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Late Paleozoic underplating in North Xinjiang: Evidence from shoshonites and adakites

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ABSTRACT

Shoshonitic series volcanic rocks (SSVR) and adakites are widely distributed in the Permian terrestrial volcanic strata of the Yishijilike–Awulale range of west Tianshan, north Xinjiang, China. Isotopic dating yields Permian ages of 280–250 Ma. The SSVR include absarokite, shoshonite and banakite which are characterized by enrichment of alkalis, particularly in K, combined with lower Ti, higher Al (A/NKC = 0.70–0.99, metaluminous) and $Fe_2O_3 > FeO$. The SSVR that are rich in LILE with high REE contents and Eu/Eu* range from 0.59 to 1.30. They are rich in LREE ($(La/Yb)_N$ 2.15–11.97) and depleted in Nb, Ta and Ti (TNT negative anomalies). The adakites are metaluminous to weakly peraluminous (A/NKC = 0.85-1.16) and belong to the high-SiO_2 type of adakite (HSA, SiO_2 = 62%–71%). They are characterized by lower ΣREE with strong LREE enrichment ($(La/Yb)_N$ 13–35). Pronounced positive Eu anomalies (Eu/Eu* = 1.02–1.27), very low Yb contents and distinct TNT-negative anomalies are evident. The SSVR have $\varepsilon_{Nd}(t)$ (+1.28 to +4.92) and $(^{87}Sr/^{86}Sr)_i$ (0.7041–0.7057) that are similar to adakites in the regions which are characterized by $\varepsilon_{Nd}(t)$ = 0.95 to +5.69 and $(^{87}Sr/^{86}Sr)_i$ = 0.7050–0.7053. Trace element, REE and Sr/Nd isotopic compositions suggest that both SSVR and adakites possess similar source regions associated with underplated mantle-derived basaltic materials. Lithosphere extension driven by magmatic underplating was responsible for the generation of both the SSVR and adakites. This magmatism serves as a petrological indicator of underplating during the Permian. Obviously thickened crust (62–52 km), a complex Moho discontinuity, high heat flow (~100 $mw \cdot m^{-2}$), widespread contemporary alkali-rich granites, basic dike swarms (K–Ar ages of 187–271 Ma, Ar–Ar ages of 174–270 Ma and Rb–Sr ages of 255 ± 28 Ma; $\varepsilon_{Nd}(t)$ + 1.84 to + 10.1; $(^{87}Sr/^{86}Sr)_i$ 0.7035 and 0.7065), and basic granulites (SHRIMP U–Pb age of 268–279 ± 5.6 Ma) provide additional evidences for the underplating event in this area during Permian.

1. Introduction

Underplating refers to the process of emplacement or addition of mantle-derived basic magma to the base of the lower crust (Furlong and Fountain, 1986; Jin and Gao, 1996). As an important mechanism of crust-mantle interaction and vertical accretion of the crust, the underplating process has attracted a more widespread interest. Granitoids and associated rocks in particular have studied widely in understanding crustal evolution and continental growth (e.g., Stern, 2008; Rino et al., 2008; Ye et al., 2008). Continental growth in the Phanerozoic, particularly the late Paleozoic of the North Xinjiang has attracted much attention since the authors (Zhao et al., 1989, 1993a,b, 2006) first reported that late Paleozoic granitoids along the south margin of the Altay Mountains possess higher $^{143}Nd/^{144}Nd$ and positive $\varepsilon_{Nd}(t)$ and their source region was juvenile crust. The 1998 IGCP-420 Project lead by Prof. Bor-ming Jahn in 1998 promoted an investigation into the Phanerozoic of North Xinjiang as well as central east Asia orogenic belt (CEAOB), and a suite of late Paleozoic granitoids with high $^{143}Nd/^{144}Nd$ and positive $\varepsilon_{Nd}(t)$ were found (Kovalenko et al., 1996; Zhou et al., 1996; Han et al., 1997; Jahn, 1998; Jahn et al., 2000a,b; Chen et al., 2000; Hong et al., 2000; Wu et al., 2000; Chen and Jahn, 2004). Zhao et al. (1993a,b, 1996) proposed that the granites along the south margin of the Altay Mountains resulted from partial melting of juvenile crust and the alkali-rich granites in Ulungur area from higher degree fractional crystallization of depleted-mantle. Han et al. (1997) considered that the alkaline granites were derived from altered depleted-mantle. Zhou et al. (1996) argued that the Alataw granites were derived from the mixing of crust and mantle. In contrast, Hong et al. (2000) suggested new crust formed by subducted ocean crust may have been the source region. The formation mechanism of juvenile crust or mantle-derived materials was widely considered to be related to underplating. Jahn (1998) proposed that the underplating mantle-derived magma interacted and melted together with pre-existing granulite. Han et al., (1996) suggested that the underplating of mantle-derived magma took place on the crust-mantle interface or in the lower crust. Hong et al. (2000) considered that the underplating of basic magma promoted the partial melting of the crust formed by subducted ocean crust prior to 800–600 Ma.

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Additional evidence for the underplating event during the Late Paleozoic in north Xinjiang, has been reported in various studies (Yang et al., 2007; Wang et al., 2008; Xiao et al., 2008; Gao et al., in press). Since 2000, late Paleozoic shoshonitic series volcanic rocks (Zhao et al., 2000, 2004a,b) and adakites (Xiong et al., 2001; Xu et al., 2001; Wang et al., 2003; Zhang et al., 2004; Xiong et al., 2005; Zhang et al., 2005) have been found in North Xinjiang. Zhao et al. (2006) divided the adakites of this area into a subduction-related type and an underplating-related type. The shoshonitic series volcanic rocks (SSVR), underplating-related adakites, alkali-rich granites and alkaline rocks constitute an alkali-rich igneous province in North Xinjiang (Zhao et al., 2000, 2004a,b). Permian (248–292 Ma) bimodal dykes of the adjacent Tarim Basin were recognized which indicate large-scale extension (Li et al., 2008). The late Paleozoic granites in east Tianshan with low $(^{87}Sr/^{86}Sr)_I$ ratios, relative high $^{143}Nd/^{144}Nd$ ratios and association with contemporaneous mafic and ultramafic rocks are related to the underplating event (Wang et al., 2008). From the above, it can be deduced that extensive underplating of mantle-derived magma and obvious continental growth took place during Permian times. These processes are the focus of this paper, which considers the petrology, REE and trace element geochemistry and Sr and Nd isotopic compositions of adakites and (SSVR) together with the data of a global geosciences transect (GGT) across this area, such as thickening crust, complex Moho discontinuity structure and high heat flow.

2. Shoshonitic series volcanic rocks (SSVR) and adakites as an important indicator of continental growth

2.1. Distribution of shoshonitic series volcanic rocks and adakites

The SSVR are mainly distributed in two areas, i.e., Erqisi and West Tianshan volcanic belts. The SSVR in the former are mainly composed of middle Devonian D_2 (Beitashan–D_2b, Yundukara–D_2y and Kasxiweng–D_2k groups), lower Devonian D_1t (Tuoranggekuduke Group) (partly), and lower Carboniferous C_1 (Nanmingshui–C_1n and Batamayineishan–C_1b Groups). Contemporaneous adakites from these areas not discussed in this paper because they are both related to oceanic slab subduction.

The Permian volcanic-sedimentary rocks in Tianshan are mainly composed of basic to acid rocks, which are mostly porphyries, but lack the association of andesite, dacite and rhyolite, and sedimentary rocks containing plant fossils (Zhao Junmen et al., 2003).

The SSVR constitute the majority of Permian volcanic rocks in the region and are mainly distributed in the west Tianshan volcanic belt where they are concentrated in the Yishijilike–Awulale range (from Kangsugou in the north of Zhaosu county to Naraqin on the east of Nileke county) and the east section of the Nalaqin range (from Nalaqin to Bayinbuluke). The Permian adakites of the Awulale range are mainly distributed in the area from Heishantou to Bugulagou area, around Nileke country. They are less common in the Sanchakou area of East Tianshan. The adakites are temporally and spatially associated with the SSVR, forming an E–W trending belt (Fig. 1).

2.2. Analytical methods

Major element contents were analyzed by conventional wet chemical techniques with precision 2–5%(Li, 1997). The REE and trace elements were determined by a Perkin-Elmer Sciex ELAN 6000 ICP-MS at the Guangzhou Institute of Geochemistry, Chinese Academy of Sciences. About 50 mg of powder sample was dissolved in high-pressure Teflon bomb using a $HF+HNO_3$ mixture. An internal standard solution containing the element Rh was used to monitor the signal drift counting. The USGS standards BCR-1 and BHVO-1 were chosen for calibrating element concentrations. The analytical precision for most elements was generally better than 5% (Liu et al., 1996; Li, 1997).

Sr and Nd isotopic compositions were determined on a Finnigan MAT-262 spectrometer at the Institute of Geology and Geophysics, Chinese Academy of Sciences, using the similar analytical procedure as Li and McColloch (1996). The $^{87}Sr/^{86}Sr$ ratio of standard NBS987 and $^{143}Nd/^{144}Nd$ ratio of the La Jolla standard measured during this study were 0.710234 ± 7 (2σ) and 0.511838 ± 8 (2σ), respectively. Measured $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios were normalized to $^{87}Sr/^{86}Sr=0.1194$ and $^{143}Nd/^{144}Nd=0.7219$, respectively.

The samples for Ar–Ar dating were wrapped in Sn foil and seated in 6-mm-ID evacuated quartz-glass vials together with standard (biotite) flux monitors, and irradiated for 37 h at Beijing Nuclear Research Center. All samples were step-heated using a radio-frequency finance. The Ar isotope analyses were conducted on a MM-1200 mass spectrometer at the Laboratory of Analysis Center, Guilin Resource and Geological Institute. The monitor standard was the ZBH-25 (biotie, 132.5 Ma) and ages were calculated using the constants recommend by Steiger and Jager (1977). All errors are quoted at 1σ level and do not include the uncertainly of the monitor age. The experimental procedures were described by Dai and Hong (1982) and Wang et al. (2003).

The U–Pb isotopic analyses of single zircon were performed using a Perkin-Elmer Sciex ElAN 6000 at Northwest University. A 30–40 μm of

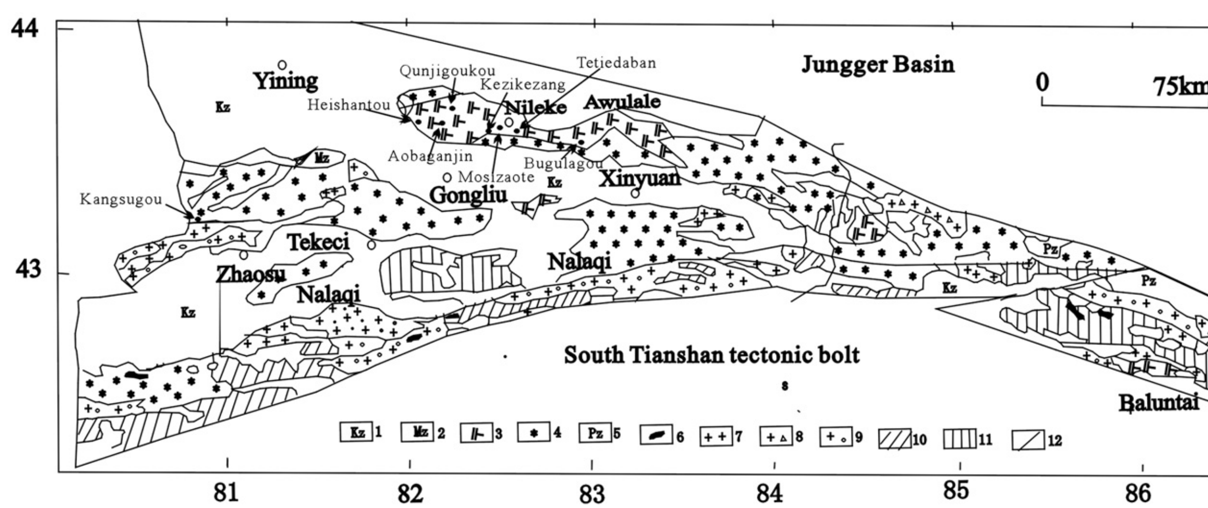

Fig. 1. Sketch map showing the distribution of shoshonitic volcanic rocks and adakites in West Tianshan. 1.Cenozoic; 2.Mesozoic; 3. Permian volcanic rocks (adakite, shoshonitic series; 4. Carboniferous volcanic rocks; 5. Proterozoic; 6. Ultramafic rocks; 7. Alkali-rich granites (C_1–P_2); 8. Syenite porphyry; 9. Paleozoic granite; 10. Proterozoic basement; 11. Proterozoic basement; 12. Fault.