

Contrasting TiO_2/MgO ratios in the Namwon granitic complex

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ABSTRACT : We report advantages of employing MgO as a differentiation index for the Namwon granitic complex. It is shown to be much more sensitive than the usual Harker index. The complex can be divided into two groups on the basis of TiO_2/MgO ratio. The low TiO_2/MgO group consists of hornblende biotite tonalite-granodiorite, porphyritic hornblende biotite granodiorite (PHBGd) and part of biotite granite (loBG). PHBGd shows its own distinct variation in the low group. This group is characterized in most cases by the presence of hornblende, even if it occurs as a trace amount. The high TiO_2/MgO group consists of part of biotite granite (hiBG) and two mica granite. The major element differences between rock types are also apparent in biotite chemistry. These chemical data indicate that at least two distinct origins of magma are required for the complex. Two kinds of biotite granite revealed in this study show distinct geographic distribution, suggesting that a new geologic map should be made.

Key Words : Namwon granitic complex, whole rock chemistry, biotite chemistry, cryptic geologic boundary

INTRODUCTION

A granitic batholith in general consists of diverse rock types which might be originated from differentiation of a common magma, or from separate intrusions of different origins. When one interprets the origin of a suite of granitic rocks, *e.g.* a batholith, apparently associated in space and time based on chemical data, it is customary to conclude that different rock types are the result of differentiation of a common magma, if the data vary smoothly in chemical variation diagrams.

The Namwon granitic complex consists of several rock types such as tonalite, granodiorite, biotite granite, and two mica granite (Fig. 1). Previous studies of the complex concluded on the basis of field relations and major element chemistry that the different rock types are related to the differentiation of a common source magma (Hong *et al.*, 1988; Kim and Lee, 1988).

In this study, we reinterpret whole rock and biotite chemistry data for the Namwon complex, and show that the complex could have formed from

at least two distinct origins of granitic magmas.

GEOLOGIC SETTING

The Namwon granitic complex emplaced in the Youngnam massif, located near the tectonic boundary between the Ogcheon fold belt and the Youngnam massif in southwestern Korea, intrudes Precambrian basement rocks to the north and south, and the Daegang granite to the west (Fig. 1). It consists of four major rock types such as hornblende biotite tonalite-granodiorite (HBTGd), porphyritic hornblende biotite granodiorite (PHBGd), biotite granite (BG), two mica granite (TMG), and minor diorite. BG occupies a major (western and central) part of the complex and shows porphyritic texture near the western margin against the Daegang granite (Kim *et al.*, 1984). Other rock types occur mostly in the eastern part of the complex, except for diorite occurring in the middle part of the BG. Kim and Lee (1988) observed that the different rock types have intrusive relationships between them. However,

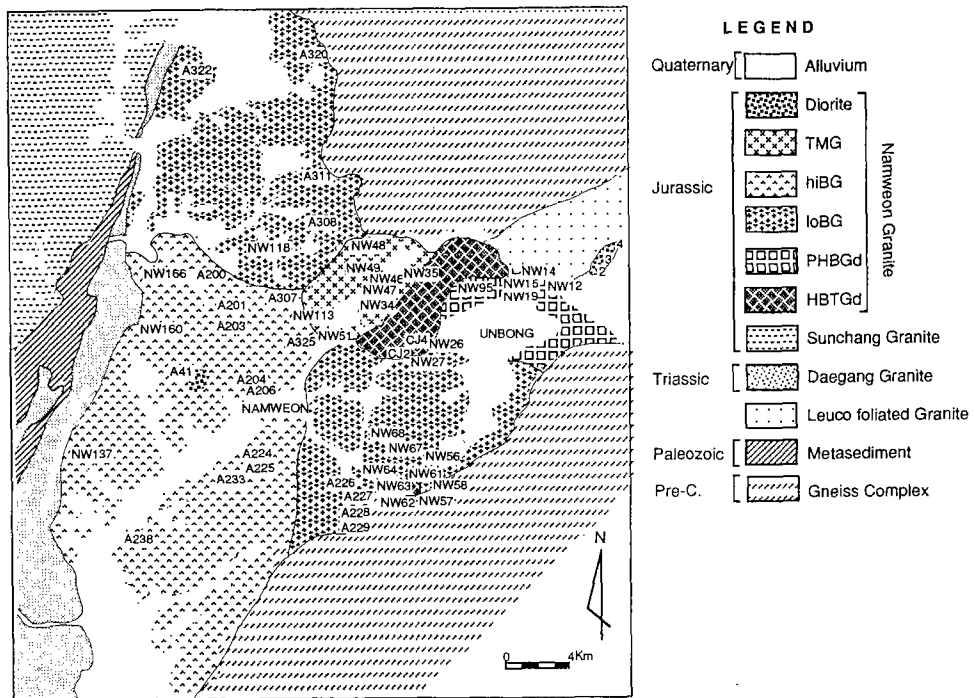


Fig. 1. Geologic map of the Namwon granitic batholith (modified from Hong *et al.*, 1988 and Kim *et al.*, 1988). Abbreviations: HBTGd, hornblende biotite tonalite-granodiorite; PHBGd, porphyritic hornblende biotite granodiorite; loBG, biotite granite with low TiO_2/MgO ratio; hiBG, biotite granite with high TiO_2/MgO ratio; TMG, two mica granite.

one of us (Hong), who did most of the field work for this study, considers that the relationships between the rock types are not certain.

The Mesozoic plutons in the study area can be divided into foliated and nonfoliated plutons. The former is considered to be related to the deformation event of the broad Honam shear zone (Yanai *et al.*, 1985). Namely, the foliated granites are interpreted as either pre- or syn-tectonic intrusives, while nonfoliated ones are post-tectonic. The Namwon complex is considered as post-tectonic intrusives because of its generally nonfoliated nature (Kim *et al.*, 1984). However, Kim *et al.* (1987) reported mylonitization in PHBGd and southeastern part of BG. Choo and Kim (1986) gave a Rb-Sr whole rock age of 211 ± 3 Ma for the BG of the Namwon complex, while Kim *et al.* (1987) reported Ar-Ar hornblende ages of 191 to 196 Ma from mylonitic PHBGd.

ANALYTICAL PROCEDURE

Major element data for 40 samples from the Namwon complex have been reported already by Hong *et al.* (1988). However, we analyzed the same samples with XRF method to check the quality of previous analyses which employed ICP-AES method, and to provide SiO_2 and H_2O data which were missing in Hong *et al.* In addition we analyzed six more samples to extend the data base for the complex. A detailed analytical procedure for the XRF analysis of the whole rock samples appears in Tsuchiya *et al.* (1989).

New major element data are shown in Table 1. Comparisons between XRF and ICP-AES data, along with 1:1 correspondence line, are shown in Fig. 2. Correlations for MgO , Fe_2O_3^* (total iron), CaO , K_2O , TiO_2 , P_2O_5 and MnO are remarkably good, except that P_2O_5 and MnO show several

Table 1. Major element data (by XRF) of the Namwon granitic complex

| Sample | HBTGd | | | | | | | | | | PHBGd | | | | | | | | | |
|----------------------------------|--------|--------|--------|--------|--------|-------|--------|-------|--------|--------|--------|--------|-------|--------|--------|--------|--------|--|--|--|
| | 26 | 27 | 57 | 61 | CJ2 | CJ4 | 12 | 14 | 15 | 19 | 36 | 95 | 14 | 15 | 19 | 36 | 95 | | | |
| SiO ₂ | 63.85 | 68.82 | 67.61 | 66.59 | 66.99 | 68.69 | 68.17 | 68.01 | 68.76 | 65.53 | 69.57 | 67.33 | 68.01 | 68.76 | 65.53 | 69.57 | 67.33 | | | |
| TiO ₂ | 0.64 | 0.40 | 0.48 | 0.57 | 0.50 | 0.32 | 0.38 | 0.36 | 0.43 | 0.61 | 0.29 | 0.55 | 0.36 | 0.43 | 0.61 | 0.29 | 0.55 | | | |
| Al ₂ O ₃ | 16.46 | 15.24 | 15.35 | 15.54 | 15.51 | 14.89 | 15.25 | 14.87 | 15.41 | 15.73 | 15.54 | 15.33 | 14.87 | 15.41 | 15.73 | 15.54 | 15.33 | | | |
| Fe ₂ O ₃ * | 5.50 | 3.52 | 4.04 | 4.50 | 4.48 | 3.49 | 4.17 | 4.62 | 4.32 | 5.67 | 3.47 | 5.08 | 4.62 | 4.32 | 5.67 | 3.47 | 5.08 | | | |
| MnO | 0.07 | 0.05 | 0.05 | 0.06 | 0.06 | 0.04 | 0.06 | 0.06 | 0.07 | 0.08 | 0.05 | 0.08 | 0.06 | 0.07 | 0.08 | 0.05 | 0.08 | | | |
| MgO | 2.13 | 1.26 | 1.54 | 1.87 | 1.69 | 1.07 | 1.03 | 0.95 | 1.10 | 1.93 | 0.73 | 1.67 | 0.95 | 1.10 | 1.93 | 0.73 | 1.67 | | | |
| CaO | 3.35 | 3.33 | 3.63 | 4.08 | 2.67 | 2.42 | 2.81 | 2.53 | 3.11 | 3.90 | 2.32 | 3.48 | 2.53 | 3.11 | 3.90 | 2.32 | 3.48 | | | |
| Na ₂ O | 3.92 | 3.61 | 3.62 | 3.96 | 3.30 | 3.07 | 3.80 | 3.51 | 3.91 | 3.51 | 3.68 | 3.76 | 3.51 | 3.91 | 3.51 | 3.68 | 3.76 | | | |
| K ₂ O | 3.72 | 3.05 | 3.04 | 1.95 | 4.61 | 4.89 | 3.47 | 4.00 | 2.82 | 1.98 | 3.78 | 2.12 | 4.00 | 2.82 | 1.98 | 3.78 | 2.12 | | | |
| P ₂ O ₅ | 0.14 | 0.09 | 0.11 | 0.13 | 0.10 | 0.08 | 0.10 | 0.10 | 0.11 | 0.15 | 0.08 | 0.13 | 0.10 | 0.11 | 0.15 | 0.08 | 0.13 | | | |
| LOI | 0.82 | 0.64 | 0.89 | 0.92 | 0.35 | 0.69 | 0.91 | 0.62 | 0.69 | 1.19 | 0.91 | 0.85 | 0.62 | 0.69 | 1.19 | 0.91 | 0.85 | | | |
| Total | 100.60 | 100.00 | 100.36 | 100.18 | 100.26 | 99.64 | 100.15 | 99.62 | 100.73 | 100.28 | 100.41 | 100.37 | 99.62 | 100.73 | 100.28 | 100.41 | 100.37 | | | |
| TiO ₂ /MgO | 0.30 | 0.31 | 0.31 | 0.31 | 0.29 | 0.30 | 0.37 | 0.38 | 0.39 | 0.32 | 0.39 | 0.33 | 0.38 | 0.39 | 0.32 | 0.39 | 0.33 | | | |
| A/CNK(mol%) | 0.99 | 1.00 | 0.97 | 0.97 | 1.02 | 1.01 | 1.01 | 1.01 | 1.02 | 1.05 | 1.08 | 1.04 | 1.01 | 1.02 | 1.05 | 1.08 | 1.04 | | | |

*Iron as total Fe₂O₃.

Table 1. (continued)

| Sample | loBG | | | | | | | | | | | | | | |
|----------------------------------|--------|--------|--------|--------|--------|-------|--------|--------|-------|--------|--------|--------|-------|-------|--------|
| | 56 | 58 | 62 | 63 | 64 | 67 | 68 | 118 | A226 | A227 | A228 | A308 | A311 | A322 | A325 |
| SiO ₂ | 73.96 | 68.51 | 68.57 | 70.31 | 66.48 | 72.50 | 69.35 | 70.12 | 69.18 | 68.68 | 71.36 | 68.11 | 68.17 | 65.54 | 76.02 |
| TiO ₂ | 0.13 | 0.42 | 0.35 | 0.33 | 0.50 | 0.21 | 0.42 | 0.29 | 0.37 | 0.39 | 0.25 | 0.42 | 0.43 | 0.52 | 0.08 |
| Al ₂ O ₃ | 14.24 | 15.39 | 15.67 | 15.04 | 16.00 | 14.16 | 15.68 | 15.18 | 15.04 | 15.67 | 14.85 | 16.12 | 15.55 | 16.46 | 14.05 |
| Fe ₂ O ₃ * | 1.36 | 3.44 | 3.34 | 2.75 | 4.19 | 2.08 | 3.31 | 3.19 | 3.19 | 3.27 | 2.42 | 3.24 | 3.23 | 3.73 | 0.92 |
| MnO | 0.02 | 0.05 | 0.05 | 0.04 | 0.05 | 0.04 | 0.05 | 0.05 | 0.05 | 0.05 | 0.04 | 0.05 | 0.05 | 0.05 | 0.02 |
| MgO | 0.39 | 1.34 | 1.15 | 1.04 | 1.75 | 0.70 | 1.31 | 1.07 | 1.06 | 1.30 | 0.81 | 1.30 | 1.30 | 1.61 | 0.23 |
| CaO | 2.54 | 3.26 | 3.34 | 2.92 | 3.78 | 2.37 | 3.60 | 2.93 | 2.99 | 2.66 | 2.52 | 3.26 | 3.00 | 3.88 | 1.96 |
| Na ₂ O | 3.58 | 3.71 | 3.96 | 3.53 | 3.70 | 3.42 | 4.02 | 3.60 | 3.60 | 3.79 | 3.62 | 3.74 | 3.68 | 3.68 | 3.58 |
| K ₂ O | 3.32 | 3.26 | 2.98 | 3.60 | 3.02 | 3.77 | 2.32 | 3.63 | 3.54 | 3.73 | 3.76 | 3.45 | 3.34 | 3.35 | 4.01 |
| P ₂ O ₅ | 0.04 | 0.10 | 0.08 | 0.08 | 0.12 | 0.06 | 0.09 | 0.08 | 0.09 | 0.09 | 0.07 | 0.12 | 0.12 | 0.13 | 0.02 |
| LOI | 0.45 | 0.89 | 0.76 | 0.79 | 1.08 | 0.63 | 0.81 | 0.62 | 0.69 | 1.15 | 0.45 | 1.02 | 1.04 | 0.78 | 0.37 |
| Total | 100.02 | 100.37 | 100.26 | 100.43 | 100.66 | 99.92 | 100.97 | 100.76 | 99.78 | 100.76 | 100.15 | 100.81 | 99.89 | 99.73 | 101.25 |
| TiO ₂ /MgO | 0.33 | 0.31 | 0.30 | 0.31 | 0.29 | 0.30 | 0.32 | 0.27 | 0.35 | 0.30 | 0.31 | 0.32 | 0.33 | 0.32 | 0.35 |
| A/CNK(mol%) | 1.01 | 0.99 | 0.99 | 1.00 | 0.99 | 1.01 | 1.00 | 1.00 | 0.99 | 1.04 | 1.02 | 1.02 | 1.03 | 0.98 | 1.02 |

Table 1. (continued)

| Sample | hiBG | | | | | | | | | | | TMG | | | | | | |
|----------------------------------|--------|--------|--------|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-------|--------|-------|--------|
| | 137 | 160 | 166 | A307 | A200 | A201 | A203 | A206 | A225 | A320 | 113 | 34 | 35 | 46 | 47 | 48 | 49 | 51 |
| SiO ₂ | 70.02 | 72.00 | 71.27 | 72.09 | 71.55 | 70.18 | 71.60 | 73.23 | 72.65 | 70.67 | 73.34 | 74.96 | 73.38 | 73.03 | 73.37 | 72.90 | 71.60 | 72.29 |
| TiO ₂ | 0.42 | 0.29 | 0.34 | 0.28 | 0.35 | 0.38 | 0.31 | 0.25 | 0.23 | 0.40 | 0.28 | 0.11 | 0.13 | 0.18 | 0.13 | 0.18 | 0.19 | 0.18 |
| Al ₂ O ₃ | 15.31 | 15.09 | 15.19 | 14.36 | 15.31 | 15.36 | 15.09 | 15.16 | 14.96 | 15.56 | 13.76 | 14.04 | 14.48 | 14.79 | 14.31 | 14.97 | 15.11 | 15.08 |
| Fe ₂ O ₃ * | 2.82 | 1.82 | 2.49 | 2.04 | 2.40 | 2.46 | 2.16 | 2.11 | 1.92 | 2.26 | 2.23 | 1.65 | 1.89 | 1.88 | 1.65 | 1.77 | 1.86 | 1.94 |
| MnO | 0.03 | 0.03 | 0.03 | 0.04 | 0.04 | 0.03 | 0.03 | 0.03 | 0.04 | 0.03 | 0.04 | 0.03 | 0.03 | 0.03 | 0.04 | 0.03 | 0.03 | 0.03 |
| MgO | 0.81 | 0.48 | 0.67 | 0.61 | 0.64 | 0.69 | 0.54 | 0.41 | 0.44 | 0.68 | 0.57 | 0.21 | 0.26 | 0.32 | 0.28 | 0.35 | 0.35 | 0.35 |
| CaO | 2.61 | 1.90 | 2.32 | 2.14 | 2.38 | 2.44 | 2.18 | 1.84 | 1.81 | 2.15 | 1.96 | 0.63 | 1.19 | 1.67 | 1.27 | 1.56 | 1.61 | 1.61 |
| Na ₂ O | 4.03 | 4.08 | 4.06 | 3.80 | 4.34 | 4.05 | 4.06 | 4.18 | 4.24 | 4.06 | 3.62 | 3.90 | 3.96 | 4.39 | 4.32 | 4.15 | 4.18 | 4.14 |
| K ₂ O | 3.34 | 3.77 | 3.48 | 3.67 | 3.13 | 3.65 | 3.76 | 3.89 | 3.69 | 3.87 | 3.74 | 4.58 | 4.16 | 3.23 | 3.83 | 4.07 | 4.13 | 4.01 |
| P ₂ O ₅ | 0.11 | 0.08 | 0.09 | 0.08 | 0.10 | 0.11 | 0.09 | 0.09 | 0.08 | 0.12 | 0.07 | 0.06 | 0.05 | 0.10 | 0.08 | 0.08 | 0.08 | 0.08 |
| LOI | 0.61 | 0.89 | 0.68 | 0.59 | 0.42 | 0.70 | 0.65 | 0.38 | 0.74 | 0.69 | 0.54 | 0.76 | 0.62 | 0.85 | 0.59 | 0.70 | 0.81 | 0.81 |
| Total | 100.10 | 100.43 | 100.61 | 99.69 | 100.65 | 100.05 | 100.45 | 101.57 | 100.79 | 100.49 | 100.14 | 100.92 | 100.14 | 100.48 | 99.86 | 100.75 | 99.94 | 100.51 |
| TiO ₂ /MgO | 0.52 | 0.60 | 0.51 | 0.46 | 0.55 | 0.55 | 0.57 | 0.61 | 0.52 | 0.59 | 0.49 | 0.52 | 0.50 | 0.56 | 0.46 | 0.51 | 0.54 | 0.51 |
| A/CNK(mol%) | 1.02 | 1.06 | 1.04 | 1.02 | 1.03 | 1.02 | 1.03 | 1.05 | 1.05 | 1.05 | 1.01 | 1.12 | 1.10 | 1.08 | 1.05 | 1.06 | 1.06 | 1.07 |

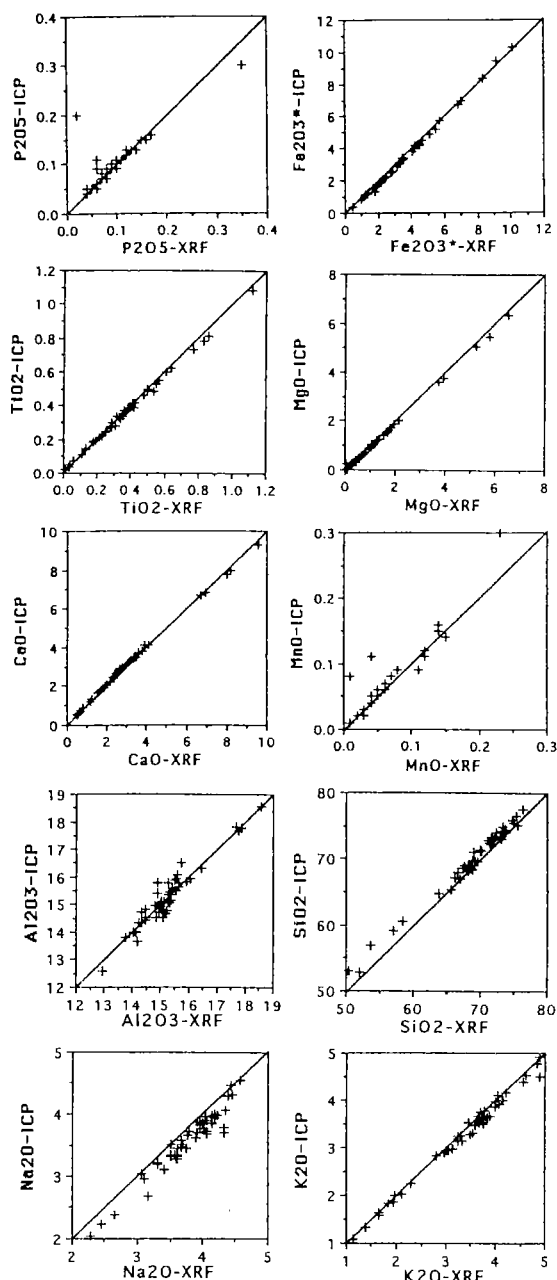


Fig. 2. Comparison between XRF and ICP-AES data.

aberrant data toward higher values for ICP method. On the other hand, correlation for Al₂O₃ values is not so good. Difference between the two methods for Al₂O₃ ranges up to about 1 wt%. SiO₂ values by ICP method quoted in Hong *et al.* (1988) are systematically higher than XRF data. This is

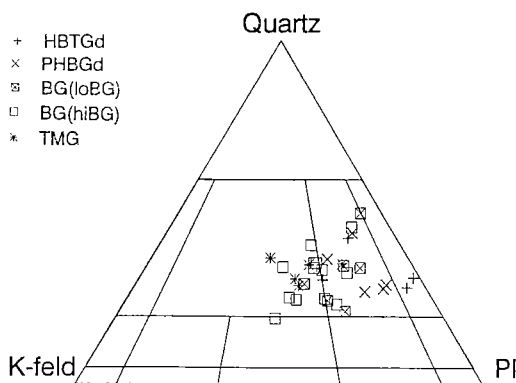


Fig. 3. Streckeisen diagram for the Namwon granitic complex. Abbreviations are the same as in Fig. 1.

conceivable since ICP data were not directly measured, but calculated assuming the analyzed samples water-free. However, directly measured values of Na₂O show systematic differences toward lower values for XRF data. The above observations mean that a caution should be taken when one compares data from different methods or from different laboratories. Thus, it is obvious to report data for well-known standard samples in order to facilitate inter-laboratory comparisons.

PETROGRAPHY

The petrography of the Namwon complex has been described previously in some detail (Kim *et al.*, 1987; Hong *et al.*, 1988; Kim and Lee, 1988). A brief summary is described in the following.

HBTGd is medium- to coarse-grained (1 to 7 mm) and mainly consists of plagioclase, quartz, K-feldspar, biotite, and hornblende. Accessory minerals are epidote, allanite, sphene, oxides, apatite and zircon. PHBGd is porphyritic (3 to 5 cm × 1 to 2 cm alkali-feldspar) and consists of quartz, plagioclase, K-feldspar and biotite. Accessory minerals are epidote (magmatic?) with allanite core, hornblende, sphene, oxides, apatite and zircon. BG is medium- to coarse-grained, and consists of quartz, plagioclase, K-feldspar, and biotite. Accessories include hornblende, epidote, allanite, sphene, oxides, apatite and zircon. Note that presence or absence of hornblende in BG appears to indicate significant chemical differences

Table 2. Mode data of the Namwon granitic complex

| Sample | HBTGd | | | | | | PHBGd | | | | | | IoBG | | | | | |
|--------------|-------|------|------|------|------|------|-------|------|-------|------|------|-------|------|------|------|--|--|--|
| | NW26 | NW27 | NW57 | NW61 | NW12 | NW14 | NW15 | NW19 | NW36 | NW58 | NW62 | NW63 | NW64 | NW67 | NW68 | | | |
| Quartz | 22.9 | 25.0 | 27.0 | 36.3 | 41.3 | 25.0 | 24.0 | 25.3 | 32.5 | 30.5 | 21.6 | 34.5 | 17.2 | 28.3 | 42.3 | | | |
| Plagioclase | 54.2 | 53.9 | 39.6 | 38.2 | 42.3 | 54.5 | 50.8 | 53.1 | 38.4 | 46.7 | 43.5 | 47.7 | 44.4 | 39.5 | 37.5 | | | |
| K-feldspar | 3.8 | 1.4 | 21.1 | 10.0 | 9.4 | 9.3 | 13.9 | 8.0 | 17.7 | 11.8 | 22.8 | 16.8 | 18.5 | 27.8 | 4.4 | | | |
| Biotite | 15.4 | 15.5 | 7.9 | 10.2 | 3.1 | 8.2 | 8.4 | 13.1 | 11.0 | 8.7 | 8.4 | 2.4 | 15.4 | 3.7 | 12.0 | | | |
| Hornblende | 1.9 | 2.7 | 1.6 | 2.0 | tr | tr | tr | — | — | tr | — | tr | — | tr | tr | | | |
| Epidote | 0.3 | 0.7 | tr | 2.7 | 1.0 | 0.5 | 0.1 | — | 1.0 | 1.6 | 1.8 | 0.8 | 3.3 | 0.3 | 1.2 | | | |
| Muscovite | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | | | |
| Allanite | 0.1 | tr | tr | tr | — | 0.2 | 0.1 | tr | — | — | — | — | 0.2 | — | 0.2 | | | |
| Sphene | 1.1 | tr | 0.3 | 0.4 | tr | 0.2 | — | tr | — | 0.3 | 0.1 | 0.4 | tr | tr | 2.0 | | | |
| Opaque oxide | 0.3 | 0.4 | 0.2 | 0.2 | 0.2 | 0.8 | 0.5 | tr | 0.3 | 0.2 | 0.1 | — | 0.1 | tr | 0.1 | | | |
| Sericite | — | — | — | — | — | — | — | — | — | — | — | tr | — | — | — | | | |
| Zircon | tr | — | tr | tr | tr | tr | tr | tr | — | tr | tr | tr | tr | tr | tr | | | |
| Apatite | tr | — | — | tr | tr | tr | tr | tr | — | tr | tr | tr | tr | tr | tr | | | |
| Total | 100 | 99.6 | 97.7 | 100 | 97.3 | 98.7 | 97.8 | 99.5 | 100.9 | 99.8 | 98.3 | 102.6 | 99.1 | 99.6 | 99.7 | | | |

Table 2. (continued)

| Sample | hiBG | | | | | | | | | | | | TMG | | | | | |
|--------------|-------|-------|-------|------|------|------|------|-------|------|------|------|------|------|------|------|-------|-------|------|
| | NW113 | NW137 | NW160 | A200 | A201 | A203 | A225 | A307 | A308 | A311 | A320 | A322 | A325 | NW34 | NW35 | NW46 | NW47 | NW49 |
| Quartz | 32.6 | 23.4 | 31.4 | 31.4 | 17.6 | 22.6 | 30.0 | 32.0 | 19.0 | 30.9 | 37.1 | 36.0 | 24.8 | 34.6 | 33.9 | 29.2 | 26.6 | 32.7 |
| Plagioclase | 31.8 | 45.3 | 40.6 | 37.8 | 35.8 | 37.7 | 46.0 | 37.2 | 42.6 | 35.0 | 33.7 | 34.8 | 38.4 | 27.3 | 45.7 | 36.2 | 36.8 | 36.8 |
| K-feldspar | 30.3 | 24.6 | 21.1 | 22.5 | 37.8 | 30.1 | 15.7 | 20.9 | 19.8 | 20.5 | 19.9 | 7.3 | 33.8 | 31.5 | 16.4 | 29.1 | 28.3 | 23.7 |
| Biotite | 3.0 | 5.0 | 6.2 | 6.6 | 6.2 | 6.6 | 5.3 | 6.2 | 13.6 | 11.7 | 6.2 | 16.2 | 2.4 | 3.2 | 1.6 | 2.3 | 3.2 | 3.8 |
| Hornblende | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Epidote | 0.6 | tr | 0.2 | 0.3 | 0.4 | 0.3 | 0.7 | 0.5 | 1.0 | 0.8 | 1.2 | 4.8 | 0.1 | — | — | — | — | — |
| Muscovite | — | — | — | — | — | — | — | — | — | — | — | — | — | 2.9 | 2.3 | 1.2 | 4.5 | 2.7 |
| Allanite | — | tr | — | tr | 0.4 | — | — | — | — | — | 0.1 | — | — | — | — | — | — | 0.2 |
| Sphene | 0.1 | — | — | — | — | — | — | 0.7 | 0.5 | 0.4 | — | 0.4 | — | tr | — | — | — | — |
| Opaque oxide | 0.1 | tr | 0.2 | 0.6 | 0.4 | 0.2 | 0.1 | 0.2 | 0.5 | 0.2 | 0.2 | — | 0.1 | — | 0.1 | — | 0.02 | 0.1 |
| Sericite | 1.2 | — | — | 0.5 | 1.2 | 2.2 | 1.9 | tr | 2.7 | — | 1.2 | — | 0.1 | tr | tr | tr | tr | tr |
| Zircon | tr | tr | tr | tr | tr | — | tr | tr | tr | 0.3 | 0.1 | — | — | tr | — | — | tr | tr |
| Apatite | tr | tr | tr | — | — | — | tr | tr | tr | — | — | — | — | — | tr | tr | tr | — |
| Total | 99.7 | 98.3 | 99.7 | 99.7 | 99.8 | 99.7 | 99.7 | 97.77 | 99.7 | 99.8 | 99.7 | 99.5 | 99.7 | 99.5 | 100 | 98.03 | 99.42 | 100 |

between BG, which will be described later. TMG is coarse-grained in general and consists of quartz, plagioclase, alkali-feldspar, biotite and muscovite. Accessories include sphene, allanite, oxides, apatite, and zircon.

Results of modal analysis for the samples discussed in this study are shown in Table 2. Some of these data are from Kim *et al.* (1987). When the mode data are plotted in the Streckeis diagram (Q-A-P), they show a trend varying from tonalite through granodiorite to granite (Fig. 3). This trend corresponds to the low-K calc-alkaline series in the classification of granite series proposed by Lamyere and Bowden (1982). The series is interpreted to be tectonically related to an early magmatic event near subduction zone during the evolution of an orogenic belt (Lamyere and Bowden, 1982).

RESULT AND DISCUSSION

Major Element Variation

The major element characteristics of the Namwon complex has been reported previously by Hong *et al.* (1988). They showed that the complex belongs to granitoids of calc-alkaline series, using the classification proposed by Irvine and Baragar (1971). Since Harker diagrams for major oxides appear in Hong *et al.* (1988), we do not duplicate them here. In general, as the amount of SiO_2 increases, that of TiO_2 , Al_2O_3 , MnO , FeO , MgO , CaO , and P_2O_5 decreases, while K_2O and Na_2O show increasing trends, albeit scattered.

In this paper, we use MgO content instead of SiO_2 as a differentiation index. Although it is a common practice to use MgO for basaltic rocks, it has been seldom used for granitic rocks. However, because MgO is a major constituent of mafic minerals such as hornblende and biotite, and because all the rocks we are considering have at least one of these phases, the MgO index can be useful for detecting variation of other elements as the fractionation of mafic minerals proceeds. Also note that MgO and SiO_2 have good negative correlation in a Harker diagram (Hong *et al.*, 1988).

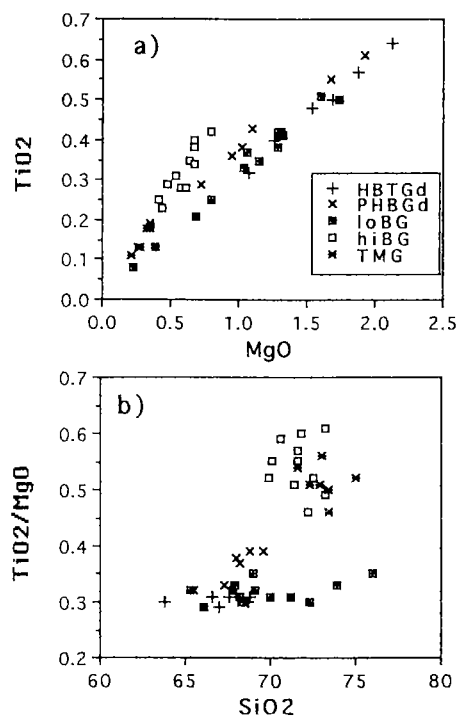


Fig. 4. (a) $\text{MgO}-\text{TiO}_2$ diagram, (b) $\text{SiO}_2-\text{TiO}_2/\text{MgO}$ diagram. Abbreviations are the same as in Fig. 1.

A major advantage of using MgO as a differentiation index would be that it is not so sensitive to potential cumulate effect of felsic minerals for major elements residing mostly in mafic minerals such as Fe, Ti, P, and Ca in part.

A significant feature in the chemistry of the Namwon complex is that it can be divided into two contrasting linear trends, low and high TiO_2/MgO groups in a $\text{MgO}-\text{TiO}_2$ plot (Fig. 4a). HBTGd and PHBGd belong to the low group and TMG to the high group. On the other hand, BG belongs to both groups. Hereafter, we call hiBG for BG with high TiO_2/MgO values and loBG with low values. The differences in TiO_2/MgO ratios are more obvious in SiO_2 vs. TiO_2/MgO plot (Fig. 4b), where the low group has TiO_2/MgO ratio of about 0.3 to 0.4 and the high group about 0.45 to 0.6. Nearly constant TiO_2/MgO ratios of HBTGd and loBG are remarkable considering a large variation of SiO_2 . On the other hand, PHBGd show increasing TiO_2/MgO ratio with SiO_2 , *i.e.*, with fractionation. Among the mineral phases containing Ti in

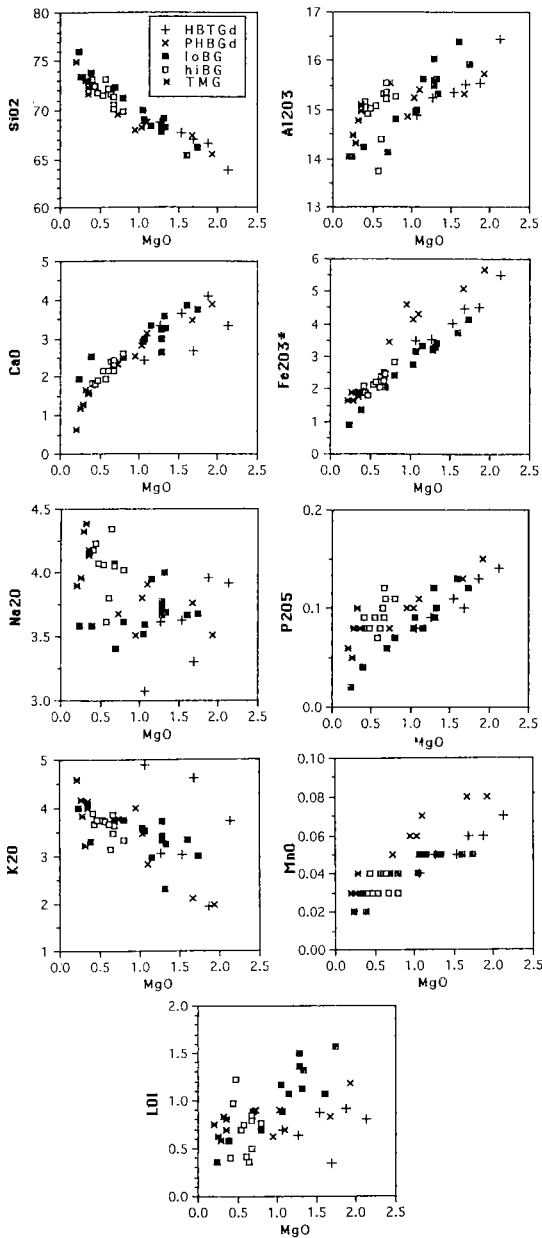


Fig. 5. MgO-variation diagrams.

granitoids are titanomagnetite and sphene. Thus, the decrease of Ti with decreasing Mg is probably associated with fractionation of such phases. Note that each lithologies occupy a distinct field in these plots, suggesting that chemical variation of individual rock types might have unique fractionation history. Although the MgO content

of both HBTGd and PHBGd varies from about 0.7 to 2.0, PHBGd tends to have slightly higher Ti content. The MgO content of loBG varies from 0.2 to 1.7, while that of hiBG from 0.4 to 0.9. The TMG has the lowest MgO contents.

Variation diagrams for other major oxides against MgO are shown in Fig. 5. In the diagrams we can observe that different TiO₂/MgO groups have distinct variations. We describe important features in the following. In general, rocks with MgO content greater than about 1 wt% show large variation than those with lower MgO. It is interesting that P₂O₅ shows almost identical variation as TiO₂. The SiO₂ content of hiBG and TMG tends to be slightly lower for given MgO, compared with that of loBG. Al₂O₃ content for the high TiO₂/MgO group shows steeper decreasing trend with MgO than the low group, implying important fractionation of feldspars for the latter. Similar trends can be found for CaO variation, suggesting that plagioclase fractionation was important for chemical variation of the low group in this case. Although Na₂O variation appears to have no well-defined trend, the distinction between the two groups are clear, with the low group having higher Na₂O contents. K₂O variations are scattered and overlap. However, the low group appears to have increasing trend of K₂O with decreasing MgO, suggesting that K-feldspar fractionation was not important in this group. This observation agrees with importance of plagioclase fractionation for the low group as shown in CaO variation. It also implies that higher Na₂O contents for the low group might be an inherent feature of original magma. The high group has higher Fe₂O₃* contents for given MgO and shallower slope than the loBG, indicating less iron depletion during fractionation. Also, note that PHBGd has higher total iron than others in the low group, which is somewhat similar to TiO₂ variation diagram.

In summary, the overall major element variations for the two groups show that fractionation of plagioclase (Al and Ca), K-feldspar (Al and K), titanomagnetite (Ti and Fe), and apatite (P) was concurrent with that of biotite and hornblende (Mg and Fe). Distinctions based on TiO₂/

MgO ratio are apparent in most variation diagrams, indicating that the two groups cannot be related to differentiation of a common magma. The variations of Al_2O_3 , CaO and K_2O suggest that plagioclase fractionation was more important, while K-feldspar less important for the high TiO_2/MgO group than the low group. The steeper slope of TiO_2 and shallower slope of Fe_2O_3^* variations for the high group compared with the low group suggest that fractionation of Ti-rich phase (ilmenite perhaps) was more important for the high group. In the low group, PHBGd might represent another distinct origin of magma, since it shows distinct variation from loBG and HBTGd in Fe_2O_3^* , P_2O_5 , MnO-, and TiO_2 - MgO diagrams.

Biotite Chemistry

Biotite chemistry in granitoids is believed to be an important indicator of physicochemical conditions of magma in which it grows (Wones, 1981; Ague and Brimhall, 1988). Thus, we may expect different biotite chemistry if there were differences in such conditions, which could imply potentially different batches of magma. We found a significant correlation between the chemistry of biotites and whole rocks in the Namwon complex. The following interpretations are based on the biotite chemistry data in Hong *et al.* (1988) and our unpublished data.

In a TiO_2/MgO (whole rock) *vs.* $\text{Mg}/(\text{Mg}+\text{Fe})$ (biotite) diagram, the data overall show a negative correlation (Fig. 6). In the figure, there are four distinct fields occupied by loBG and HBTGd, PHBGd, hiBG, and TMG. It is interesting to see that loBG and HBTGd have an intimate relationship not only in bulk rock chemistry but also in mineral chemistry. Significant difference in biotite chemistry of PHBGd from loBG and HBTGd supports the speculation made from major element variations that PHBGd may not be cogenetic with HBTGd and loBG. In any case, the above distinction could suggest different sources for each lithology. Alternatively, since $\text{Mg}/(\text{Mg}+\text{Fe})$ ratio in biotite is believed to have a close relationship with oxygen fugacity in the magma (Ague and Brimhall, 1988), the difference in $\text{Mg}/(\text{Mg}+\text{Fe})$

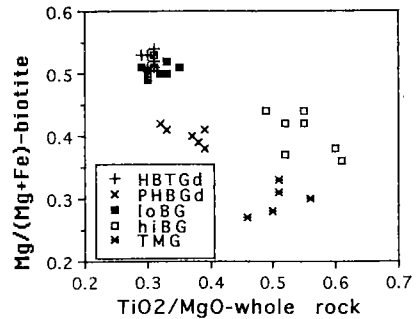


Fig. 6. Correlation diagram between TiO_2/MgO (wt%) in whole rock and $\text{Mg}/(\text{Mg}+\text{Fe})$ (per formula unit) in biotite.

within each group would be due to difference in oxygen fugacity possibly controlled by distinct mineral assemblages.

In summary, these observations indicate that the two kinds of BG revealed by whole rock chemistry are clearly distinct in biotite chemistry, suggesting different conditions or sources of magma.

Distribution of loBG and hiBG

Distribution of rocks based on TiO_2/MgO ratio is shown in Fig. 7. It appears that the distribution of the loBG and hiBG is not random, but distinct. The loBG occurs in two areas separated by hiBG: the eastern part of the BG where it is associated with hornblende-bearing HBTGd, and the northwestern part where no such rocks are associated. The distinct geographical distribution of loBG and hiBG appears to support the idea of separate intrusions for BG.

This observation suggests that a new geologic map should be made. Because of lithological similarity between the two BG, it would not be easy to detect the boundary, what could be called a cryptic boundary, between them in the field. However, presence or absence of hornblende, and whole rock and biotite chemistry would help find such a boundary.

Speculations on the Origin of different TiO_2/MgO ratios and the Source Materials

We have described that the rocks of the Namwon

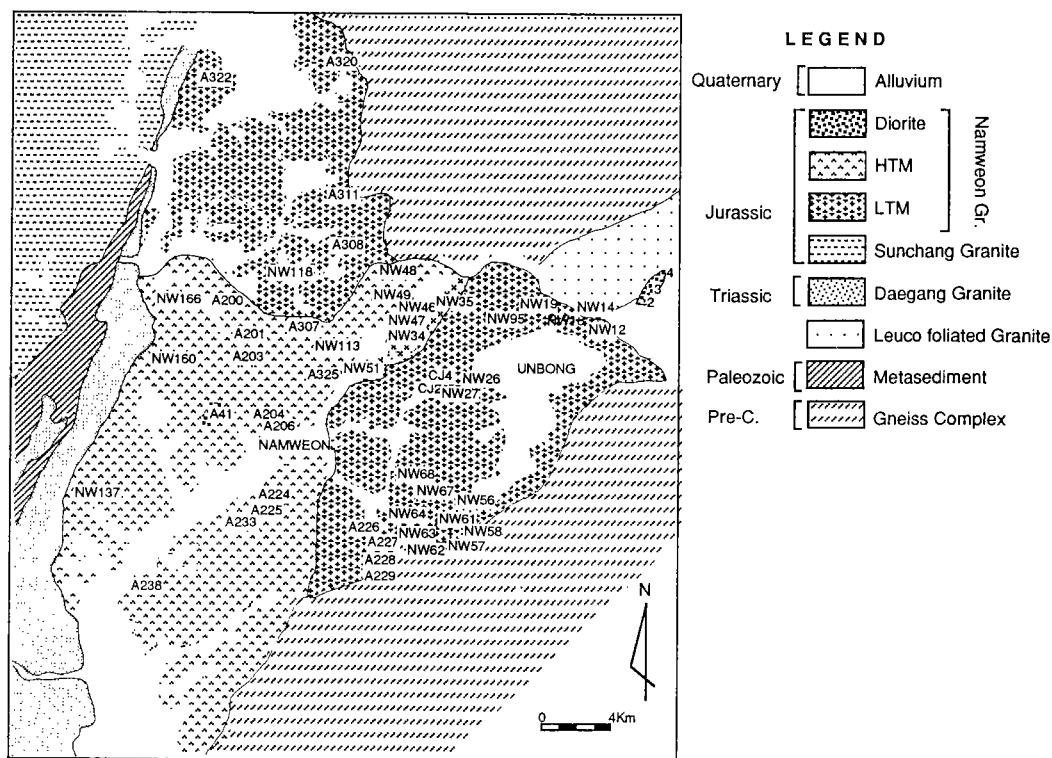


Fig. 7. Distribution of chemically distinct groups of granitic rock in the Namwon complex (LTM, low TiO_2/MgO group; HMT, high TiO_2/MgO group), which suggest intrusion of the HMT into the LTM.

complex have two distinct groups of TiO_2/MgO ratio. In the MgO variation diagrams, distinctions between the two groups were most apparent in TiO_2 , P_2O_5 , and Na_2O . Since differentiation by fractional crystallization at a given pressure cannot normally produce such a sharp break in the chemical variation diagrams shown previously, we regard that relationship between the two groups should be explained by some other processes. If a common source is considered, viable processes would be fractional crystallization at different pressures, different degree of partial melting, and assimilation or magma mixing when contamination is involved. Among these processes, assimilation and magma mixing hypothesis may tentatively be discarded, because unless such processes are complete, major element variations would appear rather gradational than with a sharp break. However, we do not completely exclude such possibilities, for sensitivity of major element chemistry in detecting such

processes is generally low compared with those of trace element and isotope data. In any case, our lack of pertinent knowledge and data in the present study does not allow us to further speculate on other potential processes.

There have been many attempts to deduce source characteristics of granitic magmas, since the proposal of Chappel and White (1974). Lithologically, the high TiO_2/MgO group (muscovite-bearing) belongs to S-type granite, while the low group (hornblende-bearing) to I-type. However, distinction between I- and S-type granites based on lithological characteristics can be ambiguous, since extreme differentiation of I-type magma can produce S-type magma (White *et al.*, 1986). Although high Sr initial ratio (0.7186 ± 0.0004) reported by Choo and Kim (1986) also suggests an S-type source for hiBG, the ratio cannot provide definitive answer for the source material, since the high Sr initial could be

interpreted as having been developed from an igneous source with high Rb/Sr ratio and/or old age. On the other hand, major element characteristics suggest both belonging to I-type. Sodium difference in granitic rocks are well known for its usefulness of dividing I- and S-type sources (White *et al.*, 1986). The high Na₂O (>3.0 wt%) content of the Namwon complex suggests igneous type source material as a whole. Alumina indices of less than 1.1 also support I-type source for the Namwon complex.

CONCLUSION

The diverse rock types of Mesozoic Namwon granitic complex, which have been believed to be products of differentiation of a uniform source, appear to have derived from at least two different origins of magma, on the basis of MgO variation diagrams (especially in TiO₂- and P₂O₅-MgO). Since the sharp break in the variation diagram cannot be produced by simple fractionation, other magmatic processes, or source differences are called for to explain the major element chemistry of the complex. High Na₂O contents of the Namwon complex suggest an igneous source material, regardless of lithology. Biotite chemistry also appears to be closely associated with whole rock chemistry. With the aid of chemical data we recognize two kinds of biotite granite showing distinct geographical distribution, which suggests that a new geologic mapping should be done. Because the chemical difference cannot be easily revealed in the mode, one would have to use chemical (whole rock and biotite) data for geologic mapping of this kind of plutonic suite.

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REFERENCES

- Ague, J.J. and Brimhall, G.H., 1988, Regional variations in bulk chemistry, mineralogy and the compositions of mafic and accessory minerals in the batholiths of California. *Geol. Soc. Am. Bull.*, 100, 891-911.
- Chappell, B.W. and White, A.J.R., 1974, Two contrasting granite types. *Pacific Geology*, 8, 173-174.
- Choo, S.H. and Kim, S.J., 1986, Rb-Sr age determinations on the Ryeongnam Massif (II): granitic gneisses and gneissic granites in the southwestern Jirisan region. Research Report KR-86-7, Korea Institute of Energy and Resources, 7-33. (in Korean).
- Hong, S.S., Kim, Y.J., and Kim, J.B., 1988, Petrochemical study on Namweon granite body in the Namweon area. *Jour. Geol. Soc. Korea*, 24 (special issue), 132-146. (in Korean).
- Irvine, T.N. and Baragar, W.R.A., 1971, A guide to the chemical classification of the common volcanic rocks. *Can. J. Earth Sci.*, 8, 523-548.
- Kim, K.B., Choi, W.C., Hwang, J.H., and Kim, J.H., 1984, Geological report of the Osu sheet (scale 1:50,000). Korea Institute of Energy and Resources, p. 38. (in Korean).
- Kim, Y.J., Kim, J.B. and Dallmeyer, R.D., 1987, Petrographic study on mylonitic granite in the Unbong-Ayoung area. *Jour. Korean Inst. Mining Geol.*, 20, 125-136. (in Korean).
- Kim, Y.J. and Lee, C.S., 1988, The study on igneous rocks and their igneous activity in the Jangsoo-Unbong area. *Jour. Geol. Soc. Korea*, 24 (special issue), 111-131. (in Korean).
- Lamyere, J. and Bowden, P., 1982, Plutonic rock types series: discrimination of various granitoid series and related rocks. *J. Vol. Geotherm. Res.*, 14, 169-198.
- Tsuchiya, N., Shibata, T., Koide, Y., Owada, M., Takazawa, E., Goto, Y., Choi, J.H., Terada, S. and Hariya, Y., 1989, Major element analysis of rock samples by X-ray fluorescence spectrometry, using scandium anode tube. *Jour. Fac. Sci. Hokkaido Univ.*, 22, 489-502.
- White, A.J.R., Holloway, J.R., Silver, L.T., Chappell, B.W., and Wall, V.J., 1986, S-type granites and their probable absence in southern North America. *Geology*, 14, 115-118.
- Wones, D.R., 1981, Mafic silicates as indicators of intensive variables in granitic magmas. *Mine. Geol.*, 31, 191-212.
- Yanai, S., Park, B.S. and Otoh, S., 1985, The Honam shear zone (S. Korea): deformation and tectonic implication in the Far East. *Sci. Pap. Coll. Arts Sci., Univ. Tokyo*, 35, 181-210.

(책임편집 : 최용주)

남원 화강암질 복합체에 나타나는 두 종류의 TiO_2/MgO 비

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요 약: 남원 화강암질 복합체의 화학적 특징은 MgO를 분화지수로 사용할 때 두드러지게 잘 나타난다. 이 지수는 통상의 하커지수보다 민감함을 보인다. 이 복합체는 TiO_2/MgO 비가 큰 HTM 그룹과 그 비가 작은 LTM 그룹으로 구분될 수 있다. LTM 그룹에는 각섬석 흑운모 토날라이트-화강섬록암, 반상 각섬석 흑운모 화강섬록암(PHBGd), 그리고 흑운모 화강암의 일부(loBG)가 속하는데, PHBGd는 이 그룹 중에서도 특징적인 화학변화를 보인다. 이 그룹은 비록 소량일지라도 각섬석이 존재하는 것이 특징적이다. HTM 그룹에는 흑운모 화강암의 일부(hiBG)와 복운모 화강암이 속한다. 주성분원소의 차이는 흑운모 화학성분에서도 분명히 나타난다. 이러한 화학자료는 적어도 두 종류의 서로 다른 기원의 마그마가 남원 복합체를 만들었음을 지시한다. 이 연구에서 확인된 두 종류의 흑운모 화강암은 지역적으로도 분명히 구분되어 분포하는데, 이는 새로운 지질도가 작성되어야함을 시사한다.

핵심어: 남원화강암질복합체, 전암 화학성분, 흑운모 화학성분, 숨겨진 지질경계