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The meta-gabbroic complex of Fushui in north Qinling orogen: A case of syn-subduction mafic magmatism

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ABSTRACT

SIMS zircon geochronology and oxygen isotopes, as well as LA-ICPMS zircon Lu–Hf isotopic analyses, were carried out on a suite of rocks from the Fushui complex to probe its origin and tectonic significance for the evolution of the Qinling Group in the north Qinling orogenic belt. The Fushui complex comprises several phases of meta-gabbros: the dominant rock type is light-colored meta-gabbro, followed by mica-bearing and dark-colored meta-gabbros, with abundant dark gabbroic enclaves with different sizes and shapes and occasional occurrence of mica-bearing gabbroic pegmatite dikes. Age determination shows that the magmatic intrusion began at about 500 Ma and surged at 490–480 Ma with the latest zircon crystallized at about 476 Ma. This age spectrum is remarkably coeval with the peak metamorphism (500–480 Ma) of the surrounding Qinling Group metamorphic rocks dated by zircons from eclogites, retrograded eclogites, HP mafic granulites and UHP felsic gneisses, representing syn-subduction mafic magmatism. These late Cambrian to early Ordovician zircons display a slightly enriched Hf isotopic feature with a limited range in $\varepsilon Hf(t)$ (-5 to -2) and yield uniform T_{DM} age (1.15–1.38 Ga). They also show a relatively small variation in $\delta^{18}O$ (6.69 ± 0.44‰ (2σ)–8.75 ± 0.34‰ (2σ)), much higher than the normal mantle value. The isotopic feature suggests that the Fushui complex was originally derived from enriched lithospheric mantle, which was metasomatized by melts from ancient continental sediments and altered MORB basalts. The Carboniferous zircons, dominantly occurring as rims of early Ordovician cores, display very similar Hf T_{DM} ages (1.19–1.27 Ga) and oxygen isotopes as their counterparts, corresponding to their recrystallization at 335 Ma during amphibolite facies metamorphism when exhumed. Our study on the Fushui complex, together with the recently reported zircon U–Pb age data on the surrounding HP–UHP metamorphic rocks demonstrates that the Qinling Group preserves a complete cycle of tectonic evolution in an orogenic belt from an oceanic basin spreading, and mini-continent formation to deep subduction of mini-continent and multiple stage exhumations.

1. Introduction

The Qinling Mountains, lying in the middle part of China, is not only a critical geographic and hydrologic demarcation line, but also an important historical and cultural boundary. The mountains resulted from the Paleozoic Qinling orogeny, was modified by Mesozoic tectonic deformation and finally affected by Cenozoic intra-plate uplift (Zhang et al., 1995, 2000; Ratschbacher et al., 2003; Dong et al., 2011a, 2011b; Bader et al., 2013; Wu and Zheng, 2013). The Qinling orogen is an important part of the Central Orogenic Belt of China, located between the North China Block (NCB) and South China Block (SCB) (Fig. 1a), and linked with the Tongbai–Dabie–Sulu orogens to the east and the Qilian–Kunlun orogens to the west. Since the 1980s, many geologists have investigated the tectonic evolution of the Qinling orogen, and numerous results have been obtained from the integration of geology, petrology, geophysics and geochemistry (e.g. Zhang et al., 1995; Meng and Zhang, 2000; Zhang et al., 2000; Ratschbacher et al., 2003; Dong et al., 2008; Yuan et al., 2008; Dong et al., 2011a, 2011b; Zhu et al., 2011; B.X. Liu et al., 2013a, 2013b; Bader et al., 2013; Wang et al., 2013a,b; Wu and Zheng, 2013; Zhang et al., 2013; Li et al., 2015). The Qinling orogen is regarded as a composite orogen that experienced multiple stages of tectonic development. The final collision between the NCB and SCB occurred in the early Mesozoic along the Mianlue suture zone (Zhang et al., 1995; Meng and Zhang, 2000; Zhang et al., 2000; Dong et al., 2011a; Wu and Zheng, 2013; Li et al., 2015), defining the present tectonic framework. The Qinling orogen comprises three major tectonic blocks: the North Qinling Belt (NQB) which includes the southern margin of the NCB; the South Qinling Belt (SQB); and the northern margin of the SCB in a sequence from the north to the south (Fig. 1b). These blocks

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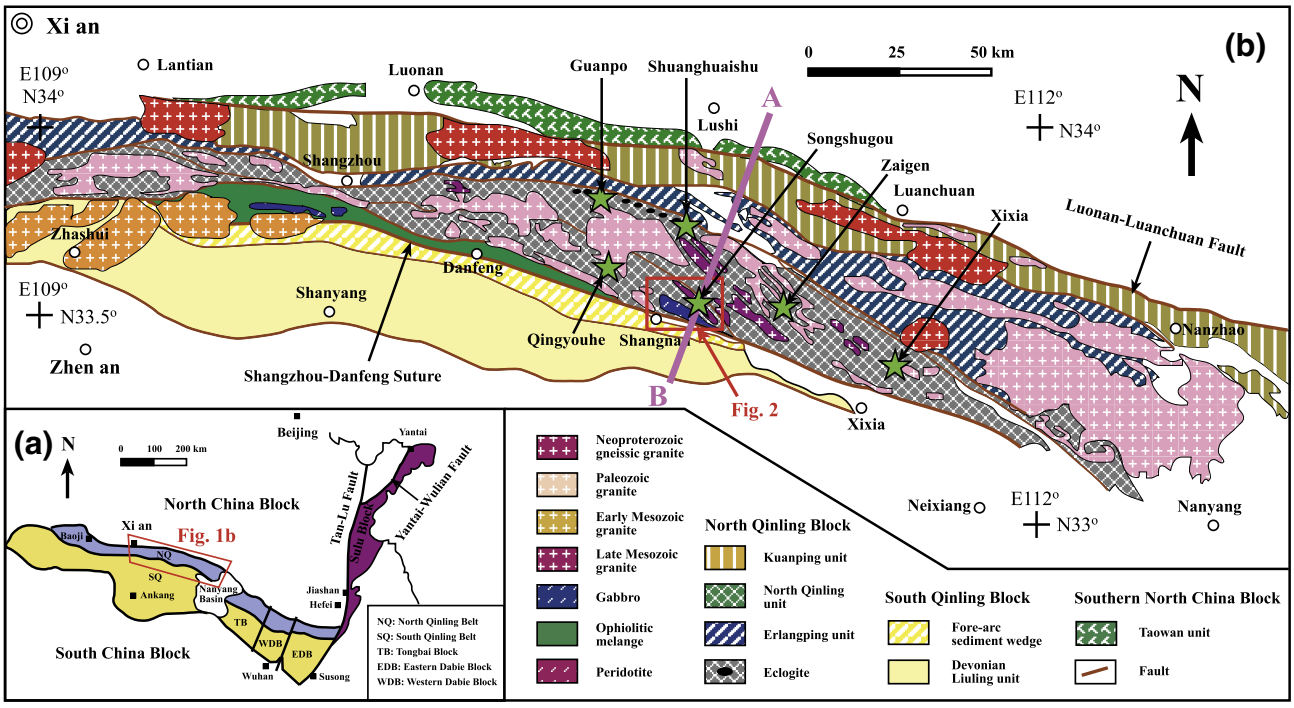

Fig. 1. Geological sketch of the Eastern North Qinling Terrane (b) with the inset map (a) showing the Qinling–Tongbai–Dabie–Sulu orogenic belts (modified after Dong et al. (2011a, 2011b) and Wang et al. (2013a, 2013b)). The star shows the locality of zircon U–Pb dating on HP–UHP metamorphic rocks in North Qinling Terrane. Line A to B shows the crustal cross-section of the eastern Qinling orogenic belt and related North and South China Blocks in Fig. 11b.

were separated by the Shangzhou–Danfeng Suture Zone (SDSZ) and Mianlue Suture Zone (MLSZ), respectively (Fig. 1b). However, the early tectonic evolution of the Qinling orogen is poorly constrained, such as the timing of oceanic crust spreading and subduction and subsequent collision resulting in the closure of Paleotethys.

The Qinling Group is a key to solve some of the key problems related to the evolution of the Qinling orogen (Fig. 1b). The Qinling Group is bound in its south by the SDSZ, which is considered as the major suture zone in the Qinling orogen. The presence of the Neoproterozoic ophiolite melange in the Qinling Group was taken as the evidence for the existence of an oceanic crust subduction and related volcanism (Dong et al., 2011a, 2011b; Wu and Zheng, 2013). In its northern and southern margins and middle part of the Qinling Group, several HP–UHP metamorphic rocks including eclogites, retrograde eclogites, HP mafic granulites and UHP felsic gneisses have been reported (Fig. 1b). Recent studies on these rocks have demonstrated that the early Paleozoic HP–UHP metamorphism was the consequence of northward continental deep-subduction along the SDSZ (Hu et al., 1994; Liu et al., 1995, 1996; Yang et al., 2002, 2003; Chen et al., 2004; Chen and Liu, 2011; Cheng et al., 2011; J.X. Zhang et al., 2011; Wang et al., 2011; Cheng et al., 2012; L. Liu et al., 2013). These new results provide insights into the process and age of subduction of the oceanic crust as well as the amalgamation among continental blocks during the early Paleozoic in the Qinling orogen. The oceanic/continental subduction and continental collision could result in HP–UHP metamorphism (L. Liu et al., 2013 and reference therein). Mafic and felsic magmatism during the subduction, collision and post-collisional processes would occur due to dehydration and change in the thermal regime of subducted and exhumed slabs in progressive and retrogressive metamorphism. The tectonic setting and origin of meta-gabbros and granitoids in the Qinling orogen can be used to constrain the above processes and the timing of closure of the oceanic basins, continental collision and exhumation. Zircons from Paleozoic granitoids in NQB show three episodes of magmatism with peaks at ~500, ~452 and ~420 Ma (Zhang et al., 2013). These magmatic pulses are generally correlated with HP–UHP metamorphism at ca. 500 Ma, retrograde granulite-facies metamorphism at ca. 450 Ma and amphibolite-facies metamorphism at ca. 420 Ma, respectively (Zhang et al., 2013). In this study, we carried out a detailed investigation on the meta-gabbroic complex of Fushui with a view to understanding the petrogenesis of this complex, and to reveal the tectonic significance.

2. Geological background

The North Qinling Belt (NQB) is bound on the north by the Luonan–Luanchuan fault and on the south by the SDSZ (Fig. 1b) and extends for more than 1000 km from east to west. The belt consists of four tectonic units, i.e. the Kuanping, Erlangping, Qinling and Danfeng Groups from north to south. The Kuanping Group displays an association of greenschists, mica–quartz schists and quartz-rich marbles, and preserves young concordant detrital zircons with ages of 550–450 Ma from meta-sandstones, confirming that this group was formed in a period from the late Neoproterozoic to the early Paleozoic (Zhu et al., 2011; Shi et al., 2013). To the south of the Kuanping Group, the Erlangping Group is dominated by greenschist- to amphibolite-facies backarc basin volcanic rocks associated with some sedimentary rocks. The Erlangping Group was intruded by 490–480 Ma granitoids (Zhang et al., 2013), suggesting its formation before 490 Ma.

The Qinling Group occurs as scattered lenticular bodies in the middle of the NQB (Fig. 1b), and consists mainly of biotite–plagioclase and garnet–sillimanite gneisses, mica–quartz schists, graphite marbles and amphibolites or garnet amphibolites, with some eclogites. Detrital zircons from the Qinling Group yield a range of ages from 1.5 to1.9 Ga (Lu et al., 2006; Shi et al., 2013) and zircon from gneissic granitoids shows an age of 950 Ma (Wang et al., 2005; B.X. Liu et al., 2013a, 2013b). These observations suggest that the protoliths of the Qinling Group were formed in the Neoproterozoic. The Danfeng Group is exposed in the southern NQB (Fig. 1b). It is composed of arc volcanic–sedimentary rocks that underwent greenschist to lower amphibolite facies metamorphism and was intruded by 430–517 Ma gabbroic rocks (Dong et al., 2011b). The youngest concordant detrital zircon age is 827 Ma,