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Geochemical and Sr–Nd–Pb–O isotopic compositions of the post-collisional ultrapotassic magmatism in SW Tibet: Petrogenesis and implications for India intra-continental subduction beneath southern Tibet

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ABSTRACT

Ultrapotassic lavas having distinct geochemical compositions (K_2O/Na_2O >2, K_2O >3%, and MgO >3%) are common and widespread on the Tibet Plateau, where they are closely linked to N–S-trending normal faults. The Tibetan ultrapotassic rocks range in age from ~8 to 24 Ma, slightly older than the spatially associated potassic rocks (10–22 Ma). These lavas consist mainly of trachyte, trachyandesite, basaltic trachyandesite, phonolite and tephriphonolite. They have high light rare earth element (LREE) and large ion lithophile element (LILE) concentrations, but are low in high field strength elements (HFSE). They are characterized by having extremely radiogenic Sr ($^{87}Sr/^{86}Sr_{(i)}=0.710719$ to 0.736451) and Pb isotopes ($^{206}Pb/^{204}Pb=$ 18.449–19.345, $^{207}Pb/^{204}Pb=15.717$–15.803, $^{208}Pb/^{204}Pb=39.443$–40.168) with unradiogenic Nd isotopes ($\varepsilon_{Nd(0)}=-7.6$ to -15) and old Nd model ages ($T_{DM}=1.3$–2.1 Ga), similar in character to the Himalaya crystalline basement. Their isotopic character is interpreted to reflect subduction of the Indian plate beneath the Lhasa terrane, leading to a highly contaminated mantle source. Delamination of the subducted oceanic/continental materials may have played an essential role in the genesis of the ultrapotassic rocks in the Lhasa terrane. The available geological, geochemical and geophysical data favor a model in which the Indian plate was subducted under southern Tibet.

1. Introduction

Northward subduction of the Indian plate beneath Tibet after the India–Asian convergence between about 55 and 65 Ma (Yin and Harrison, 2000) is one of the most interesting aspects of the geological evolution of the Tibetan Plateau, but the geological consequences of this subduction are unclear (Harrison et al., 1992; Yin and Harrison, 2000; Tapponnier et al., 2001; Johnson, 2002). Some tectonic models speculate that the Indian plate was underthrust or injected northward beneath part or all of Tibet, and link this process to the uplift of the plateau (Argand, 1924; Powell and Conaghan, 1973; Barazangi and Ni, 1982; Zhao and Morgan, 1987; Beghoul et al., 1993; Zhou and Murphy, 2005). Other models propose that the Indian plate was not emplaced beneath Tibet, but rather acted as a rigid block moving northward that caused thickening of the plateau (Molnar and Tapponnier, 1975; England and Houseman, 1986; Dewey et al., 1988;) and that led eventually to convective removal of the thickened lithospheric mantle (Houseman et al., 1981; England and Houseman, 1989). Some other models propose inward-dipping subduction (Kosarev et al., 1999; Tapponnier et al., 2001; Kind et al., 2002) or southward-directed subduction and roll-back (Willett and Beaumont, 1994). Recently acquired seismic and gravity data suggest downwelling of the Indian continental plate and its penetration into the deep lithosphere beneath the Bangong–Nujiang suture of central Tibet (Zhao et al., 1993; Jin et al., 1996; Owens and Zandt, 1997; Chen and Ozalaybey, 1998; Kosarev et al., 1999; Chemenda et al., 2000; Tilmann et al., 2003).

The widespread post-collisional magmatism that took place on the Tibetan Plateau from ~60 Ma onward provides a valuable indicator of the composition and nature of the deep lithosphere. It should record the convective thinning of the underlying lithospheric mantle and uplift of the plateau, which strongly impacted the Cenozoic global

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climate (Coulon et al., 1986; Arnund et al., 1992; Turner et al., 1993, 1996; Chung et al., 1998; Miller et al., 1999; Williams et al., 2001; Zhao et al., 2001; Ding et al., 2003; Nomade et al., 2004; Williams et al., 2004; Chung et al., 2005; Mo et al., 2006a; Guo et al., 2006; Gao et al., 2007a).

The Lhasa terrane in southern Tibet is the youngest of several terranes accreted to Asia and the closest to the suture between India and Asia. We have focused on the post-collisional ultrapotassic rocks in this terrane in order to understand their petrogenesis, to evaluate the nature of their source region, and to determine the nature of the relationship between the magmatism and the subduction of the Indian plate. We report new geochemical and isotopic data (Nd, Sr, Pb, and O isotopes) for the ultrapotassic rocks. Our results, together with other published data, show that the lithospheric mantle beneath the central and northern Tibetan Plateau (Qiangtang, Hoh Kil and West Kunlun) is an undisturbed, ancient enriched source region that has not changed since ~60 Ma. On the other hand, the mantle beneath the Lhasa terrane, although geochemically a part of this region, was strongly modified by subduction of Tethyan oceanic lithosphere and the Indian continent, particularly between about 8 and 24 Ma. We propose a two-stage upper mantle delamination model, coupled with subduction of the Indian plate, for the generation of the ultrapotassic, post-collisional magmatism of the Lhasa terrane.

2. Geological setting

2.1. Outline of Lhasa terrane

The Lhasa terrane is located in southern Tibet, between the Neo-Tethyan Bangong–Nujiang suture to the north and the Yarlung Zangbo suture to the south (Fig. 1). The Yarlung Zangbo suture marks the final collision between India and Asia at about 65 Ma (Mo et al., 2003). The southern part of the Lhasa terrane is dominated by the Gangdese batholith of late Cretaceous and early Tertiary age (Mo et al., 2005; Wen et al., 2008) and the Linzizong volcanic rocks, which were erupted between ~65 and 45 Ma (Zhou et al., 2004; Mo et al., 2006a). All of the magmatism is attributed to northward subduction of Tethyan oceanic lithosphere (Mo et al., 2007, 2008). Similar Andean-type, arc-related volcanic and intrusive rocks with Mesozoic ages are widely distributed in the middle and northern parts of the Lhasa terrane, where they are related to earlier subduction that formed the Bangong–Nujiang suture (Zhu et al., 2006).

Both the sedimentary strata and magmatic rocks in the Lhasa terrane trend east–west, roughly parallel to the Yarlung Zangbo suture. Paleozoic to Paleogene sedimentary rocks crop out in the central part of the terrane where they are associated with volcanic rocks (Yin and Harrison, 2000), such as the Jurassic–Cretaceous Yeba Formation and the Sangri Group (Zhu et al., 2008a,b). The Amdo amphibolite facies orthogneiss near the Bangong–Nujiang suture is the oldest crystalline basement known in the Lhasa terrane (852 Ma; Guynn et al., 2006). Intra-plate magmatism in the Lhasa terrane postdating the Asia–India collision is represented by ore-bearing adakites (18–12 Ma; Chung et al., 2003; Hou et al., 2004; Guo et al., 2007; Gao et al., 2007b), and potassic and ultrapotassic volcanic rocks (~24–8 Ma; Chung et al., 2005; Mo et al., 2006a). These volcanic rocks have been studied extensively over the last decade and have yielded important information on the Cenozoic evolution of the Tibetan Plateau.

2.2. General features of postcollisional potassic and ultrapotassic rocks in the Lhasa terrane

The definition of “ultrapotassic rocks” introduced by Foley et al. (1987) is based on their whole-rock chemistry other than mineralogy. The ultrapotassic rocks (K_2O/Na_2O >2, K_2O >3%, and MgO >3%) can be further divided into three sub-groups (I—lamproites, II—kamafugites and III—other rocks that occur in orogenic areas). Most of these rocks contain not only olivine, but also K-rich minerals, such as leucite and phlogopite. Commonly, ultrapotassic rocks are associated with large or super-large Cu–Au deposits (Müller and Groves, 2000).

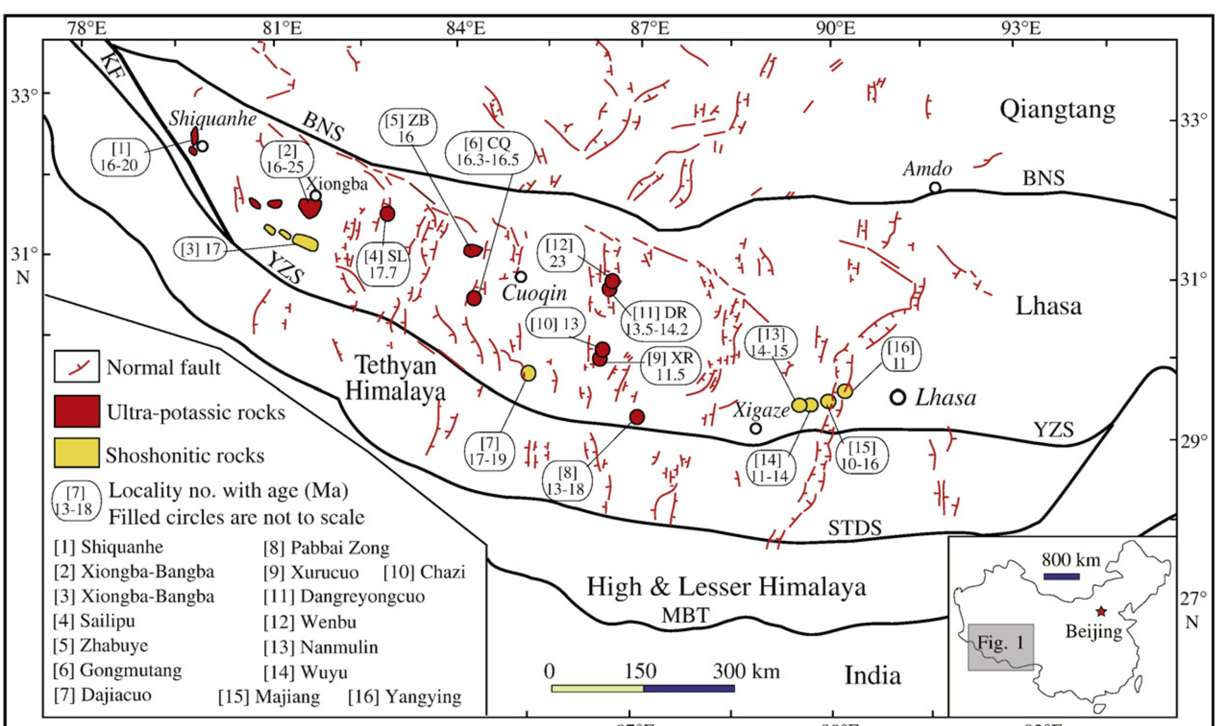

Fig. 1. Distribution of post-collisional shoshonitic and ultrapotassic volcanic rocks in the Lhasa terrane, southern Tibet (modified from Zhao et al., 2006). See Table 1 for descriptions of locality, rock type, age and data sources with the same field number for the rocks. North–south trending normal faults are after Blisniuk et al. (2001). MBT = Main Boundary Thrust; STDS = South Tibet Detachment System; YZS = Yarlung Zangbo Suture; KF = Karakorum Fault; BNS = Bangong–Nujiang Suture.