

W. David Sinclair and Ian R. Jonasson, 2014. Highly Siderophile Elements (Re, Au and PGE) in Porphyry Deposits and Their Mantle Origins. *Acta Geologica Sinica* (English Edition), 88(supp. 2): 616-618.

Highly Siderophile Elements (Re, Au and PGE) in Porphyry Deposits and Their Mantle Origins

W. David Sinclair¹ and Ian R. Jonasson¹

¹ Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, Canada K1A 0E8

1 Introduction

Re, Au and platinum-group elements (PGE) have many properties in common, in particular a strong affinity for metallic or sulphide phases, and in this regard they are commonly referred to as highly siderophile elements (HSE). During metal-silicate segregation these elements will be almost entirely stripped from the silicate portion of a melt and partitioned into metallic, sulfide-rich segregations. Such segregations, represented by base metal sulfides in upper mantle rocks, contain substantial concentrations of Re, Au and PGE, along with Cu and other metals, and are a potential source of these metals in Au-rich porphyry deposits.

2 Re, Au and PGE in Porphyry Deposits

Au grades are well documented for porphyry deposits but grades for Re and PGE are not. In the case of Re, for many deposits data is available on the Re contents of molybdenite, which range from 10s to 1000s of ppm, and Re grades can be calculated from Mo grades assuming that all Re is contained in molybdenite (e.g., Sinclair et al., 2009). This is reasonable considering that the Re content of other sulfides is typically on the order of ppb or less.

PGE in porphyry deposits consist mainly of Pd with lesser amounts of Pt. Analyses of Pd and Pt in ore as well as in Cu and Mo concentrates have been used to calculate minimum Pd and Pt grades in ore (e.g., Sinclair et al., 2009). Calculated grades for Re and Pd+Pt are shown plotted against Au grades in Figures 1 and 2.

There is good correlation between Re, Au and Pd+Pt in porphyry deposits to the extent that deposits rich in Au tend to have higher contents of both Re and Pd+Pt than Au-poor deposits. Porphyry Cu-Au deposits, with Au contents of 0.2 g/t or more, have Re contents mainly in the range of 0.05-0.5 g/t (Fig. 1), and averaging about 0.3 g/t.

Porphyry Mo deposits, which grade no more than 0.01 g/t Au, contain an average of 0.07 g/t Re.

Pd+Pt contents in porphyry Cu-Au and more Au-rich porphyry Cu deposits range from 1 to 125 ppb (Fig. 2); the average is 20 ppb. In Au-poor porphyry deposits, Pd+Pt contents vary from <0.02 to as high as 5 ppb, averaging about 1 ppb (including deposits lacking reported Au that are not shown on Fig. 2). Pd to Pt ratios are typically >1 and range as high as 41. Iridium-group PGE (IPGE: Ir, Os, Ru and Rh) do not appear to occur in significant amounts in porphyry deposits. In many cases, IPGE occur at levels that are below analytical detection and are rarely reported.

3 Re, Au and PGE in Mantle Sulfides

Sulfides are the major repository for Re, Au and PGE in the mantle. Although Fe-Ni-Cu sulfides occupy only about

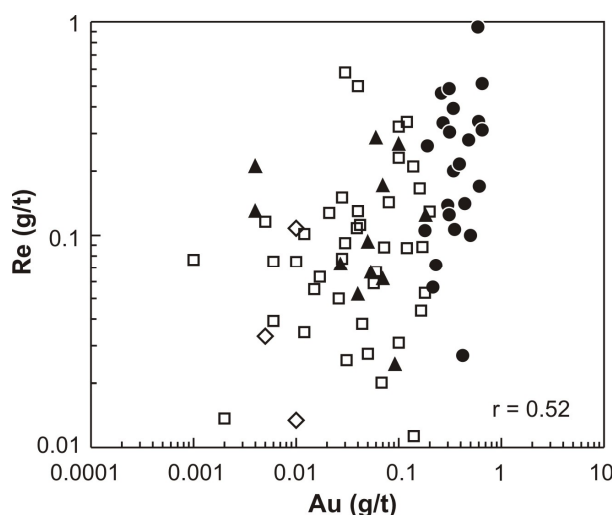


Fig. 1. Re versus Au grades in porphyry deposits. Re data are from Sinclair et al. (2009, and in prep.); Au data are from Singer et al. (2008) and mining company technical reports posted on SEDAR (<http://www.sedar.com/>). See Fig. 2 for symbol legend.

* Corresponding author. E-mail: sinclair@nrcan.gc.ca

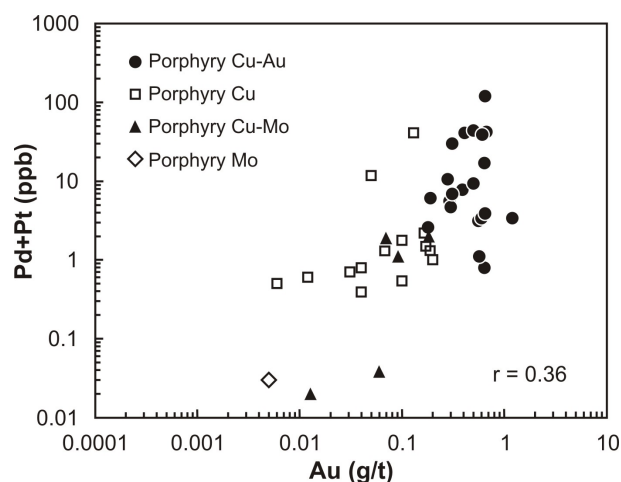


Fig. 2. Pd+Pt contents versus Au grades in porphyry deposits. Pd and Pt data are from Tarkian and Stribny (1999), Thompson et al. (2001), Economou-Eliopoulos (2005) and Sinclair et al. (2009); Au data as in Fig. 1.

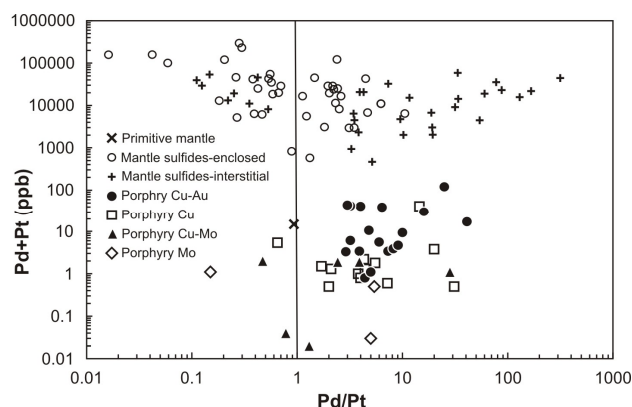


Fig. 3. Pd+Pt vs Pd/Pt. Primitive mantle data from Fischer-Gödde et al. (2011); mantle sulfide data from Alard et al. (2000), Griffin et al. (2002), Lorand and Alard (2001) and Wang et al. (2009); porphyry deposit data from Tarkian and Stribny (1999), Thompson et al. (2001), Economou-Eliopoulos (2005) and Sinclair et al. (2009).

0.1 vol % of upper mantle rocks, they contain more than 90% of the PGE (Alard et al., 2000) along with a substantial portion of the Re and Au. Primitive mantle composition has been estimated to average 14.7 ppb Pd+Pt, 0.35 ppb Re and 1.7 ppb Au (Fischer-Gödde et al., 2011). Pd+Pt contents of mantle sulfides are greater by two to four orders of magnitude and range from 500 ppb to nearly 300 ppm (Fig. 3). Re contents range from 20 ppb to 11.3 ppm and Au contents vary from 30 ppb to as much as 300 ppm.

Mantle sulfides form two distinct populations with contrasting mineralogical and geochemical characteristics

(Alard et al., 2000). One consists of spherical Fe-Ni monosulfide solid solution (mss) inclusions in olivine ("enclosed" mantle sulfides on Fig. 3). They tend to be rich in IPGE and depleted in Pd relative to Pt ($\text{Pd/Pt} < 1$). The second population consists of irregular-shaped, intergranular ("interstitial") Cu sulfide (chalcopyrite-isocubanite) and Ni sulfide (pentlandite) grains that are Pd-rich ($\text{Pd/Pt} > 1$) and relatively depleted in IPGE. Although PGE contents are much lower in porphyry deposits, these characteristics are similar, particularly for Au-rich porphyry deposits (Fig. 3).

4 Discussion

Cu- and Ni-rich mantle sulfides are crystallization products of a Cu-Ni-rich sulfide melt that coexisted with mss. During partial melting in the upper mantle, mss globules remain trapped within restitic rocks because of their tendency to adhere to silicates. In contrast, the Cu-Ni sulfide droplets, which are also rich in Pd, Pt, Re and Au, are entrained in mantle-derived magmas that can ascend to higher levels in the crust. If these hot mafic melts are injected into colder felsic porphyry-related magma, they can trigger vigorous convection and vesiculation, generating supercritical fluids that de-stabilize the sulfides in the mafic magmas and result in bulk transfer of metals and sulfur into hydrothermal ore-forming fluids. These fluids are the most likely source of Pd, Pt, Re and Au, and also much of the Cu and sulfur, in Au-rich porphyry deposits.

References

- Alard, O., Griffin, W.L., Lorand, J.-P., Jackson, S.E. and O'Reilly, S.Y., 2000. Non-chondritic distribution of the highly siderophile elements in mantle sulfides. *Nature*, 407: 891-894.
- Economou-Eliopoulos, M., 2005. PGE potential of porphyry deposits, In: Mungall, J.E. (ed), *Exploration for Deposits of Platinum-Group Elements. Mineralogical Association of Canada, Short Course Series*, 35: 203-246.
- Fischer-Gödde, M., Becker, H. and Wombacher, F., 2011. Rhodium, gold and other highly siderophile elements in orogenic peridotites and peridotite xenoliths. *Chemical Geology*, 280: 365-383.
- Griffin, W.L., Spetsius, Z.V., Pearson, N.J. and O'Reilly, S.Y., 2002. In situ Re-Os analysis of sulfide inclusions in kimberlitic olivine: New constraints on depletion events in the Siberian lithospheric mantle. *Geochemistry, Geophysics, Geosystems* 3: 1069, <http://doi.org/10.1029/2001GC000287>.
- Lorand, J.-P. and Alard, O., 2001. Platinum-group element abundances in the upper mantle: new constraints from in situ and whole-rock analyses of Massif Central xenoliths (France). *Geochimica et Cosmochimica Acta* 65: 2789-2806.
- Sinclair, W.D., Jonasson, I.R., Kirkham, R.V. and Soregaroli, A.E., 2009. Rhenium and other platinum-group metals in porphyry deposits. *Geological Survey of Canada, Open File* 6181: 1 sheet.

- Sinclair, W.D., Jonasson, I.R., Kirkham, R.V. and Soregaroli, A.E., in prep. Rhenium in Canadian mineral deposits. *Geological Survey of Canada, Open File*.
- Singer, D.A., Berger, V.I. and Moring, B.C., 2008. Porphyry copper deposits of the world: database and grade and tonnage models, 2008. *United States Geological Survey, Open-File Report*, 2008-1155.
- Tarkian, M. and Stribny, B., 1999. Platinum-group elements in porphyry copper deposits: a reconnaissance study. *Mineralogy and Petrology*, 65: 161-183.
- Thompson, J.F.H., Lang, J.R. and Stanley, C.R., 2001. Platinum-group elements in alkaline porphyry deposits, British Columbia. *Exploration and Mining in British Columbia, Mines Branch*, Part B: 57-64.
- Wang, K.L., O'Reilly, S.Y., Griffin, W.L., Pearson, N.J. and Zhang, M., 2009. Sulfides in mantle peridotites from Penghu Islands, Taiwan: melt percolation, PGE fractionation, and the lithospheric evolution of the South China block. *Geochimica et Cosmochimica Acta*, 73: 4531-4557.