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LETTER

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Giant versus small porphyry copper deposits of Cenozoic age in northern Chile: adakitic versus normal calc-alkaline magmatism

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Abstract Cenozoic magmatic activity in northern Chile led to the formation of two contrasting porphyry copper belts: (1) a Paleocene–Early Eocene belt comprising small porphyry copper deposits (e.g., Lomas Bayas) of normal calc-alkaline affinity; and (2) a Late Eocene–Early Oligocene belt hosting huge porphyry copper deposits (e.g., Chuquicamata) of adakitic affinity. Although the first belt comprises both volcanic and plutonic rocks (andesitic–basaltic and rhyolitic lavas and tuffs, and associated sub-volcanic porphyries and felsic stocks), the latter only includes intrusions (mostly granodioritic types, including porphyry copper deposits). We suggest that the Late Eocene–Early Oligocene belt formed when fast and oblique convergence between the South America and Farallon plates led to flat subduction and direct melting of the subducting plate, hence giving rise to plutonic rocks of adakitic affinity. The absence of volcanism, under prevailing compressional conditions, prevented the escape of SO_2 from the adakitic, sulfur-rich, highly oxidized magmas ("closed porphyry system"), which allowed formation of huge mineral deposits. On the contrary, coeval volcanic activity during formation of the Paleocene–Early Eocene calc-alkaline porphyries allowed development of "open systems", hence to outgassing, and therefore, to small mineral deposits.

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Introduction

The northern Chilean porphyry copper deposits (e.g., Sillitoe 1988; Maksaev 1990; Camus and Dilles 2001; among many others) with famous examples such as Chuquicamata (5.8 Gt at 0.55% Cu), La Escondida (2.3 Gt at 1.15% Cu), or El Abra (1.45 Gt at 0.55% Cu) form a N–S-trending metallogenic province of Late Eocene–Early Oligocene age (Sillitoe 1988; Fig. 1). However, there is another copper porphyry belt farther west, of Paleocene–Early Eocene age (Sillitoe 1988), with minor yet productive porphyry copper deposits such as Lomas Bayas (130 Mt at 0.53% Cu), or Spence (400 Mt at 1% Cu; Fig. 1). In this paper we relate the size of the porphyry copper deposits to type of magmatism and plate tectonic setting. Whereas the Paleocene–Early Eocene porphyry copper belt belongs to a rather typical calc-alkaline magmatic province, including both plutonic and volcanic rocks, the Late Eocene–Early Oligocene belt consists only of plutonic rocks, most of them of adakitic affinities, including giant porphyry copper deposits (e.g., Thiéblemont et al. 1997; this work).

Adakitic rocks

The term adakite comes from the island of Adak (Aleutian Islands, Alaska) and was originally defined to describe Cenozoic (<25 Ma) arc-related volcanic rocks with a number of geochemical characteristics, including $SiO_2 \geq 56$ wt%, $Al_2O_3 \geq 5$ wt%, 3 wt% $\leq$ MgO $\leq$ 6 wt%, Y $\leq$ 18 ppm, Sr$\geq$400 ppm (Defant and Drummond 1990). Contrary to normal, arc-related tholeiitic and calc-alkaline rocks that originate in the mantle wedge and later evolve by crystal fractionation or other processes, the adakitic rocks are derived from direct partial melting of a subducting slab (Defant and Drummond 1990). These authors related the magma generation to the melting of hot, young (<25 Ma) subducting lithosphere. Numerical and petrological models (Peacock et al. 1994) restrict the process to even younger subducting lithosphere (<5 Ma) at typically 60–80 km depth. However, this would leave unexplained the important adakitic magmatism recorded in many places around the world, including the Andean chain (e.g., Maury et al. 1996; Thiéblemont et al. 1997; Gutscher et al. 2000; BRGM 2001). In this respect, it has been shown that older oceanic crust (up to 50–60 Ma) can also melt during flat, fast, and/or oblique subduction episodes (Maury et al. 1996; Sajona and Maury 1998; Gutscher et al. 2000). Under such conditions the plate will melt before undergoing dehydration, at the base of the lithosphere (Gutscher et al. 2000). Another key element for slab melting is a high content of water (>10 wt% H_2O) to increase melt percentage, and thus to generate dacitic compositions