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Geochronological and geochemical features of the Cathaysia block (South China): New evidence for the Neoproterozoic breakup of Rodinia

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ABSTRACT

The Cathaysia block is an important element for the reconstruction of the Proterozoic tectonic evolution of South China within the Rodinia supercontinent. The Pre-Devonian Cathaysia comprises two litho-tectonic units: a low-grade metamorphic unit and a basement unit; the former was a late Neoproterozoic–Ordovician sandy and muddy sedimentary sequence, the latter consists essentially of metamorphosed Neoproterozoic marine facies sedimentary and basaltic rocks, and a subordinate amount of Paleoproterozoic granites and amphibolites. This block has undergone several tectono-magmatic events. The first event occurred in the late Paleoproterozoic, at ca. 1.9–1.8 Ga, and the tectonic–magmatic event dated at 0.45–0.40 Ga was resulted from the early Paleozoic orogeny that made the Pre-Devonian rocks to undergo a regional lower greenschist to amphibolite facies metamorphism. The Neoproterozoic geodynamic event is poorly understood. In this paper, new U–Pb zircon age, whole-rock chemical and zircon Hf isotopic data for mafic and felsic igneous rocks are used to constrain the tectonic evolution of Cathaysia. Zircon SHRIMP U–Pb analyses on four mafic samples yielded rather similar Neoprotorozoic ages of 836 ± 7 Ma (gabbro), 841 ± 12 Ma (gabbro), 847 ± 8 Ma (gabbro) and 857 ± 7 Ma (basalt). Combined with the published isotopic age data, most of the mafic samples dated at 800–860 Ma show geochemical characteristics of continental rift basalt. By contrast, rhyolitic samples with an age of 970 Ma have a volcanic arc affinity. All mafic samples have LREE-enriched REE patterns, and non-ophiolitic trace element characteristics. However, the zircon Hf isotopic data of mafic samples show positive epsilon $\varepsilon_{\mathrm{Hf}}(t)$ values (+4.1 to +10.5), suggesting that they were originated from a long-term depleted mantle source. All the available ages indicate that the Cathaysia block has registered two stages of Neoproterozoic magmatism. The younger stage corresponds to a continental rifting phase with emplacement of mafic rocks during the period of 860–800 Ma, whereas the older stage represents an eruption of volcanic arc rocks at about 970 Ma. These two magmatic stages correspond to two distinct tectonic settings within the framework of the geodynamic evolution of Cathaysia. Such a similar Neoproterozoic stratigraphy and magmatism between the Cathaysia, Yangtze and Australian blocks provide a significant line of evidence for placing the Cathaysia block within the Rodinia supercontinent.

1. Introduction

The reconstruction of supercontinents is an important geodynamic issue with regard to the Precambrian global tectonic framework and geological evolution. Studies of the assembly and break-up of Rodinia in the Meso- to Neoproterozoic period have been significantly advanced in recent years (Hoffman, 1991; Li et al., 2008b and enclosed references). However, the Precambrian tectonic evolution of the Cathaysia block of China is still poorly understood.

The South China Block (SCB) is composed of the Cathaysia and Yangtze sub-blocks (called commonly the Cathaysia block and the Yangtze block in literatures), which have been considered as two separate members of the Neoproterozoic Rodinia supercontinent (Li et al., 1995). Previous works suggest that similar Neoproterozoic stratigraphic successions and magmatic rocks exist between the Yangtze and the Australian continents (Li et al., 1996; Wang and Li, 2003). This seems to provide a strong argument for the involvement of the Yangtze block in the Rodinia supercontinent, from assembly to breakup during the Neoproterozoic. On the other hand, due to the lack of geochronological and geochemical data, the link between the Cathaysia block and Rodinia has not been established like between the Yangtze block and Rodinia.

Cathaysia is separated from the Yangtze block by a Neoproterozoic ophiolitic suture (Xu and Qiao, 1989; Shu et al., 1994; Shu

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and Charvet, 1996) along the Shaoxing–Jiangshan–Pingxiang fault. The Shaoxing–Jiangshan–Pingxiang fault has been considered as a collisional zone between the Yangtze and Cathaysia blocks during the early Neoproterozoic, around 900 Ma (Shu et al., 1994; Li et al., 2002b, 2003a, 2008a, 2009; Ye et al., 2007; Yao et al., 2011). The NE-trending Zhenghe–Dapu fault zone occurs within the Cathaysia block, and cuts Neoproterozoic rocks of Cathaysia (Fig. 1). Neoproterozoic muddy to sandy sediments and volcanic rocks are distributed both sides of the Zhenghe–Dapu fault. The fossil-bearing Carbo-Permian and Cambro-Ordovician sequences have also been identified on both sides of the Zhenghe–Dapu fault (Lu et al., 1994; Yu, 1994; Shu et al., 2009). Some mafic–ultramafic and bimodal igneous rocks with a late Neoproterozoic age were swarmed within the fault zone.

Neoproterozoic tectono-magmatic record (mafic, ultramafic and acidic magmatic rocks) and locally Meso-Paleoproterozoic basement are well preserved in the Wuyi and Nanling Mts. (Fig. 1; Shu, 2006; Wan et al., 2007; Yu et al., 2009; Yao et al., 2011). The Neoproterozoic sedimentary sequence contains some olistostrome features, such as various blocks with different components, sizes, shapes and ages that were interpreted as an intra-block rift formed in response to the breakup of the Rodinia supercontinent (Wang and Li, 2003). However, the detailed timing and geological setting of this olistostrome formation are unclear.

In the past two decades, numerous studies suggested that a Proterozoic basement exists in the Cathaysia block. U–Pb protolith ages, ranging from 1000 Ma to 800 Ma, obtained from igneous rocks were regarded to be related to the assembly and breakup of Rodinia (Li et al., 2005; Wan et al., 2007; Xu et al., 2005, 2007; Shu, 2006; Shu et al., 2008a; Li et al., 2010b). Moreover, some geochronological data from zircon grains from amphibolites and gneisses imply that the 1.9–1.8 Ga event was an important period for the formation of the oldest metamorphic basement of Cathaysia (Wan et al., 2007; Yu et al., 2008). In spite of the significant advance in geochronology, controversies still exist on the onset of the rifting event between Cathaysia and other parts of Rodinia (Li et al., 2009; Wang et al., 2003, 2008a,b; Xiang and Shu, 2010).

Mafic–ultramafic rocks are exposed as lenses (meter to hundred-meter size) in the upper part of the basement of the Cathaysia block. These rocks have attracted much attention and various models have been proposed: (1) an ophiolitic mélange formed by the subduction of an early Paleozoic South China Ocean (Guo et al., 1989; Wang and Mo, 1995); (2) a late Paleozoic to early Mesozoic ophiolitic suture (Xiao and He, 2005); and (3) a disrupted Precambrian intra-continental magmatic dyke swarm (Shu et al., 2008a). However, the most serious problem for all the models is the insufficient age and geochemical constraints. Consequently, the origin and emplacement time of these mafic–ultramafic rocks have not been resolved.

In this paper, we address the question of the origin and timing of the emplacement of the mafic–ultramafic rocks and their tectonic implications. Petrological, geochronological and geochemical studies were conducted on some mafic and felsic rocks from the Proterozoic basement of Cathaysia. The new results will allow us to conclude that (1) these ultramafic–mafic rocks do not represent the relics of an ophiolitic suite, (2) they were formed in an intra-continental rift setting during middle Neoproterozoic, in response to the breakup of Rodinia, and (3) the Cathaysia block was an important tectonic unit of Rodinia.

2. Geological background of the Cathaysian block

2.1. Tectonic outline

The SCB has undergone several tectono-magmatic events. The first event occurred in the late Paleoproterozoic, at ca. 1.9–1.8 Ga. This event has been argued as the most important one in the formation of the crystalline basement of Cathaysia (Wan et al., 2007; Yu et al., 2009). However, no structural evidence associated with this magmatic event is available. The second event took place during the early Neoproterozoic as a result of the collision between the Yangtze and Cathaysia blocks (Guo et al., 1989; Li et al., 1994; Shu and Charvet, 1996; Charvet et al., 1996; Chen et al., 1997; Li et al., 1999). The time of collision is constrained by available age data for rocks from the suture zone, including zircon U–Pb ages of 968–930 Ma for mafic rocks from the ophiolite (Xu and Qiao, 1989; Zhou and Zhu, 1993; Chen et al., 1991; Li et al., 1994), a glaucophane K–Ar age of 886 ± 14 Ma for blueschist (Shu et al., 1994), and several zircon U–Pb ages of 830–800 Ma for S-type granitoids (Li et al., 2003a; Zheng et al., 2008). The age of 1020–930 Ma corresponds to the subduction time of the Proto-South China Ocean (Zhou and Zhu, 1993; Zhou et al., 2002, 2004, 2009), the 866 ± 14 Ma age might represents the time of collision (Charvet et al., 1996), and the 850–800 Ma age was considered as the time of post-collisional magmatism or a consequence of the breakup of Rodinia (Li et al., 2008b, 2009, 2010a).

As documented in the following sections, a Neoproterozoic tectono-magmatic event occurred also within the Cathaysia block along the Zhenghe–Dapu fault zone.

The Silurian sequence is absent in the Cathaysia block due to an uplift since the late Ordovician. The uplift was a response to the early Paleozoic tectono-magmatic event. This event that welded again the Cathaysia and Yangtze blocks, is marked by an important deformation with regional-scale folding and faulting and granitic magmatism (Shu et al., 2008c; Faure et al., 2009; Charvet et al., 2010). The termination of the orogeny is indicated by unconformable deposition of middle to late Devonian molasse of 1–2 km thickness. Recent studies have revealed a top-to-the-south ductile decollement and widespread crustal melting at about 450–400 Ma (Wang et al., 2003, 2007; Faure et al., 2009). Locally, a top-to-the-north ductile shearing was recently observed in the areas near or to the north of the Shaoxing–Jiangshan–Pingxiang fault (Shu et al., 2008c; Charvet et al., 2010). This early Paleozoic orogenic event reworked the geographic framework of Cathaysia (Rong et al., 2010), and is interpreted as an intra-continental orogeny within the SCB (Shu et al., 2008c; Faure et al., 2009; Li et al., 2010b).

Two major litho-tectonic units can be recognized in the Cathaysia block: a low-grade metamorphic unit and a basement unit. The low-grade metamorphic unit is represented by a late Neoproterozoic to Ordovician sandstone–mudstone slaty sequence. The basement unit is composed of early Neoproterozoic sandstone, mudstone and volcanic rocks in the Nanling–Yunkai area and Paleoproterozoic granites, metasedimentary and volcanic rocks in eastern Cathaysia (Wuyishan segment) (JBGMR, 1984; FBGMR, 1985; Li, 1997; Yu et al., 2009) that were later metamorphosed into micaschist, amphibolite and gneiss (Yu et al., 2008; Li et al., 2010b).

2.2. Petrotectonic assemblages of the basement unit

The basement unit is also called the pre-Nanhua System in the Chinese literature. It is composed mainly of Neoproterozoic marine facies sedimentary and basaltic rocks, and a subordinate amount of Paleoproterozoic granites and metamorphic rocks (including amphibolites in the Tianjingping formation and migmatites and gneisses in the Badu Group) (Li, 1997; Yu et al., 2009). Late granitoids intruded the Neoproterozoic rocks (JBGMR, 1984; FBGMR, 1985). The protolith of the meta-volcanic rocks was dated at 1000–800 Ma (Wan et al., 2007; Shu et al., 2008a; Li et al., 2010a), whereas the Paleoproterozoic granites and amphibolites were dated at 1890–1766 Ma by zircon U–Pb method (Li, 1997; Gan et al.,