JAPANESE ANTARCTIC RESEARCH EXPEDITION

ANTARCTIC GEOLOGICAL MAP SERIES
SHEET 36 ONGUL ISLANDS

Explanatory Text of Geological Map
of
Ongul Islands, Lützow-Holm Bay, Antarctica

Masahiro ISHIKAWA, Kazuyuki SHIRAISHI, Yoichi MOTOYOSHI
Noriyoshi TSUCHIYA, Toshiaki SHIMURA and Keizo YANAI

NATIONAL INSTITUTE OF POLAR RESEARCH

TOKYO, MARCH 1994

Explanatory Text of Geological Map of Ongul Islands, Lützow-Holm Bay, Antarctica

Masahiro ISHIKAWA[1], Kazuyuki SHIRAISHI[2], Yoichi MOTOYOSHI[2], Noriyoshi TSUCHIYA[3], Toshiaki SHIMURA[4] and Keizo YANAI[2]

1. Introduction

The Ongul Islands (69°01'S, 39°32'E), which include East Ongul Island, West Ongul Island, Ongulkalven, Teöya and neighboring islands, lie approximately 5 km west of the eastern coastline of Lützow-Holm Bay in Queen Maud Land, East Antarctica. The main base of the Japanese Antarctic Research Expedition (JARE), Syowa Station (69°00'22"S, 39°35'24"E), is located on the northern coast of East Ongul Island (Fig. 1). The Lützow-Holm Bay coastline was first discovered from the air and photographed by Lars Christensen of a Norwegian expedition in 1937. Part of Lützow-Holm Bay was again photographed by the U.S. Navy plane during the High Jump Operation in 1947. In 1956, the Ongul Islands were landed on for the first time by members of JARE. A preliminary geological survey and investigation of the Ongul Islands were carried out by members of the first wintering party of JARE-1 in 1956-1958 (TATSUMI *et al.*, 1957a, b; TATSUMI and KIKUCHI, 1959a, b). Geology and petrography of East Ongul Island were studied in detail by JARE-4 in 1960-1961 (KIZAKI, 1962, 1964). After a more detailed investigation of the Ongul Islands by JARE-9 (YANAI *et al.*, 1974a, b, 1975a, b), JARE parties have been carrying out supplementary geological surveys of the Ongul Islands.

This new edition of the Antarctic Geological Map Series, Sheet 36 "Ongul Islands" (1:10,000) was compiled on the basis of unpublished field data by JAREs in addition to the previously issued Sheet 1, "East Ongul Island" (1:5,000) (YANAI *et al.*, 1974a), Sheet 2, "West Ongul Island" (1:5,000) (YANAI *et al.*, 1974b), Sheet 4, "Ongulkalven Island"

1) Institute of Geology and Paleontology, Faculty of Science, Tohoku University, Aramaki, Aoba-ku, Sendai 980-77.

2) National Institute of Polar Research, 9-10, Kaga 1-chome, Itabashi-ku, Tokyo 173.

3) Department of Resources Engineering, Faculty of Engineering, Tohoku University, Aramaki, Aoba-ku, Sendai 980-77.

4) Graduate School of Science and Technology, Niigata University, 2-8050, Ikarashi, Niigata 950-21.

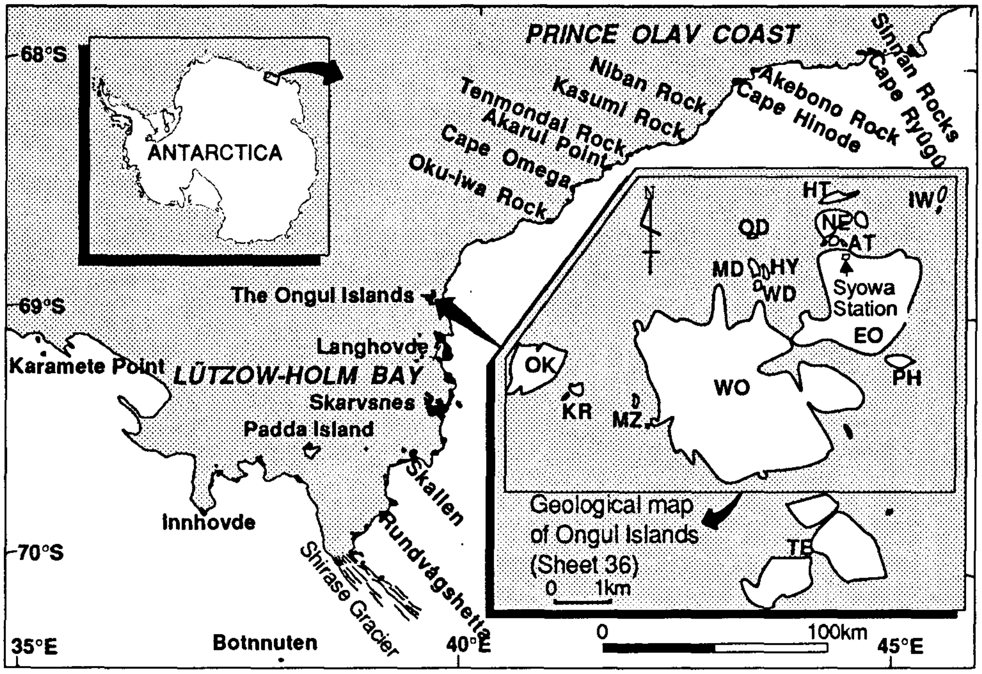


Fig. 1. Location map of the Ongul Islands. AT : Antenna Island, EO : East Ongul Island, HT : Hatusima Island, HY : Hiyoko Island, IW : Iwa-zima Island, KR : Kurumi Island, MD : Mendori Island, MZ : Mame-zima Island, NE : Nesöya, OK : Ongulkalven, OD : Ondori Island, PH : Pollholmen, TE : Teöya, WO : West Ongul Island.

(1:5,000) (YANAI *et al.*, 1975b) and recent field and laboratory works listed at the end of the text.

2. General Geology

The terrain of the Lützow-Holm Bay region is a part of the Lützow-Holm Complex (LHC) which has been well characterized geologically and petrologically (YOSHIDA 1978; HIROI *et al.*, 1983, 1986, 1987, 1991; MOTOYOSHI, 1986; MOTOYOSHI *et al.*, 1989; SHIRAISHI *et al.*, 1987; KAWASAKI *et al.*, 1993). The LHC is bounded to the east by the Late Proterozoic Rayner Complex and to the west by the Yamato-Belgica Complex (SHIRAISHI *et al.*, 1987). The LHC contains a diversity of rock types, including calcareous, pelitic, quartzo-feldspathic, intermediate, basic and ultrabasic rocks. The metamorphic grade increases from the upper amphibolite-facies in the east, to granulite-facies in the southwest (at the outlet of the Shirase Glacier), and then decreases further westward. Migmatization is widespread in the upper amphibolite-facies to the transitional zone between the upper amphibolite- and granulite-facies zones. The peak metamorphic conditions at the highest granulite-facies zone are estimated to be 800-850 °C, 7-8 kbar (MOTOYOSHI *et al.*, 1989; HIROI *et al.*, 1991). A prograde metamorphic evolution from the kyanite to the sillimanite stability fields is constrained by inclusions such as kyanite and staurolite (HIROI *et al.*, 1983; MOTOYOSHI, 1986), and a succeeding decompression (clockwise *P-T* path) is deduced by the well-preserved reaction textures of minerals in various rock types (HIROI *et al.*, 1986; KAWASAKI *et al.*, 1993). The metamorphic rocks in LHC show evidence of 521-550 Ma granulite-facies metamorphism (SHIRAISHI *et al.*, 1994). The contrasting geological and petrological features as well as the published isotopic ages were previously used to imply that the LHC and YBC represented paired metamorphic complexes reflecting the result of a continent-continent collision (SHIRAISHI *et al.*, 1987; HIROI *et al.*, 1991).

The Ongul Islands are part of granulite-facies terrain, where orthopyroxene commonly occurs in ordinary basic to intermediate compositions (BANNO *et al.*, 1964a, b; KIZAKI, 1964; SUWA, 1968; YOSHIDA, 1978, 1979a, b; YOSHIDA *et al.*, 1982; SUZUKI, 1982, 1983, 1986; HIROI *et al.*, 1983, 1986, 1987; MOTOYOSHI, 1986; SHIRAISHI *et al.*, 1992b), in the LHC, and they are underlain by various kinds of metamorphic rocks and minor pegmatites. Pyroxene gneiss is a common lithology in the mapped area. Garnet gneiss dominantly occurs in the eastern area (East Ongul Island and Nesöya), whereas the garnet-biotite gneisses, augen gneiss and some granitic gneisses occur dominantly in the western area (West Ongul Island and Ongulkalven). Most rock types have been affected by a number of deformation events (folding, boudinization, shear and fault zone formation, and emplacement of pegmatite).

3. Metamorphic Rocks

Metamorphic rocks are classified into the following rock types for mapping units, based on the modes of occurrence and lithology:

1) Pyroxene gneiss (Gp)
2) Hornblende gneiss (Gh)
3) Garnet-biotite gneisses
    a) Garnet-biotite gneiss (Ggb)
    b) Augen gneiss (Ga)
    c) Garnet-bearing granitic gneiss (Ggg)
4) Garnet gneiss (Gg)
5) Calc-silicate rock (Cs)
6) Marble (M)
7) Metabasites (Mb)
    a) Pyroxenite
    b) Hornblendite

c) Amphibolite
d) Hornblende-peridotite
e) Garnet clinopyroxenite
f) Garnet hornblendite
g) Garnet-orthopyroxene amphibolite (Am)

8) Microcline gneissose granite (Grm)
9) Hornblende-biotite gneissose granite (Grh)

Chemical compositions of the representative rock types are listed in Table 1.

3.1. Pyroxene gneiss (Gp)

Pyroxene gneiss is the dominant rock type of intermediate compositions over the Ongul Islands. It occurs widely as massive layers with partially developed compositional layering in the eastern part of East Ongul Island and in West Ongul Island; however, it also occurs as thin layers intercalating with hornblende gneiss in the western part of East Ongul Island. The gneiss is generally medium-grained and granoblastic (Plate 3A), but locally it is well-foliated and contains elongated hornblende and aggregates of pyroxenes. The main constituents are feldspars (50-70%*), quartz (20-30%), clinopyroxene (0-10%), orthopyroxene (10-30%) and hornblende (<10%). Typical mineral assemblages are:

(1) clinopyroxene + orthopyroxene + hornblende + biotite + plagioclase + quartz,
(2) orthopyroxene + hornblende + biotite + plagioclase + K-feldspar + quartz.

Orthopyroxene weakly shows pink to green pleochroism. Tiny garnet occasionally occurs as inclusions within plagioclase of mineral assemblage (2). Accessory minerals are magnetite, apatite and zircon. Muscovite, calcite and chlorite locally occur as retrograde products. Several pyrrhotite veins are found in the pyroxene gneiss at the southeastern coast of East Ongul Island (KIZAKI, 1964; SHIBUYA and KIZAKI, 1967b). Representative microprobe analyses of minerals in the pyroxene gneiss of assemblage (2) are given in HIROI and ONUKI (1985).

3.2. Hornblende gneiss (Gh)

Hornblende gneiss is intermediate in composition. Major constituents are hornblende (10-30%), biotite (*c.* 10%), feldspars (50-70%) and quartz (20-30%). The hornblende gneiss is abundant in the western part of East Ongul Island and in the eastern part of West Ongul Island, and occurs as thin layers intercalating with pyroxene gneiss or metabasites in places. On the other hand, pyroxene gneiss adjacent to pegmatite has been converted into the hornblende gneiss and biotite schist on a scale of several tens of centimeters (KIZAKI,

* % with parenthesis after mineral names means the approximate modal proportion in most samples.

Table 1. Chemical analyses of metamorphic rocks from the Ongul Islands.

Sp. No.	6803 2402	6803 2310	6803 0103	8101 2804A	6802 2607	8101 2804B	6802 1514	6803 2313	6809 0706	6802 2002	8101 2804C
SiO_2	63.56	61.85	54.26	61.61	65.32	64.97	68.83	68.68	48.34	76.11	64.41
TiO_2	1.79	0.97	1.84	0.92	0.73	1.02	0.86	0.60	1.92	0.30	1.13
Al_2O_3	14.64	15.43	17.44	16.34	14.46	15.48	13.18	14.74	20.91	13.01	17.12
Fe_2O_3	0.58	1.22	1.74	1.41	2.16	1.33	2.26	0.75	0.63	0.67	1.10
FeO	6.46	5.45	7.33	3.71	3.16	3.60	4.52	3.46	10.34	0.87	3.25
MnO	0.13	0.08	0.14	0.14	0.06	0.12	0.12	0.06	0.21	tr	0.12
MgO	0.95	3.10	2.74	2.48	1.62	1.93	0.49	1.27	4.71	0.55	2.57
CaO	3.17	4.90	5.76	4.90	3.31	4.35	3.61	2.31	4.96	3.12	3.34
Na_2O	3.48	3.15	4.38	3.62	3.24	4.12	1.46	3.28	3.47	3.27	4.16
K_2O	3.94	2.60	2.61	3.93	4.20	2.45	3.89	4.52	2.97	1.36	2.29
$H_2O(+)$	0.88	0.91	1.09	0.47	1.19	0.41	0.75	0.43	0.97	0.26	0.40
$H_2O(-)$	0.14	0.24	0.12	0.04	0.12	0.03	0.12	0.10	0.16	0.12	0.03
P_2O_5	0.07	0.08	0.05	0.22	0.07	0.16	0.12	0.07	0.07	0.02	0.15
Total	99.79	99.89	99.50	99.79	99.64	99.97	100.21	100.27	99.66	99.96	100.07

Sample No. (locality)	Rock name	
68032402 (West Ongul Island)	pyroxene gneiss (Gp)	(YANAI *et al.*, 1974b)
68032310 (Mame-zima Island)	pyroxene gneiss (Gp)	(YANAI *et al.*, 1974b)
68030103 (West Ongul Island)	pyroxene gneiss (Gp)	(YANAI *et al.*, 1974b)
81012804A (West Ongul Island)	pyroxene gneiss (Gp)	(HIROI and ONUKI, 1985)
68022607 (West Ongul Island)	hornblende gneiss (Gh)	(YANAI *et al.*, 1974b)
81012804B (West Ongul Island)	"local" hornblende gneiss (Gh)	(HIROI and ONUKI, 1985)
68021514 (West Ongul Island)	garnet gneiss (Gg)	(YANAI *et al.*, 1974b)
68032313 (Mame-zima Island)	garnet-biotite gneiss (Ggb)	(YANAI *et al.*, 1974b)
68090706 (Kurumi Island)	garnet-biotite gneiss (Ggb)	(YANAI *et al.*, 1975)
68022002 (West Ongul Island)	garnet-bearing granitic gneiss (Ggg)	(YANAI *et al.*, 1974b)
81012804C (West Ongul Island)	biotite schist	(HIROI and ONUKI, 1985)

1964; HIROI and ONUKI, 1985). HIROI and ONUKI (1985) defined the former as "regional" hornblende gneiss, and the latter as "local" hornblende gneiss. Regional hornblende gneiss is a weakly foliated, medium-grained rock with granoblastic texture. The layering structure, composed of melanocratic (biotite- and hornblende-rich) and leucocratic(K-feldspar, plagioclase and quartz-rich) layers (several mm in thickness), is characteristic (Plate 2A). Hornblende shows mineral lineation, and it is generally parallel to compositional layering and fold axes of dominant isoclinal folds (F_n). Mineral assemblages of the regional hornblende gneisses are as follows;

(1) hornblende + biotite + plagioclase + K-feldspar + quartz,

(2) hornblende + biotite + scapolite + plagioclase + K-feldspar + quartz,

(3) clinopyroxene + hornblende + biotite + plagioclase + K-feldspar + quartz.

The mineral assemblages (1) and (2) are widespread. The clinopyroxene-bearing rock occurs in the western part Lake Ô-ike of West Ongul Island. Retrograde muscovite, calcite and

Table 1. (continued)

Sp. No.	6809 1201-2	8401 0309A	6803 2704	6803 2304	6803 2701	6803 2702	6803 2703	8102 0109B	8401 0504	6803 2303
SiO_2	44.49	42.12	53.20	52.41	51.53	50.44	44.49	53.41	46.34	44.20
TiO_2	0.24	0.12	0.22	0.25	0.08	0.52	1.19	0.26	2.18	0.42
Al_2O_3	13.69	15.79	2.70	0.76	4.48	18.00	12.26	0.77	4.37	15.38
Fe_2O_3	1.19	5.79	1.03	1.12	1.29	0.11	1.94	2.37	3.91	4.53
FeO	11.36	5.50	8.74	22.14	18.80	9.64	5.65	7.60	13.73	15.48
MnO	0.14	0.15	0.28	0.24	0.22	0.15	0.16	0.14	0.27	0.48
MgO	14.17	20.82	24.16	22.10	22.35	8.20	11.82	15.71	12.83	8.65
CaO	9.38	6.82	6.78	0.18	1.27	8.00	17.31	17.83	12.62	6.96
Na_2O	1.87	1.37	0.33	0.53	0.34	2.68	1.42	0.87	0.94	1.93
K_2O	1.25	0.88	0.34	0.13	0.08	0.45	0.99	0.06	0.61	0.30
$H_2O(+)$	1.85	0.60	2.03	tr	tr	0.88	1.54	0.47	1.49	1.27
$H_2O(-)$	0.16	0.02	0.10	0.19	0.06	0.21	0.45	0.19	0.28	0.20
P_2O_5	0.11	----	0.12	0.07	0.05	0.14	0.03	tr	0.42	0.09
Total	99.90	99.98	100.03	100.12	100.55	99.42	99.25	99.68	99.99	99.89

Sample No. (locality)	Rock name	
68091201-2 (Antenna Island)	hornblendite (Mb)	(YANAI *et al.*, 1974a)
84010309A (West Ongul Island)	spinel-orthopyroxene hornblendite (Am)	(HIROI *et al.*, 1986)
68032704 (East Ongul Island)	pyroxenite (Mb)	(YANAI *et al.*, 1974a)
68032304 (East Ongul Island)	pyroxenite (Mb)	(YANAI *et al.*, 1974a)
68032701 (East Ongul Island)	orthopyroxenite (Mb)	(YANAI *et al.*, 1974a)
68032702 (East Ongul Island)	pyroxenite (Mb)	(YANAI *et al.*, 1974a)
68032703 (East Ongul Island)	pyroxenite (Mb)	(YANAI *et al.*, 1974a)
81020109B (Ongul Island)	pyroxenite (Mb)	(HIROI *et al.*, 1986)
84010504 (West Ongul Island)	pyroxenite (Mb)	(HIROI *et al.*, 1986)
68032303 (East Ongul Island)	garnet hornblendite (Mb)	(YANAI *et al.*, 1974a)

chlorite are included in addition to the mineral assemblages listed above. Both hornblende and biotite in the regional hornblende gneiss are rich in Ti (TiO_2 = 2.02 wt% in hornblende, and 5.03 wt% in biotite) and F (F = 0.38 wt% in hornblende, and 0.72 wt% in biotite), respectively (KANISAWA *et al.*, 1979). The regional hornblende gneiss of the mineral assemblage (1) and (2) has higher rock oxidation ratios and MgO/(MgO + FeO) ratios than pyroxene gneiss and local hornblende gneiss (HIROI and ONUKI, 1985). This is in harmony with the difference in oxide mineral assemblages. Representative microprobe analyses of minerals both in the regional hornblende gneiss and the local hornblende gneiss are given in HIROI and ONUKI (1985). Microprobe analyses show that the regional hornblende gneiss occured under lower granulite-facies conditions, and that the difference in mineralogy between pyroxene gneiss and local hornblende gneiss may be shown by an isochemical reaction (HIROI and ONUKI, 1985).

3.3. Garnet-biotite gneisses

Table 1. (continued)

Sp. No.	68091 201-1	6802 1509	6801 2101	8312 2708	6802 2405	6804 0105	8401 0405	8401 0503	8101 08I-11	6802 2014	8101 2804D
SiO_2	40.14	40.15	48.66	48.33	33.85	44.20	44.37	46.81	46.88	72.40	69.94
TiO_2	0.56	0.78	0.17	0.61	4.76	0.59	0.08	0.19	0.29	0.16	0.86
Al_2O_3	20.79	16.85	23.57	14.69	20.11	26.26	26.96	9.49	2.82	14.45	15.02
Fe_2O_3	0.46	1.35	1.37	1.34	3.22	0.77	1.23	5.75	1.53	0.98	0.65
FeO	19.42	17.06	4.44	7.23	13.08	6.58	3.87	13.49	7.78	1.10	1.73
MnO	0.49	0.31	0.06	0.17	0.31	0.09	0.07	0.27	0.19	0.02	0.06
MgO	10.82	9.65	4.49	9.65	5.24	6.02	6.69	16.78	22.79	0.31	0.21
CaO	6.00	9.34	9.56	12.15	13.44	11.19	13.71	5.06	13.20	1.14	0.98
Na_2O	0.56	1.48	3.88	2.71	1.20	2.47	1.64	0.46	0.72	3.24	2.72
K2O	0.24	0.87	1.53	1.28	1.75	0.63	0.31	0.62	0.57	5.75	7.46
$H_2O(+)$	0.34	1.85	2.18	1.58	2.41	0.89	0.86	1.03	3.17	0.63	0.39
$H_2O(-)$	0.11	0.12	0.21	0.14	0.21	0.08	0.20	0.04	0.04	0.10	0.02
P_2O_5	0.11	0.14	0.14	0.12	0.21	0.17	----	----	0.01	0.06	0.10
Total	100.04	99.95	100.26	100.00	99.79	99.94	99.99	99.99	99.99	100.33	100.14

Sample No. (locality)	Rock name	
68091201-1 (Antenna Island)	garnet hornblendite (Mb)	(YANAI *et al.*, 1974a)
68021509 (West Ongul Island)	garnet clinopyroxenite (Mb)	(YANAI *et al.*, 1974b)
68012101 (East Ongul Island)	amphibolite (Mb)	(YANAI *et al.*, 1974a)
83122708 (East Ongul Island)	amphibolite (Mb)	(KANISAWA *et al.*, 1987)
68022405 (West Ongul Island)	garnet amphibolite	(YANAI *et al.*, 1974b)
68040105 (Wakadori Island)	garnet-orthopyroxene amphibolite (Am)	(YANAI *et al.*, 1974b)
84010405 (West Ongul Island)	garnet-orthopyroxene amphibolite (Am)	(HIROI *et al.*, 1986)
84010503 (West Ongul Island)	garnet-orthopyroxene amphibolite (Am)	(HIROI *et al.*, 1986)
8101081-11 (East Ongul Island)	hornblende peridotite (Mb)	(HIROI *et al.*, 1986)
68022014 (West Ongul Island)	microcline gneissose granite (Grm)	(YANAI *et al.*, 1974b)
81012804D (West Ongul Island)	microcline pegmatite	(HIROI and ONUKI, 1985)

On the basis of the modal proportion of mafic minerals such as garnet and biotite, and their textures, garnet-biotite gneisses which are mainly composed of garnet, biotite, plagioclase, K-feldspar and quartz, are subdivided into three rock types for mapping units, (a) garnet-biotite gneiss, (b) augen gneiss, (c) garnet-bearing granitic gneiss.

3.3.1. Garnet-biotite gneiss (Ggb)

Garnet-biotite gneiss (Ggb) in a narrow sense is a leucocratic, well foliated, fine- to medium-grained rock of pelitic to semi-pelitic composition, which contains a considerable amount of garnet (>10%) and biotite (>10%). The typical garnet-biotite gneiss (Ggb) is characterized by more abundant garnet and biotite compared to augen gneiss (Ga) and garnet-bearing granitic gneiss (Ggg). It occupies the central part of West Ongul Island and most of the area of Ongulkalven. It is commonly intercalated with augen gneiss and pyroxene gneiss, and also occurs as thin layers (about 1 cm in thickness) intercalated with garnet gneiss in East Ongul Island. The garnet-biotite gneiss exhibits compositional banded textures composed of melanocratic and leucocratic bands, which are parallel to lithological boundaries (Plate 2B). In addition, aligned biotite grains define strong foliations parallel to compositional banded structures except at the hinge of isoclinal folds where biotite grains exhibit axial planar foliations. Orthopyroxene-bearing rock was found from the southeastern area of West Ongul Island.

3.3.2. Augen gneiss (Ga)

Augen gneiss, a member of the garnet-biotite gneisses, is a well foliated, pink-colored, coarse-grained quartz (10-30%)-K-feldspar (>50%)-plagioclase (5-20%) rock with subordinate amounts of garnet (<10%) and biotite (*c.* 10%). It is equivalent to "porphyroblastic gneiss" defined by YANAI *et al.* (1974b). The augen gneiss occurs widely in the central part of West Ongul Island, and locally in the western area of West Ongul Island and the eastern area of Ongulkalven. Coarse-grained K-feldspar (up to 4 cm in size) is characteristic of augen gneiss (Plate 2C). Quartz and K-feldspar show mineral lineations. Biotite generally exhibits foliation.

3.3.3. Garnet-bearing granitic gneiss (Ggg)

Garnet-bearing granitic gneiss, a member of the garnet-biotite gneisses, is a reddish to pink-colored, medium-grained quartz (15-40%)-K-feldspar (10-40%)-plagioclase (10-40%) gneiss with minor amounts of biotite (5-15%) and garnet (<5%). It is distributed as concordant sheets (from ten to several tens of meters in thickness and up to several hundreds of meters in length) in West Ongul Island and Ongulkalven.

3.4. Garnet gneiss (Gg)

Garnet gneiss is white- to gray-colored, massive, medium-grained rock. It is abundant in the eastern half of East Ongul Island, central part of Nesöya, and the western half of Pollholmem. It is also intercalated with pyroxene gneiss in western part of East Ongul Island and near Lake Ô-ike of West Ongul Island. The garnet gneiss exhibits granoblastic texture, and the gneissose structure is not clear in hand specimens (Plate 2D). The main mineral constituents are:

(1) garnet + plagioclase + K-feldspar + quartz,

(2) garnet + clinopyroxene + plagioclase + K-feldspar + quartz.

The mineral assemblage (1) is common in the Ongul Islands. The melanocratic garnet-biotite gneiss occurs as thin layers (1 cm in thickness) within the garnet gneisses. The Fe-rich clinopyroxene (ferroaugite) is found in the garnet gneiss of assemblage (2) near Syowa Station on East Ongul Island (MOTOYOSHI, 1986). KIZAKI (1964) first described molybdenite impregnation in garnet gneiss from Nesöya Island. However, MATSUEDA *et al.* (1983) re-examined it and found it to be a graphite. The graphite impregnation occurs in the garnet gneiss in many places in the Ongul Islands.

3.5. Calc-silicate rock (Cs)

Calc-silicate rock, which was called a feldspathic band by KIZAKI (1964) and YANAI *et al.* (1974a), is a white-colored, massive, medium- to coarse-grained rock, showing granoblastic texture. The calc-silicate rock occurs as layers of approximately a few meters in thickness at the eastern part of East Ongul Island. A typical mineral assemblage is:

1) scapolite + plagioclase ± hornblende ± biotite ± muscovite,

which was described by SUZUKI (1979). The anorthite content of plagioclase and meionite content of scapolite range from 46 to 51 mol%, and from 50 to 52 mol%, respectively (SUZUKI, 1979). The mineral assemblage of the more aluminous part is:

2) corundum + spinel + scapolite + sericite ± biotite + plagioclase.

Corundum, spinel and sericite form pink-colored rounded domains of a few centimeters in diameter (Plate 3B). The scapolite-absent mineral assemblage is:

(3) hornblende ± spinel ± biotite + plagioclase.

This part partially contains garnet which is generally mantled by hornblende and plagioclase (Plate 3C). Spinel + plagioclase occurs as a rounded domain in this part (Plate 3D).

3.6. Marble (M)

Thin layers (10 to 15 cm in thickness) of pure marble have been found along metabasite in the western part of West Ongul Island. Adjacent to the surrounding metabasite, skarn minerals such as clinopyroxene, amphibole, phlogopite, scapolite, calcite and plagioclase occur.

3.7. Metabasites (Mb)

Metabasites are defined as mafic to ultramafic rocks of basic to ultrabasic composition. They occur as thin layers, lenses and blocks and often show thin alternation of some kinds of metabasites. The mineral assemblage is highly variable to lead to a diversity of rock names. Garnet-free ultramafic rocks are classified into pyroxenite and hornblendite depending on the modal proportion of pyroxene and hornblende. Relatively plagioclase-rich, garnet-free mafic rock is termed amphibolite. Garnet clinopyroxenite and garnet hornblendite are recognized as garnet-bearing ultramafic rocks. Garnet-othopyroxene amphibolite is a relatively plagioclase-rich mafic to ultramafic rock of ultrabasic composition. In particular, olivine-rich metabasite is termed hornblende peridotite.

3.7.1. Pyroxenite

Pyroxenite is characterized by more abundant pyroxene than hornblende in modal proportion and minor amount (commonly <5 %) of plagioclase. It is medium- to coarse-grained rocks exhibiting granoblastic polygonal texture. The garnet-absent mineral assemblage is :

(1) clinopyroxene + orthopyroxene ± hornblende ± biotite ± plagioclase.

Isolated blocks and lenses, up to several meters in diameter, of the pyroxenites are distributed within pyroxene gneiss and hornblende gneiss throughout the Ongul Islands (Plate 4A).

3.7.2. Hornblendite

Hornblendite is a coarse-grained rock characterized by more abundant hornblende than pyroxene in modal proportion), with or without plagioclase (commonly <5 %). The following mineral assemblages are observed in the hornblendite:

(1) clinopyroxene + orthopyroxene + hornblende + biotite + plagioclase,

(2) spinel + orthopyroxene + hornblende + biotite + plagioclase.

The hornblendite of assemblage (1) occurs as boudinaged layers (up to several meters in thickness) within garnet gneiss in Antenna Island and within garnet-biotite gneiss in West Ongul Island. Hornblende typically exhibits strong mineral lineation. The spinel-orthopyroxene hornblendite of assemblage (2) is distributed in the garnet-orthopyroxene amphibolite in the central part of West Ongul Island (Plate 3E). Spinel + orthopyroxene intergrowth is common in the spinel-orthopyroxene hornblendite (HIROI *et al.*, 1986).

3.7.3. Amphibolite

Amphibolite is a mafic rock of basic composition, which is characterized by relatively abundant plagioclase (15-30%), hornblende (40-70%) and pyroxene (5-20%), and lack of garnet. The amphibolite occurs as concordant layers (a few meters in thickness) within the garnet gneiss in East Ongul Island and within the pyroxene gneiss in West Ongul Island, and it locally forms as rounded block (up to several meters in diameter) within the pyroxene gneiss in East Ongul Island. This rock is a medium-grained rock exhibiting gneissose texture and remarkable mineral lineation of hornblende. The main mineral assemblages are:

(1) orthopyroxene + hornblende ± biotite + plagioclase,

(2) clinopyroxene + hornblende ± biotite + plagioclase.

The trace element chemistry of the amphibolite was analyzed by KANISAWA *et al.* (1987).

3.7.4. Hornblende peridotite

Hornblende peridotite is characterized by common olivine (*c.* 30%), clinopyroxene (*c.* 20%), orthopyroxene (*c.* 20%) and hornblende (*c.* 30%), with minor biotite (Plate 3F). A lens-shaped block (several tens of centimeters in diameter) of hornblende peridotite crops out within the pyroxene gneiss in East Ongul Island (HIROI *et al.*, 1986) and Pollholmen (SUZUKI, 1986).

3.7.5. Garnet clinopyroxenite and garnet hornblendite

Garnet clinopyroxenite and garnet hornblendite are ultramafic rocks, characterized by abundant garnet, clinopyroxene and hornblende with or without orthopyroxene and plagioclase (Plate 2E). They are equivalent to the "hornblende eclogite" described by YANAI *et al.* (1974a, b). They occur as concordant lenses and thin layers (up to a few tens of meters in thickness) within garnet gneiss in East Ongul Island, and within the pyroxene gneiss in West Ongul Island. Mineral assemblages are represented by:

(1) garnet + clinopyroxene ± orthopyroxene ± hornblende ± biotite ± plagioclase,

(2) garnet ± clinopyroxene ± orthopyroxene + hornblende ± biotite ± plagioclase.

The modal proportion of clinopyroxene and hornblende is highly variable. Garnet clinopyroxenite grades into garnet hornblendite with increasing modal proportion of hornblende. They exhibit compositional bands composed of garnet-rich bands and clinopyroxene-hornblende-rich bands. Orthopyroxene is partially intergrown with plagioclase around garnet (Plate 3G). The similar intergrowth of orthopyroxene and plagioclase has been reported from Austhovde in the far southwest of this area (HIROI *et al.*, 1986).

3.7.6. Garnet-orthopyroxene amphibolite (Am)

Garnet-orthopyroxene amphibolite is a medium- to coarse-grained, foliated rock of ultrabasic composition. It is characterized by garnet (<10%), orthopyroxene (5-30%) and hornblende (30-80%), and absence of clinopyroxene (Plate 2F). The garnet-orthopyroxene amphibolite occurs as mappable-scale lenses (up to several tens of meters in thickness) within the pyroxene gneiss in the central-northern part of West Ongul Island. The main mineral constituents are:

(1) garnet + orthopyroxene + hornblende ± biotite + plagioclase,

(2) spinel + garnet + orthopyroxene + hornblende + biotite + plagioclase.

Spinel is commonly intergrown with orthopyroxene (Plate 3H), suggesting that these minerals may have been produced during the decompressional stage (HIROI *et al.*, 1986).

3.8. Microcline gneissose granite (Grm)

Microcline gneissose granite is mainly composed of quartz (>20%), microcline (>60%) and minor amounts of plagioclase and biotite (Plate 2G). The granite is reddish to pinkish in color due to abundant microcline, and it is a fine- to medium-grained rock showing strong foliation of elongated quartz. The granite usually occurs as layers in the central-northern part of West Ongul Island. These layers are considered to be of igneous origin because they discordantly cut the pyroxene gneiss and the garnet-orthopyroxene amphibolite.

3.9. Hornblende-biotite gneissose granite (Grh)

The hornblende-biotite gneissose granite is a fine-grained, leucocratic rock consisting of hornblende (*c.* 5%), biotite (*c.* 3%), plagioclase (5-10%), K-feldspar (*c.* 60%) and quartz (*c.* 15%). Subconcordant bodies of the granite are exposed in the central part of West Ongul Island and in East Ongul Island.

4. Pegmatites

Pegmatites are classified into two types: microcline pegmatite and clinopyroxene-hornblende pegmatite.

4.1. Microcline pegmatite

The constituent minerals are biotite, muscovite, plagioclase, microcline, quartz and magnetite with minor apatite, allanite and zircon. The microcline pegmatite occurs as dikes throughout the Ongul Islands. The boundaries between microcline pegmatite and host gneisses are commonly sharp, but locally the hornblende gneiss and biotite schist replacing the pyroxene gneiss are found along the boundary (see Section 3.2). SHIBUYA and KIZAKI (1967a) reported a minor amount of ilmenite in the microcline pegmatite. MATSUMOTO and SAKAMOTO (1980) described "metamict cerianite" from Nesöya. However, the microprobe analysis and X-ray powder study revealed that the "metamict cerianite" turned out to be a metamict allanite, and in addition, thorianite was found as minor inclusions in the allanite (MATSUBARA *et al.*, 1992). Graphic intergrowth of garnet and quartz is found from the microcline granite in Nesöya (SUZUKI and MATSUMOTO, 1992).

4.2. Clinopyroxene-hornblende pegmatite

Dikes of clinopyroxene-hornblende pegmatite have been found throughout East Ongul Island, which corresponds to hornblende pegmatite of KIZAKI (1964). The modal proportion of this pegmatite depends on the surrounding rocks. The pegmatite, which is intruded into the metabasite, is composed largely of clinopyroxene and plagioclase with minor amounts of hornblende (Plate 2H). In contrast, the pegmatite , which is intruded into the other gneisses, is composed of K-feldspar, quartz, hornblende and plagioclase, with minor clinopyroxene (KIZAKI, 1964).

5. Geologic Structures

The metamorphic rocks commonly show compositional layering (several cm in thickness) which are generally parallel to lithological boundaries. The regional strikes of these foliations are generally N-S to NNW-SSE with dipping 60°-25° E in the Ongul Islands. However, on an outcrop-scale, foliations are intensely folded by isoclinal folds. In paticular, regional strikes are disturbed around East Ongul Island, Pollholmen and Nesöya (Plate 1) due to large-scale overturned antiform. In contrast to compositional layering, aligned biotite grains in garnet-biotite gneisses exhibit axial planar foliations of the isoclinal folds. This texture means that biotite grains crosscut the compositional bands at the hinges of the isoclinal folds while they are nearly parallel to the bands at the limbs of the isoclinal folds. The majority of the metamorphic rocks have a granoblastic texture.

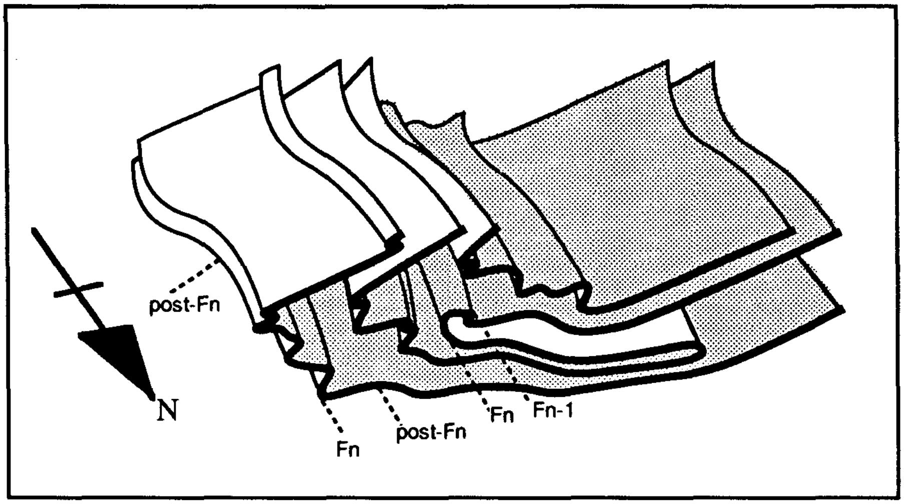


Fig. 2. Schematic illustration of outcrop-scale fold structures at the Ongul Islands,

However, some metamorphic rocks show mineral lineations defined by elongated quartz, orthopyroxene aggregates and preferred orientation of hornblende. Here we define the mineral lineations as L_n lineations. The trends of L_n mineral lineations are generally NNW-SSE, and they are generally parallel to the compositional bands and fold axes of the isoclinal folds. Both the foliations and the mineral lineations were re-oriented by two stages of gentle folding with N-S and E-W trending axes. Details of the deformations are described below.

5.1. Folding

Field correlation shows four folding phases termed F_{n-1}, F_n, F_{n+1} and F_{n+2} in order of development (Fig. 2). These folds suggest all kinds of lithologies of the Ongul Islands behaved as ductile materials at the earlier stage.

5.1.1. F_n folding

The geological cross section demonstrates presence of large-scale isoclinal overturned folds (*e.g.* large-scale overturned antiform in East Ongul Island). We can also see isoclinal, overturned, recumbent folds of outcrop-scale with subhorizontal fold axes (Fig.2). These folds are the dominant folds, termed F_n folds. Trends of fold axes are NNW-SSE, and are parallel to those of L_n mineral lineations (*e.g.* hornblende in hornblende gneiss, orthopyroxene aggregates in pyroxene gneiss). This suggests that F_n folding and formation of the L_n mineral lineation were nearly coeval. Axial surfaces of F_n folds are represented by axial planar foliations of biotite grains, and they generally dip 30° to 70° E, except for at eastern half of East Ongul Island where dip angles are lower due to the effect of later folding. The wavelength of F_n folds, which ranges up to hundreds of meters, depends on the layer thickness, suggesting that F_n folds are buckled folds (Plate 4B). The F_n folding corresponds to D1 folding (YOSHIDA, 1978) and F1 folding (T. ISHIKAWA, 1976; MATSUMOTO *et al.*, 1982). The intense folding represents the intense deformation of metamorphic rocks.

5.1.2. Pre-F_n folding

F_n folds partially deformed pre-F_n folds (F_{n-1}), which are isoclinal, recumbent or overturned (Plate 4C). Fold axes are subhorizontal and subparallel to fold axes of F_n folds, and axial surfaces of F_{n-1} folds are oblique to foliations formed by aligned biotite grains.

5.1.3. Post-F_n folding

Post-F_n folding is represented by gentle to open folds. One type of post-F_n fold has subhorizontal axes plunging NNE-SSW and subvertical axial planes striking NNE-SSW. These folds clearly disturbed the regional dips of axial surfaces of F_n folds and foliations of aligned biotite grains (Plate 4D). Another type of post-F_n fold is characterized by subhorizontal fold axes trending E-W and subvertical axial planes striking E-W. The regional plunges of the F_n fold axes and L_n mineral lineations are disturbed by this folding. Due to these two kinds of post-F_n folds, dome and basin structures are recognized in places. The timing of these two stages of gentle folding is not clear at the Ongul Islands.

5.2. Ductile boudinization

Metabasites, which are characterized by higher strength than quartz-feldspar-rich gneisses (pyroxene gneiss, hornblende gneiss garnet-biotite gneisses), generally occur as symmetrical boudinaged lenses (Plate 4E). Generally, boudin necks indicate NNW-SSE stretching. In addition, N-S trending boudin necks are recognized. The intense deformation is suggested by ductile boudinization.

5.3. Fracturing of metabasite

Brittle-fractured blocks of metabasites locally occur in the garnet gneiss throughout East Ongul Island. The blocks range in diameter from a few to several tens of meters. The compositional layering within fractured blocks is oblique to the lithological boundary (Plate 4F, G). F_n isoclinal folds and post-F_n gentle folds having NNE-SSW axial traces are commonly observed in the fractured blocks, indicating that the fracturing of metabasites has occured after the formation of F_n isoclinal folds and gentle folds. This deformation means that metabasites behaved as brittle materials due to cooling after the formation of gentle folds while quartzo-feldspathic lithologies still behaved as ductile materials.

5.4. Thrusting

In the western part of East Ongul Island, KIZAKI (1964) reported a minor thrust shear zone dipping 50° E. The displacement is unknown.

5.5. Faulting

Large-scale ENE-WSW trending faults are recognized in West Ongul Island and Pollholmen. These faults cut axial traces of folds. These faults record a dextral component of shear, indicating eastward movement of the northern area. Strike-slip displacements range up to several tens of meters.

5.6. Emplacement of clinopyroxene-hornblende pegmatite

Clinopyroxene-hornblende pegmatite dikes were emplaced in East Ongul Island. They cut F_n isoclinal folds and post-F_n gentle folds. These clinopyroxene-hornblende pegmatites occur in two main sets: an E-W trending parallel set in the eastern part of East Ongul Island, and a NE-SW and NW-SE trending set in the central and western half of East Ongul Island (KIZAKI, 1964). Emplacement of these clinopyroxene-hornblende pegmatites is deduced to have taken place under the granulite-facies *P-T* conditions because orthopyroxene + plagioclase symplectites mantle garnet grains and partially fill fractures within garnet, along which clinopyroxene-hornblende pegmatites were intruded (Plate 4H).

5.7. Emplacement of microcline pegmatite

Microcline pegmatites occur as NE-SW and NW-SE trending dikes (KIZAKI, 1964), and cut the F_n isoclinal folds and post-F_n gentle folds. These microcline pegmatites were intruded locally into fault planes. Therefore the emplacement of microcline pegmatite appears to have taken place after or nearly contemporaneously with faulting in the Ongul Islands.

6. Geochronology

Before the 1980's, there were a few isotopic ages for the basement rocks in the present area. They are Rb-Sr and K-Ar ages for biotite, K-feldspar and whole-rock (Table 2). Most mineral ages are concentrated around 500 Ma, which has been interpreted to be the time of regional metamorphism or granite intrusion (*e.g.* YANAI and UEDA, 1974).

SHIBATA *et al.* (1985) reported Rb-Sr mineral isochron of 482.5 ± 9.5 Ma for hornblende-biotite gneissose granite from East Ongul Island. In addition, they measured K-Ar ages for metamorphic minerals separated from the biotite-hornblende gneiss. This age is consistent with the previous mineral ages. Especially, it is noteworthy that K-Ar age of biotite (480 ± 15 Ma) is younger than that of hornblende (502 ± 15 Ma), reflecting the cooling history.

Table 2. Rb-Sr and K-Ar mineral ages of the metamorphic rocks from the Ongul Islands.

Method	Age (Ma)*	Mineral (Rock)	Locality	Sample No.	ref.
Rb-Sr mineral isochron	482.5±9.5 (I**=0.71095±0.00014)	K-feldspar, plagioclase, whole rock	East Ongul Is.	80EO125	1
Rb-Sr	726	K-feldspar (gneiss)	West Ongul Is.	A02	2
	508	Biotite (gneiss)	West Ongul Is.	A02	2
	500±30	Biotite (gneiss)	West Ongul Is.	57122307	3
K-Ar	560	Biotite (garnet-bearing granitic gneiss)	West Ongul Is.	68022002	4
	539	Biotite (garnet-biotite gneiss)	Kurumi Is.	68090706	4
	533	Biotite (hornblendite)	Antenna Is.	68091201-2	4
	517	Biotite (pyroxenite)	East Ongul Is.	68032704	4
	515	Biotite (garnet-biotite gneiss)	Kurumi Is.	68090706	4
	502±15	Hornblende (biotite-hornblende gneiss)	East Ongul Is.	79022004	1
	485	Biotite (hornblende gneiss)	West Ongul Is.	68022609	4
	480±15	Biotite (biotite-hornblende gneiss)	East Ongul Is.	79022004	1
	467	Biotie (garnet hornblendite)	Antenna Is.	68091201-1	4
	421	Mafic fraction (hornblende gneiss)	East Ongul Is.	AO2	5
	399	Biotite (microcline gneissose granite)	West Ongul Is.	68022014	4
	387	Whole rock (hornblende gneiss)	East Ongul Is.	AO2	5
	350	Salic fraction (hornblende gneiss)	East Ongul Is.	AO2	5

* ages measured before 1970 are calculated by the older decay constants.

** initial ratio

1: SHIBATA *et al.* (1985) 2: MAEGOYA *et al.* (1968) 3: NICOLAYSEN *et al.* (1961)
4: YANAI and UEDA (1974) 5: KANEOKA *et al.* (1968)

SHIBATA *et al.* (1986) successively reported Rb-Sr whole rock isochron ages from the metamorphic rocks of East Ongul Island including Nesöya which is a small island situated to the North of East Ongul Island. Among seventeen samples from East Ongul Island, only ten samples define an isochron of 683.1 ± 13.2 Ma with an initial ratio of 0.70471 ± 0.00011. The MSWD for this isochron is 0.80. Five samples from a single outcrop yield an isochron age of 574 ± 128 Ma and initial ratio of 0.7050 ± 0.003. Four samples from Nesöya give an isochron age of 722.1 ± 82.2 Ma with an initial ratio of 0.70625 ± 0.00073. However, the data points are significantly scattered (MSWD = 9.4) and the reduced line might be errorchron.

Recently, U-Pb dating on zircons from metasedimentary gneisses from the Lützow-Holm Complex has been conducted with the ion microprobe (SHRIMP) at the Australian National University (FANNING *et al.*, 1991; SHIRAISHI *et al.*, 1992a, 1994). One of the samples in this project is a garnet-biotite gneiss from West Ongul Island. Twenty-two points were analyzed in eighteen zircon grains. Seven of these zircons contain Late Archaean to Early Proterozoic (2740-1497 Ma) components. The structured grains have centers that give discordant $^{207}Pb/^{206}Pb$ ages of ~2415 to ~1980 Ma with rims at ~530 Ma. Four clear rounded and elongate grains yield a variety of $^{207}Pb/^{206}Pb$ ages ranging from discordant at ~2740 Ma to concordant at 1855 Ma. The other zircons are dominated by a 532 ± 6 Ma crystallization event as derived from the weighted mean $^{206}Pb/^{238}U$ ages. This is therefore considered to give the age of the high-grade metamorphic event that affected these zircons.

500-550 Ma ages are ubiquitous for the rims of zircons from other ice-free areas in the Lützow-Holm Complex as well and attributed to the age of the high-grade metamorphism and intense deformation of the Lützow-Holm Complex (FANNING *et al.*, 1991; SHIRAISHI *et al.*, 1992a, 1994). The discrepancy between the Rb-Sr isochron age and the U-Pb zircon age is not certain. One possibility is that the various types of rocks used for Rb-Sr isochron dating could not define the unique Sr initial ratio. Rb-Sr mineral isochron and K-Ar biotite and hornblende ages of 502-469 Ma (SHIBATA *et al.*, 1985) are regarded as later cooling ages.

References

BANNO, S., TATSUMI, T., KUNO, H. and KATSURA, T. (1964a): Mineralogy of granulite facies rocks in the area around Lützow-Holm Bay, Antarctica. JARE Sci. Rep., Ser. C (Geol.), **1**, 1-12.

BANNO, S., TATSUMI, T., OGURA, Y. and KATSURA, T. (1964b): Petrographic studies on rocks from the area around Lützow-Holmbukta. Antarctic Geology, ed. by R. J. ADIE. Amsterdam, North-Holland, 405-414.

FANNING, C.M., HIROI, Y., MOTOYOSHI, Y., SHIRAISHI, K., NAKAI, Y., ELLIS, D.J. and BLACK, L. (1991): Evolution of the Lützow-Holm Complex, East Antarctica: Geological, petrological and geochronological constraints. Abstracts, Sixth International Symposium on Antarctic Earth Sciences, Tokyo, Natl Inst. Polar Res., 139.

HIROI, Y. and ONUKI, H. (1985): Hornblende gneisses from Syowa Station, East Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **37**, 63-81.

HIROI, Y., SHIRAISHI, K., YANAI, K. and KIZAKI, K. (1983): Aluminum silicates in the Prince Olav and Sôya Coasts, East Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **28**, 115-131.

HIROI, Y., SHIRAISHI, K., MOTOYOSHI, Y., KANISAWA, S., YANAI, K and KIZAKI, K. (1986): Mode of occurrence, bulk chemical compositions, and mineral textures of ultramafic rocks in the Lützow-Holm Complex, East Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **43**, 62-84.

HIROI, Y., SHIRAISHI, K., MOTOYOSHI, Y. and KATSUSHIMA, T. (1987): Progressive metamorphism of calc-silicate rocks from the Prince Olav and Sôya Coasts, East Antarctica. Proc. NIPR Symp. Antarct. Geosci., **1**, 73-97.

HIROI, Y., SHIRAISHI, K. and MOTOYOSHI, Y. (1991): Late Proterozoic paired metamorphic complexes in East Antarctica, with special reference to the tectonic significance of ultramafic rocks. Geological Evolution of Antarctica, ed. by M.R.A. THOMSON *et al.* Cambridge, Cambridge Univ. Press, 83-87.

ISHIKAWA, T. (1976): Superimposed folding of the Precambrian metamorphic rocks of the Lützow-Holm Bay region, East Antarctica. Mem. Natl Inst. Polar Res., Ser. C (Earth Sci.), **9**, 1-41.

KANEOKA, I., OJIMA, M., OJIMA, M., AYUKAWA, M. and NAGATA, T. (1968): K-Ar ages and palaeomagnetic studies on rocks from the east coast of Lützow-Holm Bay, Antarctica. Nankyoku Shiryô (Antarct. Rec.), **31**, 12-20.

KANISAWA, S., ONUKI, H. and YANAI, K . (1979): Chemical characteristics of biotites and hornblendes from metamorphic rocks around Lützow-Holmbukta, East Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **14**, 153-163.

KANISAWA, S., YOSHIDA, T. and ISHIKAWA, K. (1987): Preliminary study on trace element geochemistry of metabasites around Syowa Station and the adjacent areas. Proc. NIPR Symp. Antarct. Geosci., **1**, 98-106.

KAWASAKI, T., ISHIKAWA, M. and MOTOYOSHI, Y. (1993): A preliminary report on cordierite-bearing assemblages from Rundvågshetta, Lützow-Holm Bay, East Antarctica: Evidence for a decompressional P-T path? Proc. NIPR Symp. Antarct. Geosci., **6**, 47-56.

KIZAKI, K. (1962): Structural geology and petrology of the East Ongul Island, East Antarctica. Part I. Structural geology. Nankyoku Shiryô (Antarct. Rec.), **14**, 27-35.

KIZAKI, K. (1964): Tectonics and petrography of the East Ongul Island, Lützow-Holm Bukt, Antarctica. JARE Sci. Rep., Ser. C (Geol.), **2**, 1-24.

MAEGOYA, T., NOHDA, S. and HAYASE, I. (1968): Rb-Sr dating of the gneissic rocks from the east coast of Lützow-Holm Bay, Antarctica. Mem. Fac. Sci. Kyoto Univ., Ser. B, **35**, 131-138.

MATSUBARA, S., KATO. A. and MATSUMOTO. Y. (1992): Re-examination of "metamict cerianite" from Nesöya Island, Antarctica. Kazan to Ganseki no Tankyu-Nihon kara Chûgoku, Nankyoku e-(Exploration of Volcanoes and Rocks in Japan, China and Antarctica. Commemorative Papers for Prof. Yukio Matsumoto), ed. by Commemorative Committee for Prof. MATSUMOTO YUKIO. Yamaguchi, Commemorative Committee for Prof. MATSUMOTO YUKIO, 493-496 (in Japanese).

MATSUEDA, H., MOTOYOSHI, Y., SUZUKI, T. and MATSUBAYA O. (1983): Nankyokusan graphite to molybdenite. Abstract, Fourth NIPR Symposium on Antarctic Geosciences. Tokyo, Natl Inst. Polar Res., 4-6 (in Japanese).

MATSUMOTO, Y. and SAKAMOTO, A. (1980): Preliminary report on metamict cerianite from Nesöya, Lützow-Holmbukta, East Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, 18, 103-111.

MATSUMOTO, Y., NISHIDA, M., YANAI, K. and KOJIMA, H. (1982): Geology and geologic structure of the northern Ongul Islands and surroundings, East Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **21**, 47-70.

MOTOYOSHI, Y. (1986): Prograde and progressive metamorphism of the granulite-facies Lützow-Holm Bay region, East Antarctica. D.c. thesis, Hokkaido Univ., 238 p.

MOTOYOSHI, Y., MATSUBARA, S. and MATSUEDA, H. (1989): *P-T* evolution of the granulite-facies rocks of the Lützow-Holm Bay region, East Antarctica. Evolution of Metamorphic Belts, ed. by J.S. DALY *et al.* Oxford, Blackwell, 325-329 (Geol. Soc. Spec. Pub., No. 43).

NAKAJIMA, T., SHIBATA, K., SHIRAISHI, K., MOTOYOSHI, Y. and HIROI, Y. (1988): Rb-Sr whole-rock ages of metamorphic rocks from Eastern Queen Maud Land, East Antarctica (2): Tenmondai Rock and Rundvågshetta (Abstract). Proc. NIPR Symp. Antarct. Geosci., **2**, 172

NICOLAYSEN, L.O., BURGER, A.J., TATSUMI, T. and AHRENS, L.H. (1961): Age measurements on pegmatites and a basic charnockite lens occurring near Lützow-Holm Bay, Antarctica. Geochim. Cosmochim. Acta, **22**, 94-98.

SHIBATA, K., YANAI, K. and SHIRAISHI, K. (1985): Rb-Sr mineral isochron ages of metamorphic rocks around Syowa Station and from the Yamato Mountains, East Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **37**, 164-171.

SHIBATA, K., YANAI, K. and SHIRAISHI, K. (1986): Rb-Sr whole-rock ages of metamorphic rocks from eastern Queen Maud Land, East Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **43**, 133-148.

SHIBUYA, G. and KIZAKI, K. (1967a): Mineralogical notes on ilmenite from East Ongul Island, Antarctica. Mineral. J., **5**, 199-212.

SHIBUYA, G. and KIZAKI, K. (1967b): Pyrrhotite from Ongul Island, Antarctica. Sci. Rep. Yamaguchi Univ., **17**, 1-8.

SHIRAISHI, K. , HIROI, Y., MOTOYOSHI, Y. and YANAI, K. (1987): Plate tectonic development of late Proterozoic paired metamorphic complexes in eastern Queen Maud Land, East Antarctica. Gondwana Six: Structure, Tectonics and Geophysics, ed. by G.W. MCKENZIE. Washington, D.C., Am. Geophys. Union, 309-318 (Geophys. Mon. **40**).

SHIRAISHI, K. , HIROI, Y., ELLIS, D.J., FANNING, C.M., MOTOYOSHI, Y. and NAKAI, Y. (1992a): The first report of a Cambrian orogenic belt in East Antarctica - an ion microprobe study of the Lützow-Holm Complex. Recent Progress in Antarctic Earth Science, ed. by Y. YOSHIDA *et al.* Tokyo, Terra Sci. Publ., 67-73.

SHIRAISHI, K. , HIROI, Y., SHIMIZU, Y. and MOTOYOSHI, Y. (1992b): Ultrabasic metamorphic rocks from the Lützow-Holm Complex, East Antarctica - Late Proterozoic ophiolites -. Kazan to Ganseki no Tankyu-Nihon kara Chûgoku, Nankyoku e-(Exploration of Volcanoes and Rocks in Japan, China and Antarctica. Commemorative Papers for Prof. Yukio Matsumoto), ed. by Commemorative Committee for Prof. MATSUMOTO YUKIO. Yamaguchi, Commemorative Committee for Prof. MATSUMOTO YUKIO, 479-486 (in Japanese).

SHIRAISHI, K., ELLIS, D.J., HIROI, Y., FANNING, C.M., MOTOYOSHI, Y. and NAKAI, Y. (1994): Cambrian orogenic belt in East Antarctica and Sri Lanka: Implications for Gondwana assembly. J. Geol., **102**, 47-65.

SUWA, K. (1968): Petrological studies on the metamorphic rocks from the Lützow-Holmbukta area, East Antarctica. 23th Int. Geol. Comgr., **4**, 171-187.

SUZUKI, M. (1979): On the scapolite-plagioclase equilibrium found in the Cape Omega and East Ongul Island areas, East Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **14**, 140-152.

SUZUKI, M. (1982): On the association of orthopyroxene-garnet-biotite found in the Lützow-Holmbukta region, East Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **21**, 86-102.

SUZUKI, M. (1983): Preliminary note on the metamorphic conditions around Lützow-Holm Bay, East Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **28**, 132-143.

SUZUKI, M. (1986): Short note on ultramafic granulites in the Ongul Islands area, East Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **43**, 85-100.

SUZUKI, M. and MATSUMOTO. Y. (1992): Almandinous garnet-quartz symplektite in pegmatite from Nesöya Island, East Antarctica. Kazan to Ganseki no Tankyu-Nihon kara Chûgoku, Nankyoku e-(Exploration of Volcanoes and Rocks in Japan, China and Antarctica. Commemorative Papers for Prof. Yukio Matsumoto), ed. by Commemorative Committee for Prof. MATSUMOTO YUKIO. Yamaguchi, Commemorative Committee for Prof. MATSUMOTO YUKIO, 487-491 (in Japanese).

TATSUMI, T., KIKUCHI, T. and KUNO, H. (1957a): Nankyoku chiiki no chishitsu. Chigaku Zasshi, **703**, 17-33 (in Japanese).

TATSUMI, T., KIKUCHI, T. and KUNO, H. (1957b): Preliminary report of geological study by the first Japanese Antarctic Research Expedition. Nankyoku Shiryô (Antarct. Rec.), **1**, 14-16 (in Japanese).

TATSUMI, T. and KIKUCHI, T. (1959a): Report of geomorphological and geological studies of the wintering team (1957-58) of the first Japanese Antarctic Research Expedition. Part 1. Nankyoku Shiryô (Antarct. Rec.), **7**, 1-16 (in Japanese).

TATSUMI, T. and KIKUCHI, T. (1959b): Report of geomorphological and geological studies of wintering team (1957-58) of the first Japanese Antarctic Research Expedition. Part 2. Nankyoku Shiryô (Antarct. Rec.), **8**, 1-21 (in Japanese).

TATSUMI, T. and KIKUCHI, T. (1961): Geology of the region around Syowa Station, Ongul Island, Lützow-Holm Bay, Antarctica. Nankyoku Shiryô (Antarct. Rec.), **11**, 42.

YANAI, K. and UEDA, Y. (1974): Absolute ages and geological investigations on the rocks in the area around Syowa Station, East Antarctica. Nankyoku Shiryô (Antarct. Rec.), **48**, 70-81 (in Japanese).

YANAI, K., KIZAKI, K., TATSUMI, T. and KIKUCHI, T. (1974a): Geological map of East Ongul Island, Antarctica. Antarct. Geol. Map Ser., Sheet 1 (with explanatory text 13 p.). Tokyo, Natl Inst. Polar Res.

YANAI, K., TATSUMI, T. and KIKUCHI, T. (1974b): Geological map of West Ongul Island, Antarctica. Antarct. Geol. Map Ser., Sheet 2 (with explanatory text 5 p.). Tokyo, Natl Inst. Polar Res.

YANAI, K., TATSUMI, T., KIKUCHI, T. and ISHIKAWA, T. (1975a): Geological map of Teöya, Antarctica. Antarct. Geol. Map Ser., Sheet 3 (with explanatory text 3 p.). Tokyo, Natl Inst. Polar Res.

YANAI, K., TATSUMI, T. and KIKUCHI, T. (1975b): Geological map of Ongulkalven, Antarctica. Antarct. Geol. Map Ser., Sheet 4 (with explanatory text 3 p.). Tokyo, Natl Inst. Polar Res.

YOSHIDA, M. (1978): Tectonics and petrology of charnockites around Lützow-Holmbukta East Antarctica. J. Geosci., Osaka City Univ., **21**, 65-152.

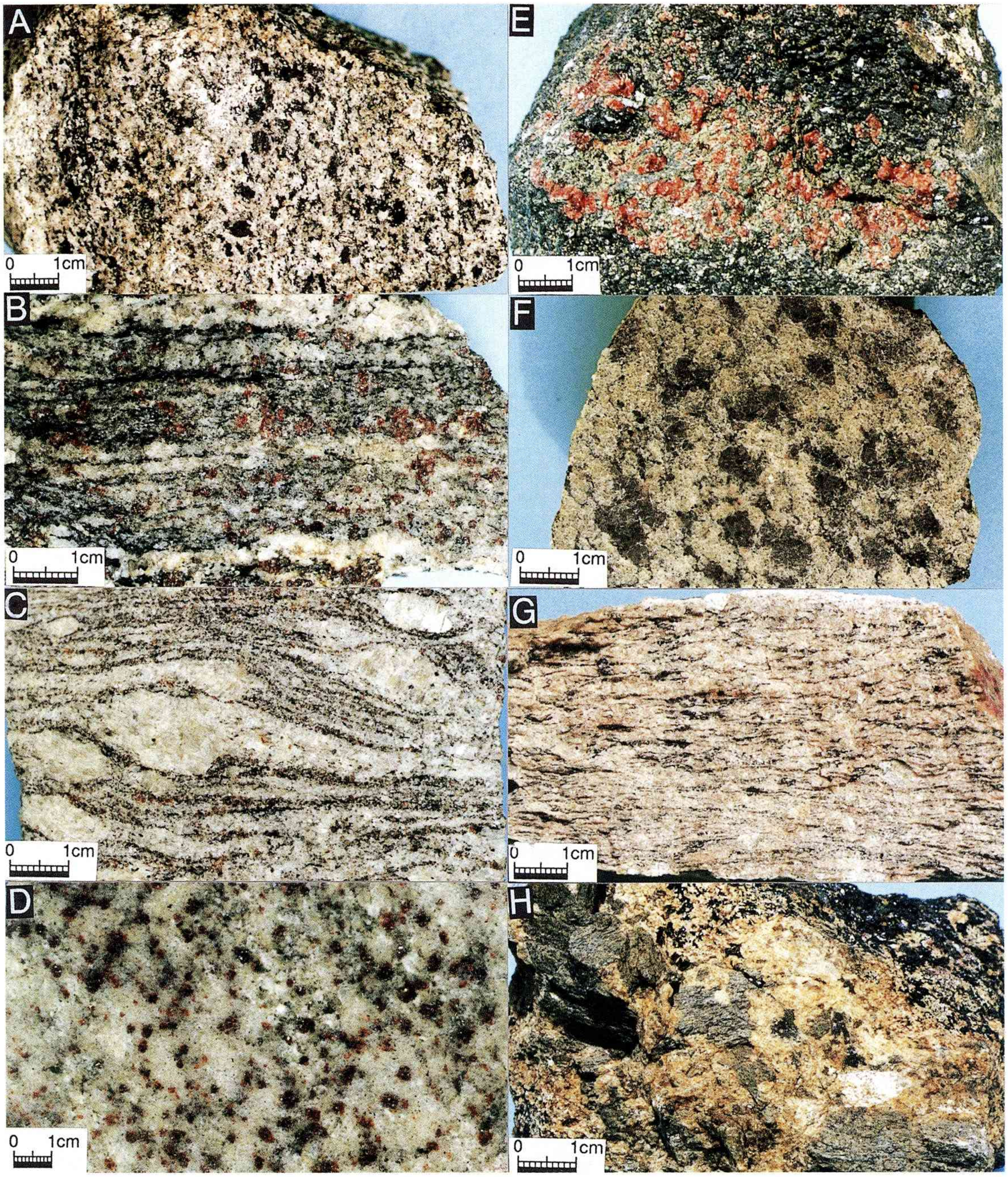
YOSHIDA, M. (1979a): Tectonics and metamorphism of the region around Lützow-Holmbukta, East Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **14**, 28-40.

YOSHIDA, M. (1979b): Metamorphic conditions of the polymetamorphic Lützow-Holmbukta region, East Antarctica. J. Geosci., Osaka City Univ., **22**, 97-139.

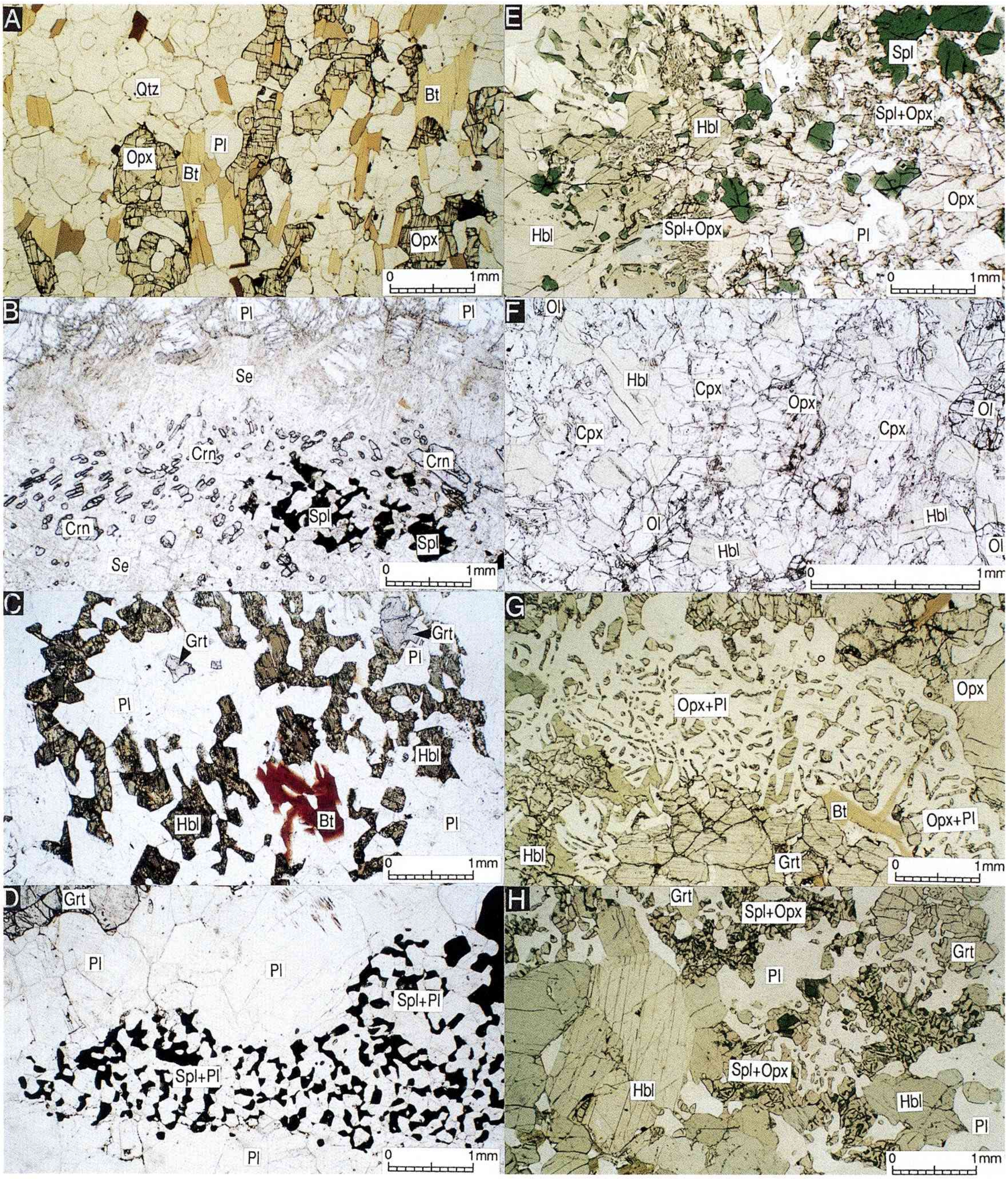
YOSHIDA, M., YANAI, K., YOSHIKARA, S., ISHIKAWA, T. and KANISAWA, S. (1982): Tectonics and microtexture of charnockites around Lützow-Holmbukta, East Antarctica. Antarctic Geoscience, ed. by C. CRADDOCK. Madison, Univ. Wisconsin Press, 511-519.

Aerial photograph of East Ongul Island (C32AV-3, C16-16). Major antiform is characteristic in this region.

Plate 2

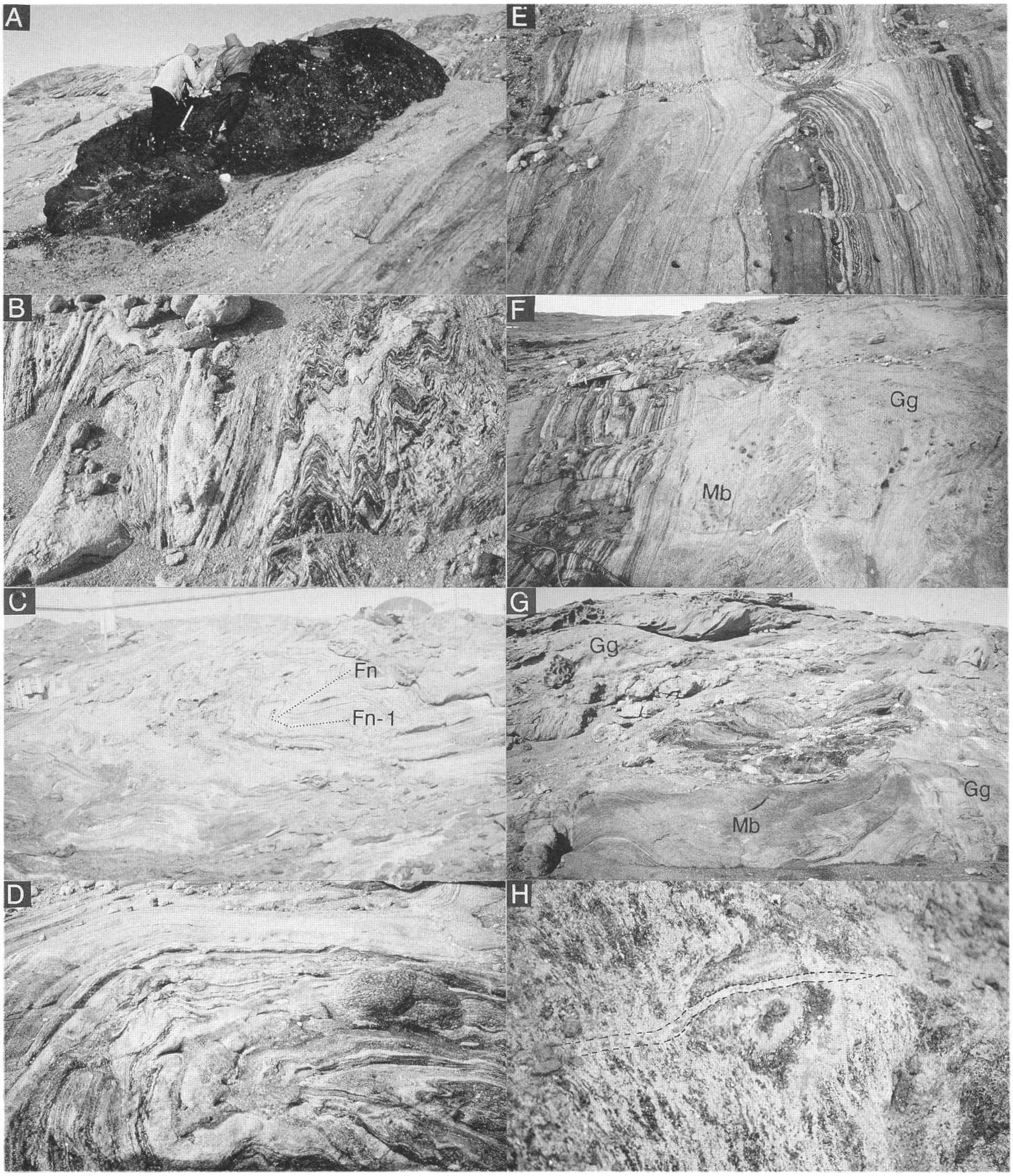


A : Hornblende gneiss (84010509) from West Ongul Island. B : Garnet-biotite gneiss (68022505) from West Ongul Island. C : Augen gneiss (68022504) from West Ongul Island. Note coarse-grained K-feldspar crystals. D : Garnet gneiss (68021514) from West Ongul Island. E : Garnet clinopyroxenite (J33ES23A) from East Ongul Island. F : Garnet orthopyroxene amphibolite (84010405) from West Ongul Island. G : Microcline gneissose granite (68022016) from West Ongul Island. H : Clinopyroxene-hornblende pegmatite (J33ES31B) from East Ongul Island. Note coarse-grained clinopyroxene crystals. Dark part is garnet hornblendite.



Photomicrograph of metamorphic rocks. Bt = biotite, Crn = corundum, Grt = garnet, Hbl = hornblende, Opx = orthopyroxene, Pl = plagioclase, Qtz = quartz, Se = sericite, Spl = spinel. Plane polarized light. A : Pyroxene gneiss (68022406) from West Ongul Island. B : Corundum-spinel domain in calc-silicate rock (J33ES40) from East Ongul Island. C : Hornblende + plagioclase intergrowth around garnet in calc-silicate rock (J33ES34) from East Ongul Island. D : Spinel + plagioclase domain in calc-silicate rock (J33ES34) from East Ongul Island. E : Spinel + orthopyroxene intergrowth in spinel-orthopyroxene hornblendite (84010309A) from West Ongul Island. F : Hornblende peridotite (810108I-11 collected by Y. HIROI) from East Ongul Island. G : Garnet, hornblende and intergrowth of orthopyroxene + plagioclase in garnet hornblendite (J33ES31) from East Ongul Island. H : Garnet and intergrowth of spinel + orthopyroxene within plagioclase in garnet-orthopyroxene amphibolite (84010405) from West Ongul Island.

Plate 4



A : Large pyroxenite block (81020109B) within well-layered "regional" biotite-hornblende gneiss from West Ongul Island (HIROI et al., 1986). B : Fn isoclinal to close folds at East Ongul Island. The wavelength ranges up to 1 m. C : Fn-1 isoclinal fold refolded by Fn folds at East Ongul Island. The wavelength of Fn-1 folds is about 0.5 m. D : Fn isoclinal folds refolded by post-Fn gentle folds at East Ongul Island. The wavelength of gentle folds is about 4 m. E : Boudinaged garnet hornblendite (dark layer) at East Ongul Island. The garnet hornblendite is about 20 cm in thickness. F : Boundary between garnet gneiss (Gg) and fractured amphibolite (Mb) at East Ongul Island. Fn isoclinal folds are observed in the aphibolite block (up to 50 m in diameter). G : Fractured block (about 5 m in diameter) of amphibolite (Mb) in garnet gneiss (Gg) at East Ongul Island. Post-Fn gentle folds are observed in the amphibolite block. H: Orthopyroxene + plagioclase intergrowth mantles garnet in garnet hornblendite at East Ongul Island. The intergrowth partially fills a fracture within garnet where clinopyroxene-hornblende pegmatite were intruded. Garnet is about 3 cm in diameter.

Antarctic Geological Map Series

Sheet 1	East Ongul Island 1:5,000	March 1974
Sheet 2	West Ongul Island 1:5,000	March 1974
Sheet 3	Teöya 1:5,000	March 1975
Sheet 4	Ongulkalven Island 1:5,000	March 1975
Sheet 5	Langhovde 1:25,000	March 1976
Sheet 6 & 7	Skarvsnes 1:25,000	March 1977
Sheet 8	Kjuka and Telen 1:25,000	March 1979
Sheet 9	Skallen 1:25,000	March 1976
Sheet 10	Padda Island 1:25,000	March 1977
Sheet 11	Cape Hinode 1:25,000	March 1978
Sheet 12	Lützow-Holm Bay 1:250,000	March 1989
Sheet 13	Prince Olav Coast 1:25,0000	March 1989
Sheet 14	Sinnan Rocks 1:25,000	March 1983
Sheet 15	Cape Ryûgû 1:25,000	March 1980
Sheet 16	Akebono Rock 1:25,000	March 1986
Sheet 17	Niban Rock 1:25,000	March 1983
Sheet 18	Kasumi Rock 1:25,000	March 1984
Sheet 19	Tenmondai Rock 1:25,000	March 1985
Sheet 20	Akarui Point and Naga-iwa Rock 1:25,000	March 1984
Sheet 21	Cape Omega 1:25,000	March 1979
Sheet 22	Oku-iwa Rock 1:25,000	March 1981
Sheet 23	Honnör Oku-iwa Rock 1:25,000	March 1987
Sheet 24	Rundvågskollane and Rundvågshetta 1:25,000	March 1986
Sheet 25	Botnneset 1:25,000	March 1987
Sheet 26	Strandnibba 1:25,000	March 1985
Sheet 27 (1)	Mt. Fukushima, Northern Yamato Mountains 1:25,000	March 1978
Sheet 28	Central Yamato Mountains, Massif B and Massif C 1:25,000	March 1982
Sheet 29	Belgica Mountains 1:25,000	March 1981
Sheet 30	Southern Yamato Mountains (Massif A and JARE-IV) 1:25,000	March 1988
Sheet 31	Balchenfjella 1:100,000	March 1991
Sheet 32	Widerøefjellet 1:100,000	March 1992
Sheet 33	Bergersenfjella 1:100,000	March 1993
Sheet 36	Ongul Islands 1:10,000	March 1994