Boundary Project: Rock Creek Area (NTS 082E/02W, 03E), Southern British Columbia

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KEYWORDS: Quesnellia, Knob Hill Complex, Anarchist schist, Brooklyn Formation, Rock Creek

INTRODUCTION

The Boundary Project was initiated in 2005 with the purpose of better characterizing the lithological and geochemical variations within and between the various Paleozoic sequences in the southern Okanagan region along the Canada-United States border. These occur within Quesnel Terrane, which is dominated by Paleozoic mafic volcanic and pelitic rocks, unconformably overlain by Triassic and Jurassic volcanic and sedimentary rocks. In the Boundary District, such sequences include the Knob Hill Complex, Attwood Formation, Kobau Group and the Anarchist schist. These are exposed between downfaulted blocks of Tertiary volcanic and sedimentary cover preserved in structural keels between gneissic domes (Fig 1). In 2006, fieldwork was concentrated in the Rock Creek and Johnstone Creek areas, south and west of the Kettle River valley (NTS 082E/02W, 03E).

Six weeks of fieldwork in 2006 were primarily conducted in the area south of Rock Creek and in the Johnstone Creek area, west of the Kettle River and as far north as Conkle Lake. Sampling for geochemistry and geochronology was also carried out in the Greenwood area. Fieldwork was focused on

- new mapping in Rock Creek and Johnstone Creek areas in order to produce a new geological map of the southern Kettle River valley area and to contribute to a compilation map for the Greenwood sheet (Massey, 2007);
- collecting geochemical samples from volcanic rocks in the Knob Hill Complex and Anarchist schist;
- identifying and collecting suitable materials for geochronological age determinations of the Paleozoic sequences and Jurassic intrusions;
- investigating the use of lithogeochemistry to characterize and discriminate the various Paleozoic and Jurassic argillaceous sequences.

PREVIOUS WORK

The Rock Creek area has a mining history dating from the first discoveries of placer gold in the 1860s and lode deposits in the 1880s. The first geological report was that of Bauerman (1885) as part of the Boundary Commission Expedition of 1859 to 1861. Regional mapping has been undertaken by Brock (1902, 1903, 1905a, b), Daly (1912), Cairnes (1940), Little (1957, 1961, 1983), Monger (1968), Church (1980), Templeman-Kluit (1989a, b) and Fyles (1990). Adjacent areas in Washington State have been mapped by Umpleby (1911), Fox (1970, 1978), Pearson (1967) and Stoffel (1990), and mineral deposits reviewed by Moen (1980).

PALEOZOIC SEQUENCES OF THE ROCK CREEK AREA

Paleozoic rocks underlie two separate areas, the Rock Creek and Johnstone Creek areas, each with distinct characteristics. Previous workers included all these rocks within the Anarchist schist (Daly, 1912; Cairnes, 1940; Little, 1957). However, mafic volcanic flows and cherts in the Johnstone Creek area are contiguous with similar outcrops of the Knob Hill Complex on the east side of the Kettle River valley (Fyles, 1990; Massey, 2006). It is thus proposed to extend the Knob Hill Complex designation to these rocks. The term Anarchist schist is retained for the sequence of metasedimentary rocks and metabasalts south of Highway 3, between Osoyoos and Rock Creek. Though the rock units of the Anarchist schist are similar to those of the Knob Hill Complex, the Anarchist schist is distinguished in being more argillaceous and more complexly deformed. It is also proposed to apply the Anarchist schist designation to similar rocks in the Greenwood area, which Fyles (1990) and Massey (2006) had included in the Knob Hill Complex.

The ages of the Anarchist schist and Knob Hill Complex are still poorly determined. No paleontological or geochronological data are available for the Anarchist schist in the study area. Rubidium-strontium geochronology in the Osoyoos area only records Tertiary metamorphic ages (Ryan, 1973). A Carboniferous to Permian age was assigned to the Knob Hill Complex by Little based on a single macrofossil locality (Little, 1983, locality F7, p 12). However, this same limestone bed has yielded conodonts of Late Devonian, Frasnian age (Orchard, 1993). Determinable radiolarian are rare in the cherts of the Knob Hill Complex, though one sample has yielded a Late Pennsylvanian to earliest Permian age (Table 1). Church (1986) reported a K-Ar whole rock age of 258±10 Ma (Permian) for uralitized gabbro from the Winnipeg mine. However, the reliability of such K-Ar whole rock ages is very suspect and it is doubtful that this is recording a crystallization age. A coarse-grained gabbro sample, also from the Winnipeg mine area, has yielded a small amount of zircon. Preliminary analyses of 16 of the best quality zircons by Mortensen (pers comm, 2006) suggest ages that range between 390 and 340 Ma,

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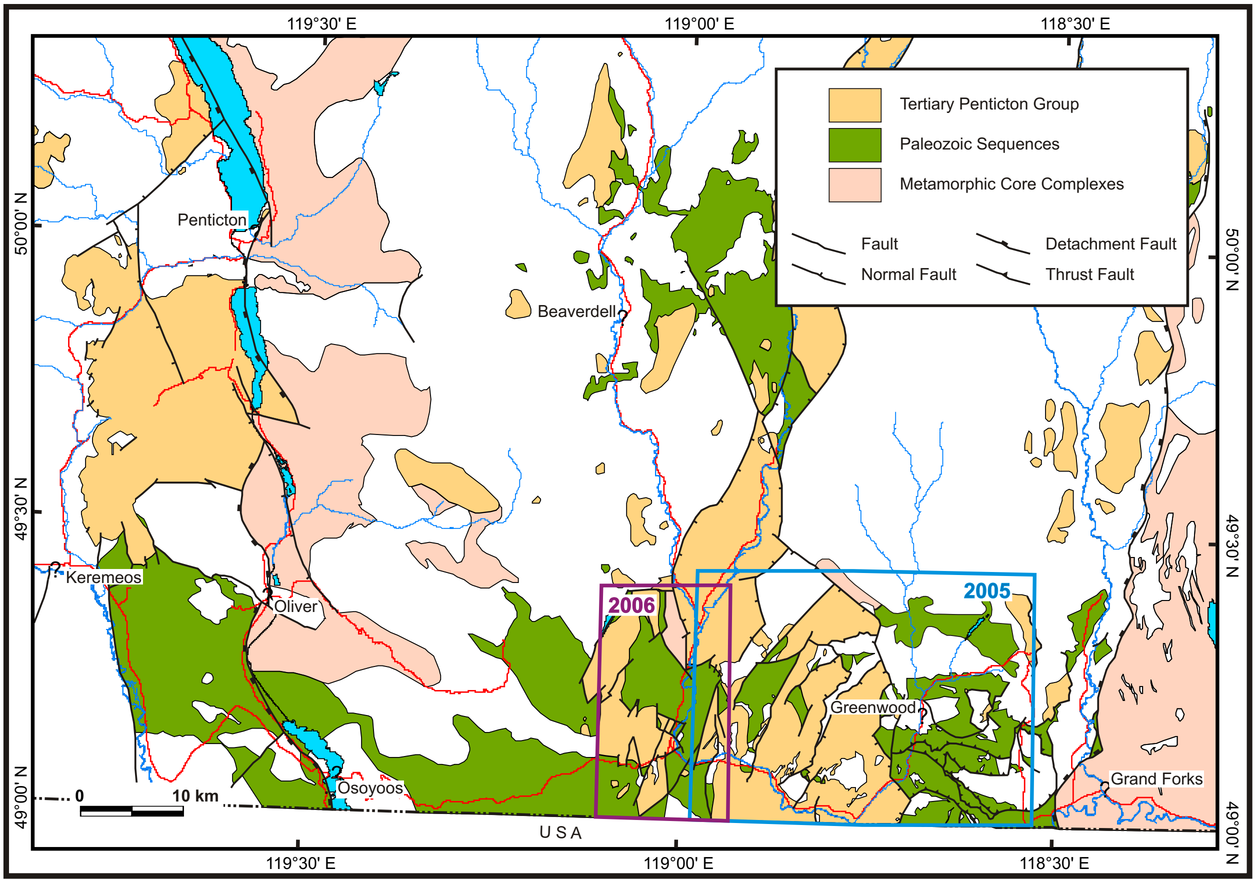

Figure 1. Distribution of Paleozoic Quesnellian rock suites in the Boundary District (south-central part of NTS 082E), southern BC, amended from the digital geology map of British Columbia (Massey *et al.*, 2005).

TABLE 1: RADIOLARIA DETERMINATIONS FROM CHERT OF THE KNOB HILL COMPLEX, BC. DETERMINATIONS MADE BY CORDEY (2006).

	Sample number 05NMA-16-007	Sample number 05NMA-22-014
Location	Lee Main road, approximately 1/2 km north of Matthews Lake	Riverside Road, approximately 2 km southeast of Zamora
Coordinates		
Lat/Long	49.127866°N, 118.863477°W	49.139180°N, 118.963673°W
UTM (zone 11)	5443342N, 364053E	5444784N, 356777E
Geological unit	Knob Hill Complex	Knob Hill Complex
Lithology	black chert, pyrite	light green chert
Occurrence of radiolarians	confirmed	confirmed
Preservation	poor to moderate	poor to moderate
Radiolarian taxa	*Entactinia* sp. ?*Latentibifistula* sp. *Schaferbergia* sp.	*Entactinia* sp. *Latentibifistula* sp. *Schaferbergia* sp. *Pseudoalbaillella bulbosa* Ishiga
Other	silica fragment (matrix), a few pyrite aggregates, rare sponge spicules (undiagnostic)	silica fragment (matrix), a few pyrite aggregates
Age	Carboniferous - Permian	Late Pennsylvanian - Earliest Permian (Kashimovian - Asselian)
Comment	range is based on the common occurrence of quoted genera, no further precision is possible	range is based on the common occurrence of *Pseudoalbaillella bulbosa* Ishiga

middle Devonian to early Mississippian. Further processing of this sample, and new samples collected in 2006, is continuing.

Knob Hill Complex

The Knob Hill Complex is composed of chert, argillite, basalt, gabbro and serpentinite that constitute a disrupted ophiolite (Little, 1983; Dostal *et al.*, 2001). Stratigraphic relationships between map units are not always clear in the Greenwood area. However, in the area north of Rock Creek and east of the Kettle River valley, gabbro and serpentinite pass northwards, and probably upwards, into greenstone, mixed greenstone and chert and finally into chert and argillite. This pattern is repeated on the west side of the valley in the Johnstone Creek area, although disrupted by north-northeast-trending Tertiary faults.

SERPENTINITE AND GABBRO UNITS

Intrusive components of the complex are limited to the Highway 33 and Hulme Creek areas. Serpentinite is typically black to bright green. It is often phyllitic to schistose but may show boudinaged kernels of hard coherent serpentinite in the foliated matrix. Cores of relict pyroxenite occur, though rarely. Calcite veining is common. Listwanite is exposed in outcrops along Highway 33. The carbonate-rich rock is pale buff on fresh surfaces but typically bright orange on weathered surfaces with white quartz veins.

Gabbro is composed of white plagioclase and green to black pyroxenes extensively replaced by hornblende. Chlorite is common on fractures and in shears. The gabbro is generally coarse grained and massive but can show a characteristic variable and patchy texture, with coarse-grained gabbro phases grading into finer microgabbro or even coarser pegmatitic phases.

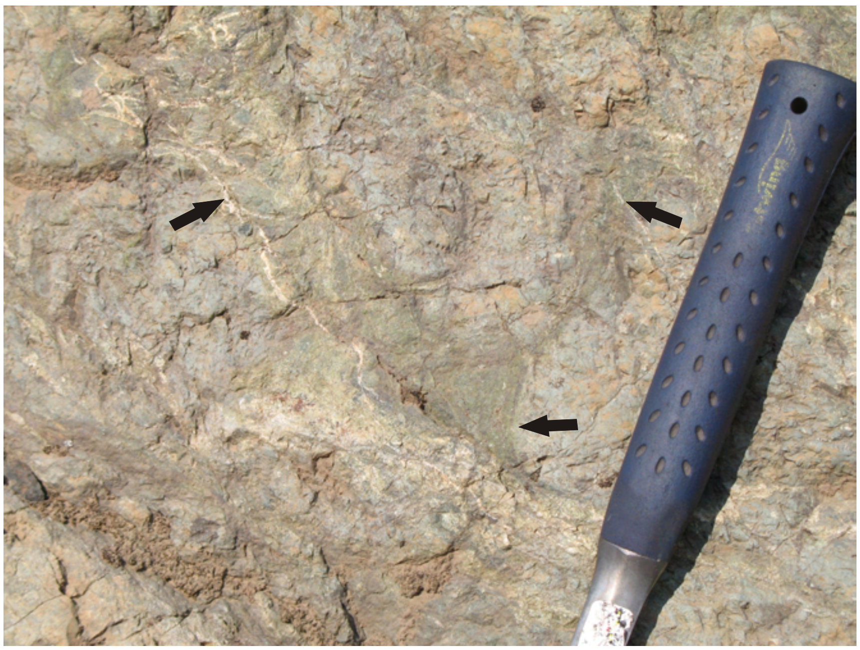

Figure 2. Chloritic pillow selvedges in Knob Hill Complex greenstone; arrows point to selvedges. Hammer for scale (06NM24-05, UTM zone 11, 5443064N, 351166E, NAD 83).

GREENSTONE UNIT

Basaltic greenstones are mostly massive flows; medium grey to green and aphyric, though rare feldspar, pyroxene and magnetite are seen. Alteration is variable and can be quite extensive. Chlorite, epidote, calcite and quartz are common alteration minerals in veins, fractures and within the rock. Pillow structures are rare though irregular chloritic bands appear to be selvedges (Fig 2). Minor breccia, agglomerate, tuff and chlorite schist occur between flows (Fig 3) as do chert, cherty argillite and rare grey limestone beds. Chert beds can be significant enough in some areas to designate as a mixed greenstone-chert unit transitional to the chert-argillite unit.

Figure 3. Basalt volcanic breccia, Knob Hill Complex (06NMA19-01-03, UTM zone 11, 5443064N, 351240E, NAD 83).

Geochemical studies of the Knob Hill Complex greenstone are still ongoing. Preliminary interpretation of new and published (Dostal *et al.*, 2001) data from the Greenwood area suggests the presence of three distinct magma suites within the lavas: a) a typical mid-ocean ridge basalt (MORB) suite, b) an enriched MORB suite and c) an island-arc tholeiite (IAT) suite (Fig 4, 5, 6). Further geochemistry is underway to enhance the database and determine if there are

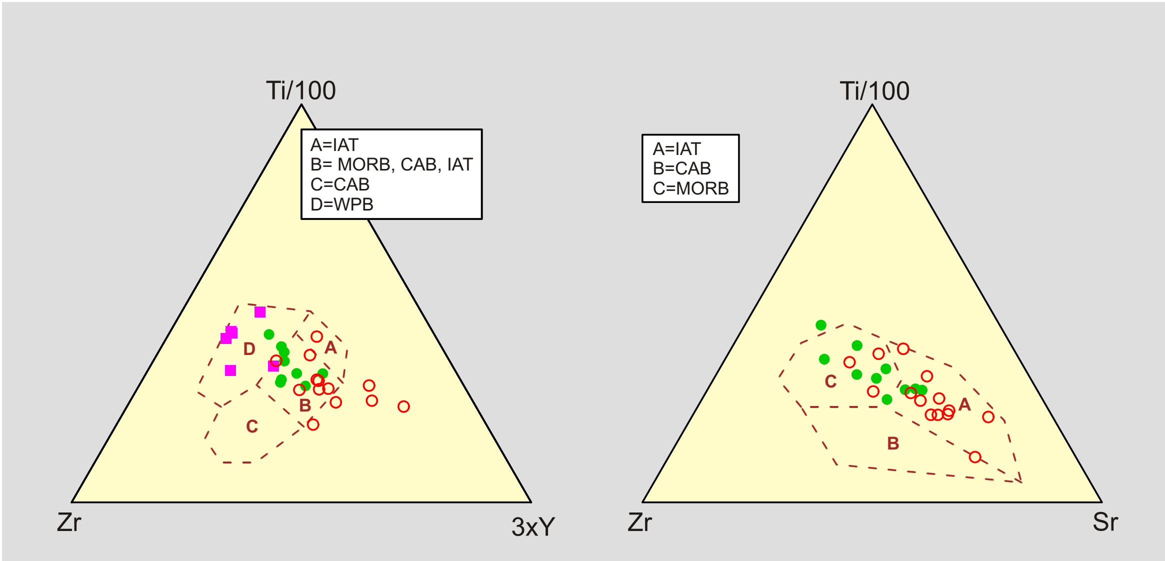

Figure 4. Discriminant triangle plots, Ti-Zr-Y and Ti-Zr-Sr, for Knob Hill Complex greenstone; petrotectonic fields (*after* Pearce and Cann, 1973). Abbreviations: IAT, island-arc tholeiite; MORB, mid-ocean ridge basalt; CAB, calcalkaline basalt; WPB, within-plate basalt. Filled circles: MORB suite samples; filled squares: enriched MORB suite samples; open circles: IAT suite

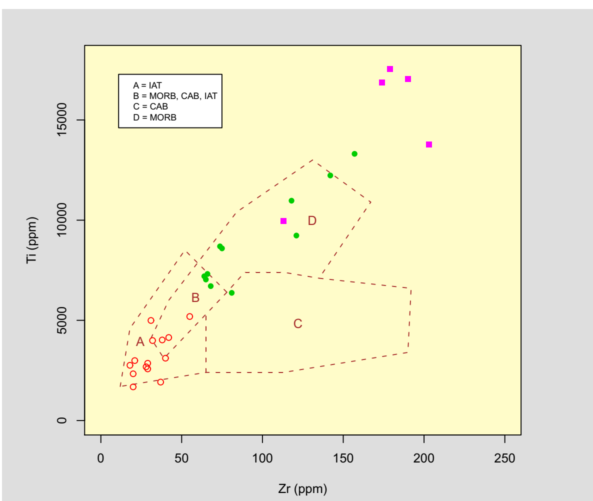

Figure 5. Discriminant plot, Ti-Zr, for Knob Hill Complex greenstone; petrotectonic fields (*after* Pearce and Cann, 1973). Abbreviations: IAT, island-arc tholeiite; MORB, mid-ocean ridge basalt; CAB, calcalkaline basalt. Filled circles: MORB suite samples; filled squares: enriched MORB suite samples; open circles: IAT suite samples.

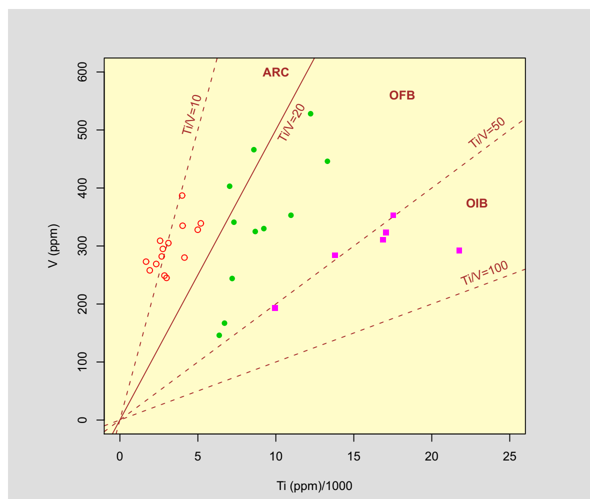

Figure 6. Discriminant plot, Ti-V, for Knob Hill Complex greenstone; petrotectonic fields (*after* Shervais, 1982). Abbreviations: ARC, island-arc tholeiite; OFB, ocean-floor basalt; OIB, ocean-island basalt and alkalic basalt. Filled circles: MORB suite samples; filled squares: enriched MORB suite samples; open circles: IAT suite samples.

any spatial or stratigraphic controls on the distribution of these suites.

CHERT-ARGILLITE UNIT

Sedimentary rocks in the Knob Hill Complex are typically fine grained, mainly grey to white cherts interbedded with grey to black argillites, black siliceous argillites and occasional chert breccia. Cherts are highly fractured and jointed, tend to be massive to thickly bedded and only rarely show ribbon structures (Fig 7). The cherts are variably recrystallized producing a fine to medium-grained saccharoidal texture and destroying any radiolaria. Chert breccias contain angular to subrounded clasts of chert and cherty tuff in a siliceous matrix and are usually associated with unbroken chert.

Anarchist Schist

The Anarchist schist can be subdivided into a metasedimentary unit and a metavolcanic unit, delineated on the dominant lithologies within them. Stratigraphic relationship between the units is uncertain. Deformation of the

Figure 7. Ribbon chert of the Knob Hill Complex. Hammer for scale (06NMA22-04, UTM zone 11, 5445398N, 352228E, NAD 83).

schists is much higher than observed in the Knob Hill Complex, involving at least two phases of deformation. Schistosity generally trends east-southeast with medium to steep northerly dips. Several areas, however, are marked by northeasterly trending schistosity with steep or moderate northwesterly dips. Secondary spaced cleavages in quartzites also trend north to northeast. However, lack of distinctive marker beds makes tracing of folds almost impossible.

METASEDIMENTARY UNIT

The metasedimentary unit is dominated by quartzite, argillaceous quartzite and meta-argillites with minor metabasalt and limestone. The quartzite and metachert are typically white to pale grey or darker bluish grey. Beds are usually 1 to 2 m thick but can reach up to 10 m. They may show a knobby or irregular weathered surface. They are variably recrystallized with a fine to medium-grained sugary texture. They may be massive or show dark and light laminations and banding (Fig 8a, b). Ribbon bedding is occasionally preserved.

Phyllitic to schistose argillaceous metasedimentary rocks are darker, with fine-grained black chlorite or biotite schist layers interlayered with lighter quartz-rich layers (Fig 8c). The schistosity is commonly crenulated and contorted, and quartz veining may also be contorted and augened (Fig 8d). Some thicker, less siliceous meta-argillites are carbonaceous. White, sulphurous-smelling barite beds and pods are found interbedded with meta-argillite on the Lapin property (MINFILE 082ESW 256; MINFILE, 2006) west of Budy Creek (Fig 9).

Minor limestone beds vary from 1 to 10 m thick. They are white to grey, fine to medium grained and recrystallized.

METAVOLCANIC UNIT

The metavolcanic unit comprises greenstone flows with minor breccia and tuff and minor metasedimentary rocks. Greenstone flows are massive, medium to dark grey or black. They are fine grained and generally aphyric, though rare feldspar crystals are seen. Chlorite±epidote alteration is common, along with veining of quartz±chlorite±calcite. The flows may be magnetic, with magnetite present in rock and veins. Tuffaceous interbeds are altered to green quartz-chlorite±sericite schist.

THE MIGHTY WHITE DOLOMITE

A thick dolomite unit occurs at the Mighty White dolomite mine (MINFILE 082ESE 200), south of Rock Creek. This is a fine to equigranular, medium-grained, white crystalline dolomite. It is massive, with no apparent bedding, and intruded by dark grey-green chloritic dikes. Chlorite-epidote skarn is apparent around the margins of the dikes.

The relationship of the dolomite to the rest of the Anarchist schist is enigmatic. It is much thicker than the minor limestone seen elsewhere, and unique in being dolomitic. It is underlain by a distinctive foliated greenstone (Fig 10) that passes down into more usual massive greenstone. The gneissic-like foliation dips moderately to shallowly to the east and could possibly be mylonitic resulting from the structural emplacement of the dolomite on top of the basalt. No indicators of sense of motion were apparent though, nor is there any obvious source of origin nor correlatives for the dolomite.

OTHER PRE-JURASSIC ROCKS OF THE ROCK CREEK AREA

Proterozoic (?) Orthogneiss

Orthogneiss forms an inlier in the Ed James Lake area, lying structurally beneath the Knob Hill Complex, though

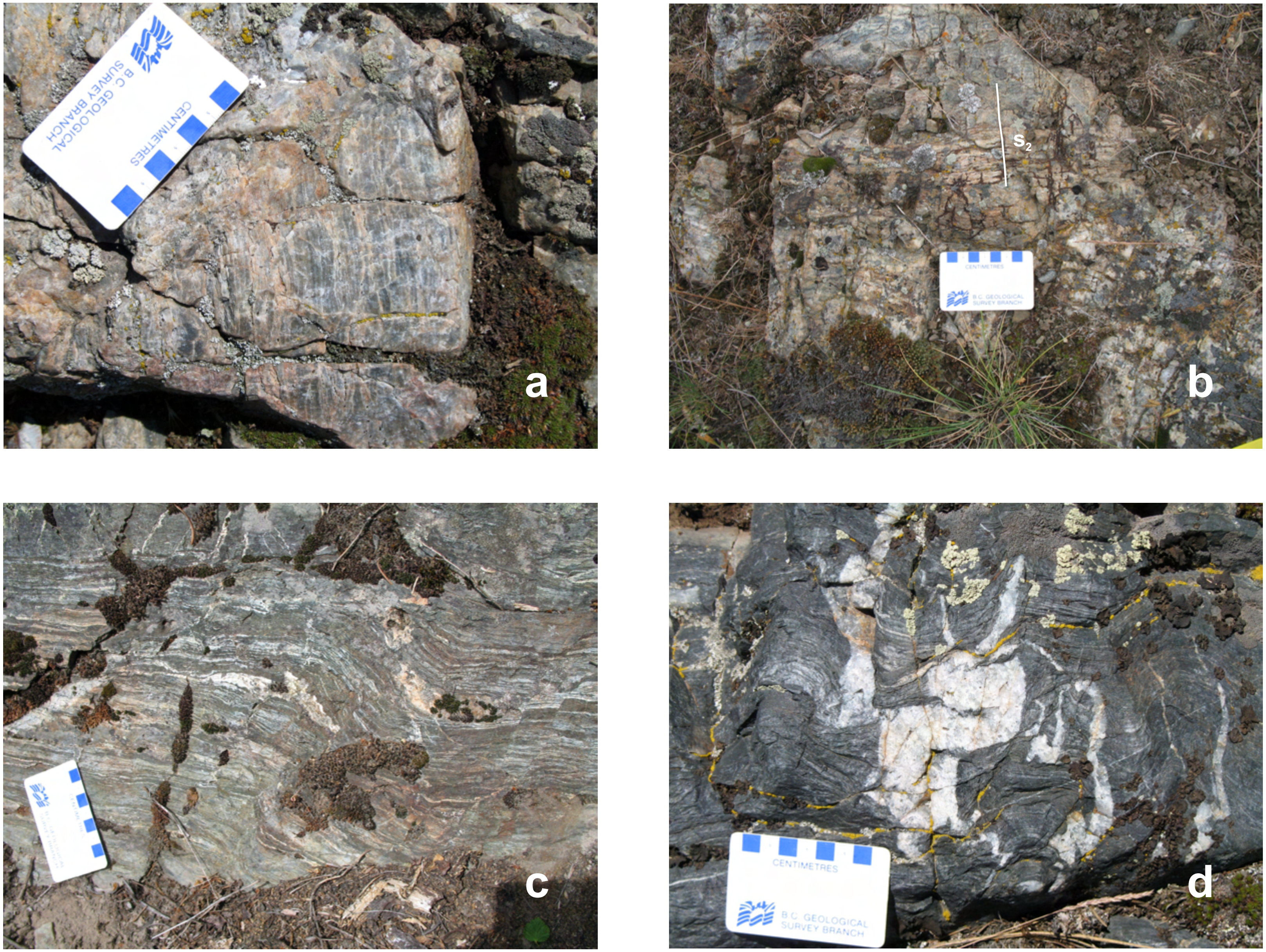

Figure 8. Typical rock types of the Anarchist schist metasedimentary unit: a) laminated quartzite (metachert) (06NMA09-05, UTM zone 11, 5433188N, 354076E, NAD 83); b) laminated quartzite with spaced cleavage (s_2) (06NMA08-11, UTM zone 11, 5432800N, 353609E, NAD 83); c) argillaceous metasedimentary rocks (06NMA02-11, UTM zone 11, 5431735N, 355263E, NAD 83); d) deformed quartz vein in meta-argillite (06NMA09-16, UTM zone 11, 5433145N, 354173E, NAD 83).

the bounding fault is not exposed. Schistosity within the gneiss is flat to dipping moderately to the east, matching that in the overlying Knob Hill Complex rocks, and suggests an easterly dipping extensional fault. A subvertical normal fault bounds the gneiss to the east, putting it in contact with Tertiary volcanic and sedimentary rocks. The gneiss is tentatively correlated with gneiss of the Proterozoic Grand Forks Gneiss Complex, which shares a similar structural relation to the Knob Hill Complex in the Grand Forks area (Höy and Jackaman, 2005), or with the Vaseaux gneiss of the Okanagan Valley.

A variety of orthogneiss is seen. A grey biotite-feldspar-quartz gneiss is most common (Fig 11a). It is coarse grained and well foliated, with schistosity resulting from the alignment of biotite porphyroblasts. White feldspar porphyroblasts (Fig 11b) range up to 5 mm in size, forming small augens. Biotite forms large clots, up to 2 cm in diameter, within the foliation plane giving a spotted appearance to the rock when broken appropriately. Variation in mineral proportions results in colour banding (Fig 11c) and a variation from diorite to granodiorite in composition. A distinctive coarse-grained, pink augen gneiss is also common (Fig 11d). Large pink potassium-feldspar augens are scattered in a foliated biotite-feldspar-quartz groundmass.

The gneiss is intruded by an unfoliated leucogranite (Fig 11a). This is a medium to coarse-grained rock, generally white on both weathered and fresh surfaces, but occasionally showing a pinkish hue on fresh surfaces. The rock is composed predominantly of white feldspar and quartz with minor biotite; colour index is less than 5. Pegmatitic phases contain pink potassium-feldspar.

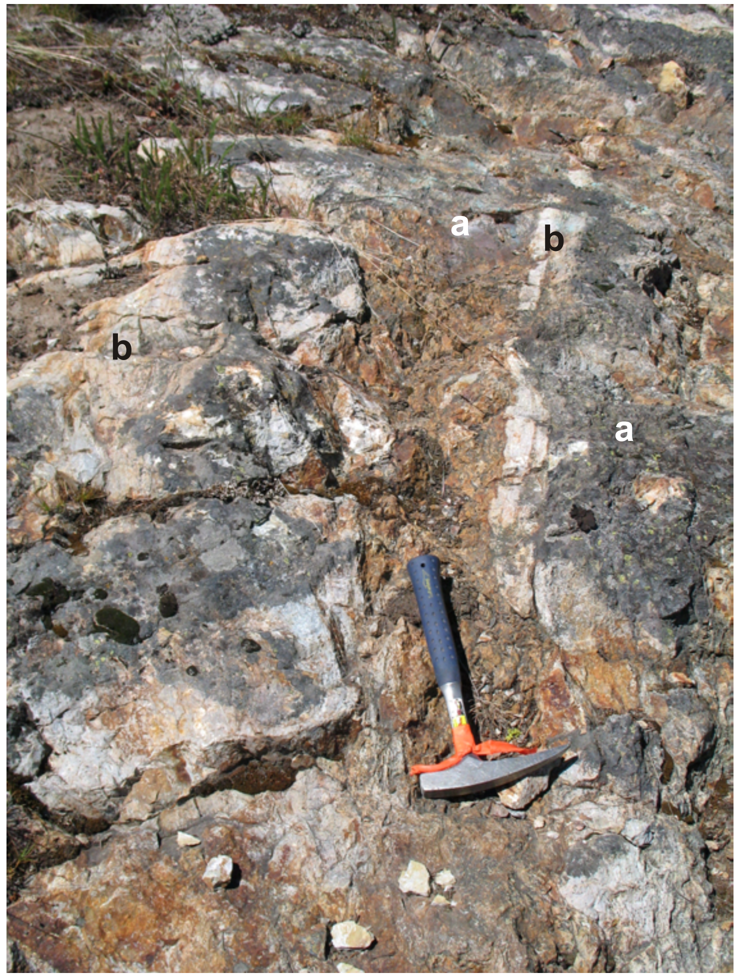

Figure 9. Barite interbedded with meta-argillite (b) of the Anarchist schist (a), Lapin property. Hammer for scale.

Brooklyn Formation

Conglomerate and limestone of the Middle Triassic Brooklyn Formation have previously been included in the Anarchist schist (*e.g.*, Little, 1961). They form scattered outcrops in the Johnstone Creek area and more extensive outcrops in the area south of Rock Creek, between Budy Creek and the Bridesville-Rock Creek Road. These units unconformably overlie the Anarchist schist and Knob Hill Complex rocks.

Sharpstone conglomerate is polymictic though dominated by angular to subrounded clasts of a variety of cherts and cherty argillites in a chert-rich matrix. Minor greenstone and argillite clasts are also seen. Commonly the clasts are granule to pebble size. Limestone clasts are seen in the area east of Budy Creek, but are notably lacking in the Johnstone Creek area. Where present, the limestone clasts are larger than other clasts and may be up to 15 cm in size. Interbeds


Figure 10. Foliated (possibly mylonitized) greenstone in the footwall of the Mighty White dolomite (06NMA02-04, UTM zone 11, 5431791N, 356073E, NAD 83).

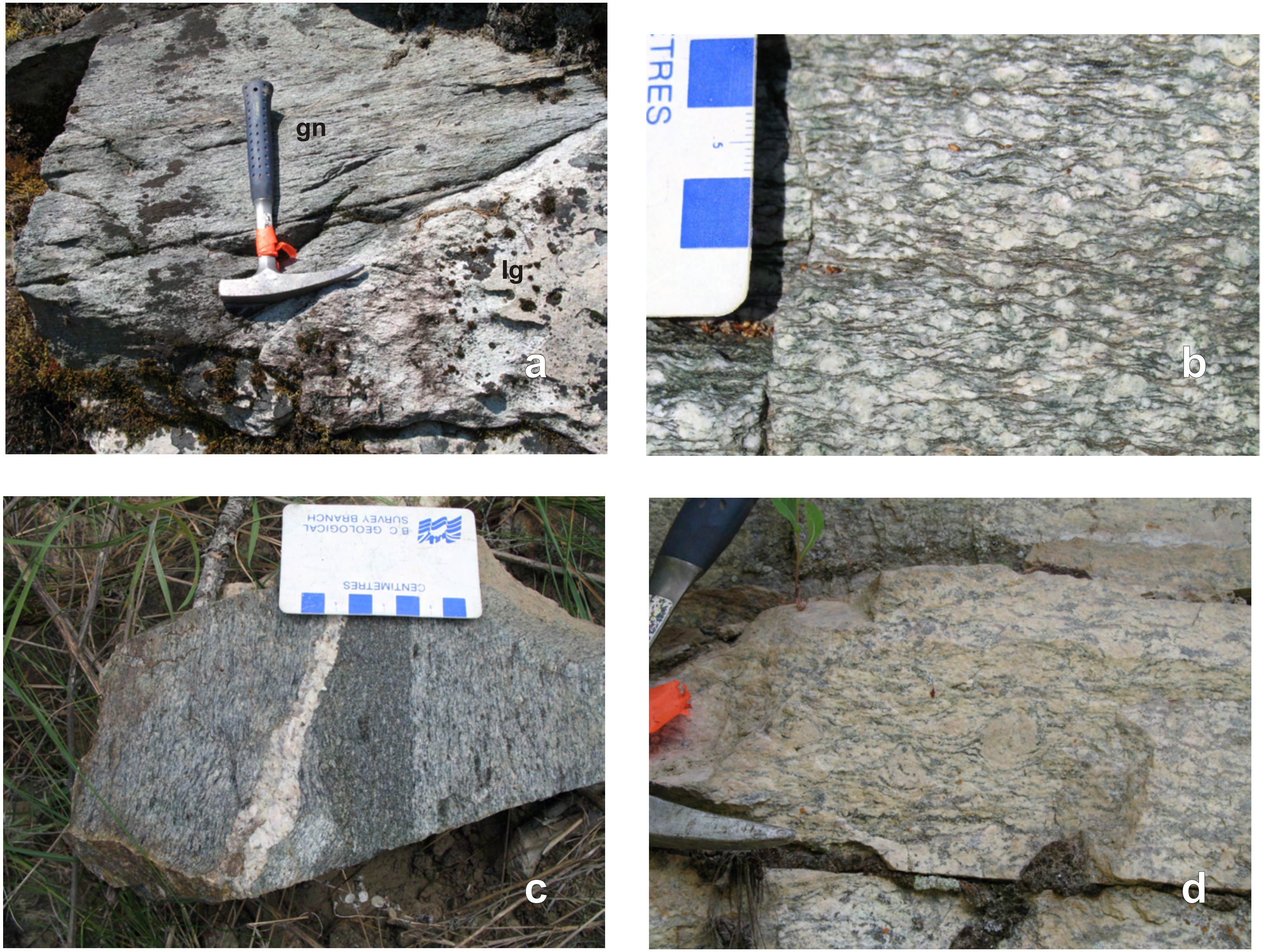

Figure 11. Varieties of gneiss from the Ed James Lake area: a) grey biotite-feldspar-quartz gneiss (gn) intruded by leucogranite (lg) (06NMA22-12, UTM zone 11, 5446243N, 352916E, NAD 83); b) feldspar porphyroblasts in biotite-feldspar gneiss (06NMA23-07, UTM zone 11, 5444280N, 353711E, NAD 83); c) compositional banding in grey gneiss (06NMA22-17, UTM zone 11, 5446621N, 352437E, NAD 83); d) potassium-feldspar augen gneiss (06NMA22-14, UTM zone 11, 5446634N, 353223E, NAD 83).

of gritty sandstone and argillite can occur with the conglomerate.

Limestone overlies the sharpstone conglomerate in the Budy Creek area. Limestone is massive and poorly bedded, white to grey on fresh surfaces with pale buff to grey weathered surfaces. Though some of the limestone is fine grained and powdery, it is more commonly medium to coarse grained, equigranular and sparry in texture. Recrystallization and skarning is evident along the margins of the Jurassic diorite. Monolithic limestone breccias may have resulted from paleokarstification (Fig 13). Other limestone conglomerate contains rounded to subrounded pebbles of cherty argillite, chert and limestone in a medium-grained calcareous matrix.

Volcanic rocks of the Brooklyn Formation are limited to the area adjacent to the Washington border, south of the Bridesville-Rock Creek Road. Greenstone flows are grey to green, fine grained, aphyric or sparsely pyroxene and magnetite-phyric. Chlorite and epidote are common as alteration and in veins. Flows are massive, though rare varioles may suggest some pillow flows (Fig 14). Tuff, breccia, chlorite schist and quartz-chlorite schist also occur.

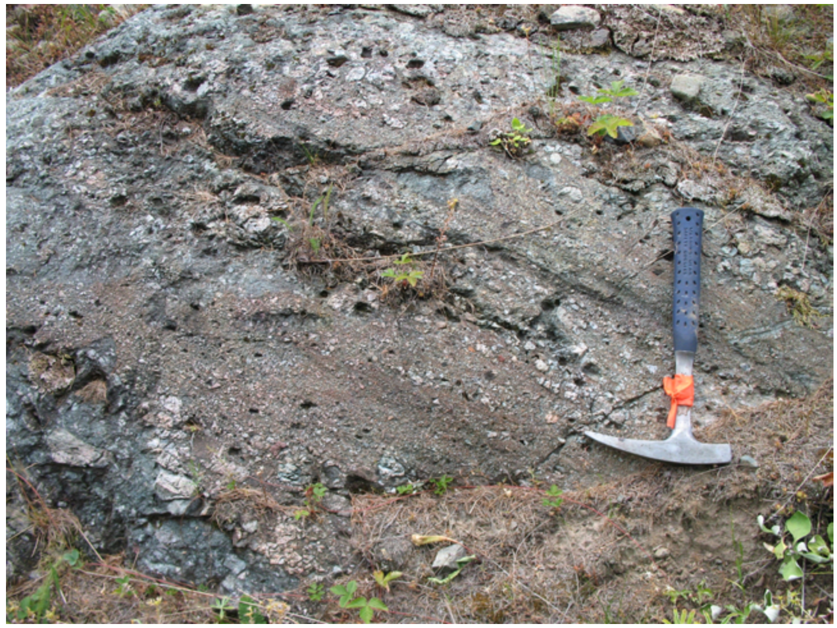

Figure 12. Sharpstone conglomerate with gritstone interbeds, Middle Triassic Brooklyn Formation. Hammer for scale (06NMA21-18, UTM zone 11, 5441144N, 348947E, NAD 83).

Figure 13. Limestone breccia, Middle Triassic Brooklyn Formation. Coin for scale (06NMA14-20, UTM zone 11, 5430277N, 348449E, NAD 83).

STRUCTURAL RELATIONSHIP OF PALEOZOIC UNITS

The Paleozoic rocks of the Greenwood-Rock Creek area are preserved in a series of northward-dipping thrust sheets (Fig 15). Many of the bounding thrusts are marked by serpentinite layers or pods. Tertiary extensional faulting has disrupted and modified the thrust sheets and makes correlation difficult between the Greenwood and Rock Creek areas. Detailed descriptions of the thrust sheets in the Greenwood map area have been provided by Fyles (1990) and summarized by Massey (2006).

The sheets are informally numbered from south to north, structurally from bottom to top (Fig 15). Only thrust sheets 2 and 5 appear to continue into the Rock Creek area. These are occupied by the Anarchist schist and Knob Hill Complex, respectively. Fyles (1990) suggested the presence of thrust sheet 1 in the Myers Creek area. In the Greenwood area, this thrust sheet is underlain by argillites ascribed to the Attwood Formation, with overlying Triassic Brooklyn Formation volcanic rocks. However, the correlation of the argillites south of the No 7 fault is debatable and these may be Jurassic (*see* discussion in Massey [2007]). Furthermore, south of Rock Creek, the Myers Creek quartz diorite stock is found in contact, either faulted (Fig 16) or intrusive, with quartzite and metasedimentary rocks of the Anarchist schist not Attwood Formation argillite.

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Figure 14. Varioles in possibly pillowed basalt, Middle Triassic Brooklyn Formation (06NMA15-11, UTM zone 11, 5430006N, 350332E, NAD 83).

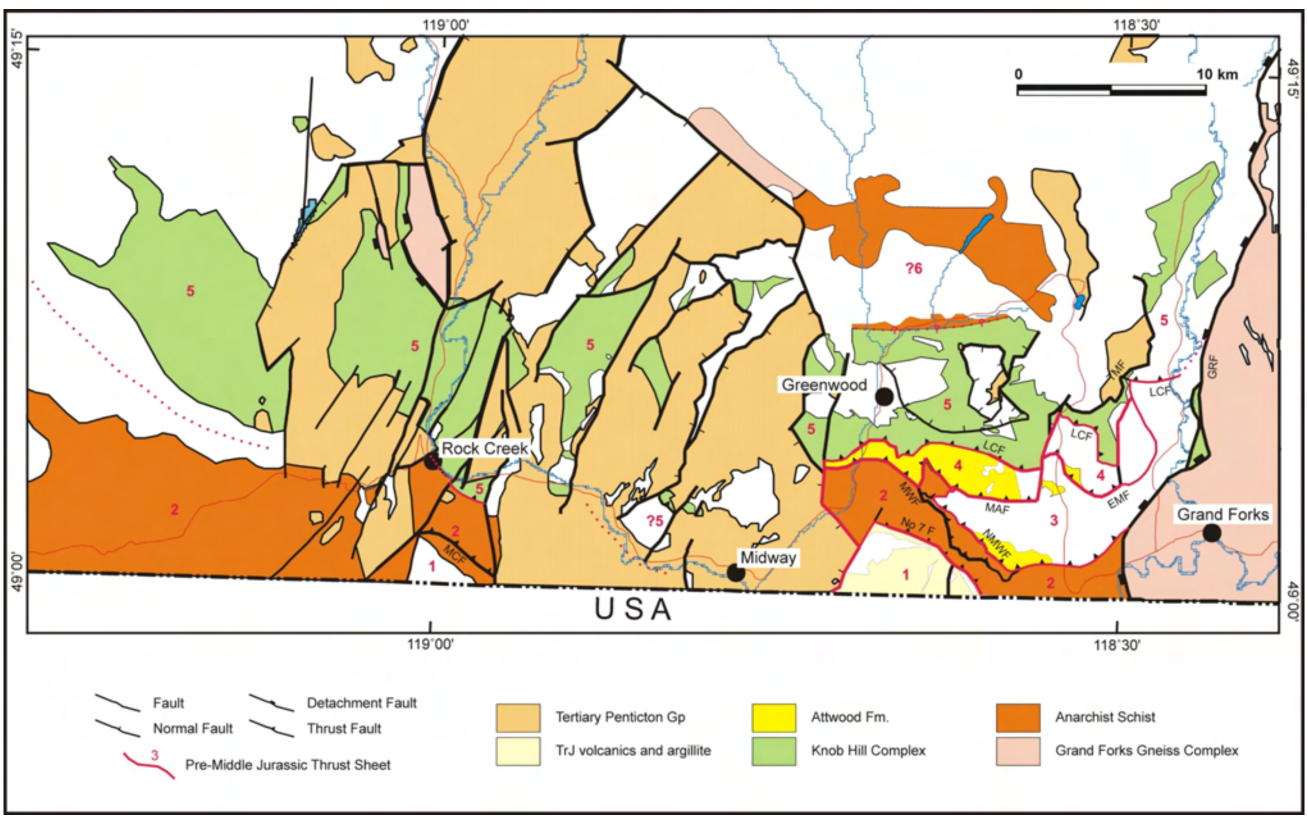

Figure 15. Main structural elements of the Greenwood-Rock Creek area, outlining the major thrust sheets (numbered 1–6) containing the Paleozoic and Mesozoic sequences (*modified from* Fyles, 1990). Abbreviations: No 7 F, Number 7 fault; MWF, Mount Wright fault; NMWF, North Mount Wright fault; MAF, Mount Attwood fault; LCF, Lind Creek fault; EMF, Eagle Mountain fault; TMF, Thimble Mountain fault; GRF, Granby River fault.

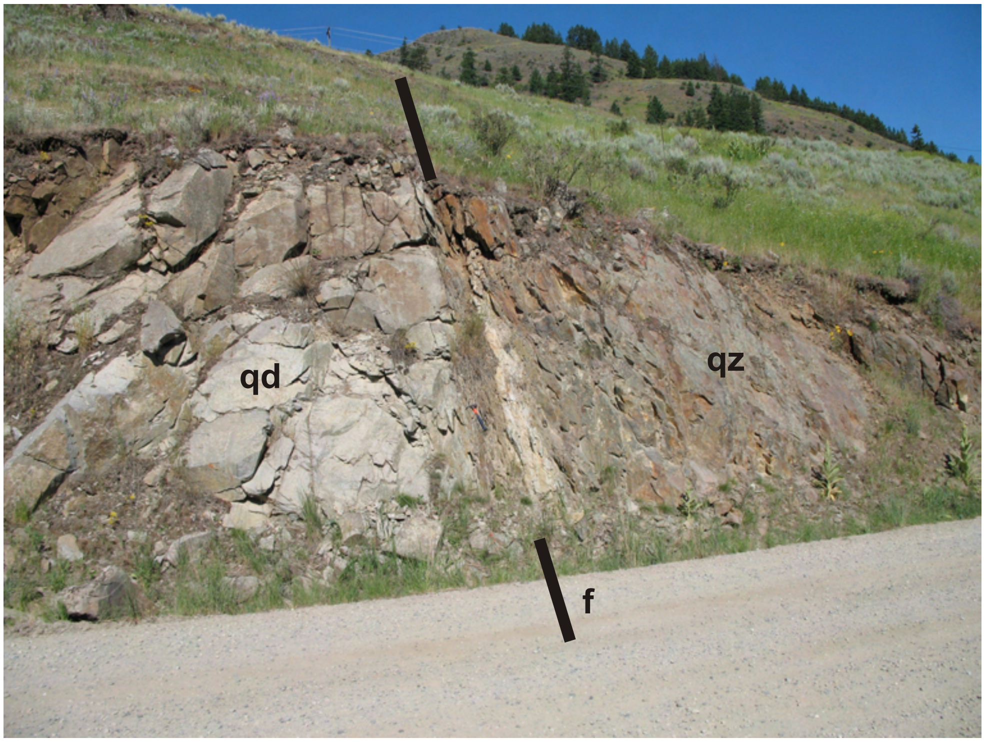

Figure 16. Faulted contact (f) between the Myers Creek quartz diorite (qd) and quartzite of the Anarchist schist (qz) exposed in a roadcut adjacent to Myers Lake, BC (06NMA05-01, UTM zone 11, 5431245N, 352934E, NAD 83).

and landowners in the Myers Creek area and along Highway 33 graciously allowed access to their properties. The author also acknowledges the indispensable assistance of Eric Westberg during fieldwork and in the office.

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