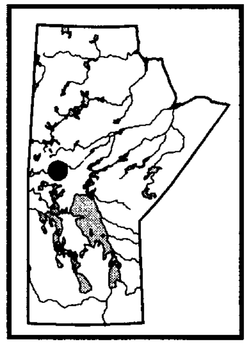


GS-8: GEOCHEMISTRY OF PALEOPROTEROZOIC VOLCANIC ROCKS IN THE PHOTO LAKE AREA, FLIN FLON BELT (PART OF NTS 63K16)

by Alan H. Bailes

Bailes, A.H. (1997): Geochemistry of Paleoproterozoic volcanic rocks in the Photo Lake area, Flin Flon Belt (part of NTS 63K16); **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1997, p. 61-72.

SUMMARY

Precise (XRF, ICP-MS) geochemical analyses of selected volcanic rocks from the Photo Lake area were acquired in 1996 and 1997 as a follow up to detailed mapping (1:5 000 and 1:10 000 scale) undertaken in 1994 (Bailes and Simms, 1994; Bailes *et al.*, 1994) and 1996 (Bailes, 1996; Bailes *et al.*, 1996). These analyses demonstrate that the Photo Lake sequence is tholeiitic, bimodal (mafic/felsic), with an island arc geochemical signature. Furthermore, all volcanic rocks in the Photo Lake area belong to the "evolved arc" portion of the Snow Lake arc assemblage (as defined by Bailes and Galley, 1996).

Until discovery of the Photo Lake Cu-Zn-Au VMS deposit, all Cu-rich deposits were located in the "primitive arc" (*e.g.* the Anderson area Cu-rich deposits). This study confirms that the Cu-rich Photo Lake deposit is hosted by "evolved arc" rhyolites and that it represents a new and unique VMS environment in the Snow Lake district. An examination of the chemistry of felsic volcanic rocks in the Photo Lake area suggests that the VMS-hosting Photo Lake rhyolite is correlative with the Ghost Lake rhyolite but not necessarily with felsic volcanic gniesses that occur northwest of Bolloch Lake or between Squall Creek and the Ham pluton.

INTRODUCTION

This report concludes a cooperative project conducted by Manitoba Energy and Mines (MEM) and Hudson Bay Exploration and Development (HBED). The objective of the project was to provide a sound geological framework for future exploration activities in the Photo Lake area after the 1994 discovery of a Cu-Zn-Au rich volcanic-hosted massive sulphide (VMS) zone, now the Photo Lake mine, in the Snow Lake arc assemblage at the east end of the Flin Flon Belt (Fig. GS-8-1).

The mapping shows that the Photo Lake VMS deposit occurs within a different stratigraphic setting than other VMS deposits in the Snow Lake area (Bailes *et al.*, 1996a). Geochemistry of the volcanic rocks at Photo Lake was undertaken so that this potentially productive package could be more completely characterized and more easily followed and recognized elsewhere.

The geology of the Photo Lake area (Fig. GS-8-2) is reported in Bailes (1996). In summary, the area is underlain by *ca.* 1.89 Ga metavolcanic and associated synvolcanic intrusive rocks, intruded by the synkinematic Chisel Lake layered mafic to ultramafic pluton. All rocks are overprinted by lower to middle almandine amphibolite facies mineral assemblages that were produced during a *ca.* 1.81 Ga regional metamorphic event that reached approximately 5 kb and 535° C at Photo Lake (Menard and Gordon, 1995). The volcanic and sedimentary rocks at Photo Lake include an 'older' and 'younger' sequence. The 'older' sequence consists largely of felsic flows, volcaniclastic rocks and derived gneisses whereas the 'younger' sequence comprises dominantly mafic voclaniclastic rocks of the Threehouse formation. The Photo Lake VMS deposit is hosted by the Photo Lake rhyolite, in the 'older' volcanic sequence.

Bailes and Simms (1994) reported evidence for a potential unconformity at the base of the younger Threehouse sequence, which they suggested explains angular truncation of 'older ' stratigraphic units at its base. However re-examination of a critical outcrop during the 1997 field season suggests that this may not be a valid interpretation and that the two sequences are conformable.

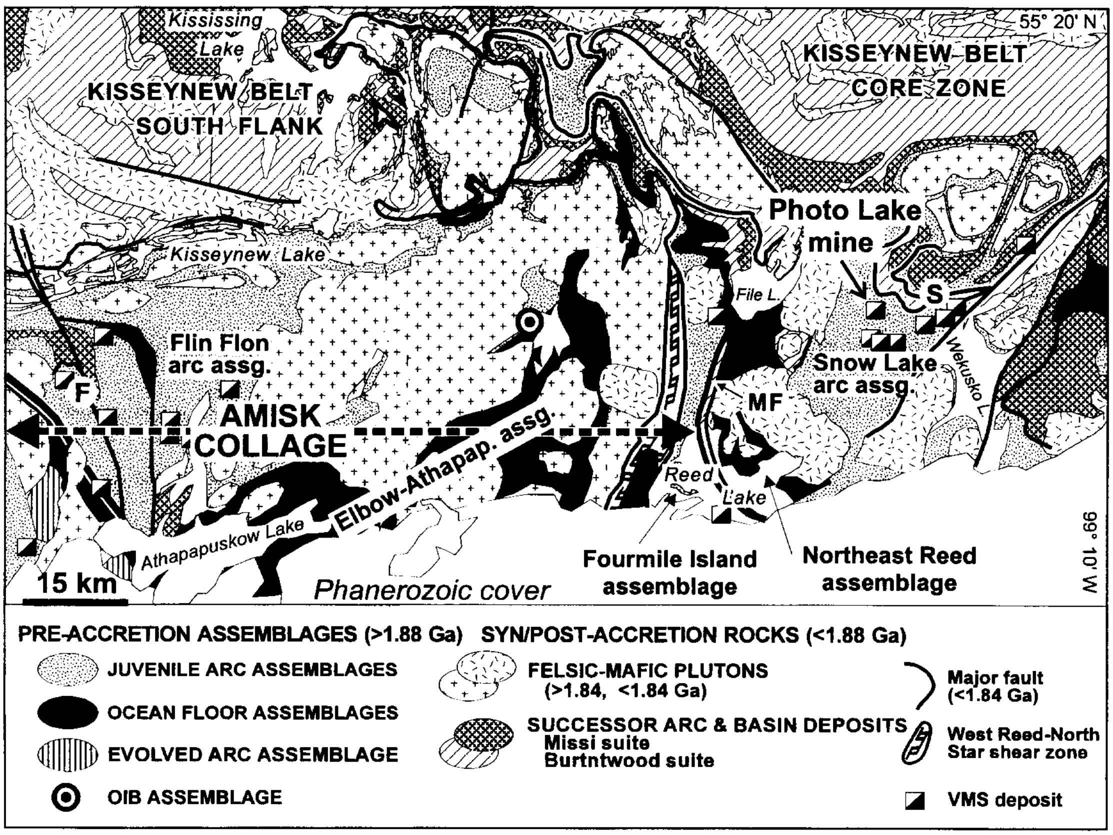


Figure GS-8-1: Simplified geological map of the central and eastern portion of the Flin Flon Belt showing major tectonostratigraphic assemblages and plutons, and locations of mined VMS deposits. F: Flin Flon, S: Snow Lake, ML: Morton Lake fault zone. Filled rectangle shows location of Photo Lake map area.

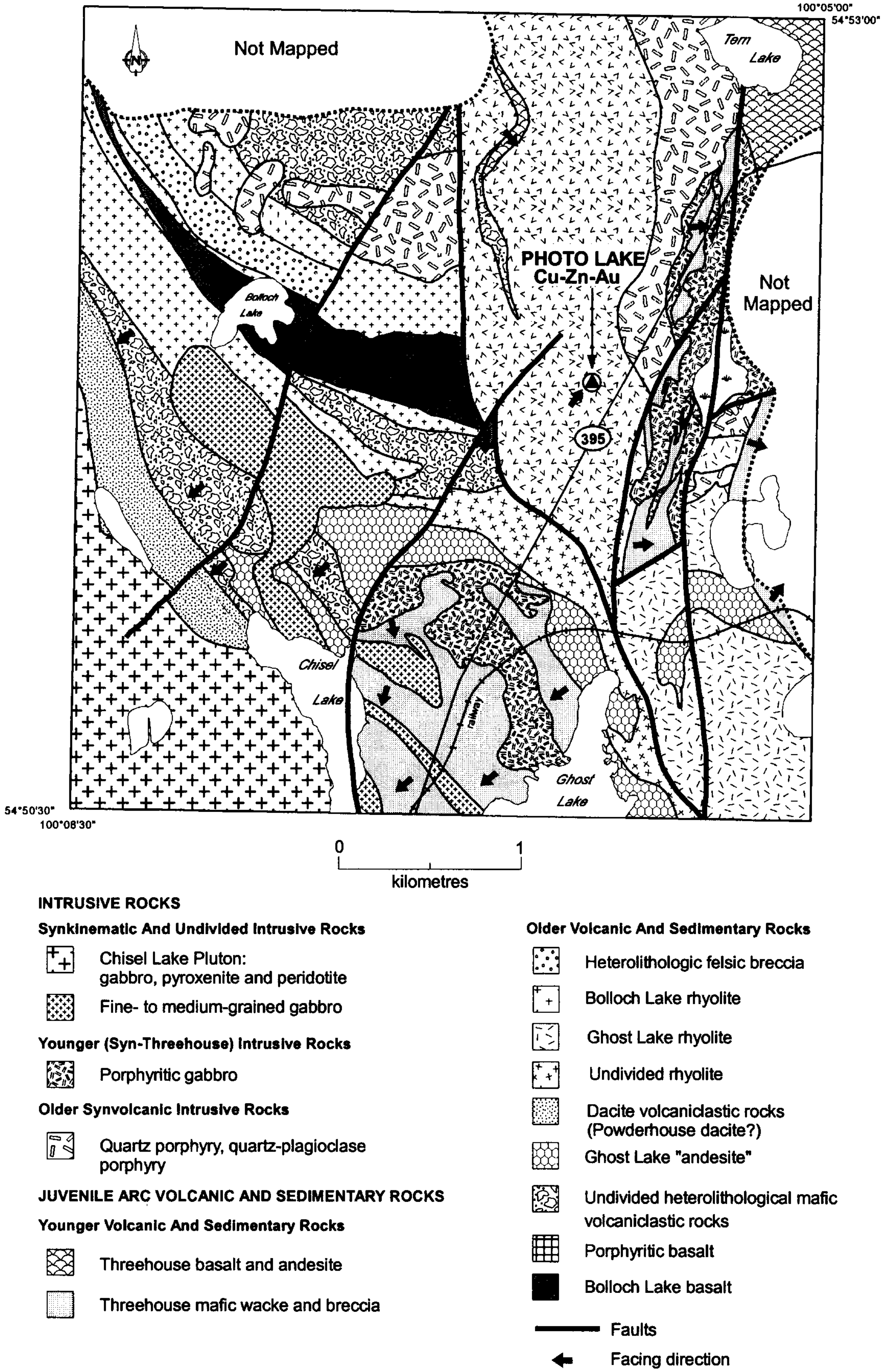


Figure GS-8-2: Simplified geology of the Photo Lake area from Bailes et al. (1996).

SAMPLING AND ANALYTICAL PROCEDURES

Samples were collected specifically for geochemical analysis. They are mainly from mesoscopically least altered rocks, but do include some altered rocks. Both sample types were trimmed to remove weathered surfaces, joints and veinlettes, and contain a minmum number of amygdales. Samples collected from clearly altered rocks or to test for suspected alteration have not been used on any geochemical plots in this report without being clearly identified. Samples were analyzed for a complete spectrum of whole rock, trace and rare earth elements using a combination of XRF (XRAL Laboratories) and ICP-MS (University of Saskatchewan) analytical procedures.

GEOCHEMISTRY

Mafic volcanic rocks

Although mafic flows are a minor rock lithology in the Photo Lake area (Figure GS-8-2), geochemical dicriminants for potential tectonic environment of emplacement of mafic rocks (*e.g.* Pearce, 1996) are better documented than for felsic rocks. Thus, basalt geochemistry is important for establishing the tectonic environment of deposition for the intercalated and much more voluminous felsic volcanic host rocks of the Photo Lake VMS deposit. With this objective in mind 2 samples of Bolloch Lake basalt and 9 samples of Threehouse Lake basalt and its subvolcanic gabbro feeders were analyzed for major, trace and rare earth elements.

The Bolloch Lake (BLB) and Threehouse (THB) mafic flows are basalt to basaltic andesites in composition with major element compositional ranges as follows (see also Table GS-8-1):

	Bolloch Lake mafic flows	Threehouse mafic flows
SiO_2	51.5-54.2 wt.%	51.6-52.1 wt.%
MgO	3.4-4.7 wt.%	5.1-7.6 wt.%
CaO	8.1-10.2 wt.%	8.2-10.58 wt.%
Al_2O_3	14.6-15.8 wt.%	13.9-17.2 wt.%
TiO_2	0.57-0.70 wt.%	0.30-0.43wt.%
Ni	<10 ppm	5-28 ppm
Cr	7-9 ppm	10-195 ppm

They are subalkaline (Figs. GS-8-5 and 6), tholeiitic (Figs. GS-8-3a, 3b and 6a) and similar to other arc basalts lower in the Snow Lake Arc Assemblage (Bailes and Galley, 1996).

Both BLB and THB display typical arc signatures on MORB-normalized trace element diagrams (Fig. GS-8-4) including positive Th and negative Nb anomalies, depleted Zr and Hf, and a trough at Ti. They display the enrichment in light rare earth elements (LREE; Fig GS-8-3c) and elevated ratios such as Th/Yb (Fig. GS-8-3d) that characterize stratigraphically higher "evolved arc" rocks in the Snow Lake arc assemblage (Bailes and Galley, 1996). Both BLB and THB display similar patterns to other "evolved arc" mafic volcanic rocks on Figure GS-8-4 (Moore, Bolloch, Threehouse, Lost) and are readily distinguished from patterns displayed by the stratigraphically underlying "primitive arc" basalts (Welch) and overlying MORB basalts (Snow Creek). Although they display broadly similar patterns on the MORB-normalized trace element diagrams to the Moore Lake basalt (Fig. GS-8-3), they are distinctly less enriched in high field strength elements (HFSE, *e.g.* Zr, Y, Ti), large ion lithophile elements (LILE, *e.g.* Th) and LREE elements. The unique chemistry of BLB and THB relative to other basalts in the Snow Lake area is further reflected in the other geochemical plots in Figures GS-8-3 and 4.

Geochemistry of BLB and THB mafic flows demonstrates that they have island affinity and belong to the "evolved arc" sequence of the Snow Lake arc assemblage. Along with other "evolved arc" basalts they display features that reflect complex conditions of magma genesis where older crustal fragments and previously formed arc segments added a diversity to magma generation that is not evident in the underlying "primitive arc" Welch basaltic andesites and bonninitic flows.

Felsic volcanic rocks

Most VMS deposits in the Flin Flon and Snow Lake mining districts are spatially associated with rhyolite flows (Syme and Bailes, 1993). This association of VMS deposits with felsic volcanic rocks is clearly evident for the Photo Lake Cu-Zn-Au VMS deposit which is located in a thick, monotonous sequence of massive, aphyric to sparsely porphyritic felsic rocks and derived felsic gneisses informally termed the Photo Lake rhyolite (PLR; Bailes, 1996). Two similar, large, but fault-bounded, bodies of felsic rocks also occur in the Photo Lake map area but have uncertain relationships to PLR. They are informally referred to as the Ghost Lake rhyolite (GLR), occurring northeast of Ghost Lake, and the Bolloch Lake rhyolite (BLR), located northwest and southeast of Bolloch Lake (Fig. GS-8-2).

A total of 24 XRF plus ICP-MS geochemical analyses of PLR (14 analyses), GLR (6) and BLR (4) rhyolites were undertaken with the following objectives: (1) to identify any subtle chemostratigraphy in PLR; (2) to provide criteria to make stratigraphic correlations between PLR and other the rhyolite bodies at Ghost Lake and Bolloch Lake, and (3) to characterize the VMS-hosting PLR as a method of identifying this prospective unit elsewhere in the Snow Lake area. Additionally, 9 geochemical analyses of the Ghost Lake andesite (GLA) and 3 of the Powderhouse dacite (PWD) were undertaken with two objectives in mind: (1) to determine the original composition and affiliations of GLA, which owes its present, largely andesitic, composition to alteration, and (2) to compare rocks mapped as Powderhouse dacite in the Photo Lake area with those occurring in the type area south of the Chisel Lake Zn-rich VMS deposits.

On an AFM diagram (Fig. GS-8-6a) Photo Lake area felsic rocks (large symbols) and mafic rocks (small symbols) are clearly tholeiitic. The felsic rocks fall on the boundary between metaluminous and peraluminous on a diagram of $Al_2O_3/(Na_2O + K_2O)$ *vs.* $Al_2O_3/(CaO + Na_2O + K_2O)$. On a diagram of Rb *vs.* Y + Nb (Fig. GS-8-6c) they fall in the field of volcanic arc granite (VAG; Pearce *et al.*, 1984))

Photo Lake rhyolite (PLR)

PLR consists of a monotonous, 1 Km wide (map width) sequence of massive aphyric to sparsely porphyritic felsic flows and derived felsic gneisses that locally contain quartz amygdales, quartz-filled gas cavities and local massive lobes with intervening microbreccia. Although no internal subdivisions of PLR were mapped and no facing directions for these strata were observed, the rhyolites have tentatively been interpreted to top to the east-northeast on the basis of one pillow top in an intercalated mafic flow and the presence of hydroythermally altered rocks southwest of the Photo Lake VMS deposit. The Photo Lake VMS "horizon" is interpreted to be coincident with the base of an up to 90 m thick unit of intercalated heterolithologic mafic breccia that trends north-northwest (see Bailes ,1996, for discussion). The mafic breccia unit divides the felsic package equally into a stratigraphically lower (west and southwest) and upper (east and northeast) package (Figure-8-2).

A suite of 14 samples collected from least altered Photo Lake rhyolite, although displaying considerable variation in such elements as Zr (52 - 105 ppm, one at 32 ppm), shows no consistent differences between the southwest and northeast package nor to those samples collected within 100 m of the Photo Lake VMS "horizon". The variations that do exist in PLR are interpreted to be unrelated to stratigraphy and to represent the natural range of composition of this rhyolite package.

Although identified during field mapping as rhyolites, analyses of samples of PLR demonstrate them to be andesite to rhyolite in composition (62 to 82 wt.% SiO_2), with most being either rhyodacites or rhyolites (Fig. GS-8-5a). On a plot of Zr/TiO_2 *vs.* Nb/Y (Fig. GS-8-5b) PLR falls in the basaltic andesite, andesite and dacite fields, but assigning composition on the basis of this diagram is not recommended as Flin Flon and Snow Lake area volcanic rocks display lower than normal Zr contents (Syme and Bailes, 1993). Stern *et al.* (1995) interpret Flin Flon and Snow Lake volcanic rocks to be derived from a Zr-depleted, refractory mantle. Some of the low and high values of SiO_2 in PLR likely reflect alteration effects. This is in part attributable to the fact that some samples are from lobes (often selectively silicified in subaqueous flow complexes) and others from interlobe hyaloclastite (most susceptible to hydrothermal alteration).

Despite the apparent variation in major elements, PLR displays only minor differences on chondrite normalized REE plots (Fig. GS-8-7); this is consistent with experience elsewhere in the Flin Flon Belt where REE elements appear to be relatively immobile in volcanic rocks, even those that have been effected by weak to moderate hydrothermal alteration and subsequent regional metamorphism (Stern *et al.*, 1995; Bailes and Galley,

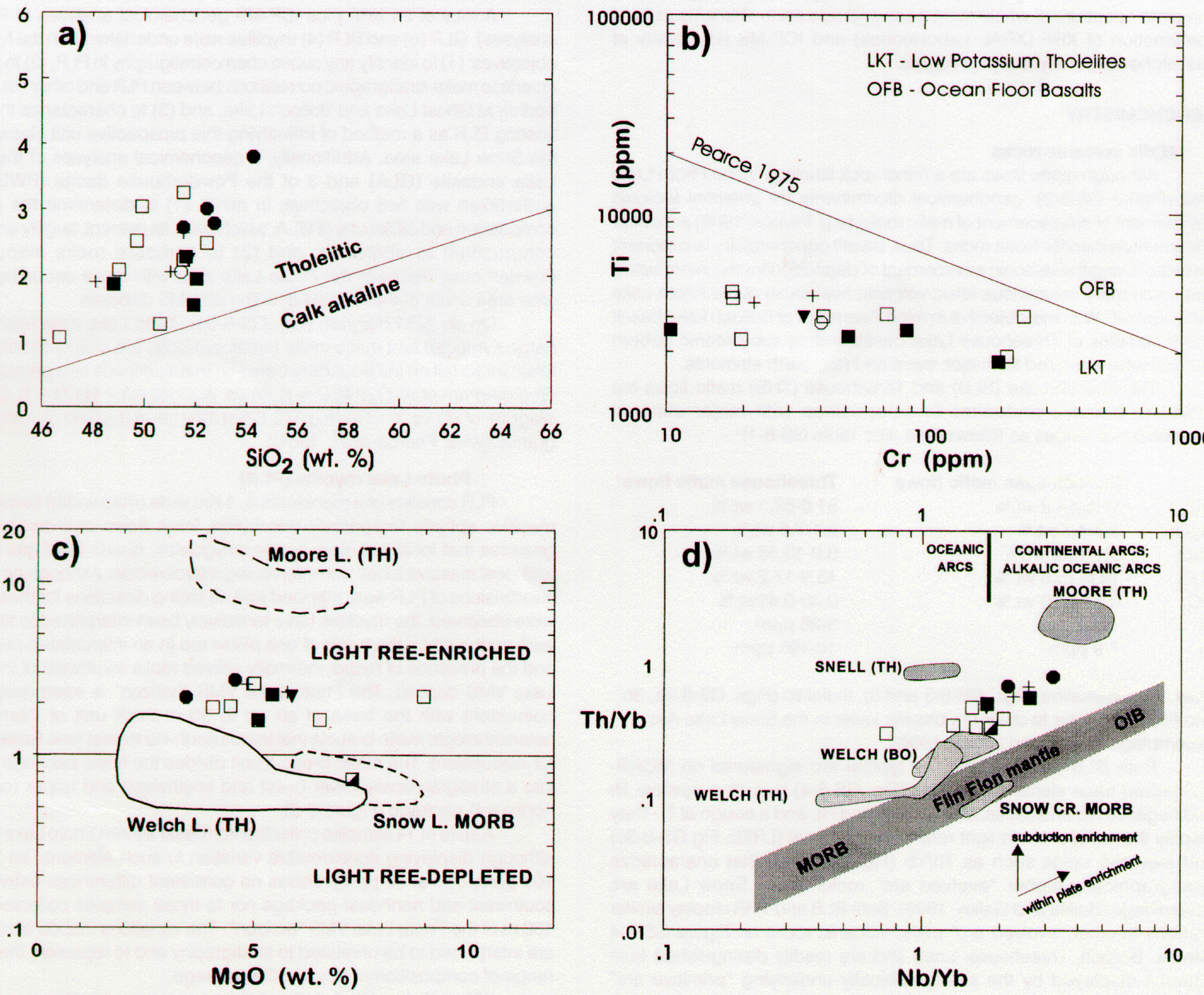


Figure GS-8-3: Photo Lake area mafic flows and synvolcanic intrusions on various geochemical discrimination diagrams: (a) SiO_2 vs. FeO/MgO, plot in the tholeiitic field (boundaries from Gill (1981)); (b) Cr vs. Ti, plot in island arc field (boundaries from Pearce, 1975); (c) MgO vs. La/Yb, plot in light REE-enriched field (boundaries from Stern et al., 1995); (d) Nb/Yb vs. Th/Yb (boundaries from Stern et al., 1995, modified from Pearce, 1983).*

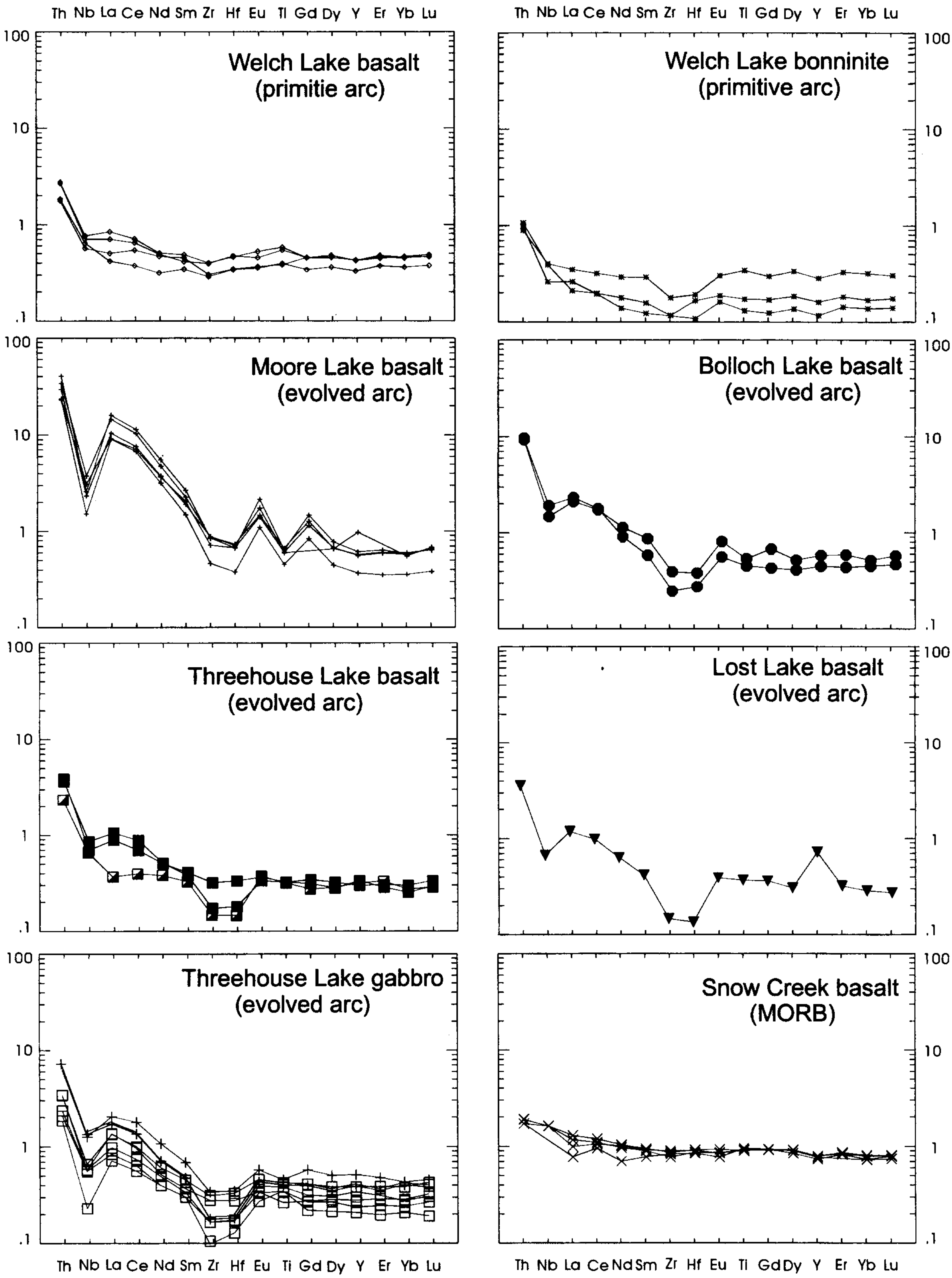
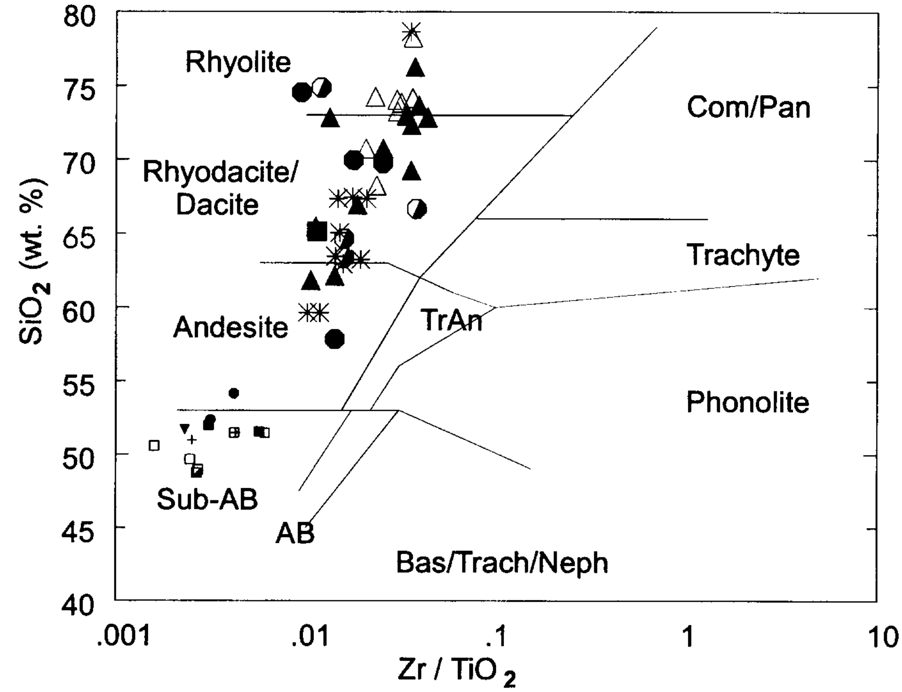


Figure GS-8-4: Least mobile elements in Photo Lake area mafic flows and synvolcanic intrusions on N-MORB-normalized incompatible element diagrams (after Sun and McDonough, 1989). Elements are arranged in order (to right) of decreasing inconpatibility in MORB-source mantle.



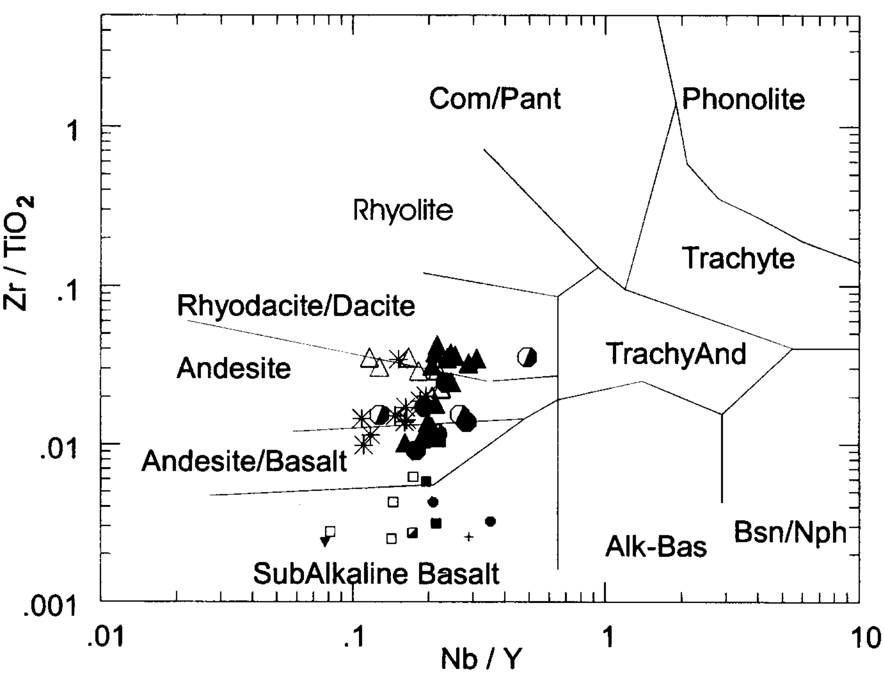


Figure GS-8-5: Photo Lake area volcanic rocks plotted on chemical rock discrimination diagrams (from Winchester and Folyd, 1977) (a) Zr/TiO_2 vs. SiO_2; (b) Nb/Y vs. Zr/TiO_2.

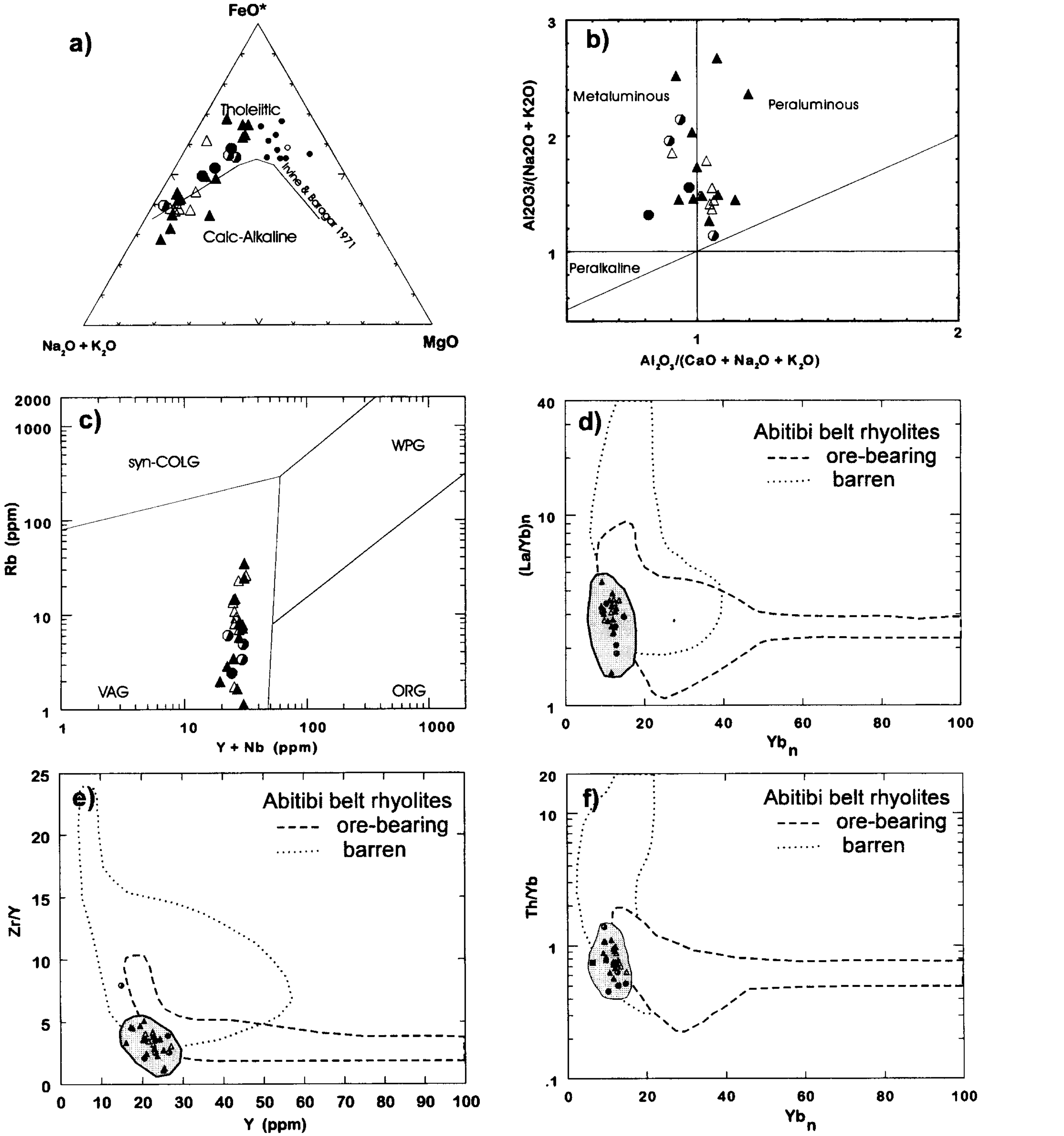


Figure GS-8-6: Photo Lake area felsic volcanic rocks on various geochemical discrimination diagrams: (a) AFM diagram (Irvine and Baragar, 1971); (b) Al_2O_3/(CaO+Na_2O+K_2O) vs. Al_2O_3/ (Na_2O+K_2O) (Maniar and Piccolli); (c) Y+Nb vs. Rb (Pearce et al., 1984); (d) Yb_n vs. $(La/Yb)_n$ (Barrie et al., 1993); (e) Y vs. Zr/Y (Barrie et al., 1993); (f) Yb_n vs. Th/Yb (Barrie et al., 1993).

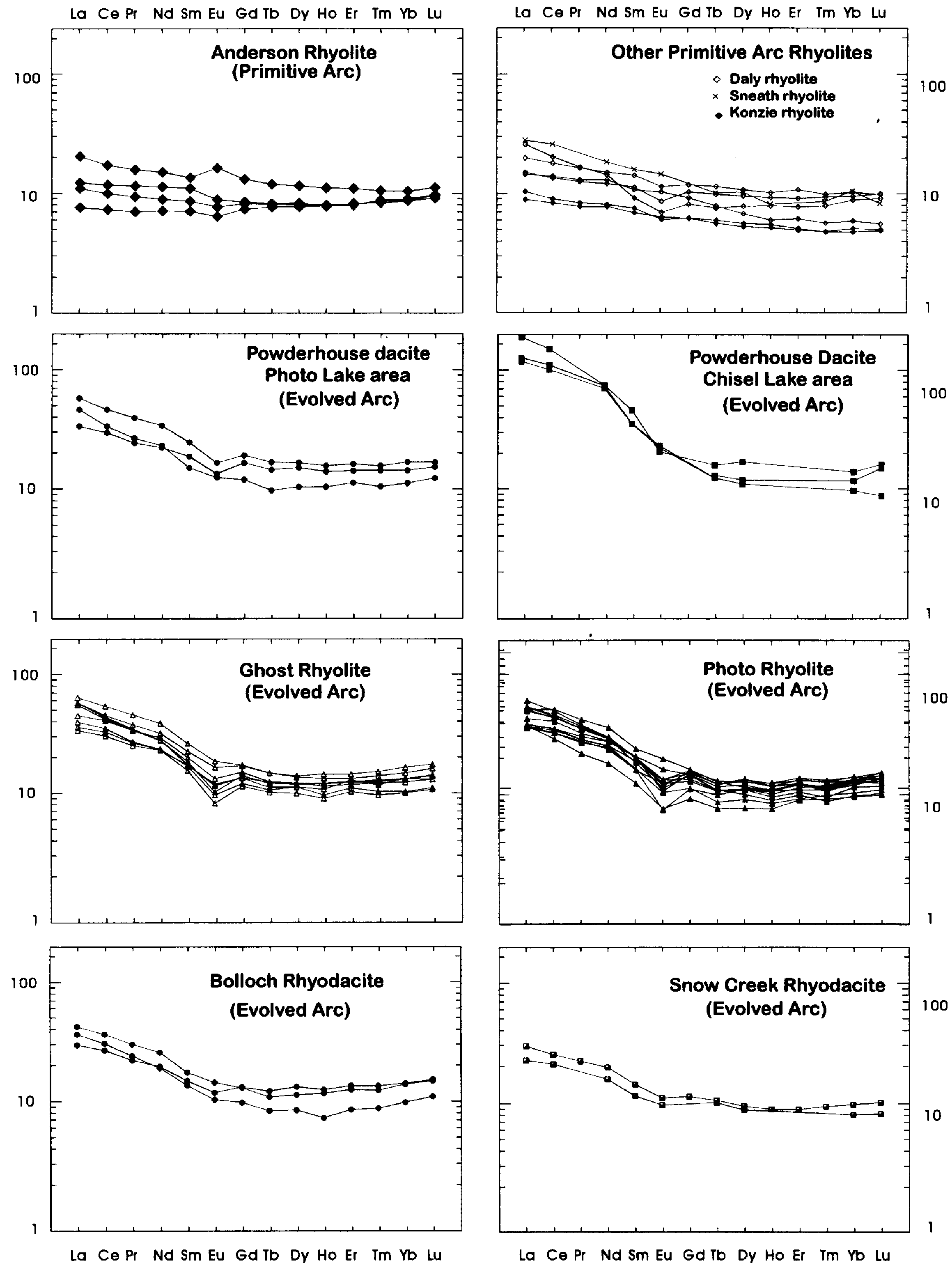


Figure GS-8-7: Photo Lake area felsic volcanic rocks and comparison analyses on chondrite-normalized REE plots (after Sun and McDonough, 1989).

Table GS-8-1a

Major element data for whole rocks, Photo Lake

SAMPLE	Rock Type	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	MnO	TiO_2	P_2O_5	LOI
07-96-5589-1-1	Powderhouse dacite	58.23	13.68	14.48	2.87	3.53	6.18	0.19	0.09	0.59	0.16	<0.10
07-96-5592-1-1	Powderhouse dacite	75.02	12.37	3.36	0.55	5.25	2.22	0.32	0.07	0.46	0.37	0.5
07-96-5605-1-1	Powderhouse dacite	70.11	12.46	7.77	1.53	2.66	4.77	0.15	0.06	0.42	0.07	<0.15
07-94-5095-1-1	Ghost rhyolite	68.76	14.3	6.74	1.35	1.93	5.45	0.89	0.09	0.37	0.13	0.7
07-94-5360-1-1	Ghost rhyolite	73.29	13.2	4.09	1.09	2.94	3.72	1.18	0.06	0.32	0.11	0.6
07-94-5407-1-1	Ghost rhyolite	74.79	12.48	4.15	0.78	2.06	4.26	0.97	0.07	0.32	0.12	1.01
07-94-5403-1-1	Ghost rhyolite	71	14.24	4.3	0.6	4.43	4.27	0.6	0.09	0.33	0.13	0.74
07-96-5502-1-1	Ghost rhyolite	74.65	12.59	4.09	0.69	2.18	4.75	0.64	0.07	0.26	0.08	0.85
07-96-5510-1-1	Ghost rhyolite	78.26	10.99	3.68	0.45	1.48	4.61	0.2	0.07	0.21	0.06	0.05
07-96-5548-1-1	Ghost rhyolite	74.66	11.67	5.17	0.34	5.09	0.88	1.74	0.16	0.24	0.04	0.8
CH-90-15-1903'	Ghost rhyolite	74.37	12.38	4.82	0.66	1.46	5.01	0.75	0.09	0.28	0.17	0.75
07-94-5089-1-1	Ghost "andesite"	64.3	15.14	7.58	1.06	6.78	4.07	0.53	0.1	0.33	0.12	1.57
07-94-5090-1-1	Ghost "andesite"	63.74	14.45	9.13	2.12	5.67	3.91	0.26	0.16	0.45	0.1	0.76
07-94-5093-1-1	Ghost "andesite"	67.86	13.89	7.81	1.38	3.21	4.28	0.92	0.17	0.35	0.13	0.46
07-94-5405-1-1	Ghost "andesite"	67.88	14.48	7.24	1.87	1.84	4.84	1.23	0.13	0.4	0.1	1.23
07-94-5406-1-1	Ghost "andesite"	66.81	14.77	7.36	1.36	5.05	3.78	0.26	0.1	0.4	0.13	0.45
07-96-5497-1-1	Ghost "andesite"	63.68	14.46	9.23	2.71	5.14	3.44	0.7	0.16	0.39	0.1	0.4
07-96-5573-1-1	Ghost "andesite"	78.94	10.13	3.62	0.82	3	3.1	0.13	0.06	0.19	0.0	0.3
07-96-5573-1-2	Ghost "andesite"	60.03	15.28	10.86	2.72	6.05	4.16	0.18	0.19	0.45	0.06	0.35
07-96-5440-1-1	Ghost "andesite"	60.55	16.43	9.35	1.85	6.48	4.22	0.24	0.17	0.51	0.2	0.1
CH-90-15-597'	Ghost "andesite"	65.68	14.53	8.2	1.67	4.37	3.92	0.92	0.18	0.45	0.07	0.25
07-94-5009-1-1	Photo rhyolite	73.68	12.33	5.05	0.49	2.62	4.61	0.85	0.09	0.21	0.07	1
07-94-5011-1-1	Photo rhyolite	69.7	14.48	5.37	2.37	1.45	5.94	0.21	0.07	0.3	0.09	0.91
07-94-5044-1-1	Photo rhyolite	65.4	13.08	10.25	2.13	4.96	2.94	0.34	0.16	0.47	0.27	0.56
07-94-5058-1-1	Photo rhyolite	74.84	11.29	5.74	0.50	5.31	0.59	1.3	0.13	0.24	0.06	0.86
07-94-5120-1-1	Photo rhyolite	68.03	12.59	9.12	1.51	5.37	2.16	0.49	0.2	0.37	0.15	1.63
07-94-5128-1-1	Photo rhyolite	62.09	13.97	13.56	2.54	3.16	3.51	0.13	0.26	0.5	0.28	0.59
07-94-5242-1-1	Photo rhyolite	82.27	9.05	2.69	0.26	2.63	2.46	0.37	0.04	0.17	0.05	0.23
07-94-5244-1-1	Photo rhyolite	81.36	10.95	0.88	0.11	0.47	5.64	0.3	0.01	0.21	0.07	0.19
07-94-5248-1-1	Photo rhyolite	72.73	13.16	5.12	0.71	2.22	4.9	0.75	0.08	0.25	0.07	0.54
07-94-5257-1-1	Photo rhyolite	77.31	11.96	2.98	0.73	1.67	4.63	0.37	0.06	0.22	0.07	0.43
07-94-5267-1-1	Photo rhyolite	62.05	14.33	11.05	2.29	5.52	3.29	0.46	0.2	0.52	0.29	0.6
07-94-5270-1-1	Photo rhyolite	71.59	12.24	6.55	1.62	2.84	3.67	0.95	0.12	0.31	0.11	1.4
07-94-5291-1-1	Photo rhyolite	74.46	12.73	3.95	0.67	2.29	4.91	0.62	0.07	0.23	0.07	0.91
07-94-5399-1-1	Photo rhyolite	73.41	13.68	3.42	0.83	1.25	5.79	1.18	0.07	0.28	0.09	0.28
07-94-5400-1-1	Photo rhyolite	73.09	12.93	4.97	0.92	3.94	1.49	2.21	0.12	0.25	0.08	0.64
07-94-5031-1-1	Bolloch dacite	65.5	13.77	9.1	1.92	4.61	3.96	0.49	0.15	0.38	0.12	2.09
07-94-5106-1-1	Bolloch dacite	63.65	14.76	9.31	2.36	4.88	3.9	0.45	0.14	0.44	0.11	1.05
07-94-5110-1-1	Bolloch dacite	67.45	15.78	6.65	0.44	0.54	7.93	0.78	0.03	0.32	0.08	0.42
07-94-5103-1-1	Bolloch basalt	52.53	14.64	15.37	4.54	10.19	1.62	0.18	0.25	0.59	0.09	1.36
07-94-5067-1-1	Bolloch basalt	54.09	15.77	14.47	3.39	8.07	2.81	0.26	0.2	0.7	0.24	0.98
07-94-5300-1-1	Threehouse basalt	51.98	17.19	11.95	5.4	9.86	2.78	0.19	0.18	0.43	0.05	1.07
07-94-5304-1-1	Threehouse basalt	65.22	16.4	5.18	2.17	5.55	4.64	0.25	0.12	0.37	0.09	0.52
07-96-5461-2-1	Threehouse basalt?	52.02	16.73	13.21	5.11	8.28	3.78	0.23	0.17	0.43	0.04	0.5
07-94-5332-1-1	Threehouse gabbro	50.73	15.54	13.01	8.95	7.54	3.25	0.18	0.23	0.51	0.06	1.41
07-94-5333-1-1	Threehouse MFIV	48.91	15.64	15.46	7.29	8.51	3.32	0.18	0.21	0.4	0.09	1.42
07-94-5378-1-1	Threehouse gabbro	49.87	19.87	12.66	4.44	9.32	2.69	0.36	0.16	0.56	0.07	0.92
07-96-5427-2-1	Threehouse gabbro	52.35	15.76	14.94	4.09	8.4	2.99	0.55	0.23	0.63	0.06	0.2
07-96-5453-2-1	Threehouse gabbro	49.53	15.37	15.57	6.58	10.82	1.11	0.22	0.24	0.51	0.05	0.15
07-96-5466-1-1	Threehouse gabbro	52.46	16.91	12.83	5.07	9.27	2.52	0.3	0.2	0.39	0.05	0.25
07-94-5318-2-1	Mafic dyke	51.09	16.13	13.42	5.76	11.66	0.91	0.11	0.24	0.59	0.09	1.66
07-94-5171-1-1	Gabbro	52.09	16.79	14.48	4.86	9.57	1.05	0.12	0.24	0.68	0.12	1.15

All by XRF; major elements recalculated to 100% volatile free; total iron as Fe2O3

Table GS-8-1b

Trece Element Data (ppm) for Whole Rocks, Photo Lake

SAMPLE	Rock Type	Cr	Ni	Sc	V	Rb	Ba	Sr	Cs	U	Pb	Th	Zr	Y	Ta	Hf	Nb	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
07-96-5589-1-1	Powderhouse dacite	6	4	46.8		0.96	302	129	0.09	0.92	2.05	1.33	81.7	23.3	0.34	2.32	6.5699:	8.38	19.75	2.49	11.15	3.1	0.88	3.79	0.61	4.34	0.91	2.71	0.43	2.67	0.43
07-96-5592-1-1	Powderhouse dacite	1	14	36.8		2.42	85	339	0.05	0.54	10.88	0.98	42.4	20.5	0.16	1.26	3.64	11.14	22.05	2.71	11.59	2.56	0.83	2.86	0.43	3.14	0.71	2.21	0.32	2.15	0.36
07-96-5605-1-1	Powderhouse dacite	12	12	24.5		0.98	125	170	0.0	0.76	5.37	1.59	102.3	26.3	0.27	2.72	6.12	13.49	29.22	3.81	16.24	3.93	1.06	4.3	0.69	4.71	1.01	3.04	0.46	3.06	0.47
07-94-5095-1-1	Ghost rhyolite	<6	<7	22.2	35	10.75	87	54	0.24	0.68	2.02	1.67	84.7	20.8	1.47	2.35	4.67	8.7	20.88	2.66	11.91	2.97	0.82	3.25	0.5	3.46	0.68	2.24	0.33	2.05	0.34
07-94-5360-1-1	Ghost rhyolite	<6	<7	19.6	23	22.84	114	76	0.16	0.8	5.04	1.89	94.1	22.6	1.23	2.53	4.92	10.03	23.64	2.84	12.09	2.93	0.68	2.97	0.48	3.48	0.75	2.56	0.37	2.57	0.39
07-94-5407-1-1	Ghost rhyolite	<6	<7	17.5	14	13.37	168	61	0.15	0.68	2.9	1.63	72.1	20.2	1.76	1.9	4.52	9.21	22.3	2.79	11.94	2.72	0.59	2.83	0.46	3.11	0.64	2.1	0.31	2.01	0.33
07-94-5403-1-1	Ghost rhyolite	<6	<7	19.7	27	6.93	99	87	0.11	1.06	3.26	1.83	66.5	23	0.99	1.97	4.74	11.23	27.07	3.43	14.75	3.39	0.9	3.59	0.55	3.72	0.79	2.38	0.38	2.41	0.39
07-96-5502-1-1	Ghost rhyolite	2	2	14.2		8.05	112	82	0.06	0.79	7.55	1.91	74.6	21.6	0.18	2.09	3.94	13.91	28.67	3.52	14.13	3	0.8	3.28	0.54	3.65	0.83	2.48	0.4	2.54	0.42
07-96-5510-1-1	Ghost rhyolite	1	1	17.7		1.73	27	66	0.01	0.86	3.09	2.26	73	22.7	0.17	1.85	2.65	13.39	27.72	3.45	14.08	3.15	0.72	3.4	0.53	3.71	0.82	2.48	0.39	2.57	0.41
07-96-5548-1-1	Ghost rhyolite	1	1	22.8		25.92	419	210	0.23	0.86	10.15	1.97	82.8	27.1	0.21	2.21	4.52	13.89	29.61	3.78	15.93	3.76	1.09	3.99	0.64	4.18	0.97	2.84	0.46	3.11	0.5
CH-90-15-1903'	Ghost rhyolite	2	0.0	25.5		9.23	82	90	0.09	1.28	5.83	1.97	85.4	23.2	0.15	2.36	2.96	15.2	34.54	4.5	18.75	4.31	1.21	4.05	0.64	4.11	0.9	2.63	0.43	2.82	0.47
07-94-5089-1-1	Ghost "andesite"	<6	<7	20.3	40	3.48	183	180	0.03	0.66	2.71	1.69	60.3	23.9	1.15	1.71	4.43	12.28	27.29	3.42	14.4	3.38	1.26	3.73	0.55	3.57	0.81	2.4	0.34	2.45	0.36
07-94-5090-1-1	Ghost "andesite"	<6	<7	30.1	113	0.92	124	252	0.02	0.44	2.94	1.18	62.7	23.8	1.39	1.73	3.83	6.68	16.52	2.13	9.7	2.49	0.76	3.12	0.49	3.57	0.79	2.38	0.36	2.46	0.38
07-94-5093-1-1	Ghost "andesite"	6	<7	22.8	56	16.91	239	166	0.32	0.7	2.96	1.74	71	24.1	1.22	1.99	4.71	7.49	20.35	2.53	11.17	2.61	0.78	3.1	0.51	3.62	0.75	2.49	0.37	2.58	0.41
07-94-5405-1-1	Ghost "andesite"	<6	<7	23.9	57	13.93	118	54	0.27	0.56	1.45	1.35	68.6	24.6	1.02	1.63	3.99	8.05	18.99	2.56	11.1	2.81	0.77	3.17	0.51	3.74	0.83	2.64	0.36	2.62	0.42
07-94-5406-1-1	Ghost "andesite"	<6	<7	24.3	64	1.43	58	142	0.0	0.59	2.11	1.49	57.3	23.7	0.9	1.63	3.88	8.28	21.64	2.54	11.41	2.93	0.81	3.25	0.52	3.9	0.82	2.57	0.41	2.59	0.37
07-96-5497-1-1	Ghost "andesite"	2	4	29.5		11.39	252	93	0.18	0.58	5.27	1.29	58.4	19.3	0.09	1.62	2.85	4.93	11.68	1.52	7.05	2.09	0.63	2.73	0.46	3.25	0.71	2.14	0.33	2.17	0.35
07-96-5573-1-1	Ghost "andesite"	1	1	19.7		0.74	34	189	0.08	1.49	3.86	1.6	66.3	22.6	0.15	1.72	3.42	11.19	23.99	3.04	13.14	2.94	0.91	3.2	0.52	3.65	0.84	2.48	0.39	2.51	0.4
07-96-5573-1-2	Ghost "andesite"	1	5	34.6		0.64	28	120	0.07	0.45	8.17	0.84	44.8	17.7	0.08	1.33	1.96	2.09	5.13	0.79	4.28	1.59	0.79	2.34	0.41	2.89	0.66	2.1	0.32	2.09	0.34
07-96-5440-1-1	Ghost "andesite"	2	1	31.7		1.16	60	164	0.04	0.52	4.97	0.99	57.4	21.4	0.13	1.73	2.51	5.76	13.28	1.77	7.89	2.11	0.75	2.78	0.47	3.38	0.78	2.35	0.37	2.37	0.41
CH-90-15-597'	Ghost "andesite"	1	1	30.9		16.18	293	153	0.31	0.5	3.53	1.16	65.6	23.9	0.09	1.9	2.59	7.77	17.32	2.33	10.2	2.71	0.75	3.31	0.56	3.98	0.92	2.72	0.42	2.77	0.46
07-94-5009-1-1	Photo rhyolite	6	<7	16.5	22	7.77	113	73	0.21	0.89	1.25	2.45	89.2	24.4	1.17	2.53	5.27	10.69	26.79	3.29	13.96	3.38	0.73	3.53	0.53	3.98	0.79	2.58	0.39	2.5	0.44
07-94-5011-1-1	Photo rhyolite	<6	<7	30.8	5	1.64	15	190	0.14	0.95	3.79	2.57	104.6	20.5	0.96	2.79	6.35	12.47	32.9	4.14	17.54	3.93	1.26	3.77	0.55	3.48	0.73	2.18	0.34	2.32	0.4
07-94-5044-1-1	Photo rhyolite	6	<7	36	46	3.43	83	197	0.08	0.53	2.35	1.4	51.5	21.1	1.18	1.44	3.93	9.37	23.05	2.96	12.86	3.21	0.88	3.2	0.48	3.32	0.66	2.09	0.3	2.23	0.35
07-94-5058-1-1	Photo rhyolite	7	<7	23	10	24.33	222	73	0.23	0.9	4.66	1.91	28.1	25.1	2.13	0.71	5.41	12.45	28.66	3.54	14.49	3.38	0.89	3.7	0.56	3.77	0.84	2.66	0.4	2.64	0.44
07-94-5120-1-1	Photo rhyolite	<6	<7	30.1	46	5.73	100	166	0.17	0.74	1.85	1.71	65.3	22.9	0.9	1.72	4.87	9.08	22.07	2.81	12.42	2.75	0.83	3.09	0.47	3.36	0.72	2.42	0.36	2.5	0.4
07-94-5128-1-1	Photo rhyolite	6	<7	38.2	49	1.13	53	234	<0.01	0.73	2.13	1.75	69.1	25.3	1.7	1.89	5.01	5.47	16.24	1.74	7.93	2.41	0.79	3.57	0.57	3.81	0.83	2.65	0.38	2.42	0.4
07-94-5242-1-1	Photo rhyolite	<6	1	11.3	14	1.96	31	101	0.0	0.88	3.08	1.67	53.6	16.1	0.92	1.47	3.31	9.45	19.96	2.33	9.52	2.2	0.54	2.29	0.35	2.43	0.54	1.83	0.29	1.89	0.3
07-94-5244-1-1	Photo rhyolite	<6	<7	11.2	7	4.89	263	61	0.14	0.92	2.07	2.13	79.1	17.2	0.98	2.12	4.21	1.94	9.64	0.68	2.88	0.94	0.26	1.28	0.27	2.31	0.61	1.97	0.31	1.99	0.34
07-94-5248-1-1	Photo rhyolite	<6	<7	16.2	26	8.29	152	221	0.46	0.96	3.53	2.31	87.4	22.7	1	2.27	5.36	12.16	28.46	3.59	14.51	3.11	0.77	3.43	0.48	3.38	0.75	2.42	0.33	2.42	0.38
07-94-5257-1-1	Photo rhyolite	<6	<7	13.4	19	2.85	43	147	0.04	0.86	3.47	2.07	80	17.7	1.31	2.23	4.52	12.96	29.27	3.52	14.83	3.38	0.83	3.39	0.48	3.07	0.62	1.99	0.28	1.92	0.31
07-94-5267-1-1	Photo rhyolite	9	<7	35.1	64	5.15	236	471	0.16	0.53	2.73	1.38	53.6	23.7	1.13	1.42	3.82	9.61	23.67	3.12	13.81	3.48	1.06	3.46	0.51	3.61	0.74	2.37	0.34	2.43	0.37
07-94-5270-1-1	Photo rhyolite	<6	<7	23.8	12	14.79	125	158	0.27	0.64	1.59	1.58	76.9	20.7	1.66	1.71	5.1	9.7	23.63	2.95	12.77	2.81	0.71	2.75	0.39	2.81	0.59	1.86	0.31	2.02	0.33
07-94-5291-1-1	Photo rhyolite	<6	1	14.6	18	7.23	66	116	0.18	0.97	2.86	2.26	87.8	24.4	1.31	2.29	5.18	14.51	31.87	3.78	14.83	3.4	0.89	3.54	0.53	3.83	0.79	2.43	0.35	2.47	0.38
07-94-5399-1-1	Photo rhyolite	<6	0.0	17	21	14.36	207	42	0.35	1.07	2.79	2.49	91.4	19.5	1.38	2.56	5.61	9.31	22.13	2.89	12.07	2.76	0.53	2.72	0.44	3.38	0.69	2.26	0.37	2.53	0.42
07-94-5400-1-1	Photo rhyolite	<6	0.0	16.3	29	34.53	499	262	0.31	0.83	3.36	2.08	32.4	25.5	1.09	0.82	5.23	13.14	29.93	3.69	15	3.35	0.8	3.64	0.53	3.94	0.83	2.54	0.39	2.67	0.4
07-94-5031-1-1	Bolloch dacite	6	<7	27.3	24	3.36	88	128	0.01	0.85	2.47	1.66	58.7	23.2	1.24	1.54	6.17	10.36	23.91	3.04	12.87	2.96	0.95	3.11	0.48	3.43	0.79	2.45	0.38	2.63	0.43
07-94-5106-1-1	Bolloch dacite	<6	<7	30.4	114	4.87	118	232	0.07	0.5	1.87	1.35	67.7	26.5	0.63	1.81	3.38	7.62	18.27	2.33	10.17	2.57	0.8	3.15	0.53	3.94	0.84	2.63	0.41	2.68	0.44
07-94-5110-1-1	Bolloch dacite	<6	<7	31.5	2	6.01	54	41	0.27	0.88	1.2	2.69	118.6	14.9	1	3	7.5	9.08	20.48	2.5	9.91	2.38	0.71	2.42	0.38	2.65	0.52	1.75	0.28	1.94	0.33
07-94-5103-1-1	Bolloch basalt	9	<7	63.4	503	0.94	30	102	<0.01	0.56	2.04	1.16	19	13	0.87	0.58	4.55	5.91	13.59	1.62	6.81	1.58	0.59	1.63	0.26	1.92	0.42	1.34	0.21	1.42	0.22
07-94-5067-1-1	Bolloch basalt	<6	<7	51	249	0.76	55	190	0.01	0.72	1.33	1.12	29.9	16.7	0.76	0.81	3.48	5.35	13.21	1.81	8.46	2.34	0.85	2.56	0.36	2.43	0.55	1.8	0.25	1.62	0.27
07-94-5300-1-1	Threehouse basalt	86	17	65.4	404	1.06	60	160	<0.01	0.16	1.17	0.46	13.5	9.9	0.67	0.39	2.11	2.77	6.98	0.93	3.93	1.05	0.36	1.21	0.19	1.34	0.3	0.89	0.12	0.81	0.14
07-94-5304-1-1	Threehouse basalt	30	<7	32.6	167	1.24	146	91	0.0	0.42	1.8	0.98	41.1	12.7	0.7	0.98	2.71	3.76	8.33	1.1	4.81	1.27	0.38	1.7	0.28	1.88	0.42	1.32	0.19	1.31	0.2
07-96-5461-2-1	Threehouse basalt?	10	12	52		1.16	89	240	0.01	0.18	1.15	0.49	24.9	8.8	0.05	0.72	1.71	2.34	5.47	0.77	3.88	1.13	0.39	1.33	0.22	1.54	0.32	0.95	0.15	0.96	0.16
07-94-5332-1-1	Threehouse gabbro	244	54	58.5	315	0.7	38	125	0.0	0.13	0.82	0.29	8.3	6.7	0.28	0.3	1.51	2.44	5.56	0.74	3.36	0.92	0.32	0.93	0.15	1.12	0.24	0.67	0.11	0.73	0.1
07-94-5333-1-1	Threehouse MFIV	51	16	79.5	460	0.51	18	113	0.0	0.11	0.84	0.28	10.9	8.9	0.49	0.3	1.53	0.92	2.97	0.51	2.78	0.86	0.38	1.01	0.18	1.29	0.29	0.98	0.13	0.83	0.13
07-94-5378-1-1	Threehouse gabbro	9	12	50.4	377	4.76	99	433	0.14	0.13	1.2	0.33	14	11	0.43	0.4	1.57	2.84	6.46	0.85	4.19	1.03	0.46	1.34	0.23	1.6	0.34	1.07	0.15	0.97	0.16
07-96-5427-2-1	Threehouse gabbro	18	13	57		3.66	267	418	0.14	0.16	8.83	0.48	26.6	12.4	0.08	0.78	1.79	3.93	8.75	1.14	5.12	1.38	0.54	1.74	0.28	2.02	0.45	1.33	0.2	1.35	0.22
07-96-5453-2-1	Threehouse gabbro	41	24	63.5		0.9	56	96	0.0	0.1	1.63	0.26	14	7.6	0.02	0.41	0.62	2.08	4.88	0.68	3.37	0.92	0.39	1.14	0.19	1.4	0.29	0.84	0.13	0.85	0.14
07-96-5466-1-1	Threehouse gabbro	20	15	56.1		1.71	85	230	0.03	0.11	4.92	0.48	23.9	9	0.35	0.65	1.56	3.96	8.42	1.05	4.38	1.12	0.4	1.16	0.22	1.49	0.34	0.99	0.15	1	0.17
07-94-5318-2-1	Mafic dyke	22	9	78.3	558	1.09	28	350	<0.01	0.32	1.91	0.97	15.2	12.6	0.76	0.43	3.64	4.99	11.8	1.41	6.04	1.45	0.51	1.68	0.25	1.83	0.39	1.2	0.18	1.41	0.2
07-94-5171-1-1	Gabbro	9	<7	55.1	455	1.03	17	465	<0.01	0.53	2.9	0.88	29.2	16.7	1.09	0.8299:	3.42	5.95	15.69	2.13	9.13	2.1	0.68	2.45	0.38	2.66	0.53	1.64	0.23	1.52	0.24

1996). On the chondrite normalized plots, the Photo Lake rhyolite displays: an elevated light rare earth element (LREE) pattern with a negative slope to Eu; flat heavy rare earth element (HREE) patterns; and, typically, small negative Eu anomaly. The elevated, negative sloping LREE and flat normal HREE patterns displayed by PLR are characteristic of other evolved arc felsic rocks (Fig. GS-8-7) and are in marked contrast to primitive arc rhyolites (Fig. GS-8-7a and 7b) that display flat or only slightly negative REE profiles.

Ghost Lake rhyolite (GLR)

GLR consists of massive, aphyric to sparsely porphyritic felsic flows that commonly contain quartz amygdales, quartz-filled gas cavities and local massive lobes with intervening microbreccia. They are identical to PLR but are separated by a fault. Nine geochemical analyses of the Ghost Lake rhyolite were undertaken to test the possible equivalence of GLR and PLR.

On all plots in Figures GS-8-5 to 7, geochemical analyses of GLR and PLR are virtually indistinguishable. This is particularly true of chondrite normalized REE plots (Fig. GS-8-7), with both GLR and PLR displaying identical LREE enriched patterns, including small negative Eu anomalies for most samples. The implication is that the GLR and PLR rhyolite domains are likely part of the same felsic flow complex.

Ghost Lake andesite (GLA)

Ghost Lake "andesite" (GLA) forms narrow units within the Ghost Lake rhyolite as well as a more prominent domain extending northwest of Ghost Lake and north of Chisel Lake. GLA consists of massive aphyric flows locally characterized by large (up to 7 cm diameter) quartz-filled gas cavities. The flows include irregular domains of medium to dark green weathering melanocratic rocks and intervening areas of light green to grey weathering leucocratic rocks, with some of the rocks displaying prominent zones of rusty weathering. During previous mapping these rocks have been classified as felsic volcanic rocks and as mafic flows (Harrison, 1949; Williams, 1966; Bailes and Galley, 1992). During mapping of the Photo Lake area (Bailes *et al.*, 1996) this problematic rock lithology was mapped as separate unit, and the conclusion made that it represents a domain of hydrothermally altered felsic flows.

In order to test the assumption that GLA represents altered felsic rocks and not altered mafic rocks, a suite of 9 samples from GLA was geochemically analyzed by the same analytical procedures as other Photo Lake area rocks. On a plot of Zr/TiO_2 *vs.* SiO_2 (Fig. GS-8-5a), GLA is commonly more mafic than PLR, GLR or other felsic flows, but does overlap their compositional range (large symbols). GLA does not overlap the compositional range of associated mafic flows (small symbols). On a plot of Nb/Y *vs.* Zr/TiO_2, a plot designed to minimize the effects of alteration by employing relatively immobile elements, the Ghost Lake "andesite" clearly plots with other Photo Lake felsic rocks and not with Photo Lake mafic rocks, supporting the interpretation that GLA was produced by alteration of associated felsic rocks.

Bolloch Lake rhyolite (BLR)

Bolloch Lake rhyolite (BLR) consists of felsic orthogneiss, northwest of Bolloch Lake, and less strongly recrystallized equivalents southeast and east of Bolloch Lake; the latter locally consists of domains (lobes?) of massive rhyolite and intervening domains of monolithologic breccia (microbreccia?). The relationship between these felsic rocks and the other major felsic units, PLR and GLR, is uncertain. This package of felsic rocks correlates along strike to the north and west with a prominent package of felsic gneisses (Harrison, 1949), so it is important to know if this unit correlates with the VMS-hosting PLR sequence.

Four samples of Bolloch Lake felsic rocks were analyzed. On a plot of Zr/TiO_2 *vs.* SiO_2 (Fig. GS-8-5a) they clearly plot separately from PLR and GLR with lower overall SiO_2 content (63-67 wt.%, one anomalous analysis at 75 wt.%). On chondrite normalized REE plots they show broad similarity to PLR and GLR but are not as prominently LREE enriched nor do they have the negative Eu anomaly. They do, however, display similar REE profiles as the Snow Creek rhyodacite (Fig. GS-8-7a), which lies higher in the stratigraphic section than the PLR and GLR. Thus, although the Bolloch Lake felsic rocks show some broad similarities to PLR an GLR, there is no conclusive data to suggest they are correlative with PLR and GLR and some evidence that they may correlate with felsic flows stratigraphically higher in the Snow Lake arc assemblage.

Powderhouse dacite (PWD)

Powderhouse dacite is a distinctive package of felsic volcaniclastic rocks forming the stratigraphic footwall to the Zn-rich VMS deposits at Chisel Lake. Analyzed samples from the type area south of the Chisel Lake mine display prominent elevated LREE contents (Fig. GS-8-7d) that serve to distinguish this unit from other felsic units in the Snow Lake area. A suite of dacitic volcaniclastic rocks from the southwest part of the Photo Lake area are texturally similar to the Powderhouse dacite.

In order to establish whether rocks mapped as Powderhouse dacite in the Photo Lake area are equivalent to those south of the Chisel Lake VMS deposits, 3 samples of the Photo Lake unit were analyzed. The Photo Lake dacitic volcaniclastics display lower Zr values (42-102 ppm compared to 131-152 ppm) and much lower contents of LREE (Fig. GS-8-7c). Thus the dacites in the southwest corner of the Photo Lake map area, although texturally similar, are certainly not direct equivalents and may not be related to the Powderhouse dacite at the Chisel mine site.

Comparison to Abitibi Belt rhyolites

Barrie *et al.* (1993) has identified some of the geochemical parameters that distinguish VMS-rich and VMS-poor rhyolite sequences in the Archean Abitibi Belt. Geochemical analyses of Photo Lake area felsic rocks have been plotted on these discrimination diagrams (Figs. GS-8-6d, 6e and 6f); note that the fields of Barrie *et al.* (1993) have been generalized from specific mining camps to the broader fields of "ore-bearing" and "barren". Photo Lake felsic rocks fall on the periphery of the ore-bearing field and just within the barren fields on these diagrams. They do, however, fall within the same fields as rhyolites associated with the Flin Flon area VMS deposits (Syme *et al.*, in prep.).

Bailes and Galley (1996) have previously noted that rhyolites associated with VMS deposits in Snow Lake do not display the same features as do Archean rhyolites associated with VMS deposits in the Abitibi Belt. This probably stems from derivation of Snow Lake magmas from a more depleted mantle source, as noted by Stern *et al.* (1995), with resultant fundamental variations in trace element characteristics. The implication is that trace element characteristics of VMS-rich and VMS-poor rhyolites are not necessarily transferable from one area to another and may have to be developed individually for each mining district or camp.

ECONOMIC IMPLICATIONS

VMS deposits are invariably spatially associated with rhyolite flow complexes. This examination of the geochemistry of volcanic rocks at Photo Lake is an important step in characterizing the geochemistry of the contained felsic rocks and placing limitations on correlation between the various felsic lithologies.

The mafic and felsic volcanic rocks of the Photo Lake area comprise a tholeiitic, bimodal (mafic/felsic) sequence with an island arc chemical signature. Furthermore, they belong to the "evolved arc" part of the Snow Lake arc assemblage as defined by Bailes and Galley (1996), confirming that the Cu-rich Photo Lake deposit represents a new and unique VMS environment in the Snow Lake district.

The rhyolite (PLR) that hosts the Photo Lake VMS deposit has a distinct geochemical signature that is duplicated by the Ghost Lake rhyolite and, therefore, these rhyolite domains are interpreted to be part of the same complex. This suggests that the Ghost Lake rhyolite may have potential for not only Chisel Lake Zn-rich VMS mineralization (the traditional view) but also for Photo Lake-type Cu- and Au-rich VMS mineralization. The Ghost Lake rhyolite is locally intercalated with Ghost Lake "andesite", a widely distributed altered felsic rock, further enhancing the overall potential of this rhyolite body.

The Bolloch Lake rhyolite, part of a recrystallized felsic orthogneiss sequence that extends north of the map area to the west of Squall Creek, has more affinities to the Snow Creek rhyolite than it has to the Photo Lake rhyolite. The implication is that the Bolloch Lake rhyolite may is not related to the Photo-Ghost rhyolite complex but, rather, that it may correlate with felsic rocks, such as the Snow Creek rhyolite, that occur higher in the stratigraphy of the Snow Lake arc assemblage. This interpretation, places the Bolloch Lake rhyolite in a succession that to date has not produced any known VMS deposits.

Rhyolites in the Photo Lake area do not display the same geochemical features as do VMS deposit-associated rhyolites from the Archean Abitibi Belt, although they do display similar characteristics to

VMS-hosting rhyolites at Flin Flon. Geochemical criteria developed to distinguish between "ore-bearing" and "barren" rhyolites for the Abitibi belt should be used with caution in the Proterozoic Flin Flon Belt. A project to establish geochemical criteria to distinguish "ore-bearing" from "barren" rhyolites specific to the Paleoproterozoic Flin Flon Belt is currently in progress.

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