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Cortlandtite from Tomiyama-mura, Aichi Prefecture, Japan*

——A Contribution to the Genesis of Cortlandtites in the Ryôke Zone——

By

Toshio KUTSUKAKE

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Abstract

Cortlandtite occurs as a small stock-like mass in the gneiss in the present area. It is composed mainly of poikilitic hornblende, olivine and orthopyroxene as primary constituents. Secondary minerals are spinel (pleonaste), colourless amphibole, actinolite, anthophyllite, chlorite, muscovite, prehnite and others.

This rock must have been formed as a cumulate through the crystallization of a basic magma, under relatively high water-vapour pressure as well as solid-pressure up to about 7 kb, corresponding to the middle crust under the Ryôke zone. This mother basic magma would have crystallized to the norites in the Ryôke zone.

It has been intruded into the gneiss in solid-state after the culmination of the Ryôke regional metamorphism. At the time of upsidence, it suffered the retrogressive metamorphism from the amphibolite facies, through the greenschist facies to more lower facies.

Introduction

In the Ryôke zone, there occur cortlandtites as small independent mass and/or as local facies of the olivine norite masses. It is sole ultrabasic rock, so far reported from the Ryôke zone (RESEARCH GROUP OF PERIDOTITE INTRUSION, 1967). Cortlandtites have been described from several localities, such as Osafuji-mura (YAGI, 1944), Kimen-san (YOSHIZAWA, 1951) and Zenifudô (KAWATA and YAMADA, 1957) in the Chûbu district, Mitsue-mura (SUWA, 1961) and Amano-kagu-yama (HIRAYAMA and KISHIMOTO, 1957) in the Kinki district, and Kaji-shima (YOSHIMURA, 1940) in the Setouchi district.

Since the name "cortlandtite" was adopted to this type of rock by WILLIAMS (1886), genetical discussions on this rock have been contended hitherto. Now it is generally accepted that the rock was formed by the accumulation of early crystallized minerals from a basic magma under high water-vapour pressure and thereafter suffered deuteric alteration. However, it is not settled so far as to the genesis and geological meanings of these rocks in the Ryôke zone.

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During field work on the Ryôke metamorphic rocks in this area, the present author found a small mass of cortlandtite. In this paper, he describes its mode of occurrence, petrography, chemistry and mineralogy, and discusses its genetical nature and metamorphism.
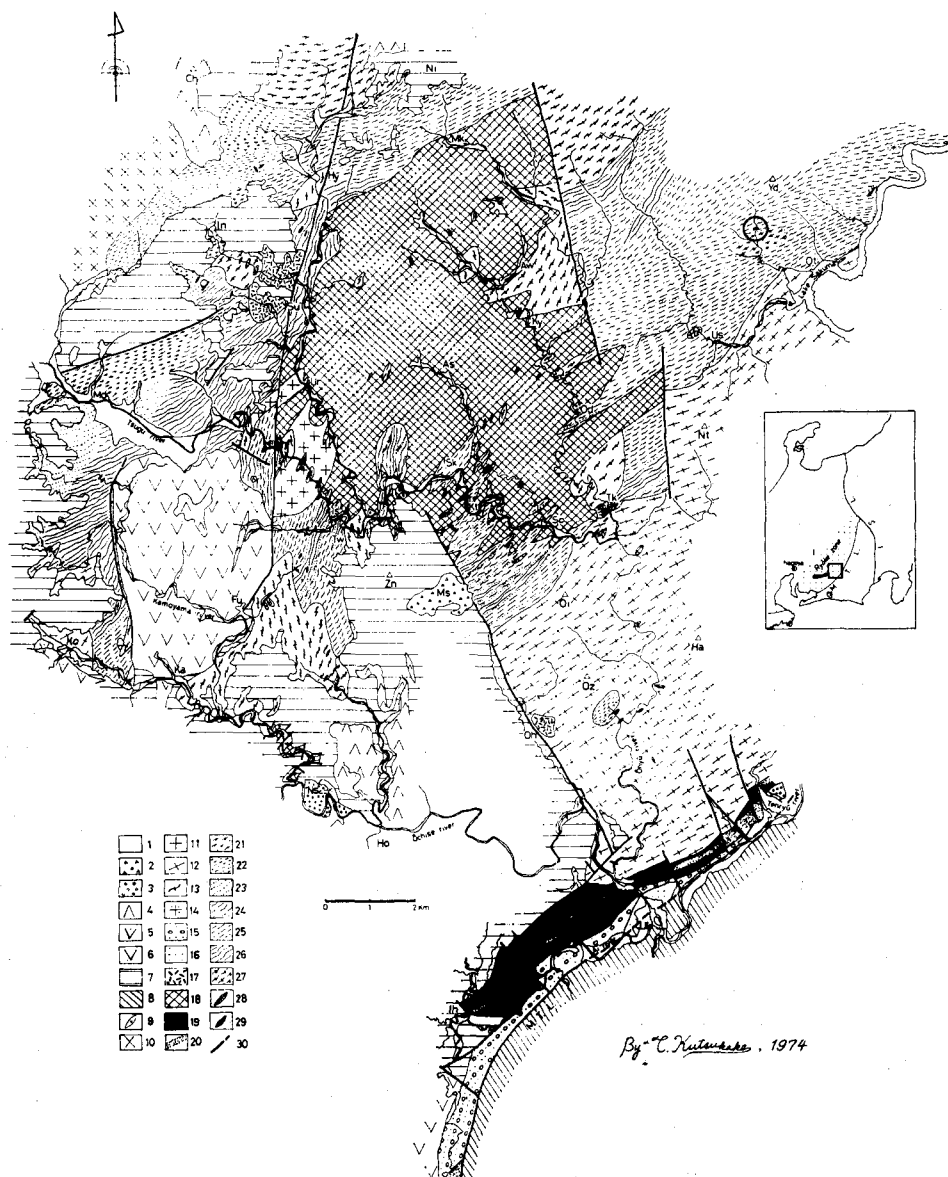

Fig. 1.

Geological outline

Tomiyama-mura is adjacent to Toyone-mura, and the general geology of this area has already been reported (KUTSUKAKE, 1975, 1976a, 1977). This area consists mainly of gneisses of sedimentary origin and the Tenryûkyô granite of harmonic concordant. General trend is E–W~N70°E. Geological map is shown in Fig. 1. Metamorphism is characterized by the transition of andalusite to sillimanite in pelitic rocks, and belongs to zone IIa of KUTSUKAKE (1977), corresponding to the first sillimanite zone of HAYAMA (1964).

Mode of occurrence

The mass of cortlandtite, $3 m \times 7 m$ in extent, is located in the gneiss of sedimentary origin. Geological sketch-map of the mass and its surroundings is shown in Fig. 2. Photographs of the outcrop are also shown in Plate 1. On both the sides of the mass, it contacts with the gneiss bounded by the slightly moved faults as shown in Fig. 2. At the boundaries between the two different rock types, i.e. cortlandtite and gneiss, no reaction zones can be recognized. Moreover, quartzofeldspathic ptygmatic veinlets, abundantly found in the surrounding gneisses, never occur in the cortlandtite. The mass is homogeneous, composed exclusively of cortlandtite.

Petrography

This rock is dark greenish coloured, coarse-grained and massive. Poikilitic hornblende attains to 7 mm in diameter and lustrous on cleavage planes under the Sunshine and looks like diallage (Plate 1-3).

Fig. 1. Geological map of the Toyone-mura area.

1. Alluvium, 2. Debris, 3. Terrace deposit, 4. Basalt and andesite, 5. Dacite, 6. Rhyolite, 7. Tertiary sediments, 8. Sambagawa schists, 9. Busetsu granite, 10. Inagawa granite, 11. Mitsuhashi granite, 12. Tenryûkyô granite, 13. Kamihara quartz diorite, 14. Fine-grained biotite granodiorite, 15. Mylonite, 16. "Hälleflinta", 17. Gabbro, 18. Metabasite, 19. Hornfels (pelitic and psammitic), 20. Hornfels derived from chert, 21. Mica schist (pelitic), 22. Mica schist (psammitic), 23. Quartz schist, 24. Gneiss (pelitic), 25. Gneiss (psammitic), 26. Quartz gneiss, 27. Nebulitic gneiss, 28. Metamorphic rock derived from "Schalstein", 29. Marble, 30. Fault.

M.T.L. Median Tectonic Line, I.S.L. Itoigawa-Shizuoka Line. Large open circle indicates the locality of the cortlandtite.

Locality name As: Asakusa, Aw: Awase, Ch: Chausu-yama, Fu: Futto, Ha: Hanare-yama, Ho: Hongô, Hy: Hiyosawa, Ih: Ichihara, In: Inoshikori, Ka: Kami-Awashiro, Ko: Kobayashi, Kt: Kakinotaira, Ky: Kashiyage, Md: Midashi, Mk: Makino-shima, Ms: Misono, Ni: Niino-tôge, Ns: Naka-Shitara, Nt: Nihon-ka-tsuka-yama, Od: Ôdachi, Oh: Ôhata, Oi: Ôiwa-dake, Os: Ôsawa, Ot: Ôtani, Oz: Ôzasa-yama, Sk: Shimo-Kurokawa, So: Sogawa, Su: Sakauba, Tk: Tashika, Ts: Tsugawa, Tw: Tawagane-tôge, Uk: Urakawa, Ur: Ure, Us: Urushijima, Yd: Yatsudake-yama, Zn: Zinno-yama.
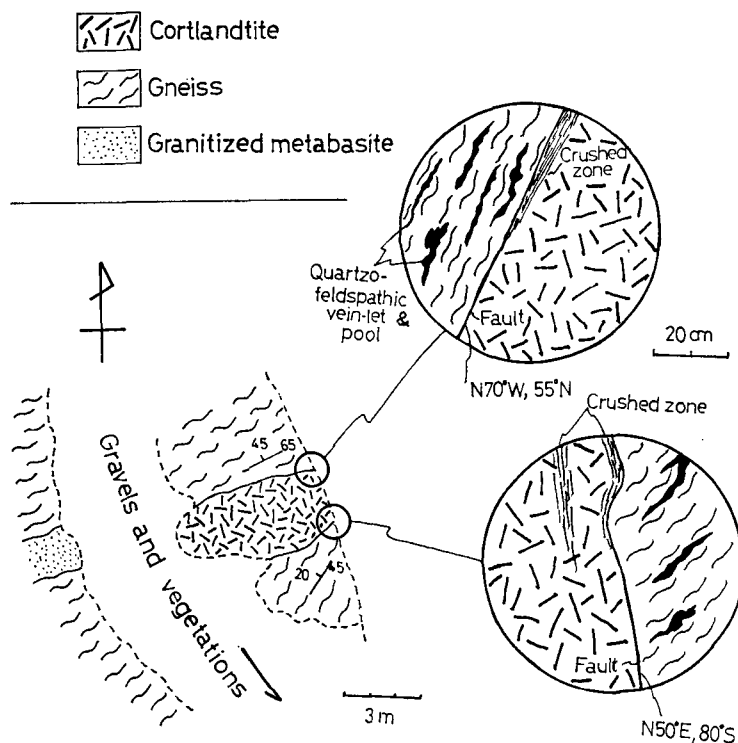
Fig. 2.   Schematic sketch of the outcrop.

Under the microscope, original hornblendic parts are now scattered, separated by hedges made of secondary minerals.   As primary minerals, poikilitic brown hornblende, olivine and orthopyroxene are main constituents.   Besides these, small amounts of ilmenite, picotite and sphene are observed.   Brown hornblende is poikilitic, from its nature this rock is attributed to cortlandtite, and includes rounded olivine crystals. (Plate 2-1, 2).   But, it never includes orthopyroxene which is developed between hornblende crystals and rarely encloses the parts of olivine (Plate 2-3).   Very fine-grained picotite and sphene are included in olivine.

Colourless amphibole surroundes hornblende with distinct boundary, and it also includes olivine crystals.   It looks like that hornblende and colourless amphibole are in zonal structure.   Colourless amphibole is separated into several blocks with zigzag suture-lines and shows intense undulatory extinction.   Undulation becomes stronger toward the margin of the amphibole crystals.

Between the olivine and its host hornblende, the aggregate (not symplektite-like) of spinel and actinolite is developed, suggesting their reaction products of the formers (Plate 2-4).   Also, along the contact between orthofyroxene and hornblende thin

corona made of fiberous actinolitic materials is observed.

Various secondary minerals, actinolite, anthophyllite, chlorite, prehnite, muscovite, sericite and others, fill the interstices between the original hornblendic parts.

Chemical composition

Chemical analysis of this rock was made for major and some minor elements, with the results as shown in Table 2. Due to the abundance of hornblende, this rock is rich in alumina and alkalies. As regard to minor elements, it is rich in Rb and Sr, poor in Ni, and moderate in Co and Cu, in comparison with the average values given by GOLES (1967) for ultramafic rocks. High content of Rb is conspicuous.

Representative chemical compositions of cortlandtites and the allied rocks are compiled in Table 3, for comparison. In spite of their diversity in mineralogical compositions and mode of occurrence, they have quite similar chemical compositions. Examining in detail, the Tomiyama rock is slightly rich in Al_2O_3, but poor in CaO.

Mineralogy

Chemical compositions and optical properties are presented for major constituent minerals.

1. *Olivine*

Olivine is rounded crystals, almost always included by hornblende. Rarely it is partly embedded by orthopyroxene. Frequently it alters to yellowish green serpentinous matter.

Optical properties are as follows:

$\alpha = 1.683$

$\beta = 1.703$ $\qquad (-)2V = 83°, 84°,$

$\qquad\qquad\qquad\qquad 86°, 87°.$

$\gamma = 1.722$

Chemical composition is shown in Table 4. It belongs to chrysolite in classification of DEER *et al.* (1962).

2. *Orthopyroxene*

It is xenomorphic crystals and never included in the hornblende. It is present in individuals in contact with the hornblende. Between the orthopyroxene and hornblende, thin corona of radial actinolite (?) needles can be observed (Plate 2-2). Parallel crystallization of orthopyroxene and hornblende is suggested from their mutual textural relations. Exsolution lamellae are not found in it. Optical properties are as follows:

Table 1. Modal composition of the cortlandtite (Vol. %)

Olivine	6.9
Orthopyroxene	2.1
Hornblende (brown)	27.3
Amphibole (colourless)	11.4
Actinolite	24.2
Chlorite	4.5
Prehnite	2.0
Muscovite	9.4
Sericite	2.8
Spinel	1.2
Ores	0.4
Others	2.7
Total	100.0

Table 2. Chemical composition and C. I. P. W. norm of the cortlandtite (Specimen No. 74032301)

		C. I. P. W. norm		
		or		4.02
		ab		5.16
SiO_2	45.53	an		21.28
TiO_2	0.46	di	wo	1.10
Al_2O_3	9.54		en	0.81
Fe_2O_3	3.39		fs	0.19
FeO	8.82	hy	en	27.36
MnO	0.19		fs	6.35
MgO	22.46	ol	fo	19.46
CaO	4.90		fa	4.98
Na_2O	0.61	mt		4.92
K_2O	0.68	il		0.87
H_2O (+)	3.26	ap		0.14
H_2O (−)	0.13	water		3.39
P_2O_5	0.06	Total		100.03
		Co		94.7 ppm
Total	100.03	Ni		455
		Cu		36.4
		Zn		107
		Rb		23.8
		Sr		113

Anal. T. Kutsukake

Table 3.   Chemical compositions of cortlandtites

	1	2	3	4	5	6	7
SiO_2	45.53	43.90	41.34	47.13	43.15	44.45	42.43
TiO_2	0.46	0.43	0.53	0.55	2.28	1.21	0.96
Al_2O_3	9.54	5.62	10.48	7.81	9.53	6.40	5.50
Fe_2O_3	3.39	4.36	1.41	2.07	3.40	2.91	2.62
FeO	8.82	7.80	17.13	9.02	11.46	7.89	2.62
MnO	0.19	0.17	0.05	0.35	0.18	0.17	—
MgO	22.46	23.42	19.71	15.03	16.89	25.05	30.79
CaO	4.90	10.02	7.56	14.17	8.58	8.52	4.78
Na_2O	0.61	0.67	0.78	0.48	1.51	0.92	0.81
K_2O	0.68	0.27	0.38	0.52	0.76	0.54	0.44
H_2O (+)	3.26	3.56	0.27	2.82	1.28	1.83	1.69
H_2O (−)	0.13	0.33	0.06	—	0.76	—	—
P_2O_5	0.06	0.18	0.01	0.39	0.13	0.11	0.08
Total	100.03	100.73	99.71*	100.34	100.61**	100.00	100.00

* includes NiO 0.005, CoO 0.004, and B_2O_3 0.002.
** includes CO_2 0.34.
1. Cortlandtite from Tomiyama-mura, Aichi Prefecture, Japan.   Anal. T. KUTSUKAKE.
2. Cortlandtite from Osafuji-mura, Nagano Prefecture, Japan.   Quoted from YAGI (1944).   Anal. K. YAGI.
3. "Olivine amphibolite" from Mitsue-mura, Nara Prefecture, Japan.   Quoted from SUWA (1961). Anal. Y. SUWA.
4. Cortlandtite from Nishi-Dôhira, Ibaraki Prefecture, Japan.   Quoted from WATANABÉ (1921). Anal. TAKAYANAGI.
5. Cortlandtite from Stony Point, N. Y., U.S.A.   Quoted from IDDINGS (1913).   Anal. STEIGER.
6. Cortlandtite, average composition of six analysed cortlandtites.   Quoted from DALY (1933).
7. Hornblende peridotite, average composition of five analysed hornblende peridotites.   Quoted from NOCKOLDS (1954).

$$\alpha = 1.676 \qquad (-)2V = 77.5°, 82° \qquad \text{Disp.} \quad r<v, \text{ weak}$$
$$\beta = 1.684$$
$$\gamma = 1.687$$

Pleochr. weak $\left\{ \begin{array}{l} \text{X} = \text{light reddish yellow} \\ \text{Y} = \text{light brownish yellow} \\ \text{Z} = \text{light green} \end{array} \right.$

Chemical composition is shown in Table 4.   This is relatively rich in alumina. This composition belongs to bronzite.

3.   *Hornblende*

Poikilitic hornblende is exclusively brownish variety.   It is clouded with fine exsolved materials (probably ilmenite) arranged along cleavages.   Optical properties are as follows:

Table 4. Chemical compositions of olivine and orthopyroxene

	Ol	Opx
SiO_2	37.50	53.50
TiO_2	0.01	0.24
Al_2O_3	0.01	3.37
ΣFeO	22.47	13.50
MnO	0.25	0.25
MgO	39.32	28.56
CaO	0.04	0.93
Na_2O	0.00	0.01
K_2O	0.00	0.01
Total	99.60	100.37

	Numbers of ions on the basis of	
	4 oxygens	6 oxygens
Si	0.982	1.906 ⎫ 2.00
Al^{IV}	—	0.094 ⎭
Al^{VI}	0.000 ⎫	0.048 ⎫
Ti	0.000 ⎪	0.006 ⎪
ΣFe	0.492 ⎪	0.402 ⎪
Mn	0.006 ⎬ 2.04	0.008 ⎬ 2.02
Mg	1.536 ⎪	1.517 ⎪
Ca	0.001 ⎪	0.035 ⎪
Na	0.000 ⎪	0.000 ⎪
K	0.000 ⎭	0.000 ⎭

Mg	75.7	Mg	77.6
		Fe	20.6
Fe	24.3	Ca	1.8

EPMA anal. Y. Miyake and Y. Yamaguchi

$\alpha=1.638$ $(+)2V=80°, 84°$ $c\wedge Z=22°$ Disp. $r>v$, weak

$\beta=1.650$

$\gamma=1.664$

Pleochr. { X=light brownish yellow

Y=light yellowish brown

Z=light brown

$\gamma-\alpha=0.026$

Chemical composition is shown in Table 5, column I. This composition can be regarded to be a common hornblende. Electron-probe scanning proved that it has quite uniform chemical composition all over the grain, and does not show any remarkable zoning.

Table 5. Chemical compositions of amphiboles

	I	II
SiO_2	43.77	53.40
TiO_2	2.67	0.19
Al_2O_3	14.16	5.36
ΣFeO	6.80	10.33
MnO	0.12	0.24
MgO	16.88	22.69
CaO	11.81	5.19
Na_2O	1.75	0.73
K_2O	0.34	0.05
Total	98.30	98.18

Numbers of ions on the basis of 23 oxygens

	I	II
Si	6.210 } 8.00	7.420 } 8.00
Al^{IV}	1.790	0.580
Al^{VI}	0.577	0.297
Ti	0.285	0.020
ΣFe	0.807 } 5.25	1.200
Mn	0.014	0.028 } 7.22
Mg	3.571	4.701
Ca	1.795	0.772
Na	0.480 } 2.34	0.196
K	0.062	0.009
$\dfrac{100\,Mg}{Fe+Mn+Mg}$	81.3	79.3

EPMA anal. Y. MIYAKE and Y. YAMAGUCHI

The primary poikilitic amphibole in cortlandtite has been believed to be edenite since ESKOLA's (1914) study on this type of rock in the Orijärvi region, southwestern Finland. However, precise determination of its chemical composition has not been made so far, partly because of the difficulty to separate it from inclusions. Now, it has been definitely shown by the present study that the poikilitic amphibole is a common hornblende.

4. *Colourless amphibole*

As above mentioned, it is always present as outer zoned rim around hornblende. It is separated into several blocks of random orientations, and shows intense undulatory extinction. It is probably of metamorphic origin. Optical properties are as follows:

$\alpha=1.638$
$\beta=1.649$ $(+)2V=80.5°$ $c\wedge Z=19°$ Disp. $r>v$, weak.

$$\gamma = 1.663$$
$$\gamma - a = 0.025$$

From its optics alone, it can be a variety of cummingtonite. But, electron-probe analysis shows that this amphibole has a quite peculiar chemical composition, that is, the composition intermediate between common hornblende and cummingtonite (Table 5, column II). This has abnormally high contents of Al_2O_3, CaO and Na_2O, in comparison with the usual cummingnites (KLEIN, 1964). Also, electron-probe scanning revealed that this mineral has a quite uniform chemical composition for all over the grain, showing no exsolution lamellae.

This may be a new type of amphibole. Further crystallo-chemical investigation of this peculiar amphibole is still in progress in collaboration with Dr. K. TOMITA, a mineralogist of our Department.

5. *Actinolite*

Actinolite is the most abundant of the secondary minerals. It is usually columnar to fibrous in subparallel or radial aggregates. It is frequently associated with vermicular spinels. It is almost colourless. Optical properties are as follows:

$$a = 1.628$$
$$\beta = 1.642 \qquad (-)2V = 85° \qquad c \wedge Z = 15°$$
$$\gamma = 1.651 \qquad \text{Disp.} \quad r < v, \text{ weak} \qquad \text{Absorp.} \quad X = Y = Z$$
$$\gamma - a = 0.023$$

6. *Anthophyllite*

At the margin of the colourless amphibole, flaser anthophyllite is developed (Plate 2-2). It also occurs as associated with actinolite (Plate 2-6). It is usually slender crystals and nearly colourless. Optical properties are as follows:

$$a = 1.639$$
$$\beta = 1.640 \qquad (+)2V = 76.5°, 79° \qquad \text{Disp.} \quad r < v, \text{ weak}$$
$$\gamma = 1.655_5$$
$$\gamma - a = 0.016_5$$

7. *Chlorite*

It forms aggregate composed of its fine flakes, and probably derived from actinolite by metamorphism or alteration. Optical properties are as follows: $\gamma = 1.611$, $(+)2V = $ ca. 10°. These optical properties suggest that this chlorite belongs to prochlorite and adjacent varieties in Winchell's nomenclature.

8. *Prehnite*

It usually occurs in aggregates of sheaflike. It is very fine grained and almost colourless in thin section. Optic axial angle $(+)2V = 70°$.

9. *Muscovite*

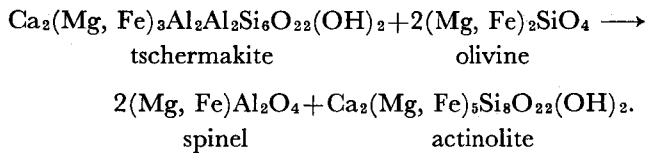It is developed obliquely to the direction of other minerals, and seems to have

replaced actinolite.   Optical properties are; $\gamma=1.590$; $(-)2V=21°$.

10.   *Sericite*

It is commonly in fine-grained, felted to sheddy aggregates.

11.   *Spinel*

Spinel, usually associated with actinolite, is developed between olivine and hornblende (Plate 2-5).   It is vermicular grains and grass green in colour, suggesting to be pleonaste.   It has an index of refraction $n=1.737$.   The formation of spinel is due to the following reaction:

$$Ca_2(Mg, Fe)_3Al_2Al_2Si_6O_{22}(OH)_2+2(Mg, Fe)_2SiO_4 \longrightarrow$$

tschermakite   olivine

$$2(Mg, Fe)Al_2O_4+Ca_2(Mg, Fe)_5Si_8O_{22}(OH)_2.$$

spinel   actinolite

This is the same kind of reaction observed in the "olivine amphibolite" of the Mitsue-mura, reported by Suwa (1961, p. 259).   Pleonaste is commonly found in cortlandtites.

12.   *Opaque minerals*

Observation under the reflected light revealed that the granular grains of opaque minerals are almost *ilmenite*, and small amounts of sulfide minerals (probably *pyrrhotite* and *chalcopyrite*) are detected.   Small needle-like opaques exsolved from the silicate minerals are ilmenite.

13.   *Other minerals*

Very fine-grained minerals included in olivine are brown coloured *picotite* and *sphene*.   The latter mineral is identified by its strong dispersion.

Discussions

1.   Depth of formation

If the equilibria of the primary minerals of this cortlandtite were attained, the mineral assemblage of olivine-orthopyroxene-amphibole belongs to Hornblende peri-dotite facies (VI) in O'Hara's (1967) mineral facies classification of ultrabasic rocks. When anorthitic plagioclase and diopside, are also compartible, frequently found in the cortlandtites in the Ryôke zone, the assemblage belongs to Hornblende-plagioclase peridotite facies (V).   In the tentative $P-T$ diagram, these assemblages are limited by about 900°C in the uppermost temperature and about 7 kb in the uppermost pressure.   This pressure value corresponds to approximately 20 km in depth in the earth's crust.   Thus, these rocks must have been formed at the depth not so deep as the lower crust and/or upper mantle beneath the Ryôke zone.   It is proper to regard that they have been formed in the middle crust between 10 to 20 km in depth.

2. As a cumulate from basic magma

The textural relationships of the primary minerals suggest the following crystallization sequence of them: olivine→orthopyroxene and hornblende. The parallel crystallization of the orthopyroxene and hornblende is to be paied attention to. In the experiments on basalt-water system, the parallel crystallization of clinopyroxene and amphibole has been recognized under some high water-vapour pressure. In a natural high alumina basalt, for example, clinopyroxene and amphibole similutaneously start their crystallization at about 8 kb water-vapour pressure (YODER and TILLEY, 1962). Although any orthopyroxenes have not been recorded in the basalt-water systems (e.g., HOLLOWAY and BURHNAM, 1972), the parallel crystallization of orthopyroxene and hornblende can be supposed under relatively high-water vapour pressure, on the analogy of the clinopyroxene-amphibole relations. Therefore, it is considered that the primary minerals of the cortlandtite were early crystallized ones from a basic magma, of which crystallization took place under high water-vapour pressure. And the rock can be regarded as a cumulate from a basic magma.

The intimate association of the cortlandtite with the olivine norites in the Ryôke zone suggest their proximity of blood. The basic magma which formed cortlandtite as a cumulate at some depth, would have solidified to the olivine norite ultimately.

Recently BEST (1970, 1975) reported the amphibole-bearing peridotitic inclusions from basanitic and nephelinitic volcanic rocks. And he suggested that the silica-undersaturated hydrous basic magma must have been in the upper mantle. The textures of those inclusions are equivalent to that of the cortlandtite, and characterized by the presence of poikilitic amphibole. Although their mineralogical compositions are different from that of the cortlandtite, due to the difference of the condition of formation, i.e., under higher pressures, very similar mechanism of formation as a cumulate can be safely assumed. Hydrous basic magmas at various depths could form diverse amphibole-bearing ultrabasic cumulates, according to their chemical compositions and conditions.

Mg/Fe ratios in the minerals, such as olivine and pyroxenes, are higher in the cortlandtite than those of the olivine norites in the Ryôke zone (YOSHIMURA, 1940; KUTSUKAKE, 1974), and there exist considerable gaps between them. This fact suggests the two-stage crystallization of the original basic magma; the first stage crystallization resulted in the formation of cortlandtite, and the second one is the solidification of the left magma to olivine norite. The former crystallization must have taken place in the deeper level than the latter beneath the Ryôke zone.

3. Metamorphism and alteration

Mutual relationships of the minerals of this rock is summarized in Fig. 3. Metamorphic changes of the minerals are of retrogressive ones, and very similar to those of the gabbroic rocks in the Toyone-mura (KUTSUKAKE, 1974). Recrystallization of minerals of later-stage, such as chlorite and prehnite can also be regarded as the results
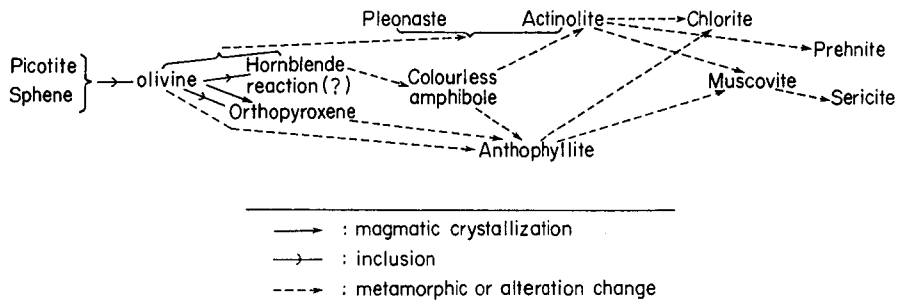
Fig. 3. Mutual relations of the constituent minerals in the cortlandtite.

of hydrothermal alteration.   Moreover, spinel-actinolite symplektites have been described from many gabboric rocks as to be of deuteric phenomena.   Thus, the later-stage changes in this rock can also be attributed to deuteric alteration during the magmatic crystallization, and it does not necessarily belong to metamorphism.   However, the recrystallization of colourless amphibole and anthophyllite would belong to 'normal' metamorphic one.   Colourless amphibole, among others, probably represents the products of the amphibolite facies metamorphism, although its stability field is not known at present.

As already mentioned, no reaction zone can be recognized between the cortlandtite and the surrounding gneiss.   This fact shows that the both rocks have not suffered the same metamorphism, that is, the Ryôke regional metamorphism.   This mass must have intruded into the gneiss in solid-state after the culmination of the regional metamorphism.   And during ascending of the mass, the rock has suffered the retrogressive metamorphism from the amphibolite facies through the greenschist facies to more lower facies.

Concluding remarks

In view of its mineralogical relations and compositions, the cortlandtite of this subject can be considered to have been formed as a cummulate from a basic magma, which solidified to the olivine norite in the Ryôke zone.   Crystallization and accumulation took place in the middle crust beneath the Ryôke zone, and the mass was intruded into the gneiss as a solidstate after the culmination of the Ryôke regional metamorphism.   During the upsidence of the mass, it suffered the retrogressive metamorphism.

Acknowledgements

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Explanation of Plates

Plate 1

Figs. 1–2. Photographs of the outcrop.
     Co: cortlandtite, Gn: gneiss
     Broken line indicates the boundary between the cortlandtite and gneiss.
Fig. 3. Hand-specimen of the cortlandtite.
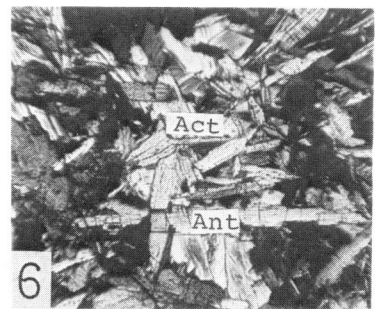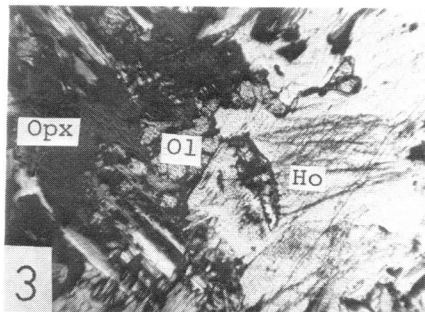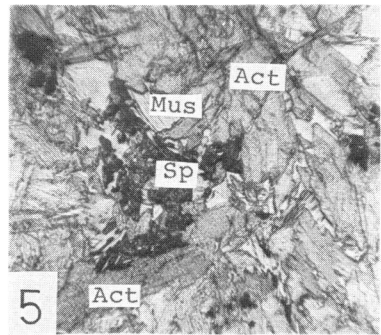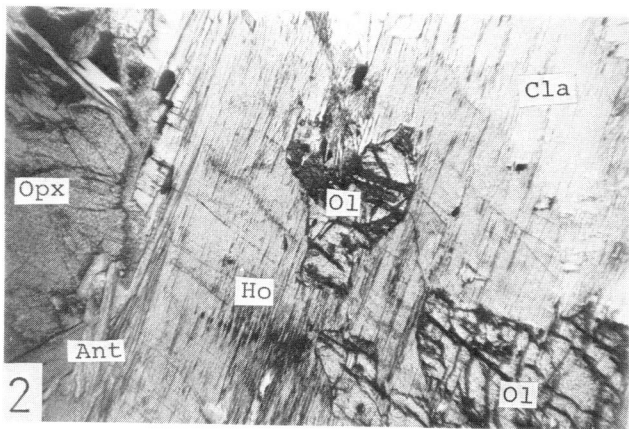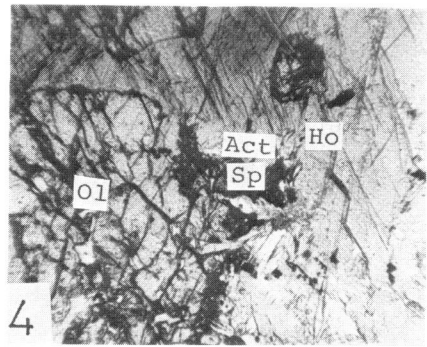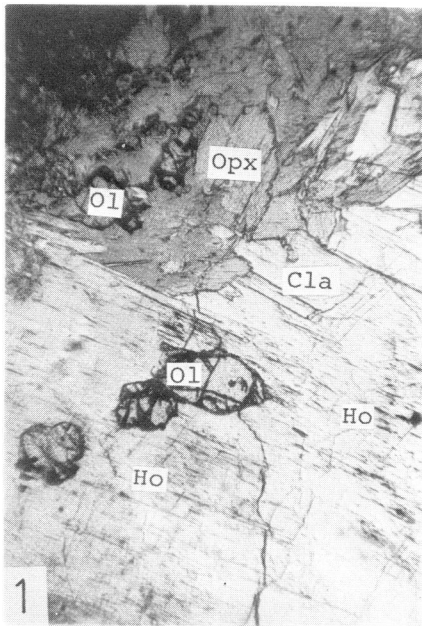
Plate 2

Figs. 1–6. Photomicrographs of the cortlandtite.
     Act: actinolite, Ant: anthopyllite, Cla: colourless amphibole, Ho: hornblende, Mus: muscovite, Ol: olivine, Opx: orthopyroxene, Sp: spinel.

KUTSUKAKE: Cortlandtite from Tomiyama-mura

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