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The migration of Tarim plume magma toward the northeast in Early Permian and its significance for the exploration of PGE-Cu–Ni magmatic sulfide deposits in Xinjiang, NW China: As suggested by Sr–Nd–Hf isotopes, sedimentology and geophysical data

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ABSTRACT

It is well known that a genetic link exists between the formation of ultramafic-rocks-hosted PGE-Cu–Ni sulfide deposits and the eruption of associated continental flood basalts. We here present a new model for the relationship between the Cu–Ni deposits located along the northeastern margin of Tarim and the internal Tarim basalt. Sr–Nd isotope and Hf isotope two-stage crust model ages T^{c}_{DM} indicate that whereas the Cu–Ni deposits along the northeastern margin of Tarim have Neoproterozoic and Mesoproterozoic lithology contamination, the surrounding rocks of Cu–Ni deposits in Beishan (Pobei) and Central Tianshan do not have Neoproterozoic lithologies. We propose that this is the result of mixing with the Neoproterozoic rocks in the interior of Tarim block. There is also an east–west trending positive magnetic anomaly belt in the central Tarim Basin, while Early Permian mafic–ultramafic rocks found along the northeastern margin of Tarim probably have a relationship with the Tarim Basin basalt. According to the Bouguer gravity map, the Bachu area near the center of Early Permian plume has high gravity values, with the northeastern high gravity belt in the central Tarim Basin possibly the result of a tilt of the mantle plume to the southwest below the Tarim block, which could be consistent with the earlier uplift and denudation in northeastern Tarim and later in southwestern Tarim from the Early Carboniferous to the Late Permian, as well as with observed uplift in the Bachu area in the Permian. We infer that the tilt of a mantle plume to the southwest below the Tarim block led to the inclined attitude of overlying rocks, with Early Permian magma flowing toward the northeast margin of Tarim. Based on this model, new PGE-Cu–Ni magmatic sulfide deposits related to Early Permian mafic–ultramafic intrusions may be found in the southwest area of Beishan, although this area is covered by Mesozoic and Cenozoic sediments.

1. Introduction

Several magmatic Cu–Ni sulfide deposits and other occurrences related to Early Permian mafic–ultramafic rocks have recently been discovered in the northeastern part of Tarim in northwest China: (1) Permian continental flood basalts in the western and central parts of the Tarim Basin, particularly in the Keping and Bachu area (Fig. 1b), constitute the 274–290 Ma Tarim Large Igneous Province (TLIP), characterized by the widespread distribution of basalts (ca. 250,000 km^2) including picrite, as well as widely developed mafic dyke swarms and coeval mafic–ultramafic intrusions (Chen et al., 1997; Jiang et al., 2006, 2007; Li et al., 2011; Y.Q. Li et al., 2012; Z. Li et al., 2012; Pirajno et al., 2008, 2009; Qin et al., 2011; San et al., 2010; Su et al., 2011a,b, 2012; Tang et al., 2011; Tian et al., 2010; Wei et al., 2014; Yang, 2011; C.L. Zhang et al., 2008; Z. Zhang et al., 2008; Zhang et al., 2010a,b; M. Zhang et al., 2011; Zhou et al., 2004). Early Permian basalts have also been found in the Beishan area (Jiang et al., 2007; Mao et al., 2012; Xia, 2012; Y. Zhang et al., 2011). A number of Ni–Cu-(PGE) magmatic ore deposits related to these mafic–ultramafic intrusions, such as the Huang Shandong and Tula'ergen Cu–Ni sulfide deposits in Eastern Tianshan, the Baishiquan and Tianyu sulfide deposits in Central Tianshan, and the Pobei Cu–Ni sulfide deposits (Poyi and Poshi deposits) in Beishan, have been reported along the northeastern margin of the Tarim Basin (Fig. 1c) (Chai et al., 2008; Han et al., 2004; Jiang et al.,

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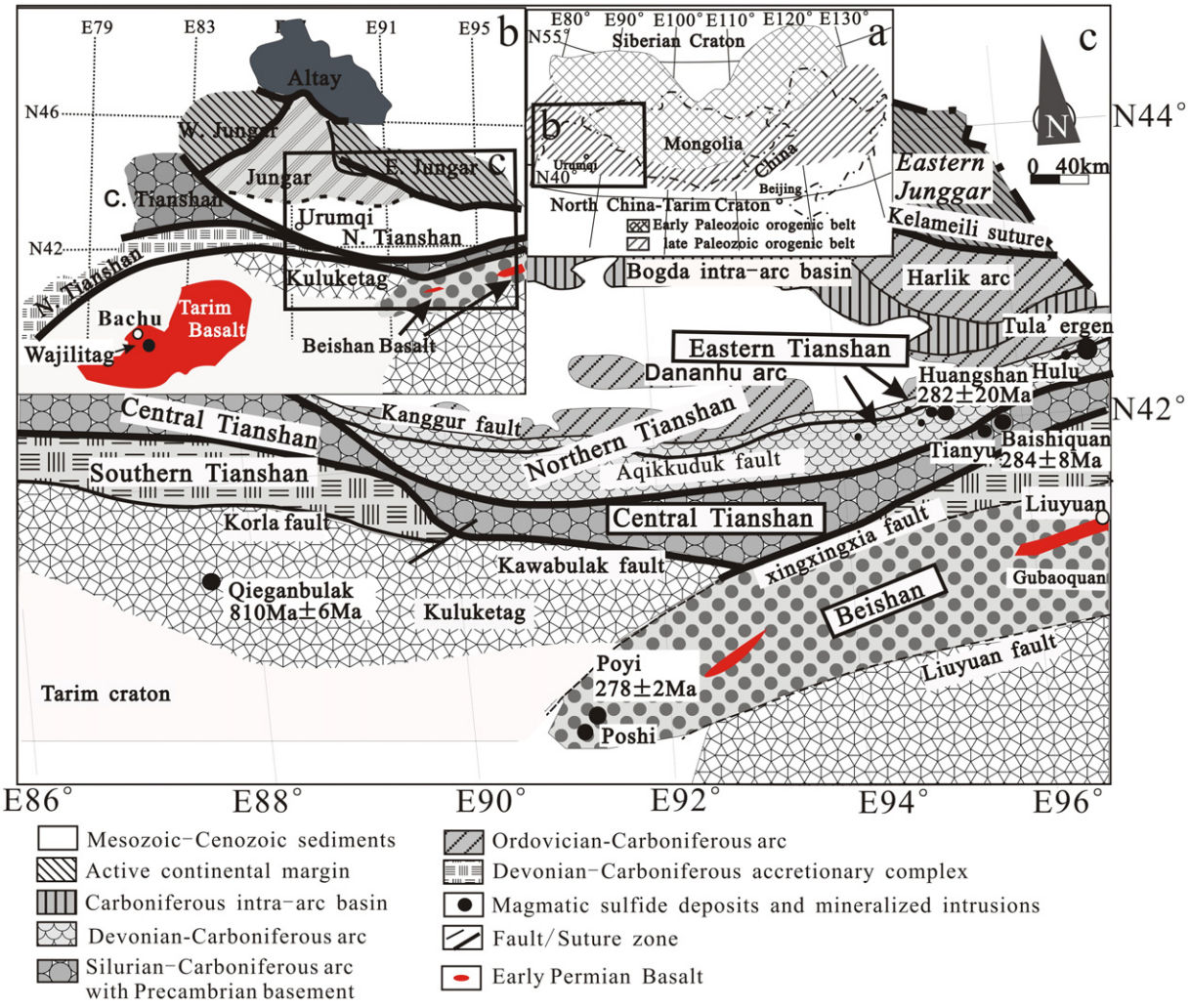

Fig. 1. Tectonic units and distribution of magmatic deposits and Early Permian basalts in Northern Xinjiang, Northwest China (modified after BGMRXUAR, 1993; Xiao et al., 2004; Yu et al., 1999). Age resource: (Jiang et al., 2007, 2012; Mao et al., 2003; Wu et al., 2005; Zhang et al., 2007).

2006; Mao et al., 2008; Qin et al., 2011; San et al., 2010; Tang et al., 2011). The total nickel resources present in these deposits account for 13.8% of the proven nickel resources and more than 90% of new reserves in China. This discovery makes Xinjiang the second-most important district for nickel resources in China (Mao et al., 2008; Qin et al., 2011; Z. Zhang et al., 2008). The Wajilitag Early Permian V–Ti–Fe deposits have also been found in the Bachu area (Fig. 1b) (Li et al., 2001; C.L. Zhang et al., 2008; Zhang et al., 2014). (2) The presence of Early Permian picrites in Tarim (Tian et al., 2010): Picrite is directly derived from the asthenosphere and indicates the existence of mantle plume (Saunders, 2005; Zhang et al., 2006), most probably the hottest part (Coffin and Eldholm, 1994) or center (Gill et al., 1992; Hill, 1991). (3) Coeval dyke swarms: Radial dyke swarms are also characteristic of a mantle plume (Baragar et al., 1996; Campbell, 2001). The Beishan area has a large number of Early Permian swarms of diabase dykes, which show negative Zr and Hf anomalies in the primitive mantle-normalized spider diagram, with $(Sm/Yb)_N$ (1.01–1.8). These features indicate that the diabase dike swarms may have originated from the asthenosphere and were the product of a mantle plume (Yang, 2011).

On the basis of the above geological facts, many geologists believe that Cu–Ni magmatic sulfide deposits and other occurrences related to Early Permian mafic–ultramafic rocks are associated with the Tarim Large Igneous Province (TLIP), which is generally considered to be mantle-plume-related (Chen et al., 1997; Jiang et al., 2006, 2007; Li et al., 2011; Y.Q. Li et al., 2012; Z. Li et al., 2012; Qin et al., 2011; San et al., 2010; Su et al., 2011a,b, 2012; Tang et al., 2011; Tian et al., 2010; Wei et al., 2014; Yang, 2011; Zhou et al., 2004).

Although the mantle-plume model can explain the above observations, the question remains as to why continental flood basalts and Cu-Ni magmatic sulfide deposits related to mafic–ultramafic intrusions are mainly distributed in the middle, western, and northeastern margin of the Tarim Basin, respectively. On the basis of Sr–Nd–Hf isotope, sedimentological and geophysical data, we attempt to identify the relationship between the mafic–ultramafic rocks of the inner Tarim Basin and those on its northeastern margin. We propose a model of the Tarim mantle plume magma migrating toward the northeast and point out that new PGE-Cu–Ni magmatic sulfide deposits related to Early Permian mafic–ultramafic intrusions may be found in the southwestern area of Beishan.

2. Geologic setting

The Precambrian basement of the Tarim Basin is composed of three parts: the north Tarim massif (craton), the south Tarim block (craton), and the Neoproterozoic central fault zone (Li et al., 2008). The north Tarim cratonic block amalgamated with the south Tarim craton during the Neoproterozoic and formed the central Tarim fault (Li et al., 2005, 2008); volcanic eruptions and intrusions of magma along this fault account for gravity and magnetic anomalies (Hou and Yang, 2011; Wu