ON THE SCAPOLITE-PLAGIOCLASE EQUILIBRIUM FOUND IN THE CAPE OMEGA AND EAST ONGUL ISLAND AREAS, EAST ANTARCTICA

Morihisa SUZUKI

Institute of Geology and Mineralogy, Faculty of Science, Hiroshima University, Higashi-sendamachi 1-chome, Hiroshima 730

Abstract: The association of scapolite and plagioclase from the Cape Omega and East Ongul Island areas of East Antarctica is briefly discussed with special reference to the petrogenetic significance. In the former area, the association is found in metabasites enclosed in the amphibolite facies metamorphites and pink granite. In the latter area, the association is observed in the feldspathic rock, which seems to be emplaced in the granulite facies rocks. Based on the mineralogical investigations, the association in the Cape Omega area suggests the equilibration under the granulite facies, while that in East Ongul Island under the amphibolite facies or lower. Summarizing the geological and petrological characters of the metamorphites concerned, the time and space relationship of metamorphic processes between the two areas are discussed.

1. Introduction

The association of scapolite and plagioclase sometimes gives an effective key to clarify the metamorphic conditions. In East Antarctica, the occurrence of scapolite has been noted from some areas. BANNO *et al.* (1964) and TATSUMI *et al.* (1964) reported the occurrence from the marbles in the Lützow-Holm Bay area. SUWA and TATSUMI (1969) also found a zoned scapolite associated with pargasite, phlogopite, dolomite and apatite from a vein in calcareous metamorphites in the Skallen area. Russian geologists also gave descriptions of scapolite in calciphyres and marbles from Enderby Land, Bunger Oasis and Queen Maud Land areas (RAVICH and KAMENEV, 1975). However, few discussions have been made on the scapolite-plagioclase association in Antarctica.

During the course of the field investigation by the 18th Japanese Antarctic Research Expedition 1976–78 (JARE–18), the author has newly found some rocks showing the stable association of scapolite and plagioclase.

In this report, the representative rocks from the Lützow-Holmbukta region are described in connection with their petrogenetic significance, and a model for the metamorphic condition and the history of the region are presented.

2. Modes of Occurrence and Petrography of Scapolite-Bearing Rocks

Scapolite is occasionally found in some kinds of metamorphites in the Lützow-Holmbukta region. The modes of occurrence and petrological characters of the scapolite-bearing rocks in the Cape Omega and East Ongul Island will be briefly summarized in the following.

2.1. The Cape Omega area

In the area, there occur various kinds of metamorphites derived from basic, pelitic, psammitic and calcareous rocks. It is noteworthy that so-called metabasites metamorphosed from some kinds of calcareous, basic and ultrabasic rocks are widely distributed (SUZUKI, 1979). Scapolite is found in some of these metabasites, of which two representatives are described below with respect to their modes of occurrence and petrography.

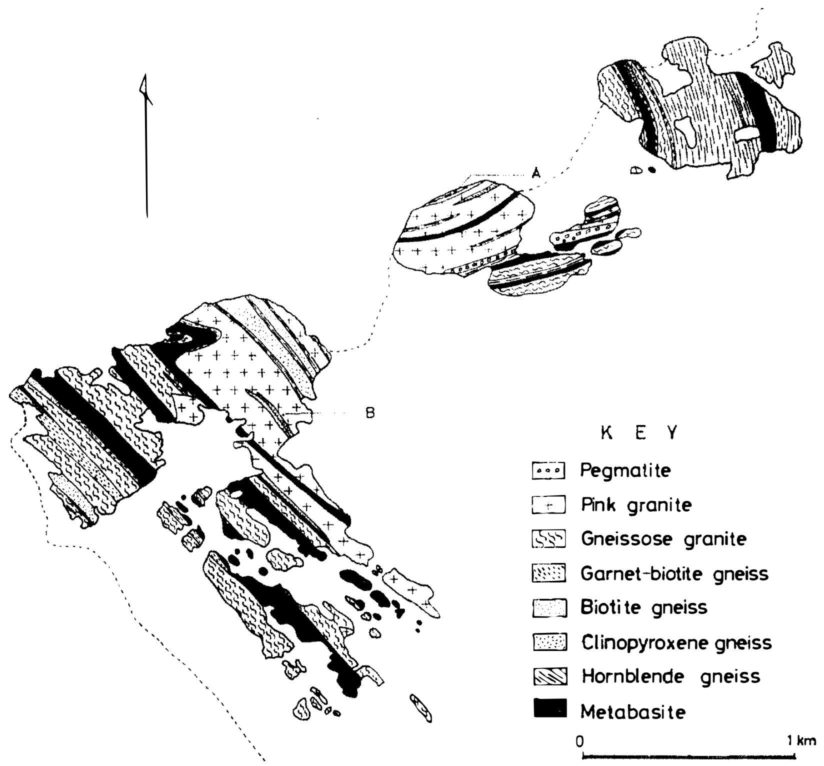

Fig. 1. Geological map of the Cape Omega area. Points A and B show the localities of metabasites.

2.1.1. Specimen No. 77010804

The rock is found in the central part of the area (Locality A in Fig. 1). It occurs as a nearly rectangular body of 1.7×0.8 m in the surrounding gneisses, which are mainly composed of the alternations of rocks of basic, psammitic and calcareous origins. Pink granite characterized by the presence of pinkish microcline occurs in close association with the gneisses (Fig. 2).

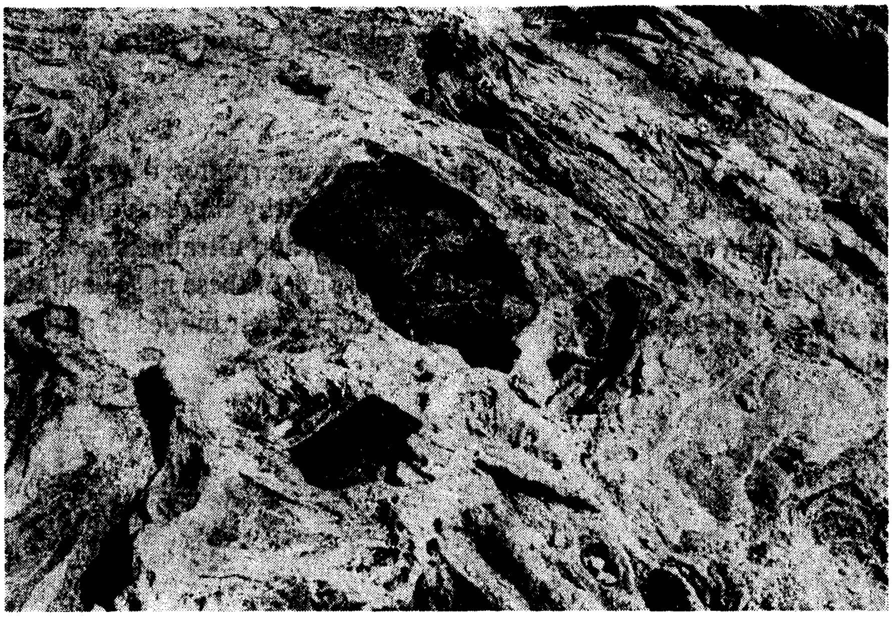

Fig. 2. Photograph showing the mode of occurrence of metabasite (specimen No. 77010804) in the Cape Omega area.

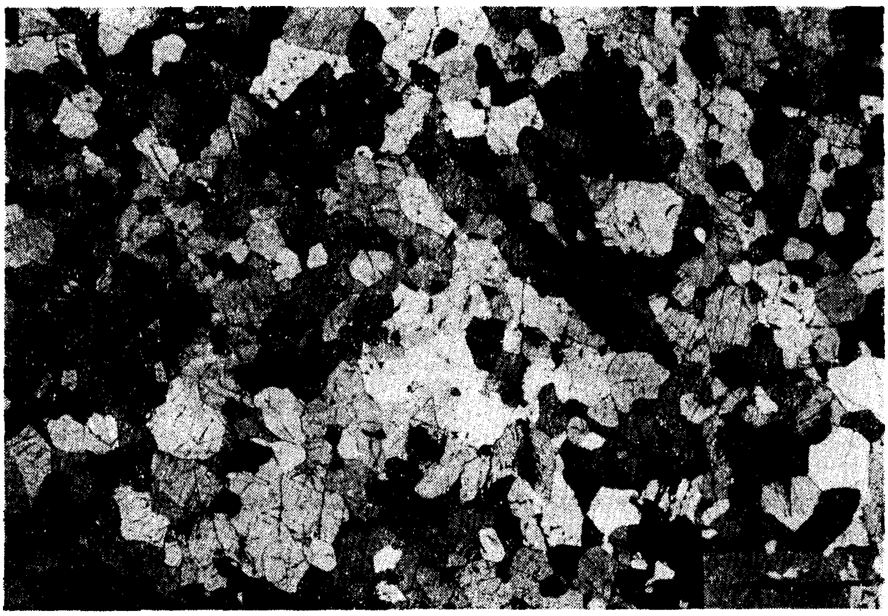

Fig. 3. Photomicrograph of the specimen 77010804. Scale bar=0.1 mm. White: scapolite, gray with distinct cleavage: clinopyroxene, gray without distinct cleavage: plagioclase.

The specimen concerned is massive in appearance and dark green in color. Under the microscope, the fine- to medium-grained granoblastic texture is characteristic (Fig. 3). The metamorphic assemblage of the rock is clinopyroxene, garnet, scapolite and plagioclase.

Chemical compositions of the major constituents are shown in Table 1. Clino-

Table 1. Chemical compositions of the main constituent minerals in metabasite (specimen No. 77010804) from the Cape Omega area.

	1	2	3	4	5	6
SiO_2	46.6	38.1	44.3	43.9	44.8	44.1
TiO_2	0.52	0.52	0.04	0.04	0.05	0.05
Al_2O_3	5.02	14.0	35.7	35.6	27.4	27.5
FeO*	14.8	14.5	0.25	0.24	0.18	0.26
MnO	0.67	1.58	0.11	0.08	0.09	0.12
MgO	8.48	0.53	0.03	0.01	0.03	0.03
CaO	23.4	30.1	20.0	20.0	19.0	19.2
Na_2O	0.67	0.02	0.57	0.62	2.97	3.06
K_2O	0.05	0.04	0.04	0.05	0.20	0.20
Total	100.2	99.4	101.0	100.5	94.7	94.5
			Numbers of ions			
O	6.000	24.000	32.000	32.000		
Si+Al					12.000	12.000
Si	1.813	6.165	8.139	8.114	6.980	6.914
Al	0.230	2.672	7.740	7.758	5.020	5.086
Ti	0.015	0.063	0.005	0.006	0.006	0.006
Mg	0.492	0.128	0.008	0.004	0.007	0.006
Fe″	0.483	1.964	0.038	0.038	0.023	0.034
Mn	0.022	0.216	0.016	0.013	0.013	0.016
Ca	0.974	5.221	3.932	3.953	3.166	3.219
Na	0.051	0.006	0.202	0.224	0.895	0.930
K	0.003	0.009	0.010	0.011	0.040	0.041
Meion.**					77.5	77.2
Ab			4.8	5.3		
An			95.0	94.4		
Or			0.2	0.3		

1: Clinopyroxene, 2: Garnet, 3: Plagioclase-1, 4: Plagioclase-2, 5: Scapolite-1, 6: Scapolite-2.

* Total Fe as FeO

** Meionite mole $\% = \frac{(Ca+Mg+Fe+Mn+Ti)}{(Na+K+Ca+Mg+Fe+Mn+Ti)} \times 100$

pyroxene is plotted in the ferrosalite region with the composition of $Ca_{49.4}Mg_{25.0}$ $Fe+Mn_{25.6}$. It is noteworthy that the Al_2O_3 content in the clinopyroxene is considerably high, so that stoichiometric estimation of the net content of FeO is not so easier. Garnet is the member of grossular with the CaO content around 30% in weight. Plagioclase has the composition of 95% anorthite content. Scapolite is always associated with plagioclase and shows the composition about 77% in meionite molecule.

2.1.2. Specimen No. 77010907A

The rock is found in the western part of the area (Locality B in Fig. 1). It occurs as a small rhombic body, each side 25 cm, enclosed in pink granite (Fig. 4).

Fig. 4. Photograph showing the mode of occurrence of metabasite (specimen No. 77010907A) in the Cape Omega area.

The specimen is massive and dark green in color, just like the specimen mentioned above. Microscopically, it is characterized by the medium-grained granoblastic texture. Scapolite grains are rather coarser in size among the constituent minerals (Fig. 5). The main constituent minerals are scapolite, plagioclase, garnet, clinopyroxene, potassium feldspar and quartz.

Chemical compositions of the main constituents are shown in Table 2. The composition of clinopyroxene is $Ca_{49.9}Mg_{24.3}$ $Fe+Mn_{25.8}$ plotted in the field of ferrosalite. The Al_2O_3 content is lower than that in the specimen described above. Garnet is high in grossular content. Potassium feldspar is always microcline with the composition of $Or_{92.4}Ab_{6.8}An_{0.8}$. Plagioclase has the chemical composition in the range of 86 to 90% in anorthite content. Scapolite has the meionite content around 80 mole %.

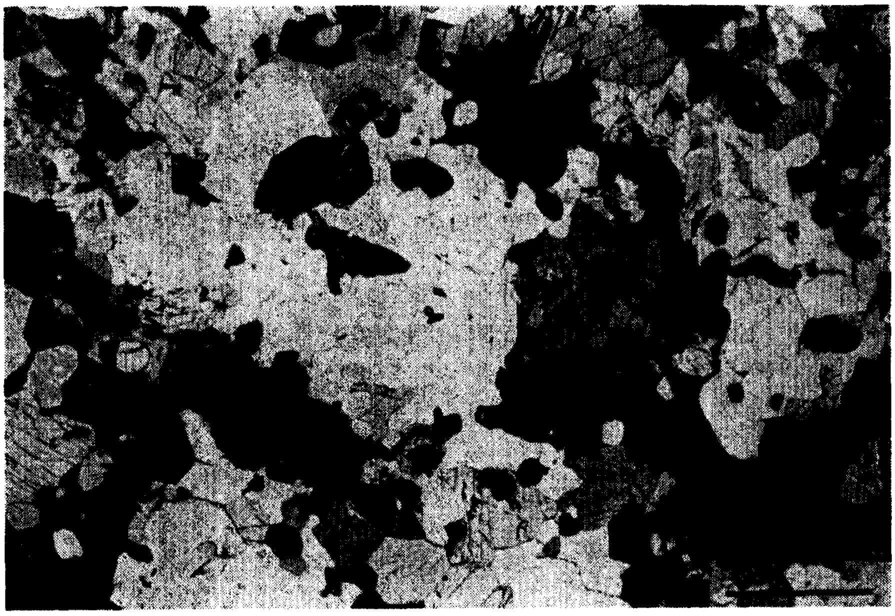

Fig. 5. Photomicrograph of the specimen 77010907A. Scale bar=0.1 mm. Coarse and white: scapolite, gray with distinct cleavage: clinopyroxene, gray without distinct cleavage: plagioclase.

Fig. 6. Photomicrograph of the specimen 77012001. Scale bar=0.1 mm. White: scapolite, gray: plagioclase.

Table 2. Chemical compositions of the main constituent minerals in metabasite (specimen No. 77010907A) from the Cape Omega area.

	1	2	3	4	5	6	7
SiO_2	49.7	37.6	64.8	45.1	46.7	44.3	44.1
TiO_2	0.18	0.43	0.06	0.03	0.04	0.03	0.02
Al_2O_3	2.52	12.3	17.9	33.9	31.4	26.7	26.5
FeO*	14.6	16.0	0.10	0.18	0.24	0.22	0.18
MnO	0.25	0.49	0.03	0.03	0.01	tr.	0.01
MgO	8.88	0.19	0.03	0.02	0.02	0.05	0.04
CaO	23.9	32.9	0.03	18.5	17.5	20.2	19.0
Na_2O	0.46	0.02	0.76	1.21	1.48	2.52	2.84
K_2O	0.01	0.02	15.9	0.03	0.04	0.12	0.11
Total	100.5	99.9	99.6	99.0	97.4	94.1	92.8
				Numbers of ions			
O	6.000	24.000	32.000	32.000	32.000		
Si+Al						12.000	12.000
Si	1.913	6.145	12.025	8.414	8.812	7.011	7.023
Al	0.115	2.358	3.922	7.471	6.998	4.989	4.977
Ti	0.005	0.053	0.008	0.005	0.006	0.003	0.002
Mg	0.510	0.046	0.008	0.006	0.005	0.013	0.011
Fe″	0.471	2.189	0.015	0.028	0.038	0.030	0.024
Mn	0.008	0.068	0.004	0.004	0.002	—	0.001
Ca	0.986	5.758	0.005	3.696	3.547	3.420	3.237
Na	0.034	0.008	0.275	0.437	0.542	0.773	0.876
K	—	0.004	3.760	0.008	0.010	0.023	0.023
Meion.**						81.3	78.5
Ab			6.8	10.5	13.1		
An			0.8	89.3	86.7		
Or			92.4	0.2	0.2		

1: Clinopyroxene, 2: Garnet, 3: Microcline, 4: Plagioclase-1, 5: Plagioclase-2, 6: Scapolite-1, 7: Scapolite-2

* Total Fe as FeO

** See Table 1 for the calculation of meionite mole %

2.2. *East Ongul Island*

As discussed by many Japanese geologists, such as BANNO *et al.* (1964), KIZAKI (1964), YANAI *et al.* (1975) and so on, the area is characterized by the extensive development of metamorphics formed under the granulite facies. Such metamorphic rocks as pyroxene gneiss, garnet gneiss, hornblende gneiss and metabasites are the representatives. A rock with stable association of scapolite and plagioclase has been

Table 3. Chemical compositions of the main constituent minerals in feldspathic rock (specimen No. 77012001) from East Ongul Island.

	1	2	3	4	5	6	7	8	9	10
SiO_2	55.9	56.2	57.0	57.4	51.3	52.0	51.9	52.0	40.5	36.1
TiO_2	0.05	0.04	0.02	0.06	0.06	0.03	0.05	0.05	2.98	3.84
Al_2O_3	27.6	26.9	26.4	26.3	25.1	24.5	24.8	24.2	12.2	13.8
FeO*	0.18	0.18	0.17	0.17	0.24	0.20	0.21	0.20	19.5	23.3
MnO	0.06	0.03	0.07	0.04	0.08	0.10	0.13	0.08	0.40	0.33
MgO	0.02	0.03	0.02	0.02	0.04	0.04	0.03	0.02	6.97	9.29
CaO	10.7	10.4	9.98	9.58	13.0	12.3	12.6	12.4	11.2	0.04
Na_2O	5.60	5.67	5.91	5.95	5.67	5.68	5.87	5.70	1.33	0.08
K_2O	0.23	0.35	0.37	0.40	1.53	1.66	1.71	1.69	2.53	9.38
Total	100.3	99.8	99.9	99.9	97.0	96.5	97.3	96.3	97.6	96.2
	Numbers of ions									
O	32.000	32.000	32.000	32.000					23.000	22.000
Si+Al					12.000	12.000	12.000	12.000		
Si	10.057	10.155	10.268	10.330	7.613	7.712	7.668	7.748	6.252	5.592
Al	5.846	5.733	5.610	5.569	4.387	4.288	4.332	4.252	2.218	2.516
Ti	0.006	0.005	0.003	0.009	0.006	0.004	0.005	0.005	0.347	0.447
Mg	0.006	0.008	0.004	0.004	0.008	0.009	0.007	0.005	1.606	2.145
Fe″	0.028	0.028	0.025	0.025	0.030	0.024	0.026	0.025	2.524	3.014
Mn	0.009	0.005	0.011	0.006	0.010	0.012	0.017	0.010	0.052	0.043
Ca	2.061	2.004	1.927	1.848	2.067	1.962	1.998	1.987	1.846	0.007
Na	1.951	1.988	2.065	2.076	1.633	1.633	1.682	1.646	0.398	0.023
K	0.053	0.081	0.086	0.093	0.290	0.315	0.324	0.322	0.499	1.854
Meion.**					52.4	50.8	50.6	50.8		
Ab	47.5	48.3	50.1	51.2						
An	51.2	49.7	47.8	46.5						
Or	1.3	2.0	2.1	2.3						

1: Plagioclase-1, 2: Plagioclase-2, 3: Plagioclase-3, 4: Plagioclase-4, 5: Scapolite-1
6: Scapolite-2, 7: Scapolite-3, 8: Scapolite-4, 9: Hornblende, 10: Biotite
* Total Fe as FeO
** See Table 1 for the calculation of meionite mole %

newly found.

2.2.1. Specimen No. 77012001

The rock is found near the Miharasi Peak (Miharashi Iwa) in the easternmost part of the Island (Locality A in Fig. 7). After KIZAKI (1964), the rock is called a feldspathic band. It is reported that the band has enclaves of the surrounding pyroxene gneiss, showing an agmatitic appearance.

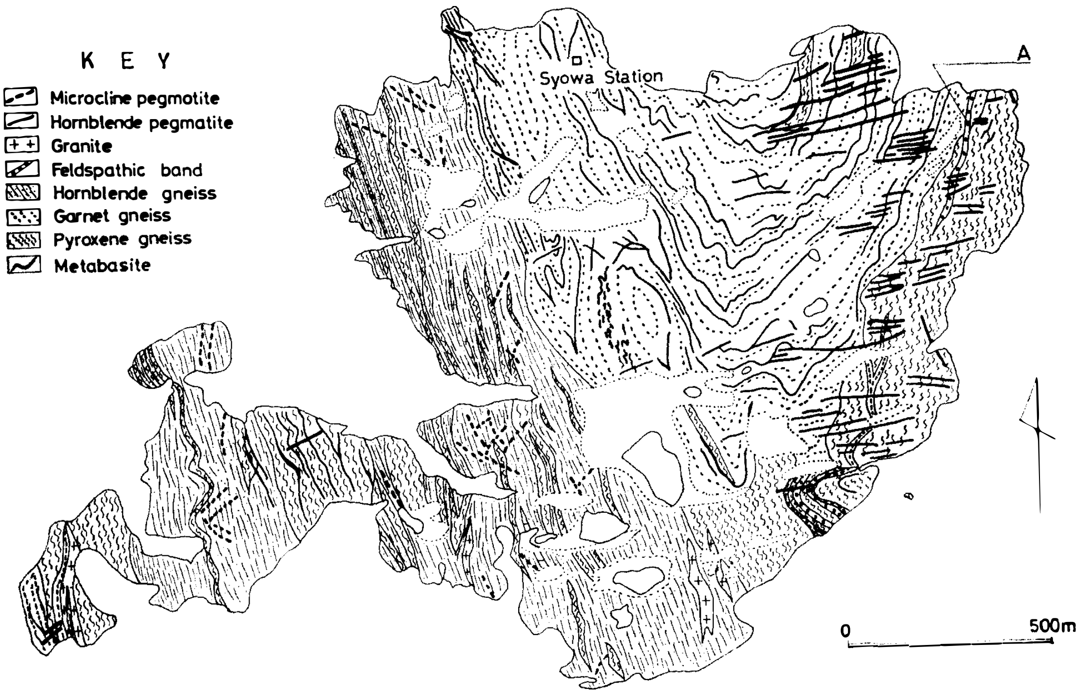

Fig. 7. Geological map of East Ongul Island (after KIZAKI, 1964). Point A shows the locality of feldspathic rock (specimen No. 77012001).

The specimen is whitish in color, massive and coarse-grained. The microscopic texture is characteristically equigranular, and the main constituents are scapolite and plagioclase associated with smaller amounts of biotite, muscovite and hornblende. The grains of scapolite are developed showing a sieve-like texture (Fig. 6).

The chemical compositions of plagioclase and scapolite are given in Table 3. The anorthite content of plagioclase and the meionite content of scapolite are ranging from 46 to 51 %, and from 50 to 52%, respectively.

3. Scapolite-Plagioclase Equilibrium

As already discussed by HIETANEN (1967), HAUGHTON (1971) and SUZUKI (1977), scapolite is generally more calcic than the coexisting plagioclase in the metamorphic assemblage, and at a higher metamorphic grade such as the granulite facies, the calcium content of scapolite with respect to that of plagioclase may decrease or maintain a relatively constant value. As a result, the mole percent value of anorthite in plagioclase can exceed that of meionite in scapolite.

The compositions of scapolite-plagioclase pairs from the area under discussion are summarized in Table 4. Fig. 8 shows the correlation between the mole percent of anorthite in plagioclase versus that of meionite in scapolite from various metamorphic terrains. In the figure, all plots by HIETANEN and by SUZUKI (1977) are the pairs

Table 4. Summary of the compositions of coexisting scapolite and plagioclase from the Cape Omega and East Ongul Island areas.

Specimen No.	Locality	Meionite % in scapolite	Anorthite % in plagioclase
77010804	Cape Omega	77.5	95.0
		77.2	94.4
77010907A	Cape Omega	81.3	89.3
		78.5	86.7
77012001	East Ongul Island	52.4	51.2
		50.8	49.7
		50.6	47.8
		50.8	46.5

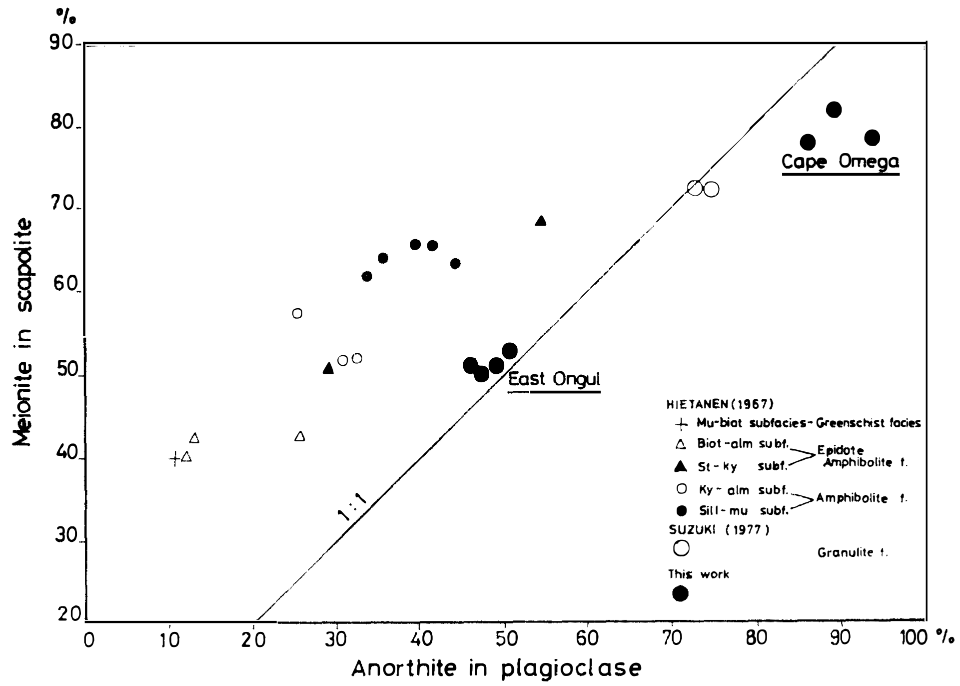

Fig. 8. Mole percent anorthite versus mole percent meionite in coexisting plagioclase and scapolite as related to the metamorphic grade.

in the metamorphites derived from calcareous and pelitic rocks.

It should be noted from Fig. 8 that in the specimens formed under the lower grade metamorphic conditions the values of meionite percent exceed those of anorthite percent, each point being plotted above the 1 : 1 line. Meanwhile, the points of the specimens from the area of the granulite facies metamorphism are plotted on or below the line. Among the pairs in the specimens discussed, those from the Cape

Omega area are plotted below the line, whereas those from East Ongul Island are above.

SUZUKI (1979) presented that the metamorphism in the Cape Omega area could be divided into at least two stages. The older one is under the granulite facies and the younger one under the amphibolite facies. Using the garnet-biotite geothermometer, the metamorphic temperature has been estimated at $828 \pm 50°C$ in the former stage and $593 \pm 50°C$ in the latter, assuming the total pressure in each metamorphic stage as 5 kb (SUZUKI, 1979).

With these results in mind, although the problem on the dependence of chemical compositions of minerals upon the bulk rock chemistry is still left unsolved, it may well be seen in Fig. 8 that scapolite-plagioclase pairs from the Cape Omega area suggest the formation under the granulite facies metamorphic condition and that the pairs from East Ongul Island suggest the formation under the amphibolite facies or lower.

4. Discussion on the Metamorphism in Lützow-Holmbukta

As discussed by SUZUKI (1979), the metamorphic grade in the Cape Omega area is in general the amphibolite facies. The rocks with stable association of scapolite and plagioclase are found as irregularly shaped bodies in the surrounding amphibolite facies gneisses and granite. Judging from the mode of occurrence, there is no tectonic discontinuity of a large scale between the scapolite-bearing rocks and the surroundings, which are characterized by the mineralogy of the amphibolite facies. There seems to exist no such a simple thermal structure that the amphibolite facies rocks progressively grade into the granulite facies ones under discussion. Then, it should not be unreasonable to assume that, in the Cape Omega area, a few rocks with the granulite facies metamorphic assemblages of the older phase have escaped the later alteration under the amphibolite facies condition to result in the sporadic occurrence of the rocks among the amphibolite facies metamorphites. In East Ongul Island, the scapolite-bearing feldspathic rock occurs apparently penetrating the surrounding granulite facies rocks. The feldspathic rock itself suggests that it was recrystallized under the condition of the amphibolite facies or lower. The rock seems to have been metamorphosed after was emplaced in the granulite facies rocks.

Next, the difference of the metamorphic temperature during the later metamorphic episode between the Cape Omega area and East Ongul Island must be discussed.

In the Cape Omega area, it is possible to consider that the later amphibolite facies metamorphism was so intensive that most of the granulite facies metamorphic assemblages were decomposed. While, in East Ongul Island, the later metamorphism was not so intensive that almost all of the granulite facies assemblages could be preserved. The rarely-found rock suggesting the amphibolite facies or lower seems to have been metamorphosed after its emplacement in the granulite facies surroundings.

Therefore, it may well be said that the thermal gradient during the later phase metamorphism was such that the temperature increased eastwards from East Ongul Island to the Cape Omega area.

In this connection, it is noteworthy that the pink granite which is ubiquitously developed in the Cape Omega area occurs rarely in East Ongul Island. The metamorphism of the later phase may be closely related to the activity of the pink granite.

5. Conclusions

In this paper, the description of metamorphic rocks with the stable association of scapolite and plagioclase from the areas of Cape Omega and East Ongul Island have been given with the following results.

1) In the Cape Omega area, metabasites with the above-mentioned association crop out as irregularly shaped enclaves in the surrounding amphibolite facies metamorphites and pink granite.

2) In East Ongul Island, the association is observed in the feldspathic rock, which may have been emplaced or intruded in the granulite facies metamorphites.

3) Judging from the distribution relation of Ca and Na between coexisting scapolite and plagioclase, the metamorphic grade suggested by the association in the Cape Omega area may be the granulite facies, while that in East Ongul Island is of the amphibolite facies or lower.

4) In the Cape Omega area, the granulite facies metabasites have been sporadically preserved among the rocks metamorphosed under the amphibolite facies of the later phase. While, in East Ongul Island, the feldspathic rock has been metamorphosed after it was emplaced in the granulite facies metamorphites.

5) The metamorphism of the later phase had such a thermal structure that the temperature increased eastwards, from East Ongul Island to the Cape Omega area.

Acknowledgments

The author wishes to express his sincere gratitude to all of the members of JARE–18 for their kind assistances and cooperations throughout his field work. He is also indebted to Prof. George KOJIMA of Hiroshima University and to Associate Prof. Kanenori SUWA of Nagoya University for their critical discussions.

References

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

HAUGHTON, D. R. (1971): Plagioclase-scapolite equilibrium. Can. Mineral., **10**, 854–870.

HIETANEN, A. (1967): Scapolite in the belt series in the St. Joe-Clearwater region, Idaho. Geol. Soc. Am., Spec. Pap., **86**, 1–56.

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

RAVICH, M. G. and KAMENEV, E. N. (1975): Crystalline Basement of the Antarctic Platform. New York, John Wiley, 574 p.

SUWA, K. and TATSUMI, T. (1969): Pargasite and zincian spinel in calcareous metamorphic rocks from the Skallen district, east coast of Lützow-Holmbukta, East Antarctica. J. Geol. Soc. Jpn., **75**, 225–229.

SUZUKI, M. (1977): Polymetamorphism in the Hida Metamorphic Belt, central Japan. J. Sci. Hiroshima Univ., Ser. C, **7**, 217–296.

SUZUKI, M. (1979): Metamorphic and plutonic rocks in the Cape Omega area, East Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **14**, 128–139.

TATSUMI, T., KIKUCHI, T. and KIZAKI, K. (1964): Geology of the region around Lützow-Holmbukta and the "Yamato Mountains" (Dronning Fabiolafjella). Antarctic Geology, ed. by R. J. ADIE. Amsterdam, North-Holland, 293–303.

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

(Received January 9, 1979; Revised manuscript received April 28, 1979)