Polar Geosci., 12, 87–100, 1999

# PETROGRAPHY AND GEOCHEMISTRY OF MAFIC AND ULTRAMAFIC ROCKS FROM TONAGH ISLAND IN THE NAPIER COMPLEX, EAST ANTARCTICA: A PRELIMINARY REPORT

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***Abstract:*** The geology of Tonagh Island is divided into five geological units. The boundaries among the units are thrusts or shear zones. Tonagh Island is dominated by mafic to felsic layered gneisses. Metamorphosed ultramafic rocks are locally exposed. The dolerite dykes cut the host gneiss and the shear zone, and have chilled margins. Lithological features for mafic and metamorphosed ultramafic rocks on Tonagh Island are classified into the following nine types: 1) two pyroxene gneiss; 2) garnet-bearing two pyroxene gneiss; 3) brown hornblende two pyroxene gneiss; 4) biotite-bearing two pyroxene gneiss; 5) fine- grained garnet two pyroxene gneiss; 6) pyroxenite; 7) websteritic peridotite; 8) hornblende-bearing lherzolitic peridotite; and 9) dolerite. The fine-grained garnet two pyroxene gneiss occurs as dyke cutting the foliation and the layering of the host gneiss. The hornblende-bearing lherzolitic peridotites are considered to be intrusive rocks based on geological investigation. The MORB normalized trace element patterns of the dolerite and the fine-grained garnet two pyroxene gneiss are similar to those of the within-plate basalt. Some of the mafic gneisses and the metamorphosed ultramafic rocks have high MgO contents (up to 31 wt%), and are plotted in the komatiitic field on the ($Fe_{total}$+Ti)-Al-Mg diagram. The brown hornblende two pyroxene gneiss, the websteritic peridotite and the hornblende-bearing lherzolitic peridotite show similar REE patterns such as light REE enrichment. These geochemical features imply that original rock of some mafic gneiss and metamorphosed ultramafic rocks from Tonagh Island were Archaean komatiitic rock.

**key words**: Napier Complex, Tonagh Island, Archaean, geochemistry, komatiitic rock

## 1. Introduction

The Napier Complex is an Archaean craton in the East Antarctic Shield. It consists of ultrahigh-temperature (UHT) granulite facies metamorphic rocks, characterized by spinel-quartz, sapphirine-quartz and orthopyroxene-sillimanite-quartz associations (*e.g.* SHERATON *et al.*, 1980, 1987). Metamorphic *P-T* conditions are up to 1100 MPa and 1100°C (*e.g.* HARLEY and HENSEN, 1990). The dominant rock types are pyroxene- and garnet-bearing quartzofeldspathic gneisses of igneous origin (orthogneiss), with subordinate mafic granulite, pyroxenite, and various siliceous, aluminous and ferruginous metasediments (SHERATON *et al.*, 1980, 1987). Tonalitic orthogneiss had intruded into the crust c. 3900–3800 Ma, as revealed by ion microprobe U-Pb analysis of zircon (BLACK *et al.*, 1986; HARLEY and BLACK, 1997). Granitic intrusive rocks and mafic dykes are also present (SHERATON and BLACK, 1981).

Geochemical studies including isotope chemistry for the mafic and metamorphosed ultramafic rocks from the Napier Complex have been conducted by previous workers (*e.g.* SHERATON and BLACK, 1981; SHERATON *et al.*, 1987; OWADA *et al.*, 1995; TAINOSHO *et al.*, 1997). SHERATON *et al.* (1987) revealed that some mafic rocks from the Napier Complex have similar geochemical features to Archaean komatiitic rock. TAINOSHO *et al.* (1997) interpreted that the mafic gneisses are derived from different source material compared with that of the felsic gneiss. The nature and origin of the mafic rocks, however, are not fully understood.

JARE-39 did a detailed geological survey on Tonagh Island. In this paper, we describe petrographical and geochemical characteristics of the mafic and metamorphosed ultramafic rocks.

## 2. Geological Outline of Tonagh Island

Tonagh Island, located in the southern part of Amundsen Bay, consists of various kinds of metamorphic rocks, *e.g.*, quartzofeldspathic gneiss, mafic gneiss, metapelite and metamorphosed ultramafic rock, and subordinate amount of two types of unmetamorphosed intrusive rocks (dolerite and granitic pegmatite).

The geology of Tonagh Island is divided into five geological units (Units I to V, from north to south) in terms of lithological and structural features (Fig. 1). The boundaries among units are NE-SW to E-W trending steeply north dipping thrusts or shear.

Unit I consists of layered gneiss, which is a combination of the following five rock types on a scale of 1–20 m in thickness: quartzofeldspathic gneiss, mafic gneiss, pelitic gneiss, calc-silicate gneiss and metaironstone. Units II and III are characterized by widespread distributions of layered gneisses. Two pyroxene mafic gneiss and garnet-orthopyroxene gneiss are dominated by the upper structural levels of Units II and III. Garnet-two pyroxene mafic dyke had intruded into the central part (Units II and III) of the Island. Unit IV consists mainly of layered gneiss, which is underlain by a narrow zone between Units III and V. The quartzofeldspathic gneiss from Unit IV is characterized by mylonitic deformation, although the mafic gneiss does not show apparent deformational, but contains biotite. Unit V is widely occupied by orthopyroxene-bearing quartzofeldspathic gneiss with trace amounts of mafic gneiss, pelitic gneiss and metaironstone. Metramorphosed ultramafic rocks sporadically occur through all of the units.

Metamorphic foliations in each unit are different. The foliations in Unit I strike NE-SW and dip to SE or NW with a steep angle (50°–80°). These in Units II and III show almost the same trend as those in Unit I, but gentler dip (15°–40°) to the NW. In Units

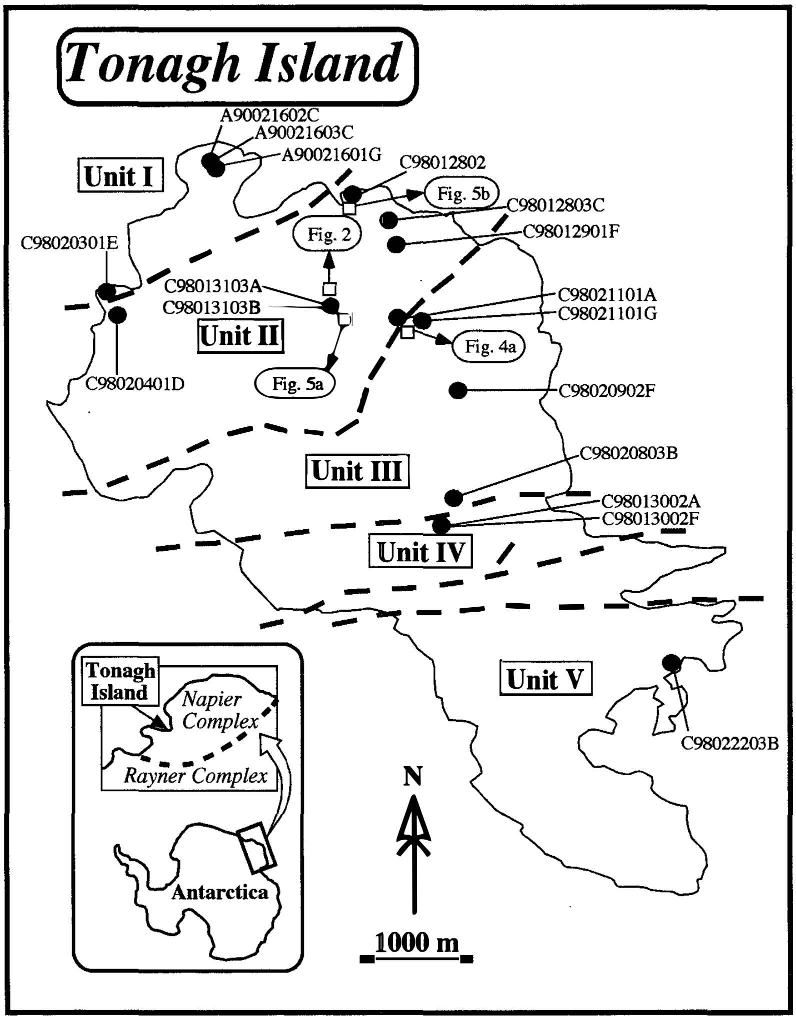


*Fig. 1. Unit division and sampling locations of the analyzed mafic gneiss and the metamorphosed ultramafic rocks. The broken lines indicate large shear and thrust zones.*

IV and V, the foliations strike NE-SW and dip to the north with moderate angle (20°–60°).

## 3. Metamorphosed Mafic Rock (Mafic Gneiss)

Metamorphosed mafic rocks are classified into the following five types: 1) two pyroxene gneiss; 2) garnet-bearing two pyroxene gneiss; 3) brown hornblende two pyroxene gneiss; 4) biotite-bearing two pyroxene gneiss; and 5) fine-grained garnet two pyroxene gneiss. The brown hornblende two pyroxene gneiss occurs as thick layers in Units I and II. The quartzofeldspathic gneiss (Fig. 2), an intrusive precursor of the quartzofeldspathic gneiss, cuts the foliation of the brown hornblende two pyroxene gneiss. Representative petrographic features observed in each rock type are shown in Fig. 3.

### *3.1. Two pyroxene gneiss*

Two pyroxene gneiss occurs in Units I, II, III and V. This gneiss is observed as

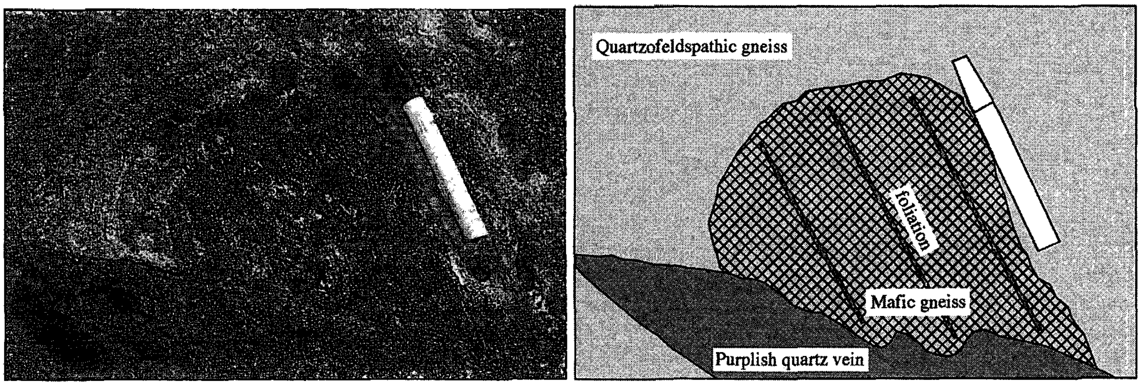


*Fig. 2. Close up view of the contact between the mafic gneiss and the quartzofeldspathic gneiss. Note that the foliation of the mafic gneiss is oblique against the contact.*

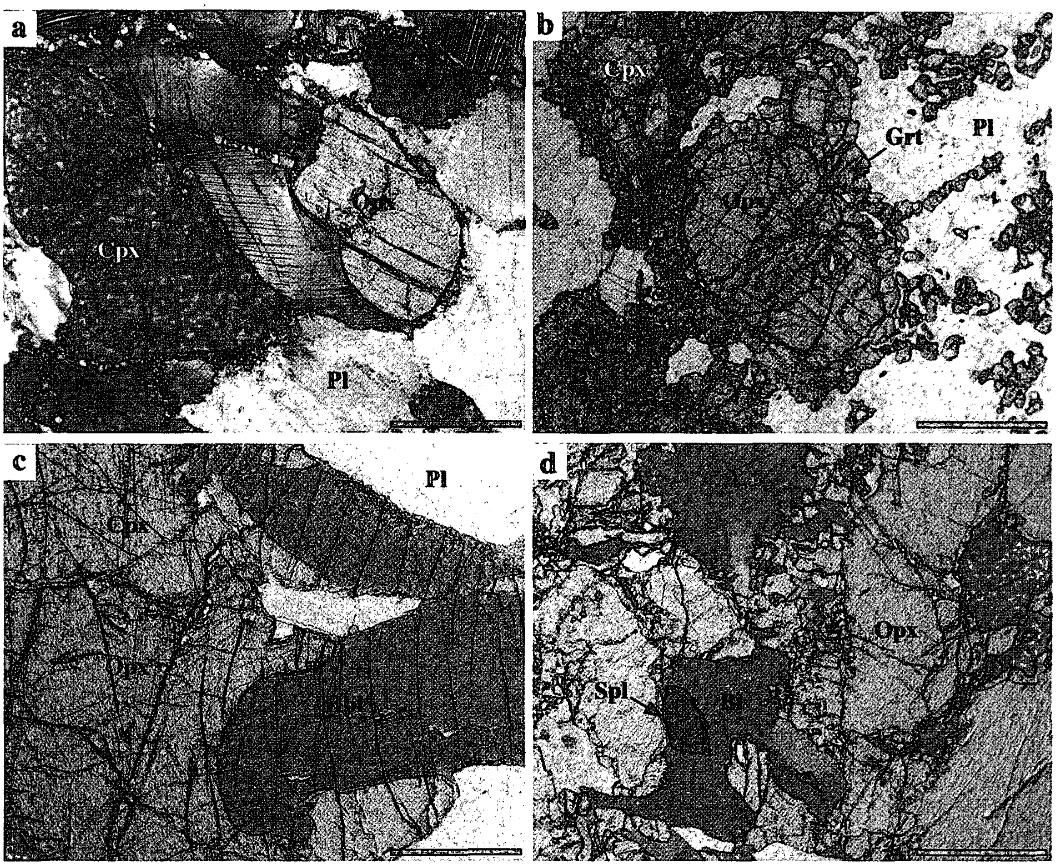


*Fig. 3. Photomicrographs for the mafic gneisses. All scale bars are 0.5 mm. Abbreviations of mineral names are after* KRETZ *(1983). a: Two pyroxene mafic gneiss (cross polarized light; XPL). b: Garnet-bearing two pyroxene gneiss (plane polarized light; PPL). c: Brown hornblende two pyroxene gneiss (PPL). d: Biotite-bearing two pyroxene gneiss (PPL).*

both thick and thin layers in Units I, II and III, and Unit V. Most of the two pyroxene gneisses are medium-grained rock with granoblastic texture. Figure 3a shows a photomicrograph of the typical two pyroxene gneiss. The observed mineral assemblages in the

two-pyroxene gneiss are as follows.
1) orthopyroxene + clinopyroxene + plagioclase ± quartz,
2) orthopyroxene + clinopyroxene ± olivine + plagioclase.

Apatite and Fe-Ti oxides occur as accessory minerals. Most of these assemblages contain retrograde hornblende and biotite.

*3.2. Garnet-bearing two pyroxene gneiss*

Garnet-bearing two pyroxene gneiss occurs in all of the units as a constituent member of the layered gneiss. This gneiss is medium-grained rock with granoblastic texture. Pyroxene porphyroblasts with garnet corona are characteristic features of this type of gneiss (Fig. 3b). Small grains of green hornblende locally occur in interstitial areas between garnet and pyroxene. The following are the observed peak metamorphic mineral associations in this gneiss.
1) orthopyroxene + clinopyroxene + garnet + plagioclase + quartz,
2) orthopyroxene + clinopyroxene + garnet + plagioclase ± hornblende + quartz.

Apatite and Fe-Ti oxides occur as accessory minerals. Most of these assemblages contain retrograde biotite.

*3.3. Brown hornblende two pyroxene gneiss*

Brown hornblende two pyroxene gneiss is characterized by the presence of coarse-grained brown hornblende that coexists with pyroxene and plagioclase. This gneiss occurs as a thick layer in Units I and II. Compositional banding associated with the metamorphosed ultramafic layer sometimes develops in the thick layer.

The brown hornblende two pyroxene gneiss is medium to coarse -grained rock, dark grayish brown to light grayish brown in color. The gneiss exhibits the granoblastic texture (Fig. 3c). Peak mineral assemblages are as follows.
1) orthopyroxene + clinopyroxene + brown hornblende + spinel + plagioclase,
2) orthopyroxene + clinopyroxene + brown hornblende + plagioclase.

Apatite and Fe-Ti oxides occur as accessory minerals. Most of these assemblages contain retrograde green hornblende and biotite.

Brown hornblende, locally including tiny needles of Fe-Ti oxide minerals (ilmenite?), is included in pyroxene. Petrographical features indicate the brown hornblende to consist of peak metamorphic minerals similar to pyroxene and plagioclase (Fig. 3c).

*3.4. Biotite-bearing two pyroxene gneiss*

Biotite-bearing two pyroxene gneiss is observed in the layered gneiss from Unit IV. This gneiss appears dark brown to grayish brown in color because of large amounts of reddish brown biotite. Biotite, orthopyroxene, clinopyroxene, garnet, spinel and plagioclase are major constituents (Fig. 3d). Orthopyroxene is surrounded by biotite.

*3.5. Fine-grained garnet two pyroxene gneiss (metamorphosed dyke)*

Fine-grained garnet two pyroxene gneiss is a metamorphosed mafic rock as a dyke cutting across the foliation and layering of the host gneisses. This rock had undergone folding and mylonitic deformation along the shear zone (Figs. 4a, b). Constituent min-

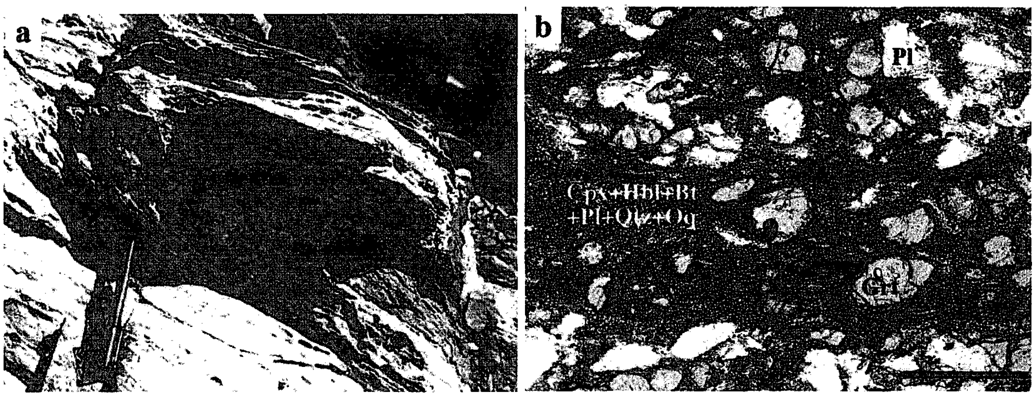


*Fig. 4. Occurrence and photomicrograph of the fine-grained garnet two pyroxene gneiss (metamorphosed dyke). a: The metamorphosed dyke (black thin layer) attended to fold structure along the shear zone between Units II and III. b: Mylonitic texture is characterized by plagioclase and garnet porphyroclast (PPL). The scale bar is 0.5 mm.*

erals are garnet, clinopyroxene, orthopyroxene, hornblende, plagioclase and quartz. Fe-Ti oxide minerals occur as accessory minerals. Retrograde biotite surrounds orthopyroxene.

## 4. Metamorphosed Ultramafic Rock

Metamorphosed ultramafic rocks occur as thin layers (a few ten centimeters to meters in thickness), lenses and/or blocks. Some metamorphosed ultramafic rocks appear as thin layers within the thick mafic gneiss, and are concordant with compositional banding of the mafic gneiss (Fig. 5a). Most importantly, the metamorphosed ultramafic layer is locally oblique against the layers of the neighboring quartzofeldspathic gneiss (Fig. 5b). This suggests intrusive precursors of the metamorphosed ultramafic rocks.

The metamorphosed ultramafic rocks show massive and medium- to coarse-grained rock, and are subdivided into the following three rock types: 1) pyroxenite; 2) websteritic peridotite; and 3) hornblende-bearing lherzolitic peridotite.

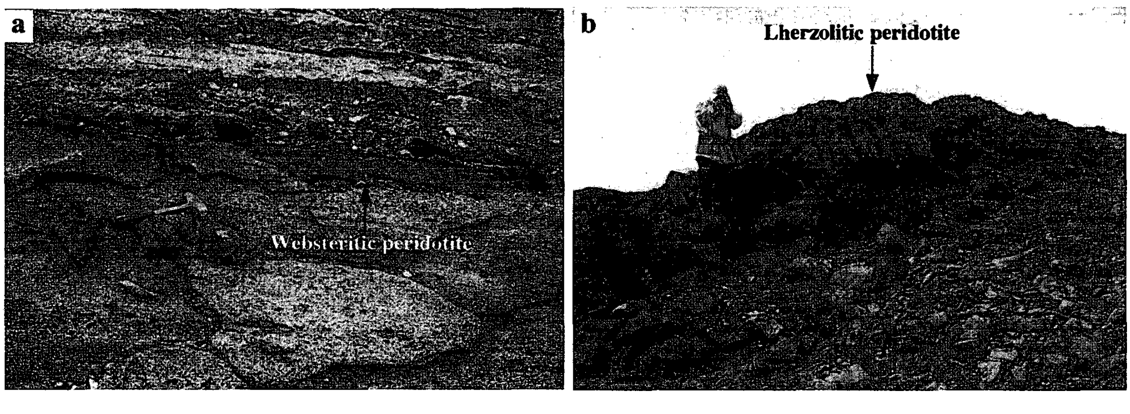


*Fig. 5. Occurrence of metamorphosed ultramafic rocks. a: Websteritic peridotite occurring as thin layer in the mafic gneiss. b: Ridge shaped lherzolitic peridotite layer. This layer seems to be oblique against the neighboring layer or foliation of the layered gneiss.*

The pyroxenite is mainly composed of orthopyroxene and clinopyroxene. The websteritic peridotite consists mainly of orthopyroxene, clinopyroxene and olivine. Brown to brownish green spinel, phlogopite, pale brown to colorless hornblende and rarely plagioclase are also present as primary minerals (Fig. 6a). Euhedral apatite is observed in the layered type websteritic peridotite as an inclusion in plagioclase and pyroxene (Fig. 6a).

Figure 5b shows field occurrence of the hornblende-bearing lherzolitic peridotite. The layer of this peridotite is discordant with thin alternation layers of the mafic and quartzofeldspathic gneisses. The lherzolitic peridotite (sample C98012802) consists mainly of olivine (37.1 modal%), clinopyroxene (16.8%), orthopyroxene (27.5%) and hornblende (12.9%), with trace amounts of spinel, magnetite and apatite. The rock is generally medium- to coarse-grained with granoblastic texture (Fig. 6b). Hornblende is medium in grain size and brown to pale brown in pleochroism. It contains many opaque minerals (ilmenite?). Subhedral apatite locally occurs in olivine (Fig. 6c). Hornblende is included in olivine as poikilitic inclusions (Fig. 6d).

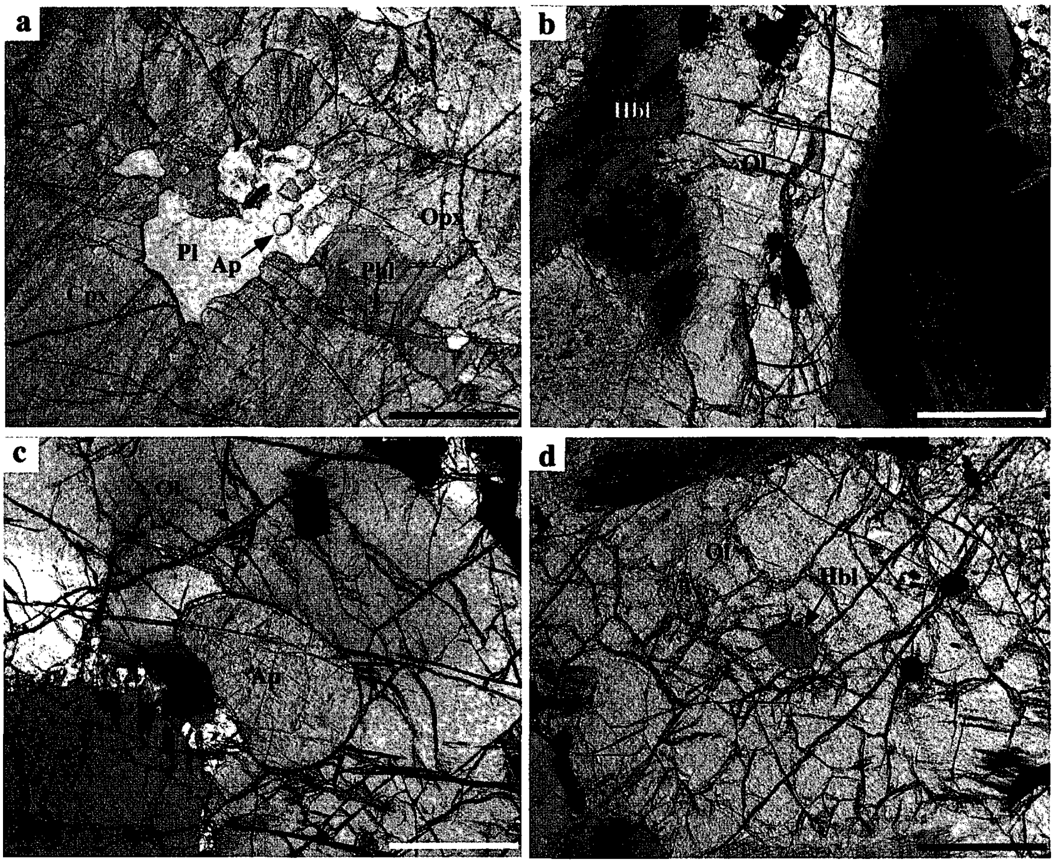


*Fig. 6. Photomicrographs for the metamorphosed ultramafic rocks. Scale bars are 0.5 mm for a, b and d, and 0.2 mm for c. a: Websteritic peridotite. Note that small and euhedral grain of apatite is included in plagioclase (PPL). b: Hornblende-bearing lherzolitic peridotite (PPL). c: Hornblende-bearing lherzolitic peridotite (XPL). Note that subhedral apatite is included in olivine. d: Hornblende-bearing lherzolitic peridotite. Note that hornblende is included in olivine (PPL).*

## 5. Unmetamorphosed Mafic Rock

Unmetamorphosed mafic rock occurs in dolerite dykes. The dolerite cuts across the layered structure of the metamorphic rocks and large shear zone, which is regarded as the boundary between Units II and III. The width of this dyke varies from a few centimeters to several meters. The dolerite has a distinctive chilled margin on the scale of several centimeters although thin intrusions lack the chilled margin.

The dolerite contains phenocrysts of purplish brown clinopyroxene, biotite, plagioclase and garnet with fine-grained groundmass (green amphibole, clinopyroxene and plagioclase) (Fig. 7). The chilled margin of this rock has the same minerals as its core without biotite (Figs. 7a, b). Fe-Ti oxide minerals and apatite occur as accessory minerals.

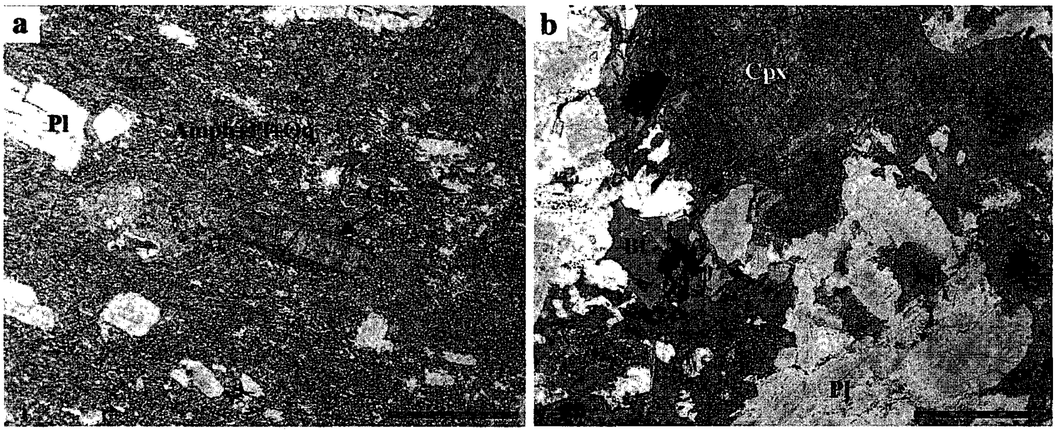


*Fig. 7. Photomicrographs for the dolerite dyke. Scale bars are 0.5 mm. a: Fine-grained part (marginal facies) (PPL). b: Coarse-grained part (PPL).*

## 6. Geochemistry

Samples without obvious alteration and mylonitization have been chosen for whole rock analysis from all Units of Tonagh Island. Major and trace elements were analyzed with the XRF of the Center for Instrumental Analysis at Yamaguchi University. Rare earth elements were determined by Inductively Coupled Plasma Mass spectrometry (ICP-MS) at the Curtin University of Technology. The representative bulk chemical compositions of these rocks are listed in Tables 1 and 2.

The $SiO_2$ contents of the unmetamorphosed dolerite dykes range from 48 to 49 wt%. Chemical compositions among the measured samples are similar regardless of the grain sizes of samples and widths of intrusions. These dolerites are characterized by high $Na_2O/K_2O$ (2.24 to 2.43) ratios and high $TiO_2$ (2.07 to 2.16 wt%) contents. Figure 8 shows trace element concentrations normalized to the composition of average MORB. The normalized pattern of the dolerite resembles that of the within-plate basalt. The fine-grained garnet two pyroxene gneisses (metamorphosed dyke) are also plotted in this figure. The normalized abundance of the metamorphosed dyke is higher in Zr and Y and lower in Sr, Nb and P than that of the dolerite although the pattern is similar to that of the dolerite.

*Table 1. Representative bulk chemical compositions for the mafic rocks and the metamorphosed ultramafic rocks.*

| | Unmetamorphosed mafic rock | | Metamorphosed mafic rock | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Sample | C98012803C | C98012901F | C98021101A | C98021101G | A90021601G | A90021602C | C98012801B | C98013103A | C98020803B |
| Occurrence | dyke | dyke | dyke | dyke | layer | layer | layer | layer | layer |
| Rock Type | dolerite | dolerite | FGPG | FGPG | BHPG | BHPG | BHPG | BHPG | GPG |
| Unit | - | - | - | - | Unit I | Unit I | Unit II | Unit II | Unit III |
| $SiO_2$(wt%) | 49.29 | 49.27 | 48.77 | 49.53 | 54.82 | 50.36 | 50.48 | 47.06 | 51.64 |
| $TiO_2$ | 2.13 | 2.07 | 2.01 | 1.78 | 0.45 | 1.11 | 0.92 | 0.41 | 0.74 |
| $Al_2O_3$ | 13.54 | 13.75 | 12.46 | 12.74 | 12.86 | 8.72 | 16.08 | 19.14 | 15.02 |
| $Fe_2O_3$ | 14.75 | 14.45 | 18.21 | 17.04 | 10.59 | 15.03 | 10.42 | 9.30 | 13.55 |
| MnO | 0.20 | 0.19 | 0.28 | 0.27 | 0.17 | 0.23 | 0.14 | 0.12 | 0.18 |
| MgO | 6.09 | 6.41 | 4.59 | 5.09 | 10.51 | 14.76 | 8.82 | 11.40 | 6.93 |
| CaO | 9.10 | 9.55 | 8.39 | 9.01 | 8.87 | 8.10 | 11.35 | 11.18 | 9.70 |
| $Na_2O$ | 2.20 | 1.96 | 2.31 | 2.31 | 2.03 | 1.17 | 2.36 | 1.48 | 2.66 |
| $K_2O$ | 0.98 | 0.85 | 1.01 | 0.83 | 0.40 | 1.03 | 0.31 | 0.17 | 0.21 |
| $P_2O_5$ | 0.23 | 0.21 | 0.21 | 0.18 | 0.08 | 0.26 | 0.12 | 0.02 | 0.07 |
| Total | 98.51 | 98.71 | 98.24 | 98.77 | 100.78 | 100.77 | 100.99 | 100.27 | 100.70 |
| Ba (ppm) | 260 | 240 | 260 | 240 | 80 | 340 | 80 | <20 | 100 |
| Cr | 50 | 61 | 13 | 29 | 829 | 2149 | 505 | 247 | 22 |
| Nb | 17 | 15 | 7 | 5 | 4 | 7 | 5 | 3 | 6 |
| Ni | 48 | 51 | 16 | 20 | 195 | 800 | 198 | 372 | 66 |
| Rb | 27 | 24 | 24 | 15 | 11 | 44 | 4 | <2 | <2 |
| Sr | 434 | 426 | 208 | 214 | 85 | 141 | 145 | 130 | 152 |
| V | 362 | 364 | 459 | 413 | 224 | 227 | 202 | 103 | 236 |
| Y | 57 | 51 | 98 | 71 | 22 | 29 | 15 | 10 | 19 |
| Zn | 114 | 106 | 137 | 126 | 76 | 96 | 64 | 63 | 102 |
| Zr | 138 | 128 | 162 | 145 | 65 | 114 | 76 | 28 | 89 |

Total iron as $Fe_2O_3$.

Notes: FGPG=fine-grained garnet two pyroxene gneiss, BHPG=brown hornblende two pyroxene gneiss, GPG=garnet-bearing two pyroxene gneiss, PG=two pyroxenen gneiss, BPG=biotite-bearing two pyroxene gneiss, HPL=hornblende-bearing lherzolitic peridotite, WP=websteritic peridotite, PX=pyroxenite

*Table 1 (continued).*

| | Metamorphosed mafic rock | | | Metamorphosed ultramafic rock | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample | C98020902F | C98013002F | C98022203B | C98020301E | C98012802 | A90021603C | C98013103B | C98013002A |
| Occurrence | layer | layer | layer | lens | discordant layer | lens | lens | block |
| Rock Type | PG | BPG | GPG | HLP | HLP | WP | WP | PX |
| Unit | Unit III | Unit IV | Unit V | Unit I | Unit II | Unit I | Unit II | Unit IV |
| $SiO_2$ (wt%) | 52.70 | 45.07 | 58.03 | 46.83 | 43.95 | 53.30 | 42.33 | 42.04 |
| $TiO_2$ | 0.75 | 0.98 | 0.72 | 0.71 | 0.51 | 0.33 | 0.37 | 0.77 |
| $Al_2O_3$ | 14.56 | 15.09 | 14.82 | 4.49 | 4.30 | 3.49 | 10.58 | 13.86 |
| $Fe_2O_3$ | 12.29 | 15.27 | 12.37 | 15.66 | 15.14 | 12.24 | 15.16 | 19.25 |
| MnO | 0.17 | 0.23 | 0.12 | 0.19 | 0.20 | 0.21 | 0.20 | 0.19 |
| MgO | 8.55 | 11.87 | 4.36 | 26.20 | 31.05 | 23.71 | 23.22 | 15.99 |
| CaO | 7.42 | 9.51 | 5.69 | 5.33 | 4.97 | 6.84 | 6.19 | 6.60 |
| $Na_2O$ | 3.05 | 0.53 | 2.94 | 0.24 | 0.36 | 0.32 | 0.51 | 0.60 |
| $K_2O$ | 0.53 | 1.38 | 0.71 | 0.43 | 0.06 | 0.00 | 0.17 | 0.31 |
| $P_2O_5$ | 0.07 | 0.06 | 0.07 | 0.05 | 0.02 | 0.04 | 0.03 | 0.05 |
| Total | 100.09 | 99.96 | 99.81 | 100.13 | 100.56 | 100.48 | 98.76 | 99.66 |
| | | | | | | | | |
| Ba (ppm) | 190 | 170 | 200 | <20 | 40 | 40 | 60 | 40 |
| Cr | 432 | 149 | 108 | 1695 | 2142 | 5408 | 1139 | 137 |
| Nb | 10 | 6 | 12 | 7 | 3 | <2 | 3 | 6 |
| Ni | 47 | 97 | 48 | 1621 | 1786 | 738 | 1147 | 115 |
| Rb | <2 | 26 | 10 | 3 | 6 | <2 | <2 | 3 |
| Sr | 126 | 66 | 147 | 16 | 36 | 18 | 20 | 21 |
| V | 217 | 283 | 189 | 221 | 199 | 105 | 149 | 322 |
| Y | 34 | 23 | 15 | 29 | 19 | 13 | 15 | 36 |
| Zn | 111 | 84 | 92 | 631 | 87 | 151 | 146 | 174 |
| Zr | 84 | 35 | 41 | 102 | 55 | 38 | 32 | 46 |

*Table 2. Rare earth element compositions for the mafic gneiss and the metamorphosed ultramafic rocks.*

| Sample | C98013103A | C98013103B | C98020301E | C98012802 |
|---|---|---|---|---|
| Occurrence | layer | lens | lens | discordant layer |
| Rock Type | BHPG | WP | HLP | HLP |
| Unit | Unit II | Unit II | Unit I | Unit II |
| La (ppm) | 2.95 | 1.72 | 9.98 | 5.35 |
| Ce | 6.44 | 5.16 | 22.73 | 13.74 |
| Pr | 0.81 | 0.78 | 2.75 | 1.78 |
| Nd | 4.10 | 4.35 | 13.16 | 8.88 |
| Sm | 1.20 | 1.30 | 3.05 | 2.22 |
| Eu | 0.52 | 0.42 | 0.65 | 0.67 |
| Gd | 1.44 | 1.57 | 3.03 | 2.32 |
| Tb | 0.27 | 0.32 | 0.51 | 0.39 |
| Dy | 1.60 | 1.88 | 2.77 | 2.13 |
| Ho | 0.34 | 0.41 | 0.52 | 0.41 |
| Er | 0.91 | 1.16 | 1.40 | 1.06 |
| Tm | 0.14 | 0.19 | 0.21 | 0.16 |
| Yb | 0.95 | 1.32 | 1.33 | 0.99 |
| Lu | 0.15 | 0.22 | 0.20 | 0.15 |

Abbreviations of rock type are the same as in Table 1.

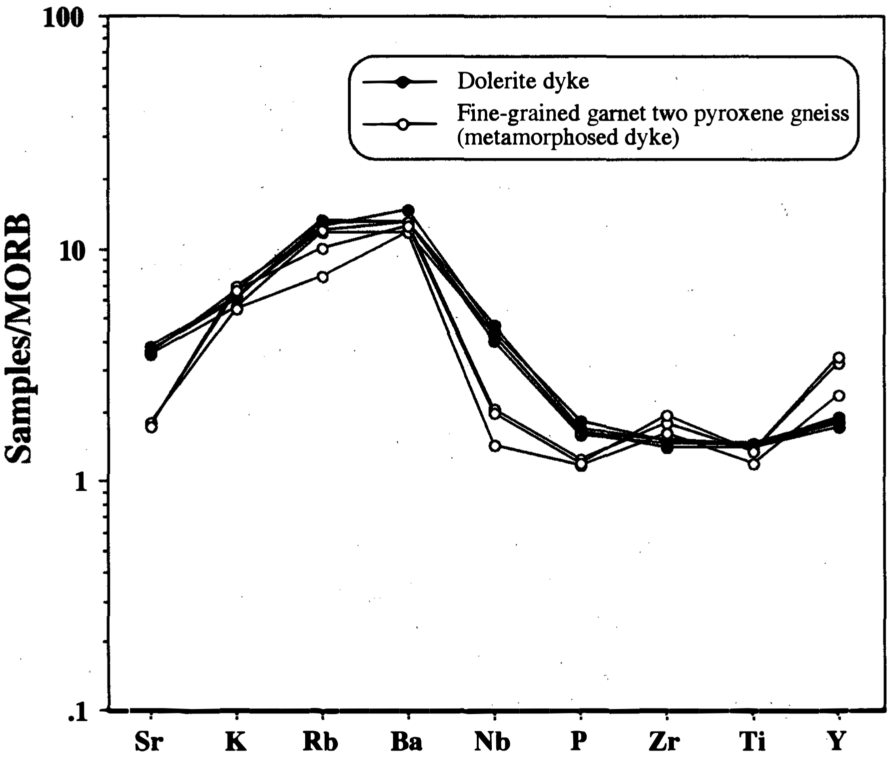


*Fig. 8. MORB normalized trace elements pattern for the dolerite dyke and the fine-grained garnet two pyroxene gneiss (metamorphosed mafic dyke).*

The $SiO_2$ contents of mafic gneisses and the metamorphosed ultramafic rocks range from 42 to 55 wt%. Some of these rocks are characterized by high MgO (up to 31 wt%), Cr (up to 5400 ppm) and Ni (up to 1800 ppm) contents. Figure 9 shows plots of atomic ($Fe_{total}$+Ti) - Al - Mg for the mafic gneisses and metamorphosed ultramafic rocks, showing calc-alkaline, tholeiitic and komatiitic fields after JENSEN (1976). These rocks plot within the range from komatiitic to tholeiitic fields.

Chondrite normalized REE patterns for the mafic gneiss and the metamorphosed ultramafic rocks are shown in Fig. 10. Samples C98013103A and C98013103B collected from Unit II are brown hornblende two pyroxene gneiss as the thick mafic layer and the websteritic peridotite, respectively. Other two samples are hornblende-bearing lherzolitic peridotite (Fig. 1). Samples C98012802 and C98020301E are considered to be intrusive rocks from geological evidence (Fig. 5). These four samples contain hornblende, and show a similar REE pattern such as light REE enrichment (Fig. 10). Differences of light

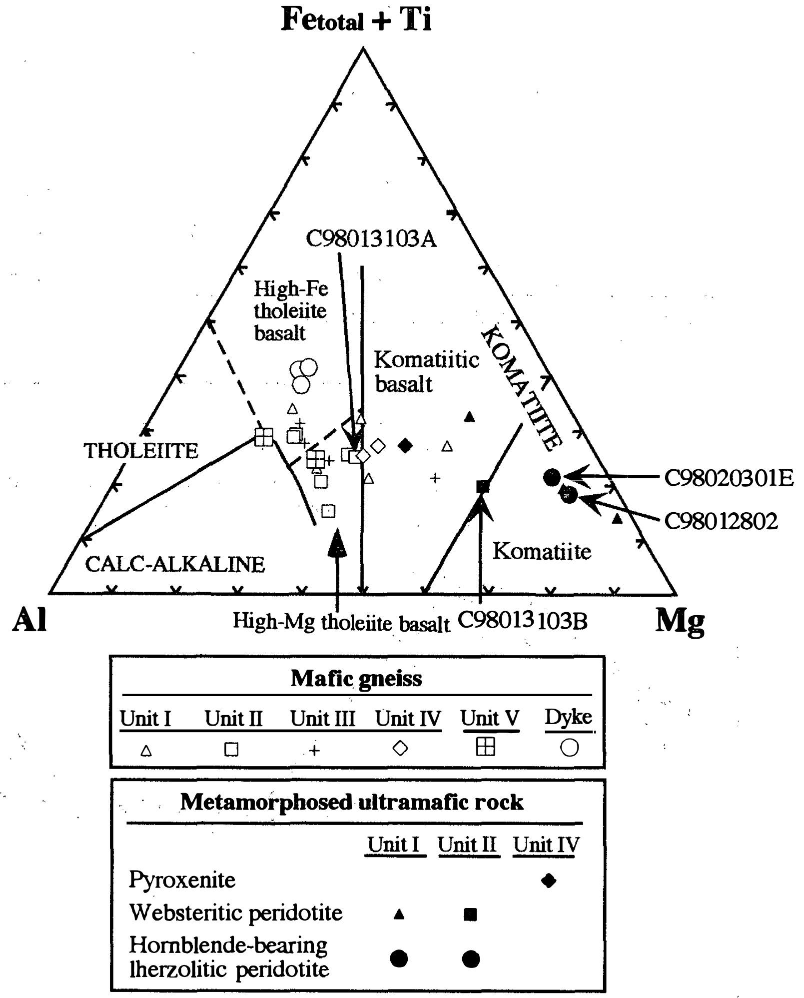


*Fig. 9. ($Fe_{total}$+Ti) - Al - Mg diagram (JENSEN, 1976) for the mafic gneisses and the metamorphosed ultramafic rocks from Tonagh Island. Some mafic gneisses and metamorphosed ultramafic rocks are plotted within the komatiitic field. Rare earth element analysis is carried out on the samples (C98012802, C98013103A, C980123103B and C98020301E).*

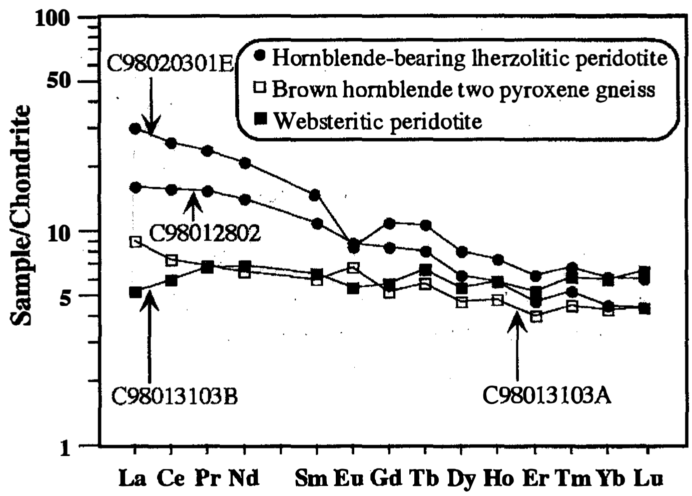


*Fig. 10. Chondrite normalized REE pattern for the mafic gneiss and the metamorphosed ultramafic rocks from Tonagh Island. Sample numbers are also marked. Shaded field indicates compositional range of komatiitic rocks from the Barberton greenstone belt (SUN and NESBITT, 1978 and JAHN et al., 1982).*

REE enrichment may reflect the modal abundance of apatite. Indeed, samples C98012802 and C98020301E contain euhedral and subhedral apatite (*e.g.* Fig. 6c), whereas two other samples contain rare apatite under the microscope. These REE patterns are plotted within the field of the komatiitic rocks from the Barberton greenstone belt, South Africa (Fig. 10).

## 7. Discussion and Conclusions

ISHIZUKA *et al.* (1998) and OSANAI *et al.* (1999) noted that the mafic gneiss layers are locally oblique against the layers or foliation of the neighboring garnet felsic gneiss. Moreover, the mafic gneiss grain size is observed to gradually change from fine-grained near the contact with the garnet felsic gneiss to coarse-grained in the center of the layer (ISHIZUKA *et al.*, 1998). They interpreted this to mean that some mafic gneiss was originally intrusive rock. As already described, precursors of hornblende-bearing lherzolitic peridotites are considered to be intrusive rocks. In this peridotite, hornblende occurs as poikilitic inclusions in olivine (Fig. 6d). Moreover, subhedral apatite is included in olivine (Fig. 6c). These textures imply that the peridotite had crystallized from melt, and may still remain in igneous phases such as apatite and probably hornblende.

Ultramafic cumulate and gabbro of komatiitic and other high-MgO units in Precambrian greenstone belts contain minor to major amounts of igneous amphibole (STONE *et al.*, 1997). One of the critical characters of the igneous amphibole is that it occurs as part of mineral inclusions within olivine (STONE *et al.*, 1997). This texture is very similar to that of the hornblende-bearing lherzolitic peridotite from Tonagh Island (Fig. 6d). Chemical compositions for some mafic gneisses and the metamorphosed ultramafic rocks from Tonagh Island are plotted within the field of komatiitic compositions (Fig. 9). Geochemical features such as light REE enrichment of rocks from Tonagh Island (Fig. 10) resemble those of komatiite as Barberton greenstone belt, South Africa

(SUN and NESBITT, 1978; JAHN *et al.*, 1982). Hence, the above described petrographical and geochemical features for the rocks from Tonagh Island imply that some original rocks had similar petrologic character to komatiitic rocks from the Archaean greenstone belt.

## Acknowledgments

We are grateful to Profs. M. ARIMA and H. ISHIZUKA for critical reading and useful comments. We would like to express our sincere thanks to all members of JARE-39, led by Profs. K. SHIBUYA and K. MORIWAKI. Thanks also go to all crew members of the SHIRASE for their help during construction of base camp.

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*(Received April 20, 1999; Revised manuscript accepted June 7, 1999)*