

THE STRATIGRAPHY AND GEOCHEMISTRY OF THE SOUTHERN PACQUET HARBOUR GROUP, BAIE VERTE PENINSULA, NEWFOUNDLAND: IMPLICATIONS FOR MINERAL EXPLORATION

S.J. Piercey, G.A. Jenner and D.H.C. Wilton
Department of Earth Sciences, Memorial University of Newfoundland
St. John's, Newfoundland, Canada, A1B 3X5

ABSTRACT

The Ordovician southern Pacquet Harbour Group of the Baie Verte Peninsula has considerable potential to host VMS mineralization. A magmatic stratigraphy for the group is proposed that corresponds to three phases of igneous activity: Phase 1, consists of pillowed and massive lavas, felsic intrusive and volcanic rocks, and mixed volcanoclastic sedimentary rocks; Phase 2, consists of plagioclase porphyritic diabase dykes and sills and related gabbro and diorite; and Phase 3, consists of fine-grained mafic dykes. Geochemically, the rocks of Phase 1 are predominantly boninitic, suggesting a coevality between the mafic and felsic phases, whereas those of Phases 2 and 3 range from calc-alkalic, transitional arc, P-MORB, and N-MORB.

The close association of podiform, massive and auriferous stockwork sulphides to the Phase 1 rocks suggest that the inherent petrological characteristics of boninite genesis (refractory source melts, high-heat flow providing an adequate heat pump, impermeable felsic cap, and extensional stresses) have been fundamental in the formation of observed sulphides. Furthermore, their genesis provides a number of ingredients essential for the formation of significant quantities of VMS mineralization similar to those observed in other parts of Newfoundland and elsewhere. Only minor fluid-inclusion and stable-isotope data are available; however, in combination with the geology and host-rock geochemistry, a preliminary model is derived for the genesis of the southern Pacquet Harbour Group sulphides, and it is presented here.

INTRODUCTION

The Pacquet Harbour Group (PHG) is an incomplete Early Ordovician ophiolitic sequence consisting dominantly of mafic volcanic rocks, lesser felsic volcanic rocks, mixed mafic and felsic volcanoclastic rocks, and shallow-level intrusive rocks, which crop out in the north-central part of the Baie Verte Peninsula, Newfoundland (Figures 1 and 2; Hibbard, 1983; Piercey, 1996). These rock types are, and have been, prolific hosts to over 47 million tonnes of Cu-Zn±Au±Ag volcanogenic massive-sulphide mineralization (VMS) that have been mined from six different deposits over the last 50 years (Dimmell, 1996). Of these six deposits, five were located in the region north of the Rambler Brook Fault; a fault that separates the northern, polydeformed and polymetamorphosed part of the group from the southern part, which has a single penetrative fabric and greenschist-grade metamorphism (Hibbard, 1983; Piercey, 1996). The concentration and direction of exploration toward the northern part has resulted in much of the southern part not being surveyed; this paper will concentrate on the latter region and illustrate why it has considerable potential to host base-metal mineralization.

OBJECTIVES

Within this southern region, and indeed throughout the PHG, numerous problems exist with respect to the stratigraphy, geochemistry, and the relationship between the mafic and felsic phases of the group. This paper will provide new insight into these problems using an integrated dataset of host-rock geochemistry (trace- and rare-earth elements), sulphur-isotope geochemistry, and fluid-inclusion data. Furthermore, it will also show that the southern Pacquet Harbour Group has the necessary ingredients to be a prolific host of VMS mineralization and will provide a preliminary model for the genesis of the massive sulphides.

REGIONAL GEOLOGY

The PHG is located (Figure 1) in the western Dunnage Zone (terrace) within the Notre Dame Subzone (Williams 1978, 1979; Williams and Hatcher, 1983; Williams *et al.*, 1988), which is believed to represent an assemblage of volcanic arcs, back-arc basins and supra-subduction zone spreading centres (Swinden *et al.*, 1988; Swinden, 1991). Within the Notre Dame Subzone, the PHG is part of the Baie

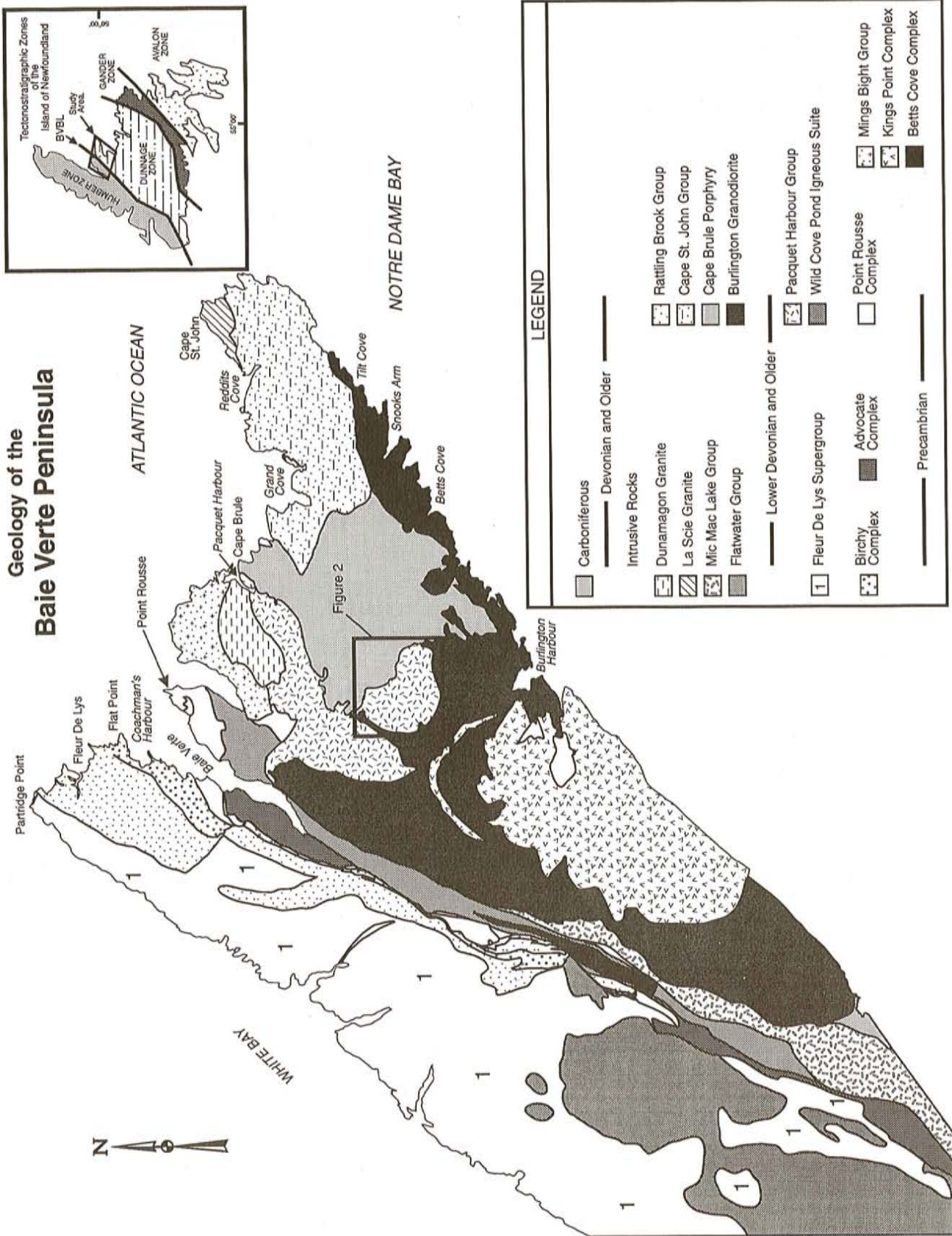


Figure 1. Geology of the Baie Verte Peninsula and location of the study area; geology modified after Hibbard (1983).

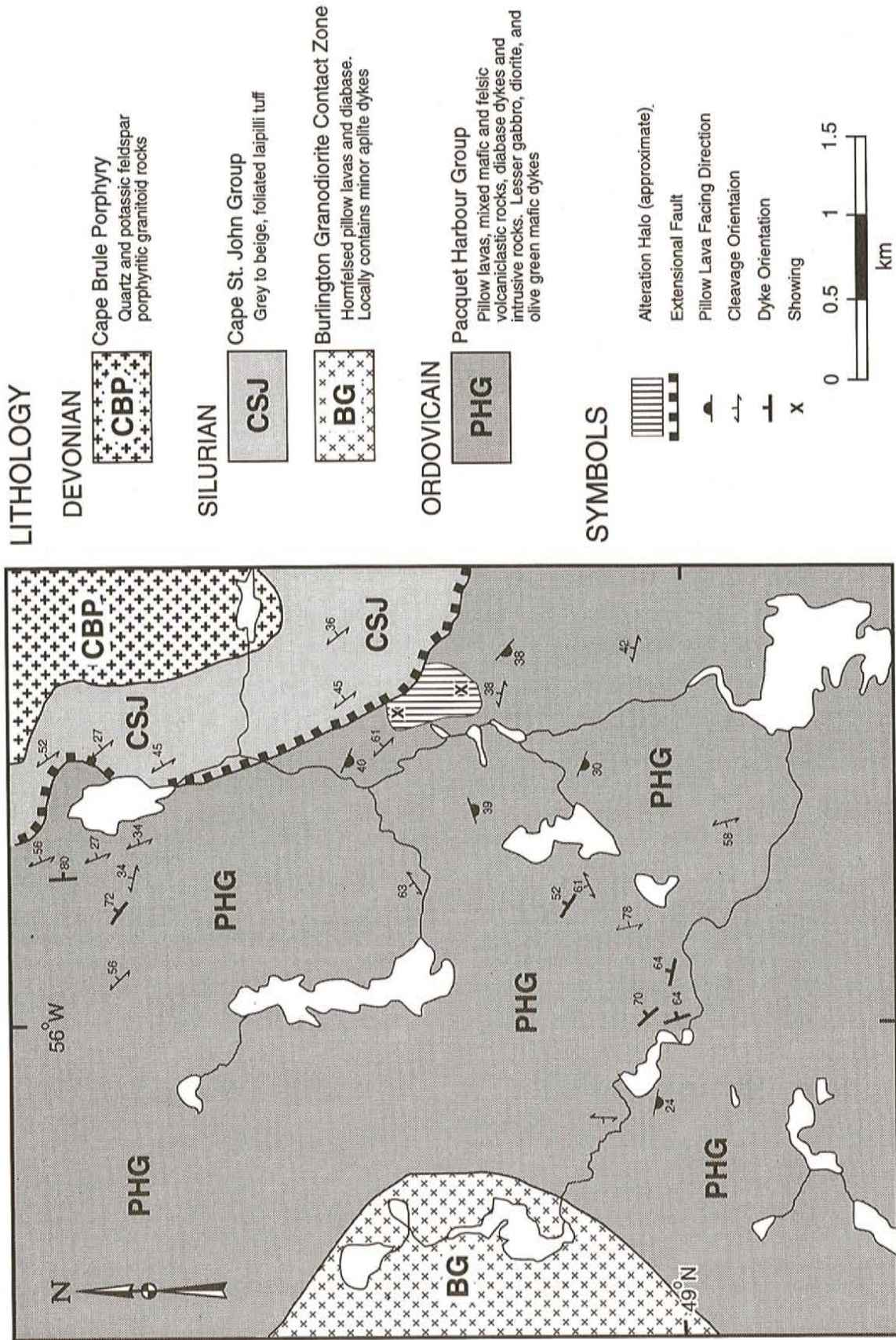


Figure 2. Simplified geology of the southern Pacquet Harbour Group volcanic rocks and location of the Brass Buckle Showing (alteration halo); geology after Piercey (1996) and Hibbard (1983).

Verte Belt and it consists of ophiolitic rocks, volcanic cover sequences, and intrusive rocks that make up the eastern part of the Baie Verte Peninsula (Figure 1; Hibbard, 1983). This belt is separated from the metamorphic, metaclastic and granitoid rocks of the Fleur de Lys Belt by the Baie Verte–Brompton Line (BVBL; Figure 1), a major structural suture that defines the collisional boundary between the Humber and Dunnage zones (Williams, 1978, 1979; Williams and St. Julien, 1982; Hibbard, 1983; Williams and Hatcher, 1983).

In the southern region, the PHG is overlain by the Silurian subaerial felsic volcanic rocks of the Cape St. John Group (CSJG) that is in unconformable and extensional fault contact with the underlying PHG (Figure 2; Hibbard, 1983; Piercey, 1996). The southern PHG is also intruded by Silurian to Devonian, felsic plutonic rocks including the Burlington Granodiorite and the Cape Brulé Porphyry; the latter intrudes the group to the west and south and the former to the north and east. The Burlington Granodiorite has been dated at 440 ± 2 Ma and 432 ± 2 Ma (G. Dunning and P. Cawood, unpublished data, 1992), however, the Silurian to Early Devonian Cape Brulé Porphyry has yet to be accurately dated (Figures 1 and 2; Hibbard, 1983).

Regionally, the PHG is most closely correlative with the ophiolitic Betts Cove Complex (BCC) of the Baie Verte Belt, based on the remarkable similarities in volcanic stratigraphy and pillow-lava geochemistry (Figure 1; Hibbard, 1983; Piercey, 1996). Low TiO_2 lavas of the BCC are strikingly similar to the boninitic lavas of the PHG, whereas the later MORB phases of the PHG are similar to the Snooks Arm Group, a cover sequence that overlies the BCC (Jenner, 1977; Jenner and Fryer, 1980; Coish *et al.*, 1982; Hibbard, 1983; Piercey, 1996). Such lithostratigraphic and geochemical correlation between these two units suggests the possibility of significant VMS mineralization within the southern PHG because the Tilt Cove and Betts Cove VMS deposits (now exhausted) are hosted within the BCC low- TiO_2 lava sequences (Strong and Saunders, 1988). Other partial correlatives of the group include the Birchy Complex and Pelée Point schist of the Baie Verte Belt, and possibly the Lushs Bight Group of western Notre Dame Bay (Hibbard, 1983; Kean *et al.*, 1995).

GEOLOGY AND MAGMATIC STRATIGRAPHY

The geology and stratigraphy of the southern PHG consist of five major rock types, these are: 1) pillowed and massive lava flows and associated volcanoclastic sedimentary rocks; 2) felsic intrusive and volcanic rocks; 3) plagioclase porphyritic diabase intrusive rocks and related dykes; 4) gabbro and diorite intrusive rocks; and 5) fine-grained olive-green mafic dykes. These rocks exhibit a well-defined crosscutting magmatic stratigraphy, which records three distinct phases of igneous activity that correspond to the

three-fold magmatostatigraphic subdivisions proposed for the southern lobe of the group (Figure 3).

Corresponding to the first phase of igneous activity are pillowed and massive mafic lava flows, felsic volcanic and intrusive rocks, and related mixed mafic–felsic volcanoclastic sedimentary rocks; collectively called stratigraphic Unit 1 of submarine volcanic origin (Figure 3). Pillowed and massive lava flows are both cut by, and intrusively intermingled with, rhyolitic to rhyodacitic intrusive and volcanic rocks. The intermingled nature of these felsic intrusive and volcanic rocks, along with both mafic and felsic fragments in the volcanoclastic sedimentary rocks, suggests a coeval evolution for both the mafic and felsic phases (Figure 3).

Stratigraphic Unit 2 consists of plagioclase porphyritic dykes and sills, and related sills of gabbro and diorite that appear to be of subvolcanic affinity (Figure 3). The dykes and sills of diabase associated with this stratigraphic unit are randomly oriented and are found crosscutting the lithologic units of stratigraphic Unit 1. Similarly, sills and plugs of gabbro and diorite cut the markers of stratigraphic Unit 1 and represent the deeper level, slower cooled portions of these higher level diabase sills.

The final phase of igneous activity, stratigraphic Unit 3, consists of fine-grained, 5- to 20-cm-wide, olive-green mafic dykes that have a close similarity to basalt in composition (Figure 3). Like the second phase dykes, these dykes are randomly oriented and cut both younger stratigraphic units.

All the three stratigraphic units of the southern PHG exhibit evidence of hydrothermal alteration and have been regionally metamorphosed to middle-greenschist facies (Hibbard, 1983; Piercey, 1996). Most of the pillow lavas, massive lavas, and fine-grained, olive-green dykes contain some or all of the following minerals: chlorite, epidote, tremolite, actinolite, sericite, carbonate, quartz and lesser zeolite. Similarly, the stratigraphic Unit 2 plagioclase–porphyritic dykes and sills, show similar alteration, but to a lesser extent. These alteration assemblages are typical of seawater hydrothermal alteration and middle greenschist-facies regional metamorphism.

Mineralization

Mineralization within the southern PHG occurs in the northeastern part of the study area at the Brass Buckle Showing. Within this area, the rock types consist of intrusively intermingled pillow lavas, rhyolite and rhyodacite and mixed volcanoclastic sedimentary rocks, all of which have extensive sericite, silica, chlorite, epidote, and carbonate alteration. At the Brass Buckle Showing, two occurrences are present consisting of, a) volcanogenic hosted base-metal sulphides, and b) auriferous vein-hosted sulphides. The dom-

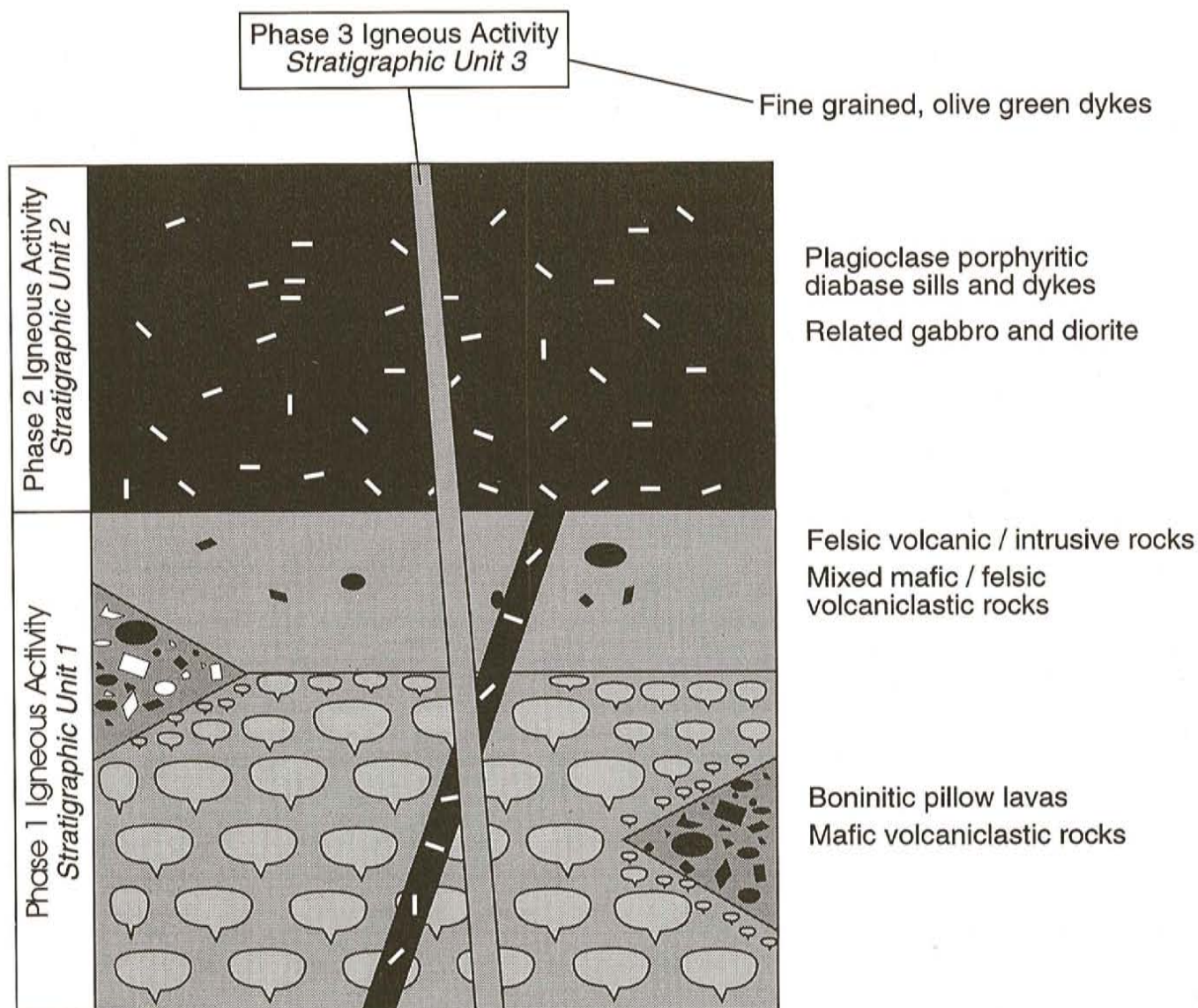


Figure 3. *Stratigraphic column illustrating the relationship of rock units and phases of igneous activity.*

inance of Cu and Zn sulphides and their lithotectonic setting suggest that the base-metal sulphides are similar to Cyprus-Type VMS mineralization.

The VMS occurrence is associated with a 30-m-wide outcrop of rhyodacitic intrusive rocks containing angular amygdaloidal mafic and brecciated mafic fragments. The massive sulphides themselves are hosted within the rhyodacites often in proximity to pods of quartz-rich material. The massive sulphides have a similar podiform nature to the quartz-rich areas and are approximately 60 by 30 cm and contain predominantly pyrite and chalcopyrite and lesser amounts of sphalerite and bornite. Approximately 20 m north of the podiform zone, 30- to 40-cm-wide auriferous quartz veins are present containing both magnetite and specular hematite; assay values from this vein have yielded values of 0.7 and 0.3 g/t Au.

In the northern part of the Brass Buckle Showing sericite and silica alteration are ubiquitous and, as in the southern part of the showing, 5 to 10 cm pods of medium-grained pyrite and chalcopyrite are present. However, unlike the southern part, small 3 cm pods of malachite and fuchsite mica are abundant; the latter mineral suggests the presence of gold mineralization in this region as well.

GEOCHEMISTRY

SAMPLE SELECTION AND GEOCHEMICAL ANALYSES

Twenty-nine samples were collected for geochemical analysis based on crosscutting stratigraphic relations and the need to provide a wide areal geochemical coverage for the various rock units of the southern PHG. The 29 samples

analyzed included, 9 pillow lavas and basalt flows, 12 plagioclase porphyritic diabase and fine-grained mafic dykes, 4 plagioclase porphyritic diabase sills, 2 rhyodacites, and 2 gabbros. Supplementing this data set were data for 19 pillow-lava samples provided by H.S. Swinden (unpublished data, personal communication, 1996).

The 29 collected samples and Swinden's 19 samples were analyzed for the trace elements, Sc, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, Ga, As, P, S, Cl, Rb, Sr, Y, Zr, Nb, Ba, Ce, Th, and U, and major elements Na, Mg, K, Ca, Al, and Si by pressed-powder pellet X-ray fluorescence, following the method of Longerich (1995). Limits of detection, sensitivity, and the precision and accuracy of this method is outlined by Longerich (1995).

Initial trace-element data from X-ray fluorescence were screened using Ti-Zr (Pearce and Cann, 1973) Ti-V (Shervais, 1982) and Th-Zr-Nb (Wood, 1980) discrimination diagrams to select samples for subsequent rare-earth element (REE) and selected trace-element analyses. Of the 29 samples, 19 were analyzed for the REE: La, Hf, Ta, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu; and the trace elements Y, Zr, Nb, and Ti by sodium peroxide sinter, Inductively-Coupled-Plasma Mass-Spectrometry (ICP-MS) method of Longerich *et al.* (1990, 1993). From Swinden's samples, 10 pillow lavas were analyzed for the same element suite by the acid dissolution ICP-MS method of Longerich *et al.* (1993) and Jenner *et al.* (1990).

Two samples of pyrite were analyzed for their sulphur-isotope composition. The quartz vein-hosted pyrites were initially separated from the quartz by crushing and subsequent picking under microscope. Sample preparation was carried out following the method of Rafter (1965) with subsequent analyses using a PRISM 903 Gas Chromatograph Mass Spectrometer (GC-MS).

Fluid inclusions analyses were also completed. The measurements were carried out using a Fluid Inc. heating/freezing stage attached to an Ortholux II Pol-BK Leitz microscope. The thermocouple was calibrated over -56.6 to $+374.1^{\circ}\text{C}$ using two BDH chemical standards and four synthetic fluid inclusions prior to determination of the thermal data for the fluid inclusions. Estimated errors between measured and reported temperatures for all six standards were $< \pm 0.8$ and mostly $< \pm 0.1$.

RESULTS

Pillow Lavas: Discrimination Diagrams

Pillow lava samples were discriminated by the Ti-Zr (Pearce and Cann, 1973), the Ti-V (Shervais, 1982) and the Th-Zr-Nb (Wood, 1980) diagrams resulting in well-defined

geochemical divisions of the lava samples. On the Ti-Zr diagram, most samples are clustered in the lower, left hand corner of the diagram (Figure 4a), comparable to the field for modern boninites (Jenner, 1981, 1982); only sample 2141019 varied (Table 1), having a low K tholeiite behaviour (Figure 4a).

Further screening by the Ti-V diagram indicates a similar subdivision of the lavas, with most exhibiting minimal Ti spread with varying V content, hence displaying an arc character (Figure 4c). Only two samples vary from this behaviour, sample 214019 lies in the central part of the diagram and exhibits MORB/BAB characteristics; sample SP-9.2E lies in the upper right-centre part of the diagram outside this field (Figure 4c). Most of the lava samples plot in field D of the Th-Zr-Nb diagram (Figure 4e), typical of destructive plate margin basalts, whereas sample 2141019 lies in field A (N-MORB), and SP-9.2E does not plot in any field.

Other Rock Types: Discrimination Diagrams

Using the same discrimination diagrams as for the lavas, the other rock types in the group exhibit highly variable geochemistry. On the Ti-Zr diagram, most of the rock types lie in field D or just outside of it, indicating a geochemical behavior consistent with ocean-floor basalt/MORB (Figure 4b). Exceptions to this are sample SP-5.18C (olive dyke) which has a boninitic affinity like the pillow lavas lying in the lower left hand corner of the diagram; whereas samples SP-2.10B (gabbro) and SP-6.6B lie in field C exhibiting calc-alkalic affinity (Figure 4b).

On the Ti-V diagram most samples plot in the central part of the diagram in the MORB/BAB field and are of non-arc affinity (Figure 4d). Contrasting this behaviour are samples SP-2.10B and SP-6.6B which lie just to the left of the MORB/BAB samples; sample SP-6.11D which lies on the edge of the MORB/BAB-alkaline basalt fields (just below the 50 line; Figure 4d); and sample SP-5.18C which lies in the extreme left of the diagram, exhibiting boninitic chemistry (Figure 4d). Similar to the previous diagrams, most of the samples lie in field A of the Th-Zr-Nb diagram with N-MORB chemistry, while sample SP-2.10B straddles field A and D (N-MORB-IAT fields); sample SP-6.10C lies in field D exhibiting IAT chemistry; sample SP-2.10A lies in field B with E-MORB chemistry; and sample SP-6.6B lies in the lower left hand corner exhibiting boninitic chemistry (Figure 4f).

Pillow Lavas: REE Geochemistry

Lavas analyzed for REE content were plotted on primitive-mantle normalized plots, normalized to Hofmann's (1988) primitive-mantle values. These plots subdivided the lavas into two groups: 1) lavas of boninitic affinity, and 2) lavas of non-boninitic affinity. Of the 17 lava samples, 13

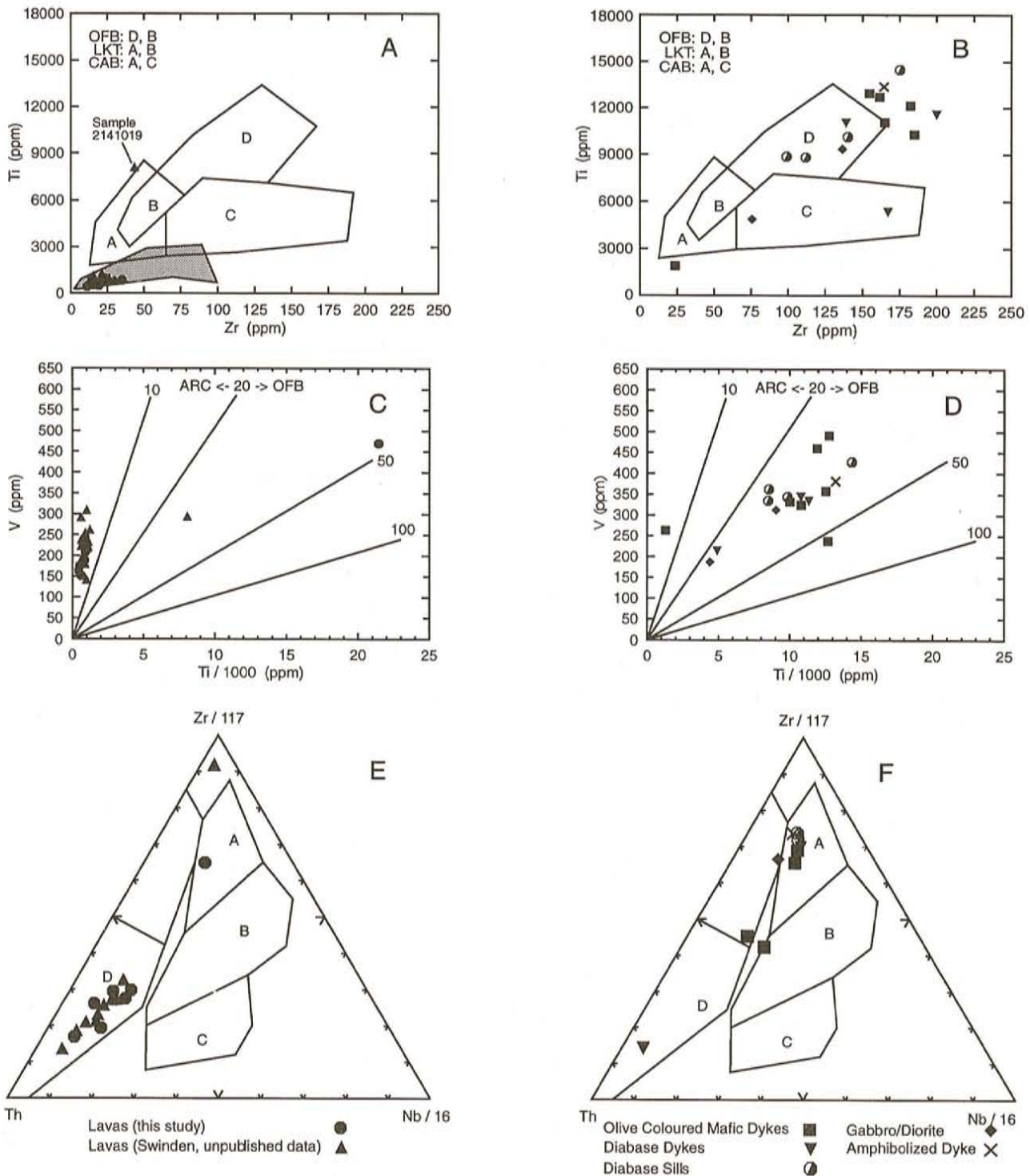


Figure 4. Discrimination diagrams for rock units: a) and b), Ti-Zr diagram for lavas and other rocks, fields after Pearce and Cann (1973); c) and d), Ti-V diagram for lavas and other rocks, fields after Shervais (1982); e) and f) Th-Zr-Nb diagram for lavas and other rocks (fields after Wood, 1980).

had characteristics of both modern and ancient boninitic lavas (Figure 5a; Cameron *et al.*, 1979; Jenner, 1981,1982; Coish, 1989; Crawford *et al.*, 1989; Pearce *et al.*, 1992). These characteristics are, that they plotted with a distinctive U-shaped REE pattern, the Nb content was less than that of Th and La (arc signature), MREE was depleted relative to HREE and LREE, Zr had greater content than that of Nd and Sm, and all were enriched in LREE and LFSE (Figure 5).

Variants from this behaviour include samples 2141015 and 2141016 (Table 1) which have an arc signature, similar to the boninitic lavas but lack a pronounced U-shaped pattern, have smaller Zr peaks, less depleted in MREE, and have a greater enrichment in LREE (Figure 5). These samples are interpreted as being calc-alkaline. Samples 2141019 and SP-9.2E have MORB geochemical affinities contrasting with arc affinity of both the boninitic and calc-alkalic lavas (Figure 5). Sample 2141019 exhibits a LREE depletion and relatively flat MREE to HREE, typical of N-MORB chemistry (Figure 5). Similarly, sample SP-9.2E has similar MREE to HREE behavior with the exception of a greater enrichment in LREE and has a Zr peak, typical of E-MORB affinity (Figure 5b).

Other Rock Types: REE Geochemistry

Similar to the lavas, the other rock types were separable into geochemically coherent groups, these are: 1) fine-grained, olive-green dykes; 2) plagioclase porphyritic diabase dykes; 3) diabase-gabbro intrusive rocks; and 4) rhyodacitic intrusive rocks. The two dyke groups range from N-MORB, transitional arc, E-MORB, to calc-alkaline in geochemical character. Of the 7 dykes analyzed, 4 exhibit N-MORB chemistry similar to lava sample 2141019, with a LREE depletion and relatively flat MREE-HREE, whereas sample SP-2.10A exhibits LREE enrichment similar to SP-9.2E and has an E-MORB affinity (Figure 6). Sample SP-6.10C has a similar pattern to sample SP-9.2E with the exception of a slight Nb trough, suggesting a transitional-arc chemistry (Figure 6). Sample SP-6.6B is different when compared to the other dykes and has a calc-alkalic trend, not dissimilar to modern bajaites from California (Bigioggero *et al.*, 1995).

Plagioclase porphyritic diabase sills and the related gabbro have signatures of N-MORB affinity except that they contain a Zr peak (Figure 6). Rhyodacitic samples have a REE pattern similar to that of boninitic lavas with the exception of higher LREE content, and Piercey (1996) suggested that they are felsic derivatives of the boninitic lavas (Figure 5c).

Sulphur-Isotope Geochemistry

Two samples of pyrite from the auriferous quartz veins of the Brass Buckle Showing were analyzed for their sulphur-isotope composition. $\delta^{34}\text{S}$ ratios obtained from the two pyrite

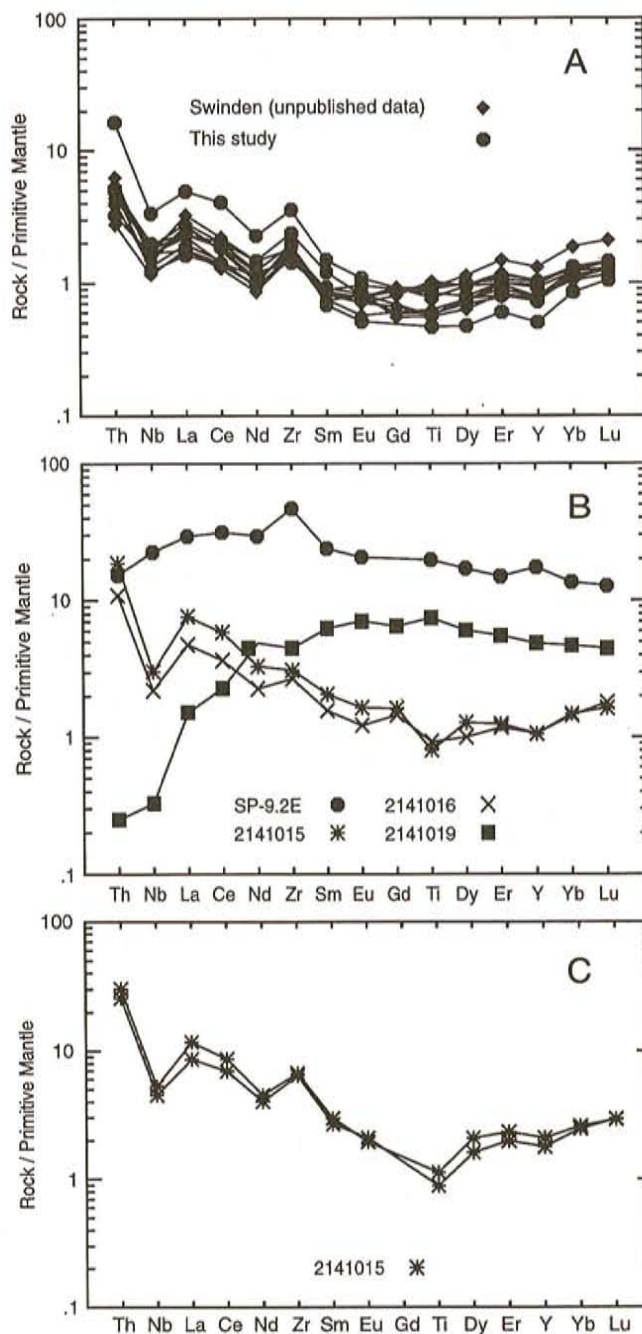


Figure 5. Primitive-mantle normalized plots of A) lavas of boninitic affinity, B) lavas of non-boninitic affinity, and C) rhyodacite. Primitive-mantle normalization values from Hofmann (1988).

samples were +4.4 and +5.1‰, well within the range for Cyprus-Type VMS deposits (cf., Ohmoto and Rye, 1979; Hoefs, 1981; Rollinson, 1993). Values within the range observed are typical of inorganic reduction of seawater sulphate at high temperatures within a hydrothermal ore system (Ohmoto and Rye, 1979; Rollinson, 1993). Furthermore, the lower end value of +4.4‰ is slightly lower than

Table 1. Geochemical data for rocks of the southern Pacquet Harbour Group

Sample Rock Type	SP-2.3A Pillow	SP-3.3 Pillow	SP-5.9A Pillow	SP-6.10B Pillow	SP-9.2E Pillow	SP-11.1C Pillow	SP-11.5B Pillow	2141001 Pillow	2141002 Pillow
SiO ₂	56	58.23	51.54	52.17	63.58	50	51.26	56.25	53.82
TiO ₂	0.08	0.14	0.15	0.1	3.58	0.07	0.16	0.16	0.11
Al ₂ O ₃	8.35	10.44	9.09	6.45	16.52	5.81	8.81	12.22	9.65
FeO*	8.13	7.25	8	7.78	-	9.44	12.01	8.07	8.43
MnO	0.17	0.14	0.16	0.23	0.37	0.18	0.21	0.16	0.19
MgO	16.74	12.82	20.78	16.93	-	27.9	20.61	11.14	15.32
CaO	7.93	7.12	8.27	14.79	8.79	6.24	6.2	9.36	10.55
Na ₂ O	2.52	2.75	1.88	1.43	5.63	0.28	0.5	2.5	1.69
K ₂ O	0.07	1.06	0.1	0.08	0.81	0.05	0.23	0.1	0.22
P ₂ O ₅	0.02	0.03	0.02	0.02	0.73	0.01	0.02	0.02	0.01
Total	100	100	100	100	100	100	100	100	100
Cr	1344	607	1346	1365	64	2412	2096	649	1619
Ni	260	104	320	388	22	615	483	95	403
Sc	42	37	41	43	45	43	50	43	41
V	175	188	208	151	470	163	233	241	193
Cu	2	7	9	32	29	0	2	20	7
Pb	-	0	2	11	15	1	2	-	-
Zn	-	2	7	69	153	78	33	62	82
S	744.37	212.25	210.75	100.33	1730.65	97.56	94.8	-	-
As	4.65	-	4.65	9.07	9.59	1.73	8.35	-	-
Rb	0	16	2	-	31	1	6	2	6
Ba	2	151	3	13	75	-	5	25	56
Sr	39	76	81	251	262	2	17	163	104
Ga	9	5	7	8	32	5	9	9	8
Ta	0.82	1.08	0.62	1.11	1.35	-	0.45	0.07	0.05
Nb	0.8	2.1	1	1.2	13.9	0.8	1.1	1	0.9
Hf	0.48	0.84	0.48	0.37	7.96	-	0.49	0.4	0.51
Zr	19	35	15	14	456	11	23	15	18
Y	2	4	4	3	69	2	4	5	3
Th	0.42	1.33	0.26	0.42	1.24	-	0.4	0.42	0.51
La	1	3.01	1.09	1.42	18.04	-	1.42	1.37	1.66
Ce	2.19	6.51	2.24	3	50.34	-	3.27	2.31	2.83
Pr	0.28	0.72	0.27	0.35	7.42	-	0.42	0.37	0.37
Nd	1.16	2.71	1.15	1.43	35.17	-	1.75	1.34	1.22
Sm	0.26	0.58	0.34	0.36	9.27	-	0.47	0.33	0.29
Eu	0.07	0.16	0.14	0.12	3.01	-	0.12	0.11	0.08
Gd	-	-	-	-	-	-	-	0.47	0.31
Tb	0.05	0.09	0.08	0.07	1.75	-	0.09	0.09	0.06
Dy	0.3	0.6	0.51	0.49	10.95	-	0.63	0.72	0.48
Ho	0.08	0.13	0.13	0.11	2.2	-	0.13	0.19	0.12
Er	0.25	0.41	0.42	0.34	6.26	-	0.44	0.62	0.37
Tm	0.05	0.07	0.06	0.06	0.87	-	0.07	0.1	0.07
Yb	0.35	0.55	0.5	0.47	5.63	-	0.54	0.77	0.5
Lu	0.07	0.09	0.09	0.08	0.81	-	0.09	0.13	0.09
Cl	154.38	119.02	200.77	74.53	104.46	231.06	346.87	-	-

Table 1. *Continued*

Sample Rock Type	2141003 Pillow	2141004 Pillow	2141005 Pillow	2141006 Pillow	2141007 Pillow	2141008 Pillow	2141009 Pillow	2141011 Pillow	2141012 Pillow
SiO ₂	53.46	54.95	53.9	52.14	51.28	57.25	51.16	52.45	55.42
TiO ₂	0.19	0.09	0.14	0.14	0.21	0.15	0.19	0.1	0.18
Al ₂ O ₃	12.54	7.99	11.35	12.9	11.09	12.38	11.82	10.32	11.87
FeO*	8.19	9.45	14.49	9.54	15.16	6.48	8.3	9.07	9.86
MnO	0.17	0.17	0.25	0.2	0.24	0.12	0.15	0.22	0.19
MgO	14.18	14.84	12.18	15.38	11.92	10.35	16.5	15.34	11.15
CaO	8.26	10.31	6.99	7.34	9.05	9.4	10.08	11.31	8.11
Na ₂ O	2.92	2.03	0.58	2.31	1.02	3.84	1.73	1.03	3.1
K ₂ O	0.08	0.15	0.13	0.04	0.01	0.02	0.05	0.15	0.09
P ₂ O ₅	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.01	0.01
Total	100	100	100	100	100	100	100	100	100
Cr	1212	1359	1179	1366	1764	574	1709	2144	940
Ni	350	373	284	294	459	127	415	478	249
Sc	38	37	44	47	43	55	42	44	49
V	221	185	247	232	263	255	234	223	224
Cu	4	4	6	5	16	5	5	4	21
Pb	-	-	-	-	-	-	-	-	-
Zn	66	53	76	79	65	23	42	77	81
S	-	-	-	-	-	-	-	-	-
As	-	-	-	-	-	-	-	-	-
Rb	1	3	4	1	1	1	2	3	1
Ba	27	52	29	21	36	27	39	23	19
Sr	121	67	103	70	73	149	95	119	159
Ga	8	6	10	7	10	9	10	9	9
Ta	0.05	-	-	-	-	-	-	0.07	-
Nb	0.8	1	1	1	-	1	1	1	1
Hf	0.42	-	-	-	-	-	-	0.52	-
Zr	15	16	23	29	22	24	16	17	20
Y	4	4	3	3	5	4	4	3	4
Th	0.33	-	-	-	-	-	-	0.43	-
La	1.21	-	-	-	-	-	-	2.01	-
Ce	2.36	-	-	-	-	-	-	3.54	-
Pr	0.32	-	-	-	-	-	-	0.47	-
Nd	1.11	-	-	-	-	-	-	1.74	-
Sm	0.32	-	-	-	-	-	-	0.34	-
Eu	0.1	-	-	-	-	-	-	0.1	-
Gd	0.41	-	-	-	-	-	-	0.34	-
Tb	0.08	-	-	-	-	-	-	0.06	-
Dy	0.6	-	-	-	-	-	-	0.47	-
Ho	0.14	-	-	-	-	-	-	0.11	-
Er	0.47	-	-	-	-	-	-	0.4	-
Tm	0.08	-	-	-	-	-	-	0.07	-
Yb	0.53	-	-	-	-	-	-	0.5	-
Lu	0.09	-	-	-	-	-	-	0.08	-
Cl	-	-	-	-	-	-	-	-	-

Table 1. *Continued*

Sample	2141013	2141014	2141015	2141016	2141017	2141018	2141019	SP-6.6A	SP-11.1D
Rock Type	Pillow	Pillow	Pillow	Pillow	Pillow	Pillow	Pillow	Rhyodacite	Rhyodacite
SiO ₂	73.52	53.82	62.25	53.58	53.62	54.22	47.07	70.76	74.1
TiO ₂	0.16	0.1	0.15	0.17	0.1	0.17	1.35	0.16	0.2
Al ₂ O ₃	11.61	10.95	10.56	13.4	10.88	11.14	16.08	12.78	11.93
FeO*	3.04	8.52	6.99	9.28	8.8	7.34	9.53	2.8	3.31
MnO	0.16	0.18	0.14	0.18	0.14	0.12	0.16	0.04	0.04
MgO	2.83	15.73	9.03	14.17	13.13	13.38	10.81	3.73	4.24
CaO	2.7	7.51	6.88	6.98	11.24	11.28	12.72	3.09	1.83
Na ₂ O	5.78	3.02	3.86	1.38	2.03	2.06	2.08	6.44	4.28
K ₂ O	0.15	0.15	0.11	0.86	0.04	0.27	0.15	0.15	0.3
P ₂ O ₅	0.03	0.02	0.03	0.02	0.02	0.01	0.05	0.05	0.3
Total	100	100	100	100	100	100	100	100	100
Cr	755	1820	648	1168	1177	1098	535	34	15
Ni	103	385	113	298	326	328	217	9	1
Sc	41	46	37	52	36	46	44	10	18
V	142	238	180	310	293	218	295	57	53
Cu	5	61	5	16	9	4	66	27	23
Pb	-	-	-	-	-	-	-	3	3
Zn	13	76	46	62	67	34	66	-	-
S	-	-	-	-	-	-	-	78.81	84.67
As	-	-	-	-	-	-	-	4.24	5.25
Rb	3	2	2	18	1	3	2	2	0
Ba	38	26	18	129	7	64	22	12	28
Sr	69	36	104	136	119	100	146	163	142
Ga	7	7	7	13	8	10	17	8	9
Ta	-	0.07	-	0.1	0.06	-	-	2.06	3.26
Nb	1	1.2	1.9	1.4	0.9	0.7	0.2	2.8	3.3
Hf	-	0.46	0.71	0.7	0.41	0.42	1.07	1.56	1.46
Zr	23	19	30	26	16	15	44	62	65
Y	3	3	4	4	3	4	19	7	8
Th	-	0.36	1.52	0.89	0.31	0.22	0.02	2.1	2.46
La	-	1.73	4.69	2.93	1.63	1.1	0.93	5.27	7.2
Ce	-	3.24	9.43	5.89	2.85	2.06	3.69	11.12	13.86
Pr	-	0.43	1.09	0.71	0.37	0.3	0.96	1.23	1.51
Nd	-	1.47	3.93	2.71	1.3	1.02	5.85	4.79	5.39
Sm	-	0.31	0.8	0.61	0.28	0.33	2.43	1.04	1.15
Eu	-	0.12	0.24	0.18	0.12	0.11	1.04	0.3	0.28
Gd	-	0.3	0.83	0.74	0.28	0.45	3.32	-	-
Tb	-	0.06	0.12	0.1	0.05	0.09	0.6	0.16	0.21
Dy	-	0.44	0.81	0.64	0.4	0.61	3.88	1.03	1.33
Ho	-	0.12	0.17	0.16	0.09	0.14	0.79	0.25	0.29
Er	-	0.33	0.52	0.49	0.34	0.49	2.33	0.82	0.97
Tm	-	0.06	0.08	0.08	0.06	0.08	0.32	0.14	0.15
Yb	-	0.43	0.61	0.6	0.44	0.52	1.95	1.02	1.07
Lu	-	0.07	0.1	0.12	0.08	0.09	0.28	0.19	0.19
Cl	-	-	-	-	-	-	-	65.15	105.07

Table 1. *Continued*

Sample	SP-11.5B	2141001	2141002	2141003	2141004	2141005	2141006	2141007	2141008	2141009
Rock Type	Pillow	Pillow	Pillow	Pillow	Pillow	Pillow	Pillow	Pillow	Pillow	Pillow
SiO ₂	51.26	56.25	53.82	53.46	54.95	53.9	52.14	51.28	57.25	51.16
TiO ₂	0.16	0.16	0.11	0.19	0.09	0.14	0.14	0.21	0.15	0.19
Al ₂ O ₃	8.81	12.22	9.65	12.54	7.99	11.35	12.9	11.09	12.38	11.82
FeO*	12.01	8.07	8.43	8.19	9.45	14.49	9.54	15.16	6.48	8.3
MnO	0.21	0.16	0.19	0.17	0.17	0.25	0.2	0.24	0.12	0.15
MgO	20.61	11.14	15.32	14.18	14.84	12.18	15.38	11.92	10.35	16.5
CaO	6.2	9.36	10.55	8.26	10.31	6.99	7.34	9.05	9.4	10.08
Na ₂ O	0.5	2.5	1.69	2.92	2.03	0.58	2.31	1.02	3.84	1.73
K ₂ O	0.23	0.1	0.22	0.08	0.15	0.13	0.04	0.01	0.02	0.05
P ₂ O ₅	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02
Total	100	100	100	100	100	100	100	100	100	100
Mg#	75.35	71.11	76.41	75.51	73.66	59.96	74.19	58.34	74	77.99
Cr	2096	649	1619	1212	1359	1179	1366	1764	574	1709
Ni	483	95	403	350	373	284	294	459	127	415
Sc	50	43	41	38	37	44	47	43	55	42
V	233	241	193	221	185	247	232	263	255	234
Cu	2	20	7	4	4	6	5	16	5	5
Pb	2	-	-	-	-	-	-	-	-	-
Zn	33	62	82	66	53	76	79	65	23	42
S	94.8	-	-	-	-	-	-	-	-	-
As	8.35	-	-	-	-	-	-	-	-	-
K	-	855	1801	685	1264	1044	346	90	168	433
Rb	6	2	6	1	3	4	1	1	1	2
Ba	5	25	56	27	52	29	21	36	27	39
Sr	17	163	104	121	67	103	70	73	149	95
Ga	9	9	8	8	6	10	7	10	9	10
Ta	0.45	0.07	0.05	0.05	-	-	-	-	-	-
Nb	1.1	1	0.9	0.8	1	1	1	-	1	1
Hf	0.49	0.4	0.51	0.42	-	-	-	-	-	-
Zr	23	15	18	15	16	23	29	22	24	16
Ti	-	988	681	1113	548	816	812	1230	909	1127
Y	4	5	3	4	4	3	3	5	4	4
Th	0.4	0.42	0.51	0.33	-	-	-	-	-	-
U	-	0.1	0.12	0.13	-	-	-	-	-	-
La	1.42	1.37	1.66	1.21	-	-	-	-	-	-
Ce	3.27	2.31	2.83	2.36	-	-	-	-	-	-
Pr	0.42	0.37	0.37	0.32	-	-	-	-	-	-
Nd	1.75	1.34	1.22	1.11	-	-	-	-	-	-
Sm	0.47	0.33	0.29	0.32	-	-	-	-	-	-
Eu	0.12	0.11	0.08	0.1	-	-	-	-	-	-
Gd	-	0.47	0.31	0.41	-	-	-	-	-	-
Tb	0.09	0.09	0.06	0.08	-	-	-	-	-	-
Dy	0.63	0.72	0.48	0.6	-	-	-	-	-	-
Ho	0.13	0.19	0.12	0.14	-	-	-	-	-	-
Er	0.44	0.62	0.37	0.47	-	-	-	-	-	-
Tm	0.07	0.1	0.07	0.08	-	-	-	-	-	-
Yb	0.54	0.77	0.5	0.53	-	-	-	-	-	-
Lu	0.09	0.13	0.09	0.09	-	-	-	-	-	-
Cl	346.87	-	-	-	-	-	-	-	-	-
Density	2.77	2.63	2.69	2.66	2.69	2.74	-	-	-	-

Table 1. *Continued*

Sample	21411011	2141012	2141013	2141014	2141015	2141016	2141017	2141018	2141019	SP-11.1C
Rock Type	Pillow	Pillow	Pillow	Pillow	Pillow	Pillow	Pillow	Pillow	Pillow	Pillow
SiO ₂	52.45	55.42	73.52	53.82	62.25	53.58	53.62	54.22	47.07	50
TiO ₂	0.1	0.18	0.16	0.1	0.15	0.17	0.1	0.17	1.35	0.07
Al ₂ O ₃	10.32	11.87	11.61	10.95	10.56	13.4	10.88	11.14	16.08	5.81
FeO*	9.07	9.86	3.04	8.52	6.99	9.28	8.8	7.34	9.53	9.44
MnO	0.22	0.19	0.16	0.18	0.14	0.18	0.14	0.12	0.16	0.18
MgO	15.34	11.15	2.83	15.73	9.03	14.17	13.13	13.38	10.81	27.9
CaO	11.31	8.11	2.7	7.51	6.88	6.98	11.24	11.28	12.72	6.24
Na ₂ O	1.03	3.1	5.78	3.02	3.86	1.38	2.03	2.06	2.08	0.28
K ₂ O	0.15	0.09	0.15	0.15	0.11	0.86	0.04	0.27	0.15	0.05
P ₂ O ₅	0.01	0.01	0.03	0.02	0.03	0.02	0.02	0.01	0.05	0.01
Total	100	100	100	100	100	100	100	100	100	100
Mg#	75.08	66.84	62.34	76.68	69.72	73.13	72.68	76.46	66.89	84.04
Cr	2144	940	755	1820	648	1168	1177	1098	535	2412
Ni	478	249	103	385	113	298	326	328	217	615
Sc	44	49	41	46	37	52	36	46	44	43
V	223	224	142	238	180	310	293	218	295	163
Cu	4	21	5	61	5	16	9	4	66	0
Pb	-	-	-	-	-	-	-	-	-	1
Zn	77	81	13	76	46	62	67	34	66	78
S	-	-	-	-	-	-	-	-	-	97.56
As	-	-	-	-	-	-	-	-	-	1.73
K	1281	762	1275	1220	950	7119	335	2204	1264	-
Rb	3	1	3	2	2	18	1	3	2	1
Ba	23	19	38	26	18	129	7	64	22	-
Sr	119	159	69	36	104	136	119	100	146	2
Ga	9	9	7	7	7	13	8	10	17	5
Ta	0.07	-	-	0.07	-	0.1	0.06	-	-	-
Nb	1	1	1	1.2	1.9	1.4	0.9	0.7	0.2	0.8
Hf	0.52	-	-	0.46	0.71	0.7	0.41	0.42	1.07	-
Zr	17	20	23	19	30	26	16	15	44	11
Ti	618	1101	982	630	873	1003	605	1041	8097	-
Y	3	4	3	3	4	4	3	4	19	2
Th	0.43	-	-	0.36	1.52	0.89	0.31	0.22	0.02	-
U	0.26	-	-	0.18	0.56	0.42	0.14	0.1	-	-
La	2.01	-	-	1.73	4.69	2.93	1.63	1.1	0.93	-
Ce	3.54	-	-	3.24	9.43	5.89	2.85	2.06	3.69	-
Pr	0.47	-	-	0.43	1.09	0.71	0.37	0.3	0.96	-
Nd	1.74	-	-	1.47	3.93	2.71	1.3	1.02	5.85	-
Sm	0.34	-	-	0.31	0.8	0.61	0.28	0.33	2.43	-
Eu	0.1	-	-	0.12	0.24	0.18	0.12	0.11	1.04	-
Gd	0.34	-	-	0.3	0.83	0.74	0.28	0.45	3.32	-
Tb	0.06	-	-	0.06	0.12	0.1	0.05	0.09	0.6	-
Dy	0.47	-	-	0.44	0.81	0.64	0.4	0.61	3.88	-
Ho	0.11	-	-	0.12	0.17	0.16	0.09	0.14	0.79	-
Er	0.4	-	-	0.33	0.52	0.49	0.34	0.49	2.33	-
Tm	0.07	-	-	0.06	0.08	0.08	0.06	0.08	0.32	-
Yb	0.5	-	-	0.43	0.61	0.6	0.44	0.52	1.95	-
Lu	0.08	-	-	0.07	0.1	0.12	0.08	0.09	0.28	-
Cl	-	-	-	-	-	-	-	-	-	231.66
Density	-	-	2.39	2.67	2.55	2.67	2.68	2.66	-	-

Table 1. *Continued*

Samples	SP-2.3B	SP-2.10A	SP-5.18C	SP-6.10C	SP-6.11D	SP-11.1A	SP-2.10B	SP-3.3A	SP-5.9
Rock Type	Olive dyke	Olive dyke	Olive dyke	Olive dyke	Olive dyke	Olive dyke	Gabbro	Diabase Dyke	Diabase Dyke
SiO ₂	53.16	51.4	50.38	52.51	53.09	50.45	47.2	50.21	51.87
TiO ₂	2.09	1.99	0.22	1.81	2.12	2.13	0.73	1.67	1.8
Al ₂ O ₃	12.89	12.09	10.07	13.4	13.12	13.9	17.39	12.94	12.02
FeO*	8.8	12.88	9.04	10.89	11.75	11.79	8.24	11.2	10.06
MnO	0.12	0.26	0.21	0.21	0.27	0.22	0.19	0.21	0.19
MgO	9.81	7.87	18.29	7.19	6.01	7.13	12.61	9.39	7.99
CaO	9.78	8.53	10	9.77	9.12	11.07	8.94	10.63	12.1
Na ₂ O	3.06	1.78	1.61	3.37	3.85	2.85	4	2.32	3.45
K ₂ O	0.05	2.94	0.17	0.3	0.34	0.22	0.06	1.12	0.23
P ₂ O ₅	0.24	0.26	0.02	0.56	0.34	0.24	0.12	0.31	0.29
Total	100	100	100	100	100	100	100	100	100
Cr	104	56	1320	140	104	134	414	281	189
Ni	37	21	339	13	18	42	78	39	36
Sc	44	50	50	47	37	55	35	53	40
V	358	460	263	325	238	491	187	332	345
Cu	183	84	1	18	120	70	4	50	66
Pb	7	3	1	6	18	7	3	4	4
Zn	-	88	77	46	102	74	33	26	-
S	375.52	700.82	64.3	444.24	1531.27	2416.84	240.33	509.79	337.14
As	7.11	10.21	-	6.24	13.6	13.25	8.97	9.85	16.32
Rb	0	74	4	6	9	5	1	19	4
Ba	-	309	46	27	20	79	3	109	14
Sr	309	298	126	247	241	255	280	288	494
Ga	22	22	11	20	25	22	19	22	20
Ta	1.45	1.08	-	1.28	-	-	0.56	0.98	1.23
Nb	4.6	11.6	1.6	7.1	9.9	10	1.7	5.9	3.9
Hf	3.88	3.52	-	3.62	-	-	1.75	3.91	3.11
Zr	161	182	24	165	279	155	76	185	139
Y	38	38	6	38	67	36	18	36	33
Th	0.34	1.4	-	1.26	-	-	0.22	0.46	0.27
La	5.05	11.47	-	10.12	-	-	2.61	6.59	4.55
Ce	15.38	28.12	-	25.62	-	-	7.74	18.82	13.72
Pr	2.62	3.97	-	3.71	-	-	1.25	2.88	2.28
Nd	13.73	18.41	-	17.72	-	-	6.55	14.44	12.05
Sm	4.64	4.86	-	4.95	-	-	2.01	4.49	3.84
Eu	1.57	1.64	-	1.7	-	-	0.82	1.46	1.59
Tb	1.04	0.93	-	0.95	-	-	0.49	0.91	0.83
Dy	6.47	5.8	-	6.11	-	-	2.98	5.77	5.35
Ho	1.36	1.25	-	1.3	-	-	0.6	1.17	1.11
Er	3.85	3.51	-	3.68	-	-	1.74	3.26	3.08
Tm	0.57	0.51	-	0.54	-	-	0.25	0.49	0.44
Yb	3.67	3.14	-	3.42	-	-	1.63	2.97	2.8
Lu	0.56	0.49	-	0.51	-	-	0.26	0.46	0.44
Cl	171.27	128.22	352.63	413.69	769.66	452.63	74.49	154.97	782.78

Table 1. *Concluded*

Samples	SP-5.15A	SP-5.18A	SP-5.18B	SP-6.6B	SP-6.10A	SP-9.2A	SP-11.5A	SP-11.1B	SP-11.6B
Rock Type	Diabase Dyke	Diabase	Diorite	Diabase Dyke	Diabase Sill	Diabase Dyke	Diabase Sill	Diabase Dyke	Diabase
SiO ₂	50.77	47.68	50.13	50.18	49.73	51.27	51.22	50.53	50.22
TiO ₂	0.13	1.43	1.51	0.82	1.64	2.2	2.4	1.89	1.42
Al ₂ O ₃	9.53	13.96	13.92	10.97	13.03	11.95	12.35	13.85	15.61
FeO*	9.15	10.67	10.15	8.02	11.05	10.22	11.72	10.97	9.74
MnO	0.22	0.2	0.21	0.14	0.22	0.19	0.24	0.21	0.2
MgO	17.29	10.76	10.26	16.56	9.78	9.22	7.91	8.44	7.63
CaO	10.26	12.51	10.37	9.65	10.6	11.38	10.26	10.47	12.2
Na ₂ O	1.49	2.49	2.23	2.98	3.44	3.01	3.31	2.86	2.47
K ₂ O	1.15	0.11	1.01	0.31	0.25	0.39	0.33	0.49	0.31
P ₂ O ₅	0.02	0.19	0.2	0.36	0.26	0.16	0.26	0.28	0.19
Total	100	100	100	100	100	100	100	100	100
Cr	1893	317	328	899	259	166	118	226	242
Ni	364	80	48	301	60	44	37	45	54
Sc	46	51	44	28	44	60	55	44	64
V	227	362	313	215	344	382	428	335	335
Cu	1	89	113	11	41	66	69	25	149
Pb	3	11	7	5	2	7	6	9	1
Zn	84	15	29	13	51	21	45	42	41
S	155.29	1009.17	553.93	134.75	347.69	279.32	913.35	155.68	1641.22
As	-	18.91	14.51	0.38	-	22.4	11.71	9.36	2.79
Rb	21	2	25	3	4	9	6	8	7
Ba	281	-	101	111	23	23	54	91	65
Sr	85	246	246	267	240	237	268	337	249
Ga	10	18	18	14	19	19	22	22	19
Ta	0.7	-	-	1.19	1.08	1.39	1.2	-	-
Nb	1.4	5.3	4.7	8.1	3.4	3.3	3.8	8.4	5.3
Hf	0.48	-	-	3.67	3.15	3.49	3.74	-	-
Zr	22	99	137	167	140	164	175	200	112
Y	3	24	31	16	34	39	43	34	27
Th	0.35	-	-	8.05	0.25	0.3	0.29	-	-
La	1.19	-	-	37.67	4.75	1.66	5.13	-	-
Ce	2.43	-	-	74.31	13.95	15.71	15.73	-	-
Pr	0.28	-	-	8.51	2.27	2.5	2.56	-	-
Nd	1.06	-	-	32.81	11.5	13.03	13.58	-	-
Sm	0.32	-	-	5.84	3.66	4.08	4.29	-	-
Eu	0.11	-	-	1.27	1.34	1.41	1.62	-	-
Tb	-	-	-	0.58	0.82	0.93	0.96	-	-
Dy	0.46	-	-	3.2	5.29	5.9	6.55	-	-
Ho	0.11	-	-	0.58	1.12	1.29	1.33	-	-
Er	0.36	-	-	1.59	3.09	3.75	3.87	-	-
Tm	0.07	-	-	0.22	0.46	0.51	0.55	-	-
Yb	0.51	-	-	1.39	2.9	3.39	3.52	-	-
Lu	0.1	-	-	0.21	0.44	0.48	0.52	-	-
Cl	225.25	249.79	342.31	136.67	176.37	372.43	873.97	149.37	322.02

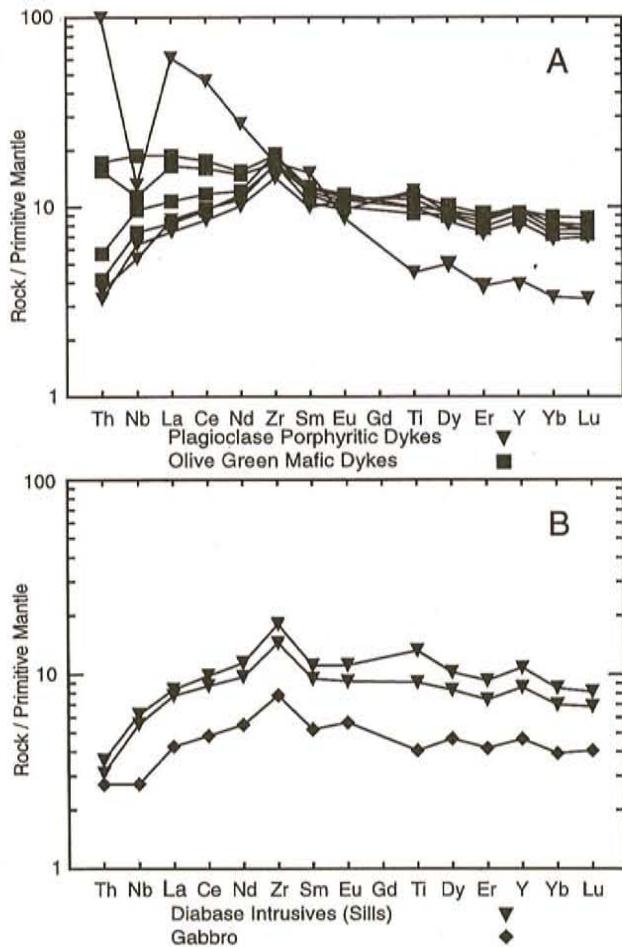


Figure 6. Primitive-mantle normalized plots of a) plagioclase porphyritic dykes and olive green mafic dykes, and b) diabase intrusives and gabbro. Primitive-mantle normalization values from Hofmann (1988).

values typical of VMS mineralization (generally between +5 to +8‰) suggesting that there may have been some magmatic water input ($\delta^{34}\text{S} \approx 0\text{‰}$) into the hydrothermal fluid system.

The $\delta^{34}\text{S}$ values for the Brass Buckle sulphides are different from values derived for pyrite separates from mesothermal lode-gold deposits elsewhere on the Baie Verte Peninsula (D. Wilton, unpublished data). Pyrite from the Deer Cove gold deposit has a $\delta^{34}\text{S}$ value of +7.8‰, and pyrite from the Dorset gold occurrence ranges from +6.8 to +7.4 ‰; both of these vein systems are hosted by ophiolitic rocks of the Point Rouse Complex, correlative with the PHG. A pyrite sample from the Stucky Vein, a mesothermal(?) gold vein in the PHG at the Rambler camp, analyzed as +6.5‰.

FLUID INCLUSIONS

Fluid inclusions were examined in doubly polished wafers of quartz vein material from the southern vein occur-

rences at the Brass Buckle Showing for their compositional, freezing and heating data.

Based on Roedder's (1984) definitions, the inclusions analyzed were primary two-phase inclusions some with halite daughter minerals. Salinities range from 12.6 to 17.3 wt% $\text{NaCl}_{\text{EQUIV}}$ and T_{HOMO} were 149–193°C. It appears that the veins were emplaced at low pressures, hence the homogenization temperatures (T_{HOMO}) are probably close to the actual trapping temperatures.

Compared with CO_2 -bearing fluid inclusions from mesothermal lode-gold occurrences elsewhere in Newfoundland and on the Baie Verte Peninsula (D. Wilton and D. Evans, unpublished data, 1996), the Brass Buckle inclusions are distinctly different in their high salinity, relatively lower T_{HOMO} and non CO_2 -bearing nature. The Brass Buckle fluid inclusions cannot be classified as mesothermal, but in fact are quite similar in terms of composition and geothermometry to fluid inclusions from stringer zones at the Hellyer VMS deposit (Zaw *et al.*, 1996).

DISCUSSION

GEOCHEMISTRY AND STRATIGRAPHY: IMPLICATIONS FOR MINERAL EXPLORATION

The use of isotope and trace-element geochemistry to assess the economic potential of Dunnage Zone ophiolites is not new (*cf.*, Swinden *et al.*, 1989; Swinden, 1991). Using stratigraphic, isotopic and trace-element geochemical results, this discussion will assess the problems (which have yet to be addressed) and comment on why the southern PHG has considerable potential to host VMS mineralization.

Stratigraphically, the southern PHG exhibits a chemostratigraphic evolution from predominantly boninitic lavas (stratigraphic Unit 1) to minimal calc-alkalic material, to transitional arc, and MORB activity (stratigraphic Units 2 and 3), which suggest that the southern PHG records the evolution of a primitive-arc to incipient back-arc basin development (Piercey, 1996).

Such paleotectonic development, in tandem with the geochemical characteristics of the southern PHG, provide four criteria of fundamental importance in the genesis of VMS mineralization. These are: 1) arc volcanism (Swinden *et al.*, 1989; Swinden, 1991); 2) refractory source melts (Swinden *et al.*, 1989; Swinden, 1991); 3) an adequate heat pump for seawater circulation; and 4) rifting (Sillitoe, 1982; Cathles *et al.*, 1983; Swinden *et al.*, 1989; Swinden, 1991). Each of these factors must be discussed with respect to the southern PHG.

Criteria 1, 2, and 3 are associated with the inherent thermal characteristics of boninite genesis that are generally

accepted as being products of the early (primitive) evolution of an intraoceanic island arc (Crawford *et al.*, 1989; Stern and Bloomer, 1992; Pearce *et al.*, 1992; Bloomer *et al.*, 1995). In such settings, the genesis of boninitic lavas involves the high temperature (ca. 1200°C), low pressure (1.5 to 5 kbar) melting of a refractory harzburgitic mantle that has undergone at least one, and possibly two, prior melting events involving the extraction of MORB-like magmas (Crawford *et al.*, 1989; Pearce *et al.*, 1992). Such tectonic and chemical characteristics satisfy both criteria 1 (arc volcanism) and criteria 2 (refractory source melts). Furthermore, the high temperatures required for the genesis of the boninitic lavas also provide an adequate heat pump for the VMS hydrothermal system; hence, satisfying criteria 3.

The satisfaction of criteria 4 (rifting) can be attained if both the tectonic nature associated with boninite genesis and the paleotectonic development of the southern PHG are considered. Stern and Bloomer (1992) and Bloomer *et al.* (1995) advocate the importance of extensional stress in the genesis of boninitic lavas. They have suggested that the downgoing plate in the early stages of intraoceanic island-arc development created a 'trench suction' effect, which in turn induced an extensional stress in the overriding plate. These extensional stresses allowed for the decompression melting of the refractory harzburgitic mantle source and created multiple fractures (and possibly rifts) in the overriding plate. Fractures created in this manner provided excellent conduits for the downward percolation of seawater and an upward path for metal-rich hydrothermal fluids.

Similarly, the paleotectonic development of the southern PHG supports rifting as an important factor in the genesis of VMS mineralization in the region. The rapid transition from early, primitive-arc volcanism (boninites) to incipient back-arc basin development (MORB) suggest that mature-arc igneous activity was short lived and was interrupted by incipient rifting and back-arc basin development. This would further support the suggestion that VMS mineralization associated with the southern PHG is somewhat, if not directly, related to rifting.

TENTATIVE MODEL FOR THE GENESIS OF THE BRASS BUCKLE VOLCANOGENIC MASSIVE SULPHIDES

A well-constrained model for the genesis of the VMS deposits of the southern PHG cannot be provided due to the minimal amounts of isotopic and geochemical data for the sulphide occurrences. However, the geochemistry of the host rocks, nature of sulphide mineralization and minor isotope data do provide some insights into the possible genesis of the massive and stockwork sulphides from the southern PHG. A possible model for the genesis of Brass Buckle volcanogenic massive sulphides is presented.

The initial emplacement of Phase 1 boninitic pillow lavas (and related rocks) within the southern PHG was closely accompanied by the generation of numerous fractures in the oceanic crust and the emplacement of a subvolcanic magmatic source. Shortly following the emplacement of the boninitic lavas, was the emplacement of coeval felsic volcanic and intrusive rocks. The latter providing an adequate impermeable barrier to which subsequent upwelling hydrothermal fluids would be trapped ('impermeable cap'; Lydon, 1988; Franklin, 1993, 1996).

Fracturing induced by boninite genesis allowed for the downward percolation of seawater, which at depth and in proximity to the subvolcanic magma source for Phase 1 rocks, underwent high-temperature inorganic reduction of seawater sulphate (and possible mixing with minor magmatic water) resulting in a lower pH hydrothermal fluid (Bischoff and Seyfried, 1978; Gibson *et al.*, 1983; Seyfried and Janecky, 1985; Lydon, 1988; Franklin, 1993, 1996). This lower pH fluid reacted with the mafic rocks (\pm sulphides therein), and/or sedimentary and felsic rocks leaching base metals \pm Au \pm Ag \pm SiO₂ from this 'reservoir zone' (Hodgson and Lydon, 1977; Lydon, 1988; Franklin, 1993, 1996).

Continued heating of this metal- and sulphide-rich hydrothermal fluid resulted in upwelling along preexisting faults, fractures, or magma conduits where upon reaching the impermeable felsic intrusive barrier precipitated sulphide- and silica-rich pods upon cooling. Furthermore, underlying this, a SiO₂-Fe-Cu-Au-enriched stockwork feeder system developed consisting of auriferous pyrite-bearing quartz veins such as that present at the Brass Buckle.

Although this model is tentative, it does explain the geological, geochemical, and isotopic trends that are observed in the southern PHG. Further quantification and testing of this model is required, and only continued exploration, sulphide sampling and combined geological and geochemical research will prove or disprove this present model.

CONCLUSIONS

The Ordovician southern PHG of the Baie Verte Peninsula has considerable potential for volcanogenic massive-sulphide mineralization. However, understanding this mineralization requires an understanding of the stratigraphy, geochemistry, and the petrologic relationship between the mafic and felsic phases of the group. This paper has attempted to accomplish these goals with the hopes of stimulating interest in economic mineralization in this region.

The stratigraphy of the southern PHG consists of three stratigraphic elements that correlate to three events of igneous activity. Phase 1 igneous activity and stratigraphic Unit 1 consists of pillowed and massive lava flows, felsic intrusives

and volcanics, and mixed volcanoclastic sedimentary rocks. Geochemically, the mafic and felsic phases of the group are characterized by boninitic chemistry suggesting that the mafic and felsic phases are genetically related and have erupted and intruded coevally. Phase 2 igneous activity is characterized by plagioclase porphyritic diabase dykes and sills, and related gabbro and diorite, whereas Phase 3 igneous activity is characterized by the presence of fine-grained olive-green mafic dykes (closely resembling the composition of basalt). Geochemically, these latter two groups range in chemistry from calc-alkaline, transitional arc, P-MORB, and N-MORB.

Mineralization is located within the northeastern portion of the southern PHG and consists of podiform pyrite and chalcopyrite with lesser sphalerite and bornite. Hosting these sulphides are rhyodacite intrusives and auriferous stockwork-like quartz-vein-hosted mineralization. The dominance of Cu+Zn sulphides and the primitive nature of the mafic and felsic phases associated with the sulphides suggest Cyprus-Type VMS mineralization. The auriferous vein systems have both isotopic and fluid inclusion characteristics similar to VMS stringer zones rather than mesothermal lode gold systems as previously thought. Furthermore, isotope and fluid inclusion characteristics for vein-hosted mineralization are distinctly different from other mesothermal lode gold occurrences on the Baie Verte Peninsula, containing lighter $\delta^{34}\text{S}$ values and higher salinity, lower homogenization temperature and non-CO₂-bearing fluid inclusions.

The geochemistry of the host rocks in this area and the lithotectonic affinity of the sulphide mineralization suggest that the southern PHG has considerable potential to host significant VMS mineralization. The inherent thermal and genetic character of boninite genesis provide: 1) a means of ground preparation for the downward percolation of seawater and upwelling of metal-rich hydrothermal fluids; 2) an adequate heat pump to induce the reduction of seawater sulphate to sulphide and subsequent leaching of base and precious metals; 3) arc volcanism; and 4) refractory source melts. Furthermore, an integrated petrologic-metallogenic model for their genesis suggests that initial mafic and felsic volcanism and intrusion provided an impermeable cap that trapped upwelling hydrothermal fluids. The downwelling fluids reacted with, and leached, base metals from the oceanic crust (and sediments?) and the subsequent upwelling and entrapment by the rhyodacite cap resulted in the precipitation of sulphide pods, and SiO₂+Au+Cu-rich fluids in the stockwork source vein system as hydrothermal fluids cooled.

Although having considerable potential for VMS mineralization, only further exploration and research on this southern lobe will tell if this region has the prosperous resources that have graced the northern lobe of the group for close to 40 years.

ACKNOWLEDGMENTS

Without the help of numerous people, the production of this paper would not have been possible. SJP would like to thank Deborah Bear for her cheerful field assistance during the field work associated with this study and Adam Szybinski for numerous discussions pertaining to various aspects of the southern Pacquet Harbour Group. A. Weick analyzed the two pyrite samples for their sulphur-isotope composition and C. Collins undertook the fluid inclusion analyses. Similarly, Scott Swinden is thanked for access to unpublished data pertaining to the lavas of the Pacquet Harbour Group. Funding for this project was provided by NSERC operating grants to GAJ and DHCW and the Geological Survey of Canada Contract to GAJ. Al Sangster of the Geological Survey of Canada was responsible for GSC project management and is greatly thanked for his assistance and understanding during the many phases of this project.

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