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Post-collisional carbonatite-hosted rare earth element mineralization in the Hongcheon area, central Gyeonggi massif, Korea: Ion microprobe monazite U-Th-Pb geochronology and Nd-Sr isotope geochemistry

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ABSTRACT

The Hongcheon area in the central Gyeonggi massif is a unique carbonatite locality in South Korea. The age and petrogenesis of this uncommon rock type and associated rare earth element (REE) mineralization still remain uncertain. The NNE trending, 20–50 m wide and ~2 km long Fe-REE ore bodies are hosted within a swarm of carbonatite dykes intruding Precambrian basement gneisses. The intrusive nature of the dykes, fenite alteration halos, exsolution intergrowths of constituent minerals and stable isotope data in the literature collectively attest to the ore formation by crystallization of carbonatite magma. The carbonatites are composed primarily of dolomite, ankerite, siderite, magnetite, monazite, apatite, strontianite and pyrite with subordinate quartz, barite, columbite, fergusonite and calcite. The principal carrier phase of REEs is monazite. The REE contents of monazite vary narrowly (TREO = 66.1–69.4 wt.%) irrespective of the textural occurrence. Although the monazite shows a sample-to-sample variation in La/Nd ratio, the textural varieties from each rock sample are similar with respect to this ratio. Thorium contents in monazite are consistently low (average = ca. 2500 ppm) with unusually high (average = ca. 2200) Th/U ratios. Sensitive high-resolution ion microprobe (SHRIMP) dating of monazite yielded a weighted mean $^{208}Pb/^{232}Th$ age of 232.9 ± 1.6 Ma, which agrees with a weighted mean $^{206}Pb/^{238}U$ age of 227.2 ± 8.3 Ma within uncertainties. This age, coupled with comparable intrusion ages documented for kimberlites and monzonite-syenite-gabbro-mangerite suite from central Korea, demonstrates the occurrence of mantle-derived alkaline igneous activities and associated REE mineralization following the North and South China collision. The intrusion of the Hongcheon carbonatite and potassic or ultrapotassic suite in central Korea may have resulted from the post-collisional detachment of the subducted slab and consequent upwelling of hot asthenosphere and melting of the overriding lithospheric mantle. Initial Nd-Sr isotopic ranges of the Hongcheon carbonatite (ε_{Nd} = ca. −26, $^{87}Sr/^{86}Sr$ = 0.703–0.706) and previous trace element data deny a petrogenetic linkage with the coeval silicate magmas. The metasomatism in the lithospheric mantle source of the Hongcheon carbonatite must have occurred in the distant past (>1.7 Ga) to generate significantly negative ε_{Nd} values.

1. Introduction

Carbonatites, defined by the IUGS classification system as igneous rocks composed of >50 modal % magmatic carbonate and containing <20 wt.% SiO_2, are an important igneous source of rare earth elements (REEs) (Chakhmouradian and Zaitsev, 2012). This uncommon rock type usually coexists with alkaline silicate rocks, and carbonate-rich melts derived from subcontinental lithospheric or asthenospheric mantle domains can concentrate REEs by about two orders of magnitude through differentiation processes including fractional crystallization and/or immiscible separation from silicate magmas (Hoatson et al., 2011; Chakhmouradian and Zaitsev, 2012; Veksler et al., 2012). On the other hand, a broad spectrum of carbonatite petrogenesis is addressed by approximately one-fourth of worldwide localities that have no associated igneous silicate rocks (Woolley and Kjarsgaard, 2008; Pirajno, 2015). Carbonatites typically occur in intracontinental rift-related settings but are also found in post-collisional environments (Hou et al., 2006; Chakhmouradian et al., 2008; Woodard and Hetherington, 2014). Age determination of carbonatites may therefore provide an important clue in recognizing a specific tectonic episode.

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Magmatic carbonate rocks occur rarely in the Korean Peninsula. Yang et al. (2003) reported the occurrence of intrusive carbonatites containing a magnetite deposit and associated ultramafic rocks from Ulsan, southeastern Korea. The authors interpreted that the Ulsan carbonatites depleted in REEs (total REE < 20 ppm) and high field strength elements (HFSEs) ([Zr] < 5 ppm, [Y] < 20 ppm and [Nb] = ~1 ppm) were generated by the melting/fluxing of crustal carbonate materials (i.e. Lentz, 1999). In South Korea, REE-enriched carbonatites have been reported from only one locality, Hongcheon in the central Gyeonggi massif. The age and source material of this unique rock type and associated REE ores, however, still remain uncertain.

This study presents sensitive high-resolution ion microprobe (SHRIMP) U-Th-Pb dating results of monazite, the main carrier phase of REEs in the Hongcheon carbonatite. The Nd-Sr isotopic compositions of the carbonatites and Precambrian wall rocks were also analyzed to trace the metal source. The implications of SHRIMP age and Nd-Sr isotopic features are discussed in the context of Mesozoic collisional tectonics.

2. Geological background and sample collection

The central Korean Peninsula is characterized by the Precambrian Gyeonggi and Nangrim massifs and the surrounding Imjingang and Okcheon fold-and-thrust belts (Fig. 1a). The Gyeonggi massif consists primarily of Paleoproterozoic basement gneisses and overlying supracrustal sequences. The former experienced two crustal thickening events that occurred in Paleoproterozoic (ca. 1.88–1.85 Ga) and Triassic (ca. 245–230 Ma) times (Lee and Cho, 2003; Lee et al., 2014; Yengkhom et al., 2014; Oh et al., 2015). The Paleoproterozoic event produced granulite facies metamorphism and widespread partial melting. The second event was associated with the collisional orogeny and resulted in high-pressure metamorphism highlighted by the occurrence of eclogitic amphibolite in the western Gyeonggi massif (Oh et al., 2005). Another line of evidence for the continental collision is provided by nearly coeval (ca. 230 Ma) occurrences of alkaline igneous rocks (kimberlite-monzonite-syenite-gabbro-mangerite) in the Gyeonggi massif (Oh et al., 2006; Choi et al., 2009; Williams et al., 2009; Seo et al., 2010, 2015; Cheong et al., 2015b), the Okcheon belt (Cheong et al., 2015a), and the southern margin of the Nangrim massif (Peng et al., 2008; Yang et al., 2010) (Fig. 1a).

The geology of the Hongcheon area is represented by Precambrian basement gneisses and presumably Middle Jurassic (ca. 162 Ma, Sagong et al. 2005) granitoids (Fig. 1b). The Precambrian basement rocks comprise banded biotite gneisses and biotite-hornblende gneisses. The former shows a well-developed compositional layering consisting of biotite-rich dark bands and garnet porphyroblast-bearing quartzofeldspathic leucosome. The latter is composed mainly of quartz, plagioclase, biotite, hornblende and perthite with subordinate garnet, epidote, titanite, apatite, magnetite and zircon. These gneisses experienced amphibolite facies peak metamorphism followed by near-isothermal decompression (Cho and Kim, 1993). Recently Kim et al. (2013) reported Paleoproterozoic (1.93–1.83 Ga) SHRIMP U-Pb ages of magmatic and metamorphic zircons from the banded biotite gneisses. We collected four samples from the banded biotite gneisses (samples 304-1 and 305-2) and biotite-hornblende gneisses (samples 305-1 and 305-4) for Nd-Sr isotopic analyses.

The carbonate rocks and associated Fe ores in the Hongcheon area were once considered to be of metasedimentary origin (Lee and Lee, 1989; Lee, 1998), but subsequent studies (Lee et al., 2002; Park and Lee, 2003; Kim et al., 2005) revealed several lines of evidence for their igneous origin such as exsolution intergrowths of constituent minerals and typical carbonatite-like oxygen and carbon isotopic compositions. Carbonatites hosting Fe-REE deposits are emplaced along the boundary between the banded biotite gneiss and the biotite-hornblende gneiss as a swarm of dominantly NNE trending, westward dipping dykes (Fig. 1b). The main carrier phases of Fe and REEs are magnetite and monazite, respectively. The 20–50 m wide ore bodies are traced for about 2 km, but dominantly occur in three sites named hereafter as the northern,

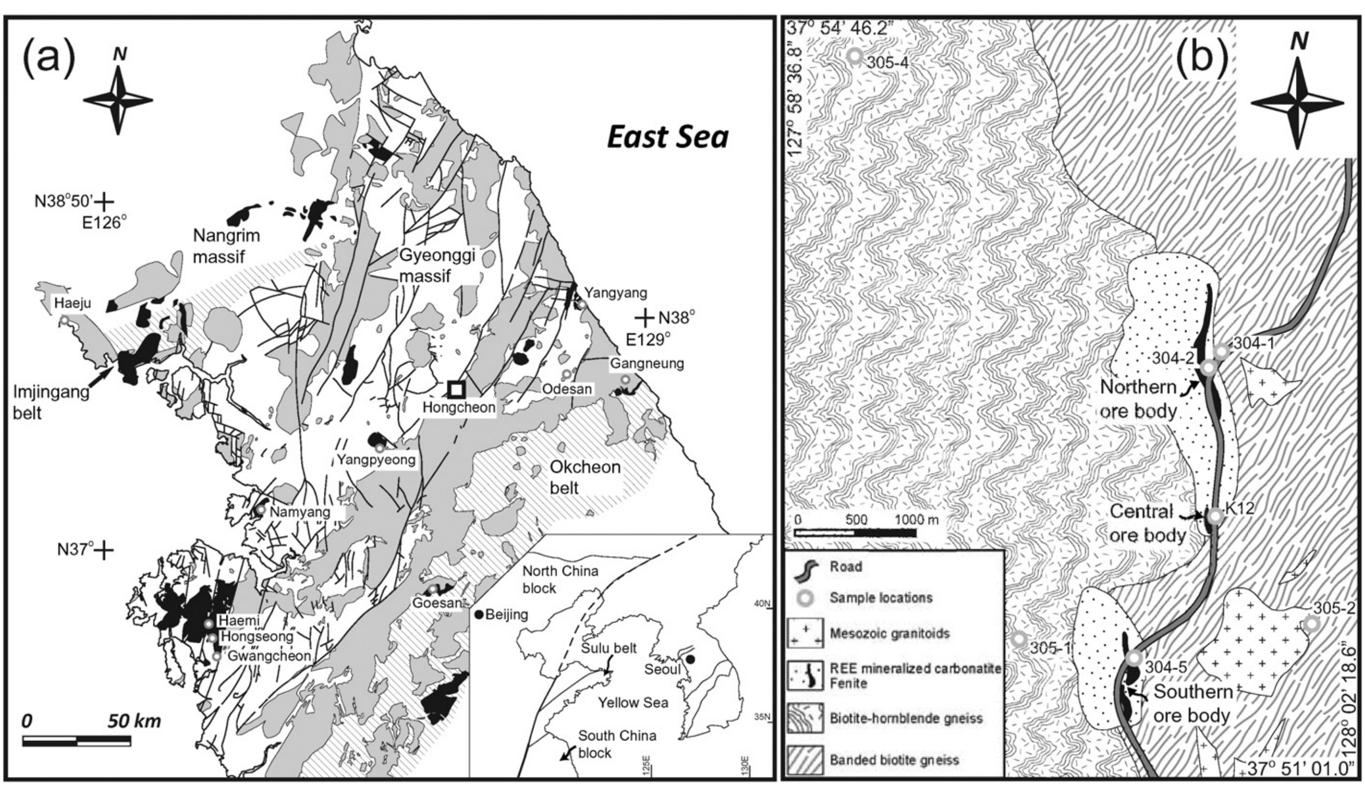

Fig. 1. (a) Distribution of Triassic (in black) and Jurassic-Cretaceous (in grey) plutons in the central Korean Peninsula (modified after KIGAM, 2001). The Hongcheon area (small open square) is located in the central part of the Gyeonggi massif. Lineaments are shown by solid lines. Inset figure shows tectonic provinces of East Asia including the Korean Peninsula. (b) Simplified geologic map of the Hongcheon area (modified after Lee et al., 2002), with sample locations.