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Source of Mesozoic intermediate-felsic igneous rocks in the North China craton: Granulite xenolith evidence

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ABSTRACT

Four intermediate to felsic igneous rocks from the Zhangjiakou region, along the northern margin of the North China craton, have magmatic zircon U–Pb ages from 122 to 144 Ma. Two of these samples have inherited zircon U–Pb ages of ~2.5 Ga, similar to the zircon ages of rocks from the surrounding granulite terrain. Zircons from two intermediate composition granulite xenoliths (JN0811 and JN0919) in the nearby Cenozoic Hannuoba basalts yield two groups of ages. The rims have concordant Mesozoic ages mostly between 120 and 145 Ma, coeval with the Mesozoic intermediate-felsic magmatism in the region, while the cores have discordant U–Pb ages with upper-intercepts of ~2.5 Ga, overlapping the zircon ages of granulite terrain rocks, and lower-intercept ages of ~130 Ma, approximating the ages of the Mesozoic intermediate-felsic magmatism. The Sr–Nd isotopic compositions of the Mesozoic intermediate-felsic igneous rocks are completely different from those expected for basaltic melts from either the lithospheric mantle or the asthenospheric mantle, precluding a derivation by extensive fractional crystallization of mantle-derived magmas. The lack of correlation between $(^{86}Sr/^{87}Sr)_i$, $\varepsilon_{Nd(t)}$ and SiO_2 for the Mesozoic igneous rocks, the very narrow range of zircon $\varepsilon_{Hf(t)}$ for individual intermediate-felsic igneous rocks, and simple binary mixing calculations argue against them being formed by mixing between mantle-derived magma and preexisting crust that has extremely evolved Sr–Nd isotopic compositions like granulite xenoliths JN0811 and JN0919. Hf isotopic compositions of the Mesozoic zircons and whole-rock geochemistry show that the granulite xenoliths with extremely evolved Sr–Nd isotopic compositions have not undergone partial melting during the Mesozoic and thus do not contribute to the Mesozoic intermediate-felsic magmas. Further comparisons show that the source rocks for the Mesozoic intermediate-felsic magmas likely were late Archean lower crustal rocks similar in chemical and isotopic compositions to rocks with $SiO_2 < 62$ wt.% from the granulite terrain. If so, pyroxene-rich mafic granulite xenoliths found in the Hannuoba basalts could be restites left behind after the partial melting of the late Archean lower crust. The results shed new light on the origin for Mesozoic zircons in granulite xenoliths from Nushan, at the southern margin of the North China craton. We suggest that the widespread Mesozoic intermediate-felsic igneous rocks in the eastern North China craton are most likely derived from partial melting of the intermediate-mafic rocks of the late Archean lower crust.

1. Introduction

Intermediate to felsic composition igneous rocks are the most abundant constituents of the upper continental crust. Because of their lithological and geochemical diversity, however, the origins of intermediate-felsic rocks remain a subject of much debate. Some intermediate-felsic rocks may form by fractionation of mantle-derived magmas with or without contamination by preexisting crustal rocks (Kemp et al., 2007; Schmitt et al., 2002), thereby representing new additions to the crust. Others may be derived by partial melting of middle to lower crust (Jiang et al., 2007; Jung et al., 2002; Pankhurst and Rapela, 1995), thus reflecting reworking of pre-existing crust.

The sub-continental lithospheric mantle beneath the eastern part of the North China craton is widely regarded to have experienced considerable thinning during the Phanerozoic (Gao et al., 2002; Griffin et al., 1998; Menzies et al., 1993). Accompanying the lithospheric thinning, Mesozoic magmatism, which is dominated by felsic rocks with subordinate intermediate rocks and minor mafic rocks, is extensive and widespread in the eastern North China craton. Most of the Mesozoic intermediate-felsic rocks have evolved Sr–Nd isotopic compositions and have been variably interpreted to be derived from ancient lower crust (Jiang et al., 2007), Mesozoic newly underplated

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lower crust (Cai et al., 2005) and an enriched lithospheric mantle with or without incorporation of a small amount of lower crustal components (Chen et al., 2003, 2004). Also, the extent of this magmatism raises a number of important questions. How does the lower crust act in response to the lithospheric thinning? What role does the lower crust play in the genesis of the Mesozoic magmatism?

Abundant mantle and lower crustal xenoliths are entrained in the Cenozoic Hannuoba basalts in the Zhangjiakou region along the northern margin of the North China craton. In the same area, Precambrian granulites and Mesozoic intermediate-felsic volcanic and intrusive rocks are widely distributed (Fig. 1). The granulite terrain has been considered to represent an exposed Archean lower crustal section (Zhai, 1996). The coexistence of mantle-derived alkalic basalts, upper mantle xenoliths, lower crustal xenoliths, Precambrian granulite terrain and Mesozoic magmatism provides a unique opportunity to investigate whether the lower crustal granulite xenoliths are remnants of the Precambrian lower crust or underplated products of Mesozoic mantle-derived magmas. The xenoliths also can be used to address the question of whether the Mesozoic intermediate-felsic igneous rocks reflect growth of new continental crust, reworking of older crust, or mixing between new mantle-derived magmas and older crust. In this paper, U–Pb zircon ages and whole-rock chemical and isotopic measurements are reported for seven granulite xenolith samples and four Mesozoic intermediate-felsic rocks from the Zhangjiakou region. This work builds on a previous study (Jiang and Guo, 2010), expanding the dataset discussed previously to include 10 new samples along with Hf isotope data for all the zircons analyzed for U–Pb systematics. The Hf isotope data, in particular, add important new constraints on the relationship of the granulites to the Mesozoic igneous events. We use these new data in conjunction with literature data to constrain the age, compositional and isotopic compositions of the source rocks for the Mesozoic intermediate-felsic rocks in the Zhangjiakou region. The results are further compared with data for the Nushan granulite xenoliths at the southern margin of the north China craton and for Mesozoic intermediate-felsic rocks occurring in other parts of the North China craton.

2. Geologic setting

The North China craton can be divided into the Eastern Block, the Western Block and the intervening Trans-North China Orogen based on age, lithological assemblage, tectonic evolution and P–T–t paths. The craton was stabilized during late Paleoproterozoic time and subsequently covered by a thick sequence of Proterozoic to Paleozoic sediments (Zhao et al., 2001). The sub-continental lithospheric mantle beneath the eastern part of the North China craton appears to have experienced a dramatic change from a Paleozoic cratonic mantle to a Cenozoic "oceanic" lithospheric mantle, accompanied by considerable thinning of the lithosphere (Gao et al., 2002; Griffin et al., 1998; Menzies et al., 1993). In the Mesozoic, the eastern part of the craton experienced widespread tectonothermal reactivation. Mesozoic igneous (both volcanic and intrusive) rocks are widely distributed in the eastern North China craton. The Mesozoic igneous rocks are dominated by felsic rocks, with subordinate intermediate rocks and minor mafic rocks.

The Zhangjiakou region is situated at the northern margin of the North China craton (Fig. 1). Mesozoic intermediate-felsic volcanic and intrusive rocks are widely distributed in the region. The Cenozoic Hannuoba basalts cover an area of 1700 km^2 and entrain abundant mantle and lower crustal granulite xenoliths. Surface exposures of the granulite terrain occur nearby and consist mainly of granulites of mafic to silicic composition with subordinate amphibolite facies rocks. The rocks have been considered to represent an exposed lower crustal section (Zhai, 1996). U–Pb zircon dating yields both ~2.5 and ~1.8 Ga ages for rocks from the terrain. The ~2.5 Ga ages were considered to reflect their protolith age while the ~1.8 Ga ages were interpreted to date metamorphism (Guo et al., 2005; Jiang et al., 2010). Further comparisons show that granulites from the terrain are different from the granulite xenoliths. Although the granulite xenoliths might just sample unexposed portions of this shallow granulite terrain, the granulite xenoliths show a number of differences compared to the rocks of the exposed granulite terrain. Mineralogically, amphibole is a ubiquitous mineral in the granulites from the terrain while absent in

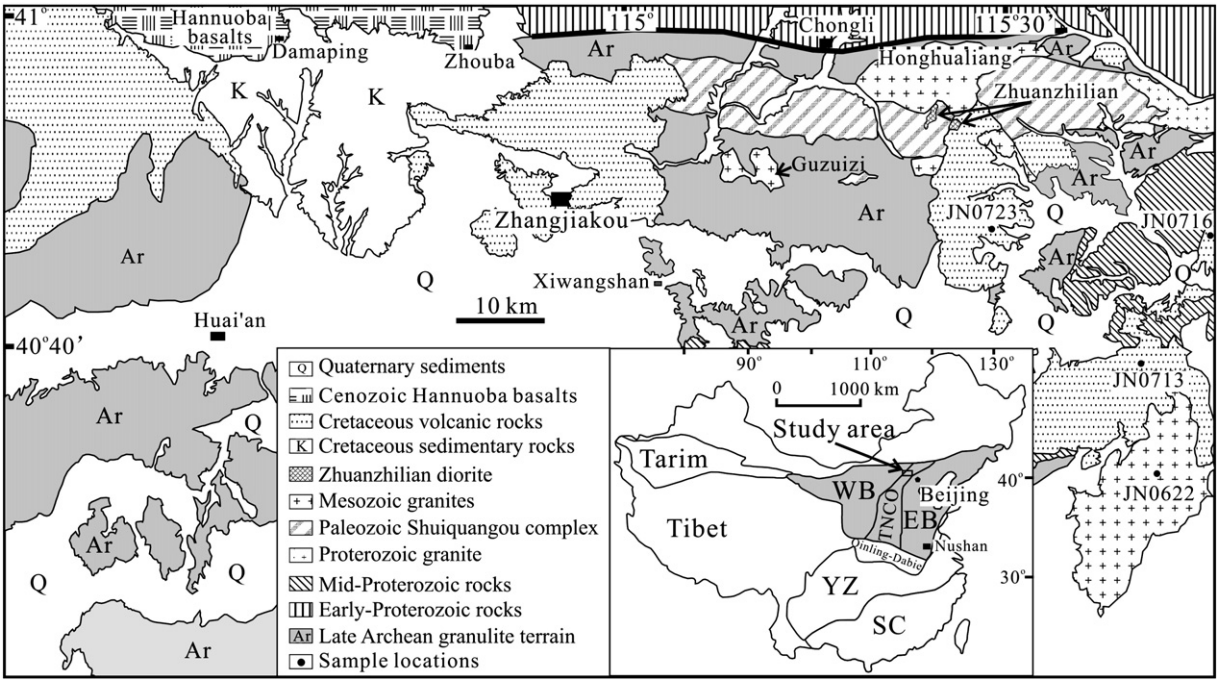

Fig. 1. Simplified geological map of the Zhangjiakou region shows the distribution of the Mesozoic intermediate-felsic igneous rocks, the granulite xenolith-bearing Hannuoba basalts and the late Archean granulite terrain. The granulite xenoliths were collected from Damaping. Inset shows major tectonic divisions of China, where YZ and SC denote the Yangtze craton and South China orogen. Also shown are the subdivisions of the North China craton (Zhao et al., 2001), where EB, TNCO and WB denote the Eastern Block, Trans-North China Orogen and Western Block.