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Provenance of Cretaceous sandstone in the southeastern Yeongdong Basin, Korea, revealed by the chemical Th-U-Total Pb isochron ages of detrital monazites

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INTRODUCTION

The Yeongdong Basin, one of small Cretaceous non-marine basins in the southwestern Korean Peninsula, comprises ca. 6~8 km thick siliciclastic sequences of alluvial, fluvial and lacustrine sediments (Lee and Paik, 1989, 1990; Chun et al., 1993). In the southeastern part of the Yeongdong Basin, petrographic analyses of sandstones and conglomerates suggest that the clastic materials were mostly derived from granite and gneiss terrains. Judging from the apparent paleoflow directions measured from either gravel imbrication, scour wall and scour axes or plunge of trough axes, sediments were supplied from the south. Up to now, however, no detailed analysis has been carried out to identify what is the suite of corresponding bedrocks.

For single and/or subgrain dating of monazite and other Th- and U-bearing minerals, such as zircon and xenotime, chemical Th-U-total Pb isochron method (CHIME) has been recently developed on the basis of precise electron microprobe analyses (Suzuki et al., 1991, 1992; Suzuki and Adachi, 1991a, b; Adachi and Suzuki, 1992). This method offers high spatial resolution (1-3 μm) and is well suited to study sedimentary and metasedimentary rocks, where mineral grains are not chronologically uniform (Suzuki and Adachi, 1994). Since monazite is a ubiquitous accessary mineral in clastic, igneous and metamorphic rocks, and contains very little initial Pb compared with radiogenic Pb (*e.g.* Williams *et al.*, 1983; Corfu, 1988), it gives essentially concordant U-Pb and Th-Pb ages (*e.g.* Burger *et al.*, 1965; Grauert *et al.*, 1974; Koppel, 1974) as well as reliable chronological information.

We made CHIME age determinations on detrital monazites in three sandstone samples from the southeastern part of the Cretaceous Yeongdong Basin, in order to shed light on the identification of the suite of corresponding bedrocks. Also made was the CHIME dating of monazite from a granite gneiss sample of the Yeongnam Massif in Gimcheon area. The age spectra of detrital monazites coupled with paleoflow directions and petrographic analysis will provide an important criterion to clarify the proper source rocks. This is the first documentation of age spectra of detrital monazites from clastic sediments in the Yeongdong Basin, and here, we present the dating results, and discuss the provenance nature of the clastic rocks.

GEOLOGIC SETTING

In the southwestern Korean Peninsula, there exist small-scale, Cretaceous nonmarine basins were formed along a series of NE-SW trending strike-slip faults which were developed along northern and southern boundaries of Ogcheon Fold Belt (Reedman and Um, 1975; Chun and Chough, 1992). The Yeongdong Basin, one of these Cretaceous basins, is an elongated half-graben basin with a length of about 50 km and a width of 8-10 km. The basin was developed through left-lateral strike- slip movements during Cretaceous period (Lee and Paik, 1990).

The sedimentary succession of the Yeongdong Basin can be divided into two depositional sequences on the basis of mudstone key bed which is characterized by extensive exposures and laterally continuous mappable unit between two depositional sequences (Kim, 1996). Each sequence represents its own unique depositional system and comprises an alluvial fan and associated downslope fluvial and lacustrine systems. Sequence development appears to have shifted toward the northeast, whereas the sediments of each depositional systems are thought to have been derived from specific local sources located at the northern and southern basin margins and drained toward the basin center (Lee and Paik, 1990; Kim, 1996).

The succession of the southeastern part of the Yeongdong Basin consists dominantly of conglomerate with subordinate (gravelly) sandstone and mudstone. Clasts in conglomerate range in size from granule to boulder (maximum size: 1.85m in long diameter), and comprise angular to subrounded granite (foliated granite, porphyritic granite, two-mica granite and leucogranite), banded gneiss, and schist. The succesion is bounded by fault to the southeast and is in contact with Precambrian gneiss and schist which are included in the Yeongnam Massif (Shimamura, 1925; Yun and Park, 1968; Won and Kim, 1969; Kim and Hwang, 1986).

The Yeongnam Massif in Sangju-Gimcheon-Geochang area, to southeast of the Yeongdong Basin, comprises Precambrian parangneiss, granitic gneiss and amphibolite, age-unknown metasediments and Permian to Cretaceous granitic rocks. The Precambrian paragneiss, granitic gneiss and amphibolite formed under the amphibolite to upper-amphibolite facies conditions and were overprinted by the retrogressive metamorphism of amphibolite and/or greenschist facies conditions (Lee, 1980; Lee et al., 1981; Song and Lee, 1989). They were intruded by Mesozoic granitic rocks. The gneissic and granitic rocks of the Yeongnam Massif in the Sangju-Gimcheon-Geochang area have been dated by several workers (Choo and Kim, 1985; Kim et al., 1989; Lee et al., 1992; Park et al., 1993). The reported age data are summarized in Table 1 and their locations appear in Fig. 1.

CHIME MONAZITE AGES

CC-2: Medium- to fine-graned sandstone

Monazite grains from this sample, 80-250 μm in size, are euhedral to sbhedral and pale yellow in color. A total of 178 spots on 45 monazite grains were analyzed. The ThO_2 content ranges from 2.28 to 17.69%, the UO_2 content from 0.019 to 0.746%, and the PbO content from 0.019 to 0.62%. Analytical data are plotted on the PbO vs. ThO_2^* diagram (Fig. 2). Individual monazite grains are chronologically homogeneous. They are classified into three age groups, Middle Jurassic (40 grains), Late Permian (4 grains) and Middle Precambrian (1 grain). If we regress 157 data points on 40 Middle Jurassic grains, we obtain an isochron of 172.3±3.1 Ma (MSWD=0.16) with an intercept value of 0.0014±0.0008. Similarly, 15 data points on 4 Late Permian grains

Table 1. Isotopic ages of granitic and gneissic rocks from Yeongnam Massif distributed in Sangju-Gimcheon-Geochang area.

No.	Rock	Locality	Material Analysed	Isotopic Age (Ma)	Geological Period	Reference
(1)	Granite (I)	Gimcheon	whole rock	172±28 (Rb-Sr)	Mid.-Jura.	Choo, S.H. & Kim, S.J. (1985)
(2)	Granite (II)	Gimcheon-Sangju	whole rock	177±73 (Rb-Sr)	Mid.-Jura.	Choo, S.H. & Kim, S.J. (1985)
(3)	Hornblende Diorite	Geochang	hornblende	179±9 (K-Ar)	Mid.-Jura	Kim, Y.J. et al. (1989)
(4)	Hornblende Granite	Geochang	hornblende	178±9 (K-Ar)	Mid.-Jura.	Kim, Y.J. et al. (1989)
(5)	Hornblende-biotite Granodiorite	Geochang	hornblende	181±9 (K-Ar)	Mid.-Jura.	Kim, Y.J. et al. (1989)
(6)	Two-mica Granite	Geochang-Goryong	whole rock	276±33 (Rb-Sr)	Early Perm.	Park, Y.S. et al. (1993)
(7)	Hornblende-biotite Granodiorite	Geochang-Goryong	whole rock	253±53 (Rb-Sr)	Late Perm.	Park, Y.S. et al. (1993)
(8)	Syenite	Geochang-Goryong	whole rock	227±17 (Rb-Sr)	Late Tria.	Park, Y.S. et al. (1993)
(9)	Hornblende Gabbro	Haeinsa	hornblende	204±10 (K-Ar)	Early Jura.	Kim, Y.J. et al. (1989)
(10)	Migmatitic Gneiss (I)	Gimcheon	whole rock	1608±100 (Rb-Sr)	Precambrian	Choo, S.H. & Kim, S.J. (1985)
(11)	Migmatitic Gneiss (II)	Gimcheon	whole rock	402±10 (Rb-Sr)	Silurian	Choo, S.H. & Kim, S.J. (1985)
(12)	Biotite Gneiss	Gimcheon	whole rock	1047±69 (Sm-Nd)	Precambrian	Lee, S.G. et al. (1992)
(13)	Granitic Gneiss	Gimcheon	whole rock	1699±591 (Sm-Nd)	Precambrian	Lee, S.G. et al. (1992)

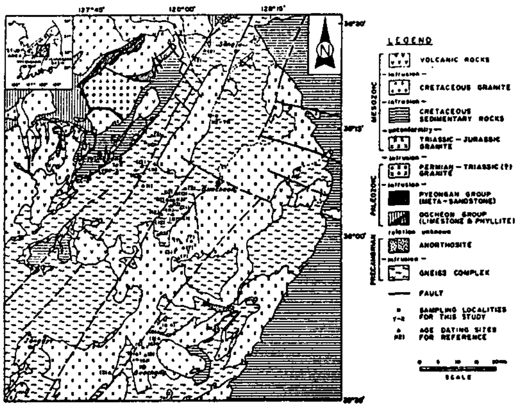

Fig. 1. --Geologic and isotopic age dating sample site map of the Yeongnam Massif distributed in Sangju-Gimcheon-Geochang area (modified after Song and Lee, 1989; Kim et al., 1989; KIGAM, 1995).

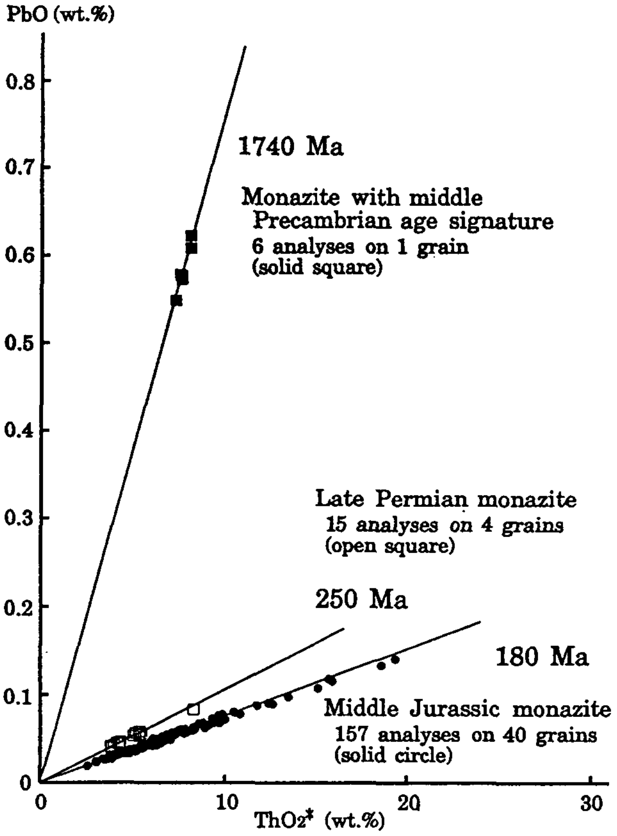

Fig. 2. Plot of PbO vs. ThO_2^* for monazite grains from medium- to fine-grained sandstone (sample no. CC-2) of the SE Yeongdong Basin. The ThO_2, UO_2, and PbO values of each point are listed in Appendix.

yield an isochron of 235.6±15.0 Ma (MSWD =0.04) with an intercept value of 0.0028 ±0.0029. For Middle Precambrian monazite grain, no reliable isochron age can be obtained owing to the small variation in the ThO_2^* content; 1740 Ma age, the average of 6 apparent ages, possibly dates the time of crystallization of monazite.

YDJ-3: Medium-grained sandstone

Monazite grains from this sample are pale yellow, largely subhedral, and range in size from 70 to 200 μm with an exceptionally large grain of 300 μm. A total of 198 spot on 54 grains were analyzed. The ThO_2 content ranges from 3.16 to 29.65%, the UO_2 content from 0.03 to 1.62%, and the PbO content from 0.023 to 0.571%.

Analytical data are plotted on the PbO vs. ThO_2^* diagram (Fig. 3). They are classified into three age groups, Middle Jurassic (50 grains), Late Permian (2 grains) and Middle Precambrian (2 grains). Individual monazite grains, except 1 Middle Precambrian grain, are chronologically homogeneous. Regression of 185 data points on 40 Jurassic grains gives an isochron of 176.9±1.7 Ma (MSWD=0.10) with an intercept value of 0.0001± 0.0005. Seven data points on 2 Late Permian grains are regressed with an isochron of 255.5±28.4 Ma (MSWD=0.21) with an intercept value of -0.0016±0.0081.

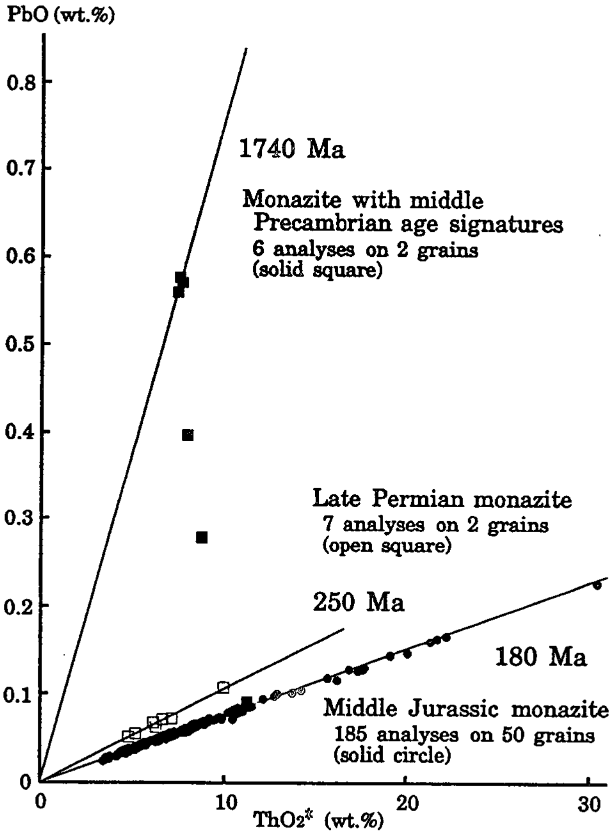

Fig. 3. Plot of PbO vs. ThO_2^* for monazite grains from medium-grained sandstone (sample no. YDJ-3) of the SE Yeongdong Basin. The ThO_2, UO_2, and PbO values of each point are listed in Appendix.

Y-2: Fine-grained sandstone

Monazite grains from this sample, 50-125 μm in size, are subangular to rounded. A total of 250 spots on 46 monazite grains were analyzed. The ThO_2, UO_2 and PbO contents are in the ranges of 2.64-15.37%, 0.02-1.74%, and 0.023-0.801%, respectively.

The analytical data are plotted on the PbO vs. ThO_2^* diagram (Fig. 4). This population is characterized by a large number of Late Permian monazites: they amount to 15 grains, while 28 grains are referred as Middle Jurassic. Also found are 2 Middle Precambrian grains and 1 possible Silurian grain. Most Late Permian monazites are chronologically uniform, but some grains have a mantle of Middle Jurassic age. The Silurian monazite grain is mantled by Late Permian rim. The Middle Precambrian monazite grains have a rim of 250 and 450 Ma, respectively. Regression of 158 data points on 28 homogeneous Middle Jurassic monazites yields an isochron of 179.9±2.9 Ma (MSWD=0.15) with an intercept value of 0.0006±0.0008, and regression of 64 data points on 13 homogeneous Late Permian monazites does an isochron of 246.8±5.2 Ma (MSWD=0.11) with an intercept value of 0.0002±0.0012. The homogeneous core of 1 Middle Precambrian monazite yields an isochron of 1738±36 Ma (MSWD=0.03) with an intercept value of -0.0041±0.0151.

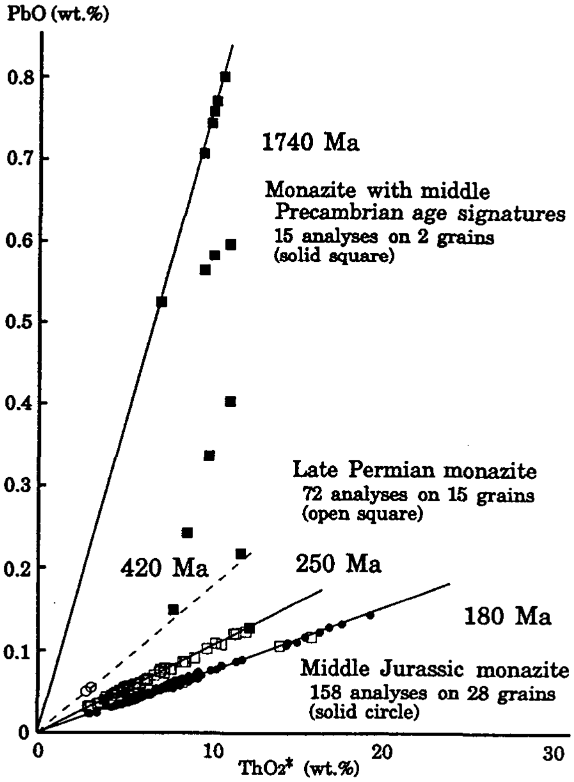

Fig. 4. Plot of PbO vs. ThO_2^* for monazite grains from fine-grained sandstone (sample no. Y-2) of the SE Yeongdong Basin. The ThO_2, UO_2, and PbO values of each point are listed in Appendix.

112-YN: Granitic gneiss (? Foliated granite)

A total of 82 spots on 18 monazite grains were analyzed. Monazites contain 2.52-17.13% ThO_2, 0.030-0.371% UO_2, and 0.028-0.190% PbO. Data points except those on 1 grain, are regressed with an isochron of 251.2±3.0 Ma (MSWD=0.10) with an intercept value of 0.0001±0.0007 (Fig. 5). Seven data points on 1 grain show a different trend from the 251.2 Ma trend, and yield an isochron of 368.4±18.8 Ma (MSWD=0.06) with an intercept value of -0.0031±0.0039. This monazite grain is regarded as xenocryst, and the 251.2 Ma monazite age is referred as the emplacement time of the foliated graite in the latest Permian.

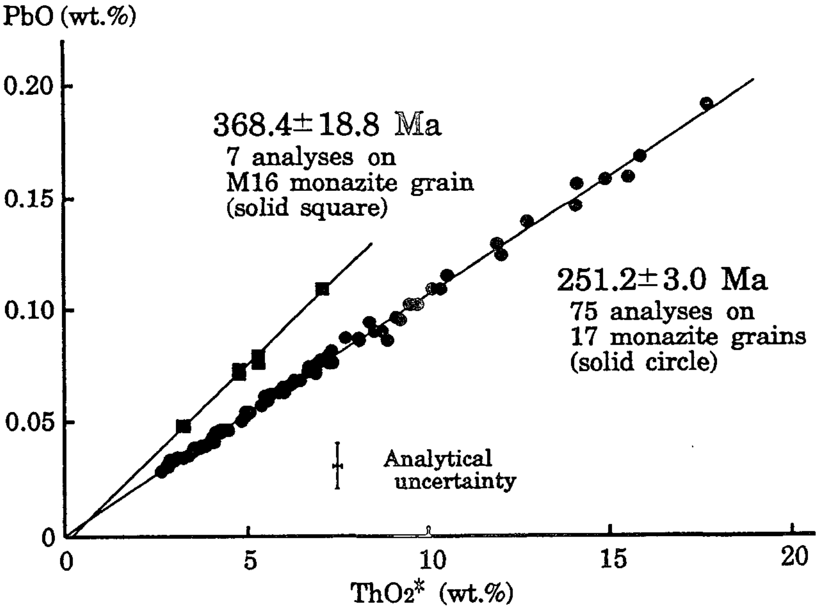

Fig. 5. Plot of PbO vs. ThO_2^* for monazite grains from foliated granite (sample no. 112-YN) of the Yeongnam Massif in the Gimcheon area. The ThO_2, UO_2, and PbO values of each point are listed in Appendix.

DISCUSSION AND CONCLUDING REMARKS

The age of detrital monazites in CC-2, YDJ-3 and Y-2 sandstone samples from the southeastern part of the Yeongdong Basin concentrate at Middle Jurassic (about 180 Ma; 119 grains) with subordinate concentrations at Late Permian (about 250 Ma; 21 grains) and Middle Precambrian (about 1200 Ma; 2 grains, and about 1750 Ma; 3 grains). One Silurian (about 420 Ma) monazite with a Late Permian rim was also recognized. Mineral and clast compostions of the sandstones and associated conglomerates suggest the predominace of granitic and metamorphic rocks in the provenance. Paleoflow analyses indicate that the clastic materials were supplied from the south (360°-040°).

To the south of the Yeongdong Basin, there exist granitic and metamorphic rocks of the Yeongnam Massif. The metamorphic rocks of the Sangju-Gimcheon- Geochang area show isotopic ages of 402 ± 10 Ma (Choo and Kim, 1985), 1047 ± 69 Ma (Lee et al., 1992), 1608 ± 100 Ma (Choo and Kim, 1985) and 1699 ± 591 Ma (Lee et al., 1992) (Table 1). This age spectrum is almost similar to that for detrital monazites in the sandstones. The CHIME monazite ages of about 180 and 250 Ma also accord well with the isotopic ages for granitic rocks (172 ± 28 and 177 ± 73 Ma, Choo and Kim, 1985; 170 ± 9, 178 ± 9, 181 ± 9 Ma and 204 ± 10, Kim et al., 1989; 227 ± 17, 253 ± 53 and 276 ± 33 Ma, Park et al., 1993) (Table 1). Furthermore, the present CHIME monazite dating revealed that granitic gneiss in the west of Gimcheon (Fig. 1) is also of Late Permian (251.2 ± 3.0 Ma). The chronological data coupled with petrographic and paleoflow data strongly suggest that the metamorphic and granitic rocks in the Yeongnam Massif are the corresponding rocks for the clastic sediments in the Cretaceous Yeongdong Basin.

The frequency of the Late Permian detrital monazite in Y-2 sandstone sample is distinctly higher than that in CC-2 and YDJ-3 sandstone samples from the lower stratigraphic position (Figs. 2, 3, and 4). The stratigraphic position of Y-2 sandstone sample is the transition zone between two depositional sequences. The transition from depositional sequence I to depositional sequence II in the southern Yeongdong Basin is characterized by abrupt emplacement of conglomerate and gravelly sandstone over mudstone. The obvious change in depositional regime across the sequence boundary can be presented as evidence for the emplacement (or rejuvenation) of stream channels and basinward transport of coarser grained sediments. These temporal and spatial changes from depositional sequence I to sequence II lead to speculate that development of depositional systems is mainly controlled by tectonic activity linked with strike-slip movement at the time of deposition. The development of extensive underlying dark mudstone beds can be presented as circumstantial evidence of tectonic subsidence in lacustrine regime prior to the tectonic movement.

Considering the characteristics of sequential development patterns, the distinct change in the frequency of the Late Permian detrital monazites is closely related with the tectonic evolution of the Yeongdong Basin through time. Namely, the source terrain underwent tectonic movements and then the clastic materials with 250 Ma age could be actively linked with the drainage system of the Yeongdong Basin. Since clastic materilas with 180 and 1750 Ma ages were still important in the Y-2 sandstone, the change may be attributed to the rejuvenation of strike-slip movement along the southeastern basin margin.

The present study demonstrates that the CHIME dating of detrital monazites can provide a useful information for the provenance analysis. Sedimentary petrological study together with CHIME geochronology will be an important key to the tectonic and paleogeographic reconstruction of Cretaceous basins in the Korean Peninsula.

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