has southeasterly striking axial surfaces and moderately plunging axes. The Whitewater drag fold, near Retallack (Hedley, 1945), is of this relative age. The absolute age of this event is uncertain.

The later phase is only locally well developed. Axial surfaces strike south to southwesterly and folds plunge moderately to steeply south and verge to the west. Slip-cleavage surfaces forming secondary foliation are locally developed, especially along Wilson Creek southwest of Marten Mountain and near the bend in regional structural trends north of Mount Buchanan where later folds are associated with southwesterly trending faults (Fig. 36.3). The age of this event is also uncertain except that the faults near the bend in structural trends postdate the Schroeder Fault and are possibly younger than Middle Jurassic. Interference relationships of these two later fold phases are exposed in outcrops of Slocan Group grey phyllite about 13 km along highway 31A, west of Kaslo village.

Late faulting

Moderately to steeply dipping faults with clay gouge zones are exposed along the eastern margin of the study area. Displacement along these faults is unknown but cannot be significant because the overall sequence of major rock units is not interrupted by these features. Granitic dykes are broken and warped in drag folds suggesting right-lateral movement along a fault in Davis assemblage 4.5 km east of Mount Cooper. These dykes are correlated with the Middle Jurassic granitic plutonism, so these faults are post-Middle Jurassic.

Mineral deposits

Gold and silver have been extracted from several mines and properties in the map area. Cairnes (1934) and Maconachie (1940) have described many of the mineral deposits in the area. In general, most properties are located on or near northeast-trending quartz-galena-sphalerite-pyrite-chlocopyrite veins with rusty-weathering carbonate alteration envelopes. Sulphide minerals are occasionally found in northwest-trending veins. Mineralized quartz veins are commonly found along the margins of the ultramafic unit and are spatially associated with feldspar porphyry or granitic dykes, although genetic relationships between dykes and veins are uncertain. Precious and base metal values have also been reported from alteration zones on the margins of granitic stocks along North Cooper Creek and from the Marten conglomerate near Kane Creek. Pyrite pods occur along bedding in Slocan grey phyllite and sandstone along Wilson Creek.

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