

Geological Survey of Canada

RHENIUM AND OTHER PLATINUM-GROUP METALS IN PORPHYRY DEPOSITS

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Introduction

and other petroleum products. Rhenium is also used in tungsten-rhenium and molybdenum-rhenium alloys, which have a diversity of applications such as electrical contacts, flashbulbs, heating elements, thermocouples, vacuum tubes and x-ray tubes and targets. In recent years, the demand for rhenium has increased, in part due to supply disruptions, and prices have risen as high as US\$10,000 per kg. It is currently the sixth most expensive traded metal (Table 1).

	Table 1. The ten mos	st expensive traded meta	ıls (19 March 2009)
$\overline{}$	Flomont	Price in \$/ka	Price in \$/07

No.	Element	Price in \$/kg	Price in \$/oz
1	Rhodium	35,365	1,100
2	Platinum	35,043	1090
3	Gold	30,540	950
4	Iridium	12,380	385
5	Osmium	12,217	380
6	Rhenium	7,500	233
7	Ruthenium	6,400	199
8	Palladium	2,570	80
9	Germanium	920	29
10	Hafnium	800	25

Source: Lipmann Walton & Co. Ltd. (www.lipmann.co.uk)

Industrial Sources of Rhenium

abundance in most rocks is measured in parts per billion or less and minerals in which rhenium is a major constituent are rare. Rhenium is concentrated by magmatic-hydrothermal processes and in one notable and apparently unique occurrence at Kudriavy volcano in the Kuril arc, rhenium is actively deposited as (Tessalina et al., 2008). Rhenium is similar geochemically to molybdenum and is levels in excess of 4% Re (e.g., Melfos et al., 2001). Molybdenites with the highest concentrations of rhenium are typically associated with copper-rich deposits, particularly porphyry copper deposits (e.g., Berzina et al., 2005), and these deposits are the primary industrial source of rhenium. Rhenium can also be transported by low-temperature hydrothermal and diagenetic processes and concentrated in anoxic sediments such as highly carbonaceous black shales. Dzhezkazgan in Kazakhstan and in the Kupferschiefer of Poland and Germany ranges from 1 to 21 ppm and these deposits are currently the second most important source of rhenium. Rhenium is also recovered as a byproduct from in situ leaching of sandstone-hosted uranium deposits in Uzbekistan

Rhenium is one of the most widely dispersed elements in the earth's crust. Its

Samples and Analytical Methods

Samples for this study were collected from active mines as well as from mineral deposits and occurrences. From active mines, mill concentrates of molybdenite were obtained whenever possible. For other deposits and occurrences, molybdenite concentrates were produced from representative hand samples, including drill core, by hand picking coarse grains or by bench-scale floatation concentration. In the case of deposits for which molybdenite concentrates could not be obtained, typical ore samples or heavy mineral concentrates obtained by panning were analyzed. Samples were analyzed for Re and Mo, and in many cases Au and other elements, by neutron activation. The reliability of neutron activation analysis for Re and Mo in particular has been affirmed by several different laboratories yielding results within ±10% on selected reference samples. All the analyses, representing more than 180 Canadian and some foreign localities, will be included in a GSC open file report to be released in 2009 (Jonasson et al., in prep.). The results for BC and Yukon porphyry deposits are summarized here in Table 2

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Table 2. Re and Au contents of molybdenites from BC and Yukon porphyry deposits

		Re	ppm			Διι	ppm							
Deposit		Ave	Min	Max		Ave	Min	Max	Size (Mt)*	Cu%	Mo%	Au g/t	Re g/t**	Cu/Mo
Porphyry Cu and Cu-Mo de Bethlehem-Huestis	posits	in the Hi	ghland V	alley dist	rict	0.27			1.4	0.4	0.005	0.010	0.035	80
	1				4	0.37			1.4		0.005	0.012		
Bethlehem-Iona Bethlehem-JA ¹	1	1015	200	0.40	1	1.12			29.5	0.52	0.006	0.012	0.102	87
	4	222	200	246		0.5			260	0.43	0.017	0.01	0.063	25
Highmont - East Pit	1	530			1	0.5			123	0.25	0.024	0.004	0.212	10.4
Highmont - West Pit	2	157	137	176	2	0.6	0.2	0.9	15	0.15	0.05	0.004	0.131	3
Lornex	1	345			1	0.4	0.1	1.1	460	0.404	0.014	0.006	0.081	29
Valley	1	294			1	1.5			791	0.44	0.0067	0.006	0.033	66
Porphyry Cu deposits														
Catface	1	59			1	0.3			308	0.37	0.0072		0.007	51
Gibraltar	4	443	238	750	2	2.7	0.5	4.84	935	0.29	0.006		0.044	48
Granisle	4	526	522	528	4	8.0	0.6	1	171.2	0.43	0.005	0.13	0.044	86
Huckleberry	2	253	247	258	2	0.4	0.37	0.5	73.4	0.49	0.014	0.04	0.059	35
Island Copper	2	1784	1704	1863	2	1.5	1.0	1.9	600	0.338	0.0088	0.19	0.262	38
Mount Washington	2	1066	608	1524	2	0.7	0.3	1.1	0.389	1.07				
OK	1	746			1	1.9	0.0		64	0.34	0.016		0.199	21
	·	7-10			'	1.0				0.01	0.010		0.100	2.
Porphyry Cu-Mo deposits														
Berg	4	152	67	215	4	1	0.5	1.8	238	0.39	0.031	0.06	0.079	12.6
Brenda	12	115	95	145	12	2.4	0.8	8.5	181.7	0.152	0.037	0.013	0.071	4.1
Cash ²	2	92	54	129					36	0.28	0.021		0.032	13.3
Casino ²	4	197	65	289					559	0.25	0.025		0.082	10
Maggie	1	643			1	0.88			181.4	0.28	0.029		0.311	9.7
Old Fort	1	159			1	16				0.21	0.024		0.064	8.8
Schaft Creek ³	1	590							1393	0.25	0.019	0.18	0.187	13.2
Susap	1	130			1	0.5			1.5	0.155	0.045		0.098	3.4
Whiting Creek	4	92	13	172	4	0.4	0	0.96	123.5	0.062	0.025		0.038	2.5
Porphyry Cu-Au deposits														
Ajax West	1	3161			1	6			365	0.31	0.005	0.2	0.263	62
Bronson Slope	1	180			1	7.48			79	0.31	0.005	0.44	0.203	28
Ingerbelle	1	1620			1	25			78.2	0.17	0.000	0.44	0.018	165
Kemess South ⁴	2	3858	3106	4609	'	25			213	0.329	0.002	0.17	0.514	28
					2	42.4	10.0	15.4	l					
Mitchell (Sulphurets)	2	7590	7012	8170	2	13.1	10.9	15.4	734	0.18	0.005	0.69	0.633	36
Taseko (Empress)	1	154			1	0.1			10	0.61		0.79		
Porphyry Mo deposits														
Adanac	4	12	8	22	4	0.4	0.19	0.54	143.7	0.001	0.059		0.012	0.02
Anticlimax (Crazy Fox)	4	54	9	96	3	0.4	0.07	1.02						
Boss Mountain	7	80	49	157	4	0.3	0.11	0.68	63		0.074		0.099	
Carmi	3	58	10	139	3	1.9	0.71	4.09	20.7		0.064		0.062	
Cassiar Moly	2	9	3	14	1	0.7			12.2		0.026		0.004	
Endako 1	12	35	15	67	12	0.44	0.11	1.75	600	0.002	0.07		0.041	0.03
Endako 2	3	302	204	397	3	0.15	0.1	0.23		0.002	0.07		0.352	0.03
Glacier Gulch (Davidson)	2	38	34	41	2	0.3	0.2	0.4	75.3	0.04	0.177		0.112	0.23
Kitsault	2	80	57	102	1	1.34			104	0.004	0.115		0.153	0.03
Lucky Ship	1	41			1	1.16			61.5		0.067		0.046	
Mount Haskin	1	108			1	0.2			12.247		0.09		0.162	
Nithi Mountain	1	120			1	3			12.217		0.00		0.102	
Red Bird	2	25	6	43	1	0.37			75.3	0.07	0.065		0.027	1.08
Red Mountain (Yukon)	1	32	U	40	'	0.37			187	0.07	0.003		0.027	1.00
,	1				4	0.40			10/					
Roundy Creek	7	59	4.5	00	1	0.12			100 5		0.065		0.064	
Storie Moly	3	20	15	22	1	2.2			100.5		0.078		0.026	
Tidewater	2	61	13	109	1	0.15			9.07		0.06		0.061	
Trout Lake (Max)	2	65	56	73	1	<0.2			42.9		0.12		0.130	
Porphyry W-Mo deposits														
Logtung	1	22			1	0.6			163		0.031		0.011	
		_			_		_		_	_				

*Geological resource, including production plus measured, indicated and/or inferred reserve **Minimum rhenium grade assuming that rhenium is contained primarily in molybdenite

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Rhenium in Molybdenite from Porphyry Deposits

ranging up to 8170 ppm Re (Mitchell) and 3858 ppm Re (Kemess South), but including relatively low values such as 180 ppm Re (Bronson Slope) and 154 deposits are also high, ranging up to 1500 ppm at Oyu Tolgoi in Mongolia and 2070 ppm Re in the Pebble West deposit in Alaska.

Porphyry Cu deposits

Molybdenites from porphyry Cu deposits have Re contents that range from 59 ppm (Catface) to more than 1500 ppm Re at Mount Washington and as high as the Re contents of molybdenites can be much higher, ranging to nearly 3500 ppm at Cerro Verde (Peru) and to more than 4000 ppm at Kounrad (Kazakhstan) and Morenci (Arizona).

porphyry Cu and Cu-Au deposits. In BC and Yukon deposits, the range from is from 13 ppm Re (Whiting Creek) to 590 ppm Re in the Schaft Creek deposit. deposits range from 3 ppm Re (Dexing, China) up to 2000 ppm at Bingham (Utah). Molybdenites from some porphyry-type occurrences in northern Greece molybdenites that range from 7260 ppm to 42,100 ppm (Melfos et al., These are the highest recorded contents of Re in molybdenite and are atypical

significant deposits have a more limited range of 9 ppm Re (Cassiar Moly) to 108 Endako samples that contained 204 to 397 ppm Re. These appear to represent a including a run-of-the-mill concentrate, that ranged from 15 to 67 ppm Re and are similar, ranging from 6 ppm Re (Sorskoie, Russia) to 182 ppm Re (Mount Tolmin, Washington). There appears to be no significant difference in the Re Henderson, which average 35 and 14 ppm respectively, compared to fluorinepoor deposits such as Endako (35 ppm Re), although molybdenite in one sample from the Quartz Hill deposit in Alaska contained 149 ppm Re. Mount Tolmin, with the highest Re-in-molybdenite content (182 ppm), also contains appreciable

porphyry Cu deposits.

Molybdenites from porphyry W-Mo deposits have low Re contents similar to Re-in-molybdenite content is 22 ppm. In other Canadian deposits, the range is from 6 ppm Re (Sisson Brook, New Brunswick) to 190 ppm Re (Lake George, New Brunswick). Rhenium content in molybdenites from foreign porphyry W-Mo

Variation in Re and Au Contents of Molybdenite

grade of the deposit decreases. The plot of Re content in molybdenite versus Cu/Mo content of Mo (%) the deposits (Fig. 2) shows a positive correlation of about the same magnitude. These plots show that the Re content of molybdenite is highest in copper-rich porphyry deposits that have lowest contents of molybdenum.

In addition to concentrating Re, molybdenite in porphyry deposits also concentrates Au to a degree that reflects the gold content of the deposit. Figure 3 shows that molybdenites from porphyry Mo and W-Mo deposits, which have low contents of Re, generally have low Au contents of less than 1 ppm Au, although they range up to 4 ppm Au have Au contents that range from 1.9 ppm (Island Copper) to as high as 25 ppm (Ingerbelle)

grade in associated deposits. Molybdenites with the highest Re contents are associated with porphyry Cu-Au deposits (e.g., Mitchell) and Auwhereas porphyry Cu and Cu-Mo deposits that have lower Re-in-molybdenite contents also tend to have the lower Au contents. Porphyry Mo and W-Mo deposits, which have the lowest Re-inmolybdenite contents, contain negligible Au.

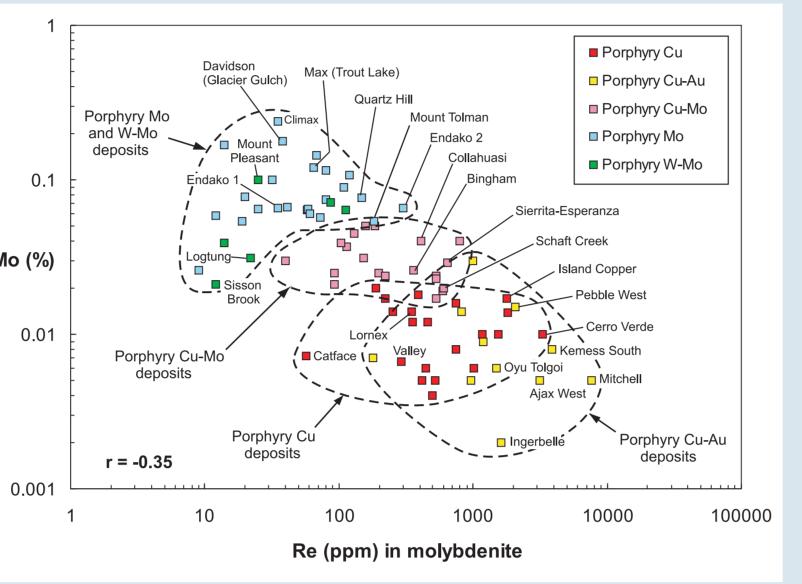


Figure 1. Re content of molybdenite versus Mo grade of porphyry deposits

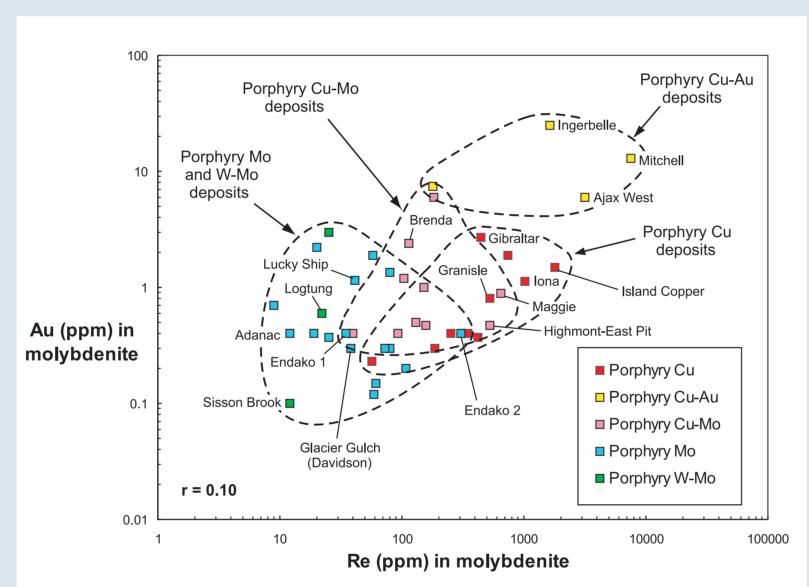


Figure 3. Re content of molybdenite versus Au content of molybdenite in

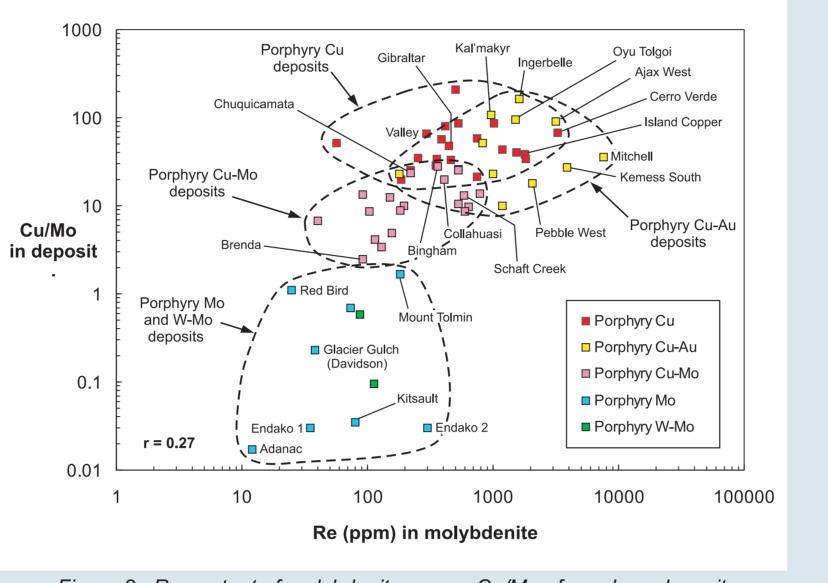


Figure 2. Re content of molybdenite versus Cu/Mo of porphyry deposits.

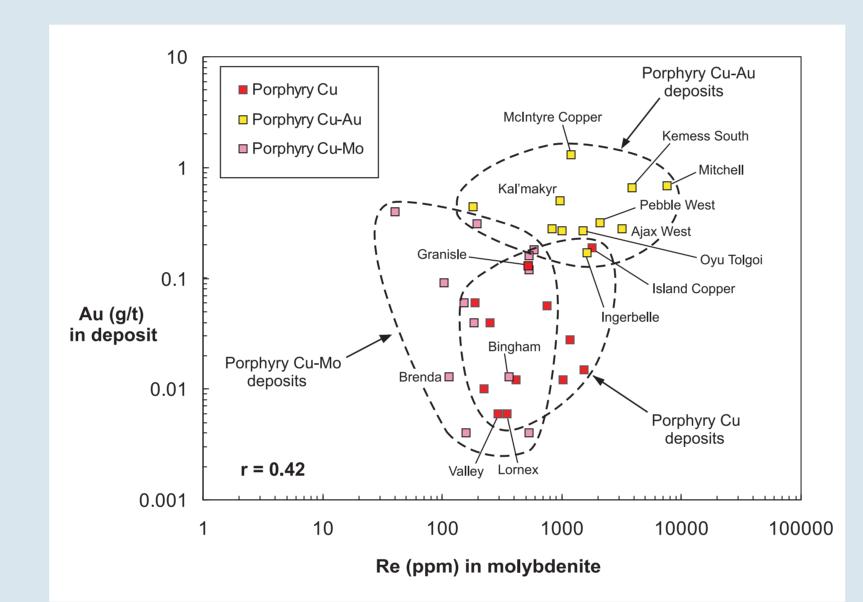


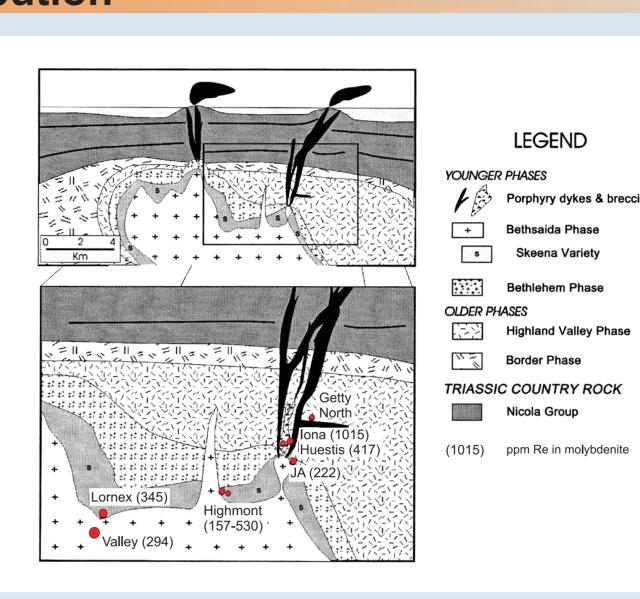
Figure 4. Re content of molybdenite versus Au grade of porphyry deposits.

Spatial and Temporal Variations in Re Distribution

Temporal variations in Re distribution may also present. For example, in the Kitsault porphyry Mo deposit, molybdenites from four successive mineralization stages increased in Re content from 36 to 129 ppm (Giles and Schilling, 1972). At the Endako porphyry Mo deposit, Selby and Creaser (2001) recognized two periods of molybdenum mineralization, the first characterized by a Re content of 20.0 ppm, and the second by molybdenites containing 6.5 to 38.4 ppm Re. mineralization at Endako and are similar in Re content to the majority of our samples from Endako that averaged 35 ppm Re (Endako 1 in Table 2). Three molybdenite samples with substantially higher Re contents (Endako 2: 204 to 397 ppm) suggest that a third stage of mineralization may be present.

Highland Valley district, British Columbia

consisting of roughly concentric phases that are progressively younger from the lower Cu/Mo values and their molybdenites generally have lower Re contents in border of the batholith inward (Fig. 7). Mineralization episodes in the batholith the range from 157 ppm to 530 ppm Re. were associated mainly with the two youngest phases (McMillan, 2005). The first produced the Iona and Huestis deposits (as well as others such as Jersey, Krain reflects crystallization and degassing history of the batholith. The earliest-formed was associated with emplacement of the Bethsaida phase and resulted in the district (1015 ppm Re in the Iona molybdenite). In contrast, deposits related to Highmont, Lornex, Valley and JA deposits. According to McMillan (2005), the the Bethsaida phase exhibit lower Re-in-molybdenite values that decrease with formation as schematically illustrated in Figure 7. The Iona and Huestis deposits Re). We attribute this trend to increasing depletion of Re in the Bethsaida are associated with subvolcanic breccias and porphyry dike swarms and appear magma as the magma crystallized and degassed and produced the associated to have formed in the shallowest and coolest settings. The Highmont deposit, deposits. Content of both Mo and Re are depleted relative to Cu in the deposits, which is associated with a large porphyry dike and minor breccia, and the Lornex but the increasingly lower content of Re in molybdenite indicates that Re became and Valley deposits, which have few associated dikes and no associated breccia, depleted at a greater rate than Mo. Consequently, molybdenite in the Valley formed in progressively deeper and hotter settings. The setting of the JA deposit, which formed at the deepest level and latest in the crystallization history deposit, which is associated with an aplitic stock that intruded near the contact of has a relatively low Re content (294 ppm), despite the fact that the deposit has a the Bethlehem and Guichon phases, is ambiguous but considered to be slightly relatively high Cu/Mo value (74.6). deeper than that of the Highmont deposit (McMillan, 2005).



McMillan, 2005).

Rhenium contents of molybdenites from Highland Valley deposits range from 157 to 1015 ppm Re, typical of most porphyry Cu and Cu-Mo deposits (Table 2), and appear to fall into two groups. Deposits related to the Bethlehem phase have the molybdenite content (Fig. 7). Deposits related to the Bethsaida phase have

Grade-Tonnage Characteristics of Re in Porphyry Deposits

the Re in a deposit is taken up by molybdenite, the less molybdenite in a (~35 ppm Re). deposit, the higher its Re content, and vice versa.

appreciable differences exist between the overall Re contents of Mo- approximately 27 t was recovered. Large porphyry Mo deposits contain comparable Endako deposit prior to mining was on the order of 25 t Re, although no production deposits are due primarily to simple mass balance phenomena; because all Re from Endako has been reported, likely due to the low content of Re in molvbdenite

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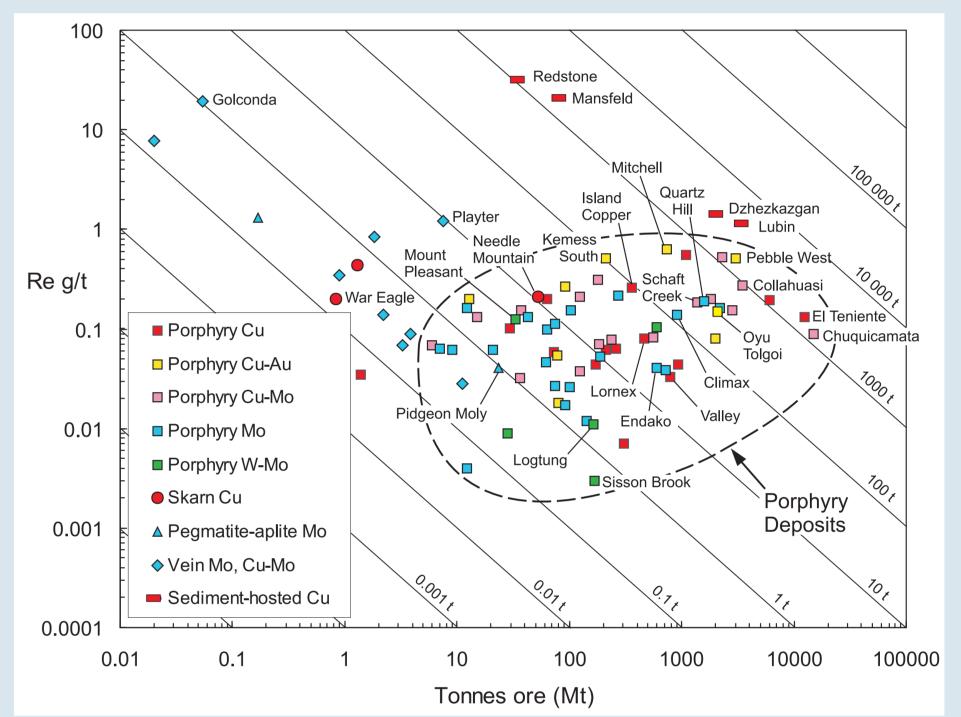


Figure 8. Re grade versus tonnage for Canadian and selected foreign deposits. Diagonal lines

rhenium content of other sulfides is typically on the order of parts per billion or less. Rhenium grades calculated for BC-Yukon porph deposits are included in Table 2 and rhenium grades versus tonnages these and other Canadian deposits, and selected foreign deposits, are

References

Variation in Re and Platinum-Group Metal Contents of Porphyry Deposits

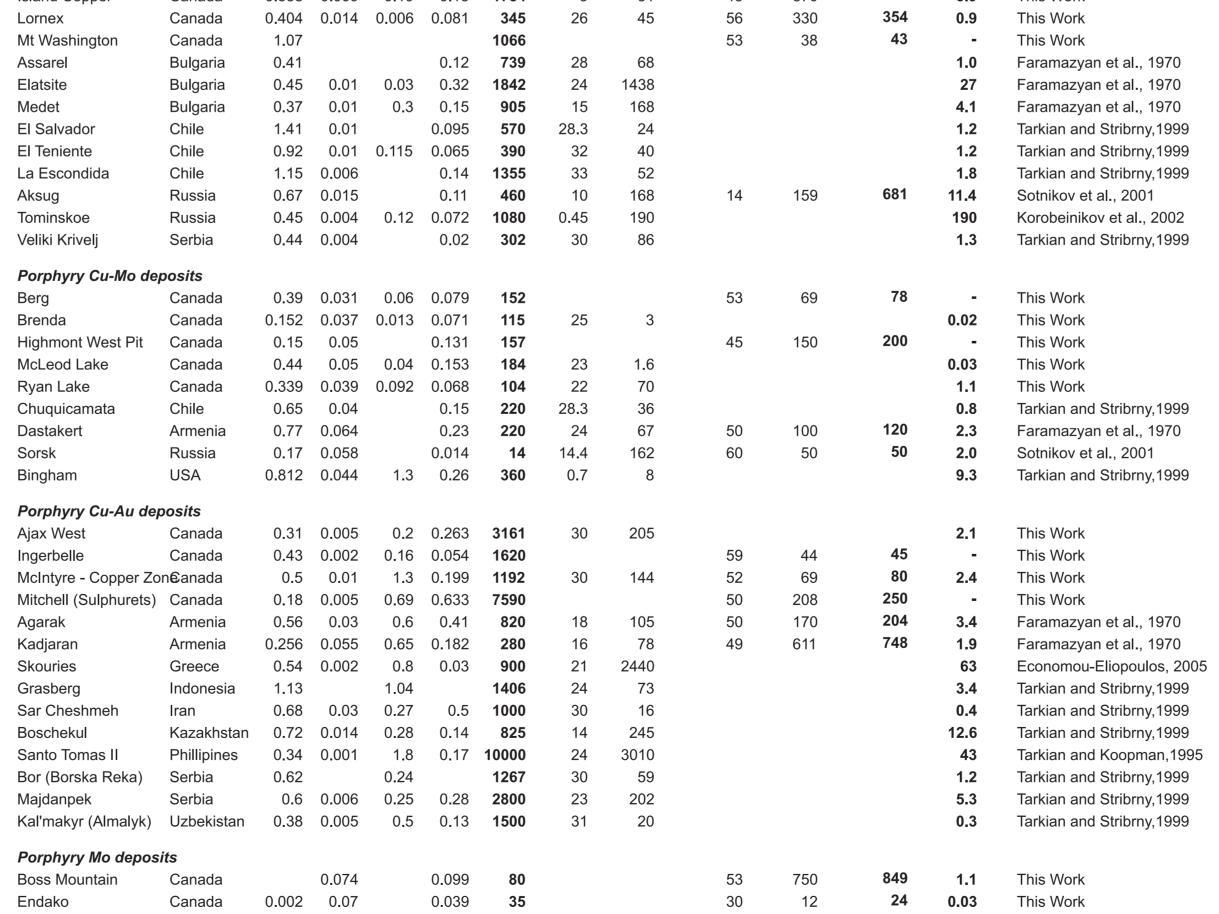
Rhenium and the platinum-group elements have many properties in common, in particular a strong affinity for metallic or sulphide phases, and they are grouped together with gold as the highly siderophile elements (Brenan, 2008). It should not be surprising, therefore, that porphyry deposits with high contents of rhenium might also be enriched in platinum-group metals.

Analyses of Pt and Pd in molybdenite and in copper concentrates from Canadian deposits are presented in Table 3, along with comparable analyses from foreign deposits reported in the literature. These data have been used to calculate minimum Pt and Pd contents in ore. Variations between Re and Pt+Pd in molybdenite and between Re in molybdenite and Pt+Pd in ore are shown in Figures 5 and 6

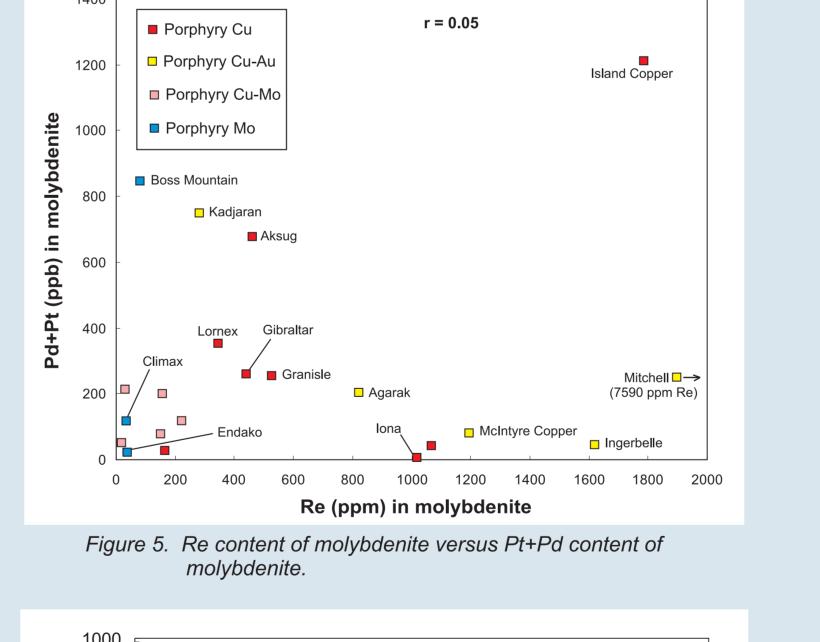
Figure 5 shows that molybdenites from porphyry deposits can concentrate platinum-group metals, with Pt+Pd content ranging as high as 1214 ppb (Island Copper). However, no obvious correlation exists between Re content and Pt+Pd content (r=0.05). Molybdenites from most porphyry Mo and Cu-Mo deposits have Pt+Pd contents that range from 24 to 200 ppb, except for molybdenite from the Boss Mountain porphyry Mo deposit, which contains 849 ppb Pt+Pd. Molybdenites from porphyry Cu and Cu-Au deposits have Pt+Pd contents similar to those from porphyry Mo and Cu-Mo deposits, with the exception of molybdenite from Island Copper (1214 ppb), Kadjaran (748 ppb) and Aksug (681).

Much better correlation exists between Re content of molybdenite and overall Pt+Pd grade of the deposit (r=0.20). Figure 6 shows that porphyry Mo and Cu-Mo deposits have lower Pt+Pd contents ranging from 0.03 ppb (Endako) to 2.3 ppb (Dastakert), whereas porphyry Cu and Cu-Au deposits have Pt+Pd contents that range from 0.03 ppb (Don Rouyn) to as high as 190 ppb (Tominskoe) Figures 5 and 6 reflect the fact that platinum-group metals are sequestered primarily in copper sulphides, rather than is molybdenite. However, they also demonstrate that platinum-group metals, like Au, are concentrated in porphyry deposits along with Re and that high contents of Re in molybdenite can be an indicator of high levels of platinum-group metals.

Table 3. Pt and Pd contents of molybdenite and Cu concentrates from Canadian and foreign porphyry deposits Deposit Country Cu% Mo% Au g/t Re g/t Re-moly Cu concentrate Mo concentrate Pd+Pt in Pd+Pt in Reference for PGE Data ppm % Cu Pd+Pt ppb % Mo Pd+Pt ppb moly ppb* ore ppb **0.6** This Work 54 6 **7 -** This Work **1.0** Faramazyan et al., 1970 **27** Faramazyan et al., 1970 **4.1** Faramazyan et al., 1970 **1.2** Tarkian and Stribrny, 1999 **1.2** Tarkian and Stribrny, 1999 **1.8** Tarkian and Stribrny, 1999 0.67 0.015 0.11 **460** 10 168 14 159 **681 11.4** Sotnikov et al., 2001



*Pt+Pd content of molybdenite concentrate normalized to 60% Mo (stoichiometric Mo content of molybdenite



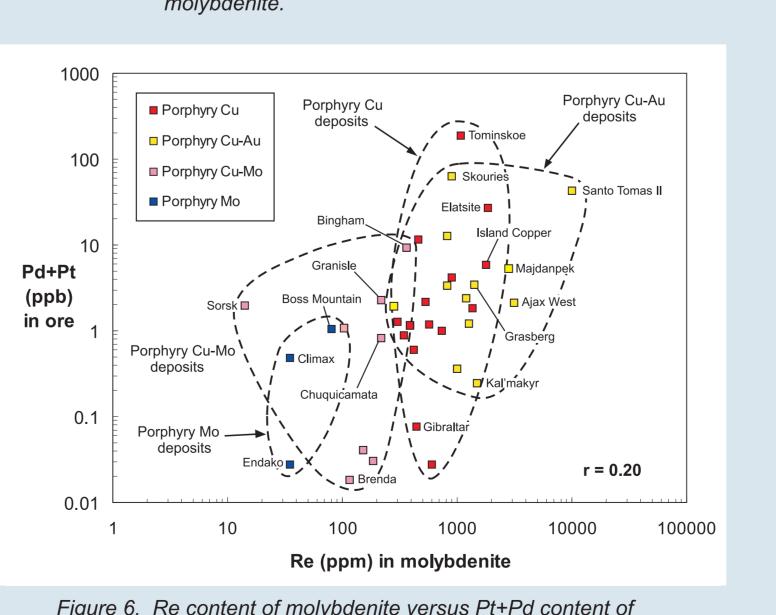


Figure 6. Re content of molybdenite versus Pt+Pd content of

Rhenium in Other Types of Deposits

Sediment-hosted copper deposits are the second most important source of rhenium after porphyry deposits. The rhenium content of deposits such as Dzhezkazkan (Kazakhstan) and in the Kupferschiefer of Poland and Germany ranges from 1 to 21 ppm Re. The Re appears to be concentrated in sulphide- and organic-rich sections that also carry elevated levels of platinum group metals. Our analyses of samples from Redstone (NWT) and other sediment-hosted copper deposits and occurrences in Canada indicate that comparable levels of Re are present and suggest that Re should not be overlooked as a potential byproduct.

Other types of deposits Mo-bearing deposits that also contain rhenium include skarns, vein and pegmatite-aplite deposits. The Re content of molybdenite from skarn deposits ranges as high as 521 ppm Re in the War Eagle deposit in the Whitehorse Copper Belt and 759 ppm Re in the Little Billie deposit on Texada Island. Molvbdenite from the Needle Mountain skarn Cu deposit of Gaspé Copper contains 353 to 371 ppm

Rhenium content of molybdenites from vein deposits is generally less than 300 ppm Re. Two notable exceptions are the Golconda Cu-Mo vein in British Columbia, which has Re contents in molybdenite that range from 1095 to 1335 ppm Re, and the Playter Mo vein in Ontario, which has molybdenite containing 200 to more than 900 ppm Re.

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