Geology of the Takhanne River (NTS 115A/2) and Kluhini River (115A/7) map areas, southwest Yukon

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ABSTRACT

Bedrock mapping of the Takhanne River (NTS 115A/2) and Kluhini River (NTS 115A/7) map areas in southwest Yukon extends previous mapping of the Coast plutonic complex from the Haines Junction area south to the British Columbia border. The area is characterized by deformed and metamorphosed rocks of the Yukon-Tanana terrane and other Paleozoic to Mesozoic rocks that occur as roof pendants within the Paleocene Ruby Range plutonic suite. Yukon-Tanana rocks appear to be thrust over the Paleozoic to Mesozoic rocks to the west, possibly during Late Cretaceous shortening. Metamorphic mineral assemblages indicate a southwest decrease in metamorphic grade with rocks of the Yukon-Tanana terrane showing P-T conditions of 635-655°C and 6.3-7.9 kbar and rocks in the southernmost part of the study area exhibiting relatively low (~3.5-4 kbar) pressures related to intrusion of the Ruby Range suite. The regional stratigraphic relationships of the Paleozoic to Mesozoic rocks in the study area are not well constrained. They may be related to one of three regionally significant units: 1) the Jura-Cretaceous Dezadeash Formation; 2) the Triassic and older Bear Creek assemblage; or 3) the Kluane schist.

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INTRODUCTION

Bedrock mapping in southwest Yukon during the summer of 2014 covered areas southeast of Haines Junction, east and southeast of Dezadeash Lake, to the British Columbia border (NTS 115A/2 and 7; Figs. 1 and 2). Previous regional bedrock mapping of this area, between 1946 and 1950 by Kindle (1952), provided a broad geological framework for the relationships between Paleozoic to Cenozoic metamorphic and plutonic rocks. This report extends detailed 1:50 000-scale bedrock mapping initiated in 2011 to the north of the present study area (Israel *et al.*, 2011; Israel and Westberg, 2011; Israel and Westberg, 2012; Israel and Kim, 2014). More specifically, the current study continues 1:50 000-scale bedrock mapping initiated in the Granite Lake area to the north (Israel and Kim, 2013, 2014), and further investigates the nature and extent of lithostratigraphic successions defined in that region in an effort to clarify the genetic and structural relationships between Paleozoic metamorphic assemblages, and younger (Mesozoic to Cenozoic) overlap assemblages and intrusive rocks. The purpose of this project is to determine geologic relationships between the diverse lithotectonic elements and to increase understanding of the overall tectonic and metallogenic evolution of southwest Yukon.

Exposure in the area is excellent along high peaks and ridges and very poor in the wide bush-covered valleys. Access relies primarily on helicopter, although a number of bedrock outcrops are found along, and close to, the Haines Road, south of Dezadeash Lake (Fig. 1).

REGIONAL GEOLOGY

The bedrock geology of southwest Yukon is characterized by the juxtaposition of Neoproterozoic to Mesozoic terranes, parallel to the main northwest-trending Cordilleran structural grain. The terranes are from west to east: Alexander, Wrangellia, Yukon-Tanana and Stikinia (Fig. 1).

The Alexander terrane and Wrangellia, which together form the Insular terranes, were accreted to the western margin of the Intermontane terranes (Yukon-Tanana and Stikinia in southwest Yukon) during the Middle Jurassic or possibly earlier (McClelland *et al.*, 1992; van der Heyden, 1992; Nelson *et al.*, 2013). In southwest Yukon, the Insular terranes are juxtaposed against the Intermontane terranes along the Denali fault; a large, crustal-scale, dextral strike-slip fault with an offset of as much as 400 km that occurred during the latest Cretaceous (?) through the Cenozoic.

Two assemblages of metamorphosed sedimentary and volcanic rocks occur between the Insular and Intermontane terranes (Fig. 1). The Kluane schist, which structurally underlies the Yukon-Tanana terrane, is a sequence of quartz-biotite schist that is interpreted to represent one of several Jura-Cretaceous basins that formed at the boundary between the Intermontane and Insular terranes (Israel *et al.*, 2011; Nelson *et al.*, 2013). The Shakwak fault, an inferred structural feature of unknown kinematics, separates the Kluane schist from the Bear Creek assemblage to the southwest (Fig. 1). The Bear Creek assemblage is characterized by strongly deformed and metamorphosed intermediate to mafic volcanic flows and volcaniclastic rocks interlayered with meta-siltstone, mudstone and sandstone (Israel *et al.*, 2014). The age of the Bear Creek assemblage is Late Triassic and older but its relationships within the regional stratigraphic framework is not known.

The Jura-Cretaceous turbiditic deposits of the Dezadeash Formation overly Wrangellia, the Alexander terrane and rocks assigned to the Bear Creek assemblage (Fig. 1). The Dezadeash Formation is part of several Jura-Cretaceous basins that occur along the boundary of the Insular and Intermontane terranes, including the Nutzotin (in eastern Alaska) and Gravina basins (in southeast Alaska). In southwest Yukon, rocks of the Dezadeash Formation are strongly deformed by at least two phases of folding, and metamorphosed to lower greenschist facies (Eisbacher, 1976).

The Paleocene Ruby Range batholith intrudes across the structural boundary between the Kluane schist and Yukon-Tanana terrane. The Ruby Range suite occurs as a northwest-trending batholith of felsic to intermediate composition, extending to the southeast into northern British Columbia, and cut off by the Denali fault at its northwest end (Fig. 1). The base of the batholith is foliated, grading upward into massive, undeformed intrusive rock (Israel *et al.*, 2011). The Ruby Range batholith ranges from ~64 to ~57 Ma (Israel *et al.*, 2011; Israel and Westberg, 2012).

LITHOLOGY

The Ruby Range batholith intrudes Yukon-Tanana schist, gneiss and a poorly defined succession of Paleozoic to Mesozoic metasedimentary rocks. All of these rocks are separated from the Dezadeash Formation and rocks of Wrangellia by the Tatshenshini fault in Yukon and the Denali fault in northwestern British Columbia (Fig. 2).

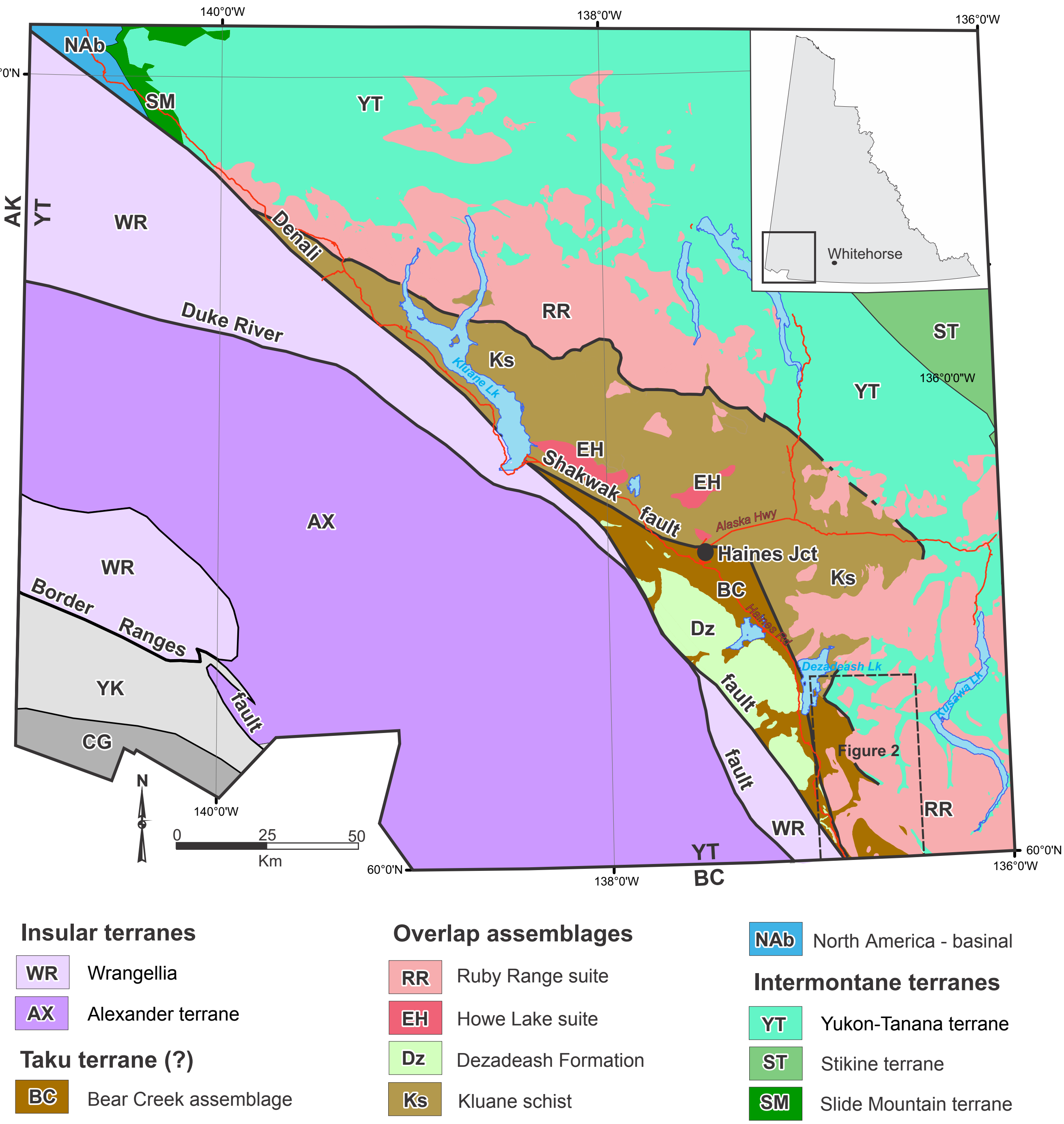
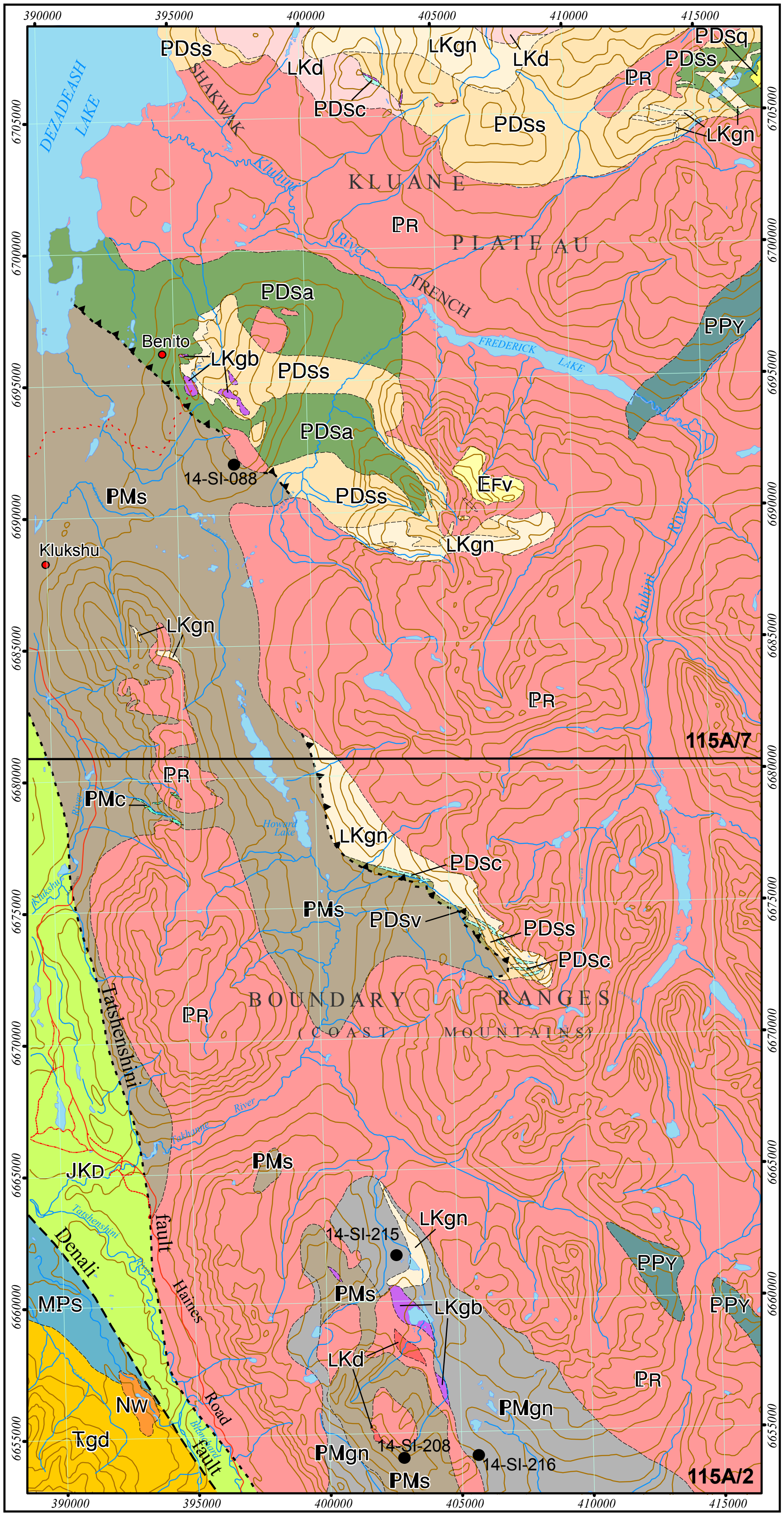
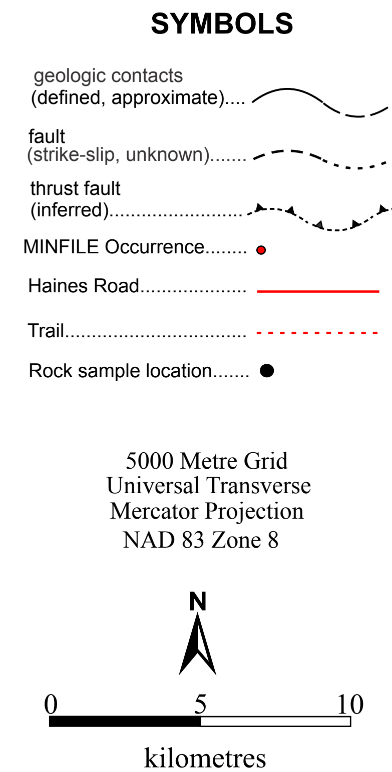


Figure 1. *Terrane map of southwest Yukon (modified after Nelson et al., 2013). Inset map shows location with respect to the rest of Yukon. Location of the study area (Fig. 2) is shown by dashed line box. AK-Alaska, YT-Yukon Territory, BC-British Columbia.*





MINFILE		
Number	Name	Deposit Type
115A022	Klukshu	VMS
115A023	Benito	unknown

Figure 2. *Preliminary bedrock geology map of the Takhanne River (NTS 115A/2) and Kluhini River (NTS 115A/7) map areas. Legend is on opposite page.*

LEGEND

OVERLAP ASSEMBLAGES

NEOGENE

WRANGELL VOLCANIC ROCKS:

Nw basaltic-andesitic, andesitic and dacitic lava flows; dacite and rhyolite domes; minor silicic pyroclastic deposits;

EOCENE (?)

FREDERICK LAKE VOLCANIC COMPLEX:

EFv coherent flow-banded andesitic to dacitic lavas and subvolcanic intrusions; silicic tuff and lapilli

PALEOCENE

RUBY RANGE BATHOLITH (ca. 64-57 Ma):

PR medium to coarse-grained, equigranular, light grey to white biotite +/- hornblende granodiorite; fine to coarse-grained, salt and pepper hornblende +/- biotite quartz diorite; biotite, muscovite K-feldspar pegmatite dikes; in part coeval with Rhyolite Creek volcanoplutonic complex

LATE CRETACEOUS (?)

LKgb coarse-grained, dark brown-black, hornblende +/- biotite, plagioclase, pyroxene, grabbro dikes and stocks

LKd fine to coarse-grained hornblende diorite to tonalite with abundant garnets; locally grading into garnet amphibolite

LKgn medium to coarse-grained, mylonitic to weakly deformed, biotite, quartz +/- garnet orthogneiss; dark grey weathered, dark and light grey banded fresh; commonly interlayered with biotite schist or amphibolite of Snowcap assemblage; inferred Late Cretaceous in age, but could be as old as Permian

LATE JURASSIC TO EARLY CRETACEOUS

DEZADEASH FORMATION:

JKD interbedded light to dark buff-grey lithic greywacke, sandstone, siltstone, thin dark grey shale, argillite and conglomerate; mass-flow conglomerate; rare light grey tuff

TRIASSIC

MOUNT BEATON BATHOLITH (ca. 217 Ma):

Tgd medium to coarse-grained, unfoliated, hornblende diorite to hornblende, biotite, quartz diorite; salt and pepper appearance; locally abundant dark grey fine-grained gabbro; may in part be equivalent to Early Cretaceous Kluane Ranges Suite

TAKU TERRANE (?)

PALEOZOIC TO MESOZOIC

PMc white to beige weathered limestone and marble; strongly deformed; light to dark grey bands found throughout; structurally and stratigraphically interleaved with **PMs**

PMs fine to medium-grained, garnet-biotite schist and metasedimentary rocks; brown to rusty weathered, dark grey fresh; layers variably richer in quartz or biotite

PMgn medium- to coarse-grained, orange weathered, dark grey to black, biotite-quartz-feldspar +/- kyanite-sillimanite paragneiss; fine-grained, banded grey to dark grey metasedimentary rocks

WRANGELLIA

MISSISSIPPIAN-CARBONIFEROUS

STATION CREEK FORMATION:

MPs basalt flows and breccia; volcaniclastic siltstone and sandstone; crystal tuff and chert

YUKON-TANANA TERRANE

PROTEROZOIC TO PERMIAN

PPY Undivided Yukon Tanana terrane rocks; intensely deformed schist, orthogneiss, and calc-silicates rocks; greenschist to amphibolite facies

PROTEROZOIC TO DEVONIAN

SNOWCAP ASSEMBLAGE:

PDsq medium-grained, sugary, massive to banded and strongly folded light grey weathered quartzite; felsic metavolcanic rocks and biotite psammitic schist

PDsv brown-rusty weathered, dark grey metavolcanic sandstone and conglomerate; dark grey-green garnet-biotite metabasalt; fine-grained dark grey metasedimentary rocks; interlayered with marble of the Snowcap assemblage

PDsc fine to medium-grained, grey-cream weathered, light grey to white marble occurring as lenses and thick layers (up to several metres wide) within schist, orthogneiss, metavolcanic or metasedimentary rocks; locally associated with ultramafic rock lenses; internally strongly deformed

PDsa medium-grained, dark and light grey banded amphibolite gneiss with abundant garnets; fine-grained dark green to black garnet amphibolite schist; fine- to medium-grained, rusty-brown weathered, dark green massive metabasalt

PDss fine to medium-grained, light to dark grey and brown weathered biotite, muscovite, quartz, garnet schist; locally abundant aluminosilicates (sillimanite, +/- kyanite); locally migmatitic

YUKON-TANANA TERRANE (PPY)

The Yukon-Tanana terrane occurs as isolated remnants of a Neoproterozoic (?) to Paleozoic continental margin assemblage intruded by Mesozoic to Cenozoic intrusive rocks of the Ruby Range batholith. Yukon-Tanana rocks immediately north of the present study area are thrust over the Kluane schist (Israel *et al.*, 2011). Rocks assigned to the Yukon-Tanana terrane consist dominantly of schist, orthogneiss, and calc-silicates. Metamorphic mineral assemblages indicate that Yukon-Tanana rocks range from upper greenschist to amphibolite facies. They are intensely deformed, with tight centimetre-scale microfolds indicating a dominant S to SSW vergence of larger-scale folds. Internally, mappable units are complexly deformed, showing evidence for multiple phases of deformation. Based mainly on lithologic composition and texture, rocks of the Yukon-Tanana terrane in southwest Yukon are interpreted to be part of the Neoproterozoic to Devonian Snowcap assemblage, the oldest part of the Yukon-Tanana terrane (Colpron *et al.*, 2006). The Snowcap assemblage in southwest Yukon comprises five main mappable units.

Snowcap Assemblage

Biotite-muscovite schist (PDss)

The rocks considered to be the lowest structural level of the Yukon-Tanana terrane in the study area are characterized by a thick, extensive package of pale to dark brown-rusty weathered, fine to medium-grained, garnet-biotite-muscovite-quartz schist (Fig. 3a). The schist outcrops mainly in the northern and central part of the study area (Fig. 2). Thickness of this unit is not known as its lower contact is inferred to be a fault, and the upper contact with the overlying amphibolite is not exposed. The amount of biotite varies throughout the unit, sometimes dominating the rock with few other minerals other than quartz. Garnet, kyanite ± sillimanite are locally abundant. The texture and mineralogy of the schist sometimes makes it difficult to distinguish it from the granodiorite orthogneiss that intrudes into, and is structurally interleaved with it. The age of this unit is not known but it is likely pre-Carboniferous based upon its assignment to the Snowcap assemblage.

Metabasalt/Amphibolite (PDsa)

This unit comprises amphibolite schist to gneiss, and massive greenstone. It outcrops extensively in the central part of NTS 115A/7 where it is structurally interleaved and infolded with the underlying schist of unit PDss (Fig. 2). The unit occurs mainly as dark grey to black, coarse to fine-grained amphibolite composed of hornblende, plagioclase, biotite and variable amounts of garnet (Fig. 3b). Amphibolite gneiss locally displays fine black and white banding where segregation of leucocratic feldspar and quartz layers occurs. Exposures of massive greenstone occur within the more typically gneissic rocks where locally the greenstone is rusty brown weathered, displaying what may be primary vesicles. Orthogneiss (likely LKgn) is commonly interlayered with amphibolite gneiss, as observed in the northeastern part of the map area (Fig. 2).

The protolith of the greenstone is likely a mafic volcanic rock, while the amphibolite gneiss could be mafic intrusions. The close spatial relationship between the greenstone and gneiss may suggest the gneiss is closely related to greenstone, possibly being subvolcanic intrusions. As with the underlying schist, the age of the amphibolite unit is not constrained but is likely pre-Carboniferous.

Quartzite (PDsq)

A unit of light grey to pinkish weathered quartzite interlayered with possible felsic metavolcanic rocks is exposed in the northeasternmost part of the study area (Fig. 2). The quartzite is typically thinly banded and displays a sugary texture. The light and dark bands within the quartzite are excellent at displaying the strongly folded nature of the unit (Fig. 3c). Exposure of this unit is not extensive within the mapped area, but where present the quartzite appears to be overlying the amphibolite unit. The thickness of the quartzite in the study area is unknown from present data but must be at least several tens of metres based upon outcrops visited during this study and previous years (Israel and Kim, 2013).

Metavolcanic/metavolcaniclastic rocks (PDsv)

A sequence of metavolcanic and metavolcaniclastic rocks is found spatially associated with the marble of unit PDsc (Fig. 3d). The lower contact of the metavolcanic unit is not exposed and it is difficult to determine its relationship with underlying units. PDsv comprises brown, rusty weathered, dark grey metavolcanic sandstone, conglomerate and dark grey-green garnet-biotite-metabasalt. It is distinct from other metabasalt/amphibolite (*e.g.*, PDsa) assemblages based on lithology, texture, and stratigraphic associations. PDsv is found at the base of, and interlayered with, overlying marble (PDsc) in the central part of the study area, southeast of Howard Lake (Fig. 2). Thin, brown weathered quartzite bands are interlayered with the metavolcanic rocks near the marble. The thickness of this unit is about 20 m, but it is likely structurally thickened. The age of the unit is not known, it has been assigned to the Snowcap assemblage and therefore by definition likely pre-Carboniferous in age; however, it is possible the unit might be the lowest member of the Finlayson assemblage, a Devonian to Mississippian package of metavolcanic and metasedimentary rocks within the Yukon-Tanana terrane.

Marble (PDsc)

Marble is best preserved in the central part of the study area, where relatively continuous northeast dipping beds can be followed for hundreds of metres, interlayered with thicker sections of schist (PDss), orthogneiss (LKgn), and metavolcanic rocks (PDsv). The marble is typically grey-cream weathered, pale to medium grey, thinly to thickly layered, and locally interbedded with 20 to 30 cm-thick dark brown-rusty weathered layers of quartzite (Fig. 3e). Interlayered with pure marble are coarser grained, more silica-rich layers suggestive of calcareous

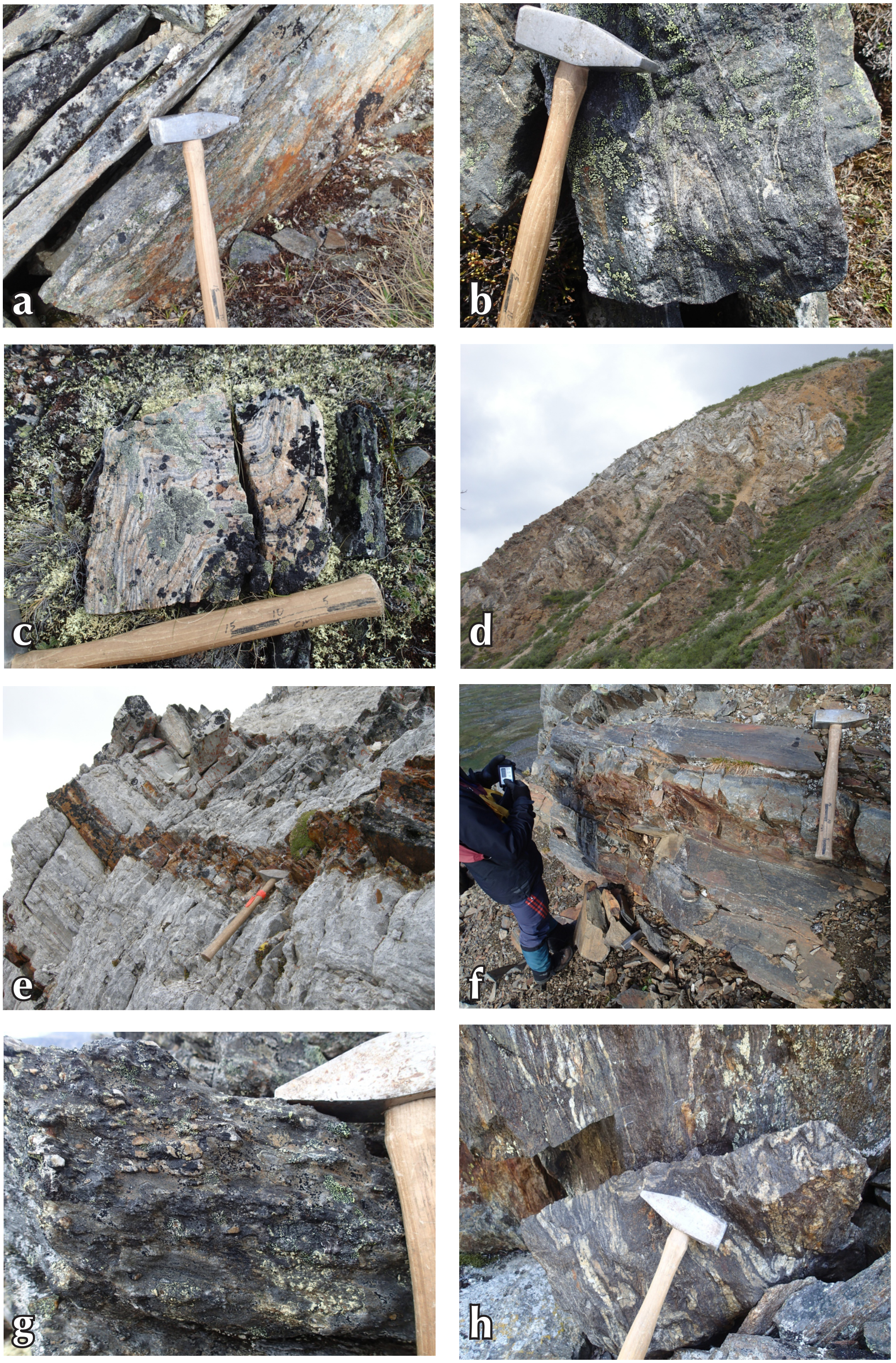


Figure 3. *(a) Garnet-muscovite-biotite-quartz schist of the lower Snowcap assemblage, unit* PDss*; (b) strongly deformed amphibolite gneiss of unit* PDsa*; (c) banded, light grey to pinkish quartzite of unit* PDsq*; (d) interlayered volcanic, volcaniclastic, and carbonate rocks of the upper Snowcap assemblage, unit* PDsv *and* PDsc*; (e) marble with thin interbed of orange/brown weathered quartzite in the upper Snowcap assemblage; (f) primary bedding within Paleozoic to Mesozoic (*PMs*) metamorphosed siltstone/sandstone turbidites; (g) quartzite clasts within meta-conglomerate of unit* PMs*; (h) paleozoic to Mesozoic migmatitic paragneiss of unit* PMgn.

sandstone to calcareous mudstone protoliths. The thickness of individual marble sections can be up to 50 m; however field associations and successive interlayering of marble with metavolcaniclastic or metabasaltic rocks suggest the existence of a several hundred metres-thick composite sequence, likely resulting from structural thickening. Marble is internally strongly deformed, with tight, isoclinal folds and interference patterns indicating several phases of deformation.

PALEOZOIC TO MESOZOIC METAMORPHIC ROCKS

A package of metasedimentary and paragneissic rocks occupy much of the central part of the map area (Fig. 2). These rocks are different enough from those of the Yukon-Tanana terrane that they have been mapped as separate stratigraphic entities. They are interpreted to structurally underlie the Yukon-Tanana terrane; however their age and stratigraphic affinity remains unknown.

Metasedimentary rocks (PMs)

Garnet-biotite ± staurolite ± kyanite-bearing metasedimentary rocks cover a large portion of the western and southern part of the study area. They are dominantly composed of fine to medium-grained meta-sandstone, siltstone and mudstone (Fig. 3f). Primary stratigraphic layering is well-preserved, as are sedimentary structures such as graded beds and cross-bedding. Biotite-rich layers can take on a schistose appearance and a through going foliation is found in all rock types. Rare beds of meta-conglomerate are found within the metasedimentary succession, commonly several metres in thickness (Fig. 3g). Clasts within the meta-conglomerate are exclusively quartzite, between one and five centimetres in diameter. Together, the metasedimentary succession appears to represent a turbidite sequence. The thickness of the unit is not well-constrained but is probably at least several hundred metres. Locally preserved carbonate layers are found in the west-central part of the map area (unit PMc). These are discontinuous bands of white to beige marble up to several tens of metres thick. They are interleaved with metasedimentary rocks of PMs and often form large pods. The age of these rocks is unknown.

Paragneiss (PMgn)

A distinct succession of garnet-sillimanite ± andalusite-bearing rocks is mapped in the southernmost part of the study area, and extends south of the Yukon-BC border. The unit comprises orange weathered dark grey to black, biotite-quartz-feldspar paragneiss, as well as finer grained, banded grey to dark grey metasedimentary rocks containing variable amounts of biotite. Locally the rock is migmatitic with leucosomes parallel to and crosscutting foliation (Fig. 3h). The paragneiss appears to pass gradationally up into the overlying metasedimentary unit described above. Intrusive contacts exist between this succession and the undeformed to weakly foliated granodiorite and hornblende-diorite of the Ruby Range suite and Late Cretaceous gabbroic intrusions.

DEZADEASH FORMATION (JKD)

The Dezadeash Formation is composed of meta-sandstone, siltstone and mudstone, interpreted to be a thick turbidite succession (~3000 m; Eisbacher, 1976). Its age is constrained by Oxfordian to Valanginian fossil collections (Late Jurassic to Early Cretaceous; Eisbacher, 1976). The Dezadeash Formation extends east of the Denali fault from Haines Junction southward to northern British Columbia. It is exposed in the southwest corner of the map area where it is separated from the Yukon-Tanana terrane and other metamorphic rocks to the east by the Tatshenshini fault (Fig. 2; Lowey, 2000), an enigmatic structure with undefined kinematics and timing. To the west the Dezadeash Formation is juxtaposed to Paleozoic and Mesozoic rocks of Wrangellia across the Denali fault (Fig. 2). Near Million Dollar falls, rocks of the Dezadeash Formation are strongly deformed and metamorphosed and appear similar to rocks of PMs (Fig. 4a).

IGNEOUS ROCKS

Intrusive rocks occupy up to 80% of the map area (Fig. 2). The majority of these belong to the late to post-kinematic quartz-diorite, hornblende-diorite and granodiorite of the Paleocene Ruby Range batholith. Other intrusive phases, including strongly foliated to gneissic granodiorite, tonalite, diorite and gabbro, are likely Late Cretaceous and occur throughout the area. A volcanic complex of probable Eocene age (?) is reported for the first time south of Frederick Lake.

Late Cretaceous intrusive rocks (LKgn, LKgb, LKd)

Dark grey weathered, medium to coarse-grained, dark and light grey banded orthogneiss (LKgn) of granodioritic composition occurs throughout the map area (Figs. 2, 4b). The gneiss is often associated with unit PDss, but is also found interlayered with amphibolite and metabasalt (PDsa). Common minerals include plagioclase, biotite, quartz, hornblende and variable amounts of garnet. The orthogneiss shows variable degrees of internal deformation, from mylonitic fabric to areas of more massive igneous textures. The age of the orthogneiss within the mapped area is not known, however similar rocks along strike to the north are Late Cretaceous (~75 Ma; J.L. Crowley, *pers. comm.*, 2014).

Medium to coarse-grained hornblende-biotite-garnet diorite to tonalite intrusions (LKd) are mapped in the southernmost and northernmost parts of the study area (Fig. 2). The bodies in the south appear to grade locally into garnet hornblendite and massive, hornblende ± biotite diorite. The unit overall is strongly foliated to massive. Garnet within the intrusions range in size from ~2 mm up to 2 cm (Fig. 4c). Similar garnet-bearing, foliated to massive, diorite to gabbro plutons were mapped in the Granite Lake area, just north of the present map area (Israel and Kim, 2013). One such body extends south into the north-central part of NTS 115A/07, where it intrudes schist of the Yukon-Tanana terrane and probable Late Cretaceous orthogneiss (Fig. 2). Rocks of unit LKd are intruded by granodiorite of the Ruby Range suite. The age of garnet-bearing diorite is not well constrained, but is likely Late Cretaceous, similar to unit LKgn.

Gabbroic dikes and larger intrusive bodies occur throughout the study area (LKgb). They intrude metamorphosed country rock and commonly have brown to black weathered surfaces and dark greyish green fresh surfaces (Fig. 4d). Most are coarse grained, dominantly composed of hornblende ± pyroxene and plagioclase. Secondary mineral phases include biotite, epidote and chlorite. All gabbro bodies observed are undeformed. The relationships between the gabbro and other intrusive rock types are not clear, except that they are intruded by undeformed granodiorite of the Ruby Range suite, likely making the gabbro Late Cretaceous in age.

Ruby Range Suite (PR)

The dominant intrusive phase in the study area belongs to the Ruby Range suite, comprising grey-beige-rusty weathered, white to grey, medium to coarsely crystalline, biotite-bearing granodiorite. It is generally undeformed, but locally grades into weakly to moderately foliated granodiorite. Composition of the Ruby Range suite changes somewhat towards the south, where hornblende-biotite-phyric quartz diorite to granodiorite dominates. Exposures here are white to pale grey, coarsely crystalline and contain plagioclase, hornblende and biotite, and varying amounts of quartz. Flattened, elongated xenoliths of darker, biotite and hornblende-rich rock are commonly aligned parallel to foliation (Fig. 4e). Several pegmatite dikes commonly crosscut other igneous phases of the Ruby Range batholith. They are very coarse grained, and contain quartz, plagioclase, K-feldspar, biotite and muscovite. Pegmatite dikes range from 20-30 cm to several metres-wide and are likely the last phases of Ruby Range-related magmatism.

The Ruby Range suite intrudes all other rocks types in the field area except the volcanics discussed below. Ages for the Ruby Range suite north of the present study area are Paleocene and range from 61 Ma to 55 Ma (Israel and Westberg, 2012).

Frederick Lake volcanic complex (EFv)

Volcanic rocks covering an area of approximately 2 km by 2 km south of Frederick Lake (Fig. 2) are not identified on previous maps (Kindle, 1952). They comprise a range of coherent and fragmental volcanic units of intermediate to felsic compositions. Dacitic to andesitic breccia and flow-banded layers composed of plagioclase and quartz phenocrysts in a light to dark grey fine-grained, aphanitic groundmass are either volcanic flows or subvolcanic intrusions (Fig. 4f). Orange weathered, pale grey-green, very fine grained rhyodacite represents the most felsic coherent phase and contains minor pyrite. Finally, flow-banded rhyolitic ash tuff, crystal lapilli tuff and breccia were mapped. These coherent flows and subvolcanic intrusions, as well as volcaniclastic facies (breccia, tuff and lapilli), are interpreted as part of a large volcanic complex. Only the southern and western contacts of this complex are defined where volcanic rocks overlie undeformed granodiorite of the Ruby Range batholith. Several U/Pb samples were collected to assess age relationship with the surrounding intrusive rocks, but it is inferred from field relationships that the volcanic rocks may be Paleocene in age.

STRUCTURE AND METAMORPHISM

The dominant foliation within the schist and gneiss strikes northwest and dips moderately to steeply towards the northeast. This foliation is folded by tight to isoclinal, upright to overturned folds (Fig. 5a) that generally trend northwest and southeast. These folds are deformed by a later phase of tight folds that plunge towards the northeast. Northwest-trending folds may be related to an inferred thrust fault that places rocks of the Yukon-Tanana terrane over unit PMs in the central part of NTS 115A/7 (Fig. 2).

Figure 4. *(a) Strongly deformed and metamorphosed Jura-Cretaceous turbidites of the Dezadeash Formation near Million Dollar falls; (b) isoclinally folded Late Cretaceous orthogneiss; (c) garnet-rich hornblende diorite found in the southern part of the study area; (d) dark grey to orange weathered, hornblende±pyroxene gabbro of probable Late Cretaceous age; (e) large mafic xenolith within quartz diorite of the Paleocene Ruby Range suite; (f) slightly flow banded, beige to brown weathered rhyodacite of the Frederick Lake volcanic complex.*

Folds near this fault have sheared upper limbs suggesting tops towards the southwest motion (Fig. 5b). Moderately northeast-dipping shear zones found throughout the area outline high-strain areas that underwent at least some apparent dextral translation (Fig. 5c). True kinematics of these shear zones is not well constrained as no good lineation was observed at these localities. The timing of motion across these shear zones is unknown.

Metamorphic grade in the area generally decreases from northeast to southwest. Kyanite and garnet are abundant within Yukon-Tanana schist in the northern part of the map area (Fig. 5d). Metapelitic rocks in the footwall of the thrust fault separating the Yukon-Tanana terrane from unit **PMs** contain garnet, kyanite, staurolite as well as biotite, muscovite and quartz (Fig. 6a; Sample 14-SI-088 on Fig. 2). This mineral assemblage indicates middle amphibolite facies metamorphism and intermediate pressure conditions. A preliminary phase diagram for this rock indicates stability of the mineral assemblage Ky-St-Grt-Bt-Ms-Ilm over the P-T interval of 635-650°C and 6.3-6.7 kbars (Fig. 7). Staurolite and kyanite are generally aligned with main through going fabric (defined by biotite and muscovite) with some curved inclusion trails observed within staurolite suggesting a pre to syn-porphyroblast development of the foliation (Fig. 6a,b).

In contrast rocks found farther south and southwest exhibit metamorphic assemblages indicative of much lower pressures. The metasedimentary rocks of unit **PMs** in the far south of the map area have the mineral assemblage biotite, cordierite, plagioclase, quartz, staurolite, sillimanite and minor phases including graphite (Fig. 5e; Sample 14-SI-208 on Fig. 2). Staurolite is wrapped by the main foliation and partially replaced by relatively inclusion-free cordierite (Fig. 6c). Cordierite also forms single porphyroblasts that grow across the main foliation. A sample of the paragneiss found northeast and topographically lower than 14-SI-208 has the mineral assemblage biotite, quartz, plagioclase, cordierite, sillimanite, muscovite and minor phases (Sample 14-SI-215 on Fig. 2). The rock has prominent ellipsoidal white nodules that are typically 2-7 mm in length, are flattened and define a lineation. They are composed of cordierite, which encases sillimanite (Fig. 6d). The sillimanite-cordierite nodules may represent the location of pseudomorphed porphyroblasts, possibly of staurolite (?). The strained nature of the cordierite suggests it experienced some deformation, possibly syn-intrusive. A final sample of the paragneiss from the southernmost part of the map area has a similar mineral assemblage to the previous two samples but has abundant andalusite (Fig. 5f). Porphyroblasts of andalusite and lesser staurolite are partially replaced by cordierite, which forms moats around their embayed margins (Fig. 6e). Cordierite found both within the matrix and as primary porphyroblasts is rich in graphite. Andalusite and staurolite are partially replaced by sillimanite as small crystals within microboudins and as long needles across pseudomorphs (Fig. 6e,f). Both andalusite and staurolite are wrapped by the matrix foliation whereas replacing and matrix cordierite is not. The early porphyroblast assemblage (St+And) typically forms at ~3.5-4 kbar. The late cordierite is also indicative of low pressures. A sequence involving early St+And followed by Sil+Crd is compatible with a single intrusion-related period of heating, with waning deformation.

DISCUSSION

The Takhanne River and Kluhini River map areas are characterized by roof pendants of metamorphosed siliciclastic, volcanic and carbonate rocks of the Yukon-Tanana terrane and other Paleozoic to Mesozoic units. Paleocene granodiorite enclose these pendants along with probable Late Cretaceous foliated to gneissic intermediate intrusive rocks.

Quartz-muscovite schist, amphibolite, minor marble and quartzite assigned to the Yukon-Tanana terrane are likely part of the Snowcap assemblage and possibly the Finlayson and Klinkit assemblages of the younger parts of the terrane, deformed and metamorphosed multiple times. Similar rocks are found along strike to the north of the present map area, where they are thrust over rocks of the Kluane schist (Israel and Kim, 2014). In the present map area, the Yukon-Tanana terrane is inferred to be thrust over metasedimentary Paleozoic to Mesozoic rocks. These Paleozoic to Mesozoic rocks (unit **PMs**) bear some resemblance to the Dezadeash Formation, as both units are interpreted as turbidite sequences mostly composed of sandstone, siltstone and mudstone. Correlation of unit **PMs** with the Dezadeash Formation would suggests a direct structural contact with rocks of the Yukon-Tanana terrane. Alternatively, Paleozoic to Mesozoic schist and gneiss of unit **PMs** could be part of either the Kluane schist or the Bear Creek assemblage. Both the Bear Creek assemblage and the Kluane schist are found along strike to the north; however their southern continuation into the Kluhini River and Takhanne River areas is not well understood. Where mapped in detail, the Bear Creek

Figure 5. *(a) Early isoclinal folds within amphibolite orthogneiss; (b) tight to isoclinal, overturned fold with sheared upper limb located near the structural contact between the Yukon-Tanana terrane and Paleozoic to Mesozoic schist; (c) moderately northeast-dipping ductile shear zone cutting through Paleozoic to Mesozoic schist, exhibiting apparent dextral sense of motion; (d) large kyanite porphyroblasts in schist of the Yukon-Tanana terrane; (e) staurolite porphyroblasts rimmed by cordierite (white) within Paleozoic to Mesozoic schist; (f) andalusite porphyroblasts within Paleozoic to Mesozoic paragneiss.*

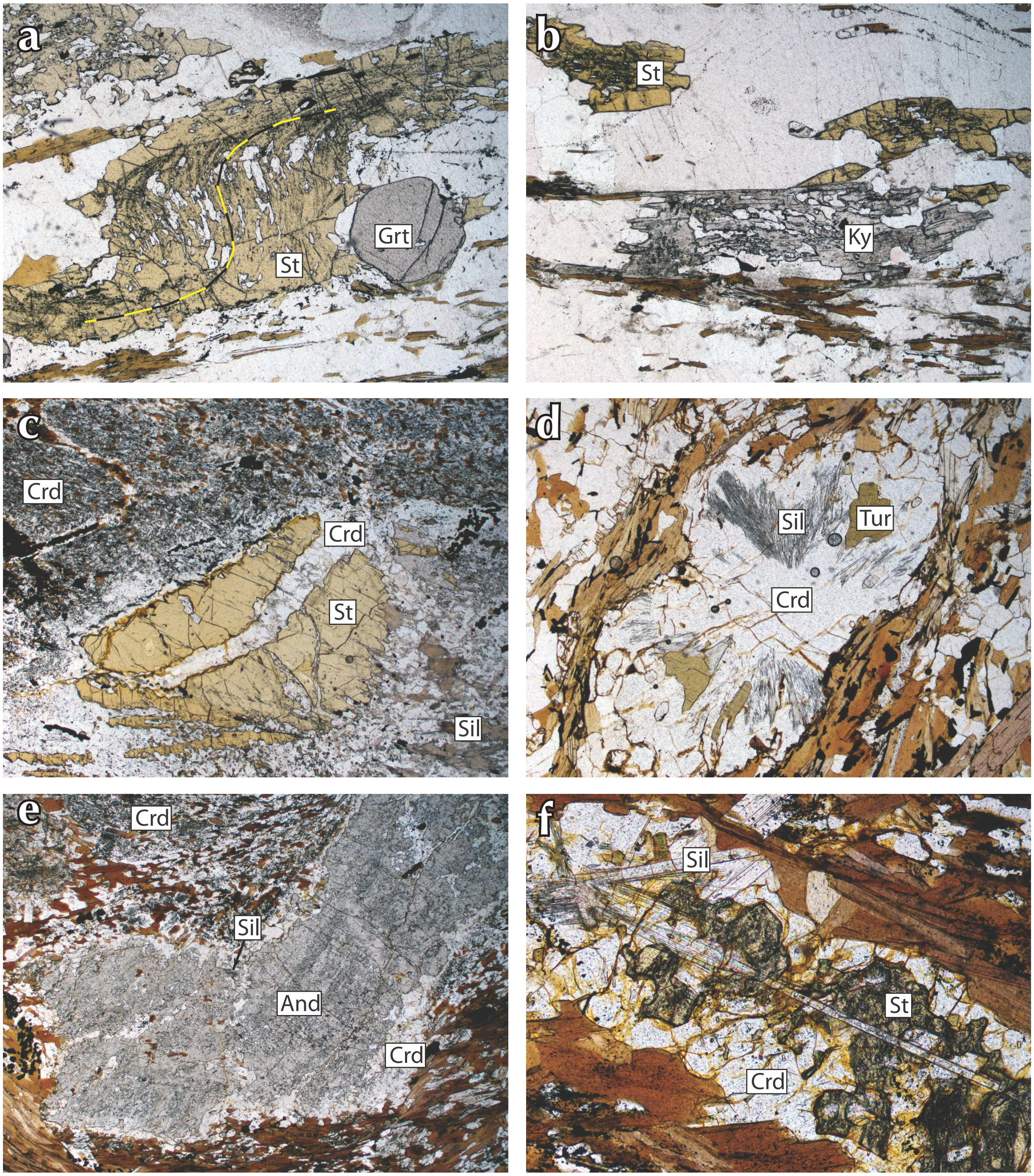


Figure 6. Photomicrographs taken in plane polarized light. (a) Staurolite and garnet porphyroblasts in sample 14-SI-088. Folded inclusion trails are preserved in the staurolite. Field of view = 3 mm. (b) Poikilitic kyanite and staurolite porphyroblasts in sample 14-SI-088. The long axis of the kyanite crystal is parallel to the foliation in the matrix, which is defined by preferentially aligned biotite and muscovite. Field of view = 3 mm. (c) Partly replaced staurolite porphyroblast in sample 14-SI-208. Inclusion-poor cordierite forms a continuous rim around staurolite. Cordierite porphyroblasts are rich in graphite inclusions. Field of view = 6 mm. (d) Nodule composed of cordierite with inclusions of radiating sillimanite and tourmaline in sample 14-SI-215. The matrix of the rock comprises biotite, quartz, plagioclase, cordierite and minor phases. Field of view = 3 mm. (e) Andalusite porphyroblast with a continuous rim of cordierite in sample 14-SI-216. Unlike the inclusion-poor cordierite that directly replaced andalusite, small cordierite porphyroblasts in the matrix are rich in graphite inclusions. Field of view = 6 mm. (f) Staurolite porphyroblast partly replaced by sillimanite (needles) and cordierite (continuous rim) in sample 14-SI-216. Field of view = 1.5 mm.

assemblage comprises mainly metamorphosed and deformed metavolcanic and metasedimentary rocks (Israel *et al.*, 2014). The metavolcanic rocks are intermediate to mafic flows and volcaniclastic rocks while the sedimentary portion of the unit is characterized by mudstone, siltstone and minor sandstone and calcareous mudstone. In other places the unit is almost entirely metabasalt structurally interleaved with thin bodies of ultramafic rocks. The Paleozoic to Mesozoic rocks in the present map area are dominantly sedimentary with no metavolcanic components; however, the sedimentary sequence is similar to that of the sedimentary portion of the Bear Creek assemblage. The Kluane schist on the other hand is dominantly a sedimentary unit. It is characterized by a fairly monotonous sequence of quartz-biotite schist, with little variation except for a paragneissic component found close to the structural boundary with the Yukon-Tanana terrane. It is possible that the Paleozoic to Mesozoic rocks found within the present map area are the southern extension of the Kluane schist. The local occurrence of carbonate horizons and the turbiditic nature of the Paleozoic to Mesozoic rocks are not really compatible with the monotonous quartz-biotite schist of the Kluane schist.

The juxtaposition of the various rock units likely occurred during southwest-directed shortening in the Late Cretaceous. The timing of deformation is probably related to foliation development within Late Cretaceous intrusive rocks structurally interleaved with Yukon-Tanana rocks. Whether this event coincided with peak metamorphic conditions is yet to be determined. Low-pressure metamorphism is likely associated with the intrusion of the large volume of the Paleocene Ruby Range suite. There is some evidence, such as locally foliated Ruby Range suite and deformed low-pressure assemblages within the Paleozoic to Mesozoic rocks, to suggest at least some deformation was occurring in the Paleocene.

Similar structural and metamorphic histories are described for rocks in southeast Alaska near the city of Juneau. In that area, rocks of Yukon-Tanana terrane are interpreted to be thrust over rocks of the Taku terrane and the Gravina assemblage (Gehrels *et al.*, 1992; Miller *et al.*, 2000). The Taku terrane is a Paleozoic to Mesozoic metasedimentary and metavolcanic assemblage (Saleeby, 2000; Gehrels, 2002) that has elements similar to the Bear Creek assemblage, and the Gravina assemblage is the along-strike equivalent to the Dezadeash Formation (McClelland *et al.*, 1992; Gehrels and Kapp, 1998).

CONCLUSION

The Kluhini and Takhanne River map areas are characterized by Yukon-Tanana terrane and Paleozoic to Mesozoic metamorphic rocks enclosed in Paleocene granodiorite of the Ruby Range suite. Late Cretaceous deformation led to the structural emplacement of Yukon-Tanana terrane over Paleozoic to Mesozoic schists and gneisses. The Paleozoic to Mesozoic rocks bear some similarities to the Dezadeash Formation, as well as the Bear Creek assemblage and the Kluane schist.

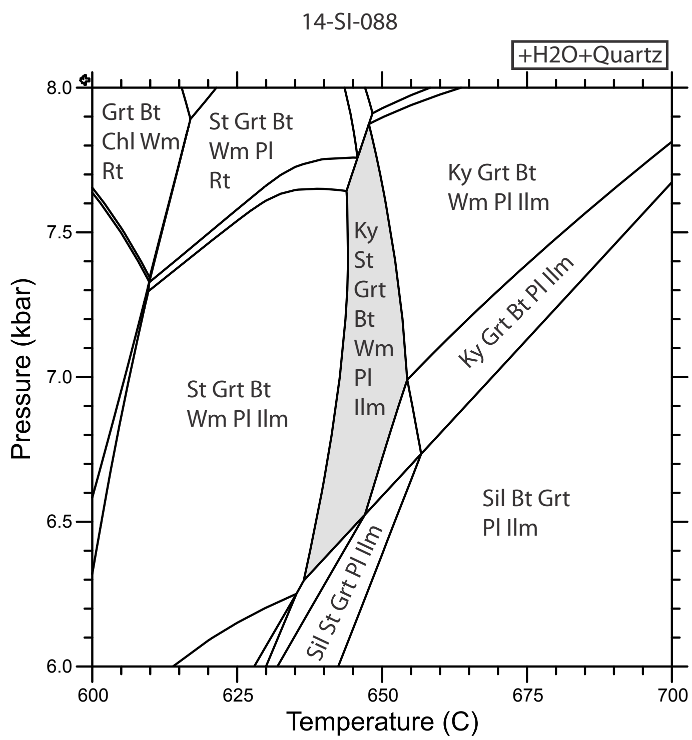


Figure 7. *Equilibrium assemblage diagram for schist sample 14-SI-088. The assemblage Ky-St-Grt-Bt-Ms-Pl-Qtz-Ilm indicates that peak metamorphism took places under middle amphibolite facies, intermediate pressure conditions (~635-650°C, ~6.3-7.8 kbar). The equilibrium assemblage diagram was produced using Theriak-Domino software. Modeling was carried out in the ten-component system* $MnO-Na_2O-CaO-K_2O-FeO-MgO-Al_2O_3-SiO_2-H_2O-TiO_2$ *(MnNCKFMASHT).* P_2O_5 *was removed from the bulk composition by projection from apatite. The thermodynamic database of Holland and Powell (1998) was used in conjunction with the solution models listed in Pattison and Tinkham (2009). A pure* H_2O *fluid phase was assumed to be present in excess throughout the P-T range.*

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