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Composition of the Tarim mantle plume: Constraints from clinopyroxene antecrysts in the early Permian Xiaohaizi dykes, NW China

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ABSTRACT

Numerous alkaline basaltic dykes crosscut the Early Permian Xiaohaizi wehrlite in drill-cores and syenite intrusion in the Tarim large igneous province, NW China. One basaltic dyke contains abundant clinopyroxene macrocrysts with strong resorption textures. Such a textural disequilibrium is consistent with their contrasting chemistry between the macrocrysts (Mg# = 80–89) and the host dyke (Mg# = 39, corresponding to Mg# = 73 of clinopyroxene in equilibrium with the dyke), indicating that they are not phenocrysts. The clinopyroxene macrocrysts are characterized by low TiO_2 (0.26–1.09 wt.%), Al_2O_3 (1.15–3.10 wt.%) and Na_2O (0.16–0.37 wt.%), unlike those in mantle peridotites but resembling those in layered mafic intrusions in the same area. The clinopyroxene macrocrysts and the clinopyroxenes from the Xiaohaizi cumulate wehrlites define a coherent compositional trend and have identical trace element patterns, pointing to a comagmatic origin for these crystals. Accordingly, the macrocrysts cannot be xenocrysts foreign to the magmatic system. Rather they are antecrysts that crystallized from progenitor magmas and have been reincorporated into the host dyke before intrusion. The $^{87}Sr/^{86}Sr_i$ (0.7035–0.7037) and εNd_i (4.5–4.8) of the clinopyroxene macrocrysts with high Mg# (80–89) are apparently lower and higher than their respective ratios of the clinopyroxenes in the wehrlites (Mg# = 75–84, $^{87}Sr/^{86}Sr_i$ = 0.7038–0.7041, εNd_i = 1.0–1.9). This difference in isotopes can be accounted for by assimilation and fractional crystallization (AFC) process operated during the formation of the Xiaohaizi intrusion. In this sense, the clinopyroxene macrocrysts record the composition of the uncontaminated Tarim plume-derived melts.

1. Introduction

The Permian is featured by the emplacement of four large igneous provinces (LIP) in eastern Asia, namely the Siberian traps (~251 Ma; Kamo et al., 2003), Emeishan basalts (~260 Ma; Chung and Jahn, 1995; Shellnutt et al., 2012; Xu et al., 2008; Zhong et al., 2014; Zhou et al., 2002), Tarim basalts (280–290 Ma, Wei et al., 2014a,b) and Panjal traps (~290 Ma; Shellnutt et al., 2014). Abundant layered mafic intrusions are distributed in the Siberian and Emeishan LIPs. They have been intensively studied for their unique mineral endowment (i.e., PGE, Cr, Ni, V, Ti), notably the Noril'sk–Talnakh Ni–Cu–PGE deposits in the Siberian Traps (e.g., Hawkesworth et al., 1995; Naldrett et al., 1992) and the Panzhihua and Hongge V–Ti-magnetite deposits in the Emeishan LIP (e.g., Bai et al., 2012; Pang et al., 2008; Zhou et al., 2005). Compared with the Siberian Traps and Emeishan LIP, studies of the Tarim LIP are still at the very early stage.

Layered mafic intrusions are sporadically distributed in the Early Permian Tarim LIP, NW China, e.g., the Xiaohaizi intrusion (Wei et al., 2014b), Wajilitag complex (Cao et al., 2014; Li et al., 2012b; Zhang et al., 2008a) and Piqiang complex (Zhang et al., 2010a). V–Ti-magnetite mineralization is associated with the Wajilitag complex (Cao et al., 2014; Li et al., 2012a). Strong negative aeromagnetic anomaly also makes the Xiaohaizi area a potential target of Fe–Ti oxide deposits. Industrial drilling has revealed large volumes of mafic igneous rocks at depth. One drill-core (ZK4202) has recovered ~750 m thick of wehrlites cumulated from a melt that had previously experienced fractional crystallization (Wei et al., 2014b). However, the bottom of the igneous sequence was not reached and the mineral assemblage below the wehrlites (i.e., derived from more primitive magmas) remains unknown.

There are increasing evidences that mineral phases are commonly not in equilibrium with their host glass/groundmass (e.g., Davidson et al., 2007; Francalanci et al., 2012; Moore et al., 2014; Ubide et al., 2014a,b). Large crystals in porphyritic rocks, which have traditionally been interpreted as phenocrysts, are demonstrated in many cases to be ‘antecrysts’; that is, large crystals that according to their chemical composition may not have shared common histories or crystallized from the magma in which they are now hosted. Rather, they may have grown within the same magmatic system but in a more primitive magma (Charlier et al., 2005; Davidson et al., 2007; Francalanci et al., 2012;

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Jerram and Martin, 2008; Larrea et al., 2013; Ubide et al., 2014a,b). Such antecrysts in basaltic rocks provides an opportunity to study the composition of more primitive magmas. Numerous mafic dykes occur in the Xiaohaizi area and crosscut the sedimentary strata and/or the Xiaohaizi cumulate wehrlites. One basaltic dyke crosscutting the sedimentary strata contains unusually abundant clinopyroxene macrocrysts. A careful mineralogical and geochemical study of these macrocrysts is critical to understand their origin and genetic relation to the cumulated rocks in the same area. It may also yield information for the lithology of the concealed pluton beneath the Xiaohaizi area.

In this study, we present in-situ major and trace element abundances, and Sr–Nd isotopic compositions of the clinopyroxene macrocrysts in the Xiaohaizi basaltic dyke. We demonstrate that these clinopyroxene macrocrysts are antecrysts rather than phenocrysts and are genetically related to the Xiaohaizi cumulate wehrlites. The Sr–Nd isotopic compositions of the clinopyroxene macrocrysts approximately represent that of the uncontaminated Tarim plume-derived melts.

2. Geological background

2.1. Regional geology

The Tarim Craton in northwest China is surrounded by the Tianshan orogenic belt to the north, and the Kunlun and Altyn orogenic belt to the south (Fig. 1a and b). The Tianshan orogenic belt is part of the Central Asian Orogenic Belt (CAOB) which is the largest Phanerozoic orogen in the world (Han et al., 2011 and references therein). The craton was amalgamated with the southern CAOB during the Late Paleozoic (BGMRXUAR, 1993; Han et al., 2011; Li et al., 2006) and is composed mainly of Archean tonalite–trondhjemite–granodiorite (TTG) gneisses and amphibolites, and Proterozoic metamorphic rocks, schist, marble, mafic dykes, bimodal volcanic rocks, granitoids and glacial deposits (BGMRXUAR, 1993; Hu et al., 2000; Lu et al., 2008). The basement is overlain by a thick sedimentary sequence that includes Ordovician, Permian and Cretaceous strata (BGMRXUAR, 1993; Zhang, 2003).

A large volume of Early Permian basalts, as well as ultramafic–mafic–felsic intrusions and mafic dykes, are exposed around the margins of the Tarim Craton. Because most of the surface of the craton is covered by the Taklamakan Desert, the full extent of the Tarim LIP remains uncertain. Industrial geophysical surveys and oil exploration suggest that the Permian basalts may extend over an area of 250,000 km^2–300,000 km^2 in the interior of the craton (Tian et al., 2010; Yang et al., 2007a). Based on compilation of published age data, the basaltic volcanism took place in the interval 292–286 Ma ago (Wei et al., 2014a). In addition to the voluminous flood basalts, several small-volume mafic–ultramafic intrusions also sporadically crop out at Bachu and Piqiang, closely associated with syenites and granitoids and crosscut by numerous mafic dykes and quartz syenite porphyries. They were formed mainly during 278–284 Ma (Li et al., 2011b; Yang et al., 1996, 2006, 2007b; Zhang and Zou, 2013; Zhang et al., 2008a, 2010a).

2.2. The Xiaohaizi intrusion and dykes

The early Permian Xiaohaizi intrusion is round in shape and crops out about 28 km southeast of the Bachu city in the Tarim Craton, southern part of Xinjiang Province (Fig. 1b). It is composed predominantly of syenites and quartz syenites (Wei and Xu, 2011) and subordinate cumulate wehrlites occurring around the syenites in the field (Fig. 1c). Industrial drilling has revealed large volume of mafic igneous rocks buried underground around the syenites (Wei et al., 2014b). One drill-core (ZK4202) has recovered about 750 m thick of cumulate wehrlites composed of cumulus olivine and clinopyroxene, and interstitial plagioclase and Fe–Ti oxides (Wei et al., 2014b). They form a surface exposure of >18 km^2, and intrude the Silurian–early Permian strata (BGMRXUAR, 1993). Previous investigations demonstrated that the Xiaohaizi syenites and wehrlites were emplaced during 277–282 Ma (Li et al., 2007; Wei

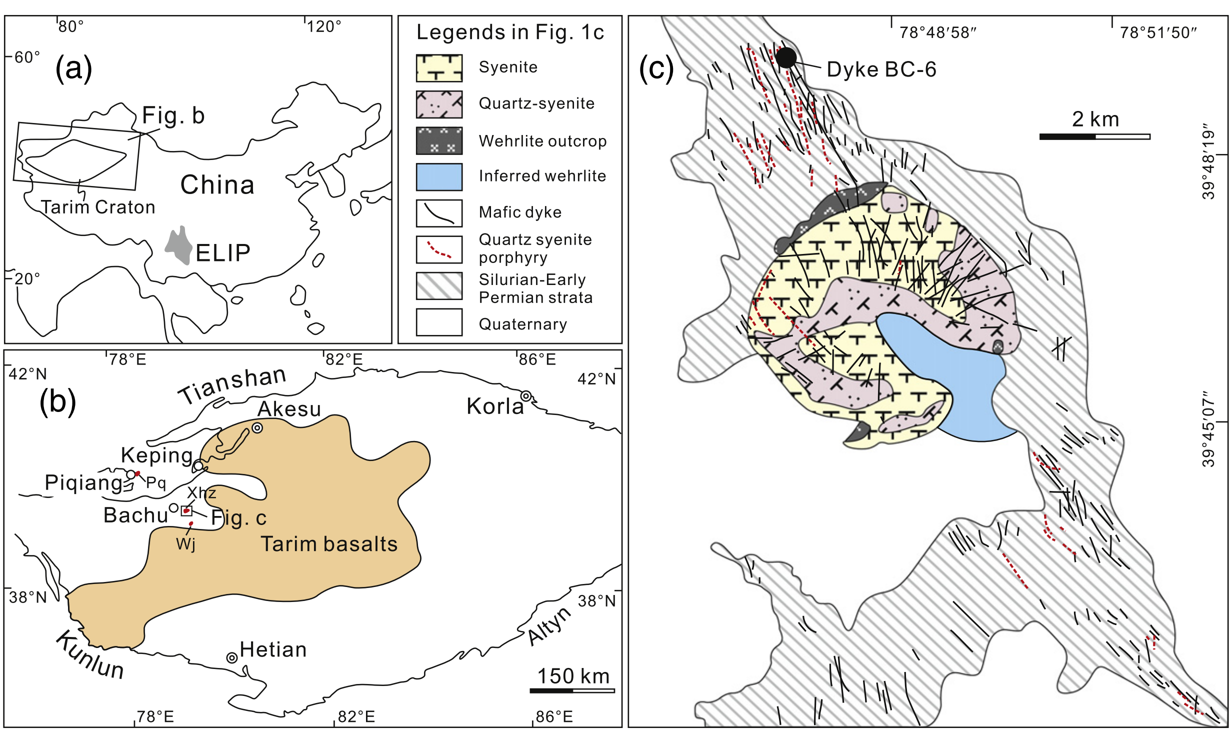

Fig. 1. (a) Locations of the Tarim Craton and Emeishan large igneous province (ELIP) with outline of (b) (modified after Zhou et al., 2009). (b) Simplified geological map of the Tarim Craton, showing the distribution of the Permian basalts and ultramafic–mafic–felsic complexes around Bachu in the Tarim Craton, Xinjiang Province (modified after BGMRXUAR, 1993; Yang et al., 2007a; Wei et al., 2014a). Abbreviations here: Xhz, Xiaohaizi intrusion; Wj, Wajilitag complex; Pq, Piqiang complex. (c) Detailed geological map of the Xiaohaizi syenites, wehrlite outcrops and inferred wehrlites from drill-cores (Wei et al., 2014b) crosscut by numerous mafic and felsic dykes in the Xiaohaizi area (modified after Wei et al., 2014a). Also shown is the location of the clinopyroxene macrocrysts-hosted dyke (BC-6; Wei et al., 2014a). Area expanded in (c) is outlined in (b).