Earth Evolution Sciences, Vol. 7, pp. 3-9, March, 1, 2013

Petrochemical characteristics of the Buncheon granitic gneiss, northeastern part of the Yeongnam massif, South Korea

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Abstract

The petrochemical studies were performed on the Proterozoic Buncheon granitic gneiss, northeastern part of the Yeongnam massif, South Korea. The Buncheon granitic gneiss (1970 Ma), which is a main granitic unit in NE Yeongnam massif, is typical foliated biotite granite with SiO_2 content of 71.7-80.2 wt. % and shows calc-alkaline chemical affinities. Chemical variation diagrams gave a sign of fractionations of plagioclase, biotite, K-feldspar, zircon and apatite from the parental magma. Taking already reported Sr and Nd isotope values into account, the parental magma for the Buncheon granitic gneiss is assumed to have been generated from isotopically homogeneous souce, probably from lower crust, but not from metasedimentally crustal sources. These data and trace element characteristics indicate that the original magma of the Buncheon granitic gneiss was formed in volcanic arc with subduction zone or syn-collisional tectonic setting, associated closely with the amalgamation of the supercontinent Columbia.

Keywords: Buncheon granitic gneiss, Yeongnam massif, Proterozoic, Petrochemistry, South Korea

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Introduction

The Korean Peninsula is made up by three main Precambrian massifs and two suture zones (Fig.1). The Nangrim massif in North Korea has been generally correlated to the North China Block, but various models have been proposed for the correlation of the other tectonic units to eastern China. Cluzel et al. (1991) and Yin and Nie (1993) proposed similar models in which the Gyeonggi massif and Okcheon belt are northeastern extension of the South China Block, whereas the Yeongnam massif continues from the North China Block. In these models, collision suture (Qingling-Dabie-Sulu belt) between the North and South China blocks is considered to extend to the Imjingang belt. These correlation models are partly supported by paleomagnetic results (Uno, 1999 and Uno and Chang, 2000). However, the lithological and chronological similarities of the basement rocks between Gyeonggi and Yeongnam massifs have led to the model that the two massifs (Gyeonggi and Yeongnam massifs) formed a single continental block including the Okcheon belt (e.g., Lee et al., 1988; Lee and Cho, 1995; Cheong et al., 2000; Chough et al., 2000).

On the other hand, Oh et al. (2006), Kim et al. (2006) and, Oh and Kusky (2007) advocated a new correlation model in which the Dabie-Sulu belt in China extended to Triassic Hongseong-Odesan belt in Gyeonggi massif, but not to the Imjingng belt. In this model, the southern part of Gyeonggi massif and Okcheon belt correspond to the South China block and Nanhua Rift, respectively, and the Yeongnam massif to the Cathaysia block in China. At the same time, Zhai et al. (2007) and Suzuki (2009), more recently Chang and Zhao (2012) proposed a crustal detachment model that the Yangtze block (northern part of South China block) collided with the Korean Peninsula, followed by dextral shear movement between the two blocks. In their model, the collision suture in China extends to the northwestern part of the Korean peninsula and turns to the south along the western margin of the Peninsula, and further extends to Japan. In this case, the Korean Peninsula including Gyeonggi and Yeongnam massifs, and Imjingang and Okcheon belts, as a whole, correlate to the eastern extension of North China Block.

In this controversial situation in Korean Peninsula and eastern China, petrological and petrochemical studies for the dominantly basement rocks are fundamentally important for understanding the tectonic correlation and history in eastern Asia.

The Buncheon granitic gneiss is one of the large batholith in NE Yeongnam massif and exposes in wide area (more than 50 km in length). The petrochemical studies are scarce for the Buncheon granitic gneiss, except the studies by Choo and Hong (1984) and Hong (1985). In this short article, we present petrographical and petrochemical data for the Buncheon granitic gneiss, and discuss rock chemistry, affinities and tectonic setting.

Geologic outline and Petrography

The Yeongnam massif is bounded by a dextral shear zone (Honam sear zone) with the Okcheon belt to the north, and the southern parts of the massif are overlain unconformably by the Cretaceous Gyeongsang basin. The Yeongnam massif consists of high-grade gneisses and schists with sedimentary and igneous origin. In northeastern part of the Yeongnam massif, metasedimentary rocks including orthogneiss and schist, amphibolite (Wonnam Group and Yulli Group), and some units of granitic gneisses are widely developed. The granitic gneisses are assumed to intrude the metasedimentary rocks of the Wonnam Group and Yulli Group (Kim et al., 1963). These metamorphic rocks are unconformably covered by Phanerozoic sedimentary rocks and are intruded by Jurassic and Cretaceous granitic rocks. The granitic gneisses with various sizes are well-foliated biotite gneiss and aplitic gneiss with augen and banded structures.

Upper amphibolite-facies metamorphism had earlier been thought to have occurred in the whole Yeongnam massif (e.g., Kim, 1991; Lee et al., 1981). However, recently granulite-facies metamorphic records were reported from the metasedimentary rocks in the northeastern part of the massif (730-870 °C and 4.8-6.8 kb; Yi, 2000; Kim and Cho, 2003). Also Kwon et al. (1995) revealed granulite-facies metamorphic condition (767-815 °C and 6.0-8.4 kb) from granitic gneisses and metabasites in Punggi area, northeastern part of

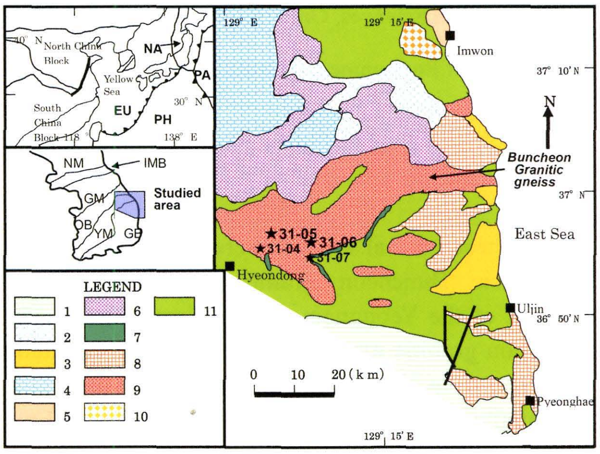

Fig. 1. Simplified geological map of the northeastern part of the Yeongnam massif, South Korea (modified from KIGAM, 1995 and Chang et al., 2003). Tectonic terrains of East Asia modified from Ernst et al. (1988) (upper left side map). PA, Pasific plate; PH, Philippine Sea plate; EU, Eurasia plate; NA, North America Plate. Tectonic unit of the Korean Peninsula after Kim (1987) (left middle-Korean Peninsula map). NA, Nangrim massif; IMB, Imgingang belt; GM, Gyeonggi massif; OB, Okcheon belt; YM, Yeongnam massif; GB, Gyeonsang basin. Abbreviation (right side geological map) 1, Gyeongsang Supergroup; 2, Cretaceous volcanic rocks; 3, Mesozoic granite; 4, Joseon Supergroup; 5, Imwon leucogranite; 6, Hongjesa granitic gneiss; 7, Okbang amphibolite; 8, Pyeonghae granitic gneiss; 9, Buncheon granitic gneiss; 10, Icheon granitic gneiss; 11, Gneiss complex (Wonnam Group and Yulli Group). Sample locations are shown in the map. Filled stars show the locations of rocks samples.

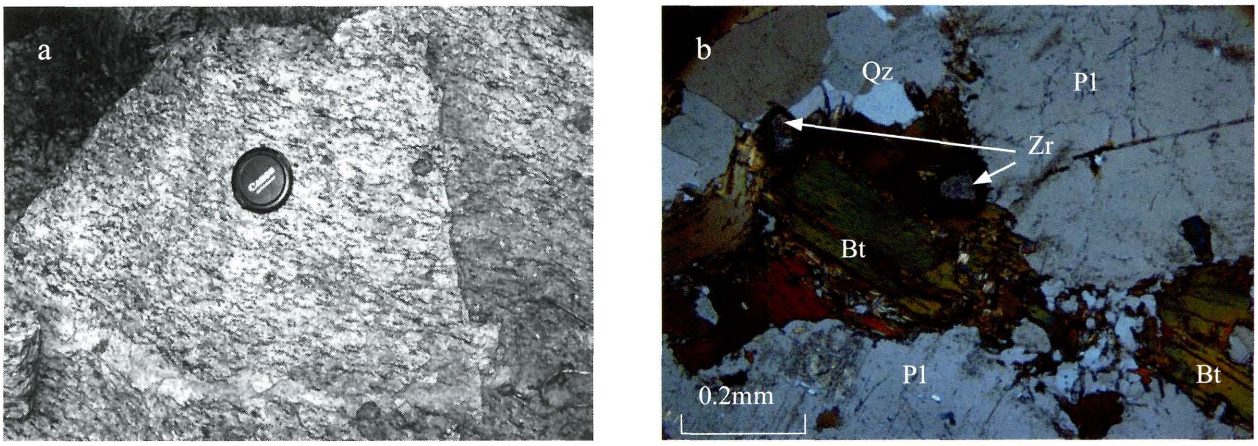

Fig. 2. a: Photograph of outcrop of the Buncheon granitic gneiss (foliated structure is seen). b: Photomicrograph of representative granitic gneiss (31-07) (Qz, quartz; Pl, plagioclase; Bt, biotite; Zr, zircon).

the massif. In the southwestern part of the massif, the evidences of granulite-facies metamorphiosm were also conducted from the porphyroblastic gneiss and charnockite (~800°C and 3.5-6 kb; Kim et al., 1999; Song, 1999). These studies seem to give a consensus that the Yeongnam massif undergone granulite-facies peak metamorphism, followed by amphibolite-facies or lower-grade metamorphic overprint. Arakawa et al. (2003) compared the chemistry of amphibolites in the eastern part of Yeongnam massif, and proposed the existence of both within-plate and volcanic arc types.

Most of the published age data for the formation and metamorphism of the basement rocks in the Yeongnam massif are concentrated in middle Proterozoic (2.3-1.7 Ga) (Chang and Lee, 1993; Chang et al., 1993; Park et al., 1993; Lee et al., 1994; Kwon et al., 1995; Kim and Turek, 1996; Turek and Kim, 1996; Chang et al., 2003) with some exceptions of Archean ages of zircon (Turek and Kim, 1996) and Nd model ages (Lan et al., 1995). By the recent SHRIMP U-Pb zircon age determination, the precise oldest age (2.51 Ga) was yielded for the Icheon granitic gneiss (Cho, 2006).

The Bunceon granitic gneiss is located in the central part of the NE Yeongnam massif, with large batholith in the center and some separated small units in the margin (Fig. 1). The granitic gneiss is generally well foliated and variously mylonitized in part. Main mineral assemblage of the Buncheon granitic gneiss is quartz, K-feldspar, plagioclase, biotite, and accessories are zircon, apatite and opaque minerals (Fig. 2). The granitic gneiss is grouped into typical granite. Rock samples were collected from the western part of the main unit (Fig. 1). The isotopic ages of the Buncheon granitic gneiss have been reported by some authors. Hong (1985) presented a well-fitted whole rock Rb-Sr isochron age of 2097 ± 4 Ma. Arakawa et al. (2001) reported preliminary Rb-Sr and Sm-Nd whole rock isochron ages of 2045 ± 207 Ma and 2002 ± 61 Ma, respectively. Compared to these ages, a slightly younger zircon age of 1963 ± 5 Ma by conventional U-Pb method using TIMS was obtained (Chang et al., 2003). Later, Arakawa et al. (2006) reported SHRIMP U-Pb zircon ages centered in 1970 Ma from two rock samples of the Buncheon granitic gneiss. These ages and their reliability of the Buncheon granitic gneiss will be discussed elsewhere.

Analytical Procedures

Least altered rock samples were selected for chemical analysis by careful petrographic examination. Major and some trace element concentrations were measured with an X-ray fluorescence (XRF) spectrometer (Philips 2400) at the Saitama University. Rare earth element (REE) and Hf, Ta, Nb, U and Th concentrations were determined by inductively coupled plasma-mass spectrometer (ICP-MS) at Activation Laboratories, Canada.

Table 1. Bulk rock chemical compositions of Buncheon granitic gneiss in NE Yeongnam massif, South Korea

Sample no.	31-04	31-05	31-06-01	31-06-02	31-07
Locality	PH210	PH211	PH212	PH212	PH213
SiO_2 (%)	71.73	71.31	78.42	78.88	80.15
TiO_2	0.29	0.31	0.17	0.18	0.15
Al_2O_3	13.42	14.38	11.01	10.56	10.22
Fe_2O_3*	2.73	2.98	1.98	2.16	1.69
MnO	0.03	0.04	0.03	0.03	0.01
MgO	0.57	0.80	0.34	0.36	0.25
CaO	1.51	2.15	1.20	1.27	0.80
Na_2O	3.63	3.43	2.74	2.75	2.14
K_2O	4.34	4.10	3.68	3.19	3.97
P_2O_5	0.09	0.10	0.05	0.07	0.04
LOI	2.12	0.85	0.52	0.66	0.68
V ppm	16	27	11	15	8
Cr	128	105	63	141	70
Ni	38	44	26	70	23
Cu	5	4	8	48	7
Zn	32	58	54	30	25
Rb	243	256	259	226	261
Ba	336	427	159	136	147
Sr	118	143	56	53	44
Nb	14.3	13.0	11.7	11.6	13.2
Zr	175	177	118	155	131
Y	32	30	29	34	26
Hf	4.8	4.8	4.3	4.8	4.1
Ta	1.04	1.41	1.60	1.52	2.26
Pb	4	21	20	14	14
Th	39.5	23.7	45.0	75.8	51.8
U	4.77	5.45	8.64	18.00	5.81
La ppm	58.14	35.00	40.16	27.86	44.55
Ce	116.1	70.29	87.12	61.11	95.40
Pr	14.42	8.78	11.34	8.03	11.55
Nd	47.10	29.10	38.09	28.33	38.01
Sm	8.48	5.40	7.86	6.57	6.92
Eu	0.64	0.58	0.28	0.28	0.24
Gd	7.50	4.96	6.92	6.42	6.10
Tb	1.21	0.91	1.18	1.26	1.06
Dy	5.80	4.83	5.65	6.44	4.75
Ho	0.97	0.89	0.89	1.08	0.69
Er	2.55	2.64	2.34	2.90	1.74
Yb	2.01	2.47	1.55	2.06	1.38
Lu	0.24	0.38	0.18	0.26	0.18

* Total iron as Fe_2O_3.

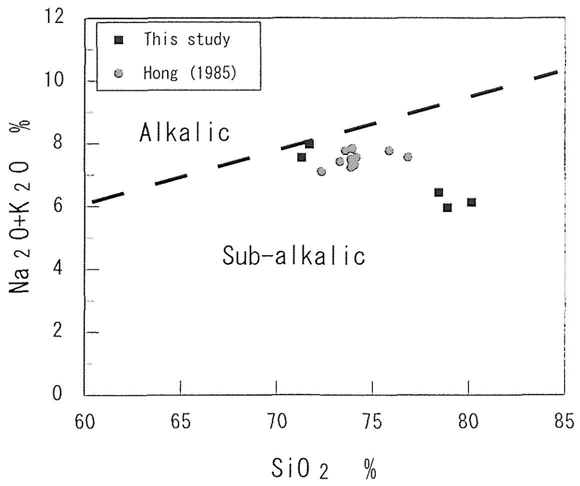

Fig. 3. SiO_2 – Na_2O+K_2O wt.% diagram for the Buncheon granitic gneiss.
Also shown are data by Hong (1985) for comparison.

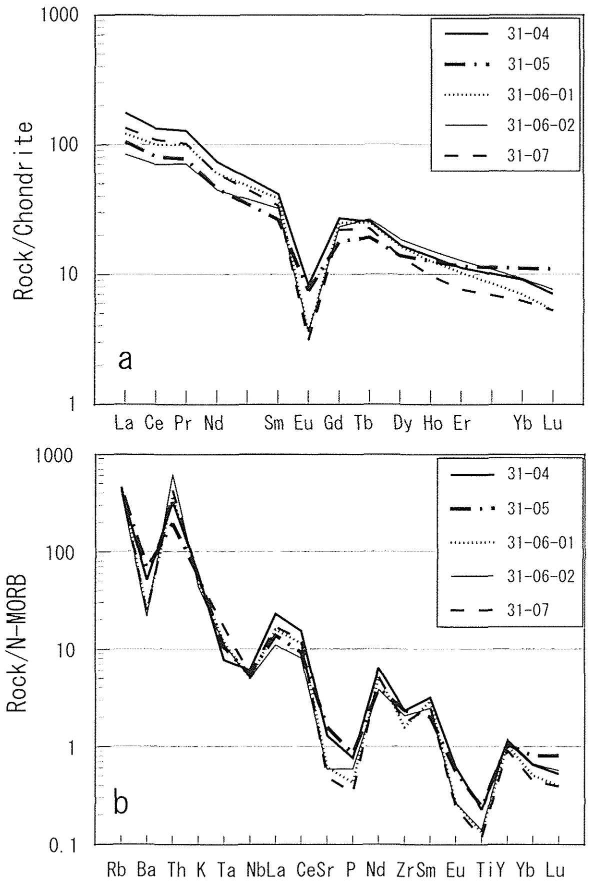

Fig. 4. Chondrite-normalized rare earth element (REE) patterns (a) and N-MORB normalized incompatible element patterns for representative samples of the Buncheon granitic gneiss. Nomalizing values of REE are from Nakamura (1974) and incompatible element contents from Sun and McDnough (1989).

Results and Discussion

Major and trace element concentrations for five Buncheon granitic gneisses are listed in Table 1, and a chemical variation diagram (SiO_2 % - Na_2O+K_2O %) is shown in Fig. 3. The SiO_2 contents of the Buncheon granitic gneiss range in 71.7-80.2 wt. %, and Fe_2O_3* and K_2O contents are 2.0-3.0 wt. % and 3.2-4.3 wt. %, respectively. In other element variation diagrams (not shown), the linear variation trends are recognized. The decreasing Fe_2O_3*, TiO_2, MgO, CaO, Al_2O_3, Na_2O contents are associated with increasing SiO_2 contents (Table 1). Some decreasing contents of Sr, Nb and Zr are also related to increasing SiO_2 contents. Theses chemical characteristics probably suggest the fractionation of biotite, plagioclase, ilmenite and zircon from the parental granitic magma. Most of the measured samples show calc-alkaline chemical affinities.

Figure 4a exhibits chondrite-normalized rare earth element (REE) patterns for the granite samples. The Buncheon granites have light rare earth element (LREE) enriched and heavy rare earth element (HREE) depleted patterns with distinctive negative Eu anomalies. The depletion of HREE and the values (depths) of Eu negative anomalies are correlated with increasing SiO_2 contents. These results are consistent with above fractionation model estimated from major and trace element variation diagrams (see Table 1 and Fig. 3). The N-MORB normalized multi-element patterns (Fig. 4b) show significant enrichment in highly incompatible elements (Rb, Th, K, Th, La and Ce) and depletion of Sr, P, Eu, Ti. The negative spikes of Ba, Sr, P, Eu and Ti may be results of fractionation of plagiocalse, biotite, ilmenite and apatite. These results are also concordant with above results. The negative anomalies of Ta and Nb, which are general characteristics of subduction related magmas (Saunders and Tarney, 1979; Wilson, 1989), are identified in the diagrams, though these negative anomalies are sometimes interpreted to be due to the crustal assimilation during the magma emplacement (e.g., Cox and Hawkesworth, 1985; Jahn et al., 1999).

For Sr and Nd isotope data, Arakawa et al. (2001) reported relatively homogeneous values for the Buncheon granitic gneiss. The initial $^{87}Sr/^{86}Sr$ and εNd values are scattered around 0.708 and –2.1, respectively. These homogeneous (narrow ranges of) Sr and Nd isotope ratios of the large granitic batholith are rare in the Proterozoic massif in South Korea. This is suggestive of isotopic homogeneity of the materials from which the Buncheon granitic magma originated. This result precludes the basement metasedimentary rocks (Wonnnam Group and Yulli Group) for the source materials of the granitic magma. Presumably the parental magma was generated in the lower crustal source with homogeneous isotope values.

The tectonic discrimination diagrams using trace element contents and ratios are useful for identifying the tectonic setting for the emplacement of the granitic magma. In (Y + Nb) - Rb plot (Pearce, 1984) (Fig. 5), the Buncheon granitic rocks are plotted in the boundary region between volcanic arc granite (VAG) and syn-collision granite (syn-COLG). In the other diagram (Y-Nb), the data are also scattered between VAG and syn-collision granite (not shown in the figure). The Ta and Nb negative anomalies in Fig. 4b are consistent with the volcanic arc granite (VAG) for the tectonic situation of the Buncheon granitic gneiss. These chemical and isotopic data clearly show that the original magma(s) of the Buncheon granitic gneiss was formed in Proterozoic subduction-related arc setting. This granitic magmatism, which is a part of extensive activities of felsic magmas (1930-1990 Ma) in Yeongnam massif, probably correlate to the granitic magmatism in the Gyeonggi massif (e.g., Kim et al., 1999; Sagong et al., 2003; Horie et al., 2009), and may also to those in North Korean massifs (e.g., Zhao et al., 2006). These widespread magmatic activities in Korean Peninsula may have occurred simultaneously with those in the eastern part of the North China Block (e.g., Chang and Zhao, 2012), though this correlation between the Korean massifs and the older blocks in eastern China is still uncertain. These magmatic activities in those regions are assumed to have been closely related to the assembly of the supercontinent Columbia (e.g., Rogers and Santosh, 2002).

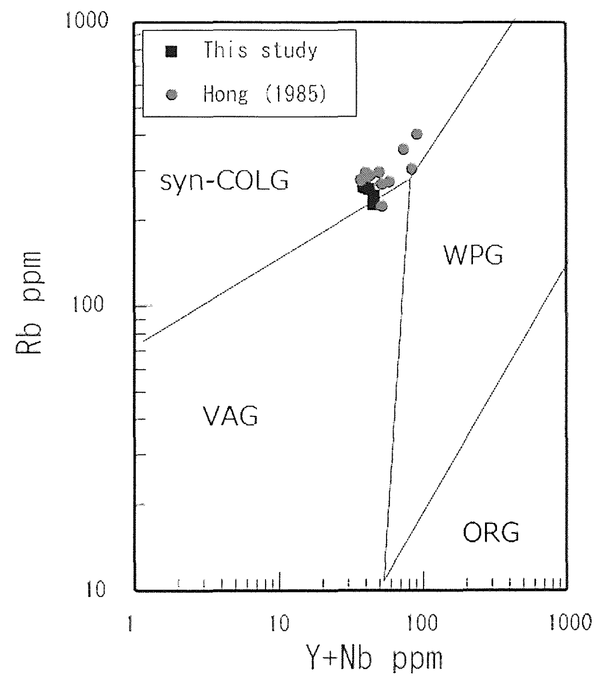

Fig. 5. Y+Nb – Rb diagram of the Buncheon granitic gneiss. VAG: Volcanic-arc granite, WPG: Within-plate granite, syn-COLG: Syn-collision granite (according to Pearce et al., 1984).

More various chemical data may be needed for more precise determination of magma genesis and tectonic situation for the granitic gneisses in the Yeongnam massif, and for tectonic comparison with other granitic gneisses in the Proterozoic massifs in Korea and eastern China.

Concluding remarks

The Buncheon granitic gneiss is one of the large granitic batholith forming the Proterozoic basement rocks in northeastern part of the Yeongnam massif, South Korea. The granitic gneiss is a typical foliated (metamorphosed and deformed) biotite granite with high SiO_2 contents and indicates calc-alkaline chemical affinities. During the magma evolution, the fractionations of plagioclase, biotite, ilmenite and apatite are assumed to have occurred. Relatively homogeneous Sr and Nd isotope values manifest that the parental magma for the Buncheon granitic gneiss was generated from isotopically homogeneous source, probably from lower crust, but not from the surrounding metasedimentally crustal sources. Geochemical data show that the magmatic emplacement of the Buncheon granitic gneiss occurred in volcanic arc or syn-collisional tectonic setting. The widespread magmatic activity including the Buncheon granitic gneiss is assumed to have occurred through the formation of the Korean older basements, probably within the development of the Meso-Proterozoic (1.8-2.1 Ga) supercontinent.

Acknowledgments

We would like to thank D. Y. Kim and H. S. Yi for supporting the sample collections in the field. Thanks are also going to T. Tsunogae for his critical reading of the manuscript. This work is supported in part by a Grant-in Aid for Scientific Research from the Japan Society for the Promotion of Sciences.

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