Fieldwork in the Sylvester allochthon, Cassiar Mountains, British Columbia: Investigations of the Rapid River tectonite and the Slide Mountain terrane

James J. Ryan[1, a], JoAnne Nelson[2], and Cees van Staal[1]

[1] Geological Survey of Canada, Vancouver, BC, V6B 5J3
[2] British Columbia Geological Survey, Ministry of Energy and Mines, Victoria, BC, V8W 9N3
[a] corresponding author: jryan@nrcan.gc.ca

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Abstract

Back-arc extension during Devonian-Mississippian eastward subduction beneath the western flank of ancestral North America led to separation of Yukon-Tanana terrane from Laurentia, and opening of the Slide Mountain marginal ocean basin. Rocks exposed in imbricated thrust sheets of the Sylvester allochthon record the opening and closing of this marginal basin. At the highest structural level in the allochthon, the Rapid River tectonite is interpreted as a remnant of Yukon-Tanana basement. Pre-Late Devonian deformation in the Rapid River tectonite may represent collision of an exotic arc terrane with the outer peri-Laurentian margin that was the precursor to east-dipping subduction. Preliminary observations indicate that at least part of the Rapid River tectonite has a protolith of mafic mylonite and marble, possibly representing parts of a primitive arc. At two localities the tectonite is intruded by late synkinematic diorite/gabbro-tonalite-trondjemite plutons, one of which has been previously dated (ca. 362 Ma). Limited shear-sense indicators in the mylonite show top-to-the-northwest displacement.Thrust panels in the lower part of the Sylvester allochthon expose ultramafic-gabbro-supracrustal complexes that represent the youngest pre-accretionary phase in the YTT-Slide Mountain system. Near Zus Mountain northeast of the Cassiar townsite, and near Blue Dome 20 kilometres to the north, partly serpentinized harzburgite tectonites form the lower parts of thrust panels within the Slide Mountain terrane. These tectonites are overlain by interlayered peridotite tectonite, lherzolite, dunite, and gabbro; all are cut by trondhjemite dikes. The trondhjemite dikes cut previously serpentinized hosts, suggesting their emplacement during or after exhumation. At Zus Mountain, a large gabbro body overlies the ultramafites. At the Blue Dome section, seafloor deposits of locally pillowed basalt and radiolarian chert directly overlie the ultramafic rocks. This section also contains polymictic conglomerates with mainly 1 to 5 cm-sized angular clasts derived from subjacent units. Mafic clasts contain an internal ductile deformation fabric. The conglomerates indicate exhumation and erosional unroofing of previously deformed rocks, possibly along penecontemporaneous faults. Notably lacking are the sheeted dike complexes that intervene between ultramafic and supracrustal sections found in classical ophiolites. The Sylvester rocks may not have formed through 'normal' sea-floor spreading. Instead, they more closely resemble sections formed at slow-spreading ridges or hyperextending margins where the subcontinental mantle is exhumed by low-angle detachment faults. A previously dated (ca. 268 Ma) trondhjemite dike from the Zus Mountain area is coeval with similar dikes in Slide Mountain ophiolites in the Yukon, but significantly younger than supracrustal successions elsewhere in the Slide Mountain terrane. The late ocean opening documented in the Sylvester allochthon and the Yukon was broadly coeval with ocean closing elsewhere, as ocean crust was consumed by westerly subduction beneath the Yukon-Tanana terrane.

Keywords: Sylvester allochthon, Slide Mountain terrane, Yukon-Tanana terrane, Rapid River tectonite, Devonian, Permian, ophiolites

1. Introduction

This report summarizes two weeks of fly camp-based fieldwork in the Cassiar Mountains of northern British Columbia (Fig. 1) aimed at assessing two elements of the Sylvester allochthon: 1) the timing, nature, and tectonic cause of deformation in the Rapid River tectonite and 2) the history of ophiolites in the Slide Mountain terrane as a constraint on timing and mechanisms of basin formation. Work from two camps in the Dalton Creek-Four Mile River and Cry Lake areas (Fig. 1) investigated the Rapid River tectonite, the highest structural slice in the Sylvester allochthon. It rests structurally on 'Division III', an imbricated sequence of Paleozoic arc-related rocks, which in turn structurally overlies the imbricated marginal basin assemblage of the Slide Mountain terrane (Nelson, 1993). Nelson and Friedman (2004) correlated the Rapid River tectonite to mainly siliciclastic rocks of the Snowcap assemblage, which forms the basement of the Yukon-Tanana terrane (Colpron et al., 2006). Intruded by at least one Late Devonian (ca. 362 Ma) late synkinematic pluton (Gabrielse and Harms 1989; Gabrielse et al., 1993), the Rapid River tectonite offers a rare opportunity to study Devonian tectonic processes, which in most of the peri-Laurentian terranes have been obscured by Mississippian and younger deformation processes.

We also examined well-exposed ultramafic-mafic complexes of the Slide Mountain terrane in the Zus Mountain and Blue Dome areas (Fig. 1). The focus of this fieldwork was to evaluate if these complexes represent dismembered ophiolite

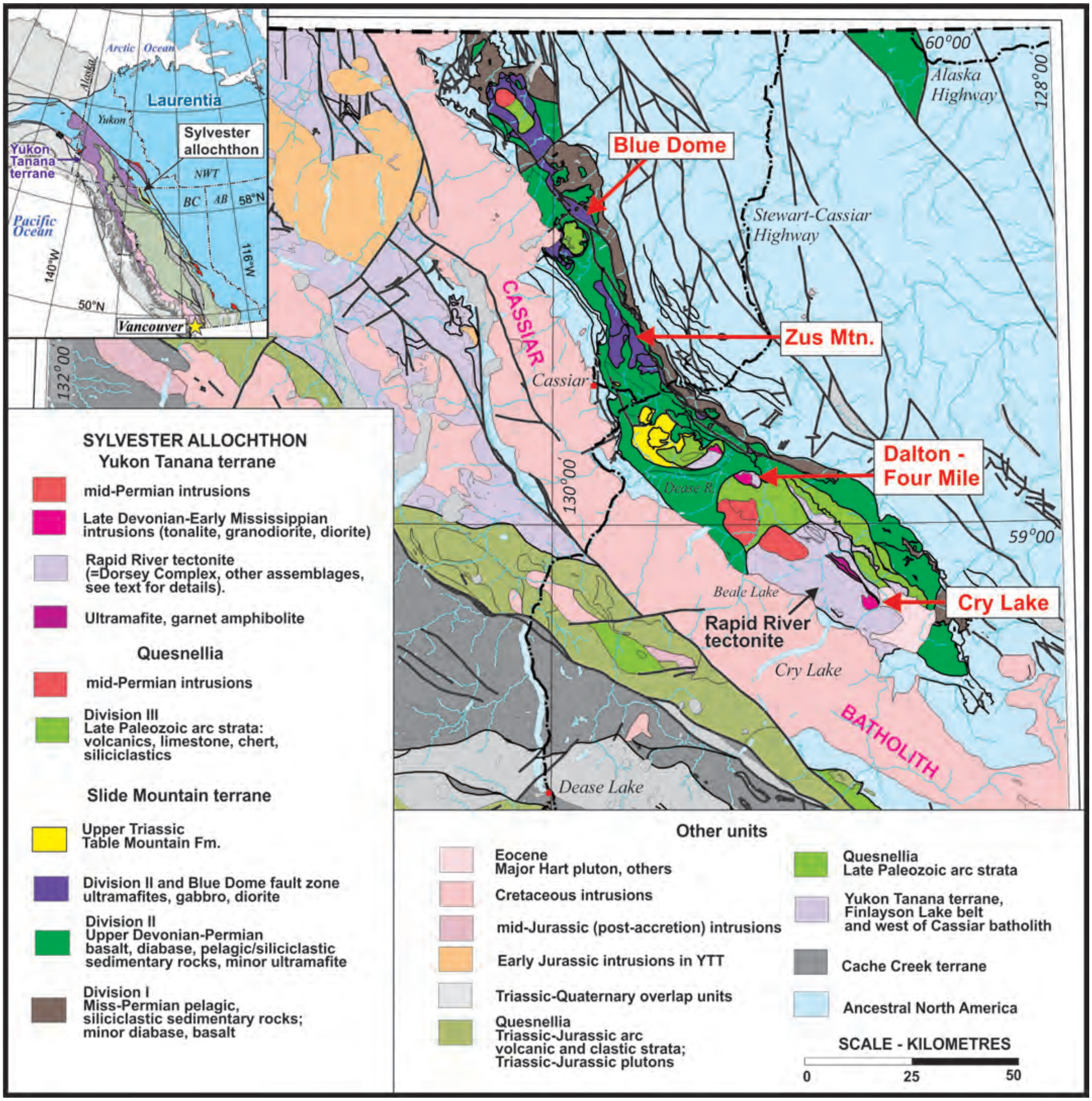

Fig. 1. Location of the Sylvester allochthon and 2014 study sites. General geology from Nelson and Friedman (2004).

massifs formed from 'normal' ocean-spreading or if they constitute Alpine-type peridotites formed during magma-poor hyperextension that exhumed mantle onto the seafloor (Manatschal et al., 2011).

2. The Rapid River tectonite and synkinematic intrusions

The Rapid River tectonite, first recognized in the Dalton-Four Mile area by Harms (1990), is an assemblage of mainly siliceous rocks that display ductile strain at a high structural level in the Sylvester allochthon. Gabrielse (1998) included this assemblage in a unit of tectonized mafic metavolcanic rocks, chloritic phyllite, marble, siliceous cataclasite, and mylonitized intrusive rocks between Dease River and Cry Lake, which he tentatively correlated with the parautochthonous Kootenay terrane of southeastern British Columbia. However, the structural position of the unit above the Slide Mountain terrane indicates that it is allochthonous. It was assigned to the Yukon-Tanana terrane by Nelson and Friedman (2004), based on similarities between the amphibolite-facies, siliciclastic-metabasalt-ultramafic assemblage near Beale Lake in the

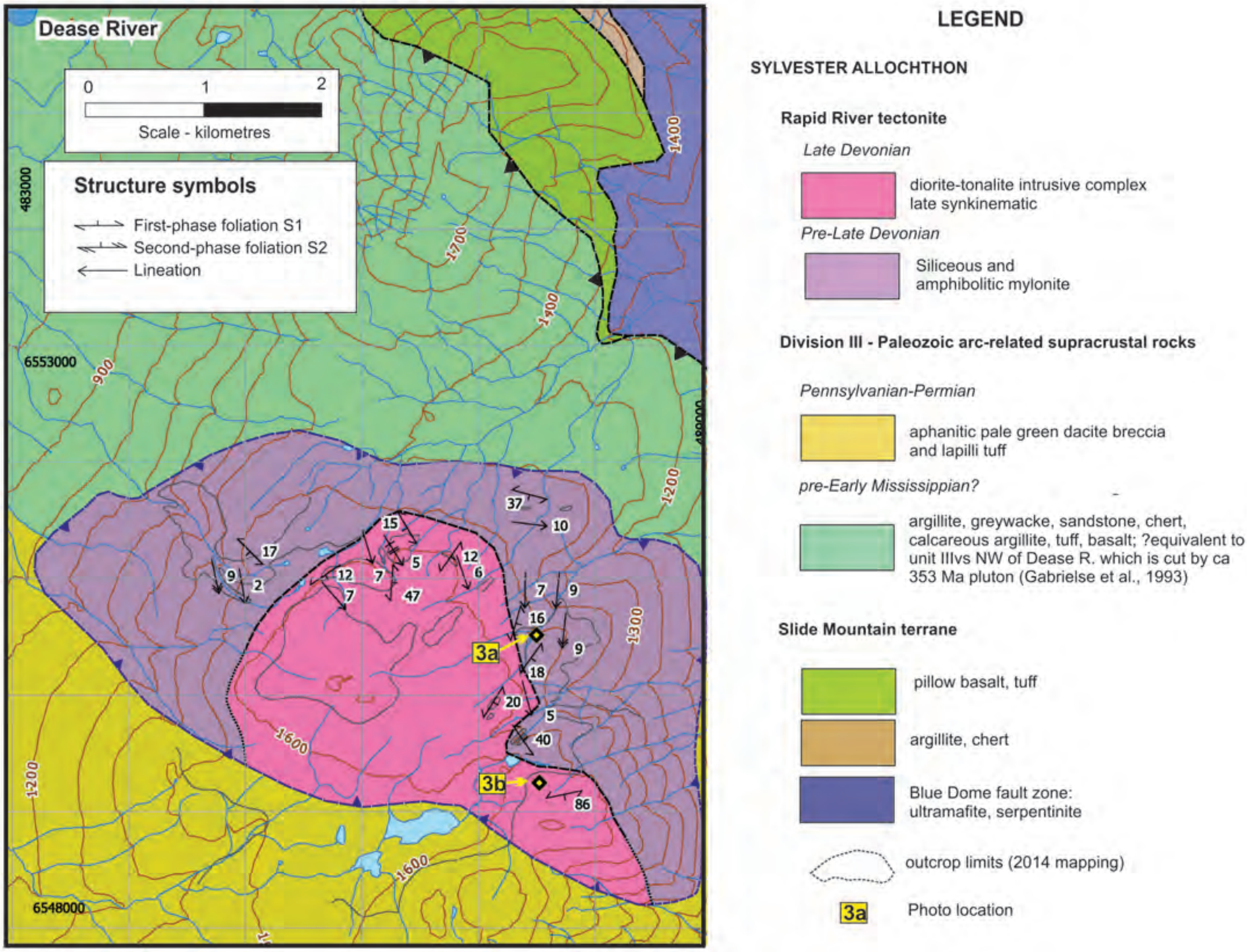

Fig. 2. Dalton Creek-Four Mile River area geology. Geology from Gabrielse and Harms (1989) updated with our 2014 mapping. UTM Zone 9, NAD 83.

Sylvester allochthon (Nelson and Lepage, 2002) and the Dorsey complex west of the Cassiar batholith (Fig. 1). It is likely however, given the variety of lithologies it includes, that the Rapid River tectonite comprises more than one assemblage. It is intruded by synkinematic plutons of known (Four Mile; Gabrielse et al., 1993) and suspected (Cry Lake, Gabrielse, 1998) Devonian age.

Our work focused on: 1) constraining the age of early deformation in the Rapid River tectonite; 2) evaluating if the tectonite is equivalent to the Dorsey complex (Snowcap assemblage) or if other assemblages are present; and 3) establishing the kinematic history and origin of the tectonite. We therefore focused on the two areas in which Devonian plutons are known or suspected to exist.

2.1. Dalton-Four Mile area

Tectonised rocks in the Dalton-Four Mile area include both siliceous and mafic mylonites (Fig. 2). Both are extremely fine grained, tectonically layered on mm to cm-scale, and display well-developed stretching lineations, indicating that they accommodated high strain. Rare relict textures in the siliceous mylonite indicate a tonalitic protolith (Fig. 3a). The foliation is gently dipping except near the margins of the allochthon, and the stretching lineation plunges shallowly southward (160-180°, Fig. 2). Local shear bands and sigma porphyroclasts indicate a top-to-the north-northwest sense of shear. Lineation trends are considerably more northerly than the northwesterly folds and lineations that developed in the Sylvester allochthon and underlying Laurentian strata as it was assembled and emplaced on the continent margin. A sample of the mylonitized tonalite was collected for U-Pb gechronology to establish the early deformation history of the Rapid River tectonite.

The Dalton-Four Mile pluton (Figs. 2, 3b), mapped by Gabrielse and Harms (1989), yielded a ca. 362 Ma U-Pb zircon crystallization age, with significant ca. 2.23 Ga inheritance (Gabrielse et al., 1993). It occupies a higher structural position than the tectonite. The pluton grades downward from mainly hornblende diorite into tonalite and trondhjemite, and appears to form a sheeted sill complex. At its lower contact, plutonic rocks interfinger with the tectonite, clearly cutting the early foliation.

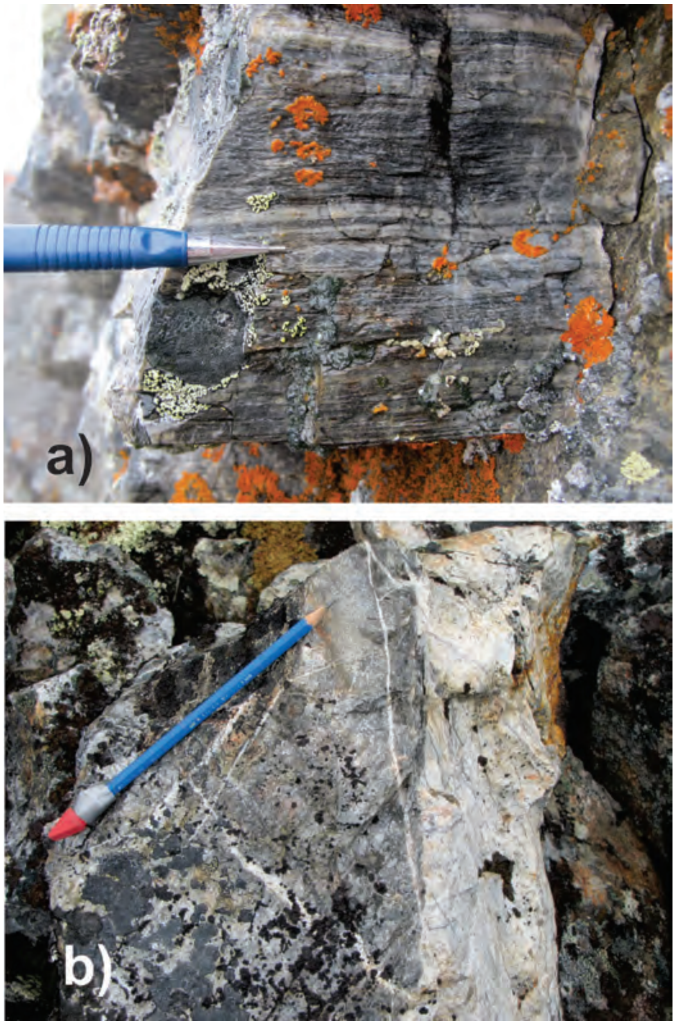

Fig. 3. Rapid River tectonite and Late Devonian intrusion in Dalton-Four Mile area. **a)** Mylonitized tonalite sill 'siliceous tectonite' (487498 E, 6550515 N). **b)** Late-stage post-kinematic aplite dike cutting foliated diorite of Late Devonian pluton, pencil aligned parallel to foliation (487522 E, 6549248 N). UTM Zone 9, NAD 83.

Some phases display well-developed stretching lineations and a weak to moderate foliation, whereas others are unfoliated and crosscut fabrics (Fig. 3b). We agree with Gabrielse and Harms (1989) that it was emplaced late in the kinematic history of the tectonite. We collected a sample from this body for U-Pb geochronology to better separate crystallization from inherited zircon fractions and obtain a more precise emplacement age.

2.2. Cry Lake area

In the Cry Lake area, the Rapid River tectonite consists mostly of heterogeneous, layered to laminated, fine-grained mylonitized amphibolite (Figs. 4, 5a), with scattered lenses of marble and calc-silicate (Fig. 6). The interpreted protolith is a mainly basaltic succession with small limestone lenses. Also present are layered siliceous mylonites and mylonitized tonalites similar to those in the Dalton-Four Mile area. Mylonitic fabrics are steeply dipping and northwesterly striking (Fig. 4). The stretching lineation, somewhat less well developed than in the Dalton-Four Mile area, trends northwest, parallel to the hinge lines of major folds. Sinistral shear-sense indicators (shear bands; Fig. 5b) were observed at two locations. Map relationships (Fig. 4) suggest that an originally gently dipping tectonite fabric was steepened by later folding. Based on simple unfolding of the shallowly plunging folds in the Cry Lake area, the fabrics in the Rapid River tectonite would have had a top-to-the northwest sense of shear, in common with the Dalton-Four Mile area.

The tectonite assemblage is intruded by an unnamed diorite-gabbro body. Within 50 metres of its margins, this body and the Rapid River tectonite are cut by abundant tonalitic to trondhjemitic dikes and sills. The main body consists mostly of hornblende-plagioclase-bearing diorite or gabbro (Fig. 5c). The hornblende crystals tend to be equant, possibly pseudomorphous after pyroxene. Patches of hornblendite may be replacements of clinopyroxenite; hornblendite also occurs as xenoliths in intrusive breccias. Hornblende increases in modal abundance near the xenoliths. The body is an intrusive complex that comprises multiple phases of varying composition and texture. Although generally undeformed, it is cut by discrete, narrow, high-strain zones. Although the diorite-gabbro lacks obvious free quartz, we collected a sample for U-Pb zircon geochronology to establish the upper limit to when the Rapid River tectonite was deformed.

Three phases of dikes can be recognized within 50 m of the upper contact between the main mafic pluton and the Rapid River tectonite. The earliest phase dikes are hornblende-phyric dacite, and are more deformed (e.g. boudinaged) than the later two sets (Fig. 5d). Bladed hornblende phenocrysts help define the foliation, and some are augen shaped. The second dike set is characterized by leucotonalite aplite, and lesser medium-grained tonalite (Fig. 5d). The first two dike phases were deformed at elevated temperature (Fig. 5e). Their emplacement may not have been greatly separated in time. A third set of crosscutting thin leucocratic aplite (trondhjemite?) dikes are the least deformed, although they exhibit minor syn-magmatic shear offsets (Fig. 5d). The progressive nature of the deformation suggests that the dikes are late syn-kinematic. The first two phases of dikes and apophyses of the diorite are folded, and axial planes of the folds (Fig. 5f) are generally parallel to the steep overall fabric in the Rapid River tectonite at this locality. We collected a trondhjemite sample from the late syn-tectonic, second-phase aplite for U-Pb geochronology.

3. Ophiolites in the Slide Mountain terrane

The Slide Mountain terrane represents the remnants of a mid- to late-Paleozoic back-arc ocean basin that opened between Laurentia and the arc-frontal Yukon-Tanana terrane (eg., Murphy et al., 2006; Piercey et al., 2006; Nelson et al., 2006). To further evaluate relationships between the Yukon-Tanana terrane and the ancient North American margin, and to consider the history of rifting and sea-floor spreading recorded by the Slide Mountain terrane, we examined extensive ultramafic-mafic complexes in the Zus Mountain and Blue Dome areas

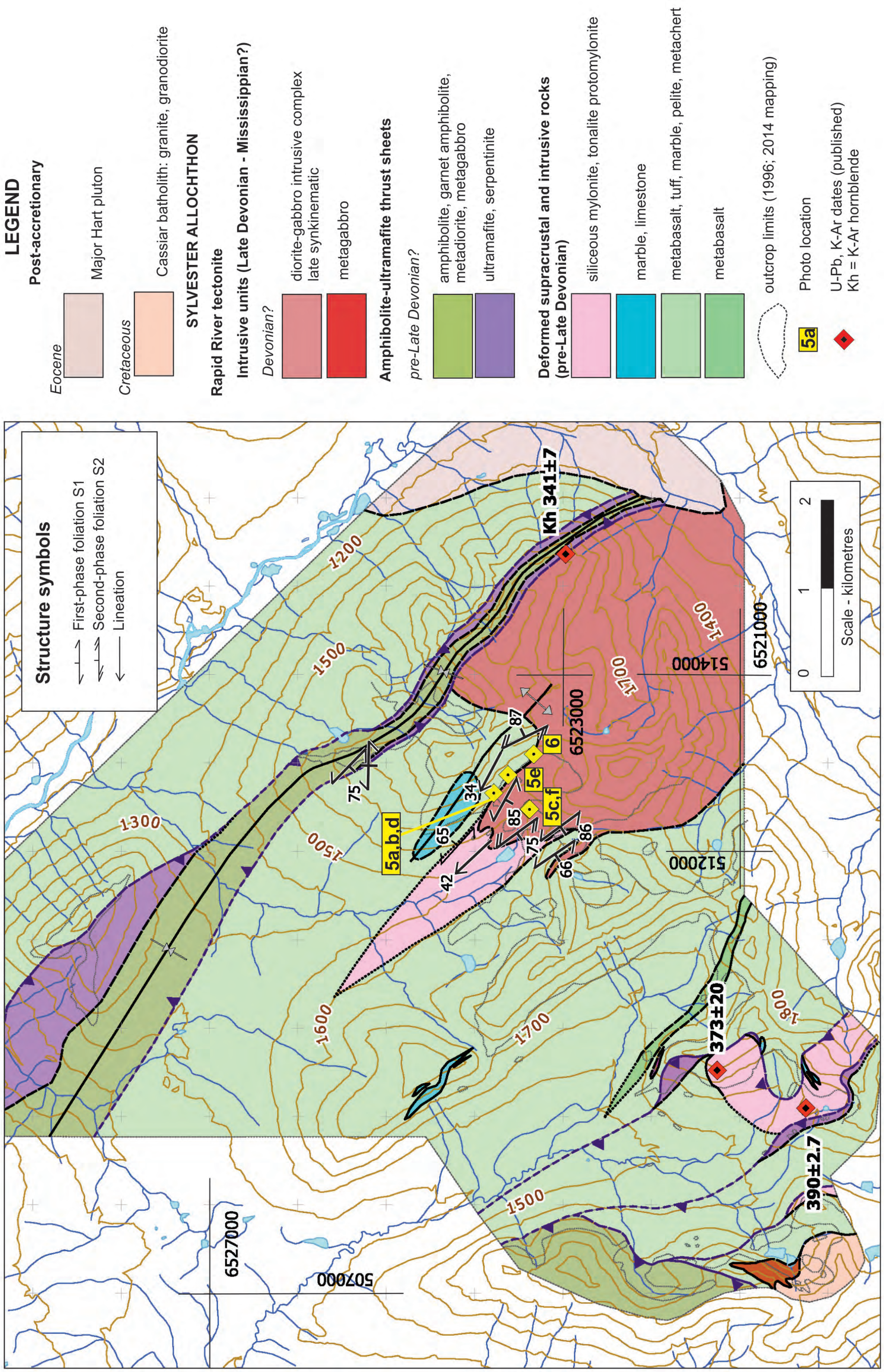

Fig. 4. Cry Lake area geology. Geology from Gabrielse (1994, 1998), J. Nelson, unpublished mapping, 1996, and our 2014 observations.

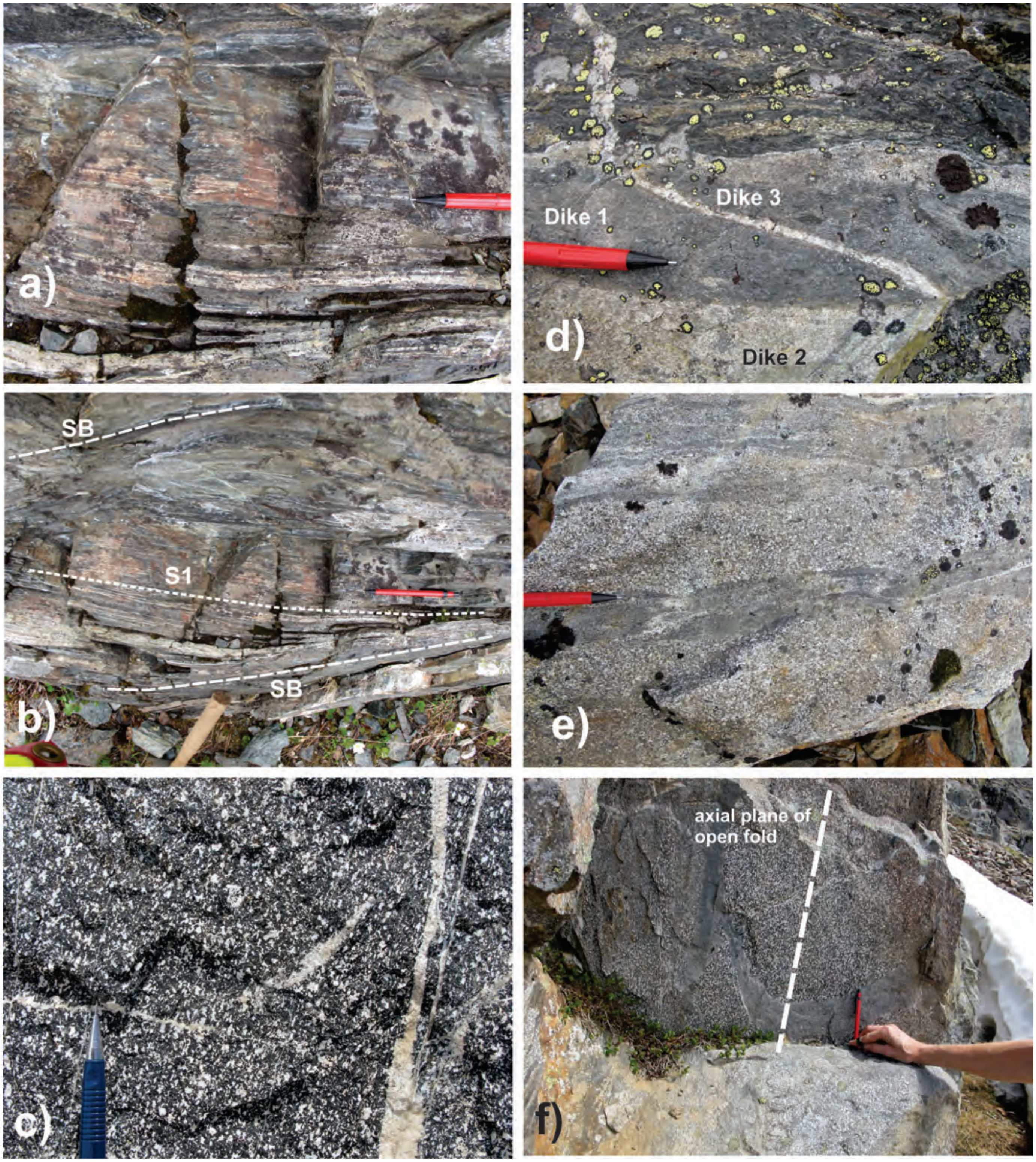

Fig. 5. Cry Lake tectonites and phases of late synkinematic pluton. **a)** Mylonitic amphibolite schist (512660 E, 6523782 N). **b)** Sinistral sense of shear recorded by large-scale shear bands in amphibolite of the Rapid River tectonite (512660 E, 6523782 N). **c)** Coarse-grained, diorite in main body of pluton; weak foliation defined by alignment of plagioclases from lower left to top right (512476 E, 6523377 N). **d)** Three generations of dikes cut the tectonite foliation. Dike 1 is folded and well foliated, and some hornblende crystals are augen-shaped, Dike 2 is moderately foliated tonalite, Dike 3 is very weakly foliated, cross-cutting leucotonalite aplite (512660 E, 6523782 N). **e)** Multi-phase dioritic intrusions at contact between diorite and tectonite; the dikes are synkinematic, with ductile sub-solidus fabrics (512865 E, 6523620 N). **f)** Coarse diorite phase of the pluton, with weak shape fabric parallel to axial plane of fold. Finer-grained dikes are also folded with the same axial plane. This phase of folding may have steepened the attitudes of the high strain fabric of the Rapid River tectonite (512479 E, 6523383 N).

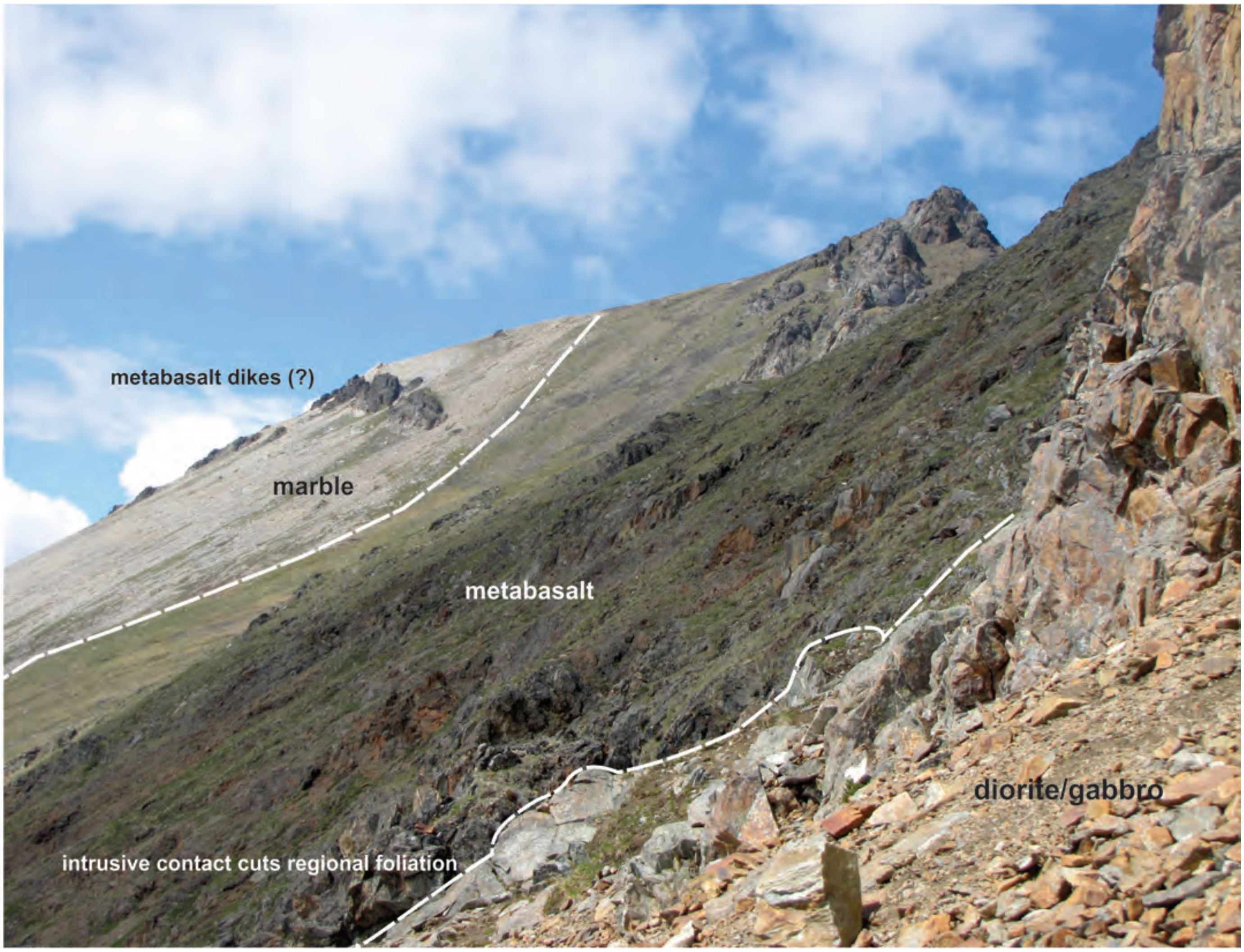

Fig. 6. Looking northwest from contact of synkinematic pluton into Rapid River tectonite (513100 N, 6523330 N). Dark, foliated rocks are mylonitized metabasalts. Marble body on ridge is cored by metabasalt. Axis of isoclinal antiform passes through it (Fig. 4). Pluton cuts across foliation, but is locally ductilely sheared and contact appears to be folded along with host rocks, with detail shown in Fig. 5f.

of the Sylvester allochthon (Fig. 1). We focus on establishing the tectonic setting and origin of these complexes, testing if they represent classical ophiolites formed by 'normal' sea-floor spreading; or rather at slow spreading ridges or hyperextending margins where subcontinental mantle is exhumed by low-angle detachment faults.

3.1. Zus Mountain area

The Sylvester allochthon east and north of the Cassiar townsite (Fig. 1) contains two imbricated ultramafite-gabbro complexes (Nelson and Bradford, 1993). The base of the lowest imbricate (Cassiar complex; age unknown) hosts the past-producing Cassiar asbestos mine. We interpret that this imbricate reappears in the valley of Quartzrock Creek (Fig. 7). West of Quartzrock Creek, this sheet is structurally overlain by a second imbricate containing the Zus Mountain ultramafite and gabbro (Fig. 7). The Zus Mountain ultramafite is a typical serpentinized mantle tectonite composed of heavily serpentinized harzburgite (Fig. 8a) to lherzolite. The ultramafic rocks are characterized by well-stretched pyroxene crystals, and are Cr-spinel bearing. Dunite forms patchy bodies and dikes with diffuse margins (Fig. 8b). Common in the upper part of the ultramafite are dikes of leucogabbro and trondjhemite. One of the trondhjemite dikes has yielded a U-Pb age of ca. 268 Ma (Gabrielse et al., 1993; Figs. 4, 8c). Above the ultramafite, forming the upper ridges and peak of Zus Mountain, is a large body of gabbro (30% clinopyroxene-70% calcic plagioclase; Fig. 9). It displays distinct compositional layering parallel to its basal contact, particularly a prominent pale-coloured band (Fig. 9) that we interpret as a leucogabbro sill along a fault. The gabbro displays a foliation defined by a strong preferred dimensional orientation of apparently unbroken pyroxene and plagioclase that may be of high-temperature origin. Rocks in a gully immediately north of the gabbro (Fig. 7) appear to mark a northwest-dipping cataclasitic fault zone that may signify late movement along the gabbro-ultramafite contact. This contact is also exposed along an old exploration road on the eastern side of the study area, where serpentinite near the contact displays

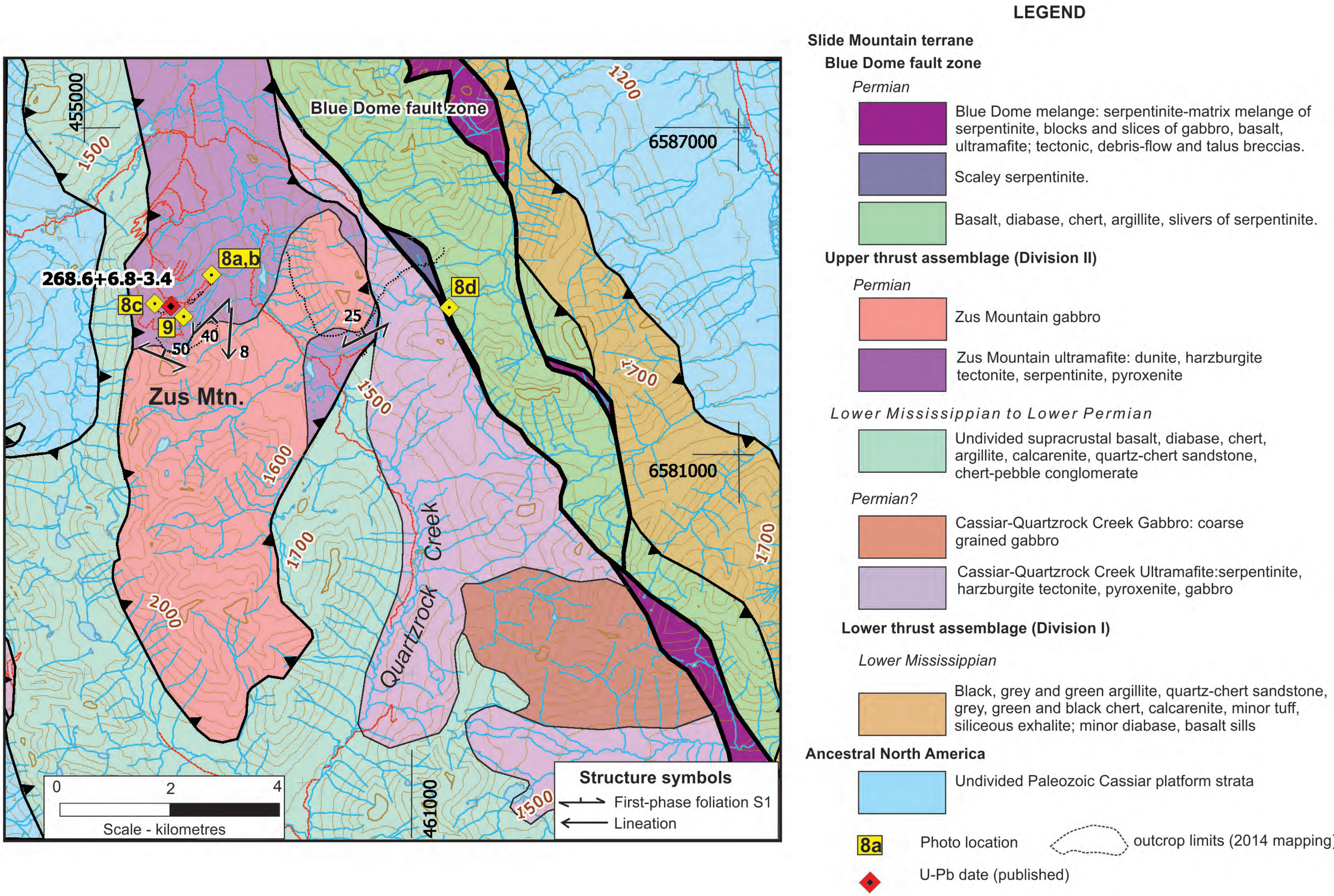

Fig. 7. Zus Mountain area geology. Note: cataclasite exposure in small gully is located between Fig. 9 photo site and S1 symbol with 40° dip. Geology from Nelson et al. (1989). UTM Zone 9, NAD 83.

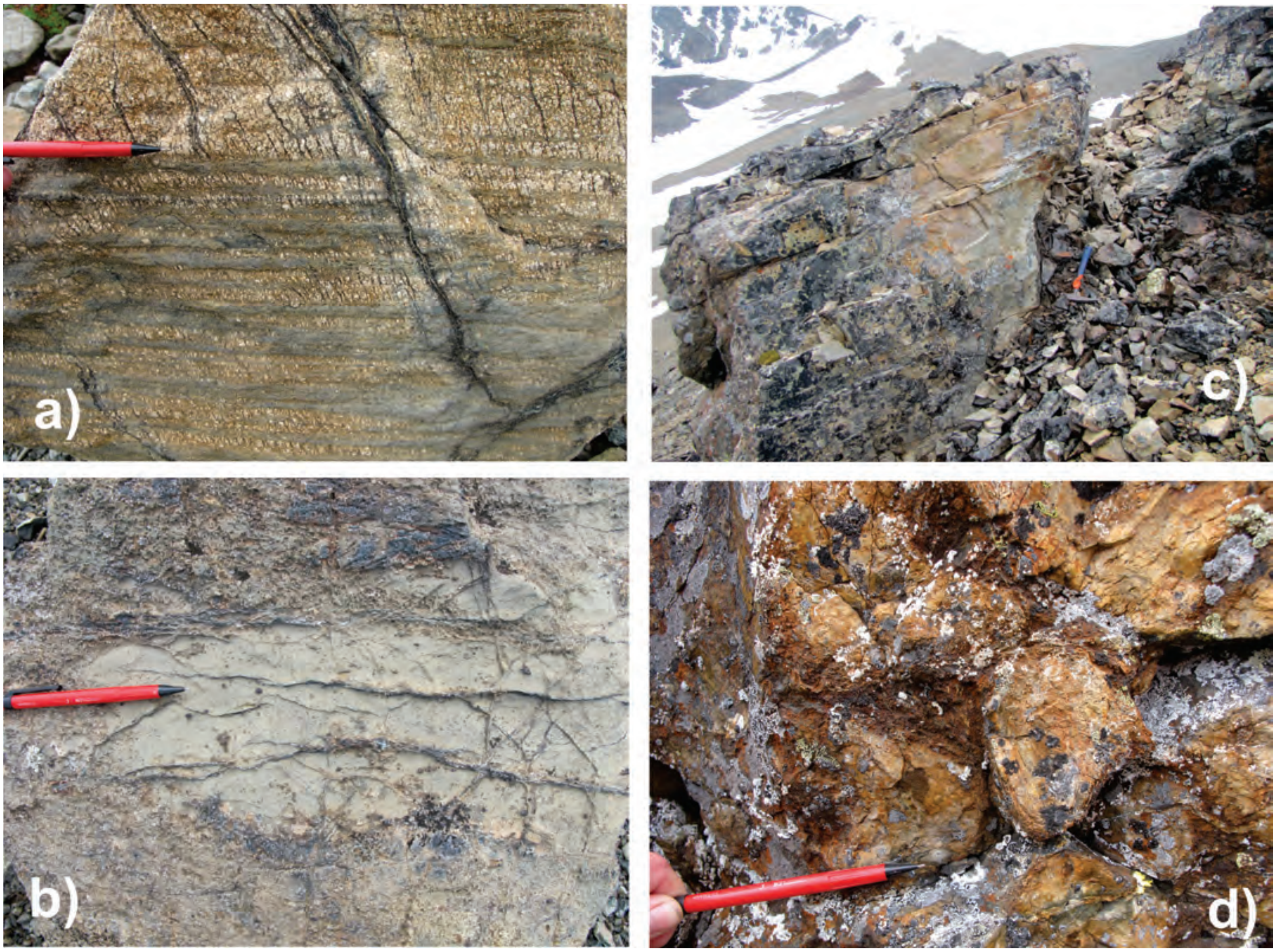

Fig. 8. Zus Mountain ultramafite, gabbro, and related phases. **a)** Well-banded serpentinized harzburgite (mantle tectonite), with chrysotile veins; relict domains of stretched pyroxene (457326 E, 6584312 N). **b)** Chromite-bearing patchy dunite vein intruded into harzburgite (457326 E, 6584312 N). **c)** Middle Permian trondjemite dike (ca. 268 Ma) cuts serpentinized ultramafite, chilled curviplanar margin above hammer (456581 E, 6583735 N). **d)** Concentric-zoned basalt pillows with thin selvages, hyaloclastite (brown patches) preserved in pillow interstices (461684 E, 6583714 N).

strong carbonate-quartz alteration (listwanitized).

Also on the eastern side of the study area, the structural contact between the Cassiar complex and Zus Mountain rocks in the overlying imbricate is marked by a thin chert unit (Fig. 7). In the Cassiar complex, below and to the east of the chert, is an extensive body of harzburgite with stretching lineations defined by bastite pseudomorphs after pyroxene. As at Zus Mountain, the harzburgite exhibits patches of Cr-spinel-bearing dunite intrusions. To the east, across the steeply dipping Blue Dome fault zone, are prehnite-pumpellyite facies basaltic flows with local well-preserved pillow structures (Fig. 8d). The marked contrast in strain between the little-deformed pillow basalts, and the more highly deformed chert-argillite horizons, suggests that the chert horizons may have been weak layers that accommodated shear displacement.

3.2. Blue Dome area

The objectives of our work in the Blue Dome area (Fig. 10) were to: 1) better characterize a well-exposed oceanic crustal section that lies between strands of the Blue Dome fault (Nelson et al., 1988); 2) better define the tectonic significance of the Blue Dome fault; and 3) determine the kinematics and nature of the fault movement(s) accommodated by the Blue Dome fault. As described below, a west to east transect along 'Liguria' ridge (Fig. 10) documents a mantle to sea floor transition.

The structurally lower, western end of the Liguria ridge is underlain by serpentinized ultramafic rocks varying between lherzolite and harzburgite compositions, and generally preserving 1-2 cm partial or complete pseudomorphs after pyroxene (Fig. 11a). Interlayering of dunite and lherzolite was observed. Some peridotites are strongly deformed, with stretched and augen-shaped pyroxene crystals and bastite pseudomorphs (Fig. 11b), textures that are compatible with

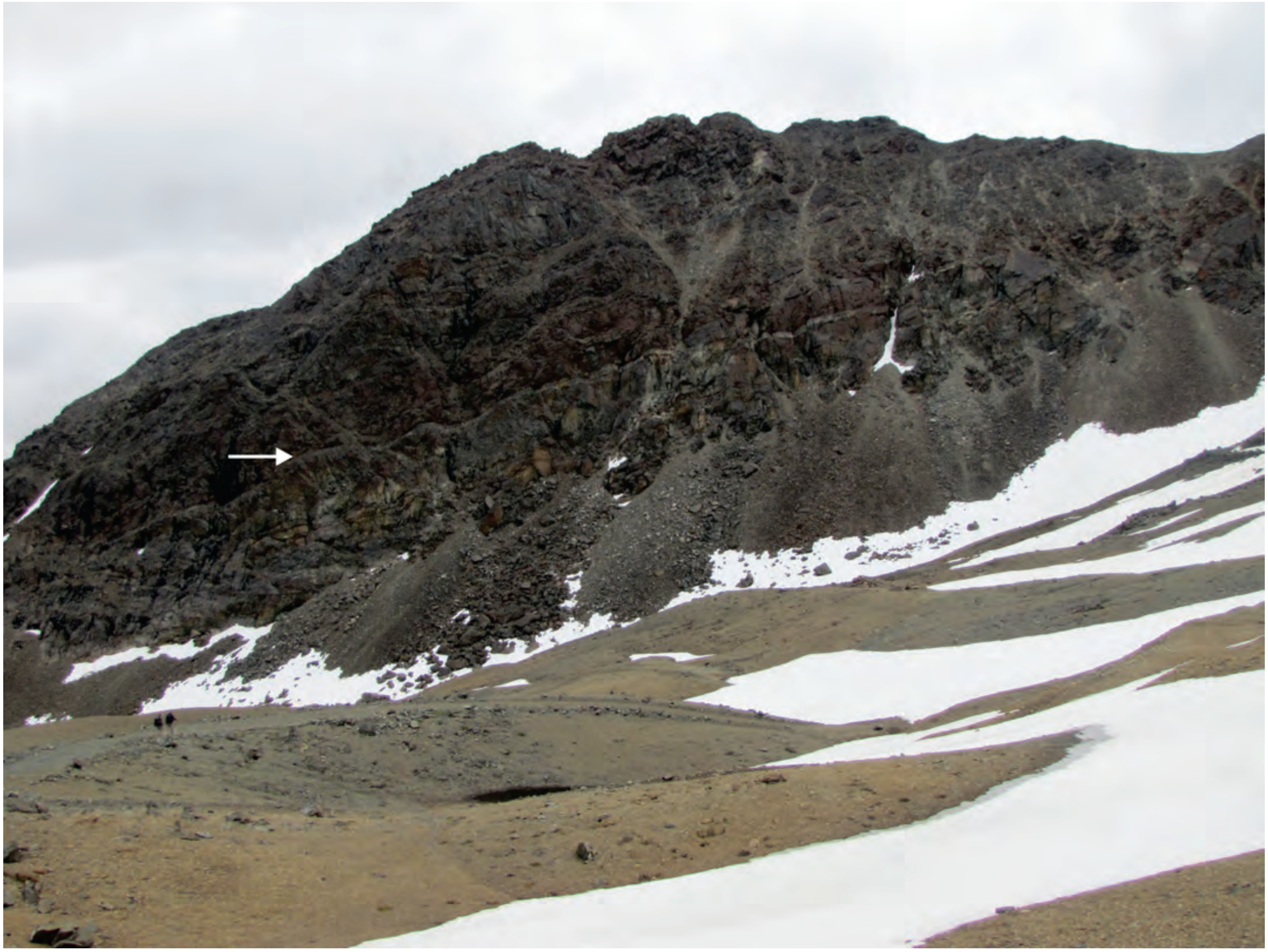

Fig. 9. The Zus Mountain ultramafite-gabbro complex. Foreground ultramafite contains abundant pods and patches of dunite. The rugged cliffs are in the overlying layered gabbro; leucogabbro sill indicated by arrow follows igneous layering and fabric. View to south from 456700 E, 6583600 N.

the high-temperature deformation regime in which mantle tectonites develop. These rocks have abundant serpentine veins throughout. Trondhjemite dikes cut the well-deformed peridotites, unfoliated lherzolite, and previously brecciated serpentinite. Some of the dikes define parallel arrays spaced at 50 to 100 m wide intervals (Fig. 11c). In contrast, other more shallowly dipping dikes in serpentinite exhibit highly irregular apophyses (Fig. 11d), possibly due to emplacement in a near-surface, thoroughly hydrated host. Although trondhjemite intrusion postdates at least some serpentinization, these apophyses suggest that intrusion was synchronous with motion on exhumation-related faults that brought rocks to higher levels in the crust where they were susceptible to serpentinization. Dating of the dikes would therefore be a proxy for the time of exhumation, and we collected several samples of trondhjemite for U-Pb dating. At one locality the trondhjemite is coarse grained and spatially associated with coarse-grained (pegmatitic) leucogabbro (Fig. 11e). Pegmatitic varieties of the trondhjemite have coarse (1 cm) quartz phenocrysts (Fig. 11f).

At structurally higher levels along the Liguria ridge transect, the abundance of diabase dikes and/or sills increases. Locally, the diabases appear brecciated. Upward, plagioclase-phyric basalts transition to basalt flows that are locally pillowed (Fig. 12a) and brecciated. Some of the basalt is variolitic. Local chert bodies (interlayers?) contain radiolaria. The volcanic flows and radiolarian-bearing chert signify that this part of the transect represents seafloor deposits stratigraphically overlying exhumed mantle.

At the eastern end of the transect is a strand of the Blue Dome fault. Near it, brecciated gabbro-diabase is cut by dense swarms of minor faults and zones of cataclasite (Fig. 12b), infilled by reticulated quartz-plagioclase veins that could be related to the trondhjemites seen immediately to the west. Some cataclasite zones appear to have significant offsets (eg., 3 cm wide with at least 3 m of offset; Fig. 12c). These zones are intruded by basaltic dikes with chilled margins, that are also faulted, but with much less offset (Fig. 12d), suggesting that, although synkinematic, they postdate the main episode of cataclastic

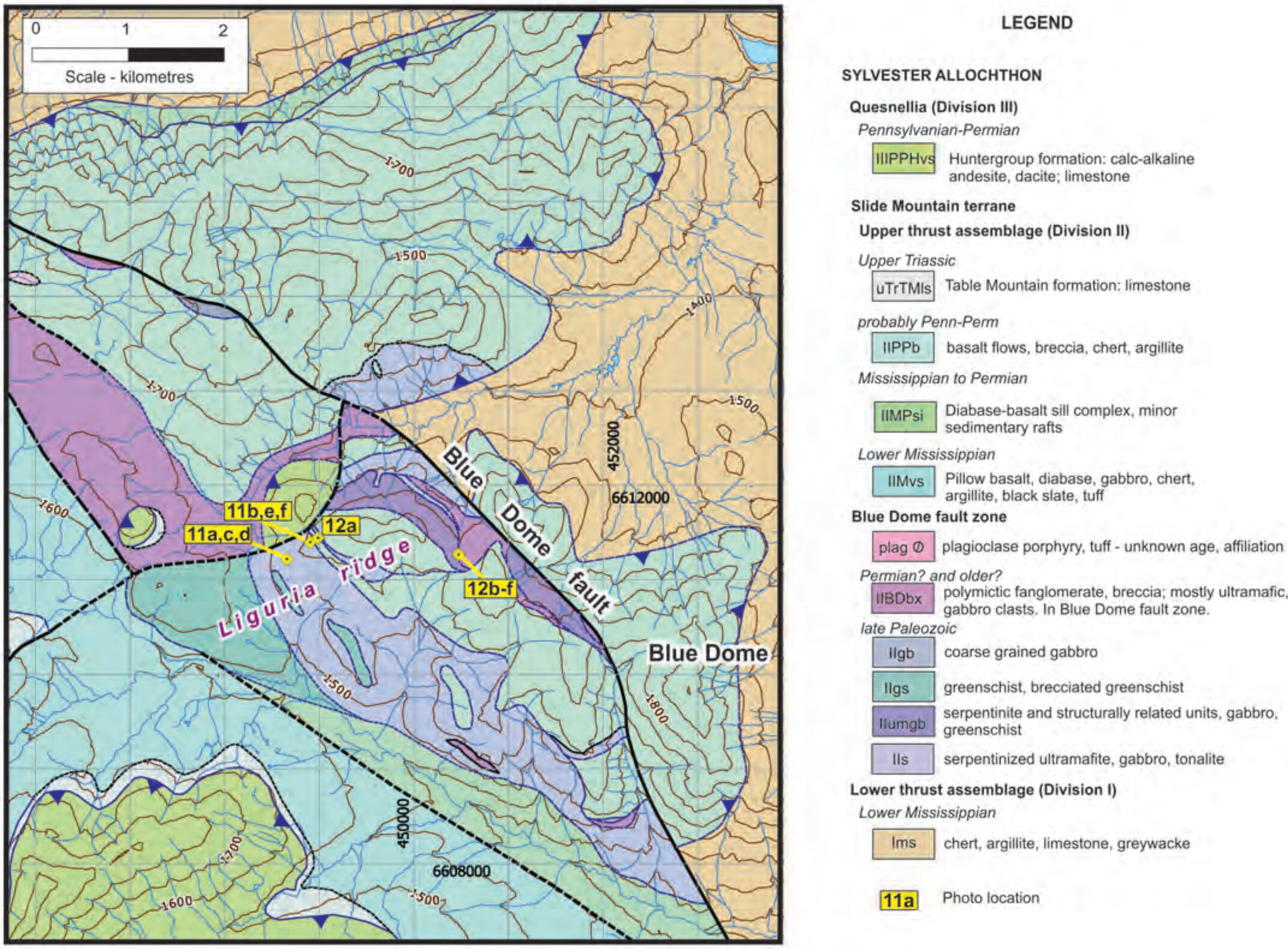

Fig. 10. Blue Dome area geology; from Nelson et al. (1988). UTM Zone 9, NAD 83.

faulting. It is possible that the basalt dikes are feeders to the pillow basalts observed at higher levels and, if so, indicate that basaltic effusion was broadly synchronous with movement on this fault strand.

Immediately east of the cataclastic zone in the gabbro-diabase unit is a lens of polymictic conglomerate up to 70 m thick (Fig. 10). The conglomerate contains angular (locally rounded), 1-5 cm clasts, supported by a sandstone matrix (Fig. 12e). Local sandstone layers separate conglomeratic beds (Fig. 12f). The clast suite consists of abundant intermediate plutonic rocks, basalt, gabbro, and very rare ultramafites. Significantly, the mafic clasts generally contain an internal foliation, pointing to unroofing of previously deformed rocks and penecontemporaneous faulting. Some gabbro-diabase clasts exhibit textures similar to the cataclasites exposed only 20 m to the west. We interpret that this unit represents sedimentation related to a fault scarp recorded by the cataclastic gabbro. Although ultramafic clasts are very rare at this locality, ultramafic rocks are exposed elsewhere along the Blue Dome fault and constitute the predominant clasts in breccias and ophicalcites (Nelson and Bradford, 1993), likely reflecting deeper levels of exhumation and erosion.

4. Discussion

4.1. Rapid River tectonite

The Rapid River tectonite in the Cry Lake and Dalton-Four Mile areas consists mainly of amphibolite-facies, mylonitized mafic volcanic rocks with sparse marble lenses. The highly siliceous felsic bands structurally intercalated with the supracrustal tectonites are mylonitized felsic intrusions and, to a lesser extent, metamorphic segregations and/or veins; evidence of a sedimentary origin is lacking. The mafic protolith of this assemblage is in marked contrast to the prominent silicicastic rocks in Dorsey assemblage in the Beale Lake area between Cry Lake and the Four Mile River area (Fig. 1) west of the Cassiar batholith (Nelson and Friedman 2004). Hence we consider that the Rapid River tectonite is a distinct tectonostratigraphic assemblage (cf. Nelson and Friedman, 2004), perhaps recording relatively shallow-water, volcanic-rich deposition in a primitive, pre-Late Devonian arc. Possible analogues include the basaltic Knob Hill complex and meta-igneous Trail gneiss, which are part of the Devonian and older Okanagan subterrane of southern Quesnellia in southeastern British Columbia (Simony et al., 2006; Massey, 2007).

The Rapid River tectonite is characterized by a high-

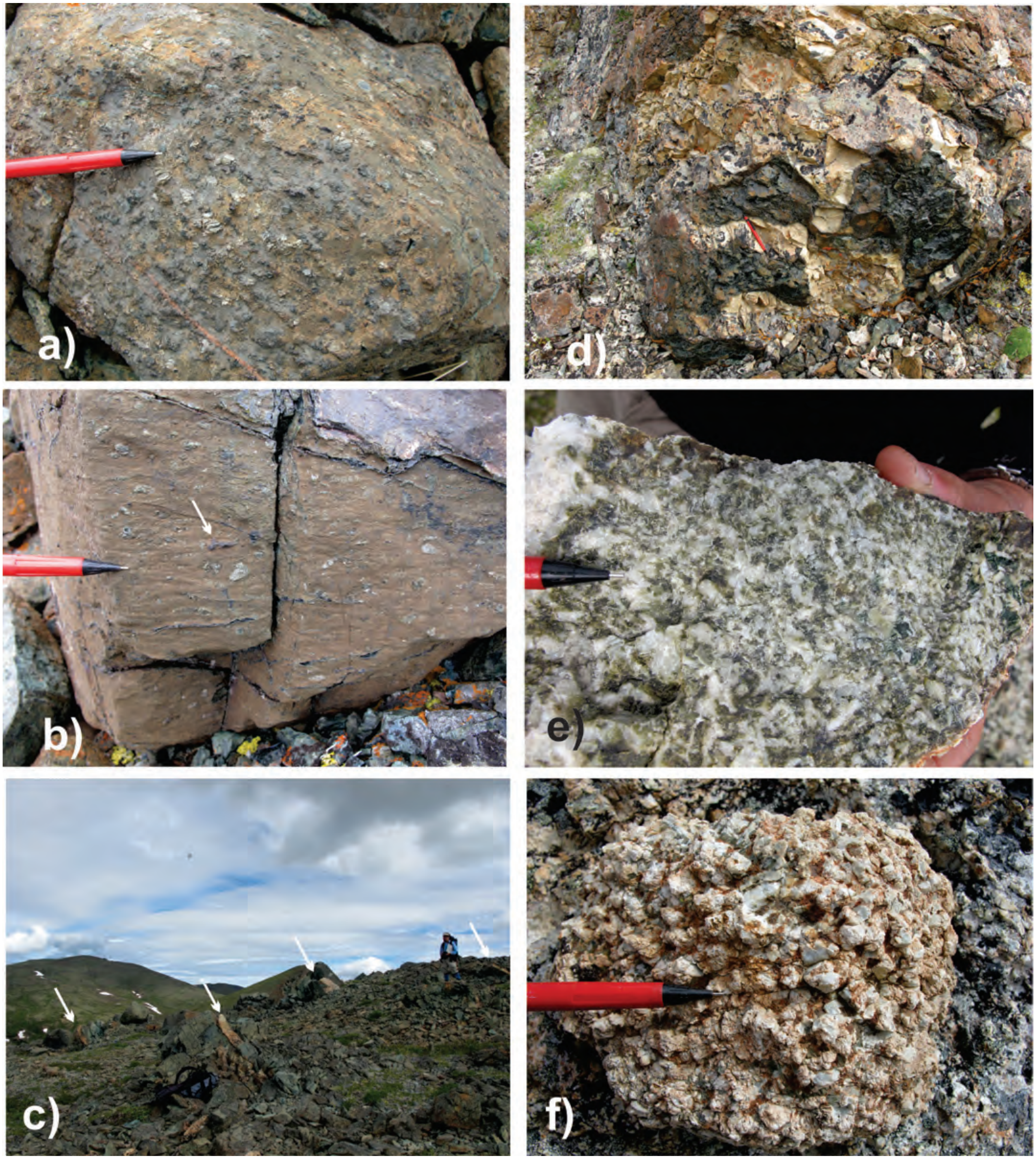

Fig. 11. Blue Dome area rocks and rock relationships. **a)** Pyroxene-phyric harzburgite; pyroxene partly altered to bastite (448657 E, 6611219 N). **b)** Peridotite tectonite with shaped pyroxene augen and chromite (448905 E, 6611399 N). **c)** Set of planar trondhjemite dikes (arrows) cutting lherzolite breccia (448657 E, 6611219 N). **d)** Apophyses of trondhjemite dike cutting serpentinized lherzolite breccia (448657 E, 6611219 N). **e)** Coarse-grained, pegmatitic hornblende leucogabbro spatially associated with trondhjemite (448905 E, 6611399 N). **f)** Pegmatitic trondhjemite (with cm-scale quartz phenocrysts) from a 10 m-thick intrusive sheet. (448905 E, 6611399 N).

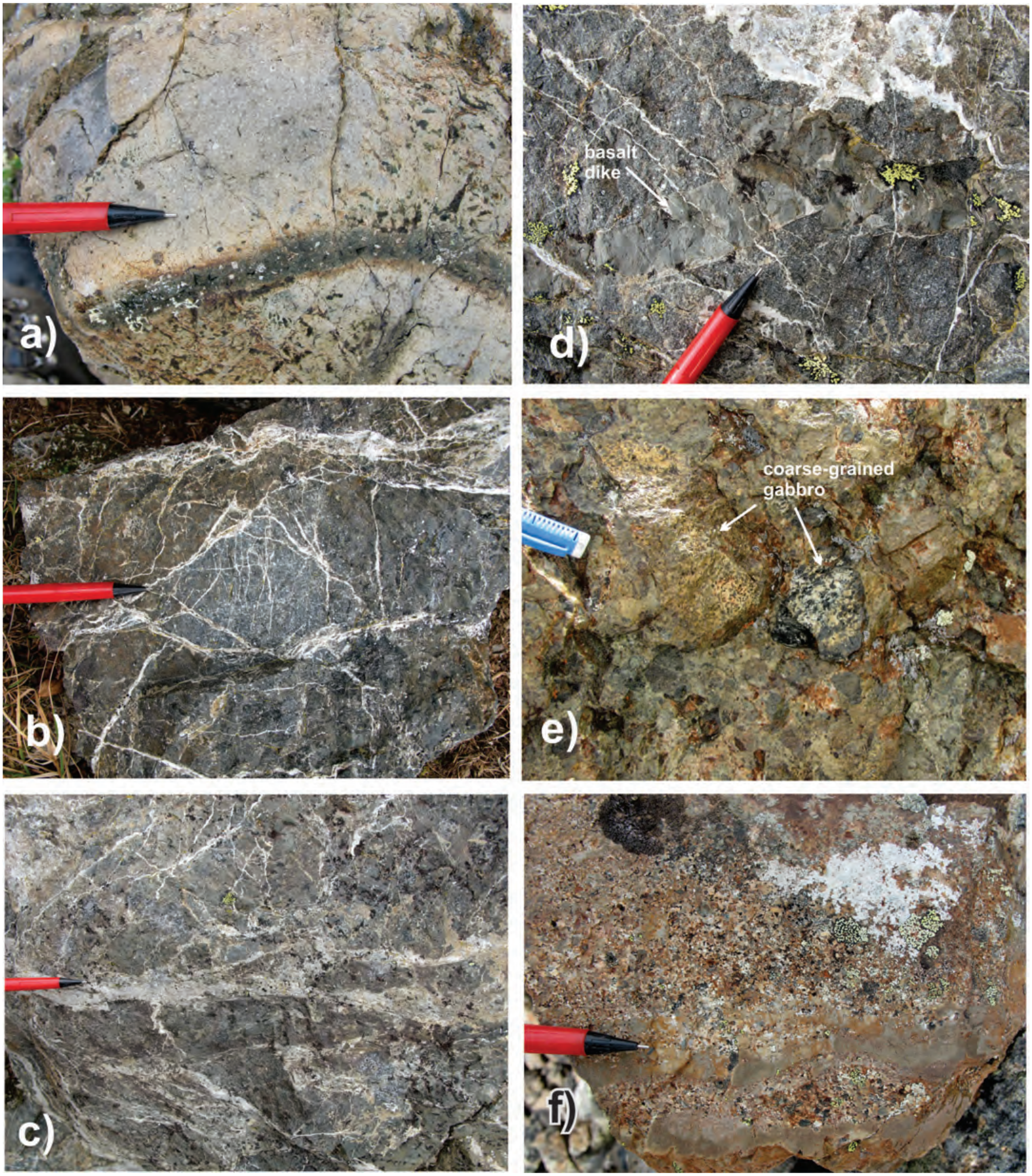

Fig. 12. Blue Dome area rocks and rock relationships, continued. **a)** Plagioclase-phyric basalt to andesite; dark-toned pillow selvage below pen. (448986 E, 6611444 N). **b)** Brecciated, cataclastically deformed gabbro-diabase; fractures and small shears healed with white plagioclase-quartz. **c)** Cataclastic breccia zone with significant offsets in gabbro-diabase. (450473 E, 6611266 N). **d)** Grey basalt dike cuts brecciated gabbro-diabase but shows minor brittle offsets on small shears filled with white quartz-feldspar (450473 E, 6611266 N). **e)** Moderately sorted, polymictic conglomerate with predominantly angular clasts in a sandstone matrix. Two coarse-grained gabbro clasts indicated (450473 E, 6611266 N). **f)** Interstratified polymictic granulestone and sandstone. (450473 E, 6611266 N).

strain, well-developed L-S fabric, indicating strong non-coaxial deformation, typical of a major ductile shear zone. What remains uncertain is if the shear zone accommodated contractional or extensional strain and which geological bodies were juxtaposed across it.

We note the following significant similarities between the Dalton-Four Mile and Cry Lake intrusive complexes: 1) both are mafic intrusions with more felsic marginal phases; 2) both are layer-parallel on a large and small scale; and 3) both are late syn-kinematic. Therefore our current interpretation is that both plutonic complexes are part of a single suite, which includes the 362 Ma granitoid dated by Gabrielse et al. (1993). This assertion will be tested by additional geochronological studies. The samples we collected for geochronology will also help to better constrain the duration of the non-coaxial deformation accommodated by this tectonite. Previous work in the area indicates that the protoliths of mylonitic intrusive rocks are as old as 390 Ma (Nelson and Friedman, 2004). It is possible that the high-strain deformation recorded by the Rapid River tectonite represents an early collision between an arc-related terrane of unknown provenance (represented by the mafic-marble tectonites and Early Devonian intrusions) and the leading edge of the Laurentian margin, the remnants of which may be represented by the Dorsey complex. This postulated collision would have been before the main onset of Late Devonian-Mississippian (363-345 Ma) arc activity built upon the substrate of theYukon Tanana terrane (cf. Piercey et al., 2006), predating the generally accepted time of subduction initiation along the western margin of Laurentia.

4.2. Ophiolites in the Slide Mountain terrane

Ultramafic-mafic complexes in the Slide Mountain terrane contain heavily serpentinized harzburgite to lherzolite, locally preserving serpentine (after elongated olivine) and bastite (after pyroxene crystals or aggregates) pseudomorphs. Such rocks are typical of mantle tectonites (Mercier and Nicolas, 1975). The rocks are commonly Cr-spinel bearing and locally contain patches and dikes of dunite and pyroxenite. Small intrusive bodies of leucogabbro to trondhjemite are relatively abundant, but layered mafic-ultramafic cumulates and sheeted dikes typical of oceanic lower crust are notably absent. In general, the Zus Mountain, Cassiar and Blue Dome ultramafic bodies appear to be fragments of exhumed lithospheric mantle that became the substrate to the products of syn-rifting mafic magmatism, mainly represented by mafic plutonic rocks but also by basalts. Lithospheric extension is clearly expressed along the Blue Dome fault zone, which may be a zone of synvolcanic extensional faults, rather than simply a fossil transform fault as previously suggested (Nelson, 1993).

Sparse leucogabbro and trondhjemite intrusive samples from the Slide Mountain terrane in the Sylvester allochthon and southern Yukon have yielded mainly Permian ages between 274 and 265 Ma (Gabrielse et al., 1993; Murphy et al., 2006; van Staal et al., 2012 and unpublished results), which are a proxy for the time of mantle exhumation and related mafic magmatism during early seafloor development. These ages are anomalously young relative to Late Devonian to Early Permian volcanic rocks of the Slide Mountain terrane that indicate that Slide Mountain ocean started to open in the Late Devonian-Mississippian and continued opening through the Pennsylvanian-Early Permian (Nelson, 1993). However, detailed examination of radiolaria and conodont data (Appendix 1 in Nelson and Bradford, 1993) suggests that ocean sedimentation and basalt volcanism were not continuous from early Mississippian to Permian. Rather, separate Mississippian and Late Pennsylvanian-Early Permian pulses appear to be separated by a notable gap during the Early to Middle Pennsylvanian, ending before the 274-265 Ma intrusive cluster. The evidence for Middle Permian hyperextension and the onset of proto-oceanic crust formation at that time suggest that the existing tectonic models are in need of modification. Possibly, distinct Mississippian and Permian basins, currently grouped together in the Slide Mountain terrane, record different episodes of subsidence separated by poorly defined episodes of basin inversion.

5. Conclusions

Field investigations in the Sylvester allochthon in 2014 provide new insights into the evolution of late Paleozoic arc-back-arc systems of western Laurentia. The Rapid River tectonite in the Dalton-Four Mile and Cry Lake areas has a protolith of mafic mylonite and marble. These rocks may signify part of a primitive arc that was mylonitized and then intruded by late synkinematic diorite/gabbro-tonalite-trondjemite plutons. One of the plutons has previously been dated at ca. 362 Ma. This deformation was part of a tectonic event that set the stage for initiation of arc magmatism on the western Laurentian margin, followed by opening of the Slide Mountain back-arc ocean basin.

The ultramafic part of ophiolite complexes in the Slide Mountain terrane in the Zus Mountain and Blue Dome areas comprises a lower part of serpentinized harzburgite tectonite that is overlain by interlayered peridotite tectonite, lherzolite, dunite, and gabbro, all cut by trondhjemite dikes. Some trondhjemites cut previously-serpentinized hosts, and probably were emplaced during mantle exhumation. At Zus Mountain, a large gabbro body overlies the ultramafites. In the Blue Dome section, basalt, diabase, radiolarian chert and polymictic conglomerates overlie the ultramafites and were probably deposited shortly after their exhumation onto the seafloor. Lacking is an intervening unit of sheeted dikes, such as found in classical ophiolites, implying that the ophiolites did not form through ‘normal’ sea floor spreading. They more closely resemble slow-spreading ridges or hyperextending margins where the subcontinental mantle is exhumed by low-angle detachment faults. A ca. 268 Ma trondhjemite dike from the Zus Mountain area is coeval with similar dikes in Slide Mountain ophiolites of the Yukon, but significantly younger than the basaltic flow and sedimentary sequences elsewhere in the Slide Mountain terrane. The late (ca. 275-265 Ma) sea-floor spreading of the Slide Mountain ocean was broadly coeval with sea-floor closing, as oceanic crust subducted beneath the eastern margin of YTT and generated ca. 273-239 Ma eclogites (Erdmer et al., 1998).

Continued petrological and geochronological investigation of samples from the mafic-ultramafic complexes of the Slide Mountain and Yukon-Tanana terranes in Yukon and northern British Columbia will better document the genesis and setting of these tectonically important rock packages which, in turn, will help establish the evolution of the peri-Laurentian margin through mid- to late Paleozoic time.

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References

Devine, F.D., 2005. Geology of the southern Campbell Range, southeastern Yukon: implications for the tectonic evolution of Yukon-Tanana terrane. M.Sc. thesis, Carleton University, Ottawa, Ontario, 136 p.

Devine, F.D., Carr, S.D., Murphy, D.C., Davis, W.J., Smith, S. and Villeneuve, M., 2006. Geochronological and geochemical constraints on the origin of the Klatsa metamorphic complex: implications for Early Mississippian high-pressure metamorphism within Yukon-Tanana terrane. In: Colpron, M. and Nelson, J.L. (Eds.), Paleozoic Evolution and Metallogeny of Pericratonic Terranes at the Ancient Pacific Margin of North America, Canadian and Alaskan Cordillera. Geological Association of Canada, Special Paper 45, pp. 107-130.

Erdmer, P., Ghent, E.D., Archibald, D.A. and Stout, M. Z. 1998. Paleozoic and Mesozoic high-pressure metamorphism at the margin of Ancestral North America in central Yukon. Geological Society of America Bulletin, 110, 615-629.

Gabrielse, H., 1994. Geology of Cry Lake (104I) and Dease Lake (104J/E) map areas, north central British Columbia. Geological Survey of Canada, Open File Map 2779, scale 1:50 000.

Gabrielse, H., 1998. Geology of Cry Lake and Dease Lake map areas, north-central British Columbia. Geological Survey of Canada, Bulletin 504, 147 p.

Gabrielse, H. and Harms, T.A., 1989. Permian and Devonian plutonic rocks in the Sylvester allochthon, Cry Lake and McDame map areas, northern British Columbia. In: Current Research Part E, Geological Survey of Canada Paper 89-1E, pp. 1-4.

Gabrielse, H., Mortensen, J.K., Parrish, R.R., Harms, T.A., Nelson, J.L., and van der Heyden, P., 1993. Late Paleozoic plutons in the Sylvester Allochthon, northern British Columbia; In: Radiogenic Age and Isotopic Studies, Report 7, Geological Survey of Canada, Paper 93-2, pp. 107-118.

Harms, T.A. 1990. Complex tectonite suite in the Sylvester allochthon. Geological Association of Canada, Program and Abstracts. v. 15, p. A-54.

Manatschal, G., Sauter, D., Karpoff, A.M., Masini, E., Mohn, G. and Lagabrielle, Y. 2011. The Chenaillet Ophiolite in the French/Italian Alps: An ancient analogue for an oceanic core complex? Lithos, 124, 169-184.

Massey, N.W.D. 2007. Boundary project: Rock Creek area (NTS 082/02W, 03E), southern British Columbia. In: Geological Fieldwork 2006. B.C. Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Paper 2007-1, pp. 117-128.

Mercier, J.-C. C. and Nicolas, A. 1975. Textures and fabrics of upper-mantle peridotites as illustrated by xenoliths from basalts. Journal of Petrology, 16, 454-487.

Murphy, D.C., Mortensen, J.K., Piercey, S.J., Orchard, M.J., and Gehrels, G.E., 2006. Mid-Paleozoic to early Mesozoic tectonostratigraphic evolution of Yukon-Tanana and Slide Mountain terranes and affiliated overlap assemblages, Finlayson Lake massive sulphide district, southeastern Yukon. In: Colpron, M. and Nelson, J.L. (Eds.), Paleozoic Evolution and Metallogeny of Pericratonic Terranes at the Ancient Pacific Margin of North America, Canadian and Alaskan Cordillera. Geological Association of Canada, Special Paper 45, pp. 75-105.

Nelson, J.L. 1993. The Sylvester allochthon: upper Paleozoic marginal basin and island arc terranes in northern British Columbia. Canadian Journal of Earth Sciences, 30, 631-643.

Nelson, J.L., Harms, T., Bradford, J.A., Green, K.C. and Marsden, H. 1988. Geology and patterns of mineralization, Blue Dome map area, British Columbia (104P/12). British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Open File 1988-10, scale 1:25 000.

Nelson, J.L., Bradford, J.A., MacLean, M. and Maddison, L. 1989. Geology and metallogeny of the Cassiar and McDame map areas, British Columbia (104P/3, 5). British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Open File 1989-9, 4 sheets, scale 1:25 000.

Nelson, J.L. and Bradford, J.A., 1993. Geology of the Midway-Cassiar area, northern British Columbia (104O, 104P). British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Bulletin 83, 94 p., geologic map, scale 1:100 000.

Nelson, J.L. and Friedman, R., 2004. Superimposed Quesnel (late Paleozoic-Jurassic) and Yukon-Tanana (Devonian-Mississippian) arc assemblages, Cassiar Mountains, northern British Columbia: Field, U-Pb and igneous petrochemical evidence. Canadian Journal of Earth Sciences, 41, 1201-1235.

Nelson, J., and Lepage, L.D. 2002. Geology and mineral occurrences, Beale Lake map area (NTS 104I/14N). British Columbia Ministry of Energy and Mines, British Columbia Geological Survey Open File Map 2002-6, scale 1:50 000.

Nelson, J., Harms, T., Bradford, J., Green, K., and Marsden, H., 1988. Blue Dome map area (104P/12); geology and metallogeny. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Open File 1988-10, 6 sheets, scale 1:25 000.

Piercey, S.J., Nelson, J.L., Colpron, M., Dusel-Bacon, C., Simard, R.-L., and Roots, C.F., 2006. Paleozoic magmatism and crustal recycling along the ancient Pacific margin of North America, northern Cordillera. In: Colpron, M. and Nelson, J.L. (Eds.), Paleozoic Evolution and Metallogeny of Pericratonic Terranes at the Ancient Pacific Margin of North America, Canadian and Alaskan Cordillera. Geological Association of Canada, Special Paper 45, pp. 281-322.

Simony, P. S., Sevigny, J. H., Mortensen, J. K. & Roback, R. C.

2006. Age and origin of the Trail Gneiss Complex: Basement to Quesnel terrane near Trail, southeastern British Columbia. In: Colpron, M. & Nelson, J. L. (Eds.) Paleozoic evolution and metallogeny of pericratonic terranes at the ancient Pacific margin of North America, Canadian and Alaskan Cordillera. Geological Association of Canada, Special Paper 45, pp. 505-515.

van Staal, C., Escayola, M., McClelland, W., Petrie, M., Gilotti, J. and Ryan, J.J., 2012. Some comments on the Paleozoic tectonic history of the Yukon-Tanana terrane –Slide Mountain trrane system. 2012 Cordilleran Tectonics Workshop Abstracts, February 24-26, 2012, Victoria, BC, p. 57.