THE EMPRESS CU-AU-MO DEPOSIT - GEMSTONE AND INDUSTRIAL MINERALS POTENTIAL

G.J. Simandl and K.D. Hancock, B.C. Geological Survey
E. Lambert, Consultant
P. Hudon, McGill University
J. Martignole, Université de Montréal
W.W. Osborne, Westpine Metals Ltd.

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INTRODUCTION

This article describes the geology and industrial mineral potential of corundum, pyrophyllite and andalusite at the Empress deposit in the Taseko Lakes area (Figure 1). The Empress is a copper-gold-molybdenum porphyry deposit located 225 kilometres north of Vancouver and 50 kilometres northwest of Goldbridge and the Bralorne mining camp. Fine-grained corundum, in association with andalusite-pyrophyllite rock, was reported in several drill holes (Lambert, 1989, 1991a and b) and a boulder containing coarse corundum was found in a trench in 1990. The potential of corundum mineralization has not been previously investigated. Corundum is closely associated with andalusite/pyrophyllite-bearing rocks that may also have commercial applications.

Corundum is an alumina-rich mineral (Al_2O_3) that may be of variable color due to substitution of metal ions for Al^{3+}. It is usually grey, blue-grey, brown, yellow, green or colourless. Its gemstones are known by their colours, red for ruby and blue for sapphire. The red color is linked to Cr^{3+} content, while blue and green corundum have significant Ti^{4+}, Fe^{3+} and Fe^{2+} and in some cases V^{5+}, Co^{2+} or Ni^{2+} (Phillips and Griffen, 1981). Most corundum gemstones are produced from placer or residual deposits derived by weathering and reworking of primary deposits. Primary sapphire and ruby are formed at depth in association with intrusive rocks such as syenites, nepheline syenites and monzonites or quartz-free, "desilicated" pegmatites emplaced into ultramafic rocks or carbonates. Sometimes corundum is found as xenocrysts, from the above sources, in alkaline dikes, lava flows or diatremes that originated at depth. They may also be formed by regional or contact metamorphism of alumina-rich sediments and paleoregoliths. Primary corundum, typically not of gem quality, also has been reported in several relatively shallow porphyry or epithermal deposits by Gustafson and Hunt (1975), Lowder and Dow (1978), Brimhall (1977), Wojdak and Sinclair (1984) and Price (1986). The Empress porphyry occurrence may be of this type.

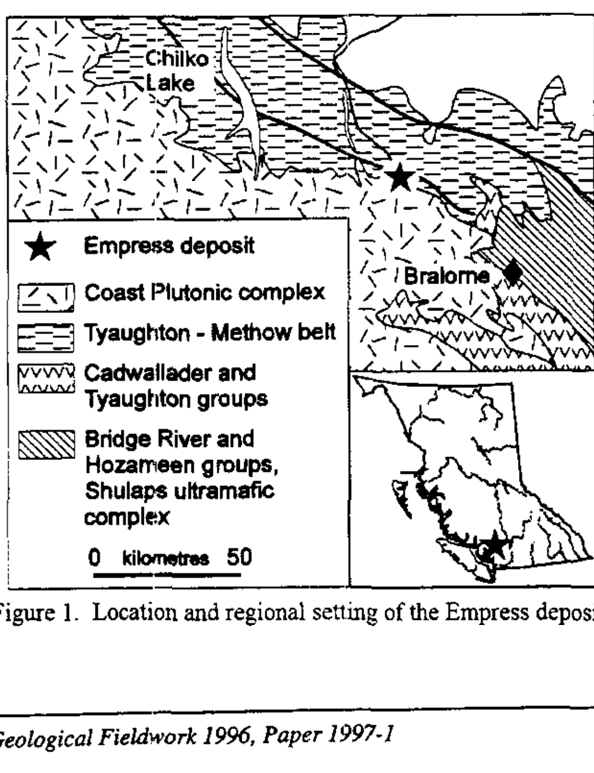

Figure 1. Location and regional setting of the Empress deposit.

Andalusite and pyrophyllite are minerals with industrial applications including refractories, whiteware, chemical and agricultural uses. Andalusite-pyrophyllite-quartz rock has been mined in the United States for ceramic applications. Since pyrophyllite is commonly associated with other minerals from which it may not be readily separated, mineral assemblages and chemical composition are important parameters that may limit or enhance a potential market from any given source. Refractory grade pyrophyllite presently sold in the United States comprises 40 to 50 percent pyrophyllite, 30 to 45 percent quartz, 5 to 15 percent kaolinite and 1 to 3 percent muscovite. Low-grade pyrophyllite-quartz rock with trace kaolinite, diaspore, muscovite, andalusite and corundum is sometimes used in ceramics, tiles, agricultural-grade pesticide carriers, fertilizer and animal feed preparations (Ciullo and Thompson, 1994).

GEOLOGICAL SETTING

The Empress deposit is located near the eastern margin of the Coast Plutonic Complex in rocks of the Tyaughton basin (Figure 1). The regional geology of the area has been described by Tipper (1978), Glover *et al.* (1986), McLaren and Rouse (1989) and Schiariazza *et al.*

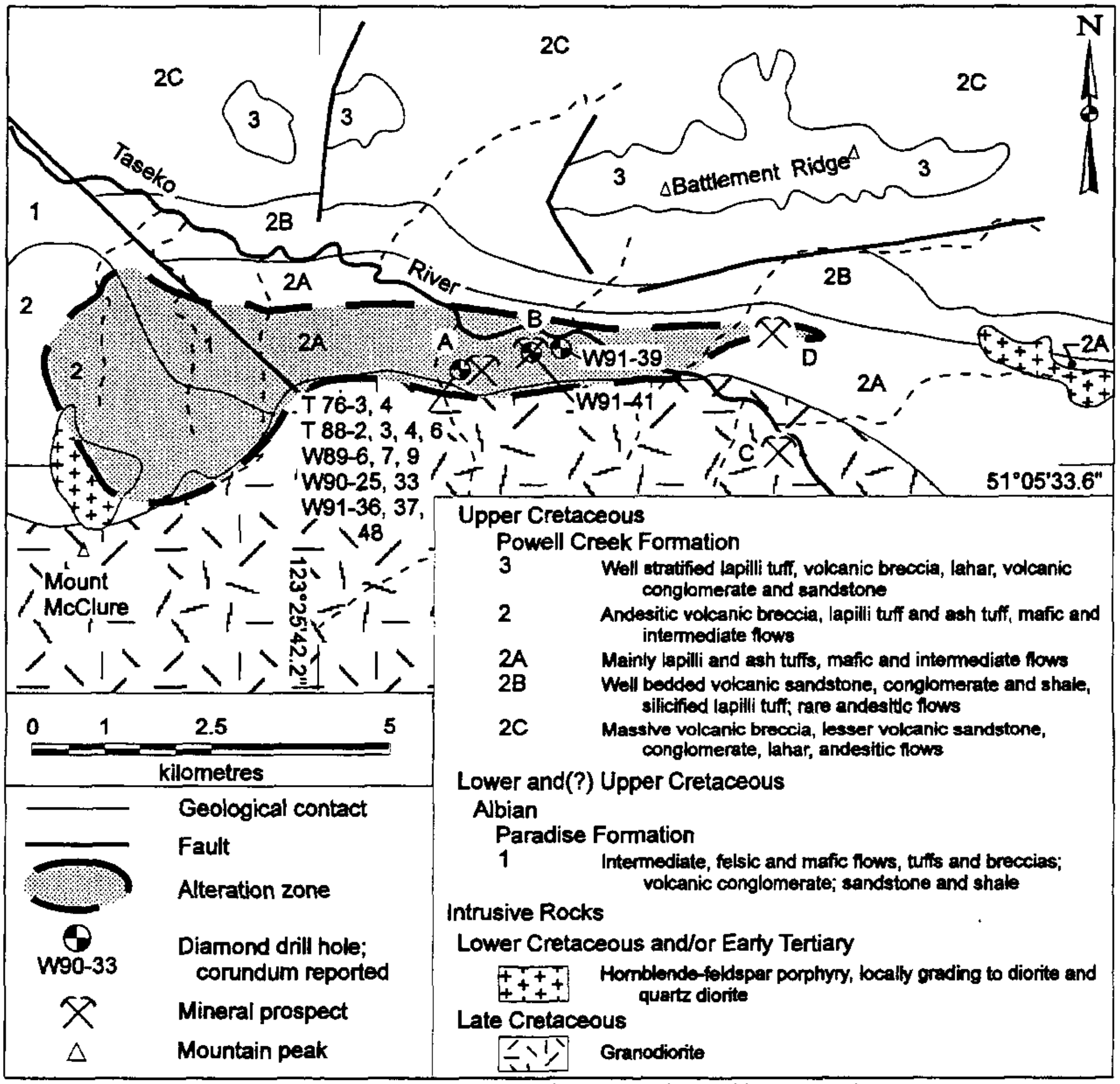

Figure 2. Geology of the Empress deposit (modified from Schiariazza *et al.*, 1993).

(in press). Rocks outcropping in the deposit area belong to the Upper Cretaceous Powell Creek and Lower to Upper(?) Cretaceous Paradise formations. The deposit is located within an alteration zone that is 11 kilometres long and up to 3 kilometres wide (Figure 2). There are substantial changes in the nature and intensity of alteration within the outlined area (McMillan, 1976; Bradford, 1985; Price, 1986). Because of the high degree of alteration and few outcrops, the nature of the protolith within the alteration zone in the Empress area is not well established. Rocks hosting the Empress deposit are believed to be mainly volcaniclastic rock and mafic to intermediate flows (McMillan, 1976; Schiariazza *et al.*, 1993). Large masses of Late Cretaceous granodiorite of the Coast Plutonic complex outcrop south of the alteration zone. Smaller intrusions of Lower Cretaceous to Early Tertiary age consist of hornblende-feldspar porphyry which locally grades into diorite and quartz diorite.

DEPOSIT GEOLOGY

The Empress deposit is in an area with very little outcrop and nearly all information was acquired from drill core. Near surface, the contact between rocks of the Powell Creek Formation and the Late Cretaceous granodiorite is nearly subvertical. Drilling indicates that it is sub-horizontal at depth, towards the Taseko River (Figure 3). Westpine Metals Ltd. geologists divide the host rocks into four alteration assemblages and one intrusive unit: quartz rock, quartz-magnetite rock, plagioclase-quartz-pyrophyllite-andalusite rock, quartz-andalusite-pyrophyllite rock and granodiorite-quartz monzonite (Osborne and Allen, 1995). These rock types are the product of alteration, in a porphyry system, of a volcanic or volcaniclastic protolith (McMillan, 1976).

Quartz rock (QR) is typically light grey and weathers brown. It consists of quartz grains (90 to 95%) that are equigranular and subrounded. It contains minor quantities of magnetite (1 to 5%) and trace amounts of pyrophyllite, clay, chlorite, carbonate, sphene, pyrite and chalcopyrite. There is no consensus on the origin of this lithology. In various areas of the property, Westpine geologists interpret QR as an altered volcanic rock and they interpreted relict planar textures as banded rhyolite and welded tuff (Lambert, 1988, 1989, 1991a and b). Other workers interpret the protolith as volcaniclastic rocks (McMillan, 1976) or altered volcaniclastic tuffs (Madiesky, 1994).

Quartz magnetite (QM) rock consists mainly of quartz and magnetite. The magnetite content varies from 5 to 70 percent by volume, but typical content varies from 10 to 20 percent. Chlorite and hematite are minor constituents. The distinction between the QM and QR units is based on the magnetite content. Magnetite occurs as interstitial grains, fracture fillings and cement. The interstitial nature of magnetite and its occurrence as fracture fillings suggests that the protolith of QM was identical to QR and that iron came in at a later stage.

The plagioclase-quartz-pyrophyllite-andalusite (PQSA) unit is very heterogeneous. It consists of several distinct alteration assemblages that are too limited in extent to be treated separately at the current scale. The most characteristic lithology of this unit is relatively coarse-grained (2 mm to 150 mm) cream-coloured, grey or white plagioclase lenses, layers or irregular masses. These masses are rarely more than a few metres in apparent thickness in drill core. At surface, large blocks

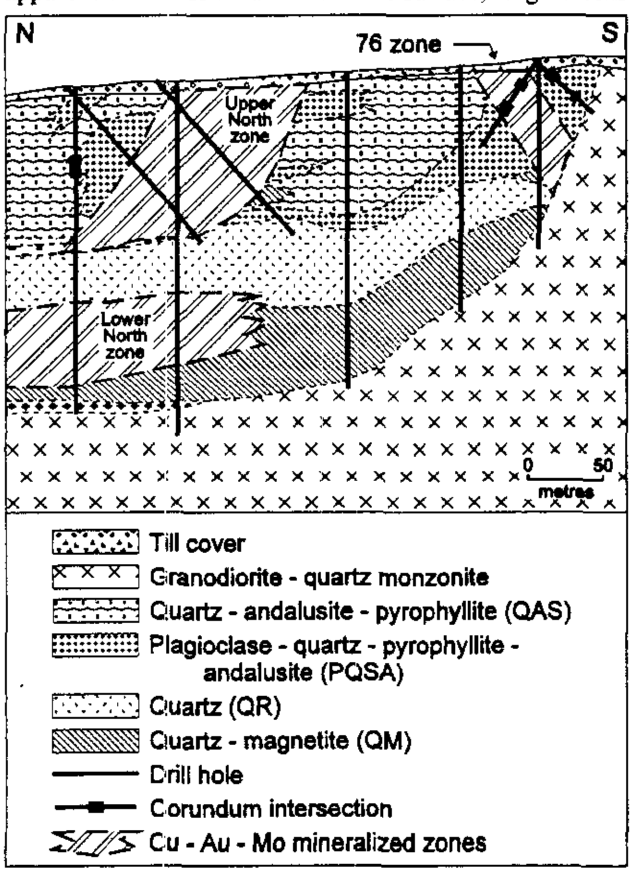

Figure 3. Cross section of the Empress deposit. For location see Figure 2; A - Empress deposit, B - East Zone, C - Buzzer occurrence, D - Taylor Windfall deposit (modified from Osborne and Allen, 1995).

of this material are several metres across. They are intimately associated with pale green, fine-grained to aphanitic zones consisting mainly of muscovite and pyrophyllite, fine sericite and andalusite-rich areas that are highly irregular in shape. The pyrophyllite-andalusite zones are typically bluish grey. Corundum, magnetite and chlorite are the most common accessory minerals. Corundum typically occurs in quartz-free zones within this rock unit.

Quartz-andalusite-pyrophyllite (QAS) rock is equigranular with grains less than 1 millimetre in size to aphanitic. Minor mineral constituents include magnetite, clay, chlorite and gypsum. Weathered surfaces are typically yellow stained from the weathering of pyrite and fresh surfaces are sugary and grey. Quartz-andalusite-pyrophyllite rock does not contain the coarse plagioclase that can be observed in PQSA.

Granodiorite-quartz monzonite weathers buff and is white to bluish on fresh surface. It is medium to coarse grained and equigranular. It consists of feldspar, quartz, hornblende and biotite with minor titanite. This intrusive rock is the footwall to the deposit and forms the southern limit to the deposit.

Copper-gold mineralization occurs in three areas, the Lower North, Upper North and 76 zones of the Empress deposit (Figure 3). These zones host a mineral resource of 10 004 000 tonnes grading 0.61 percent Cu and 0.789 grams per tonne Au, using a cut-off grade of 0.4 percent Cu (Osborne and Allen, 1995).

The age of mineralization was bracketed by K/Ar dating using biotite. Samples of granodiorite, the alteration zone and a post-mineral dike yielded dates of 86.7 ±2.6, 84.9 ±2.5 and 84.7 ±2.5 Ma respectively (McMillan, 1976). Chalcopyrite sometimes forms rims around corundum so it is probably older than 84.7 ±2.5 Ma.

Corundum-bearing Rocks and Assemblages

Corundum-bearing rocks were intersected in 16 drill holes. As indicated above, it is hosted within plagioclase-quartz-pyrophyllite-andalusite (PQSA) rocks as defined by Westpine Metals Ltd. geologists. However, detailed examination of corundum-bearing rocks indicates that this mineral typically is found adjacent to a light grey or pinkish, coarse-grained feldspathic rock comprised mainly of albite and strongly zoned orthoclase. This feldspar-rich rock is quartz-free and has been intersected over apparent thicknesses of a few centimetres to several metres. Typically, corundum comprises trace amounts to two percent of the rock over widths of generally 0.6 to 21 metres, with one intersection of 34 metres, most of it within andalusite-pyrophyllite-sericite rock. Usually, corundum occurs within andalusite but a few corundum grains are encased directly in feldspar. The corundum observed in drill core is dark to light blue in colour and the grains are commonly less than two millimetres in size. However, blue-black, euhedral crystals up to 3 centimetres in length with hexagonal prism or steep hexagonal dipyramidal forms (Plate 1), approaching barrel-shaped crystals, occur in surface float overlying

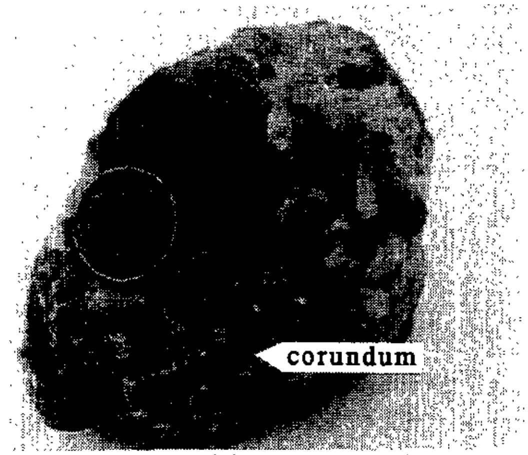

Plate 1. A rock fragment containing coarse, dark blue, doubly terminated corundum crystals, found in overburden above the 76 zone, Empress deposit area.

the 76 zone. A heavy mineral concentrate of overburden from the 76 zone contains dark-blue corundum and colorless corundum crystals that sometimes have light blue patches or blue, hexagonal cores. Petrographic examination of corundum from the host rock indicates that most of the fine-grained crystals are microfractured or contain inclusions of pyrophyllite or diaspore. Some of the coarser crystals have relatively fracture free zones several millimetres across that may be gem quality. Individual corundum crystals are separated from the host by pale grey halos, 2 to 5 millimetres wide, that consist mainly of coarse muscovite. Some corundum grains within copper-gold mineralized zones are rimmed by sulphides.

The corundum crystals are nearly pure Al_2O_3 but contain detectable concentrations of Fe, Ti and Cr (Table 1). Some crystals are chemically zoned. The zoning and observed textures such as coronas around corundum crystals clearly indicate that the Empress deposit system was not in equilibrium at the time of corundum formation. The stability field of corundum in the system $HCl\text{-}H_20\text{-}(Al_2O_3)\text{-}K_2O\text{-}SiO_2$ at 0.5 kb and 400°C, in terms of the ratios of activity (a) of K^+ to H^+ and activity of SiO_2, is shown in Figure 4 (Bowers *et al.*, 1984). The figure may be an oversimplification, but it is useful in illustrating that pyrophillite is not in equilibrium with corundum. Muscovite coronas surrounding corundum and the relatively restricted occurrence of corundum within a large alteration zone may simply be the result of changing conditions, such as the activity of silica or potassium and hydrogen within the system. It is therefore possible that corundum is limited to a metasomatic halo genetically related to the coarse-grained albite-orthoclase

TABLE 1. MINERAL CHEMISTRY OF REPRESENTATIVE CORUNDUM CRYSTALS; EMPRESS DEPOSIT.

Sample	7	9	10
SiO_2	0.000	0.000	0.000
TiO_2	0.051	0.428	0.033
Al_2O_3	99.324	98.126	99.997
Cr_2O_3	0.037	0.002	0.104
FeO	1.116	2.233	0.596
MnO	0.008	0.000	0.001
MgO	0.000	0.01	0.000
CaO	0.000	0.000	0.000
Total	100.536	100.799	100.731
Si	0.0000	0.0000	0.0000
Al	1.9880	1.9713	1.9924
Ti	0.0007	0.0055	0.0004
Fe	0.0158	0.0318	0.0084
Cr	0.0005	0.0000	0.0014
Mg	0.0000	0.0003	0.0000
Mn	0.0001	0.0000	0.0000
Ca	0.0000	0.0000	0.0000
Total	2.0051	2.0089	2.0027

Note: Major oxides and cationic proportions calculated on a three oxygen basis.

TABLE 2. MINERAL CHEMISTRY OF REPRESENTATIVE ANDALUSITE CRYSTALS; EMPRESS DEPOSIT.

Sample	1	2	3	4
SiO_2	35.580	35.958	36.657	36.435
TiO_2	0.049	0.049	0.019	0.049
Al_2O_3	61.094	62.137	62.625	61.89
FeO	1.324	0.844	0.247	1.144
MnO	0.000	0.000	0.000	0.010
MgO	0.032	0.001	0.019	0.019
CaO	0.000	0.000	0.000	0.015
K_2O	0.012	0.022	0.012	0.011
Total	99.091	99.064	99.561	99.573
Si	1.0027	0.9843	0.9946	0.9934
Al	1.9739	2.0049	2.0028	1.9890
Fe	0.0304	0.0193	0.0056	0.0261
Mg	0.0013	0.0022	0.0000	0.0008
Ti	0.0010	0.0010	0.0004	0.0010
Mn	0.0000	0.0000	0.0000	0.0002
Ca	0.0000	0.0000	0.0000	0.0004
K	0.0004	0.0008	0.0004	0.0004
Total	3.0096	3.0126	3.0038	3.0113

Note: Major oxides and cationic proportions calculated on a five oxygen basis.

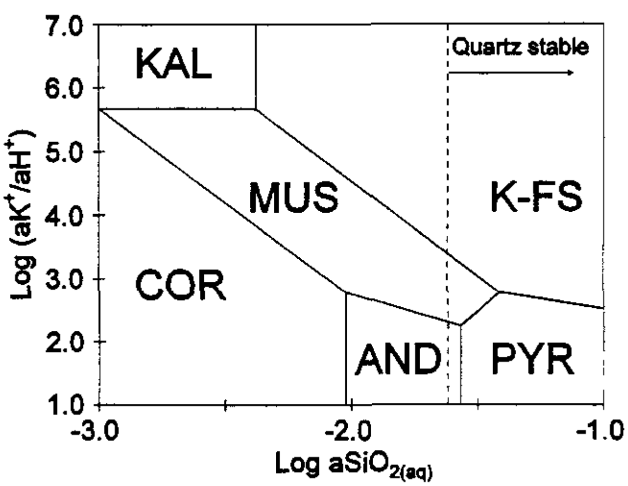

Figure 4. The system $HCl\text{-}H_20\text{-}(Al_2O_3)\text{-}K_2O\text{-}SiO_2$, at 0.5 kb and 400°C. The vertical dotted line represents the saturation limit of quartz. Abreviations: COR - corundum, AND - andalusite, PYR - pyrophyllite, K-FS - Alkali Feldspar, KAL - Kalsilite (From Bowers *et al.*, 1984).

TABLE 3. MAJOR ELEMENT ANALYSES OF TYPICAL ANDALUSITE AND PYROPHYLLITE-BEARING ROCKS - EMPRESS DEPOSIT.

Rock type	Drill hole	Depth	Al_2O_3	CaO	Cr_2O_3	Fe_2O_3	K_2O	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	LOI	Total
AR	W89-1	238-239	15.60	7.31	<0.01	5.61	0.05	0.10	0.02	0.11	0.15	55.80	0.51	7.95	93.20
KSA	W89-2	97-98	20.00	3.90	<0.01	4.37	4.38	0.17	0.06	3.37	0.50	57.00	0.56	3.55	97.90
PSA	W90-18	227-228.5	13.60	0.55	0.02	16.60	2.99	0.35	0.09	1.10	0.14	57.30	0.48	6.75	100.00
SAR	W89-1	171-172	18.00	0.43	0.01	7.14	1.37	4.84	0.05	0.58	0.17	59.50	0.61	6.60	99.30
QAS	W90-19	274-275	25.20	1.44	0.02	4.66	2.30	0.10	0.02	1.18	0.12	58.30	0.72	4.10	98.20
PQSA	W91-41	110	32.59	2.14	0.03	7.18	3.31	0.15	0.08	3.75	0.21	45.52	1.21	3.25	99.42
PQSA	W91-41	305	13.05	1.13	0.02	2.23	2.92	0.08	0.02	4.54	0.07	70.68	0.63	1.90	97.27
PQSA	W91-40	572	26.97	1.88	0.03	11.98	1.86	0.22	0.09	2.55	0.04	48.69	1.09	4.36	99.76
PQSA	W91-38	30	20.74	4.83	0.02	3.51	1.02	0.28	0.06	6.29	0.24	56.80	0.89	4.45	99.13
PQSA	W91-38	421	20.76	1.66	0.01	4.30	2.55	0.13	0.02	6.06	0.04	59.74	0.77	2.59	98.63
PQSA	W91-39	45	33.14	1.63	0.03	11.77	2.79	0.19	0.03	3.56	0.20	42.54	1.18	2.46	99.52
PQSA	W91-49	304	18.26	5.96	0.02	1.92	3.97	0.36	0.12	3.29	0.14	56.53	0.72	7.61	98.90
PQSA	W89-8	88	14.53	3.91	0.03	4.68	2.03	0.04	0.02	1.71	0.50	65.58	0.66	6.19	99.88
PQSA	W89-8	374	35.29	1.57	0.03	3.81	5.44	0.22	0.01	2.22	0.20	45.99	0.12	4.35	99.25
PQSA	W90-19	60	25.26	3.78	0.02	3.15	4.52	0.09	0.02	3.07	1.37	52.99	1.02	4.36	99.65
PQSA	W90-19	326	24.24	2.00	0.01	1.36	8.28	0.06	0.03	3.58	0.87	55.63	1.24	2.05	99.35
PQSA	W90-21	111	27.26	2.90	0.01	0.69	2.55	0.06	<0.01	4.19	0.10	56.88	0.53	3.74	98.91
PQSA	W90-20	128	14.57	1.35	0.02	7.68	5.76	0.10	0.07	2.12	0.26	63.53	0.56	3.02	99.04
PQSA	W90-23	65	32.72	1.14	0.03	4.71	5.55	0.27	0.06	1.66	0.43	47.28	1.24	4.25	99.34
PQSA	W90-23	304	7.31	1.41	0.04	14.86	1.43	0.17	0.03	1.00	0.30	70.41	0.72	2.32	100.00
PQSA	W90-27	171	28.30	0.93	0.04	1.68	2.88	0.07	<0.01	4.15	0.18	57.87	0.88	2.81	99.79
PQSA	W89-3	84	16.64	2.96	0.03	2.45	1.04	0.37	0.02	6.03	0.30	64.17	1.11	3.81	98.93
PQSA	W89-3	284	17.21	3.49	0.02	2.19	1.38	1.55	0.03	5.54	0.12	63.98	0.64	3.06	99.21
PQSA	W89-5	85	20.35	2.79	0.04	5.21	1.83	1.69	0.04	5.56	0.48	56.21	0.82	4.90	99.92
PQSA	W90-30	198	22.97	4.59	0.04	3.80	4.65	0.10	0.06	2.90	0.30	54.54	0.65	4.24	98.84
PQSA	W90-31	253	25.77	4.29	0.02	5.83	4.89	0.19	0.09	3.01	0.33	46.54	0.86	8.13	99.95
PQSA	W91-37	339	16.14	2.45	0.04	3.06	1.24	0.27	0.01	5.92	0.01	66.53	0.13	2.72	98.52
PQSA	W88-3	59	16.25	1.92	0.03	1.22	7.48	0.07	0.03	1.97	0.47	66.27	0.81	2.63	99.15
*	76WJ-37		16.99	0.05		0.28	0.075	0.03	<0.003	0.120	0.13	71.43	0.923		99.08
*	76WJ-42		17.50	0.04		0.67	0.034	0.02	0.003	0.082	0.40	74.11	0.876		97.61
average			21.53	2.66	0.02	5.27	3.23	0.44	0.04	3.25	0.29	57.24	0.76	4.22	
median			20.55	2.07	0.02	4.34	2.84	0.17	0.03	3.18	0.21	56.94	0.72	3.96	
standard deviation			7.02	1.68	0.01	4.06	2.02	0.95	0.03	1.79	0.28	7.54	0.29	1.81	
maximum			35.29	7.31	0.04	16.60	8.28	4.84	0.12	6.29	1.37	70.68	1.24	8.13	
minimum			7.31	0.43	0.01	0.69	0.05	0.04	0.01	0.11	0.01	42.54	0.12	1.90	

Key: PQSA: plagioclase-quartz-pyrophyllite-andalusite; AR: andalusite; KSA: K-feldspar-pyrophyllite-andalusite: PSA: plagioclase-pyrophyllite-andalusite: SAR: pyrophyllite-andalusite; QAS: quartz-andalusite-pyrophyllite; R: rock

Notes: Samples 76WJ-37 and 42 were collected by McMillan (1976) and are for comparison only Statistical analyses are for samples collected by Wespine Metals Ltd. (Madeisky, 1994).

TABLE 4. PYROPHYLLITE-BEARING MATERIALS WITH CURRENT INDUSTRIAL APPLICATIONS

Source	Product	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	LOI
USA	Refractory	75.0	19.3	0.8	0.1	0.1	0.2	0.1	–	3.9
	Whiteware	80.9	13.8	0.2	–	–	2.3	0.4	0.1	2.3
South Korea	Refractory	73-77	18-19	0.15-0.25	–	–	–	–	–	3.8-3.45
	Ceramic	76-80	15-19	0.15-0.30	–	–	–	–	–	3.3-3.[illegible]

(Sources: Ciullo and Thompson, 1994; Harben 1995) rock that may have a pegmatitic affinity. Work is in progress to better evaluate the potential of the 76 zone of the Empress deposit and overlying overburden as a source of sapphire and to explain the origin of the corundum.

Andalusite-pyrophyllite

The andalusite crystals from the Empress deposit have relatively low iron content (Table 2) and could satisfy current refractory specifications. However the andalusite-bearing rocks are generally too fine-grained to be processed into high-grade concentrates that could compete with South African material.

A large number of drill core samples were analyzed for metallic elements (Lambert, 1988, 1989, 1991a and b), but little major element data is available from the property. Table 3 shows the composition of andalusite-pyrophyllite-muscovite-bearing rocks compiled from Madeisky (1994). Unfortunately, these analyses are not supported by detailed petrographic or X-ray diffraction studies. The table indicates that these rocks are relatively rich in alumina, low in silica and that there are large variations in the concentrations of other major oxides. Typical properties of American and South Korean refractory and whiteware grade pyrophyllite are given in Table 4 for comparison. Most of the rocks from the Empress deposit appear to be high in Fe_2O_3, CaO, Na_2O and K_2O. Unfortunately, detailed sample and petrographic descriptions were not done, so it is not known if the high Fe_2O_3 content is due to the presence of sulphides and iron oxides or other sources. It is assumed that the relatively high CaO, Na_2O and K_2O contents are due to the presence of feldspar and mica. Although the andalusite-pyrophyllite bearing rocks from the Empress deposit do not meet current specifications for traditional North American refractory or ceramic applications, they may have industrial applications in domains with less stringent specifications. Two samples analysed by McMillan (1976) (Table 3) have similar compositions to andalusite-pyrophyllite products currently in the market place but are slightly high in TiO_2. Because pyrophyllite has a low unit value, $20.00 to $300.00 per tonne FOB depending on grade and degree of processing, it is important to consider transportation costs to markets.

Rare Earth Minerals

A rare reddish brown, rare earth element (REE) - bearing mineral, with brownish irradiation halos up to 0.5 centimetres in radius occurs within plagioclase-pyrophyllite-andalusite-bearing lithologies. Its distribution is erratic and it is present in trace amounts. This mineral was tentatively identified as bastnaesite ((Ca, La) CO_3F). A carbonate-phosphate-sulphide boulder, 30 by 30 by 25 centimetres was found by Westpine geologists near the corundum-bearing zone and probably contains rare earth elements. Furthermore, REE-bearing phosphate was described in concentrations of up to five percent with tennantite, energite, chalcopyrite and sphalerite in two main veins at the nearby Taylor-Windfall gold deposit (Price, 1986). These occurrences indicate that the area may have some exploration potential for REE's.

SUMMARY

The copper, gold and molybdenum potential of the Empress deposit was discussed by Osborne and Allen (1995). The non-metallic mineral potential of this deposit remains to be established. Corundum crystals from the Empress deposit are typically dark blue, subhedral to euhedral and a fraction of a millimetre to one centimetre in cross section. Some transparent, colourless crystals were found in overlying sediments. Coarse crystals contain numerous inclusions of pyrophyllite, but parts of them, up to several millimetres in size, are fracture and inclusion-free. The potential of this deposit as a source of corundum depends on the proportion and quality of coarse corundum crystals, their abundance and distribution either in residual soils, placers or primary host rock. Andalusite-pyrophyllite rocks may have industrial applications if produced as a by-product of metal mining, although the cost of transportation to markets may be prohibitive. Andalusite crystals within the Empress deposit area are too fine grained to be economically upgraded to compete with South African and French concentrates currently on the market. The area might also have Rare Earth element exploration potential.

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