Tectonic controls on Ni and Cu contents of primary mantle-derived magmas for the formation of magmatic sulfide deposits

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**ABSTRACT**

We have modeled the genesis of primary mantle-derived magma to explore the controls exerted on its Ni-Cu ore potential by water content, pressure, and mantle potential temperature ($T_p$). During decompression melting, Ni concentration in primary magma decreases with an increasing degree of melting, which is in contradiction to long-held understanding obtained from previous isobaric melting models. Pressure exerts a first-order control on the ore potential of primary plume-derived melt, such that plumes rising beneath thick lithosphere with melting paths terminating at relatively high pressure generate Ni-rich melts. Additionally, as plumes with higher $T_p$ produce more Ni-rich melt at a higher pressure, the magmatism related to hotter plume-centers may have the greatest ore potential. On the other hand, the strong dependence of Cu behavior upon the presence or absence of residual sulfide is partly countered in decompression melting. Significant influences of mantle-contained water on Ni and Cu partitioning are restricted to low-degree melting. While release of H₂O in lithosphere delamination may trigger voluminous magmatism, the Ni concentration in the melt is far lower than in melt generated from plumes. Furthermore, if isobaric melting dominates when the subcontinental lithospheric mantle (SCLM) is heated by underlying hotter plumes, the plume-lithosphere interaction plays no active role in the Ni ore potential of primary magma because derived melt volumes are relatively small. In subduction zones, flux-melting of the mantle wedge tends to generate cool Ni-poor melts, however hot subduction zones may produce magmas with increased metal concentrations. Overall, the anticipated ranges of Ni contents in primary melts are strongly controlled by tectonic setting, with a range of 100–300 ppm in subduction zones, 230–450 ppm in mid-ocean ridges, and 500–1300 ppm in plume suites. There are only minor differences in the Cu concentrations of primitive magmas generated from diverse tectonic settings, despite the variations in Cu partitioning behaviors.

**Keywords:** Mantle partial melting, Ni and Cu partitioning behaviors, tectonic settings, ore potential of primary magma, forward model; Planetary Processes as Revealed by Sulfides and Chalcophile Elements

**INTRODUCTION**

Magmatic Ni-Cu-(PGE) sulfide deposits, hosting ~56% and >96%, respectively, of global resources of Ni and PGEs, are formed as the result of segregation and accumulation of immiscible sulfide liquids from mafic and/or ultramafic mantle-derived magmas (Arndt et al. 2005; Barnes and Lightfoot 2005; Naldrett 2010, 2011; Mungall 2014; Barnes et al. 2016; Barnes and Robertson 2018). The characteristics of primary magma that promote the formation of magmatic Ni-Cu-(PGE) deposits in various tectonic settings still remain poorly constrained (Arndt et al. 2005; Zhang et al. 2008) despite the general consensus that picritic and komatiitic magmas are best. Although the existence of an unusually metal-rich primary melt has not been widely considered as a necessity for the formation of most magmatic Ni-Cu-(PGE) deposits, it is also evident that relatively metal-poor magmas would not be optimal. Petrological information regarding primary magma composition that can be obtained from intrusive samples is not straightforward because primary magmas are likely to be modified by partial crystallization and assimilation, as well as mixing in crustal environments (Herzberg and Asimow 2015).

The use of forward models to compute the geochemistry of melts and partitioning behaviors of Ni, Cu, and PGEs during partial melting offers us a distinctive angle to explore the ore potential of primary magma. Naldrett (2010, 2011) modeled the partitioning behaviors of Ni, Cu, Pt, and Pd in the isobaric melting of primitive mantle, an approach followed in several more recent studies (e.g., Li et al. 2012; Lightfoot et al. 2012; Jowitt and Ernst 2013; Mao et al. 2014). Lee et al. (2012) quantified the evolution of Cu concentrations in mantle-derived melts by modeling fractional melting of a fertile mantle at fixed proportions of mineral phases and P-T conditions, advocating Cu content can be used to trace the presence of sulfide in the source (Liu et al. 2014; Le Roux et al. 2015). More recently, polybaric melting models were developed to predict the concentrations of PGE in primary melt and the corresponding restites (Mungall and Brenan 2014; Aulbach et al. 2016), as well as the sulfur budget in MORBs (Ding and Dasgupta 2017). The compositions of primary melts can be controlled by: (1) the composition and thermal state of mantle source; (2) the type