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Oxidation condition and metal fertility of granitic magmas: evidence from zircon trace-element data from porphyry Cu deposits in the Central Asian orogenic belt

Ping Shen*, Keiko Hattori, Hongdi Pan

*Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, China, Email: pshen@mail.iggcas.ac.cn

Porphyry copper deposits are associated with oxidized felsic magmas. Such oxidized magmas are considered to supply metals and S to ore deposits. Ce is 4+ in oxidized conditions and readily incorporated into zircon, which produces positive Ce anomalies. Previous studies show that the Ce^{4+}/Ce^{3+} ratios in zircon can be used as a proxy for oxygen fugacity of magmas. The ratios successfully discriminate fertile igneous rocks from barren rocks. The Central Asian Orogenic Belt (CAOB) hosts a number of porphyry Cu deposits with significant range in size including large- and small-size deposits. The CAOB, therefore, presents an opportunity to evaluate the relationship between the oxidation condition and metal-fertility of granitic magmas.

We examined intrusions from the 13 ore-bearing intrusions in 9 porphyry Cu deposits (with 0.6 to 12 Mt Cu), including Bozshakol, Nurkazghan, Kounrad, Borly, Aktogai, and Koksai in Kazakhstan, Baogutu and Tuwu-Yandong in China, and Erdenet in Mongolia. The ore-bearing intrusions are granodiorite (Aktogai, Kounrad, Borly, Koksai, and Erdenet), diorite (Baogutu, Nurkazgan), and tonalite (Bozshakol, Tuwu-Yandong). As the concentrations of La and Pr in zircon are very low, commonly < 5 ppb, and close to detection limits, we calculated Ce^{4+}/Ce^{3+}following the method described by Ballard et al. (2002). In our calculation, Ce^{3+} was evaluated from the concentrations of Nd, Sm, Gd, Tb, Dy, Y, Ho, Er, Yb, Lu in zircon grains and bulk rocks. The results show that all zircon grains have high Ce^{4+}/Ce^{3+} ratios, ranging from 29 to 592. Large (>2-4 Mt Cu) deposits contain zircon grains with Ce^{4+}/Ce^{3+}ratios greater than 120, whereas, small (<1 Mt Cu) deposits contain zircon grains with Ce^{4+}/Ce^{3+}ratios lower than 100. The results indicate that Ce^{4+}/Ce^{3+} ratios increase with increasing Cu tonnage of deposits. The Ce^{4+}/Ce^{3+} ratios greater than 120 could be considered to be porphyries associated with large deposits in the CAOB. Zircon Eu/Eu* ratios generally increase from small to large deposits except for two intrusive rocks from the Erdenet and Tuwu-Yandong deposits. Low Eu/Eu* in zircon grains in the latter two deposits are explained by removal of Eu^{2+} by early plagioclase crystallization. Ratios of Ce^{4+}/Ce^{3+}in zircon are influenced by not only oxidation conditions of magmas but also the compositions of magmas. Granitoid intrusions have all similar mineralogy and similar ratios of Al/(Na+K), ranging from 1.40 to 2.80 (av.1.87 ± 0.37). Therefore, the values of Ce^{4+}/Ce^{3+} reflect fO_2 of the parental magmas. Higher Ce^{4+}/Ce^{3+} values from large deposits suggest that they crystallized from more oxidized magmas. There is a clear relationship between calculated $\log(f_{O2})$ values and the size of deposits, with NNO+2 values separating large porphyry deposits from small deposits. The data of zircon Ce^{4+}/Ce^{3+} ratios and associated oxygen fugacity values in magma from ore-bearing intrusions indicate that more oxidized magmas are associated with the formation of larger porphyry Cu deposits. The data of this study may be useful in regional exploration for porphyry Cu deposits.