

## HIGHLY METAMORPHOSED ALTERED ROCKS ASSOCIATED WITH THE OSBORNE LAKE VOLCANOGENIC MASSIVE SULFIDE DEPOSIT, SNOW LAKE AREA, MANITOBA

CALVERT C. BRISTOL

*Department of Geology, Brandon University, Brandon, Manitoba R7A 6A9*

EDGAR FROESE

*Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8*

### ABSTRACT

The Osborne Lake Cu-Zn orebody, in the northeastern part of the Snow Lake area of Manitoba, consists of a single lens of massive sulfide mineralization enclosed in felsic volcanoclastic rocks. The orebody and host rocks have been metamorphosed to the highest grade of regional metamorphism in the Snow Lake area, corresponding to the biotite-sillimanite-almandine zone. Wallrock alteration is reflected in the depletion of Ca and Na, and the enrichment of Mg and Fe. Alteration zones are characterized by cordierite, gedrite, staurolite and, more rarely, coarse-grained chlorite and phlogopite. Gahnite, commonly enclosed by cordierite, is present in some altered rocks. These highly metamorphosed altered rocks probably represent original zones of chloritization typically associated with volcanogenic massive sulfide deposits.

**Keywords:** volcanogenic massive sulfide deposit, metamorphosed alteration zones, cordierite-gedrite rocks, gahnite, Snow Lake, Manitoba.

### SOMMAIRE

Le gisement Cu-Zn de Osborne Lake, dans le secteur Nord-Est de la région du lac Snow, au Manitoba, exploite une seule lentille minéralisée en sulfures massifs dans une séquence de roches volcanoclastiques felsiques. Le gisement et les roches encaissantes ont été sujets à une recristallisation métamorphique dans la zone à biotite-sillimanite-almandin, indication du degré de métamorphisme le plus élevé de la région. L'altération de l'encaissant a causé un appauvrissement en Ca et Na, et un enrichissement en Mg et Fe. Les zones d'altération contiennent cordierite, gedrite, staurolite et, plus rarement, chlorite à grains grossiers et phlogopite. Gahnite, généralement entourée de cordierite, est présente par ci, par là. Ces roches fortement métamorphosées représenteraient des zones originelles de chloritisation qui caractérisent les gisements de sulfures massifs volcanogéniques.

(Traduit par la Rédaction)

**Mots-clés:** gisement de sulfures massifs volcanogéniques, zones d'altération métamorphosées, roches à cordierite-gedrite, gahnite, lac Snow, Manitoba.

### INTRODUCTION

The Osborne Lake orebody is the most easterly of several economic massive sulfide deposits in the Snow Lake area of northern Manitoba (Fig. 1). Alteration in the area of the Anderson Lake orebody has been examined in detail (Walford & Franklin 1982, Trembath & Turnock 1985, Trembath 1986, Trembath *et al.* 1987). A study of the Linda deposit is in progress (Zaleski & Halden 1988). In this paper, the alteration associated with the Osborne Lake orebody, represented mainly by cordierite - gedrite rocks, is described and compared to other types of alteration more common in the Snow Lake area. This investigation is of particular interest because the Osborne Lake orebody and its associated zones of alteration have been metamorphosed to a higher grade than the other deposits in the area. The presence of alteration was not recorded in an earlier study of the ore (Sangameshwar 1968). Sabina (1972) reported gedrite from the Osborne Lake mine, but the tabulation by Price (1977) lists Osborne Lake as having no wallrock alteration.

The geology of the Snow Lake area has been described by Froese & Moore (1980). Metavolcanic and metasedimentary rocks of the Amisk Group are overlain by metasedimentary rocks of the Missi Group. The massive sulfide deposits occur in felsic volcanoclastic rocks of the Amisk Group. Figure 1 shows three isograds representing the boundaries between four metamorphic zones: chlorite-biotite, chlorite-biotite-staurolite, biotite-staurolite-sillimanite, and biotite-sillimanite-almandine. The Osborne Lake orebody is located in the zone of highest metamorphic grade.

### GEOLOGY OF THE OREBODY

The orebody and the alteration zones are shown in Figure 2, a composite plan of the 442 m, 579 m, and 838 m mine levels, and in Figure 3, a vertical cross-section on the 2134 m mine grid line. The orebody consists of a lens of massive sulfide, striking

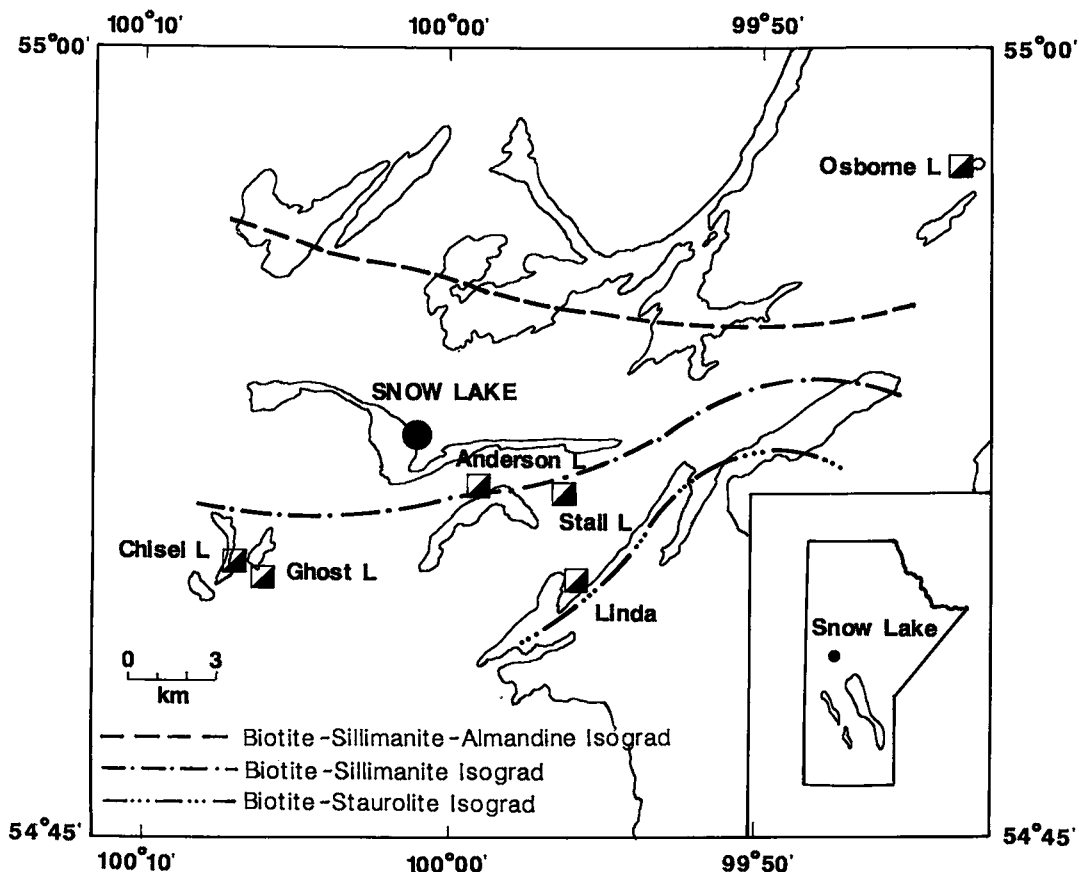


FIG. 1. Location of some ore deposits, Snow Lake area, Manitoba. Metamorphic isograds from Froese & Moore (1980).

045°, dipping 65° northwest and plunging 30° southwest, conformable to the enclosing rocks. The strike length of the orebody is 232 m, averaged over 13 mine levels. Strike lengths of the orebody on three representative mine levels are: 64 m (152 m level), 375 m (487 m level), and 112 m (838 m level). The average width of the ore zone is 8 m. The highest level mined is the 140 m level, and the lowest, the 838 level. The orebody does not crop out. From 1968 to 1983, 2,852,007 tonnes of ore grading 3.14% Cu and 1.52% Zn were mined. Ore reserves remaining in 1983 were 528,054 tonnes grading 2.54% Cu and 1.28% Zn (Esposito 1986).

A second zone of sulfide mineralization, grading 1.0% copper and 1.9% zinc, is located in the footwall, parallel to the orebody (Fig. 2). This zone is about 0.8 m thick and extends from a depth of 152 m to below a depth of 640 m, from where it continues down-plunge, untraced. At a depth of 305 m, this zone lies 15 m from the ore zone, diverging downward from it to a separation of about 30 m at a depth of 640 m (F. Bill, pers. comm.).

The ore is composed mainly of pyrrhotite and pyrite and lesser amounts of chalcopyrite and sphalerite. Galena is rare. Arsenopyrite was reported by Sangameshwar (1968). As observed in other examples of highly metamorphosed Fe sulfide ore, pyrrhotite is abundant, and coarse textures without preferred orientation are common (Templeman-Kluit 1970, Bristol 1984). Both hexagonal and monoclinic pyrrhotite are present (Bristol 1974). The sphalerite has a high MnS content; maximum reported amounts are 2.33 mole % (Bristol 1974) and 8.58 mole % (Sangameshwar 1968). FeS contents of sphalerite, which coexists with pyrite and pyrrhotite, range from 8.26 to 11.69 mole % (Bristol 1974) and, in samples studied by Sangameshwar (1968), from 3.76 to 15.61 mole %.

Two alteration zones, both located in the footwall, are associated with the orebody. The main alteration zone, 6 to 17 m wide, is adjacent to the ore at a depth of 305 m and again from 396 m to 457 m below surface. Below 457 m the zone divides. Alteration accompanies the ore to below the 838 m mine

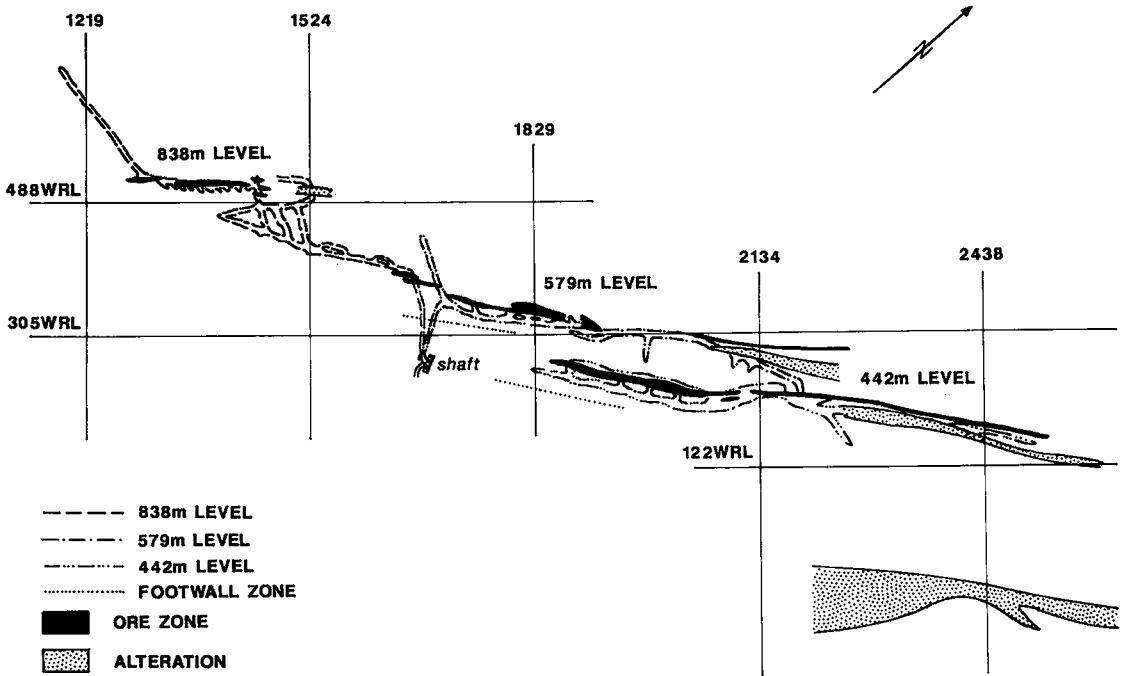


FIG. 2. Composite plan of the 442 m, 579 m, and 838 m mine levels, Osborne Lake mine. Mine reference grid shown in meters.

level. The greater portion, however, plunges gently northeast, away from the orebody. A second zone of alteration, intersected in four drill holes from the 442 m mine level, is about 25 m thick and lies 243 to 275 m from the orebody. It has been traced for a strike length of 243 m.

CHEMICAL COMPOSITION OF THE ROCKS

The 838 m level and decline provided a section across the alteration zone and adjacent wallrock. Selected samples of unaltered and altered rocks have been analyzed for major elements (Table 1) in order to examine the effects of metasomatism. Sample locations are shown in Figure 4. The most drastic compositional change brought about by alteration is extreme depletion in Ca and Na, a feature typical of alteration associated with volcanogenic massive sulfide deposits (Franklin 1986). This effect may be shown graphically by plotting rock compositions (molecular proportions) on a diagram of  $A = Al_2O_3 - K_2O$ ,  $K = K_2O \cdot Al_2O_3$ , and  $F = FeO + Fe_2O_3$  (as FeO) + MgO, effectively projecting through CaO and Na<sub>2</sub>O (Fig. 5). Only minerals coexisting with quartz are shown on this diagram and, for this reason, sample OS-10 has not been plotted. If Ca and Na depletion were the only metasomatic changes, the resulting compositions would give

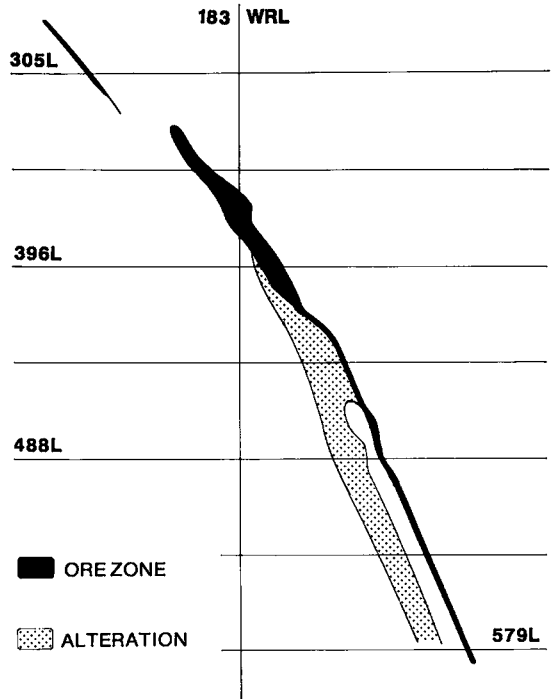


FIG. 3. Vertical cross section, 2134 m mine grid line, Osborne Lake mine.

TABLE 1. ROCK COMPOSITIONS AND MODES OF SAMPLES FROM THE 838 m LEVEL AND DECLINE, OSBORNE LAKE MINE

	OS-1	OS-2	OS-4	OS-7*	OS-10*	OS-12*	OS-13*	OS-14*	OS-15*	OS-22A*	OS-24*	OS-29	OS-30	OS-32	OS-36
SiO <sub>2</sub>	62.80	58.10	65.20	61.90	31.40	67.40	47.00	72.10	71.00	75.20	47.50	63.80	73.90	49.30	77.30
TiO <sub>2</sub>	0.46	0.45	0.43	0.30	0.40	0.23	0.27	0.21	0.25	0.15	0.30	0.33	0.25	0.56	0.16
Al <sub>2</sub> O <sub>3</sub>	13.60	15.90	14.30	11.80	22.80	9.52	18.00	10.90	12.30	7.40	14.60	14.20	11.70	16.30	10.40
Fe <sub>2</sub> O <sub>3</sub>	1.30	0.88	1.69	---	1.64	0.20	---	1.14	0.74	0.68	0.84	0.75	0.31	---	0.46
FeO	6.98	7.78	7.21	7.03	9.49	10.20	10.01	5.85	6.61	4.09	8.90	5.11	2.58	5.46	1.76
MnO	0.11	0.09	0.16	0.08	0.05	0.10	0.09	0.04	0.05	0.04	0.10	0.24	0.05	0.11	0.08
MgO	1.97	2.08	2.53	6.53	18.30	4.89	10.40	4.72	4.26	3.86	11.10	3.11	1.25	5.37	0.72
CaO	2.44	4.01	4.25	0.35	0.20	0.53	0.87	0.38	0.30	1.94	0.30	2.93	2.19	5.58	1.36
Na <sub>2</sub> O	2.28	5.29	1.94	0.36	0.48	0.17	0.37	0.23	0.12	0.15	0.32	3.10	3.14	0.51	3.82
K <sub>2</sub> O	4.38	1.60	2.86	2.38	5.84	0.72	1.37	0.90	0.99	1.73	4.35	2.15	1.47	3.50	0.92
P <sub>2</sub> O <sub>5</sub>	0.20	0.10	0.11	<0.01	<0.01	0.11	0.18	0.08	0.05	0.03	0.17	0.15	0.14	0.21	0.05
CO <sub>2</sub>	0.50	0.92	0.44	0.95	0.46	0.24	1.50	0.36	0.36	0.86	0.94	0.66	0.94	2.12	0.90
H <sub>2</sub> O	0.9	1.1	1.2	2.3	4.6	0.3	3.4	1.0	1.3	1.2	3.6	1.0	0.7	2.3	0.5
FeS <sub>2</sub>	0.02	0.34	0.02	4.94	4.23	2.04	5.07	0.54	1.25	1.14	6.72	0.34	0.13	9.50	0.13
TOTAL	97.9	98.6	102.3	98.9	99.9	96.7	98.5	98.5	99.6	98.5	99.7	97.9	98.8	100.8	98.6
quartz	20	15	20	10		20	20	25	25	20	10	15	15	40	70
plagioclase	40	50	25		tr		10			15		50	60	15	20
K-feldspar	10														
biotite	25	20	25	30	55	10	35	15	15	20	20	25	25	35	10
garnet	5	tr	20			5		tr				10			
hornblende		15	10												
staurolite				20		15		20	30			20			
anthophyllite						20	10	15	10		25	10			
cordierite				30		30	20	25	20	20	20				
spinel				5	10										
pyrite				2	5	tr	5	tr	tr	tr	5	tr	tr	10	
pyrrhotite				3		tr									
chlorite					30										
magnetite				tr		tr						15			
ilmenite						tr									

Composition in weight %; Total S calculated as FeS<sub>2</sub>

\* Altered rocks

Analysts: Bondar-Clegg and Company, except H<sub>2</sub>O by Analytical Chemistry Section, Geological Survey of Canada

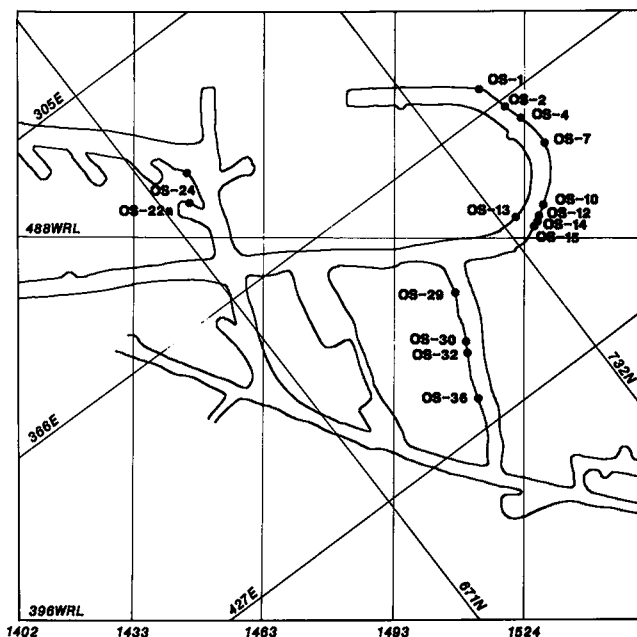


FIG. 4. Sample locations, 838 m mine level and decline, Osborne Lake mine.

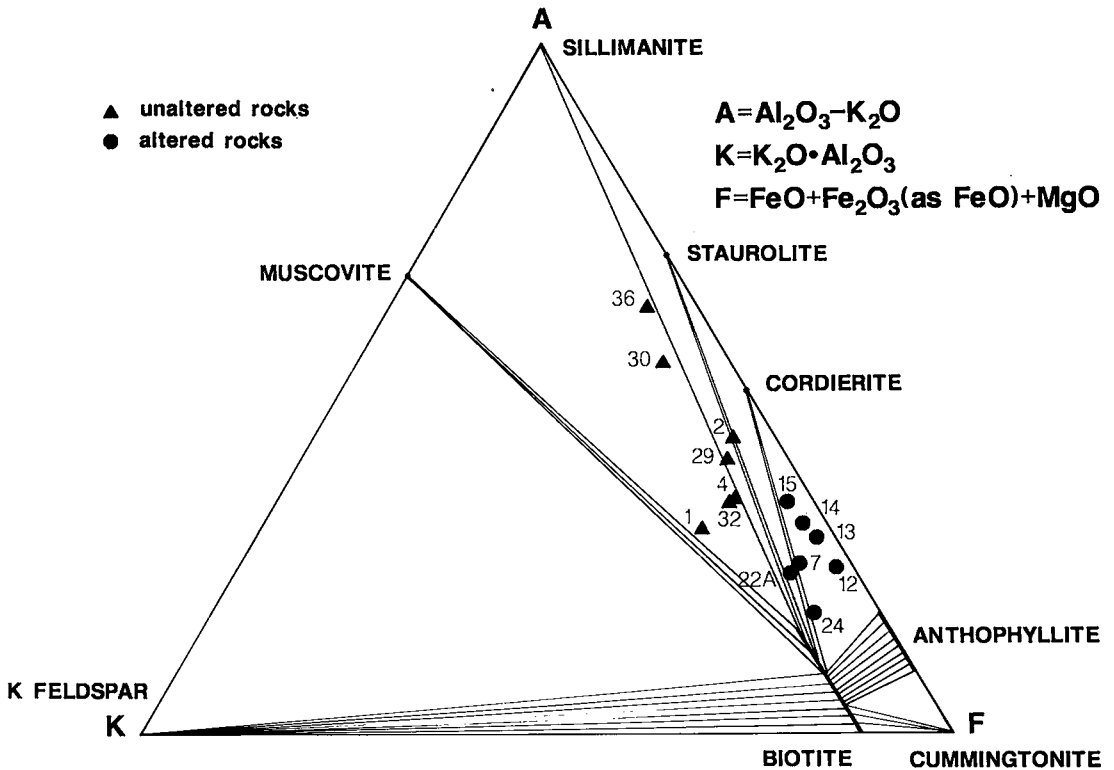


FIG. 5. Rock compositions plotted on an AKF diagram. "Anthophyllite" includes gedritic compositions.

rise to mineral assemblages including muscovite, biotite, staurolite and sillimanite. Such rocks, with kyanite present instead of sillimanite, are common at the Anderson Lake mine (Walford & Franklin 1982). In altered rocks near the Osborne Lake orebody, however, other metasomatic changes are evident. In particular, a decrease in  $Al/(Al + Fe + Mg)$  is required to allow the formation of cordierite-gedrite rocks. In view of the suggested immobility of Al (Grant 1986, MacLean & Kranidiotis 1987), it is more likely that Fe and Mg were added to the rock rather than Al being removed. An extreme form of alteration, characterized by Mg enrichment and severe Si depletion, has produced chlorite-biotite rocks. Such rocks are found immediately adjacent to the orebody and in central portions of the alteration zone sampled in the 838 m decline (e.g., sample OS-10).

#### GRADE OF METAMORPHISM

Mineral analyses were obtained employing a Material Analysis Company electron microprobe equipped with a Kevex 7000 energy-dispersion spectrometer standardized against natural minerals and

metals. Analytical conditions and data reduction were processed on a Digital PDP1103-L computer using the software EDDI (G. Pringle, Geological Survey of Canada). Operating conditions were: accelerating voltage 20 kV, sample current 10 nA, measured on a standard kaersutite, acquisition time 50 seconds. The relative accuracy of the analyses is 1–2% of the amount present for major elements, increasing to 10% of the amount present for minor elements. Results were fully corrected for background, overlap and matrix effects (ZAF). The overlap correction was made by means of overlap coefficients measured on peaks for pure elements. The matrix correction employed is a modified version of that of Love & Scott (1981). The background correction was taken from Myklebust *et al.* (1979).

The unaltered host-rocks are fine- to medium-grained gneisses that probably were derived from felsic volcanoclastic rocks. Most of the unaltered rocks consist of quartz, plagioclase, biotite and garnet. Potassium feldspar is a rare constituent. A few samples contain hornblende. Chemical compositions of minerals in one unaltered rock (OS-4) are given in Table 2.

Altered rocks are coarser grained. Their unusual

TABLE 2. CHEMICAL COMPOSITIONS OF MINERALS, OSBORNE LAKE MINE

	OS-4			OS-7				OS-12					OS-10		
	Bt	Alm	Hbl	Bt	St	Crđ	Gah	Bt	St	Crđ	Alm	Ged	Bt	Chl	Hc
SiO <sub>2</sub>	35.57	37.66	41.65	38.86	27.95	48.64	---	37.75	27.52	48.37	38.13	44.68	39.08	26.70	---
TiO <sub>2</sub>	1.82	---	0.34	0.69	0.65	0.07	---	2.25	0.73	0.07	---	0.21	0.59	0.11	---
Al <sub>2</sub> O <sub>3</sub>	16.57	21.88	13.61	17.49	52.93	33.79	56.63	16.69	52.68	33.69	22.57	14.42	17.87	23.51	60.60
FeO	24.16	26.07	22.00	11.09	10.36	3.87	11.69	15.64	12.62	5.68	29.32	21.85	8.72	10.01	25.04
MnO	0.12	3.67	0.22	0.05	0.35	0.23	0.23	---	0.09	0.04	0.44	0.18	0.04	0.02	0.32
MgO	9.12	1.96	6.98	18.75	2.98	11.15	4.86	15.48	2.91	10.57	7.61	14.84	20.87	27.67	9.58
CaO	---	8.99	11.26	---	---	---	---	---	---	---	2.15	0.44	---	---	---
Na <sub>2</sub> O	---	---	0.80	0.17	---	0.52	---	0.04	---	0.35	---	2.55	0.18	---	---
K <sub>2</sub> O	9.35	---	1.47	8.52	---	0.04	---	8.09	---	---	---	---	8.35	---	---
ZnO	---	---	---	---	3.24	---	25.80	---	1.83	---	---	---	---	---	3.87
Total	96.71	100.23	98.33	95.62	96.46	98.31	99.21	95.94	98.38	98.77	100.22	99.17	95.70	88.02	99.41
Ions per Formula															
Si	2.736	2.984	6.311	2.802	3.932	4.927	---	2.773	3.877	4.911	2.958	6.477	2.781	2.582	---
Ti	0.105	---	0.039	0.037	0.069	0.005	---	0.124	0.077	0.005	---	0.023	0.032	0.008	---
Al	1.502	2.043	2.430	1.486	8.776	4.034	1.944	1.445	8.747	4.031	2.063	2.464	1.499	2.680	1.952
Fe <sup>3+</sup>	---	---	0.352	---	---	---	0.056	---	---	---	---	---	---	---	0.048
Fe <sup>2+</sup>	1.554	1.727	2.436	0.669	1.219	0.328	0.228	0.961	1.487	0.482	1.902	2.649	0.519	0.810	0.524
Mn	0.008	0.246	0.028	0.003	0.042	0.020	0.006	---	0.011	0.003	0.029	0.022	0.002	0.002	0.007
Mg	1.046	0.231	1.577	2.016	0.625	1.684	0.211	1.695	0.611	1.600	0.880	3.207	2.214	3.989	0.390
Ca	---	0.763	1.828	---	---	---	---	---	---	---	0.179	0.068	---	---	---
Na	---	---	0.235	0.024	---	0.102	---	0.006	---	0.069	---	0.717	0.025	---	---
K	0.917	---	0.284	0.784	---	0.005	---	0.758	---	---	---	---	0.758	---	---
Zn	---	---	---	---	0.337	---	0.555	---	0.190	---	---	---	---	---	0.078
H	2.000	---	2.000	2.000	1.222	---	---	2.000	1.345	---	---	2.000	2.000	4.000	---
O	12.000	12.000	24.000	12.000	24.000	18.000	4.000	12.000	24.000	18.000	12.000	24.000	12.000	18.000	4.000
quartz, plagioclase An <sub>55.3</sub> , biotite, garnet, hornblende			quartz, biotite, staurolite, cordierite, gahnite, magnetite, pyrite, pyrrholite Fe <sub>0.89</sub> S, sphalerite Zn <sub>0.90</sub> Fe <sub>0.10</sub> S, chalcopyrite				quartz, staurolite, cordierite, almandine, gedrite, biotite, magnetite, ilmenite, pyrite, pyrrholite, sphalerite, chalcopyrite, galena					biotite, chlorite, hercynite, plagioclase An <sub>96.4</sub>			

Total iron expressed as FeO

Electron-microprobe analyses by M. Bonardi (silicates and spinels) and D. C. Harris (sulfides), Geological Survey of Canada

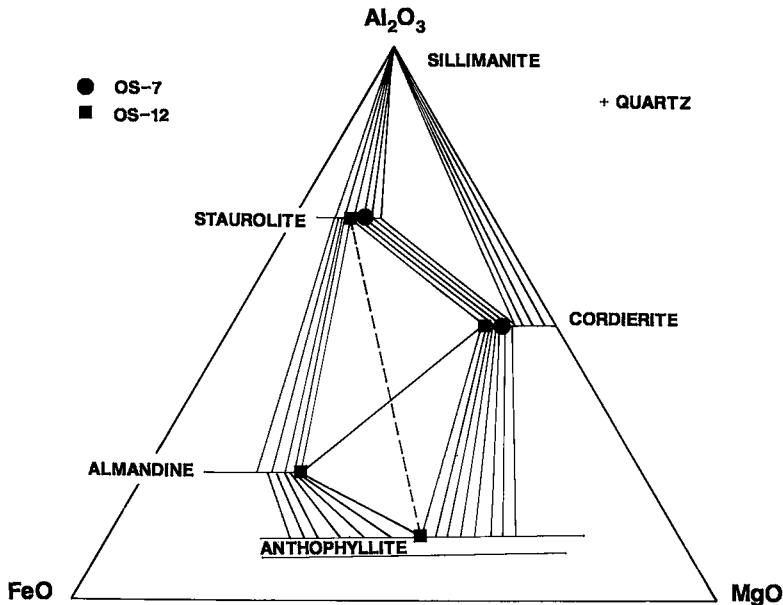
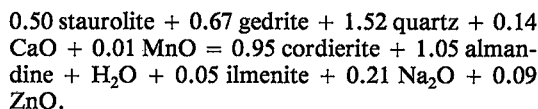


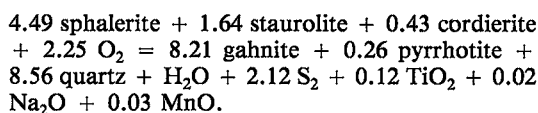
FIG. 6. Phase relations in the system Al<sub>2</sub>O<sub>3</sub> - FeO - MgO. "Anthophyllite" includes gedritic compositions.

composition permits the appearance of aluminous minerals. Mineral assemblages of altered rocks are given in Table 1, and compositions of minerals from these rocks are given in Table 2. At constant pressure, temperature and activity of  $H_2O$ , and in the presence of quartz, the minerals staurolite, anthophyllite-gedrite, cordierite and almandine can be represented approximately in the system  $Al_2O_3 - FeO - MgO$  (Fig. 6). Staurolite occurs as isolated grains surrounded by cordierite; it was not observed in contact with gedrite. These facts suggest that the following reaction has gone to the right:



The reaction was balanced using mineral compositions from sample OS-12 (Table 2). It was assumed that the fluid phase supplied Ca and Mn and removed Na and Zn. The stable mineral assemblages are staurolite-cordierite-almandine and cordierite-almandine-gedrite; the latter assemblage also was reported by Froese & Moore (1980) from the biotite-sillimanite-almandine zone.

Gahnite is present in sample OS-7. Gahnite may be formed by the reaction of sphalerite with aluminous minerals (Spry & Scott 1986). In the present case, a possible reaction would involve staurolite and cordierite. Using mineral compositions from sample OS-7 (Table 2), the following reaction can be balanced:



It was assumed that Ti, Na and Mn were removed in the fluid phase.

The chlorite in sample OS-10 appears to be a prograde mineral. It could have been stabilized at the metamorphic grade of the biotite-sillimanite-almandine zone owing to its Mg-rich composition and the absence of quartz (Chernosky *et al.* 1988).

#### CONCLUSIONS

Although it has been subjected to the highest grade of regional metamorphism recorded in the Snow Lake area, the Osborne Lake orebody retains significant geological and geochemical characteristics of Precambrian volcanogenic Cu-Zn massive sulfide deposits. Other deposits in the Snow Lake area, in the vicinity of Stall and Anderson Lakes, are characterized by the predominance of potassic and

aluminous alteration (Walford & Franklin 1982). In contrast, the altered rocks associated with the Osborne Lake orebody have been interpreted as metamorphosed chloritic rocks, typical of the alteration associated with volcanogenic massive sulfide deposits. It has been suggested that infiltrated seawater was the source of magnesium for the chloritic alteration (Roberts & Reardon 1978, Franklin 1986). The chlorite-biotite rocks represent extreme alteration due to leaching of Si and Fe, as described by MacLean & Kranidiotis (1987).

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