Current Research (1989) Newfoundland Department of Mines, Geological Survey of Newfoundland, Report 89-1, pages 81-95

ASPECTS OF THE MID-PALEOZOIC MAGMATIC HISTORY OF THE SOUTH-CENTRAL HERMITAGE FLEXURE AREA, NEWFOUNDLAND

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ABSTRACT

The Burgeo intrusive suite, a mainly synkinematic polyphase complex containing dated Silurian plutons, intrudes lower to mid-Paleozoic rocks on the southwest coast of Newfoundland. It comprises gabbro, quartz diorite, biotite ± hornblende tonalite, granodiorite and granite, and biotite ± muscovite granite. At its western and eastern limits, respectively, the suite is intruded posttectonically by the Devonian Chetwynd Granite and the possibly synchronous François granite. These are high-level granites that cross-cut adjacent mylonite zones developed within the Burgeo intrusive suite and its country rocks.

The Burgeo intrusive suite shows a continuum in geochemical variation from 49 percent to 79 percent SiO_2, similar to that seen in calc-alkaline suites, but there is a greater abundance of high-silica and alkali-enriched granites. It is probable that the mafic rocks and lower-silica granitoids are related to the subduction zone and lower-crust magmatism and subsequent fractionation, whereas the higher-silica granites reflect high-level crustal melts. The François and Chetwynd granites have restricted SiO_2 compositions (mainly >71 percent). Both granites are strongly depleted in Sr and ferromagnesian elements and the François granite is enriched in Rb, U and Th. The granites are probably high-level crustal melts, which have fractionated biotite, plagioclase and K-feldspar. Small intrusions of similar lithology are amongst the latest phases of the Burgeo intrusive suite.

Known mineralization associated with the Burgeo intrusive suite is concentrated in the Grey River area, where extensive wolframite-bearing quartz veins are present. A small gold occurrence has also been reported from this area. Molybdenite mineralization is locally developed in aplites of the suite. The most differentiated parts of the posttectonic intrusions are potential targets for granophile element mineralization.

INTRODUCTION

Voluminous granitoid batholiths are the dominant component of the Appalachian orogen in south-central Newfoundland (Figure 1). These composite intrusive suites were emplaced into mainly lower to mid-Paleozoic greenschist and amphibolite facies country rocks, during the polyphase tectonothermal event that affected the region in the Silurian (e.g., O'Brien *et al.*, 1986; Dunning *et al.*, 1988). The country rocks, which are almost completely enveloped by intrusions, are mostly volcanic and sedimentary protoliths. They include elements of the Dunnage and Gander zones of the Appalachian mobile belt (Williams, 1979; Williams *et al.*, 1988; Williams *et al.*, 1989) and the Hadrynian to Cambrian (Dunning and O'Brien, *in press)* Grey River enclave (Blackwood, 1985a), currently of uncertain affinity. In southern Newfoundland, these rocks define the sinuous oroclinal structure known as the Hermitage Flexure (Williams *et al.*, 1970). In addition to composite batholiths, smaller plutons of epizonal, high-silica granite, are widely spaced along the entire southern coast (Dickson *et al.*, 1988) and cross-cut regional fabrics in both the country rocks and the earlier granites, and are of Devonian or presumed Devonian age.

The following discussion deals with the geology and geochemistry of three mid-Paleozoic intrusions from the south-central part of the Hermitage Flexure area. These are: the synkinematic, polyphase Burgeo intrusive suite[1], the posttectonic Devonian Chetwynd Granite (Cooper, 1954) and the posttectonic François granite (Poole *et al.*, 1985). These three intrusions have been recently mapped at 1;50,000 scale (see O'Brien *et al.*, 1986) and systematic geochemical sampling on a 4-km^2 grid is essentially complete, providing a total of 822 samples, which have been analyzed for major- and trace-elements. U–Pb age determinations on two phases of the Burgeo intrusive suite have been completed (Dunning *et al.*, 1988). Geochronological and geochemical studies and detailed mapping are continuing.

GEOLOGY OF THE INTRUSIONS

Burgeo Intrusive Suite

The Burgeo intrusive suite (Figure 1) is a polyphase intrusive body of batholithic proportions (circa. 3000 km^2; O'Brien and Dickson, 1986) composed of a continuum of compositions, from gabbro through tonalite and granodiorite

This project is a contribution to the Canada–Newfoundland Mineral Development Agreement, 1984–1989

[1] "Burgeo intrusive suite" is a new name to be proposed elsewhere. It replaces the Burgeo Batholith of Williams (1978) and the Burgeo granite of O'Brien and Tomlin (1984, 1985) and Dickson *et al.* (1985).

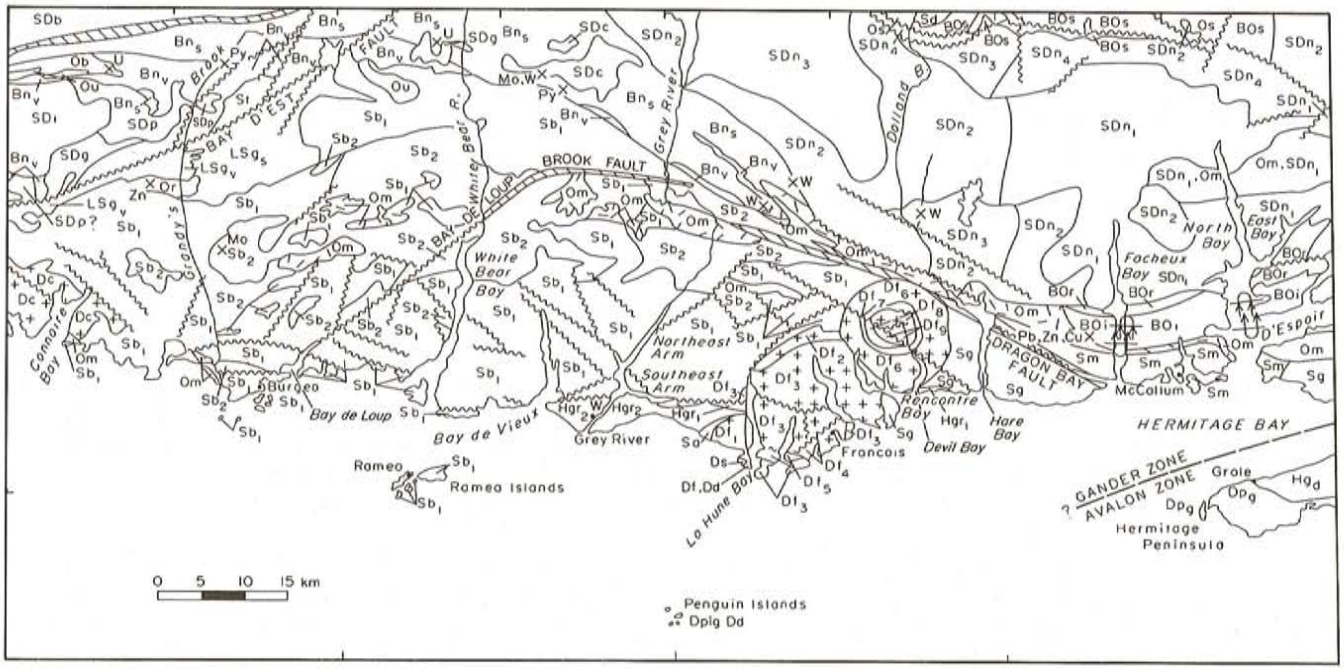

Figure 1. *Geology of the Burgeo (11P) map area; modified from O'Brien et al. (1986).*

LEGEND

DEVONIAN

Ds *Red and green conglomerate, sandstone, shale and limestone*

Dd *Undivided early and late, massive diabase dykes*

Df FRANCOIS GRANITE: *pink, massive, biotite granite;* Df_1, *buff, medium grained, feldspar porphyritic granite;* Df_2, *coarse grained equigranular granite;* Df_3, Df_6, *coarse grained, K-feldspar porphyritic granite;* Df_4, Df_8, *buff, medium grained, feldspar porphyritic adamellite and granite;* Df_5, *pink to white, fine grained, quartz-feldspar-biotite porphyritic granite;* Df_7, *medium grained, K-feldspar porphyritic granite;* Df_9 *medium grained equigranular granite*

Dc CHETWYND GRANITE: *medium to coarse grained, equigranular to K-feldspar porphyritic, biotite granite*

Dpg PASS ISLAND GRANITE: *pink, medium to coarse grained, K-feldspar porphyritic, biotite-hornblende granite*

Dpig PENGUIN ISLANDS GRANITE: *pink, medium grained, K-feldspar porphyritic, biotite granite*

Dg *Undivided, medium to fine grained, biotite ± hornblende granite*

SILURIAN–DEVONIAN

SDg *Medium grained muscovite granite and felsite*

SDi IRONBOUND MONZONITE: *massive to locally foliated, medium grained, plagioclase porphyritic, biotite ± hornblende monzonite with minor granodiorite and granite*

SDp PETER SNOUT GRANITE: *massive to weakly foliated, fine to medium grained, equigranular, biotite ± muscovite granite*

SDc COCHRANE POND GRANITE: *massive to weakly foliated, fine to medium grained, muscovite ± biotite granite*

SDn SDn_1, *weakly foliated, medium grained, equigranular to porphyritic, biotite ± muscovite granodiorite, with minor garnet-muscovite granite;* SDn_2, *massive to weakly foliated, medium to coarse-medium grained, K feldspar porphyritic, biotite granite;* SDn_3, *massive to weakly foliated, medium to coarse-medium grained, K-feldspar porphyritic, biotite-muscovite granite;* SDn_4, *strongly deformed to mylonitic, medium to coarse grained, K-feldspar porphyritic, biotite granodiorite, and medium grained equigranular muscovite-garnet granite*

SILURIAN

Sd Dolland Pond Formation: *cleaved pebble conglomerate and breccia, interbedded with shale and sandstone*

Sa *Fine to coarse grained, hornblende gabbro, including hornblendite, diorite and amphibolite*

Sb BURGEO GRANITE: Sb_1, *coarse-medium to coarse grained, massive to foliated, feldspar porphyritic, biotite ± hornblende granodiorite, tonalite and gabbro;* Sb_2, *medium grained, foliated equigranular to porphyritic, biotite ± muscovite ± garnet granodiorite and granite, locally containing abundant migmatite inclusions*

Sm McCALLUM GRANITE: *foliated to mylonitic, medium to coarse grained, equigranular to feldspar porphyritic, biotite granite and granodiorite*

Sg GAULTOIS GRANITE: *mainly coarse grained, strongly foliated to mylonitic, feldspar porphyritic, biotite granodiorite and granite, including minor, medium grained, equigranular granite*

St TOP POND TONALITE: *foliated, medium grained, equigranular, hornblende ± biotite tonalite*

LA POILE GROUP

LSg Georges Brook Formation: LOg_V, *rhyolite flows, ash-flow tuffs, agglomerate, reworked volcaniclastics, minor mafic flows, pyroclastics and dikes;* LOg_S, *fine to coarse grained, locally cross-stratified sandstone, including quartz-pebble and quartz-cobble conglomerate*

ORDOVICIAN?

Om *Migmatite, agmatite, paragneiss and associated granitoids; locally includes migmatized metasedimentary rocks of known Ordovician age*

Ob BAGGS HILL GRANITE: *massive to weakly foliated, quartz-feldspar porphyritic granite, granodiorite and quartz-feldspar porphyry*

ORDOVICIAN

Os Spruce Brook Formation: *strongly foliated psammitic and semipelitic schist and minor schistose felsic volcanic rocks; locally extensive, cleaved, quartz-pebble conglomerate and quartzite*

BAY DU NORD GROUP

Bn Bn_V, *felsic pyroclastic rocks, rhyolite, and welded tuff associated with mafic volcanic rocks and clastic sedimentary rocks;* Bn_S, *psammite, semipelite and pelite, including quartz-rich sandstone and quartz-pebble conglomerate*

BAIE D'ESPOIR GROUP

BOr Riches Island Formation: *semipelitic schist, including thin to thick bedded psammitic schist and minor quartzite*

BOi Isle Galet Formation: *felsic volcanic rocks and overlying graphitic pelite, arenite and minor tuff, conglomerate, limestone and ampbibolite*

BOs Salmon River Dam Formation: *psammite and pelite containing minor calcareous psammite and limestone*

ORDOVICIAN OR EARLIER

Or ROTI GRANITE: *foliated, equigranular, medium grained, biotite granodiorite and quartz-feldspar porphyry.*

Ou *Layered metagabbro and metadiabase; minor pyroxenite and peridotite; rare mafic volcanic rocks*

HADRYNIAN TO CAMBRIAN

Hgr GREY RIVER ENCLAVE: Ogr_1, *felsic tuff and minor metasedimentary rocks;* Ogr_2, *migmatized pelitic and psammitic schist, mafic schist and amphibolite; minor gabbro, peridotite and granitoid gneiss*

HADRYNIAN

Hgd GROLE DIORITE: *medium to coarse grained, hornblende-pyroxene gabbro and hornblende-biotite diorite, and quartz diorite* to granite. The oldest rocks, which are intruded and variably assimilated by several younger plutons, are the most mafic in composition and include mainly hornblende gabbro, biotite–hornblende tonalite and quartz diorite; these underlie small areas and are unseparated from other phases of Sb_1, on the regional map (Figure 1). The gabbroic rocks are most common on the Ramea Islands and the Burgeo Islands, where they are associated with diorite. Diabase dykes are common on Ramea Great Island, where brecciated and mylonitic gabbro and granite are cut by massive diabase dykes. Away from its southernmost exposures, diabase dykes in the Burgeo intrusive suite are comparatively rare. The concentration of possibly several generations of dykes, along the coast, may reflect a fundamental weakness in the crust in this area. Foliated quartz diorite and granodiorite form a separate pluton in the northern part of the suite (part of Unit Sb_1), west of White Bear River (see O'Brien and Dickson, 1986). Its genetic relation to other parts of the suite is enigmatic.

The most diagnostic and widespread lithology within the Burgeo intrusive suite, which comprises most of Unit Sb_1, is coarse grained, K-feldspar-porphyritic, biotite $\pm$ hornblende granite and granodiorite. In the west, these rocks are divisible into K-feldspar and plagioclase phenocryst-rich and sparsely porphyritic phases, a biotite-rich (up to 30 percent modal biotite) phase, as well as a unit rich in cognate mafic xenoliths (O'Brien and Tomlin, 1985). The biotite-rich porphyritic phases are, in places, compositionally similar to the most differentiated parts of the older elements of the suite, possibly supporting a genetic relationship between them. Variably sheared, pink granite intrudes some of the above rocks and forms a separate unit in the south-central part of the suite between Bay de Loup and Burgeo.

The youngest, regionally extensive component is medium grained, biotite $\pm$ muscovite granite (Unit Sb_2) that outcrops in a 10 to 15-km-wide east-trending band, forming the core of the suite. Locally, small bodies of massive, coarse grained, leucocratic biotite granite, similar to that found in the Chetwynd and François granites, intrude the older phases.

Enclaves of orthogneiss, migmatite and mafic to ultramafic rocks are widespread within the Burgeo intrusive suite. In the northern part of the suite, amphibolitized gabbro and diabase and minor serpentinized ultramafic rock form a large roof pendant surrounded by granite (O'Brien and Tomlin, 1984). This unit may either be an ophiolitic remnant, correlative with similar Cambro–Ordovician mafic–ultramafic complexes to the northwest and west (e.g., Chorlton, 1980a), or relics of the amphibolite terrane of the southern Hermitage Flexure. Farther south, mafic migmatite and gneissic granite form xenoliths within the suite (O'Brien and Tomlin, 1985). These may be equivalent to either deeper level metamorphic and intrusive rocks of Silurian age or to the pre-Silurian elements of the Hermitage Flexure, exposed elsewhere in southern Newfoundland. Ovoid to tabulate mafic igneous xenoliths are common within felsic phases throughout the Burgeo intrusive suite. These may represent reworked early mafic phases of the suite, disruption of mafic rich bands produced by gravitational layering within the magma chamber, or globular enclaves formed by disaggregation of co-existing mafic phases (c.f., Vernon *et al.*, 1988).

Almost all the elements of the suite contain an inhomogeneously developed fabric, which is in many places penetrative. The main fabric in the older porphyritic granite phases has been correlated with the regional first (D_1) fabric of the adjacent Ordovician rocks (Chorlton, 1980a; Blackwood, 1984). Away from the margin of the suite, the relation of fabric development in subsequent phases, to that in the country rock is difficult to ascertain, given the inhomogeneous nature of the deformation, the uncertainty in correlating fabrics amongst intrusive units and the overall synkinematic nature of the suite. Major mylonite zones are developed within porphyritic granitoid phases along the southern boundary of the suite with the Grey River enclave, at Grey River (Blackwood, 1985a), and near its northern contact with the Ordovician Bay du Nord Group. The northern mylonite zone, which is the on-strike equivalent of the Dragon Bay Fault (Blackwood, 1985b), swings east–west from the contact, and demarcates the northern limit of migmatite within the intrusive suite east of the Bay de Loup Brook Fault (Figure 1; Dickson *et al.*, 1985).

The Burgeo intrusive suite intrudes metasedimentary and radiometrically-dated (468 Ma; Dunning *et al.*, 1986) metavolcanic rocks of the Bay du Nord Group along much of its northern contact. The latter is part of the Exploits Subzone of the Dunnage Zone (Williams *et al.*, 1988). Southeast of the Bay D'Est Fault, the suite intrudes sedimentary and minor associated volcanic rocks, assigned to the Silurian La Poile Group (O'Brien, 1983; Dunning *et al.*, 1988). The metavolcanic, metasedimentary and gneissic rocks of the Grey River enclave, lie to the south of the Burgeo intrusive suite and are in fault contact with it (Blackwood, 1985a). Possible equivalents of the suite are the Otter Point (O'Brien, 1987) and Gaultois (Colman-Sadd, 1974) granites. They are separated from it by the posttectonic François and Chetwynd granites that define the suite's eastern and western limits (see below).

Dunning *et al.* (1988) report U–Pb ages on two of the main plutons of the Burgeo intrusive suite. A coarse-grained, foliated, K-feldspar-porphyritic, biotite granite (Unit Sb_1), west of White Bear River, has a zircon (crystallization) age of 429 $^{+5}_{-3}$ Ma and a titanite (metamorphic) age of 417 $\pm$ 2 Ma. Lithologically similar granite, exposed at the contact with the Bay Du Nord Group in the Dolland Brook area, contains the D_1 fabric of the country rocks (Blackwood, 1984). Medium grained, weakly foliated, equigranular biotite–muscovite granite (Unit Sb_2), which cross-cuts the older dated phase, has a zircon age of 415 $\pm$ 2 Ma. These ages are interpreted to bracket the main period of Silurian synkinematic granite intrusion and the regional D_1 deformation of the country rocks (Dunning *et al.*, 1988). The contrasting compositions and 10 Ma age difference between the two dated plutons suggests that they may not be linked by petrogenetic processes.

Higgins (1980) reported Rb–Sr whole rock ages from undeformed, K-feldspar-porphyritic biotite granite from the Burgeo intrusive suite in the Grey River area. Three samples of this granite gave an isochron age of 405 ± 10 Ma, with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7092. One of the samples used gave a K/Ar (biotite) age of 462 ± 18 Ma. The old K/Ar age was interpreted by Higgins (1980) to be erroneous and due to excess argon.

Chetwynd Granite

The Chetwynd Granite is a posttectonic, Devonian intrusion (Dallmeyer, 1980; Chorlton and Dallmeyer, 1986) composed of leucocratic, biotite granite. Two main regionally mappable phases are recognizable: these are fine- to coarse-grained, equigranular granite and K-feldspar ± quartz-porphyritic granite, containing adamellite variants. Rapakivi texture is locally well preserved in phenocryst-rich cumulate rocks. The more quartz-rich, silicic granites occupy higher ground than the less siliceous, quartz-poor, K-feldspar-rich variety (see below). The former lithology locally cross-cuts the less differentiated phases. The granite intrudes the westernmost extension of the Burgeo intrusive suite, and cross-cuts foliations within it and all the adjacent units (Chorlton, 1978; O'Brien and Tomlin, 1985; O'Brien, 1987). The western contact of the granite is semicircular in outline, whereas in the east, the contact is more irregularly shaped and locally rectilinear (Figure 1). Although the granite is posttectonic with respect to the regional deformation, it is affected by late northwest-trending structures, which may have been instrumental in defining the shape of the granite in its eastern portions. The presence of miarolitic cavities, tuffisite, and granophyre within the granite are indicative of high-level emplacement. The occurrence of associated sanidine-bearing porphyry dykes that are compositionally similar to the granite, within adjacent country rocks, is a further indication of the granite's epizonal character. These and related rhyolite and quartz–sanidine-porphyry dykes occur up to 15 km from the Chetwynd Granite. Screens of deformed Burgeo intrusive suite, La Poile Group, and older metamorphic rocks are common within the Chetwynd Granite and range in size from a square metre to several square kilometres.

The Chetwynd Granite cross-cuts folds and fabrics in dated Silurian strata as well as structures and major faults in the pre-Silurian succession (O'Brien, 1987, 1988). The granite yields a cooling age of 372 ± 5 ($^{40}Ar/^{39}Ar$ biotite) and a U–Pb zircon crystallization age of 377 ± 20 Ma (Dallmeyer, 1980; Chorlton and Dallmeyer, 1986).

François Granite

The François granite is a high level, posttectonic granite intrusion, consisting of two overlapping, circular ring complexes that create a distinctive bilobate map pattern (Figure 1). The pluton is one of a number of posttectonic, highly differentiated, high-silica granite intrusions that form an east-trending, 350-km-long belt along the southcoast of Newfoundland (Dickson *et al.*, 1988). The granite outcrops at the eastern limit of the Burgeo intrusive suite and separates it from the Gaultois granite, an extensive synkinematic granitoid that is continuous eastward to the Hermitage Bay Fault (Blackwood and O'Driscoll, 1976). The earliest phases of the François granite include early, coarse grained, massive, equigranular (Unit Df_2) and K-feldspar-porphyritic–biotite granite (Units Df_3 and Df_6), which together form the outer rings of both lobes. A prominent buff to grey, massive, relatively biotite-rich, plagioclase–K-feldspar-porphyritic biotite granodiorite (Unit Df_8) forms a ring intrusion, adjacent to the highly differentiated aplitic core in the northeastern complex. It is the penultimate phase of intrusion in the northeastern complex and is also the granite's most mafic phase. The same rock type (Unit Df_4) forms a sill-like intrusion in the southwestern lobe. Massive, aplitic, biotite granite (Unit Df_9) forms the central portion of the northeast lobe.

The François granite and associated dykes posttectonically intrude the Bay du Nord Group, the Burgeo intrusive suite and the Gaultois granite, and host xenoliths of these units. The granite post-dates movement on both the Dragon Bay Fault zone and the mylonite zone that form the northern boundary of the Grey River enclave. Rhyolitic, aplitic, quartz–sanidine porphyry and granite dykes occur up to 10 km north of the François granite and have intruded the nearby Unit SDn_2 of the North Bay granite suite, which has been dated at 396 Ma (U–Pb zircon; Dunning *et al.* 1988). At La Hune Bay, a sequence of gently dipping, coarse grained, subaerial clastic sediments are interpreted to nonconformably overlie the François granite (Blackwood, 1985a). The sequence is assumed to be Devonian or younger in age (Blackwood, 1985a), mainly because of lithological similarity to fossiliferous Devonian strata farther east in Fortune Bay. Both the granite and its cover are cross-cut by fine grained diabase dykes.

GENERAL GEOCHEMICAL CHARACTERISTICS OF THE INTRUSIONS

Burgeo Intrusive Suite

The Burgeo intrusive suite displays a broad and continuous compositional variation, with a range in silica values from 45.5 to 77.8 weight percent (Table 1; Figure 2). This variation generally follows an evolutionary trend with early gabbroic rocks intruded by porphyritic biotite granites and late biotite–muscovite and high-silica granites. Major- and trace-element variations within the entire suite follow the expected differentiation trends: there is a steady decrease in FeO, MgO, CaO, Sr, Zr, F and an increase in K_2O, Rb and U (see Figure 3 for examples; also Table 2). The agpaitic index [mol.(Na_2O+K_2O)÷Al_2O_3] is always less than 1 indicating that the suite is peraluminous to metaluminous. The variation in the AFM diagram (Figure 4) shows a tight coherence possibly indicating petrogenetic relationships between the various units.

Chetwynd Granite

The Chetwynd Granite is characterized by a high mean silica value and ranges from 62.5 to 78.1 wt. percent (Table 1). This range is reflected in the wide variation of values for

Table 1. Statistics for major oxides (in weight %) and trace elements (in grams per tonne) in the Burgeo intrusive suite, Chetwynd and François Granites.

	Burgeo			Chetwynd			François		
	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.
SiO_2	67.7	77.8	45.5	73.6	62.5	78.1	74.5	79.8	69.1
Al_2O_3	15.1	20.5	11.7	13.7	17.0	12.0	13.5	15.4	10.5
Fe_2O_3	1.19	5.19	.01	.75	1.75	.12	.51	1.61	.04
FeO	2.19	7.97	.01	.62	3.91	.01	.68	2.31	.01
MgO	1.30	13.90	.03	.38	3.08	.03	.21	.76	.02
CaO	2.30	9.56	.07	.81	3.23	.08	.61	1.83	.09
Na_2O	3.35	5.72	1.50	3.55	4.48	2.89	3.71	6.34	2.90
K_2O	4.62	9.29	.33	5.72	8.11	3.88	5.23	7.03	3.32
TiO_2	.59	1.96	.03	.30	.82	.05	.17	.51	.03
MnO	.08	.22	.01	.04	.14	.01	.05	.11	.01
P_2O_5	.19	.66	.01	.06	.27	.01	.04	.14	.01
L.O.I.	.89	3.89	.32	.55	.37	.13	.60	1.49	.32
	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.
Li	42	166	1	21	51	6	52	129	9
Be	4	22	1	3	6	1	6	69	2
F	595	2616	14	402	1142	35	492	1937	24
V	64	470	1	17	148	2	5	7	1
Cr	28	309	1	14	164	1	9	1	38
Ni	9	377	1	3	46	1	1	8	1
Cu	13	562	1	4	23	2	3	45	1
Zn	52	130	5	32	71	7	33	78	5
Ga	21	101	8	29	91	17	21	33	11
Rb	190	512	4	229	367	131	388	1131	144
Sr	200	531	4	74	203	1	72	287	3
Y	33	122	1	49	133	7	51	241	6
Zr	174*	642	10	157	423	25	106	312	21
Nb	15	44	1	20	43	4	29	97	8
Mo	3	61	1	3	21	1	2	8	1
Ag	.1	.3	.1	.1	.3	.1	.1	.2	.1
Sn	1	40	1	1	8	1	1	13	1
Ba	648	3775	5	278	823	6	200	729	1
La	34	149	1	45	124	5	33	158	1
Ce	82	205	1	112	271	8	86	294	1
W	1	18	1	2	8	1	1.4	22	1
Pb	23	61	2	26	39	7	32	81	4
Th	18	99	0	28	63	1	42	89	8
U	3.6	41.5	1	3.7	9.4	.1	10.3	41.7	1.7

* n = 255 (samples from NTS sheets 11P/10 and 11 only)

CaO, MgO, FeO and Al_2O_3. Trace elements such as Sr, V, Zr and Y also display a wide range of values (Table 1). The lower silica granites are the K-feldspar-megacrystic variety containing cumulate feldspar, which clearly increases the proportions of K_2O, Na_2O, CaO and Al_2O_3, and decreases the proportion of SiO_2, in the rock (Table 2).

The higher silica granites are strongly depleted in F, Sr, MgO and CaO, and K_2O also shows a negative correlation with SiO_2. Rb/Sr ratios increase strongly with a small increase in SiO_2, although Rb only doubles in abundance (Figure 3; Table 2). These variations are reflected by a decrease in modal biotite and feldspar. Incompatible elements such as U and

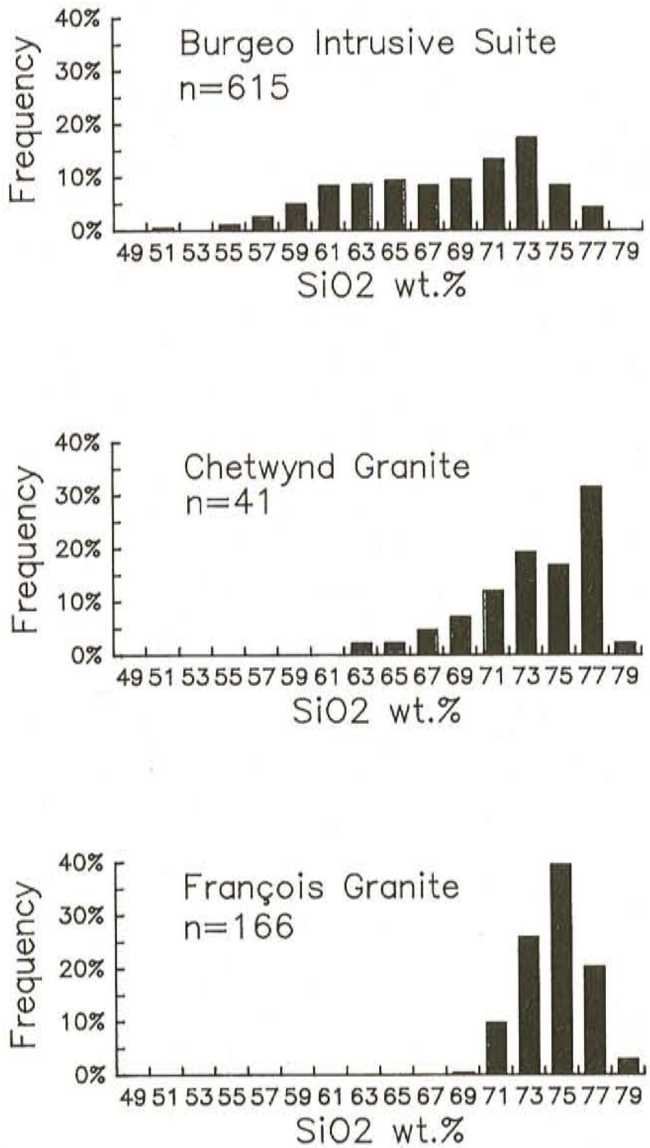

Figure 2. *Plot of SiO_2 frequency distributions for the Burgeo intrusive suite, Chetwynd and François granites.*

Th, and granophile economic elements such as Mo, Sn, W and Cu, show no significant enrichment with SiO_2.

François Granite

The François granite is lithologically similar to the Chetwynd Granite, but is characterized by more extreme depletion and enrichment of trace elements. It shows a more restricted silica range, higher mean silica, greater depletion of certain components such as CaO, MgO, Cu and Sr, and stronger enrichment of some incompatible elements, e.g., U, Th and Rb (Table 1; Figure 3). Variation diagrams show a pronounced increase in Rb/Sr ratios, F and U, and only small changes in SiO_2. Enrichment and depletion are greatest in the late, leucocratic, aplite (Unit Df_5), which occurs as dykes, and forms the core of the northeastern lobe of the granite (Unit Df_9) (Table 2). The relatively mafic granodiorite (Units Df_4 and Df_8) is also lowest in silica and consequently contains the highest CaO, MgO, FeO and Sr values and the lowest Rb, U and Th values (Table 2). These variations are reflected in airborne radiometric maps of Broome *et al.* (1987), which clearly show that the François granite is distinctly radiogenic compared with the adjacent granites. This is also seen in Table 1 and Figure 3, which show that the François granite contains the highest U, Th and Pb values. Isolated anomalous Cu, Sn and W values occur, but mean values are not significantly enriched.

DISCUSSION

Petrogenesis

Most granitoid units discussed above contain an abundance of K_2O and inherited zircons indicative of a continental-crust component in the magmas. The initial $^{87}Sr/^{86}Sr$ ratio of 0.7092 obtained by Higgins (1980) is also indicative of a significant continental-crust component in the granites. However, the gabbroic units reflect a mantle-derived component. The variety of rock types within the Burgeo intrusive suite is similar to calc-alkaline suites such as the Sierra Nevada Batholith (Bateman and Chappell, 1979) or the Coastal Batholith of Peru (Cobbing and Pitcher, 1972) and adjacent complexes (e.g., Kontak *et al.*, 1984; see Figure 4). However, in the Coastal Batholith of Peru, tonalite is the dominant lithology having subsequent intrusion of lesser amounts of granite. This evolutionary trend is typical of calc-alkaline complexes developed at the outer edge of continental magmatic arcs. The abundance of relatively potassic granite found in the Burgeo intrusive suite is unlike that found in calc-alkaline suites such as the Sierra Nevada. Another granite-dominated suite, such as that of southwest England, which contains abundant K-feldspar-porphyritic granite, may provide a closer comparison for the K-feldspar-rich units of the Burgeo intrusive suite.

Studies on the Coastal Batholith of Peru (see Harmon and Barreiro, 1984) support a subduction-related origin for most of the Coastal Batholith associated with extensive fractional crystallization of early tonalite to produce the later granodiorite and granite plutons. Contamination and/or partial melting of continental crust is considered to be a minor component in the Peruvian granitoids, even though the plutons were intruded into geosynclinal metasediments, e.g., Atherton (1984). A similar evolution is proposed for the granites from southern Chile by Bartholemew and Tarney (1984). They conclude, however, that the generation of large masses of potassic granite, 25-km wide and perhaps several hundred kilometres in lateral extent, remains a problem.

A lead isotope study of plutonic rocks from the Western and Coastal Cordilleras, in Peru, by Mukasa and Tilton (1984), showed a spatial association of basement lead in the Phanerozoic plutonic rocks and exposed Precambrian granulitic gneisses. The more felsic rocks appeared to contain an old crustal Pb component interpreted to be the result of high-level mixing of gneisses with mantle-derived material.

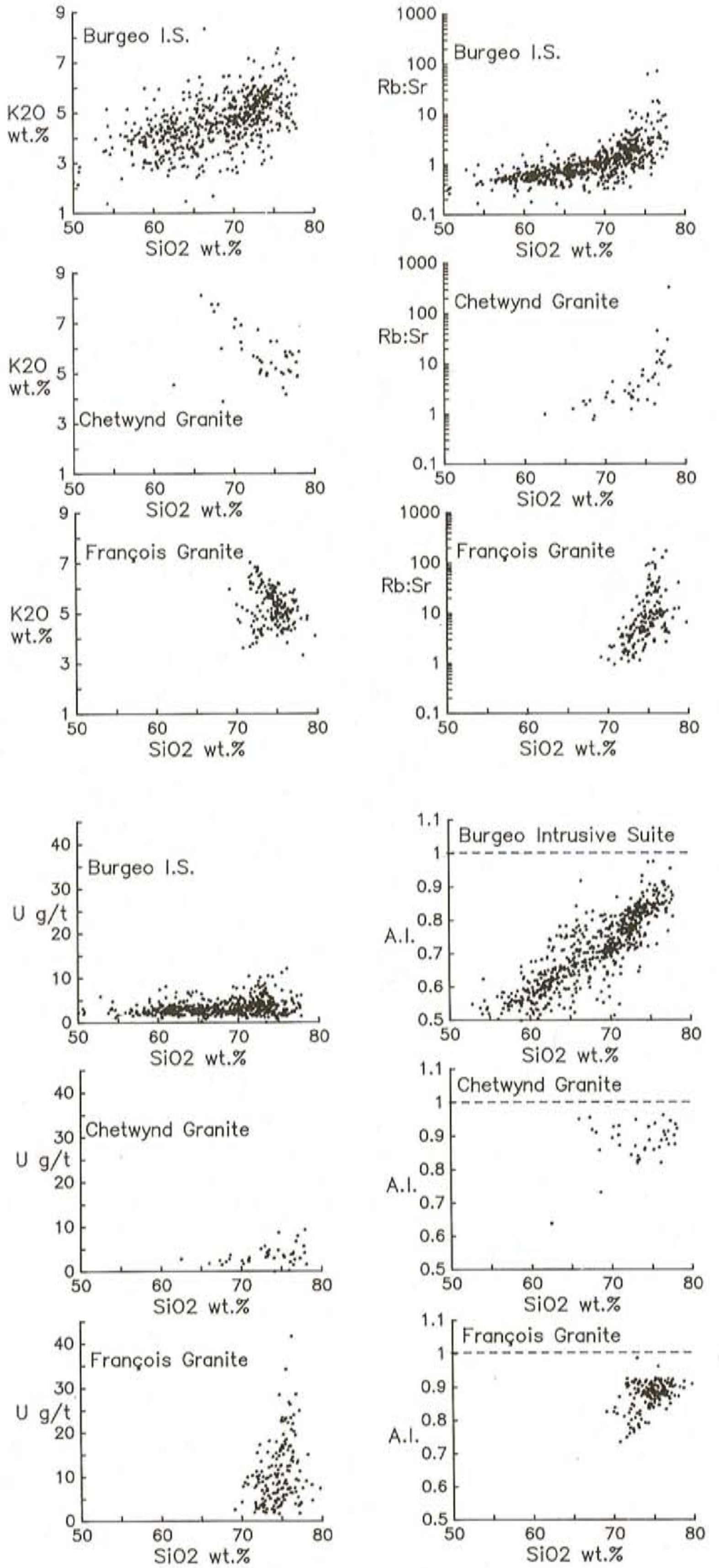

Figure 3. *Harker variation diagrams for the Burgeo intrusive suite, Chetwynd and François granites.*

Table 2. Analyses of representative samples from the Burgeo intrusive suite, Chetwynd and François granites. Major elements in weight percent; trace elements in grams per tonne.

	Burgeo Intrusive Suite				Chetwynd Granite		François Granite			
Unit	Sb_1	Sb_1	Sb_1	Sb_2	Dc	Dc	Df_2	Df_6	Df_8	Df_9
Rock	tnlt	grnt	grnt	grnt	grnt	grnt	grnt	grnt	grdr	grnt
type+	a	b	c	d	e	f	g	h	i	j
SiO_2	65.6	59.7	76.4	71.55	70.95	77.85	76.65	74.45	71.80	75.90
Al_2O_3	15.42	16.65	13.09	13.79	14.91	12.03	12.10	13.76	14.82	13.27
Fe_2O_3	1.37	1.30	.54	.70	.79	.58	.32	.33	.44	.30
FeO	2.74	4.78	.23	1.04	.84	.21	.78	.85	1.15	.54
MgO	1.47	2.96	.15	.47	.52	.15	.12	.16	.50	.08
CaO	2.87	4.38	.35	1.22	1.04	.52	.37	.78	1.25	.16
Na_2O	3.36	3.03	3.02	3.43	3.97	3.19	3.35	3.27	4.13	4.29
K_2O	4.35	4.40	6.41	5.20	5.96	4.87	5.08	6.12	4.49	4.37
TiO_2	.73	1.08	.13	.32	.35	.16	.15	.17	.26	.09
MnO	.10	.13	.03	.06	.05	.03	.04	.04	.07	.04
P_2O_5	.24	.39	.03	.10	.07	.03	.02	.04	.09	.02
L.O.I.	1.08	1.03	.52	.72	.82	.57	.49	.39	.77	.75
Li	117	36	28	46	26	18	29	43	92	44
Be	.	.	3	.	2	3	4	4	7	6
F	696	.	92	.	390	169	159	348	530	282
V	91	127	6	39	30	7	1	1	14	1
Cr	26	72	9	5	21	12	7	6	8	5
Ni	9	25	1	1	2	1	1	1	2	1
Cu	8	23	1	2	3	3	1	1	4	10
Zn	50	81	18	44	32	12	31	29	52	30
Ga	19	18	17	15	22	20	19	20	26	29
Rb	185	184	313	89	236	264	206	318	362	762
Sr	189	320	39	106	137	31	19	75	217	23
Y	46	38	12	20	60	20	39	37	62	141
Zr	368	.	67	279	144	57	102	113	123	69
Nb	17	17	9	17	16	16	21	15	32	59
Mo	3	4	2	3	2	2	2	2	2	2
Ag	.1	.	.1	.1	.1	.1	.1	.1	.1	.1
Sn	.	.	1	.	2	1	1	1	1	2
Ba	648	955	82	357	510	54	72	243	585	52
La	35	23	12	53	24	17	36	35	6	11
Ce	74	57	9	102	91	51	110	124	38	39
W	.	.	1	.	2	1	1	1	1	2
Pb	18	14	28	28	25	27	18	23	30	48
Th	17	.	45	24	19	28	31	40	35	48
U	3.1	.	3.6	4.5	3.1	4.2	3.9	4.9	8.0	16.9

+ a: tonalite #1941337; b: mafic porphyritic granite #1940444; c: high-silica granite #2242002; d: biotite−muscovite granite #1941202; e: coarse granite #1940934; f: medium granite #1940693; g: coarse equigranular granite #2242034; h: equigranular granite #2242035; i: porphyritic biotite granodiorite #2242023; j: medium equigranular granite #2242018

The hornblende-bearing granodioritic, tonalitic and gabbroic intrusions of the Burgeo intrusive suite may likewise represent a mantle-derived component. The biotite ± muscovite granodiorites and granites in the Burgeo intrusive suite, and their common association with migmatitic metasediments, may be the result of high-level melting of continental crust induced by emplacement of more mafic magmas. Dunning (*in* O'Brien *et al.*, 1986) notes that the results of isotopic studies, on the adjacent Silurian La Poile Group, indicate that either Grenville-aged continental crust or sediment derived from it was involved in melting to produce the La Poile magma. A similar source would also

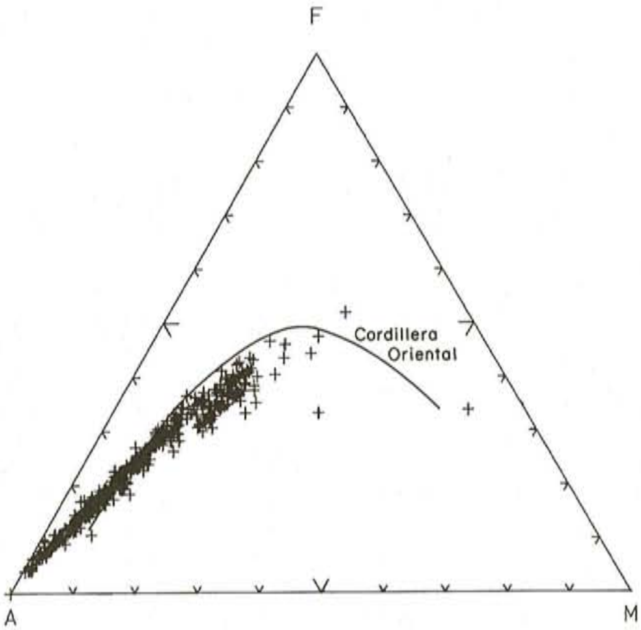

Figure 4. *Plot of total alkalis ($Na_2O+K_2O = A$):(total iron as $FeO = F$):($MgO=M$) for the Burgeo intrusive suite; trend shown is for calc-alkaline plutons of the Cordillera Oriental, Peru (from Kontak et al., 1984).*

be available for the later Burgeo intrusive suite granites. Using the classification of Pearce *et al.* (1984), the Burgeo intrusive suite should display geochemical features of volcanic-arc granites and/or syn-collision granites. A plot of Rb versus Y+Nb (Figure 5) shows that the majority of samples from the Burgeo intrusive suite fall in the volcanic-arc and within-plate granite fields. However, many samples lie in the within-plate field, usually represented by alkaline and peralkaline granites, indicating that the field boundaries are not precise.

The Chetwynd and François granites are high-silica, highly differentiated, two-feldspar, biotite granites that lack basic and intermediate phases (Figures 2 and 3). Both granites were intruded to high structural levels and, in the case of the François granite, ring complexes were developed. Late-stage crystallization of water-saturated melts is indicated by the presence of miarolitic cavities, tuffisites and granophyre. The primary magma was undersaturated in water as shown by its ability to rise through the crust and probably had only about 10 percent crystals as indicated by rhyolitic porphyry dykes in the country rocks. Similarly, the eastern margin of the northeastern complex of the François granite is a 20-m-wide, chilled zone with coarse biotite, quartz, alkali feldspar and plagioclase phenocrysts set in an aplitic matrix.

The François granite is particularly enriched in Rb, U and Th compared with the Burgeo intrusive suite (Figure 3; Table 1). Both granites are strongly depleted in FeO, MgO, CaO, Cu and Sr (Table 1). In the François granite, the late emplacement of plagioclase–porphyritic granite indicates that fractional crystallization of plagioclase occurred in both ring complexes. This is also shown by the strong depletion of Sr

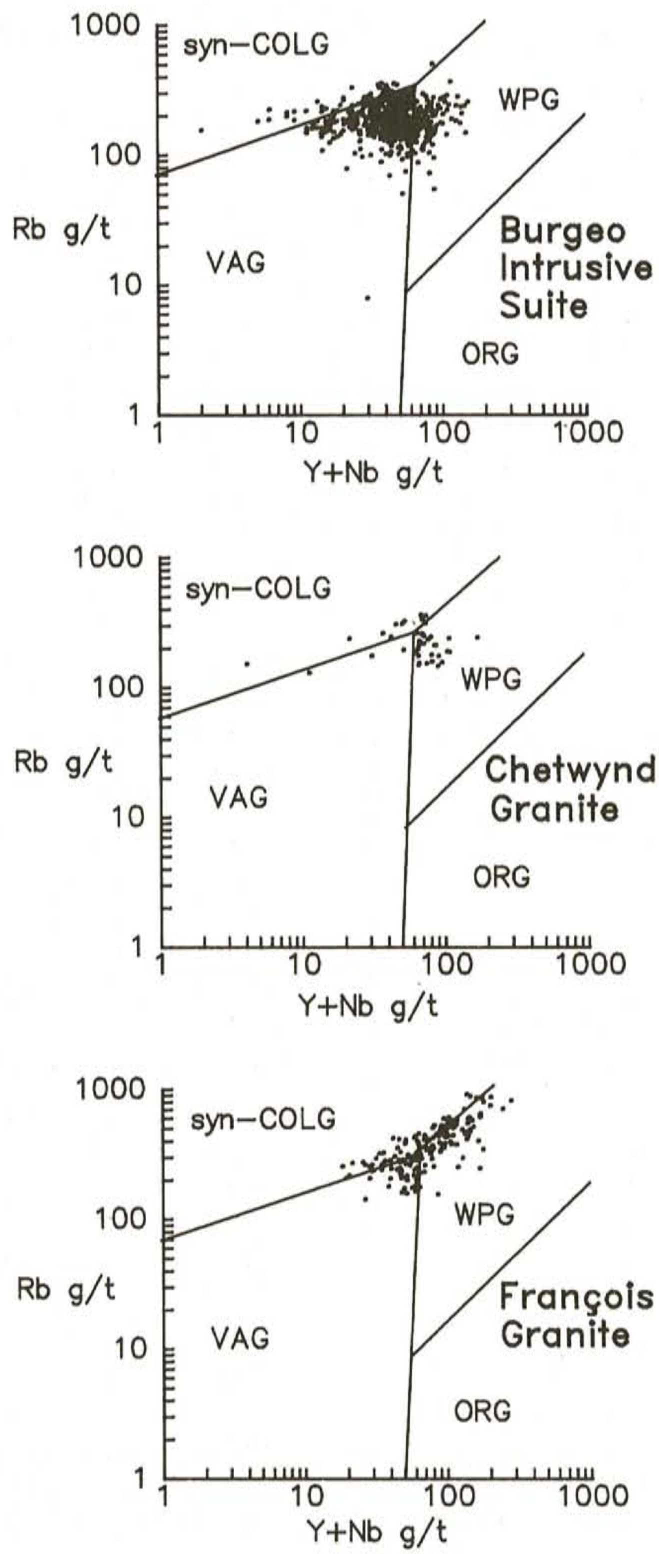

Figure 5. *Plot of Rb versus Y+Nb for the Burgeo intrusive suite, François and Chetwynd granites; fields for "volcanic arc granites" (VAG), "ocean ridge granites" (ORG), "syn-collisional granites" (syn-colg), and "within plate granites" (WPG) from Pearce et al. (1984).*

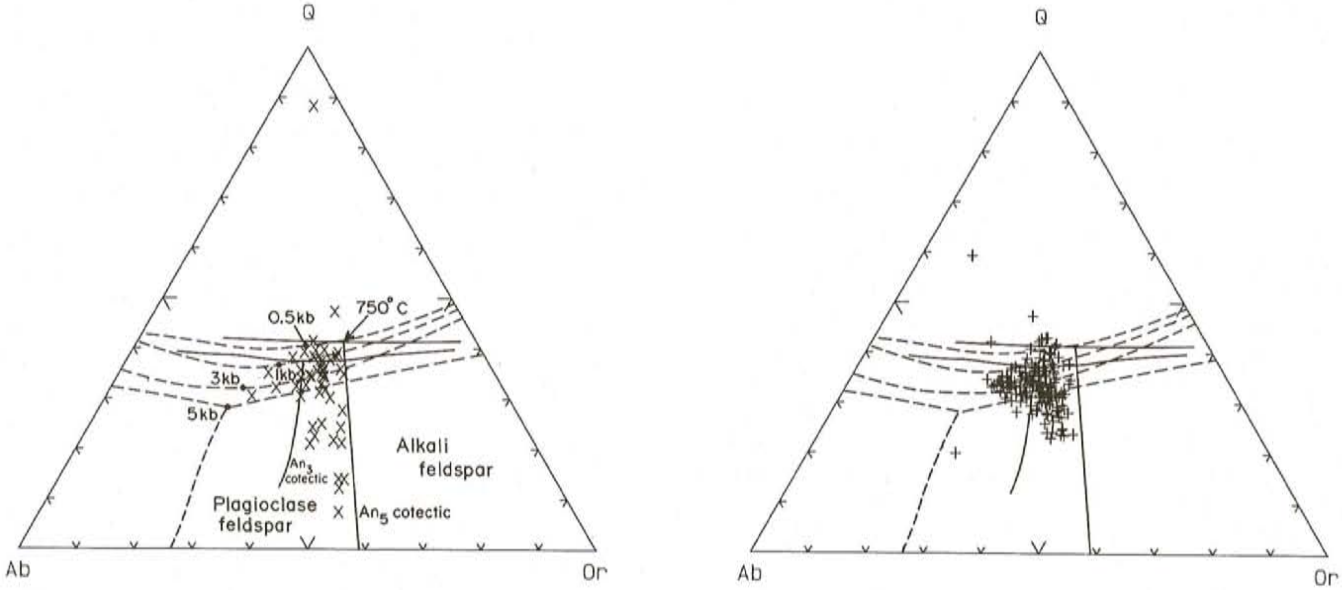

Figure 6. *Plot of normative Q:Ab:Or ratios for the Chetwynd and François granites with cotectics from Tuttle and Bowen (1958) and An_5 from James and Hamilton (1969).*

and CaO in the subsequent intrusion, which forms the core of the northeastern ring complex and has Rb/Sr ratios in excess of 100 (see Figure 3). The François granite contains rare, biotite-rich, cumulate layers indicating that fractionation of biotite could be the cause of the strong depletion of FeO and MgO. The depletion trend shown by K_2O indicates that K-feldspar was also fractionated out during crystallization.

Some units of the Burgeo intrusive suite, in the Bay de Vieux area, are composed of undeformed, biotite-poor granite similar to the Chetwynd and François granites and may be about the same age. Thus the Chetwynd and François granites may represent the final episode of Burgeo plutonism.

The low CaO content and therefore normative anorthite, of the Chetwynd and François granites, allows the use of the normative quartz–albite–orthoclase diagrams of Tuttle and Bowen (1958) and James and Hamilton (1969) to give an estimate of P_{H_2O}–T conditions for crystallization of the magmas. Figure 6 shows that the François and Chetwynd granite compositions cluster around the ternary minimum of 725°C, in the water-saturated granite system at 1 kilobar P_{H_2O}. An origin by fractional crystallization of a non-minimum melt, parent magma is indicated for the Chetwynd Granite by the trend along the Ab–Or cotectic in a system with 3 to 5 percent An at 1 kilobar P_{H_2O} (James and Hamilton, 1969) and suggests that crystallization occurred in the temperature range 875 to 750°C. The lack of a trend toward the Ab–Or join in the François granite indicates that the magmas crystallized at a lower temperature and the magma composition was close to a minimum melt.

The Chetwynd and François granites are similar to those of southwest England being high-level, alkali feldspar-porphyritic biotite granites. The only significant differences are the abundance of Sn–W mineralization and apparent abundance of primary muscovite in the southwest England granites. These may reflect differences in source rocks. Pearce *et al.* (1984) have indicated that the southwest England granites, although undeformed, belong to the syn-collisional granite group. Using the Rb versus Y+Nb plot (Figure 5) it is clear that the François and Chetwynd granites, do not lie within the syn-collisional granite field. However, the chronology and geological setting of these granites indicate that they are the product of a major orogeny.

Relationship of Intrusion to the Development of Major Structures

Minimum ages of movement on several of the major faults in the Hermitage Flexure area are given by cross-cutting relationships of dated granites and, in one case, mineralized veins. The Chetwynd Granite is described by Chorlton (1980b) as brecciated by the latest movements of the Bay d'Est Fault, indicating that the latest movements are post-377 Ma. The Dragon Bay Fault zone is cut by the François granite. Although undated, the François granite is similar to the Middle Devonian (approximately 367 Ma; Kontak *et al.* 1988) Ackley Granite and to the Chetwynd Granite. These correlations would imply that movement on the fault ceased by the Middle Devonian. Similarly, the fault contact with the Grey River enclave and associated shear zones within the Burgeo intrusive suite are truncated by the François granite. At Grey River, wolframite-bearing quartz veins cut mylonitized Burgeo granitoids and the Grey River enclave metamorphic rocks. Higgins (1980) reports a series of K/Ar (muscovite) ages from the veins, which indicate a long period of vein emplacement from 386 Ma to 329 Ma. These concentrate in the range 360–370 Ma, which could possibly include the age of the François granite. A sample of shear zone granite gave a K/Ar (biotite) age of 395 ± 8 Ma.

Mineralization and Exploration Potential

Known metallic mineralization associated with the Burgeo intrusive suite, and the Chetwynd and François granites is of limited extent. Wolframite-bearing quartz vein mineralization was discovered in 1955 (Bahyrycz, 1956) in the metamorphic rocks at Grey River and in the adjacent granite of the Burgeo intrusive suite. Associated base metals include molybdenite, chalcopyrite, galena and sphalerite. Surface drilling and extensive underground exploration were carried out and high-grade mineralization was discovered. Numerous reports are available on the geology and metallurgy of the tungsten deposits, e.g. Bahyrycz (1956, 1957); Higgins (1980, 1985); and Mathieu (1961). These indicate that high-grade tungsten ore is present in an extensive quartz vein system with the major veins extending for 1 to 2 km.

Following the discovery of the Grey River tungsten prospect, prospecting by the Buchans Mining Company in the upper Grey River area, during the late 1950's, resulted in the discovery of numerous, tungsten and pyrite showings in the vicinity of the contact of the Burgeo intrusive suite and the Bay du Nord Group.

Along Dog Cove Brook, about 5 km north of the main Grey River tungsten vein system, Bahyrycz (1956) reported widespread mineralized quartz veins in a fault zone. The veins carried Cu, Pb, Zn and Fe sulphides and assayed anomalous gold and silver. The highest values were obtained from just west of 'Beaver Pond', where galena–sphalerite–pyrite mineralization occurs in a quartz vein enclosed by altered granite. This was subsequently confirmed by Thurlow (1981). The altered granite wallrock assayed 2.90 oz/ton Au over 1 ft (Bahyrycz, 1956) and 0.74 oz/ton Au over 1.83 ft (Thurlow, 1981).

Molybdenite mineralization occurs in the Burgeo intrusive suite about 16 km north of Burgeo (O'Brien, 1983). The mineralization occurs as disseminations in widespread aplite veins.

McConnell (1985) reported anomalous Sn, Pb and W values from the François granite but mineralization has not yet been discovered. The François granite is anomalously radioactive and contains distinctly higher F, U, Th and Pb values than the Burgeo intrusive suite and the Chetwynd Granite. The François granite is extensively altered in places with kaolinization of feldspars and black quartz crystals. This is perhaps a result of radiation damage. The locally high fluorine content of biotite-poor granites indicates that fluorine was concentrated in the system and hydrothermal alteration is locally present. McConnell (1985) noted that topaz was discovered in a loose block in the Devil Bay area, and this is clearly indicative of hydrothermal mineralization.

Highly differentiated, fluorine-rich parts of the Chetwynd Granite have been identified (O'Brien, unpublished data) and these have potential for granophile mineralization. The spatial relationship, on a regional scale, between gold mineralization at Hope Brook (e.g. O'Brien, 1987, 1988) and the Chetwynd Granite may reflect some genetic relation between the two, and perhaps highlight the importance of the late high-silica granites in the metallogenic evolution of the region.

The metasedimentary and associated rocks, east of Grey River, contain an extensive silica deposit, which has been interpreted as either a vein or a metasediment. This deposit has been assessed by Butler and Greene (1976) who report a proven tonnage of 12 million short tons (approximately 11 million tonnes) averaging 95.5 percent SiO_2 and 1.9 percent Al_2O_3 with selected portions containing higher silica and lower alumina values.

There is only minor hydrothermal alteration associated with the major shear zones. Sericitization and chloritization are common along the faults. The Bay de Loup Brook Fault, 10 km north of Bay de Loup, is extensively silicified with milky quartz and trace amounts of pyrite cementing fault-brecciated granite.

ACKOWLEDGMENTS

This paper has benefitted from critical reviews by Andrew Kerr and Stephen Colman-Sadd.

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