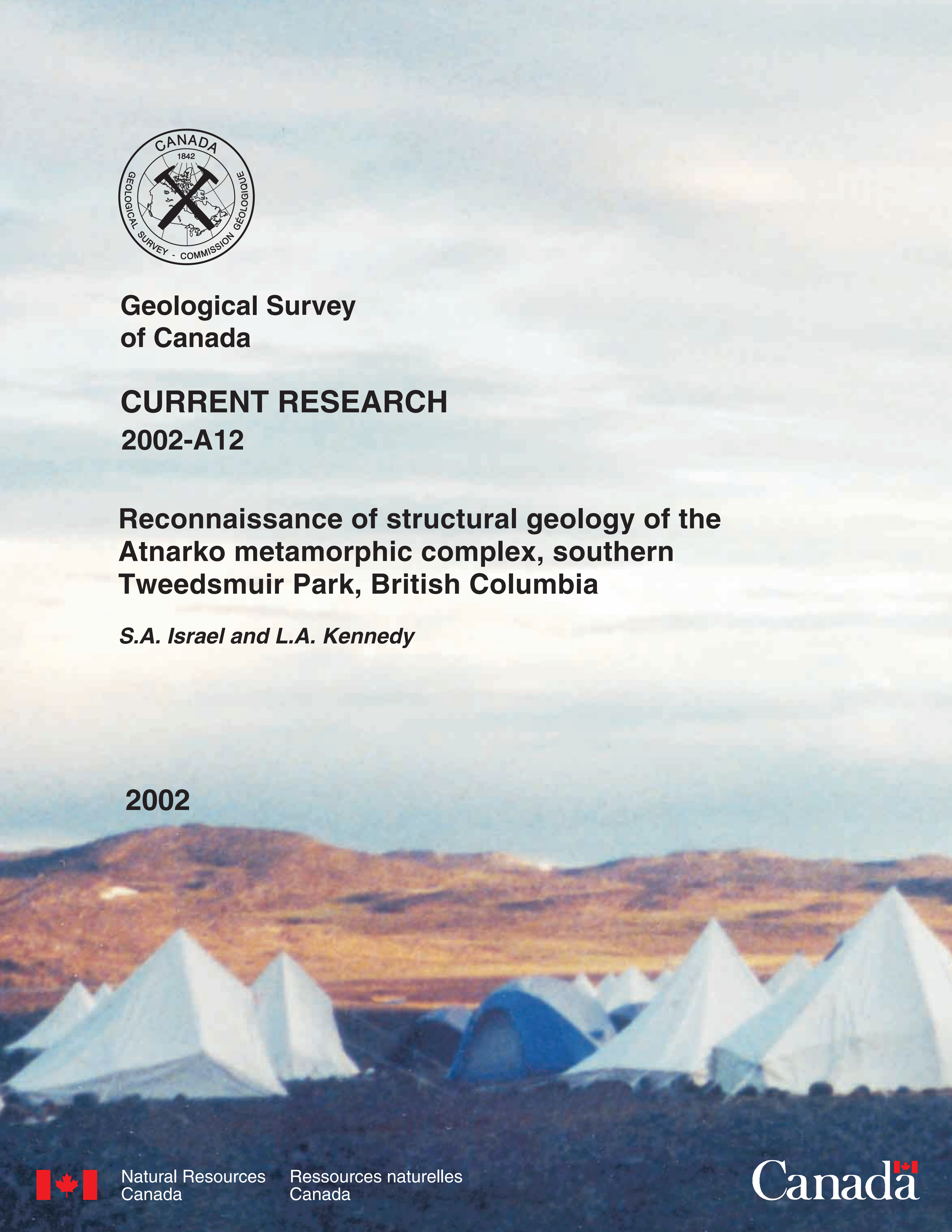

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Reconnaissance of structural geology of the Atnarko metamorphic complex, southern Tweedsmuir Park, British Columbia

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Reconnaissance of structural geology of the Atnarko metamorphic complex, southern Tweedsmuir Park, British Columbia[1]

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Abstract: The Atnarko metamorphic complex consists of polydeformed, Jurassic to Tertiary, intermediate plutonic and volcanic rocks. Northwest-striking fabrics dominate the southern portion of the complex, whereas northeast-striking fabrics dominate the northern portion of the complex. The central portion contains fabrics of both orientations. Large northwest- and north-striking, dextral, mylonite zones crosscut the main gneissic fabric, as do smaller sinistral and dextral, east-striking, ductile shear zones. At least three phases of folding are documented; F_1 and F_2 folds are tight to isoclinal with coplanar fold axes, and F_3 folds are open to closed with east- to southeast-plunging fold axes. Brittle deformation, expressed as large, north-striking, steeply dipping shear zones and discrete, randomly orientated fractures crosscut all other structures. Ages of deformation and the regional significance of these structures are not yet known and are the subject of ongoing research.

Résumé : Le complexe métamorphique d'Atnarko est formé de roches volcaniques et de roches plutoniques de composition intermédiaire du Jurassique au Tertiaire qui portent les traces de multiples déformations. Des fabriques de direction nord-ouest sont prédominantes dans la partie méridionale du complexe, tandis que dans la partie nord, ce sont les fabriques de direction nord-est qui dominent. Au centre, on trouve des fabriques des deux directions. De larges zones de mylonite qui témoignent d'un déplacement dextre et montrent des directions nord et nord-ouest recoupent transversalement la principale fabrique gneissique, tout comme le font d'ailleurs de plus petites zones de cisaillement ductile de direction est à déplacement dextre et à déplacement senestre. Au moins trois phases de plissement sont documentées : les plis P_1 et P_2, de serrés à isoclinaux, possèdent des axes coplanaires; les plis P_3, d'ouverts à fermés, présentent des axes qui plongent dans une direction variant de l'est au sud-est. Une déformation fragile, qui se manifeste sous forme de grandes zones de cisaillement abruptes de direction nord ainsi que de fractures distinctes d'orientations aléatoires recoupent toutes les autres structures. L'âge de la déformation et l'importance régionale de ces structures ne sont pas encore connus et font présentement l'objet d'études additionnelles.

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[1] Contribution to the Bella Coola Targeted Geoscience Initiative Project.

INTRODUCTION

This paper reports the preliminary results from the first field season (2001) of reconnaissance lithological and structural mapping (1:20 000 scale) within the Atnarko metamorphic complex, located within southern Tweedsmuir Provincial Park, near Bella Coola, British Columbia (portions of NTS 93 C, 92 N, and 93 D; Fig.1). The project is associated with the Geological Survey of Canada Bella Coola project, a Targeted Geoscience Initiative (TGI).

This portion of the project forms the basis for S. Israel's Ph.D. thesis, the objectives of which are 1) to decipher the structural and metamorphic history (e.g. geometry, kinematics, timing) of the Atnarko complex; 2) to determine the physical conditions of deformation and the mechanisms responsible for mid-crustal deformation during large-scale terrane accretion; 3) to place the Atnarko metamorphic complex into a regional tectonic framework; and 4) to produce a conceptual model for the tectonic evolution of this part of the Coast Belt. This work builds upon earlier studies of the Atnarko metamorphic complex by van der Heyden (1989, 1990, 1991) and previous mapping by Tipper (1969), Baer (1973), and Roddick and Tipper (1985).

GEOLOGICAL SETTING

The Atnarko metamorphic complex is located near the boundary of the Coast Belt and Intermontane Belt of the Canadian Cordillera. The Intermontane Belt, in this region, is represented by Middle Jurassic Hazelton Group, which is part of the younger portion of the Upper Paleozoic to Middle Jurassic Stikine terrane. Hazelton Group volcanic rocks, and associated plutonic rocks outcrop extensively to the northwest of the Atnarko metamorphic complex (Diakow et al., 2002). Early Cretaceous Monarch volcanic rocks found within the Coast Belt are regionally extensive to the north, west, and south of the complex (van der Heyden, 1990, 1991; Rusmore et al., 2000; Struik et al., 2002). Large areas to the east of the complex are covered by the Late Jurassic Hotnarko volcanic rocks, which have been associated with a Late Jurassic magmatic arc (van der Heyden, 1990, 1991). Large volumes of Middle Jurassic to Tertiary plutonic rocks occupy the entire region within and surrounding the Atnarko metamorphic complex and are associated with the Coast plutonic complex (van der Heyden, 1990, 1991; Rusmore et al., 2000; Hrudey et al., 2002).

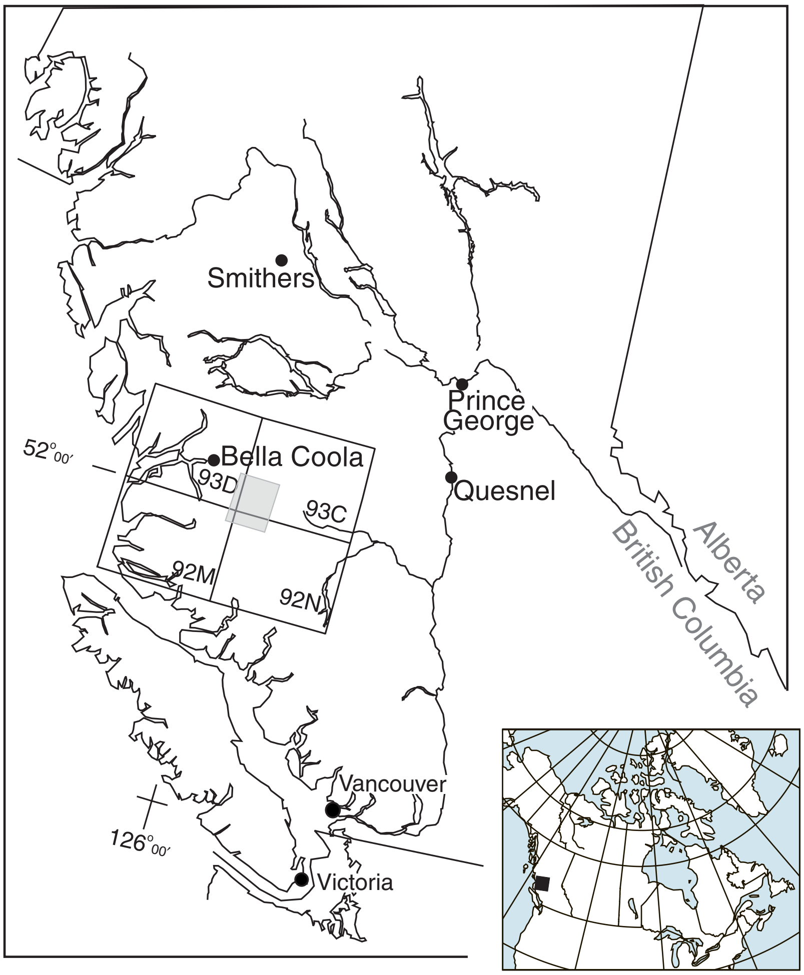

Figure 1.

Location of the project area (indicated by small grey box).

The Bella Coola region is structurally complex, and records multiple deformation events from the Jurassic to Eocene. The Monarch volcanic rocks are interpreted to be associated with an extension event in the Early Cretaceous (Mahoney et al., 2002). Evidence for mid-Cretaceous contraction, expressed as northeast-verging folds and thrust faults, is extensive and is correlated with the well documented East Waddington thrust belt exemplified to the southeast of the Atnarko metamorphic complex (Rusmore and Woodsworth, 1994; Rusmore et al., 2000; Mahoney et al., 2002) and a more regional system of northeast-vergent structures in the Intermontane Belt (Evenchick, 1991). Contraction continued into the Early Tertiary and was accompanied by transpressional, dextral strike-slip faulting along the entire western Cordilleran margin (Rusmore et al., 2000; Mahoney et al., 2002). Tertiary (Eocene) extension is known to have occurred to the northwest and southeast of the region, exposing several metamorphic core complexes along the Intermontane/Insular boundary (e.g. Friedman and Armstrong, 1988).

ATNARKO METAMORPHIC COMPLEX

The AMC is composed of variably metamorphosed and deformed, Middle Jurassic to mid-Cretaceous, plutonic and volcanic rocks, intruded by undeformed, Late Cretaceous to Tertiary plutonic rocks. (van der Heyden, 1990, 1991; Fig. 2). The boundaries of the complex are not well constrained. Van der Heyden (1990, 1991) proposed that the complex is nonconformably overlain by Middle Jurassic Hotnarko volcanic rocks to the east and the Early Cretaceous Monarch volcanic rocks to the west. A portion of the western boundary is interpreted to coincide with the steeply dipping Talchako fault, which parallels the length of the Talchako River (Fig. 2). The southern boundary is believed to extend into the Mount Waddington map area, where Roddick and Tipper (1985) mapped a large expanse of highly deformed rocks.

Based on reconnaissance mapping and subsequent preliminary age dating, van der Heyden (1991), proposed that the Atnarko metamorphic complex underwent at least three temporally distinct structural events. Ductile shearing along the western margin of the complex is interpreted to have occurred after intrusion of Middle Jurassic quartz diorite bodies. This was followed by dextral shearing along the eastern margin of the complex in the Early Cretaceous, and the entire Atnarko metamorphic complex was subsequently affected by ductile shearing associated with mid-Cretaceous contraction.

Jurassic rocks

The Atnarko metamorphic complex is composed predominantly of intermediate plutonic rocks that are interpreted to be Middle to Late Jurassic in age (van der Heyden, 1991; this study; Fig. 2). Where undeformed, these plutons range in composition from quartz diorite to granodiorite, and locally, gabbro, diorite, and tonalite. They are generally medium to coarse grained, with up to 30% biotite and hornblende typically altered to chlorite. The majority of the intermediate plutonic rocks are gneissic, with layering defined by alternating layers of mafic and felsic material (Fig. 3). Van der Heyden (1991) reported a U-Pb age of 156 ±2 Ma for a gneissic quartz diorite located at the southwest corner of the Atnarko metamorphic complex.

Large rafts and screens of metavolcanic rocks are found within the quartz diorite and granodiorite. Van der Heyden (1990) interpreted the metavolcanic enclaves as rocks belonging to either the Hazelton Group or the Hotnarko volcanic rocks. The enclaves are very fine grained, display textures typical of static recrystallization, and are locally metamorphosed to amphibolite facies. Enclaves of biotite schists are rare and their interpreted protoliths are sedimentary rocks associated with the volcanic units.

Early to mid-Cretaceous rocks

Limited age dating indicates that Early to mid-Cretaceous plutonic rocks underlie a large part of, and are restricted to, the north and southeastern Atnarko metamorphic complex. These consist mainly of fine- to medium-grained quartz diorite to granodiorite, with common biotite and hornblende. Distinguishing these rocks from the older plutonic bodies is difficult and only possible where intrusive contacts are exposed. Van der Heyden (1991) identified two Cretaceous plutons within the Atnarko metamorphic complex. One in the north, near Ptarmigan Lake, with a U-Pb age of 114.8 ±0.3 Ma, and one in the southeast, the Wilderness Lake pluton, with an age of 142 ±0.5 Ma.

The AMC is bounded on the southwest by the Early Cretaceous Monarch volcanic rocks. They consist of green to beige volcanic breccia composed entirely of angular to subangular clasts of andesite within a fine- to medium-grained matrix of the same material (Fig. 4). The breccias are interbedded with andesitic flows or sills several metres in width. Rusty, dark-brown-weathered argillite is commonly found as thick (up to tens of metres) discontinuous beds within both the breccias and andesites. The nature of the contact of the Monarch volcanic rocks with the Atnarko metamorphic complex is still suspect. Van der Heyden (1990, 1991) reported a nonconformable contact between the volcanic rocks and an undeformed quartz diorite that he correlates with the Atnarko metamorphic complex. Mapping in 2001 identified several north- and northwest-vergent thrust faults near the contact between the two units, which may suggest that the western boundary is a faulted contact.

Latest Cretaceous to Tertiary rocks

Suspected latest Cretaceous to Tertiary, relatively unaltered, medium- to coarse-grained, granodiorite to tonalite bodies are found throughout the Atnarko metamorphic complex (Fig. 5). The interpreted age for these bodies is based upon their intrusive relationship with the dated mid-Cretaceous pluton near Ptarmigan Lake.

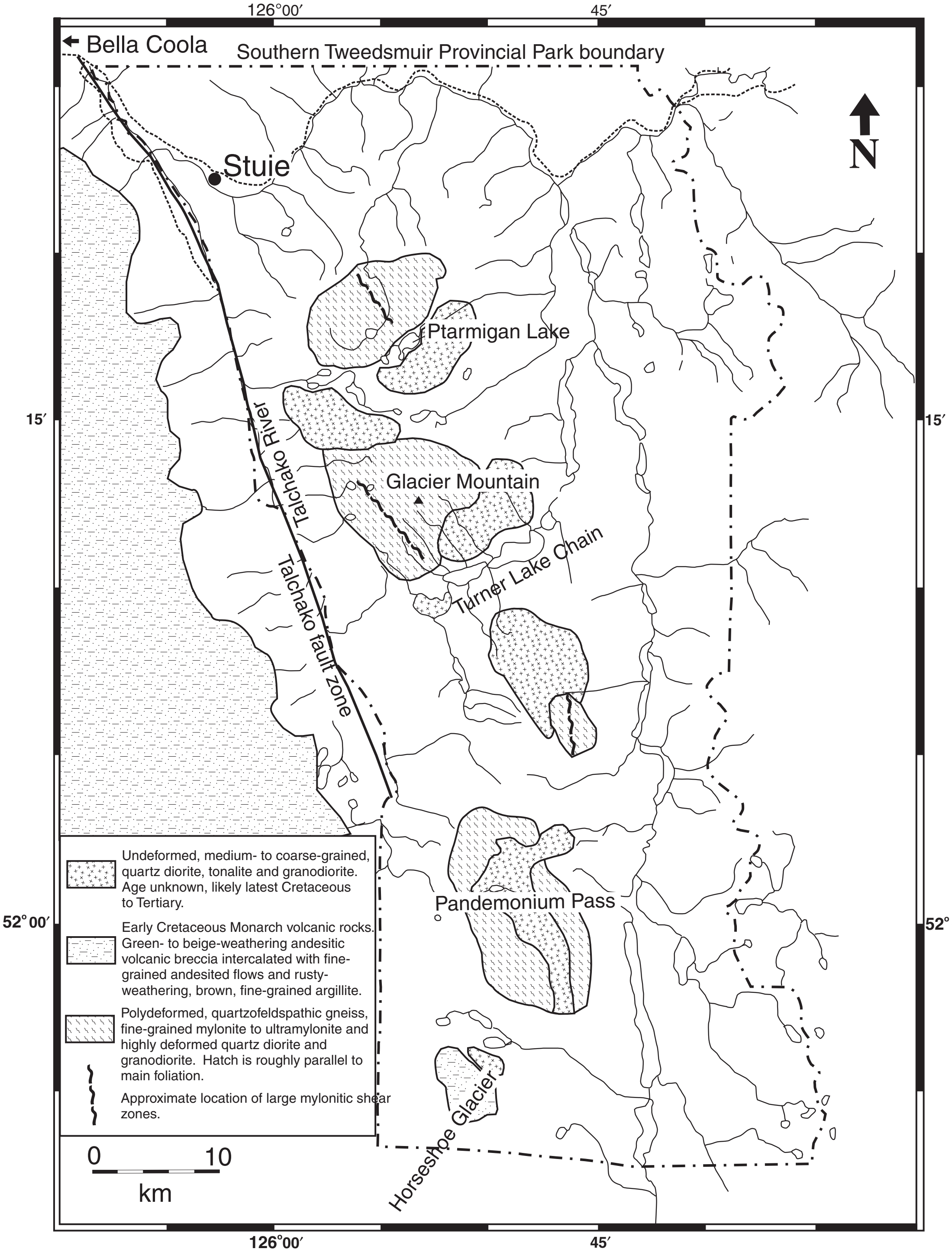

Figure 2. Schematic geology map of the Atnarko metamorphic complex, showing the distribution of high-strain rocks and undeformed plutons mapped in 2001. The dotted line represents the boundary of south Tweedsmuir Provincial Park. Location is outlined in Figure 1.

Figure 3. *Polydeformed gneiss from the Glacier Mountain area.*

Figure 4. *Andesitic volcanic breccia of the Monarch volcanic rocks.*

Figure 5. *Undeformed tonalite intruding quartz diortitic gneiss, near Pandemonium Pass.*

STRUCTURE

Van der Heyden (1990, 1991) identified several phases of deformation in the Atnarko complex. For the purpose of this section it is convenient to separate the Atnarko metamorphic complex into three subdivisions; Ptarmigan Lake, Glacier Mountain, and Pandemonium Pass areas (Fig. 2). Below, we describe the structures observed in the field. The lack of age dates precludes firm temporal constraints on the evolution of the structures.

Ptarmigan Lake

The Ptarmigan Lake area is dominated by northeast-striking, steeply dipping, penetrative foliations (S_T) within biotite granodiorite (Fig. 6a). The area contains tight to isoclinal folds with fold axes plunging moderately towards the east. Mineral stretching lineations were rare, but, where present, plunge steeply southeast. Northwest-striking mylonite shear zones are common and are up to several metres wide. At some localities, the mylonites grade into moderately deformed plutonic host rock, whereas at other localities, the mylonite fabrics are oblique to gneissic foliation with the resulting 'drag' indicating an apparent dextral sense of shear. Several smaller (up to 1 m wide), north-striking, mylonitic shear zones crosscut the S_T, also with an apparent dextral offset (Fig. 7). No crosscutting relationships between the northwest- and north-striking mylonites were observed. Brittle deformation is manifested as discrete fractures up to several centimetres in width that crosscut all structures and have both sinistral and dextral apparent offsets.

Glacier Mountain

The Glacier Mountain area is underlain by undeformed quartz diorite and tonalite, gneiss and mylonite (Fig. 2). Gneissic foliation (S_T) dips steeply, but has no consistent strike (Fig. 6b). At least three phases of folding are present. The F_1 and F_2 folds are tight to isoclinal with F_2 folding resulted in a Type III refolding of F_1 (Fig. 8). F_3 fold axes are open to closed, and trend mainly towards the east-southeast. Mineral stretching lineations associated with S_T are folded and consequently have variable plunge directions (Fig. 6b). The area is deformed by east- and north-striking ductile shear zones that show evidence of both sinistral and dextral movement. They are up to several metres wide, but generally only several tens of centimetres. As in the Ptarmigan Lake area, no direct field evidence has yet been found to indicate the temporal relationship between the differently orientated shear zones; however, they formed after development of S_T as they crosscut it everywhere and also crosscut all phases of folding. Northwest-striking, steeply dipping mylonite zones several metres wide are found near the southern portion of the Glacier Mountain area. They are defined by very fine-grained, layered ultramylonites that exhibit both sinistral and dextral shear-sense (Fig. 9). No crosscutting relationships with the smaller shear zones were observed. Several brittle shear zones were identified that strike northwest and north, are steeply dipping, and have both sinistral and dextral apparent offset. Although quite common, these brittle shear zones were no more than several centimetres in width and display very little offset.

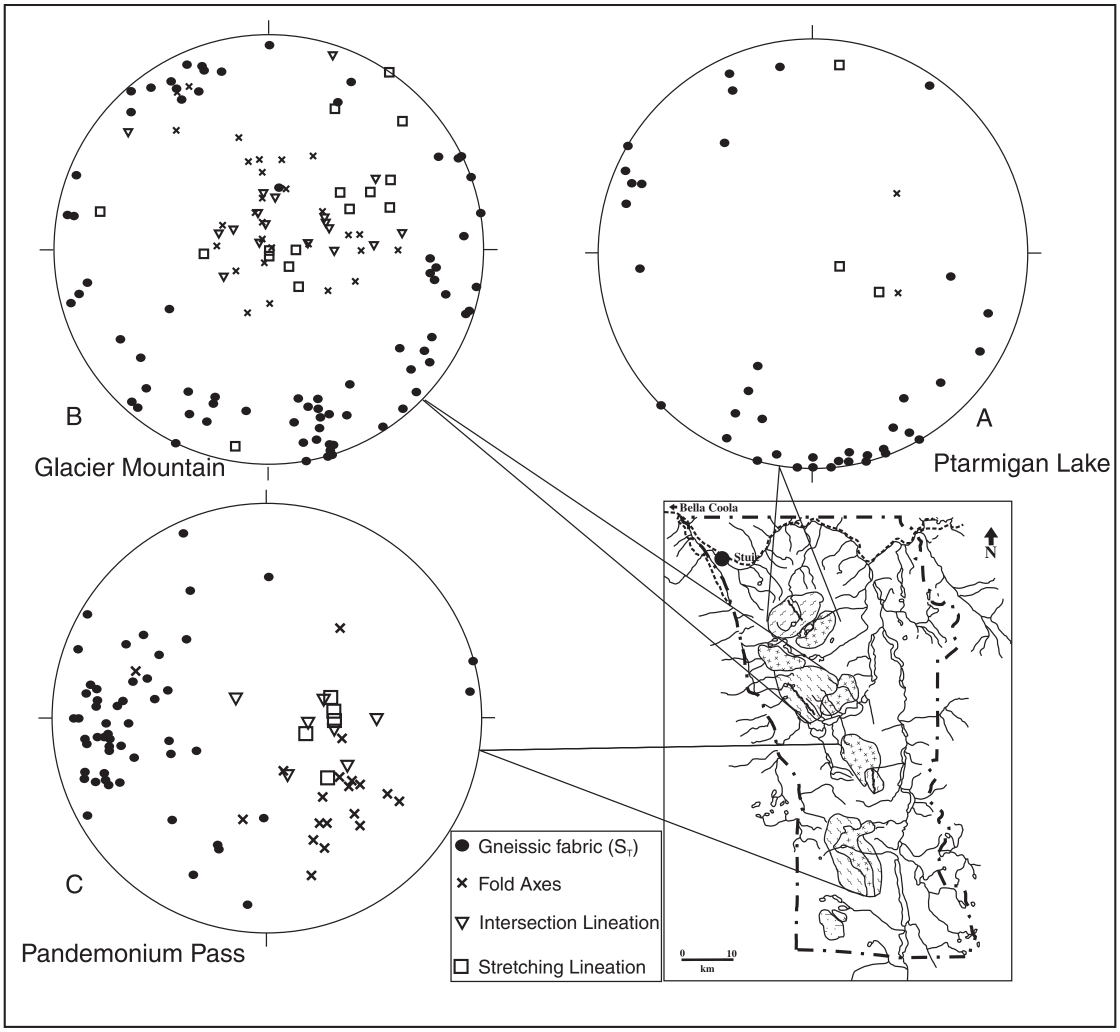

Figure 6. Lower hemisphere projection, equal area stereonet plots from, **A**) Ptarmigan Lake area, **B**) Glacier Mountain area, and **C**) Pandemonium Pass area.

Figure 7. Ductile shear zone from the Ptarmigan Lake area. Drag folding of S_T suggests apparent dextral sense of shear.

Figure 8. Type II re-folded folds from the Glacier Mountain area.

Pandemonium Pass

The area around Pandemonium Pass encompasses the mapped area between the Turner Lake Chain in the north and Horseshoe Glacier in the south (Fig. 2). The area is characterized by steeply dipping, north to northwest gneissic (S_T) foliation (Fig. 6c). At least three phases of folding were identified in the Pandemonium Pass area with F_1 and F_2 folds tight to isoclinal, with axes that plunge steeply towards the southeast. F_3 folds are open to closed, and fold axes plunge moderately towards the southeast. Mineral stretching lineations associated with S_T, defined by stretched quartz, consistently plunge steeply east-southeast, possibly suggesting formation occurred post-F_3 folding. Several large (tens of metres wide), northwest-striking, steeply dipping mylonite zones were identified. Boudinaged quartz veins and vergence of minor shear-zone-related folds indicate apparent dextral sense of shear across the zones (Fig. 10). The presence of quartz veins suggests at least some brittle/ductile behaviour for portions of the shear zones. Smaller, centimetre-scale, east-striking, ductile shear zones cut across both S_T and the mylonite zones.

Figure 9. *Fine-grained, northwest-striking mylonite to ultramylonite from the Glacier Mountain area. Minor folds within shear zone suggest top to the right (dextral) shear.*

Figure 10. *Boudinaged quartz vein within mylonite zone, suggesting an apparent dextral sense of shear, Pandemonium Pass area.*

Figure 11. *Amphibolite xenolith within polydeformed gneiss, Pandemonium Pass area.*

They have both sinistral and dextral shear sense, based on drag folding of the S_T fabric. Large brittle structures were identified that strike north and dip moderately to steeply towards the east. Many of these features occur as reactivated structures along mylonite zones. Small, discrete, brittle structures that do not have a dominant orientation or movement sense are ubiquitous in the Pandemonium Pass area.

METAMORPHISM

Metamorphic grade in the Atnarko metamorphic complex is generally greenschist facies with only local development of amphibolite-grade xenoliths within highly deformed gneisses (Fig. 11). The exception to this is amphibolite development along one northwest-striking mylonite zone near Glacier Mountain and large exposures of amphibolite-grade rocks in the Wilderness Lake pluton (van der Heyden, 1990, 1991); however these were not examined during the 2001 field season. Garnet is locally present within gneissic and mylonitic rocks within the Glacier Mountain area.

DISCUSSION

Preliminary investigation in the summer of 2001 confirmed van der Heyden's (1990, 1991) evidence for multiphase deformation within the Atnarko metamorphic complex. It is clear from the structural data from Ptarmigan Lake, Glacier Mountain, and Pandemonium Pass that some deformation events affected the entire complex, whereas other events appear to be locally contained. The most obvious differences in the three domains are the orientation of the main gneissic fabric (S_T) and the decrease in intensity of superimposed deformation north of Glacier Mountain. From south to north, S_T changes from a well defined north-northwest-striking, steeply dipping feature to northeast-striking feature. The difference in orientation is attributed to two separate events (van der Heyden, 1991). The more randomly orientated fabrics seen in the Glacier Mountain area may reflect the domainal boundary contained within the central portion of the complex where the structures reflect the effects of both deformation events. The earlier deformation event is inferred to be late-Middle to Late Jurassic, the later deformation event is inferred to be mid-Cretaceous (van der Heyden, 1991).

North- and northwest-striking mylonite zones crosscut the gneissic fabric in all domains, indicating that a complex-wide pervasive, ductile event postdates the mid-Cretaceous deformation. East-striking mylonite zones found in the Glacier Mountain and Pandemonium Pass areas crosscut the polyphase folding; however, their age and significance has not yet been established. Brittle structures are common to all domains, and suggest a young (at least post-mid-Cretaceous) deformation event.

The key to unraveling the complex history of deformation and plutonism within the Atnarko metamorphic complex lies in precise U-Pb and Ar-Ar geochronology combined with detailed structural mapping. To this end, several samples were collected in 2001. U-Pb analyses of plutonic rocks will constrain the timing of crystallization and provide lower and upper ages for deformation and Ar-Ar analyses of minerals formed during deformation will provide absolute timing of deformation.

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