U-Pb GEOCHRONOLOGY, Pb ISOTOPIC SIGNATURES AND GEOCHEMISTRY OF AN EARLY JURASSIC ALKALIC PORPHYRY SYSTEM NEAR LAC LA HACHE, B.C.

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INTRODUCTION

The Ann property is located within the Quesnel Terrane of the Intermontane Belt in south-central British Columbia (Figures 33-1 and 33-2). It is approximately 19 kilometres northeast of Lac La Hache, B.C., near the northwestern edge of map sheet 92P14W (approximate coordinates: latitude 51°58'N, longitude 121°19'W). Topography in the region consists of moderately sloping hills and wide densely forested valleys.

Previous field work has shown that the geology of the Ann property resembles that of other alkaline copper-gold porphyry systems in the Quesnel terrane (most notably Mt. Polley, Copper Mountain and Afton/Ajax) in terms of overall lithologies and styles of mineralization.

The focus of this study was to constrain the timing of mineralization, and to place the volcanic and intrusive units in the study area into a regional tectonic framework. New U-Pb dates, trace-Pb isotopic analyses and some whole rock geochemistry are reported for rocks within the Spout/Peach Lake study area (Figure 33-2). It is hoped that possible correlations with other copper-gold porphyry deposits in the southern Canadian Cordillera may be made, ultimately leading to a more focused and improved approach to mineral exploration in this region.

The southern half of the Ann property (Figure 33-3) was chosen for detailed study based primarily on the fact that this includes areas of less subdued relief and reasonably good exposure, and was also the focus of recent trenching and drilling activity. Field samples used for geochronologic, trace-Pb isotopic and geochemical work were collected from the Ann property and other localities within the Spout/Peach Lake study area.

Detailed petrology, structural data, distribution of lithologic units, and the nature of hydrothermal alteration and mineralization for rocks at the Ann property study area are not presented in this paper; for further discussions concerning this research the reader may refer to Whiteaker (1996).

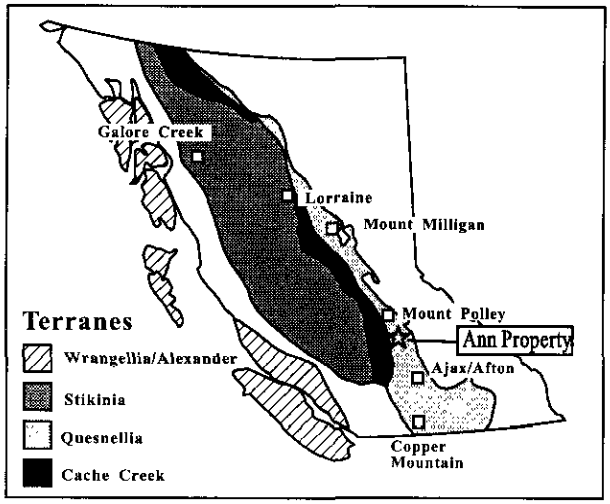

Figure 33-1. Location of the Ann property and the distribution of significant alkalic copper-gold porphyry systems in the Canadian Cordillera.

PREVIOUS WORK

Previous regional-scale mapping in the study area (Campbell and Tipper, 1971) shows it to be underlain by Early Jurassic alkalic plutons, dykes and small dioritic to syenitic stocks. These rocks intrude broadly coeval volcanic rocks and sediments of the Late Triassic-Early Jurassic Nicola Group, which consist mainly of augite-phyric andesite to basaltic flows, volcanic breccias and tuffs and associated argillite, greywacke, limestone and clastic breccias. Regionally developed plutonic rocks include granodiorite to quartz-monzonite (Takomkane batholith), quartz diorite and syenodiorite. Subsequent detailed mapping and exploration throughout the study area was performed by Asarco Exploration Co. (Gale, 1991) and Regional Resources Ltd./GWR Resources Inc. (von Guttenberg, 1994; Blann, 1995), who recognized similar lithologies.

No previous isotopic ages are available for rocks at the Ann property. Leech et al. (1963) reported a K-Ar biotite date of 187±14 Ma for the Takomkane batholith that lies to the east of the study area. Calderwood et al. (1990) reported a preliminary U-Pb zircon upper intercept age of 207±5 Ma for the same body.

REGIONAL GEOLOGY

The Nicola Group is an assemblage of submarine and subareal arc volcanic and volcaniclastic rocks and related sediments that is interpreted to have been produced above an east-dipping subduction-accretion zone. This arc apparently developed outboard of ancestral North America during the Late Triassic and was active into Early Jurassic time (Mortimer, 1987). The volcanic rocks were subsequently intruded by broadly coeval intrusions of alkalic to calc-alkalic composition that may in part represent plutonic roots to the arc volcanoes (Preto 1979, Saleken and Simpson, 1984).

The Nicola Group has been divided into four lithologic assemblages (Monger 1989): a western volcanic belt composed of mafic to felsic, calc-alkalic volcanic and volcaniclastic rocks; a central volcanic belt consisting predominantly of alkalic to calc-alkalic basalt and andesite flows, volcanic breccias and lahars; an eastern volcanic belt composed primarily of alkalic intermediate and mafic flow and fragmental rocks; and an eastern sedimentary assemblage of greywacke, argillite, tuff and limestone, which is overlain by volcanic rocks of the eastern volcanic belt. Lithologies within the Nicola Group across the study area suggest correlation with the central and/or eastern volcanic belt of Monger (1989). Preto (1972) suggests that active faulting during Nicola volcanism may have controlled the emplacement and shape of subsequent intrusive bodies. East-west and northwest trending faults are interpreted to be cut by north trending structures (Preto, 1979).

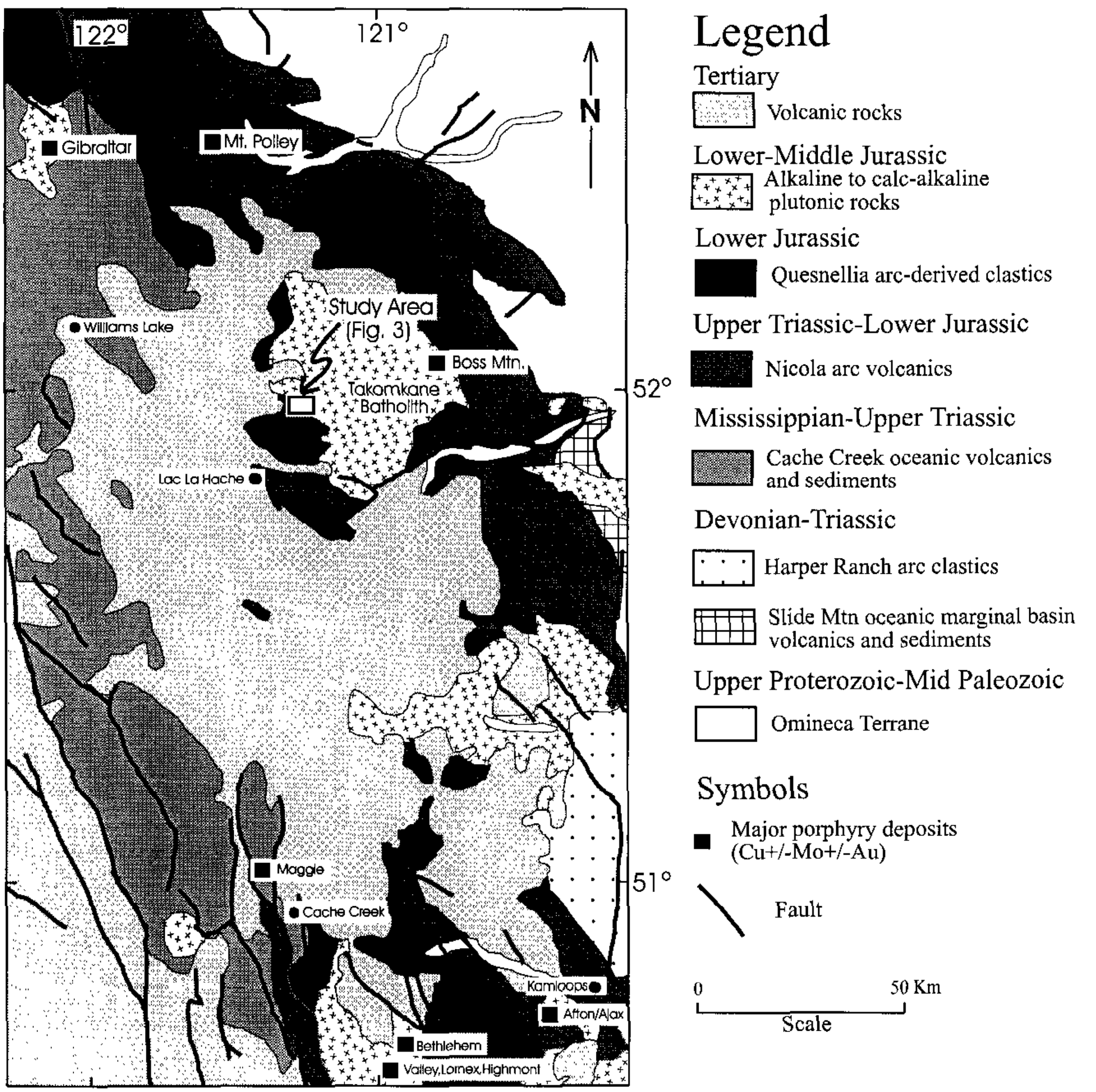

Figure 33-2. Regional geology of the southern Canadian cordillera near the Ann property study area (modified from Wheeler and McFeely, 1991).

LOCAL GEOLOGY

The general scarcity of outcrop and extensive overburden in the study area, coupled with the fact that almost all of the rocks on the property display weak to intense propylitic to potassic alteration, make field identification and correlation of lithologic units difficult. On the basis of detailed surface mapping, drill core logging and petrographic studies several distinct lithologic units, alteration types and styles of mineralization have been defined.

Nicola Group rocks which underlie the study area include massive basalt and basalt-dominated polymictic breccias, and augite- and hornblende-phyric andesite and basalt. These rocks commonly display pervasive propylitic alteration (chlorite-epidote-calcite-sericite), but where directly in contact with intrusive bodies are intensely potassically altered (potassium feldspar ± biotite ± magnetite), and locally hornfelsed. Very strong propylitic and potassic alteration of Nicola Group volcanic rocks has destroyed much of the primary textures which often makes petrographic distinction between basaltic or andesitic protoliths difficult.

Local outcrops of pyroclastic beds, limestone and minor clastic breccia outside of the Ann property (Figure 33-3) exhibit weak to strong propylitic alteration and/or skarning.

Feldspar-porphyritic andesite (possibly a high-level comagmatic Nicola intrusion) also occurs on the property. This unit is interpreted to be Late Triassic-Early Jurassic in age based on both local stratigraphic sequences and evidence which suggests that propylitic alteration throughout this unit may be related to an adjacent, cross-cutting monzonite intrusion (considered to be Early Jurassic in age; see later discussion).

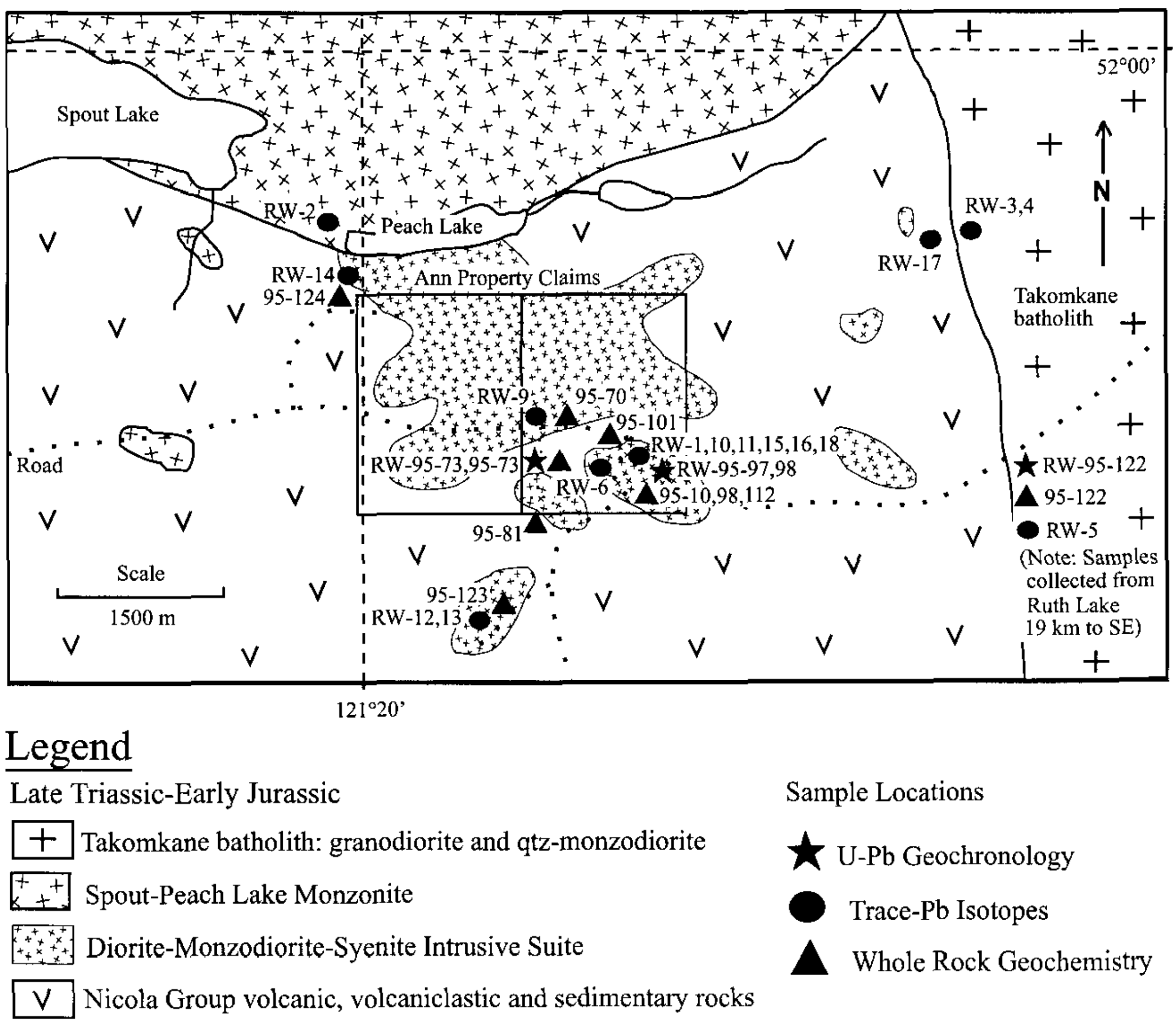

Figure 33-3. Simplified geology of the Spout/Peach Lake study area near the Ann property (after Campbell and Tipper,1971; von Guttenberg,1994; Blann,1995; Whiteaker, 1996), showing geochronologic, trace-Pb isotope and geochemical sample sites.

Several intrusive bodies are exposed within the study area and appear to be part of a large polyphase intrusive suite that consists of dominantly fine-medium grained diorite, monzonite and syenite, with minor pyroxenite and gabbro. Locally, this intrusive suite contains abundant, variably resorbed, angular xenoliths of mafic volcanic, gabbroic and granitic composition. On the southeast portion of the Ann property, the intrusive suite is cut by a medium-grained, unmineralized, quartz-hornblende-feldspar porphyry (QHFP) dyke. In addition, numerous 5 to 20 cm wide, hydrothermal breccia bodies cut the diorite-monzodiorite complex. One of these breccia bodies has been intercepted in a recent drillhole adjacent to the QHFP dyke; at this locality the breccia contains fine-coarse grained blebs of pyrite-chalcopyrite-magnetite ± bornite (Whiteaker, 1996), as well as elevated gold and silver values (Blann, 1995).

Intrusive rocks throughout the study area display both pervasive and structurally-controlled hydrothermal alteration. Generally the rocks show moderate to intense propylitic (chlorite-epidote-calcite-sericite) to potassic (potassium feldspar-biotite-magnetite ± chlorite ± epidote ± albite) alteration. In places, severe potassic 'flooding' of diorite-monzodiorite has entirely obliterated primary rock textures and mineralogy. In outcrop, these rocks weather a distinctive chalky pinkish-white colour and commonly contain abundant resistant circular green epidote 'patches' and veins enclosed by pink potassium feldspar.

Mineralization in the study area appears to be intimately associated with zones of strong-intense potassic and propylitic alteration. The mineralization occurs primarily within dioritic to monzodioritic intrusive rocks, but is locally common within Nicola volcanic rocks adjacent to these intrusions. Sulphides (pyrite-chalcopyrite ± bornite) occur mainly as sparse disseminations and replacements of mafic minerals, but are also prominent within potassium feldspar epidote-chlorite ~ magnetite ± albite veinlets. Some malachite fracture coatings are present across the Ann property where roadcuts have exposed mineralized Nicola volcanic rocks.

Unmineralized, multilithic intrusive breccias (mafic volcanic, diorite and syenite fragments), crop-out locally throughout the southern portion of the Ann property and are exposed for widths of up to 150 m. The relationship between these breccias and the polyphase intrusive suite is not known.

Numerous red-orange to pinkish, narrow (<15cm wide) syenite-monzonite dykes occur across the Ann property and cross-cut both the Early Jurassic intrusions and the Late Triassic volcanic rocks. These dykes may suggest a deep late-stage potassic (syenitic) core to the intrusive complex.

The Takomkane batholith crops on the eastern side of the study area (Figure 33-3). The subsurface lateral extent of this large granodiorite to quartz-monzonite body, with respect to the rocks and stratigraphy at the Ann property, is presently unknown.

Relatively fresh mafic volcanic rocks of presumed Tertiary age unconformably overlie both the Late Triassic Nicola volcanic rocks and the Early Jurassic intrusions on the Ann property. These rocks include dark-grey to black amygdaloidal hornblende porphyritic basalt and feldspar porphyritic basalt. Although these units are regionally widespread, they have been almost entirely removed from the immediate study area by Pleistocene glaciation.

GEOCHRONOLOGY

No previous isotopic age data exists for any of the intrusive bodies or volcanic rocks on the Ann property. Dating of other alkalic copper-gold porphyry systems within the Quesnel Terrane has produced U-Pb dates that mainly range from 210 to 200 Ma (Early Jurassic; Mortensen et al., 1995). The only exceptions are intrusions in the Mount Milligan area, which have yielded U-Pb zircon ages of 183±3 Ma (Mortensen et al., 1995).

Age control for rocks at the Spout/Peach Lake study area was essential to help determine the relative timing of the emplacement of intrusions into the Late Triassic Nicola Group volcanic rocks and the genesis of mineralization on the property, and to facilitate correlation of associated Cu-Au mineralization on the Ann property with that of other alkalic porphyry systems in the Canadian Cordillera. In addition, the age of the Takomkane batholith, a large calc-alkalic pluton, which lies directly to the east of the Ann property is, at present, poorly constrained. Available dates for the Takomkane batholith are a K-Ar biotite age of 187±14 Ma (Leech et al., 1963) and a U-Pb zircon upper intercept age of 207±5 Ma (Calderwood et al., 1990

U-Pb zircon and titanite analytical data for a diorite phase of the diorite-monzodiorite intrusive complex, a quartz-hornblende-feldspar porphyry dyke, a porphyritic andesite (possibly a high level, subvolcanic intrusion) and the Takomkane batholith are presented here. Sample localities are shown on Figure 33-3. Mineral separations and isotopic analyses were carried out at the University of British Columbia Geochronology Laboratory, using analytical methodology as described in Mortensen et al. (1995). The analytical data are given in Table 33-1 and plotted on convential U-Pb concordia diagrams in Figure 33-4 (a), (b), (c) and (d).

Feldspar-Porphyritic Andesite

A small outcrop of porphyritic andesite occurs on the west side of the study area (sample RW-95-73, Figure 33-3). Contacts with surrounding units are not exposed, and the aphanitic groundmass and moderate alteration masks the exact nature of this unit. It is interpreted to represent a high-level (sub-volcanic) intrusion associated with Nicola Group volcanic rocks. Field relationships suggest that it cross-cuts basalt-dominated polylithic breccia and has itself been intruded and propylitically altered by an adjacent xenolithic monzonite stock. A small amount of inclusion-free, pale amber, subhedral to euhedral zircon grains was recovered from the sample. Three fractions form a linear array just below concordia between 200-187 Ma (Figure 33-4a). A weighted average of the $^{207}Pb/^{206}Pb$ ages of the three analyses is 203.9±4.2 Ma, which is interpreted to be the crystallization age of the unit. Two unabraded fractions of titanite were also analyzed (Table 33-1). The analyses are discordant with $^{206}Pb/^{238}U$ ages of 194 Ma and 172 Ma, likely reflecting post-crystallization Pb-loss.

Diorite

A sample of diorite was collected from an outcrop recently exposed by the construction of a drill-road near an outcrop of the QHFP dyke (sample RW-95-97, Figure 33-3). Based on core logging, extensive feldspar staining and observed field relationships, this diorite is interpreted to be a phase of the main diorite-monzodiorite intrusion. The sample yielded a small number of tabular to equant, pale yellow zircons as well as clear to amber-yellow, broken, subhedral titanite grains. Two fractions of abraded zircon were analyzed. Both yielded discordant results indicative of the presence of an older inherited zircon component. No meaningful age could be determined from the zircon analyses. Three fractions of unabraded titanite were also analyzed. All three fractions give concordant analyses, with a total range of age of $^{206}Pb/^{238}Pb$ ages of 203±4 Ma which is interpreted as the age of crystallization for the diorite phase (Figure 33-4b).

Table 33-1. U-Pb analytical data.

Fraction[1]	Wt	U^2	Pb*[3]	$^{206}Pb^4$ / ^{204}Pb	Pb^5	^{208}Pb [6]	Isotopic ratios (1σ,%)[7]			Apparent ages (2σ,Ma)[7]	
	mg	ppm	ppm	^{204}Pb	pg	%	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$
RW-95-73: Porphyritic andesite; UTM 616750E, 5757500N											
AA: t,200,s	0.135	90	4	242	105	35.2	0.03055 (0.24)	0.2094 (0.87)	0.04972 (0.72)	194.0 (0.9)	182 (33)
BB: t,180,s	0.118	388	12	115	814	17.8	0.02705 (0.55)	0.1904 (1.7)	0.05107 (1.4)	172.0 (1.9)	244 (64)
A: N1,80-100,s,a	0.046	592	20	5129	10	15.4	0.03155 (0.10)	0.2183 (0.20)	0.05018 (0.13)	200.3 (0.4)	203.4 (5.9)
B: N1,80-100,s	0.049	668	21	1021	62	14.6	0.02983 (0.10)	0.2065 (0.19)	0.05020 (0.15)	189.5 (0.4)	204.5 (6.9)
C: N1,80-100,s	0.028	736	23	909	43	15.4	0.02950 (0.11)	0.2042 (0.37)	0.05019 (0.30)	187.4 (0.4)	204 (14)
RW-95-97: Diorite; UTM 617850E, 5757720N											
AA: t,90-180,s	0.300	105	5	72	1202	40.7	0.03201 (1.0)	0.2129 (3.7)	0.04825 (3.1)	203.1 (4.0)	112 (146)
BB: t,90-180,s	0.265	108	5	106	668	40.3	0.03202 (0.61)	0.2198 (2.2)	0.04978 (1.8)	203.2 (2.5)	185 (86)
CC: t,90-180,s	0.290	117	6	94	918	39.6	0.03231 (0.71)	0.2214 (2.6)	0.04969 (2.1)	205.0 (2.8)	181 (100)
B: N5,+134,s	0.032	570	18	916	39	10.5	0.03051 (0.15)	0.2276 (0.32)	0.05410 (0.22)	193.7 (0.6)	375 (10)
C: N5,+134,s	0.030	484	18	986	34	11.0	0.03626 (0.12)	0.3522 (0.26)	0.07046 (0.18)	229.6 (0.5)	94.7 (7.2)
RW-95-98: Quartz-hornblende-feldspar porphyry dyke; UTM 617850E, 5757750N											
A: N5,90-120,e	0.113	990	22	719	236	6.0	0.02327 (0.18)	0.1602 (0.40)	0.04995 (0.28)	148.3 (0.5)	193 (13)
B: N5,90-120,e	0.166	954	26	847	350	5.7	0.02888 (1.0)	0.1992 (1.1)	0.05003 (0.25)	183.5 (3.8)	197 (12)
C: N5,70-100,s	0.179	1236	28	811	413	6.8	0.02328 (0.26)	0.1601 (0.34)	0.04987 (0.17)	148.3 (0.8)	189.1 (8.1)
A2: N5,70-100,s	0.020	1162	27	925	40	6.4	0.02441 (0.10)	0.1683 (0.31)	0.05001 (0.23)	155.5 (0.3)	195 (11)
B2: N5,70-100,s	0.034	1394	32	1000	71	6.9	0.02386 (0.10)	0.1646 (0.40)	0.05002 (0.34)	152.0 (0.3)	196 (16)
RW-95-122: Takomkane batholith; UTM 635750E, 5743125N											
AA: t,+149,s	0.940	92	4	235	78	37.1	0.03053 (0.27)	0.2119 (0.94)	0.05033 (0.77)	193.9 (1.0)	210 (36)
BB: t,+149,s	0.810	71	3	253	472	36.5	0.03045 (0.25)	0.2111 (0.87)	0.05027 (0.70)	193.4 (0.9)	207 (33)
A: N1,+149,s,a	0.584	278	8	7996	38	8.7	0.03048 (0.14)	0.2097 (0.15)	0.04989 (0.05)	193.6 (0.5)	189.8 (2.1)
B: N1,+149,s,a	0.525	226	7	7187	31	8.4	0.03004 (0.28)	0.2088 (0.31)	0.05041 (0.18)	190.8 (1.1)	214.1 (8.5)
C: N1,+149,s,a	0.092	247	7	3099	14	8.3	0.03045 (0.11)	0.2097 (0.23)	0.04996 (0.15)	193.3 (0.4)	193.3 (6.9)

Notes: Analytical techniques are listed in Mortensen et al. (1995).

[1] Upper case letter(s) = fraction identifier; t=titanite; all others zircon. N1, N5 = nonmagnetic at given degrees side slope on Franz isodynamic magnetic separator. Front slope for all fractions=20°. Grain size given in microns. a = abraded, e=elongate prisms, s=stubby to equant grains.

[2] U blank correction of 1pg ± 20%; U fractionation corrections were measured for each run with a double ^{233}U-^{235}U spike (about 0.005/amu).

[3] Radiogenic Pb.

[4] Measured ratio corrected for spike and Pb fractionation of 0.0043/amu ± 20% (Daly collector) and 0.0012/amu ± 7% (Faraday collector) and laboratory blank Pb of 10pg ± 20%. Laboratory blank Pb concentrations and isotopic compositions based on total procedural blanks analysed throughout the duration of this study.

[5] Total common Pb in analysis based on blank isotopic composition.

[6] Radiogenic Pb.

[7] Corrected for blank Pb, common Pb, and U. Common Pb corrections based on Stacey Kramers model (Stacey and Kramers, 1975) at the age of the rock or the $^{207}Pb/^{206}Pb$ age of the fraction.

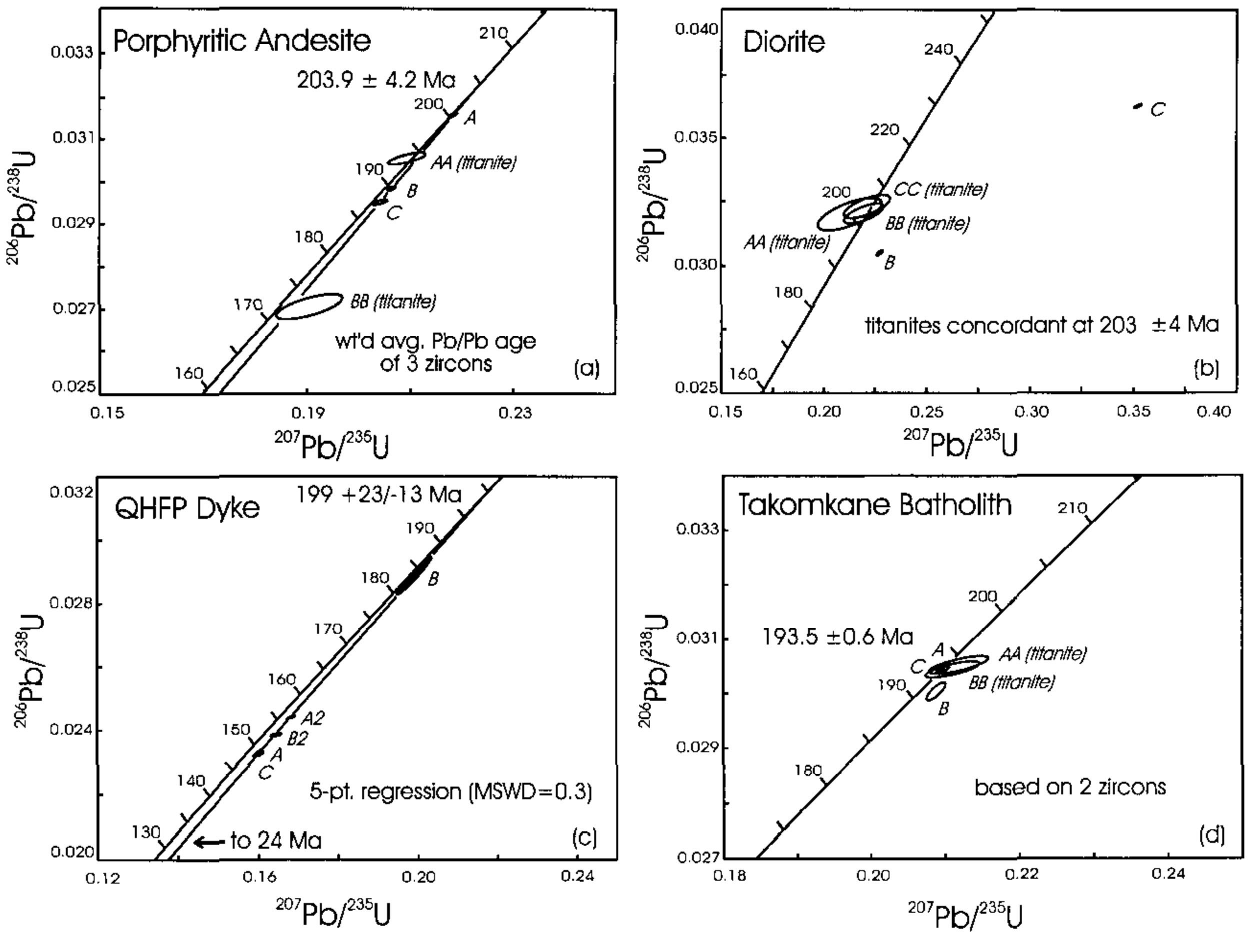

Figure 33-4. U-Pb concordia plots for samples from Ann property study area and the Takomkane batholith. Ellipses are plotted at the 2σ level of precision.

Quartz-Hornblende-Feldspar Porphyry (QHFP) Dyke

A quartz-hornblende-feldspar porphyry dyke (QHFP dyke) was sampled in a freshly uncovered outcrop in a road cut near an area of recent drilling in the diorite unit (sample RW-95-98, Figure 33-3). A relatively fresh sample was collected which provided a small number of small transparent light-yellow to orange-amber euhedral zircons of tabular and prismatic morphology. This unit had previously been inferred to be of Tertiary age. However, five fractions of unabraded zircons define a linear array with upper and lower concordia intercept ages of 199 +23/-13 Ma and 24 Ma, respectively (MSWD=0.3) (Figure 33-4c). Because of the fine grain size of the zircons and the small amount recovered, none of the fractions were abraded prior to dissolution. The data array reflects moderate to strong post-crystallization Pb-loss, however there is no indication of any inherited zircon component present. The upper intercept of 199 Ma is therefore interpreted as the best etimate for the crystallization age of the rock.

Takomkane Batholith

Medium-grained, equigranular, fresh to very weakly altered granodiorite was collected from a steep outcrop at the southern end of Ruth Lake approximately 19 kilometres southeast of the study area (Figure 33-3; approximate coordinates: latitude 51°49'30" N, longitude 121°01'30" W). The Takomkane batholith is exposed nearer to the Ann property but in heavily forested, low, marshy areas where the granodiorite shows moderate weathering and is therefore unsuited for geochronological study. The granodiorite sample yielded abundant high-quality, coarse, transparent and pale amber, euhedral zircons. Inclusion-free zircons were chosen and divided into three fractions which were strongly abraded. Two of the three zircon fractions were concordant with $^{206}Pb/^{238}U$ ages of 193.5±0.6 Ma (Figure 33-4d), which is interpreted to be the crystallization age of the unit. A third zircon fraction is slightly discordant, reflecting a trace amount of inheritance coupled with minor Pb-loss. Two fractions of euhedral, medium-yellow titanite were also analyzed and yielded concordant analyses with a $^{206}Pb/^{238}U$ age of 193.7±1.2 Ma.

Geochronology Discussion

New U-Pb ages reported here for rocks on and near the Ann property lead to the following conclusions:

- The presumed Early Jurassic age of diorite on the Ann property has been confirmed at 203±4 Ma.
- An Early Jurassic age of 203.9±4.2 for a feldspar-porphyritic andesite body suggests that intrusive rocks and at least some of the Nicola Group volcanic rocks in the area are coeval.
- Although the new U-Pb age for the QHFP dyke is not tightly constrained, it indicates that the dyke is also an Early Jurassic intrusion and clearly not Tertiary as previously suggested by Blann (1995) and von Guttenberg (1994).
- The tightly constrained U-Pb zircon age of 193± 0.6 Ma for the Takomkane batholith supercedes an earlier reported U-Pb age of 207±5 Ma for this body (Calderwood et al., 1990). Both samples were collected from essentially the same outcrop near Ruth Lake, close to the centre of the batholith. Different phases of the Takomkane have been reported (Campbell and Tipper, 1971) and may result in slight variations in cooling histories from the core to the outer edge of the pluton. A K-Ar biotite date of 187±14 Ma for the Takomkane batholith (Leech et al, 1963) was done on a sample collected near the northeast corner of the pluton and probably reflects relatively slow cooling of the batholith through the argon blocking temperature of the biotite. The calc-alkalic Takomkane batholith therefore is clearly younger than the smaller alkalic intrusions on the Ann property.

TRACE Pb ISOTOPIC ANALYSIS

Trace Pb isotopic compositions were determined for potassium feldspars from intrusive bodies and for sulphide samples collected both regionally and within the study area (Figure 33-3). The purpose of this study was to attempt to relate the different styles of regional and local mineralization and alteration with intrusive suites interpreted to be genetically linked with mineralization. Analytical results are presented in Table 33-2 and plotted on Figure 33-5 (a), (b) and (c). Several conclusions can be drawn from the data set:

Pb isotopic compositions of sulphide samples collected from hydrothermal breccia bodies in the study area, as well as veins hosted within the diorite-monzodiorite intrusive complex (samples 10, 11, 15, 16 and 18), and a mineralized monzodiorite body (samples 12 and 13) to the southwest of the study area are very similar to those from feldspar from both altered diorite in the study area and altered monzonite (sample 2) collected west of Peach Lake. The feldspar Pb compositions are thought to represent primary igneous compositions, whereas the sulphide Pb compositions provide an isotopic 'fingerprint' for the hydrothermal system that produced the mineralization. The data suggest that the mineralizing fluids were ultimately derived from the dioritic to monzonitic magmas.

Sulphides that occur in fracture-controlled veins (sample 14) within a moderately altered monzonitic intrusive body southwest of Peach Lake (Figure 33-3) give much more radiogenic Pb isotopic compositions than other sulphides and feldspars analyzed from the Ann property. This likely indicates that the Peach Lake occurrence is unrelated to other occurences in the study area, and may be considerably younger.

Feldspar Pb analyses from unaltered massive granodiorite and from a potassium feldspar-pegmatite phase of the Takomkane batholith (samples 5 and 3, 4 respectively) define a field that is distinct from the other feldspar and sulphide samples analyzed from the study area. These data suggest that the Takomkane batholith was not genetically related to mineralization and alteration in the study area.

A bornite-chalcopyrite skarn (sulphide sample 17) that occurs northeast of the Ann property less than 300 metres from an outcrop of the Takomkane batholith (Figure 33-3) shows a similar trace Pb isotopic signature to those within the study area. This suggests that the skarn-forming event was related to the same magmatic/hydrothermal event that formed other mineral occurences in the area, rather than to the Takomkane batholith, as had previously been thought.

WHOLE ROCK GEOCHEMISTRY

Whole rock chemical compositions for a limited suite of intrusive and volcanic rocks on or near the Ann property are given in Table 33-3. Samples comprise Nicola Group basalt, porphyritic andesite, diorite, gabbro, quartz-hornblende-feldspar porphyry (QHFP), monzonite, monzodiorite, Takomkane granodiorite and Tertiary (?) basalt. An attempt was made to select the freshest samples available for each unit of interest.

Nicola Group volcanic rocks and intrusions of the diorite-monzodiorite suite are alkaline to mildly sub-alkaline. However, the QHFP dyke and the Takomkane batholith both lie in the sub-alkaline field of an alkaline affinity diagram (Figure 33-6a).

Widespread metasomatic overprinting and the fine grained nature of Nicola group volcanic rocks mask geochemical differences between andesitic and basaltic protoliths; however whole rock geochemical analysis suggests a basaltic composition (Table 33-3) for at least some of the volcanic rocks.

A plot of Na_2O versus K_2O subdivides intrusive alkaline rocks into high-potassic, potassic and sodic series (Figure 33-6b). All intrusive samples collected at the Ann Property (with the exception of the QHFP dyke) plot in the potassic field. Trace element compositions place all intrusive bodies sampled within the volcanic arc granitoid field on a Rb versus (Y+Nb) discrimination diagram.

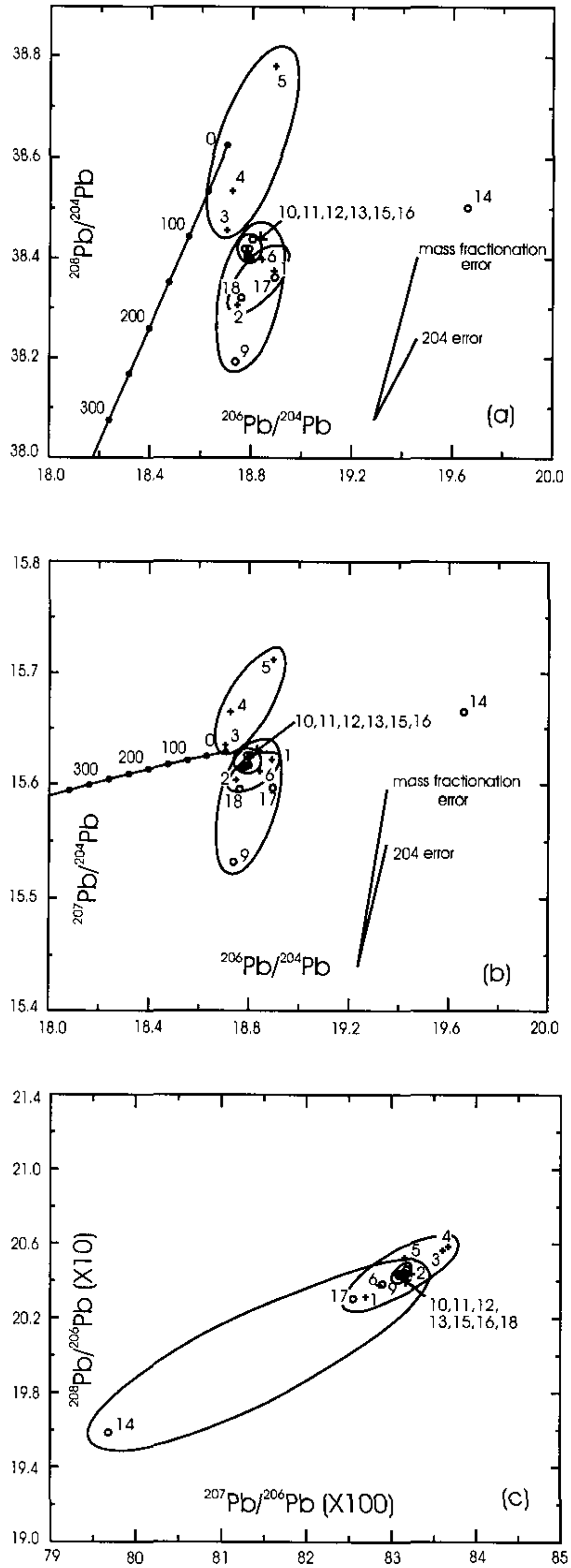

Figure 33-5. Trace-Pb isotope plots of (a) $^{208}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$, (b) $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ and (c) $^{208}Pb/^{206}Pb$ versus $^{207}Pb/^{206}Pb$ for sulphide (circles) and feldspar (crosses) samples collected across the Ann Property study area.

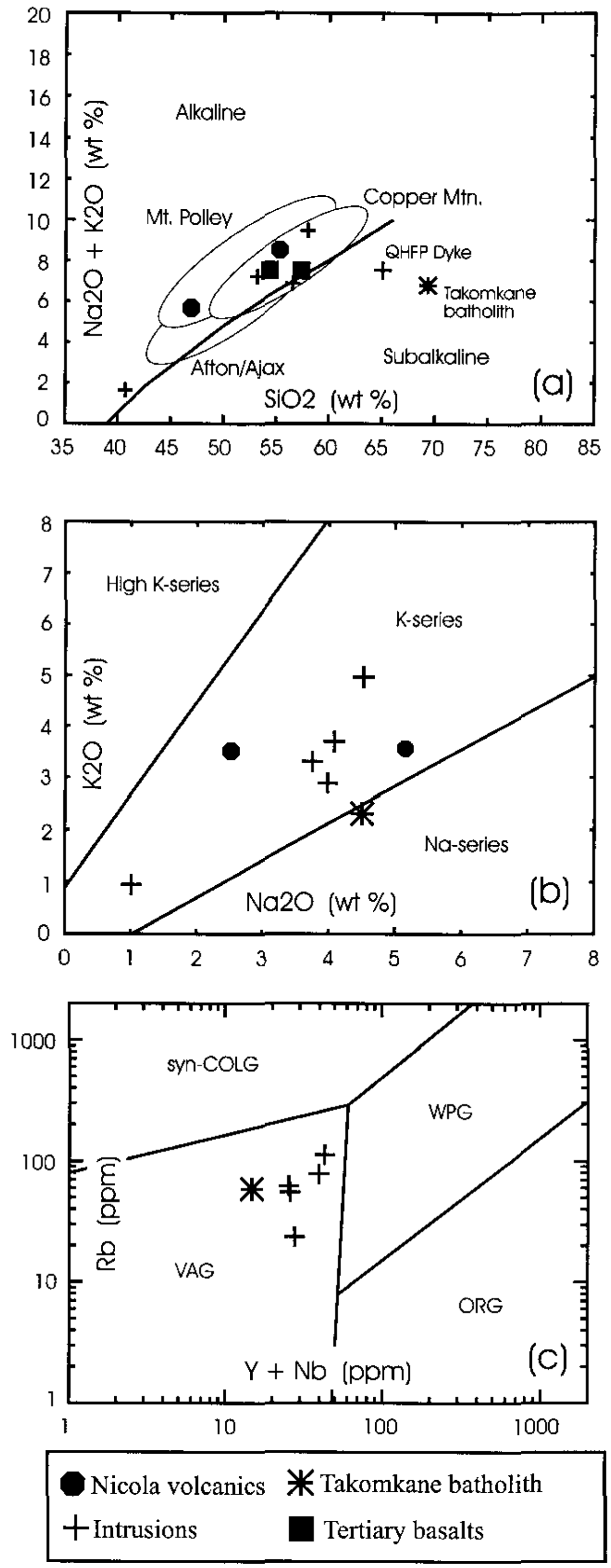

Figure 33-6. Classification of intrusive and volcanic rocks as plotted on (a) alkaline affinity diagram (Irvine and Barager, 1971), (b) Na_2O vs. K_2O (Middlemost, 1975) and (c) on a tectonic affinity diagram which plots Rb vs. Y+Nb (Pearce et al., 1984); abbreviations are volcanic arc granite (VAG), ocean ridge granite (ORG), within plate granite (WPG) andsyn-collisional granite (syn-COLG).

Table 33-2. Common-Pb isotopic data.

Sample Number	Description[1] /Occurrence	Location (UTM)	$^{208}Pb/^{204}Pb$ (± 1σ, %)	$^{207}Pb/^{204}Pb$ (± 1σ, %)	$^{206}Pb/^{204}Pb$ (± 1σ, %)	$^{208}Pb/^{206}Pb$ (± 1σ, %)	$^{207}Pb/^{204}Pb$ (± 1σ, %)
RW-1	o,f,a; diorite phase of intrusive complex at Ann property study area	617850E 5757750N	38.375 (0.071)	15.622 (0.067)	18.89 (0.069)	20.315 (0.018)	82.701 (0.017)
RW-2	o,f,a; monzitic intrusion near west end of Peach Lake	614240E 5760200N	38.307 (0.004)	15.604 (0.003)	18.745 (0.003)	20.435 (0.002)	83.242 (0.001)
RW-3	o,f,u; pegmatitic-granodiorite from western edge of Takomkane batholith	621500E 5760400N	38.456 (0.012)	15.635 (0.008)	18.702 (0.011)	20.563 (0.005)	83.604 (0.007)
RW-4	o,f,u; pegmatitic granodiorite from western edge of Takomkane batholith	621500E 5760400N	38.535 (0.005)	15.665 (0.003)	18.722 (0.003)	20.583 (0.004)	83.674 (0.001)
RW-5	o,f,u; Takomkane grandiorite collected at SE end of Ruth Lake	635750E 5743125N	38.780 (0.019)	15.712 (0.016)	18.894 (0.017)	20.525 (0.009)	83.158 (0.006)
RW-6	o,f,a; potassically altered diorite phase of study area intrusive complex	617500E 5757500N	38.398 (0.011)	15.612 (0.009)	18.842 (0.01)	20.379 (0.004)	82.860 (0.003)
RW-9	o,py-cp,a; potassically altered xenolithic monzonite intrusion	616750E 5757800N	38.193 (0.065)	15.532 (0.065)	18.737 (0.065)	20.384 (0.007)	82.897 (0.005)
RW-10	c,py; hydrothermal breccia/vein-fill hosted within diorite-monzodiorite intrusive complex at study area	617850E 5757750N	38.401 (0.007)	15.617 (0.003)	18.796 (0.005)	20.431 (0.005)	83.088 (0.003)
RW-11	c,py; hydrothermal breccia/vein-fill hosted within diorite-monzodiorite intrusive complex at study area	617850E 5757750N	38.438 (0.005)	15.626 (0.003)	18.804 (0.004)	20.441 (0.003)	83.100 (0.003)
RW-12	c,py; vein-fill within moderately altered monzodiorite intrusion	617000E 5756125N	38.419 (0.03)	15.615 (0.03)	18.772 (0.03)	20.466 (0.003)	83.183 (0.003)
RW-13	c,py; vein-fill within moderately altered monzodiorite intrusion	617000E 5756125N	38.419 (0.005)	15.626 (0.005)	18.790 (0.005)	20.447 (0.001)	83.164 (0.002)
RW-14	c,py; vein-fill within monzonitic intrusion SW of Peach Lake	614240E 5759700N	38.502 (0.01)	15.665 (0.009)	19.659 (0.01)	19.585 (0.003)	79.686 (0.002)
RW-15	c,py; hydrothermal breccia hosted within diorite-monzodiorite intrusive complex at study area	617850E 5757750N	38.402 (0.01)	15.620 (0.005)	18.789 (0.008)	20.439 (0.006)	83.136 (0.006)
RW-16	c,py; hydrothermal breccia hosted within diorite-monzodiorite intrusive complex at study area	617850E 5757750N	38.405 (0.005)	15.616 (0.005)	18.784 (0.005)	20.446 (0.001)	83.139 (0.001)
RW-17	o,bo; skarn near western edge of Takomkane batholith	621275E 5760300N	38.362 (0.005)	15.597 (0.003)	18.893 (0.004)	20.305 (0.003)	82.553 (0.003)
RW-18	c,py; vein-fill associated with hydrothermal breccia hosted within study area intrusive complex	617850E 5757750N	38.3219 (0.03)	15.596 (0.026)	18.760 (0.03)	20.427 (0.007)	83.134 (0.013)

[1] o=outcrop sample; c=core sample;f=feldspar; py=pyrite; cp=chalcopyrite; bo=bornite; a=altered; u=unaltered

Table 33-3. Whole rock chemical analyses and normative mineralogy for volcanic and intrusive rocks.

	Sample#	95-10	95-112	95-122	95-123	95-124	95-98	95-70	95-73	95-81	95-101
	Rock	Gabb	Dior	Grdior	Mnzdior	Mnz	QHFP	NiBslt	NiPrAn	TPBslt	TABslt
SiO2	wt %	40.22	52.49	68.83	57.47	55.56	61.2	46.2	54.58	52.53	54.51
Al2O3	wt %	15.43	18.52	16.12	18.15	17.82	14.27	16.04	20.12	18.45	17.04
TiO2	wt %	1.15	0.61	0.23	0.66	0.54	0.38	1.07	0.44	1.21	0.71
Fe2O3	wt %	16.28	7.93	2.69	6.34	7.21	3.61	13.04	7.3	7.25	6.93
MnO	wt %	0.27	0.26	0.09	0.18	0.17	0.08	0.19	0.08	0.13	0.13
MgO	wt %	6.91	2.99	0.94	1.81	2.47	3.88	6.15	2.21	2.47	2.13
CaO	wt %	16.04	8.1	3.49	4.61	7.37	3.31	9.55	5.05	6.5	5.87
Na2O	wt %	0.88	3.76	4.42	4.44	3.9	3.72	2.33	5.02	3.73	3.65
K2O	wt %	0.75	3.36	2.35	4.95	2.88	3.37	3.26	3.39	3.55	3.48
P2O5	wt %	0.84	0.56	0.1	0.48	0.36	0.21	0.57	0.48	0.74	0.56
Cr2O3	wt %	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01
SUM	wt %	98.78	98.59	99.27	99.1	98.29	94.05	98.41	98.68	96.57	95.02
LOI	wt %	0.88	0.83	0.64	0.91	1.2	5.51	1.05	1.03	3.05	4.32
Ba	ppm	279	989	799	1247	862	1235	566	815	1511	1572
Rb	ppm	24	61	61	115	56	73	95	56	87	108
Sr	ppm	1300	1291	558	739	949	656	827	1105	1035	974
Nb	ppm	<5	<5	<5	7	<5	12	<5	<5	11	<5
Zr	ppm	88	127	125	185	107	165	102	166	197	193
Y	ppm	25	25	15	35	25	25	21	23	24	26
Th	ppm	<5	<5	11	<5	<5	19	<5	<5	<5	<5
U	ppm	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5

Normative Mineralogy

Qtz	mol %	0	0	57.8	0	2.84	39.53	0	0	0	9.09
Cor	mol %	0	0	0.19	0	0	0	0	0.07	0	0
Zir	mol %	0.02	0.04	0.02	0.05	0.03	0.03	0.03	0.05	0.06	0.05
Or	mol %	0	17.99	7.38	27.6	15.99	13.72	15.95	18.32	20.1	19.13
Alb	mol %	0	26.61	21.07	37.57	32.87	22.96	6.17	38.02	32.05	30.43
An	mol %	29.13	21.49	8.94	14.1	21.23	8.44	19.57	20.35	22.12	18.41
Lc	mol %	3.6	0	0	0	0	0	0	0	0	0
Ne	mol %	6.4	3.95	0	0	0	0	11.12	3.17	0	0
Di	mol %	22.3	11.96	0	4.72	11.18	2.05	16.74	0	4.44	5.53
Hy	mol %	0	0	4.09	4.43	13.63	12.15	0	0	6.93	14.36
Oliv	mol %	29.94	15.36	0	8.75	0	0	26.7	18.03	9.32	0
Cs	mol %	4.47	0	0	0	0	0	0	0	0	0
Cr	mol %	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Ap	mol %	0.89	0.66	0.07	0.59	0.44	0.19	0.62	0.57	0.93	0.68
Ilm	mol %	3.24	1.92	0.43	2.17	1.77	0.91	3.08	1.4	4.03	2.3

Lithology Abbreviations

Gabb=Gabbro	QHFP=Quartz-Hornblende-Feldspar Porphyry
Dior=Diorite	NiBslt=Nicola Basalt
Grdior=Granodiorite	NiPrAn=Nicola Porphyritic Andesite
Mnzdior=Monzodiorite	TPBslt=Tertiary Porphyritic Basalt
Mnz=Monzonite	TABslt=Tertiary Amygdaloidal Basalt

Normative Mineralogy Abbreviations

Qtz=quartz	An=anothite	Oliv=olivine
Cor=corundum	Lc=leucite	Cs=DiCaSilicate
Zir=zircon	Ne=nepheline	Cr=chromite
Or=orthoclase	Di=diopside	Ap=apatite
Alb=albite	Hy=hypersthene	Ilm=illenite

A plot of Na_2O versus K_2O subdivides intrusive alkaline rocks into high-potassic, potassic and sodic series (Figure 33-6b). All intrusive samples collected at the Ann Property (with the exception of the QHFP dyke) plot in the potassic field. Trace element compositions place all intrusive bodies sampled within the volcanic arc granitoid field on a Rb versus (Y+Nb) discrimination diagram (Figure 33-6c).

Alkalic porphyry deposits of the Canadian Cordillera have been divided into silica-saturated and silica-unsaturated categories by Lang et al. (1995). Silica-unsaturated types are associated with alkalic rocks that have leucite and/or nepheline in their modal or normative mineralogy, (e.g., Mount Polley, Galore Creek and Lorraine); whereas silica-saturated systems (e.g., Copper Mountain, Afton-Ajax and Mount Milligan) are associated with alkalic rocks with modal or normative quartz and lacking feldspathoids. No quartz or feldspathoids were observed during petrographic examination of intrusive and volcanic rocks from the study area. Normative mineralogy, however, shows that samples of gabbro and diorite from the Ann property are nepheline-leucite-normative and nepheline-normative respectively (Table 33-3). As well, samples of Nicola Group basalt and porphyritic andesite are nepheline-normative. Except for a monzodiorite sample collected from an adjacent property none of the rocks on the study area are quartz-normative. Preliminary normative chemical analyses of rocks at and near the Ann property therefore suggest that it should be classified as a silica-undersaturated alkalic porphyry system.

DISCUSSION AND CONCLUSIONS

Lithological assemblages, and styles of alteration and mineralization throughout the Ann property study area indicate that it is an alkalic Cu-Au porphyry system similar to other alkalic deposits within Quesnellia. The study area is underlain by an Early Jurassic diorite-monzodiorite intrusive suite emplaced into Late Triassic-Early Jurassic Nicola Group volcanic rocks. The latter rocks consist of massive and polymictic mafic volcanic breccia, augite-phyric andesite, feldspar-hornblende-phyric basalt and porphyritic andesite. Collectively these rocks are interpreted to form part of a comagmatic volcanic sequence (Figure 33-7) that is thought to be coeval with the local stocks, sills and dykes.

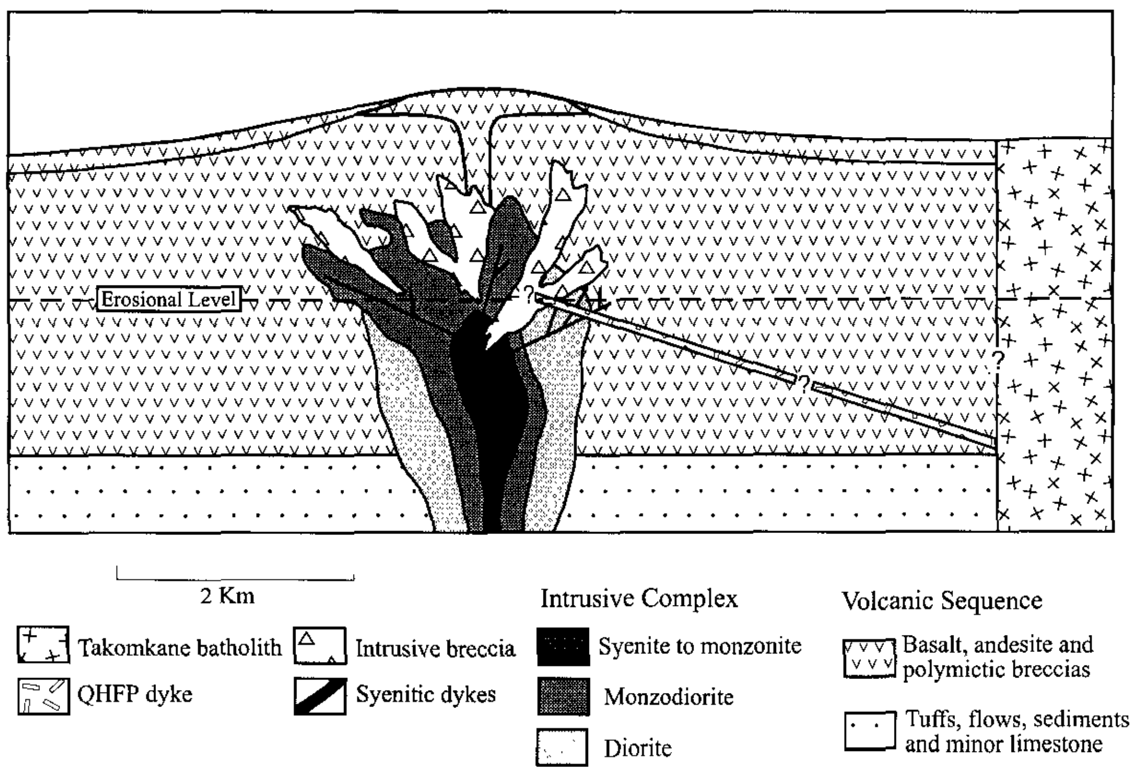

Figure 33-7. Idealized cross-section through the Late Triassic to Middle Jurassic volcanic and intrusive complex at the Ann property study area. Spatial relationships between volcanic and intrusive rocks at the study area, the quartz-hornblende-feldspar porphyry dyke (QHFP), and the Takomkane batholith are speculative.

Geochemically all the intrusive and volcanic rocks at the Ann Property are of alkaline affinity with the exception of the younger Takomkane granodiorite batholith and a quartz-hornblende-feldspar porphyry dyke (QHFP dyke) which are calc-alkaline. On an Rb versus (Y+Nb) diagram all intrusive rocks in the study area, as well as the Takomkane batholith, plot within the island arc granitoid field. The volcanic rocks and the diorite-monzodiorite intrusive suite are cut by a large unmineralized polylithic intrusive breccia containing angular to subrounded fragments of mafic volcanic and intrusive rocks of dioritic to syenitic composition. An unmineralized calc-alkalic quartz-hornblende-feldspar porphyry dyke (QHFP dyke) cross-cuts the intrusive complex and may be related to regional calc-alkaline magmatic activity.

Hydrothermal alteration throughout the study area is complex and variable. Potassic alteration has affected primarily plutonic rocks and is characterized by potassium feldspar-biotite-magnetite ± chlorite ± epidote ± sulphide ± albite assemblage. Within this alteration package are small, generally east-west trending zones of intense potassic feldspar `flooding' where alteration is characterized by a secondary potassic feldspar-epidote-biotite-magnetite and sparsely disseminated pyrite-chalcopyrite ± bornite assemblage. Surrounding the potassic zone are propylitically to potassically altered intrusive phases, Nicola Group volcanic rocks and intrusive breccias. These most commonly contain a secondary mineral assemblage of epidote-magnetite-chlorite-potassium feldspar-calcite-sericite-biotite ± albite ± pyrite ± chalcopyrite ± bornite.

Mineralization at the Ann property study area is both fracture-controlled and disseminated. It is most closely associated with zones of moderate to intense potassic-propylitic alteration. Sulphides (pyrite-chalcopyrite ± bornite) occur mainly as disseminations and mafic replacement but are locally abundant in veinlets with potassic feldspar-epidote-chlorite ± magnetite ± albite.

Elevated copper-gold values are known to exist within narrow zones of hydrothermal breccia that cut the diorite-monzodiorite suite at the Ann property adjacent to the QHFP dyke. This type of mineralization (pyrite-chalcopyrite-bornite with gold and abundant magnetite), occurs in veinlets (<1-2 cm), and as disseminated blebs interstitial to brecciated and potassically to albitically altered breccia clasts. The role, if any, of the nearby QHFP dyke in concentrating and remobilizing sulphides and gold associated with hydrothermal brecciation is uncertain.

Trace Pb isotope analyses were performed on feldspars from intrusive bodies and sulphide samples collected both regionally and from the Ann property. The data suggests that the mineralizing fluids that formed the Cu-Au mineralization within the diorite-monzodiorite intrusive complex and regionally were derived from dioritic to monzonitic magmas. Feldspars from the Takomkane batholith have distinctly different isotopic signatures than the other feldspar and sulphide samples analyzed and therefore may be unrelated to mineralization and alteration in the study area.

New U-Pb zircon and titanite ages for rocks at the Ann property and for the Takomkane batholith support previous tectonostratigraphic interpretations that these plutonic bodies represent intrusions emplaced into Quenellia during Middle Jurassic time either during, or just prior to, accretion with cratonic North America. The alkalic diorite-monzodiorite intrusive complex was emplaced during Early Jurassic (203±4 Ma) time into a Late Triassic-Early Jurassic Nicola Group volcanic sequence. The Early Jurassic age for a porphyritic andesite (203.9±4.2 Ma) suggests that Nicola Group volcanism continued into Early Jurassic time in the area.

The alkaline intrusive bodies of the Ann Property most closely compare to the mainly Early Jurassic (208-199 Ma) Copper Mountain Suite of plutons, as defined by Woodsworth et al. (1991). This plutonic suite forms a roughly linear, northwest-trending belt of small alkalic intrusions stretching the length of Quesnellia and typically range from diorite to syenite in composition (Lang et al., 1995, and Woodsworth et al., 1991). The Copper Mountain Suite of intrusions hosts several important Cu-Au ± Mo porphyry-style deposits, including Mount Polley, Afton-Ajax, Copper Mountain and Galore Creek. The Guichon Plutonic Suite is a mainly latest Triassic to Early Jurassic (210-200 Ma) group of large, primarily calc-alkalic, granodiorite plutons which also scatter along the length of Quesnellia. These intrusions typically have elongate shapes suggesting emplacement may have been controlled by either pre- or synplutonic faults (Gabrielse, 1991). However, the new U-Pb zircon date of 193±0.6 Ma (Early Jurassic) reported here for the calc-alkalic Takomkane batholith indicates a slightly younger age than the rest of the Guichon Plutonic Suite in which it has previously been included. This younger date alone does not preclude the possibility of inclusion within the Guichon Suite but rather may indicate emplacement of this suite over a longer period of time than had previously been thought.

Both the Copper Mountain and Guichon Suites are spatially and temporally related to volcanic rocks of the Nicola Group (Mortimer,1986). The Guichon Suite has been linked to the calc-alkalic western facies of the Nicola Group island arc assemblage (Monger, 1985), and the smaller, alkalic plutons of the Copper Mountain Suite may be related, as comagmatic equivalents, to the alkaline rocks of the central and eastern Nicola volcanic facies (Barr et al., 1976). Petrographic observations of both volcanic and intrusive rock types coupled with new geochronology for the Ann property alkalic diorite-monzodiorite intrusive complex support the interpretation that the system correlates with the Copper Mountain Suite of intrusions that were emplaced into a central or eastern facies of the Nicola Group. Preto (1979) concluded that these intrusions represent subvolcanic roots of a Late Triassic to Early Jurassic, west-facing island arc.

Despite strong geochemical differences, the alkalic intrusions at the Ann Property and the calc-alkalic Takomkane batholith show a relatively close spatial and temporal relationship. This indicates that both alkaline and subalkaline magmatism occurred during Early Jurassic time in this area, but does not resolve the question of whether a genetic link exists between these two intrusive suites.

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