Precambrian Research 298 (2017) 439–461

Contents lists available at ScienceDirect

Precambrian Research

journal homepage: www.elsevier.com/locate/precamres

Metamorphic and magmatic evolution of the Paleoproterozoic gneisses in the Sancheong area, Yeongnam Massif, South Korea, and their implications to the tectonics in the Northeast Asia

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ARTICLE INFO

Article history:
Received 22 December 2016
Revised 1 June 2017
Accepted 3 June 2017
Available online 8 June 2017

Keywords:
Paleoproterozoic
Southwestern Yeongnam Massif
Metamorphism
Post-collision
Tectonic evolution

ABSTRACT

The Sancheong area in the southwestern Yeongnam Massif mainly consists of Precambrian paragneisses (quartz-feldspathic and garnet gneiss), orthogneiss (porphyritic gneiss) and anorthosite and is important for an understanding the tectonic evolution of the southern part of the Korean Peninsula and Northeast Asia. The Precambrian paragneisses in the Sancheong area underwent intermediate-P/T metamorphism (quartz-feldspathic gneiss; 730 °C and 12.2 kbar). The intermediate-P/T metamorphism was overprinted by regional low-P/T metamorphism (750–820 °C and 7.0–9.0 kbar) which was followed by amphibolite-facies retrograde metamorphism. In contrast, the orthogneiss only experienced the low-P/T (750–800 °C and 8.0–8.7 kbar) metamorphism followed by the amphibolite-facies retrograde metamorphism. Zircon U–Pb dating indicates that the intermediate-P/T metamorphism likely occurred at ca. 1880–1920 Ma and that the low-P/T metamorphism occurred at ca. 1855–1859 Ma. The whole-rock geochemical data and zircon U–Pb ages indicate that the protolith of the porphyritic gneiss and the anorthosite were emplaced in a post-collisional tectonic setting during ca. 1872–1880 Ma and ca. 1860 Ma, respectively. These data suggest that the Sancheong area underwent continental collision associated with the intermediate-P/T metamorphism (ca. 1920–1880 Ma) and post-collisional igneous activity associated with the low-P/T metamorphism during the Paleoproterozoic (ca. 1856–1880 Ma). Similar Paleoproterozoic tectonic events were recently reported from the eastern Cathaysia Block, suggesting that the Yeongnam Massif may have a close affinity to the eastern Cathaysia Block.

1. Introduction

Studies on the correlation between Precambrian rocks on the Korean Peninsula and in China have been carried out for a long time because it is important to understand the Precambrian tectonic evolution of Northeast Asia, including the Korean Peninsula and China (Zhao et al., 2006; Wu et al., 2007; Choi et al., 2008; Yu et al., 2009, 2012; Peng et al., 2012; Kim et al., 2014a,b; Lee et al., 2014a,b, 2016a,b; Yengkhom et al., 2014; Oh et al., 2015; Yuan et al., 2015; Zhang et al., 2016). However, the correlation remains controversial. One of the problems is the uncertain tectonic evolution of the Yeongnam Massif (YM) in the Korean Peninsula. The YM is one of the basement units of the Korean Peninsula and mainly consists of Precambrian gneisses. Traditionally, the YM has been correlated to the North China Craton (NCC), but it has recently begun to be correlated with the South China Craton (SCC) (Oh, 2006, 2015; Oh and Kusky, 2007). Yu et al. (2009) also suggested that the eastern Cathaysia Block (CB) in the SCC may have a close relationship with the YM in the Korean Peninsula based on similar petrology, geochronology and isotopic compositions, although the Precambrian tectonic evolution of the CB is unclear.

The Sancheong area, which is the focus of this study, is located in the southwestern YM and is well known for its large anorthosite, charnockite and ortho- and paragneisses (the major axis is ~50 km long) that formed during the Paleoproterozoic. According to previous studies, these rocks formed in a post-collisional tectonic setting (Kim et al., 2014b; Lee et al., 2014b). Recently, Kim et al. (2014b) suggested that the protolith of the orthogneisses in the Sancheong area was emplaced during ca. 1.87–1.86 Ga and was metamorphosed shortly after emplacement, but the age of meta-

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http://dx.doi.org/10.1016/j.precamres.2017.06.001
0301-9268/

morphism has not been determined. On the other hand, Lee et al. (2014b) argued that a hornblende gabbro and an anorthosite were emplaced at ca. 1.87 Ga and 1.86 Ga, respectively, and that the mafic granulite and garnetiferous migmatite surrounding the anorthosite were metamorphosed at ca. 1.86 Ga. Considering the results of Kim et al. (2014b) and Lee et al. (2014b), the metamorphic ages of most gneisses in the Sancheong area, with the exception of the gneisses around the anorthosite, are still unclear. Moreover, the metamorphic ages (1858 ± 4 Ma and 1860 ± 5 Ma) obtained by Lee et al. (2014b) overlap the youngest intrusion age (1863 ± 5 Ma) of the orthogneiss reported by Kim et al. (2014b) within the error range. Therefore, it is necessary to determine the exact timing of magmatic and metamorphic events in the Sancheong area.

The Precambrian gneisses in the Sancheong area were generally considered to have undergone granulite-facies metamorphism (Kim et al., 2002; Lee et al., 2004, 2015; Song, 1999). However, the metamorphic evolution of the Sancheong area remains unclear due to the following reasons. The mineral pair used in P–T estimation in previous studies is problematic. The peak and retrograde metamorphic P–T conditions reported by Song (1999), Kim et al. (2002) and Lee et al. (2004) were estimated using the compositions of garnet and orthopyroxene. The garnets have chemical zoning from core to rim, whereas the orthopyroxenes do not exhibit chemical zoning, indicating that the garnet cores are not equilibrated with the orthopyroxene. It means that the peak metamorphic conditions calculated using garnet cores and orthopyroxene cores are unreliable. As a result, several different P–T paths have been suggested in previous studies. Song (1999) and Lee et al. (2004) suggested a clockwise P–T path, whereas Kim et al. (2002) reported a counterclockwise P–T path. In addition, Lee et al. (2015) argued that the gneisses around the anorthosite underwent high-temperature contact metamorphism. Therefore, it is also necessary to study the metamorphic evolution of the Sancheong area more clearly and to determine the tectonic evolution of the Sancheong area by combining the metamorphic evolution with magmatic and metamorphic ages.

In this study, the metamorphic evolution of the Sancheong area is investigated based on the P–T estimation using conventional geothermobarometry and the Perple_X program. The origin of the Paleoproterozoic orthogneisses is examined using whole-rock geochemical data. Zircon U–Pb dating, along with rare earth element (REE) analysis of the zircon, using a sensitive high-resolution ion microprobe (SHRIMP) was conducted to determine the timing of the magmatic and metamorphic events. Finally, we interpret the tectonic evolution of the southwestern YM based on the results of this and previous studies. In addition, the tectonic evolution of the YM is compared with the Gyeonggi Massif (GM), the SCC and the eastern North China Craton (NCC).

2. Regional geology

Along with the Nangrim Massif and the GM, the YM forms the basement of the Korean Peninsula and is located in the southern part of the Korean Peninsula (Fig. 1a). The YM is separated from the GM by the Phanerozoic Ogcheon belt (Fig. 1a). In the northeastern YM, the arc (ca. 1.99–1.97 Ga) and syn-collisional or arc-related magmatism (ca. 1.86–1.85 Ga) occurred together with amphibolite- to granulite-facies metamorphism (Lee et al., 2005, 2010; Kim et al., 2012, 2014a). However, post-collisional magmatism accompanied by low-P/T metamorphism (ca. 1.88–1.86 Ga) was reported from the southwestern YM, without ca. 1.99–1.97 Ga magmatism (Song, 1999; Kim et al., 2002, 2014b; Lee et al., 2004, 2014b).

The Sancheong area, the focus of this study, is located in the southwestern YM and is characterized by the occurrence of north-south-trending ortho- and paragneisses (Fig. 1b). Quartz-feldspathic, garnet and migmatitic paragneisses were intruded by orthogneisses (augen, porphyritic, leucocratic and hornblende gneisses), charnockite and hornblende gabbro during ca. 1.86–1.88 Ga (Kim et al., 2014b; Lee et al., 2014b). The charnockite is divided into massive and foliated types and is considered to have undergone granulite-facies metamorphism (Kim et al., 2002; Lee et al., 2004). The paragneisses, orthogneisses and charnockite were intruded by an anorthosite complex that is composed of anorthosite, leucogabbro, oxide-bearing leucogabbro and gabbro. The anorthosite was emplaced at ca. 1.86 Ga in a post-collisional tectonic setting, triggering granulite-facies metamorphism in the surrounding area (Lee et al., 2014b, 2015). The anorthosite is divided into massive and foliated types based on the texture (Kang and Lee, 2015). However, the two types of anorthosite originated from a single magma source characterized as a highly aluminous gabbroic magma, and their different textures formed through multiple differentiations and polybaric crystallization (Kang and Lee, 2015).

A minor Neoproterozoic porphyritic metagranite formed at ca. 908 Ma was found (Kim et al., 2014b). The Neoproterozoic porphyritic metagranite shows negative Nb, Ta and Ti anomalies and enrichments of the large-ion lithophile elements (LILEs), which are indicative of typical arc-related magmatism (Kim et al., 2014b). However, it is difficult to identify the contact relationship between the Paleoproterozoic rocks and the Neoproterozoic metagranitoid.

The Precambrian gneisses were intruded by Mesozoic gabbro, diorite, syenite and granite (Cheong and Kim, 2012 and references therein). The Mesozoic plutonic rocks are mainly distributed in the northern part of the Sancheong area and sporadically occur as independent small stocks. The emplacement of the plutonic rocks occurred during the early Triassic to early Jurassic, and the Mesozoic plutonic rocks are considered to have formed in a subduction-related tectonic setting (Ok et al., 2015 and references therein). The Precambrian basement and Mesozoic plutonic rocks in the southeastern part of the study area are covered by Cretaceous sedimentary rocks (Kang and Lee, 2015). The Cretaceous sedimentary rocks mainly consist of mudstone, sandstone and conglomerate and contain various fossils, such as trace fossils, mollusks, and vertebrata, including dinosaurs (Lee et al., 2007 and reference therein).

3. Petrography

Among the various types of Precambrian para- and orthogneisses, the quartz-feldspathic, garnet and porphyritic gneisses and anorthosite in the western part of the Sancheong area were investigated. The petrography and representative mineral assemblages of these rocks are described below.

The quartz-feldspathic gneiss shows bright colors due to high contents of quartz and feldspar (Figs. 1, 2a). This gneiss has a granulose structure with a less foliated structure compared to the other gneisses in the study area (Fig. 2a). The quartz-feldspathic gneiss mainly consists of garnet, K-feldspar, plagioclase, quartz and biotite with minor ilmenite (Fig. 3a). The garnets generally occur as porphyroblasts (maximum diameter: 2.5 cm), and the cores of the garnet porphyroblasts have inclusions, such as biotite, K-feldspar, plagioclase, quartz, ilmenite and rutile (Fig. 3b). Sphene is observed as relics within ilmenite inclusions, suggesting that sphene may have been stable with ilmenite and rutile before ilmenite and rutile became stable without sphene (Fig. 3c). Fine-grained garnets (<200 μm) observed around the garnet porphyrob-