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Fast cooling following a Late Triassic metamorphic and magmatic pulse: implications for the tectonic evolution of the Korean collision belt

Koen de Jong [a,*], Seokyoung Han [a,1], Gilles Ruffet [b,c]

[a] School of Earth and Environmental Sciences, Seoul National University, 599 Gwnangno, Gwanak-gu, 151-747 Seoul, Republic of Korea
[b] CNRS (CNRS/INSU) UMR 6118, Géosciences Rennes, 35042 Rennes Cedex, France
[c] Université de Rennes I, Géosciences Rennes, 35042 Rennes Cedex, France

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A B S T R A C T

We discuss the evolution of Korea in the context of a relatively short-lived, tectonically induced, magmatic and metamorphic pulse that affected large portions of the crust of the peninsula's southern part during the Late Triassic. Recent $^{40}Ar/^{39}Ar$ single grain laser step-heating dates imply a prolonged metamorphic recrystallization between 243 and 220 Ma, which occurred in distinct phases that were not coeval throughout the peninsula. We obtained identical plateau ages between 231.4 ± 0.8 and 228.9 ± 0.8 Ma (1σ; 85–95% ^{39}Ar release) on single grains of detrital muscovite from Jurassic sandstones (Gimpo Group). A literature review shows that the ages of detrital muscovites are identical to: (1) concordant $^{40}Ar/^{39}Ar$ ages of biotite (228 Ma) and amphibole (230 Ma) in amphibolites of the Deokjeongri Gneiss Formation and the Weolhyeonri Complex, pointing to very rapid cooling of 100–150 °C/Ma, and (2) 231–229 Ma muscovite from the low-grade metamorphic mid-Paleozoic turbidites of the Taean Formation. The efficiency of cooling is further underlined by the near-coincidence of these $^{40}Ar/^{39}Ar$ ages with 243–229 Ma (average: 234.6 Ma) zircon U–Pb ages in the Gyeonggi Massif and the Hongseong belt, in the literature. It is argued that the Late Triassic magmatic and metamorphic pulse is superimposed on an earlier tectono-metamorphic event, possibly related to collision, indicated by: (1) ~243–237 Ma muscovite ages, or age components in age spectra, and (2) two generations of folds and associated tectonic foliations truncated by ~229.5-Ma-old syenites and earlier mafic dykes. The Late Triassic thermal pulse could have been the result of post-collisional delamination of the lower crust and uppermost mantle, and/or oceanic slab break-off, which is also suggested by almost coeval, widespread mantle-sourced Mg-rich potassic magmatism. Continuing ductile deformation is shown by mylonitization of Late Triassic magmatic rocks; an ~220 Ma muscovite age may be related to this.

1. Introduction

The Korean Peninsula forms part of an orogenic system where prolonged deformation, metamorphism and magmatism combined to create great complexity that has challenged geoscientists of different breeds for several decades. Most studies on the geology of Korea are focused on the study of high-pressure metamorphic rocks (e.g., Cho et al., 2007; Kim et al., 2006; Kwon et al., 2009; Lee and Cho, 2003; Oh et al., 2005, 2014; Ree et al., 1996; S.W. Kim et al., 2011b), litho-tectonic units (e.g., Chough et al., 2000, 2013; Oh, 2012; Oh et al., 2009; S.W. Kim et al., 2008) or more recently age distributions of detrital zircons (e.g., Cho et al., 2010; Jeon et al., 2007; Kim et al., 2014a) and their correlations across the Yellow Sea to China and more specifically to the Qinling–Dabie–Sulu belt. Instead of such model-driven approaches, the goal of the present paper is rather to reconstruct geological processes, and to elucidate the tectonism responsible for them, ultimately aiming at placing the geological evolution in a geodynamic context. Isotope geochronology is instrumental in our effort, because every tectonic model should be based on well-constrained ages for different events.

Currently, the architecture and evolution of the Korean tectonic system are yet far from clear and timing of major events is not yet well constrained. Relatively commonly occurring isotopic ages between ca. 290 and 215 Ma in some of the tectonic terranes, show that the peninsula was affected by Permo-Triassic metamorphism and consequently by tectonism. The occurrence of amphibolite bodies with very rare relics of pervasively retrogressed mafic high-pressure granulite and eclogite (Kim et al., 2006; Oh et al., 2005; Park et al., 2014b; Zhai et al., 2007) suggests subduction to depths in the order of 60–75 km. Yet, the age of subduction and collision is not well known as zircons from these rocks yielded U–Pb dates of 240 ± 5 and 231 ± 3 Ma (Guo et al., 2005; Kim et al., 2006; Park et al., 2014b). Many mountain belts that formed by crustal thickening were later in their tectonic evolution affected by horizontal crustal extension and associated lithospheric thinning and intruded by mantle-sourced Mg-rich potassic magmatic rocks (e.g., Bianchini et al., 2008; Davies and von Blanckenburg, 1995;

* Corresponding author. Tel.: +82 2 880 6632.
E-mail address: keuntie@yahoo.com (K. de Jong).
[1] Tel.: +82 2 880 6632.

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Dilek and Altunkaynak, 2009; Duggen et al., 2005; Fowler et al., 2008; Gill et al., 2004; Jiang et al., 2013; Liégeois and Black, 1987; Turner et al., 1996; von Raumer et al., 2014). von Blanckenburg and Davies (1996) pointed out that associated late syn-collisional basaltic (lamprophyric, high-K calc-alkaline) and granitoid magmatism are the most valuable witnesses of slab break-off. A late Triassic gabbro–monzonite and syenite–granite suite with medium- and high-K calc-alkaline composition and shoshonitic affinity is also present in all major tectonic terranes of the Korean tectonic system (Fig. 1). Most plutons are between 233 and 224 Ma old, with only two bodies being older, viz., 237 and 240 Ma (Choi et al., 2009; J.M. Kim et al., 2011; Jeong et al., 2008; Kee, 2011; Oh et al., 2006b; Peng et al., 2008; S.W. Kim et al., 2011a; Seo et al., 2010; Williams et al., 2009; Wu et al., 2007). 237–228 Ma mineral ages in (migmatitic) gneisses in large parts of central Korea imply a coeval regional metamorphic event. The Carnian to early Norian magmatic suite is usually interpreted as due to a change of tectonic regime subsequent to plate collision from compressional to tensional (S.W. Kim et al., 2011a; Williams et al., 2009), often linked to asthenospheric upwelling induced by lithospheric delamination (Choi et al., 2009), or oceanic slab break-off (Oh, 2012; Seo et al., 2010). Two alkali granites with A-type geochemistry yielded identical 219.3 ± 3.3 Ma and 219.6 ± 1.9 Ma U–Pb Sensitive High-Resolution Ion Micro-Probe (SHRIMP) ages on zircon (Cho et al., 2008), which the authors interpreted as dating the extensional tectonism subsequent to major collision.

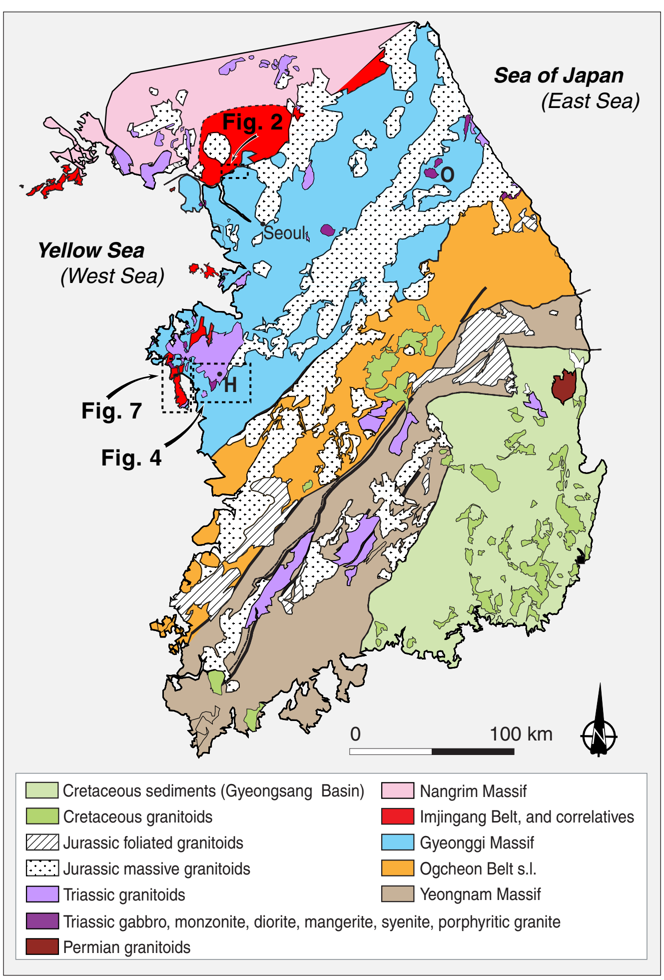

Fig. 1. Tectonic sketch map of the southern part of the Korean Peninsula. Maps of key areas discussed are outline; locations referred to in the text are marked; H, Hongseong; O, Odesan.

The above overview shows that some of the currently available age estimates for the high-pressure metamorphism and the Late Triassic magmatism and associated regional high-temperature metamorphism that took place at low- to intermediate-pressure are the same. However, the Late Triassic magmatism is often linked to delamination/slab detachment, which in tectonic models occurs significantly later than the high-pressure event. This underscores the difficulty linking U–Th–Pb age data of polygenetic accessory minerals to the evolution of assemblages of metamorphic minerals or to fabric-forming main phase silicates. In contrast to accessory mineral dating, $^{40}Ar/^{39}Ar$ dating is applied to rock-forming and fabric-forming K-bearing minerals. This is a big advantage as their growth can be more straightforwardly correlated to major phases of the tectono-metamorphic evolution of rocks. In the present paper we report new high-quality $^{40}Ar/^{39}Ar$ age determinations between 231 and 229 Ma obtained from a number of detrital grains from metamorphic muscovite, some of which have a biotite core. We put these new dates into perspective with recently published isotopic ages in the ca. 243–220 Ma range obtained by $^{40}Ar/^{39}Ar$ laser-probe and SHRIMP of metamorphic silicates and accessory minerals (e.g., de Jong and Ruffet, 2014a,b; de Jong et al., 2014; Han, 2014; Oh et al., 2014; Park et al., 2014b; Kim et al., 2014a; Kim et al., 2014b) from different key areas along the northern and western margins of the Gyeonggi Massif (Figs. 2, 4, 7), combined with structural and other field data. Especially, information offered by low-grade metamorphic middle Paleozoic sediments (Taean Formation) on Anmyeon Island (Fig. 7), place important constraints on the tectonic evolution, as in contrast to the other key locations these rocks have only experienced early Mesozoic deformation and metamorphism. This approach helps to meet a major geochronological challenge of obtaining age estimates for the duration and speed of tectonic and metamorphic processes in the Korean orogenic system, and to constrain timing of different phases during the evolution — information that is currently lacking. With this new information, pointing to very fast cooling in the late Triassic, we attempt to elucidate the meaning of the regional post-collisional magmatic–metamorphic pulse, and aim to put up a model for the tectonic evolution of the Korean Peninsula during this period. We use the most recent international chronostratigraphic chart of the International Commission on Stratigraphy (Cohen et al., 2013; updated) to transfer isotopic dates to chronostratigraphical ages.

2. Regional geology

Much of Korea consists of Precambrian continental crust formed from material extracted from the mantle in the late Neoarchean, subsequently strongly affected by Paleoproterozoic high-grade metamorphism and magmatism, peaking in the 1.93–1.83 Ga period (Lee and Cho, 2012). The Precambrian basement is subdivided into three gneiss terranes, viz. the Nangrim, Gyeonggi and Yeongnam Massifs, from North to South (Fig. 1). Of these three, only the Gyeonggi Massif has been seriously affected by Triassic metamorphism, as recorded in isotopic ages of U-bearing accessory minerals in the 250–215 Ma range, but mostly between 235 and 231 Ma (Cho et al., 2013b; D.L. Cho et al., 1996; J.M. Kim et al., 2008; K.H. Kim et al., 2008; Kee, 2011; Kim et al., 2006; Kim et al., 2009; Lee et al., 2014; Oh et al., 2006b, 2015; S.W. Kim et al., 2008; Suzuki, 2009; Yengkhom et al., 2014; Yi and Cho, 2009). The three Precambrian terranes are separated by two belts of multiple-deformed and metamorphosed sedimentary and volcanic rocks of late Neoproterozoic to middle and late Paleozoic age: the Imjingang and Ogcheon Belts (Fig. 1; e.g., Kim, 1998; Chough et al., 2000; Lim et al., 2005; Cho et al., 2007, 2013a; Kee, 2011; Choi et al., 2012). Multiply deformed greenschist facies metamorphic middle Paleozoic turbidites (Figs. 1, 7; Taean Formation), which are comparable to similar series in the Imjingang Belt and part of the southwestern Ogcheon Belt (Cho et al., 2013a; Choi et al., 2008; Kee, 2011; Kim et al., 2014a; So et al., 2013), crop out discontinuously along the western margin, and structurally uppermost part, of the Gyeonggi Massif (Fig. 1). These middle Paleozoic meta-sedimentary terranes, draped around the