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Crustal contamination and sulfide immiscibility history of the Permian Huangshannan magmatic Ni-Cu sulfide deposit, East Tianshan, NW China

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ABSTRACT

The Huangshannan mafic–ultramafic intrusion is a Permian Ni–Cu sulfide-bearing intrusion in the southern margin of the Central Asian Orogenic Belt. The intrusion consists of an ultramafic unit, which is composed of lherzolite and olivine websterite, and a mafic unit, which is composed of olivine gabbronorite, gabbronorite and leuco-gabbronorite. This intrusion was formed by two separate pulses of magma: a more primitive magma for the early ultramafic unit and a more evolved magma for the late mafic unit. U–Pb isotope geochronology of zircon from the mafic unit yields an age of 278 ± 2 Ma. According to its olivine and Cr-rich spinel compositions, the estimated parental magma of lherzolite for the Huangshannan intrusion has 12.4 wt.% MgO, indicating picritic affinity. Fractional crystallization modeling results and the presence of rounded sulfide inclusions in an olivine crystal (Fo 86.7) indicate that sulfide immiscibility was achieved at the beginning of olivine fractionation. Co-magmatic zircon crystals from gabbronorite have a $\delta^{18}O$ value close to 6.5‰, which is 1.2‰ higher than the typical mantle value and suggests significant crustal contamination (~20%). The positive $\varepsilon_{Hf}(t)$ values of co-magmatic zircon (which vary from +9.2 to +15.3) and positive whole rock $\varepsilon_{Nd}(t)$ values (which vary from +4.7 to +7.8) also indicate that the parental magma was derived from a depleted mantle source and contaminated by 5–20% juvenile arc crust and then by ~5% upper crustal materials. However, modeling results of sulfur content at sulfide saturation reveal that such a large amount of crustal contamination is not sufficient to trigger sulfide saturation in the parental magma, which strongly suggests that external sulfur addition, probably during contamination, has played a critical role in causing sulfide immiscibility. Furthermore, the arc magmatism geochemical signatures of the Huangshannan intrusion, such as significant Nb and Ta depletion relative to La and low Ca contents in olivine, are interpreted as the result of slab-derived fluid modification during previous subduction. We speculate that the contamination of juvenile arc crust may have occurred in the lower crust because of picritic magma underplating and that partial melting in the mantle was triggered by the impingement of a mantle plume or lithosphere delamination in a post-subduction environment.

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1. Introduction

Magmatic Ni–Cu sulfide mineralized mafic–ultramafic intrusions are commonly found at the margins of cratons (Maier and Groves, 2011). However, Ni-Cu deposits that occur at the convergent margins of Phanerozoic plates, far from craton boundaries, have been increasingly reported in recent years. Examples of the latter include the Xiarihamu deposit (Li et al., 2015) and a number of magmatic sulfide deposits that are hosted in small mafic–ultramafic intrusions in East Tianshan in the Central Asian orogenic belt (CAOB) (Gao and Zhou, 2013; Li et al., 2012b; Mao et al., 2008; Qin et al., 2011; Zhou et al., 2004). Crustal contamination and crustal sulfur addition were very likely triggers of sulfur–saturation in mafic magmas, which formed Ni–Cu–(PGE) sulfide deposits (Naldrett, 2011 and references therein). The former triggers sulfide immiscibility by reducing the sulfur content at sulfide saturation, and the latter induces sulfide segregation by increasing the sulfur content in the magma (Li and Ripley, 2009). However, the cause of sulfide saturation in the Ni-Cu associated mafic–ultramafic

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intrusions in East Tianshan remains controversial. Some researchers proposed that crustal contamination and olivine fractionation at depth (Sun et al., 2013; Tang et al., 2011, 2012; Mao et al., 2015) played a key role in triggering sulfide immiscibility, whereas some researchers believed that crustal sulfur addition during magma ascent was the more important factor (Gao et al., 2013; Deng et al., 2014; Xue et al., 2016; Zhao et al., 2015).

The Huangshannan deposit, which contains ~30 Mt of sulfide ore with 0.4 wt.% Ni and 0.1 wt.% Cu, is among the most recently discovered Ni–Cu deposits in the CAOB. The nature of the parental magma composition, role of crustal contamination and cause of sulfide saturation are still unclear. In addition, the olivine in the Huangshannan deposit has higher Fo values (Mg/(Mg + Fe)) than the two largest Ni–Cu deposits (Huangshandong and Huangshanxi) in East Tianshan (Mao et al., 2014b, 2015; Sun et al., 2013). Thus, this deposit offers an ideal opportunity to study the parental magma and crustal contamination of this type of intrusion in the region.

In this study, we use zircon U–Pb and O–Hf isotopic data, whole rock Sr–Nd isotopic data and olivine, Cr-rich spinel and clinopyroxene compositions to evaluate the parental magma composition, crustal contamination and triggers of sulfide saturation to better understand the origin of the Permian Huangshannan deposit. We suggest a petrogenetic model for the Huangshannan Ni-Cu sulfide deposit based on our new results and available regional geological constraints.

2. Geological background

The CAOB is a large amalgamation of Phanerozoic accreted arcs and microplates that are situated between the Siberian craton to the north and the Tarim–Sino–Korean cratons to the south and is one of the largest accretionary arcs and micro-continents (Jahn, 2004; Xiao et al., 2004). Mafic–ultramafic intrusive and extrusive rocks formed during the accretion of continental blocks, and terranes of different geodynamic origins are widely distributed in the CAOB, including intrusions in Kazakhstan (Khromykh et al., 2011), Mongolia (Izokh et al., 2011), Russia (Vorontsov et al., 2008), and NW China (Qin et al., 2011 and references therein). Permian mafic–ultramafic intrusions with Ni–Cu sulfide mineralization in NW China commonly occur at the rim of the Tarim craton (East Tianshan) and far from the Tarim craton (East Junggar) (Fig. 1a).

The eastern part of the Chinese Tianshan is referred to as East Tianshan. This region is located in the northeastern Tarim craton and hosts most of the Ni–Cu sulfide-bearing mafic–ultramafic intrusions in NW China (Fig. 1b). This area can be subdivided into North Tianshan (Jueluotage) and Central Tianshan from the north to the south. Central Tianshan is bordered by the Beishan region at the northeastern rim of the Tarim craton (Fig. 1b). Abundant ophiolites are exposed along the suture between Central Tianshan and Beishan. U–Pb zircon geochronology of ophiolites, including Hongliuhe, Kawabulak and Huoshishan (HSS) and Niujuanzi

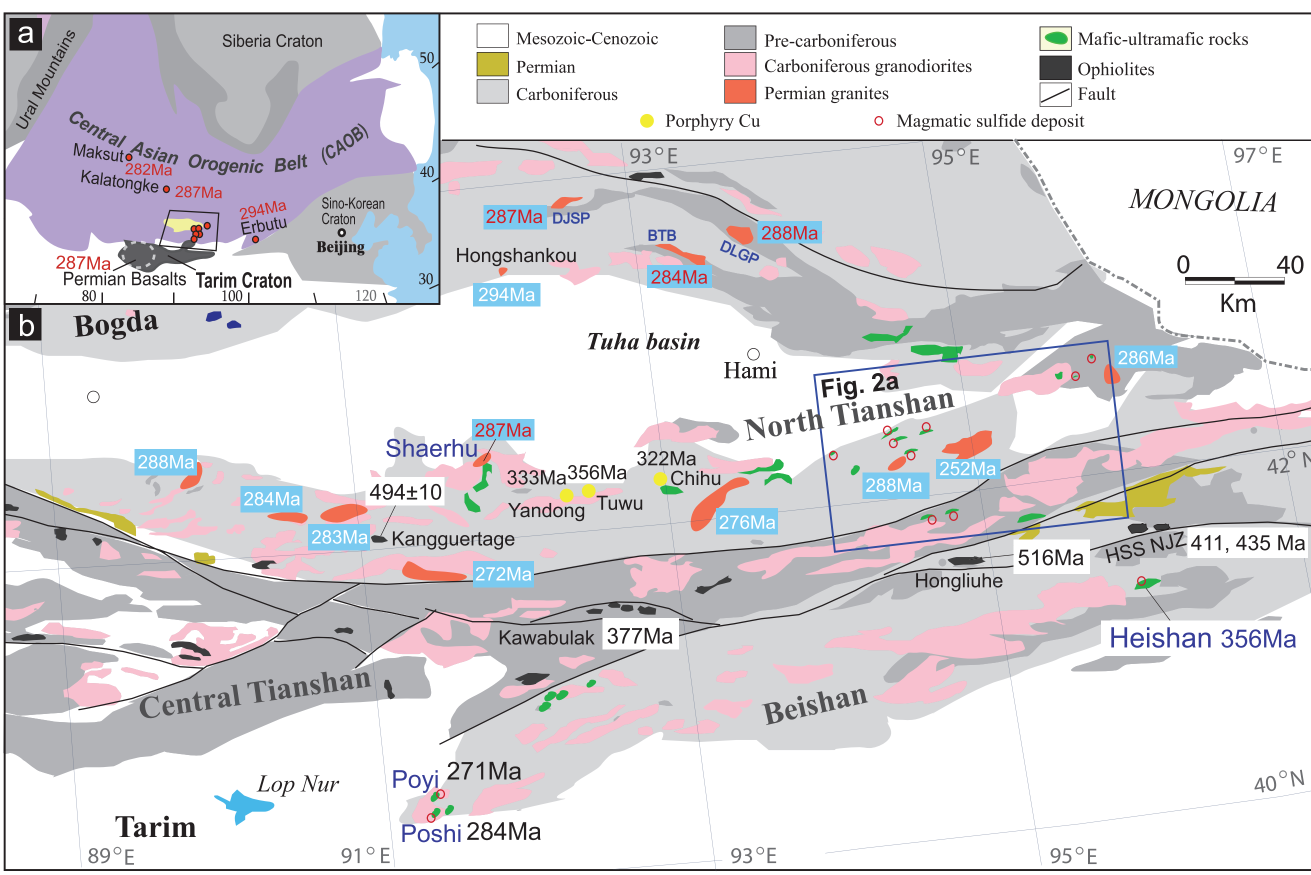

Fig. 1. Simplified geological map of the Central Asian Orogenic Belt (a, modified after Jahn, 2004) and East Tianshan (b, modified from Xiao et al., 2004), which shows the distribution of the Permian basalts, mafic–ultramafic intrusions and associated sulfide deposits, ophiolites, granite plutons and porphyry Cu deposits. Data sources of the mafic–ultramafic intrusions: Kalatongke (Han et al., 2004), Maksut (Khromykh et al., 2011). (b) Zircon U–Pb ages for the mafic–ultramafic intrusions in Beishan: Heishan (Xie et al., 2012), Poyi and Poshi (Qin et al., 2011). Zircon U–Pb ages for ophiolites: Hongliuhe ophiolite (Zhang and Guo, 2008), HSS and NJZ ophiolite (Tian et al., 2014), Kawabulak ophiolite (Xiao et al., 2008). Zircon U–Pb ages of granite plutons: DJSP, BTB and DLGP (Yuan et al., 2010); Shaerhu (Mao et al., 2014a); others in North Tianshan (Zhou et al., 2010). Zircon U–Pb ages for plagiogranite from porphyry Cu deposits: Chihu (Wu et al., 2006b), Tuwu (Qin et al., 2002).

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