The Duke River fault, southwest Yukon: Preliminary examination of the relationships between Wrangellia and the Alexander terrane

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ABSTRACT

The Duke River fault is a terrane-bounding structure that separates the Alexander terrane from Wrangellia in southwest Yukon. Detailed geological mapping and sampling of three key areas along the fault was completed in August 2009. In these areas, the fault juxtaposes multiply folded, pervasively foliated, greenschist facies rocks of the Alexander terrane against low-grade Wrangellian rocks that record only one phase of folding. Shear bands, fold orientations, rotated grains, lineations, mica fish and fault plane orientations indicate that the Alexander terrane has been thrust over Wrangellia. Preliminary $^{40}Ar/^{39}Ar$ ages from muscovite grains that may have been reset by motions along the Duke River fault or grown during faulting range from 90-104 Ma, suggesting that movement along the fault is at least as old as Cretaceous. Miocene felsic intrusions and Miocene to Pliocene crustal tuffs of the Wrangell lavas have been deformed by the Duke River fault, suggesting movement occurred as recently as the Pliocene.

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INTRODUCTION

The western margin of the North American Cordillera in western Canada is composed of the Alexander terrane and Wrangellia (Fig. 1). These terranes were amalgamated to form the Insular superterrane (or composite terrane) prior to its accretion to the North American margin in the Middle Jurassic to Early Cretaceous (Monger *et al.*, 1982; van der Heyden, 1992; Wheeler *et al.*, 1991). The tectonic evolution of, and relationships between, the Insular terranes prior to, and after, accretion are not well understood in Yukon. The Duke River fault is a terrane-bounding structure that separates Wrangellia and the Alexander terrane in southwest Yukon and northwestern British Columbia (Fig. 1). The Duke River fault is exposed over much of its strike length and provides an excellent opportunity to study the geological relationships between the Alexander terrane and Wrangellia.

Previous studies suggest the Duke River fault is a post-Triassic dextral strike-slip fault that has accommodated major displacements (Dodds and Campbell, 1992). This contrasts with recent studies that have interpreted seismic and earthquake data along the Duke River fault to indicate reverse oblique movement along the fault (Page *et al.*, 1991; Power, 1988).

The objectives of this study are: 1) to determine the timing and kinematics of movement along the Duke River fault; 2) to restore motion along the Duke River fault and to examine its association with other major faults that have affected Wrangellia and the Alexander terrane; and 3) to establish a pre-Tertiary tectonic framework for the outboard margin of the Cordillera in western Canada and southeast Alaska.

Detailed mapping of the Duke River fault has resulted in six 1:10 000-scale geologic maps of exposures of the fault in southwest Yukon, three of which are presented in this paper. A suite of samples has been collected for petrographic work, and ^{40}Ar/^{39}Ar and U-Pb geochronology. In this paper, we compare Wrangellian rocks to adjacent rocks of the Alexander terrane, illustrating their contrasting structure and metamorphic character. Microscopic and outcrop-scale structural features from different localities are presented to illustrate the kinematic history of the fault. Preliminary ^{40}Ar/^{39}Ar ages of mica grains collected within fault fabrics in the Duke River fault and U-Pb ages of intrusive rocks that have been deformed by the fault are also presented. Preliminary results show that the Duke River fault is dominantly a thrust fault that places multiply deformed greenschist facies Alexander terrane rocks over less deformed, lower-grade rocks of Wrangellia. The fault may be as old as Cretaceous and as young as Miocene.

REGIONAL GEOLOGY

WRANGELLIA

Stratigraphy

Wrangellia is made up of a Paleozoic island arc sequence overlain by a thick package of early Mesozoic flood basalts and sedimentary rocks that were formed outboard of the North American margin. It extends from central Alaska to southern British Columbia (Fig. 1). The Skolai Group is the oldest succession of layered rocks in Wrangellia in southwest Yukon. The Skolai Group consists of Mississippian to Permian volcanic and volcaniclastic rocks of the Station Creek Formation and sedimentary rocks of the Hasen Creek Formation (Smith and MacKevett, 1970; Read and Monger, 1976). The Station Creek Formation includes a lower package of basic to intermediate porphyritic flows with plagioclase and pyroxene phenocrysts and an upper package of volcaniclastic rocks ranging from coarse breccias to fine tuffs (Smith and MacKevett, 1970; Read and Monger, 1976). The Hasen Creek Formation gradationally overlies the Station Creek Formation and consists of chert, black shale, minor conglomerate and limestone that contains Early Permian fossils (Smith and MacKevett, 1970; Read and Monger, 1976). Thin units of Middle Triassic *doenella*-bearing siltstones unconformably overlie the Hasen Creek Formation, and are locally preserved in graben-like structures (Israel *et al.*, 2007; Israel and Cobbett, 2008). Basal conglomerates of the Nikolai Formation normally overlie these siltstones. The basal conglomerate of the Nikolai Formation is overlain by a package of amygdaloidal basalt flows that are up to 3000 m thick (Read and Monger, 1976). Locally, thin-bedded, bioclastic limestone and green and maroon shales are interbedded with flows near the top of the formation. Basalt of the Nikolai Formation has been interpreted as being part of a large igneous province derived from plume-related processes (Greene *et al.*, 2008). The Upper Triassic Chitistone limestone and interbedded limestone and calcareous and carbonaceous sedimentary rocks of the McCarthy Formation conformably overlie the Nikolai Formation (Read and Monger, 1976; Israel and

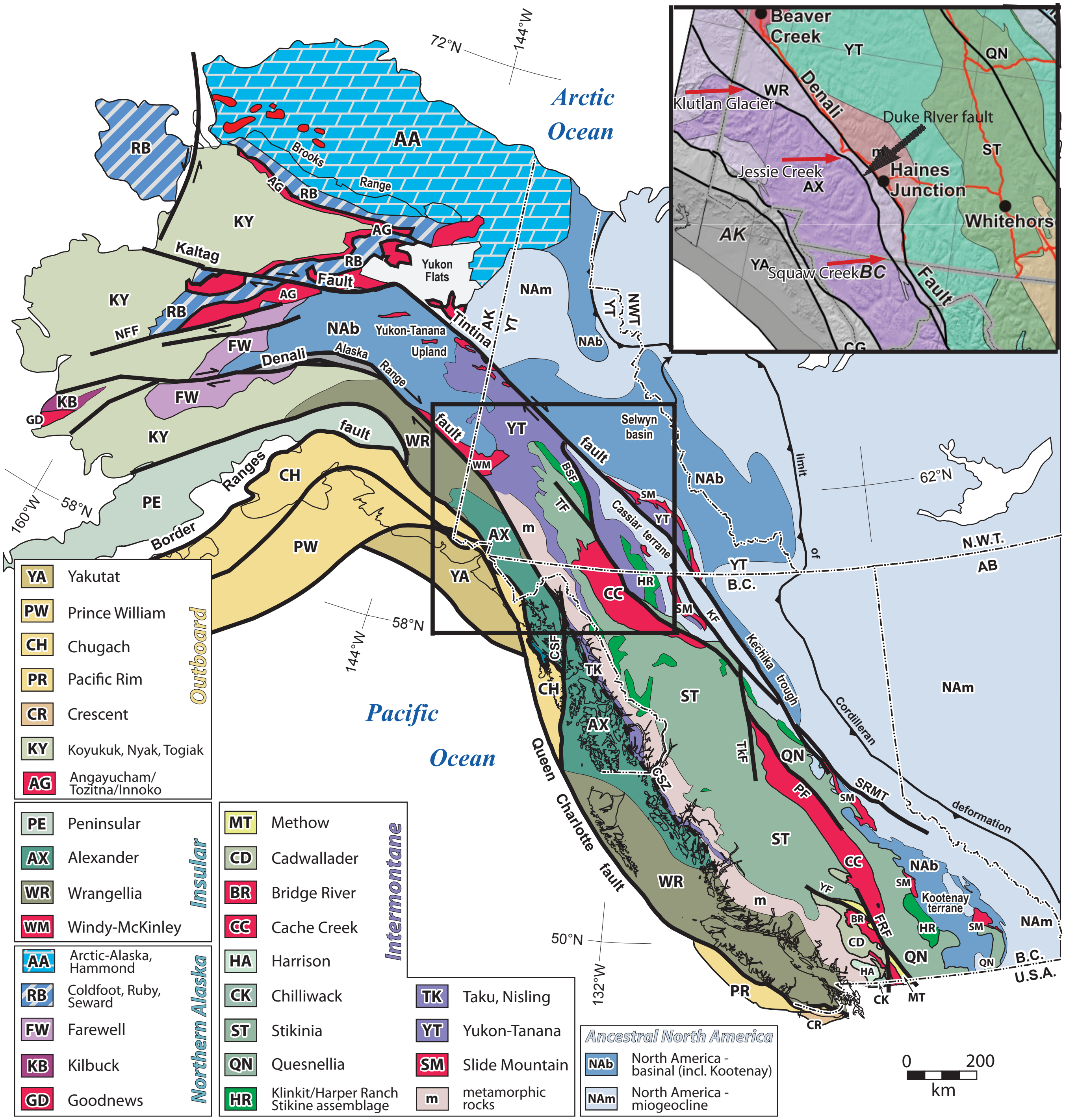

Figure 1. *Location of Insular terranes of the Canadian Cordillera (Colpron et al., 2006). The Duke River fault separates Wrangellia from the Alexander terrane as shown in the inset by the black arrow. Locations of maps presented in this paper are indicated by red arrows in the inset.*

Cobbett, 2008). Gypsum is found in the lower portions of the Chitistone limestone (Israel *et al.*, 2006; MacKevett, 1971; Read and Monger, 1976). The gypsum varies in thickness from metre-scale deposits to accumulations up to several hundred metres thick.

Intrusive Rocks

Coarse-grained, pyroxene-bearing gabbros of the Steele Creek complex sit unconformably under the Hasen Creek Formation. The gabbros are Latest Devonian in age and are the oldest identified rocks in Wrangellia in southwest Yukon; they likely represent part of the basement that the Skolai Group was deposited upon (Read and Monger, 1976). Plutons ranging in age from Late Triassic to Late Miocene intrude rocks of Wrangellia. Late Triassic mafic and ultramafic intrusive rocks of the Kluane Ultramafic Suite that are inferred to be part of the magmatic system that fed the basalts of the Nikolai formation (Hulbert, 1997) have long been known in the area. Recently, medium to coarse-grained granodiorite to tonalite of Late Triassic age was also recognized (Israel and Cobbett, 2008) having been mapped previously as part of the lithologically similar Early Cretaceous Kluane Ranges Plutonic Suite. The Kluane Ranges Suite is the most abundant intrusive rock in the area. It includes medium to coarse-grained diorite to granodiorite. Locally, medium-grained hornblende-pyroxene gabbro and biotite-hornblende diorite belonging to the Pyroxenite Creek Ultramafic unit have been mapped intruding rocks of Wrangellia. The youngest intrusions are Middle to Late Miocene, felsic to mafic bodies of the Wrangell Plutonic Suite.

Structure

Wrangellia has been affected by several deformation events beginning as early as pre-Middle Triassic and continuing until the present day, as indicated by ongoing seismic activity along faults bounding Wrangellia (Read and Monger, 1976; Power, 1988; Israel and Cobbett, 2008). In southwest Yukon, Wrangellia is characterized by dominantly northwest-trending structures. A pre-Middle Triassic compressional event has been inferred on the basis of folded Paleozoic strata overlain by relatively undeformed Triassic strata, the absence of Early Triassic rocks and the unconformable contact between Triassic and Paleozoic stratigraphy (Read and Monger, 1976; Israel and Cobbett, 2007, 2008). A second, post-Triassic, pre-middle Cretaceous compressional event is characterized by well-documented regionally extensive, tight to isoclinal folds and accompanying northeast- and southwest-verging thrust faults (Read and Monger, 1976; Israel and van Zeyl, 2005; Israel and Cobbett, 2007). Finally, Wrangellia has been cut by post-Cretaceous strike-slip and associated second-order faults that includes up to 370 km of right-lateral movement along the Denali fault and associated structures as well as an unknown amount of movement along the Duke River fault (Read and Monger, 1976; Lowey, 1998; Israel and van Zeyl, 2005; Israel and Cobbett, 2008). Many of the Cretaceous and older structures were reactivated during this time.

ALEXANDER TERRANE

The Alexander terrane is exposed in southeast Alaska, southwest Yukon and parts of northwestern British Columbia (Fig. 1). It includes intrusive, volcanic and sedimentary rocks that range in age from Cambrian to Late Triassic (Gehrels and Saleeby, 1987).

New studies from Alaska and southwest Yukon suggest that the Alexander terrane as defined by Gehrels and Saleeby (1987) differs from Alexander terrane in peninsular Alaska and from Alexander terrane exposed in southwest Yukon (St. Elias Alexander; S. Karl and C. van Staal, pers. comm., 2009). Gehrels and Saleeby's (1987) work shows that the Alexander terrane in Alaska is made up of a series of amphibolite-grade metamorphic rocks that were affected by an Ordovician orogenic event (The Wales orogeny). These rocks formed the basement to a younger sequence of arc rocks that, together with the older rocks, were deformed by the Klakas orogeny. This tectonic event began in earliest Devonian time, before the deposition of Triassic strata (Gehrels and Saleeby, 1987). In contrast, the St. Elias Alexander terrane consists of an Early Paleozoic carbonate-dominated passive margin that was built on an older arc sequence consisting of basalt and volcaniclastic rocks (Dodds and Campbell, 1992). The St. Elias Alexander terrane rocks have been affected by tectonism of Klakas age, but do not show evidence of the older Wales orogeny. This paper only discusses the St. Elias Alexander rocks and does not consider the Alexander terrane exposed in Alaska and British Columbia.

In Yukon, the Alexander terrane is made up of successions of siliciclastic rocks, carbonates and volcanic rocks of a variety of ages. The oldest exposed rocks are the Cambrian to Ordovician Donjek formation, which consists of greywacke and greenstone with a minor component of carbonate. These rocks are overlain by the Lower Ordovician to Devonian Goatherd formation which comprises dominantly carbonate and clastic rocks. A similar package of carbonate and clastic rocks of Silurian to Devonian age make up the Bullion formation and are exposed throughout the Alexander terrane in southwest Yukon. The youngest package of layered rocks in the St. Elias Alexander terrane is the Devonian to Upper Triassic Icefield formation. This package consists of pelitic, carbonate and volcanic rocks.

Intrusive Rocks

Two main episodes of plutonism affected St. Elias Alexander rocks. The first of these is the Icefield Ranges Suite which is Pennsylvanian to Permian in age, the second is the Late Jurassic to Early Cretaceous Saint Elias Suite. The Icefield Ranges Suite consists of biotite-hornblende syenite, quartz monzodiorite and diorite and is observed to stitch together rocks of the Alexander terrane and Wrangellia (Gardner *et al.*, 1988). The Saint Elias Suite consists of non-porphyritic to porphyritic (K-feldspar) biotite-hornblende granodiorite. Gabbro and ultramafic bodies found near the Duke River fault intrude rocks of the Alexander terrane and may be part of the Late Triassic and (?) older Kluane Ranges mafic-ultramafic suite that intrudes rocks of Wrangellia. Relatively fresh and undeformed hornblende ± biotite granodiorite to porphyritic (K-feldspar) hornblende granodiorite of the Miocene Wrangell Suite intrude the Alexander terrane throughout southwest Yukon.

Structure

The Alexander terrane rocks have been metamorphosed to greenschist facies and are pervasively foliated. A northwest structural trend is observed throughout the terrane and includes folds and metamorphic fabrics (Dodds and Campbell, 1992). Two regional-scale phases of folds are found that are pre-Jurassic in age and are likely at least partially contemporaneous with the intrusion of the Pennsylvanian Icefield Ranges Suite (Read and Monger, 1976; Gardner *et al.*, 1988; Dodds and Campbell, 1992). Several phases of faulting affect Alexander terrane rocks in southwest Yukon. These include thrust faults of uncertain age, steeply dipping strike-slip faults related to the Denali and Duke River fault systems, and normal faults that appear to be quite young (Dodds and Campbell, 1992).

OVERLAP ASSEMBLAGES

Several packages of rock are shown to overlie both the Alexander terrane and Wrangellia. The oldest of these are Upper Jurassic to Lower Cretaceous turbidites of the Dezadeash Formation. The Dezadeash Formation is associated with several similarly aged basins that developed between the Insular and Intermontane terranes during middle Mesozoic time (Smith and MacKevett, 1970; Read and Monger, 1976; McClelland *et al.*, 1992; van der Heyden, 1992). Terrestrially deposited clastic sedimentary rocks of the Oligocene Amphitheatre Formation overlie both the Alexander terrane and significant parts of Wrangellia and were deposited in extensional and compressional basins developed along the Duke River and Denali fault systems (Read and Monger, 1976; Ridgeway *et al.*, 2002). Miocene to Pliocene and (?) younger volcanic rocks of the Wrangell volcanic formation outcrop extensively throughout southwestern Yukon.

DUKE RIVER FAULT, GEOLOGY, STRUCTURE AND METAMORPHISM

Preliminary data from three of the six areas along the Duke River fault that have been mapped for this study are presented and discussed here. These data include lithologic descriptions, petrographic analyses and preliminary geochronology from the southeastern-most, the central and northwestern-most exposures of the Duke River fault.

SQUAW CREEK

The Duke River fault in the Squaw Creek area is exposed in a steep-sided canyon that starts near the Yukon-British Columbia border and extends for about six kilometres to the northwest. In the Squaw Creek area, a deformed gabbro belonging to the Pyroxenite Creek ultramafic suite intrudes tuffs and volcaniclastic rocks of the Station Creek Formation on the north side of the Duke River fault (Fig. 2). Miocene to Pliocene crystal tuff and basalt flows of the Wrangell volcanic formation overlie the Station Creek Formation and the gabbro but are not found on the south side of the fault. Wrangell tuffs near the Duke River fault are foliated (Fig. 3a). Rocks of the Station Creek Formation are deformed by open folds that trend northwest and southeast. The metamorphic grade of these rocks is prehnite/pumpellyite.

In contrast, rocks of the Alexander terrane on the south side of the Duke River fault comprise an assemblage of foliated calcareous and carbonaceous siltstones, phyllitic volcaniclastic rocks, greenschist and massive to layered marbles. The upper walls of the Squaw Creek canyon are dominantly made up of competent marble (Fig. 3b). The main foliation in the Alexander terrane rocks strikes

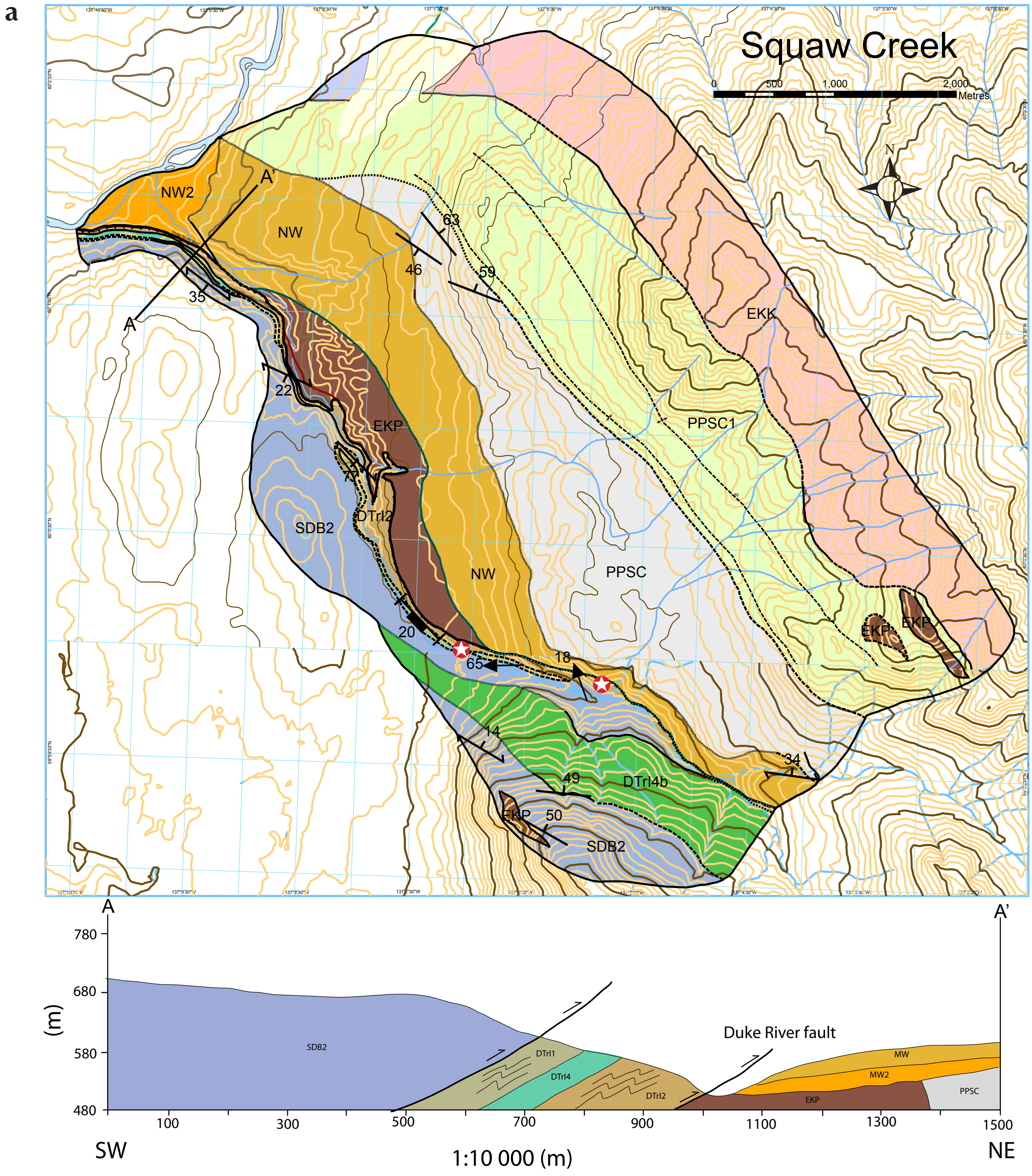

Figure 2. (a) *Geologic map and cross section (line A-A′) of the Squaw Creek area.*

b

LEGEND

MIOCENE TO PLIOCENE AND (?) YOUNGER

Wrangell Lavas

NW	Dark grey to black, fine-grained amygdaloidal basalt
NW2	Beige fresh and weathered, fine-grained crystal lithic tuff

LATE EARLY CRETACEOUS

Pyroxenite Creek Ultramafic

EKP	Green, medium-grained, foliated, plagioclase, clinopyroxene, chlorite and epidote gabbro
EKK	Medium grey, medium to coarse-grained, biotite-hornblende granodiorite, quartz diorite, quartz monzonite, and hornblende diorite

WRANGELLIA

UPPER TRIASSIC

Chitistone

uTrC	Light to dark grey, thinly bedded limestone and limestone breccia

LATE TRIASSIC AND (?) OLDER

Kluane Mafic and Ultramafic Suite

PTrK	Black to dark green, medium-grained pyroxenite
PTrK2	Green, medium-grained hornblende-actinolite gabbro

PENNSYLVANIAN TO (?) LOWER PERMIAN

Skolai Group: Station Creek Formation

PPSC1	Laminated to thinly bedded, light grey to light green volcanic tuff and volcaniclastic siltstone; local crystal-rich tuffs interbedded with fine-grained volcanic ash
PPSC	Green, fine-grained volcanic breccia and basalt flow

Skolai Group: Hasen Creek Formation

PHC	Interbedded dark grey and brown-weathered siltstone, mudstone and medium to coarse grained sandstones; grey pebble conglomerate and light brown fossilstone; rare thinly bedded black chert

ALEXANDER

PALEOZOIC, (?) DEVONIAN AND/OR YOUNGER

Steele Creek Suite

PSC	Massive, locally foliated, grey-green, medium to coarse-grained, hornblende pyroxene gabbro; minor medium-grained gabbro diabase and leucocratic gabbro
DMr	Green, fine-grained mafic rock
MGr	Pinkish, fine to medium-grained quartz, feldspar granite

DEVONIAN TO UPPER TRIASSIC (?) AND OLDER

Icefield Formation

DTrI1	Light green, fine to very fine grained, volcaniclastic rock; very fine grained samples could be phyllonites
DTrI2	Dark grey to black, fine grained, carbonaceous phyllite to mica schist; local dark to light grey ribbon chert and occasional fine to medium-grained lithic sandstone
DTrI3	Dark green volcanic breccia with clasts up to 25 cm in diameter having significant reaction rims; local plagioclase-phyric and/or amygdaloidal and vesicular basaltic flows
DTrI4	Grey, thinly bedded limestone and dark grey, bedded calcareous siltstone
DTrI4b	Undifferentiated greenshist interfoliated with meta-siltstone and carbonate
DTrI6	White to grey, massive marble; locally brecciated
DTrI7	Interbedded, green, fine-grained volcaniclastic sandstone, maroon and green volcanic conglomerate and basalt flows; occasional very fine-grained tuffaceous horizons; local layers of lithic conglomerate with clasts of chert and siltstone and occasional beds of shale or slate

SULURIAN AND DEVONIAN

Bullion formation

SDB1	Beige to grey to orange weathered, massive to thinly bedded to brecciated carbonate
SDB2	Grey to brown, fine-grained, carbonaceous mica schist; local quartzite

SYMBOLS

geologic contacts
(defined, approximate, inferred, covered).......

mapping limit..

fault; movement not known
(defined, approximate, inferred, covered).......

fold axial trace
(anticline, overturned-anticline; syncline, overturned-syncline) ....

dyke, vein...

bedding (tops known, inclined, vertical)..........

foliation (dominant, late).................................

fold axis (dominant phase, Z-fold)...................

intersection lineation.......................................

stretching lineation, mineral lineation.............

location of Argon-Argon samples.................... ✪

Figure 2. *continued* ***(b)*** *Map legend for geologic maps of Squaw Creek, Jessie Creek and Klutlan glacier areas.*

approximately east and dips moderately to the south. Siltstone and volcaniclastic rocks of the Alexander terrane exhibit three phases of folding. The first phase is manifested as millimetre-scale folded layers in the siltstone and is associated with the dominant foliation (Fig. 3c). This foliation is tightly folded by the second phase of folding which has a well-developed axial-planar cleavage in the hinges (Fig. 3d). The third phase comprises brittle, asymmetric kink folds which refold the first two phases of folding. This late phase commonly occurs in gouge zones, has shallowly dipping hinges that trend eastward, and verge to the north-northeast (Fig. 3d).

The Duke River fault is characterized by a 10 to 20-m-wide cataclastic zone that parallels the dominant foliation in the hanging wall (Fig. 3e). Marble of Alexander terrane is structurally above the cataclastic zone and remains intact. Brittle foliations associated with the fault zone occur within the siltstone or volcaniclastic units, strike southeast and have moderate southwest dips. The gabbro of the Pyroxenite Creek ultramafic suite is more intensely foliated and altered in the bottom of the canyon where it is closest to the cataclastic zone. Thin sections from layered carbonate of the Bullion formation near the fault, show sinistral shear bands in fine-grained muscovite layers. The dominant lineation in the layered carbonate rocks

Figure 3. ***(a)*** *Foliated crystal tuff of the Wrangell volcanics near Squaw Creek.* ***(b)*** *Marble of Bullion formation sitting structurally above Duke River fault gouge zone.* ***(c)*** *Phase one folds in siltstone near Squaw Creek.* ***(d)*** *Axial-planar cleavage in phase two folds near Squaw Creek.* ***(e)*** *Kink folds in fault gouge near Squaw Creek. These folds strike approximately east and verge to the north-northeast.*

plunges approximately 55° towards 200°. Preliminary ^{40}Ar/^{39}Ar dating constrains the age of muscovite in the fault zone to the middle Cretaceous (90-104 Ma).

JESSIE CREEK

The Jessie Creek map area is roughly 140 km along strike to the northwest from the Squaw Creek area. At Jessie Creek, the Duke River fault is exposed in a narrow valley between steep-sided mountains of the Kluane Ranges (Fig. 1 inset).

On the north side of the fault, rocks of Wrangellia consist of siltstone and sandstone of the Hasen Creek Formation and the overlying Chitistone limestone. The thinly bedded Chitistone limestone becomes brecciated near the Duke River fault. Both the Chitistone limestone and the rocks of the Hasen Creek Formation have been tightly folded (Fig. 4).

The rocks of the Alexander terrane consist of two distinct assemblages. The first assemblage is found directly adjacent to the Duke River fault and consists of Triassic

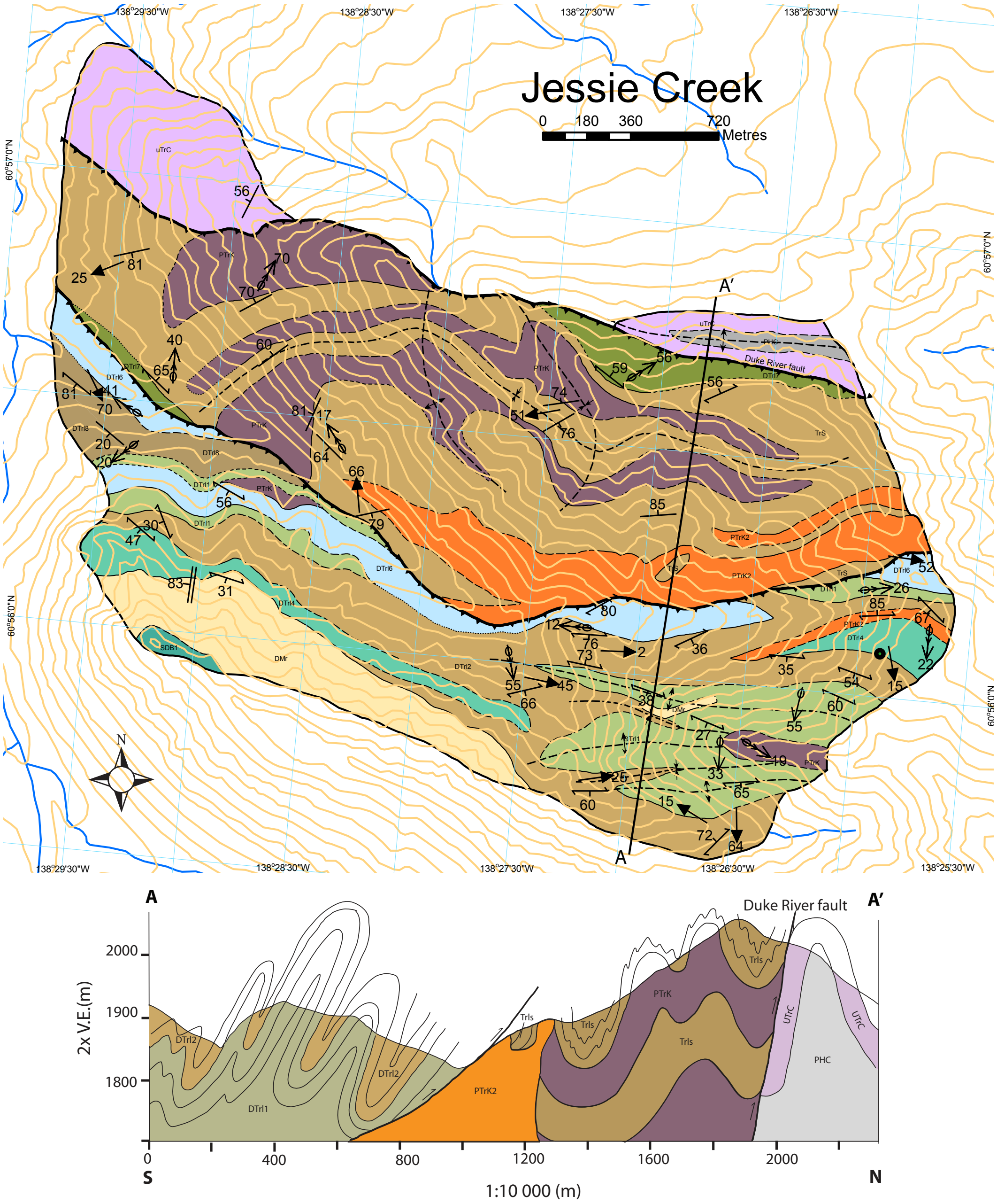

Figure 4. *Geologic map and cross section (line A-A′) of the Jessie Creek area. Refer to Figure 2b legend for symbol and unit descriptions.*

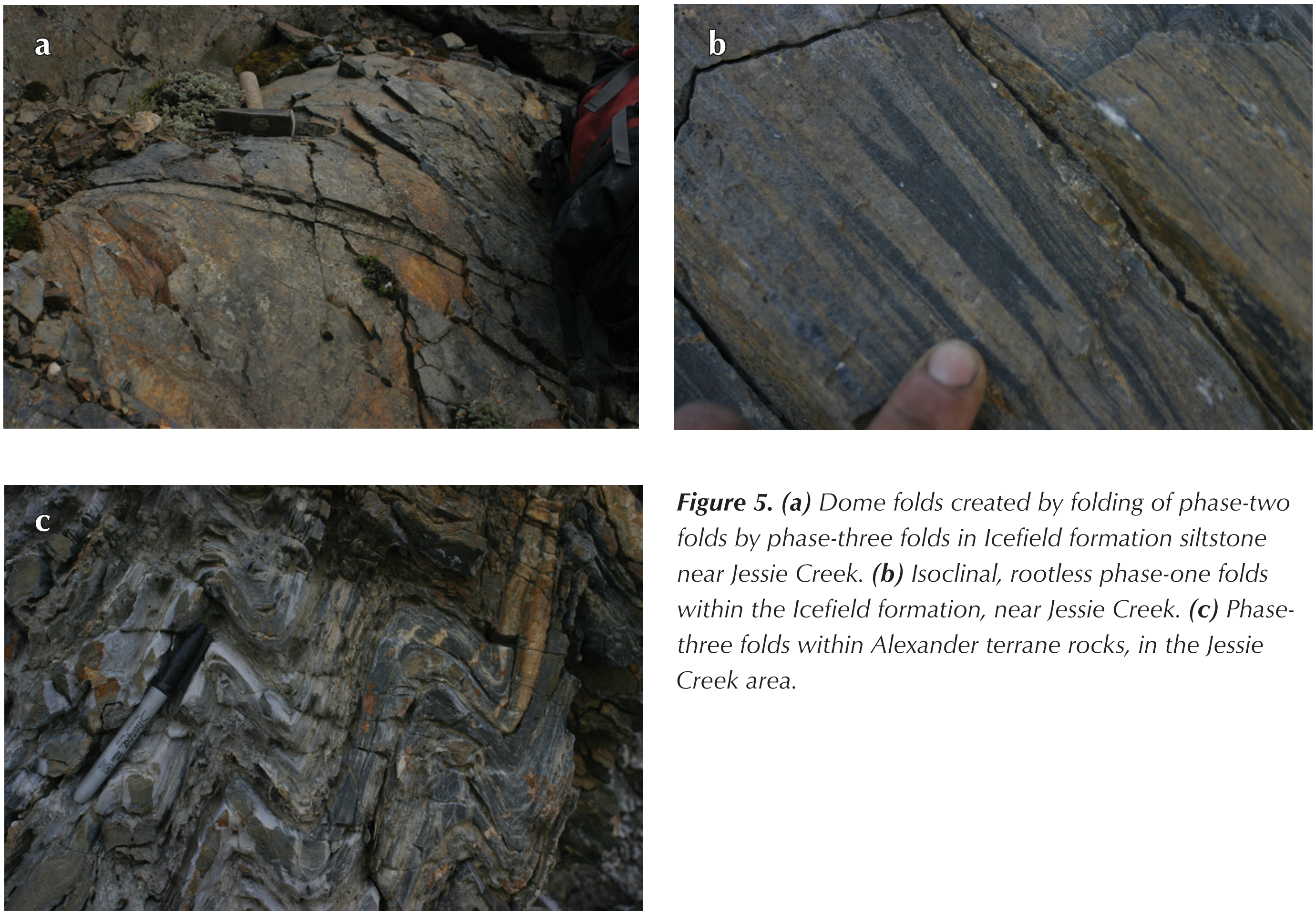

Figure 5. (a) *Dome folds created by folding of phase-two folds by phase-three folds in Icefield formation siltstone near Jessie Creek.* ***(b)*** *Isoclinal, rootless phase-one folds within the Icefield formation, near Jessie Creek.* ***(c)*** *Phase-three folds within Alexander terrane rocks, in the Jessie Creek area.*

calcareous siltstone interbedded with ribbon chert and volcanic conglomerate. Beds of conglomerate grade upwards into sandstone beds. The whole assemblage is intruded by gabbro and pyroxenite of probable Late Triassic age. The second assemblage of Alexander terrane rocks is in fault contact with the first and includes Devonian volcaniclastic and volcanic rocks, carbonaceous siltstone, banded marbles and locally quartzite.

The two assemblages described above are further distinguished by differences in structural styles. The Triassic rocks are deformed by three phases of folding. The first phase consists of isoclinal folds that are locally preserved in the siltstones. However, the preservation of the folds is not adequate to obtain an orientation. This early phase is folded by a second phase that tightly folds the siltstone unit and more openly folds the cherts. The third phase of folding is hard to characterize because the hinges are nowhere exposed. Its existence is inferred because the phase-two folds regularly change orientations from southeast trending to northeast trending. These third-phase folds openly fold the phase-two folds. The beds of siltstone are deformed by phase-two and phase-three folds, resulting in complex interference patterns including dome-and-basin (Fig. 5a). The Devonian package of rocks is deformed by up to four phases of folding. The first phase is rarely preserved but locally can be seen as isoclinal, sometimes rootless folds in fine-grained volcaniclastic rocks (Fig. 5b). Phase-one folds have been refolded by a second phase that is responsible for the dominant foliation. The phase-two foliations are tightly folded by asymmetric phase-three folds that have shallowly east-west plunging, curvilinear fold hinges (Fig. 5c). These asymmetric folds verge to the north in some outcrops and to the south in others. A final set of open folds deforms all these rocks. The Triassic package of rocks does not seem to have been affected by the first phase of deformation that folded the Devonian rocks. Phase-one folds in the Triassic rocks are likely equivalent to phase-two folds in the Devonian package. Likewise, phases three and four in the Devonian rocks are most likely equivalent to phases two and three in the Triassic package.

In this area, the Duke River fault is marked by the contact between Chitistone limestone (usually brecciated) and either gabbros or siltstones belonging to the Alexander terrane. This contact is poorly exposed and kinematic and geometric data for the Duke River fault is interpreted from the rocks exposed on either side of the fault.

KLUTLAN GLACIER

The westernmost exposure of the Duke River fault in Yukon occurs along a ridge near the Klutlan Glacier, a few kilometres from the Alaska border (Fig. 1). In this area, the Duke River fault juxtaposes rocks of the Station Creek Formation against a variably deformed, medium-grained, hornblende, pyroxene gabbro to leuco-gabbro that has slivers of serpentinized ultramafic rock throughout (Fig. 6).

On the northern side of the Duke River fault, volcanic and volcaniclastic rocks of the Station Creek Formation are deformed into an upright syncline with thinly bedded

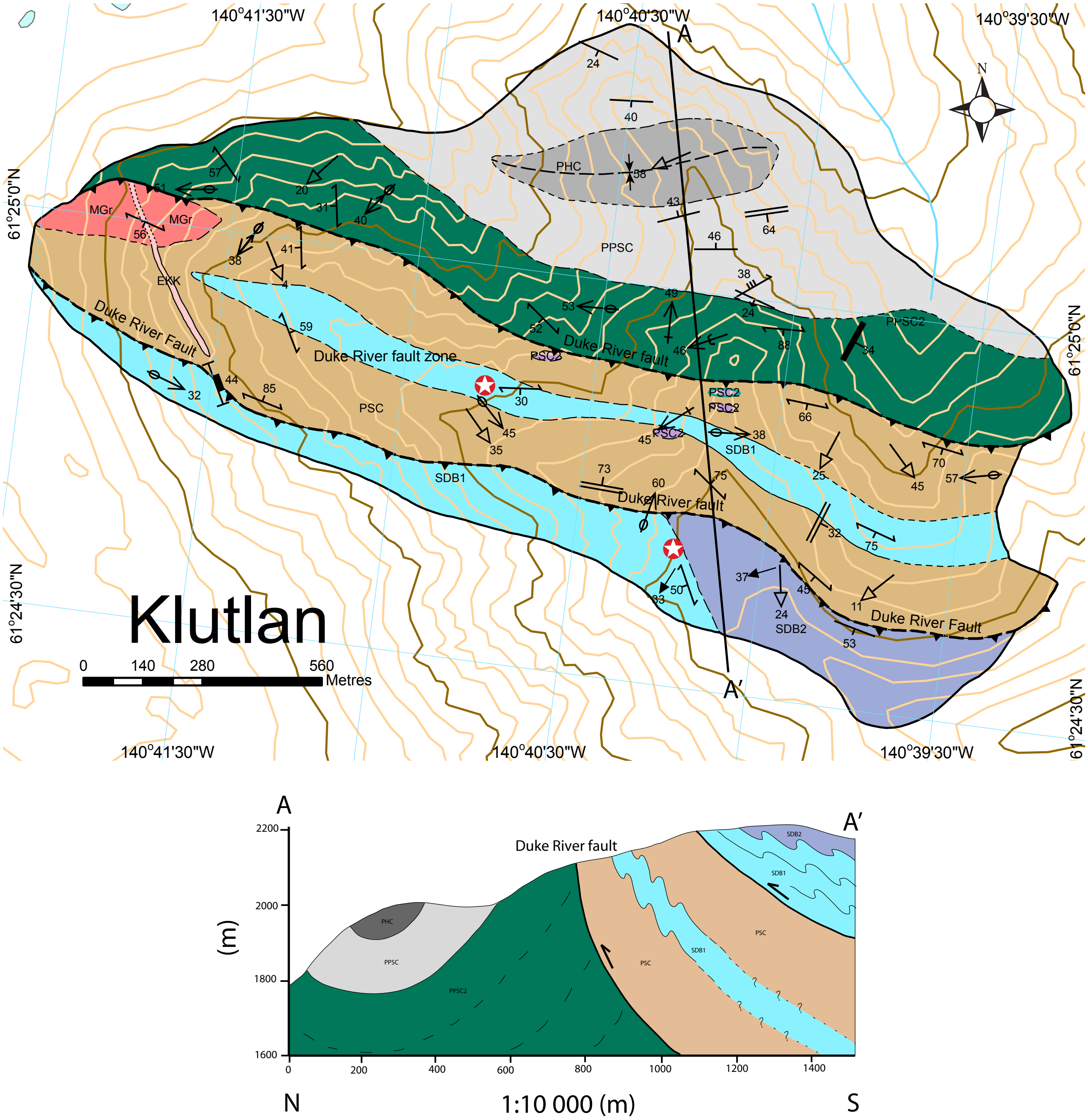

Figure 6. Geologic map and cross section (line A-A′) of the Klutlan Glacier area. Refer to Figure 2b legend for symbol and unit descriptions.

sandstones and siltstones of Hasen Creek Formation in its core. This synform trends east and is sub-parallel to the Duke River fault. Locally, the Station Creek Formation is intruded by amygdaloidal fine-grained, dark brown, basaltic dykes.

South of the Duke River fault, the Alexander terrane consists of two assemblages. A deformed gabbro is in fault contact with a Silurian to Devonian limestone, muscovite schist, greenschist and minor quartzite (Fig. 6). A thin sliver of the mica schist is within the gabbro body; however, any evidence of an intrusive contact between the schist and the gabbro has been obscured by complex structures related to the adjacent faults. The gabbro is sheared in most places and locally contains fuchsite. Layers within the quartzite show dynamically recrystallized quartz grains that are inter-foliated with layers of muscovite (Fig. 7a). Foliation in the quartzite is symmetrically and openly folded and the muscovite grains are crenulated. A cataclastic zone approximately 5-10 m wide is between the gabbro and the Bullion formation south of the Duke River fault. Foliation in the gabbro and schists dominantly strike east and mainly dip to the south, although locally these structures dip shallowly to the north. Stretching lineations developed on the main foliation within the schists plunge moderately to the southeast.

The Alexander terrane in this area has been affected by a series of intrusions. An altered, pinkish, fine to medium-grained, quartz, feldspar granitic rock intrudes the Alexander terrane rocks near the Duke River fault and is foliated (Fig. 7b). A purple, fine-grained intermediate dyke crosscuts most structural fabrics and shows minor, brittle offsets in the fault zone (Fig. 7c). This dyke cannot be traced across the contact between the foliated rocks and the Station Creek Formation, suggesting the Duke River fault may have offset it. However, exposure in this area is poor and the dyke may simply disappear under colluvium on the north side of the fault. Crosscutting the gabbro and the Alexander terrane rocks are dark brown to black, fine-grained basaltic to dioritic dykes that do not appear to be deformed by the Duke River fault. Again, these dykes are not seen crosscutting the fault, but may be equivalent to the fine-grained dykes that intrude the Station Creek Formation rocks.

Preliminary age data from the Alexander terrane rocks in this area include ^{40}Ar/^{39}Ar dates from muscovite grains and a U-Pb age from a felsic intrusion. Preliminary ^{40}Ar/^{39}Ar dates for muscovite from within the quartzite yield a Permian age (256 Ma). A mineral lineation

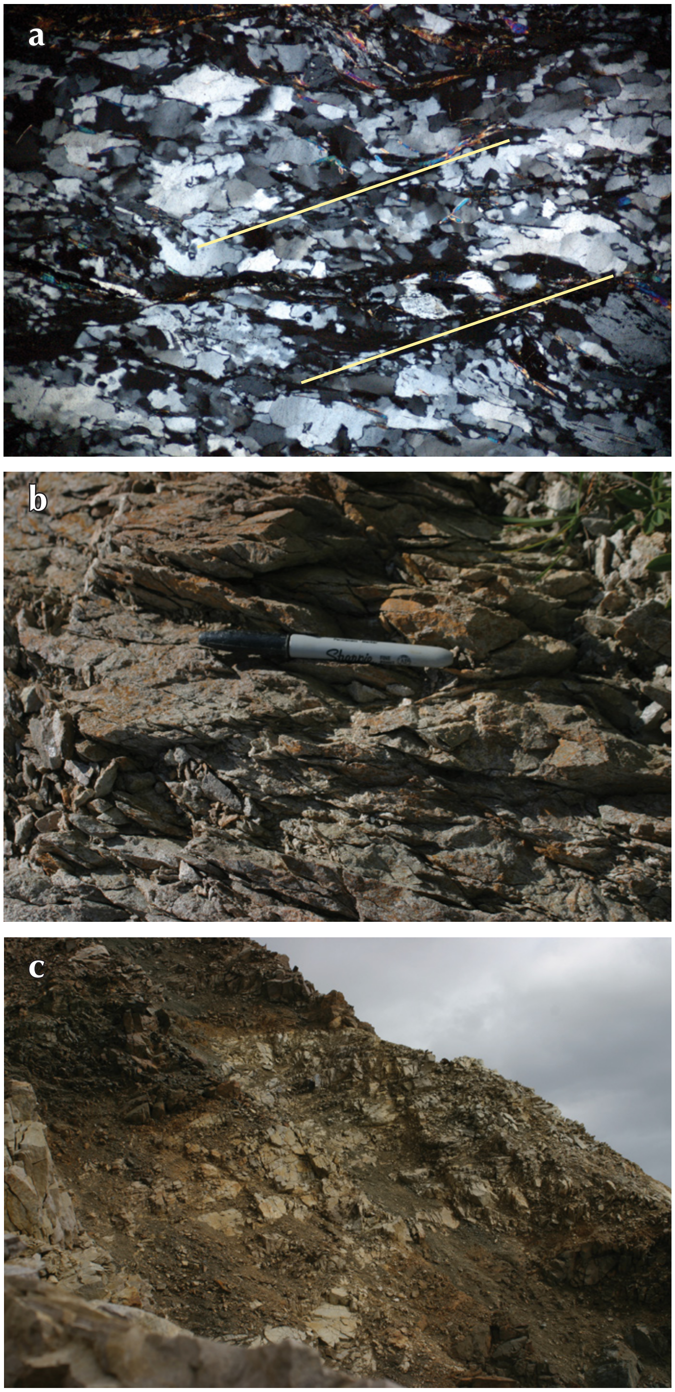

Figure 7. (a) *Cross-polar photomicrograph of quartzite from the Bullion formation near Klutlan glacier showing dynamically recrystallized quartz and sinistral shear bands. Width of photograph is ~3.9 mm.* ***(b)*** *Felsic intrusion that has been deformed by the Duke River fault.* ***(c)*** *Felsic to intermediate dyke that crosscuts foliated Alexander terrane rocks and has subsequently been offset by late motion along the fault.*

developed along the main foliation within the quartzite plunges moderately to the south-southwest. Muscovite grains from within the schist that occurs as a sliver in the gabbro have returned a preliminary $^{40}Ar/^{39}Ar$ Permian age (267 Ma). A preliminary U-Pb age of Early Mississippian (~351 Ma) was obtained from the foliated intrusion.

DISCUSSION

In the three mapped areas described above, the Duke River fault separates two very different assemblages of rocks. These differences include stratigraphic relationships, contrasting metamorphic grade and deformation histories. These differences suggest that the Duke River fault has accommodated significant amounts of movement.

Lithologies and the ages of rock units on either side of the Duke River fault are markedly different. For example, near Jessie Creek, a package of Triassic siltstones, ribbon cherts, gabbros and a stretched pebble conglomerate are in fault contact with Chitistone limestone. Although the units are comparable in age, the rocks do not appear to have formed in a similar environment. Further, near the Klutlan Glacier and Squaw Creek areas, the Silurian to Devonian Bullion formation consists of mainly carbonate rocks and is juxtaposed against volcanic and volcaniclastic rocks of the Pennsylvanian to Permian Skolai Group. The contrast in formation ages coupled with the different environments that these packages of rocks formed in, suggests the Duke River fault represents a suture between two terranes that evolved separately in different environments.

The St. Elias Alexander terrane, as suggested by Read and Monger (1976) and confirmed in this study, has been regionally metamorphosed to greenschist facies. This is indicated by the presence of actinolite and epidote within gabbros that intrude the Alexander terrane rocks near Jessie Creek (Fig. 8a). The Alexander terrane rocks have experienced a much higher grade of metamorphism than the relatively unmetamorphosed rocks of Wrangellia,

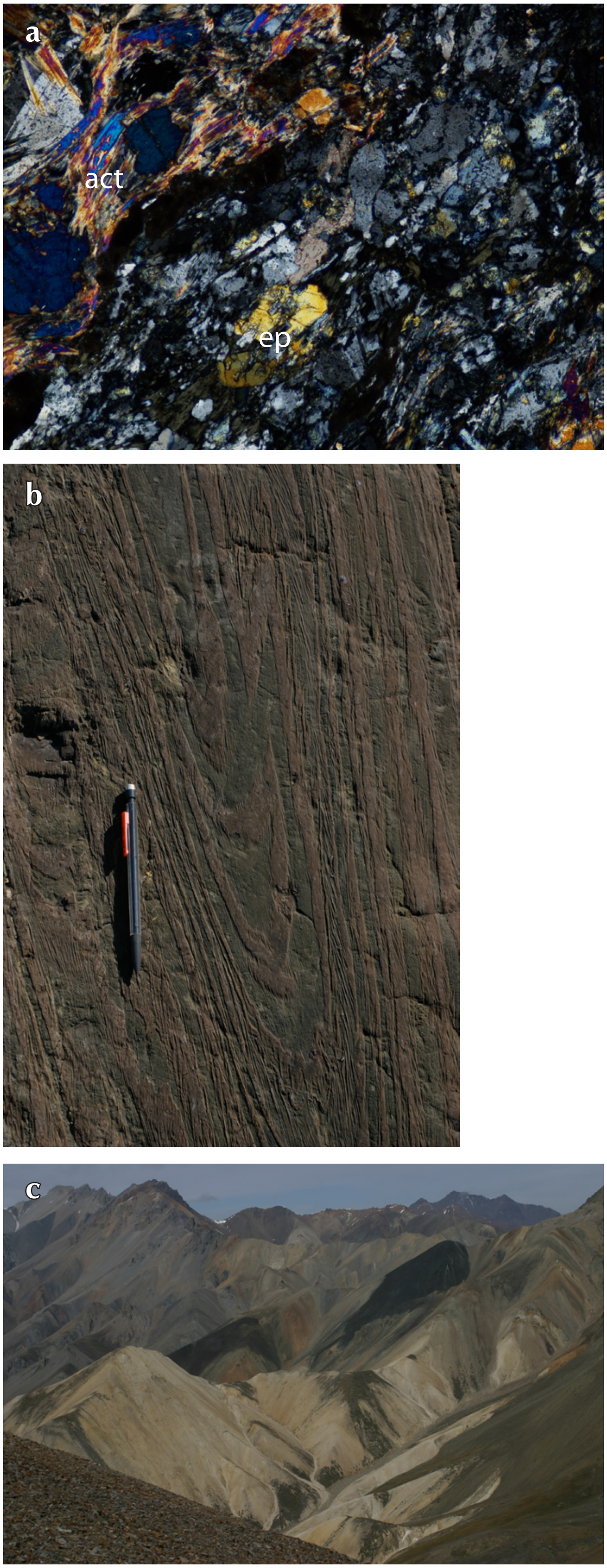

Figure 8. (a) *Photomicrograph of gabbro that intrudes the Alexander terrane. Note the formation of epidote (ep) and actinolite (act) suggesting this rock underwent greenschist grade metamorphism. Width of photograph is ~1.7 mm.* ***(b)*** *Refolded folds within the Donjek formation indicating regional polyphase deformation.* ***(c)*** *Felsic intrusion of the Miocene Wrangell Suite is deformed by the Duke River fault.*

suggested by the presence of prehnite found in the Nikolai basalts (Dodds and Campbell, 1992; Read and Monger, 1976; Greene *et al.*, 2009). The contrast in metamorphic grade across the fault suggests either that the Alexander rocks have been uplifted significant distances with respect to Wrangellia along the Duke River fault, or that strike-slip displacement along the Duke River fault has transported the previously uplifted Alexander rocks next to Wrangellia.

The Alexander terrane has undergone more extensive regional deformation than the Wrangellian rocks. Rocks belonging to the Alexander terrane, several tens of kilometres away from the Duke River fault, exhibit fold interference patterns indicative of polyphase deformation (Fig. 8b). In the study areas, only one phase of folding is seen in Wrangellia (Dodds and Campbell, 1992). The difference in number of phases of deformation affecting the two terranes suggests that the Alexander terrane was affected by more than one phase of deformation before it became juxtaposed against Wrangellia.

In general, rocks become progressively more deformed closer to the Duke River fault. For example, outcrops of the Chitistone limestone become brecciated within a few hundred metres of the fault and carbonaceous phyllitic siltstone of the Alexander terrane show up to four phases of folding within one kilometre of the fault.

TIMING OF THE DUKE RIVER FAULT

Motion along the Duke River fault likely occurred over a prolonged period of time. The Permian ages (267 Ma and 265 Ma) from the Klutlan Glacier area, either represent a resetting of muscovite by heat generated during movement on the Duke River fault, or movement along the fault that separates the gabbro from the schist, or date a previously unrecognized regional deformation event that affected the Alexander terrane in Permian time. The crenulated nature of the muscovite could reflect the two phases of regional deformation that were discussed above. Given that the foliation in the dated sample is at a high angle to the fault fabrics and that the lineation trends nearly 90° from lineations near the fault, it seems more likely that these ages date a regional deformation event.

The significance of the Cretaceous ^{40}Ar/^{39}Ar ages from the Squaw Creek area are unclear and can be explained by two different processes. The micas could have either formed or been thermally reset during movements along the fault in Cretaceous time, or they may have been thermally reset by the Cretaceous Pyroxenite Creek ultramafic intrusion. The youngest movement along the Duke River fault is documented by deformation of the Wrangell lavas and associated intrusive rocks. Middle to Late Miocene (?) quartz-feldspar porphyry west of the Jessie Creek area is deformed by the Duke River fault (Fig. 8c) as are Miocene to Pliocene crystal tuffs in the Squaw Creek area. Both of these features demonstrate that the Duke River fault was active after the Miocene and possibly the Pliocene.

KINEMATICS OF THE DUKE RIVER FAULT

The sense of motion along the Duke River fault can be determined from a combination of outcrop and thin-section scale observations. In the Squaw Creek area, kinematic indicators at the outcrop-scale are best observed in the cataclastic zone. Asymmetric kink folds within this zone suggest they formed in a compressional environment. These kink folds verge to the north-northeast which suggest the Alexander terrane has been placed over Wrangellia along the Duke River fault. The foliations within the cataclastic zone dip ~35° to the south which is a favourable orientation for a thrust fault. Shear bands in thin sections cut parallel to lineations formed on the main fault foliation confirm a thrust sense of motion. Movements along the Duke River fault near Jessie Creek are less certain but likely also place the Alexander terrane northwards over Wrangellia along a steeply south-dipping reverse fault (Fig. 4). In the Klutlan area, the Duke River fault dips steeply to the south. Shear bands at outcrop scale suggest the Alexander terrane is being placed over Wrangellia along a reverse fault (Fig. 6). The fault that separates the gabbro from the schistose rocks south of the Duke River fault dips moderately to the south and is characterized by a cataclastic zone 5-10 m thick. Lineations on east-striking foliation planes within this fault, coupled with northwest-verging folds, suggest the Bullion formation is being thrust over the gabbro. The difference in metamorphic grade across all mapped areas of the Duke River fault can also be explained by thrusting, placing higher grade rocks over lower grade rocks. Although a complete kinematic history of the fault cannot be presented at this time it is clear that there has been a large amount of displacement along the Duke River fault.

SUMMARY

The Duke River fault juxtaposes two terranes that contrast in terms of metamorphic grade, degree of deformation and lithologies. On the southwest side of the fault, the Alexander terrane consists of multiply folded, Silurian to Devonian carbonates and clastic rocks and Devonian to Upper Triassic volcanic, pelitic and carbonate rocks. These rocks have been intruded by gabbros, ultramafics, granitoids and basaltic to intermediate dykes. The Alexander terrane rocks have been metamorphosed to greenschist facies and locally show up to four phases of folding.

Across the Duke River fault, Wrangellia consists of Pennsylvanian to Permian volcanic, volcaniclastic and sedimentary rocks and Upper Triassic limestones. Wrangellia has been intruded by gabbros, granitoids and fine-grained basaltic dykes. These rocks have been affected by low-grade metamorphism and one phase of folding.

Shear bands, fold orientations, rotated grains, mica fish and fault-plane orientations indicate that the Alexander terrane has been thrust over Wrangellia along the Duke River fault.

Preliminary ^{40}Ar/^{39}Ar age dates ranging from 90-104 Ma from muscovite grains that may have been reset by motions along the Duke River fault or grown during faulting suggest that the fault is at least as old as Cretaceous. Miocene felsic intrusions and Miocene to Pliocene crystal tuffs of the Wrangell lavas have been deformed by the Duke River fault suggesting major movement occurred along the fault as recently as the Pliocene.

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