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Ordovician appinites in the Wugongshan Domain of the Cathaysia Block, South China: Geochronological and geochemical evidence for intrusion into a local extensional zone within an intracontinental regime

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ABSTRACT

Palaeozoic mafic igneous rocks are potentially significant in constraining the tectonic nature and evolution of the Kwangsian Orogeny in the eastern South China Block, yet they have received little attention because of their limited outcrop. Geochemistry and geochronology was carried out on newly identified Ordovician ultramafic–mafic appinites in the Wugongshan Domain of the Cathaysia Block. Seven appinite samples yielded $^{206}Pb/^{238}U$ crystallisation ages ranging from 452 ± 4 Ma to 473 ± 3 Ma. Abundant 480–500 Ma zircon xenocrysts and/or inherited zircons were found in the appinites, possibly indicating an earlier magmatism episode in the early Palaeozoic period. The Wugongshan appinites are ultramafic to mafic in composition, and the ultramafic rocks display features of cumulates (high concentrations of MgO, Fe_2O_{3t}, Cr, Ni, and low concentrations of total alkali and total rare earth elements [REE]). The appinite geochemistry displays: relatively flat chondrite normalised REE patterns with slight enrichment in light REE and weak negative Eu anomalies; enrichment in large-ion lithophile elements (such as Rb, K), and weak depletion in Nb–Ta in primitive mantle normalised trace element patterns. We suggest that the Wugongshan appinites likely originated from an ancient metasomatised mantle, and that crustal assimilation, fractional crystallisation (AFC), magma mingling and hydration were involved in the petrogenetic process, based on the combination of geochemistry, crust-like bulk Sr, Nd and zircon Hf isotopic compositions ($\varepsilon_{Nd}(t) = -8.2$ to -3.2, initial $^{87}Sr/^{86}Sr$ ratios of 0.7067–0.7144, zircon $\varepsilon_{Hf}(t)$ values peaking at -9 to -3) and regional geological data. Further considering the alignment and chronology of the appinites, we suggest that the appinitic magmas probably were emplaced along the Jiangshan–Shaoxing Fault in a local extensional zone in an intracontinental regime in the early Palaeozoic.

1. Introduction

Appinites (also known as appinitic rocks or appinitic suite) are a group of coeval plutonic and/or hypabyssal rocks, ranging from ultramafic to felsic, and calc-alkaline to shoshonitic in composition (Castro et al., 2003; Fowler, 1988; Hall, 1967; Hamidullah, 2007; Molina et al., 2009, 2012; Murphy, 2013; Scarrow et al., 2009), in which hornblende is the dominant mafic mineral and typically occurs both as large prismatic phenocrysts and in the finer grained matrix (Murphy, 2013). This unusual rock suite is typically considered to have crystallised under high vapour pressure and fluid-rich conditions (Hamidullah, 2007; Murphy, 2013). Appinites usually are spatially and temporally associated with coeval granitoids (e.g., Castro et al., 2003; Fowler and Henney, 1996; Galán et al., 1996; Molina et al., 2009, 2012; Scarrow et al., 2009) and have genetic linkages with several enigmatic rock suites (including shoshonites, lamprophyres, sanukitoids, TTG suites, high-Mg andesites and adakites) (Murphy, 2013 and references therein).

Moreover, appinites are petrogenetically connected with transcurrent fault movements (Castro et al., 2003; Galán et al., 1996; Jacques and Reavy, 1994; Murphy and Hynes, 1990; Pe-Piper et al., 2010; Roberts et al., 2000; Rogers and Dunning, 1991; Zhang et al., 2012c) and critical geodynamic processes such as post-subduction slab break-off or delamination (Atherton and Ghani, 2002; Bea et al., 1999; Fowler et al., 2008; Neilson et al., 2009; Ye et al., 2008; Zhang et al., 2012b,c) during the final stage of an orogeny. Therefore, constraining the petrogenesis of appinites can provide important clues to sources of orogenic magmas, and aid in understanding the tectonic nature and evolution of

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ancient convergent plate margins (e.g., Atherton and Ghani, 2002; Castro et al., 2003; Fowler et al., 2001, 2008; Murphy, 2013; Murphy et al., 2012; Neilson et al., 2009; Ye et al., 2008; Zhang et al., 2012b,c).

The early Palaeozoic orogenic belt in the eastern South China Block (SCB) is traditionally referred to as the "Caledonian Orogeny" in Chinese literature and recently also as the "Wuyi–Yunkai Orogeny" (Li et al., 2010; Yang et al., 2010) or the "Kwangsian Orogeny" (Chen et al., 2010; Wang et al., 2010, 2011, 2012a,b), the last of which is adopted in this paper. The tectonic pattern and nature of this Palaeozoic tectonothermal event in the eastern SCB has long been a subject of debate (e.g., Li et al., 2010; Wang et al., 2011, 2012a,b) because of the limited available constraints on this event. Some researchers believe that the SCB became a united block due to Neoproterozoic amalgamation and thus that the Kwangsian Orogeny was an intracontinental fold orogen (e.g., Charvet et al., 2010; Faure et al., 2009; Li et al., 2010, 2011; Shu, 2006; Shu et al., 2008; Wang et al., 2007, 2011, 2012a,b; Zhang et al., 2009a, 2012a). Other researchers suggest that a narrow-strip Huanan Ocean existed from the late Neoproterozoic to the early Palaeozoic between the Yangtze and Cathaysia Blocks, and that the Kwangsian Orogeny was related to the closure of the Huanan Ocean (e.g., Guo et al., 1989; Liu and Xu, 1994; Yang and Mei, 1997; Yin et al., 1999).

We have discovered and mapped previously unknown Ordovician ultramafic–mafic appinites in the Wugongshan Domain of the Cathaysia Block. Here we present a comprehensive study of the Wugongshan appinites, including: petrography, mineral chemistry, zircon U–Pb dating and Hf isotopic compositions and whole-rock geochemistry. Based on these data, we elucidate the petrogenesis of the appinites, provide important information on the tectonic nature and evolution of the Kwangsian Orogeny in the eastern SCB, and add a new model to the possible array of tectonic settings of appinites.

2. Geological setting

The SCB consists of the Yangtze Block in the northwest and the Cathaysia Block in the southeast (Fig. 1b). The northeasterly trending Jiangshan–Shaoxing Fault (JSF) is considered to be the Neoproterozoic suture between the two blocks, and the Chenzhou–Linwu Fault to be the southwards extension of the JSF by some researchers (Fig. 1b) (e.g., Li et al., 2005, 2008; Wang et al., 2012a). The SCB has experienced four major tectonic events since the Proterozoic, namely the Jiangnan Orogeny (Neoproterozoic), Kwangsian Orogeny (early Palaeozoic), Indosinian movement (Triassic), and Yanshanian movement (Jurassic–Cretaceous). The earliest event corresponds to the Neoproterozoic amalgamation between the Yangtze and Cathaysia blocks that resulted in the formation of the united SCB (Wang et al., 2012b and references therein). The Palaeozoic Kwangsian Orogeny resulted in intensive deformation, strong folds, unconformities between Early Palaeozoic strata (e.g., Charvet et al., 2010; Li et al., 2010; Wang et al., 2012b and references therein), the occurrence of voluminous granitoids (Li et al., 2010; Sun, 2006; Wang et al., 2011, 2012b; Zhang et al., 2012a), and high-grade metamorphism (e.g., Liu et al., 2010a; Wan et al., 2010; Wang et al., 2007, 2012a,b and references therein).

Most of the Palaeozoic granitoids in the eastern SCB are distributed in a northeasterly trending zone ranging from the Wuyi Domain to the Yunkai Domain (named as Wuyi–Yunkai Domain) within the Cathaysia Block, but some are located along both sides of the boundary between the Yangtze and Cathaysia blocks (Fig. 1b). The granitoids are strongly peraluminous to metaluminous and have been classified as S-type granites (Lou et al., 2005; Sun, 2006; Wang et al., 2007, 2011, 2012a,b and references therein; Wang et al., 2013b; Zhang et al., 2012a).

3. Field relations, petrography and mineralogy

3.1. Field relations

The Wugongshan Domain is south of the middle part of the suture zone between the Yangtze and Cathaysia blocks. Igneous rocks in the Wugongshan Domain are composed of dominant Kwangsian (Palaeozoic) granitoids, minor Indosinian (early Mesozoic) and Yanshanian (late Mesozoic) granites. The Palaeozoic granitoids are massive or gneissic, having zircon U–Pb ages of 420–455 Ma (Lou et al., 2005; Wang et al., 2011; Zhang et al., 2012a and our unpublished data).

The appinites identified in this work are located in three regions within the domain (Fig. 1b), and some of them were previously mapped as Yanshanian intrusions. These appinitic intrusions and several Palaeozoic granitic plutons crop out along the south of the JSF in the Wugongshan Domain (Fig. 1b–c). Where the three general outcropping areas of appinitic rocks are discussed separately below, they are referred to by their geographic locations, i.e. Yanxi, Hongjiang, and Maixie.

The appinites mainly crop out as small stocks within or near the margins of Palaeozoic granitic plutons (Fig. 2a–c), ranging from dozens to hundreds of metres in size, with a minority occurring as dykes intruding into granites or into Cambrian or Sinian metasediment. Contact zones between the appinites and granitoids can be either sharp or gradational, and small-scale magma mingling between mafic magma and felsic magma (less than ten metres wide) are usually observed (Fig. 3a), producing a hybrid rock of intermediate composition. Mafic microgranular enclaves (Fig. 3b) in the granitoids become more abundant towards the contact zones. The appinitic stocks usually can be divided into three zones: an outer zone of hybrid rocks consisting of quartz diorite, diorite; an intermediate zone consisting of more mafic hornblende–gabbro; and an inner zone dominated by ultramafic hornblendite and/or pyroxene–hornblendite (Fig. 3c, d).

The Yanxi appinites in Xiajiang County mainly crop out as two small stocks (Fig. 2a). The larger Yanxi stock occurs in a NW–SE trending strip, 15–40 m wide and about 1000 m long. This stock contacts granite dated at ca. 450 Ma (our unpublished data) from NW to SE, and intrudes Sinian strata to the northeast. The smaller Yanxi stock is located within a granitic pluton and consists of medium- to fine-grained hornblende–gabbro and diorite, showing transitional boundaries with the host granite, indicating that the felsic and mafic rocks formed contemporaneously.

The Hongjiang appinites in Yichun City occur as several dykes and an elongated stock about 600 m long and 10–20 m wide (Fig. 2b). The Hongjiang appinitic dykes consist of medium- to fine-grained hornblende–gabbros, intruding ca. 450 Ma granites (our unpublished data) or Cambrian metasediment, with sharp contacts. The Hongjiang appinitic stock comprises medium-grained quartz diorite and/or diorite, medium-grained hornblende–gabbro, and coarse-grained hornblendite.

Several small appinitic intrusions have been found near Maixie Town in Xingan County (Fig. 2c). We collected four samples from the largest Maixie intrusion, which spreads along a northeast-trending strip with an exposed width of 0.5 km and length of 2.5 km. This appinitic intrusion intrudes Sinian metasediments and was itself subsequently intruded by ca. 435 Ma granodiorites (Nong et al., 2012) in the southern part of its current exposure. The Maixie appinites consist of dominant coarse pyroxene–hornblendite and hornblendite, and subordinate medium- to fine-grained hornblende–gabbro (Fig. 3d, g, h).

3.2. Petrography and mineralogy

Lithologies of the appinites in the Wugongshan Domain (collectively called the Wugongshan appinites in the following description and discussion) consist of pyroxene–hornblendite, hornblendite, hornblende–gabbro and diorite.

Within the Wugongshan appinites, pyroxene–hornblendite and hornblendite are characterised by abundant subhedral to euhedral