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Timing of metamorphism in the central Sør Rondane Mountains, eastern Dronning Maud Land, East Antarctica: Constrains from SHRIMP zircon and EPMA monazite dating

Tatsuro Adachi[a,*], Yasuhito Osanai[a], Tomokazu Hokada[b], Nobuhiko Nakano[a], Sotaro Baba[c], Tsuyoshi Toyoshima[d]

[a] *Division of Earth Sciences, Faculty of Social and Cultural Studies, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan*
[b] *National Institute of Polar Research, 10-3 Midori-cho, Tachikawa, Tokyo 190-8518, Japan*
[c] *Department of Natural Environment, University of the Ryukyus, 1 Senbaru, Nishihara, Okinawa 903-0213, Japan*
[d] *Department of Geology, Faculty of Science, Niigata University, 8050 Ikarashi 2-no-cho, Niigata-shi, Niigata 950-2181, Japan*

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ABSTRACT

In order to understand the tectonic evolution of the Sør Rondane Mountains, eastern Dronning Maud Land, East Antarctica, sensitive high resolution ion microprobe (SHRIMP) U–Pb zircon dating and electron probe micro analyzer (EPMA) U–Th–Pb monazite dating were carried out on igneous rocks and metamorphic rocks whose *P*–*T* conditions have been well-constrained. Metamorphic rocks from northern part of Austkampane area recording a clockwise *P*–*T* path yield 600–640 Ma as the timing of peak granulite-facies metamorphism and 550–570 Ma for subsequent retrograde metamorphism. The same age relations were obtained from the metamorphic rocks from Brattnipene and eastern Menipa areas recording an anti-clockwise *P*–*T* path. Contemporaneous peak metamorphism with contrasting *P*–*T* paths can be explained by thrusting up (obduction) of the unit showing a clockwise *P*–*T* path onto the unit showing an anti-clockwise *P*–*T* path at ca. 660–640 Ma, which is considered to be the main metamorphic event. Metamorphic rocks from Lunckeryggen, southern Walnumfjella and western Menipa areas that preserve amphibolite-facies peak metamorphic conditions and are unaffected by the retrograde hydration, yield ca. 550 Ma. Ages of 500–550 Ma were also obtained on igneous rocks distributed throughout the whole area. Based on the close age relation between metamorphism of amphibolite-facies rocks and igneous activity, it is likely that metamorphism at ca. 550 Ma was caused by emplacement of voluminous igneous bodies. These precise correlation of metamorphic evolution and age would provide strong constraints on the construction of a tectonic model for Gondwana amalgamation.

1. Introduction

The Sør Rondane Mountains, which are located in eastern Dronning Maud Land, East Antarctica, have been considered to be situated in the suturing orogens of Gondwana, such as, East Africa Antarctic Orogen (EAAO, Jacobs and Thomas, 2002), or East Africa Orogen and Kuunga Orogen (Meert, 2003). Therefore, the mountains have attracted interest as potentially a key area for understanding the geological phenomena during amalgamation of the Gondwana supercontinent. Geochronological data can provide critical information in the study of tectonic history of an orogeny, especially in conjunction with data on the metamorphic pressure–temperature (*P*–*T*) evolution.

In the early stage of geochronological work in the Sør Rondane Mountains, Rb–Sr and K–Ar dating were obtained throughout the mountains and gave ages from 420 to 500 Ma, which was attributed to an intense thermal event associated with plutonic activity (e.g. Picciotto et al., 1964; Takahashi et al., 1990; Grew et al., 1992). Shiraishi and Kagami (1992) reported ca. 1000 Ma from orthogneiss determined by Sm–Nd and Rb–Sr whole-rock isochron methods, and considered this age to be the timing of granulite-facies metamorphism. They also obtained internal mineral isochrons from orthogneisses and paragneisses, which yielded 556 Ma and 624 Ma ages for Rb–Sr and Sm–Nd systems, respectively. These ages were interpreted as the timing of thermal and hydration events associated with granitic intrusions (Shiraishi and Kagami, 1992).

Asami et al. (1996, 1997, 2005) reported U–Th–Pb monazite and zircon EPMA ages in granulites from the Sør Rondane Mountains. Monazite from granulite-grade metamorphic assemblages yielded chemical Th–U–total Pb isochron method (CHIME) ages in the range from 510 to 550 Ma, which was interpreted as the

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[*] Corresponding author.
E-mail address: t-adachi@scs.kyushu-u.ac.jp (T. Adachi).

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timing of granulite-facies metamorphism. The authors explained previously measured ages of ca. 1000 Ma as ages of the formation of protoliths, either of igneous or high-grade metamorphic lithologies.Shiraishi et al. (2008) reported sub-grain U–Pb ages of zircon measured by Sensitive High Resolution Ion Micro Probe (SHRIMP) over a widespread area of the mountains. According to them, granulite-facies metamorphism took place at ca. 600–650 Ma and amphibolite-facies metamorphism at ca. 550–570 Ma. However metamorphic rocks in the Sør Rondane Mountains have had a complex metamorphic history (e.g. Asami et al., 1992; Adachi et al., 2012) including intense retrograde hydration (Adachi et al., 2010). Therefore, relating metamorphic events to their timing should require a comprehensive petrological investigation. Recently, Adachi et al. (2012) reinvestigated metamorphic rocks in the central Sør Rondane Mountains and classified them into three types based on difference of recorded metamorphic history. In this study, U–Pb zircon SHRIMP dating and U–Th–Pb monazite EPMA dating have been carried out on petrologically well constrained samples investigated by Adachi et al. (2012). These results allow us to put geological meanings on the obtained ages precisely and to construct a tectonic model of the Sør Rondane Mountains.

2. Geological background

The Sør Rondane Mountains are located between 22° to 28° E and 71.5° to 72.5° S in East Antarctica. They are underlain by medium to high-grade metamorphic rocks intruded by granitoids, syenites and minor mafic dykes (Fig. 1; e.g. Shiraishi et al., 1991, 1997). Ultramafic, mafic and intermediate metamorphic rocks in the central part of the mountains indicate that the magmatic protoliths have geochemical affinities with oceanic, island arc, accretionary complex and continental margin arc settings in modern plate tectonics (Osanai et al., 1992; Ishizuka et al., 1996). Orthogneisses having a felsic composition (meta-tonalite) dominant in the southwestern part of the mountains are supposed to have formed from a hot subducting plate (Ikeda and Shiraishi, 1998).

The mountains have been divided into the Northeastern (NE) Terrane and the Southwestern (SW) Terrane based on metamorphic grade and lithology (Osanai et al., 1992). This division is updated as shown in Fig. 1, and a boundary between the NE and SW Terranes is defined as the Main Tectonic Boundary (Osanai et al., 2013). Additionally the NE Terrane has been subdivided into units A and B and the SW Terrane into units C, D and D′ (see Osanai et al., 2013, for more details). The units A, B and C are dominated by amphibolite- to granulite-facies metamorphic rocks of pelitic, psammitic, and felsic compositions with minor amounts of mafic rocks, marbles and calcsilicates. The *P*–*T* conditions recorded in rocks of these units have been estimated to be 800 °C and 0.7–0.8 GPa at peak metamorphism, and 530–580 °C and 0.55 GPa during subsequent amphibolite-facies retrograde metamorphism (e.g., Asami et al., 1992; Asami and Shiraishi, 1987; Shiraishi and Kojima, 1987; Osanai et al., 1988; Grew et al., 1989). Asami et al. (2007) also reported sapphirine + kyanite and spinel + kyanite composite inclusions in garnet from the Balchenfjella area, which indicate 860–895 °C and 1.2 GPa. Recently Adachi et al. (2012) reinvestigated metamorphic rocks mainly distributed in the northern part of Austkampane area (unit B) and the Brattenipene area (unit C), and suggested that the former preserve a clockwise *P*–*T* path; ca. 800 °C and 0.4–0.5 GPa at peak metamorphic conditions after the decompression and subsequent isobaric cooling accompanying hydration, and that the latter records an anti-clockwise *P*–*T* path; peak metamorphic conditions of ca. 800 °C and 0.7–0.8 GPa after the compression and subsequent isobaric cooling with hydration. These differences in the *P*–*T* paths in each unit are consistent with recent reports: a clockwise path in unit B for pelitic gneiss from northern part of Austkampane (Hokada et al., 2009), an anticlockwise path in unit C for pelitic gneisses from Brattnipene (Baba et al., 2012) and for garnet-amphibolite from the southern part of Austkampane (Nakano et al., 2012). The units D and D′ are composed mainly of greenschist- to amphibolite-facies metamorphic rocks of felsic and intermediate compositions. The metamorphic conditions of these units are estimated to be those of the upper amphibolite facies, followed by retrogression and accompanying mylonitization (Shiraishi and Kojima, 1987). Adachi et al. (2012) investigated metamorphic rocks mainly distributed in the Lunckeryggen area (unit D) and suggested that they preserve signatures of prograde metamorphism and amphibolite-facies peak metamorphic conditions.

In the whole area of the mountains, foliations and lithological boundaries strike dominantly E–W and dip S to SSW, except in the southern part of the Brattnipene area, where a large-scale fold zone is developed. Undeformed pegmatitic and granitic intrusions are found over the entire area. These intrusions strike NW–SE and dip NE or SW. They are associated by mylonitization related to the activity along a normal fault, indicating extensional tectonics (Toyoshima et al., 2008).

3. Sensitive high resolution ion micro probe (SHRIMP) zircon U–Pb dating

3.1. Samples and analytical procedures

Zircon grains were separated from each sample, mounted in epoxy and polished to expose cross-sections through the grains. The surface of grain mounts was washed with 2% HCl to remove any lead contamination and then coated with high-purity gold using an evaporative coater prior to analysis. Backscattered electron and cathodoluminescence (CL) imaging was performed with a Scanning Electron Microscope (JEOL JSM-5900LV) at the National Institute of Polar Research, in order to observe the internal structures of zircons and to select analytical spots. Representative analyzed grains and spots are shown in Fig. 3.

The present study compiles U–Pb zircon analyses for 13 samples obtained with the Sensitive High Resolution Ion Micro Probe (SHRIMP II) facilities at the National Institute of Polar Research, Japan. An O_2^- primary ion beam of ca. 1.5 nA was used to sputter an analytical spot of < 25 μm diameter on the polished mount. Samples selected for analysis are listed in Table 1. Localities are shown in Fig. 1 and modes of occurrence of representative analyzed samples are shown in Fig. 2.

The procedures for Pb and U isotopic analyses of zircon follow Compston et al. (1984) and Williams (1998). Abundance of U was calibrated against standard SL13 (238 ppm), and U–Pb measurements were calibrated against ^{204}Pb-corrected (Pb/U)/(UO/U)^2 values for standard FC1 (1099 Ma, Paces and Miller, 1993). For each standard dataset, scatter on (Pb/U)/(UO/U)^2 ratios and external spot-to-spot errors are quoted with data from each sample in Tables 2–14.

Data reduction and processing was performed using the Excel add-in program SQUID (v.1.12a; Ludwig, 2001) and plots were generated using ISOPLOT (v.3.50; Ludwig, 2003). All measurements on zircon were corrected for common Pb content using measured ^{204}Pb and a Stacey and Kramers (1975) model for ages approximating those of standard and unknown zircon ages (see Ludwig, 2001, for details). Wherever possible, pooled ages were calculated from single analytical sessions using the Concordia Age function of SQUID, which has the advantage of providing a test of concordance between pooled ^{206}Pb/^{238}U and ^{207}Pb/^{206}Pb ages. Mean ^{206}Pb/^{238}U ages for pooled data are also provided in the Tera-Wasserberg