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Fluid-present disequilibrium melting in Neoarchean arc-related migmatites of Daeijak Island, western Gyeonggi Massif, Korea

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ABSTRACT

The melting process of meta-igneous rocks was investigated via field, petrographic and geochemical analyses of the Neoarchean (~2.51 Ga) migmatite complex in Daeijak Island, western Gyeonggi Massif. This complex consists primarily of garnet-free amphibolites and tonalitic migmatites, both of which contain hornblende, plagioclase and quartz as major constituents. Neosomes and leucosomes in the migmatite have dioritic–tonalitic and tonalitic–trondhjemitic compositions, respectively. Compositions of hornblende (X_{Fe} = 0.39–0.42) and plagioclase ($An_{24–27}$) vary little between the neosomes and leucosomes. The amphibolites show distinct depletions in Nb, Ta, Zr, and Ti relative to large ion lithophile elements, suggesting an arc-related origin for their basaltic protolith. Leucosomes have lower contents of K_2O, MgO, FeO^*, TiO_2, Zr, Rb, and rare earth elements (REE) than amphibolites and neosomes, but are higher in SiO_2, Na_2O, and Sr contents. Leucosomes and neosomes have positive [$(Eu/Eu^*)_N$ = 1.32–7.26] and negative (0.71–0.97) Eu anomalies, respectively, which are attributed to the variable degree of plagioclase fractionation during the partial melting. The *P–T* condition for the migmatite formation was estimated to be ~700–730 °C and 4.7–5.5 kbar, primarily based on the hornblende–plagioclase thermobarometry and phase equilibria. Various lines of textural evidence, such as the channel flow of melt along migmatitic layers and the segregation of melt into shear bands or boudin necks suggest a syn-deformation crystallization of melt. Chemical disequilibrium in migmatites is documented not only by petrographic and geochemical data but also by the REE modeling between melt product and source rock. Disequilibrium process is most likely attributed to the rapidity of melt extraction or migration, compared to chemical diffusion rate. In summary, the fluid-present disequilibrium melting of dioritic–tonalitic protoliths has produced tonalitic–trondhjemitic leucosomes in a dynamic arc environment prevalent in the Neoarchean crust of the Korean Peninsula as well as the Shandong Peninsula, North China Craton.

1. Introduction

The anatexis or partial melting of mafic to intermediate igneous sources is a widespread phenomenon in high-temperature orogenic belts or magmatic arc and plays a key role for governing rheological behavior and chemical differentiation of continental crust (e.g., Brown et al., 1995; Sawyer et al., 2010). The anatectic melt produced from partially molten rocks at middle- to lower-crustal depths is commonly extracted from the source area and transported to the upper crust. The formation, extraction and migration of melt strongly affect the mineralogy and rheology of host rocks from the magmatic to subsolidus stages and are controlled by near- and far-field stresses which are accompanied by the gravitation-, pressure-, and/or surface tension-induced forces (Brown, 2010; Sawyer, 2001). The evidence for melt extraction or segregation in partially-molten rocks is ubiquitous at the hand specimen or outcrop scales (e.g., boudin necks, veins, dykes, and shear bands; Kisters et al., 2009; McLellan, 1988; Oliver and Barr, 1997; Pattison and Harter, 1988; Reichardt and Weinberg, 2012a; Weinberg and Mark, 2008). Moreover, the rapidity of melt extraction often results in chemical disequilibrium between the melt and residual phases as described below.

Geochemical evidence for the extraction of partially-equilibrated melt has been documented in contact aureoles (Näslund, 1986), mafic migmatites (Sawyer, 1991) and pelitic migmatites (Jung et al., 1998, 1999; Watt and Harley, 1993; Watt et al., 1996). In the leucosomes of migmatites, depleted REE abundances and positive Eu anomalies are generally attributed to disequilibrium melting (e.g., Barbey et al., 1989; Bhadra et al., 2007; Jung et al., 1998, 1999; Sawyer, 1991; Watt et al., 1996) or to metamorphic differentiation (e.g., Sawyer and Barnes, 1988; Whitney and Irving, 1994). Anatexis triggered by mafic magmatism is a common phenomenon in arc environments, where intense thermal flux and strong near or far-field stress are prevalent (e.g., Barnes et al., 2002; Corona-Chávez et al., 2006; Garrido et al., 2006; Otamendi et al., 2009). Thus, arc-related migmatites are useful for investigating the crustal differentiation and melting or segregation processes in magmatic arcs. However, dynamic or disequilibrium melting in the middle–lower crust of magmatic arc is rarely reported

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primarily because melts are easily modified and contaminated by magmatic underplating or local hybridization of granitic magma (Barnes et al., 2002; Reichardt et al., 2010).

The Neoarchean (~2.51 Ga) migmatite complex in Daeijak Island, Gyeonggi Massif (Cho et al., 2008) offers an opportunity to investigate partial melting processes in a middle to lower crustal segment of a magmatic arc. Tonalitic migmatites that represent this basement complex are intimately associated with mafic bodies of variable size, consisting of garnet-free amphibolites. In this study, we present field, petrographic, and geochemical data to better understand the H_2O-present melting process in mafic to intermediate igneous rocks. Our result suggests that dynamic melting is operative in the middle to lower crust of this Neoarchean magmatic arc and attests to the rapidity of melting processes such as melt migration and/or intra-crustal differentiation.

2. Geological setting and petrography

The Precambrian basement of the Korean Peninsula comprises Nangrim, Gyeonggi and Yeongnam massifs, from north to south (Fig. 1a). These massifs, primarily consisting of high-grade gneisses and schists, are separated by the Imjingang and Ogcheon fold-thrust belts (Cho et al., 2007, 2013). Major lithologies of the Gyeonggi Massif include quartzo-feldspathic gneisses, banded gneisses, and migmatites together with minor schists, amphibolites, calc-silicates, and quartzites (Lee et al., 2003). These amphibolite- to granulite-facies gneisses underwent multiple episodes of metamorphism and deformation, which were variably dated at Neoarchean to Triassic (Cho et al., 2008; Kim et al., 2008; Lee and Cho, 1995).

The small twin islands of Daeijak and Soijak in the western Gyeonggi Massif are largely composed of tonalitic migmatites, granodioritic gneiss, and K-feldspar gneiss overlain by the deformed sedimentary cover of the Early Jurassic Daedong Supergroup (Fig. 1b). The Daeijak migmatite complex, which represents the only outcrop exposure of the Neoarchean gneiss in South Korea, was interpreted by Cho et al. (2008) to be correlative with tonalite–trondhjemite–granodiorite (TTG) gneisses widespread in the Shandong Peninsula, China (Hou et al., 2006; Jahn et al., 2008). Similar to the TTG terrane in China, this complex is characterized by the occurrence of various types of tonalitic migmatites together with large blocks or layers of dioritic amphibolites. Minor tonalitic patches, or dykes, within the blocks of amphibolite are apparently continuous with stromatic or patchy leucosomes that envelop these mafic bodies. Varieties of diatexitic migmatites, such as the schollen migmatite, are widespread. Amphibolites and migmatites are commonly sufficiently deformed and have penetrative foliations which are subparallel to the stromatic leucosomes. The foliations generally trend NW to NNE and dip gently to moderately toward the north. Stretching and mineral (prismatic amphibole or lath-like plagioclase) lineations plunge moderately toward the northeast (Fig. 1b). The migmatite complex is intruded by Triassic (~230 Ma, Cho et al., unpublished data) granites.

2.1. Amphibolites

Garnet-free amphibolites occur primarily as medium- to coarse-grained, massive blocks which are surrounded by leucotonalites. Some mafic blocks (e.g., sample DE34-7a) contain the network of hornblende-bearing leucosomes which show diffuse boundaries with hornblende-rich melanosomes (Fig. 2a). Small, irregular patches of former in-situ melt are rare and suggest that melting is incipient (Fig. 2b). Mineral assemblages of the amphibolites consist of hornblende, plagioclase, quartz,

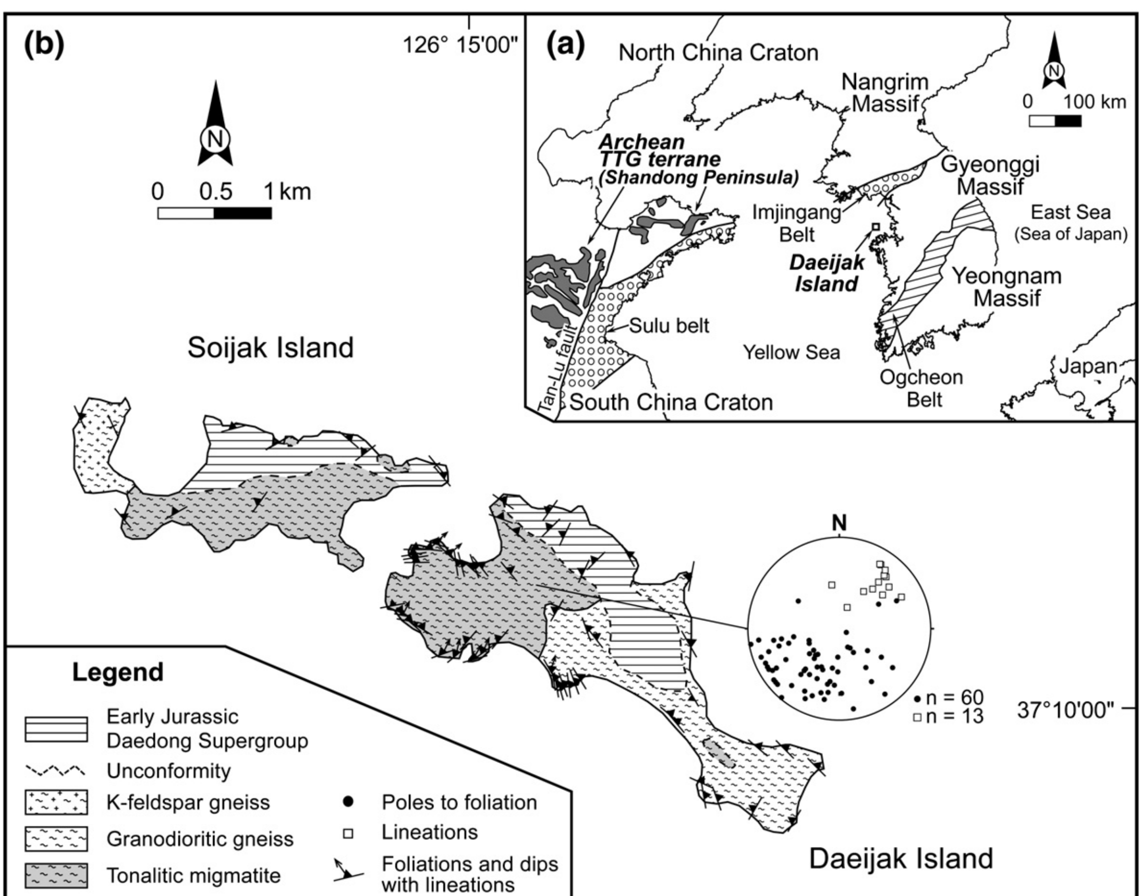

Fig. 1. (a) Simplified tectonic province map of East Asia. (b) Geologic map of Daeijak and Soijak Islands. Foliations and lineations of migmatites are plotted on a stereogram of lower-hemisphere, equal area projection.