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Crustal evolution of the Precambrian basement in the Korean Peninsula

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ABSTRACT : The Sm-Nd isotopic data on the Precambrian gneisses from Gyeonggi and Sobaegsan Massifs are presented and the crustal evolution of the Precambrian basements of the Korean Peninsula is discussed with that of the Precambrian basements of East Asia. Sm-Nd isochron plots on whole rock samples from Sobaegsan Massif give the following ages and initial Nd values. Biotite gneisses: 1.05± 0.07 Ga with ε_{Nd} (1.05 Ga)= −12.5± 0.4 (2σ); granitic gneisses: 1.70± 0.59 Ga with ε_{Nd} (1.70 Ga)= +9.5± 6 (2σ). Initial Nd isotopic evolution diagram for the Precambrian orthogneisses from Sobaegsan Massif with the Precambrian orthogneisses in northeastern China and Japan reveals the existence of early Archean depleted-mantle in east Asia and suggests the prevalence of nearly common or similar source accountable for these Precambrian gneisses. Such a common source is shown to have LREE-enriched feature and to have been formed from the depleted-mantle in the late Archean of ca. 2.6 Ga. On the other hand, the Sobaegsan granitic gneisses in Korea are concluded to have different evolution history. Our Sm-Nd study clearly discloses that some Precambrian orthogneisses from Korea had evolved from the protolith having the similar or same geochemical properties with the Precambrian orthogneisses in Japan and northeastern China. In addition, crustal formation age of Gyeonggi Massif in southern Korea may be different from that of Sobaegasn Massif.

Key Words : Initial Nd values, depleted-mantle, LREE crustal formation age

INTRODUCTION

In recent years, intense geochronological studies, including Sm-Nd, Rb-Sr, K-Ar and U-Pb systems, of Chinese Precambrian rocks have been carried out and schemes of crustal evolution of the Chinese continent have been proposed (e.g., Jahn and Zhang,1984; Huang *et al.*, 1986; Jahn et al., 1987, 1988; Jahn, 1990a, b; Jahn and Ernst, 1990; Liu *et al.*, 1991). By contrast, the Korean Precambrian rocks have only been studied sporadically (Gaudette and Hurley, 1973; Na and Lee, 1973; Na *et al.*, 1982; Choo and Kim, 1985; Kwon and Jeong, 1990; Lee *et al.*, in press).

In Japan, Rb-Sr and K-Ar ages of 2.0-1.5 Ga have been reported for metamorphic rocks in the Jurassic Kamiaso conglomerate from central Japan (Shibata *et al.*, 1971; Shibata and Adachi, 1972 and 1974) and a Sm-Nd age of 2.3 Ga for metamorphic rocks from Oki island in East Sea (Tanaka and Hoshino, 1986). These are the only known Precambrian rocks in Japan.

It is well known that the Sm-Nd isotopic system is less susceptible to alteration or metamorphism than Rb-Sr and K-Ar systems. Consequently, isochron date by Sm-Nd analyses is more likely to reflect primary crystallization age of igneous protolith of metamorphic rocks. In addition, the Nd isotopic data could provide useful information on geochemical evolution of crust and mantle.

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In the present study, we present Sm-Nd isotopic data on the Precambrian gneisses from the Gyeonggi and Sobaegsan Massifs, in order to clarify geochemical relationship of the Precambrian rocks in the two areas. In addition, we discuss the crustal formation age of the Korean Peninsula in comparison with Nd isotope ratios of the Precambrian gneisses of East Asia including Japan.

GEOLOGICAL BACKGROUND AND SAMPLES

The Korean Peninsula is a part of the Sino-Korean Craton and consists of the Precambrian Nangrim Massif, Gyeonggi Massif and Sobaegsan (or Youngnam) Massif (Fig. 1). These massifs consist of the gneiss complexes which are considered to be of late Archean ages. Detailed geological and geochronological studies has not been established yet. In addition, on the basis of initial Nd isotope ratio, Lee *et al.* (in press) suggested that orthogneisses of the Sobaegsan Massif have the nearly same geochemical source with those of northeastern China (Hebei and Shanxi Province) and Japan.

Gyeonggi Massif

This massif is mainly composed of Precambrian metamorphic rocks of igneous and sedimentary origin. The metamorphosed sedimentary and igneous sequences in this massif are so complicated that it is difficult to divide them into stratigraphic units. Biotite gneisses occur widely, and grade into schists, porphyoblastic gneisses and granitic gneisses. The regularly alternated bands of mafic and felsic minerals forming melanosome and leucosome in biotite gneisses are often destroyed in places by metasomatic migmatization.

Biotite gneisses having well-developed banded structures are selected from Yongin area in this massif. Biotite gneisses are composed of biotite, plagioclase, quartz, sillimanite, garnet, cordierite, K-feldspar. In addition, quartzofeldspathic gneisses are also selected for comparison of Nd isotope composition with the biotite gneisses. Individual

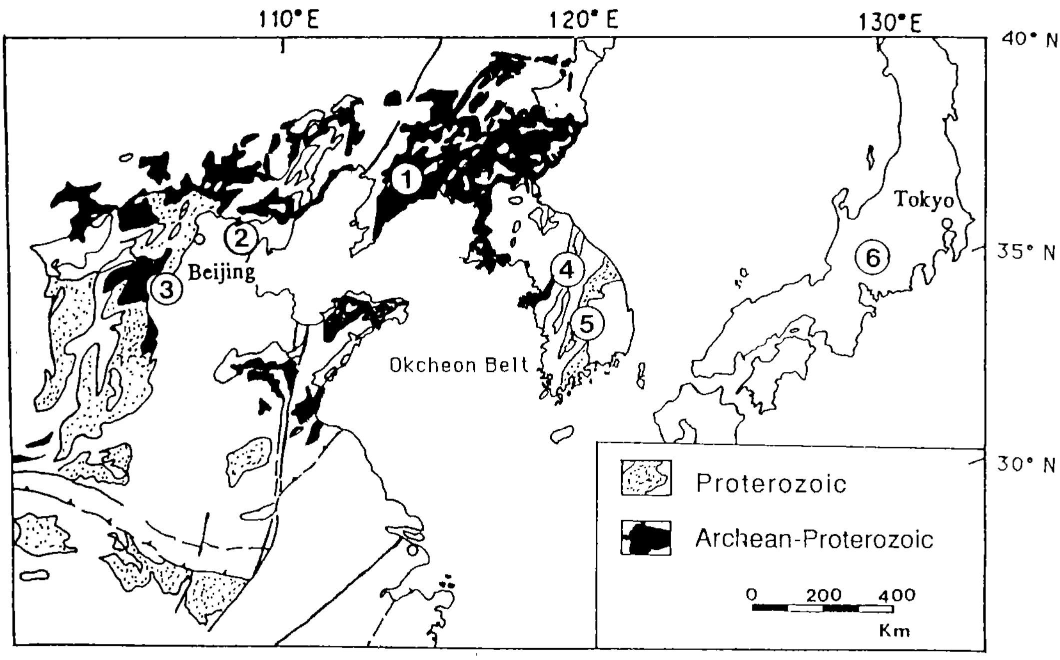

Fig. 1. Simplified geological map of the Precambrian terrain in Sino-Korean craton, together with sample localities. Numbered regions are 1: Liaoning Province, 2: Hebei Province, 3: Shanxi Province, 4: Gyeonggi Massif, 5: Sobaegsan Massif, 6: Kamiaso. (After Jahn, 1990b).

sample locations are given in the Appendix I. The boundary between biotite gneisses and quartzofeldspathic gneisses varies gradually. These quartzofeldspathic gneisses are composed of quartz, plagioclase, K-feldspar, biotite and lesser amounts of muscovite, epidote and accessory minerals. All of the samples have suffered polymetamorphism under high-grade metamorphism up to the upper amphibolite facies (Lee, 1985: Kim, 1989).

Sobaegsan Massif

The Sobaegsan Massif is one of the Precambrian basements in the southern Korea with the Gyeonngi Massif and is bounded on the northwest by the Okcheon Belt. This massif is mainly composed of Precambrian gneiss and schist complexes and Mesozoic granites. These metamorphic rocks have been metamorphosed to amphibolite facies of the low pressure facies series (Na, 1987).

Nine samples of gneisses are selected for isotopic analysis (See Appendix II). Five of them are biotite gneisses and the others are granitic gneisses. All samples show well developed foliation and are composed of quartz, K-feldspar, plagioclase, biotite, garnet, and lesser amounts of muscovite, epidote and accessory minerals. More detailed geological descriptions were given by Song (1989) and Song and Lee (1989). Granitic gneisses occurs as relicts or xenolith in biotite gneisses. Choo and Kim (1985) reported a Rb-Sr whole rock age of about 1.8 Ga for the granitic gneisses from northeast part in this area and considered it as a metamorphic age.

ANALYTICAL PRECEDURES

Slices of whole rock samples were crushed into grains of several millimeter and about 20-50 gr of the grains collected was pulverised. About 0.5-1 gr of powder sample was completely decomposed by HF and $HClO_4$ using teflon beaker. Sm and Nd were separated from the major elements by an AG 50 W-X8 resin column in HCl media, while Nd fraction was isolated using an AG 50 W-X8 resin column with α-hydroxy-isobutyric acid.

Sm and Nd abundances were determined using a JEOL JMS-05RB mass spectrometer by the isotope dilution method. Nd isotopic compositions were measured as Nd^+ with a VG-354 mass spectrometer equipped with five Faraday collectors using Re triple-filament-system. The measured Nd isotopic ratios were normalized to $^{146}Nd/^{144}Nd=0.7219$. The $^{143}Nd/^{144}Nd$ values for LaJolla Nd standard and for Johnson Matthey Nd_2O_3 (JMC 321) were 0.511826 ± 0.000003 (2σ) and 0.511120 ± 0.000003 (2σ) on 10 and 20 measurements, respectively. Isochron ages were calculated with the regression method of York (1969).

RESULTS

Nd isotopic ratios and Nd and Sm abundances are listed in Table 1, together with $\varepsilon_{Nd}(T)$ values. In the calculation of $\varepsilon_{Nd}(T)$ values, the following present-day parameters are used; $(^{143}Nd/^{144}Nd)_{CHUR}=0.512638$ and $(^{147}Sm/^{144}Nd)_{CHUR}=0.1966$ (Wasserburg *et al.*, 1981). The decay constant used for the calculation of Sm-Nd age is $\lambda\ ^{147}Sm=6.54\times10^{-12}\ yr^{-1}$.

Fig. 2 shows $^{143}Nd/^{144}Nd-^{147}Sm/^{144}Nd$ diagrams. As shown in Fig. 2, the Sm-Nd data for granitic gneisses (Fig. 2a: SO1) and biotite gneisses (Fig. 2b: SO2) of the Sobaegsan Massif in southern Korea give ages of 1.70 ± 0.59 Ga (2σ) with an initial $^{143}Nd/^{144}Nd$ ratio of 0.51093 ± 0.00033 (2σ) [$\varepsilon_{Nd}(1.70\ Ga)=+9.5\pm6$], and 1.05 ± 0.07 Ga (2σ) with an initial $^{143}Nd/^{144}Nd$ ratio of 0.51065 ± 0.00002 (2σ) [$\varepsilon_{Nd}(1.05\ Ga)=-12.5\pm0.4$], respectively. Choo and Kim (1985) reported the metamorphic age of 1.8 Ga of granitic gneisses by Rb-Sr age dating. Our Sm-Nd age of 1.70 Ga for the granitic gneisses is in accordance with the 1.8 Ga Rb-Sr age by Choo and Kim (1985) within analytical error. More detailed discussion about the age relationship and petrogenesis between biotite gneiss and granitic gneiss will be given in another paper with addition of chemical compostions (major and REE geochemistry), Sr and Ce isotopic data.

Table 1. Sm-Nd Isotopic Data for the Metamorphic Rocks in Korea

Sample	Nd (ppm)	Sm (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	ε_{Nd}* (T)	T_{DM}** (Ga)
1)Sobaegsan Massif						
Biotite Gneisses						
3303	31.13	5.76	0.1119	0.511411± 8	−12.6	2.29
K-11	15.35	3.30	0.1297	0.511537± 9	−12.5	2.57
K-13	70.79	12.12	0.1035	0.511363± 9	−12.4	2.36
K-58a	71.40	11.20	0.0948	0.511304± 8	−12.4	2.16
K-59	50.59	7.66	0.0924	0.511274± 8	−12.7	2.15
Granitic Gneisses						
4-82	31.03	4.09	0.0796	0.511803± 8	+9.2	1.43
4-106	15.04	2.40	0.0963	0.511995± 10	+9.4	1.38
143	39.06	5.40	0.0817	0.511896± 9	+9.8	1.38
K-10	26.51	3.64	0.0829	0.511872± 7	+9.9	1.37
2)Gyeonggi Massif						
Quartzofeldspathic gneisses						
C-78	37.68	7.08	0.1136	0.511274± 8	+1.2	2.56
O-64	30.75	5.32	0.1045	0.511202± 9	+1.9	2.46
O-65	32.41	6.07	0.1131	0.511239± 8	+0.6	2.59
H-13	43.43	7.93	0.1103	0.511263± 8	+2.1	2.50
H78-2	47.06	8.20	0.1053	0.511263± 6	+2.3	2.53
Biotite Gneisses						
G-24	45.98	7.90	0.1039	0.511219± 9	+2.4	2.42
G-36	35.34	6.13	0.1048	0.511212± 7	+2.4	2.45
B-2	59.13	9.98	0.1021	0.511246± 8	+2.3	2.35
B-15	59.97	10.13	0.1020	0.511175± 7	+2.2	2.44

*$\varepsilon_{Nd}(T) = [(^{143}Nd/^{144}Nd)_{sample}(T)/(^{143}Nd/^{144}Nd)_{CHUR}(T) - 1] \times 10^4$
where $(^{143}Nd/^{144}Nd)_{CHUR}(0) = 0.512638$ and $(^{147}Sm/^{144}Nd)_{CHUR}(0) = 0.1966$.
Initial values are calculated at 1.05, 1.70 and 2.67 Ga for Sobaegsan biotite gneisses, Sobaegsan granitic gneisses and Gyeonggi gneisses, repectively.
**$T_{DM} = \lambda^{-1}(Sm)\ln[1 + \{(^{143}Nd/^{144}Nd)_{sample}(0) - (^{143}Nd/^{144}Nd)_{DM}(0)\}/\{(^{147}Sm/^{144}Nd)_{sample}(0) - (^{147}Sm/^{144}Nd)_{DM}(0)\}]$
Present-day parameters: $(^{143}Nd/^{144}Nd)_{DM}(0) = 0.513153$, $(^{147}Sm/^{144}Nd)_{DM}(0) = 0.225$ (Liew and McCulloch, 1985).

The gneisses from the Gyeonggi Massif show restricted ranges of $^{147}Sm/^{144}Nd$ (from 0.105 to 0.114) and $^{143}Nd/^{144}Nd$ (from 0.51111 to 0.51127). Therefore, it is very difficult to get Sm-Nd whole rock isochron age for these samples. Now some Rb-Sr age data were reported Na and Lee (1973) and Choo and Kim (1984). Choo and Kim reported 2.67 Ga of Rb-Sr age for banded gneiss in Gong-Ju area. Na and Lee (1973) reported a Rb-Sr age of 2.67 Ga for three gneisses and one schist. Hence, on the basis of this 2.67 Ga of Rb-Sr age, average initial Nd value of Gyeonggi gneiss samples is calculated to be ca. +1.7 from our Sm-Nd data (Table 1).

DISCUSSION

Ages and initial ε_{Nd} values of the Sobaegsan and Gyeonggi Massifs are summarized in Fig. 3, where the data for the Chinese Precambrian rocks reported by Huang *et al.* (1986), Jahn *et al.* (1987), Sun *et al.* (1990) and Lee *et al.* (in press) are also plotted.

However, we should note the fact that the point of granitic gneisses from the Sobaegsan Massif clearly deviate from the line A in Fig. 3 and falls on another line D. This line D connecting Hebei amphibolite point at 3.6 Ga and 4.56 Ga-CHUR point gives $\varepsilon_{Nd}(0) = +14$ at zero-age (present) intercept in Fig. 3.

The value of $\varepsilon_{Nd}(0) = +10$ is typical of normal mid-oceanic-ridge basalts (N-type MORB) and the value of Nd $= +14$ is also among the reported ε_{Nd} values for MORB. The lines C and D in Fig. 3 give $^{147}Sm/^{144}Nd$ ratios of 0.2136 and 0.2198, which are slightly lower than the representative

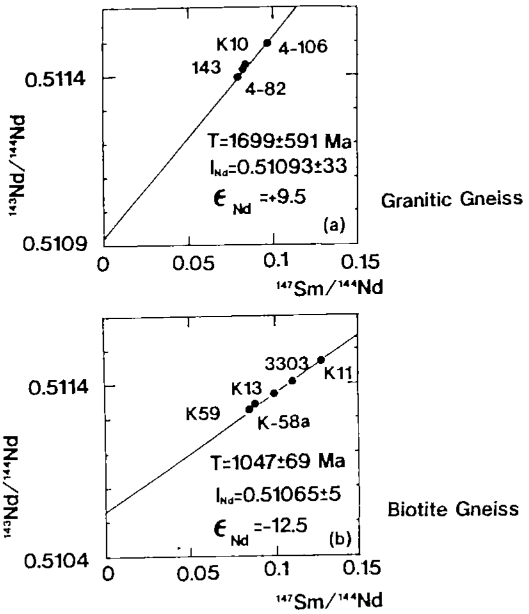

Fig. 2. Sm-Nd isochron diagrms for the Precambrian rocks from southern Korea; a) Sobaegsan granitic gneisses, b) Sobaegsan biotite gneisses.

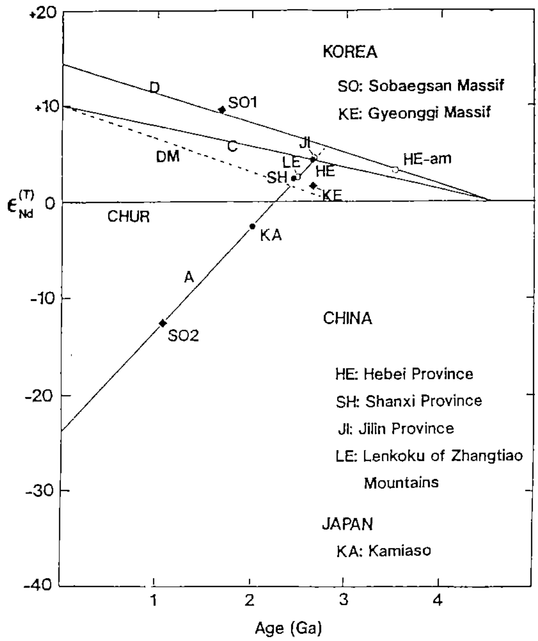

Fig. 3. Nd isotopic evolution diagram for the Precambrian rocks from southern Korea (Sobaegsan and Gyeonggi), central Japan (Kamiaso) and northeast China (Liaoning, Hebei and Shanxi); LA: Liaoning Province, HE: Hebei Province, SH: Shanxi Province, JI: Jilin Province, LE: Lenkoku of the Zhongtiao Mountains, SO1: Sobaegsan granitic gneisses, SO2: Sobaegsan biotite gneisses; KA: Kamiaso. The data for the rocks from the Zhongtiao Mountains of east-central China, Jilin of eastern Liaoning and Hebei were taken from Sun etal.(1990), Huang *et al.* (1986) and Jahn *et al.* (1987), respectively. The lines A, B, C and D connect the following points: line A, the points of the Hebei (HE), Shanxi (SH), Kamiaso (KA) from Lee *et al.* (in print) and Sobaegsan biotite gneisses (SO2) studied here; CHUR point at 4.56 Ga; line C, present-day depleted mantle with $\varepsilon_{Nd}(0)=+10$ and CHUR point at 4.56 Ga; line D, Hebei amphibolit point at 3.6 Ga and CHUR point at 4.56 Ga. The line DM is drawn using the $^{147}Sm/^{144}Nd=0.225$ and $^{143}Nd/^{144}Nd=0.513153$, which are given as the present-day parameters for depleted mantle by Liew and McCulloch (1985).

value for depleted mantle (e.g., 0.2238 or 0.225; Hawkesworth and van Calsteren, 1984; Liew and McCulloch, 1985). Huang *et al.* (1986) suggested that the geochemistry of the early Archean mantle in east Asia may have been similar to that of the modern upper mantle with severe depletion with respect to magmaphile elements. Lee *et al.* (in press) reported that most of the Kamiaso, Shanxi and Hebei gneisses and the Sobaegsan biotite gneisses have Sm/Nd ratio of 0.08-0.14 and they have a close genetic relationship in REE (rare earth element) geochemistry. Our results, along with those obtained by Jahn and Ernst (1990), confirm the suggestion given by Huang *et al.* (1986).

The line A in Fig. 3 implies that the Precambrian orthogneisses including amphibolites from Japan, Korea and the eastern China had nearly common source which had been derived from the depleted mantleat 2.62 or 2.77 Ga at which the line A intersects the lines C and D. It could be suggested that, in east Asia, continental crust with LREE-enriched pattern had been differentiated from depleted mantle at the late Archean and these LREE-enriched patterns had similar LREE-inclinations to those observed for the present patterns (Lee *et al.* in press).

In contrast to these gneisses under consideration, biotite-poor granitic gneisses from Sobaegsan are considered to have been derived directly from the depleted mantle as a newly added continental crust. Initial ε_{Nd} value at 1.7 ± 0.59 Ga for the granitic gneisses is calculated to be $+9.5\pm 6$ from the Sm-Nd isochron plot of Fig. 3a and suggests highly depleted source for these gneisses. Sivell and McCulloch (1991) reported that Hart Range meta-igneous complex of central Australia was derived from highly-depleted mantle source with $\varepsilon_{Nd}=+6.9$ to $+8.2$ at 1.8 Ga. The obtained initial ε_{Nd} value for the Sobaegsan granitic gneisses is essentially comparable to that of the Hart Range meta-igneous complex.

The ages around 1.7 or 1.8 Ga for the granitic gneisses may represent formation age of original igneous rocks, while the Sm-Nd age of 1.05 Ga for the biotite gneisses may represent the time of migmatization or granitization. Difference in initial ε_{Nd} value between biotite gneisses and granitic gneisses implies that these two types of gneisses had been derived from different sources.

An average value for the Gyeonggi gneisses, which is calculated by our Sm-Nd data and reported Rb-Sr age (Na and Lee, 1973), plots near line A in Fig. 3. Even though it has an insufficient data by lacking of the Sm-Nd isochron age and needs a more detailed geological, geochemical and tectonical study, such a deviation strongly suggests a possibility that the basement of Gyeonggi Massif has a different crustal formation age from that of Sobaegsan Massif.

CONCLUDING REMARK

It is true that further geochronological, geochemical and geological studies will make clearer the geological interpretation of individual events in Korean Peninsula. However, our Sm-Nd study confirmed the existence of Precambrian depleted mantle in Korea Peninsula. It was also suggested that LREE-enriched continental crust was fractionated from the depleted mantle of the late Archean of 2.6 or 2.8 Ga and at about 1.7 Ga. The protolith of granitic gneisses in Sobaegsan Massif was fractionated from the depleted mantle at middle Proterozoic of ca. 1.7 Ga, while protolith accountable for the biotite gneisses of Sobaegsan Massif had been formed at the latter event of 2.6 or 2.8 Ga. The protolith of biotite gneiss of Sobaegsan Massif had essentially the same LREE patterns as those of the Precambrian orthogneisses of northeast China and Japan. Most of orthogneisses from Hebei, Shanxi, Sobaegsan and Kamiaso were formed from the LREE-enriched continental crust at different ages during the late Archean and the Proterozoic eons.

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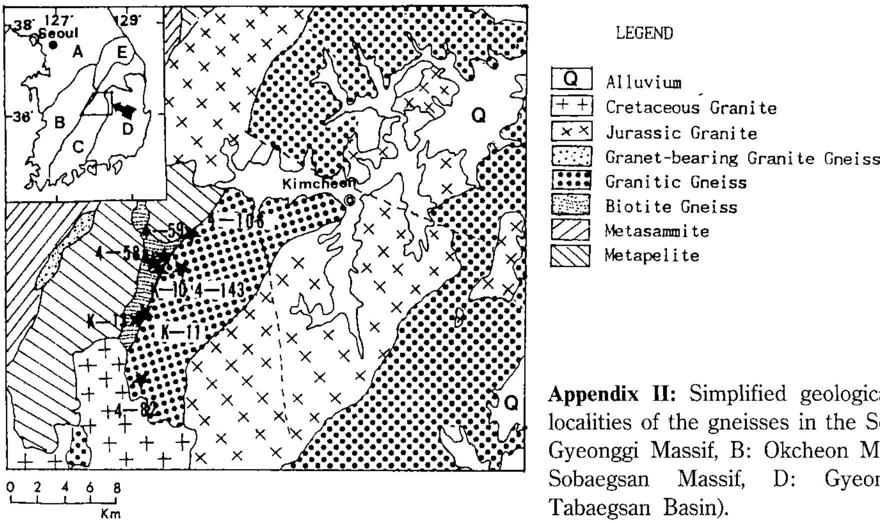
(책임편집 : 권성택)

Appendix I: Sample locations of gneisses in the Gyeonggi Massif

Biotite gneisses
G-24: 127° 15′ 5″ E and 37° 05′ 57″ N
G-36: 127° 15′ 3″ E and 37° 07′ 52″ N
B-2: 127° 23′ 23″ E and 37° 08′ 55″ N
B-15: 127° 17′ 32″ E and 37° 05′ 57″ N

Quartzofeldspathic gneisses
C-78: 127° 42′ 9″ E and 37° 36′ 14″ N
H78-2: 127° 47′ 27″ E and 37° 58′ 28″ N
H-13: 127° 8′ 48″ E and 37° 13′ 37″ N
O-65: 127° 8′ 17″ E and 37° 13′ 37″ N
O-64: 127° 13′ 7″ E and 37° 12′ 28″ N



Appendix II: Simplified geological map and sample localities of the gneisses in the Sobaegsan Massif (A: Gyeonggi Massif, B: Okcheon Metamorphic Belt, C: Sobaegsan Massif, D: Gyeongsang Basin, E: Tabaegsan Basin).

韓半島 先캠브리아紀 基底岩의 地殼形成史

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요 약: 경기육괴와 소백산의 일부 선캠브리아기 암석에 대한 Sm-Nd 同位元素 자료의 결과를 기초로 하여 한반도 및 동아시아의 기저암의 地殼形成史를 고찰하였다. 소백산 육괴의 흑운모 편마암으로부터는 1.05± 0.07 Ga [ε_{Nd} (1.05 Ga)= −12.5± 0.4], 화강암질 편마암으로부터는 1.70± 0.59 Ga[ε_{Nd} (1.70 Ga)= +9.5± 6]의 Sm-Nd 연대가 얻어졌다. 중국 동북부(河北省, 山西省)와 일본의 카미아소(上痲生)의 Nd 初期值와 소백산 육괴의 Nd 初期值에 의한 進化圖는, 동아시아에 있어서 初期原生代의 결핍된 맨틀 (depleted-mantle)의 존재를 말해주며, 위에서 언급한 암석들에 대한 설명으로써 지구화학적으로 거의 동일(혹은 유사)한 기원물질이 유력함을 시사해준다. 이 공통의 기원물질은 輕稀土類(LREE)가 부화(enriched)된 양상을 보이면서, 약 2.6∼2.7 Ga의 후기 원생대 당시의 결핍된 (depleted mantle)로부터 진화되어져 왔다. 반면에, 일부 화강암질 편마암은 같은 소백산 육괴내의 흑운모 편마암과는 다른 지각 진화사를 가지면서 발달되어 졌다. 본 연구 결과는 한국의 일부 선캠브리아기의 정편마암이 일본 및 중국 북동부의 선캠브리아기의 정편마암과 유사한 지구화학적 성질을 갖는 기원암으로부터 진화되어 왔음을 나타내 준다. 아울러 경기육괴의 지각형성시기는 소백산 육괴와 다르다고 사료되어 진다.

핵심어 : Nd 初期值, 결핍된 맨틀, 輕稀土類, 地殼形成時期

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