Mapping in the Tatsi and Zymo ridge areas of west-central British Columbia: Implications for the origin and history of the Skeena arch

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Abstract

Economically significant porphyry and related mineralization is genetically associated with the Bulkley (Late Cretaceous) and Babine and Nanika intrusive suites (Eocene) in central British Columbia. These intrusions and mineral occurrences are largely restricted to the Skeena arch, a northeast-trending paleohigh that extends transverse to the general trend of Stikine terrane. Elongate intrusions and linear trends of intrusions that suggest emplacement was partially localized along the Skeena arch, and strata of the Skeena Group (Lower Cretaceous) are deformed into northeast trending folds. Stratigraphic relationships across the Skeena arch indicate that it became an arc-transverse paleotopographic high between the Middle Jurassic and Early Cretaceous. The northeast-trending folds, along with the northeasterly orientation of plutonic suites and the Skeena arch as a whole, are thought to be manifestations of a fundamental arc-transverse structural anisotropy.

Keywords: Skeena arch, Skeena Group, Netalzul volcanics, Telkwa Formation, Bulkley suite, Babine suite, Nanika suite, Stikinia, folding, arc transverse, porphyry

1. Introduction

Reactivation of pre-existing structures is regarded as a mechanism to localize emplacement of porphyry intrusions and provide conduits for hydrothermal fluids (Heidrick and Titley, 1982; Richards, 2000; Richards et al., 2001; Tosdal and Richards, 2001). In arc terranes, transverse structures are considered preferential hosts for porphyry intrusions and mineralization, particularly where they intersect arc-parallel structures (Schmitt, 1966; Glen and Walshe, 1999; Richards et al., 2001; Hill et al., 2002; Garwin et al., 2005; Gow and Walshe, 2005).

The Skeena arch is an ENE-trending structure that is transverse to the trend of the Stikine arc terrane in central British Columbia (Fig. 1). Lower Jurassic and older rocks exposed along its crest are flanked by Middle Jurassic to Lower Cretaceous units deposited in the Bowser basin to the north and Nechako basin to the south (Fig. 1; Tipper and Richards, 1976a). Most mineral occurrences along the arch are interpreted as being genetically related to the Bulkley (Late Cretaceous) and Babine and Nanika (Eocene) intrusive suites (MacIntyre, 2006). These suites, as well as the Topley and Kleanza suites (Late Triassic to Early Jurassic), align along the northeasterly trend of the Skeena arch (Fig. 1). Despite regional (Tipper and Richards, 1976b) and more detailed (MacIntyre et al., 1989; Desjardins et al., 1990; Nelson et al., 2006, 2008, 2009; Nelson and Kennedy, 2007) mapping, the structural history of the Skeena arch and, in particular, the significance of its arc-transverse orientation, has not been well established.

To develop a better understanding of structural controls on mineralization in the Skeena arch, herein we present the results of 1:20,000-scale mapping in two areas lacking detailed study: near Zymo ridge northeast of Red Canyon Creek; and near Tatsi in the south Howson Range (Fig. 2). Parallel stratigraphic relationships, structural features, and intrusive-mineralization trends of differing ages suggest a long-lived underlying control.

2. Geological setting

Mississippian to Neogene rocks in the Skeena arch (Fig. 2) record island arc magmatism and related sedimentation, followed by continental margin arc magmatism and siliciclastic sedimentation. Mississippian to Permian rocks of the Mt. Attree Formation represent a nascent island arc that terminated with deposition of Ambition Formation limestone (Permian) and then a thin, unnamed Middle Triassic chert-argillite unit (Nelson et al., 2006). Triassic plutonic rocks of the Stuhini arc have been documented in the Skeena arch, although coeval extrusive rocks have not (Deyell et al., 2000).

Upper Triassic to Lower Jurassic arc volcanic rocks of the Telkwa Formation (lower part of Hazelton Group) form most exposures in the Skeena arch. The Telkwa Formation includes rocks that define a transition from subaerial to marine environments from west to east (Tipper and Richards, 1976a). The plutonic equivalents of Telkwa Formation extrusive rocks are the Topley and Kleanza suites, which are distributed in a

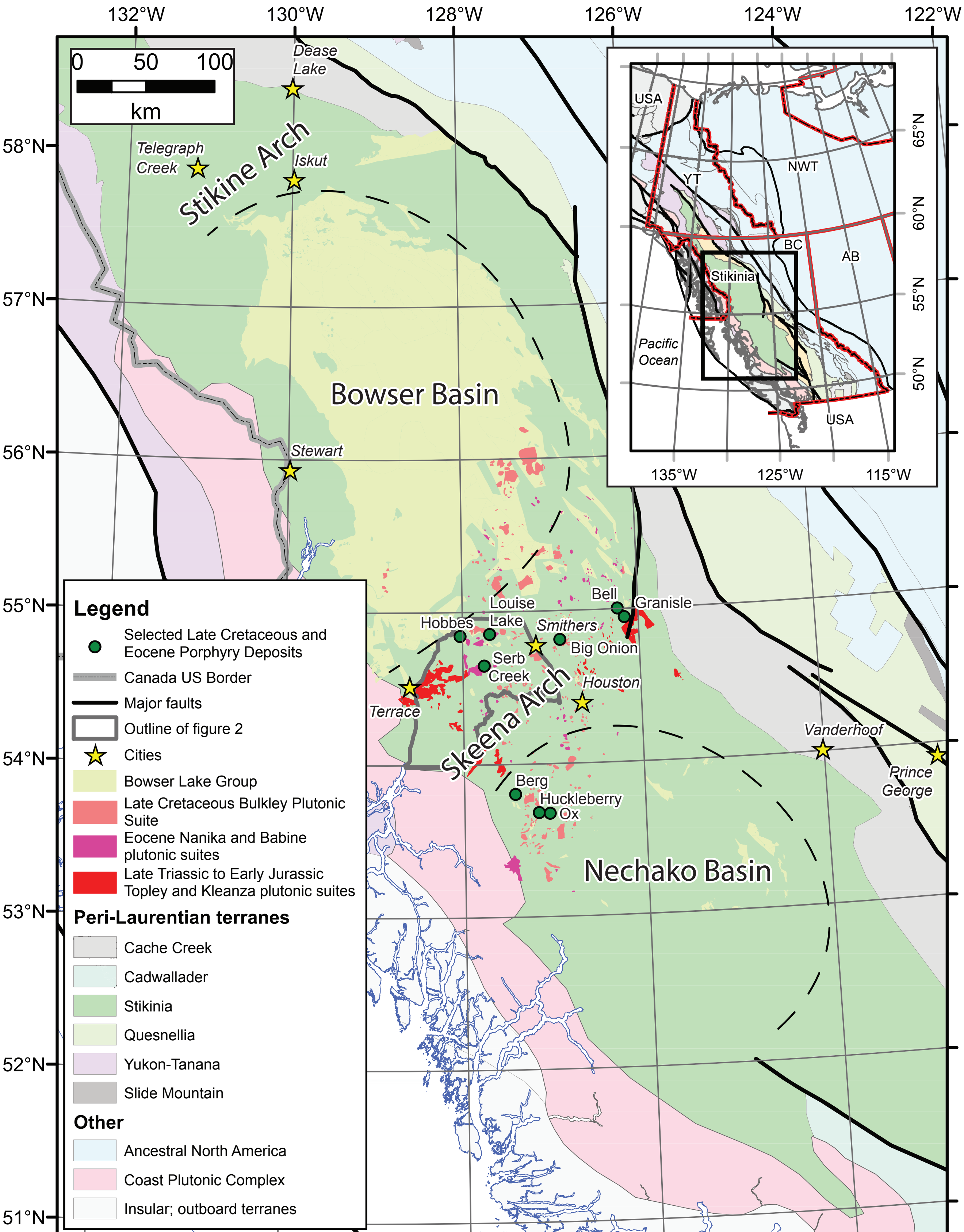


Fig. 1. Location of study area in the context of central British Columbia geology. Terranes modified after Colpron and Nelson (2011) and Nelson et al. (2013). Outlines of the Bowser and Nechako basins modified after Tipper and Richards (1976a).

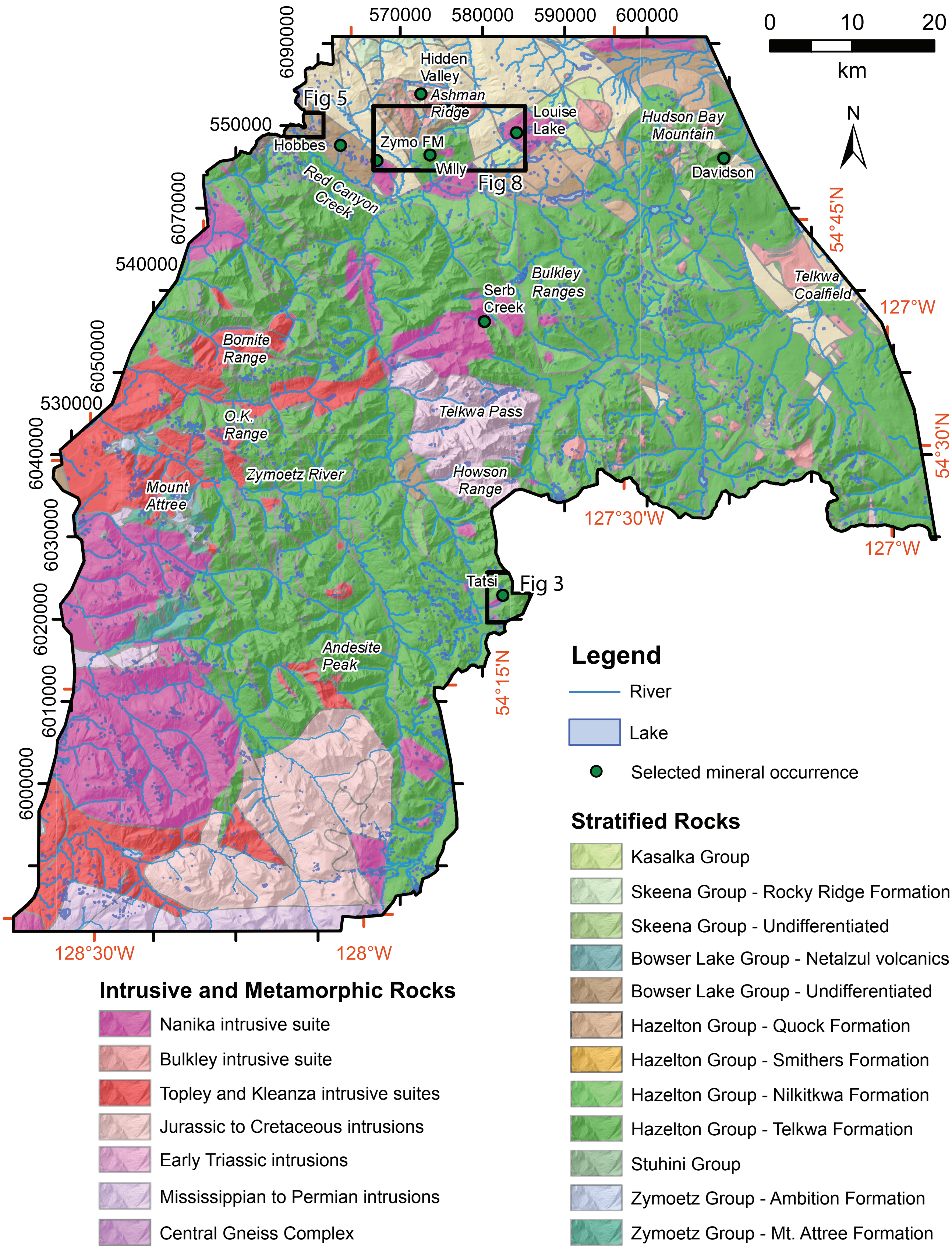


Fig. 2. Simplified geology of western Skeena Arch and locations of detailed study areas. Geology modified after British Columbia digital geology compilation (Cui et al., 2015).

northeasterly trend along the axis of the Skeena arch (Nelson, 2017; Figs. 1, 2). Elsewhere in the Stikine terrane, large porphyry and related deposits are genetically associated with Late Triassic and Early Jurassic plutons (Logan and Mihalynuk, 2014). Comparable deposits have not yet been identified in the Skeena arch.

Hazelton arc volcanism waned through the Early and Middle Jurassic, with deposition of mixed volcanic and sedimentary rocks of the Nilkitkwa Formation followed by tuffaceous sedimentary rocks of the Smithers and Quock formations (Gagnon et al., 2012). The Stikine terrane accreted to western North America during the Middle Jurassic, with southwest-vergent fold and thrust deformation documented along the Stikine-Cache Creek terrane boundary (Schiarizza and MacIntyre, 1999; Mihalynuk et al., 2004). At the eastern margin of the Skeena arch, Schiarizza and MacIntyre (1999) documented a southwest-vergent thrust fault crosscut by a 165 +2/-1 Ma pluton (U-Pb zircon, Ash et al., 1993).

Accretion was followed by marine sedimentation in the Bowser and Nechako basins (Fig. 1). Middle Jurassic marine deposits are not widespread across the Skeena arch and are limited to isolated localities, such as southwest of Telkwa Pass, where Callovian (Middle Jurassic) fossils have been found in the Bowser Lake Group (Fig. 2; Pálfy et al., 2000). Along the northern margin of the Skeena arch, the Quock Formation is gradationally overlain by Middle Jurassic to Lower Cretaceous marine sedimentary rocks of the Bowser Lake Group (Gagnon et al., 2012). Lower to Upper Cretaceous Skeena Group sedimentary rocks gradationally overlie the Bowser Lake Group within the Bowser basin (Smith and Mustard, 2006), but unconformably overlie the Telkwa Formation in central Skeena arch (Fig. 3; Palsgrove and Bustin, 1991). The Skeena arch was therefore a paleotopographic high by at least the Early Cretaceous. Late Cretaceous to Oligocene rocks obscure older stratigraphic relationships along the southern margin of the Skeena arch.

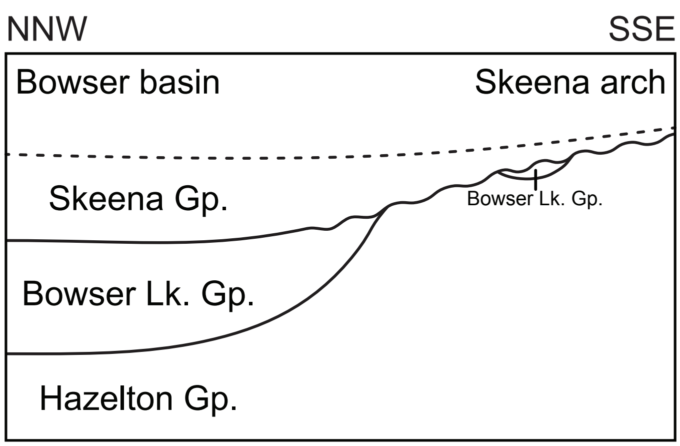


Fig. 3. Schematic cross section from the Bowser basin to the Skeena arch during the Early Cretaceous. Straight solid lines reflect conformable contacts, wavy solid lines reflect unconformable contacts, and dashed line is Earth's surface. The Skeena Group conformably overlies the Bowser Lake Group in the Bowser basin but unconformably overlies the Hazelton Group in the Skeena arch.

The Bulkley (Late Cretaceous) and Nanika and Babine (Eocene) plutonic suites, hosts to porphyry mineralization, are widely distributed across the Skeena arch (Fig. 1; MacIntyre, 2006). Although the overall distribution of the Late Cretaceous intrusions follows a broadly north-south trend (Fig. 1), individual intrusions define map traces that trend northeast. For example, at the Huckleberry main zone, a northeasterly shear zone controls the shape of the stock and mineralization (Jackson and Illerbrun, 1995), and the Hidden Valley prospect (MINFILE 093L 076) displays a similar trend. The Babine suite intrusions in the eastern Skeena arch are strongly localized along northwest-trending dextral strike-slip faults (Carter et al., 1995; Dirom et al., 1995). The overall extent of Eocene intrusions follows a northeasterly trend, along the axis of the Skeena arch (Fig. 1).

Upper Paleozoic and Upper Triassic strata near Terrace are deformed by northeast-trending, regional-scale folds, and the upper Paleozoic rocks contain a southeast- to east-dipping foliation. These structures are latest Triassic or older because they are crosscut by a ca. 200 Ma phase of the Kleanza pluton (U-Pb zircon, Gareau et al., 1997; Nelson et al., 2008; Angen, 2009). Deformation of Jurassic and younger strata in the Skeena arch west of Smithers and east of the Coast Belt is minimal, predominantly block faulting (MacIntyre et al., 1989; Desjardins et al., 1990). Minor northwest-trending folds are documented in the Telkwa coalfields area (Ryan, 1993).

Relative to the inverted basins that flank it, the Skeena arch region exhibits minimal deformation. Strata of both the Bowser and Nechako basins display folds and thrusts formed during the Cretaceous (Evenchick, 1991; Angen et al., 2016). In the Bowser basin, uncommon northeast-trending folds are interpreted to reflect Early Cretaceous sinistral transpression. These structures developed before northeast-vergent folds considered to record mid- to Late Cretaceous orthogonal shortening (Evenchick, 2001; Waldron et al., 2006). Northeast-trending folds in the southeastern part of the Bowser basin have been attributed to heterogeneities from basement promontories during overall northeast-vergent shortening (Sutherland-Brown, 1960; McMechan, 2007). Folds documented in Nechako basin are consistent with ENE-vergent shortening during the mid-Cretaceous (Hayward and Calvert, 2011; Angen et al., 2016). The western Skeena arch appears to have been unaffected by Cretaceous northeast-vergent deformation. The sole exception is an inferred top-to-the-northeast thrust fault that crosses the Skeena River northeast of Terrace (Nelson et al., 2008). Eocene extensional deformation formed northwest-trending graben across much of the arch (MacIntyre, 1998; Angen, 2009).

3. Map unit descriptions

3.1. Stratified rocks

3.1.1. Telkwa Formation (Hazelton Group)

In the Tatsi area (Figs. 2, 4), the Telkwa Formation consists mainly of well-bedded maroon tuffs referred to as the Howson facies, and interpreted as subaerial deposits, by Tipper and

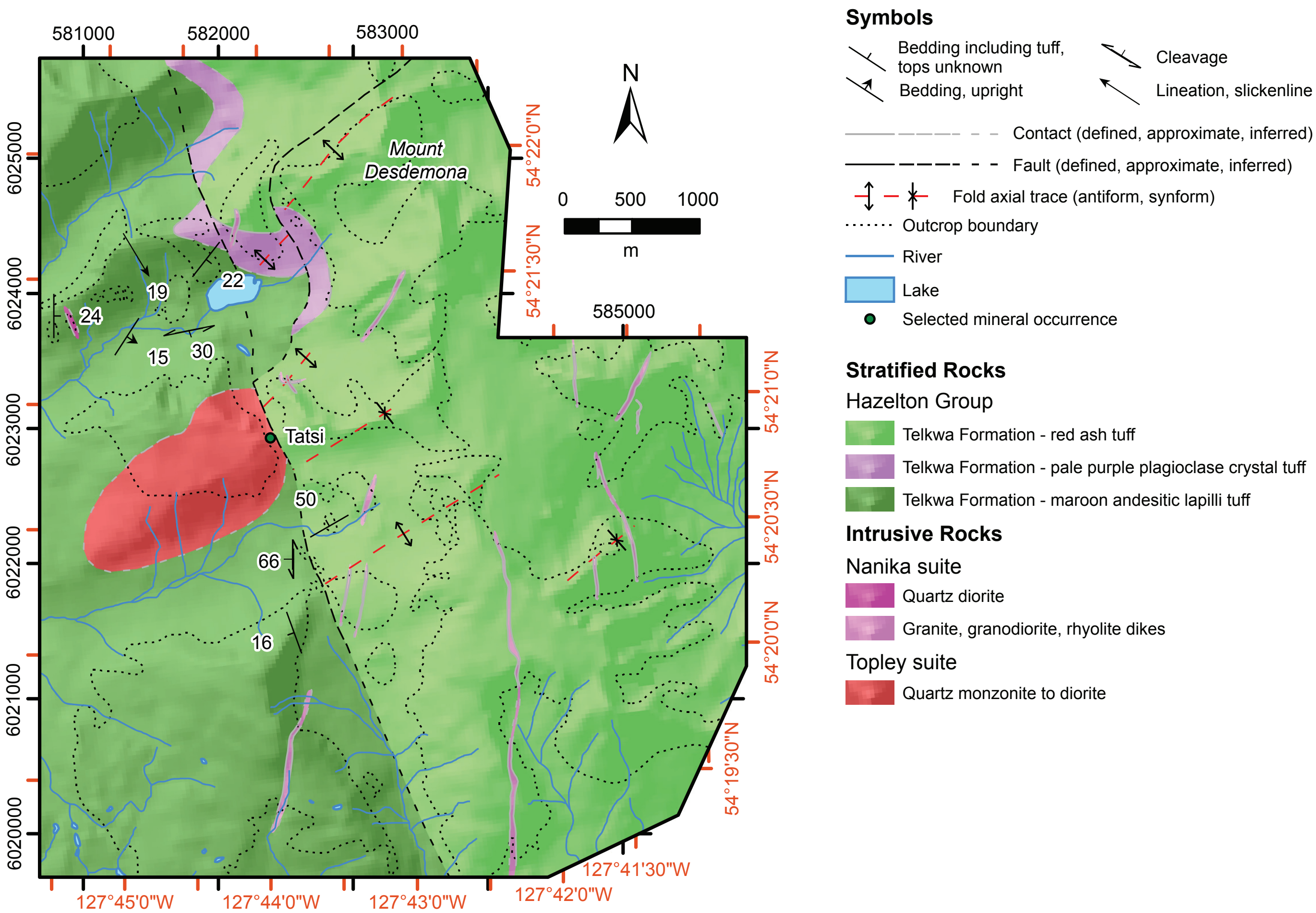


Fig. 4. Bedrock geology of the Tatsi map area, southern Howson Range. See Figure 2 for location.

Richards (1976b). The interpreted base of the Telkwa Formation is exposed north of the Tatsi area. It is marked by a discontinuous cobble conglomerate overlying chlorite- and epidote- altered mafic volcanic rocks that are tentatively considered part of the Stuhini Group. The conglomerate contains well-rounded cobbles of dark green chlorite and epidote altered mafic volcanic rocks in a maroon to dark purple ash matrix (Fig. 5a). It is overlain by interbedded ash tuff, plagioclase crystal tuff,

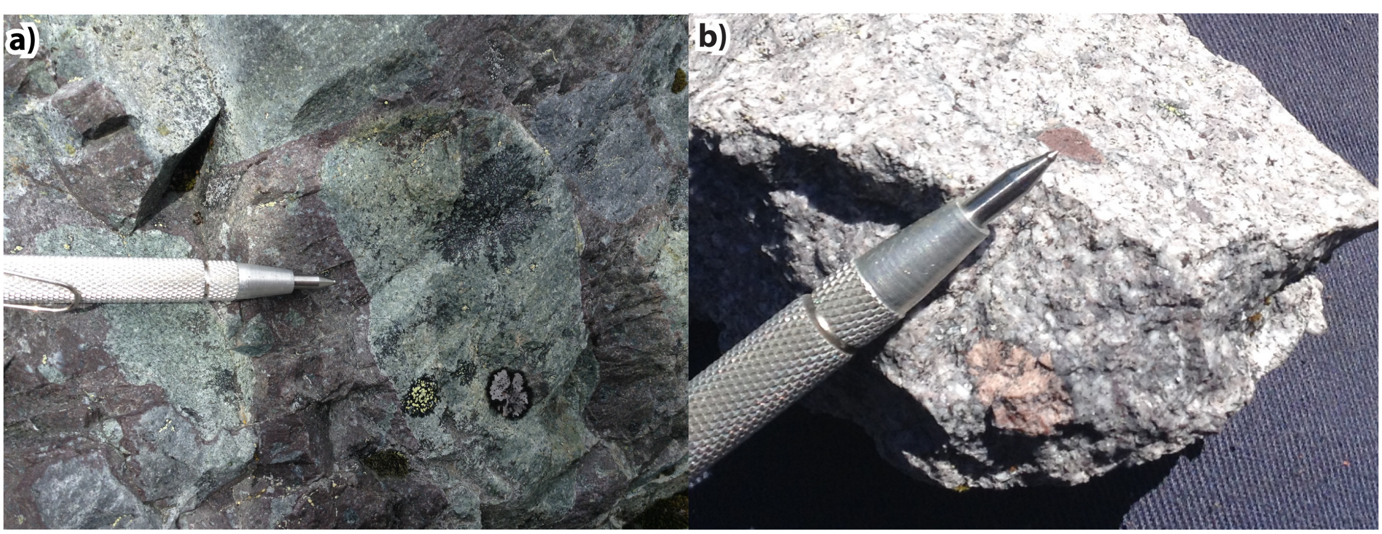


Fig. 5. Features of the Telkwa Formation in the southern Howson Range. **a)** Conglomerate with subangular to rounded dark green mafic volcanic clasts in a maroon ash matrix. **b)** Distinctive pale purple crystal tuff marker in the Tatsi area.

lapilli tuff, and dark green amygdaloidal basalt flows. Basalt flows decrease up section, passing into maroon ash to lapilli tuff with ubiquitous plagioclase and local quartz phenocrysts. Minor dark grey siltstone and very fine-grained sandstone are interbedded with tuff.

The stratigraphically lowest rocks in the Tatsi area are thick bedded (up to 30 metres) maroon andesitic lapilli tuffs, about 300 metres thick, that are conformably overlain by a light grey to purple crystal-lithic lapilli tuff marker bed. The marker bed contains up to 35% plagioclase crystals (up to 3 mm) and maroon lapilli similar to the underlying andesitic tuffs, set in a pale grey to purple groundmass (Fig. 5b). It is overlain by at least 200 metres of well-bedded brick red tuffs within which are white sills of biotite hornblende granodiorite. This section of laterally continuous tuff beds differs markedly from highly heterogeneous flow and volcaniclastic stratovolcano deposits in the Telkwa Formation near Terrace (Nelson et al., 2006; 2008; Nelson and Kennedy, 2007; Barresi et al., 2015) and are likely distal equivalents.

3.1.2. Bowser Lake Group

The Bowser Lake Group is exposed in the southwest corner of the Zymo ridge area (Fig. 6). It consists of interbedded light grey sandstone, fossiliferous dark grey siltstone, and green to grey andesite flows and lapilli tuffs. The basal contact of the Bowser Lake Group is well documented near Quinlan Mountain immediately west of the Zymo ridge area and at Ashman Ridge to the east (Fig. 2), where siliceous mudstone and tuff of the Quock Formation transition conformably to black and dark grey siltstone, sandstone, and shale (Nelson and Kennedy, 2007; Evenchick et al., 2010; Gagnon et al., 2012).

Sandstone and siltstone beds are 10 cm to 2 m thick. Sandstones are medium to coarse grained and contain granulestone lenses up to 10 cm thick (Fig. 7a). Some bedding planes are marked by fossilized plant debris. Clasts in conglomerate are subangular to subrounded. Most are felsic volcanic rocks with lesser black chert. Exotic chert clasts are ubiquitous in the Bowser Lake Group, but the felsic volcanic clasts are of more local derivation, probably from the Skeena arch (Nelson and Kennedy, 2007). Siltstone beds contain abundant bivalve and belemnite fossils. The combination of bivalve, belemnite, and plant fossils in the same sequence indicate alternating marine and continental sedimentation.

Dark grey, plagioclase-phyric andesite flows have aphanitic chilled margins and peperitic textures along contacts with sandstones. Lenses of hyaloclastite occur within sandstone beds close to andesite flows. Lapilli tuffs contain mostly plagioclase-phyric andesite fragments and lesser white, aphanitic rhyolite fragments. One lapilli breccia contains abundant bivalve and belemnite fossils (Fig. 7b). This breccia is interpreted as a volcanic debris flow that incorporated an unconsolidated fossil bed. Flows with peperitic textures, chilled margins, sandstones with lenses of hyaloclastite, and fossiliferous lapilli breccia indicate coeval volcanism and submarine sedimentation.

We interpret that Bowser Lake Group rocks in the Zymo ridge area are part of the Netalzul volcanics and Muskaboo Creek assemblage (Tipper and Richards, 1976a; Evenchick et al., 2008; 2010). The Muskaboo Creek assemblage was previously referred to as the the Suskwa facies of the former Trout Creek assemblage (Richards and Jeletzky, 1975; Tipper and Richards, 1976a). Upper Jurassic volcanic rocks of the Netalzul volcanics have been documented along the eastern and southern margins of the Bowser basin (Tipper and Richards, 1976a), and Upper Jurassic to Lower Cretaceous volcanic rocks are a significant component of the Bowser Lake Group in the Nechako Plateau (Diakow et al., 1997; Friedman et al., 2001).

3.1.3. Bulkley Canyon and Laventie formations (Skeena Group)

The Skeena Group is well exposed in the Zymo ridge area where it includes nonmarine polymictic conglomerate, sandstone, siltstone, and mudstone (Fig. 6). The lower contact is obscured by vegetation, but bedding is parallel to that in underlying Bowser Lake Group rocks. A clastic dike that cuts the lowermost Skeena Group contains subangular to subrounded fragments of felsic volcanic rocks and chert, similar to the underlying Bowser Lake Group. The Bowser Lake Group was therefore unconsolidated at the onset of Skeena Group deposition. This is consistent with the interpretation (Smith and Mustard, 2006) of a conformable contact between these two groups in southern Bowser basin. In contrast, in the Telkwa coalfield in the central part of Skeena arch, the Skeena Group unconformably overlies the Hazelton Group (Fig. 2; Palsgrove and Bustin, 1991).

3.1.3.1. Bulkley Canyon Formation

At the base of the Skeena Group in the Zymo ridge study area, the Bulkley Canyon Formation (Bassett and Kleinspehn, 1997) is about 200 m thick and consists of cobble conglomerate, sandstone and siltstone. It is light to dark grey on fresh surfaces but weathers bright orange-red. Thick beds of framework-intact polymictic conglomerate (5-30 m) contain subrounded- to well-rounded, locally imbricated clasts of mainly volcanic rock, with lesser plutonic, chert, and sandstone in a matrix of coarse sand. Interpenetration of clasts in conglomerate was observed (Fig. 8b). Arkosic sandstone beds separate conglomerate beds. They are 1 to 5 m thick and exhibit cross stratification. Wood fossils are common, but coal beds are lacking. Some sandstone beds contain brown weathering pods up to 2 m long by 30 cm thick with calcareous cement. Sparse imbricated clasts and cross stratification are consistent with flow towards the northwest and northeast.

3.1.3.2. Laventie Formation

The Bulkley Canyon Formation grades up section to a unit of fine-grained sandstone, siltstone and mudstone, which also weathers orange-red (Fig. 8c), the Laventie Formation of Bassett and Kleinspehn (1997). Sandstone and siltstone form laterally continuous beds 10 to 100 cm thick; black shales form rare beds >4 m thick. Uncommon beds with a carbonate

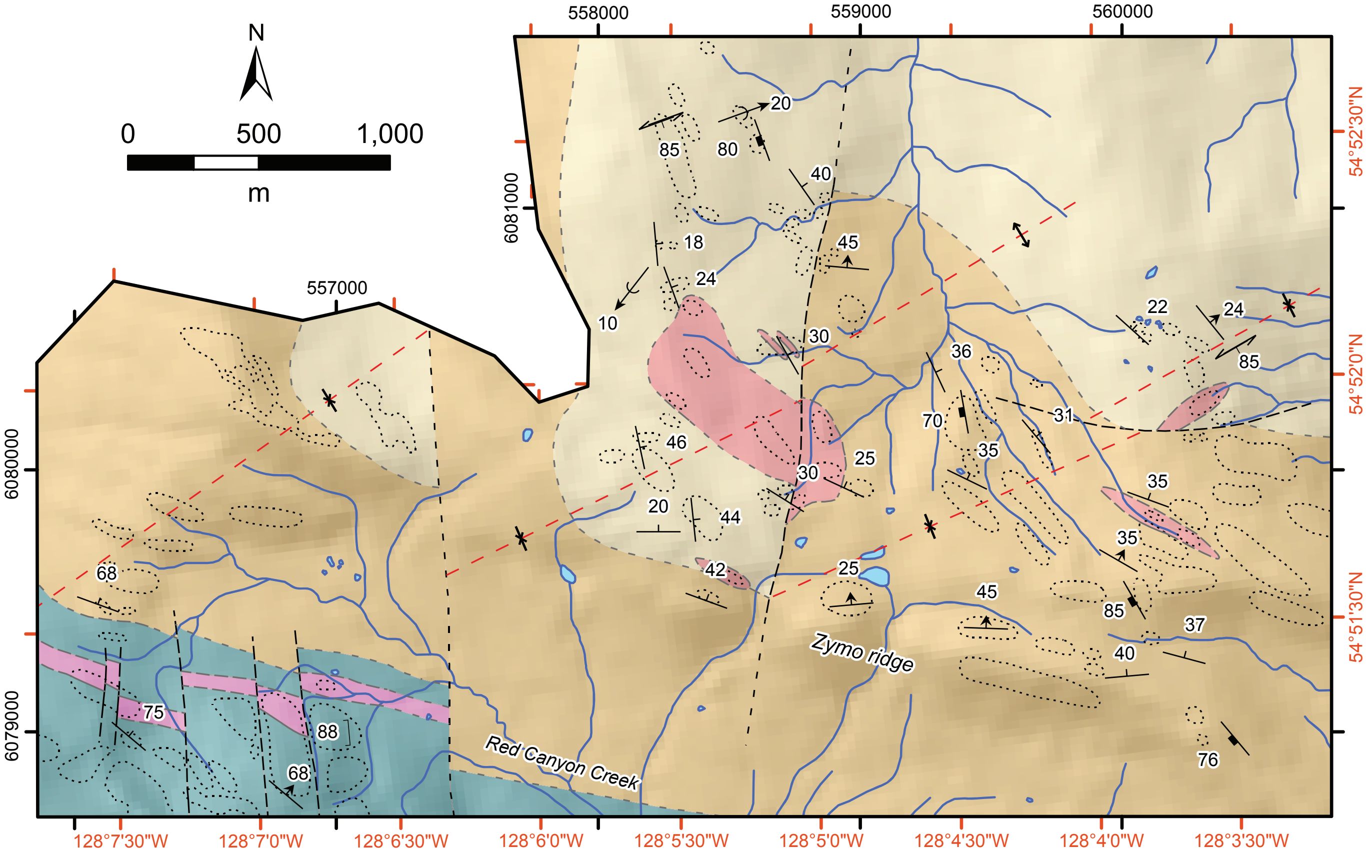


Fig. 6. Bedrock geology of the Zymo ridge area. See Figure 2 for location.

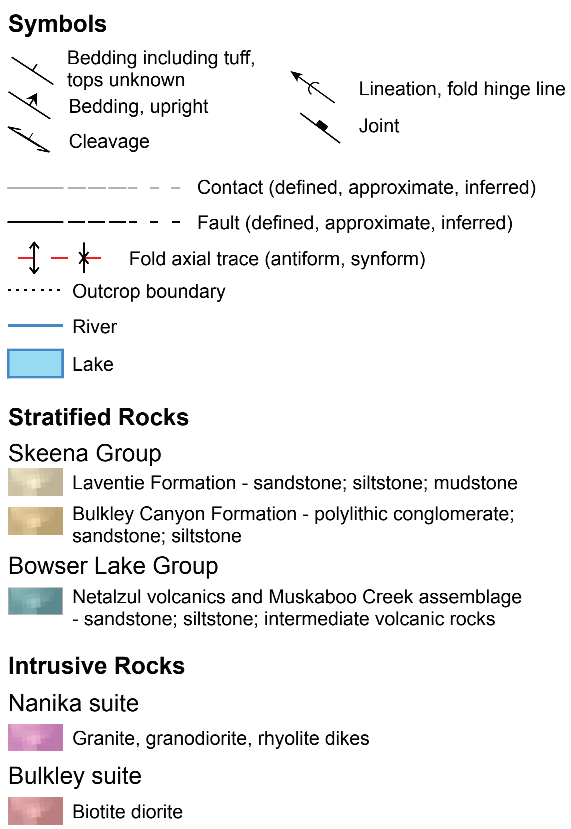


Fig. 6. Continued.

cement are rich in bivalve and gastropod fossils. Elsewhere in the southern part of the Bowser basin, the Laventie Formation is gradationally overlain by the Rocky Ridge Formation and the Rocher Deboule Formation (Bassett and Kleinspehn, 1997).

3.2. Plutonic suites

3.2.1. Topley suite (latest Triassic to Early Jurassic)

A coarse-grained equigranular quartz monzonite to diorite stock crosscuts Telkwa andesitic tuffs in the Tatsi area (Fig. 4). Different phases of the stock contain variable plagioclase feldspar (30-55%), pink K-feldspar (up to 25%), quartz (up to 15%) and hornblende and biotite (10-20%). These phases display inconsistent crosscutting relationships. Microdiorite xenoliths are ubiquitous. Mineralized quartz and quartz-carbonate veins and alteration locally crosscut the stock (Tennant and Tompson, 1995).

3.2.2. Bulkley suite (Late Cretaceous)

Several small (5 to 10 m wide) diorite dikes and one larger stock (~1 km by 500 m) were observed in the Zymo ridge area (Fig. 6). The dikes trend northwesterly and northeasterly. They are fine grained and composed of dark grey diorite to quartz diorite with up to 5% biotite. Some dikes contain hornblende phenocrysts up to 3 mm long. Similar fine-grained diorite intrusions, interpreted as part of the Bulkley Suite, are spatially associated with Cu-Au mineralization at the Hobbes porphyry prospect (Laird, 2012). A plagioclase phyric diorite near the

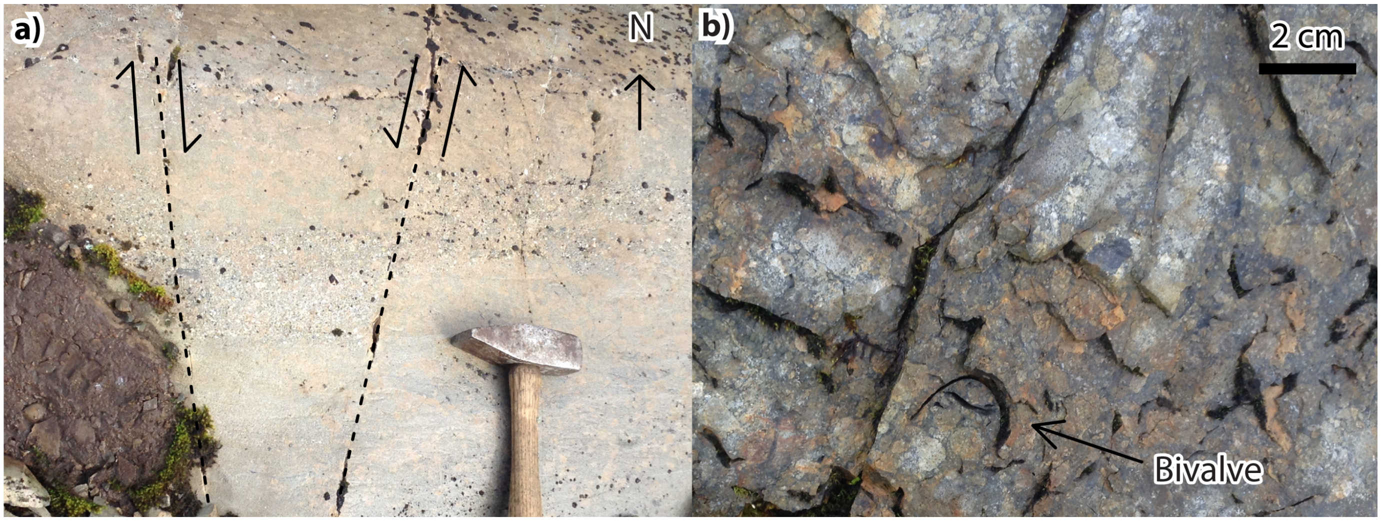
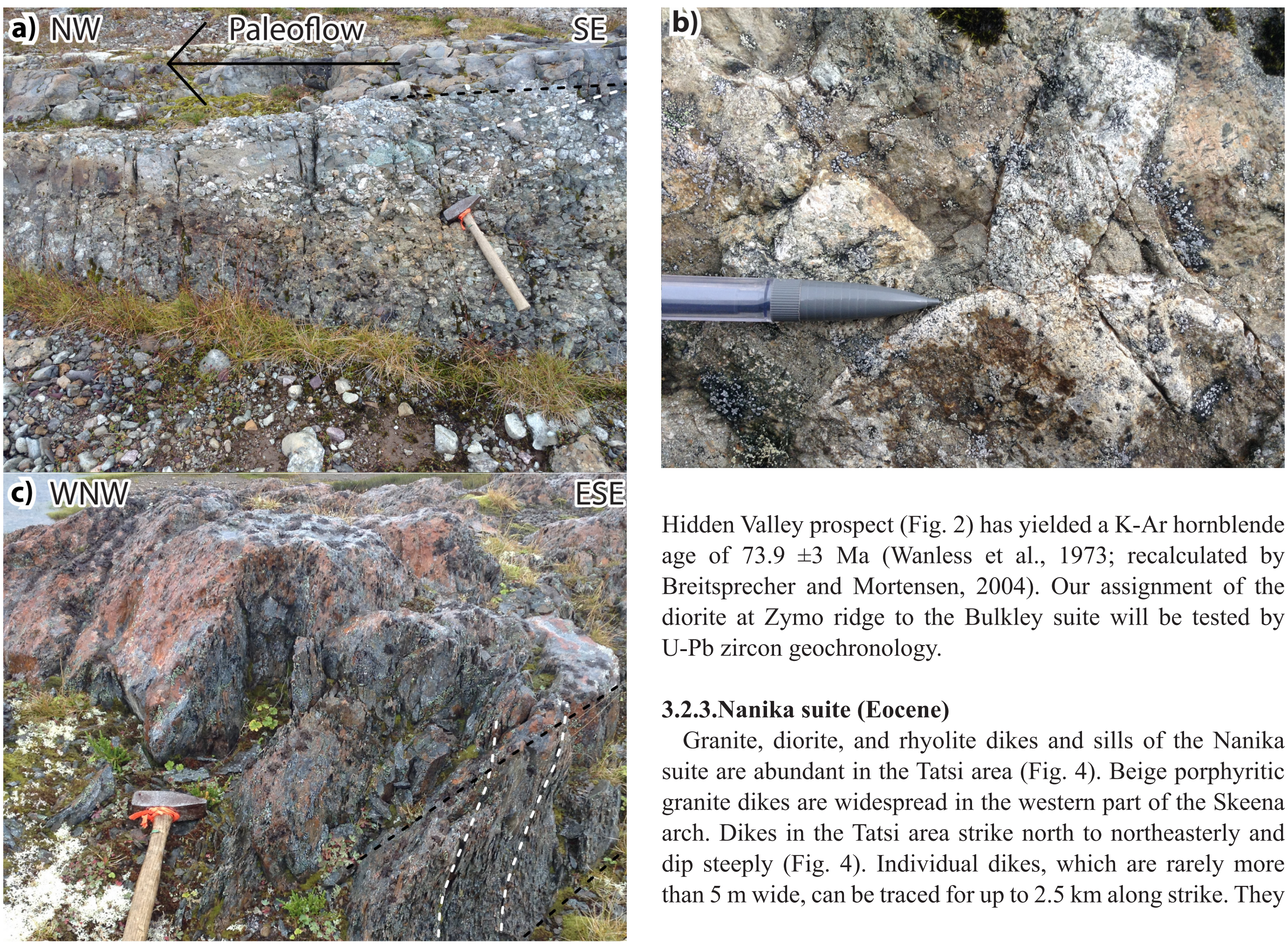


Fig. 7. Features of the Bowser Lake Group in the Zymo ridge area. **a)** Granulestone lens in Bowser Lake Group sandstone. Nearly parallel north-striking (±10°) minor faults offset the conglomerate lens in opposite directions, reflecting the geometry of offset map units. **b)** Lapilli breccia containing bivalve fossils.



Hidden Valley prospect (Fig. 2) has yielded a K-Ar hornblende age of 73.9 ±3 Ma (Wanless et al., 1973; recalculated by Breitsprecher and Mortensen, 2004). Our assignment of the diorite at Zymo ridge to the Bulkley suite will be tested by U-Pb zircon geochronology.

3.2.3.Nanika suite (Eocene)

Granite, diorite, and rhyolite dikes and sills of the Nanika suite are abundant in the Tatsi area (Fig. 4). Beige porphyritic granite dikes are widespread in the western part of the Skeena arch. Dikes in the Tatsi area strike north to northeasterly and dip steeply (Fig. 4). Individual dikes, which are rarely more than 5 m wide, can be traced for up to 2.5 km along strike. They

Fig. 8. Features of the Skeena Group near Zymo ridge. **a)** Polymictic conglomerate in the Bulkley Canyon Formation. Pebbly layer within sandstone lens marks cross bedding consistent with paleoflow towards the northwest. Dashed black line traces bedding and dashed white line traces cross bedding. **b)** Interpenetration of clasts in conglomerate. **c)** Orange-red weathered siltstone and fine-grained sandstone of the Laventie Formation. Dashed white lines trace spaced cleavage and dashed black lines trace bedding.

contain up to 15% plagioclase, 10% hornblende, 5% biotite, and 2% quartz phenocrysts in a fine-grained grey to beige groundmass.

Medium-grained equigranular quartz diorite with locally pegmatitic margins forms a dike that crosscuts folds in the Tatsi map area (Fig. 4). It crosscuts one of the porphyritic sills described above and is therefore interpreted to be a late phase of the Nanika suite. The interior of the dike contains 7% quartz, 30% hornblende, 8% pyroxene, and 55% plagioclase. Along the pegmatitic margins are hornblende crystals, locally >5 cm long.

A beige quartz- feldspar-phyric rhyolite body occurs concordant with bedding within 100 m of the top of the Bowser Lake Group (Fig. 6). It contains 5% plagioclase and 3% quartz phenocrysts (up to 3 mm) in an aphanitic beige groundmass. It remains unclear if the body is a sill or a flow.

A series of aeromagnetic highs form a northeasterly trend immediately south of Ashman Ridge east of the Zymo ridge area (Fig. 9a; Precision GeoSurveys Inc, 2016). This trend is between the Zymo FM Zone porphyry prospect in the west and the Louise Lake porphyry prospect in the east, and includes the Willy polymetallic vein prospect. Each of these prospects is adjacent to or within a previously mapped Nanika suite intrusive body (Fig. 9b). Field mapping in the area confirmed that another aeromagnetic high along this trend corresponds to a plagioclase porphyritic diorite intrusion similar to the one at Louise Lake (Fig. 8b). The strong linear trend of these stocks suggests that a northeasterly structure likely controlled emplacement of Eocene magma locally.

4. Structure

4.1. Zymo ridge

Well-bedded Skeena Group conglomerate, sandstone and mudstone along Zymo ridge are deformed into broad, open, shallowly to moderately northeast-plunging folds with wavelengths of approximately 2 km (Fig. 6). Near the cores of larger folds are similarly oriented outcrop-scale folds with wavelengths of 10 to 20 m (Figs. 9b, 10a).

Fine-grained rocks in the Skeena Group have a steeply northwest, and less commonly southeast, dipping spaced cleavage in which microlithons between cleavage foliae are spaced from 1 to 10 cm (see Powell, 1979; Engelder and Marshak, 1985; Figs. 8b, c). The intersection of this cleavage, likely generated by pressure solution, with bedding-parallel partings results in a pencil cleavage. This cleavage is interpreted as axial planar to the northeast-plunging folds as it is relatively consistent regardless of bedding orientation. Minor refraction of cleavage is present between sandstone and siltstone layers. Pervasive southwest dipping joints are observed throughout the Zymo ridge area (Fig. 10c). These joints correspond to the AC (profile) plane of folds.

Evidence of faults in the Zymo ridge area is scarce. A west-striking fault places conglomerate against black shale; the offset

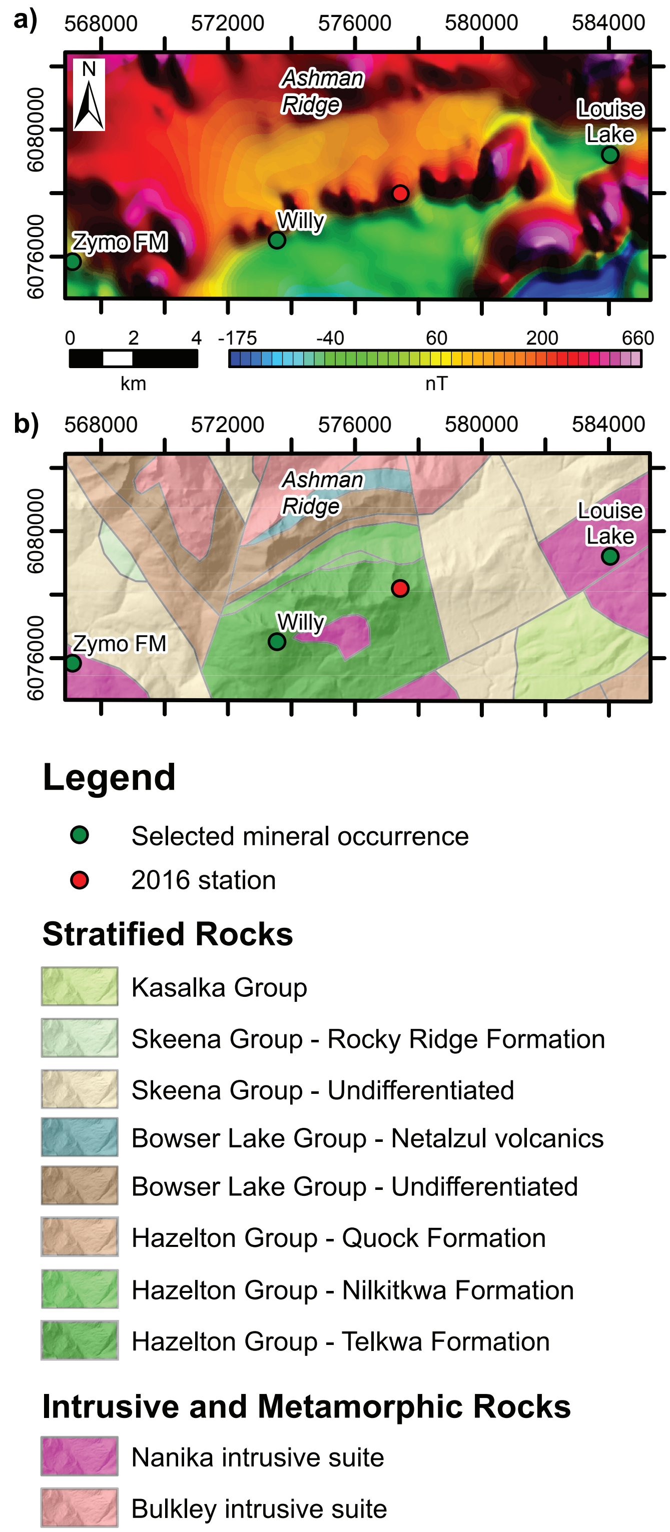


Fig. 9. a) Reduced to pole aeromagnetic map showing strong linear trend of magnetic highs between the Zymo FM and Louise Lake developed prospects (modified after Precision GeoSurveys Inc., 2016). **b)** Bedrock geology modified after British Columbia digital geology compilation (Cui et al., 2015). See Figure 2 for location.

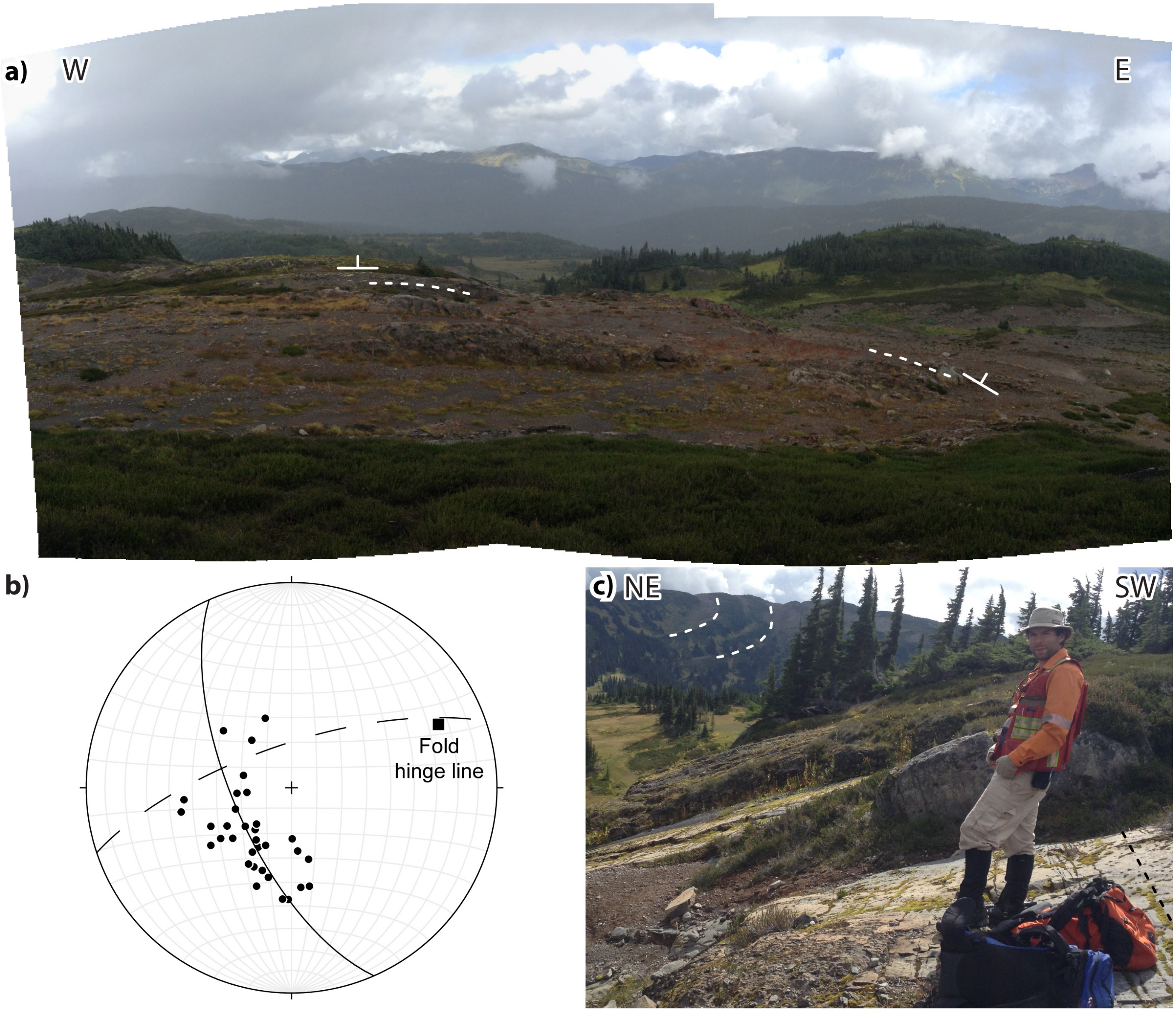


Fig. 10. Structures in the Zymo ridge area. **a)** Panorama of parasitic northeast-plunging fold. Dashed white lines trace bedding in two adjacent outcrops that dip to the north and northeast. Photo looking oblique to the hinge line of the fold. **b)** Lower hemisphere, equal area stereonet plot showing the orientation of structures in the Zymo ridge area excluding data from south of Red Canyon Creek. Black circles are poles to bedding. The fold hinge line orientation was calculated using eigenvalues of bedding measurements. Dashed line represents average orientation of cleavage. Solid line represents average orientation of AC joints. **c)** AC joints in Skeena Group sandstone. Dashed black line traces orientation of joints. White dashed lines trace bedding through hinge of a northeast-plunging syncline in the distance.

across the fault indicates either sinistral or north-side-down sense of shear (Fig. 6). A set of south-striking faults separates the Skeena Group into three folded panels with apparent west side down sense of shear. Similarly oriented faults in the Bowser Lake Group are observed to have opposing sense of shear at outcrop (Fig. 7a) and map scale (Fig. 6).

4.2. Tatsi area

The exceptionally well-bedded tuffs in the southern Howson Range are deformed into northeast trending folds. A northwest-vergent fold was observed in the cirque west of Mount Desdemona (Fig. 11a). In the northern headwall it is accentuated by a pale purple marker tuff that is offset approximately 50 m across the fault. Bedding varies between shallowly southeast and steeply northwest dipping (Fig. 11b). Folds were also identified through air photo interpretation in areas where steep terrane restricted access. Shallowly south- to southeast-dipping quartz veins at the Tatsi prospect host bornite, chalcopyrite, galena, sphalerite, electrum, and native silver (Fig. 4; Tennant and Tompson, 1995). Slickenlines along the margins of one such vein have an azimuth of 150° and a plunge of 19° (Fig. 11b). En-echelon vein sets have enveloping surfaces parallel

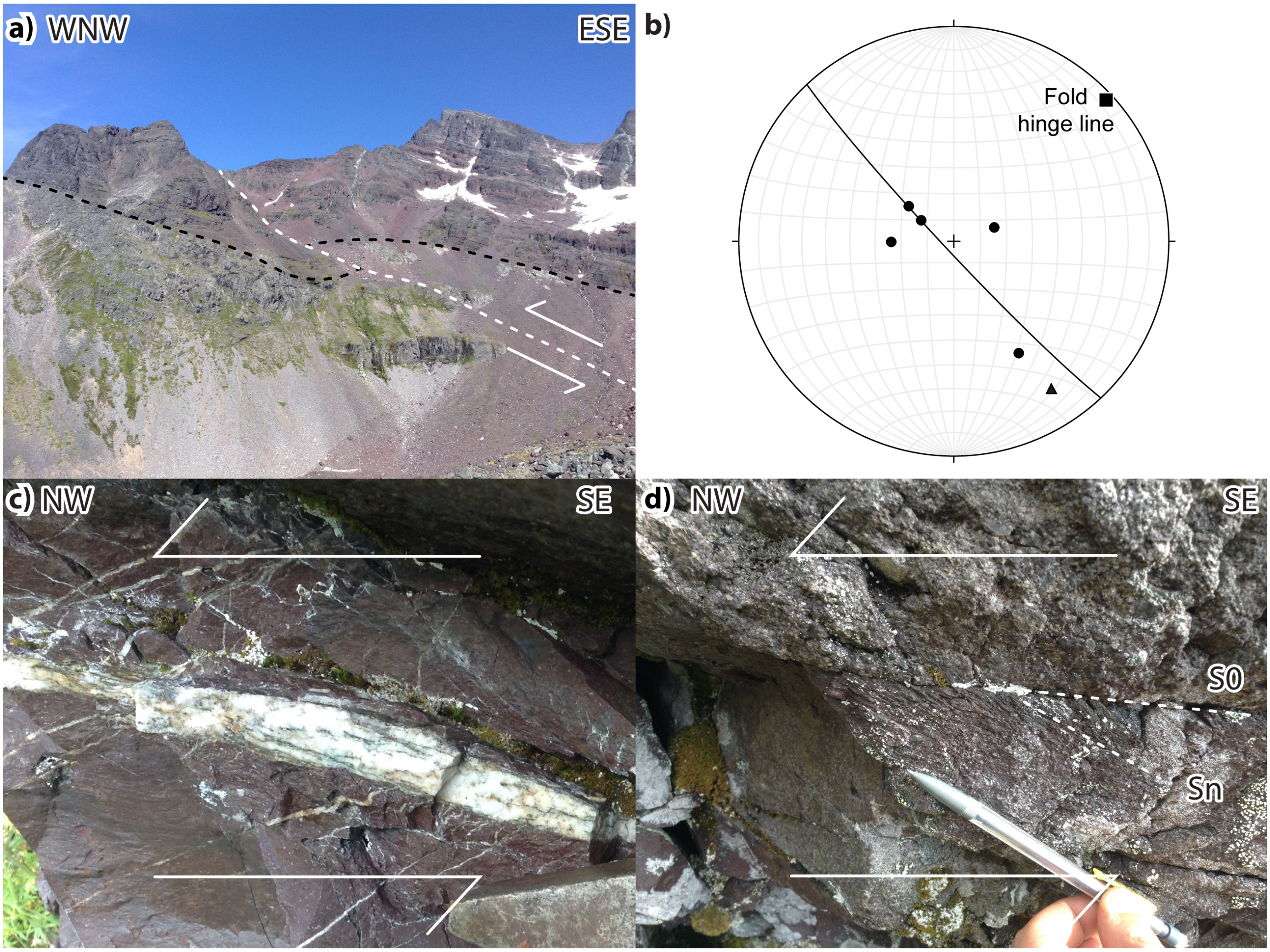


Fig. 11. Structural features in the Tatsi map area. **a)** Northwest-vergent thrust fault with minor fold. Dashed white line indicates trace of thrust. Black dashed lines indicate contact between pale purple marker crystal tuff and well bedded red tuffs. **b)** Lower hemisphere, equal area stereonet projection of structural elements in the Tatsi map area. Black circles are poles to bedding. Black Triangle is a slickenline on the surface of the mineralized vein in Figure 10c. The fold hinge line was calculated using eigenvalues of poles to bedding. The solid black line represents best-fit great circle of bedding. **c)** A south-southeast dipping mineralized vein that crosscuts weakly folded northwest dipping veinlets, interpreted sense of shear is top to the north-northwest. **d)** Weak south-southeast dipping foliation developed in fine red tuff indicating north-northwest vergence.

the southeast dipping veins. Individual veins within the sets that dip variably to the northwest; minor folds are consistent with top-to-the-northwest sense of shear (Fig. 11c). Cleavage in one fine ash tuff is oblique to bedding, dipping shallowly to the southeast, consistent with northwest vergence (Fig. 11d).

A northwest-striking, steeply west dipping fault juxtaposes andesite lapilli tuff in the lower part of the lower Telkwa Formation to the west against fine-grained red tuffs in the upper part of the Telkwa Formation to the east (Fig. 4). Near the fault, flattened lapilli in the Telkwa Formation andesitic tuffs define a moderate foliation. A quartz monzonite dike, interpreted to belong to the Topley intrusive suite, crosscuts foliation and is crosscut by several shallowly south dipping veinlets. A locally prominent set of steeply dipping joints follow the same northerly trend as the fault.

5. Discussion

The stratigraphic descriptions outlined herein support previous interpretations indicating that the Skeena arch became a northeast-trending topographic highland between Middle Jurassic and Early Cretaceous. Laterally continuous tuff beds in the Telkwa Formation in the Howson Range contrast with the high-standing volcanic edifices farther west (Barresi et al., 2015). The Telkwa Formation in the Howson Range represents the fringes of these stratovolcanoes, transitional to submarine deposition represented by the Babine shelf and Kotsine marine facies farther east (Tipper and Richards, 1976a). Submarine conditions persisted in the Middle Jurassic across most of Stikinia, extending as far south as Telkwa Pass in the Skeena arch region. The transition from the Hazelton Group to the Bowser Lake Group is gradational, marked by the upwards disappearance of distinctive tuff beds within an otherwise continuous submarine sequence (Evenchick et al., 2010; Gagnon et al., 2012). The Skeena arch underwent uplift from the Middle Jurassic to Early Cretaceous, as recorded by the transition from relatively deep-water sedimentation in the lower part of Bowser Lake Group to predominantly fluvial deposition in the lower part of the Skeena Group at Zymo ridge (Bulkley Canyon Formation). Tipper and Richards (1976a) interpreted that the Skeena arch was a sediment source for parts of the Bowser Lake Group. We interpret that the volcanic and plutonic clasts in polymictic conglomerates of the Bulkley Canyon Formation at Zymo ridge were derived locally, from the uplifted Skeena arch. Why the Skeena arch was uplifted along a northeasterly trend between the Middle Jurassic and Early Cretaceous, in contrast to the northwest trending arc axis indicated by Early Jurassic facies belts, is unknown.

The northeasterly orientation of the Skeena arch is reflected by the trend of folds and plutonic suites in it. Northeast-trending (northwest- and southeast-vergent) fold and thrust deformation is Early Cretaceous or younger because it affected the Skeena Group. Northwest-southeast shortening could have contributed to uplift of the Skeena arch. However, stratigraphic arguments indicate that the arch became a topographic high before the Early Cretaceous. This suggests that uplift of the Skeena arch was a protracted process, with later stages recorded by folds in sedimentary rocks derived from the arch. We speculate that these northeast-trending folds reflect the orientation of a deep crustal structure when considered in conjunction with other parallel features. Structures of this orientation may have been under extension during the Late Triassic to Early Jurassic, contributing to the emplacement of the Topley and Kleanza intrusive suites (Nelson, 2017). It is possible that they were inverted during the Late Jurassic to Early Cretaceous, leading to uplift of the Skeena arch and northeast trending folds in it. This geometry would be compatible with the sinistral transpressional regime interpreted to be responsible for northeast trending folds in the Skeena fold and thrust belt (Evenchick, 2001). The same deep crustal structure (or structures) is interpreted to have remained as a magma conduit into the Late Cretaceous and Eocene, leading to the widespread porphyry and related mineralization across the Skeena arch.

6. Conclusion

The Skeena arch is interpreted to reflect a fundamental, long-lived structural anisotropy in Stikine terrane. This anisotropy must have originated during the Triassic or earlier because it accommodated emplacement of Late Triassic to Early Jurassic magma. It was reactivated during inferred Early Cretaceous development of northeast-trending thrusts and folds. We speculate that uplift of the Skeena arch between the Middle Jurassic and Early Cretaceous is an early manifestation of strain that led to fold and thrust deformation. The structural anisotropy also played a role in localizing emplacement of Late Cretaceous and Eocene intrusive suites and mineralization, similar to other examples of arc transverse structures worldwide.

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