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Geochronology and geochemistry of late Archean adakitic plutons from the Taishan granite–greenstone Terrain: Implications for tectonic evolution of the eastern North China Craton

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ABSTRACT

Three groups of coeval plutonic rocks with different petrogenetic histories and geochemical features have been recognized in the Late Archean Taishan granite–greenstone terrain (TSGT) in the Eastern Block of the North China Craton. Zircon U–Pb dating indicate that they were emplaced contemporaneously at around 2.54 Ga. Geochemically, all of the three groups have high Al_2O_3 and Sr concentrations, low Y and Yb concentrations, and high Sr/Y and La/Yb ratios. They have high-SiO_2 concentrations ranging from 57.56 to 67.98 wt%, indicating that they are typical high-SiO_2 adakites. Granodiorites from the Taishan area and monzodiorites from the Zoucheng area have similar geochemistries. However, the Zoucheng monzodiorites have wider ranges in element concentrations than the Taishan granodiorites, with the latter having higher Mg numbers. The Yishui monzodiorites have higher MgO, Cr, and Ni concentrations, higher Mg numbers, and lower SiO_2 concentrations, but similar REE and spidergram patterns to the Zouchang and Taishan intruisions. These geochemical features indicate that their parental magmas were all derived from the partial melting of a downgoing oceanic slab. The Zoucheng high-SiO_2 adakitic rocks were probably produced by this process alone; however, the Taishan and Yishui high-Si adakite groups were formed by interaction between primary adakitic melts and overlying peridotitic mantle. In combination with coeval sanukitoid or low-SiO_2 adakitic magmatism in the study area, the rock association indicates partial melting of a peridotitic mantle wedge that was metasomatized by adakitic melts and aqueous fluids derived from the subducting slab, the presence of these three high-SiO_2 adakite groups supports a genetic model involving slab subduction in the Late Archean (~2.54 Ga). The adakitic intrusions and associated rocks in the region postdate the earlier (~2.7–2.6 Ga) voluminous TTG rocks suggesting that the angle of subduction changed from flat or shallow subduction, to steeper subduction likely related to the arrival of an oceanic plateau or thickened lithospheric keel at the subduction zone.

1. Introduction

Defant and Drummond (1990) first defined 'adakite' as an unusual type of magnesian andesite characterized by high Sr and low Y and Yb concentrations, and high Sr/Y and La/Yb ratios, originally found near Adak Island in the Aleutians. Increasing numbers of adakites or adakitic rocks have been described over the entire geological timescale, from Archean granite–greenstone belts to modern-day occurrences associated with subduction zones around the Pacific Rim (e.g., Kay and Kay, 1993; Peacock et al., 1994; Stern and Kilian, 1996; Jego et al., 2005; Smithies et al., 2005; Zhou et al., 2006; Manya et al., 2007; Naqvi and Rana Prathap, 2007; Zhao et al., 2007; Gregoire et al., 2008; Naqvi et al., 2009). Actually, it is difficult to relate older adakites and associated suites formed in extinct magmatic systems to tectonic settings, particularly within the Archean. It is well known that Archean crustal lithologies are dominated by tonalites, trondhjemites, and granodiorites, collectively identified as TTGs (Jahn et al., 1981; Martin et al., 1983). Moreover, these rock suites have similar features to adakites, including highly fractioned rare earth element (REE) patterns and high Sr/Y and La/Yb ratios barring their high SiO_2 and low Mg number ($SiO_2 > 64$ wt%, commonly, ~70 wt%; Mg# < 50, with an average of 0.43; Smithies, 2000; Martin et al., 2005). Therefore, identification of typical adakites or adakitic rocks within the Archean supracrustal rock series, particularly in the granite–greenstone belts, is very important to better understand the formation and evolution of crust at that time because the Archean was a significant period of widespread and voluminous crust formation, with about 90% of existing crust having formed during this period, especially during the Late Archean (Manya et al., 2007). Recently, voluminously minor adakites or

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adakitic rocks coexisting temporally and spatially with TTGs have been discovered from different granite–greenstone belts in worldwide cratons, such as the Dharwar craton of India (Naqvi and Rana Prathap, 2007; Manikyamba et al., 2009; Naqvi et al., 2009), the Superior Province of Canada (Ujike et al., 2007), the Pilbara craton of northwestern Australia (Smithies et al., 2005), the Tanzania craton in Africa (Manya et al., 2007) and the North China Craton (Wang et al., 2004).

The Eastern Block of the NCC is an important area, in which the oldest rocks in China (~3.8 Ga) were discovered (e.g., Zhao et al., 2001) and the similar key ~2.75–2.50 Ga crust-forming and tectonothermal events to other Archean cratons around the word have been identified, such as the occurrence of voluminous TTG series and minor of typical greenstone suites and intrusive rocks (Jahn et al., 1988; Cao et al., 1996; Zhang et al., 2001; Yang et al., 2008; Wang et al., 2009; Wan et al., 2011). Many recent works have revealed two crucial crust-forming episodes in the Eastern Block of NCC, mainly based on the geochronology and Nd–Hf isotope model ages for the late Archean supracrustal series and associated rocks (Jahn et al., 1988; Zhao et al., 2001; Wu et al., 2005a; Polat et al., 2006; Yang et al., 2008; Wan et al., 2011). However, more precisely geochronological data and systematically geochemical investigations for the late Archean supracrustal rock suites and intrusive rocks in the Eastern Block are still rare so far (Yang et al., 2008; Li et al., 2010), especially in the case of 2.60 ~ 2.50 Ga magmatism in the TSGT (Jahn et al., 1988; Wang et al., 2009). It still remains unknown about the real petrogenesis of these igneous rocks and even geodynamic mechanism of crustal formation in the late Archean in the Eastern Block. In this contribution, we present new geochronological and geochemical data for Late Archean intermediate–felsic plutonic rocks with adakitic affinities within the TSGT. The data are used to reveal their chronology, petrogenesis and tectonic setting, which provide further constraints on the early Precambrian evolution of the NCC.

2. Geological setting and petrography

The North China Craton formed by the amalgamation of the Eastern and Western Blocks along the Trans-North China Orogen at ~1.85 Ga (Fig. 1a; Zhao et al., 1999a,b, 2000, 2001, 2005, 2006, 2007, 2008a,b; Li and Kusky, 2007; Trap et al., 2007; Kröner et al., 2006; Liu et al., 2006; Zhang et al., 2006, 2007, 2009; Li et al., 2010; Wang et al., 2009). The Western Block is further subdivided into the Yinshan Block in the north and the Ordos Block in the south, which amalgamated along the Khondalite Belt at ~1.95 Ga (Fig. 1a; Zhao et al., 2003, 2010; Xia et al., 2006a,b, 2008, 2009; Zhao, 2009; Yin et al., 2009, 2011; Zhou et al., 2010), whereas the Eastern Block experienced a rifting event at ~1.90 Ga, forming the Jiao-Liao-Ji Belt (Fig. 1a; Luo et al., 2004, 2008; Li et al., 2005, 2006; Li and Zhao, 2007; Zhou et al., 2008; Tam et al., 2011). The Eastern Block is dominated by ~2.7–2.6 Ga TTG gneisses, mafic–ultramafic igneous rocks, ~2.52 Ga diorite, granodiorite, monzogranite and K-feldspar granite plutons, and ~2.5 Ga syntectonic charnockites, with minor 2.55–2.50 Ga bimodal volcanics and sedimentary supracrustal rocks (Zhao et al., 1998, 2001, 2005; Wu et al., 2005b, 2008; Yang et al., 2008; Jiang et al., 2010; Li et al., 2010; Wan et al., 2011). At present, the oldest known basement within the craton is located in the Eastern Block, which has been dated at 3.8 Ga (Liu et al., 1992; Wu et al., 2005a,b; Nutman et al., 2011).

The TSGT is located in western Shandong Province, within the Eastern Block, and consists of Middle Archean to Paleoproterozoic basement, partially overlain by Paleoproterozoic to Cenozoic platform cover. The Neoarchean (2.9–2.5 Ga) basement outcrops widely and is dominated by ~2.7–2.6 Ga TTG gneisses and gneissic monzogranites, accounting for 80% of the total Precambrian basement in the TSGT (Jahn et al., 1988; Kröner et al., 1998; Zhang et al., 2001). Minor ~2700–2600 Ma ultramafic to felsic volcanic and sedimentary rocks, collectively defined as the Taishan greenstone belt, occur as lenses within the TTG gneisses (Xu et al., 1992; Cao et al., 1996; Zhang et al., 2001). In addition, a number of Late Archean pyroxenite, gabbro, diorite, granodiorite, and granite plutons intrude the TTG gneisses within the TSTG (Jahn et al., 1988; Cao et al., 1996; Wu et al., 1998); field observations suggest that these later plutons are metamorphosed at lower grades than the gneissic country rocks. Recent SHRIMP zircon U–Pb dating (Table 1) yielded ages between 2535 and 2555 Ma for diorite (Hou et al., 2008; Wang et al., 2009), between 2530 and 2562 Ma, with a mean age of 2536 ± 9 Ma for granites (Shen et al., 2004, 2007; Zhao et al., 2008a; Table 1). Both diorites and granites have similar emplacement ages, suggesting that they have been emplaced at the same time.

Samples were collected from the Taishan (Fig. 1b), Zoucheng (Fig. 1c), and Yishui areas (Fig. 1d). Their spatial distributions are shown in Fig. 1a. Previous fieldwork and petrological studies indicate that rocks in the Taishan and Yishui areas are biotite granites, whereas those from the Zoucheng area are trondhjemites (Jahn et al., 1988; Shen et al., 2004, 2007; Zhang et al., 2001). However, mineralogically, the plutonic rocks from the Taishan area are granodioritic in composition whereas rocks from the Zoucheng and Yishui areas are monzodioritic (Fig. 2). The biotite granodiorite is grey, medium- to coarse-grained, and composed of subhedral plagioclase (30–40%), K-feldspar (10–20%), quartz (10–20%), and hornblende (10–30%), with minor biotite and pyroxene, and accessory minerals, e.g. apatite, zircon, magnetite, and allanite. The monzodiorite is grey to dark grey and contains plagioclase feldspar (typically andesine), K-feldspar, hornblende, minor pyroxene and biotite, and accessory zircon, apatite, magnetite, allanite, and titanite.

3. Analytical methods

3.1. Zircon U–Pb dating

U–Pb isotope compositions of zircon grains were analyzed with an Agilent 7500a quadrupole inductively coupled plasma–mass spectrometer (ICP–MS) connected to a GeoLas PLUS 193 nm ArF excimer laser ablation (LA) system, based on an upgraded Lambda Physik GeoLas CQ system, at the Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, China. Helium carrier gas transported ablated sample material from the LA cell via a mixing chamber to the ICP–MS after mixing with Ar gas. Between every five unknown analyses, standard zircon 91500 and NIST SRM 610 standards were analyzed. Details of the analytical techniques utilized are given in Wu et al. (2006). The U–Pb ages were calculated using the U decay constants of Steiger and Jager (1977) and IsoplotEx 3 software (Ludwig, 2003). Individual analyses are presented with 1σ error in Table 2

and in Fig. 3b and c, and age uncertainties are quoted at the 95% confidence level.

3.2. Whole-rock geochemical analyses

All samples had weathered rims removed and were crushed to millimeter-size chips prior to handpicking under a binocular microscope. Fresh chips were selected and washed in an ultrasonic bath before being crushed to <200 meshes in a tungsten carbide jaw crusher. A split of this sample was ground to <200 meshes in an agate ring mill, and this material was used for major and trace