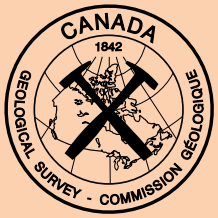

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J.L. Kraft, R.I. Thompson, and P. Erdmer

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Abstract: Devonian strata correlative with the Devonian Silver Creek and Chase formations have recently been recognized beneath argillaceous Milford Group rocks on the western margin of the northern Kootenay Arc at Upper Arrow Lake. New mapping demonstrated that those argillaceous rocks conformably overlie the Devonian units, suggesting that that component of Milford Group and overlying mafic volcanic rocks, which had both been assigned to the Slide Mountain terrane, were deposited on Devonian continental margin strata and are therefore parautochthonous. That these units were deposited on equivalents of the Silver Creek Formation implies a stratigraphic connection to the Eagle Bay assemblage. Detailed mapping in the vicinity of the Northeast Arm of Upper Arrow Lake characterized an assemblage of phyllite, limestone, quartzite, and greenstone that is interpreted as resurfacing of the Index Formation along the western limit of the Lardeau Group.

Résumé : Des strates du Dévonien corrélatives des formations dévoniennes de Silver Creek et de Chase ont récemment été reconnues sous les roches argileuses du Groupe de Milford sur la marge occidentale de la partie nord de l'arc de Kootenay au lac Arrow supérieur. De nouveaux travaux de cartographie ont démontré que ces roches argileuses reposent en concordance sur les unités du Dévonien, ce qui laisse croire que cette composante du Groupe de Milford et les roches volcaniques mafiques sus-jacentes, qui avaient toutes deux été attribuées au terrane de Slide Mountain, ont été déposées sur des strates de la marge continentale du Dévonien et sont par conséquent parautochtones. Le fait que ces unités aient été déposées sur des équivalents de la Formation de Silver Creek implique une connexion stratigraphique avec l'assemblage d'Eagle Bay. Des travaux de cartographie détaillée aux environs du bras nord-est du lac Arrow supérieur ont permis de caractériser un assemblage de phyllade, de calcaire, de quartzite et de roches vertes, que l'on attribue à une remontée à la surface de la Formation d'Index le long de la limite occidentale du Groupe de Lardeau.

INTRODUCTION

Similarities between the late Paleozoic Milford and Kaslo groups, and Eagle Bay and Fennell formations in the southern Canadian Cordillera have led to speculative correlation between these units (e.g. Okulitch, 1979; Klepacki, 1985). Field evidence of this connection has been lacking, and existing models illustrate a mid-Paleozoic ocean basin separating strata of the northern Kootenay Arc from the Eagle Bay assemblage (Klepacki, 1985; Roback et al., 1994). The presence of quartzite, mica schist, and amphibolitic schist correlative with the Devonian Chase and Silver Creek formations (Lemieux et al., 2003, 2004; Thompson et al., 2006; Lemieux, 2006) within sequences previously assigned to the Milford Group near Upper Arrow Lake and east of the Kuskanax batholith at Tenderfoot Lake (Read and Wheeler, 1976; Roback et al., 1994) has substantiated the possibility of a connection with the Eagle Bay basin and a continental depositional setting for the Milford Group.

The object of this study, part of the Geological Survey of Canada's Cordilleran TGI-3 project, is to test the hypothesis that rocks of Devonian-Mississippian age in the northern Kootenay Arc between Revelstoke and Nakusp are correlative with the Eagle Bay assemblage and may therefore represent an eastward extension of that metallotect. Twelve weeks of bedrock geological mapping have highlighted stratigraphic and structural relationships around the northern terminus of the Kuskanax batholith at the northern end of Upper Arrow Lake (NTS 82 K/6, 11, 12, 13).

REGIONAL GEOLOGY AND PREVIOUS WORK

The map area rests along the transition between low-grade or unmetamorphosed Mesoproterozoic to Mesozoic sedimentary rocks of the ancestral North American continental margin to the east, and moderately to strongly tectonized, high-grade metasedimentary, metavolcanic, and igneous rocks of uncertain affinity to the west. Greenschist- to amphibolite-facies rocks of this study occur within the hanging wall of the Columbia River fault zone, an east-dipping zone of early Tertiary normal faulting that follows the trace of the Columbia River valley (Read and Brown, 1981; Lane, 1984; but *see also* Lemieux et al., 2003, 2004; Lemieux, 2006). A pervasive schistosity has transposed bedding in all map units except in the Upper Triassic Slocan Group and Mississippian Milford Group. Protoliths are readily identified 'through' greenschist- and lower amphibolite-facies metamorphism and related deformation. The area resides at the western margin of the Kootenay Arc, a convex-east arcuate structural belt of tightly folded and faulted supracrustal rocks extending from Revelstoke southward along the eastern contact of the Kuskanax batholith to Kootenay Lake and southward and westward across the International Boundary (Fig. 1; cf. Hedley (1955); Ross (1970)). Stratigraphic constituents of the Kootenay Arc present in the study area are: the lower Paleozoic Lardeau Group, the upper Paleozoic Milford and Kaslo groups, and the Upper Triassic Slocan Group (Hyndman, 1968; Read and Wheeler, 1976). The Lardeau Group (Fyles and Eastwood, 1962) underlies the eastern limit of the map area. It is interpreted as a deeper water, carbonaceous correlative of the North American miogeocline formed during early Paleozoic foundering of the continental margin (Colpron and Price, 1995). East of Trout Lake, the Lardeau Group was divided into six formations, which are, in ascending order: grey and green phyllite, limestone, quartzite, and metabasaltic rocks of the Index Formation; black siliceous argillite of the Triune Formation; light to dark grey quartzite of the Ajax Formation; black siliceous argillite of the Sharon Creek Formation; metabasaltic rocks of the Jowett Formation; and grey and green, gritty quartzite and phyllite of the Broadview Formation (Fyles and Eastwood, 1962). The Index Formation depositionally overlies limestone of the lower Cambrian Badshot Formation (Colpron and Price, 1995; Logan and Colpron, 2006). The Lardeau Group contains at least two foliations and appears more strongly deformed than the unconformably overlying Milford Group (Fyles and Eastwood, 1962; Read, 1973; Smith and Gehrels, 1992).

The Milford Group has yielded Visean to Namurian (mid- to upper Mississippian) conodonts (Orchard, 1985) and records only one strong cleavage. Its basal conglomerate contains clasts of the Lardeau Group with randomly oriented foliation (Wheeler, 1968; Read, 1975), and the unconformity truncates folds and faults in the Lardeau Group, indicating pre-middle Mississippian tectonism (Klepacki, 1985). In the Goat Range, southeast of the study area, Klepacki (1985) subdivided the Milford Group into three fault-bounded, but depositionally linked assemblages, from east to west: Davis, Keen Creek, and McHardy. Klepacki mapped the first two overlying Lardeau Group strata. He assigned the McHardy assemblage to the Slide Mountain terrane, and interpreted it to have been deposited atop oceanic crust in a back-arc rift basin adjacent the continental margin, but he did not observe its basement. Roback et al. (1994) interpreted the McHardy assemblage and overlying greenstone of Kaslo Group to have been deposited in a marginal ocean basin between ancestral North America and an extinct Early Paleozoic arc.

All siliciclastic and metavolcanic rocks that outcrop on the east shore of Upper Arrow Lake from Nakusp to Mount Sproat (Fig. 2), excluding the Slocan Group, were assigned to the Milford and Kaslo groups, respectively (Hyndman, 1968; Read and Wheeler, 1976), until Lemieux et al. (2003, 2004) correlated calcareous quartzite with the Devonian Chase Formation and overlying metasedimentary and amphibolitic schist with the Devonian Silver Creek Formation. Correlation of the remaining metasedimentary rocks and overlying greenstone with the Milford and Kaslo groups, respectively, and their relations to the Devonian strata has therefore become uncertain.

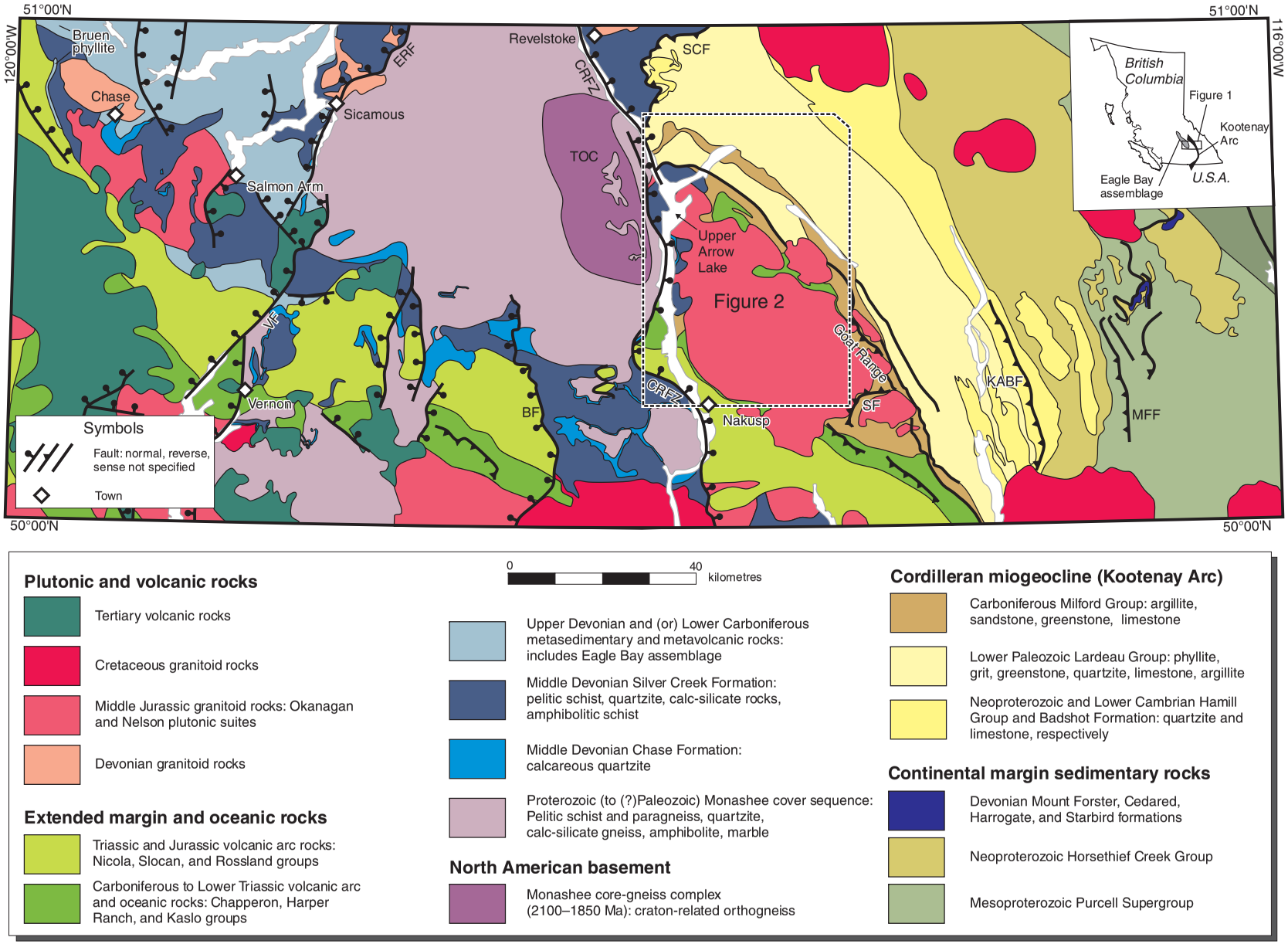


Figure 1. Simplified compilation of Vernon (NTS 82 L) and Lardeau (NTS 82 K) 1:250 000 geological map sheets (*modified from* Thompson et al., 2006). Location of Figure 2 (study area) indicated by dashed box. Abbreviations: BF = Beaven fault, CRFZ = Columbia River fault zone, ERF = Eagle River fault, KABF = Kootenay Arc boundary fault, MFF = Mount Forster fault, SCF = Standfast Creek fault, SF = Stubbs fault, TOC = Thor-Odin culmination, VF = Vernon fault.

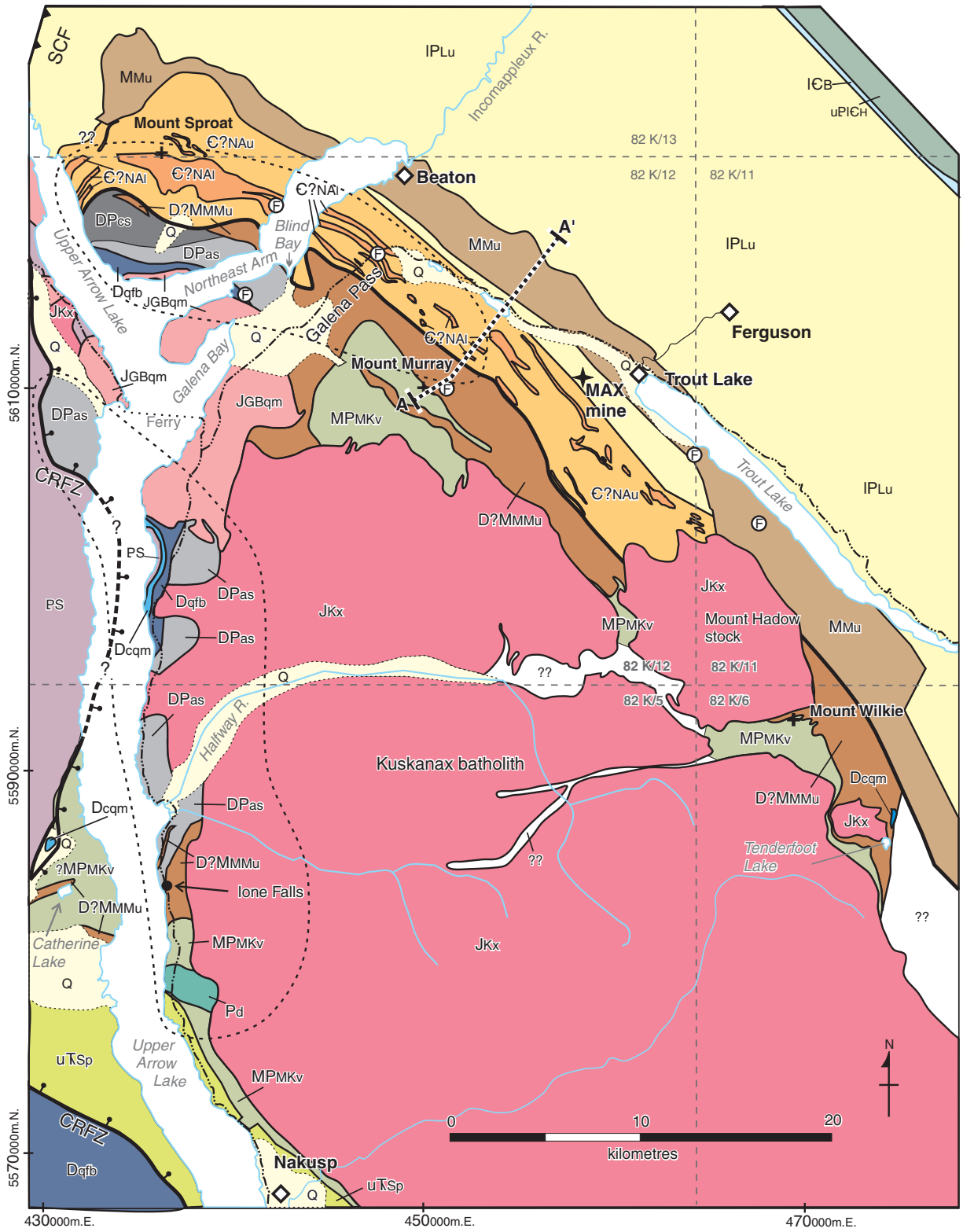
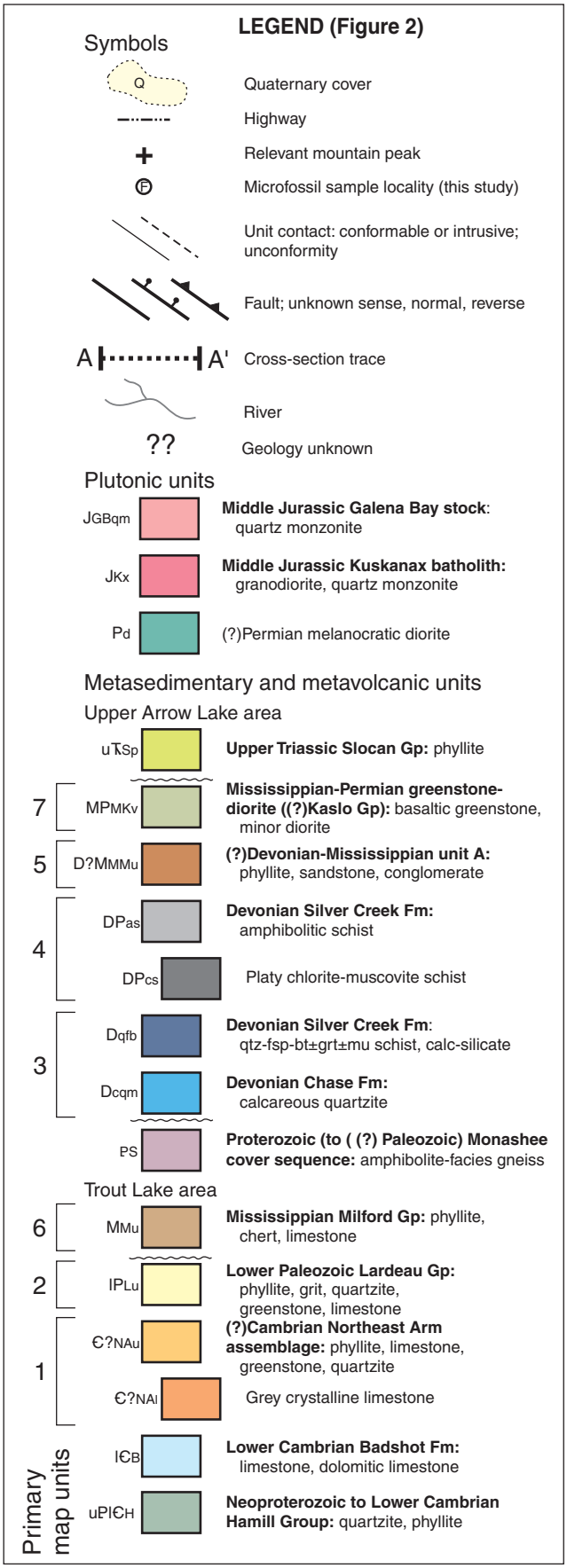


Figure 2. Geology of the Upper Arrow Lake–Trout Lake area. Geology from Lemieux (2006), Thompson et al. (NTS 82/K 1:50 000 compilation maps; in press a, b, c), and this study. Two areas with major changes are outlined with dotted lines. *See* Figure 1 for location and Figure 6 for cross-section A-A'. Abbreviations: CRFZ = Columbia River fault zone, SCF = Standfast Creek fault, qtz = quartz, fsp = feldspar, grt = garnet, mu = muscovite. Canada NTS 1:50 000 map sheets are outlined by grey dashed lines. UTM references are given in NAD 27



RESULTS OF 2006 FIELD INVESTIGATIONS

Mapping focused on re-evaluating the distribution and correlation of map units between Upper Arrow and Trout lakes, and on the relationship between the Devonian formations and overlying rocks that were assigned to the Milford Group (Read and Wheeler, 1976). Time was also dedicated to subdividing the Lardeau Group west of Beaton and Trout Lake.

Map units

Metasedimentary and metavolcanic rocks in the study area can be grouped into seven primary units, which are further subdivided in Figure 2. In inferred chronological order, these are: Northeast Arm assemblage (new term); Lardeau Group; Devonian quartzite, pelitic schist, and calc-silicate; amphibolitic schist; (?)Devonian to Mississippian metasedimentary rocks at Upper Arrow Lake, referred to herein as unit A; a greenstone and diorite unit; and strata of the Milford Group (undivided) that overlie the Lardeau Group. The Slocan Group was not studied.

Northeast Arm assemblage (1)

The authors introduce the term Northeast Arm assemblage to a belt of greenstone, limestone, phyllite, and quartzite that outcrops west of Trout Lake and Beaton. The Northeast Arm assemblage outcrops between Broadview Formation gritty phyllite and Upper Paleozoic units at Upper Arrow Lake. The strata were previously included in the undivided Lardeau Group (Read, 1976, 1977) or the Broadview Formation (Logan and Colpron, 2006).

The Northeast Arm assemblage forms a steeply northeast-dipping panel more than 2 km wide from Upper Arrow Lake north of Mount Sproat, southward to the west side of Trout Lake, where it is truncated by the mid-Jurassic Mount Hadow stock (Fig. 2). It is best exposed along the Northeast Arm shoreline (at low water) and on a ridge trending south from Mount Sproat. Although exposure is poor, the eastern contact with Broadview Formation grit appears to be gradational over tens to hundreds of metres, which would imply the sequence faces northeast. The western contact with upper Paleozoic strata at Upper Arrow Lake is abrupt and was not observed except at Blind Bay where a gently southeast-dipping gouge zone truncates Northeast Arm assemblage strata and places them over phyllitic argillite and amphibolitic schist. The westernmost (possibly lowest) unit observed is platy, greenish-grey chlorite schist on Mount Sproat. Locally, the chlorite schist is massive and displays textures compatible with a plagioclase-porphyritic volcanic protolith (Fig. 3a). Colour index and modal mineralogy (chlorite-biotite-feldspar-quartz in thin section) reflect an intermediate bulk composition. At Mount Sproat and in Blind Bay, the

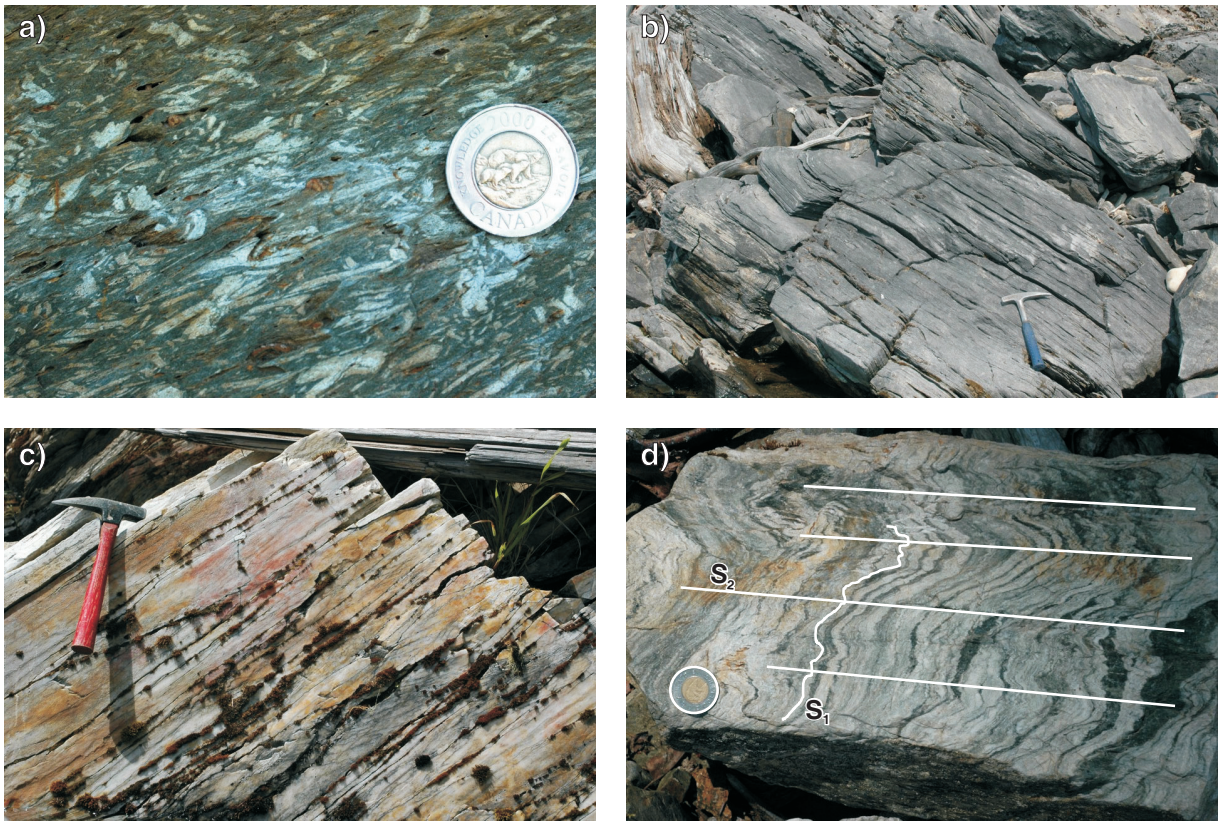


Figure 3. Photographs from the Northeast Arm assemblage. **a)** Plagioclase-(?)porphyritic texture in massive metabasalt or andesite near the western contact (?base); coin for scale is 2.7 cm. **b)** Outcrop of the abundant foliated grey limestone; hammer for scale is 30 cm long. **c)** Weathered joint surface of white orthoquartzite; trace of compositional layering slopes down to the left; hammer for scale is 30 cm long. **d)** Transposed layering, S_1, is preserved in quartzite (unlike in phyllite) and is crenulated by the dominant regional fabric, S_2; coin for scale is 2.7 cm.

schist grades eastward and upward into metaconglomerate with a chloritic matrix. Clasts are well rounded, pebble- to boulder-sized (to >20 cm), stretched quartzite and grit. The metaconglomerate grades upward into phyllitic to massive greenstone that may be pyroclastic in places and contains streaky pods and lenses of orange-buff carbonate. Next, tens of metres of white- or buff-weathering, pale grey to white, finely crystalline marble and dolostone overlain by thicker grey crystalline limestone is ubiquitous along the western margin (?base) of the Northeast Arm assemblage. The remainder of the Northeast Arm assemblage is a repeating (structurally and possibly stratigraphically) sequence of marker layers within phyllite. Markers consist of: widespread, foliated, medium-grey crystalline limestone (Fig. 3b) that forms cliffs and prominent markers that pinch and swell from zero to over 100 m thick; and white, fine-grained orthoquartzite in several laterally extensive layers from about 1 m to more than 30 m thick (Fig. 3c); orthogonal joints impart a brickwork appearance. The marker rock types are hosted in a mixture of green and grey phyllite, mafic metavolcanic rocks, rare biotite schist, and graphitic quartz-mica schist with white quartz veinlets. Metres-thick layers of black, slaty argillite, grey quartzite, and grey phyllite with millimetric magnetite porphyroblasts are rare.

The presence of two cleavages — most apparent in quartzose units where transposed layering, S_1, is preserved and defines folds with axial-planar cleavage, S_2 (Fig. 3d) — suggests a depositional age that predates Milford Group rocks.

Lardeau Group (2)

The Jowett and Broadview formations are exposed at the northeastern margin of the study area. The Jowett Formation is an olive green, weakly sheared or phyllitic greenstone that locally retains phenocrystic texture, pillow selvages, and vesicles. The interfingering and overlying Broadview Formation comprises grey, graphitic phyllite and schist with common quartz veins and a wavy foliation, and green and grey quartzite. Broadview Formation is defined by the ubiquitous presence of grey-blue quartz granules about 1–4 mm across, which characterize the "Broadview grit" (Fyles and Eastwood, 1962). Lardeau Group rocks in the study area

comprise greenschist-facies metamorphic assemblages and at least two northwest-striking fabrics; a transposition foliation, S_1, is tightly to isoclinally folded around northwest-trending chevron folds with axial-planar cleavage S_2 (Read, 1973; Smith and Gehrels, 1992). Middle Cambrian to Early Ordovician protoconodonts were recovered from marble in the northern Selkirk Mountains that is tentatively correlated with the Lardeau Group (Logan and Colpron, 2006). Its minimum age is constrained by the unconformably overlying Middle Mississippian Milford Group.

Chase Formation and overlying schist (3)

The Chase Formation quartzite is a distinctive, pitted, white calcareous quartzite that can be traced more than 200 km from the town of Chase eastward to Upper Arrow Lake (Thompson et al., 2006, and references therein). It outcrops west of Upper Arrow Lake near Catherine Lake, on the eastern shore of Upper Arrow Lake south of Galena Bay, and at Tenderfoot Lake in the extreme east of the mapped area (Fig. 1, 2). Near Nakusp, the quartzite has a sharp, transposed lower contact with sillimanite-grade paragneiss of the Monashee cover sequence (Lemieux et al., 2003). The Chase Formation quartzite grades upward into a sequence of rusty-weathering garnet-muscovite-biotite schist and calc-silicate (Fig. 4a; Dqfb on Fig. 2) that has been correlated with the Silver Creek Formation (Thompson et al., 2001, 2002; Lemieux et al., 2003; Lemieux, 2006). A mid-Devonian (Eifelian) age has been proposed for the Chase Formation and overlying schist and calc-silicate on the basis of U-Pb isotopic age constraints (Thompson et al., 2006).

Amphibolitic schist (4)

Amphibolitic schist forms a prominent map unit between Halfway River and Mount Sproat (Fig. 2). It is typically platy or compositionally banded, medium to dark grey, and contains variable proportions of medium- to coarse-grained hornblende and biotite. Epidote is common, and chlorite is locally present. Foliation surfaces frequently display coarse, feathery sprays of hornblende (Fig. 4b). Locally, amphibolitic schist grades into similar calcareous, amphibole-bearing calc-silicate or biotite±amphibole schist. At its base, amphibolitic schist is interlayered with biotite±garnet schist

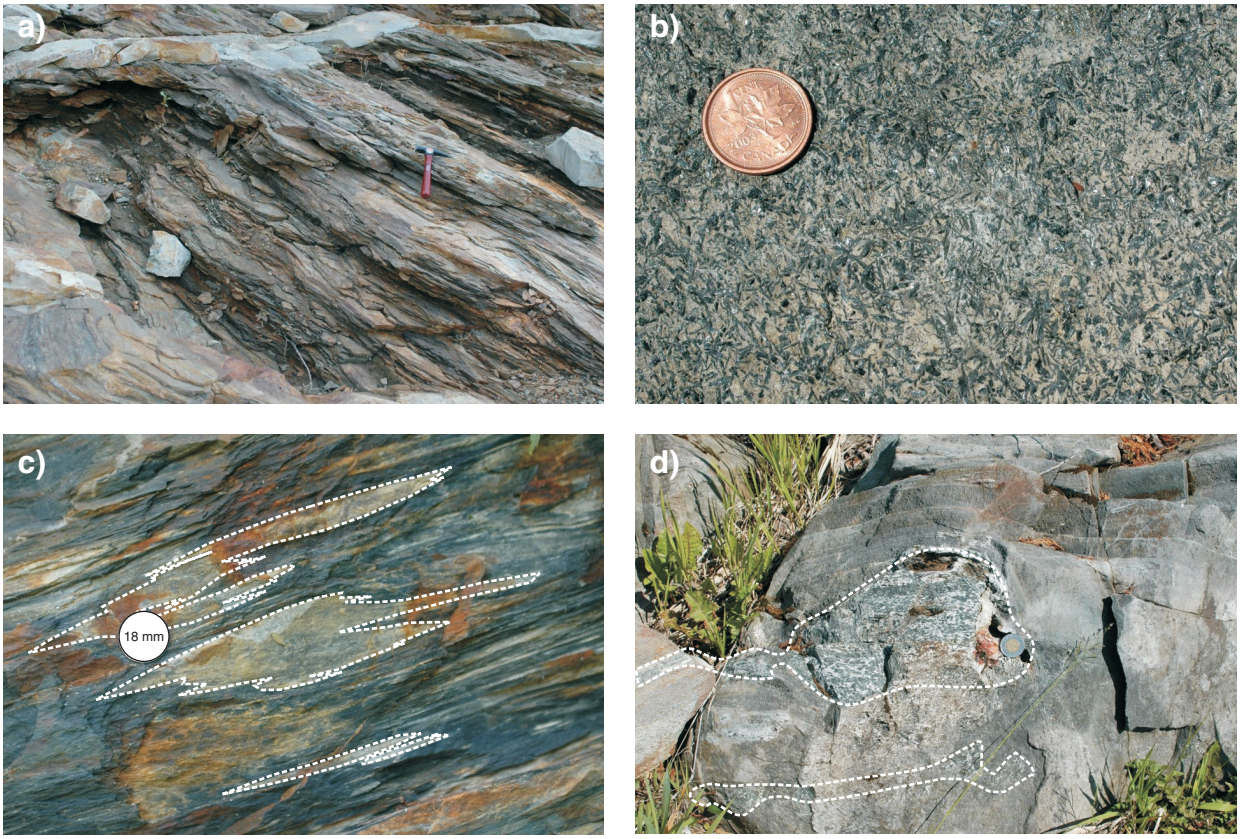


Figure 4. Photographs of the Devonian and Mississippian succession along Upper Arrow Lake. **a)** Rusty-weathering garnet-muscovite-biotite schist overlying the Chase Formation quartzite; hammer for scale is 30 cm long. **b)** Radiating, coarse hornblende on a foliation surface of the amphibolitic schist; coin for scale is 1.9 cm. **c)** Rootless folds in Devonian-Mississippian argillite of unit A near Galena Bay. **d)** Boudinaged layers of amphibolitic schist within garnet-muscovite schist (and argillite, not shown) demonstrates conformable nature of the amphibolitic schist–unit A contact; coin for scale is 2.7 cm.

that overlies Chase Formation quartzite. The top is a mixed gradation of amphibolitic schist, garnet-muscovite schist, grey metasiltstone, and quartzite pebble metaconglomerate (Fig. 4d). The unit thins considerably, from more than 1 km to less than 100 m, on the south flank of Mount Sproat. This thinning is interpreted as a lateral facies change to chlorite±muscovite schist with metres-thick layers of calc-silicate and buff-weathering, fine-grained white marble associated with black amphibolite (DPcs on Fig. 2).

Amphibolitic schist corresponds to unit 3d of Lemieux (2006) and may be correlative with amphibolite south of Nakusp on Scalping Knife Mountain (Hyndman, 1968), amphibolite in the Poplar Creek area east of the Kuskanax batholith (unit 13; Read (1973)), and amphibolite mapped in the footwall of the Standfast Creek Fault southeast of Revelstoke (unit B4c, Thompson (1978); Lemieux (2006)). The unit is younger than the Chase Formation quartzite and older than overlying Late Devonian or Early Mississippian phyllite of unit A (*see* below).

Unit A (5)

This unit outcrops along Upper Arrow Lake near Catherine Lake and Ione Falls, and in a discontinuous belt striking southeast from the Northeast Arm to Tenderfoot Lake (Fig. 2). It is a heterogeneous succession of phyllitic or siliceous argillite, banded siltstone, sandstone, and fine-grained biotite±garnet±staurolite schist with sporadic lenses of heterolithic conglomerate and rare carbonate. Quartzite-pebble metaconglomerate lenses are common near the base of the unit. Metres-thick lenses of pebble and cobble volcaniclastic metaconglomerate with amphibolitic clasts and matrix, which are similar to the underlying amphibolitic schist unit, abound near Ione Falls. White or grey crystalline limestone is rare in the west and north, and becomes more abundant toward Tenderfoot Lake. Rare isoclinal and rootless folds in argillite and limestone indicate that layering has been transposed, at least locally (Fig. 4c). The persistence of a limestone marker between Tenderfoot Lake and Mount Wilkie (Read, 1973; Roback, 1993), however, indicates that the common lateral variations may be attributable to primary facies changes rather than deformation.

Along Upper Arrow Lake, this unit is interlayered and gradational with underlying amphibolitic schist, as described above, and the top was not observed. Along a northwest-trending belt between Tenderfoot Lake and Galena Pass that constitutes the eastern limb of a large, west-facing, second generation syncline, the upper 100 m or so is rhythmically layered, whitish-brown or purple metasandstone and dark grey siltstone that locally stratigraphically interleaves with overlying greenstone (Roback et al., 1994; this study). Limestone within phyllite of unit A near Catherine Lake (the 'Catherine Lake phyllite' of Thompson et al. (2006)) yielded Fammenian or Tournaisian (Late Devonian or Early Mississippian) conodonts (Orchard, 1985). Unit A had been assigned to the Milford Group by Read and Wheeler (1976), and later to McHardy assemblage (Roback et al., 1994). It is equivalent to unit 4 of Lemieux (2006).

Greenstone-diorite unit (6)

A unit of greenstone and diorite that overlies unit A is exposed adjacent to the Kuskanax batholith near Nakusp and from Galena Pass to Tenderfoot Lake and beyond the study area. Greenstone is homogeneous, dark green or black, massive to weakly foliated, and locally displays sheared pillows or retrogressed phenocrysts. It is typically composed of fine-grained plagioclase and actinolite or hornblende with minor biotite and some chlorite. Millimetric subhedral pyrite is ubiquitous. Medium- and coarse-grained dykes, sills, and small stocks of diorite commonly intrude the greenstone, but were not observed in other map units in this area. Diorite is massive to moderately foliated.

Near Galena Pass and Tenderfoot Lake, the greenstone interlayers with underlying metasandstone of unit A. At Mount Murray, brecciation and low-angle truncation of foliation indicate a faulted contact with unit A. Neither the lower contact south of Ione Falls nor the upper contact with the Slocan Group was observed.

Diorite may correspond to the Pennsylvanian or Permian Kane Creek or (?and) the Permian or Lower Triassic Whitewater diorite intrusions that cut the Milford and Kaslo groups in the Goat Range (Klepacki, 1985). Greenstone is younger than the underlying Late Devonian or Early Mississippian Catherine Lake phyllite (of unit A) and older than the crosscutting Permian or Triassic diorite.

Milford Group (excluding potential correlatives along Upper Arrow Lake) (7)

Mississippian Milford Group strata form a northwest-trending, synclinal trough 2–3 km wide from the Goat Range to Upper Arrow Lake north of Mount Sproat. North of Trout Lake, the main unit is fissile, silver-grey phyllite, with sandy pebble conglomerate and grey crinoidal limestone near its base. South of Trout Lake, the Milford Group is more variable, comprising limy or siliceous argillite, grey to black graphitic limestone, chert, grey phyllite, and sandstone. Bedding is locally oblique to the main cleavage. The basal contact with the Lardeau Group is not well exposed in the study area; it is an angular unconformity beneath equivalent strata in the Goat Range (Klepacki, 1985). The upper contact of Milford Group in the study area is not known. Between Beaton and Trout Lake, the age of the basal Milford conglomerate is bracketed between 362 Ma (U-Pb detrital zircon; Lemieux (2006)) and ca. 345 Ma (Visean conodonts recovered from overlying limestone; Orchard (1985)).

METAMORPHISM AND STRAIN

In general, metamorphic grade and strain decrease upward through the Upper Arrow Lake stratigraphy (Fig. 5), through a condensed, but apparently continuous transition (Lemieux, 2006). Schist units immediately above the Chase Formation quartzite are completely recrystallized and bear coarse-grained, amphibolite-facies metamorphic assemblages (biotite±garnet±muscovite or plagioclasehornblende±epidote). Rocks in unit A and in the greenstone-diorite unit contain epidote-amphibolite- or amphibolite-facies mineral assemblages, but they are only weakly to moderately recrystallized and have retained primary textures and structures such as laminae and pillows. Strata of the Lardeau and Milford groups are of lower metamorphic grades than Devonian-Mississippian units in the Upper Arrow Lake area.

DISCUSSION

Correlation of the amphibolitic schist unit

Amphibolitic schist is distinguished from the greenstone-diorite unit on the basis of the following observations: mapping showed the amphibolitic schist occupying a lower stratigraphic level, whereby it grades downward into Devonian stratigraphy; diorite is common in the greenstone, but is absent from the amphibolitic schist; thick, yellow- and rusty-weathering sandstone everywhere at the base of the greenstone-diorite unit was not observed adjacent to amphibolitic schist, ruling out structural repetition; metamorphic grade and strain are consistently higher in amphibolitic schist; and the amphibolitic schist locally grades into calcareous and pelitic rocks. The present mapping suggests that the amphibolitic schist unit corresponds to unit 3d of Lemieux (2006), which he correlated with the Silver Creek Formation of Thompson et al. (2001, 2002, 2006).

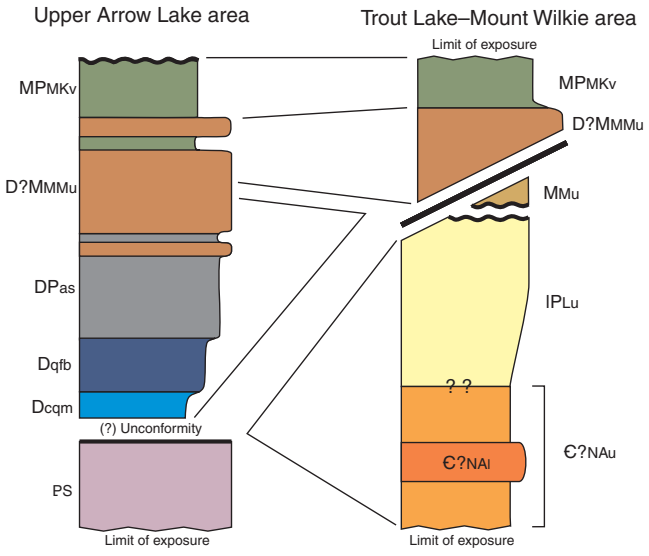


Figure 5. Schematic stratigraphic columns for the east shore of Upper Arrow Lake between Galena Bay and Nakusp, and the Trout Lake to Mount Wilkie area. Correlations and terminations of stratigraphy are indicated by the intermediate lines. Patterns and abbreviations as in Figure 2. Poor exposure allows that interleaving of MPMKv and D?MMMu along Upper Arrow Lake may be structural.

Correlation of unit A

The primary interests of 2006 field investigation were the contact relations of siliciclastic rocks in the Upper Arrow Lake to Mount Wilkie area that Roback et al. (1994) correlated with the McHardy assemblage. These rocks are designated unit A in this paper for clarity; the present authors use the term McHardy assemblage only for its type area south of Tenderfoot Lake as defined by Klepacki (1985). The conformable relationship of unit A with Middle Devonian units, and the Fammenian-Tournaisian conodonts recovered from it (Orchard, 1985), imply that its base is older than the Visean and younger Milford Group in the Goat Range (Orchard, 1985). Carbonaceous phyllite of unit A has been correlated with the Upper Devonian Bruen phyllite of the Eagle Bay assemblage in Vernon map area, which occupies the same stratigraphic position above amphibolitic schist (Thompson et al., 2006). The age of the top of unit A remains unknown, and hinges on the age of the overlying greenstone-diorite unit. That unit has been correlated with the Permian Kaslo Group (Hyndman, 1968; Read and Wheeler, 1976; Roback et al., 1994), but relations permit an age as old as late Devonian or early Mississippian. General stratigraphic consistency, the map pattern, and lithological similarities in numerous rock types are consistent with the interpretation that unit A represents a coherent succession, however Jurassic intrusions and poor exposure mask much of that unit. It is possible that better chronostratigraphic control might reveal the presence of a stratigraphic break within unit A, that would likely correspond to the Milford Group basal unconformity at Trout Lake.

Maps produced by Read (1973), Klepacki (1985), and Roback (1993) show upper phyllite and limestone of unit A and the overlying greenstone striking uninterrupted from Mount Wilkie southward into the McHardy assemblage and Kaslo Group, which would effectively prove the correlation of the top of unit A with McHardy assemblage. Mapping of this study supports extension of that phyllite and limestone package, in addition to underlying conglomerate, as far north as Galena Pass. That the base of the McHardy assemblage is a fault (Klepacki, 1985) allows the possibility that it was also deposited on the Chase and Silver Creek formation succession and has since been detached from its basement in the Goat Range. The Chase Formation quartzite, and possibly the amphibolitic schist outcrop beneath unit A at Tenderfoot Lake (Read, 1973; Lemieux, 2006; Thompson et al., 2006).

Differences in contact relations and disparities in strain and metamorphic grade between unit A and Milford Group strata at Trout Lake suggest some amount of separation at the time of deposition and during deformation; but, given that McHardy assemblage contains detritus derived from the Lardeau Group (Klepacki, 1985; Smith and Gehrels, 1992; Roback et al., 1994), correlation of McHardy assemblage with unit A of this study would imply stratigraphic linkage of the Chase and Silver Creek formations with the Milford and Lardeau groups.

Correlation of the Northeast Arm assemblage

Walker and Bancroft (1929) correlated some of the Northeast Arm assemblage units with the Badshot Formation and Hamill Group. Fyles and Eastwood (1962) were unable to confirm this correlation owing to differences in the stratigraphic sequence, and structural complexity, but did not rule it out. Strong similarities exist between Northeast Arm assemblage rock types and Fyles and Eastwood's (1962) descriptions of the Mohican, Badshot, and Index formations east of Ferguson. The assemblage of green and grey phyllite, metavolcanic rocks, conglomerate, and quartzite also resembles descriptions of the Index Formation in the northern Selkirk Mountains (Logan and Colpron, 2006). The present authors favour correlation with the Index Formation and suggest that the prominent grey limestone may correspond to the Lade Peak member. Lower buff dolomitic limestone might correspond to the Badshot Formation, and metavolcanic rocks along the transition between Northeast Arm assemblage and Broadview Formation may represent the Jowett Formation. If the (eastern) contact with the Broadview Formation is conformable, as reconnaissance suggests, the panel represents the western limb of the 'Lardeau synclinorium' (Walker and Bancroft, 1929), and the sequence faces east, although folding has likely locally reversed facing directions within the panel (Fig. 6).

The transition between Upper Arrow Lake and Trout Lake stratigraphy

This important contact occurs along the western limit of the Northeast Arm assemblage and of the Milford Group, to the north and south of the Mount Hadow stock, respectively (Fig 2). Interpreted ages and facing directions, and contrasts in structural style support a tectonic contact. The fault dips steeply to the northeast and only subtly truncates units on either side. It is folded with stratigraphy at Mount Sproat and is truncated by the Mount Hadow stock, indicating movement prior to mid-Jurassic deformation. It may join southward with a plugged fault at Mount Wilkie that Roback (1993) interpreted as juxtaposing the McHardy and Davis assemblages. The original fault, which may be transposed, is offset by younger, brittle faults such as the one observed in Northeast Arm. Correlation across the fault is possible in Mississippian units (*see* above).

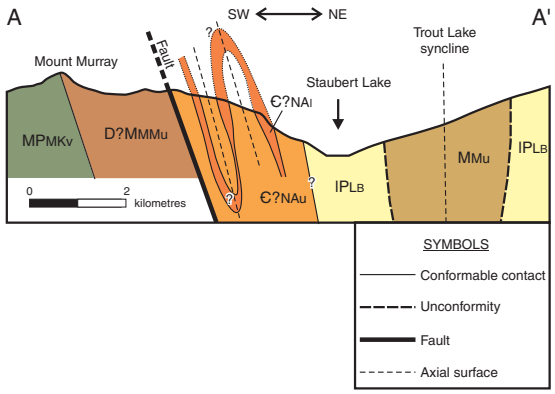


Figure 6. Natural-scale cross-section A-A' perpendicular to regional strike illustrates the attitude of units northeast of the Kuskanax batholith. Repetition of stratigraphy in the Northeast Arm assemblage suggests folding of the limestone member as shown. *See* Figure 2 for location, patterns, and abbreviations, except: IPLB = Broadview Formation (Lardeau Group).

Implications for the Milford Group

Investigations in 2006 indicate that DevonianMississippian strata of unit A were deposited atop a foundering Devonian platformal succession (the Chase and Silver Creek formations; Thompson et al. (2006)). The new data support existing correlations of younger strata in unit A with the McHardy assemblage of Milford Group (Read, 1973; Read and Wheeler, 1976; Klepacki, 1985; Roback, 1993), thus the McHardy assemblage and overlying greenstone would have been deposited on Devonian continental strata of the Eagle Bay basin, and not on oceanic crust as inferred by Klepacki (1985) and Roback et al. (1994). Geological relations at Upper Arrow Lake are consistent with correlation of the Milford Group with part of the Eagle Bay assemblage and support the hypothesis that Upper Devonian and Mississippian units from the Eagle Bay assemblage, the unit A used in this paper, and in the Goat Range record eastward transgressive onlap of those sediments from the Eagle Bay basin onto the Lardeau Group by Middle Mississippian time (Orchard, 1985).

CONCLUSIONS

The succession along the eastern shore of Upper Arrow Lake, from Galena Bay to Ione Falls, represents a stratigraphic sequence from the mid-Devonian Chase Formation quartzite to Early Mississippian and possibly younger siliciclastic and mafic volcanic rocks. Compilation of new and existing maps supports the existing interpretation that

younger members of the Upper Arrow Lake sequence may be traced into the type area of the McHardy assemblage, but the correlation remains to be tested. Map relations indicate that rocks along Upper Arrow Lake that have been correlated with the Milford (McHardy assemblage) and Kaslo groups depositionally overlie continental strata that are correlated with the Chase and Silver Creek formations. The strata at Upper Arrow Lake were likely faulted against the Lardeau Group and Davis assemblage during Jurassic (and possibly earlier) contraction.

A thick assemblage of green and grey phyllite, limestone, mafic volcanic rocks, and white quartzite that outcrops west of Trout Lake and Beaton has been distinguished from the adjacent Broadview Formation. The authors favour correlation of this 'Northeast Arm assemblage' with the Index Formation, and perhaps the Badshot Formation also.

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REFERENCES

Colpron, M. and Price, R.A.
1995: Tectonic significance of the Kootenay terrane, southeastern Canadian Cordillera: an alternative model; Geology, v. 23, p. 25–28.

Fyles, J.T. and Eastwood, G.E.P.
1962: Geology of the Ferguson area, British Columbia; British Columbia Department of Mines and Petroleum Resources, Bulletin 45, 97 p.

Hedley, M.S.
1955: Lead-zinc deposits of the Kootenay Arc; Western Miner, July, p. 31–35.

Hyndman, D.W.
1968: Petrology and structure of the Nakusp map-area, British Columbia; Geological Survey of Canada, Bulletin 161, 95 p.

Klepacki, D.W.
1985: Stratigraphy and structural geology of the Goat Ranges area, southeastern British Columbia; Ph.D. thesis, Massachusetts Institute of Technology, Boston, Massachusetts, 268 p.

Lane, L.S.
1984: Brittle deformation in the Columbia River fault zone near Revelstoke, southeastern British Columbia; Canadian Journal of Earth Sciences, v. 21, p. 584–598.

Lemieux, Y.
2006: Structure, geochronology and thermobarometry of the eastern flank of the Shuswap metamorphic complex in the Upper Arrow Lake area, southeastern British Columbia; Ph.D. thesis, University of Alberta, Edmonton, Alberta, 172 p.

Lemieux, Y., Thompson, R.I., and Erdmer, P.
2003: Stratigraphy and structure of the Upper Arrow Lake area, southeastern British Columbia: new perspectives for the Columbia River fault zone; Geological Survey of Canada, Current Research 2003-A7, 9 p.
2004: Stratigraphic and structural relations across the Columbia River fault zone, Vernon and Lardeau map areas, British Columbia; Geological Survey of Canada, Current Research 2004-A3, 8 p.

Logan, J.M. and Colpron, M.
2006: Stratigraphy, geochemistry, syngenetic sulphide occurrences and tectonic setting of the lower Paleozoic Lardeau Group, northern Selkirk Mountains, British Columbia; *in* Paleozoic Evolution and Metallogeny of Pericratonic Terranes at the Ancient Pacific Margin of North America, Canadian and Alaskan Cordillera, (ed.) M. Colpron and J.L. Nelson; Geological Association of Canada, Special Paper 45, p. 361–382.

Okulitch, A.V.
1979: Lithology, stratigraphy, structure and mineral occurrences of the Thompson-Shuswap-Okanagan area, British Columbia; Geological Survey of Canada, Open File 637, scale 1:250 000.

Orchard, M.J.
1985: Carboniferous, Permian and Triassic conodonts from the central Kootenay Arc, British Columbia: constraints on the age of the Milford, Kaslo and Slocan groups; *in* Current Research, Part A; Geological Survey of Canada, Paper 85-1A, p. 287–300.

Read, P.B.
1973: Petrology and structure of Poplar Creek map-area, British Columbia; Geological Survey of Canada, Bulletin 193, 144 p.
1975: Lardeau Group, Lardeau map-area, west half (82K west half), British Columbia; *in* Report of Activities, Part A; Geological Survey of Canada, Paper 75-1, p. 29–30.
1976: Lardeau map area (82K west half), British Columbia; *in* Report of Activities, Part A; Geological Survey of Canada, Paper 76-1, p. 95–96.
1977: Lardeau map-area, British Columbia; *in* Report of Activities, Part A; Geological Survey of Canada, Paper 77-1A, p. 295–296.

Read, P.B. and Brown, R.L.
1981: Columbia River fault zone: southeastern margin of the Shuswap and Monashee complexes, southern British Columbia; Canadian Journal of Earth Sciences, v. 18, p. 1127–1145.

Read, P.B. and Wheeler, J.O.
1976: Geology of the Lardeau west-half map-area, British Columbia; Geological Survey of Canada, Open File 432, scale 1:250 000.

Roback, R.C.
1993: Late Paleozoic to Middle Mesozoic tectonic evolution of the Kootenay Arc, northeastern Washington and southeastern British Columbia; Ph.D. thesis, University of Texas, Austin, Texas, 237 p.

Roback, R.C., Sevigny, J.H., and Walker, N.W.
1994: Tectonic setting of the Slide Mountain terrane, southern British Columbia; Tectonics, v. 13, p. 1242–1258.

Ross, J.V.
1970: Structural evolution of the Kootenay Arc, southeastern British Columbia; *in* Structure of the Southern Canadian Cordillera, (ed.) J.O. Wheeler; Geological Association of Canada, Special Paper 6, p. 53–65.

Smith, M.T. and Gehrels, G.E.
1992: Structural geology of the Lardeau Group near Trout Lake, British Columbia: implications for the structural evolution of the Kootenay arc; Canadian Journal of Earth Sciences, v. 29, p. 1305–1319.

Thompson, R.I.
1978: Geology of the Akolkolex River area; British Columbia Ministry of Energy, Mines and Petroleum Resources, Bulletin 60, 77 p.

Thompson, R.I., Glombick, P., Acton, P.S., Heaman, L., Friedman, R., Daughtry, K.L., Erdmer, P., and Paradis, S.
2002: New constraints on the age and distribution of the Chase quartzite, Vernon (82L) and Lardeau (82K) map areas: regional implications; Slave-Northern Cordilleran Lithospheric Evolution (SNORCLE) Transect and Cordilleran Tectonics Workshop Meeting, LITHOPROBE Report No. 82, p. 91–94.

Thompson, R.I., Glombick, P., Daughtry, K.L., and Erdmer, P.
2001: Upper Paleozoic stratigraphic linkage between Kootenay Arc and "Vernon antiform": new constraints on southern Canadian Cordilleran evolution; Slave-Northern Cordilleran Lithospheric Evolution (SNORCLE) Transect and Cordilleran Tectonics Workshop Meeting, Programs with Abstracts, LITHOPROBE Report No. 79, p. 104–105.

Thompson, R.I., Glombick, P., Erdmer, P., Heaman, L.M., Lemieux, Y., and Daughtry, K.L.
2006: Evolution of the ancestral Pacific margin, southern Canadian Cordillera: insights from new geologic maps; *in* Paleozoic Evolution and Metallogeny of Pericratonic Terranes at the Ancient Pacific Margin of North America, Canadian and Alaskan Cordillera, (ed.) M. Colpron and J.L. Nelson; Geological Association of Canada, Special Paper 45, p. 435–484.

Thompson, R.I., Kraft, J., and Lemieux, Y. (comp.)
in press a: Geology, Beaton, British Columbia; Geological Survey of Canada, Open File 4397, scale 1:50 000.
in press b: Geology, Camborne, British Columbia; Geological Survey of Canada, Open File 4398, scale 1:50 000.
in press c: Geology, Trout Lake, British Columbia; Geological Survey of Canada, Open File 4396, scale 1:50 000.

Walker, J.F. and Bancroft, M.F.
1929: Lardeau map-area, British Columbia: general geology; *in* Lardeau Map-area, British Columbia, (ed.) J.F. Walker and H.C. Gunning; Geological Survey of Canada, Memoir 161, p. 1–16.

Wheeler, J.O.
1968: Lardeau (west-half) map-area, British Columbia (82K west-half): Geological Survey of Canada, Paper 68-1, p. 56–58.

Geological Survey of Canada Project X94