METABASITES OF THE CAPE OMEGA AREA, EAST ANTARCTICA

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Abstract: Metabasites in the Cape Omega area, the westernmost part of the Prince Olav Coast, are classified into two types, I and II. Type I contains clinopyroxene and Type II does not. Bulk chemical compositions of both types are characterized by the abundance in alkalies, especially Na_2O. The presence or absence of clinopyroxene is controlled by the bulk chemical composition, especially by the mole ratio of $CaO/(FeO^{*}+MgO+MnO)$. Hornblende in Type I is characterized by the abundance of Si and Al^{VI} and poverty of Ti and K compared with that in Type II. The petrological and mineralogical characteristics of metabasites of the region from the Prince Olav Coast to Lützow-Holm Bay show a systematic change, suggesting that the region has undergone westward progressive metamorphism.

1. Introduction

It has been insisted that the region from the Prince Olav Coast to Lützow-Holm Bay is progressive metamorphic terrain, where the metamorphic grade gradually increased westwards from the amphibolite facies to the granulite one (HIROI *et al.*, 1983; SHIRAISHI *et al.*, 1984; SUZUKI, 1984). Among the metamorphites in the region, metabasites are significant because of the ubiquitous distribution and the petrological sensitivity to the change of metamorphic grade. These metabasites are considered to have been derived from mafic to ultramafic igneous rocks, and show various kinds of lithofacies and modes of occurrence. Their petrologic significance, however, has not yet been clarified. In this paper, the mode of field occurrence, petrographical and mineralogical characteristics of metabasites in the Cape Omega area of the Prince Olav Coast will be given. After that the regional variations of petrological features of metabasites are presented from the viewpoint of the progressive metamorphism in the region concerned.

2. Geologic Outline

The Prince Olav Coast is situated to the east of Lützow-Holm Bay. Metabasites in the Lützow-Holm Bay region commonly include orthopyroxene, clinopyroxene, hornblende with or without plagioclase and quartz (YOSHIDA, 1978; SUZUKI, 1983). Meanwhile, those in the Prince Olav Coast usually contain no orthpyroxene except for the specimens which have such an extraordinary bulk chemistry characterized by the abundance of Al and Fe^{2+} or by the poverty of Al as shown by SHIRAISHI *et al.*

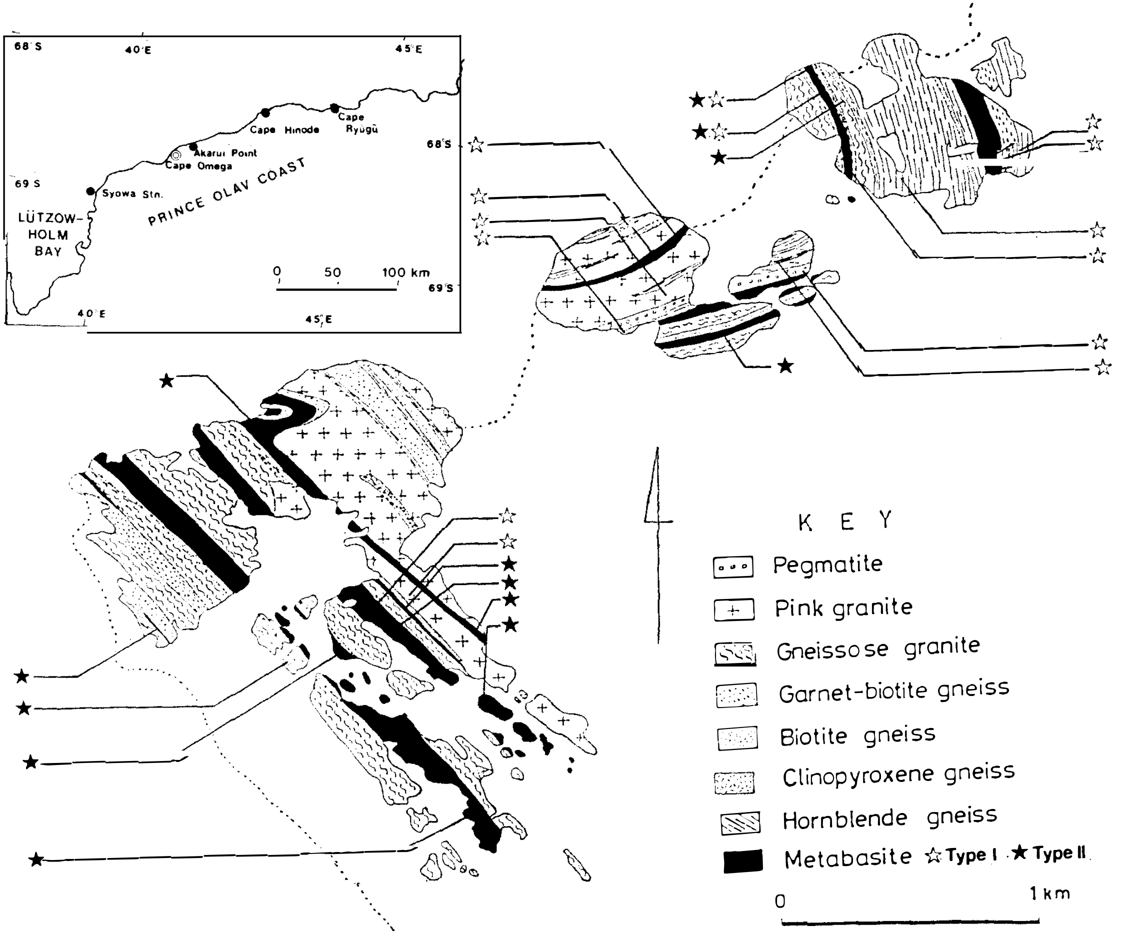


Fig. 1. Geological map of the Cape Omega area and location map of the discussed areas in the region from Lützow-Holm Bay to the Prince Olav Coast (inset).

(1984). According to them, the occurrence of orthopyroxene in the Prince Olav Coast is restricted to its western part.

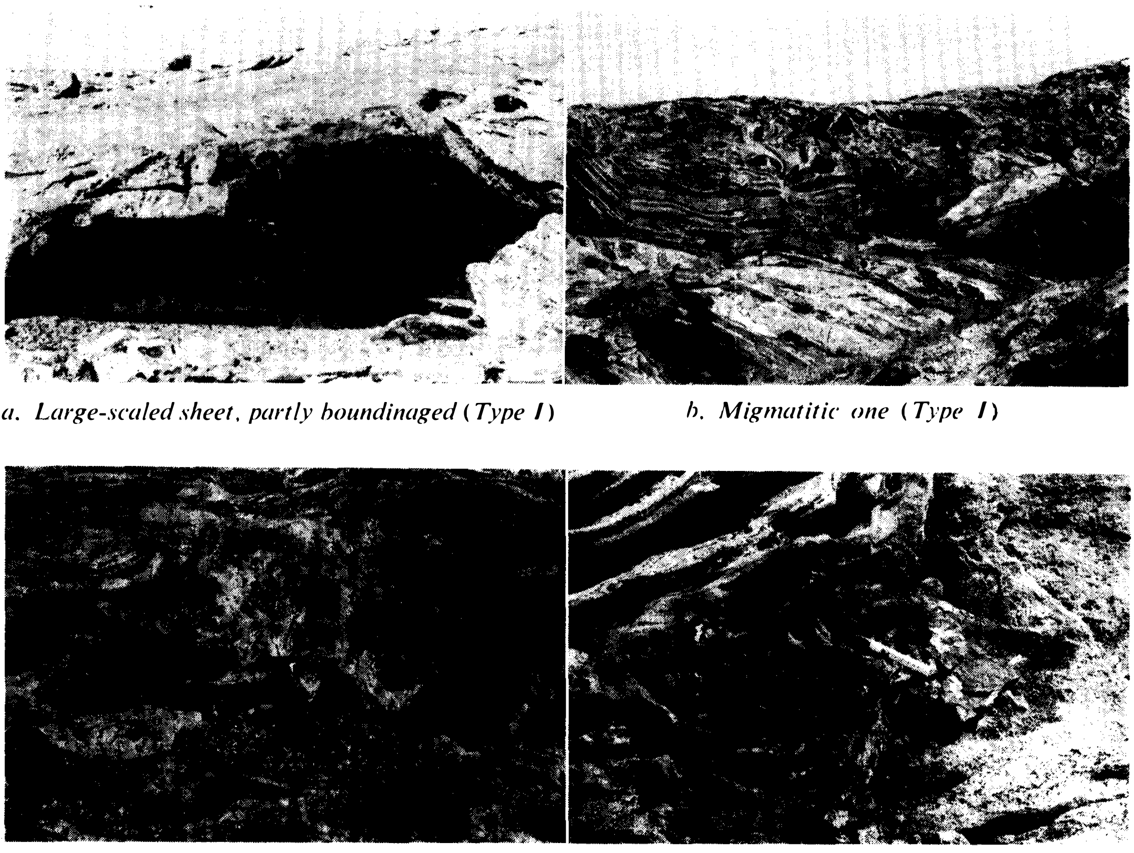
In the Cape Omega area, which is situated in the westernmost part of the Prince Olav Coast, are widely developed metamorphites originated from pelitic to psammitic, basic to intermediate and calcareous sedimentary equivalents (Fig. 1). Plutonic rocks are chiefly constituted by gneissose granite with a concordant appearance. Pink granite closely associated with pegmatite occurs showing a discordant appearance, each of which is considered to have been active during the Queen Maud orogeny of around 500 Ma ago. Metabasites commonly occur in the surrounding gneisses and granitic rocks. The metamorphic conditions of the Cape Omega area are summarized by SUZUKI (1984). According to him, some metapelites in the area have the association of orthopyroxene-garnet-biotite and Mg-cordierite-sillimanite-biotite. On the basis of the stability relationship among the above-mentioned metamorphic minerals, it is concluded that the *P-T* condition is around 680°C, 5 kb and is of the transitional grade from the amphibolite facies to the granulite facies. There seems to be no distinct tendency of gradual change in metamorphic grade within the Cape Omega area.

3. Metabasites of the Cape Omega Area

3.1. *Classification and field occurrence*

By the difference of the main constituent minerals, metabasites in the area can be classified into two types, I and II. Type I contains clinopyroxene but Type II does not. SUZUKI (1979) once described the metamorphic rocks in the Cape Omega area and included scapolite-bearing garnet-clinopyroxene rocks named eclogitic rock into the category of metabasites. Judging from the chemical compositions of constituent minerals, however, they must be highly rich in CaO in comparison with the ordinary mafic to ultramafic igneous rocks. Therefore, it is more preferable to consider that the rocks do not belong to the members of metabasites but to the calc-silicate rocks.

Metabasites in the Cape Omega area show various modes of field occurrence (Fig. 2). In a common case, they show sheet-like and boudinage appearance, the maximum thickness of which attains to 5 m. They sometimes occur as irregularly-shaped bodies with a migmatitic appearance closely associated with gneissose granite. They also occur as ball-like bodies of some tens of centimeters in diameter included in the surrounding gneisses and granitic rocks. It seems that there exists no clear correlation between the modes of field occurrence and the rock types mentioned above. However, Type II metabasites tend to occur in the western part of the area,



a. Large-scaled sheet, partly boundinaged (Type I) *b. Migmatitic one (Type I)*

c. Migmatitic one (Type II) *d. Ball-like one (Type II)*

Fig. 2. Photographs showing the modes of occurrence of metabasites.

where gneissose granite is widely developed. Meanwhile, Type I ones overlie more in the eastern part (Fig. 1).

Type I is composed mainly of clinopyroxene, brown to green hornblende, biotite, plagioclase and quartz. K-feldspar usually accompanies. Accessory minerals are sphene, apatite, zircon, ilmenite and magnetite. Under the microscope, medium-grained granoblastic texture is characteristic. Some grains of clinopyroxene and hornblende have altered to colorless amphibole from their margins and along the cleavages. Sometimes fine-grained biotite is recrystallized replacing hornblende.

Main constituent minerals of Type II are brown to green hornblende, biotite, plagioclase and quartz. K-feldspar is rarely found. As accessory minerals, apatite, zircon, magnetite and ilmenite occur, but sphene is often lacking. Microscopically, medium-grained granoblastic texture is developed. Brown to green hornblende is commonly altered to colorless amphibole and fine-grained biotite from its margin and along the cleavages as in the case of Type I.

3.2. *Bulk chemical compositions*

Bulk chemical compositions were analyzed for 6 specimens of Type I and 4 of Type II (Table 1). The SiO_2 content ranges from 43.05 to 54.80% for Type I, and 44.57 to 48.87 for Type II. The values of mg and Fe_2O_3/FeO ratios of both types are very similar to each other. Namely, the ranges of the mg values are 0.57–0.73 in Type I and 0.53–0.71 in Type II, and those of the Fe_2O_3/FeO ratios are 0.25–0.61 in Type I and 0.24–0.69 in Type II.

It is distinct that both types are generally rich in Na_2O+K_2O, almost all plotted in the alkali basalt region on the alkali-silica diagram (Fig. 3). However, some of Type I, which carry more than 50 wt% of SiO_2, are plotted in the tholeiite region. The TiO_2 content is not so different between the two types. The mole CaO/

Table 1. Bulk chemical compositions of metabasites from Cape Omega, East Antarctica.

	Type I						Type II			
	10603	10624	10626	10707	10807	10818	10605	10608	10704	10712
SiO_2	52.33	54.80	47.82	51.16	49.87	43.05	48.80	44.57	48.87	45.96
TiO_2	0.65	0.86	1.45	1.64	2.22	0.91	1.09	1.29	1.27	2.44
Al_2O_3	13.27	15.25	17.69	15.73	14.90	17.06	15.41	12.14	16.26	14.07
Fe_2O_3*	2.72	2.44	3.72	2.16	4.67	4.36	1.88	7.09	4.66	5.01
FeO**	5.60	4.95	7.26	8.52	7.67	10.20	7.69	10.28	7.06	10.10
MnO	0.27	0.26	0.27	0.24	0.36	0.42	0.26	0.60	0.37	0.37
MgO	8.47	6.17	6.58	6.44	6.54	7.49	10.36	10.82	7.11	6.49
CaO	10.36	9.38	11.30	10.31	8.88	15.24	9.83	10.77	8.40	10.62
Na_2O	3.21	4.62	3.15	2.14	3.81	1.08	2.56	1.70	3.90	2.45
K_2O	1.37	1.12	1.02	0.88	1.30	0.90	1.83	1.18	1.56	1.29
Total	98.25	99.85	100.26	99.22	100.22	100.71	99.71	100.44	99.46	98.80
mg	0.73	0.69	0.62	0.57	0.60	0.57	0.71	0.65	0.64	0.53
Fe_2O_3/FeO	0.49	0.49	0.51	0.25	0.61	0.43	0.24	0.69	0.66	0.50

* 1.111X (Total Fe as FeO–FeO**)

** Determined by $KMnO_4$ titrimetry

Analyst: M. SUZUKI

(FeO*+MgO+MnO) ratio of Type I is in the range of 0.63 to 0.81, averaging 0.69, while the ratio of Type II is as low as 0.48 to 0.62, averaging 0.53. Figure 4 is the ACF diagram showing the chemical difference between the two types. All specimens analyzed bear quartz. As easily be seen from the figure, Type I metabasite (clinopyroxene-bearing) are comparatively rich in CaO, plotted on the left-side of the tschermakite-actinolite tie line, whereas Type II ones (clinopyroxene-free) are on the

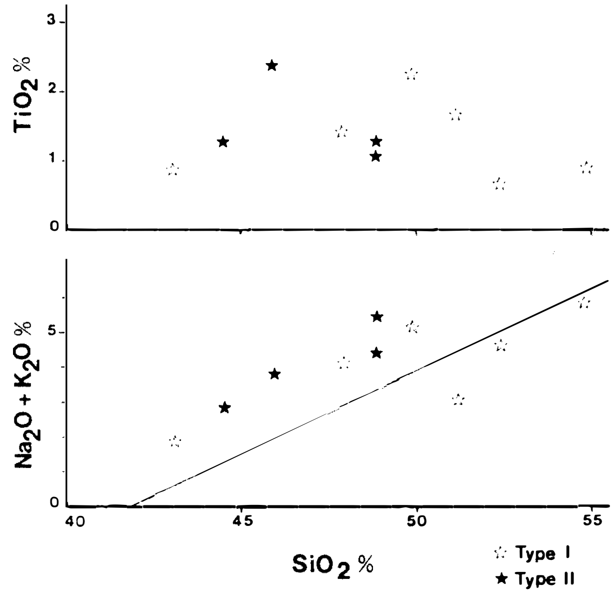


Fig. 3. TiO_2-SiO_2 and (Na_2O+K_2O)-SiO_2 diagram of metabasites in the Cape Omega area. A line in the lower diagram indicates a boundary between alkali basalts and tholeiitic basalts defined by MACDONALD *and* KATSURA *(1964).*

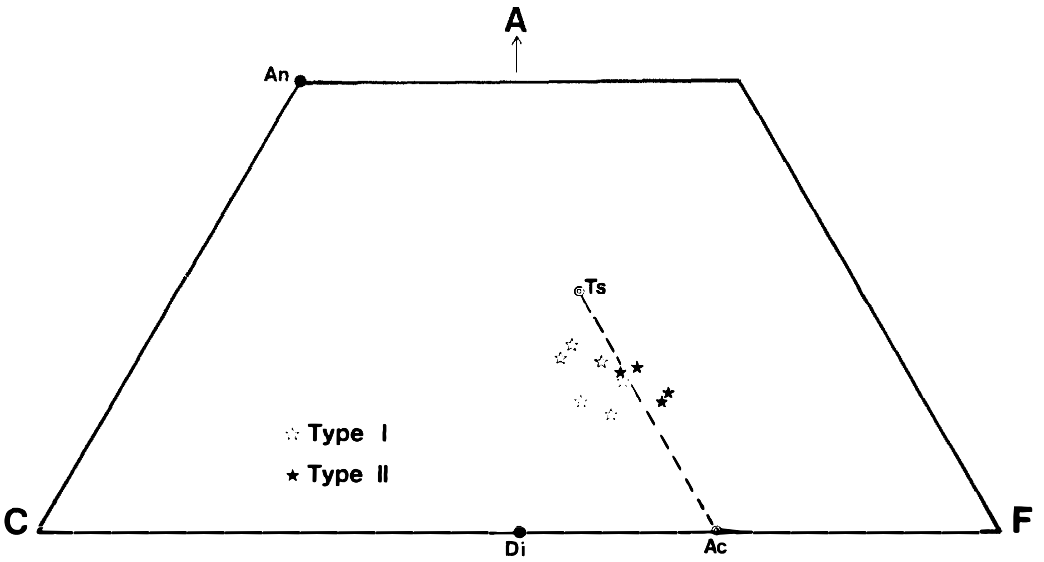


Fig. 4. ACF diagram showing the chemical difference between Type I and Type II metabasites. Ac, An, Di and Ts represent actinolite, anorthite, diopside and tschermakite, respectively.

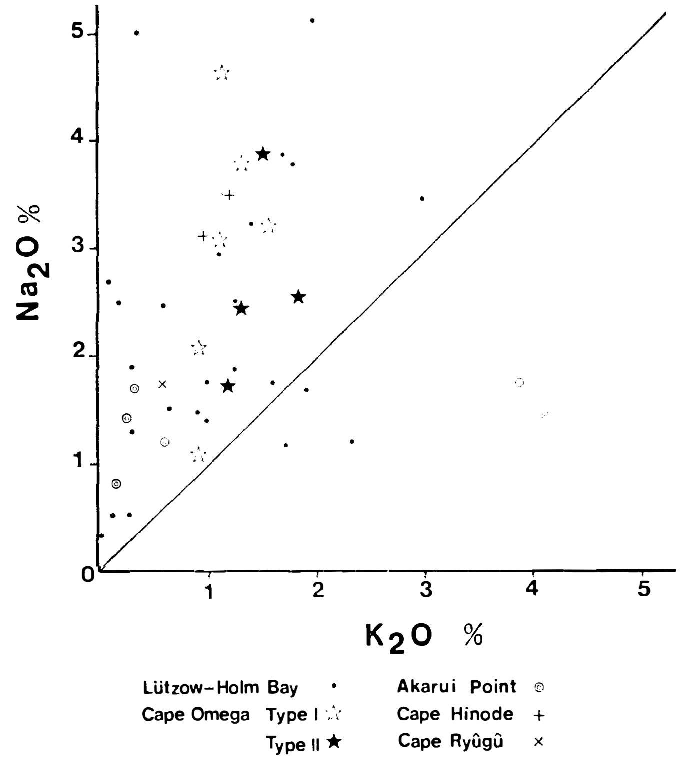


Fig. 5. K_2O-Na_2O diagram of metabasites. Source of data: Lützow-Holm Bay (Yoshida, 1978), Cape Omega (this work), Akarui Point (Kanisawa et al., 1983), Cape Hinode (Kanisawa et al., 1979b) and Cape Ryûgû (Nakai et al., 1980).

right-side. As mentioned before, the metamorphic grade seems to have no tendency to change within the narrow area of Cape Omega. Therefore, it may well be said that the difference between Types I and II, namely the presence or absence of clinopyroxene, is controlled by the bulk chemical composition.

Next, the abundance of alkalies of metabasites is worthy of note. Kanisawa *et al.* (1979b) pointed out that metabasites of the Lützow-Holm Bay region were generally rich in Na_2O, and that those of Cape Hinode in the Prince Olav Coast had the same tendency. As can be seen from Fig. 5, the metabasites of the Cape Omega area have also relatively high contents of Na_2O. Concerning the K_2O/Na_2O ratios, there is no distinct difference between Types I and II. It is interesting that almost all of metabasites of Lützow-Holm Bay and the Prince Olav Coast are plotted in the upper part of the 1 : 1 line in the figure.

3.3. *Mineralogy*

Such main constituent minerals as clinopyroxene, plagioclase and hornblende are analyzed by means of an electron probe microanalyzer. The representative analyses are given in the Appendix.

Clinopyroxene of Type I metabasites has the composition of $Ca_{47.4\text{-}50.5}Mg_{33.2\text{-}38.3}Fe_{13.8\text{-}19.4}$, plotted in the narrow region of salite (Fig. 6). The mg values range from 0.63 to 0.73. The TiO_2 and Al_2O_3 contents are rather low ranging from 0.03 to 0.22

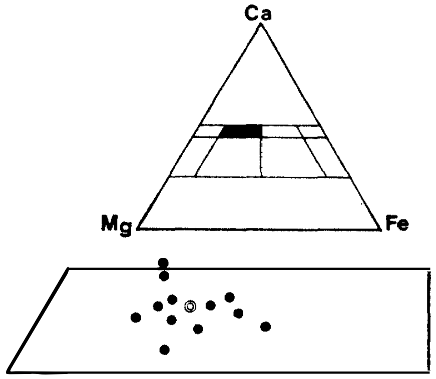


Fig. 6. Compositions of clinopyroxene in metabasites in terms of Ca, Mg and Fe.
Solid circle: Cape Omega (this work).
Double circle: Cape Hinode (Kanisawa and Yanai, 1982).

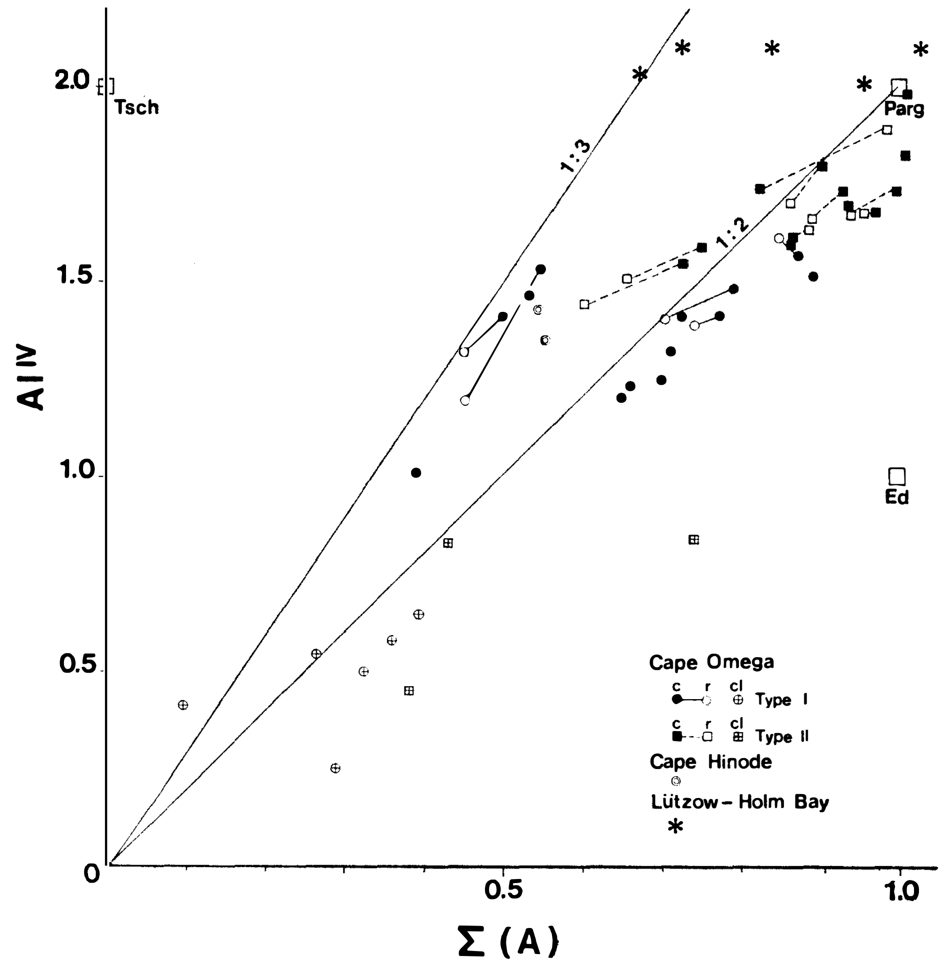


Fig. 7. Relationship between total (A) and Al^{IV} of amphiboles in metabasites. r and c mean rim and core parts of amphibole, respectively. cl means colorless amphibole. Ed, Parg and Tsch represent edenite, pargasite and tschermakite end members, respectively. Souce of data: Lützow-Holm Bay (Kanisawa et al., 1979a), Cape Omega (this work) and Cape Hinode (Kanisawa and Yanai, 1982).

and from 0.56 to 1.74, respectively. As shown in Fig. 6, the composition of clinopyroxene discussed here seems to be similar to that from Cape Hinode of the Prince Olav Coast.

In common cases, plagioclase in both types of metabasites from Cape Omega is weakly zoned. Usually, the rim part of each grain is rather rich in An, though the difference in the An content between core and rim parts is as low as within 5%. In Type I, the An contents of core and rim parts range from 19 to 28 and from 20 to 29, repsectively. Type I has only one exception (Sp. No. 10707), which contains plagioclase with higher An content around 50. In Type II, the An contents of core and rim parts in each grain range from 27 to 52 and 29 to 53, respectively. Generally speaking, it seems that there exists a range difference of the An content between both types, namely plagioclase in Type I is more sodic than that in Type II.

Hornblende in metabasites from the Cape Omega area commonly shows *Z*-axial color of brownish green to greenish brown. As mentioned before, each grain tends to be altered from its margin and along its cleavage to colorless to pale green amphibole. Judging from the texture, the amphiboles must be of retrograde origin. The chemical characteristics of hornblendes and colorless to pale green amphiboles are shown in Figs. 7 to 10. As can be seen from Fig. 7, hornblendes in Type I are poorer in Al^{IV} and total (A) than those in Type II. In both types, hornblende generally shows chemical zoning, the core part of each grain being commonly richer in Al^{IV} and total (A) than the rim part. Figure 8 is the Al^{VI}-Si diagram. Hornblendes in Type I are richer in Al^{VI} and Si than those in Type II. The general tendency of chemical zoning in each grain concerning Al^{VI} and Si cannot be observed. Figure 9 shows the relationship between the Ti content and the mg value. As for the mg value, horn-

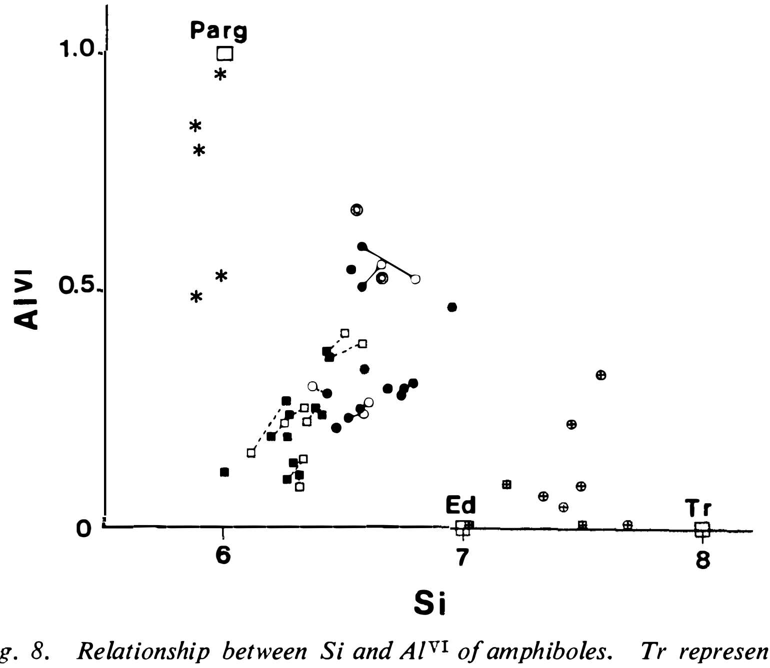


Fig. 8. Relationship between Si and Al^{VI} of amphiboles. Tr represents tremolite end member. Other abbreviations, symbols and source of data are as in Fig. 7.

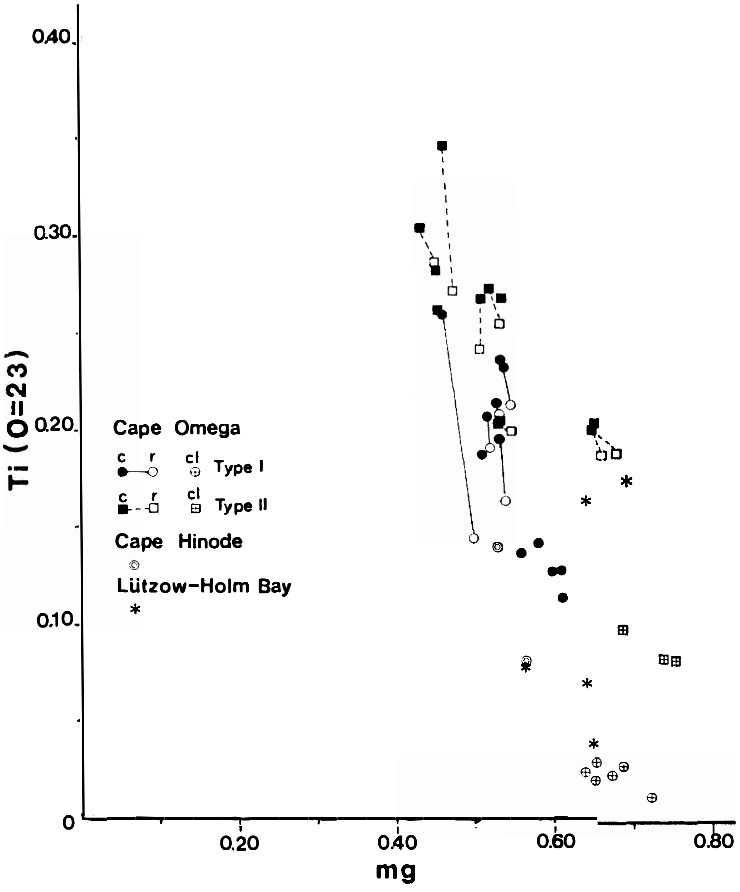


Fig. 9. Relationship between the mg value and the Ti content of amphiboles. Source of data as in Fig. 7.

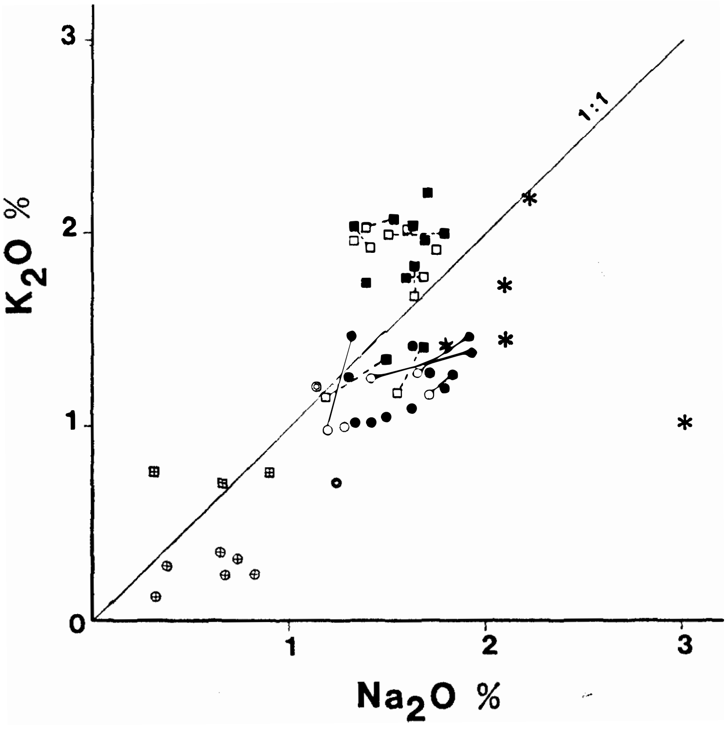


Fig. 10. K_2O-Na_2O diagram of amphiboles. Symbols and source of data as in Fig. 9.

blendes in both types are not so different with each other, but the Ti content is generally lower in Type I than in Type II. The core part of each grain in both types is usually richer in Ti than the rim part. As mentioned before, Type I metabasites usually contain sphene but Type II ones do not. The difference in the Ti content between the two types may depend partly on this fact. Moreover, it may essentially be connected with the progress of Ti-tschermakite substitution in hornblendes of Type II.

Hornblendes in Type I are apparently rather poorer in K_2O than those in Type II, plotted under the 1:1 line (Fig. 10). The bulk chemistry concerning the alkalies of both types is rather similar (Figs. 3 and 5). As already shown above, plagioclase in Type I is, in general, more sodic than that in Type II. The Na(M4) content in hornblende in Type I is rather higher than that in Type II (Appendix Tables A-2 to A-3). Therefore, the Na-Ca partition seems to be consistent between Types I and II. Thus, in Type I metabasites, apparently low K content in hornblende may be controlled by the relatively high content of Na(M4) in hornblende.

All things considered, hornblendes in Type I metabasites have the following chemical characteristics in comparison with those in Type II;

1. rich in Si (poor in Al^{IV})
2. poor in Ti (rich in Al^{VI})
3. poor in K (rich in Na (M4)).

As can be seen in Figs. 7 and 8, colorless amphiboles in both types of metabasites are rich in the tremolitic component. Moreover, it must be noted that the chemical tendency of hornblende mentioned above is also maintained in colorless amphibole of retrograde origin in both types (Figs. 7 to 10).

4. Discussion

In this section, the regional change of petrological and mineralogical characteristics of metabasites will be discussed from the viewpoint of progressive metamorphism in the region from the Prince Olav Coast to Lützow-Holm Bay.

Concerning the bulk chemical composition of metabasites in the region, the abundance of alkalies, especially Na_2O is commonly characteristic as mentioned before. It is also marked that the Fe_2O_3/FeO ratio is gradually changed. As shown in Fig. 11, the Fe_2O_3/FeO ratio tends to decrease from the eastern part of the Prince Olav Coast toward Lützow-Holm Bay. In Cape Ryûgû, Cape Hinode and Akarui Point, the mean values of Fe_2O_3/FeO are 1.65, 0.94, 0.59, respectively. In the Cape Omega area, the value becomes as low as 0.49. After that, in the Lützow-Holm Bay region, metabasites tend to have lower ratios, though scattered, the mean value of which is around 0.32. As already stated by MIYASHIRO (1973) and KANISAWA *et al.* (1979b), the Fe_2O_3/FeO ratio of metabasites has the tendency to become lower as the metamorphic grade increases. This may partly be due to the progress of dehydration reactions with the increase of the metamorphic grade. The gradual decrease of the ratio westward in the region concerned suggests the westward progressive change of metamorphic grade. Two specimens from Naga-iwa Rock (about 15 km east of Cape Omega) contain orthopyroxene (SHIRAISHI *et al.*, 1984). It is worthy of note that they have rather lower Fe_2O_3/FeO ratios (0.21 and 0.30) than the average value in Cape Omega.

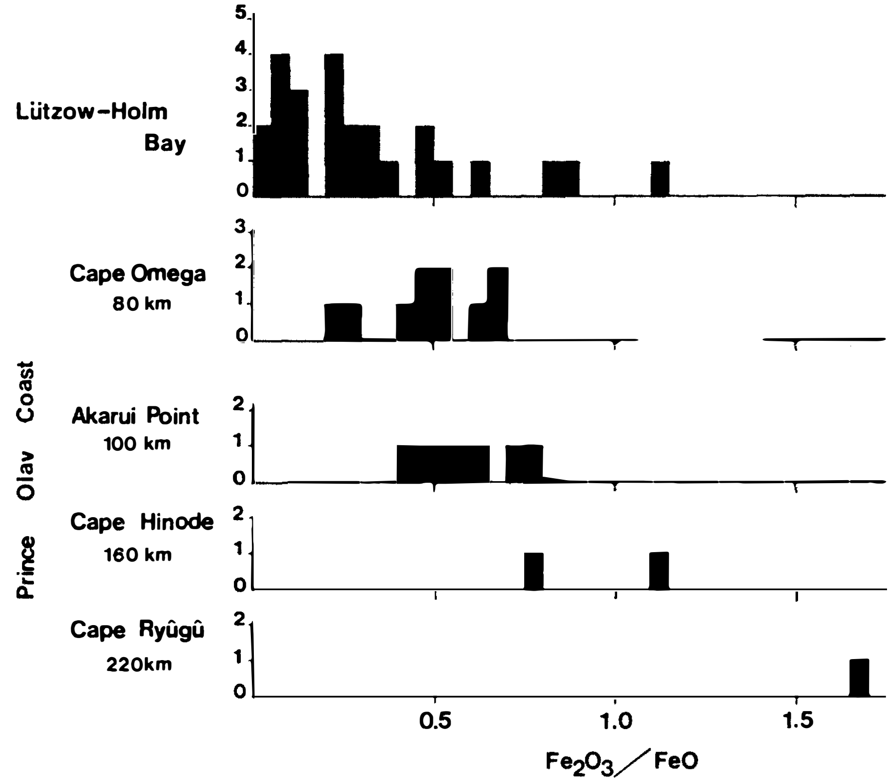


Fig. 11. *Fe_2O_3/FeO variation of metabasites in the region from Lützow-Holm Bay to Prince Olav Coast. Numbers (km) below locality names refer to the distance eastward from Syowa Station, Lützow-Holm Bay. Source of data as in Fig. 5.*

The lower values in the specimens may be connected with the appearance of orthopyroxene.

Next, the regional variation in the chemical composition of hornblende will be discussed. As is apparent in Fig. 7, hornblendes in the region from Cape Hinode through Cape Omega to Lützow-Holm Bay, have the 2:1 relation between total (A) and Al^{VI}. The compositions seem to become more pargasitic westward. Figure 8 apparently shows that the composition of hornblende becomes Si-poorer from the Prince Olav Coast to Lützow-Holm Bay. On the other hand, the relationship between Al^{IV} and Al^{VI} is not 2 : 1 (Fig. 8). It can be explained from Fig. 9 by the effect of Ti concentration in M1–M3 sites especially in Type II. It may be controlled by the progress of the Ti-tschermakite substitution. All things considered, the gradual change in hornblende composition in the area can be characterized by the tremolite →pargasite substitution, which may support the increase of metamorphic grade, and partly by the Ti-tschermakite substitution.

Thus, the gradual change in the Fe_2O_3/FeO ratio of the bulk chemical composition and in hornblende compositions may support the westward increase of metamorphic grade in the region.

In the region discussed, original rocks of metamorphites, as can be seen in the case of metabasites, have no clear distinction in their petrological characteristics among the respective areas, and they might have been derived from continuous and cognate rocks with similar tectonic setting. As shown by Yanai *et al.* (1983), the Sr-initial ratio of metamorphites around Lützow-Holm Bay is as low as 0.70480±0.00016. Therefore, they must have been emplaced in the metamorphic field soon after the formation of original rocks and they were not connected with the Archean Napier complex or its rejuvenated complex but were derived from younger rocks. Thus, the metamorphites from Lützow-Holm Bay to the Prince Olav Coast as a whole have originated from the rocks younger than the older ones of Napier complex and its equivalents.

5. Conclusion

Based upon the investigations on petrological and mineral characteristics of metabasites of Cape Omega and upon the comparison with metabasites in the region from the Prince Olav Coast to Lützow-Holm Bay, the author has come to the following conclusions.

1) The metabasites in Cape Omega can be classified into two types, I (clinopyroxene-bearing) and II (clinopyroxene-free). The difference between the two types is due to the difference of the bulk chemical compositions, especially of the mole $CaO/(FeO^*+MgO+MnO)$ ratio.

2) The metabasites in Cape Omega are rich in alkalies, especially Na_2O. This character is common among the metabasites of the region from the Prince Olav Coast to Lützow-Holm Bay.

3) The metabasites of the above-mentioned region seem to gradually change their petrological and mineralogical characteristics westward, which supports the idea that the metamorphic grade progressively increases westward.

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Appendix

Table A-1. Representative chemical compositions of clinopyroxenes in Type I metabasites.

	1	2	3	4	5
SiO_2	52.81	50.91	51.59	52.22	52.09
TiO_2	0.15	0.22	0.03	0.09	0.21
Al_2O_3	1.26	1.09	0.56	0.74	1.74
FeO*	8.36	10.71	9.07	11.79	10.16
MnO	0.72	0.78	0.63	0.52	0.70
MgO	12.11	11.72	13.91	11.33	11.91
CaO	23.86	23.11	24.08	22.45	23.00
Na_2O	0.71	0.75	0.46	0.18	1.04
K_2O	0.02	0.02	0.04	0.01	0.01
Total	100.00	99.31	100.37	99.33	100.86
O	6.000	6.000	6.000	6.000	6.000
Si	1.981	1.950	1.943	1.992	1.953
Ti	0.004	0.006	0.001	0.003	0.006
Al	0.056	0.049	0.025	0.033	0.077
Fe	0.262	0.343	0.286	0.376	0.319
Mn	0.023	0.025	0.020	0.017	0.022
Mg	0.677	0.669	0.781	0.644	0.665
Ca	0.959	0.948	0.972	0.918	0.924
Na	0.051	0.055	0.034	0.013	0.075
K	0.001	0.001	0.002	0.001	0.000

1: 10603, 2: 10623, 3: 10624, 4: 10707, 5: 10807

* Total Fe as FeO

Table A-2. Representative chemical compositions of hornblende in Type I.

	1	2	3	4	5	6	7
SiO_2	45.32	44.05	42.83	44.09	45.32	42.43	42.26
TiO_2	1.02	1.68	1.21	2.13	1.95	1.71	1.45
Al_2O_3	8.59	9.91	9.71	11.01	10.88	10.38	10.66
FeO*	14.29	17.56	16.80	15.94	15.94	16.70	16.95
MnO	0.51	0.70	0.41	0.36	0.32	0.45	0.36
MgO	12.68	10.25	12.16	10.29	10.50	10.73	11.20
CaO	12.03	11.69	11.41	11.44	11.49	12.00	12.18
Na_2O	1.42	1.79	1.64	1.36	1.29	1.94	1.62
K_2O	1.08	1.22	1.43	1.03	1.02	1.45	1.28
Total	96.94	98.85	97.60	97.65	98.71	97.79	97.96
O	23.000	23.000	23.000	23.000	23.000	23.000	23.000
Si	6.786	6.589	6.485	6.583	6.671	6.429	6.388
Al^{IV}	1.214	1.411	1.515	1.417	1.329	1.571	1.612
(Tet)	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{VI}	0.303	0.337	0.219	0.520	0.558	0.283	0.288
Fe	1.687	2.099	1.845	1.952	1.923	2.098	2.024
Mg	2.830	2.286	2.745	2.289	2.304	2.424	2.523
Ti	0.115	0.189	0.138	0.239	0.215	0.195	0.165
Mn	0.065	0.089	0.053	—	—	—	—
(M1-M3)	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Ca	1.897	1.875	1.718	1.830	1.812	1.925	1.843
Mn	—	—	—	0.045	0.039	0.057	0.047
Fe	0.103	0.098	0.282	0.039	0.039	0.018	0.119
Na	—	0.027	—	0.086	0.110	—	—
(M4)	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Ca	0.033	—	0.133	—	—	0.023	0.130
Na	0.412	0.492	0.480	0.306	0.257	0.570	0.474
K	0.207	0.233	0.276	0.195	0.192	0.280	0.248
(A)	0.652	0.725	0.889	0.501	0.449	0.873	0.852
mg	0.61	0.51	0.56	0.54	0.54	0.53	0.54

1: I0603-C, 2: I0623-C, 3: I0624-C, 4: I0707-C, 5: I0707-R, 6: I0807-C, 7: I0807-R
(C and R mean core and rim parts, respectively)
* Total Fe as FeO

Table A-3. Representative chemical compositions of hornblende in Type II.

	1	2	3	4	5	6	7	8
SiO_2	43.97	44.80	41.78	42.55	42.14	41.15	40.92	42.07
TiO_2	1.90	1.70	1.89	1.98	2.43	2.26	3.02	2.42
Al_2O_3	11.22	11.11	11.10	10.88	10.39	10.92	11.09	10.89
FeO*	12.94	12.45	17.34	17.10	17.79	17.83	19.08	19.22
MnO	0.38	0.34	0.56	0.61	0.57	0.68	0.42	0.43
MgO	13.47	13.83	11.02	11.03	10.69	11.09	9.02	9.41
CaO	12.16	12.33	12.14	12.17	12.28	12.07	12.33	12.40
Na_2O	1.64	1.36	1.60	1.69	1.65	1.62	1.55	1.38
K_2O	1.40	1.16	1.77	1.76	2.04	2.04	2.07	2.07
Total	99.08	99.08	99.20	99.77	99.98	99.66	99.50	100.29
O	23.000	23.000	23.000	23.000	23.000	23.000	23.000	23.000
Si	6.427	6.505	6.276	6.340	6.308	6.192	6.201	6.305
Al^{IV}	1.573	1.495	1.724	1.660	1.692	1.808	1.799	1.695
(Tet)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{VI}	0.361	0.407	0.241	0.251	0.141	0.129	0.182	0.229
Fe	1.498	1.414	2.080	2.079	2.201	2.127	2.419	2.396
Mg	2.933	2.993	2.466	2.449	2.385	2.488	2.038	2.102
Ti	0.208	0.186	0.213	0.221	0.273	0.256	0.344	2.273
Mn	—	—	—	—	—	—	0.017	—
(M1-M3)	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Ca	1.870	1.860	1.829	1.873	1.902	1.796	1.963	1.932
Mn	0.046	0.042	0.072	0.076	0.072	0.087	0.037	0.054
Fe	0.084	0.098	0.099	0.051	0.026	0.117	—	0.014
Na	—	—	—	—	—	—	—	—
(M4)	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Ca	0.034	0.059	0.125	0.070	0.068	0.151	0.039	0.060
Na	0.465	0.382	0.467	0.489	0.480	0.472	0.457	0.400
K	0.261	0.215	0.339	0.335	0.389	0.391	0.400	0.397
(A)	0.760	0.656	0.931	0.894	0.937	1.014	0.896	0.857
mg	0.65	0.66	0.53	0.53	0.52	0.53	0.46	0.47

1: 10605-C, 2: 10605-R, 3: 10608-C, 4: 10608-R, 5: 10704-C, 6: 10704-R, 7: 10712-C, 8: 10712-R

* Total Fe as FeO

Table A-4. Representative chemical compositions of colorless amphiboles in Types I and II.

	1	2	3	4	5
SiO_2	51.15	52.90	52.23	51.51	50.47
TiO_2	0.20	0.11	0.23	0.21	0.78
Al_2O_3	4.46	1.53	4.39	3.50	5.44
FeO*	13.52	11.83	13.60	13.38	10.89
MnO	0.67	0.47	0.34	0.52	0.52
MgO	14.03	17.45	13.88	15.28	17.17
CaO	12.73	12.13	12.18	12.32	12.77
Na_2O	0.65	0.32	0.36	0.81	0.66
K_2O	0.35	0.14	0.28	0.24	0.70
Total	97.76	96.88	97.49	97.77	99.40
O	23.000	23.000	23.000	23.000	23.000
Si	7.457	7.683	7.579	7.496	7.181
Al^{IV}	0.543	0.262	0.421	0.504	0.819
(Tet)	8.000		8.000	8.000	8.000
Al^{VI}	0.223	—	0.330	0.097	0.093
Fe	1.624	1.153	1.643	1.567	1.182
Mg	3.049	3.778	3.002	3.313	3.641
Ti	0.021	0.012	0.025	0.023	0.084
Mn	0.083	0.057	—	—	—
(M1-M3)	5.000	5.000	5.000	5.000	5.000
Ca	1.976	1.716	1.894	1.875	1.824
Mn	—	—	0.041	0.064	0.062
Fe	0.024	0.284	0.008	0.061	0.114
Na	—	—	0.057	—	—
(M4)	2.000	2.000	2.000	2.000	2.000
Ca	0.013	0.171	—	0.046	0.123
Na	0.185	0.091	0.046	0.227	0.183
K	0.065	0.026	0.052	0.045	0.128
(A)	0.263	0.288	0.098	0.318	0.434
mg	0.65	0.72	0.65	0.67	0.74

Type I; 1: 10623, 2: 10624, 3: 10707, 4: 10807, Type II; 5: 10608

* Total Fe as FeO