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The role of crustal contamination in the formation of Ni–Cu sulfide deposits in Eastern Tianshan, Xinjiang, Northwest China: Evidence from trace element geochemistry, Re–Os, Sr–Nd, zircon Hf–O, and sulfur isotopes

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ABSTRACT

Tulaergen, Xiangshan, Huangshan, Tianyu, and Baishiquan magmatic Ni–Cu sulfide deposits, which are all located in the eastern part of the Central Asian Orogenic Belt, and associated with small mafic–ultramafic intrusions with high-grade Cu and Ni orebodies have similar ages of formation. Their magma sources are MORB-like and OIB-like depleted mantle. Modeling calculations of Sr–Nd and zircon Hf isotopic data show that about 10–15% of oceanic slab components are added into the source of Baishiquan and Tianyu intrusions, but only less than 5% are in the three other intrusions. The higher degree of subduction metasomatism in the Baishiquan and Tianyu magma sources is likely the result of the Paleozoic multiple-stage subduction. Moreover, the relative enrichment of LILE, depletion of HFSE, and lower Ce/Pb ratios indicate that these intrusions experienced crustal contaminations. The effects of crustal contamination are also identified in the magmatic sulfide deposits by the higher zircon $\delta^{18}O$, higher sulfide γOs, and $\delta^{34}S$ values observed. We propose a two-stage crustal contamination model of the Tulaergen, Xiangshan, Tianyu, and Baishiquan intrusions. However, the Huangshan intrusion, which has the highest degree of crustal contamination, likely experienced only single-stage upper crustal contamination (~14.2%). The addition of crustal S appears to be directly related to triggering S saturation in these deposits. According to a simple S isotopic modeling calculation, 11%, 2.9%, 1.2% and 2.1% of the crustal sulfur addition into the parental magma would be required to form the Tianyu, Baishiquan, Xiangshan, and Tulaergen deposits, respectively.

1. Introduction

The Eastern Tianshan district occupies the middle part of the Central Asia Orogenic Belt (CAOB) and has great economic potential for polymetallic mineralization (Hong et al., 2003; Mao et al., 2008; Zhang et al., 2008a). The Huangshan–Jing'erquan ore belt is currently the largest known Cu–Ni sulfide ore belt in the Eastern Tianshan district (Fig. 1a). In the 1970s, Huangshan, Huangshandong, Xiangshan, Tudun, and Hulu Ni–Cu sulfide deposits were discovered in this region. In recent years, exploration has achieved great success in terms of magmatic Cu–Ni sulfide deposits, including the discoveries of Baishiquan and Tianyu on the northern margin of the Central Tianshan Terrane (Chai et al., 2008; Wang et al., 2007; Tang et al., 2009), and the Poshi, Poyi and Luodong deposits in the Paleozoic Beishan rift (Su et al., 2009, 2011). More recently, the Tulaergen large Ni–Cu deposit was found at the eastern end of the Huangshan–Jing'erquan ore belt (San et al., 2010). The series of mafic–ultramafic complexes and related Ni–Cu deposits (Fig. 1) have similar formation ages, mainly Permian (Mao et al., 2002; Han et al., 2004; Zhou et al., 2004; Wu et al., 2005). The distribution and occurrences of these deposits are shown in Fig. 1b, and their main geological characteristics are given in Table 1.

In the Eastern Tianshan, sulfide-bearing magmatic Ni–Cu ore deposits are interpreted to be products of high magnesia tholeiitic basaltic magmas derived from lithospheric mantle that was previously contaminated by subducted slab material (Zhou et al., 2004; Jiang et al., 2006; Chai et al., 2008; Sun, 2009; Xiao et al., 2010a; Han et al., 2010). Cu–Ni sulfide ores were segregated from crustally contaminated magmas (Chai et al., 2008; Sun, 2009; Han et al., 2010). The generation of magmatic Ni–Cu–Co–platinum group element (PGE) sulfide deposits is generally accepted to require crustal contamination of mantle-derived magmas (Lesher and Campbell, 1993; Naldrett, 1999; Ripley et al., 2002; Lightfoot and Keays, 2005). Assimilation of country-rock S, low-pressure fractionation, assimilation of felsic country rocks, and increases in magma oxygen fugacity are all considered essential to producing

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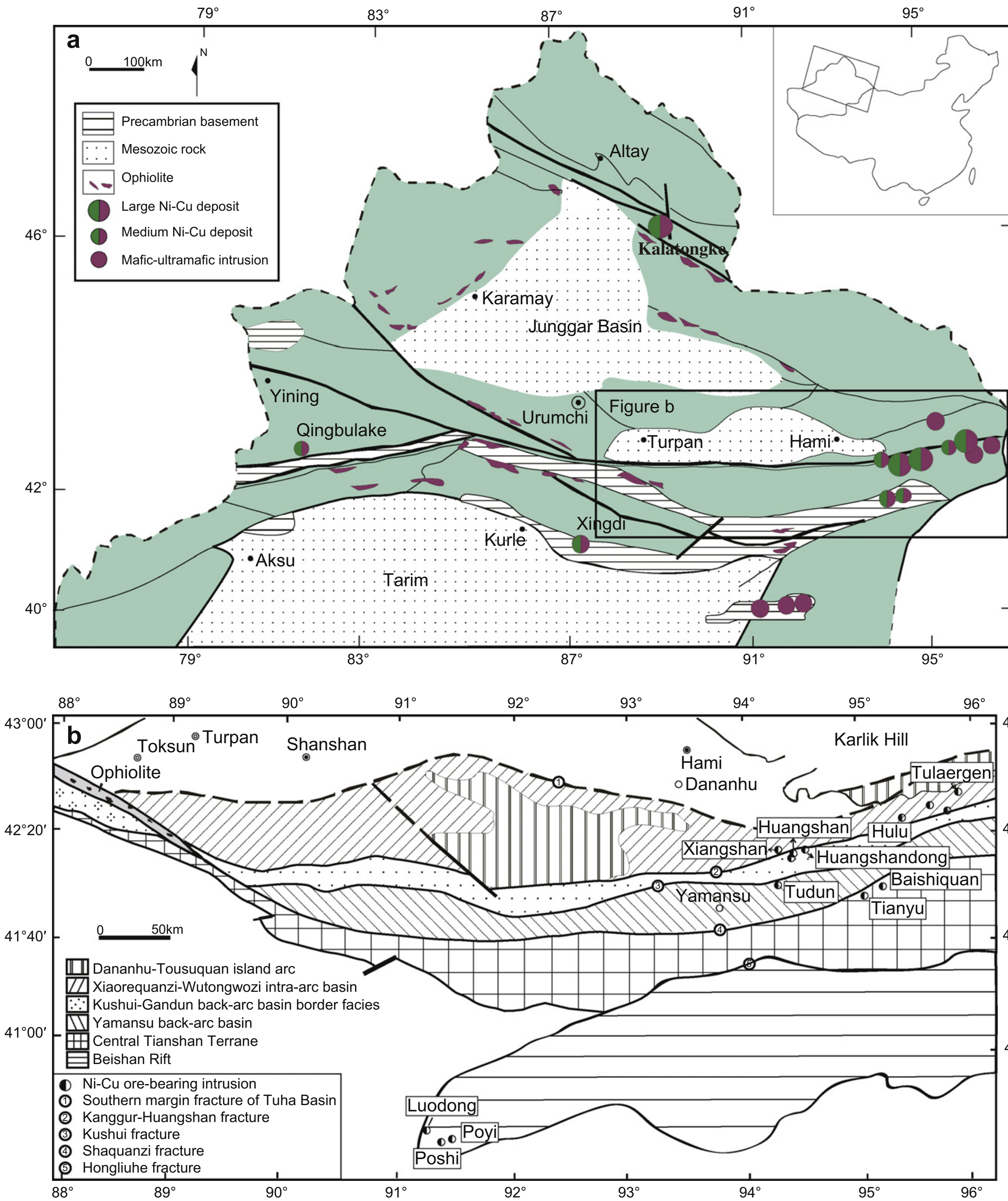

Fig. 1. Map of tectonic framework and Cu–Ni deposits/occurrences associated with mafic–ultramafic intrusions distribution in the East Tianshan region (revised after Qin et al., 2003).

S saturation during mantle magma evolution (Lesher and Campbell, 1993; Li and Naldrett, 1993; Ripley, 1999; Maier, 2005; Zhang et al., 2009). What is controversial is the role of crustal versus mantle S in both triggering and maintaining the S-saturated state of the magma, that is, whether or not large-scale ore deposits require a significant contribution of crustal sulfur. The recent application of the Re–Os sulfide chronometer has demonstrated the ability to directly date mineralization and evaluate crustal contamination in the ore-forming process (Walker et al., 1994; Yang et al., 2005; Schneider et al., 2007; Hu et al., 2008; Zhang et al., 2008b; Selby et al., 2009; Tao et al., 2010).

Here, the role of crustal contamination and the addition of crustal sulfur and its degree on the Tulaergen, Huangshandong, Xiangshan, Baishiquan and Tianyu Permian magmatic sulfide deposits