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Oxidation Conditions of Granitic Magmas Associated With Porphyry Copper Deposits in the Central Asian Orogenic Belt

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1 Introduction

Porphyry copper deposits are associated with oxidized felsic magmas (Sillitoe, 2010). Such oxidized magmas are considered to supply metals and S to ore deposits (Hedenquist and Lowenstern, 1994; Hattori and Keith, 2001; Cooke et al., 2005). 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 (e.g., Trail et al., 2012). The ratios successfully discriminate fertile igneous rocks from barren rocks (Ballard et al. 2002; Liang et al., 2006; Qiu et al., 2013; Han et al., 2013). The Central Asian Orogenic Belt (CAOB) hosts porphyry-type deposits with significant range in size including large- and intermediate-size deposits (Figure 1). The CAOB, therefore, presents an opportunity to evaluate the relationship between the oxidation condition and metal-fertility of granitic magmas.

2 Samples and Analytical Method

We examined intrusions from the 8 porphyry copper deposits; Boshekul (1 in Fig 1), Nurkazghan (2), Kounrad (3), Borly (4), Aktogai (5), and Koksai (6) in Kazakhstan, Baogutu (7) and Tuwu-Yandong (8) in China (Fig. 1). The rocks are dioritic, granodioritic, and plagiogranitic rocks. We selected 14 intrusions from these deposits. Approximately 50- 100 zircon grains were separated and mounted in Epoxy resin from individual samples. After examination of all grains with cathodeluminescence SEM (CL-SEM), representative grains with no inclusions and no sector zoning were selected for trace element analysis with a laser ablation inductively coupled plasma mass spectrometer (LA-ICP-MS) at the Geological Survey of Canada (Jackson, 2008).

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.

3 Results and Discussion

All zircon grains show oscillatory zoning due to varying Th and U in CL-SEM images. They are magmatic in origin with high Th/U ratios (from 0.3 to 0.9). The ore-bearing porphyries from the large porphyry Cu deposits show variably high Ce^{4+}/Ce^{3+} ratios in zircon. Boshekul (>4.1 Mt Cu) yielded the values ranging from 65 to 422 (av. 239 ± 104 (1σ)), Kounrad (>4.8 Mt Cu) from 76 to 483 (av. 241 ± 153 (1σ)), and Aktogai (>12 Mt Cu) from 90 to 279 (av. 182 ± 76 (1σ)). In three intermediate-size deposits, the ore-bearing porphyries show intermediate to high Ce^{4+}/Ce^{3+} ratios; Nurkazghan (>1.7 Mt Cu) show the values ranging from 74 to 374 (av. 174 ± 106 (1σ)), Koksai (>1.6 Mt Cu) from 100 to 214 (av. 166 ± 47 (1σ)), and Tuwu-Yandong (~2.0 Mt Cu) from 71 to 344 (av. 188 ± 91 (1σ)). In two small deposits, the ore-bearing porphyries display a narrow range and low values of Ce^{4+}/Ce^{3+}; Borly (0.6 Mt Cu) range from 28 to 158 (av. 68 ± 52 (1σ)), and Baogutu (0.6 Mt Cu) from 29 to 113 (av. 56 ±

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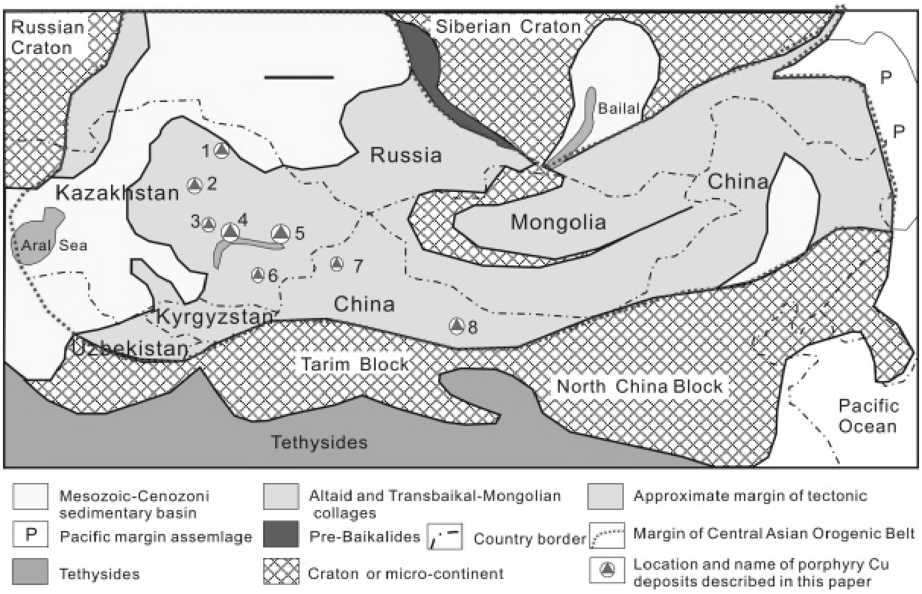

Fig. 1. Map showing the principal tectonic element of the Central Asian Oroganic Belt and the porphyry Cu deposits studied in the paper (modified after Xiao et al., 2010; Seltmann et al., 2013).
1=Boshekul; 2=Nurkazghan; 3= Kounrad; 4= Borly; 5= Aktogai; 6=Koksai; 7=Baogutu; 8= Tuwu-Yandong.

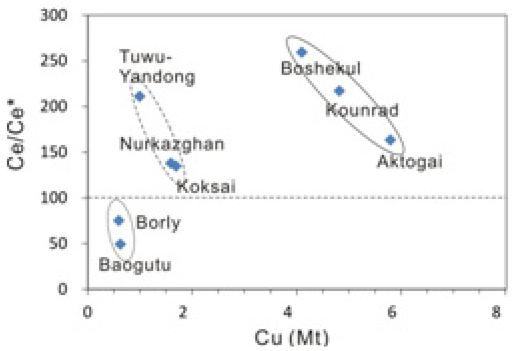

Fig. 2. Average zircon Ce^{4+}/Ce^{3+} ratios versus Cu reserves of porphyry Cu deposits in the CAOB.

35 (1σ)).

The results indicate that Ce^{4+}/Ce^{3+} ratios increase with increasing Cu tonnage of deposits (Figure 2). The Ce^{4+}/Ce^{3+} ratios greater than 120 could be considered to be porphyries associated with large and intermediate-size deposits in this belt.

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 (1σ)). 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. The information can potentially be used in exploration for porphyry Cu deposits in the CAOB.

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