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The genetic association of adakites and Cu–Au ore deposits': a reply

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Most of the world's Cu resources are hosted in the west coast of the North and South American continents along the eastern Pacific margin, with estimated total resources of over 1.8 billion tons, accounting for about 60% of the world's total Cu resource estimation (US Geological Survey Resource Estimation Team 2010). Among the world's top 25 giant porphyry Cu deposits, 20 are located there. In contrast, essentially no porphyry Cu deposits have been reported in Japan, whereas Grasberg is the only top 25 porphyry deposits along the western Pacific margin, with several smaller deposits mostly associated with the closure of back-arc basins (e.g. Cooke *et al*. 2005; Sun *et al*. 2010). The most remarkable difference is that the subducting oceanic crust in the east Pacific margin is much younger than in the west, and thus is more likely to be partially melted (Defant and Drummond 1990; Sun *et al*. 2010). Consistently, studies show that most of the porphyry Cu deposits are closely associated with adakites (Thieblemont *et al*. 1997; Sajona and Maury 1998; Oyarzun *et al*. 2001; Zhang *et al*. 2001; Ling *et al*. 2009; Sun *et al*. 2011), a special rock originally assigned to slab melting (Defant and Drummond 1990). As we discussed in detail in Sun *et al*. (2011), such slab melts have considerably higher initial Cu contents and also high oxygen fugacities, a combination promoting Cu porphyry mineralization.

It has been argued that simple fractionation of hornblende ± titanite for normal, hydrous arc magmas can form adakitic signatures, for example, high Sr/Y, La/Yb (Castillo *et al*. 1999; Richards and Kerrich 2007), and Cu deposits (Richards and Kerrich 2007). Fractionation, however, cannot explain the close association of adakite with Cu mineralization for two reasons. First, adakites are usually less fractionated than normal arc rocks; second, Cu is moderately incompatible in most rock-forming minerals, but is compatible in amphibole (GERM 2011), such that hornblende crystallization has a negative effect on Cu mineralization. Moreover, subducting older and wetter oceanic crust in the western Pacific is usually more hydrous than the younger and drier oceanic crust in the east. Fractionation of hydrous arc magmas cannot explain the distribution of either adakite or Cu porphyry within the circum-Pacific region.

Copper porphyry deposits usually reflect high oxygen fugacities as discussed in detail previously (e.g. Mungall 2002; Sun *et al*. 2004; Liang *et al*. 2006, 2009). In fact, convergent margins and normal arc rocks usually have high oxygen fugacities (e.g. Ballhaus 1993; Parkinson and Arculus 1999; Sun *et al*. 2007). Normal arc rocks, however, have no obvious genetic connection to Cu mineralization. Taking the highly uneven distribution of Cu porphyry deposits and their association with adakites into consideration, all these also argue against adakite and Cu mineralization having formed through hornblende fractionation of normal arc magmas, no matter how H_2O-rich (Richards and Kerrich 2007) or dry.

Adakite was originally proposed to represent slab melts (Defant and Drummond 1990). High Sr/Y ratios were used as an index to discriminate adakite from normal arc rocks (Defant and Drummond 1990). The problem is that high Sr/Y may be formed by a variety of processes (Wang *et al*. 2005; Huang *et al*. 2008; Wen *et al*. 2008), that is, high Sr/Y is not equal to slab melt. Recent studies show that slab melts can be discriminated from continental crust melts (Liu *et al*. 2010; Ling *et al*. 2011). As shown in Figure 3 of Sun *et al*. (2011), slab melts have systematically lower Sr/Y than lower continental crust melts. This plausibly explains that adakites of continental crust origin (e.g. those from the Dabie Mountains) tend to have higher Sr/Y, but without any indication of Cu mineralization (Wang *et al*. 2007). It is true that the continental

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crust, the mantle, and to a lesser extent, the asthenospheric mantle, are heterogeneous in terms of Cu and Au. The fact, however, is that 95% of known Cu porphyry deposits are distributed along convergent margins.

Sun *et al*. (2011) tried to explain the concept that magmas contribute to Cu (Au) mineralization through losing Cu (Au) to porphyry and epithermal ore-forming fluids (Sun *et al*. 2004). Copper is a moderately incompatible element with abundances of ~30 ppm in the primitive mantle (McDonough and Sun 1995), ~26 ppm in the continental crust (Rudnick and Gao 2003), and roughly the same value for the asthenospheric mantle. Simple magmatic processes cannot raise its concentration by more than 100 times to form Cu porphyry deposits. Instead, Cu released to fluids during sulphate reduction (which is more pronounced in more oxidized magmas) is essential for its mineralization (Sun *et al*. 2004; Sun *et al*. 2010). Therefore, magmas with higher initial Cu concentrations coupled with lower ultimate Cu concentrations, that is, lost more Cu to ore-forming fluids, should have contributed more to mineralization. As shown in figure 1 of Sun *et al*. (2011), adakites have lower ultimate Cu concentrations than arc rocks with higher initial concentrations as shown in figure 3 of Sun *et al*. (2011), such that they are more favourable for Cu mineralization.

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