Character and metallogeny of Permian, Jurassic and Cretaceous plutons in the southern Yukon-Tanana Terrane[1]

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ABSTRACT

Between the Swift and Nisutlin rivers, unmetamorphosed granite to ultramafic intrusions of four ages (from Permian through Cretaceous) span the amalgamation of Cassiar Platform with Yukon-Tanana and Cache Creek terranes. The mid-Permian granitic Ram Stock and two plutons cutting the Sylvester Allochthon lie at the edge of the Dorsey Complex, a remnant of an ancient passive margin succession that underlies the volcanic arcs of Yukon-Tanana Terrane. Middle Jurassic, locally foliated granodiorite to gabbro intrusions are metaluminous, and high in Sr and low in Ti compared to the Cretaceous suite. These 'I-type' volcanic arc plutons may be the remnants of an overlapping arc correlative with the Quesnel Terrane. The Cretaceous (113 to 98 Ma) meta- to peraluminous granites are late orogenic incipient 'A-type' plutons from highly fractionated F- and Cl-rich magmas. These generated extensive hydrothermal systems that produced tin, tungsten, molybdenum and beryl occurrences.

RÉSUMÉ

Entre les rivières Swift et Nisutlin, des intrusions granitiques à ultramafiques non métamorphisées de quatre âges (allant du Permien au Crétacé) couvrent la limite entre la plate-forme de Cassiar et les terranes de Yukon-Tanana et de Cache Creek. Le stock granitique de Ram et deux plutons du Permien moyen, recoupant l'Allochtone de Sylvester, reposent à la bordure du Complexe de Dorsey, vestige d'une ancienne succession de marge passive sous-jacente aux arcs volcaniques du terrane de Yukon-Tanana. Des intrusions de granodiorite et de gabbro foliés par endroits, datant du Jurassique moyen, sont métalumineuses, ainsi que riches en Sr et pauvres en Ti en comparaison avec la série du Crétacé. Ces plutons de type I d'arcs volcaniques peuvent représenter les vestiges d'un arc chevauchant corrélatif au terrane de Quesnel. Les granites métalumineux à hyperalumineux du Crétacé (113 à 98 Ma) sont des plutons embryonnaires tardiorogéniques de type A, qui ont pour origine des magmas très fractionnés, riches en F et en Cl. Les vastes systèmes hydrothermaux générés ont donné lieu à des occurrences d'étain, de tungstène, de molybdène et de béryl.

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INTRODUCTION

Almost 40% of the exposed bedrock in south-central Yukon and adjacent northern British Columbia is of felsic plutonic origin. Most of the plutons were intruded after the last major deformational episode and are termed post-tectonic. Isotopic dating has refined their ages (e.g., Stevens et al., 1993; Gordey et al., 1998; Roots et al., 2002; Nelson and Friedman, 2004): several are mid-Permian, many are Early Jurassic and mid-Cretaceous, and a few are Early Eocene.

Mineral occurrences are spatially associated with these plutons in the region. The occurrences which follow are from the Yukon MINFILE (Deklerk, 2003). A couple are also noted from BC MINFILE (Bradford and Jakobsen, 1988). At least ten mineral occurrences in greisen, skarn and fracture-fillings are associated with the Cretaceous Seagull Batholith (Dick, 1979; Mato et al., 1983; 105B 040) and the Thirtymile Range (50 km northwest; Liverton, 1990; 105C 038). Other deposit types are veins with chalcophile elements (silver and gold; Logjam, 105B 038), tungsten-molybdenum-bismuth-beryllium (beryl, aquamarine) porphyries (Logtung: Yukon MINFILE 105B 039, and BC MINFILE 104 016) and cassiterite-chalcopyrite breccias (STQ/Verley; 105B 078). Understanding the relationship of mineralization to the plutonic suites can be a useful tool in the continuing search for mineral deposits in the region.

In this paper we summarize the mineralogical and chemical character of three of these age-determined suites, and speculate on their origin. Isotopic age data for the Ram Stock is presented because this intrusion is important in resolving the tectonic history of southern Yukon-Tanana Terrane.

REGIONAL GEOLOGY

The plutons intrude an 80-km-wide northwest-trending belt of Yukon-Tanana Terrane (YTT). This terrane consists of polydeformed sedimentary, volcanic and plutonic rocks that have been resolved into time- and protolith-determined arc successions, above metasedimentary units of probable continental-shelf origin (e.g., Colpron and the Yukon-Tanana Working Group, 2001). Southern YTT as used in this paper corresponds to the former Dorsey Terrane (e.g., Monger et al., 1991), now an obsolete term as the units within it have direct parallels with those of YTT.

YTT is separated by transcurrent faults from Cache Creek Terrane to the west, and Slide Mountain Terrane to the east. These terranes contain stratigraphy that mainly records the evolution of mid-Paleozoic to Jurassic ocean basins, for the most part synchronous with the history of YTT. Slide Mountain Terrane is faulted to the east against marginal sedimentary rocks of ancient North America, a miogeoclinal succession of Cambrian to Permian age. In northern BC, between Dease Lake and the Rancheria River, is a klippe atop the miogeocline, which contains thrust slices of Slide Mountain and YTT (Fig. 1). This is the Sylvester Allochthon (e.g., Nelson, 1993), and is important because Slide Mountain Terrane is preserved here, while it is very thin or faulted out between YTT and ancient North America in Yukon.

The recent redefinition of YTT is based upon time-sequences rather than geographic area (c.f., Mortensen, 1992); currently, the term is restricted to the Devonian-Mississippian series of arc assemblages. In the BC-Yukon border area of YTT, these arc successions are the Big Salmon and Ram Creek complexes (Mihalynuk et al., 2000; Roots and Heaman, 2001). They lie along the west and east sides of YTT; between them a central area is underlain by Dorsey Complex, a highly strained 'basement' of siliciclastic sediments and amphibolite (Nelson, 2000), structurally overlain by basin and off-shelf sediment (Swift River Group; Nelson, 2001).

Overlapping the three complexes of southern YTT is a Late Mississippian to Triassic series of arc-related successions equivalent to the Quesnel Terrane of the southern Cordillera (Simard et al., 2003; Nelson and Friedman, 2004). An erosional unconformity and locally prominent conglomerate beneath the Klinkit Group (Simard et al., 2003) defines the irregular boundary between Quesnellia and underlying YTT.

A Permian intrusion (the Ram Stock), described in this paper, intrudes YTT just north of the Seagull Batholith. Two very large, subcircular Jurassic intrusions, the Simpson Peak and Nome Lake batholiths, in northern BC, could have supplied volcanic arc systems (Nelson and Friedman, 2004). Cretaceous and early Eocene plutons are considered post-tectonic because they intruded after these terranes were joined together. They occur in many suites (Breitsprecher et al., 2004), but we shall focus here upon the Cretaceous Hake and Thirtymile plutons, which are peculiar to southern YTT.

GRANITIC SUITES

Table 1 provides a summary of dates for plutonic rocks in the BC-Yukon border area. These dates indicate four age groupings: Late Permian (270 to 255 Ma), Early Jurassic (ca. 188 Ma), early Late Cretaceous (101 Ma), and early Eocene (58 Ma). The physical characteristics are summarized below.

LATE PERMIAN SUITE

Representatives of the Permian suite include the Ram Stock in southern Yukon, two smaller plutons in Sylvester Allochthon (Gabrielse et al., 1993), and several muscovite-bearing pegmatite dykes in northern BC (Nelson and Friedman, 2004). Only the Ram Stock is described here. It is a 26-km-long body, elongated northwest and parallel to the regional structural grain (Fig. 1). Width varies up to 3 km, the product of vertical offset on northeast-trending faults that expose different levels of a steeply dipping tabular or lenticular intrusion.

Almost all of Ram Stock is coarse-grained, equigranular hornblende>biotite quartz monzonite to granodiorite. The classic description of Poole (1956) includes microperthitic orthoclase, strained quartz and corroded ferromagnesian minerals. The range of modal analyses is shown in Table 2. It was known as the 'green granite' due to the abundant chlorite and pervasive sausseritization, yet it remains massive and resistant (Fig. 2).

The significance of the Ram Stock was first raised by R. Stevens during revision mapping (Stevens and Harms, 1995; Stevens, 1996). The top of the body (southwest contact) is intrusive into lower Dorsey Complex (Fig. 3). Within the stock, xenoliths show the same high-strain fabric as does the Dorsey host rock to the southwest. In contrast, the dykes and offshoots of Ram Stock are relatively undeformed. Thus a date for the Ram Stock provides a minimum age for the deformation that imparted a distinct texture to rocks of the Dorsey Complex. Without the date, this deformational episode cannot be conclusively distinguished from that stemming from obduction of allochthons onto ancient North America (Cordilleran orogeny). A hornblende separate analysed by the Rb-Sr method gave a 235±12 Ma date (Hunt and Roddick, 1987).

The base of Ram Stock (northeast contact, and well exposed across ridge spurs west of Hidden Lake (Fig. 2)) is a 10- to 20-m-wide mylonitic shear zone. This is the Hidden Lake Thrust, an intra-terrane fault separating Dorsey Complex from Ram Creek Complex. It extends many tens of kilometres southeast, where top-to-the-east motion is indicated (Nelson et al., 2001). Determination of the age of the Ram Stock provides a maximum age of this key thrust fault.

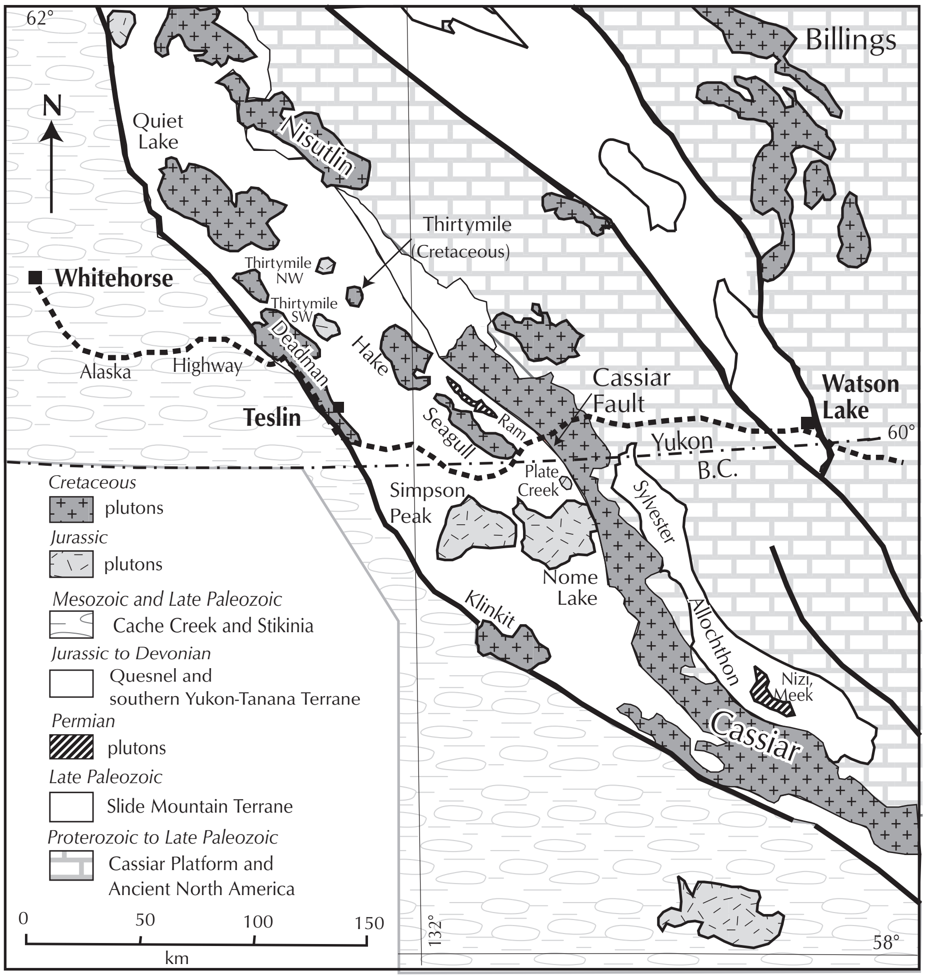


Figure 1. *The area of southern Yukon-Tanana Terrane in northern BC and Yukon, showing the distribution of major post-tectonic plutons. The outlines of Quesnellian and Yukon-Tanana Terrane rock units is from Nelson and Friedman (2004; for BC) and Colpron (draft map; for Yukon).*

Table 1. *Summary of isotopic dates for post-tectonic plutons within Yukon-Tanana Terrane.*

Name of pluton	Size	Main rock type	Minor types	Mineral occurrence (not necessarily same age)	Age, method	Reference for age
Eocene						
Logtung	2.5 km^2	monzonitic granite	felsic dykes	scheelite, molybdenite, beryl	58.6±1.5 U-Pb zircon	Mihalynuk and Heaman, 2001
Cretaceous						
Thirtymile	15 km^2	monzo- and syenogranite		Sn (tin) skarn	99±3 K-Ar on biotite hornfels	Liverton, 1990
		K-feldspar leucogranite		beryl	101±5.6 Rb/Sr	Liverton et al., 2001
Seagull	43 x 8 km	leuco quartz monzonite	alaskite	Sn, Pb, Zn skarn, wolframite	100±2.8 K-Ar	Mato et al. 1983
Hake	30 x 15 km	coarse biotite granite		Au skarn	98.3±2.9 Rb/Sr	Liverton et al., 2001
STQ	< 1 km^2	granite	alaskite	cassiterite, scheelite, molybdenite, chalcopyrite	108±2 K-Ar on biotite	Hunt and Roddick, 1987 (GSC 87-152)
Klinkit	35 x 25 km	bt-hb granite		unknown	109.4 U-Pb zircon	Roots et al., 2002
Jurassic						
Logjam pluton	4 x 3 km	hb quartz monzonite, monzogranite	diorite, peridotite	unknown	181±14 K-Ar	Hunt and Roddick, 1987 (GSC 87-151)
NW Thirtymile	12 km^2	monzogranite to granodiorite		unknown		
SW Thirtymile	20 km^2	quartz diorite, hb granodiorite	gabbro		181.5±2.5 Rb-Sr	Liverton et al., 2001
Simpson Peak	20 x 40 km	granite, quartz monzonite	hb gabbro	unknown	185±14 K-Ar on hb	Mihalynuk et al., 1998
Nome Lake	36 x 28 km	hb-bt quartz diorite to quartz monzonite	bt-hb quartz diorite margin	unknown	187±9 K-Ar on hb, bt	Mihalynuk et al., 1998
Plate Creek	12 x 6 km	hb diorite	quartz diorite	stibnite in quartz vein (Tan showing)	ca. 203 U-Pb; 197.3±0.9 U-Pb zircon	L. Heaman, pers. comm., 2002; Nelson and Friedman, 2004
Logjam diorite	7 x 1 km	hb diorite	granite to gabbro	veins w/ galena, sphalerite (Au, Ag)	186.6±5.8 ^{207}Pb/^{206}Pb	Nelson and Friedman, 2004
Swift River sills	24 x 2 km	hb diorite, tonalite	quartz diorite	Zn, Pb (Ag) skarns		
Permian						
Ram Stock	26 x 2 km	quartz monzonite, granodiorite		unknown	258±2; 258.5±1.1 U-Pb zircon	this paper
Nizi	10 x 8 km	gabbro to diorite		gossans with Cu, Ag, Zn	262±8 K-Ar on hb	Nelson and Friedman, 2004
Meek	11 x 5 km	granite		quartz veins w/ Ag-Pb-Zn±Au; gossans	270±4 U-Pb zircon; 262±2 U-Pb titanite	Nelson and Friedman, 2004

Abbreviations: bt=biotite; hb=hornblende

Figure 2. *The Ram Stock is a steeply dipping tabular intrusion; here it's about 700 m wide. This northeast view is from 364800E 6679700N in northwest corner of 105B/3 (Roots et al., 2004c). The intrusive contact is at right (here offset by a minor fault, indicated), and the granite extends to the Hidden Lake Thrust (unseen, at far left).*

Table 2. *Rock type and modal mineralogy for representative samples. Modes are estimated by the authors, except: Seagull NW (average of 24 modes, Mato et al., 1983), Thirtymile, NW and SW (point-counted, Liverton, 1990), Simpson Peak (range in 17 granitoid samples, L'Heureux, 2000).*

Granite suite	rock type	grain size	alkali feldspar	quartz	plagioclase	ferromagnesian minerals	accessory minerals
Cretaceous							
Seagull SE	quartz syenite	medium	50	25	18	5 bt	fl, ap, topaz
Seagull NW	leucogranite	fine	35 (por)	38	24	3 bt	tour orbicules, fl, ap
Thirtymile	microgranite	fine	30-40	40-55	10-15	1 bt	fl, mon, zr, py
Thirtymile	megacrystic	coarse	30-40	40-45	10-20	1-5 bt	tour cavities
Jurassic							
NW Thirtymile	monzogranite	medium	32	27	6	23 bt, 33 hb	sph, ap
SW Thirtymile	quartz diorite	fine	8	17	49	5 bt, 20 hb	ap, sph
SW Thirtymile	gabbro	fine	0	1	55	12 bt, 9 hb, 22 aug	
Logjam	granite	fine	30	25	<20	7 bt, 7 hb, 3 cpx	
Logjam	diorite	medium	0		10	40 hb, 15 opx, 2 ol	
Swift River	tonalite	fine	5	25	55	15 hb, allanite	ap, sulphide minerals, allanite?
Swift River	diorite	medium	0		45	45 hb	sulphide minerals siderite
Plate Creek	granodiorite	medium	3	20	70, zoned	4 bt, 2 hb	sulphide minerals
Simpson Pk	granite	medium	32-55	25-35	10-28	<5 bt; 1-12 hb	titanite, ap, zircon
Permian							
Ram	granite	medium	50	18	perthitic	bt (chloritized)	rutile

Abbreviations: ap=apatite; aug=augite; bt=biotite; cpx=clinopyroxene; fl=fluorite; hb=hornblende; mon=monazite; por=porphyritic; py=pyrite; sph=sphene; tour=tourmaline; zr=zircon

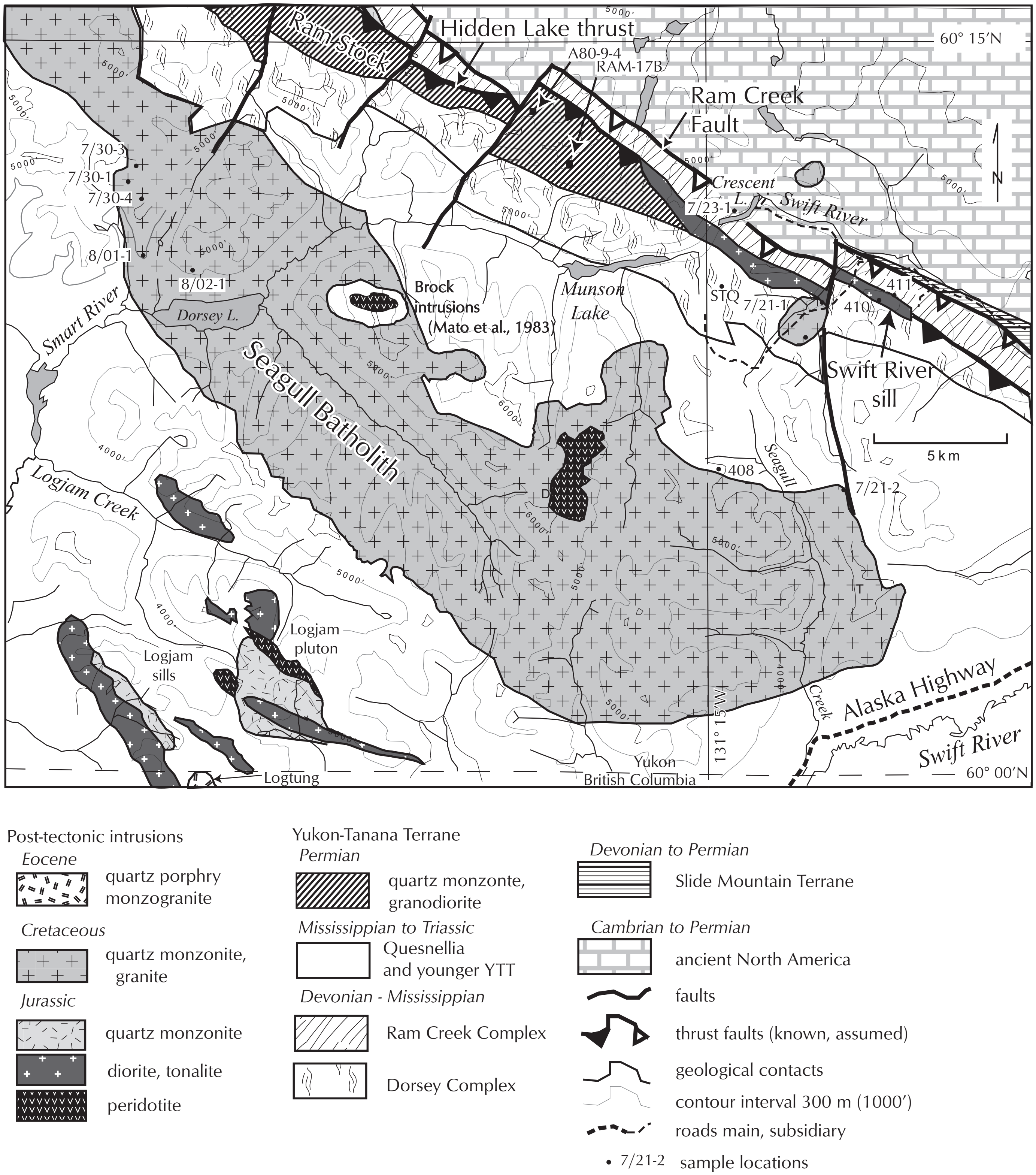


Figure 3. *Location of samples for dates and geochemistry in southeastern Ram Stock, Seagull Batholith and Swift River (Jurassic) sill. Geological contacts are simplified from Roots et al., 2004.*

Not dated, but correlated with Ram Stock on the basis of composition, is a diorite dyke on the west side of Crescent Lake that was observed to be cross-cut by the Ram Stock (Poole, 1956; J.G. Abbott, pers. comm., 1980).

Age of the Ram Stock

Two samples of the Ram Stock yielded zircon for uranium-lead dating. Sample A80-9-4 was a hand sample collected during regional mapping in the area (Abbott, 1981) that weighed ~0.3 kg. Sample RAM-17B was a larger (~10 kg) sample collected during a field trip in 2002 (locations on Fig. 3). Geochronological analyses were carried out at the Pacific Centre for Isotopic and Geochemical Research at the University of British Columbia, Vancouver, BC. Mineral separation and U-Pb analytical techniques employed are those described in Friedman et al. (2001).

Results

U-Pb analytical data are listed in Table 1 and the analytical results are plotted on a conventional concordia diagram in Figure 4. Zircons from both samples were stubby, euhedral, pale pink grains, with no internal zoning or visible cores. Two strongly abraded and two unabraded fractions were analysed from sample A80-9-4 (Table 1). The two abraded fractions (C and D) give overlapping error ellipses that lie on or near concordia, and fraction D

Table 3. *U/Pb analytical data for samples of Ram Stock.*

Sample description[1]	Weight (mg)	U (ppm)	Pb[2] (ppm)	^{206}Pb/^{204}Pb (measured)[3]	Total common Pb (pg)	% ^{208}Pb[2]	^{206}Pb/^{238}U[4] (±% 1σ)	^{207}Pb/^{235}U[4] (±% 1σ)	^{207}Pb/^{206}Pb[4] (±% 1σ)	^{206}Pb/^{238}U age (Ma; ±% 2σ)	^{207}Pb/^{206}Pb age (Ma; ±% 2σ)
Sample A80-9-4											
A: N2, 62-74,u	0.089	1330	53.8	6392	48	9.5	0.04050(0.07)	0.2875(0.11)	0.05150(0.06)	255.9(0.4)	263.2(2.9)
B: N2, 62-74,u	0.182	1382	55.8	5921	108	10.0	0.04018(0.18)	0.2846(0.20)	0.05138(0.06)	253.9(0.9)	257.7(2.9)
C: N2, 74-134	0.060	1074	43.7	8929	20	9.1	0.04089(0.09)	0.2901(0.10)	0.05145(0.07)	258.4(0.5)	261.2(3.1)
D: N2, 75-104	0.058	1119	45.3	9153	19	8.7	0.04091(0.08)	0.2899(0.10)	0.05140(0.05)	258.4(0.4)	258.9(2.4)
Sample RAM-17B											
A: N2,+104	0.027	1149	46.9	7187	11	9.3	0.04091(0.22)	0.2897(0.27)	0.05137(0.11)	258.5(1.1)	257.3(5.0)
B: N2,+104	0.035	1142	48.1	1080	10	11.1	0.04145(0.13)	0.2959(0.29)	0.05178(0.20)	261.8(0.7)	275.9(9.2)
C: N2,+104	0.050	1189	49.6	7952	19	9.8	0.04154(0.14)	0.2968(0.19)	0.05181(0.10)	262.4(0.7)	277.2(4.7)
D: N2,+104	0.062	995	40.9	2184	71	9.7	0.04106(0.12)	0.2921(0.22)	0.05161(0.13)	259.4(0.6)	268.1(5.9)
E: N2,+104	0.044	749	30.8	3137	27	9.6	0.04111(0.09)	0.2931(0.19)	0.05172(0.11)	259.7(0.5)	273.1(5.1)

[1] N2 = non-magnetic at 2 degrees side slope on Frantz magnetic separator; grain size given in microns; u = unabraded

[2] radiogenic Pb; corrected for blank, initial common Pb, and spike

[3] corrected for spike and fractionation

[4] corrected for blank Pb and U, and common Pb

Location of samples (UTM in Zone 9, NAD 83)
Sample A80-9-4 : 369815E 6678495N ; in northwest-facing cirque
Sample RAM 17-8 : 370715E 6678492N; on ridge crest

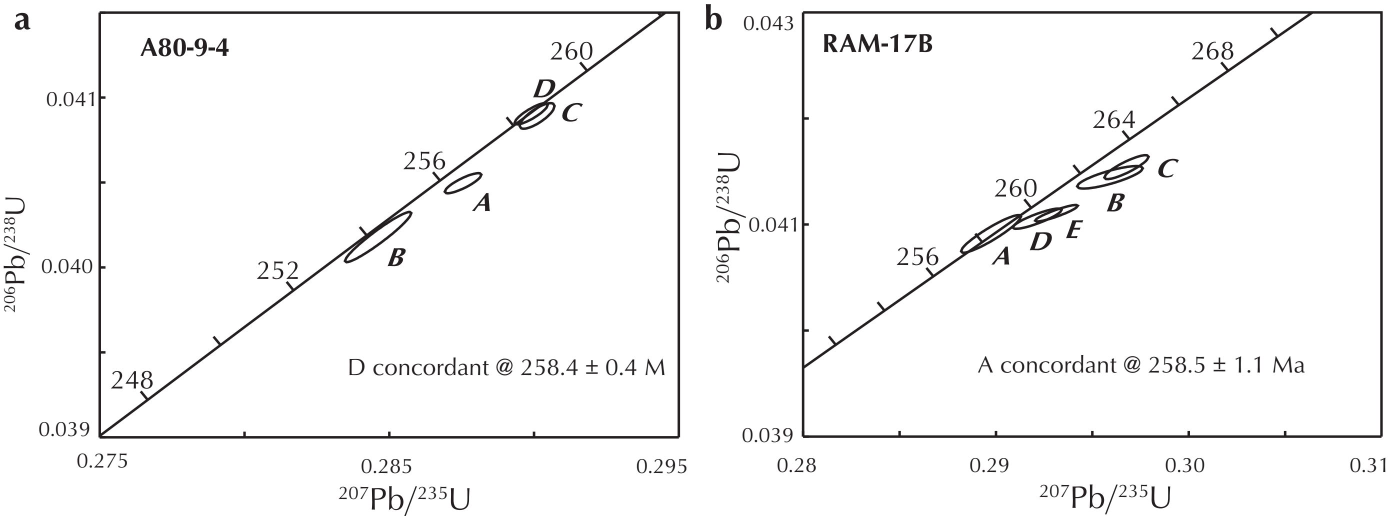


Figure 4. *Concordia plot for Ram Creek stock. The lettered fractions are described in Table 1.*

gives a concordant analysis with a $^{206}Pb/^{238}U$ age of 258.4±0.4 Ma, which is interpreted to be the crystallization age of the sample. The two unabraded fractions give younger $^{206}Pb/^{238}U$ ages (Fig. 4a) and are interpreted to have experienced minor post-crystallization Pb-loss. Five fractions of strongly abraded zircon were analysed from sample RAM-17B (Table 1, Fig. 4b). Fraction A gives a concordant analysis with a $^{206}Pb/^{238}U$ age of 258.5±1.1 Ma, which gives the crystallization age of the sample. The other four fractions yield slightly older Pb/U and Pb/Pb ages, indicating the presence of minor 'cryptic' inherited zircon components in each fraction.

Discussion

The Late Permian age for the Ram Stock: 1) indicates the penetrative strain of the Dorsey Complex is older than Permian; 2) places a maximum age on the Hidden Lake thrust and 3) represents a significant regional event in the superimposition history of YTT and Quesnellia. The dykes at the tip of the southern part of the stock yielded Permian U-Pb ages (269.8±3.2 Ma), while dates on the two plutons in Sylvester Allochthon (Gabrielse et al., 1993) are within the margin of error of Ram Stock (restoration of about 100 km dextral movement of the Cretaceous Cassiar Fault (Gabrielse, 1985) places the Ram Stock where the Sylvester Allochthon may have been physically connected, before uplift and intrusion of the intervening Cassiar Batholith; Nelson and Friedman, 2004). Other parts of YTT expose volcanic and plutonic rocks between 270 and 260 Ma that are considered a magmatic cycle (S. Piercey, 2004), although its significance remains unclear.

EARLY JURASSIC SUITE

This suite includes subcircular granite bodies ranging from tens of metres to several hundred kilometres in area, sill-like diorite to tonalite, and several dunite to pyroxenite bodies. The age of these bodies is typically 186 to 188 Ma (Table 1), but the Plate Creek stock is 10 Ma older (Nelson and Friedman, 2004). The Southwest Thirtymile is 181.5 Ma (Liverton et al., 2001); note that an adjacent pluton of Cretaceous age is called Thirtymile – an unfortunate opportunity for confusion.

Most of the felsic intrusions have steeply dipping, locally sheared margins and insignificant stoping or xenolithic screens. Many are surrounded by a broad contact metamorphic aureole. Simpson Peak and Nome Lake batholiths (Fig. 1) consist primarily of hornblende-biotite granodiorite with blade-like K-feldspar megacrysts inside a peripheral zone of foliated biotite-hornblende quartz diorite (Gabrielse, 1969). Less common are hornblende or clinopyroxene gabbro, and foliated lithodemes (Mihalynuk et al., 2000). The western side of Simpson Peak Batholith includes a late-stage, medium-grained biotite granite, characterized by white intergrowths of plagioclase and K-feldspar, as well as a leucocratic porphyry (L'Heureux, 2000).

Extreme variations in lithology, both between stocks and over a few tens of metres within them, are characteristic of the Early Jurassic suite. The intrusion at the head of Logjam Creek contains three lithodemes (Fig. 3). The earliest, of olivine clinopyroxenite to dunite (peridotite), is exposed in two bodies, separated by the second, of hornblende quartz monzonite, including a zone with blade-like K-feldspar megacrysts (Poole, 1956). The third lithodeme is massive hornblende diorite to quartz diorite, which cross-cuts the quartz monzonite and extends several kilometres as large lozenge-shaped bodies. These attest to structural anisotropy; they coincide with old faults or contacts between major rock units. For example, the tonalite-diorite sill at the head of Swift River plugs the Hidden Lake Thrust that separates the Dorsey and Ram Creek complexes (Fig. 3).

Texturally the tonalite is massive to slightly porphyritic, with locally zoned plagioclase, pink microperthite and interstitial unstrained quartz. Jurassic intrusions are characterized by the presence of hornblende (constitutes 6 to 8% of most rocks according to Poole (1956); our samples typically contained more). This contrasts with the Cretaceous granites of the region, which are virtually hornblende-free. Biotite, partly altered to chlorite and iron-oxide?, is commonly 2 to 5%. In the gabbroic lithodeme, hornblende or clinopyroxene (locally pseudomorphed by hornblende) is present. No miarolitic cavities or hydrothermal evidence was observed in the Jurassic intrusions; likely they cooled at least several kilometres beneath the surface

EARLY LATE CRETACEOUS SUITE

Cretaceous granites intrude every tectonic belt in southern Yukon, and in some cases demonstrably plug faults that separate the terranes. Most are biotite leuco-quartz monzonite, but the Seagull Batholith is about 10 Ma younger than its neighbours: the Cassiar Batholith to the east, and the Deadman Creek Batholith to the west (Gordey et al., 1998).

Information is presented here on the northwest-trending Seagull Batholith, Hake Batholith and Thirtymile pluton. These intrusions are compositionally identical, and they are likely linked beneath the surface (hereafter referred to as the Seagull-Thirtymile granite). More mineral occurrences surround these than other intrusions to east and west (Table 2). The Seagull-Thirtymile granite is not unusual in general composition (biotite leuco- quartz monzonite), but it hosts pockets and zones with unusual mineralogy and composition that have seen intensive exploration (Mato et al., 1983).

A first-order difference between the Seagull-Thirtymile granites and others is map pattern. In particular, the Seagull Batholith has an irregular outline with numerous satellite stocks (Fig. 3). Valley exposures of granite between ridges of hornfelsed and hydrothermally altered country rock, and (in places) gently dipping intrusive contacts, attest that the Seagull-Thirtymile granite is barely unroofed. It also carries large pendants; these include volcaniclastic rocks, the Brock intrusion of Mato et al. (1983; Fig 3), and a gabbro body south of Munson Lake that is probably an isolated, uplifted part of the Early Jurassic suite. The northwest trend of the Seagull-Thirtymile granite parallels that of the Jurassic diorite sills and the Ram Stock, perhaps indicative of a fundamental crustal break that focused upwelling magma in three episodes over 150 million years.

The Seagull-Thirtymile granites are characterized by high silica content and biotite is the only ferromagnesian mineral. Appreciable hornblende is only present in the porphyry lithodeme of the Thirtymile stock (Liverton, 1990). The granite has an equigranular or slightly porphyritic texture. Potash feldspar grains typically overgrow quartz and plagioclase grains at their borders, indicating partial replacement (Poole, 1956). Biotite is commonly slightly altered to chlorite.

The special areas of the granite are characterized by abundant cavities rimmed with quartz and black tourmaline, purple and green fluorite with rarer blue-green beryl and topaz. Li-rich micas in Thirtymile pluton were described by Liverton and Alderton (1994). These are zones where late-stage volatiles were concentrated, and likely were the highest points in the intrusion, now exposed by erosion.

EOCENE SUITE

The stock that hosts the Logtung tungsten-molybdenum-bismuth-beryllium (beryl, aquamarine) porphyry deposit along its northern edge yielded a U-Pb age of 58 Ma ± 1.5 (Mihalynuk and Heaman, 2001). It is a highly differentiated hypabyssal monzogranite with related felsic dykes. Different compositional lithodemes resulted from periodic tapping of an almost completely crystallized, fractionating magma chamber (Stewart and Evensen, 1983). Interaction between magmatic and other hydrothermal processes led to a texturally distinctive 'brain-rock' texture consisting of alternate-banded felsic porphyry and drusy quartz (Noble et al., 1984).

CHEMICAL CHARACTERISTICS OF THE PLUTONS

Clean, fresh, fist-sized rock samples were selected from various plutons. The trace element analyses augment previous data from the Thirtymile and Hake intrusions (Liverton, 1992; Liverton and Alderton, 1994; Liverton and Botelho, 2001). New major and minor whole-rock analyses were made for Permian and Jurassic intrusions in the Swift River area.

RESULTS

Tables 4 and 5 present the major, minor and trace element compositions of the plutonic samples, organized by age. Relatively immobile and incompatible elements are the primary basis for discussion of tectonic origin.

In terms of silica content, the Permian and Jurassic samples span an SiO_2 range from 52 to 72%, whereas all the Cretaceous granites are > 70% SiO_2. On silica bivariant plots, the Rb/Zr ratio (Fig 5a) and Ga/Al ratio (Fig. 5b) are relatively uniform for Permian and Jurassic samples (in the volcanic arc granites field of Harris et al., 1986), whereas the Cretaceous Seagull-Thirtymile samples have higher ratios, in the realm of anorogenic granites.

Rubidium and high field strength elements rise proportionally in Cretaceous granites, but not in Permian and Jurassic samples (Fig. 6a) which also have relatively low Fe/Mg, whereas the Cretaceous samples show an order of magnitude higher (Fig. 6b). The position of the samples on this diagram correspond to the fields for 'Normal' S- and I-types for the former, and A-type for the latter (according to Sylvester, 1989). The iron-rich Seagull-Thirtymile trend is unusual for S-type tin plutons world-wide, but is typical of late-orogenic (sub-alkaline in the sense of Barbarin, 1990) and anorogenic types.

A similar distinction is shown on the ternary Rb-Ba-Sr diagram (Fig. 7). The Jurassic samples cluster near the baseline, in the volcanic arc granites' field of El Bouseily and El Sokkary (1975). The Permian granite has relatively higher Ba (in the field of high-Ca granites). In contrast, the Cretaceous suite forms a steep trend along the boundary between 'within-plate' and 'collisional' granites field. Notably samples from each pluton constitute lines with slightly different slopes, and in each case, the most evolved samples are near the top (higher Rb/Sr ratio).

A common measure of fractionation of granitic magmas is the Thornton-Tuttle, or Differentiation Index, in which the

Table 4. *Major oxides, and normative mineralogy for selected samples. Oxides are in weight %. Four Cretaceous samples were analysed in 1990 at University of London using long count INAA (from Liverton and Botelho, 2001); others were done by Activation Laboratories, Ontario (#40273) using Induction-coupled optical emission spectroscopy.*

	Cretaceous					**Jurassic**			**Permian**
Location	**STQ Dyke**	**Seagull NE**		**Seagull NW**					
Sample	07/24-1	07/21-1	408	07/30-1	07/30-4	DY-12	410	411	16-10
UTM Easting**	0375600	0378580	0374410	0353430	0353800	0374410	0382117	0382265	0357595
UTM Northing	6671800	6669250	6664600	6676560	6675890	6664600	6670830	6670903	6685600
Major oxide									
SiO_2	76.08	76.53	77.13	76.11	78.48	64.8	60.43	49.88	69.43
Al_2O^3	13.54	12.65	11.76	12.62	11.91	16.5	18.23	14.39	14.87
Fe_2O_3*	1.04	1.64	1.71	1.73	1.34	4.51	5.83	9.58	2.24
MnO	0.12	0.08	0.015	0.04	0.05	0.115	0.086	0.159	0.057
MgO	0.27	0.57	0.05	0.59	0.33	1.49	1.79	7.77	0.31
CaO	3.51	3.4	0.44	3.53	3.18	4.88	5.38	10.4	1.64
Na_2O	4.75	4.91	3.2	4.92	5.02	3.46	4.36	2.76	3.45
K_2O	0.06	0.12	4.77	0.09	0.09	2.63	0.89	0.87	5.18
TiO_2	0.01	0.02	0.103	0.01	0.01	0.485	0.66	1.28	0.231
P_2O_5	0.02	0.04	0.01	0.01	0.02	0.22	0.23	0.21	0.07
S			0.004			0.004	0.001	0.008	0.004
LOI	1.33	0.44	0.46	0.63	0.43	1.04	1.98	1.85	1.13
Total	**99.4**	**99.96**	**99.63**	**99.65**	**100.43**	**100.13**	**99.88**	**99.14**	**98.6**
C.I.P.W. Normative minerals (calculated from above analyses)									
% iron used	10	10	10	10	10	20	20	20	20
quartz	36.14	35.72	38.24	34.38	39.22	20.67	15.47	0	24.7
orthoclase	28.1	29.06	28.19	29.12	29.7	15.54	5.26	5.14	30.61
albite	29.73	28.81	27.08	29.92	26.94	29.28	36.89	23.35	29.19
anorthite	1.21	2.57	2.12	2.87	1.51	21.73	25.19	24.31	7.68
calcite	2.18	0.8	0.56	0.44	0.69	0	0.86	0	0.77
diopside	0.3	0.2	0	0.1	0.13	0.87	0	20.96	
hypersthene	1.49	2.34	2.38	2.47	1.92	7.9	10.25	13.4	3.09
olivine	0.14	0.22	0	0.23	0.177	0	0	3.67	0
magnetite	0	0	0.25	0	0	1.31	1.69	2.78	0.65
ilmenite	0.05	0.09	0.2	0.02	0.05	0.92	1.25	2.43	0.44
hematite	0	0	0	0	0	0	0	0	0
apatite	0.1	0.1	0.02	0.1	0.1	0.51	0.53	0.49	0.16
D***	93.97	93.59	93.51	93.42	95.86	65.49	57.62	28.49	84.5

*Total iron expressed as Fe_2O_3 **NAD83 ***Differentiation index + Normative q+or+ab+an

Table 5. *Minor and trace elements, in parts per million. Analyses by Activation Laboratories, Ontario (A04-273) using a combination of ICP-MS, ICP-OES and INAA.*

	STQ	Seagull Batholith									Hake		Thirtymile			Plate Creek	Swift River sill		Ram Stock	Crescent Lake
	dyke	NE			NW						margin	core	even	mega	porph	diorite	tonal	diorite	gran	diorite
Sample	7/24-2	7/21-1	7/21-2	408	7/30-1	7/30-3	7/30-4	8/1-01	8/1-02	8/02-1A	8/17-2	8/17-3	97/29-1	97/28-5	HPG	DY-12	410	411	16-10	7/23-1
Ag	na	na	na	bd	na	na	na	na	na	na	na	na	na	na	na	bd	0.03	bd	bd	na
As	22.0	93.0	82.0	20.0	8.0	bd	bd	bd	14.0	12.0	bd	bd	bd	bd	bd	bd	bd	1.0	1.0	bd
Ba	29.0	45.0	17.0	29.0	15.0	93.0	43.0	278.0	354.0	408.0	375.0	270.0	108.0	322.0	756.0	1970.0	574.0	466.0	1115.0	1540.0
Be	na	na	na	6	na	na	na	na	na	na	na	na	na	na	na	2.0	2.0	2.0	3.0	na
Bi	0.3	7.2	0.1	bd	11.4	0.2	bd	0.2	0.7	0.7	bd	4.3	0.3	bd	bd	bd	bd	bd	bd	bd
Cd	na	na	na	bd	na	na	na	na	na	na	na	na	na	na	na	0.4	0.05	0.06	0.03	na
Ce	156.0	142.0	165.0	154.0	144.0	140.0	117.0	148.0	125.0	127.0	118.0	110.0	79.3	76.4	103.0	56.0	25.0	30.0	45.0	45.7
Cs	15.1	17.4	17.9	16.0	11.6	11.1	14.0	8.1	11.2	11.1	13.2	12.6	17.2	24.0	6.0	0.9	1.2	1.2	2.6	3.7
Cu	na	na	na	10	na	na	na	na	na	na	na	na	na	na	na	20	16	43	15	na
Dy	18.1	16.4	19.8	na	21.6	15.1	11.6	5.68	7.89	9.19	5.06	5.41	8.82	5.52	5.45	na	na	na	na	2.87
Er	13.3	11.1	14.0	na	14.7	9.92	8.11	3.17	5.01	5.94	3.43	3.66	6.47	3.89	3.45	na	na	na	na	1.72
Eu	0.02	0.078	0.031	bd	0.029	0.114	0.069	0.321	0.344	0.374	0.533	0.376	0.164	0.391	0.762	1.23	0.85	1.17	0.73	1.13
Ga	34.0	26.0	26.0	28.0	26.0	23.0	22.0	20.0	21.0	21.0	19.0	19.0	22.0	21.0	19.0	21.0	19.0	17.0	17.0	18.0
Gd	13.7	13.2	15.8	na	16.9	12.7	9.88	7.08	8.01	9.02	5.35	5.52	6.47	5.02	5.24	na	na	na	na	3.68
Ge	2.8	2.7	2.5	na	2.9	2	1.8	1.5	1.9	1.9	1.4	1.7	2.4	1.8	1.3	na	na	na	na	1.4
Hf	8.1	7.1	8.9	6.9	8.5	9.4	6.5	5.1	6.7	6.4	5.5	5.5	6.4	6.6	7.0	na	na	na	na	3.7
Ho	3.92	3.47	4.34	na	4.59	3.16	2.51	1.08	1.62	1.93	1.07	1.11	1.93	1.21	1.1	na	na	na	na	0.57
La	81.5	68.7	82.9	80.1	72.6	69.0	59.5	76.2	64.2	64.4	65.8	58.3	38.3	39.8	57.8	29.0	15.6	13.3	21.5	24.2
Lu	2.3	1.61	1.95	1.48	2.03	1.37	1.18	0.462	0.765	0.868	0.566	0.625	1.26	0.638	0.561	0.29	0.17	0.37	0.15	0.271
Nb	99.8	70.7	80.7	77.0	72.7	68.6	50.2	36.2	39.5	40.0	45.8	43.8	63.3	50.0	48.1	13.0	bd	8.0	10.0	14.1
Nd	60.5	54.3	61.1	51.0	60.6	54.9	44.3	52.6	46.7	47.9	37.4	35.5	28.6	26.7	35.0	27.0	9.0	14.0	12.0	20.1
Ni	bd	bd	bd	5.0	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd	9.0	9.0	56.0	6.0	bd
Pb	24.0	26.0	20.0	36.0	36.0	27.0	15.0	28.0	24.0	22.0	14.0	111.0	25.0	15.0	26.0	11.0	7.0	3.0	10.0	23.0
Pr	19.4	15.7	18.1	bd	17.0	15.4	13.1	15.6	13.7	13.9	11.9	11.2	8.64	8.02	10.5	na	na	na	na	5.3
Rb	863.0	584.0	615.0	652.0	593.0	429.0	421.0	242.0	347.0	350.0	329.0	414.0	579.0	428.0	236.0	63.0	29.0	33.0	151.0	112.0
Sb	0.2	0.6	0.7	1.2	0.3	0.6	0.4	0.5	0.4	0.4	0.5	0.5	0.3	0.5	0.2	na	na	na	na	1.3
Sm	14.7	13.1	15.0	10.6	16.0	13.1	10.1	8.9	9.3	10.0	6.5	6.8	6.6	5.4	6.2	4.5	1.4	3.6	2.17	4.03
Sn	25.0	37.0	21.0	bd	6.0	7.0	6.0	20.0	7.0	6.0	9.0	13.0	7.0	9.0	6.0	bd	bd	bd	bd	5.0
Sr	10.0	13.0	3.0	9.0	5.0	12.0	6.0	33.0	43.0	45.0	91.0	61.0	25.0	67.0	128.0	827.0	400.0	332.0	325.0	427
Ta	19.0	9.65	9.59	10.9	9.71	6.61	7.31	4.20	5.33	5.17	4.83	6.39	10.8	8.76	4.06	0.90	bd	bd	0.7	0.95
Tb	3.0	2.75	3.34	1.9	3.58	2.56	2.0	1.09	1.42	1.62	0.91	0.97	1.36	0.94	0.94	0.5	0.4	0.7	0.3	0.55
Th	67.0	65.7	93.0	44.9	83.2	47.9	52.9	42.5	50.5	49.7	66.6	69.6	57.4	55.4	43.0	5.7	4.3	1.4	16.4	14.7
Tl	6.31	5.33	4.14	na	5.17	3.45	3.14	2.04	3.22	3.28	2.24	3.38	4.83	2.84	1.32	na	na	na	na	0.75
Tm	2.19	1.66	2.08	na	2.23	1.45	1.21	0.47	0.76	0.87	0.52	0.57	1.07	0.59	0.52	na	na	na	na	0.25
U	39.7	24.9	25.3	6.7	19.4	22.1	13.2	6.01	12.8	12.9	18.3	20.4	31.3	19.5	9.35	1.6	2.0	0.5	3.2	4.66
V	bd	bd	bd	7.0	bd	bd	bd	bd	bd	bd	8.0	bd	bd	bd	15.0	76.0	27.0	238.0	22.0	96.0
Y	154.0	123.0	156.0	86.0	160.0	108.0	82.5	33.6	53.4	61.0	36.9	40.0	72.2	40.6	38.0	16.0	7.0	24.0	8.0	19.0
Yb	14.5	10.5	12.6	10.1	13.6	9.15	7.56	2.95	4.86	5.58	3.54	3.88	7.56	3.91	3.47	1.91	1.14	2.45	1.06	1.59
Zn	bd	66.0	bd	38.0	46.0	46.0	n.d.	50.0	bd	35.0	37.0	7990.0	bd	bd	bd	68.0	36.0	66.0	32.0	98.0
Zr	140	181.0	229.0	182.0	208.0	310.0	153.0	188.0	232.0	224.0	212.0	197.0	165.0	209.0	306.0	179.0	324.0	97.0	411.0	151.0

Abbreviations: marg=margin; even=equigranular lithodeme; mega=megacrystic; porph=porphyritic; tonal=tonalite; gran=granite; na=not analysed; bd=below detection

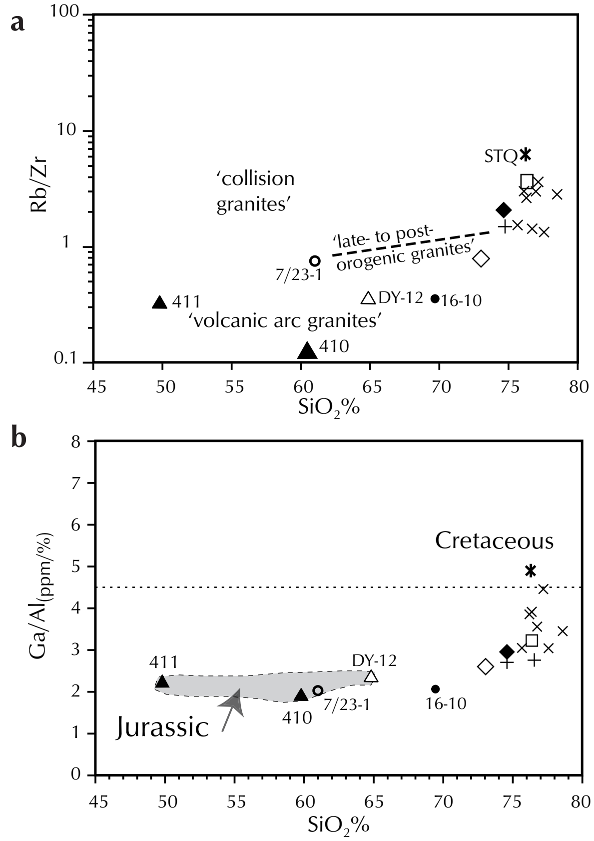


*Figure 5. Silica-variation diagrams highlight the distinction between Jurassic and Cretaceous suites: **(a)** Rb/Zr vs SiO$_2$ (fields from Harris et al., 1986); **(b)** Ga/Al vs SiO$_2$. Note that the two Permian samples (16-10 and 7/23-1) typically have an intermediate position between the relatively flat Jurassic, and the steeply rising Cretaceous fields.*

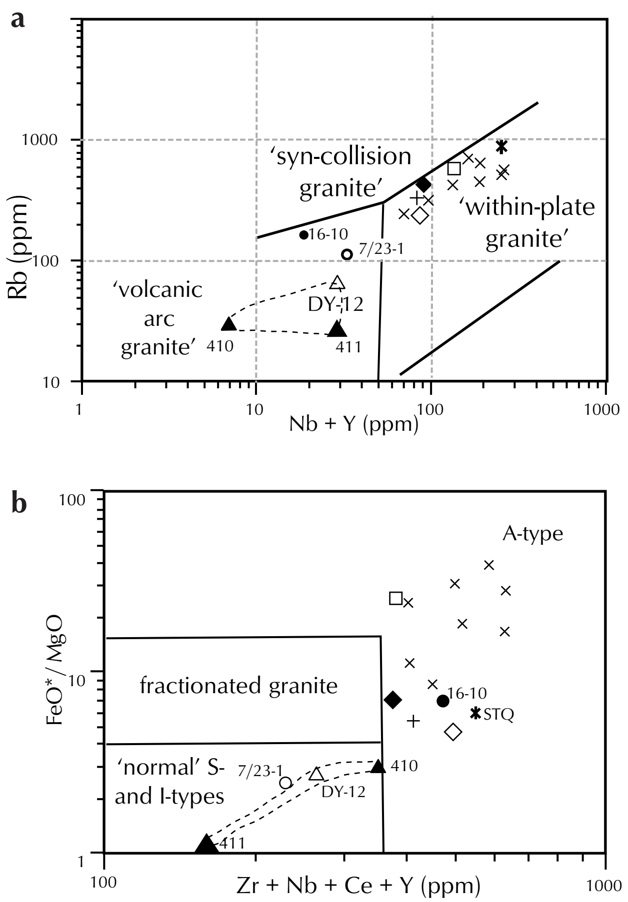
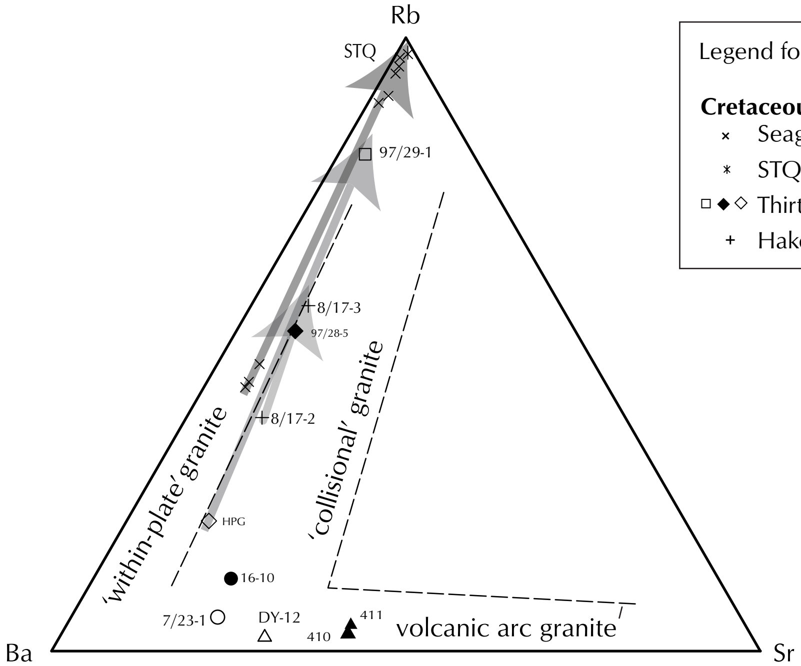


Figure 6. Tectonic discrimination diagrams, with fields according to Pearce et al. (1984) and Sylvester (1989) and Harris et al. (1986): FeO=total iron.*



Legend for Figures 5-9

Cretaceous	**Jurassic**	**Permian**
× Seagull Batholith	▲ Swift River sill	● Ram Stock
* STQ satellite	△ Plate Creek stock	○ Crescent dyke
□◆◇ Thirtymile pluton		
+ Hake Batholith		

Figure 7. Distribution of Permian, Jurassic and Cretaceous samples on the Rb-Ba-Sr ternary plot. Boundaries between the volcanic-arc granite (VAG), within-plate and collisional granites are from El Bouseilly and El Sokkary (1975). Shaded arrows highlight the steep trends of Seagull, Hake and Thirtymile samples toward the Rb apex, the result of fractionation.

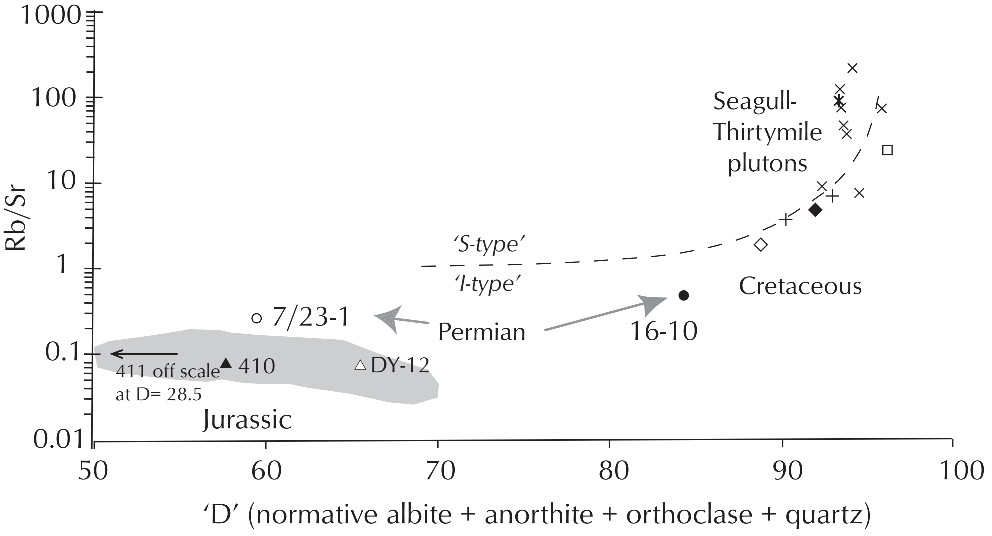


Figure 8. *Cobbing (1990) diagram shows the I-type nature of Jurassic intrusions and the intermediate nature of the Permian samples. Legend on facing page. The Cretaceous granites straddle the line separating I- and S-type granitoids, and their Rb content rises steeply when the Differentiation Index ('D') is greater than 90.*

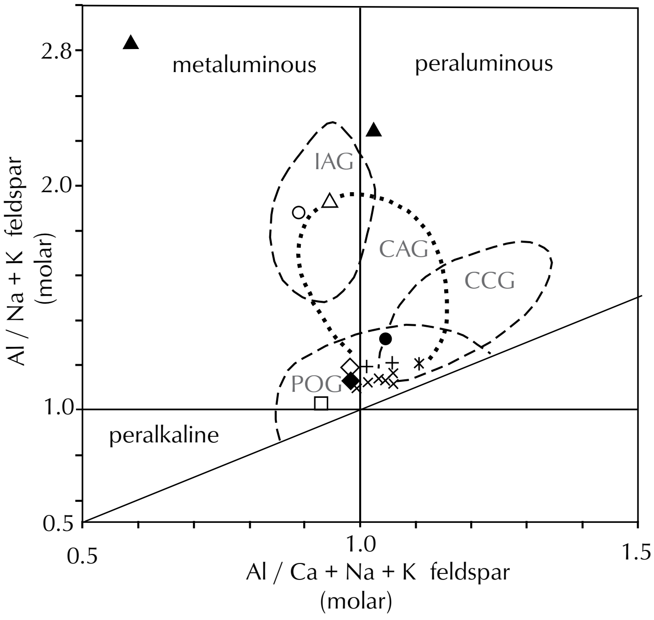


Figure 9. *The aluminum saturation (Shand) index (A/CNK=molar Al /Ca + Na + K, with correction for fugacity of Ca for apatite content). Legend on facing page. Major element compositions separate the Jurassic, as a metaluminous suite, from the Cretaceous samples, which tightly cluster in the 'post-orogenic granites' (POG) field. IAG: island-arc granite; CAG: continental-arc granites; CCG: continental collisional granite from Maniar and Piccoli (1989).*

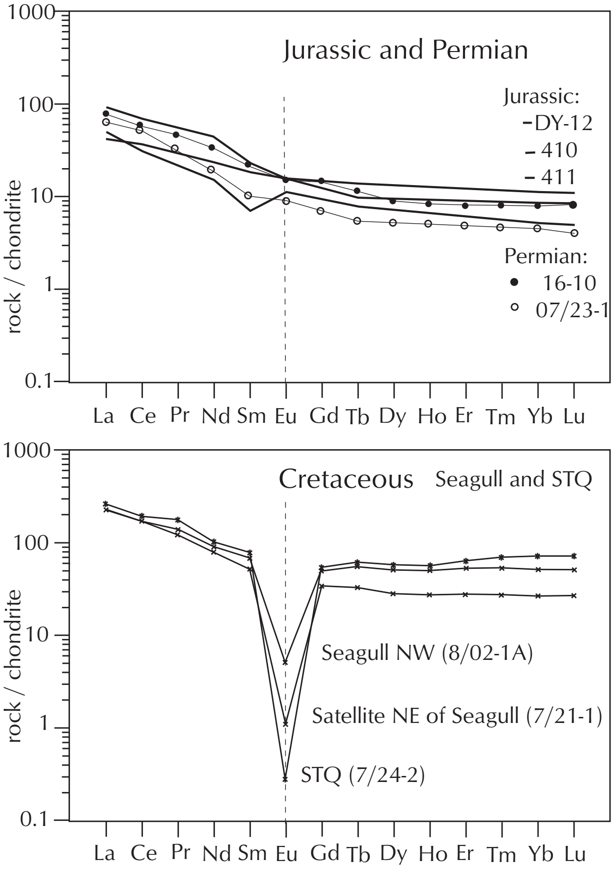


Figure 10. *Rare-earth element abundances for granites, normalized to chondrite values of Sun (1980).*

sum of the CIPW normative feldspars + quartz comprise the x-axis. On Figure 8 the Cretaceous samples form a cluster around the upward curve, rising at higher indicies of differentiation. For example, the samples of Thirtymile pluton define evolution from porphyritic, to megacrystic, to equigranular lithodemes, an increase of Rb/Sr from 2 to 12. This change matches the emplacement sequence determined from cross-cutting relationships (Liverton, 1992). The STQ sample has the highest Rb (863 ppm) of any of the samples in this dataset. It is a satellite stock of Seagull Batholith that is interpreted to have fractionated toward quartz enrichment.

The Shand Index plot (Fig. 9) demonstrates a clear distinction between the Permian and Jurassic samples, which are metaluminous and in either the island-arc or continental-arc field. The more alkaline, metaluminous to peraluminous Cretaceous plutons cluster tightly in the ‘“post-orogenic granites” field (Maniar and Piccoli, 1989).

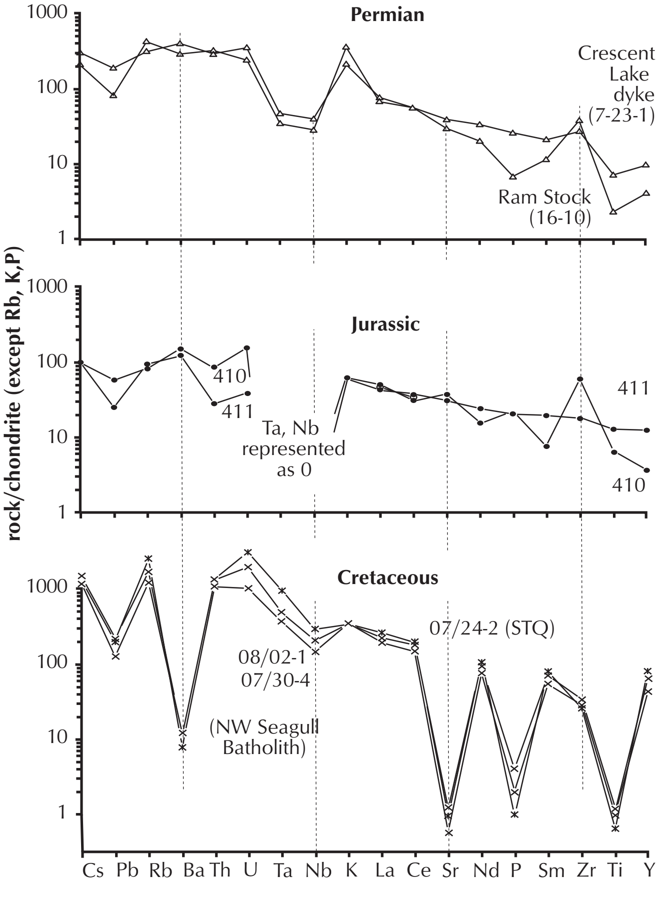


Figure 11. *Minor and trace element abundance, normalized to chondrite (Sun, 1980) shows relatively smooth trends for Permian and Jurassic intrusions diagrams. The Cretaceous samples show strong depletion in Ba, Sr, P and Ti.*

Rare-earth element plots (spidergrams) are used to display the type of fractionation. In Figure 10, the curves for samples are uniform and descend gently (more enriched in LREE than HREE), a classic within-plate signature. In contrast, the most fractionated samples, from the northwest cupola of Seagull Batholith (DU area), and the STQ satellite stock, have the deepest Eu trough, as this element is taken up in the crystallization of plagioclase. Even higher fractionation is shown at the Ork (Mindy, 105C 038B, Deklerk, 2003) near the Thirtymile pluton, where lithium-rich mica is present (Liverton, 1990).

Trace and rare-earth elements abundances normalized to chondrite show negative slopes for all the granites (Fig. 11). Among Jurassic and Permian samples, the trend is comparatively smooth, with anomalous increase in K. The Ram Stock is similar to the Meek granite pluton which displays a flat REE pattern with respect to upper mantle crustal values (Nelson and Friedman, 2004, p. 1212). The Jurassic suite has large-ion lithophile elements enriched about 100 times, and the incompatible elements about 10 times that of chondrite. Nb and Ta are very low, similar to the large Triassic-Jurassic suites in Quesnellia of southern BC, which are derived from mafic parents (Preto et al., 1979; Ghosh, 1995). All the Cretaceous samples show significant troughs for Ba, Sr, P, Ti and Pb, likely a result of the early crystallization of minerals such as feldspar and ilmenite within the magma chamber.

PLUTON COMPOSITION AND TECTONIC ORIGIN

The trace element abundances of the Permian plutons suggest that they were likely derived from an influx of enriched mantle-derived magma, accompanied by melting of the lower crust (S. Piercey, pers. comm., 2003). These Permian igneous rocks thus contrast sharply with the contemporaneous mid-oceanic ridge basalt lavas in the Campbell Range (southeast Yukon) and in the Slide Mountain Terrane, both on the east side of Yukon-Tanana Terrane (YTT). Possibly these intrusions were the last stage of a Permian magmatic event that began with arc volcanism recorded by the Klinkit Group. The rare-earth element abundances and Nd isotopic ratio of the Klinkit volcanic rocks show little evidence of crust in their genesis, and the arc is interpreted to lie above an east-dipping subduction (Simard et al., 2003). Possibly the heated lower crust at the end of this cycle gave rise to the Ram Stock and other plutons.

The composition of our samples corroborates the results of Nelson and Friedman (2004), who interpreted the magmas as being derived from melting of a previously metasomatized mantle wedge. This reflects a continental arc setting. Where was the subduction zone? Liverton et al. (2001) proposed that the subduction zone was west-dipping and led to closure of the Slide Mountain ocean beneath the leading eastern edge of YTT. The southwest dip of the units, and top-to-the-northeast sense of motion on intra-terrane faults support this hypothesis. The mafic volcanic and sedimentary rocks of Slide Mountain terrane are interpreted to have melted in the subduction zone and risen in what was likely the thickest zone of the shortened width of YTT.

The three Jurassic samples are similar to the dykes analysed by Nelson and Friedman (2004) in showing a strong arc affinity, particularly using Rb as a discriminant (Figs. 5,6 and 7). Unlike theirs, however, the Swift River sill and Plate Creek stock lack the potassic character that is typical of the Late Triassic-Early Jurassic suite that is a hallmark of Quesnellia (Mortimer, 1987; Nelson and Friedman, 2004).

The Cretaceous Seagull-Thirtymile plutons have compositions consistent with A-type or collisional granites (Figs. 5a, 6b). Their initial Sr isotopic ratios are high (0.712; Mato et al., 1983), reflecting an old, sialic source. Among the least-differentiated lithodemes, trace-element abundances are typical for such granites throughout the Cordilleran interior, and consistent with a simple Rayleigh crystal-liquid fractionation process. In samples displaying highly differentiated compositions (above 90 on the Thornton-Tuttle Differentiation Index), however, the large-ion lithophile element content rises dramatically. Ultrafractionation occurs in the presence of abundant, halogen-rich volatiles, and water vapour promotes liquid-liquid fractionation (early phase), leading to scavenging of certain metals (e.g., Newberry et al., 1990). Flourine facilitates fractionation by inhibiting the nucleation, depolymerizing silicates and depressing the solidus so that elements such as lithium and boron can move upward through the magma (C. Hart, pers. comm., 2003). The presence of lithium-bearing micas at Thirtymile pluton (Liverton and Alderton, 1994), and tourmaline orbicules and linings of miarolitic cavities in cupolas at the northwest end of Seagull Batholith, attest to this process.

METALLOGENY RELATED TO PLUTONIC SUITES

The Permian intrusions lack a distinctive metallogenic character. McPres (105B 087, Deklerk, 2003) is a copper-molybdenum-rich gossan within the Ram Stock. The Nizi pluton in the Sylvester Allochthon hosts numerous gossans with chalcopyrite in shear zones, and gold-silver-lead-zinc in quartz veins (Nelson, 2001). Some spatially associated skarns, such as Hidden (lead, zinc, silver; 105B 025, Deklerk, 2003), were probably distant from the Ram Stock, prior to movement on the Hidden Lake Thrust fault.

The Jurassic suite has associated vein and skarn occurrences. The Tan (Bradford and Jakobsen, 1988) showing is a quartz vein with stibnite and pyrite, and nearby anomalous stream sediments (Jackaman, 2000) occur near the Plate Creek stock. The Logjam occurrence (105B 038, Deklerk, 2003) consists of six quartz veins (gold, silver, lead-zinc) within a Jurassic diorite sill, but is likely younger because quartz veins are also present in the nearby Logtung (Early Eocene) intrusion.

At the head of the Swift River, along the northeast edge of YTT, are several large pyrrhotite-galena-sphalerite lenses hosted in calc-silicate layers (Bar (better known as Dan), Atom, Bom, and Munson (better known as TBMB); Deklerk, 2003 105B 026, 027, 028, 029). Some exploration programs have investigated the possibility that the adjacent volcanic rock and tuffaceous textures could indicate a syn-sedimentary (volcanogenic) origin. Galena and pyrrhotite samples from these occurrences have lead isotopic ratios that are midway between clearly epigenetic veins, and probable volcanogenic deposits in YTT, however, their modal age is broadly mid-Triassic to mid-Jurassic (Mortensen and Gabites, 2002).

Cretaceous plutons of the Seagull-Thirtymile trend were the focus of considerable exploration activity during the late 1970s as the price of tin briefly soared. Among the most explored properties were the JC, a 600-m-long tin skarn (105B 040, Deklerk, 2003) and the nearby MC sheeted tin- and sulphide-bearing veins (Mato et al., 1983; 105B 088 (called Smith), Deklerk, 2003). At the JC, tin was precipitated in an early stage within andradite skarn, but later replaced by cassiterite within 90 m of the top of the granite (Layne and Spooner, 1991). At MC, cassiterite coats 'dry' (lacking quartz) fractures in country rock (DIAND, 1981, p. 150). The mineralogy and conditions of formation of the Mindy prospect, a skarn south of the Thirtymile pluton, is documented by Liverton (1992).

CONCLUSIONS

A primary mineralogical distinction between the igneous suites is the dominance of hornblende (and in the mafic phases, clinopyroxene) in the Jurassic plutons, whereas the Seagull-Thirtymile granite lacks hornblende but is biotite-bearing. Our geochemical data, combined with previously published results for plutonic rocks, shows distinct differences between intrusive rocks 80 million years apart.

Most distinctive are Jurassic rocks, which are rich in MgO, TiO_2 and have low K_2O/Na_2O ratios, Rb and Nb. As indicated by Mortensen et al. (2000), these are metaluminous, I-type and likely derived from a mantle source.

By contrast, the Cretaceous granites are silica- and iron-rich. The K_2O/Na_2O ratio is high, Rb is very high (in the most fractionated samples), and high field-strength elements are enriched in these rocks relative to chondrites, except for Ba, Sr, Ti and P. It is a peraluminous, and A-type on discriminant diagrams (Figs. 6b and 9). Following the discussion by Creaser et al. (1991) the Seagull-Thirtymile granite could be derived from an igneous source within the lower continental crust, such as a partial melt of granodiorite to tonalite residue from previous magmatic episodes. This may explain the parallel geometry of the Seagull-Thirtymile granite with both Jurassic and Permian Ram Stock precursors.

The unusual character of the Seagull-Thirtymile granite reflects late-stage fractionation when halogen concentrations rose quickly toward the end of crystallization. This fortunate occurrence mobilized the metals and resulted in a high incidence of mineral showings. The degree of fractionation of granite samples indicated by normative minerals, Ga/Al, Rb/Zr or Rb/Sr ratios, could be used as an exploration tool.

Samples of the Permian suite are too sparse for any but the broadest conclusions. The Ram granite has high field strength element abundances, intermediate between the Jurassic and Cretaceous plutons. It lies within the range of some arc magmas, but has more crustal enrichment, indicated by higher large-ion lithophile-element abundances. Its presence indicates the Early Permian magmatism occurred beneath southern Yukon-Tanana Terrane (YTT), and prior to contraction that welded the island arcs into YTT.

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