Dease Lake Geoscience Project, Part III: Age, Emplacement and Mineralization of the Snow Peak Pluton (NTS 104J/08)

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INTRODUCTION

The Snow Peak pluton is a small, steep sided, equidimensional body located in the northwestern part of the Dease Lake map sheet (NTS 104/J08). The intrusion is a relatively homogeneous, locally porphyritic quartz monzodiorite-granodiorite, which is hosted by Early Jurassic rocks of the Takwahoni Formation (Stikine terrane) immediately south of the terrane-bounding King Salmon fault (Figure 1). Mo±Au, W mineralization is developed along west-northwest trending fracture planes in the central part of the pluton.

This paper reviews the geology of the pluton and surrounding area and presents new geochronological and petrological data concerning its age and emplacement depth. Additional information on the regional geology is included in the accompanying paper by Logan *et al.*, 2012a.

COUNTRY ROCKS

The Takwahoni Formation in this area comprises a basal unit dominated by conglomerate and sandstone, and an overlying unit, which though variable, consists mostly of fine-medium sandstone and siltstone-mudstone (Figure 1). Lithologies in the contact aureole range from thickly to very thickly bedded massive sandstone and minor conglomerate with distinctive pink granitic clasts, to homogeneous sequences of laminated siltstone-mudstone with occasional sandstone beds.

Rocks in the area have been affected by two periods of deformation. The first lead to the development of east-west trending folds that are well exposed in the cirque north of Snow Peak (Figure 2) and the local development of a north dipping penetrative cleavage in fine-grained units. These structures are manifestations of a south-verging fold and thrust belt that developed in response to the amalgamation of the Stikine and Cache Creek terranes in the Middle Jurassic. Penetrative deformation of this age is widespread in rocks north of the King Salmon fault.

A later period of deformation produced north-trending upright folds. North-trending folds with km-scale wavelengths affect the map pattern (Logan *et al.,* 2012a), but associated smaller scale structures are only locally developed. Palaeocene-Eocene strata in the adjacent (NTS 104/J07) map sheet are folded by similar north-trending structures (Ryan, 1991), suggesting north-trending folds in the area may be early Tertiary or younger.

In the vicinity of Snow Peak, the Takwahoni Formation hosts a voluminous network of dikes and sills that typically range from tens of centimetres to metres thick (Figure 2c). Most of these dikes/sills are plagioclase porphyries, which commonly contain distinctive but sparsely distributed quartz "eyes", euhedral, oscillatory-zoned 2-10 mm plagioclase phenocrysts and slender hornblende crystals 1-3 mm long in a fine grained plagioclase-rich matrix (Figure 3a). Where present quartz phenocrysts commonly have rounded and embayed margins.

The network of dikes and sills end abruptly at the contact with the Snow Peak pluton; whereas they are abundant in the Takwahoni Formation, none was observed within the pluton. An older age for the dikes is also suggested by the presence of plagioclase porphyry xenoliths within the Snow Peak pluton (Figure 3b). These dikes are undeformed and crosscut east-west trending D1 folds (Figure 2d). Plagioclase porphyry dikes/sills have not been dated in the study area, but a U-Pb age of 155.2 ±1 Ma was obtained from a dike that is texturally and mineralogical similar, from a location further east in the NTS 104J/08 map sheet (Logan *et al.*, 2012b).

Many of the plagioclase porphyry dikes in the Snow Peak area are altered. In the field, their colour ranges from pale grey to brownish grey to yellow-brown with increasing degree of alteration. Carbonate alteration is most strongly developed, with minor sericite and chlorite. Adjacent to the Snow Peak pluton, hornblende in plagioclase porphyry dikes is replaced by biotite (Figure 3c).

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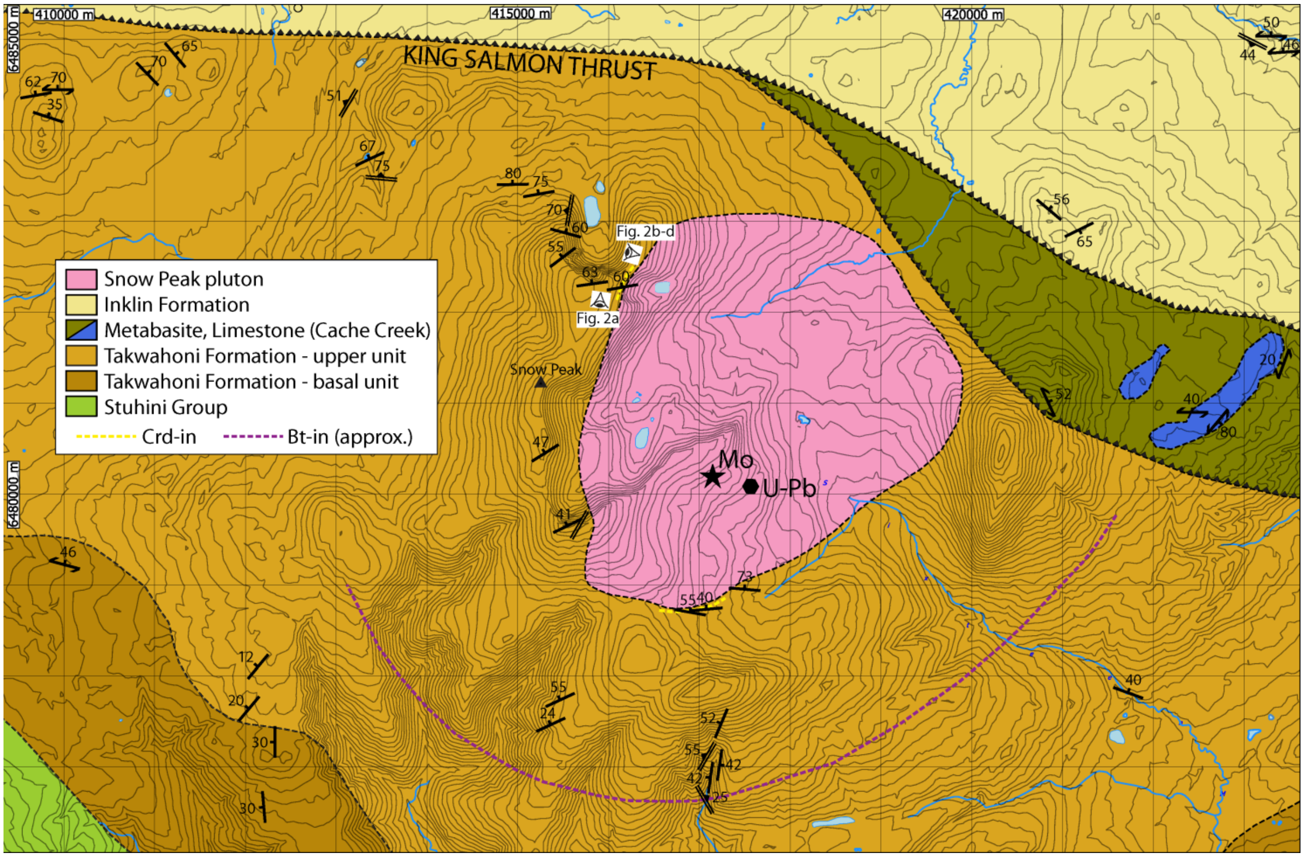

Figure 1. Map of the Snow Peak pluton and surrounding area. For location and regional geological setting, see Logan *et al.* (2012). The location of the U-Pb sample, the trench on the Mack prospect and approximate contact metamorphic isograds are shown. The eye symbols indicate the location and viewing direction of photographs shown in Figure 2.

Dikes of hornblende-plagioclase 'microdiorite' are also present in the area but are much less abundant than plagioclase porphyries. These rocks contain 1-2 mm long acicular hornblende crystals intergrown with plagioclase and are locally amygdaloidal. Non-porphyritic plagioclase-rich dikes are also present and a single outcrop of a distinctive dike (?) with primary flow banding was also encountered. This rock contains phenocrysts of plagioclase and quartz, in a matrix dominated by plagioclase and euhedral aligned biotite. Plagioclase phenocrysts are euhedral, whereas quartz ranges from euhedral to rounded and embayed.

SNOW PEAK PLUTON

The Snow Peak pluton occupies approximately 12 km^2, mostly underlying a subalpine bowl to the east of Snow Peak (Figure 1). The rock is a biotite-hornblende quartz monzodiorite to granodiorite that is locally weakly K-feldspar porphyritic (Figure 4a). CIPW normative compositions from a single sample (11JLO12-117) plot in the granodiorite field on QAP diagram (Streckeisen, 1976). Plagioclase forms oscillatory-zoned euhedral to subhedral laths that are typically 2-7 mm long. K-feldspar crystals are generally in the same size range but locally exceed 1 cm; they are anhedral-subhedral and often conform to the boundaries of plagioclase laths. The feldspars are intergrown with mafic phases and interstitial quartz. Quartz grains are generally <1 mm, but some larger 2-3 mm grains are present. Euhedral biotite and ragged acicular hornblende form crystals approximately 2 mm long and comprise approximately 5% of the rock. Euhedral titanite, magnetite and late pyrite form accessory phases. Magnetite is mostly clustered around mafic crystals, particularly hornblende, as is late replacement pyrite. There is minor alteration of mafic phases to chlorite and some sericitization of plagioclase.

Gabrielse (1998) reported a single K-Ar hornblende age of 73.5 Ma from the Snow Peak pluton, which is significantly younger than the age of other granitic intrusions in the area. New U-Pb data presented here (Figure 5) refine the age further, giving a crystallisation age of 64.4 ±0.5 Ma (earliest Palaeocene). The data were acquired by LA-ICPMS at the University of Washington, using procedures documented in the accompanying paper by Logan *et al.,* 2012b. The quoted age is a weighted mean of $^{206}Pb/^{238}U$ ages (n=44), excluding 6 outliers. This age provides an upper limit on the age of Mo ±Au, W mineralization; it also supports the conclusion reached from field relationships that the dike and sill swarm in the area is older and unrelated to the intrusion and its mineralization.

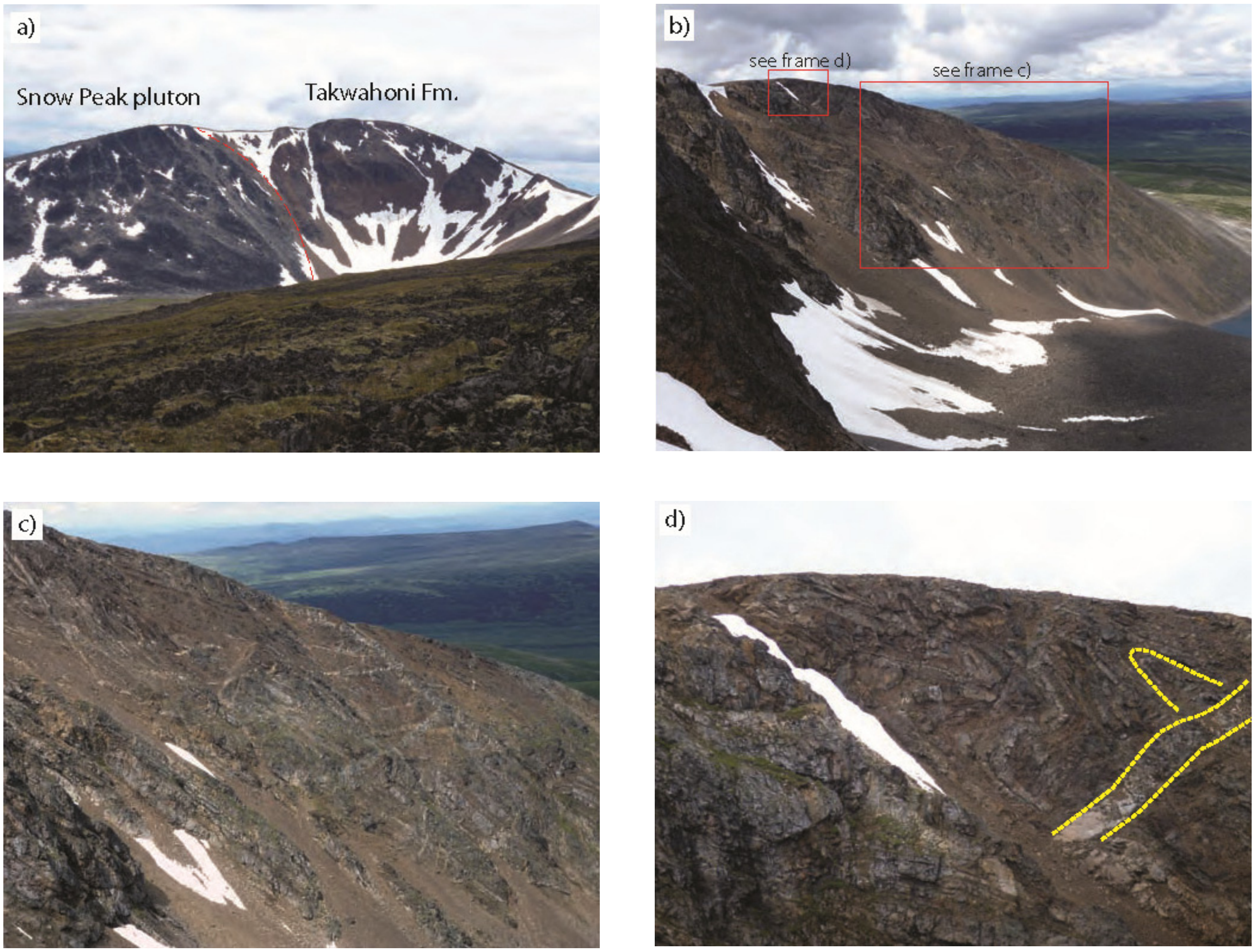

Figure 2. a) Steeply dipping contact between the Snow Peak pluton and rusty hornfelsed clastic rocks of the Takwahoni Formation. Looking south from above the north-facing cirque to the north of Snow Peak; relief is approximately 300 m. The position from which the photograph was taken is shown in Figure 1. b) Westerly view across the cirque north of Snow Peak, with insets showing the position of images in c) and d). The position from which the photographs were taken is shown in Figure 1. Relief is approximately 250 m. c) The Takwahoni Formation hosts a voluminous array of dikes and sills of plagioclase +/-quartz-eye porphyry. d) East-west trending (D1) folds with north dipping axial planes are visible in the cliff face. Undeformed dikes cut across fold axial planes and therefore postdate this deformation.

CONTACT METAMORPHISM

Intrusion of the Snow Peak pluton led to the formation of a contact metamorphic aureole in surrounding rocks of the Takwahoni Formation. The effects of contact metamorphism on rocks of the Cache Creek terrane to the northeast were not studied. In the Takwahoni Formation, the aureole is manifested in a broad region of rusty, indurated rock, which commonly has a mauve-coloured tint. The isotropic character and colour of the rock is related to the growth of fine grained metamorphic biotite, which grew with no preferred orientation. Throughout this biotite zone, much of the primary texture of the rocks is preserved, with detrital grains visible in thin section. In addition to biotite, pale green amphibole (tremolite-actinolite) crystallized in some calcareous layers.

Immediately adjacent to the intrusion (within tens of metres), fine-grained layers in the Takwahoni Formation are fully recrystallized into spotted cordierite-bearing hornfels (Figures 4b-d). Small cordierite spots generally <1 mm are abundant in pelitic layers and are concentrated in the finest grained parts of graded layers, locally producing a reversal in the direction of grain-size fining to one of coarsening. Spotted hornfels clasts are abundant in the felsenmeer that covers the area, but in situ samples were collected from only two areas - on the northwestern and southern flanks of the intrusion.

To determine P-T conditions during contact metamorphism, equilibrium assemblage diagrams were constructed for a number of samples using the software DOMINO (de Capitani and Petrakakis, 2010). These diagrams, which are specific to the rock composition for which they are constructed, depict the stable mineral assemblage as a function of temperature and pressure, assuming thermodynamic equilibrium. The phase

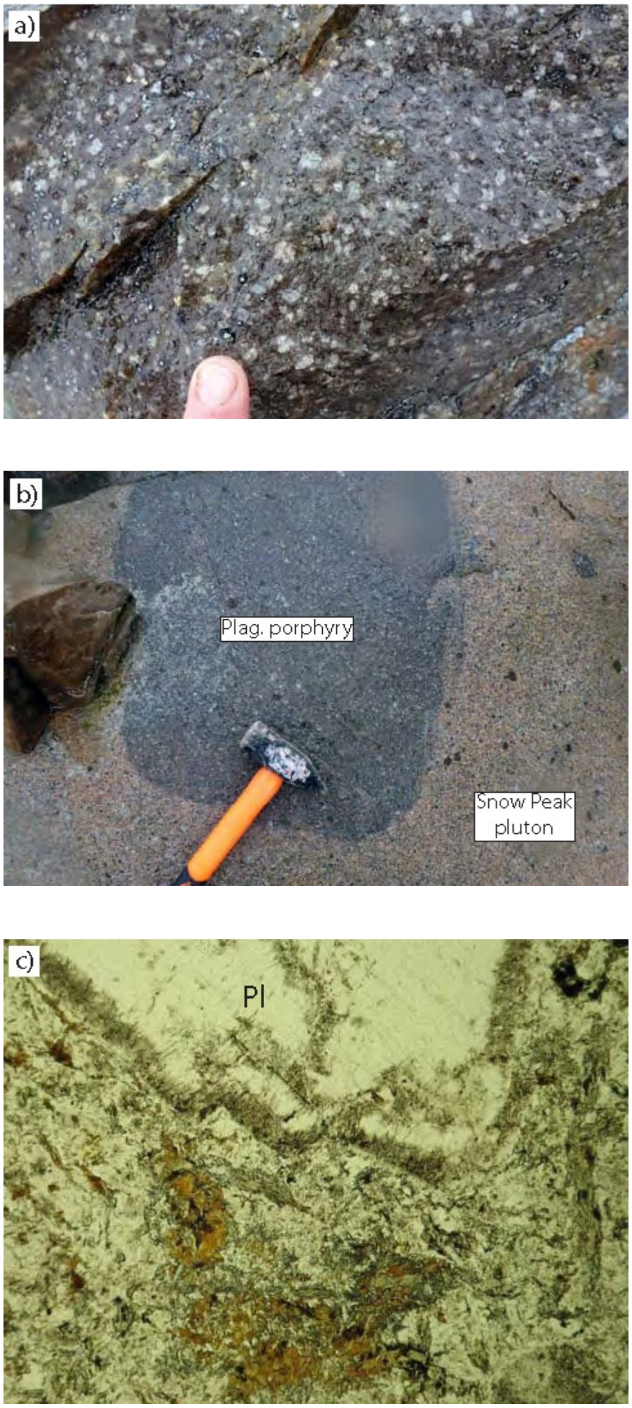

Figure 3. a) Typical plagioclase porphyry dike intruded into the Takwahoni Formation on Snow Peak showing characteristic texture of plagioclase and quartz phenocrysts within a fine grained, plagioclase-rich matrix. b) Rounded xenolith of plagioclase porphyry included in monzogranite of the Snow Peak pluton. c) Photomicrograph of plagioclase porphyry dike from west of the Snow Peak pluton showing plagioclase phenocryst and magmatic hornblende crystals replaced by secondary biotite. Field of view = 3 mm.

diagrams were constructed in the system MnO-Na2O-CaO-K2O-FeO-MgO-Al2O3-SiO2-H2O-TiO2 (MnNCK FMASHT) using version ds5.5 of the Holland and Powell (1998) thermodynamic database, and activity models listed by Coueslan *et al.,* 2011. Rock compositions were

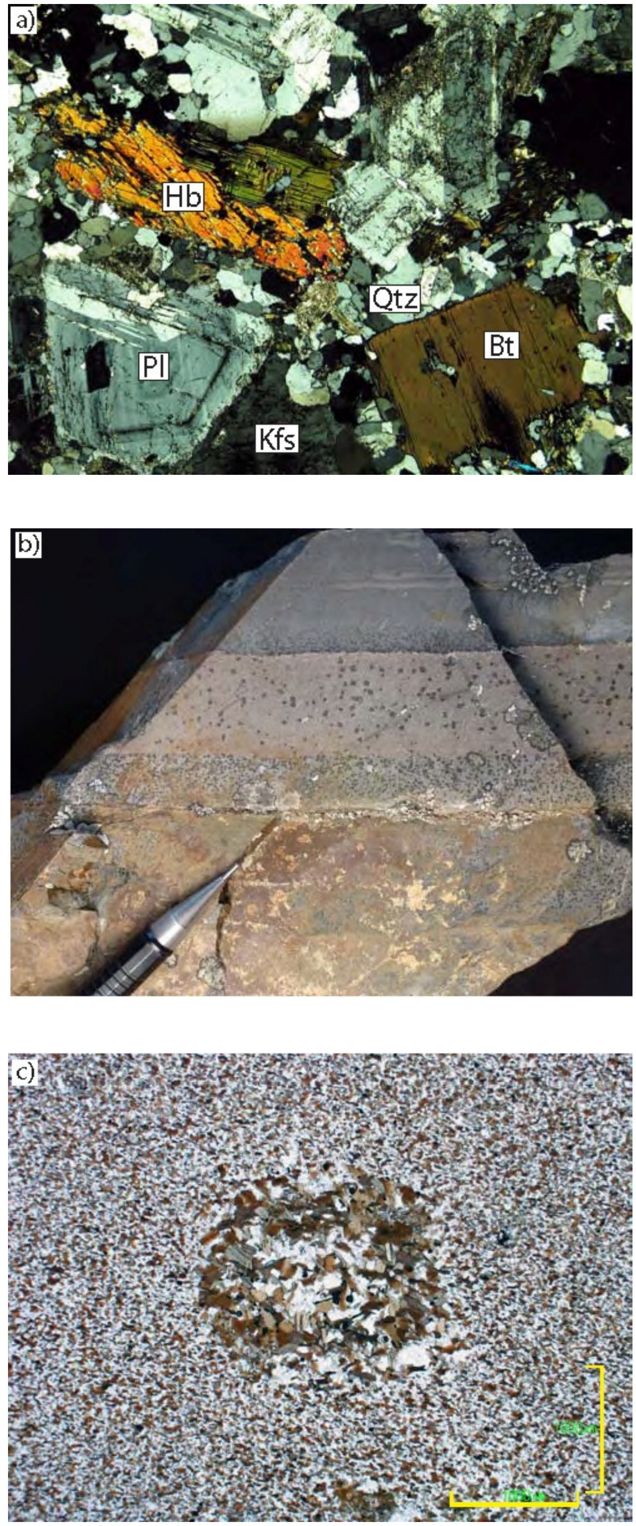

Figure 4. a) Hornblende-biotite quartz monzodiorite of the Snow Peak pluton. Oscillatory-zoned plagioclase and K-feldspar crystals are intergrown with mafic phases and finer grained quartz. Minor titanite is also present. Field of view is 3 mm, x-nicols. b) Spotted cordierite hornfels derived from a fine-grained layer in the Takwahoni Formation. Cordierite crystals (dark spots) are concentrated in pelitic layers, particularly in finest grained parts of graded layers. c) Photomicrograph of 11DMO12-97 shows cordierite porphyroblast that has been replaced by biotite and plagioclase. Scale bars are 1 mm.

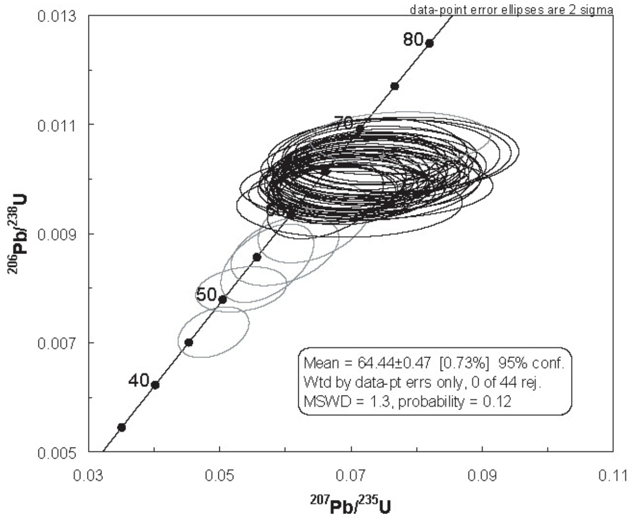

Figure 5. U-Pb Concordia plots for LA-ICPMS U-Pb data from the Snow Peak pluton. Excluding outliers, the weighted mean $^{206}Pb/^{238}U$ age is 64.4 +/-0.5 Ma. The sample was collected from (NAD 83) UTM 9V 417549 6480099, 1586 m (marked on Figure 1).

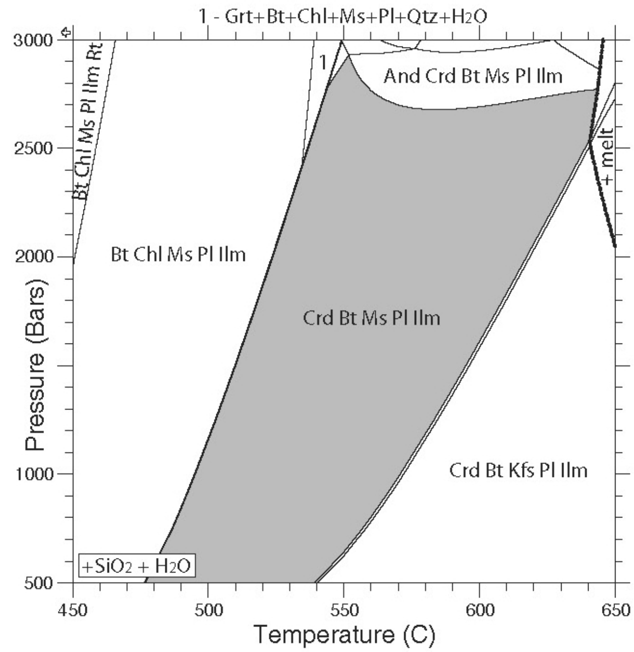

Figure 6. Equilibrium assemblage diagram for cordierite hornfels sample DMO11-39-346. The observed assemblage (shaded) implies emplacement of the pluton at P < ~2.75 kbar. The bulk composition of this sample, determined by XRF analysis, is presented in Table 1.

determined by x-ray fluorescence spectrometry (XRF) at Acme Analytical Laboratories Ltd in Vancouver.

A representative phase diagram for a cordierite-bearing hornfels (11DMO-39-346) from the southern flank of the pluton is presented in Figure 6. The observed assemblage of cordierite+biotite+muscovite+plagioclase+ quartz+ilmenite (Crd+Bt+Ms+Pl+Qtz+Ilm) is stable below ~2.75 kbar over a temperature range of approximately 500-650ºC. Higher temperatures are ruled out as there is no K-feldspar and no evidence for melting of the rock here or elsewhere in the aureole. Assuming a crustal density of 2800 kg/m^3, the cordierite-bearing assemblage implies an emplacement depth of <10 km for the pluton. This relatively shallow depth explains the absence of minerals such as andalusite, staurolite and garnet, which are commonly found in contact metamorphosed metapelites, but are generally restricted to slightly higher pressures. Equilibrium assemblage diagrams predict growth of biotite at temperatures of 300-350ºC. This is lower than is typical for metapelites (Spear, 1993), and together with the low regional metamorphic grade, may help explain the large width of the aureole relative to the size of the intrusion.

Table 1. Whole rock x-ray fluorescence (XRF) major element analysis of 11DMO39-346: a metapelitic hornfels sample from the contact aureole of the Snow Peak pluton.

SiO_2	61.70%
TiO_2	0.58%
Al_2O_3	17.10%
Fe_2O_3	7.99%
MnO	0.12%
MgO	3.77%
CaO	0.80%
Na_2O	1.66%
K_2O	4.15%
P_2O_5	0.10%
Ba	0.21%
LOI	2.15%
Total	100.34%

MO (+AU, W) MINERALIZATION

The Snow Peak pluton hosts Mo±Au and W mineralization at the Mack prospect (MINFILE 104J 014), which is located in the southern part of the intrusion (Figure 1). Mineralization comprises coarse-grained (1-7 mm) molybdenite and pyrite crystals, which are disseminated along steeply dipping west-northwest trending fractures or narrow quartz veins (Figure 7). These discrete, rust-stained fractures are spaced at intervals of approximately 15-50 cm in a zone that extends for approximately 1 km. Sandler-Brown and Nevin (1976) reported quartz-filled mineralized fractures up to 7 mm wide, and observed finer grained disseminated molybdenite and pyrite in the hostrock within the mineralized zone. Trench sampling has returned typically low Au values (<0.06 g/t) but in several cases values of 1.5 to 1.6 g/t Au accompany elevated molybdenum values in the central part of the mineralized zone (Sandler-Brown and Nevin, 1976). Scheelite is also reported. Sandler-Brown and Nevin (1976) identified a geophysical anomaly that coincides with the mineralized

Figure 7. Molybdenite and pyrite crystals on fracture plane in the Snow Peak pluton at the Mack prospect.

zone, but no drilling has taken place to assess mineralization at depth. A sample of coarse-grained molybdenite from the Mack prospect was collected and is being prepared for dating using the Re-Os method at the University of Alberta, Edmonton.

CONCLUSIONS

The Snow Peak pluton records Early Paleocene magmatism and associated Mo±Au and W mineralization that is *ca.* 10 Ma. younger than lithologic and metallogenic similar plutons of the Late Cretaceous Surprise Lake Plutonic Suite of northern British Columbia and the Yukon (Woodsworth *et al.*, 1991). This younger magmatic epoch may be the plutonic equivalent of Carmacks Group volcanism exposed further north (Lowry *et al.*, 1986; Hart, 1995).

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