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Cretaceous thermal event around the Gongsuwon thrust in the northeastern Okcheon belt: evidence from Rb-Sr geochronology of Paleozoic sedimentary rocks

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ABSTRACT: The Gongsuwon thrust together with the Deokpori (Gakdong) thrust in northeastern Okcheon belt is considered to be an important structure in understanding the tectonic evolution of the Korean peninsula following the Permian-Triassic collision between North and South China continents. We obtained Rb-Sr ages for Paleozoic sedimentary rocks around the Gongsuwon thrust to determine the age of petrographically observed thermal metamorphism and possibly constrain the movement age of the thrust. Andalusite, codierite and biotite porphyroblasts overgrow cataclastic foliation of siliceous fault rocks in the Gongsuwon thrust, indicating a post-faulting thermal metamorphism. A marble of the early Paleozoic Makgol Formation in the hanging wall (~200 m northwest from the fault zone center) and a siliceous cataclasite in the fault zone center gave Cretaceous Rb-Sr whole rock fragment ages: 113±21 (2σ) Ma and 68±17 (2σ) Ma, respectively. Sandstones of the late Paleozoic Hambaeksan Formation in the footwall (about 680 m southeast from the fault zone center) yielded an early Tertiary Rb-Sr biotite age of 56.3±6.0 (2σ) Ma, but a Paleoproterozoic Rb-Sr muscovite age of 1774±30 (2σ) Ma, suggesting that the early Tertiary thermal effect for the sandstones was strong enough to reset the Rb-Sr biotite age but weak enough not to affect the Rb-Sr muscovite age, i.e., between ~300°C and ~500°C, and that detrital muscovites in the sandstones were derived from the Precambrian basement rocks. These isotopic ages suggest that there was Cretaceous to early Tertiary thermal event around the Gongsuwon thrust, which is probably associated with well-known plutonism at that time (so-called Bulguksa granite). Available age data, albeit limited, suggest that Cretaceous to early Tertiary thermal metamorphism in the Taebaeksan basin might have been extensive. The movement age of the Gongsuwon thrust is constrained to be older than ~60 Ma.

Key words: Gongsuwon thrust, Cretaceous thermal event, Rb-Sr geochronology

1. INTRODUCTION

The Deokpori (Gakdong) thrust in the northeastern Okcheon belt is an important structure that separates two early Paleozoic sedimentary sequences of contrasting depositional environment, i.e., deep Yeongwol-type and shallow Duwibong-type of the Joseon Supergroup (Kobayashi, 1953; Cluzel et al., 1990). Cluzel (1992) considered the thrust as the extension of the Honam shear zone which he thought is a continental transform fault that formed during the Triassic collision between the North and South China continents. However, Ree et al. (2001) argued that the Deokpori thrust and the Honam shear zone are postcollisional structures developed in a continental-arc setting. Although the age of the Honam shear zone has been estimated to be Middle Jurassic (Kwon and Ree, 1997; Ree et al., 2001; Sagong et al., 2005), the age of the Deokpori thrust has not been known yet.

The Gongsuwon thrust, apparently a branch of the Deokpori thrust, is the northwestern boundary for the Bansong Group in the Taebaeksan basin (Fig. 1). There are two ideas about the relationship between the Gongsuwon thrust and the Bansong Group. One is that the Gongsuwon thrust formed after the deposition of the Bansong Group (Kim et al., 1991). The other is that the Bansong Group was deposited during the movement of the thrust (Han et al., 2006). This problem would be solved if the movement age of the Gongsuwon thrust is known.

In this study, we obtained several Rb-Sr ages from thermally metamorphosed Paleozoic sedimentary rocks around the Gongsuwon thrust in the Yeongwol area to help constrain its movement age. We discuss (1) Cretaceous to early Tertiary thermal metamorphism by hidden plutons and (2) the movement age of the Gongsuwon thrust.

2. GEOLOGICAL BACKGROUND

South Korea consists of five tectonic provinces from northwest to southeast: the Imjingang belt, the Gyeonggi massif, the Okcheon belt, the Yeongnam massif, and the Gyeongsang basin. The Gyeonggi and the Yeongnam massifs are the Precambrian terranes with high-grade gneisses and schists. The Imjingang belt is an east-trending fold-and-thrust belt that is considered to be an eastern part of the Permian-Triassic continental collision belt between the North and South China blocks (Yin and Nie, 1993; Ree et al., 1996). The Okcheon belt is the northeast-trending fold-and-

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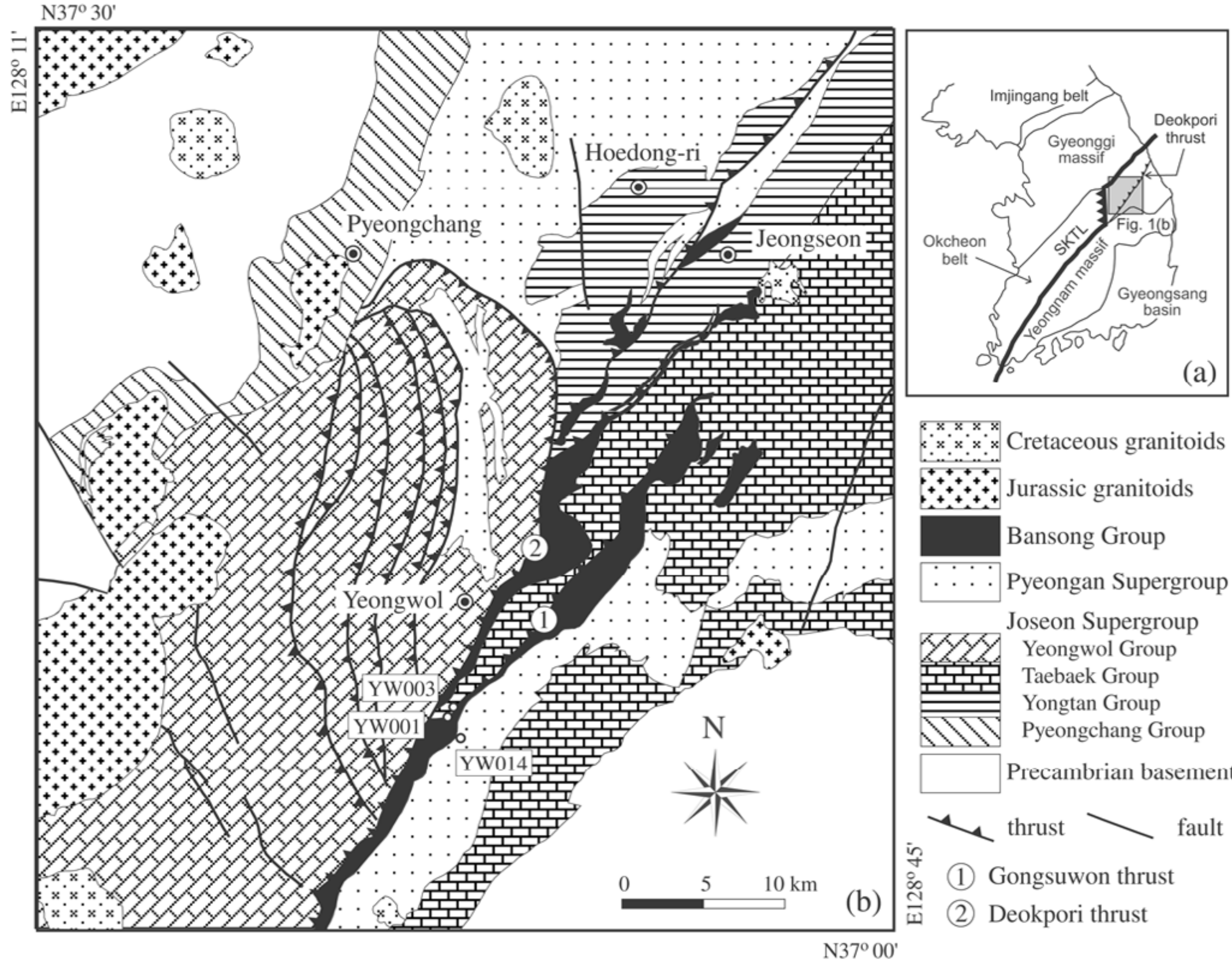

Fig. 1. (a) Index map. The bold line is the SKTL (South Korea Tectonic Line) suggested by Ree et al. (2001). (b) Geologic map of the study area with sample locations.

thrust belt and is divided into the southwestern Okcheon basin and the northeastern Taebaeksan basin (Chough et al., 2000; Ree et al., 2001). The Okcheon basin consists of the Late Proterozoic to early Paleozoic metavolcano-sedimentary rocks (Kwon and Lan, 1991; Lee et al., 1998). The Taebaeksan basin includes non- to weakly-metamorphosed fossiliferous sedimentary rocks of the early Paleozoic (Joseon Supergroup), late Paleozoic to early Mesozoic (Pyeongan Supergroup) and the middle Mesozoic (Bansong Group). The Gyeongsang basin is composed of Cretaceous-early Tertiary non-marine sedimentary rocks and intermediate to acidic volcanic rocks. During the Mesozoic time, granitoid rocks formed by continental-arc magmatism intruded extensively in Korean peninsula (Chough et al., 2000; Sagong et al., 2005).

Figure 1b shows a geological map around the Deokpori and the Gongsuwon thrusts in the Yeongwol area. The Precambrian gneisses to the northwest and to the southeast are the basement rocks belonging to the Gyeonggi massif and the Yeongnam massif, respectively. The Joseon Supergroup is divided by the Deokpori thrust into Yeongwol Group to the west and the Taebaek Group to the east (Chough et al., 2000). The Bansong Group occurs in the footwalls of the Deokpori and Gongsuwon thrusts. The exact relationship between the Deokpori and Gongsuwon thrusts is not clear at present, although the latter appears to be a branch of the former. The Bansong Group in the footwall of the Gongsuwon thrust uncomformably overlies late Paleozoic arenitic sandstone (Hambaeksan Formation of the Pyeongan Supergroup) to the east, and is structurally overlain by the early Paleozoic marbles of the Joseon Supergroup (Makgol Formation of the Taebaek Group; Chough et al., 2000) along the Gongsuwon thrust (Han et al., 2006). The Gongsuwon fault zone, ~250 m wide, consists of foliated cataclasite and ultracataclasite mainly of siliciclastcs of the Bansong Group and lensoidal carbonate blocks of the Joseon Supergroup (Han et al., 2006). Mesozoic granites intruded those sedimentary rocks.

3. SAMPLE DESCRIPTION

Samples for this study were collected from a siliceous cataclasite (YW001B) in the Gongsuwon fault zone, marbles (YW003) of the Joseon Supergroup (~200 m northwest from the fault zone center), and arenitic sandstones (YW014) of the Pyeongan Supergroup around the Gongsuwon thrust (~680 m southeast from the fault zone center; Fig. 1b).

3.1. Sample YW001B

This sample is a foliated siliceous cataclasite from the Gongsuwon fault zone and consists of fractured quartz and feldspar in a mica (both muscovite and biotite) matrix. The matrix also contains some calcite and opaque minerals. The fractured quartz grains (or quartz aggregates) and feldspar grains are angular to subangular in shape and mostly show patchy undulose extinction. The mica grains in the matrix show a preferred orientation defining the cataclastic foliation. Thermal metamorphic minerals such as andalusite, cordierite and biotite overgrow the cataclastic foliation, indicating the thermal metamorphism posterior to the faulting (Fig. 2). Andalusite grains (mostly 0.5–1.0 mm) are either idioblastic or spherulitic (Fig. 2). Cordierite grains (mostly 250–500 μm) are idioblastic to hypidioblastic. Biotite grains (mostly 50–250 μm) are acicular or stubby.

3.2. Sample YW003

This sample is marble from the Makgol Formation (Joseon Supergroup) in the hanging wall of the Gongsuwon thrust. It comprises various colored layers with 0.5–1.0 cm width. The sample YW003A consists of three colored layers: red, green and white. The reddish layers (YW003A-R) are composed mainly of calcite and amphibole. The greenish layers (YW003A-G) contain amphibole and diopside that appear to have formed by thermal metamorphism (Fig. 3). The recrystallized calcites of 2–5 mm size are the major constituent of the white layers (YW003A-W). The sample YW003B consists of black layers (YW003B-B), whitish layers (YW003B-W), and reddish layers (YW003B-R). The main components of the black layers are fine-grained calcite, amphibole, and minor opaque mineral. The whitish layers are mainly com-

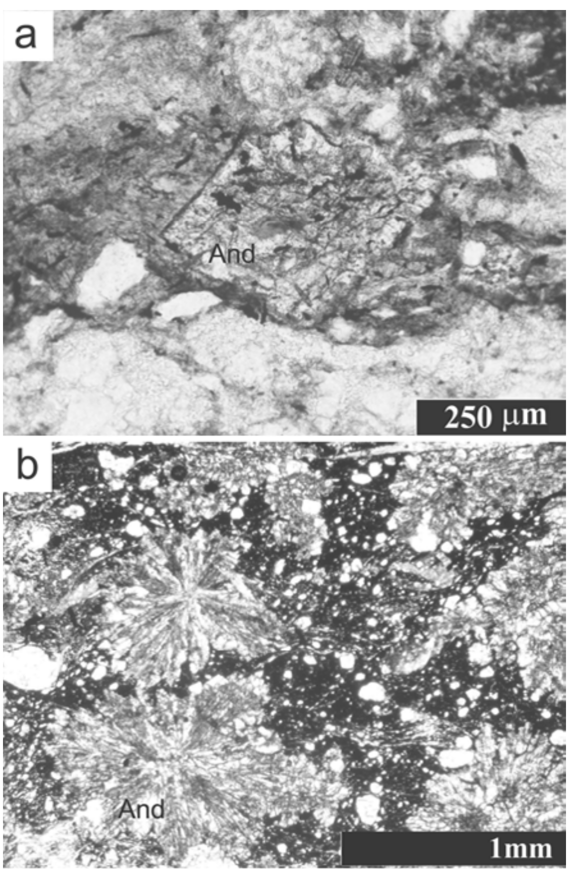

Fig. 2. Posttectonic andalusite (And) porphyroblasts (a) and spherulitic andalusites (b) overgrowing cataclastic fabrics of the fault rocks in the Gongsuwon Thrust. Plane-polarized light.

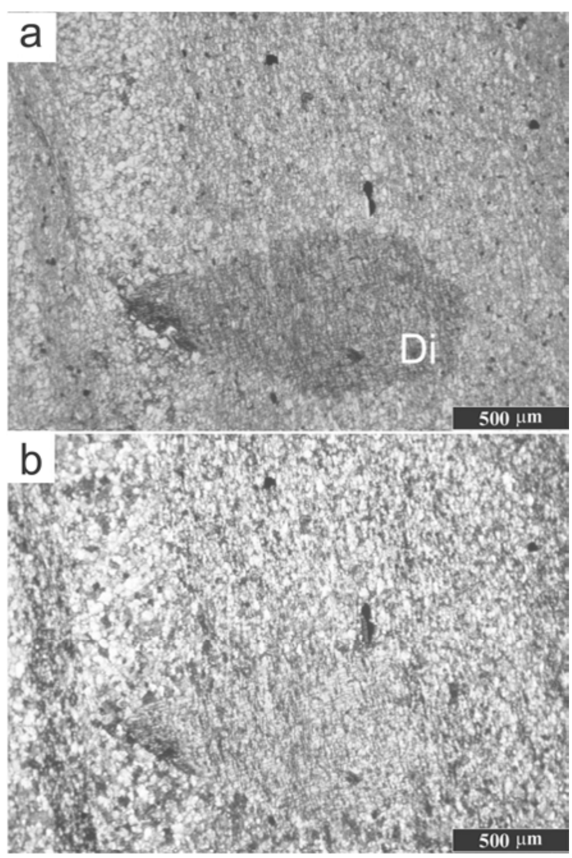

Fig. 3. Posttectonic diopside porphyroblast (Di) overgrowing the grain-shape foliation of calcites (vertical) in marble of the Makgol Formation. (a) Plane-polarized light. (b) Cross-polarized light.

posed of coarse-grained calcite. The reddish layers contain calcite and amphibole.

3.3. Sample YW014

This sample is arenitic sandstone from the Hambaeksan Formation (Pyeongan Supergroup) that is overlain uncomfortably by the Bansong Formaion in the footwall of the thrust. The sample YW014A is a fine-grained, dark gray sandstone composed mainly of quartz and biotite. Biotites are frequently altered to chlorite partially or severely. The sample YW014B is a medium-grained, light gray sandstone, and consists of quartz, muscovite and minor biotite. In these sandstones, quartz grains are mostly angular to subangular in shape. Most of the quartz grains are strain-free although some grains show undulose extinction and deformation band. In contrast, most of mica grains show undulose extinction and some kink bands. Basal planes of the mica grains tend to be parallel to bedding plane in more micaceous layers but their preferred orientation is weaker in quartz-rich layers.

4. SAMPLE PREPARATION AND ANALYTICAL PROCEDURES

Colored layers were separated from samples YW003A and YW003B, and were made into powders. The sample YW001B was crushed into rock fragments of 0.5–1 cm size. Five rock fragments were selected randomly, and were made into powders. Biotite (180–212 μm) and quartz (180–212 μm) were separated from sample YW014A, and muscovite (355–500 μm) was separated from sample YW014B, using magnetic separator and hand-picking under binocular microscope. Extra care was taken to avoid altered (chlorite-rich) grains for biotite separates of the sample YW014A.

All the mineral separates were subjected to ultrasonic cleaning with distilled water several times to remove surface impurities. Mica and quartz separates were further cleaned in warm 1N HNO_3 and 6N HCl for two hours, respectively. After addition of mixed ^{87}Rb-^{84}Sr spikes, whole rock powders and mineral separates were dissolved with a mixed acid of HF+$HClO_4$ (10:1) in Teflon vials at 120°C on the hot plate. Exceptionally, the carbonate separates of YW003A-W and YW003B-W were leached with 6N HCl to obtain pure carbonate component. The leachates were added with mixed ^{87}Rb-^{84}Sr spike, and heated at 80°C on the hot plate to ensure isotopic equilibrium between sample and spike.

Rb and Sr were extracted by the cation column method using HCl media, and loaded on Ta filament. The isotopic ratios were measured by thermal ionization mass spectrometer (VG 54-30) equipped with nine Faraday cups at Korea Basic Sciences Institute in Daejeon. Mesurements of Rb and Sr isotopic ratios were performed by static and dynamic mode, respectively. Rb and Sr contents were obtained by

Table 1. Rb and Sr contents and isotopic compositions.

Sample	Description	Rb (ppm)	Sr (ppm)	^{87}Rb/^{86}Sr	2σ	^{87}Sr/^{86}Sr	2SE$_m$
Marble (Makgol Formation of the Joseon Supergroup)							
YW003A-R	calcite and amphibole rich part	254.1	233.4	3.155	0.032	0.721373	0.000013
YW003A-G	calcite, amphibole and diopside rich part	40.5	89.8	1.304	0.013	0.719149	0.000017
YW003A-W	calcite	0.5	228.3	0.0066	0.0001	0.714821	0.000014
YW003B-B	fine-grained calcite and amphibole rich part	289.1	229.4	3.649	0.036	0.717856	0.000014
YW003B-R	calcite and amphibole rich part	56.1	236.9	0.686	0.007	0.713517	0.000013
YW003B-W	calcite	0.6	271.0	0.006	0.0001	0.712256	0.000015
Foliated cataclsite in the fault zone of the Gongsuwon thrust							
YW001B-F1	whole rock fraction	181.5	82.1	6.409	0.064	0.728854	0.000014
YW001B-F2	whole rock fraction	101.6	51.3	5.747	0.057	0.727965	0.000016
YW001B-F3	whole rock fraction	115.2	57.2	5.84	0.058	0.728446	0.000014
YW001B-F4	whole rock fraction	119.8	79.5	4.371	0.044	0.726983	0.000014
YW001B-F5	whole rock fraction	150.2	73.3	5.94	0.059	0.728588	0.000014
Sandstone (Hambaeksan Formation of the Pyeongan Supergroup)							
fine grained dark gray sandstone							
YW014A-B1	biotite	114.6	42.9	7.758	0.078	0.739892	0.000131
YW014A-B2	biotite	121.7	43.1	8.2	0.082	0.740611	0.000015
YW014A-Q	quartz	4.3	3.1	3.928	0.057	0.737159	0.000023
medium grained light gray sandstone							
YW014B-M1	muscovite	665.9	49.5	42.57	0.43	1.661546	0.000052
YW014B-M2	muscovite	656.1	44.8	46.66	0.47	1.752197	0.000058
YW014B-Q	quartz	13.6	5.6	7.05	0.18	0.748532	0.000026

*Total procedual blank is 2 pg Rb and 228 pg Sr.

isotope dilution method. Reported $^{87}Sr/^{86}Sr$ ratios were corrected for internal fractionation and spike contribution, using $^{86}Sr/^{88}Sr$=0.1194. Repeated analyses of NBS987 gave $^{87}Sr/^{86}Sr$=0.710246±0.000016 ($2\sigma_m$, n=16) during the course of analysis. All procedural blank are 2 pg Rb and 228 pg Sr. Isochron ages were calculated using the program ISOPLOT/Ex2 (Ludwig, 1999), and their errors are reported at 2σ level. Table 1 summarizes description of analyzed samples, Rb and Sr contents, and Sr isotopic ratios.

5. RESULTS AND INTERPRETATIONS

5.1. Marbles from the Makgol Formation (YW003A and YW003B)

Calcites (YW003A-W and YW003B-W) have low Rb (0.5–0.6 ppm) and high Sr contents (228–271 ppm), while the samples with high proportions of amphibole (YW003A-R and YW003B-B) contain high Rb (254–289 ppm) and Sr contents (233–237 ppm).

Three isotopic data from YW003A are too scattered to define an isochron (not shown). On the other hand, three colored layers of sample YW003B define a poorly defined isochron age of 113±21 Ma (2σ) in the $^{87}Rb/^{86}Sr$-$^{87}Sr/^{86}Sr$ diagram (Fig. 4). Since the Makgol Formation is the Early Ordovician sequence of the early Paleozoic Joseon Supergroup, the Rb-Sr rock fragment age for the marbles indicates that each layer of the sample was isotopically homogenized during a Cretaceous thermal event, which is suggested by presence of metamorphic minerals such as amphibole and diopside, and recrystallized coarse-grained calcite (Fig. 3).

5.2. Sandstones from the Hambaeksan Formation (YW014A and YW014B)

Biotites from the sandstone YW014A have Rb content of 114.6–121.7 ppm and Sr contents of 42.9–43.1 ppm. Rb

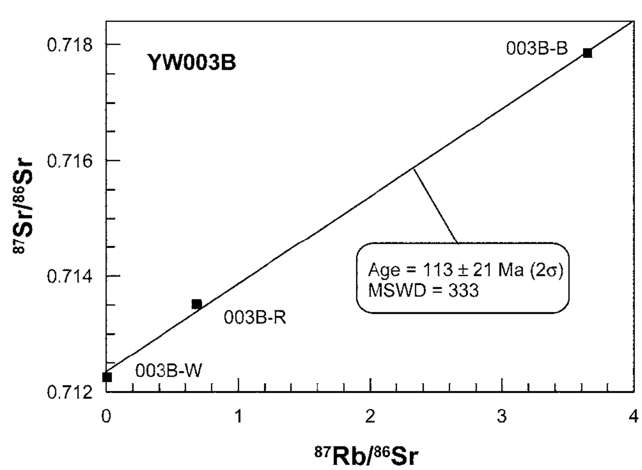

Fig. 4. Rb-Sr isochron diagram for the sample YW003B, a marble of early Paleozoic Makgol Formation of the Joseon Supergroup.

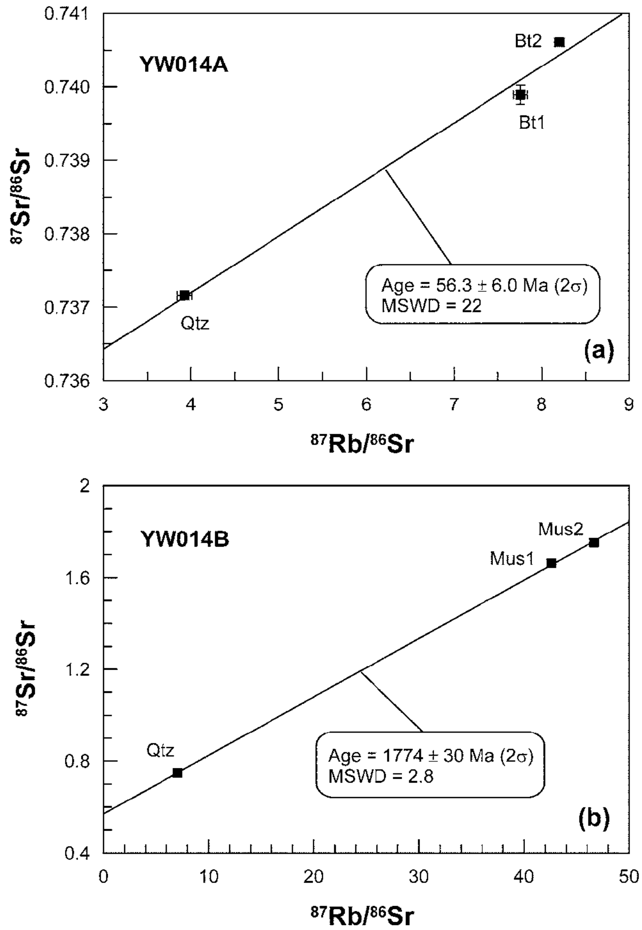

Fig. 5. Rb-Sr isochron diagrams for (a) sample YW014A and (b) sample YW014B, sandstones from late Paleozoic Hambaeksan Formation of the Pyeongan Supergroup.

and Sr contents of quartz are 4.3 ppm and 3.1 ppm, respectively. Two biotite fractions and quartz define an isochorn age of 56.3±6.0 Ma (2σ) in $^{87}Rb/^{86}Sr$-$^{87}Sr/^{86}Sr$ diagram (Fig. 5a).

Muscovites from the sandstone YW014B contain high Rb contents (656.1–665.9 ppm) and moderate Sr contents (44.8–49.5 ppm). Quartz from YW014B has more Rb and Sr contents compared with the quartz from YW014A. Muscovites and quartz from YW014B yield an isochron age of 1774±30 Ma (2σ) in $^{87}Rb/^{86}Sr$-$^{87}Sr/^{86}Sr$ diagram (Fig. 5b).

Since the Hambaeksan Formation corresponds to the middle sequence of the Pyeongan Supergroup (Late Paleozoic), the early Tertiary Rb-Sr biotite age is considered to be the time of a thermal event. On the other hand, the Paleoproterozoic Rb-Sr muscovite age indicates that muscovites in the sandstone are detrital, originated from the Precambrian basement rocks. Paleoproterozoic ages for the basement rocks in the Gyeonggi and Yeongnam massifs have been well documented (Gaudett and Hurley, 1973; Park et al., 1993; Lee et al., 1994; Kwon et al., 1995; Sagong and Kwon, 1998; Cheong et al., 2000; Sagong et al., 2003).

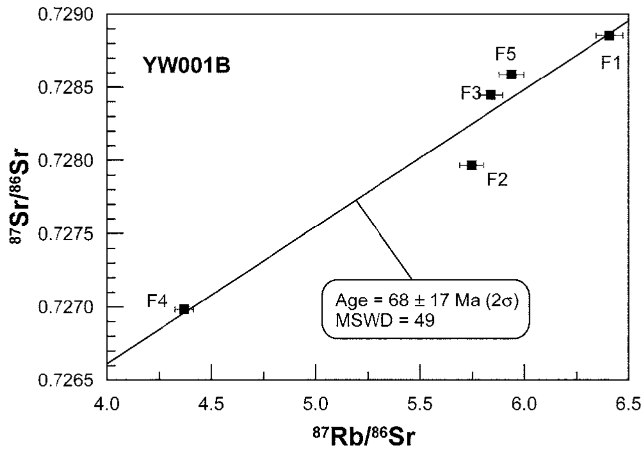

Fig. 6. Rb-Sr isochron diagram for sample YW001B, a siliceous cataclasite from the fault zone center of the Gongsuwon thrust.

Adjacent to the study area (Yeongwol), average K-Ar muscovite ages for the Proterozoic Nonggeori and Naedeongni granites are 1767±22 Ma and 1753±54 Ma (Yun, 1991), respectively, which agrees well with our Rb-Sr muscovite age. Considering early Tertiary biotite age and Paleoproterozoic muscovite age for the analyzed sandstone, we may conclude that the early Tertiary thermal event for the sandstone was strong enough to reset the Rb-Sr biotite age, but was weak enough not to disturb the Rb-Sr muscovite age, i.e., between 300°C and 500°C, the closure temperatures of the Rb-Sr biotite and muscovite ages, respectively (Wagner et al., 1977).

5.3. Foliated Siliceous Cataclasite from the Fault Zone (YW001B)

Five whole rock fragments from foliated cataclasite have 101.6–181.5 ppm Rb and 51.3–82.1 ppm Sr (Table 1), and rather poorly define an isochron age of 68±28 Ma (2σ) (Fig. 6). This age agrees within error with the Rb-Sr biotite age for the sandstone from the Hambaeksan Formation of the Pyeongan Supergroup.

6. DISCUSSION

6.1. Cretaceous to Early Tertiary Thermal Metamorphism

Our Rb-Sr ages for the sedimentary rocks around the Gongsuwon thrust indicate Cretaceous to early Tertiary thermal metamorphism. In detail, there seem to be two metamorphic events. One is the Early Cretaceous event (113±21 Ma) defined by Rb-Sr fragment age of a marble. The other is the Late Cretaceous to early Tertiary event defined by Rb-Sr fragment age (68±17 Ma) of cataclasite and Rb-Sr biotite age (56.3±6.0 Ma) of a sandstone. Note that the younger two ages agree within error to each other, and are clearly different from the older event age. Incidentally, Kwon and Park (1993) reported a U-Pb rock fragment age of 116±6 Ma from an early Paleozoic limestone of the Yongtan Group in the Hoedong-ri area, about 30 km away from Yeongwol to the NNE (Fig. 1b). This age agrees well with the Early Cretaceous age of this study, and strengthens the idea of two separate metamorphic events. Also, these isotopic ages (this study; Kwon and Park, 1993), albeit limited in number, suggest a possibility that Early Cretaceous thermal metamorphism in the Taebaeksan basin might have been extensive.

6.2. Hidden Intrusions?

As seen in the geologic map (Fig. 1b), there are no immediate intrusions around the study area that can account for the thermal metamorphism. All the granitoid plutons are at least about 20 km away from the studied samples, so that exposed granites cannot be the heat source of thermal metamorphism. Therefore, it appears that we need hidden intrusions around the study area.

It is well known that Korean peninsula experienced abundant granitoid intrusions in the Mesozoic (Kim, 1971; Chough et al., 2000; Sagong et al., 2005), and that the Cretaceous granites intruded generally at shallow level (Cho and Kwon, 1994). So, the possibility of hidden intrusions in the study area could be high. Unfortunately, detailed intrusion ages of the Cretaceous granites shown in Figure 1 are not well known, so that it is yet to be evaluated if the two metamorphic events proposed in this study are related to two distinct intrusion events separated in time.

6.3. Movement Age of the Gongsuwon Thrust

Observing porphyroblasts of andalusite, cordierite and biotite overgrowing the cataclasite foliation, Han et al. (2006) interpreted that the fault rocks of the Gongsuwon thrust experienced a thermal metamorphism after fault movement. Previously, we noted that the Rb-Sr fragment age of the cataclasite of the thrust agrees within error with the Rb-Sr biotite age of a sandstone. Since the Rb-Sr biotite age clearly represents the timing of thermal metamorphism, it appears that Rb-Sr system for fragments of cataclasite was reset during this event. So, the metamorphic age can provide the younger age limit for the thrust movement. Considering the petrographic observation of Han et al. (2006) and isotopic ages of this study, we may conclude that the Gongsuwon thrust was active before about 60 Ma.

Han et al. (2006) consider that the older age limit for the thrust movement could be the U-Pb zircon age of 187 Ma from acidic tuff of the Bansong Group. This age represents the depositional age of the Bansong Group that might have formed in close association with the movement of the Gongsuwon thrust. At present, the movement age of the Gongsuwon thrust can be constrained between 187 Ma and ca. 60 Ma.

7. CONCLUSION

1. We obtained Rb-Sr ages for the Paleozoic sedimentary rocks and cataclasite around the Gongsuwon thrust: Rb-Sr rock fragment age of 68±17 Ma from cataclasite, Rb-Sr rock fragment age of 113±21 Ma from marble, and Rb-Sr biotite age of 56.3±6.0 Ma and Rb-Sr muscovite age of 1774±30 Ma from sandstones.

2. Petrographic obvervation and isotopic ages suggest that those rocks around the Gongsuwon thrust experienced thermal metamorphism after fault movement during the Cretaceous to early Tertiary, or possibly at two distinct times, ~113 Ma and ~60 Ma.

3. Available isotopic ages (this study; Kwon and Park, 1993), although limited, suggest that Cretaceous to early Tertiary thermal metamorphism in the Taebaeksan basin could have been extensive, since it appears to be related to hidden intrusions of the well-known Bulguksa granite.

4. The movement age of the Gongsuwon thrust can be constrained between 187 Ma and ~60 Ma from available isotopic age data (this study; Han et al., 2006).

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