Journal of Asian Earth Sciences 95 (2014) 228–242

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

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

Petrogenesis of Late Permian sodic metagranitoids in southeastern Korea: SHRIMP zircon geochronology and elemental and Nd–Hf isotope geochemistry

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ARTICLE INFO

Article history:
Received 28 February 2014
Received in revised form 21 May 2014
Accepted 5 June 2014
Available online 18 June 2014

Keywords:
Tonalitic–trondhjemitic–granodioritic gneisses
Southeastern Korea
SHRIMP zircon dating
Nd–Hf isotopes
Mafic lower crust

ABSTRACT

One of the striking tectonomagmatic features recently found in southeastern Korea is the occurrence of *ca.* 250 Ma high-silica adakite. Sodic metagranitoids mainly consisting of tonalitic–trondhjemitic–granodioritic gneisses occur in the Andong-Cheongsong area adjacent to the Yeongdeok adakite site. To investigate temporal and petrogenetic relationships of these orthogneisses with the adakite, we conducted SHRIMP zircon U–Pb dating as well as elemental and Nd–Hf isotopic analyses. Zircon core ages of the orthogneisses (*ca.* 262–251 Ma) confirm the widespread occurrence of arc-related Late Permian magmatism in southeastern Korea. The Late Triassic (*ca.* 230 Ma) zircon overgrowths reflect a thermal overprint probably related to the initiation of another subduction system. The analyzed orthogneisses have major element compositions comparable to the Phanerozoic adakites and Archean TTG suite, such as high SiO_2 (58.7–65.5 wt.%) and Al_2O_3 (17.1–19.1 wt.%) contents and Na_2O/K_2O ratios (1.83–4.95). However, their moderate Sr/Y (35–43) and La/Yb (14–53) ratios and negative Eu anomalies ($Eu/Eu^* = 0.75–0.95$) are incompatible with the key features reported from the Yeongdeok adakite. Moreover, initial whole-rock ε_{Nd} (−7.9 to −3.3) and zircon ε_{Hf} (−0.3 ± 2.4) values of the orthogneisses negate a direct derivation from the subducted slab. Our elemental and Nd–Hf isotopic data collectively suggest that the protoliths of the tonalitic–trondhjemitic–granodioritic gneisses were generated by partial melting of mafic lower crust at depths shallower than the garnet stability field. Our Nd and Hf model ages of the gneisses, together with those previously reported from the Mesozoic granitoids indicate a selective involvement of young source materials along the margin of the Yeongnam massif. The Hf isotopic compositions of zircons from a trondhjemitic gneiss attest to the involvement of primitive melts during their crystallization. The ridge subduction and consequent development of a slab window may have facilitated partial melting of the subducted oceanic lithosphere and the lower crust.

1. Introduction

The *ca.* 250 Ma adakite recently reported in the Yeongdeok area, southeastern Korea (Yi et al., 2012), gave a new insight into deciphering the tectonomagmatic evolution of the Paleozoic–Mesozoic arc system at the periphery of the paleo-Asian continent. The geochemical features of the Yeongdeok pluton, such as high Sr/Y (up to 214) and La/Yb (up to 115) ratios and near mantle-like Sr and Nd isotopic compositions (Cheong et al., 2002) led Yi et al. (2012) to infer its magmatic affinity with the high-silica adakite (Martin et al., 2005) formed by partial melting of the subducted oceanic lithosphere. Yi et al. (2012) further suggested that the occurrences of adakite in southeastern Korea, and presumably in the Hida belt, central-western Japan, resulted from a hot subduction regime developing at least partly along the East Asian continental margin during the transitional Permian–Triassic period.

Tonalitic–trondhjemitic–granodioritic gneisses occur as a small plutonic body or as xenoliths within the Mesozoic granitoids in the Andong-Cheongsong area, ~30 km away from the Yeongdeok

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http://dx.doi.org/10.1016/j.jseaes.2014.06.005
1367-9120/

adakite site. The lack of geochronological and geochemical data restricts any discussion about the nature of these gneisses, although the Archean tonalite–trondhjemite–granodiorite (TTG)-like sodic suites have been the subject of intense debate with regard to their genetic linkage with the Phanerozoic adakite (Martin, 1986; Drummond and Defant, 1990; Atherton and Petford, 1993; Petford and Atherton, 1996; Martin and Moyen, 2002; Condie, 2005, 2008; Martin et al., 2005; Moyen, 2009; Moyen and Martin, 2012). This study presents new sensitive high-resolution ion microprobe (SHRIMP) zircon U–Pb ages, whole-rock elemental and Nd isotopic compositions, and zircon Hf isotopic data from the TTG-like orthogneisses. We aimed at not only documenting the timing and nature of magmatism, but also providing some geochemical constraints on the source rock of the Andong-Cheongsong orthogneisses. Our result permits us to determine their genetic relationship to the Yeongdeok adakite.

2. Geological outline and sample description

The Korean peninsula, a tectonic linkage between eastern China and the Japanese volcanic arc, is situated at the center of a huge Cordilleran-type orogenic belt extending from southeastern China to Sikhote Alin in eastern Siberia. Its geotectonic provinces comprise three Precambrian massifs (Nangrim, Gyeonggi, and Yeongnam) separated by two Neoproterozoic to Paleozoic fold-and-thrust belts (Imjingang and Okcheon), and the Cretaceous arc platform and a backarc basin collectively referred to as the Gyeongsang arc system (Chough and Sohn, 2010) (Fig. 1). Approximately one third of the landmass of the southern Korean peninsula is comprised of Phanerozoic granitoids. The granitoids were emplaced in association with the continental collision between the North and South China blocks and the (paleo-) Pacific plate subduction beneath the Eurasian continent (Cheong and Kim, 2012 and references therein). The relationship between these two orogenic events and their linkage to various magmatic and metamorphic episodes are, however, poorly constrained partly because of insufficient geochronological data.

Recent SHRIMP zircon U–Pb dating (Yi et al., 2012; Cheong et al., 2013; Jeong et al., 2014) has newly revealed the extensive occurrence of arc-related magmatism in the northern Gyeongsang basin, ranging in age from Middle Permian to Late Triassic. Yi et al. (2012) reported zircon ages of 253–247 Ma for the Yeongdeok adakite pluton. A small peridotite–pyroxenite complex, referred to as the Andong ultramafic complex, occurs to the west of Andong city (Fig. 1). The arc-related geochemistry (Whattam et al., 2011) and the SHRIMP zircon age (*ca.* 222 Ma; Jeong et al., 2014) of this complex indicate a magmatic formation above the Late Triassic subduction zone.

Undated, moderately to weakly foliated, tonalitic–granodioritic orthogneisses occur near Andong, to the west of the Yeongdeok adakite pluton (Fig. 1). These gneisses were intruded by the Early Jurassic (185 Ma; Sagong et al., 2005) Andong pluton to the north, and are in fault contact with the Cretaceous volcanosedimentary sequences to the south. They are typically composed of plagioclase, quartz, hornblende and biotite, with subordinate K-feldspar, clinopyroxene, zircon, apatite, titanite, and ilmenite. Four gneiss samples (0424-1, -2, -5, and -6A) were collected for this study. Large xenoliths of metagranitoids and metasedimentary rocks commonly occur within the orthogneisses. A well-foliated granodiorite xenolith (sample 0424-3) was also collected. This sample is composed of plagioclase, quartz, hornblende and biotite, with minor K-feldspar, muscovite, magnetite, ilmenite, titanite and zircon. A medium-grained equigranular tonalite (sample 1126-1C) consisting of quartz, biotite, plagioclase, hornblende and minor K-feldspar was collected from the central part of the Andong pluton.

The Cheongsong pluton, previously dated at the Early Jurassic (196 Ma; Sagong et al. (2005)), contains xenoliths of well-foliated trondhjemitic gneiss. A porphyritic biotite granite of the Cheongsong pluton (sample 0423-9) and a gneiss xenolith (sample 0423-10) were taken from the central part of the pluton. The trondhjemitic gneiss is composed of plagioclase, quartz and biotite, with accessory hornblende, K-feldspar, muscovite, zircon, ilmenite and magnetite. Several to tens of millimeters thick aphanitic layers, rich in quartz, plagioclase and chlorite, occur subparallel to the major foliation.

3. Analytical procedure

Major elements were analyzed on fused glass beads by X-ray fluorescence spectrometry (XRF 1700, Shimadzu) at Pukyong

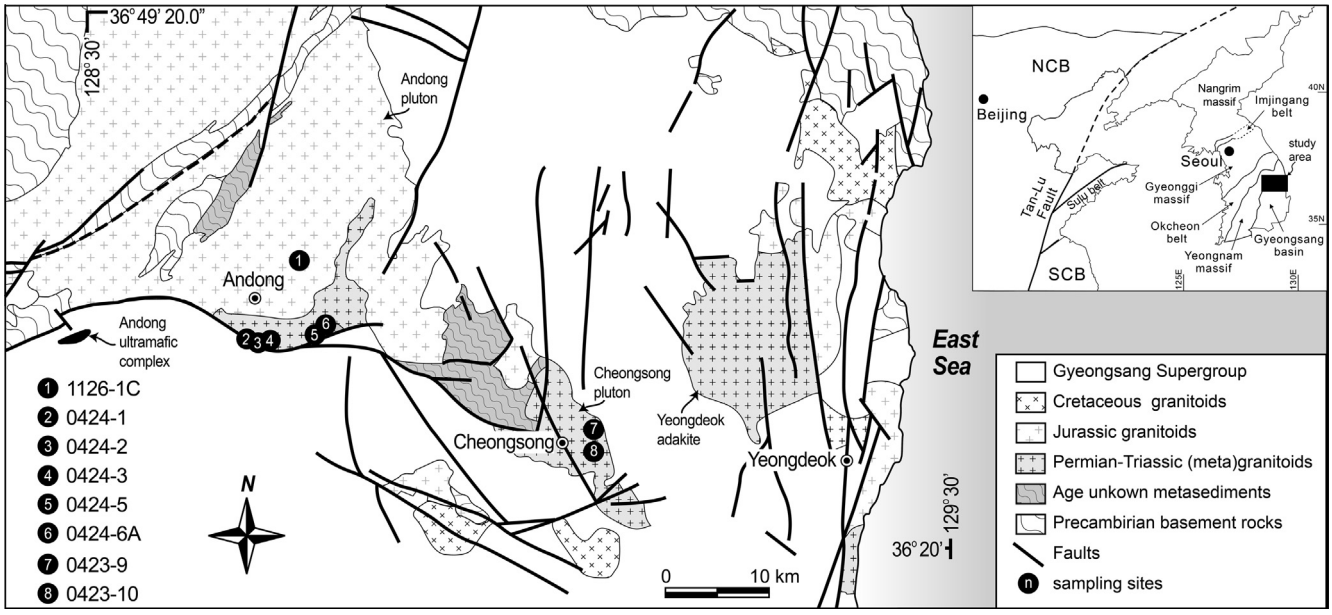

Fig. 1. Schematic geologic map of the Andong-Cheongsong-Yeongdeok area, southeastern Korea. Sample locations are also shown. Inset figure is a simplified tectonic province map of the Korean peninsula and northeast Asia. NCB, North China Block; and SCB, South China Block.