Origin of the Kootenay Lake Metamorphic High, Southeastern British Columbia

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INTRODUCTION

A narrow, elongate region of anomalously high metamorphic grade runs parallel to Kootenay Lake, in the central part of the Kootenay Arc, southeastern British Columbia. Metamorphic grade ranges from the chlorite/biotite zones on the flanks to the sillimanite+K-feldspar zone in the centre of the high. In this paper, we present a summary of structural, metamorphic and geochronological data and discuss the origin of this pattern. It is suggested that the metamorphic high results from differential exhumation during early Tertiary extensional deformation.

Background Geology

The Kootenay Arc is a narrow, curvilinear, metamorphosed and polydeformed region straddling the boundary between rocks formed on the North American continental margin and those developed in an oceanic setting to the west (Klepacki, 1985; Colpron and Price, 1995; Thompson et al., 2007). It extends in an eastward-convex arch from northern Washington State to Revelstoke, BC, and lies on the western flank of the Purcell Anticlinorium, an area characterized by open folds of Mesoproterozoic to Neoproterozoic strata. The transition from the Purcell Anticlinorium into the Kootenay Arc is characterized by an increase in metamorphic grade and complexity of deformation, and a decrease in stratigraphic age (Warren, 1997).

Neoproterozoic to Triassic metasedimentary and metavolcanic rocks host numerous Middle Jurassic (ca. 165 Ma) and mid-Cretaceous (ca. 115–100 Ma) granitic plutons and minor intrusive bodies (Fig 1). The oldest units are the quartzite-dominated Hamill Group and the carbonate Badshot-Mohican Formation. These are similar to coeval strata in the Purcell and Rocky mountains, whereas the overlying Lardeau Group differs from rocks of similar age farther east (Colpron and Price, 1995). The Lardeau Group comprises black, grey and green schist, argillite, calcsilicate and quartzofeldspathic gneiss, marble, quartzite, metaconglomerate and metabasite (Fyles, 1967; Hoy, 1980). It is unconformably overlain by the Milford Group, which includes marble, siliceous argillite, schist and chert. This is followed by the Kaslo Group, a package of mafic volcanic and volcaniclastic rocks. The youngest unit, the Slocan Group, is dominated by argillite and limestone. A summary of rock types and their ages is included in Figure 1.

There is a general westward-younging trend in the rock units across the Kootenay Arc. This is partly due to a series of subparallel normal faults mapped by Fyles (1967) on the west side of Kootenay Lake. Three major west-dipping faults were recognized. From east to west, these are the Lakeshore, Josephine and Gallagher faults (Fig 1, 2). The Schroeder fault is probably a continuation of the Lakeshore fault north of Kaslo (Klepacki, 1985).

The Middle Jurassic plutonic suite is represented by the calcalkaline Nelson batholith and associated minor bodies. The Nelson batholith is an 1800 km^2 body intruded during the interval 173 to 159 Ma (Ghosh, 1995). It ranges in composition from diorite to granite, but is dominated by porphyritic hornblende granodiorite. The Nelson batholith is unaffected by ductile deformation, except for narrow zones along its eastern margin and southern tail. It is truncated on its western margin by the Eocene Slocan Lake (normal) fault (Carr et al., 1987), but an intrusive margin is preserved along much of its eastern boundary. A contact metamorphic aureole is locally well developed around its intrusive margins (Pattison and Vogl, 2005).

The second major plutonic suite was intruded during the interval 117 to 100 Ma. Rock types include hornblende and biotite granodiorite, biotite granite and two-mica granite, which are interpreted to have been derived from crustal anatexis (Brandon and Lambert, 1993). The largest bodies of this age in the area are the Fry Creek and Bayonne batholiths, which are for the most part undeformed. Deformed equivalents include the Baldy pluton and numerous minor sheet-like bodies in higher grade areas. Locally, igneous sheets make up a high percentage of the country rock, resulting in gradational margins to parts of the Baldy pluton, the Proctor pluton and the Shoreline stock.

STRUCTURAL RELATIONS

Deformations D_1 and D_2

The outcrop pattern in the central Kootenay Arc is dominated by two generations of regionally developed folds (Fig 1, 2; Fyles, 1964, 1967; Hoy, 1980; Leclair, 1988). The earliest folds are a series of high-amplitude isoclines with an axial-planar schistosity containing a gently plunging stretching lineation. The most clearly defined F_1 folds are westward-closing recumbent anticlines

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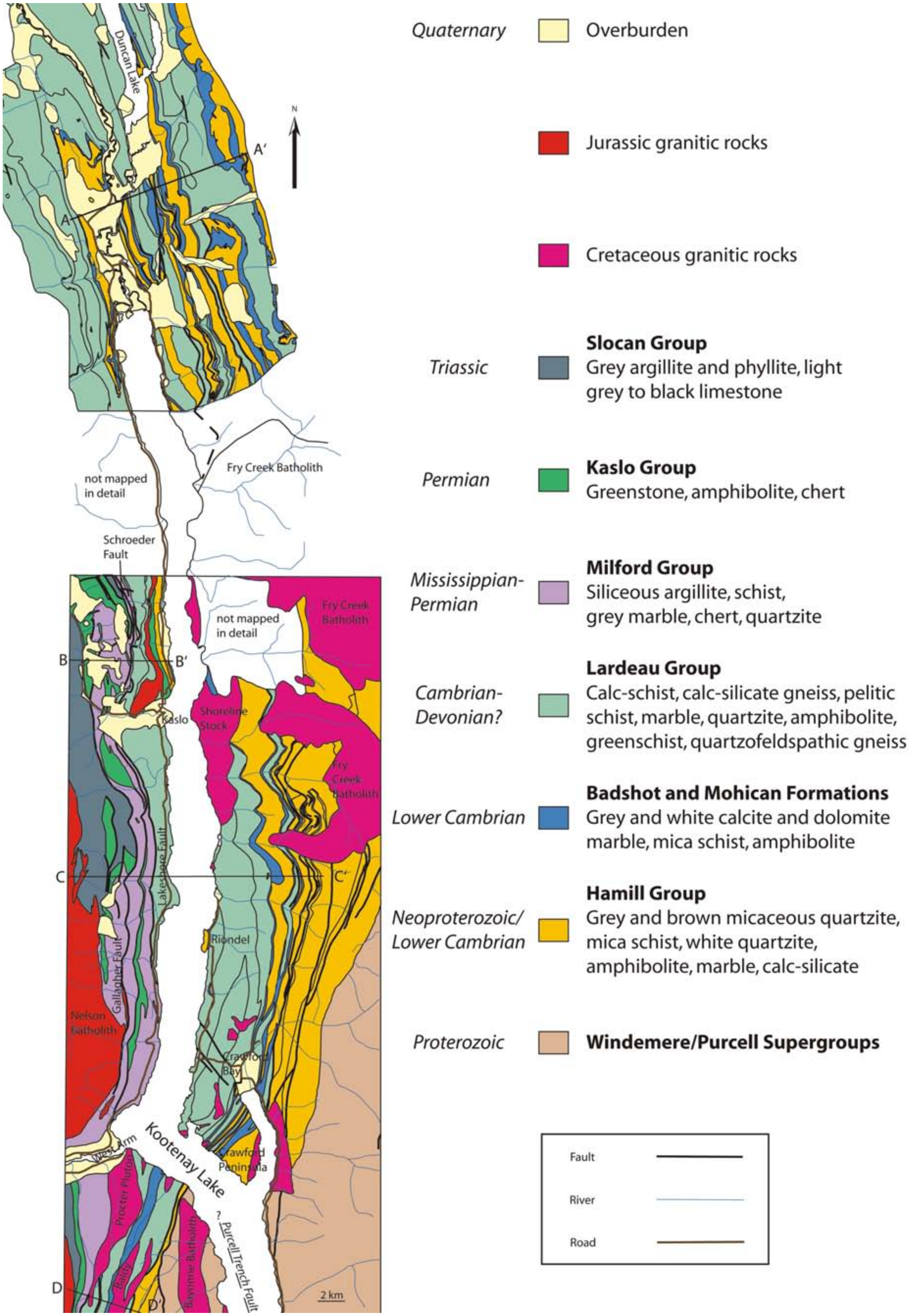

Figure 1. Geology of the central Kootenay Arc, compiled *from* Fyles (1964) and Reesor (1996). The lines of cross-sections shown in Figure 2 are displayed.

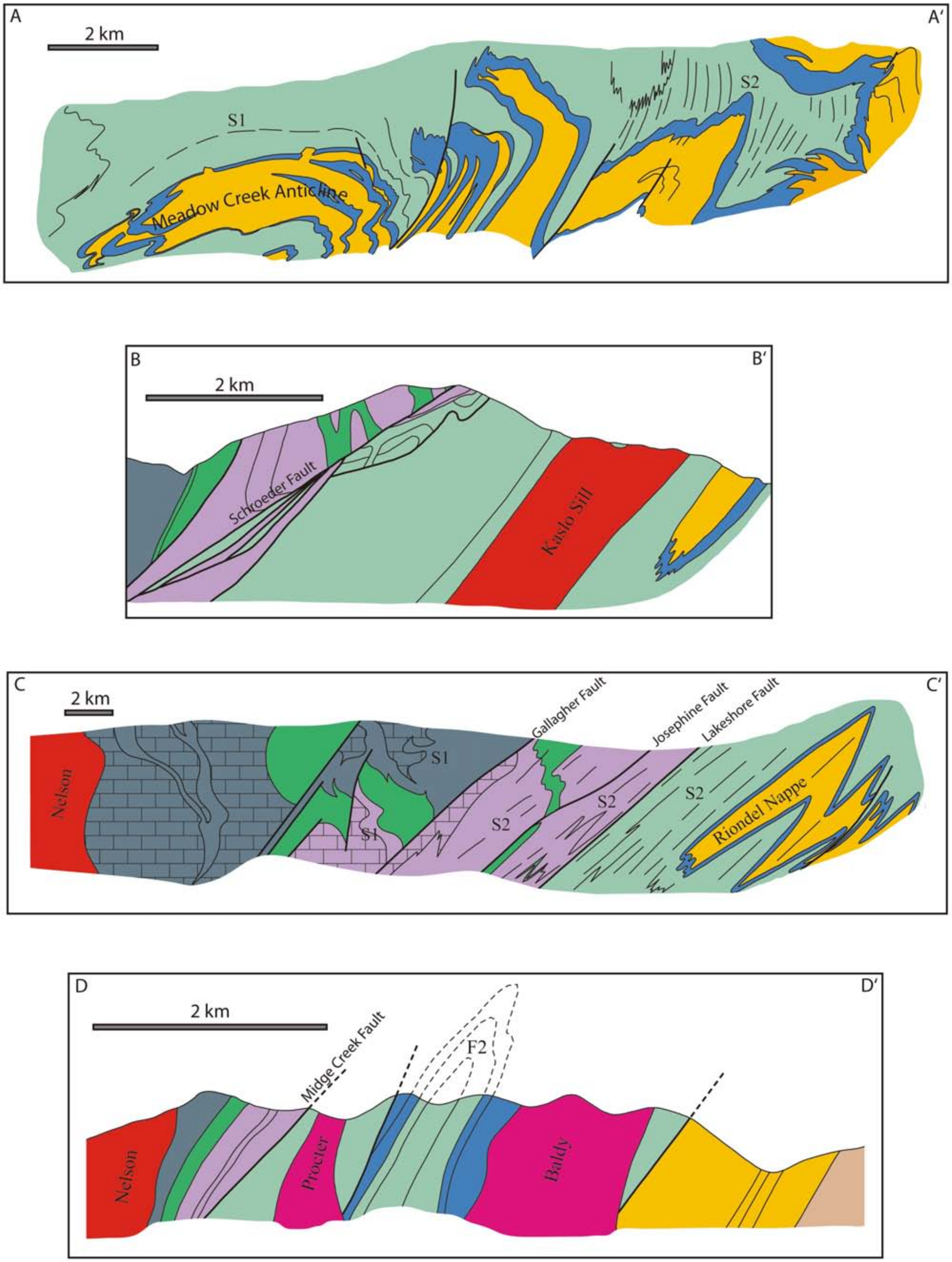

Figure 2. Vertical cross-sections across the central Kootenay Arc *from* Fyles (1964; A–A'), Klepacki (1985; B–B'), Brown et al. (1981; C–C') and Leclair (1988; D–D'). No vertical exaggeration. The lines of section are shown in Figure 1.

cored by the Hamill Group. The largest of these, the Riondel nappe (equivalent to the Meadow Creek anticline in the Duncan Lake area), has a 20 km long overturned lower limb (Fig 2a, c). Folds with similar geometry and characteristics are also developed in the Mesozoic strata exposed west of Kootenay Lake, but their full definition is hindered by a lack of continuous marker horizons. The main body of the Nelson batholith is undeformed, but foliated minor bodies of approximately the same age indicate the age of D_1 is Middle Jurassic (Warren, 1997).

The F_1 isoclines were coaxially refolded around gently plunging F_2 axes, giving rise to a type 3 interference pattern (Ramsay, 1967). Second-generation (F_2) axial planes generally dip gently to moderately steeply to the west, but steepen towards higher structural levels in the Purcell Anticlinorium (Hoy, 1980). The F_2 axes plunge gently north over most of the area, as do L_2 stretching (mineral and elongation) lineations, resulting in exposure of progressively lower structural levels towards the south.

There is spatial variation in the intensity of D_2 deformation. In the northern part of the area, and west of the Gallagher fault (i.e., at higher structural levels), F_2 folds are open to close, and are outlined by S_1 and transposed S_0. Second-phase schistosity (S_2) commonly forms a crosscutting spaced or crenulation cleavage, but rarely forms the dominant schistosity in the rock. Minor F_2 folds have curvilinear hinges, which locally diverge slightly from the trend of the L_2 stretching lineation. East of the Gallagher fault in the southern part of the area (lower structural levels), D_2 folds are tight to isoclinal and S_2 forms a continuous schistosity; S_1 is unrecognizable outside of the hinge zones of competent layers. Second-generation (F_2) fold hinges are rectilinear and are invariably parallel to the well-developed L_2 stretching lineation. Low-angle cutoffs and discontinuous lithological sequences indicate local transposition of primary compositional layering parallel to S_2. The tighter folds, straightening of fold hinges, and parallelism between fold axes and the stretching lineation are manifestations of higher D_2 strain. There is, therefore, a broad correspondence between structural level and intensity of D_2. This variation is evident across the normal faults (particularly the Gallagher and Schroeder faults) on the west side of Kootenay Lake (Fig 2). In the hangingwall of the Gallagher fault, S_1 is the dominant planar fabric and it is folded by open F_2 folds; S_1 is truncated against the fault. In the footwall, F_2 folds are tighter and S_2 is well developed.

The 115 Ma Fry Creek batholith (Brandon and Lambert, 1993) truncates D_2 folds and fabrics in the eastern part of the Riondel area. However, the northern part of the 117 Ma Baldy pluton is deformed by D_2 structures (Leclair, 1988). Although D_2 is ostensibly mid-Cretaceous, the possibility that D_2 is diachronous and/or composite cannot be ruled out.

Deformation D_3

First (D_1) and second-generation (D_2) structures share common characteristics for great lengths along strike, and have been tentatively correlated along much of the arc, from Salmo to the central Lardeau area (Fyles, 1967). This along-strike continuity contrasts with the distribution of later (D_3) structures. There is a change in the nature of D_3 deformation around the latitude of the West Arm (Fig 1), where the trend of Kootenay Lake changes from south to south-southeast. Two distinct styles of later (D_3) deformation are evident; these are referred to as D_{3N} and D_{3S} (subscripts ‘N’ and ‘S’ stand for north and south, respectively). Although described in sequence here, no age relationship between the two is implied.

DEFORMATION D_{3N}

In the central and northern parts of the area, east of the Gallagher and Schroeder faults, shear bands are variably but ubiquitously developed in micaceous horizons (Fig 3a, b). Shear bands cut down to the west more steeply than S_2 foliation, and bound lenses of rock that display sigmoidal deflections of S_2 foliation into the shear bands. The L_2 stretching lineation is folded around the open (F_{3N}) hinges. The shear bands range from sharp (commonly chlorite-rich) cleavage-forming surfaces with discrete offsets, to broader, more diffuse, inclined shear zones. These fabrics are referred to as S-C’ fabric, extensional crenulation cleavage or shear band foliation (Platt and Vissers, 1980; Ponce de Leon and Chouckroune, 1980; White et al., 1980), and record extension of S_2 during west-side-down ductile shearing (Williams and Price, 1990). Shear bands merge with S_2 and are laterally discontinuous. The shear bands and their associated folds/extensional crenulations impart an irregular, undulatory character to the S_2 surface; F_{3N} hinges have a preferred orientation, but they are discontinuous and non-cylindrical. Shear bands and associated folds are developed on a centimetre scale in pelitic layers, but metre-scale folds with the same geometry are also evident on the east shoreline of Kootenay Lake in the Riondel area (the F_3 warps of Livingstone, 1968 and Hoy, 1980). Hinges of F_{3N} folds and indistinct shear band — S_2 intersections plunge gently to moderately steeply southwest throughout the affected area. Third-generation deformation (D_{3N}) fabrics are restricted to the footwall of the Gallagher and Schroeder faults. They extend eastward from the fault a horizontal distance of >10 km (>5 km structural thickness), but much of the most intensely developed shear band foliation is found in the immediate footwall of the Gallagher fault.

The northwest margin of the mid-Cretaceous Fry Creek batholith is also affected by west-side-down ductile shearing (Fig 3d). Although the remainder of the batholith is undeformed, this zone displays S-C fabrics (Berthé et al., 1979). The affected area is along strike from a normal fault that truncates the Meadow Creek anticline, which itself lies within the region of diffuse west-side-down ductile shearing (Fig 2).

The Gallagher fault (and Schroeder fault further north) marks the upper (western) boundary of D_{3N} deformation; west-side-down S-C’ fabrics are not developed in the hangingwall to any significant degree. A broad region in the footwall is characterized by widespread, variably intense, ductile normal-sense fabrics accompanied by discrete normal faults. Although there is no direct evidence, the ductile fabrics and discrete faults are interpreted as having formed approximately synchronously, based on spatial distribution and kinematic compatibility.

DEFORMATION D_{3S}

Whereas D_{3N} resulted in extension of S_2, S_2 was shortened in the area affected by D_{3S}. Shortening is manifested in buckle folds and crenulations of S_2, with L_2 folded around hinges (Fig 3e, f). Third-generation (F_{3S}) buckles range from open to tight, and locally an axial-planar S_3 schistosity is developed. Third-generation (F_{3S}) folds plunge either

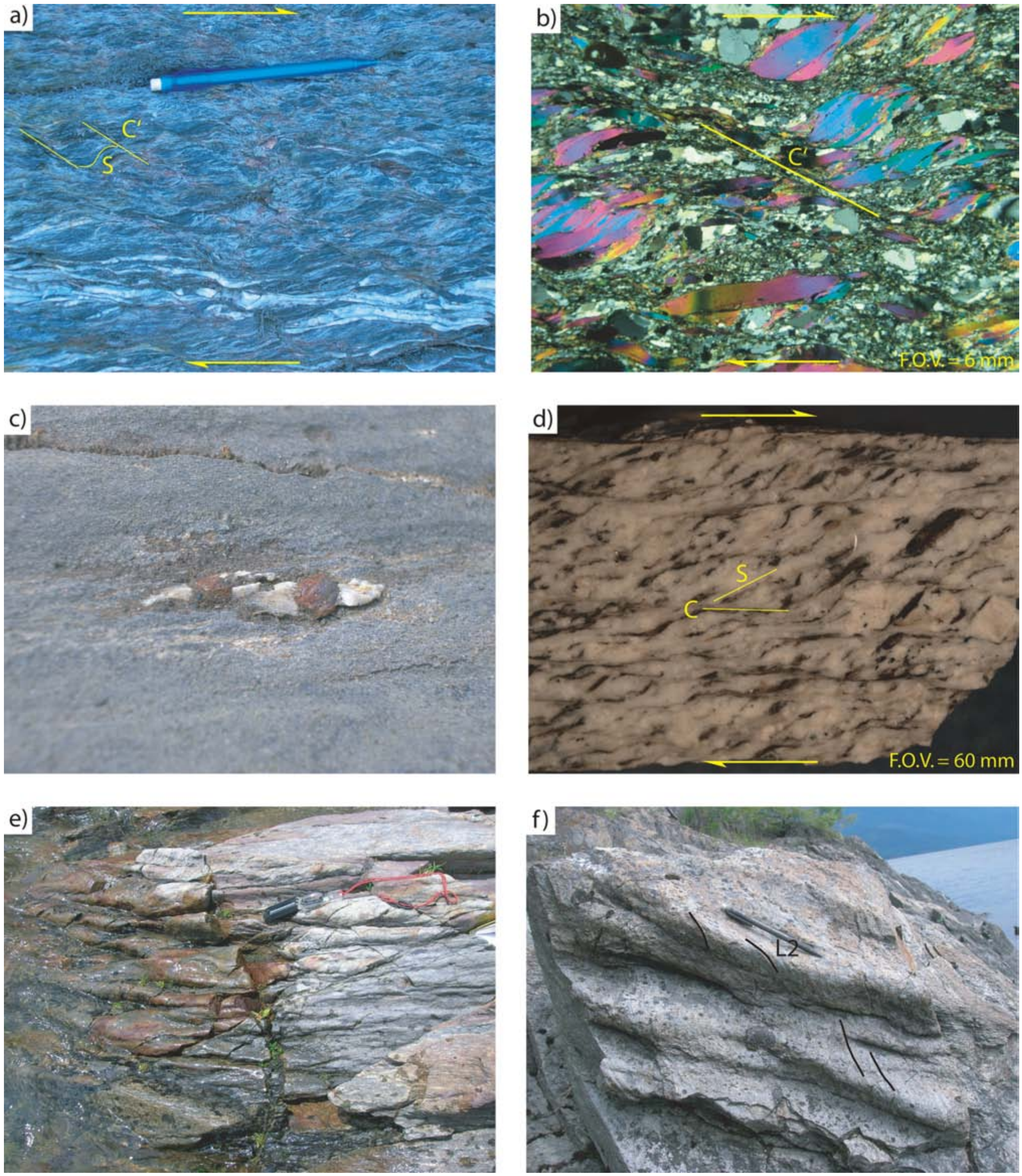

Figure 3. a) An example of S-C' fabric in Milford Group schist in the footwall of the Gallagher fault. b) Photomicrograph of S-C' fabric in Hamill Group schist, east side of Kootenay Lake. c) Subhorizontal stretching on S_1 is indicated by quartz-filled strain shadows on pyrite from the Slocan Group west of the Schroeder fault (width of photo is 5 cm). d) An example of S-C fabric indicating west-side-down shearing on the northwest margin of the Fry Creek batholith. e) Discontinuous F_{3S} hinges in the Hamill Group, Crawford Peninsula. f) Southwest-plunging F_{3S} folds showing steeply plunging L_2 passing around hinges.

southwest or northwest; over most of the Crawford Peninsula, F_3 folds plunge gently to the southwest (Fig 4). Axial planes dip moderately steeply northwest or southeast, depending on the orientation of the S_2–S_0 enveloping surface. Hinge lines of F_{3S} folds are curvilinear and discontinuous, unlike F_2 folds, which have cylindrical axes parallel to L_2. Third-generation (F_{3S}) folds range from centimetre-scale crenulations of micaceous layers and buckles of thin layers, up to folds with wavelengths >100 m. Deformation D_{3S} correlates with the D_3 of Leclair (1988) in the northern part of the Midge Creek area (south of the West Arm), and may continue further south.

RELATIONSHIP BETWEEN D_{3N} AND D_{3S}, AND TIMING OF D_3

The areas affected by D_{3N} and D_{3S} are approximately outlined in Figure 5. A question arises as to the timing relationship between D_{3N} and D_{3S}, and the reason for the change in the nature of D_3 around the bend in Kootenay Lake. Deformations D_{3N} and D_{3S} affect the same rock units. There is no difference in the nature of the layering that could lead to preferential development of buckles/shear bands in one area over the other. There is also no systematic difference in the orientation of the layering between the two areas. It is therefore concluded that there was spatial variation in the kinematics of D_3 deformation.

The location of the change between D_{3N} and D_{3S} — the bend in Kootenay Lake — coincides with the tip zone of the Purcell Trench fault, an Eocene extensional structure (Archibald et al., 1984; Doughty and Price, 1999). There is no reason why D_{3S} should be restricted to the tip zone of the fault, or that the change from D_{3N} to D_{3S} should occur at this location, unless the ductile D_{3S} deformation is genetically linked to the development of the Purcell Trench fault. As the age of the fault is known (Eocene), so is the age of D_{3S}. Given the relationship of D_{3N} to the early Tertiary Gallagher fault and the lack of overprinting relationships between D_{3N} and D_{3S}, this is most likely also the age of D_{3N}.

METAMORPHIC CONSIDERATIONS

The configuration of isograds based on the distribution of index minerals in pelitic rocks is shown in Figure 5. Pelitic layers are widely distributed, but they are commonly thin and discontinuous, and make up a small percentage of the rock volume. Their sparse occurrence in some areas introduces uncertainty into the exact position of isograds, but their wide distribution facilitates the recognition of trends in metamorphic grade. While future identification of important assemblages may locally shift the position of some isograds, the regional pattern is well established. Isograds south of the study area (in the southernmost part of Fig 5) are more poorly constrained.

Isograds run approximately parallel to strike along the central part of Kootenay Lake, but diverge from strike and converge in the northern Kootenay Lake – Duncan Lake area. South of the bend in Kootenay Lake, isograds also transect strike; they run approximately parallel to the Purcell Trench fault (PTF), which marks the eastern boundary of the Priest River complex (Doughty and Price, 1999). The amphibolite facies belt of central and northern Kootenay Lake is continuous with the Priest River complex. At the latitude of Creston, to the south, there is a gradual decrease in grade westward from the PTF, a pattern that likely continues northward towards the bend in the lake. North of here, the western boundary of the amphibolite-facies belt is for the most part fault-bounded, whereas there is a monotonic decrease in metamorphic grade on its east side, from the sillimanite+K-feldspar zone in the centre of the high to the biotite zone in the Purcell Anticlinorium. The highest grade rocks are >5 km east of the fault, around the shoreline of Kootenay Lake.

The Gallagher fault marks the western boundary of the Barrovian metamorphic high along the central part of Kootenay Lake, and it juxtaposes two contrasting metamorphic field gradients. Pelite in the footwall directly east of the fault contains garnet and staurolite, with kyanite in contemporaneous quartz-rich veins (Fig 6a). The fault marks the garnet and staurolite 'isograds'. Eastward from here, the grade increases, with pelitic rocks containing the assemblages garnet-staurolite-kyanite, garnet-kyanite, garnet-kyanite-sillimanite, garnet-sillimanite and garnet-sillimanite-K-feldspar (all with muscovite, biotite, quartz, plagioclase and accessory minerals). Porphyroblasts are wrapped by S_2, and elongate porphyroblasts (staurolite, kyanite, sillimanite) are aligned (L_2) parallel to D_2 fold axes. Deformation D_2 is mid-Cretaceous, and Leclair et al. (1993) also interpreted this as the age of peak metamorphism.

Rocks in the hangingwall of the fault record a different metamorphic history. At the latitude of Figure 2c, rocks in the hangingwall display a Buchan (low pressure) contact aureole sequence (Pattison and Vogl, 2005). Rocks immediately west of the fault are low-grade chlorite-muscovite-bearing phyllite; metamorphic grade increases towards the Nelson batholith, with hornfelsic biotite-staurolite-andalusite (±garnet) and biotite-sillimanite-garnet assemblages

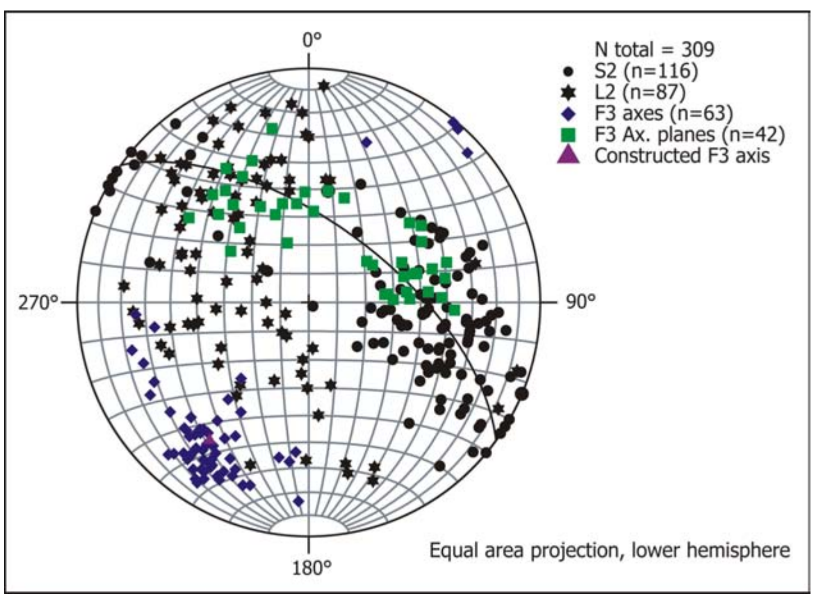

Figure 4. Structural data from the southwest-facing shoreline of the Crawford Peninsula, showing the folding of D_2 structures around F_{3S} axes.

developed close to its margin (Fig 6b). Southward from the latitude of Figure 2c, this low-pressure carapace (comprising the contact aureole and low-grade phyllite outside it) is progressively cut out by the Gallagher fault. It is absent from the easternmost part of the Nelson batholith, where the Gallagher fault separates deformed porphyritic granodiorite from Barrovian garnet-staurolite (+ vein kyanite)-bearing pelite.

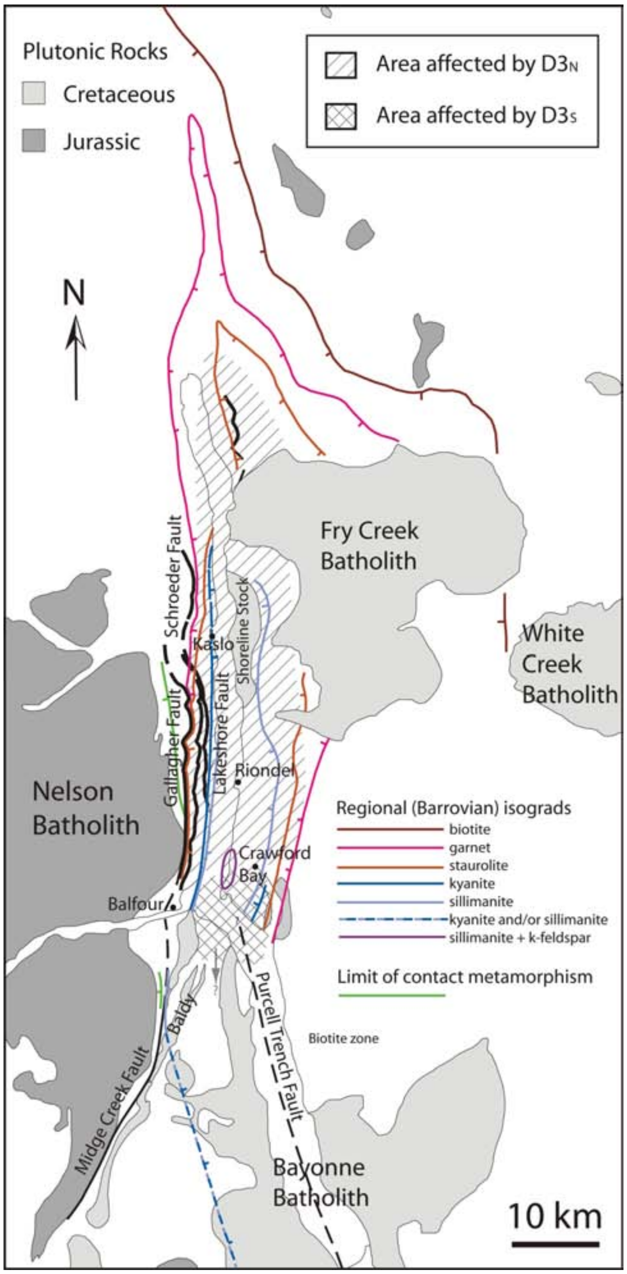

Figure 5. Isograd map of the central Kootenay Arc, compiled *from* Fyles (1964, 1967), Reesor (1973), Hoy (1980), Klepacki (1985), Leclair (1988) and new data. Ticks are on the high-grade side of the lines. Major normal faults are shown. The areas affected by D_{3N} and D_{3S} are approximately outlined, as are normal faults discussed in the text. Deformation D_{3S} correlates with the D_3 of Leclair (1988) in the northern part of the Midge Creek area (south of the West Arm), and may continue further south.

An appreciation for the significance of the metamorphic contrast across the Gallagher fault is gained by considering the pressure-temperature conditions under which assemblages on either side of the fault formed. Figure 7 displays the stable mineral assemblage as a function of pressure and temperature for a rock with the composition of an average pelite. The temperature ranges of the two sets of assemblages overlap, but there is a difference in pressure. Rocks in the contact aureole (hangingwall) were metamorphosed during the intrusion of the Nelson batholith at 3.5 to 4 kb, which is equivalent to approximately 12 to 14 km (for a crustal density of 2900 kg/m^3). Kyanite-bearing Barrovian rocks in the footwall were metamorphosed at approximately 7 kb, or a depth of around 25 km.

ARGON-ARGON GEOCHRONOLOGY

Archibald et al. (1984) carried out an extensive $^{40}Ar/^{39}Ar$ study concentrated on the southern-central part of the Kootenay Arc. They documented a trend whereby amphibolite-facies rocks in the centre of the metamorphic high yield early Tertiary mica cooling ages, whereas rocks in lower grade areas cooled earlier. North of the bend in Kootenay Lake, there is a monotonic rise in biotite cooling ages, from <55 Ma in the centre of the metamorphic high to >90 Ma in the central Purcell Anticlinorium (Fig 8). The western margin of the amphibolite-facies belt was not studied, but biotite from the main (mid-Jurassic) body of the Nelson batholith yielded Jurassic to early Cretaceous cooling ages, consistent with earlier studies.

Mathews (1983) dated samples along an east-west transect around the latitude of Figure 2c (Fig 9). Samples from the footwall of the Gallagher fault yielded $^{40}Ar/^{39}Ar$ ages of 59 Ma (muscovite) and 53 Ma (whole rock), whereas the lone hangingwall sample yielded a whole-rock cooling age of 131 Ma (early Cretaceous). The Purcell Trench fault also marks the locus of a discrete change in $^{40}Ar/^{39}Ar$ cooling ages. The difference in cooling ages across the Purcell Trench decreases from south to north, leading Archibald et al. (1984) to conclude that the fault dies out in the central Kootenay Lake region, around the inflection point in the lake.

DISCUSSION

The structural, metamorphic and geochronological evidence presented above reveals contrasts in the thermal and tectonic histories of rocks now exposed around central and northern Kootenay Lake. There is a systematic variation in structural, metamorphic and isotopic characteristics with structural level. Rocks from low structural levels, in the centre of the metamorphic high, apparently reached peak metamorphic conditions in the mid-Cretaceous and did not cool below 350°C (the closure temperature of muscovite) until the early Tertiary, when they were exhumed by D_3 extensional deformation. They record considerable D_2 strain, and experienced further ductile deformation during exhumation. Lower grade rocks at high structural levels were metamorphosed and cooled earlier, underwent mild D_2 deformation and did not experience D_3. The area west of the Gallagher fault was deformed and metamorphosed in the mid-Jurassic and cooled through the biotite closure temperature (~250°C) by the early Cretaceous. It has remained at high crustal levels since then, behaving as a relatively unmodified 'lid', while rocks at lower levels were metamorphosed and intensely deformed.

These different structural levels are juxtaposed across the Gallagher fault on the west flank of the amphibolite-facies belt. There is a discrete change in structural geology, in metamorphic grade and in $^{40}Ar/^{39}Ar$ cooling ages. This contrasts with the eastern margin, where there is a monotonic decrease in metamorphic grade and rise in cooling ages. This east-west asymmetry is a first-order characteristic of the metamorphic high and is interpreted to reflect the control of the Gallagher fault and related extensional structures on its structural, metamorphic and thermochronological architecture. In the Creston area, where the PTF marks the eastern margin of the Priest River complex, there is a similar, but reversed, east-west asymmetry in grade and cooling ages. The area south of the West Arm is a horst situated in the transfer zone between the two major faults. Early Tertiary extension did not just involve normal faulting; there was also widespread extensional shearing and folding around the tip zone of the PTF.

Given the significance of the Gallagher fault just north of the West Arm, and the close proximity of Barrovian and Buchan rocks along strike to the south (west of the Baldy pluton), the fault probably continues across the West Arm. One possibility is that it is represented by the Midge Creek fault, which separates the Lardeau and Milford groups and

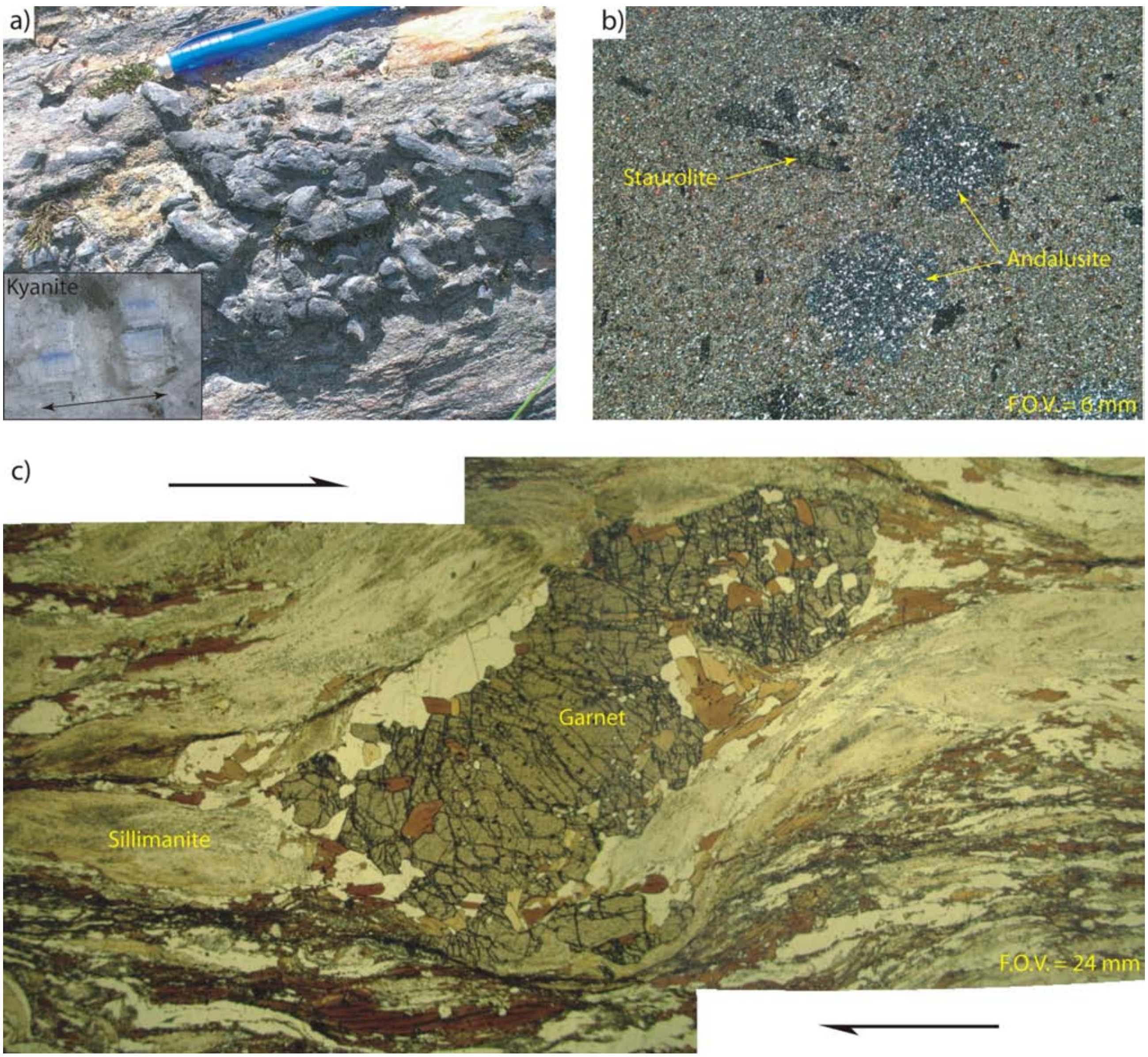

Figure 6. a) Staurolite porphyroblasts in garnet-staurolite schist directly east of the Gallagher fault (footwall). Kyanite is present in veins at this locality. Veins are synmetamorphic, as there is an increase in the abundance and size of porphyroblasts adjacent to vein boundaries. The kyanite is boudinaged, with a subhorizontal extension direction. b) Staurolite and andalusite porphyroblasts in contact metamorphosed pelite from the hangingwall of the Gallagher fault. This assemblage indicates metamorphism under significantly lower pressure conditions than the rock shown in a). c) Asymmetric strain shadows on garnet porphyroblast in garnet-sillimanite schist from the Rionde l area. Evidence for west-side-down shearing such as this is restricted to the Barrovian rocks in the footwall of the Gallagher fault.

lies between the contact aureole of the Nelson batholith and regional sillimanite zone rocks (Fig 2d). To the north, the staurolite isograd diverges from the trace of the Gallagher fault as the contrast in metamorphic grade across the fault decreases. Around Kaslo, staurolite and kyanite are restricted to the footwall of the Lakeshore-Schroeder fault, as are D_{3N} structures (Fig 5). As is the case with the Gallagher fault further south, the hangingwall contains low-grade phyllite, unaffected by $D_{3N.}$ It appears, therefore, that as the Gallagher fault dies out, the Schroeder fault becomes the major structure marking the western boundary of the metamorphic high. The relationship between isograds and faults cannot be documented in the Duncan Lake area due to the northward decrease in grade and the relative scarcity of indicative mineral assemblages.

Although there is a ~3 kb pressure difference between the contact aureole and kyanite-bearing rocks (equivalent to approximately 10 km), this cannot be translated into an estimate of vertical offset across the Gallagher fault. Assessment of displacement is complicated by uncertainty in the pressure difference across the fault itself, in the age(s) of Barrovian metamorphism and in the spacing of isobars in the footwall rocks.

There is a west to east increase in metamorphic grade in the immediate footwall of the Gallagher fault, and possibly also in the pressure of peak metamorphism. Rocks directly east of the fault (garnet-staurolite (+ vein kyanite)-bearing pelite) were metamorphosed in the kyanite field, but the pressure may not have been as high as in slightly higher grade rocks further east. This issue will be clarified with future detailed petrological study. Low-grade phyllite outside the contact aureole of the Nelson batholith was regionally metamorphosed prior to the intrusion of the batholith. If the amphibolite-facies Barrovian metamorphism is a similar age, exhumation prior to the intrusion of the Nelson batholith could account for much of the observed pressure difference. However, Leclair et al. (1993) presented evidence for a mid-Cretaceous age for Barrovian metamorphism in the sillimanite zone. If Barrovian metamorphism is mid-Cretaceous directly east of the fault, this

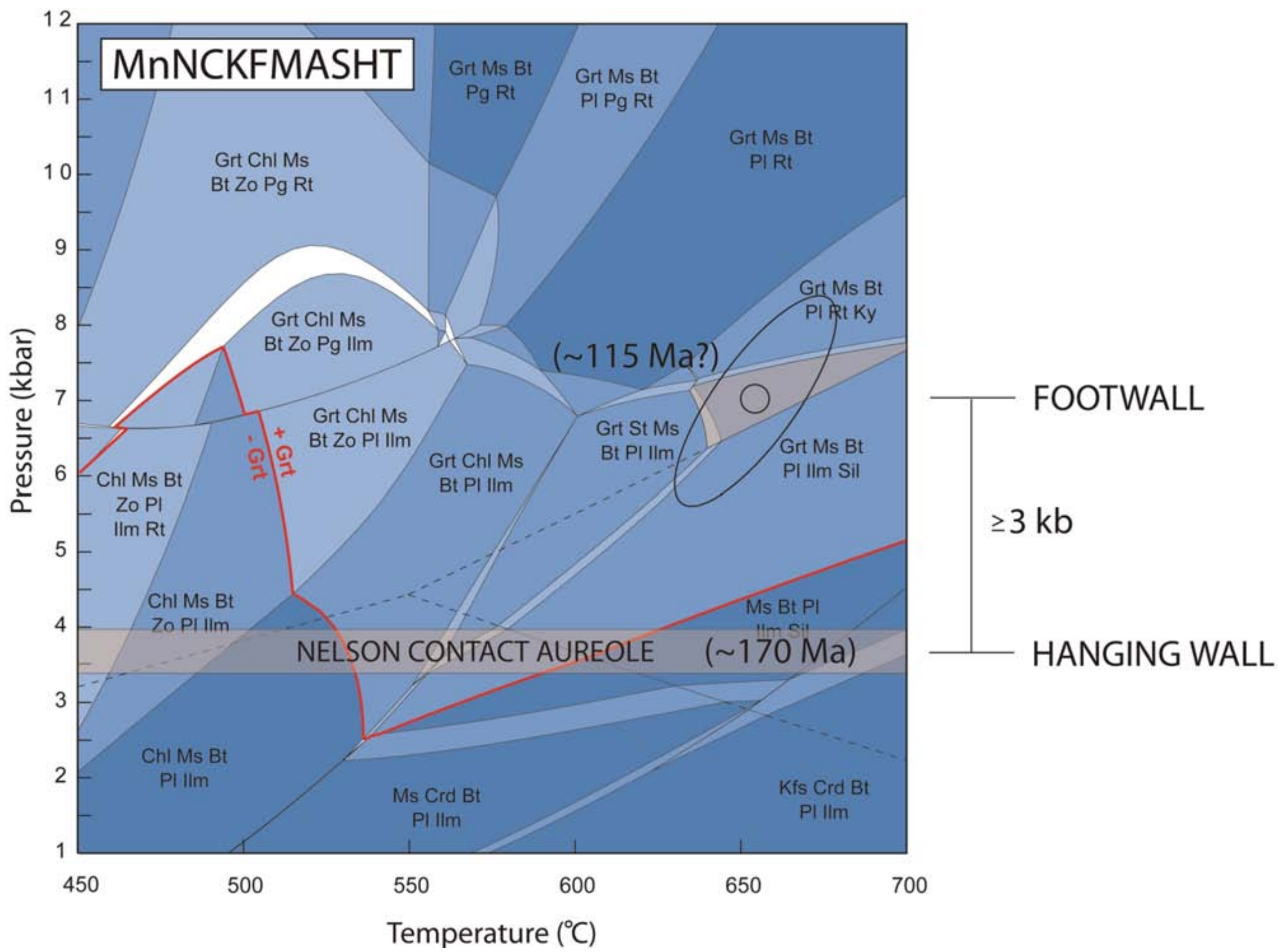

Figure 7. Mineral assemblage stability diagram for an average pelite composition *from* Tinkham and Pattison (pers comm, 2007). The lower shaded band indicates the pressure during contact metamorphism in the hangingwall of the Gallagher fault. The upper shaded areas are the garnet-staurolite-kyanite and garnet-kyanite fields (each with quartz, muscovite, biotite, plagioclase and ilmenite). These assemblages are developed in the footwall of the Gallagher fault and indicate pressures approximately 3 kb higher than those in the hangingwall. This is equivalent to a difference in burial depth of ~10 km. Also shown is a Thermocalc (Powell and Holland, 1988) average P-T estimate (with 2σ error ellipse) from a garnet-staurolite-kyanite schist collected close to the Lakeshore fault northwest of the Riondel nappe. Contact metamorphism accompanied the intrusion of the Nelson batholith around 170 Ma, whereas Barrovian metamorphism probably took place in the mid-Cretaceous.

rules out pre-Nelson batholith exhumation, and appears to require a much larger offset on the fault. Planned U-Pb dating will clarify the age(s) of peak metamorphism throughout the Barrovian sequence.

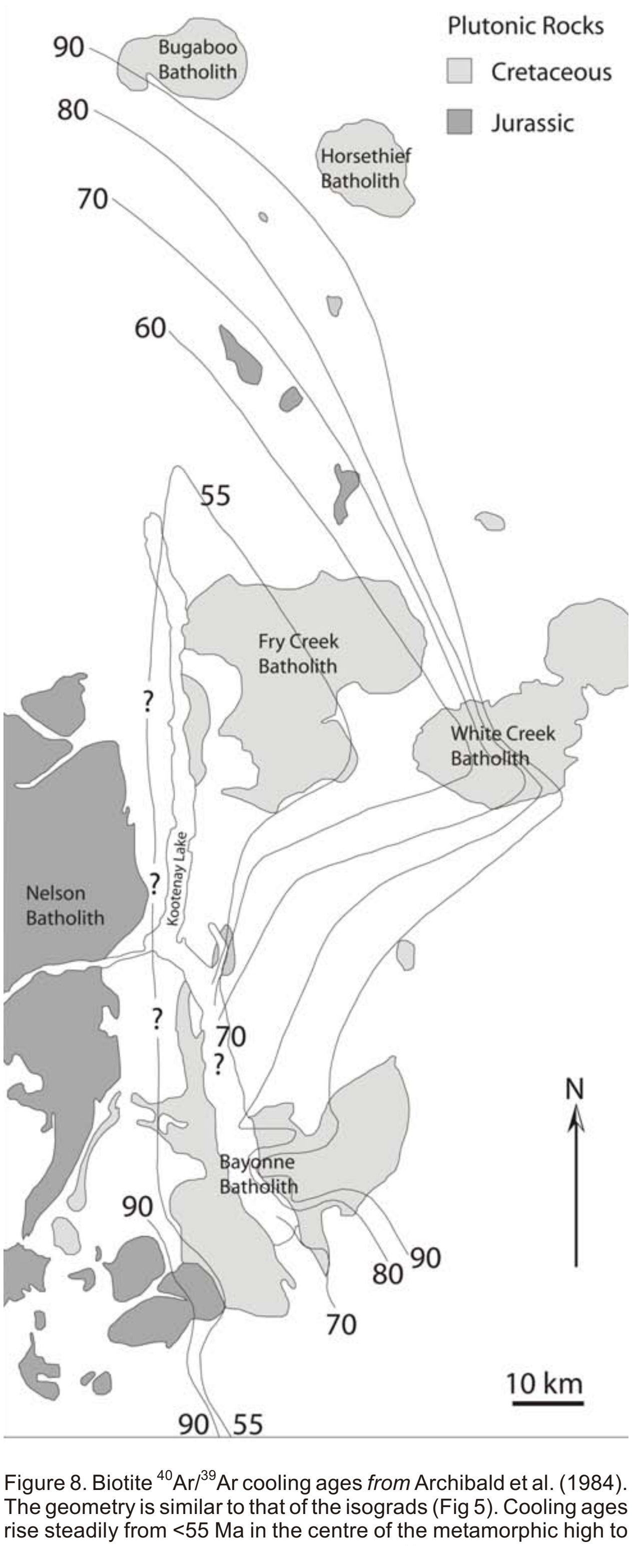

Figure 8. Biotite $^{40}Ar/^{39}Ar$ cooling ages *from* Archibald et al. (1984). The geometry is similar to that of the isograds (Fig 5). Cooling ages rise steadily from <55 Ma in the centre of the metamorphic high to >90 Ma in the Purcell Anticlinorium. The difference in cooling ages across the Purcell Trench decreases northward towards the bend in Kootenay Lake, where the Purcell Trench fault dies out and the Gallagher fault becomes the main extensional structure.

Aside from uncertainties in the peak metamorphic pressure profile and age(s) of Barrovian metamorphism, the use of metamorphic pressure contrasts to infer displacement is potentially problematic. Another complicating factor that must be considered is the possibility of late-D_2 deformation of isobars and isograds. As isobars and isograds behave as passive markers in the rock after peak metamorphic quenching, post-peak metamorphic (late D_2) thinning could have resulted in telescoping of isobars, thereby reducing the amount of offset required on the Gallagher fault to account for the observed pressure difference. Although the Gallagher fault represents a major geological discontinuity, the fact that isograds diverge from the fault trace south of Kaslo provides support for a relatively conservative estimate.

CONCLUSIONS

The metamorphic high in the central Kootenay Arc results from differential exhumation during early Tertiary extensional deformation. Deformation involved discrete faulting and ductile footwall strain. North of the bend in Kootenay Lake, the amphibolite-facies belt is fault-bounded on its west side; south of the bend it is fault-bounded on the east side. The bend in the lake marks the area where extensional strain was transferred from the Purcell Trench fault to the Gallagher-Schroeder fault system. Normal faulting was accompanied by west-side-down shearing and extension of S_2 in the footwall north of the bend, whereas S_2 was simultaneously buckled around the tip zone of the Purcell Trench fault. Normal faulting and related shearing has juxtaposed rocks with different structural and P-T-t histories.

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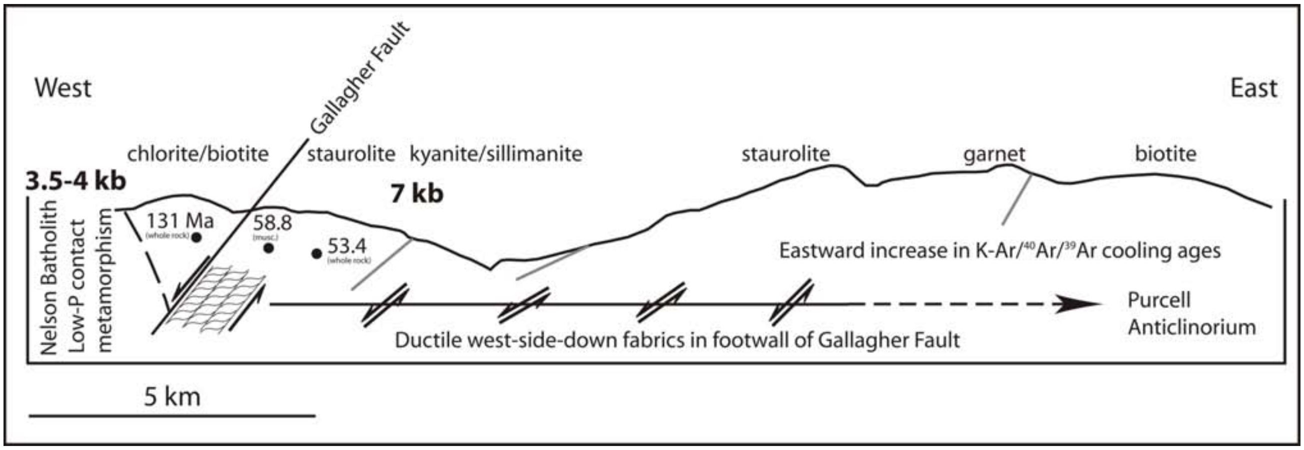

Figure 9. Cross-section across the central part of the Kootenay Arc, showing the data of Mathews (1983) in relation to the Gallagher fault, and emphasizing the asymmetry in the distribution of metamorphic grade and cooling ages. There is a sharp break in grade, structures and cooling ages across the fault, whereas the east side of the high is characterized by gradational changes in grade and cooling ages.

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