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Petrogenesis of nephelinites from the Tarim Large Igneous Province, NW China: Implications for mantle source characteristics and plume–lithosphere interaction

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ABSTRACT

The nephelinite exposed in the Wajilitage area in the northwestern margin of the Tarim large igneous province (TLIP), Xinjiang, NW China display porphyritic textures with clinopyroxene, nepheline and olivine as the major phenocryst phases, together with minor apatite, sodalite and alkali feldspar. The groundmass typically has cryptocrystalline texture and is composed of crystallites of clinopyroxene, nepheline, Fe-Ti oxides, sodalite, apatite, rutile, biotite, amphibole and alkali feldspar. We report rutile SIMS U-Pb age of 268 ± 30 Ma suggesting that the nephelinite may represent the last phase of the TLIP magmatism, which is also confirmed by the field relation. The nephelinite shows depleted Sr-Nd isotopic compositions with age-corrected $^{87}Sr/^{86}Sr$ and $\varepsilon_{Nd}(t)$ values of 0.70348–0.70371 and +3.28 to +3.88 respectively indicating asthenospheric mantle source. Based on the reconstructed primary melt composition, the depth of magma generation is estimated as 115–140 km and the temperatures of mantle melting as 1540–1575 °C. The hotter than normal asthenospheric mantle temperature suggests the involvement of mantle thermal plume. The Mg isotope values display a limited range of $\delta^{26}Mg$ from −0.35 to −0.55‰, which are lower than the mantle values (−0.25‰). The Mg isotopic compositions, combined with the Sr-Nd isotopes and major and trace element data suggest that the Wajilitage nephelinite was most likely generated by low-degree partial melting of the hybridized carbonated peridotite/eclogite source, which we correlate with metasomatism by subducted carbonates within the early-middle Paleozoic convergent regime. A plume-lithosphere model is proposed with slight thinning of the lithosphere and variable depth and degree of melting of the carbonated mantle during the plume-lithosphere interaction. This model also accounts for the variation in lithology of the TLIP.

1. Introduction

Several important large igneous provinces (LIPs) have been identified in relation to the disruption of the global supercontinent Pangea including the Siberian (~251 Ma), Emeishan (~260 Ma), Tarim (~280–300 Ma) and Panjal (~290 Ma) LIPs (Fig. 1a; Kamo et al., 2003; Shellnutt, 2014; Shellnutt et. al., 2014; Xu et al., 2014; Zhou et al., 2002; Zhang et al., 2013). Many LIPs are produced within a few million years, e.g. Siberian Traps and Emeishan LIP. However, compared with the other typical LIPs, previous petrological studies of the TLIP (Tarim LIP) have documented a long duration of magmatism (erupted from ~300 Ma to ~280 Ma) and a wide range of magmatic rock suites with distinct geochemical features (Z.L. Li et al., 2011; Li, 2013; Xu et al., 2014; Zhang et al., 2008; Zhang et al., 2013). The longevity of magmatism and wide variety in lithology implies a different melt generation mechanism, and thus detailed research on the TLIP may provide important insights into the mechanism of formation of large igneous provinces. Previous studies had suggested that syenites in the TLIP mark the last phase of magmatism (Yang et al., 2006). Our recent detailed field investigations in the Wajilitage area located in the northwestern margin of the TLIP led to the discovery of minor volumes of nephelinite carrying xenoliths of syenite. This finding adds a new lithology to the already complex sequence in the TLIP and opens the possibility that the duration of the magmatism could be even longer than previously thought. Typically, the LIPs are interpreted to be the products of the interaction of mantle plume with lithospheric mantle (e.g. Campbell and Griffiths, 1990). If this is the case, the relationship between the complex lithology in the TLIP and the mantle plume-lithosphere interaction are of prime importance.

Nephelinites are generally rare on the Earth (less than 1%). Because they represent small volume deep mantle-derived magma, and have not been significantly contaminated by crustal materials due to the rapid ascent from the mantle to surface, these rocks provide important information on the nature of the mantle source, especially that of the deep mantle. Thus the Wajilitage nephelinite can be used to constrain

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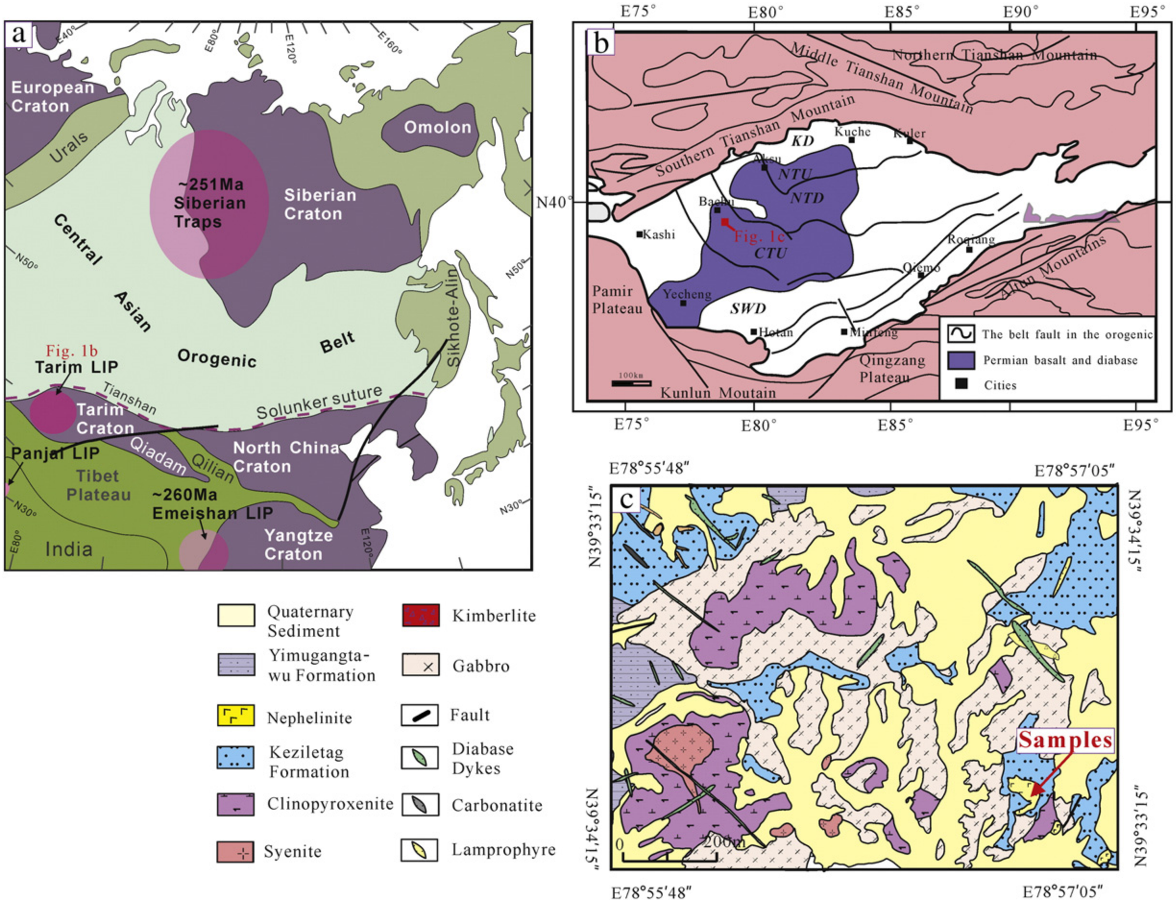

Fig. 1. (a) Distribution of the Permian flood basalts in Asia and the location of Siberian, Tarim and Emeishan large igneous provinces (modified after Z.L. Li et al., 2011). (b) Sketch geological map of the Tarim Basin showing the distribution of the Permian continental flood basalts (after Tian et al., 2010). Abbreviation: *KD* = Kuche depression; *NTU* = northern Tarim uplift; *NTD* = northern Tarim depression; *CTU* = central Tarim uplift; *SWD* = southwestern depression. (c) Simplified geological map of the Wajilitage area showing the location of the nephelinite lavas (modified after XBGMR, 1984).

the duration of the TLIP, and also to trace the mantle source compositions and the plume-lithosphere interaction. In this contribution, we report the rutile U-Pb age, major and trace element geochemistry as well as Mg-Sr-Nd isotopic data for the Wajilitage nephelinite. Based on the results, we attempt to characterize the mantle source compositions and melting conditions, which in turn have critical implications for the geodynamic evolution.

2. Geological setting

The Tarim Craton (TC) is among the three major cratons in China; the other two being the North China and Yangtze Cratons (Fig. 1a). The TC is predominantly composed of a complex Precambrian crystalline basement with a thick Phanerozoic sedimentary cover (C.L. Zhang et al., 2010; Cheng et al., 2014; Tian et al., 2010; Xu et al., 2014; Zhang et al., 2013). Silurian to Devonian arc rocks were found along the northern margin of the TC which were correlated to the southward subduction of the southern Tianshan ocean (440 to 360 Ma; e.g. Ge et al., 2012). Recent studies have revealed that a major Permian thermal event occurred in this region (Fig. 1b; e.g., Tian et al., 2010; Yu et al., 2011; Zhang et al., 2013; Zhou et al., 2009). As most of the surface of the TC is buried by the Taklamakan Desert, the information of the Permian igneous units are mainly from drill core and seismic data, together with several exposures along the margins of the Tarim Basin, such as Bachu, Keping and Puchang County. Systematic studies indicate that the Tarim igneous rocks are distributed within an area of 250,000–300,000 km^2 with an average thickness of 600 m (Fig. 1b; e.g. Xu et al., 2014), termed as Tarim large igneous province (Zhang et al., 2008; C.L. Zhang et al., 2010). The TLIP is considered as the second major LIP after the Emeishan LIP in China (e.g. Bryan and Ernst, 2008; C.L. Zhang et al., 2010; Tian et al., 2010; Xu et al., 2014).

The volcanic rocks in the TLIP consist mainly of flood basalts, with small volume of rhyolite, picrite and tuff (Chen et al., 2009; Li et al., 2012; Tian et al., 2010; Z.L. Li et al., 2011). Along the northwestern part of the TC, synchronous magmatic suites comprising small volume of A-type granites and mafic-ultramafic intrusions and dykes swarms have been also been recognized (C.L. Zhang et al., 2010; Cao et al., 2014; Yu et al., 2011; Zhang et al., 2008). The flood basalts lie over the Late Carboniferous Kangkelin Formation and are in turn covered by the Late Permian Shajingzi Formation. Hence, based on the stratigraphic correlation, the flood basalts are suggested to represent Early Permian magmatism. Stratigraphically, the Tarim flood basalts are intercalated with the Kupukuziman Formation and Kaipaizileike Formation, which include two and six volcanic-sedimentary cycles respectively (Xu et al., 2014; Zhou et al., 2009). Based on geochronological data, Xu et al. (2014) proposed that the Tarim magmatism can be divided into three major phases: 1) small volume of ~300 Ma kimberlitic rocks, which have been interpreted to mark the onset of plume-induced magmatism in the TLIP (Zhang et al., 2013); 2) ~290 Ma voluminous flood basalts and small volume of rhyolites with a bimodal nature, and mainly occurring in the interior of the Tarim Basin (e.g. Jiang et al., 2004; Tian et al., 2010; Zhou et al., 2009); and 3) ~280 Ma small volume of A-type granites and mafic-ultramafic intrusions and dykes swarms (Cao et al., 2014; Y.T. Zhang et al., 2010; Yu et al., 2011; Zhang and Zou, 2013a,b; Zhang et al., 2008). Furthermore, from the early pulse of flood basalts to the later emplacement of the intrusions, the Sr-Nd-Hf