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Comparisons among the Oortsog, Dulaan, and Nomgon mafic–ultramafic intrusions in central Mongolia and Ni–Cu deposits in NW China: implications for economic Ni–Cu–PGE ore exploration in central Mongolia

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Abstract

Although there are many mafic–ultramafic intrusions in the western and central regions of Mongolia, Central Asian Orogenic Belt (CAOB), no economic-grade Ni–Cu deposits have yet been discovered. To understand the economic Ni–Cu deposit potential of the intrusions in central Mongolia, the parental magma affinity and sulfide saturation of the Oortsog, Dulaan, and Nomgon Ni–Cu mineralized mafic–ultramafic intrusions are studied. These three intrusions are predominantly gabbroic in composition, while the Oortsog and Dulaan intrusions also contain small proportions of peridotites. The parental magmas of the Oortsog and Dulaan intrusions are tholeiitic, as indicated by their Cr-spinel and clinopyroxene compositions, whereas the parental magma of the Nomgon intrusions is likely calc-alkaline. The compositions of Cr-spinel and clinopyroxene, combined with the presence of significant Nb–Ta depletions, indicate that these rocks were most likely derived from modified mantle sources. Both the Oortsog and Nomgon intrusions form two clusters in terms of their olivine composition, suggesting that multiple magma surges were involved during their emplacement. The relatively low Fo values and Ni contents in olivine from the three intrusions compared to those from Ni–Cu deposits in NW China, as well as those in the Voisey's Bay deposit in Canada, indicate that the three intrusions were crystallized from relatively evolved magmas. The Cu/Zr ratios of rocks of the Oortsog, Dulaan, and Nomgon intrusions are higher than 1, suggesting that these rocks contain cumulus sulfide. This, coupled with the presence of rounded sulfide inclusions in olivine of the Oortsog and Dulaan intrusions, suggests that sulfide saturation occurred before or during olivine crystallization. The distribution patterns of platinum group elements (PGEs) of the Dulaan and Oortsog intrusions record slight Rh, Pt, and Pd (PPGE) enrichment relative to Os, Ir, and Rh (IPGE). Furthermore, the Ni/Cu ratios of sulfide-bearing rocks from the Oortsog intrusion vary from 1.8 to 3.8, which are consistent with those of the Ni–Cu sulfide deposits in NW China. In contrast, the Ni/Cu ratios of sulfide-bearing rocks from the Nomgon intrusion are extremely low (0.03 to 0.07). This, together with the significant enrichment in PPGE relative to IPGE, suggests that these sulfides of the Nomgon intrusion were segregated from a magma that was extremely enriched in Cu and PPGE but depleted in Ni and IPGE. The characteristics of the chalcophile elements in these intrusions are attributed to the fact that the derivation of the Nomgon magma was significantly different from that of the Dulaan and Oortsog parental magmas. Overall, although the parental magmas of the intrusions in central Mongolia are more evolved than those in NW China, they are comparable in terms of the sizes of their intrusions, constituent minerals, and mineral chemistry. These similarities suggest that the intrusions in central Mongolia have economic Ni–Cu sulfide potential. Furthermore, intrusions similar to the Nomgon intrusion may feature PGE mineralization potential.

Keywords: Central Asian Orogenic Belt; Ni–Cu deposit; platinum group elements; exploration; mafic–ultramafic intrusion; central Mongolia

Introduction

In recent decades, the occurrence of magmatic Ni–Cu sulfide deposits in orogenic belts has been widely reported (Li et al., 2015; Maier et al., 2008, 2016; Qin et al., 2003, 2011), suggesting that orogenic belts are capable of future Ni–Cu sulfide deposit exploration. The Central Asian Orogenic Belt (CAOB), also known as the Altaid Tectonic Collage, which is bounded by the Siberian craton to the north and the Tarim–North China cratons to the south (Fig. 1*a*), represents a complex evolution of Phanerozoic orogenic belts (Sengör et al., 1993; Windley et al., 2007; Xiao et al., 2004). Numerous

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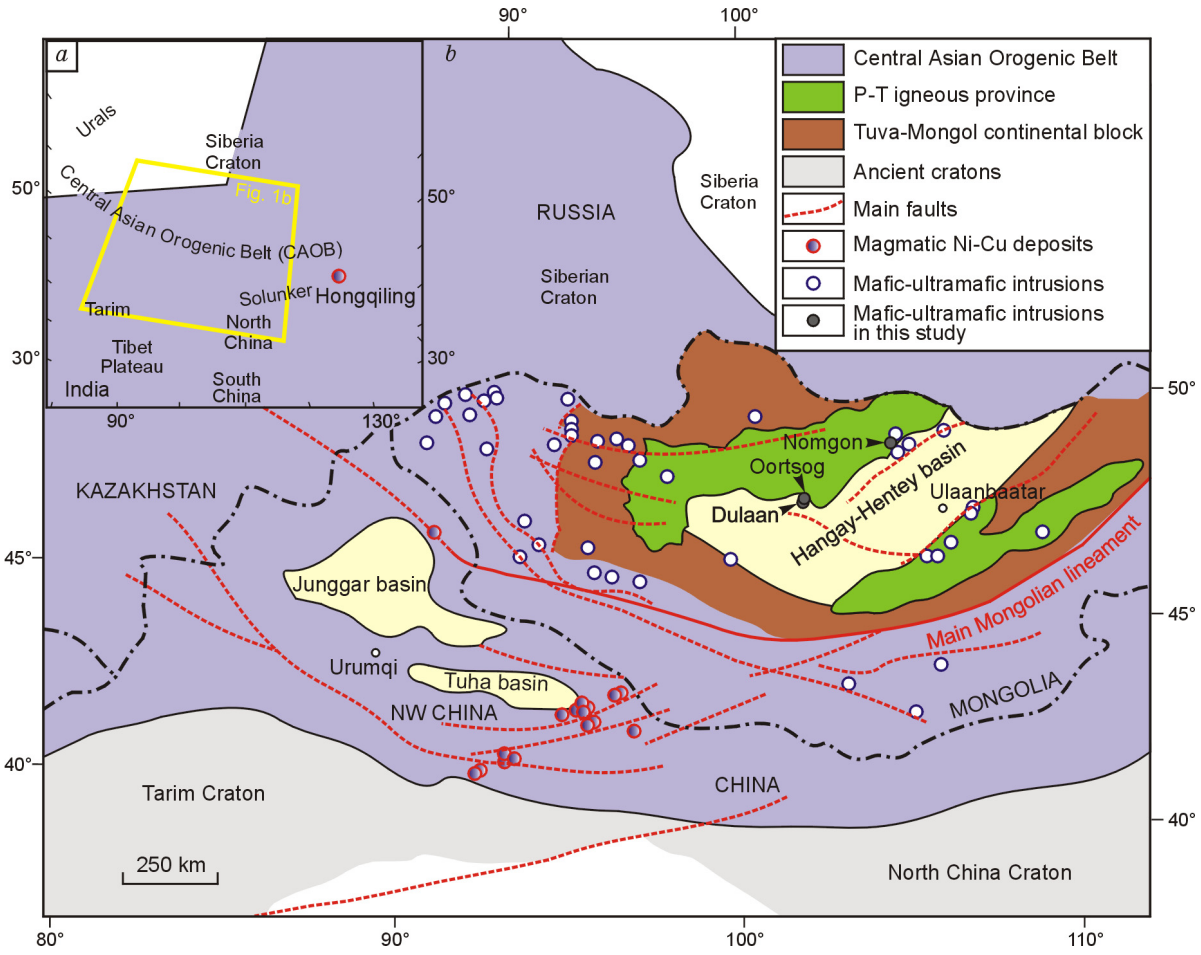

Fig. 1. Simplified map of the Central Asian Orogenic Belt, after (Sengör et al., 1993) (*a*). Distribution of mafic–ultramafic intrusions in Mongolia and magmatic Ni–Cu deposits in NW China (*b*). Data source: Ni–Cu deposits in NW China (Mao et al., 2008; Mao et al., 2014a, 2015; Qin et al., 2003, 2011; Song and Li, 2009; Su et al., 2011; Xia et al., 2013; Zhang et al., 2009; Zhou et al., 2004), magmatic Ni–Cu deposits in NE China are from (Wei et al., 2013, 2015), mafic–ultramafic intrusion in Mongolia (Dejidmaa et al., 2001), outlines of the Hangay–Hentey basin, Tuva–Mongol continental block, Permian–Triassic (P–T) igneous province (Kelty et al., 2008), and main faults (Badarch et al., 2002).

Ni–Cu sulfide deposits have been discovered in the southern margin of the CAOB in China since the 1980s. Although many mafic–ultramafic intrusions featuring Ni–Cu and/or platinum group element (PGE) mineralization in the central part of CAOB in Mongolia have been documented on the metallogenic map of Mongolia and in the literature (Izokh et al., 1990, 1998; Kozakov et al., 2007; Oyunchimeg et al., 2009; Polyakov et al., 2008), the potential of the Ni–Cu–PGE deposit within these intrusions remains ambiguous.

Studies of world-class magmatic Ni–Cu deposits reveal that the following factors are essential for generating economic Ni–Cu deposits (Barnes et al., 2016; Naldrett, 2010a,b): (1) parental magmas, derived from a mantle source, with moderate to high Ni concentrations, (2) sulfide saturation induced by the addition of crustal sulfur and/or crustal contamination, and (3) sulfide accumulation in a dynamic environment. Olivine and Cr-spinel are two minerals that crystallize early in basaltic and komatiitic magmas, therefore, their compositions can be used to indicate the composition of their parental magma (Barnes and Roeder, 2001; Barnes et al., 2013; Sobolev et al., 2007). In addition, the variation of Ni content in olivine is strongly associated with magma evolution and sulfide segregation, because Ni is compatible in olivine and strongly partitions into sulfide melt during magma evolution (Barnes et al., 2013; Li and Naldrett, 1999; Li et al., 2000, 2001, 2007), and is thus a useful indicator of the sulfide saturation process.

In this study, we study the petrology, whole rock PGE, and mineral compositions of the Oortsog, Dulaan, and Nomgon intrusions in central Mongolia to characterize the parental magma composition and sulfide saturation conditions of these intrusions. These data are then compared with published data of other economic Ni–Cu deposits in NW China, as well as Ni–Cu deposits worldwide, to better constrain the economic Ni–Cu deposit potential of these intrusions. The aim of this study is to shed light on the exploration of magmatic Ni–Cu–PGE deposits in central Mongolia.

Geological background

Based on its tectonostratigraphic, Mongolia can be subdivided into an Early Paleozoic domain in the north and a Late